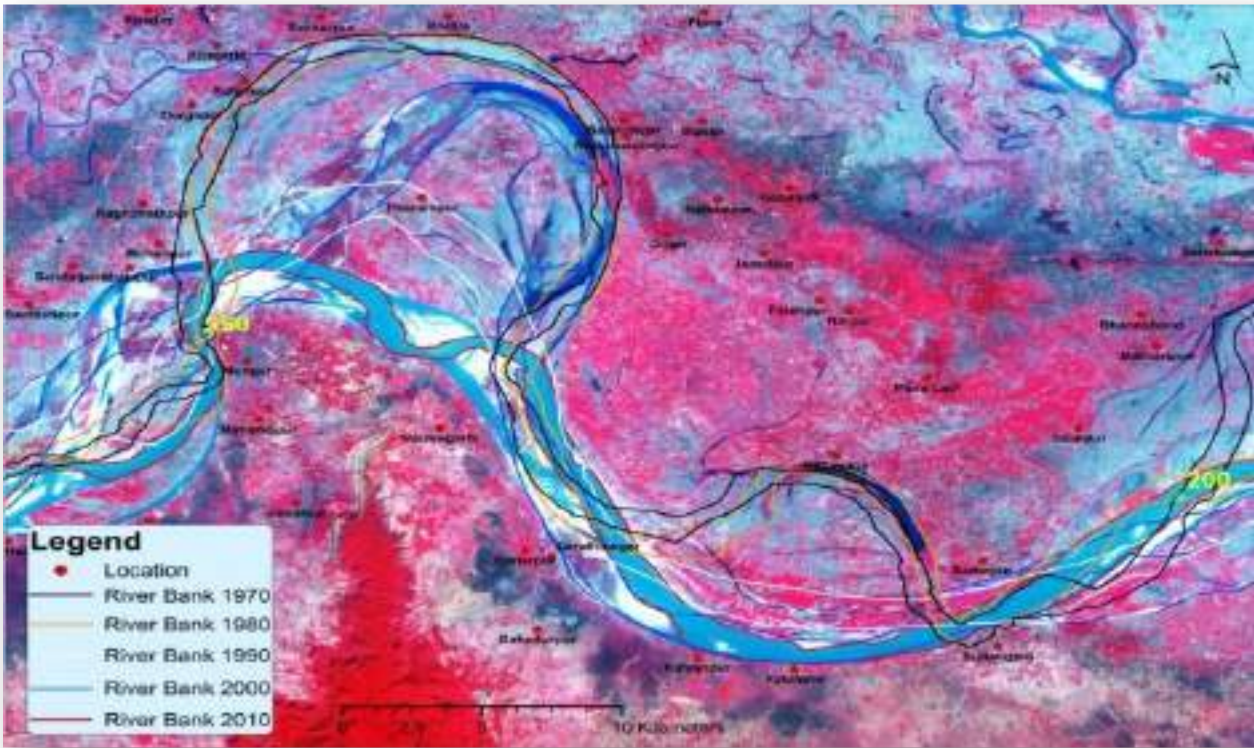
FINAL REPORT

MORPHOLOGICAL STUDY OF GANGA RIVER USING REMOTE SENSING TECHNIQUES



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Prepared for

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Executive Summary

1. River morphology deals with the plan form, cross-section and its dimension, bed forms, aggradation, degradation etc. Such morphology changes due to river hydrodynamics. Indian rivers experience large seasonal fluctuations in discharge and sediment load resulting in significant changes in their morphology. Shifting of the river course is generally accomplished by erosion of habitated and pricey agricultural area that cause tremendous losses. The sediments deposited and eroded in the river have a tremendous effect on the river cross-section and its gradient, sediment transport rate, discharge etc. Understanding of changes in the morphology of the rivers is required in the engineering projects for their planning, design and execution. With this in mind, CWC, New Delhi desires to carry out morphological study of the major Indian rivers. In this direction, CWC awarded a project entitled "Morphological study of rivers Ganga, Sharda and Rapti using remote sensing techniques" to IIT Roorkee.

2. *Following were broad objectives of the study*
   - (i) Compilation of river drainage map in GIS; changes in Land Use/Land Cover, flood affected areas, rainfall-runoff, Geology etc.
   - (ii) Hydrological analysis: Probability curve and flow rates corresponding to return period of 1.5 year and 2 year.
   - (iii) Decadal stream banks shifting and also changes in its Plan form (Sinuosity & Plan-form Index) from the base year 1970 to till 2010.
   - (iv) Work out erosion and siltation based on the banks shifting.
   - (v) Evaluate the impacts of major hydraulic structures on the river morphology.
   - (vi) Identification of critical and other vulnerable reaches and to suggest suitable river training/protection works.
   - (vii) Identification of islands/diyaras in the river and their status.
   - (viii) Reconnaissance survey for ground validation of outcomes of the study.
   - (ix) Recommendations in the respect of actionable points.
   - (x) Suggestions for the further study.

3. The Ganga is the biggest river in the Indian subcontinent in terms of water flow. The length of the Ganga river is 2,510 km while the drainage area lying in India is 8,62,769 km^2 which is nearly 26.2% of the total geographical area of the country. The tropical zones and subtropical temperature zones are most dominant in the entire Ganga basin. The hydrologic cycle in the Ganga basin is governed by the southwest monsoon. About 84% of the total rainfall occurs in the monsoon from June to September. Annual and

monsoon season precipitation, evapotranspiration, surface water availability (surface runoff) have declined in the period 1948-2012 compared to the period 1901-1947, while temperature has gone up.

4. The reach of Ganga river studied herein is from Devprayag to Farakka barrage that lies between longitudes 78°05′00" E to 88°36'30" E and latitudes 24°19'29" N to 30°10′10″ N. The total length of the Ganga river studied in this project is 1,824 km.

5. Hydrological data of Ganga river that comprises of annual maximum and minimum discharges and water levels; ten daily average discharge, sediment, and gauge at different gauging stations and were obtained from CWC, offices while relevant satellite images were procured from the National Remote Sensing Centre (NRSC), Hyderabad and downloaded from United States Geological Survey (USGS) website. SOI toposheets were obtained from SOI, Dehradun.

6. Available discharge and water level data at the various gauging sites of the Ganga river have been analysed. Exceedance probability curves have been drawn at each gauging site with the use of the available 10-daily average discharge data. Peak discharge for different return periods have also been estimated using frequency analysis.

River Morphology

7. *Planform*: Planform of the rivers may be described as straight, meandering or braided. Straight and meandering channels are described by sinuosity which is the ratio of channel length to valley length. Sinuosity ratios in the reaches 200-250 km, 600-700 km, 800-900 km and 1750-1824 km are relatively higher than the other reaches. As the average value of the sinuosity ratio for whole reach of the river is 1.38, therefore, the Ganga river is considered as sinuous river except the reaches identified above which can be classified as meander reach. A negligible progressive change in the sinuosity ratio has been found from the year 1970 to 2010.

8. Meanders in the river have been identified and found that except the meanders located upstream and downstream of Sultanganj and Munger, all other meanders (20 in number) are stable and no noticeable change in their geometry has been noticed from year 1970 to 2010.

9. Ganga river is prominently braided downstream of Haridwar, Garhmukhteswar, Ramghat (d/s of Narora), Kachchla bridge, u/s of Farrukhabad, upstream of Allahabad, Balia, Raghopur and Krusela

10. *Stream Bank Shifting*: Shift of both banks and center line in either directions has been computed for the years 1970, 1980, 1990 and 2000 with respect to year 2010 in GIS software. From the consideration of river bank

shifting, the Ganga river from Devprayag to Farakka barrage may be divided into following five reaches:

a) Devprayag (ch. 1824 km) to Haridwar (ch.1740 km): Being in hilly area, the river bank shifting is very low in this reach except for upstream of Bhimgoda barrage (Chilla) where river has shifted to the right side of the order of 1.5 km.

b) Haridwar (ch.1740 km) to Allahabad (ch. 924 km): Noticeable shifting of the river bank in the period of 1970 to 2010 has been noticed primarily at Sajanpur (Downstream of Haridwar), Dahirpur, Niranjanpur, Chhachhrauli, upstream and downstream of CCS barrage. Kamalpur, Nagla Goshain, Chhuchai, Khailwai, Moharka, Palwara, Gangwar (downstream of Anupshahr), Madkawali, Haranpur, Nanakhera, Nardauli, Kaimganj, Birpur, Yaqut Ganj, Kannauj, Bilhaur, Palhepur, Mirzapur, Shankarpur, Alipur, Arkha, and Benti lake

c) Allahabad (ch.924 km) to Revelganj (ch. 465 km): The river is more or less stable in this reach except for 50 km reach of Ganga river near Balia where mild shifting of river bank has been noticed.

d) Revelganj (ch. 465 km) to Mokamah(ch. 310 km):- The river is too wide and stable except at upstream and downstream of Digha bridge and upstream of Mokamah bridge, where major shifting of the river has been noticed.

e) Mokamah(ch. 310 km) to Farakka barrage (ch. 0):- Major shifting of river bank upto 12 km has been noticed in this reach. The river is also too wide and having meandering pattern at some locations. Prominent river bank shifting has been noticed at Khutha, Munger, Fatehpur, Madhurapur, Bhagalpur, Shahpur (upstream of Kahalgaon) and upstream of Farakka barrage.

11. *River Width & Shifting of Confluence Point*: Width of the active channel and river width based on the extreme banks have been estimated using the satellite images of years 1970-2010. From Devprayag to Haridwar, average width of the active channel is of the order of 70 m while from Haridwar to confluence of Ramganga river, the average width is about 315 m. However, downstream of the confluence of Ramganga river, the width of the active channel increases downstream non-linearly and reached to about 1636 m at Farraka barrage.

12. The average width of the river based on the extreme banks is about 4000 m from Buxar to Farakka barrage, while it is about 900 m from Allahabad to Buxar. From the foothill i.e, Haridwar to Allahabad, the average width is about 1150 m. Being in hilly area from Devprayag to Haridwar, the river width is about 130 m.

13. Two year return period discharge is considered as discharge that governs the morphological changes. The estimated discharge, Q for the two year return period at various gauging sites on the Ganga river is related with the average width, P of the active channel. The fitted equation is $P = 5.26\sqrt{Q}$ (Q in m^3/s and P in m), which is close to Lacey equation.

14. There are about 30 major tributaries of Ganga River between Devprayag and Farakka. Details of shifting of confluence points of Ganga river and its tributaries from the years 1970, 1980, 1990, and 2000 to year 2010 have been worked out. Decadal changes in the location of the confluence point are high (>2 km) for the tributaries: Ramganaga, Garra, Ghaghara, Sone, Gandak, Burhi Gandak, and Kosi.

15. The confluence point with Ramganga river has shifted by about 2.5 km downstream from the year 1980 to 2010, however, since the year 2000, the confluence point is stable. The confluence point of Garra river has moved about 6.6 km upstream from year 1990 to year 2010, and since then the confluence point is stable. In year 1990, the confluence point of Ghaghra river shifted upstream by about 12 km and since then it is more and less stable. Prior to year 1980, there was an acute meandering bend in the Ganga river near Munger. The Burhi Gandak was joining with the Ganga river from left side to the developed bend, however, after year 1980 the Ganga river took a straight path by abandoning the bend which resulted in shifting of confluence point of Burhi Gandak downstream by about 13.5 km. This confluence point is stable from year 1990 to till date. Kosi river joins the Ganga river from left side near Krusela.

Erosion and Siltation

16. Erosion and siltation studies have been carried out for the Ganga river from Devprayag to Farakka using SOI toposheets and post-monsoon decadal images from years 1970 to 2010. Based on the shifting of the extreme left and right banks, erosion and deposition have been estimated for duration from year 1970 to year 2010 and is expressed in the terms of area in km^2. Erosion and deposition maps for each reach have been prepared. Quantified erosion and siltation during the period 1970-2010 are as follow:

    Total eroded area = 44,700 ha
    Total deposited area = 1,07,094 ha
    Total eroded plus deposited area = 62,354 ha
    Net deposited area = 62,393 ha.
    Total drainage area of Ganga river =108 million ha.
    Deposited area per ha catchment area = 62393/108000000×100 = 0.06 %.

17. Ganga river is subjected to deposition in almost whole reach during the period 1970-2010. The deposition is pronounced and is of the order of 2000

ha per 50 km length of the river upstream of the Kanpur. From Kanpur to Mokamah, the deposition is of the order of 800 ha per 50 km. In the lower reach of the Ganga i.e., chainage 50 - 250 km, heavy sediment deposition of the order of 6000 ha per 50 km reach has been estimated.

18. From the consideration of the suspended sediment load, Ganga river may be divided into three distinct reaches a) Devprayag to Allahabad, b) Allahabad to Buxar, and c) Buxar to Farakka. Average suspended sediment load in the monsoon period in these reaches are 26, 108 and 189 MT/yr, respectively. Maximum SSL has been observed at Gandhighat which can be attributed to inflow of sediment from Ghaggra, Sone and Gandak rivers to Ganga river upstream of the Gandhighat.

19. Ghaggra river contributes about 130 MT/yr sediment to the Ganga river - about three times more sediment than the Kosi river. Gandak river contributes about 35 MT/yr sediment to Ganga river which is comparable to Kosi river.

20. Siltation has been observed in the Ganga river from Hathidah to Farakka. This may be due to low sediment carrying capacity of the river which can be attributed to wideness and shallowness of the river in this reach. Siltation in the upstream of the Farakka barrage up to its pondage fetch may be due to back water effect of the barrage, however, this aspect is to be investigated through modelling. Total siltation of the sediment in the reach from Buxar to Farakka is estimated as 250 MT per year.

21. Available measured cross sections of the Ganga river at the gauging stations indicate that there is no progressive aggradation or degradation in the river bed of the Ganga river from Garhmukteshwar to Farraka barrage. However, remarkable changes in the river bed over the years have been noticed at many stations. Deep section of the river has subjected to degradation at most of the stations of the Ganga river except at Hathidah where aggradation has occurred in the deep section over the years.

22. Out of 31 identified islands in Ganga river from Devprayag to Farakka barrage six islands, namely Ramchandipur, Dayalchak, Panapur, Raghopur, Madhurpur and Gobrahi are permanent in nature at least from year 1970. Other islands, like Gotani Kachar, Fatehpur Pershakhi, Jirat Lawaen Gariabad, Khuthun and Umarpur Diyara are moderately stable. Habitated islands are Kheri Kalan, Ramchandipur, Dayalchak, Panapur, Raghopur, Ratipur, Gobrahi Diyara, Baijnathpur, Saidpur Ramnagar, Rambari, Begamabad, Jalbalu and Darijayrampur.

23. Habitated islands pose major resistance to the river flow due to construction of the pucca houses which protrude significantly and results in major obstruction to the flow. Major morphological changes in the river occur near

such islands in the form of erosion, shifting of the main course, rise in water level, inundation in nearby areas during flood etc.

Major Structures on Ganga River

24. There are about 66 major structures such as railway & road bridges and barrages on Ganga River from Devprayag to Farakka. Out of which, barrages are six in number namely, Pashulok, Bhimgoda, Choudhary Charan Singh (CCS), Narora, Kanpur, and Farakka.

25. No major changes in the plan form of the river have been seen near the Pashulok, Bhimgoda, CCS and Kapur barrages from 1970 to till date. There was an island upstream of the Bhimgoda barrage of area of 0.33 km^2 approximately in 1970, however, it is eroded by the flowing water which has resulted in gradual reduction in the area of the island. Major changes have been noticed in the shifting of main course of the river at about 7 km upstream of the CCS barrage. Such shifting has resulted in heavy erosion and deposition in those areas.

26. Ganga river has been jacketed in a length of 6.5 km between railway bridge (u/s of Narora) and Narora barrage with the provision of series of spurs. The width of the channelized river is greater than the Lacey perimeter, which has resulted in heavy deposition in the form of islands. Looseness factor of the barrage is 1.63 - this high value of the looseness factor has aggravated the problem of silting upstream of the barrage.

27. Silting has occurred upstream of the Farakka barrage from 1970 to till date. Severe lateral shifting of the river upstream of the barrage has been observed in this period. The width of the active channel of the river has increased from year 1970 onwards, however, no remarkable change in the width of the river based on the extreme banks has been noticed from 1970 to 2010 upstream of the barrage. Area of islands located from Farakka barrage to Krusela has continuously increased from the year 1970 to 2010. Silting upstream of the barrage may also be attributed to high looseness factor of the barrage which is equal to 1.7.

28. There are about 49 bridges on the Ganga river from Devprayag to Farakka barrage. Morphological changes in the river have been noticed near the major bridges. Provided river training works at some of such bridges are working satisfactorily. Additional and/or repair of the existing river training works have been suggested at some of the bridge site to minimize outflanking of the bridge, erosion to the approach road etc.

Critical Reaches & Suggested Works

29. Thirty five reaches/locations are identified as critical in Ganga river, however, in twenty seven critical reaches of the Ganga river either the river is protected using spurs, embankments etc. or being in agricultural area, protection works are not economically viable. At the remaining eight critical reaches/locations near Haripur Kalan, Kangri, Sidholia Kham, Saharpur Makanpur Kham, Gunir, Bhagalpur, Rajmahal to Maharajpur and Manikchak, protection measures are suggested.

30. Methodology for the design of various river training works has been discussed and based on the morphological changes of the river, it is suggested to provide river training works in the following critical reaches of the river.

Sl. No.	*Chainage*	*Location*	*Suggested River Training Works*
a)	1745-1749 km	5 km upstream of the Bhimgoda barrage near Haripur Kalan	Series of spurs are recommended for the protection of left bank in a length of 4.15 km to control the cutting of the forest area
b)	1725-1731 km	8 km downstream of the Bhimgoda barrage near Kangri village	Series of spurs are provided, some more spurs are required in a length of 6 km towards left
c)	1436 km	Sidholia Kham	Spurs are suggested to be provided along with existing embankment in a length of 0.6 km at chainage 1436 km
d)	1446 km	Saharpur Makanpur Kham	Embankment along with spurs are suggested to be provided in a length of 1.0 km at chainage 1446 km
e)	1092-1108 km	Downstream of Baksar-Muradipur road near Gunir	Protection to right bank is required in a length of 14.5 km using boulder revetment and/or provision of series of spurs
f)	180 km	Bhagalpur	Protection measures in the form of embankment with boulder revetment and launching apron be provided near Raghopur area over a length of about 4 km to control lateral shifting towards left side
g)	36-78 km	Rajamahal to Maharajpur	Embankment along with launching apron may be provided to control the erosion of left bank in this reach in about 33 km length and lateral shifting towards left side
h)	24-34 km	Near Manikchak	Embankment along with launching apron may be provided to control the erosion towards left side in this reach in about 10 km length and lateral shifting towards left side

31. In addition to the above, the river training works shall also be provided near the a) Railway Bridge, Balawali, Laksar (Ch. 1696.5 km); b) Railway bridge, Rajghat, Narora (Ch. 1495.1 km); c) Railway & Road bridges, Kachhla (Ch. 1452.2 km); d) Ara-Chhapra road Bridge, Doriganj, Chhapra (Ch. 450 km) and e) Road Bridge - Gandhi Setu (NH 19) (Ch. 404.8 km).

32. Earthen embankments are mostly provided from Haridwar to Kanpur and from Buxar to Farrakka barrage. Major embankments are located towards right side downstream of the Haridwar; towards left side upstream of the Garhmukteswar, Narora barrage, and Farrukhabad; downstream of Buxar towards right side; towards left side downstream of the Mokama and confluence of Burhi Gandak; and downstream of the Krusela towards left side. In the lower Ganga basin, the embankments are mostly provided along left bank.

33. Design methodology of conventional river training works and also flexible system are described in the report that can be used for the design of a particular work. Sample design of guide bund and embankment/levees using conventional and flexible system are also given in the report.

34. Field reconnaissance survey was conducted at various locations like Devprayag, all the six barrages, Kanauj, Allahabad, Mirzapur, Varanasi, Revelganj, Patna, Mokamah, Begusarai, Munger, Sultanganj, Bhagalpur, Kahalgaon, Sahibganj, Rajmahal, Farakka etc. to assess the present condition of the river. The observations made during the site visits have been examined in the perspective of the outcomes of the morphological study carried out in this study.

Recommendations:

1. It is recommended to implement the suggested measures in the identified eight critical reaches of the Ganga and in the vicinity of the identified bridges. It is further suggested that such reaches/locations be studied in more details based on ground survey and analysis of high resolution satellite data.

2. Suggested measures are prioritized as follow:
   a) Railway Bridge, Balawali, Laksar (Ch. 1696.5 km): a) Suggested to provide nose to each guide bund and b) boulder revetment be provided to the right embankment of the railway track over a length of 1.5 km.
   b) Railway bridge, Rajghat, Narora (Ch. 1495.1 km): Suggested to provide nose to the left guide bund.
   c) Railway & Road bridges, Kachhla (Ch. 1452.2 km). Both the guide bunds should be extended downstream.

d) Ara-Chhapra road Bridge, Doriganj, Chhapra (Ch. 450 km). a) A truncated guide bund be provided towards right side and b) right bank u/s of bridge is to be protected to control the shifting of the river.

e) Road Bridge - Gandhi Setu (NH 19) (Ch. 404.8 km). Suggested to repair washed out portion of launching apron towards Hajipur side.

f) About 8 km downstream of the Bhimgoda barrage near Kangri village (Ch.1725-1731 km): Series of spurs are provided, some more spurs are required in a length of 6 km.

g) About 5 km upstream of the Bhimgoda barrage near Haripur Kalan (Ch.1745-1749 km): Series of spurs are recommended for the protection of left bank in a length of 4.15 km to control the cutting of the forest area

h) Bhagalpur (Ch. 180 km): Protection measures in the form of embankment with boulder revetment along with launching apron be provided near Raghopur area over a length of about 4 km.

i) Sidholia Kham (Ch.1436 km) & Saharpur Makanpur Kham (Ch. 1446 km): Spurs are suggested to be provided along with existing embankment in a length of 0.6 km at chainage 1436 km and 1.0 km at chainage 1446 km

j) Downstream of Baksar-Muradipur road near Gunir (Ch.1092-1108 km): Protection to right bank is required in a length of 14.5 km using boulder revetment and/or provision of series of spurs

k) Rajamahal to Maharajpur (Ch. 36-78 km): Embankment along with launching apron may be provided to control the erosion of left bank in this reach of about 33 km length.

l) Near Manikchak (Ch. 24-34 km): Embankment along with launching apron may be provided to control the erosion towards left side in this reach of about 10 km length.

3. It is recommended to site hydraulic structures like barrage, bridge etc. at the identified nodal points (wherein minimum morphology of the river has occurred) on the Ganga river to avoid outflanking of the river and to minimize protection works.

4. Large scale de-silting from the rivers is not recommended. Efforts shall be made to manage the sediment in the river through deploying suitable river training works. However, from the utility consideration like siltation at water intake, minimum draft requirement for navigation, skewed distribution of flow across bridges/barrages etc., it is recommended to desilt the sediment from that location.

5. Habitation shall not be allowed on the islands/diyaras that have formed in the rivers irrespective of whether they are permanent or temporary in nature. However, such islands may be used for the agricultural purpose with crops of low height.

6. Adoption of high looseness factor in the design of the barrages leads to siltation upstream of the barrage as it is noticed for the Narora and Farakka barrages. Therefore, it is recommended that looseness factor close to unity shall be adopted to control silting upstream of the barrage.

7. Formation of the Madhurapur diyaras upstream of the Mokama bridge may be attributed to backwater effect resulted due to high afflux caused by the construction of the bridge by narrowing down the width of the river to 1.6 km by deploying a guide bund towards left side. Therefore, it is recommended that length of the bridge shall be fixed keeping nominal afflux.

8. It is suggested that from Haridwar to Revelganj (Chhapra), the length of the bridge/spacing of embankment should be close to three times the Lacey parameters, however, in the reach from Revelganj to Farakka, it should be from bank to bank. Final decision in this regard is to be taken considering other factors and site conditions.

9. River training works or any other structure shall be designed in such a way that it should not encroach the flood plains of the river or it should not delink the lakes, depressed areas, wetlands etc. as such bodies provide additional storage to the river and that results in lowering the peak discharge that controls the flood.

10. Sediment management in the vicinity of a barrage shall be explored by operation of the barrage gates. For an example, gates of the barrages shall be operated such that incoming sediment can be passed downstream during the flood time, to maintain the sediment equilibrium. Further, it should be ensured that the concentrated sediment flux passed downstream should not cause major morphological changes in the downstream reaches.

11. It is further suggested that a detailed survey of the area and data collection/analysis is to be carried out before implementing the recommendations, so as to incorporate the current ground conditions and river behaviour.

Suggested Further Study:

1. Unauthorized, unscientific and unplanned mining of sand and gravel from the river has resulted in major morphological changes in river in the terms of stream bank shifting, bed degradation, bank erosion, disrupting the sediment mass balance, danger to the hydraulic structures etc. It has been seen downstream of Haridwar where Ganga river has shifted towards left side due to excessive mining. Therefore, there in a need to carry out replenishment study so that quantity of the sand and gravel to be mined can be estimated and morphological changes can be controlled.

2. Erosion and siltation in the Ganga river has been studied herein on the basis of the shifting of the banks of the river except in the reach from Buxar to Farakka in which study has been carried out based on sediment mass balance approach. This approach of the study is an indicative and does not provide the eroded/silted sediment in the terms of volume/weight. In view of this, it is suggested that the eroded/silted sediment shall be quantified on the basis of the sediment mass balance study i.e., quantity of eroded/silted sediment in a reach of the river is equal to mass of the sediment entered into the reach minus mass of the sediment gone out from the reach during a period. Collected sediment and flow data of the Ganga river and its tributaries by CWC at its H.O. can be used for this study and some data in this respect should also be collected.

3. Flood zones of the river should be identified and delineated along both the banks of river. Based on flood zone boundaries, habitation and development activities may be prohibited in such areas.

4. This study indicates that silting has occurred in almost whole the reach of Ganga river from Devprayag to Farakka barrage. This has resulted in formation of sand bars, islands, etc. and also aggravated the problem of flood. It is suggested that appropriate study should be carried out in generic basis or case to case basis to dredge out such islands/bars through non-structural measures like pilot channel, channelization etc.

5. In future, morphological studies are required to be carried out using 3D data of the terrain, as topography and slope of the region play an important role to study the morphological behavior and flood situation of the river. Laser based surveying and mapping techniques are now available which can provide 3D data with greater accuracy and speed to identify the critical regions affected by the flood due to meandering of the river.

For the dissemination of outcomes of the study carried out under the project to the potential users, a workshop on *Morphological Study of Rivers Ganga, Sharda and Rapti Using Remote Sensing Technique* was organized by Indian Institute of Technology Roorkee in association with Central Water Commission at Library building, CWC, New Delhi during 18-19 Sept. 2017. A brief note on the workshop is given in Annexure-C,

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DISCLAIMER

Utmost care has taken to process the toposheets, satellite images, hydrological data, estimation of erosion and siltation, identification of critical reaches, etc. to meet out the objectives of the study in this report, however, possibility of errors, omissions, etc. cannot be precluded.

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Chapter 1 INTRODUCTION

1.1 Introduction

The river morphology is concerned with the shapes of river channels and how they change over time. The morphology of a river channel is a function of a number of processes and environmental conditions on multiple spatial and temporal scales. Watershed features that control river morphology include topography, discharge, sediment supply and vegetation. River stability and response to changing environmental conditions are highly dependent on local context (channel type and associated degrees of freedom; the nature of the imposed sediment, hydrologic and vegetation regimes; imposed anthropogenic constraints; and the legacy of past natural and anthropogenic disturbances). Alluvial streams (rivers) are dynamic landforms subject to rapid change in channel shape and flow pattern. Water and sediment discharges determine the dimensions of a stream channel (width, depth, and meander wavelength and gradient). Characteristics of stream channels and types of pattern (braided, meandering, straight) are significantly affected by changes in flow rate and sediment discharge, and by the type of sediment load in terms of the ratio of suspended to bed load. Dramatic changes in stream bank erosion within a short time period indicate changes in sediment discharge.

River bank erosion is a natural geomorphic process which happens in all streams as modifications of channel size and shape are made to carry the discharge and sediment provided from the drainage basin. The sediments deposited and eroded in the river have a tremendous effect on river cross-sectional area, gradient, vegetation and its discharge. Therefore, due to morphological change, there is an overflow in river which causes flood in the neighbourhood. With the remote sensing- GIS integrated approach, morphological mapping of the river for the pre and post monsoon images can be easily done. Data supplied by the optical and radar satellites can be employed to invoke maps of morphological changes and flood inundation in a short period of time which is cost effective. Radar images can be used in all type of weather conditions as they can penetrate clouds, they are quite beneficial in mapping flood and are an ideal for flood monitoring, especially in complex hydraulic conditions .

Plan form of the rivers may be described as straight, meandering and braided. There is in fact a great range of channel patterns from straight through meandering to braided. Straight and meandering channels are described by sinuosity which is the ratio of channel length to valley length (Schumm, 1977). Braiding pattern of the rivers is characterized in different ways; however, most common is Plan Form Index (PFI).

The river geomorphology is the knowledge and interpretation of river processes, which generate and modify landscape's shapes (Marchetti, 2002). By flowing in a river bed composed of non-cohesive loose substances, the current modifies shape of the sections and its planimetric and altitudinal structure, thus originating morpho-dynamics processes.

The preservation of morphological shape, the change of an already-existing balance or the tendency to establish a new shape of the watercourse are the result of both varied and different river processes (erosion/deposition, sedimentation) and geological, climatic, hydrologic, hydraulic, vegetative and biological factors that could trigger, control or wipe out various river phenomena. Such processes characterize every type of river bed, therefore are not typical of any particular morphological configuration. In fact, there are varied river forms in nature corresponding to different stability conditions of beds. Tendency of river beds to have different forms relates to the geometric characteristics of the valley, response to a certain hydrometric status, flow conditions and particle size of material transported that forms the bed and on soil composition forming the banks (Lenzi et al., 2000).

Indian rivers always divulge certain special features since they experience large seasonal fluctuations in discharge and sediment load. The rivers are accustomed to a range of discharges and most rivers exhibit morphologies that are related to high-magnitude floods. The key themes in Indian river geomorphology include the hydrology of monsoonal rivers, and its forms and processes in alluvial channels; causes of avulsion, channel migration; anomalous variations in channel patterns; dynamics of suspended sediments; and the geomorphic impacts of floods. Researches indicate that the Himalayan Rivers are occupying a highly dynamic environment with extreme variability in discharge and sediment load. Earthquakes and landslides also have a great impact on these rivers from time to time. Consequently, the rivers are characterized by frequent changes in shape, size, position and planform.

There are no clear limits among the various morphological typologies but there is a continuous shift from one form to the other. For this reason, in order to be able to define the morphology of a watercourse and the typologies it is made of, one single parameter is not enough, therefore different factors must be examined and taken into consideration, such as:

- ***Sinuosity*****:** it expresses the ratio between the length of the river and the length of the valley axis (Leopold et al., 1964);
- ***Grain distribution*****:** it pertains to analyzing the particle size of the material forming the bed;
- ***Total sediment transportation*****:** defined as the sum of two components, i.e. bed load and suspended load transportation;
- ***Braiding*****:** it is the number of bars or islands situated along a given reach. It is defined as the ratio between the main channel width under flood conditions (when bed sediments are completely flooded) and its width under standard flow conditions;
- ***Vertical running off*****:** it specifies whether the stream flows deeply incised in the valley's plain or in its sediments. It is normally expressed by the ratio between the width of the flooded area and the width of the open channel, which corresponds to the bankfull discharge (Kellerhals et al., 1976; Rosgen, 1994);
- ***Width-Depth ratio*****:** it describes the size and the form factor as the ratio between the bank width of the channel, and the corresponding mean depth (Rosgen, 1994);
- ***Planimetry*****:** it explains how a watercourse flows into its drainage area;
- ***Gradient*****:** it is a very important aspect in the determination of the hydraulic, morphological and biological characteristics relating to a watercourse;
- ***Longitudinal section*****:** it is the change in height of a stream which explains how the river can be divided into morphological categories according to the gradient;
- ***Cross section*****:** it indicates the incision degree of a channel and the extent of the most important hydraulic variables.

A stream can have various channel patterns as shown in Fig. 1.1, such as braided channels, meandering channels, and straight channels. These various patterns are a response to above variables, in particular the slope/gradient and the friction in the channel (related to grain sizes).

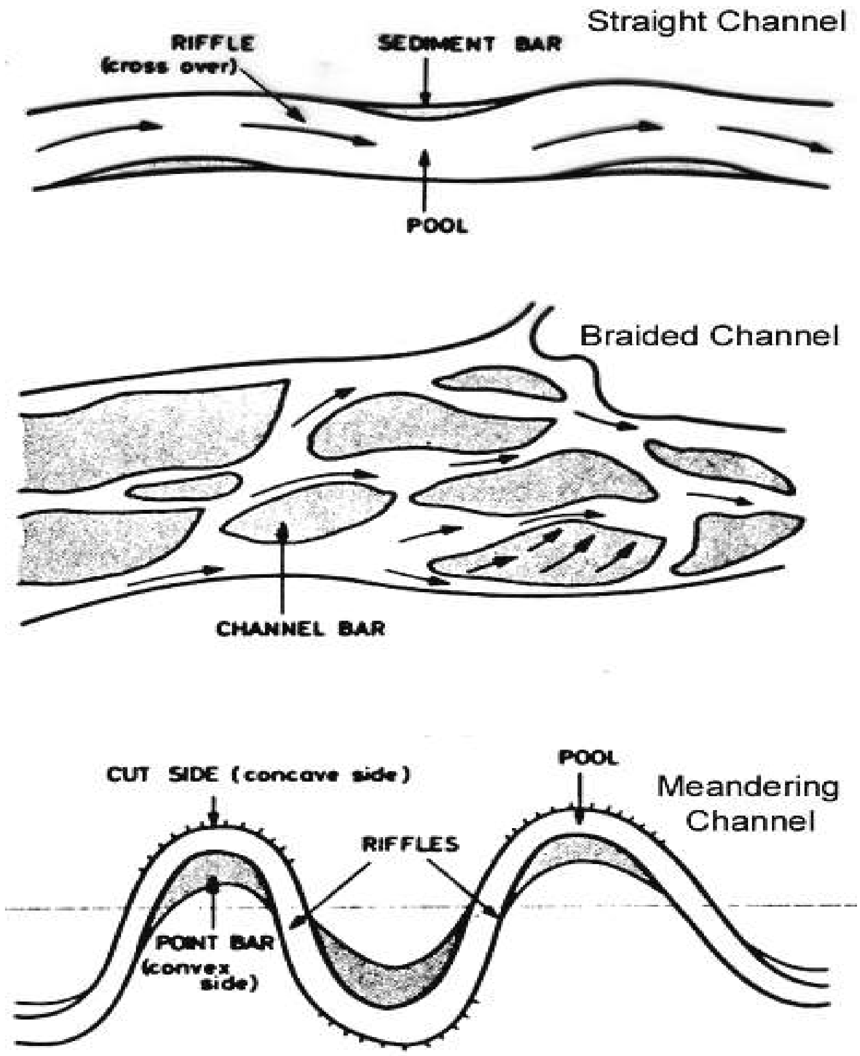


Figure 1.1 Channel patterns

1.2 Objectives & Terms of Reference

The specific objectives of works are:

i. Compile complete river drainage map in GIS by integrating available secondary maps in WRIS of CWC. Collect additional required information on major flood protection structures, existing water resources projects, important cities/ towns, CWC H.O. sites, airport, island etc., and to be integrated with final river drainage maps.

ii. Study shifting of river course and also changes in its Plan form from the base year (say 1970) till 2010, by collecting 4 sets of satellite imageries at 10 years interval in addition to one set of Survey of India toposheets for the base year on a scale of 1:50,000. In case toposheets are available for older period say 1950, the base year may be shifted accordingly.

iii. Compile Changes in Land Use/Land cover, and study of its impact on river Morphology.

iv. Channel Evolution Analysis to describe the status of the river channel. The analysis of the channel dimension, pattern, and longitudinal profile identifying distinct river reaches i.e. channel in upper reaches, channel in flood plain with bank erosion etc. This segregation of the reaches is to be determined by using Channel Evolution Analysis.

v. Work out the rate of bank erosion/deposition in terms of erosion length & erosion area w.r.t. base year at 50 km interval.

vi. The present condition of critical reaches of the main channel of river may be assessed by conducting ground reconnaissance. Field recon trips may be taken, if required.

vii. Evaluate the impacts of major hydraulic structures on morphological behavior of river course and its impacts on river morphology.

viii. Evaluate braiding pattern of river by using Plan Form Index (PFI) criteria along with its threshold classifications.

ix. Compile information (if any) on flood affected areas in the vicinity of river course prepared by NRSC using Multi-temporal satellite data of IRS WiFS (188 m) & Radarsat ScanSAR Wide & Narrow (100 m & 50 m) for flood images for Bihar.

x. Plot probability curve (Exceedance Probability vs. Flow rate) and show flow rates corresponding to return period of 1.5 year and 2 years for different CWC H.O. locations. The observed flows need to be normalized before using for analysis.

xi. Relate the morphological changes in river on the basis of available peak discharges of different years in the time domain considered in this study. Study impact of changes in annual rainfall in the basin on river morphology.

xii. Identify critical and other vulnerable reaches, locations. Analysis of respective rate of river course shifting and based on it, future predication of river course behaviors.

xiii. Suggest suitable river training works for restoration of critical reaches depending on site conditions.

1.3 Need/Scope of Study

Following are the scope of the intended study:

i. The required inventory of one set of Survey of India (SOI) toposheets in respect of reference time datum on a scale of 1:50,000 are to be procured from SOI by the Consultant. The inventory of satellite imageries having spatial resolution of 23.5 m , IRS LISS-I, LISS-II, LISS-III may be worked out covering the study area, and to be procured from NRSC.

ii. One set of SOI toposheets (say year 1970) and digital satellite imageries of IRS LISS-I, LISS-II and LISS-III sensors, comprising scenes for the years 1980, 1990, 2000 and 2010 are to be used for the present study. In case of non-availability of above data, the foreign satellite data of similar resolution may also be used. The maps and imagery are to be registered and geo-referenced with respect to Survey of India (1:50,000 scale) toposheets w.r.t. to base year by using standard technique & GIS tool.

iii. Delineation of River Bank Line, River Centre Line alongwith generation of important GIS layers of river banks, major hydraulic structures, embankments/ levees, railway bridge line, island, airport, cities/towns/villages, and important monuments etc. located in the vicinity of river banks for the selected years of the studies are to be part of studies.

iv. Estimation of left & right bank shifting amount(s) w.r.t. base year & appropriate graphical plotting of these shifting.

v. Evaluation of braiding of different river course reaches by using Plan Form Index (PFI) criteria along with its threshold classification, wherever required.

vi. Estimation and comparison of each bank erosion for different reaches in term of erosion length & erosion area of the river w.r.t. base year by using appropriate GIS tool, accordingly vulnerability index for different reaches may be evolved &

prioritized along with causative factors detail for this erosion may be worked out.

vii. Comparison of delineated different river courses on the same graphical plot on A0 size, and all plots may be arranged in a separate volume.

viii. The most critical reaches may be shown separately with appropriate suitable stream reach(es) restoration with a recommendation of suitable bank stabilization technique(s) depending upon the channel planform and condition.

ix. The cross section data available may be used for identifying riffle locations, and measure topography changes. The cross sectional data provided may be used to extract necessary information to analyze the channel, which ultimately led to identifying the channel stage or condition.

x. The plan view of various stream patterns may be used to define the geometric relationship that may be quantitatively defined through measurement of meander wavelength, radius of curvature, amplitude, and belt width. It may be done by separating river reaches based on change in valley slopes into different RDs, estimation of sinuosity, no. of bends for different RDs, average radius of curvature for each segment of the rivers defined. Based on this channel pattern analysis, proper interpretation may be given.

xi. River Channel Dimension; river channel width and the representative cross section are a function of the channel hydrograph, suspended sediments, bed load, and bank materials, etc. The future river channel dimensions may be evaluated based on the available cross-section detail for vulnerable/critical reaches of the rivers.

xii. Maximum Flow Probability curves at CWC H.O. sites located on concern river, may be developed to predict the channel discharge corresponding to 1.5 year and 2 year Return Interval (RI). These values i.e. 2 year Return Interval is widely accepted as the “Channel Forming Discharge” or “Bankfull”. These are the flows that contribute most to the channel dimension. These parameters may be used to determine the Channel Evolution Stage based on the Channel Evolution Analysis. Comparison of channel forming discharge and the maximum channel capacity may be done; accordingly interpretation about the channel carrying capacity is to be presented.

xiii. Channel profile; channel profile is commonly referred to channel slope or gradient.

The channel profile may be developed for river reach under consideration. The proper interpretation w.r.t. bed formations, aggradations, degradation etc. may be made part of studies.

xiv. Impaired stream analysis; as part of the scope of work, part of impaired streams to be identified along with the causes and sources by the consultant. Based on the causes of stream impairment, stream restoration mechanism/methods to be recommended. While stream restoration and bank stabilization techniques do improve water quality, land use practices may also be discussed, which is typically the main culprit of chemical pollution.

xv. Results & Recommendations is to be separate chapter. A proper discussion about results in respect of different reaches i.e. upper reach, middle reach & lower reach of river along with appropriate suggestions to be given.

xvi. Collection of a dditional information like Topography, Climate, Soils, Geology and Hydrology etc. required to be incorporated in the Morphological report.

xvii. Analysis of shifting of left and right banks of the rivers at about 50 kilometer interval as well as covering critical reaches of the river irrespective of river RDs interval.

xviii. Identification of flood affected areas in the vicinity of river course which have experienced frequent flooding in the past and suggesting suitable remedial measures for flood proofing for the river reaches. It was informed by NRSC representatives that NRSC derived inundation from 10 years of multi-temporal satellite data (1998-2007). Based on the frequency and extent of inundation, the flood hazard is categorized into 5 classes - Very High, High, Moderate, Low and Very Low. This helps the concerned authorities in planning developmental works in these areas. NRSC used Multi-temporal satellite data of IRS WiFS (188 m) & Radarsat ScanSAR Wide & Narrow (100 m & 50 m) for flood images. The flood hazard alongwith flood annual layers mapping has been done for Assam & Bihar. It includes complete flood hazard statistics district wise. This published information can be utilized by IIT Roorkee to cover flood affected aspects in the study.

xix. The entire satellite data used in the study by the IIT Roorkee, all analysis, results, maps, charts etc. and the subsequent report prepared shall be the exclusive property of CWC and the IIT Roorkee has no right whatsoever to divulge the information/data to others without the specific written permission of CWC.

xx. In order to ensure the desired quality of the generated outputs as well as to ensure that the GIS layers are hydrologically, hydraulically, and scientifically reasonable approximations. It was decided that the standards used for WRIS, as well as "Standards for Geomorphological Mapping Project" and "Standards for Land Degradation Mapping Project" given in manuals of NRSC may be referred.

xxi. The compilation of Changes in Land Use/Land cover, and study of its impact on river Morphology is to be incorporated in the study report. The NRSC's published information about land use and land cover maps under NRSC Bhuvan thematic service on a scale of 1:50,000 as well as 1:2,50,000 for all states can be used for this purpose.

Chapter 2 LITERATURE REVIEW

2.1 LITERATURE REVIEW

The dynamics of river and associated problems like erosion/deposition, floods in particular have been studied by many researchers around the world. Physical based research in the area of river geomorphology has pointed out the historical trends in river processes and flooding. Pioneering study in river geomorphology by Leopold and Wolman (1957) is the most noteworthy along with the work of Schumm (1963), Chorley (1969), Gregory and Walling (1973), Brice (1981) and Hooke (2006). The following section deals with the literature survey to streamline the present work.

Leopold and Wolman (1957) grouped the alluvial rivers into straight, braided and meandering on the basis of their planform, and calculated the characteristics of each of these patterns. Braided river was found to be the one that flows into two or more anastomosing channels (anabranches) around alluvial island, and in a winding course. The continuum of channel patterns from unbranched to highly braided has been quantified by the braiding index introduced by Brice (1974), which is the ratio of twice of the channel length of the islands in the reach of stream divided by the length of the reach.Channels have also been classified based on the relative percentage of bed load and suspended load they transport (Schumm, 1969).

Brice (1981) studied the meandering pattern of three reaches of the white river, Indiana. He demarcated the centroid of each bend to find out the movement in the meanders. To find out the potential of erosion in each meander bend a plot was created between angular movements of centroids and meander length. Further, he plotted the eroded area and the meander length on a scatter diagram to find out the average meander length which triggers erosion. He concluded that the erosion along straight segments of a highly sinuous channel is negligible.

Hooke (1987) stated that channel planform changes by erosion of the banks (growth of meanders), by deposition within the channel (braiding), or by cutoffs and avulsions that involve switching of channel position. Hooke (2006) elaborated the spatial pattern of instability and the mechanism of change in an active meandering river, the Dane. Nearly 100 meandering bends of the Dane river have been analyzed using historical maps and aerial photographs for the period 1981-2002. More than 20 years of monitoring of these bends provided a unique insight into the link between erosion, deposition and maximum discharge.

Mirza (1997) examined the hydrological changes that have occurred in the Ganges system in Bangladesh in the post-Farakka period (1975-1992) using relevant discharge and water level data. They developed stage-discharge relationships downstream of Farakka barrage for 1974/75, 1984/85 and 1992/93 (Figure 2.1). Their results showed that water level was continuously rising for same discharge, which signified decreasing longitudinal slope and rising bed level resulting from continuous sediment deposition on the river bed. They also found that the diversion caused considerable hydrological changes in the Ganges system in Bangladesh.

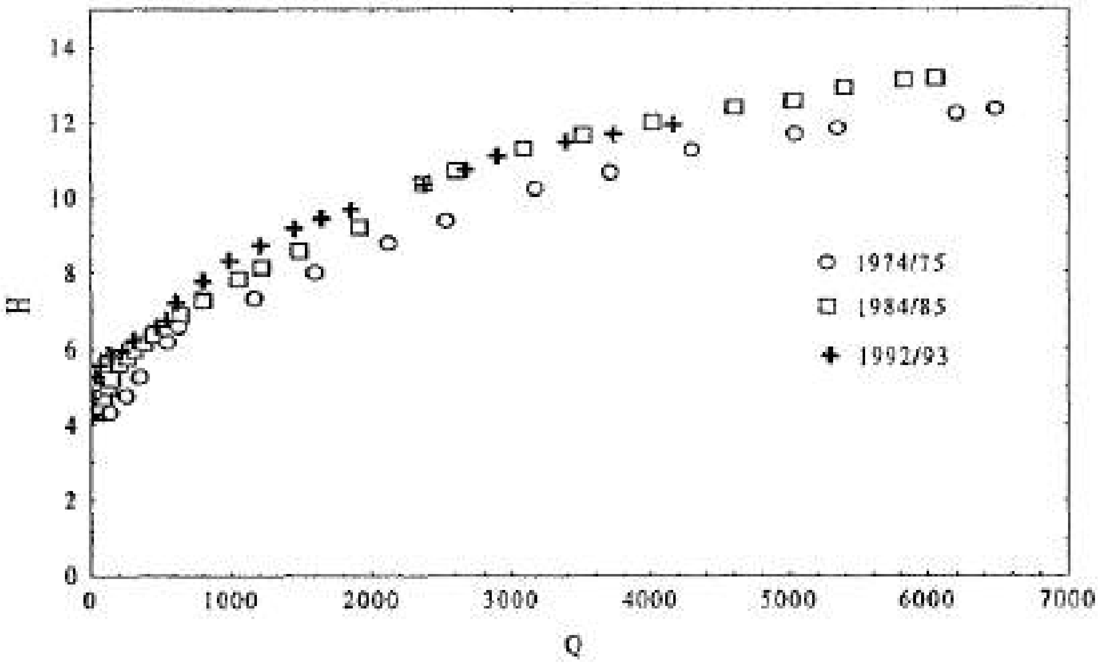


Figure 2.1 Stage-discharge relationship downstream for year 1974/75, 1984/85 and 1992/93 (Mirza 1997)

Banerjee (1999) mainly emphasized on the amount of sedimentation on the upstream and downstream of Farakka barrage. The river is severely eroding left bank in the Malda town on the upstream and right bank in the downstream in Murshidabad. The land eroded from left bank of Ganga in Malda and right bank in Murshidabad is shown in Tables 2.1 and 2.2.

Table 2.1 Ganga Bank erosion on left bank in Malda District (Banerjee 1999)

Year	Total length affected (km)	Maximum width of Erosion (m)	Approximate loss of land (ha)
1979	5.0	200	60
1980	7.0	150	105
1981	11.0	400	260
1982	5.0	150	65
1983	5.0	200	90
1984	7.0	100	70
1985	6.0	150	90
1986	6.0	200	105
1987	8.0	300	240
1988	7.0	100	70
1989	10.0	150	150
1990	8.0	200	160
1991	11.0	150	170
1992	9.0	150	130
1993	7.0	200	145
1994	7.0	1250	160
1995	8.0	200	145
1996	15.0	250	310
1997	6.0	100	60
1998	10.0	900	330

Table 2.2 Ganga Bank erosion on Right Bank in Murshidabad District (Banerjee 1999)

Year	Total length affected (km)	Maximum width of Erosion (m)	Approximate loss of land (ha)
1979	5.0	200	100
1980	6.0	250	100
1981	4.0	200	80
1982	5.0	200	90
1983	5.0	250	105
1984	22.0	700	635
1985	10.0	250	245
1986	10.0	200	180
1987	8.0	150	105
1988	9.0	300	255
1989	12.0	150	175
1990	10.0	150	120
1991	9.0	200	115
1992	6.0	400	270
1993	10.0	200	145
1994	33.0	1400	2585
1995	8.0	150	270
1996	10.0	1000	465
1997	4.0	100	40
1998	40.0	250	500

Parua (2002) studied the fluvial geomorphology of the river Ganga between Rajmabal in Bihar and Jalangi Bazar in West Bengal.,a length of about 190 km, before and after the Farakka barrage was built. The morphological characteristics of the river reach with changes between pre-barrage and post-barrage situation near Farakka were briefly described. He found that the changed flow pattern in post-barrage situation in this mighty river invited a new morphological environment and the same would take considerable time for adjustment and for attaining a dynamic stability of the river reach as was prevailing in pre-barrage days.

Rudra (2004) mainly emphasized changes in water level in dry and monsoon season in the pre and post Farakka period and concluded a continuous rise in water level on the upstream as shown in Table 2.3.

Table 2.3 Changes in water level (Rudra 2004)

Year	Approx. max. discharge (10^3 cumec)	Approx. max. water level (m)	Increase in height (m) (Original pond level: 21.95 m)
1979	42.80	22.90	0.95
1981	57.0	23.70	1.75
1983	60.5	24.90	2.95
1985	57.30	24.30	2.35
1988	68.0	25.10	3.15
1991	69.70	25.30	3.35
1993	54.20	24.10	2.15
1996	71.0	25.10	3.15
1998	75.90	25.40	3.45
2001	45.68	24.00	2.05
2003	57.52	24.78	2.83

Sarma and Phukan (2004) studied the origin and geomorphological changes of Majuli Island of the Brahmaputra River in Assam, India using SOI toposheets (1917, 1966 and 1972) and satellite data (IRS-1B LISS II data of 1996 and IRS-1D LISS III data of 2001). This study reveals that erosion is predominant in the southern boundary of Majuli Island owing to the river Brahmaputra while rate of erosion is more prominent in the south western part of the island. Increase in rate of erosion is noticeable during 1917-2001, due to this Brahmaputra has widened its channel by eroding both of its banks, particularly after the Great Assam earthquake of 1950. An increase in channel width from 35.8% to 61.2% has been measured around Majuli during the period from 1917 to 1996 due to overall northward migration of the Brahmaputra.

Lauer and Parker (2008) stated that erosion from the banks of meandering rivers causes a local influx of sediment to the river channel. Most of the eroded volume is usually replaced in nearby point bars. However, the typical geometry of river bends precludes the local replacement of all eroded material because (i) point bars tend to be built to a lower elevation than cut-banks and (ii) point bars tend to be shorter than the eroding portion of cut-banks because of channel curvature. In a floodplain that is in equilibrium (i.e., neither increasing nor decreasing in volume), sediment eroded from cut banks must be replaced elsewhere on the floodplain. The local imbalance caused by differences in bank height should be balanced primarily by overbank deposition, while the local imbalance caused by curvature should be balanced primarily by deposition in abandoned stream courses or oxbow lakes.

Nicoll and Hickin (2010) examined the planform geometry and migration behavior of confined meandering rivers at 23 locations in Alberta and British Columbia. Relationships among planform geometry variables are generally consistent with those described for freely meandering rivers with small but significant differences because of the unique meander pattern of confined meanders. Migrating confined meandering rivers do not develop cutoffs, and meander bends appear to migrate downstream as a coherent waveform.

Luchi *et al.* (2010) stated that high spatial resolution of the topographical survey allows capture of significant variations in the cross sectional morphology at the meander wavelength scale. The width-curvature behavior is correlated with the pattern of bed and banks morphology, which is different in bend apices and in meander inflections. The survey shows that the bed-form morphology can be characterized by a mid-channel bar pattern that is initiated at the inflection section and that the bed-form dynamics can be closely associated with channel width variations.

Rozo *et al.* (2014) stated that bank erosion is essential in the proper functioning of river ecosystem and it also happens in densely forested system. The identification of pixel class-change was carried out and the following changes were acknowledged: a) Deposition: when there is formation of island or floodplain from water feature; b) Erosion: when floodplain or island changes to water body; c) Erosion-Deposition: when there is change from floodplain or island to water and again to recent deposition; d) Changes between various land forms; and e) No change.

Ghosh (2014) quantifies planform of the river Teesta after Gazaldoba barrage using satellite images of years (1997, 1990, 1999 and 2008) in the GIS environments and found that the river braiding has drastically increased in the year 1999 just after the dam/barrage operation. His study highlights that Gazaldoba barrage is not solely responsible for altered river flow but the several other upstream factors are also responsible for this changes. Thus the river Teesta planform pattern has been changed from low braided to highly braided after the human induced changes in the river.

Hazarika *et al*. (2015) quantified the planform and land use changes of Gai and Simen tributaries of the Brahmaputra River, Assam, India for last 40 years using remote sensing and GIS techniques. Quantification of bank line migration shows that the river courses are unstable. A reversal in the rate of erosion and deposition is also observed. Land-use change shows that there is an increase in settlement and agriculture and a decrease in the grassland. The area affected by erosion–deposition and river migration comprises primarily of the agricultural land. Effect of river dynamics on settlements is also evident. Loss of agricultural land and homestead led to the loss of livelihood and internal migration in the floodplains. The observed pattern of river dynamics and the consequent land-use change in the recent decades have thrown newer environmental challenges at a pace and magnitude way beyond the coping capabilities of the dwellers.

Dewan *et al*. (2016) used geospatial techniques to quantify the channel characteristics of two major reaches of the Ganges system in Bangladesh over 38 years. It has covered the section of the Ganga River, from the India–Bangladesh border and the Padma, from Aricha to Chandpur. They also examined the nature and extent of bankline movements of the Ganges and Padma rivers and estimated the volume and location of both erosion and deposition in the river channel. Channel planform maps of the Ganges over 38 years revealed that the river experienced contraction and expansion as well as adjustment to its planform. Analysis of the left and right bank movement showed that each bank has particular stretches where movement is high and low.

Fluvial geomorphological studies in India have mostly focused on the river response to climate and tectonic forcing at Quaternary time scale (Chamyal *et a*l., 2003; Juyal *et al*., 2006; Sinha *et al*., 2007). Recently, studies of the hydro geomorphic behavior of river systems at modern time scale have also been initiated to understand the impact of anthropogenic forcing on geomorphic processes for some of the Indian river systems. Such studies at modern time scale have not only highlighted anthropogenic impacts on river systems but have provided significant insights to river hazards, particularly flooding and river dynamics.

Jain *et al*. (2012) reviewed the major geomorphic studies on the Indian rivers and highlighted various research questions. One of the major research concerns is the development of hydrology morphology ecology relationship in the river system and the assessment of the anthropogenic disturbances on this or a part of this relationship. Anthropogenic disturbances cause flux or slope variability in the channel, which alter the morphology and ecology of the river system.

Channel morphology is a manifestation of the river characteristics and river behavior (Gregory and Lewin, 2014). Its spatial variability not only represents the variability in hydrology and channel processes but also governs the ecological diversity in the channel. In order to understand the spatial variability, a geomorphic diversity framework has been developed for the Ganga River and its tributaries (Sinha *et al.,* 2016). The geomorphic features at different spatial scales were used in a hierarchical framework to divide the Ganga River system into different reach types.

Rivers support human population in villages and are therefore of significant interest to different workers.

The Majuli Island has been shrinking with an average erosion rate of 3.2 km^2/yr. A recent study showed that the erosion trend closely correlates with the various geomorphic parameters of the Brahmaputra River, which includes channel belt area (CHB), channel belt width (W), braid bar area (BB), channel area (CH), thalweg changes and bank line migration, which highlights the role of channel processes on the evolution and erosion of the island (Lahiri and Sinha, 2014). It was also suggested that subsurface tectonic processes also governed its evolutionary trajectory. This new understanding of the evolutionary trajectory of the Majuli Island highlights the complexity in the management of this mega- geomorphic feature.

A recent study on the stream network connectivity structure in longitudinal and lateral dimensions had shown its utility for the prediction of inundation areas in the scenario of avulsion driven flooding (Sinha *et al*., 2013). The connectivity structure was quantified by a connectivity index (Ic) defined as a function of the length and slope properties of the channel network. This topography-driven connectivity model was successfully used to simulate the avulsion pathway of the Kosi River during the August 2008 breach (Sinha, 2009). In general, avulsion prone reach of the Kosi River is characterized by different palaeo channels, which makes it difficult to predict the inundation zone due to avulsion event. However, such an approach provides a priori information about possible inundation zones and could be used to predict flood risk in populated and vulnerable regions. This study demonstrated that the mapping of connectivity structure for a stream network on a part of a fan surface can be used as an important tool in the management of flood hazards.

Formation of various barriers across the rivers like dams and barrages has also caused significant disconnectivity in the system. A number of major dams constructed on the

Himalayan and Peninsular rivers in India have disturbed the water and sediment fluxes. In the Mahanadi River basin, the time series data of the rainfall at different monthly and seasonal scales show that the rainfall trend is spatially variable (Panda *et al*., 2013).

Large dams have caused more pronounced disconnectivity on the sediment fluxes. The Peninsular rivers were characterized by significant decrease in sediment supply during the last few decades. Using hydrological data from 1986 to 2006, Panda *et al.* (2011) had shown that all the Peninsular rivers were characterized by decrease in sediment supply to ocean in response to decrease in rainfall and anthropogenic impact. The source-sink disconnectivity was more explicit in the highly regulated Narmada and Krishna rivers, where climate (rainfall variability) had no significant control on sediment flux variability. The sediment supply in the ocean had decreased by 70% in these regulated river basins.

Gupta and Subramanian (1994 and 1998) analyzed water and sediment samples collected from the Gomti river during the post-monsoon season. The results indicated almost monotonous spatial distribution of various chemical species, especially because of uniform presence of alluvium Dun gravels throughout the basin. The river annually transports 0.34×10^6 tonnes of total suspended material (TSM) and 3.0×10^6 tonnes of total dissolved solids (TDS), 69% of which is accounted for by bicarbonate ions only.

Shukla and Ashthana (2005) studied the inter linking of river in India. The interlinking river project was separated into two primary components i.e. Himalayan and Peninsular Rivers. The Himalayan component proposes 14 canals and the Peninsular component proposes. In the Himalayan component, many dams are slated for construction on tributaries of the Ganga and Brahmaputra in India, Nepal and Bhutan. The project intends to link the Brahmaputra and its tributaries with the Ganga and the Ganga with the Mahanadi River to transfer surplus water from east to west. The scheme envisages flood control in the Ganga and Brahmaputra basins and a reduction in water deficits for many states. In the Peninsular component, river interlinks were envisaged to benefit the states of Orissa, Karnataka, Tamil Nadu, Gujarat, Pondicherry and Maharashtra. The linkage of the Mahanadi and Godavari rivers was proposed to feed the Krishna, Pennar, Cauvery and Vaigai rivers. Transfer of water from Godavari and Krishnaentails pumping 1,200 cusecs of water over a crest of about 116 meters. Interlinking the Ken with the Betwa, Parbati, Kalisindh and Chambal rivers was proposed to benefit Madhya Pradesh and Rajasthan.

Latrubesse *et al*. (2005) presented an overview of tropical river systems around the world and identifies major knowledge gaps. They focused particularly on the rivers draining the wet and wet–dry tropics with annual rainfall of more than 700 mm/year. The size of the analyzed river basins varies from 104 to 6x106 km^2. They also computed the intensity of floods and discharge variability in tropical rivers. The relationship between sediment yield and average water discharge for orog0enic continental rivers of South America and Asia was also plotted. Insular Asian rivers show lower values of sediment yield related to mean annual discharge than continental orogenic rivers of Asia and South America. Rivers draining platforms or cratonic areas in Savanna and wet tropical climates are characterized by low sediment yields. Tropical rivers exhibit a large variety of channel form. In most cases, and particularly in large basins, rivers exhibit a transition from one form to another so that traditional definitions of straight, meandering and braided may be difficult to apply.

Thakur *et al*. (2012) studied the river bank erosion hazard which occurred due to morphometric change of the Ganga River in the upstream of Farakka Barrage up to Rajmahal. Morphometric parameters, such as, Sinuosity, Braiding Index, and percentage of the island area to the total river reach area were measured for the years 1955, 1977, 1990, 2001, 2003, and 2005 from Toposheets, LANDSAT and IRS satellite images and it is shown in Table 2.4.

Their analysis showed that there was a drastic increase in all of those parameters such as sinuosity, braiding index and river island area over the period of time (Table 2.4). The change in river course of Ganga during 1955, 1977, 1990 and 2005 were shown in Figure 2.2.They also found that the bank failure was occurred due to soil stratification of the river bank, presence of hard rocky area (Rajmahal), high load of sediment and difficulty of dredging and construction of Farakka Barrage as an obstruction to the natural river flow.

Table 2.4 River morphometric Parameters (Thakur *et al*. 2012)

Year	Braiding Index	Sinuosity	Island Area
1955	0.12	1.09	2.09
1977	0.82	1.12	24.86
1990	1.07	1.10	71.13
2001	1.31	1.14	90.21
2003	2.08	1.21	119.11
2005	2.17	1.25	116.87

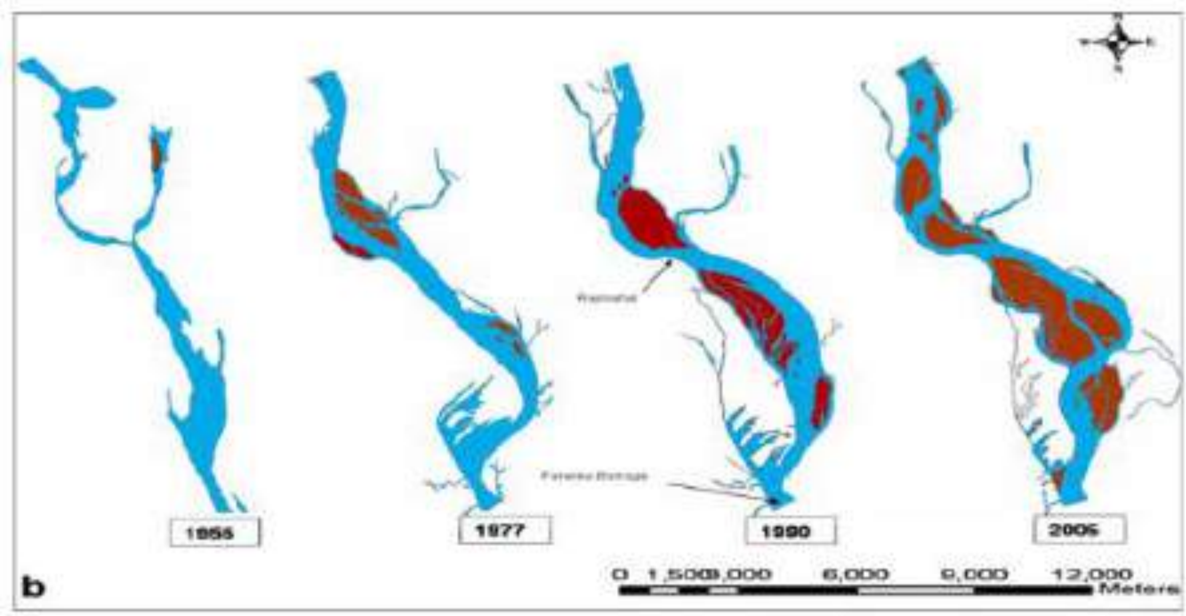


Figure 2.2 Changing course of river Ganga (Thakur *et al*. 2012)

Das *et.al.* (2012) analyzed the river bank erosion due to morphometric changes of the river Ganga in Malda district. They used logarithmic extrapolation technique to predict future scenario of river Ganga in year 2020, 2030 and 2040 as shown in Figure 2.3.

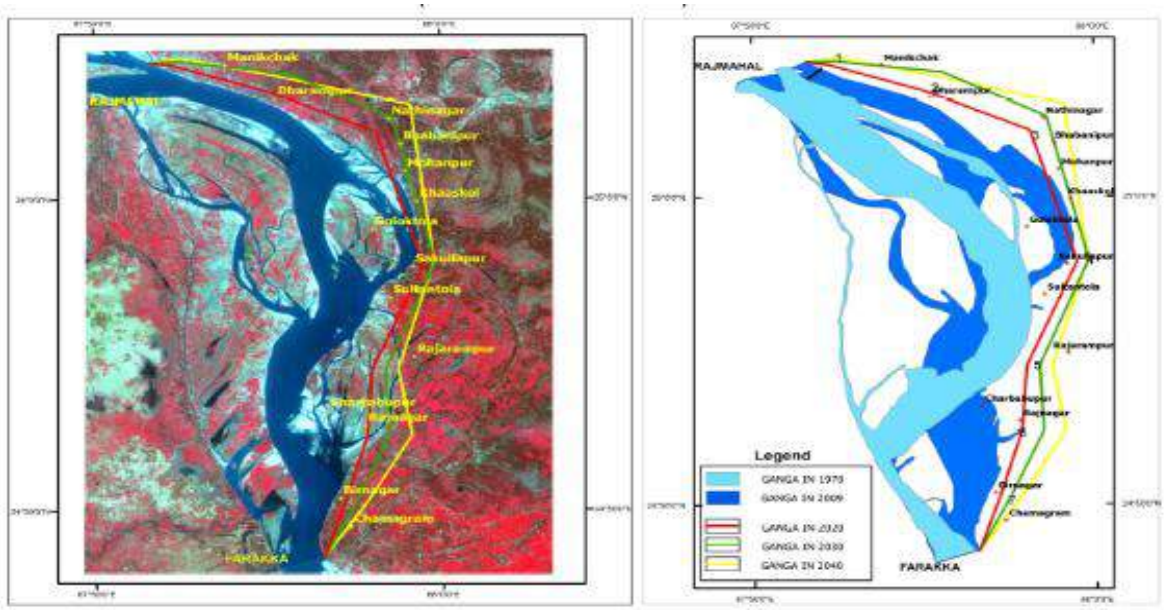


Figure 2.3 Future Statistical Scenario of Ganga in 2020, 2030 and 2040 (Das *et al.* 2012)

Sinha and Ghosh (2012) compared 1971 and 2004 maps which showed more remarkable changes in the study area. Immediately upstream of Farakka, the narrow, straight channel of 1971 was transformed into a very broad channel by 2004 encompassing numerous mid channel bars. Significant changes were also noticed downstream of Rajmahal where meandering became more pronounced by 2004. As a result, significant deposition occurred on the concave side of the channel producing a large point bar complex. Significant amount of sediments started to get trapped upstream of the barrage perhaps soon after the construction started in 1961 and large sand bars formed just upstream of Farakka barrage particularly along the western margin. In consequence to bar growth, the river started to migrate further towards the east and developed a conspicuous bend towards north-east which continues till date. This bend raised the concern for the river flanking the barrage and has led to extensive bank protection measures in recent years both upstream as well as downstream of the barrage.

Gain and Giupponi (2014) studied the impact of Farakka barrage on the Lower Ganges River flow by comparing threshold parameters for the pre-Farakka period (1934-1974) and the post-Farakka period (1975–2005). Their results demonstrated that due to water diversion by the Farakka barrage, various threshold parameters, including the monthly mean of the dry season (December–May) and yearly minimum flows, have been altered significantly.

Schwenk *et al.* (2016) studied the planform changes of large, active meandering rivers at high spatiotemporal resolutions. Through mapping of annual planforms at Landsat-pixel scale of 30 m, their results provided a basis for determining controlling factors on local planform changes and contextualizing them within the broader reach. They also introduced the RivMAP toolbox, which provides intuitive, easily-customized, and parallelizable Matlab codes for analyzing meandering river masks derived from satellite imagery, aerial photography. Based on estimates of uncertainty associated with classifying and compositing Landsat data, their techniques can provide meaningful annual morphodynamic insights in large rivers from Landsat imagery. With current Landsat data, over a dozen large, tropical meandering rivers, e.g. the Mamoré, Beni, Juruá, Fly, and Sepik Rivers, were ideal candidates for quantifying morphodynamic changes and identifying process controls on planform adjustments from Landsat imagery.

The Ganga River, India's national river, drains 2,525 km long distance and the basin covers an area of about 10,60,000 km^2 which is 26.2% of the total surface area of India (Singh 1971). The hydrology of the Ganga River is largely controlled by monsoon season rainfall and seasonality over the centuries and the river carries high discharge throughout the monsoon season but remains with low discharge during the non-monsoon period. Flood is another very common hydrological event of the river and has a key role in shaping the river hydrology along with the morphological structure (Singh 2007; Singh *et al.* 2007). However, the hydrological scenario of the river was modified abruptly particularly in the down-stream of the barrage after the commission of Farakka barrage in 1975. Since then the distribution of discharge of the Ganga River has become both a morphological as well as a political issue between India and Bangladesh (Rudra 2010).

Sinha (2005) reported that Gangetic plains exhibit remarkable geomorphic diversity, which characterized the rivers to be dominantly aggradational in the Eastern Gangetic Plains (EGP) and degradational in the Western Gangetic Plains (WGP). Data available from the Ganga river in the WGP suggest that Q_{maf} (mean annual flood) generally does not exceed the bank full discharge and therefore rivers rarely flood in this region. Flood damage reports also suggested that the area affected by floods in the WGP was almost half (~20%) of that in the EGP (~39%). Data on sediment yield of different rivers of the EGP and WGP (Figure 2.4) also indicated that the sediment supply from the upstream Himalayan catchment was variable from west (UP plains) to east (Bihar plains). The WGP rivers such as the Ganga (at

Haridwar) and Yamuna (Allahabad) were characterized by low sediment yield of 150–350 t/km^2/yr, while the EGP rivers such as the Kosi (at Barakshetra) and Gandak (at Triveni) rivers are characterized by much higher sediment yield of 1500–2000 t/km^2/yr.

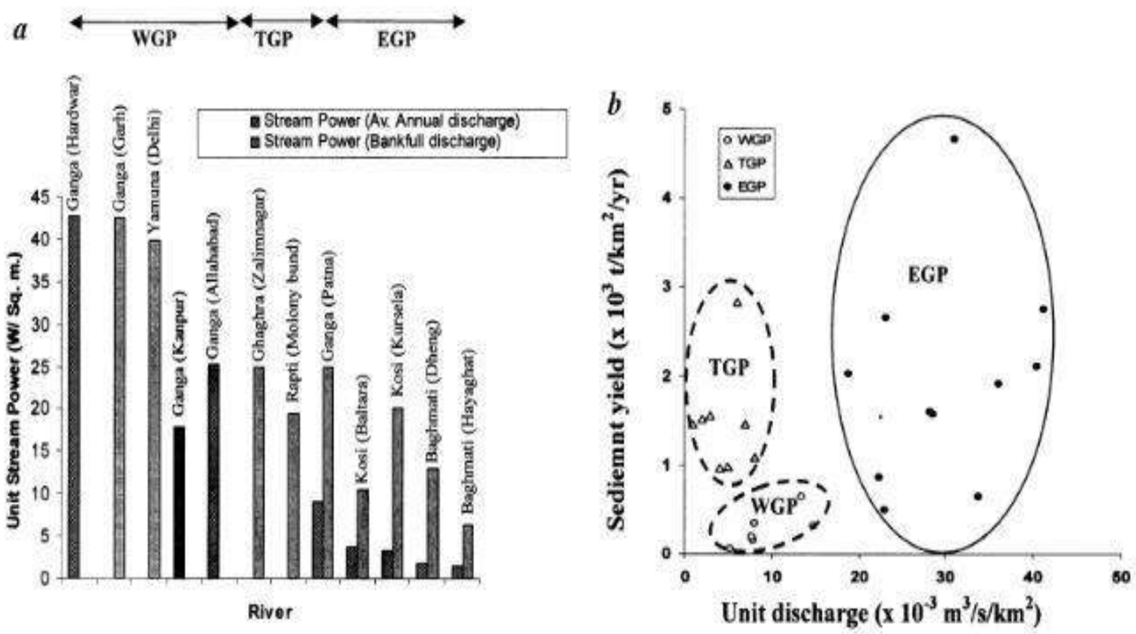


Figure 2.4 Comparison of (***a***) Unit stream power and (***b***) sediment yield of the rivers of the WGP and EGP. Unit stream power was computed using both average annual discharge and bank full discharge (Sinha 2005).

The rivers in the WGP have an order of magnitude higher stream power and have a much lower sediment yield, and this has resulted in degradation of their channel bed and development of incised channels with stable banks. With continued aggradation due to higher sediment supply, channel slope would tend to decrease, thereby decreasing stream power. Incised rivers in a degradational setting such as in the western Gangetic plains were confined and stable and showed no significant channel movements. Except some localized channel movements in Ghaghara, Rapti and Sarda in the UP plains, no large scale channel movements were reported from this area. These rivers are also not prone to flooding due to deep and incised valleys which seldom allow the water to overtop the banks. On the other hand, in areas of high sediment supply and aggradational setting, channels are prone to avulsions due to sediment logical readjustments often triggered by neotectonic movements.

Roy and Sinha (2007) analysed the confluence dynamics in the Ganga–Ramganga valley in the western Ganga plains using multi-date remote sensing images and topographic sheets for a period spanning nearly 100 years (1911–2000) indicating that new confluences were created during this period and that the confluence points had moved both upstream and downstream on a historical time scale. Major processes influencing the movement of confluence points were avulsion, local movements by cut-offs, river capture and aggradations. While the river capture has moved the confluence point upstream, the aggradations in the confluence area had moved the confluence point downstream. Avulsion moves the confluence point both upstream as well as downstream. Hydrological variability in terms of flood magnitude was recognized as one of the most important factors triggering avulsions of river channels into pre-existing channels thereby moving the confluence points. Several cut-offs and a local river capture event through lateral erosion just upstream of the confluence was identified in the study area and influenced the upstream movement of the confluence point.

Chakrapani and Saini (2009) studied the temporal variation in sediment in Alaknanda and Bhagirathi rivers (forming Ganga) and found large variation in suspended sediment load in monsoon and non-monsoon season. However, sediment load contribution from Alaknanda was greater than that from Bhagirathi.

Roy and Sinha (2014) analysed thirty years of mean monthly discharge data from various sites of the Ganga river (Garhmukteshwar, Fatehgarh, Ankinghat and Kanpur) and found that less than 40% of the flow causes effective sediment transport in the Ganga, and this can be considered as the effective discharge for suspended sediment transport. Alternatively, 50% of the sediment load for all studied sites was moved by a discharge varying between 14 and 40% of the total discharge. They observed that mean annual discharge (RI = 2.33 year) can transport only 0 to 10% of the total available sediments. A high ratio of bank full to effective discharge (Q_b/Q_e) forces the flow lines to be concentrated to the thalweg position and channels were incised.

Densmore *et al.* (2015) investigated the timing and volumes of sediment storage and release in the Dehradun, a piggyback basin developed along the Himalayan mountain front in northwestern India. Based on Optically Stimulated Luminescence (OSL) dating, they showed evidence for three major phases of aggradation in the Dun.

Pal and Pani (2016) studied the impacts of seasonality, floods and the construction of Farakka barrage on hydrology of Ganga River and it has been executed with the help of Landsat satellite images, satellite based discharge data and Gumbel’s flood frequency analysis. Their results show that the magnitude of the floods in terms of their maximum daily discharge and flood volume is higher in the up-stream than in the downstream of Farakka barrage.

Dingle *et al.* (2016) studied the basin-wide variability in incision and aggradation of the river systems across the Ganga Plain from digital topography using a swath based technique to map relative elevation of channels above or below their floodplains. They also generated new basin-wide data on subsidence rates and grain size fining rates from the proximal foreland basin near to the mountain front. Their result showed that the degree of channel entrenchment increases from east to west across the Ganga Plain, and also decreases with distance downstream. First-order subsidence velocity estimates suggest a more rapidly subsiding basin in the east Ganga Plain with rates of up to 1.6 ± 0.6mm/yr. Further west, subsidence velocity estimates decrease to as little as 0.3 ± 0.4 mm/yr. Grain size fining rates are also found to closely reflect these patterns of subsidence, with the highest fining rates observed in the east Ganga Plain and lowest in the west. Furthermore, data currently available did not support a strong west to east variation in sediment flux at the thousand year timescale. Assuming that 90 % of sediment delivered into the foreland basin is bypassed downstream, it also seems more likely that the relative fraction of bed load delivered to the basin, which is trapped upstream of the gravel-sand transition, may have a more direct role on channel morphology than the total sediment flux. They proposed that higher subsidence rates are responsible for a deeper basin in the east with perched, low gradient river channels that are relatively insensitive to climatically driven changes in base-level.

2.2 CONCLUDING REAMRKS

Review of the available literature related to morphology of the rivers indicates that various investigators have investigated the morphology of the rivers in respect of its planform change, river shifting, changes in land use and land pattern, erosion and siltation, impact of the structures on the morphology, measures for training the rivers etc. However, a comprehensive morphological study of Ganga river is not available in the literature. In view of this gap, this study has been taken up.

Chapter 3 RIVER BASIN

3.1 GANGA RIVER BASIN

The Ganga, is the biggest river in the Indian subcontinent in terms of water flow. The length of the Ganga is 2,510 km. The river has its origin in the western Himalayan ranges in the state of Uttarakhand. The followers of Hindu religion regard the Ganges to be the most sacred of all the rivers in India. The river is revered as the deity Ganga in Hindu religion. The river also has significant historical values – a number of colonial or royal capitals like Kannauj, Patliputra (modern day Patna), Allahabad, Kara, Baharampur, Murshidabad, and Kolkata are situated on the riverbanks of the Ganges.

The Ganga river catchment basin covers an area of 390,000 sq miles and supplies to one of the maximum populated areas in the world. The average depth of the Ganga river is 16 m or 52 feet and the maximum depth is 30 m or 100 feet. The river has been proclaimed as the national river of India. Ganga basin falls in four countries, namely India, Nepal, Tibet (China) and Bangladesh with major part in India. The drainage area (Fig. 3.1) lying in India is 8,62,769 km^2 which is nearly 26.2% of the total geographical area of the country. Fig. 3.2 shows sample map of Ganga river basin basic layers procured from WRIS. The salient features of the basin are given in Table 3.1.

Table 3.1 Salient features of the Ganga basin (Source: CWC, 2014)

Features of the Basin		
1	Basin Extent	73° 2' to 89° 5' E 21° 6' to 31° 21' N
2	Area (Sq.km)	10,86,000 (Total) 8,61,452 (within India)
3	Length of Ganga river (km)	2525
4	States in the basin	Uttar Pradesh (28.02%) Madhya Pradesh (21.02%) Rajasthan (13.06%) Bihar (10.86%) West Bengal (8.3%)

		Uttarakhand (6.15%) Jharkhand (5.85%) Haryana (3.99%) Chhattisgarh (2.08%) Himachal Pradesh (0.5%) Delhi (0.17%)
5	Districts (Census 2011)	252
6	Parliamentary Constituencies (2009)	239
7	Average Annual Rainfall (mm)	1,059.74
8	Average Maximum Temperature (°C)	32.05°
9	Average Minimum Temperature (°C)	18.44°
10	Total Population	32,91,55,760
11	Number of villages	2,86,557
12	Highest Elevation (m)	7,512
13	Average Annual Water Potential (BCM)	525.02
14	Live Storage Capacity of Completed Projects (MCM)	4,2060.2
15	Live Storage Capacity of Projects Under Construction (MCM)	18,600.18
16	Total Live Storage Capacity of Projects (MCM)	60,660.38
17	Utilizable Surface Water (BCM)	250
18	Number of Sub Basins	19
19	Number of Watersheds	980
20	Number of Water Resources Structures	Dams - 784 Barrages - 66 Weirs - 92 Anicuts - 1 Lifts - 45 Power Houses - 56
21	Highest Dam	Tehri dam - 260.5 m
22	Longest Dam	Nanak Sagar dam (Uttar Pradesh) - 19.2 km
23	Highest Barrage	Banbasa barrage (Uttarakhand) - 603.5 m
24	Longest Barrage	Giri barrage (Himachal Pradesh) - 619.35 m
25	Number of Irrigation projects	Major - 144 Medium - 334 ERM - 63
26	Number of HE projects	39
27	Number of Ground Water Observation wells	5745
28	Number of Hydro-Observation Sites	318
29	Number of Flood Forecasting Sites	87
30	Water tourism sites	336

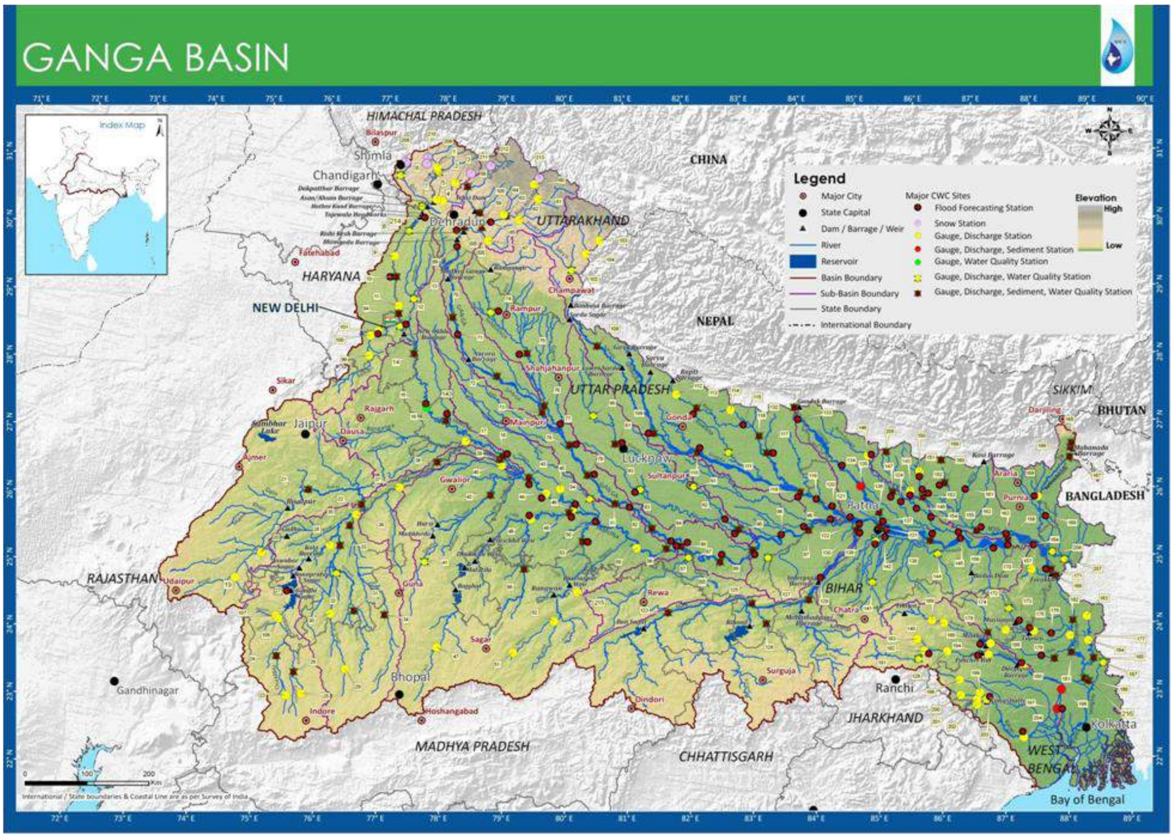


Figure 3.1 Drainage layer of Ganga basin (Source: CWC, 2014)

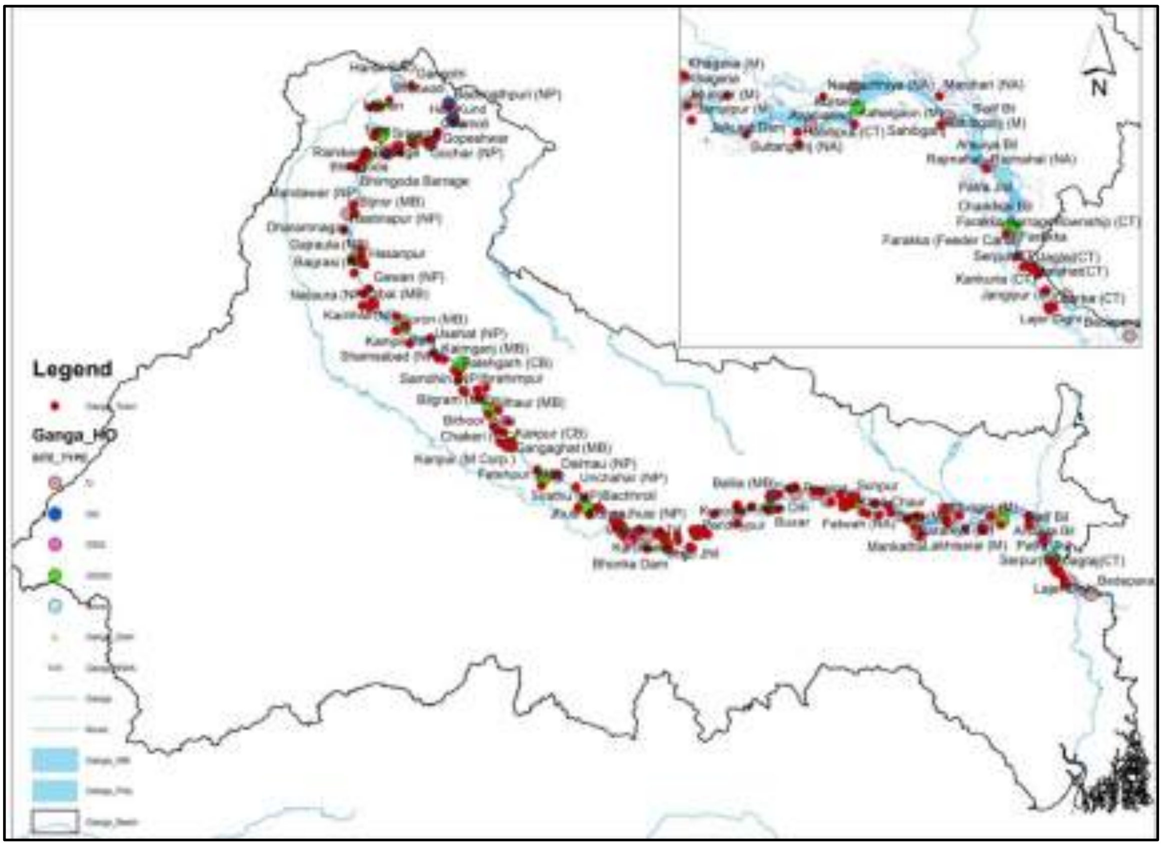


Figure 3.2 Ganga river basin basic layers (Source: WRIS)

3.2 TOPOGRAPHY

The Ganga basin comprises of three large topographic divisions of the Indian subcontinent, namely the Himalayan Young Fold Mountains, the Gangetic Plain and the Central Indian highlands. The Himalayan Fold Mountains comprise the Himalayan ranges including their foot hills with numerous snow peaks rising above 7000 m. Each of these peaks is surrounded by snow fields and glaciers. All the tributaries are characterized by well regulated flows and assured supply of water throughout the year by these glaciers. The Gangetic plains, in which the main stem of Ganga lies, situated between the Himalayas and the Deccan plateau, constitute the most of the sub-basin ideally suited for intensive cultivation. It consists of alluvial formation and is a vast flat depositional surface at an elevation below 300 m.

The Central highlands lying to the south of the Great Plains consists of mountains, hills and plateaus intersected by valleys and river plains. They are largely covered by forests. Aravali uplands, Bundelkhand uplands, Malwa plateau, Vindhyan ranges and Narmada valley lies in this region. The Gangetic plains are mostly divided into three parts, Upper Ganga plains, Middle Ganga plains and Lower Ganga plains. The Upper Ganga plain is the part of the Great Plains lying approximately between the Yamuna in the west covering the parts of Uttarakhand and Uttar Pradesh. The region is delimited in the north by 300m contour which separates it from the Garhwal - Kumaun Himalaya west of Sharda while the International boundary of Nepal marks the limit towards the east. In the south, the Yamuna demarcates its border with the Bundelkhand.

The axis of the topographic trough paradoxically lies nearer the peninsular block or along the Ganga which traverses the area in a south-southeasterly direction. Thus there is, though not perceptible, a tract adjacent to the foot hills where the slope is higher and has resulted in the preponderance of numerous small streams, assigning a somewhat medium to fine texture to this part. The southern counterparts, particularly north of the Ganga are characterized by the sluggishly-flowing streams like the Ramganga and the Ghaghara studded with ox-bows, sandy stretches (the Bhurs) etc. The topographic diversities produced by the changing river courses are predominantly observed in the Ramganga and the Ghaghara valleys, particularly in their flood plains. The streams such as the Kali, the Hindan, and the Pandu etc. have to go a long way parallel to their master streams to empty themselves.

Distinct, though areally insignificant, in topographic expressions is the Yamunapar or the Yamuna-lower Chambal tract. The deep valley separated by sharp spurs and buttresses are the main features of Upper Ganga Plain. Topographically most significant and complex part of the region is the submontane belt, running at the foot of the Siwaliks from west to east across the area on the northern border consisting of the two parallel strips, the piedmont zone, the Bhabar (the Doab region) and the adjoining relatively gently sloping Tarai belt. The Middle Ganga Plain is the largest among the three plains of the Ganga. It covers the Bihar plains and the Eastern Uttar Pradesh lying on the either side of the Ganga and the Ghaghara within the Himalayan and the peninsular ramparts on the north and the south respectively.

Structurally the region is the segment of the great Indo-Ganga trough; however it has some marginal portions of the other two major formations that are Siwaliks in the northern part of the Champaran district and the fringes and the projections of the peninsular block in the south. In general, it is below 100 m above the sea level, except that is gradually rises from Domariaganj in Basti up to 130 m in the north west and up to 150 m in the south incoperating the projections of the southern uplands; in the east the Kosi plain ranges between 30 m in the south to 75 m in the extreme north. A more pronounced relief is occasioned when the plain meets the hilly area in the north bearing the stamp of their loosely-set gravelly nature, particularly in the extreme north, where the surface appears to be broken by large rivers like the Ghaghara, the Rapti, the Gandak, the Bagmati, the Kosi etc., which comb the region with their effluents in an intricate pattern.

The Lower Ganga Plain includes the Kishanganj district of Bihar, whole of West Bengal excluding the Purulia district and the mountainous parts of Darjeeling district and most of the parts of Bangladesh. The region embraces the area from the foot of the Darjeeling Himalayas in the north to the Bay of Bengal in the south and from the edge of the Chottanagpur Highlands in the west to the border of Bangladesh and Assam in the east. Topographic expressions in the region hardly speak of any well defined stage of their evolution. The monotonous surface is dissected frequently by the channels of the tributaries or distributaries of the main stream, the Ganga. There are (i) the Malda west Dinajpur tract where the inliers of the lateritic alluvium are sufficient to break the general monotony of the plain, (ii) the tract bordering the Chottanagpur Highlands, (iii) the Midnapore Coast where the sand dunes on the terraces appear to be more significant element of landforms, (iv) the Duars of Jalpaigurl and Darjeeling.

To the east of the shoreline lies, bulge of the Ganga (Sundarbans) where the depositional activity of the stream is prominent and new surface is being continuously added. As per Digital Elevation Model (DEM) obtained from Shuttle Radar Topographic Mission (SRTM 90 m), the elevation of Ganga basin ranges from 8000 m to 0 m (near Coast) and its variations are shown in Fig. 3.3. The terrain of the basin is very rugged in the north-eastern part and flat towards downstream side. The Himalayan region of the basin contains nine of the fourteen highest peaks in the world over 8,000 m in height, including Mount Everest which is the highest point of the basin. The other peaks over 8,000 m in the basin are Kangchenjunga, Lhotse, Makalu, Cho Oyu, Dhaulagiri, Manaslu, Annapurna and Shishapangma. The Himalayan portion of the basin includes the southeastern portion of the state of Himachal Pradesh, the entire state of Uttarakhand and the extreme north-western portion of the state of West Bengal. Major area of the basin falls within 300-500 m elevation zone (CWC, 2014).

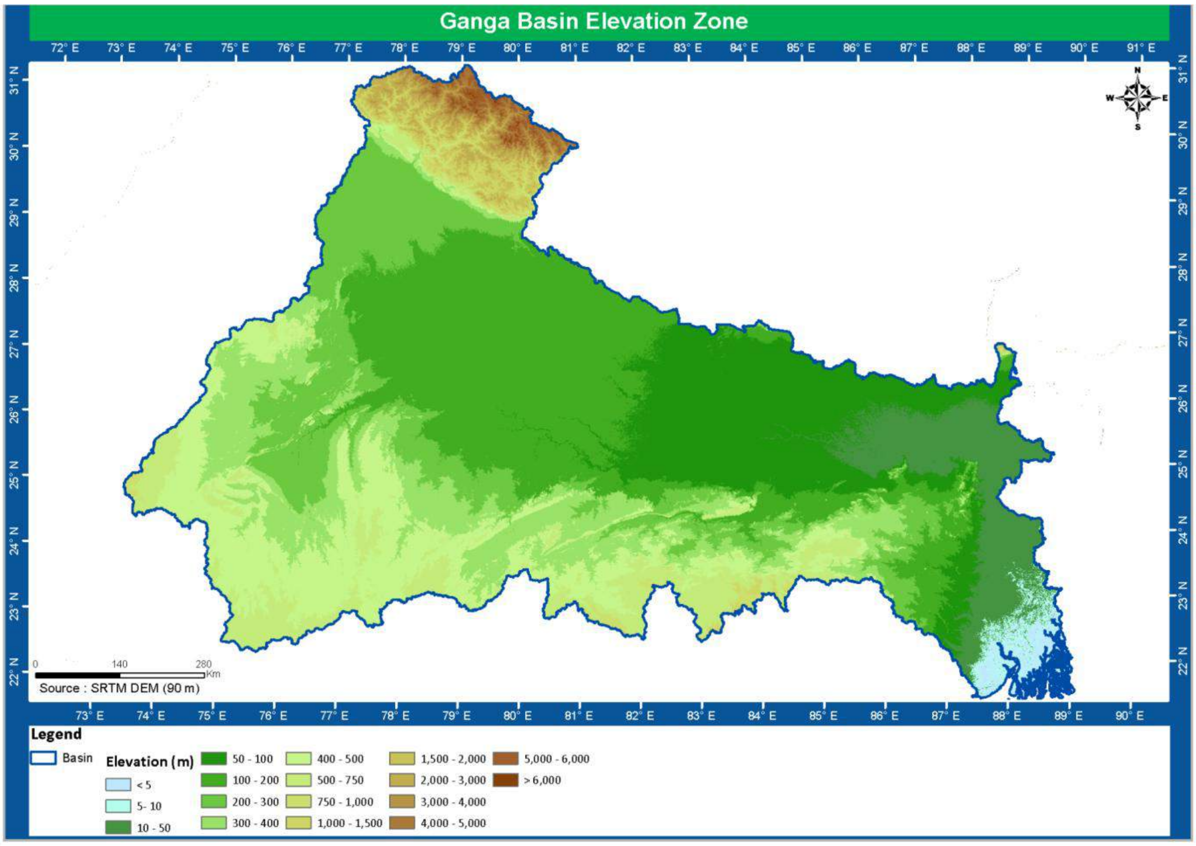


Figure 3.3 Elevation zones (Source: CWC, 2014)

3.3 CLIMATE

In India, four distinguishable temperature zones exist: tropical, sub-tropical, temperate and alpine. Among these, the tropical zones and subtropical temperature zones are most dominant in the entire Ganga basin. The tropical zone in the basin has a mean annual temperature over 24°C and mean temperature of the coldest month over 18°C and subtropical temperature zone has a mean annual temperature over 17°C - 24°C and mean temperature of January over 10°C - 18°C. The hydrologic cycle in the Ganga basin is governed by the southwest monsoon. About 84% of the total rainfall occurs in the monsoon from June to September. Consequently, stream flow in the Ganga is highly seasonal and the seasonality of flow is so acute that it even causes flood situation in the plains.

3.3.1 Temperature

The Ganga basin forms an extensive bowl of warm air, especially during the day-time. The mean maximum daily temperature even in the coldest month (January) does not fall below 21°C, except in the higher hills, whereas the air temperature starts rising rapidly all over Ganga basin from March onwards, beginning a hot season that prevails from April to June. Usually, May is the hottest month in most part of the basin, except in lower Bengal. As per IMD grid data analyzed under this project, the average annual mean temperature of Ganga basin of 35 years (1969-2004) is 24.8°C. The average annual maximum temperature of Ganga basin of 35 years (1969-2004) is 31.2°C and annual maximum temperature was noted on 1987 is 32.05°C. The average annual minimum temperature of Ganga basin of 35 years (1969-2004) is 18.44°C and annual minimum temperature was noted on 1971 is 17.68°C. The average of daily minimum, maximum and mean temperature from January to December of 35 years is shown in the Fig. 3.4.

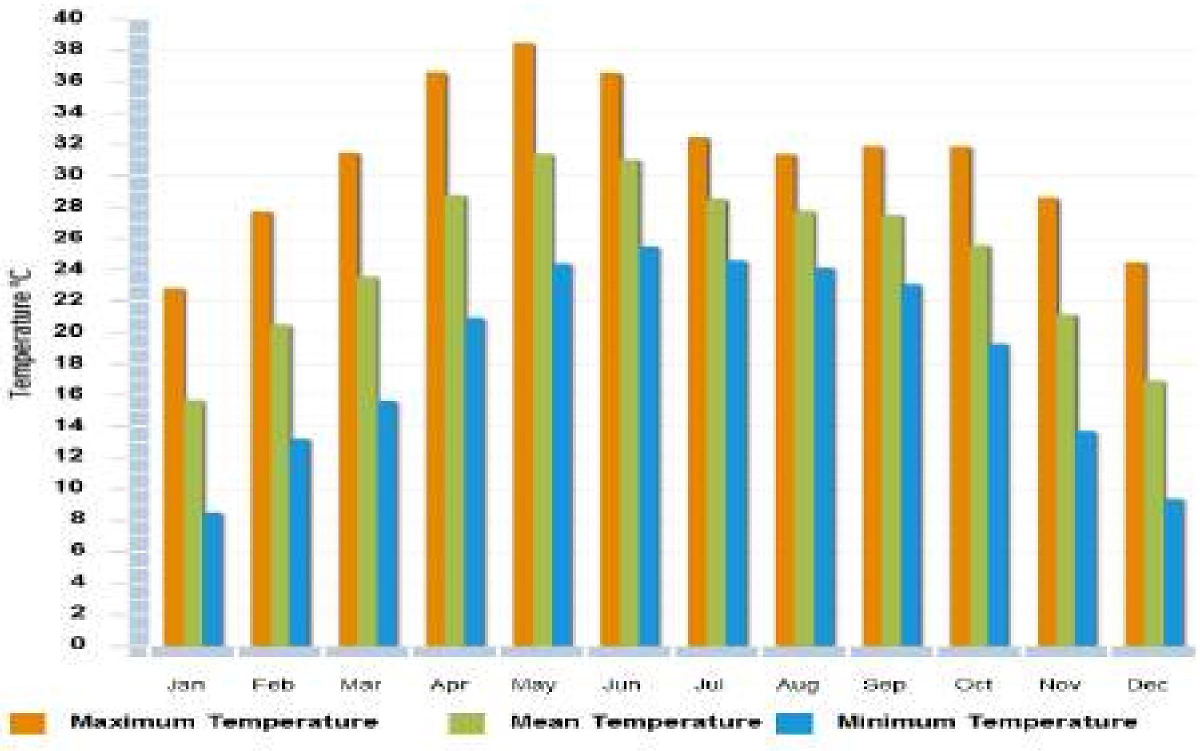


Figure 3.4 Monthly average temperature (1969-2004) (Source: CWC, 2014)

3.3.2 Rainfall-Runoff

The weather in the Ganga basin is characterized by a distinct wet season during the period of south west monsoon (June to September). The southwest monsoon causes rainfall at the mouth of the Ganga around the first week of June and advances upstream. By the end of July the monsoon reaches the western end of the Ganga basin. In the majority of the basin, the rainy season spreads over three months (July, August and September) and usually 70-80% of the total annual rainfall occurs during this period. In the eastern part of the basin, such as in West Bengal and Bihar, the wet season is longer, usually starting in June and continuing until the end of September or early October.

The average annual rainfall for Ganga basin varies from 400 - 2000 mm as is depicted in the Fig. 3.5. Based on the value of rainfall received in the area for 34 years (1971-2005), the Ganga basin can be broadly classified into 11 zones. About 27.31% of total area of Ganga basin receives a rainfall of 1000-1200 mm, 23.14% area receives 800-1000mm, 15.51 percent area of the basin receives 600-800 mm and 14.29% of basin area receives 1200-1400 mm.

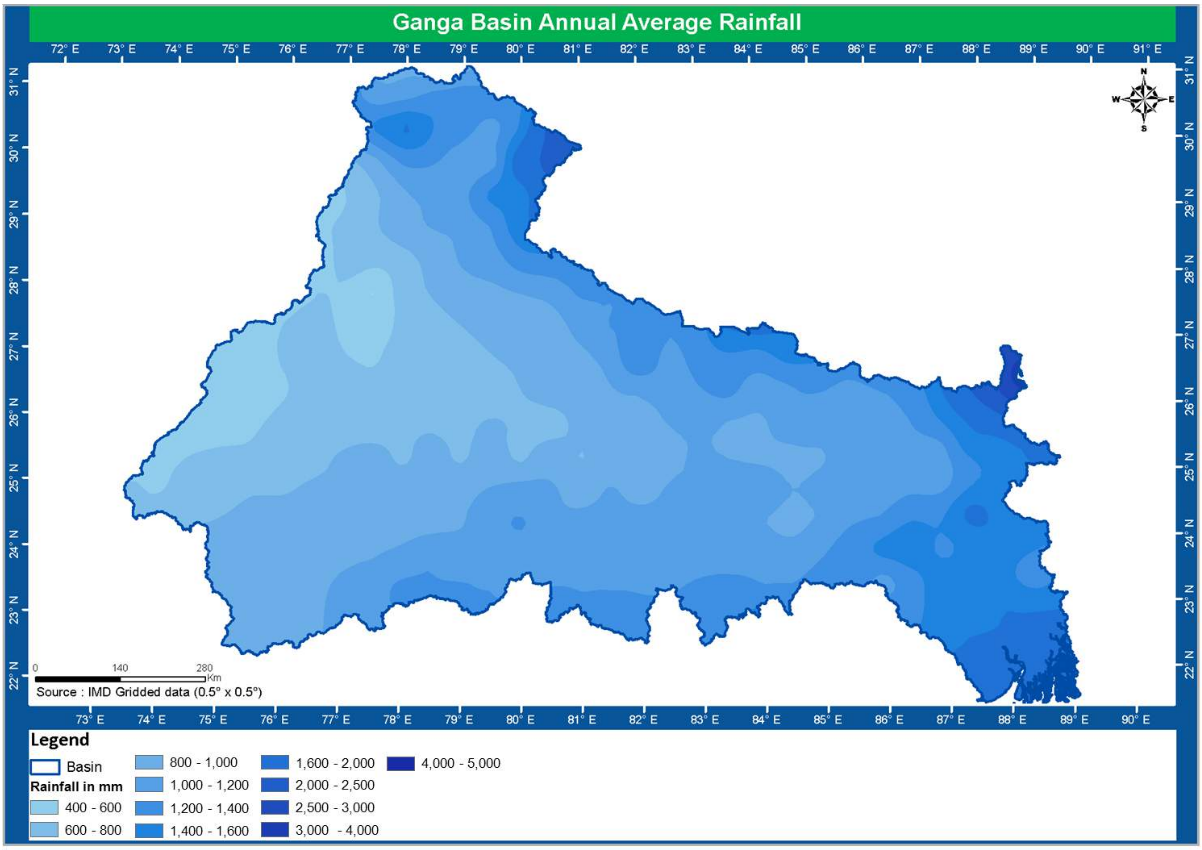


Figure 3.5 Annual average rainfall (Source: CWC, 2014)

Shah and Mishra (2016) estimated water budget in the Indian sub-continental river basins for the pre and post 1948 periods. They also highlighted the influence of large-scale climate variability on surface water availability in the sub-continental River basins. The details of surface water availability, mean precipitation and water budget for Ganga river basin are given below:

(a) Changes in the Monsoon Season surface water availability

Figure 3.6 shows mean and trends in the monsoon season surface water availability/runoff in the Indian sub-continental river basins. Mean monsoon season surface water availability varied between 50 to 1500 mm with higher values in the northeastern and Western Ghats regions and lower values in the peninsular India and western part of the Indian sub-continent (Figure 3.6a). During the monsoon season, mean surface water availability was relatively lesser in the lower Indus, western Ganges, Sabarmati, and peninsular river basins while higher in the Brahmaputra and river basins (e.g. Mahanadi, Brahmani, eastern Ganges, and Krishna) located in the core monsoon region (Figure 3.6a).

A significant decline in surface water availability was noticed in parts of the Ganges basin during the period of 1948-2012 (Figure 3.6c and 3.6e) (Shah and Mishra, 2016).

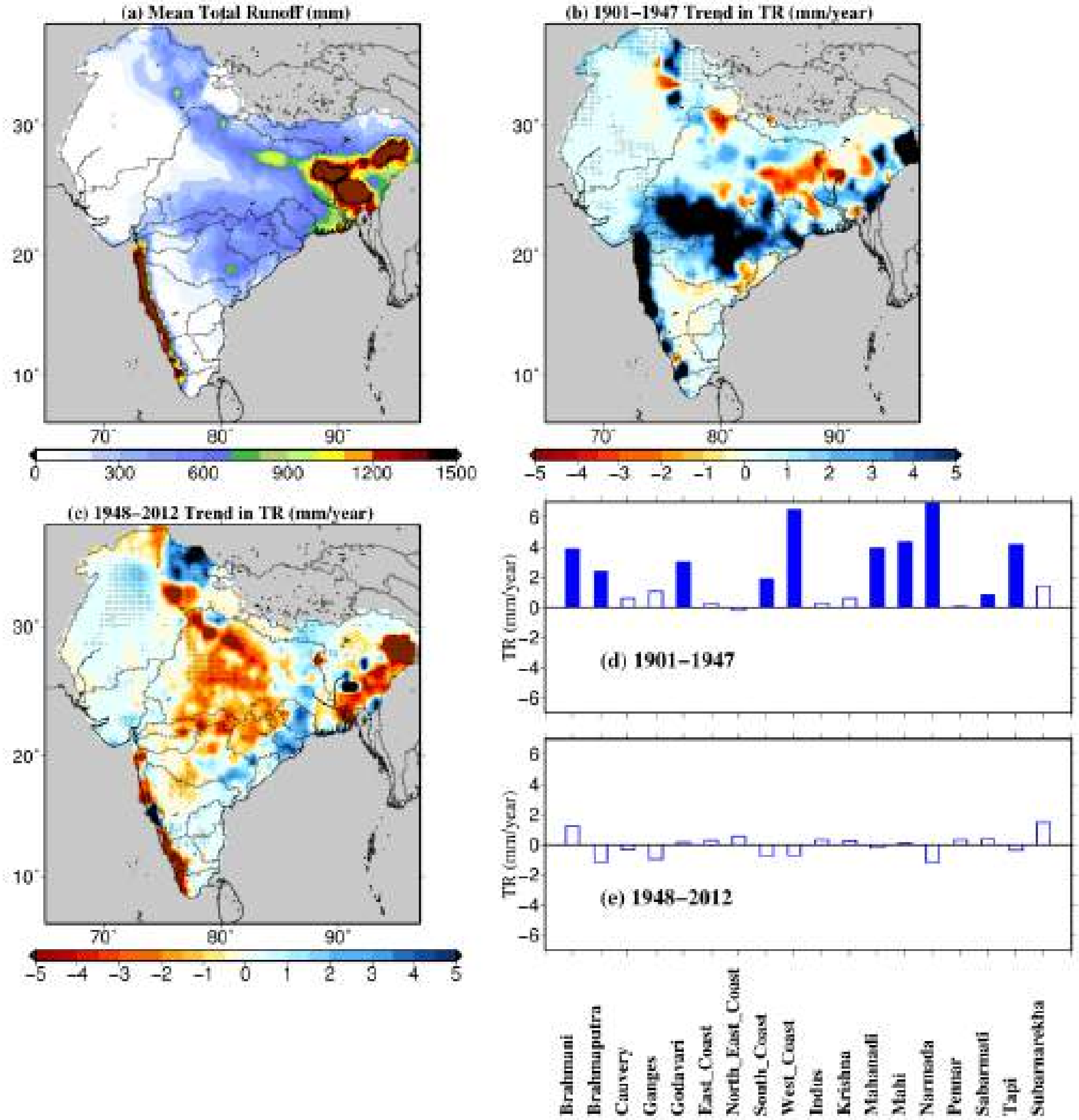


Figure 3.6 (a) Mean total runoff/surface water availability for the monsoon season during the period of 1971-2000, (b) trend (mm/year) in total runoff during the period of 1901-1947 estimated using the Mann-Kendall test, (c) same as (b) but for the period of 1948-2012, (d) trend in the monsoon season total runoff for the selected river basins for the period of 1901-1947, and (e) same as (d) but for the 1948-2012. Hollow bars in (d, e) show non-significant trends while solid bars represent significant trends for the selected periods of 1901-1947 and 1948-2012 (Shah and Mishra, 2016)

(b) Changes in basin averaged mean in the post-1948 period

They estimated changes in basin averaged mean monsoon season precipitation, evapotranspiration (ET), and surface water availability for the pre and post 1948 periods are shown in Figure 3.7. The Ganges basin experienced decline of 8% in mean monsoon season surface water availability during the post 1948 period. They found that mean monsoon season changes in (ET) and surface water availability were strongly related to the changes in precipitation rather than air temperature. For instance, mean monsoon season changes in air temperature did not show a strong association with the changes in evapotranspiration for most of the sub-continental river basins. However, a strong relationship between changes in precipitation and changes in ET was found in the sub-continental river basins. These results highlight that the historic changes in ET and surface water availability were largely driven by the changes in precipitation rather than changes in air temperature.

(c) Annual and the monsoon season water budget in the Ganga River

Annual water budget components are as follow:

	Period 1901-1947	Period 1948-2012
Precipitation P (mm) :	1166.4 mm	1112.9 mm
Evapotranspiration ET (mm)	578.7 mm	569.2 mm
Total runoff/surface water availability, TR (mm)	571.4 mm	532.7 mm
Evaporative (ET/P) %	49.60	51.10
Runoff (TR/P) ratios %	49.00	47.90

The monsoon season water budget components are as follow:

	Period 1901-1947	Period 1948-2012
Precipitation P (mm) :	971.7 mm	923.0 mm
Evapotranspiration ET (mm)	327.7 mm	320.9 mm
Total runoff/surface water availability, TR (mm)	462.7 mm	426.0 mm
Evaporative (ET/P) %	33.7	34.8
Runoff (TR/P) ratios %	47.6	46.2

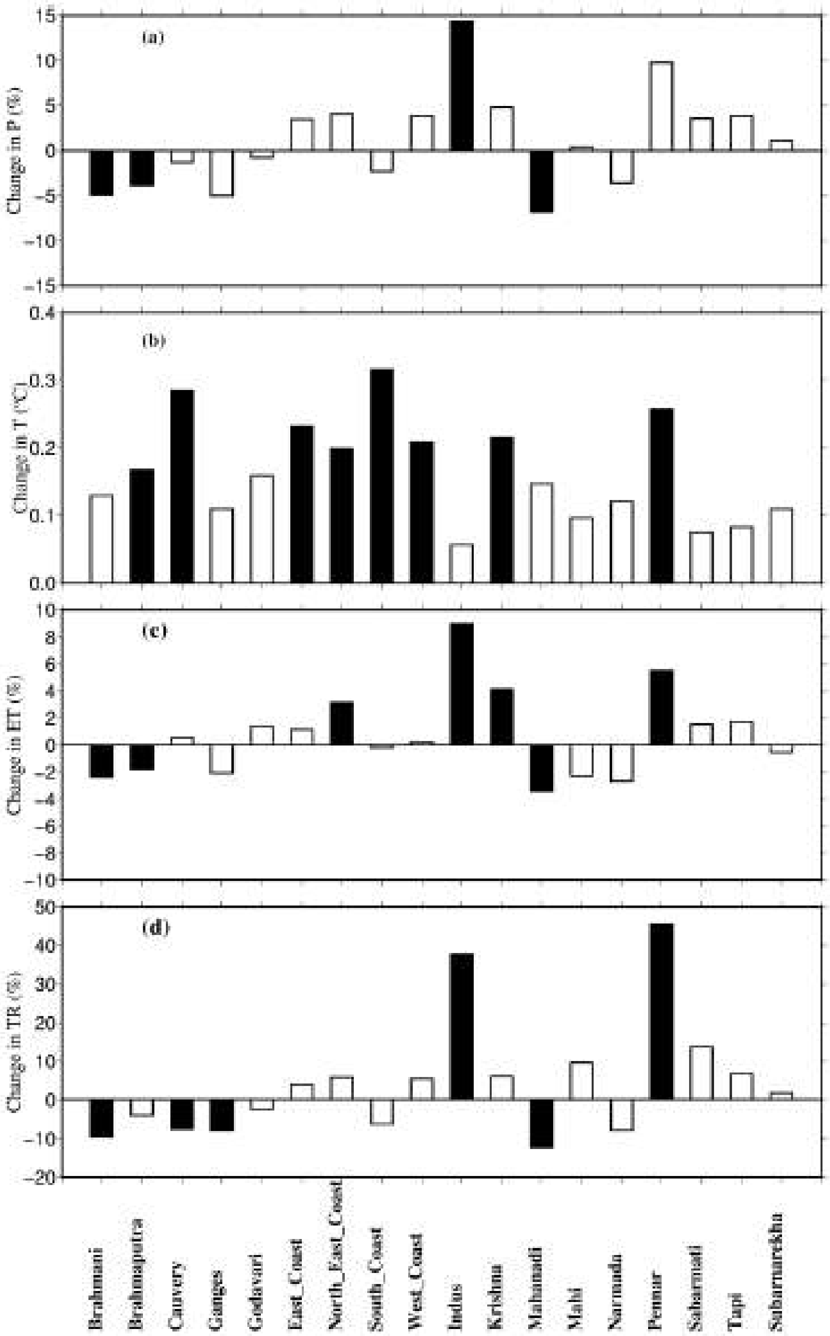


Figure 3.7 Change in the monsoon season mean air temperature, precipitation, evapotranspiration, and total runoff/surface water availability during the 1948-2012 period with respect to the 1901-1947 period. Solid bars show significant changes in mean during the recent periods at 5% significance level estimated using the two-sided Ranksum Test (Shah and Mishra, 2016)

During the period of 1948-2012, mean monsoon season and also annual precipitation declined in the Ganga river.

Changes in mean monsoon season water budget components during the 1948-2012 periods with respect to 1901-1947 periods.

Precipitation = -5.0%

Air Temperature = 0.1 ^{0}C

Evapo-transpiration = -2.1 %

Total runoff/surface water availability = -7.9 %

Declining trend in the monsoon season precipitation has been reported in several studies (Mishra et al. 2012; Bollasina et al. 2011), which may be attributed to warming in the Indian Ocean and due to the atmospheric aerosols (Bollasina et al., 2011). Mishra et al. (2012) reported a prominent pattern of year-to-year variability in the Indian summer monsoon rainfall in which declining trend in the Ganges basin is linked with positive sea surface temperature anomalies in the Indian Ocean. Increasing trend in the monsoon season precipitation during the period of 1901-1947 and decline afterward might be also linked with the multi-decadal variability (Krishnan and Sugi 2003). Ganges basin showed significantly declining trends in the monsoon season precipitation during the period of 1948-2012.

3.4 SOILS

Soil is composed of minerals, mixed with some organic matter, which differ from its parent materials in terms of its texture, structure, consistency, color, chemical, biological and other characteristics. Information on the soil profile is also required for simulating the hydrological character of the basin. The Ganga basin consists of a wide variety of soils. While soils of the high Himalayas in the north are subjected to continuous erosion, the Gangetic plain provides a huge receptacle into which thousands of meters of thick layers of sediments have been deposited to form a wide valley plain. The broad soil types in the upper Ganga basin are discussed on the basis of three broad group of landforms found in the area (Pande *et al.*, 1999):

(a) Soils in Lesser Himalayas: The soils of this region vary according to aspect, altitude and climate. On the whole, soils are generally young and with thin cover. However, the considerable depth of the soil may be observed in the valleys or on the gently inclined hill slopes. Due to sharp variations in geo-ecological conditions, the soils of this region do not form a complete group. This part is conspicuous for its wide range of parent material, vegetal cover, eco-climatological conditions, relief and topography which have given rise to a number of soil characteristics in this region. The vegetal cover is one of the most influencing factors characterizing the soil types in a particular region or locality. Soils on the slopes above 30°, due to erosion and mass-wasting processes, are generally shallow and usually have very thin surface horizons. These are skeletal soils and have medium to coarse texture depending on the type of material from which they have been derived. Valley soils are developed from colluvium and alluvium brought down from the upper slopes and, thus, is deposited in the valleys and low-lying tracts or river terraces as a process of aggradation. The southernmost zone, immediately below the foothills, has generally clay loam, loam and sandy loam soils.

Climatic differences in respect of temperature and water supply leads to development of distinct soil types in northern and southern aspects of the hills. These soils are deep to very deep and excessively drained. The soils of northern slope under forest cover are characterized by moderately deep to deep and excessively drained. These soils are gravelly loam to clay loam in texture and dark grayish brown to strongly brown in colour. The structure is poorly developed due to gravels and stones.

(b) Soils in Siwalik Structural Hills: Siwalik hills lies in the southern side of the area. These hills are located between lesser Himalayan mountain and Siwalik hills. They are moderate sloping to strongly sloping under dense to moderately dense forest cover. The soils are dark brown to very dark grayish brown in colour. The soils are moderately deep to deep and loam to clay loam in texture. These soils are excessively drained and highly eroded.

(c) Soils in Piedmont/ Flood plains: Sediments are deposited in River Ganga, and form the fluvial regions, known as flood plains. The soils vary considerably in soil moisture characteristics and sedimentation patterns. These areas are mostly under cultivation. The soils are very deep, pale brown to grayish brown developed from alluvium on very gentle to gently sloping terraces. The soils have fine loamy texture and are moderately well drained.

The Deccan plateau in the south has a mantle of residual soils of varying thickness arising out of weathering of ancient rocks of the peninsular shield. In certain parts of the Ganga basin, the soils are already showing signs of salinity (as in Haryana), alkalinity (as in western U.P.), calcareousness (as in north Bihar) and acidity (as in West Bengal) due to overuse, long occupation and continued application of inputs like excessive irrigation water and toxic agro-chemicals of various types.

Among the soil types within Ganga basin, the alluvial soil covers more than 52 percent of the basin. The alluvial deposits of the basin not only cover the great Gangetic trough, but also extend over a sizable portion of the peninsular foreland in the form of a layer less than 3 m thick. The entire alluvial formation is endowed with rich soil nutrients. The alluvial deposits of the Ganga and its tributaries, coming down the Himalaya and the peninsular foreland, have yielded annual harvests of crops for the past thousands of years with little significant deterioration. It was noted that the soil texture of most parts of the Ganga basin is fine texture but some parts of Uttarakhand and Bihar has a rocky texture and a course texture is noted in the parts of Haryana and Rajasthan. In the Upper Ganga plains, the soils are by and large homogeneous. The alluvial soils with the variants, the Usar and Bhur, depending on the drainage conditions, mechanical and chemical constituents and climatic characteristics observed. The two common types, the *Khaddar* and the *Bhangar* with different local names, with minute variations in properties, are quite widespread.

The khaddar soils, relatively rich in plant nutrients, occupy the narrow frequent siltation tracts in the flood plains of the rivers. Neutral to alkaline in reactions, these are deficient in organic materials especially phosphorous, and are sandy to loamy in texture. In the proximity of the Ganga these are loamy to sandy loam in texture i.e. Fine to medium texture while near the Yamuna the silt contents decreases giving sandy to sandy loam texture possibly due to excessive drainage. Another variant, the bhur, the sandy river deposit, is highly localized in Ramganga tract and in the narrow belt along the Ganga. The soil is more sandy in texture and workable economically only with irrigation.

Apart from the undifferentiated soils of the Siwalik fringe zone in Champaran district of Bihar, the Middle Ganga plain has broad alluvial soil. Being a common origin and almost identical ecological environment, they show in general minor variation in color, texture and moisture content etc. Because of the better drainage, except in the river beds, newer alluvial soil contains a low percentage of humus and nitrogen and little lime and consists of fine silts but may be sandy in the places as along the Ghaghara, the Gandak, and the Sone. Being more sandy or silty, it is highly friable and is rich for the rabi, zaid crops and such as annuals as sugarcane. The Bhat or calcareous soil of the eastern Saryupar and central-western North Bihar plains in the lower Gandak valley is a chemical variant of the alluvial soil. It is white in color, riverine and low lying but well drained, good for tilth and highly fertile and having high productivity.

The soil of the Lower Ganga plain has wide variety and can be groped as Laterites, red earths soils, alluvial soils and the Coastal soils. The laterite soils found in the undulating well-drained tract along the Chottanagpur highlands and possess low water-holding capacity and usually Sal forests thrive. The transported laterites deposited on the eastern flanks of the lateritic stretch are known as red soil or lateritic alluvium and are found in eastern margins of Maldah and Dinajpur districts of West Bengal. Mostly they have been brought under cultivation after deforestation which has accelerated the process of erosion. In the riverine tract of the Damodar and the Kasai have alternating sand beds and immature and irregular stratification and hence ill-developed profiles. The soils in these regions are neutral and relatively poor in plant nutrients and organic matter. The coastal soils are the outcomes of the interactions of rivers and tides and have developed in the districts of South and North 24 Parganas and Midnapore of West Bengal. The soil is saline and alkaline and contains deposits rich in Calcium, Magnesium, and half- decomposed organic matter.

The soil erosion characteristic of Ganga basin is having a general pattern of slight erosion; however some of the soils are highly susceptible to erosion. Mountain soils, submontane soils and alluvial soils, covering 58 percent of the basin area, have very high erodibility; red soils seen in the parts of Jharkhand, Chhattisgarh, Madhya Pradesh and West Bengal covering 12 percent of the basin area have severe erodibility, red & yellow soils and mixed red and black soils of Madhya Pradesh, Bihar, Chhattisgarh and Rajasthan covering an area of 8 percent have moderate erodibility, and deep black soils and medium black soils covering an area of 14 percent have low erodibility. Shallow black soils and lateritic soils mostly seen in Chottanagpur highlands covering an area of 6 percent have very low erodibility. Broadly, it can be said that soils in Haryana, Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal, through which is the main stem of Ganga and all its tributaries flow, have very high erodibility.

The basin is mostly having homogeneous terrain in plains leading to a level plain or a very gentle slope in general. But some parts of Uttarakhand, Madhya Pradesh are having a steep slope because of the lesser Himalayas and Siwalik ranges. The lower parts of the basin like Jharkhand, Chhattisgarh and parts of Rajasthan and West Bengal is having a gentle slope.

The productivity in the basin varies in a large extent. The soil productivity is very high in parts of Uttar Pradesh and the parts of Madhya Pradesh, Haryana and Rajasthan have seen less productivity compared to the others. The parts of Uttarakhand are mostly non-productive because of its hilly terrain and steep slope and gigantic drainage system. Besides paddy, this tract produces a wide variety of crops including wheat, jowar, bajra, small millets, pulses of different kinds, maize, cotton, jute and many other food and commercial crops.

3.5 RIVER VALLEY PROJECTS

Various river valley projects existing in study reach are Pashulok barrage, Bhimgoda barrage, CCS barrage, Narora barrage, Luvkhush barrage and Farakka barrage project and their brief description are given in Table 3.2.

Table 3.2 River valley projects

River valley project	Brief description
Pashulok barrage	Pashulok barrage also known as Rishikesh barrage is constructed across Ganga river at Rishikesh, Uttrakhand. This is the first barrage across Ganga river and constructed in 1980 to divert the water into a power channel from its left side which feeds water to Chilla power plant for power generation of 144 MW.
Bhimgoda barrage	Bhimgoda barrage is located at about 17 km downstream of the Pashulok barrage across Ganga river at its foothills. The length of the barrage is 453.5 m. Built as the headworks of the Upper Ganga Canal, an initial barrage was completed by 1854 and replaced twice, the final one was completed in 1983. Two canal systems offtake from this barrage - the Upper Ganga Canal and Eastern Ganga Canal.
CCS barrage	The Chaudhary Charan Singh (CCS) barrage is constructed across Ganga river near Jansath (Uttar Pradesh) in 1984. The barrage is constructed to feed Ganga water into two canals namely Madhya Ganga Canal (MGC) Phase-I (right) and MGC Phase-II (left). MGC Phase-I is functional, however, construction of the MGC Phase-II is underway

Narora barrage	Narora barrage is constructed across Ganga river near Anupshahr (UP) to divert water into two canals namely Parallel Ganga Canal and Lower Ganga Canal. Both canal offtake from right side of the river. Construction of the barrage commenced in year 1963 and completed in 1966.
Luvkhush barrage	LuvKhush barrage also known as Ganga barrage is constructed across Ganga river at Nawanganj Kanpur. The construction of barrage was started in 1995 and completed in May 2000. The purpose of barrage was to supply water to Kanpur city for domestic uses, in addition to bring the main course of Ganga river towards the main township of Kanpur.
Farakka barrage	Farakka barrage is constructed across Ganga river at about 16.5 km upstream of the border of India-Bangladesh near Jangipur, Murshidabad, West Bengal. The construction of the barrage was started in 1961 and completed in 1975. The length of barrage is 2.24 km and number of the spillway gates are 123. A canal named as feeder cannel off takes from the right side of the barrage which is 40 km long and its designed discharge is 40,000 cusec. The purpose of canal is to feed water from Ganga river to Hooghly river for flushing out the sediment deposition from the Kolkata harbor to avoid frequent mechanical dredging.

3.6 CONCLUDING REMARKS

The following points are to be noted:

1) The tropical zones and subtropical temperature zones are most dominant in the entire Ganga basin. The tropical zone in the basin has a mean annual temperature over 24°C and mean temperature of the coldest month over 18°C and subtropical temperature zone has a mean annual temperature over 17°C - 24°C and mean temperature of January over 10°C - 18°C.

2) The hydrologic cycle in the Ganga basin is governed by the southwest monsoon. About 84% of the total rainfall occurs in the monsoon from June to September. Consequently, stream flow in the Ganga is highly seasonal and the seasonality of flow is so acute that it even causes flood situation in the plains.

3) Annual and monsoon season precipitation, evapotranspiration, surface water availability (surface runoff) have decilned in the period 1948-2012 compared to the period 1901-1947, while temperature has rised.

4) Changes in mean monsoon season water budget components during the 1948-2012 periods with respect to 1901-1947 periods are as follows:

   Precipitation = -5.0%

   Air Temperature = 0.1 ^{0}C

   Evapo-transpiration = -2.1 %

   Total runoff/surface water availability = -7.9 %

Chapter 4 STUDY REACH

4.1 THE STUDY AREA

The Ganga river studied in this project work from Devprayag to Farakka barrage lies between longitudes 78°05′00" E to 88°36'30" E and latitudes 24°19'29" N to 30°10′10″ N (Fig. 4.1). The total length of the Ganga river studied in this project is 1,824 km approximately.

The entire length of Ganga river in India can be divided in three stretches, as follows:

- Upper reach from the origin to Narora;
- Middle reach from Narora to Ballia, and
- Lower reach from Ballia to its delta.

In this project, the river course from Devprayag to Farakka Barrage has been studied.

The main physical sub-divisions of the whole Ganga basin are

- The northern mountains, comprising the Himalayan ranges including their foothills
- The Gangetic plains between the Himalayas and the Deccan plateau
- The central highlands, lying to the south of the Great Plains consisting of mountains.

The major part of the geographical area of the Ganga basin lies in India and it is the biggest river basin in the country draining an area of 8,61,452 km^2 which is slightly more than one-fourth (26.3 %) of the total geographical area of the country. In India, it covers states of Uttar Pradesh, Madhya Pradesh, Rajasthan, Bihar, West Bengal, Uttarakhand, Jharkhand, Haryana, Chhattisgarh, Himachal Pradesh and Delhi. However the GIS calculated area of the basin is 8,08,337.11 km^2 (CWC, 2014).

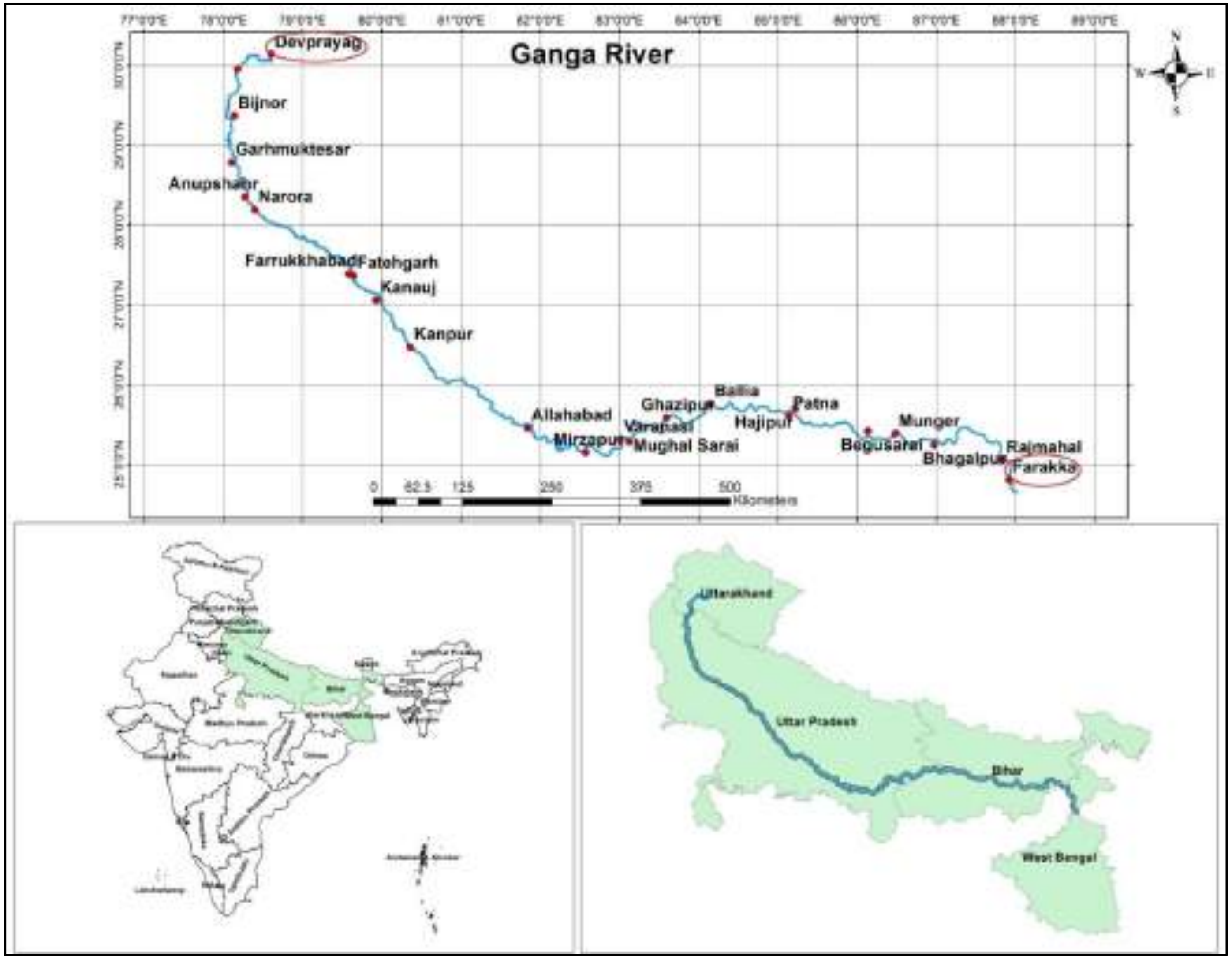


Figure 4.1 The study area

The important tributaries of Ganga river, habitation and water resources projects lying in the study reach (Devprayag to Farakka) are given in Table 4.1.

Table 4.1 Important tributaries of Ganga river, habitation and water resources projects

Important tributaries	Song	Garra	Duar	Gangi	Son
	Solani	Kali	Yamuna	Besu	Gandak
	Malin	Isan	Tons	Karamnasa	Punpun
	Baia	Morahi	Ojhala	Thora Nala	Burhi Gandak
	Mahawa	Pandu	Khajuri	Chhoti Sarju	Kosi
	Ramganga	Loni	Gomati	Ghaghara	Kalindri
Important habitat	Rishikesh	Narora	Allahabad	Buxar	Begusarai
	Haridwar	Farrukhabad	Mirzapur	Ballia	Munger
	Bijnor	Fatehgarh	Mughal Sarai	Chhapra	Bhagalpur
	Garhmukteshwar	Kannauj	Varanasi	Patna	Rajmahal
	Anupshahr	Kanpur	Ghazipur	Mokama	Farakka
Water resources projects (Fig. 4.2)	Pashulok barrage				
	Bhimgoda barrage				
	Chaudhary Charan Singh (CCS) barrage				
	Narora barrage				
	Luvkhush barrage				
	Farakka barrage				

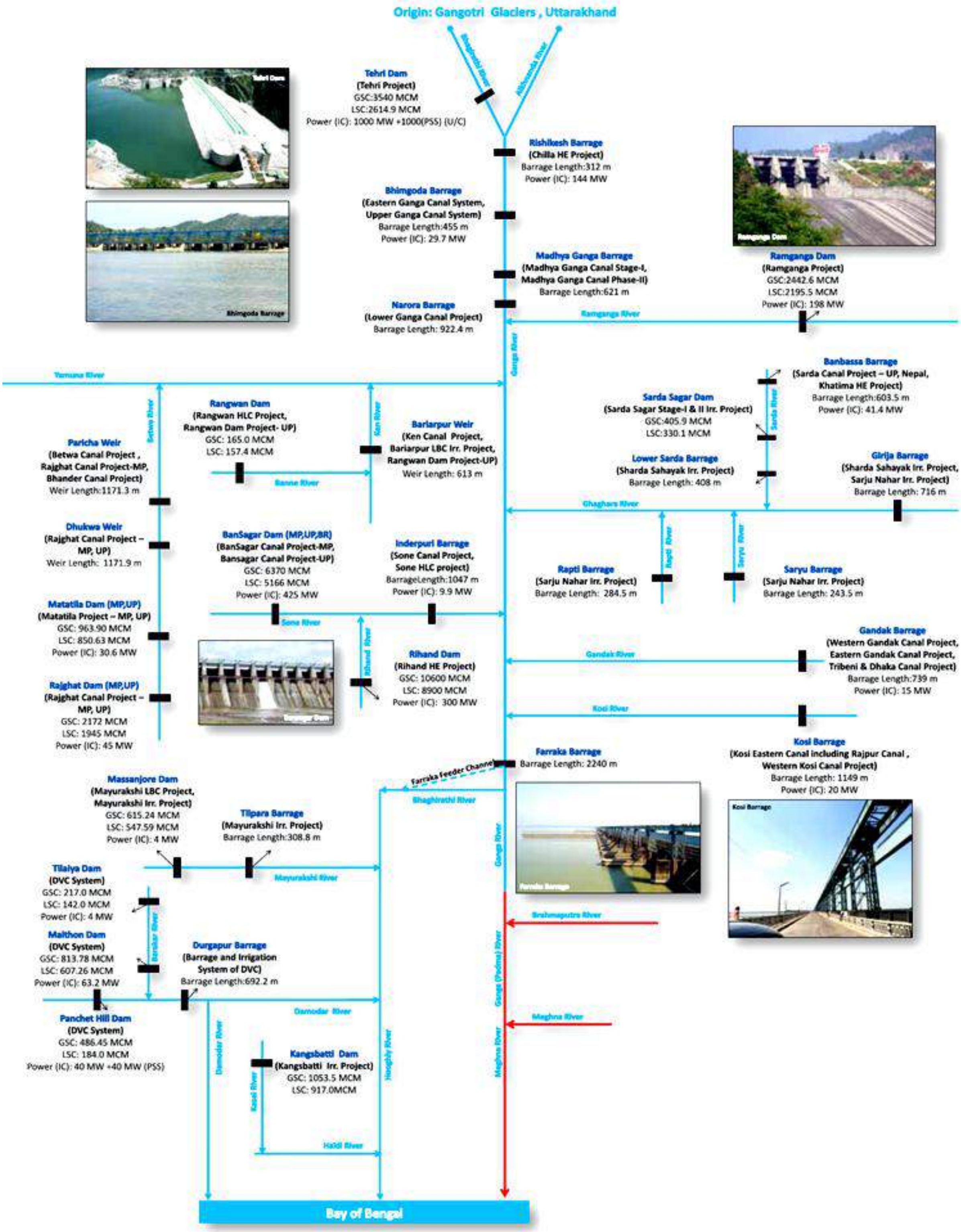


Figure 4.2 Major water resources projects (Source: INDIA-WRIS, 2012)

4.2 CONCLUDING REMARKS

Study reach of the Ganga river which is considered in the present morphological study starts from Devprayag and ends at Farakka barrage. The total length of the reach is 1,824 km and elevation varies from 500 m to 35 m. Ganga river is in hilly area from Devprayag to Haridwar with an average bed slope of 3 m/km. However, the reach from Haridwar to Farakka is flat with an average slope of 0.14 m/km. Being in the hilly area, remarkable morphological changes in the Ganga river from Devprayag to Haridwar is not anticipated, however, it would be pronounced from Haridwar to Farakka.

Chapter 5 INPUT DATA & METHODOLOGY

5.1 HYDRO-METEOROLOGICAL DATA

The various gauging sites on Ganga river from Devprayag to Farakka barrage were identified as given in Table 5.1 and shown Fig. 5.1 and requisition was sent to concerned Chief Engineers of CWC for the procurement of the data comprising 10-daily water level, discharge and silt data and also cross-section data.

Table 5.1 Hydro-meteorological data

S.No.	Gauging site	Type	State	Division
1	Deoprayag (Devprayag)	GDQ, GDSQ	Uttarakhand	Himalayan Ganga Div., Dehradun
2	Rishikesh	GDSQ	Uttarakhand	Himalayan Ganga Div., Dehradun
3	Haridwar	GD	Uttar Pradesh	M Ganga Div. II, Lucknow
4	Garhamukteshwar HO 606	GDSQ	Uttar Pradesh	M Ganga Div. II, Lucknow
5	Narora Barrage HO 1039	GD	Uttar Pradesh	M Ganga Div. II, Lucknow
6	Fatehgarh HO 605	GDSQ	Uttar Pradesh	M Ganga Div. II, Lucknow
7	Ankinghat	GD	Uttar Pradesh	M Ganga Div. II, Lucknow
8	Kanpur HO 621	GDSQ	Uttar Pradesh	M Ganga Div. II, Lucknow
9	Dalmau	GD	Uttar Pradesh	M Ganga Div. II, Lucknow
10	Kachlabridge HO 616	GDSQ	Uttar Pradesh	M Ganga Div. II, Lucknow
11	Bhitaura HO 595	GDSQ	Uttar Pradesh	M Ganga Div. II, Lucknow
12	Phaphamau (Allahabad)	GD	Uttar Pradesh	M Ganga Div. III, Varanasi
13	Chhatnag (Allahabad) HO 579	GDSQ	Uttar Pradesh	M Ganga Div. III, Varanasi
14	Mirzapur HO 628	GDSQ	Uttar Pradesh	M Ganga Div. III, Varanasi
15	Varanasi HO 654	GDSQ	Uttar Pradesh	M Ganga Div. III, Varanasi

16	Ghazipur HO 609	GD	Uttar Pradesh	M Ganga Div. III, Varanasi
17	Ballia HO 584	GD	Uttar Pradesh	M Ganga Div. III, Varanasi
18	Shahjadpur HO 646	GDSQ	Uttar Pradesh	M Ganga Div. III, Varanasi
19	Azamabad	GDSQ	Bihar	M Ganga Div. V, Patna
20	Buxar HO 940	GDSQ	Bihar	M Ganga Div. V, Patna
21	Gandhi Ghat HO 959	GDSQ	Bihar	M Ganga Div. V, Patna
22	Hathidah HO 967	GDSQ	Bihar	M Ganga Div. V, Patna
23	Farakka HO 956	GDSQ	West Bengal	L Ganga Div., Berhampur
24	Farakka (Feeder Canal) HO 957	GDSQ	West Bengal	L Ganga Div., Berhampur

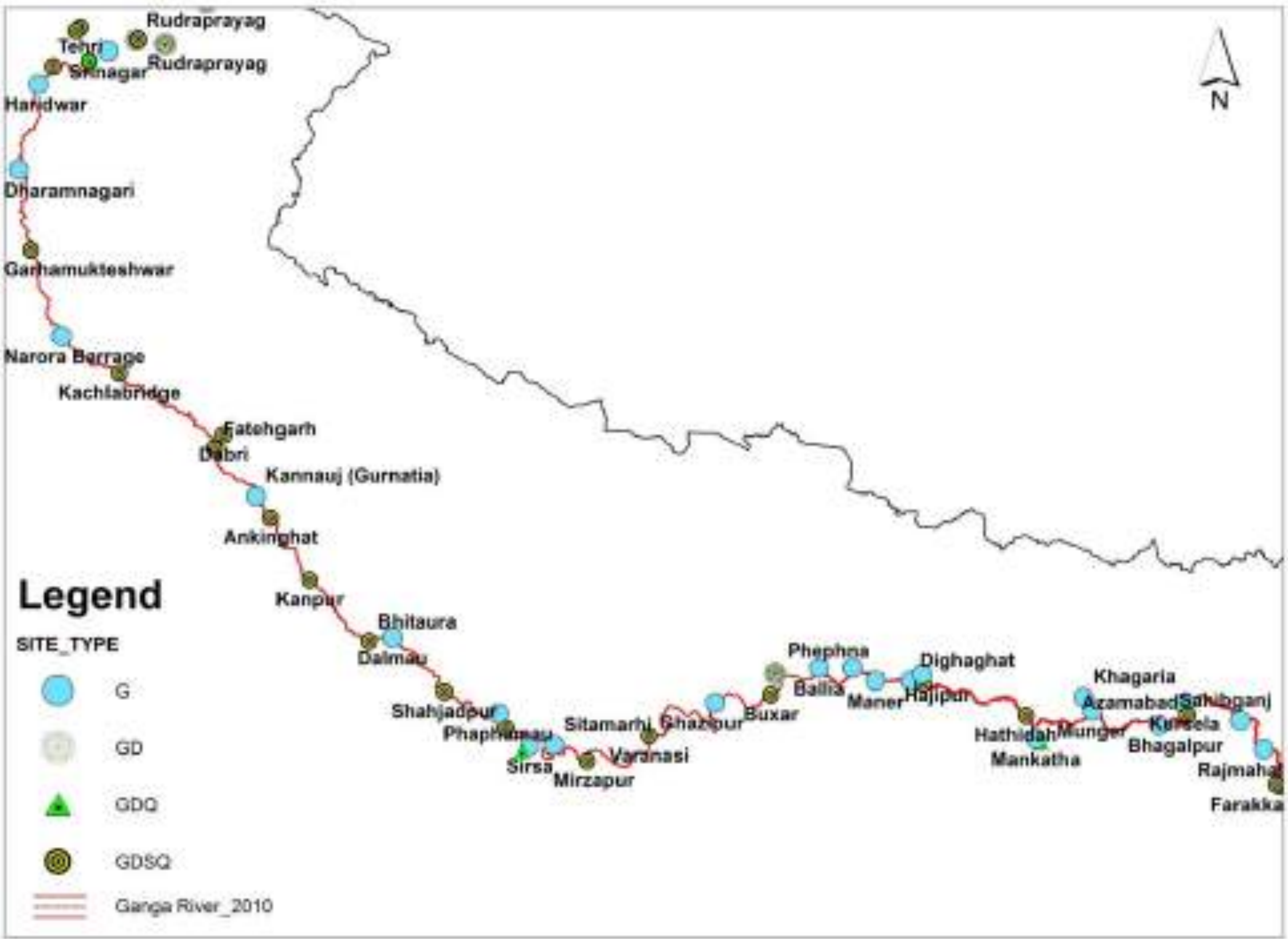


Figure 5.1 Location of gauging sites

Hydro-meteorological data that have been received from the regional offices of the CWC are given in Table 5.2.

Table 5.2 Hydro-meteorological data received from the regional offices of the CWC

S. No.	Gauging Site	W.L.	Discharge	Silt Data	Annual max. & min		X - Section	Season	
					Water level	Discharge			
1	Devprayag	-	-	-	-	-	-	-	-
2	Rishikesh	-	-	-	-	-	-	-	-
3	Haridwar	-	-	-	1972-2015		-	-	-
4	Narora	-	-	-	1990-2015 minimum n. a. between 1990-1999		-	-	-
5	Fatehgarh	Ten Daily Average 1973-2015	Ten Daily Average 1973-2015	Ten Daily Average 1978-2015	1973-2015	1973-2015	2010	Pre_M	Post_M
6	Ankin Ghat	Ten Daily Average 1969-2015	Ten Daily Average 1969-2015	Ten Daily Average 1978-2015	1969-2015	1969-2015	2010	Pre_M	Post_M
7	Kanpur	Ten Daily Average 1961-2015	Ten Daily Average 1961-2015	Ten Daily Average 1976-2015	1961-2015	1961-2015	2010	Pre_M	Post_M
8	Dalmau	-	-	-	1990-2015 minimum n. a. between 1990-1999		-	-	-
9	Kachlabridge	Ten Daily Average 1973-2015	Ten Daily Average 1973-2015	Ten Daily Average 1973-2015	1972-2015	1972-2015	2010	Pre_M	Post_M
10	Garhmukteshwar	Ten Daily Average 1968-2015	Ten Daily Average 1968-2015	Ten Daily Average 1974-2015 except 2004-2011	1968-2015	1968-2015	2010	Pre_M	Post_M
11	Bhitaura	Ten Daily Average 1972-2015	Ten Daily Average 1972-2015	Ten Daily Average 1978-except 1998-2000	1971-2015	1971-2015	2010	Pre_M	Post_M
12	Phaphamau	-	-	-	Max. 1972-2015, Min. 1976-2015	`	-	-	-
13	Chatnag (Allahbad)	Ten Daily Average 1971-2015	Ten Daily Average 1971-2015	Ten Daily Average 1973-2015	1971-2015	1971-2015	1971-2014 except 1984 in Pre Monsoon and 1974, 1975, 1984 &1993 in Post Monsoon	Pre_M	Post_M

14	Mirzapur	Ten Daily Average 1980-2015	Ten Daily Average 1980-2015	Ten Daily Average 1980-2015	1977-2015	1977-2015	1997-2014 except 1998, 1999 in Pre Monsoon and 1997 in Post Monsoon	Pre_M	Post_M
15	Varanasi	Ten Daily Average 1961-2015	Ten Daily Average 1961-2015	Ten Daily Average 1962-2015	1961-2015	1961-2015	1973-2014 except 1974,1976 &1994 in Pre Monsoon and 1973-1976 in Post Monsoon	Pre_M	Post_M
16	Ghazipura	-	-	-	1970-2015	-	-	-	-
17	Ballia	-	-	-	1971-2015	-	-	-	-
18	Shahzadpur	Ten Daily Average 1960-2014	Ten Daily Average 1960-2014	Ten Daily Average 1963-2014	1960-2014	1960-2014	1983-2014 except 1983,1992 in Pre Monsoon and 1985-1993, 2003, 2004 & 2014 in Post Monsoon	Pre_M	Post_M
19	Azamabad	Ten Daily Average 1960-2014	Ten Daily Average 1960-2014	Ten Daily Average 1986-2015 except 1989,1993 &1995	1960-2014	1960-2014	1994-2013 except 1995, 1999-2008 & 2011 in Pre Monsoon and 1994, 1997, 1999-2013 in Post Monsoon	Pre_M	Post_M
20	Buxar	Ten Daily Average 1960-2014	Ten Daily Average 1960-2014	Ten Daily Average 1986-2015 except 1989,1993 &1995	1960-2014	1960-2014	2003, 2006, 2009, 2010, 2013 in Pre Monsoon and 2002-2011, 2014, 2015 in Post Monsoon	Pre_M	Post_M
21	Gandhi Ghat	Ten Daily Average 1965-2014	Ten Daily Average 1965-2015	Ten Daily Average 1986-2013 except 989,1993 &1995	1965-2014	1965-2014	1988, 1991,1994,1999, 2002-2004, 2006, 2007, 2009, 2011-2013 in Pre monsoon and 1990, 1996, 1998, 2000 in Post Monsoon	Pre_M	Post_M
22	Hathidah	Ten Daily Average 1961-2014	Ten Daily Average 1961-2014	Ten Daily Average 1986-2013 except 1989, 1993 & 1995	1961-2014	1961-2014	2005 in Pre Monsoon and 1994-1996,1999-2001, 2003-2006, 2014, 2015 in Post Monsoon	Pre_M	Post_M
23	Farakka	Daily 1975-2014 (June-Oct.) & 2015 (June-July)	Daily 1975-2014 (June -Oct.) & 2015 (June-July)	Daily 1995-2014 (June -Oct.)	-	-	2007-2015	Pre_M	Post_M
24	Farakka (Feeder Canal)	Daily 1961-1963, 1970-2014 (June-Oct.) & 2015 (June-July)	Daily 1961-1963, 1970-2014 (June -Oct.) & 2015 (June-July)	Ten Daily 1995-2014 (June -Oct.)	-	-	2005-2015	Pre_M	Post_M

Pre_M:- Pre Monsoon, Post_M:- Post Monsoon

5.2 FLOW PROBABILITY CURVES

Flood frequency analysis has been carried out for the recorded discharge data at various CWC gauging sites on the river for the estimation of discharges for 1.5 to 2 year return periods. Discharge for higher return periods has also been estimated using frequency analysis to correlate the peak discharges with the morphological parameters of the rivers. Details of the frequency analysis are given below:

Frequency analysis of recorded maximum stream flow data is an important flood-runoff analysis tool. The objective of flood frequency analysis is to infer the probability of exceedance of all possible discharge values (the parent population) from observed discharge values (a sample of the parent population). This process is accomplished by selecting a statistical model that represents the relationship of discharge magnitude and exceedance probability for the parent population. The parameters of the models are estimated from the sample.

Commonly used methods for the frequency analysis are-

(a) Graphical methods

In this method, the annual maximum flood data are arranged in descending order and rank is assigned to each data. The highest flood data is assigned a rank 1 and second highest 2 and like-wise others. This arrangement of data gives an estimate of the exceedence probability, that is, the probability of a value being equal to or greater than the ranked value. The probability of a data being equal to or exceeded is calculated by Weibull formula

$$P = \frac{m}{N+1} \tag{5.1}$$

where m is the rank of the data and N is the total number of the data. The return period for the event

$$T = 1/P \tag{5.2}$$

A plot of discharge Q vs time T yields the probability distribution. Return period for any discharge can be read from the fitted data on the probability plot.

(b) Analytical methods

Commonly used frequency distribution functions for the prediction of extreme flood values analytically are

a) Gumbel's extreme value distribution method
b) Log-Pearson Type-II distribution
c) Log normal distribution

The best fitted probability distribution shall be used to estimate the discharge for higher return period.

(a) **Gumbel's Extreme Value Distribution method**

The annual maximum discharge for T year return period Q_T is defined as

$$Q_T = \overline{Q} + K\sigma$$

Where $\overline{Q}$ = average of annual maximum discharge

σ = standard deviation of available annual maximum discharge data

K = Frequency factor and expressed as

$$K = \frac{y_T - \overline{y}_n}{S_n}$$

y_T = reduced variate and function of return period T

$$y_T = -\left\lfloor \ln . \ln \frac{T}{T-1} \right\rfloor$$

$\overline{y}_n$ = mean and function of sample size, N

S_n = reduced standard deviation and function of N

T = Return period in year

(b) Log-Pearson Type III Distribution method

In this method, the variate is first transformed into logarithmic form and the transformed data is then analysed. For any return period T

$$Z_T = \overline{Z} + K_z \sigma_z$$

and Z =log (Q)

Where Q = variate of available flood data

σ_Z= standard deviation of the Z variate $= \sqrt{\dfrac{(Z-\overline{Z})^2}{N-1}}$

K_z = Frequency factor and function of return period T and the coefficient of skewness, C_s of variate Z.

$$C_s = \frac{N\sum(Z-\overline{Z})^3}{(N-1)(N-2)\sigma_z^3}$$

$\overline{Z}$ = mean of the variate Z

N = number of sample, i.e. discharge data

(c) Log Normal Distribution method

Log-Pearson Type III distribution reduces to Log normal distribution when the coefficient of skewness of variate Z is zero, i.e., C_s =0. Procedure for estimation of peak discharge would be same as the Log-pearson Type III distribution method. The best fitted probability distribution shall be used to estimate the discharge for higher return period.

In addition to the above, hydraulic structures constructed across and along the rivers like barrages, bridges etc shall be identified from Google earth images and details of those structures shall be collected from concerned department. The morphological changes of the river in the vicinity of the structure shall be studied using high resolution images and changes in morphology due to construction of the structure shall be assessed in the form of shifting of banks and erosion/deposition of the sediments.

5.3 TOPOSHEETS & SATELLITE DATA

For the present study, data have been procured from government agencies and organizations, like National Remote Sensing Centre (NRSC), Survey of India (SOI) etc. Details regarding topographical maps and remote sensing data used are given in Table 5.3 and the specifications of sensors are given in Table 5.4.

Table 5.3 Data used and their sources

Toposheets				
S. No.	**Data**		**Data Source**	**Scale**
	Toposheets and Year		SOI, Dehradun	1:50,000
1	**53**	G/-14 **(1974)**, 15 **(1977)** J/- 4 **(1969)**, 8 **(1967)**, 12 **(1967)** K/-1 **(1972)**, 2 **(1970)**, 3 **(1970)**, 4 **(1974)** L/-1 **(1976)**, 2 **(1970)**, 3 **(1970)**, 6, 7 (1970), 8 **(1970)**,12 **(1970)**, 16 **(1970)**		
	54	I/-9,13 M/-1, 2, 6,10,11, 12, 15 **(1976)**, 16 **(1976)** N/-13		
	63	A/-4 B/-1, 2, 5, 6, 7, 8, 11, 12, 16 F/-4 G/-1, 5, 6, 10, 11, 14,15 K/-3 **(1973)**, 4 **(1972)**, 7 **(1973)**, 8 **(1973)**, 11 **(1976)**, 12 **(1978)**, 15 **(1974)**,16 **(1972)** O/-2, 3, 4, 7, 8, 10, 11,14,15		
	72	C/-1, 2, 5, 6,9, 10, 13, 14 G/-2, 6, 7,10,11, 14, 15 K/-3 **(1984)**, 4 **(1981)**, 7 **(1980)**, 8 **(1981)**, 11 **(1980)**, 12 **(1982)**, 15 **(1980)**, 16 **(1983)** O/-1 **(1972)**,2 **(1972)**, 3 **(1974)**, 4 **(1973)**, 7 **(1974)**, 8 **(1974)**, 11 **(1974)**, 12 **(1974)**, 15 **(1974)**,16 **(1974)** P/-13 **(1975)**		

Remote Sensing Digital Data						
S. No.	Sensor	Data Source	Year	Path	Row	Date
1	Landsat MSS	GLCF & USGS website	1980	149	43	10/12/1977
				150	42	
				151	42	27/09/1980
				152	42	21/01/1980
				153	42	17/10/1980
				153	43	17/10/1980
				154	41	30/09/1980
				154	42	23/11/1980
				155	41	01/10/1980
				155	42	12/12/1980
				156	41	14/09/1980
				157	39	14/12/1980
				157	40	14/12/1980
				157	41	14/12/1980
2	IRS 1A LISS II (Each Scene of LISS II contains 4 satellite images A1, A2, B1 and B2)	NRSC Hyderabad	1990	19	50	21/11/1990
				20	50	22/10/1989
				21	50	23/11/1990
				23	50	30/01/1991
				24	50	18/12/1990
				25	49	05/10/1989
				25	50	21/04/1990
				26	48	06/11/1990
				26	49	06/10/1989
				27	48	29/11/1990
				28	46	08/10/1989
				28	47	17/10/1990
				28	48	17/10/1990
3	IRS 1C LISS III	NRSC Hyderabad	2000	96	50	17/11/2000
				97	50	15/11/2000
				97	51	15/11/2000
				98	52	27/10/2000
				99	52	08/10/2000
				99	53	08/10/2000
				100	53	13/10/2000
				101	54	18/10/2000
				102	54	16/11/2000
				103	54	15/12/2000
				104	53	02/11/2000
				104	54	02/11/2000

				105	54		25/12/2000
				106	54		19/10/2000
				107	54		17/11/2000
4	IRS P6 LISS III	NRSC Hyderabad	2010	96	50		06/11/2010
				97	50		05/12/2010
				97	51		05/12/2010
				98	52		23/10/2010
				99	52		28/10/2010
				99	53		28/10/2010
				100	53		02/11/2010
				101	54		14/10/2010
				102	54		12/11/2010
				103	54		24/10/2010
				104	53		29/10/2010
				104	54		29/10/2010
				105	54		10/10/2010
				106	54		02/12/2010
				107	54		13/11/2010
5	ResourceSat 2 LISS IV	NRSC Hyderabad	2011, 2015	96	50	B	23/10/2015
				96	50	D	23/10/2015
				96	51	B	23/10/2015
				97	50	A	15/12/2015
				97	51	A	15/12/2015
				97	51	C	15/12/2015
				97	51	D	04/10/2015
				97	52	B	04/10/2015
				98	52	A	02/11/2015
				98	52	B	09/10/2015
				98	52	D	09/10/2015
				99	52	C	25/12/2015
				99	52	D	01/12/2015
				99	53	A	25/12/2015
				99	53	B	01/12/2015
				100	53	C	12/11/2015
				100	53	D	19/10/2015
				101	53	C	17/11/2015
				101	54	A	21/02/2015
				101	54	B	28/01/2016
				102	54	A	16/12/2015
				102	54	B	22/11/2015
				102	54	C	16/12/2015
				103	53	C	03/11/2015

				103	53	D	10/10/2015
				103	54	A	03/11/2015
				103	54	B	10/10/2015
				104	53	C	08/11/2015
				104	53	D	02/12/2015
				104	54	A	08/11/2015
				104	54	D	02/12/2015
				105	54	A	13/11/2015
				105	54	B	20/10/2015
				106	54	A	01/10/2015
				106	54	B	07/09/2015
				107	54	A	17/12/2015
				107	54	C	17/12/2015
				107	54	D	23/11/2015

Table 5.4 Sensor specifications

Specification	**Landsat MSS**	**IRS 1A LISS II**	**IRS 1C LISS III**	**IRS P6 LISS III**	**Resourcesat 2 LISS IV**
Spectral Bands	1-4	1-4	1-4	1-4	1-4
Spatial Resolution (m)	60	36.25	23.5	23.5	5.0
Swath Width (km)	185×185	141	141	141	141
Radiometric Resolution (bits)	8	7	7	7	7

5.4 SOFTWARE USED

The following softwares have been used in this study and their details are given below:

1.	**ERDAS IMAGINE 10.1**	It is one of the world's leading image processing software that is developed by Leica Geosystems that work on geospatial data. It is used to perform advanced remote sensing analysis and spatial modeling to create new information. In addition, it is used to visualize the results in 2D, 3D, movies, and on cartographic quality map compositions. Optional add-on modules providing specialized functionalities are also available to enhance your productivity and capabilities. IMAGINE Virtual GIS is a powerful yet easy-to-use visual analysis tool that offers GIS functions and capabilities in a 3D environment.

2.	**ArcGIS 10.2**	ArcGIS Desktop is GIS software that is developed by ESRI. It is a group of modules that are used for different purposes (a) ArcMap: it is used for editing, mapping, geo-processing and visualization. (b) ArcCatalog: it is used to create geodatabase and shapefiles as well as for data management. (c) 3D visualization with ArcGlobe and ArcScene, (d) ArcSDE: It is used for creating online geo-database. (e) ArcServer and ArcIMS: It is used to publish GIS layers on web.
3.	**Microsoft Office**	Microsoft Office is a collection of software programs commonly used in an office environment. It is used to type letters and envelopes, create spreadsheets, make labels, and produce presentations for home or office.
4.	**Sigma Plot**	SigmaPlot is a scientific data analysis and graphing software package with an intuitive interface for all your statistical and graphical analysis.
5.	**MATLAB**	MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

5.5 ACQUISITION OF DATA AND GEO-REFERENCING OF IMAGES

Firstly, the Survey of India toposheets (1:50,000 scale) which covers the area of interest are procured. Then, these toposheets are geo-referenced and ortho-rectified using first order polynomial and Lambert Conformal Conic (LCC) projection type with the help of ERDAS Imagine 2014 software, before initiating the analysis. After geo-referencing, clipping and mosaicing have been done.

Relevant satellite images were procured from the National Remote Sensing Centre (NRSC), Hyderabad and downloaded from United States Geological Survey (USGS) website. Pre-processing of the satellite images have been carried out using filters such as histogram equalization and matching etc. to improve and equalize the brightness levels of similar features and to provide uniform information. After mosaicing the toposheets, all the satellite images were geo-referenced using image to image method by selecting several control points. The RMS error has been kept below the half pixel size. After geo-referencing, images have been mosaiced to cover the entire study area. For mosaicing feather option of the software has been used to get the seamless boundaries between different images of the same year.

5.6 METHODOLOGY FOR PLAN FORM CHANGES

Plan form of the rivers may be described as straight, meandering or braided. There is in fact a great range of channel patterns from straight through meandering to braided. Methodology adopted to fulfil the objective in respect of planform changes of the river is shown in Fig. 5.2 in the form of a methodological flowchart:

In the present study of morphology of Ganga River, sinuosity ratio and PFI index of the rivers have been estimated using the satellite images for different years. The temporal and spatial variation of sinuosity ratio and PFI index with for different reaches are shown graphically.

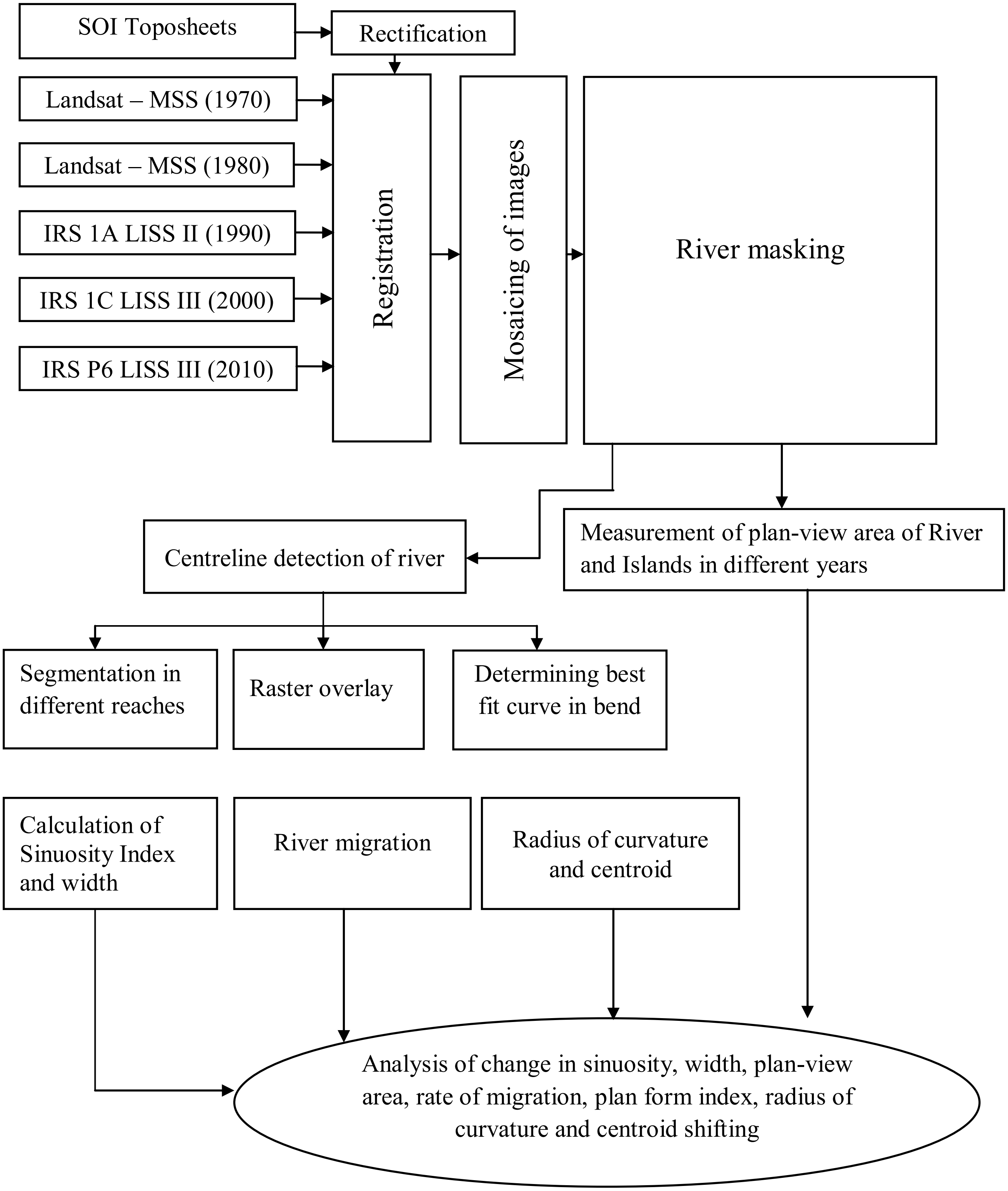


Figure 5.2 Flowchart of the methodology

5.7 CONCLUDING REMARKS

The following tasks shall be performed in this study

- Reach-wise temporal analysis of main (deeper channel), left and right bank of river.
- Estimation of eroded/deposited area of the river, and their presentation in a graphical form, with length of the river on x-axis and erosion & deposition on y-axis.
- Length-wise variation of sinuosity ratio and Plan Form Index (PFI) for the evaluation of meandering and braiding patterns of the river.
- Identification of levels of braiding using plan form index threshold values.
- Detailed analysis of the shifting of river in the critical reaches using high resolution satellite images.
- Plotting of probability curve for discharge at various gauging sites of the river using the recorded flow data for 1.5 years and 2 years return period.
- Flood discharge for higher return periods shall also be computed using the frequency analysis.
- After the identification of critical reaches, that will be characterized by major left and right bank shifting inserting heavy erosion/deposition, river training works in the form of flood walls, guide bunds, sparse submerged vanes, porcupines etc shall be suggested.
- Reconnaissance survey shall be carried out near the major hydraulic structures and also the critical reaches to assess the morphological changes of the river onset of the construction of the hydraulic structures.

Chapter 7 GEOLOGY

7.1 INTRODUCTION

The Indian subcontinent is subdivided into three major physiographic subdivisions, the Himalaya, Indo-Gangetic Plain and Peninsular India. The Indo-Gangetic Plain is the extensive alluvial plain of the Ganga, Indus and Brahmaputra rivers and their tributaries, and separates the Himalayan ranges from Peninsular India. Traditionally, geological studies concerned mainly the rock successions; hence the study of this vast alluvial plain was ignored. The extreme flatness of the region and geomorphologically monotonous character also did not attract the geomorphologists to undertake detailed investigations of this region. In the classical literature, generalized views were expressed as to the nature of this vast alluvial plain, often termed the Indo-Gangetic Trough. The vast alluvial plain was broadly classified into Older Alluvium (Bhangar) and Newer Alluvium (Khadar), each with different sediments.

River Ganga originates from Gomukh glacier in greater Himalaya region. After that it passes through Gangotri which is considered as religious origin of the river. It has varied physiographic and geologic set up from its origin to culmination point in sea. Geology imparts more influence in the upper Ganga basin, where it flows through intricate mountainous terrain.

The Ganga basin occupies a dominant position and is located in the northern and northeastern part of the Indian subcontinent between latitudes 21°58'N and 31°30'N and longitudes 73°30'E and 97°50'E. It is a long, narrow basin surrounded by mountains on all sides except for a low, unnoticeable watershed on the west, which separates the Indus basin from the Ganges basin, and the southeastern tip where the rivers, after confluence, meet the ocean at the Bay of Bengal.

Chapter- 7: Geology

The Ganga rises in the southern Himalayas on the Indian side of the Tibet border. Its five head streams the Bhagirathi, the Alakhnanda, the Mandakini, the Dhauli Ganga, and the Pindar—all rise in the Uttarakhand division of the state of UP. of these, the two main head streams are the Alakhnanda (the longer of the two) and the Bhagirathi. The Bhagirathi, which is traditionally known as the source of the Ganga, rises in India from the Gangotri glacier in the Himalayas at an elevation of about 7010 m above mean sea level. After its confluence with the Alakhnanda at Devprayag, the river assumes the name Ganga. After draining the middle ranges of the Himalayas, the river debouches into the plains at Hardwar. From Hardwar down to Allahabad where the Yamuna joins it on the right bank, there is a distance of about 720 km, it generally flows in a south–south easterly direction.

Lower down, the river flows eastward and past Varanasi, the Ganga is joined by a number of tributaries on both banks. Of the left-bank tributaries in the upstream reaches, prior to Varanasi, the Ramganga and the Gomti are the most important. The Yamuna has a number of important tributaries like the Chambal, the Sind, the Betwa and the Ken joining it from the south. The Tons and the Karamnasa are other right-bank tributaries in UP. After leaving Uttar Pradesh (UP) the Ganga forms the boundary between UP and Bihar for a length of about 110 km and in this reach the Ghaghra, which flows down from Nepal, joins it near Doriganj, Chhapra. The river then enters Bihar below Ballia and flows more or less through the middle of the state. During its course of nearly 445 km in Bihar, the river flowing eastward is joined by a number of major tributaries on both banks. The Great Gandak, the Bagmati and the Kosi, and the Burhi Gandak join it on the left bank. The first three flow down from Nepal into North Bihar. The Son, the Pun Pun, the Kiul, the Chandan, the Gerua, and others join the Ganga on the right bank. In West Bengal, the last Indian state that the Ganga enters, the Mahananda joins it from the north. The river then skirts the Rajmahal Hills to the south and flows southeast to Farakka.

The delta of the Ganga can be said to start from Farakka. The river divides into two arms about 40 km below Farakka. The left arm, known as the Padma, flows eastward into Bangladesh while the right arm, known as the Bhagirathi–Hooghly, continues to flow in a southerly direction in West Bengal. Two tributaries flowing in from the west, the Damodar and the Rupnarayan, join the Hooghly itself. Until some 300 years ago, the Bhagirathi–Hooghly constituted the main arm of the Ganga, carrying the bulk of the flow. Thereafter, the Padma arm opened up more and more, leaving Bhagirathi a mere spill channel of the Ganga flowing mostly during high stages of flow. The river ultimately flows into the Bay of Bengal, about 145 km downstream of Calcutta.

The length of the river (measured along the Bhagirathi and the Hooghly) during its course in West Bengal is about 520 km. The Ganga (Padma) in Bangladesh flows past Kushtia and Pabna until the Brahmaputra (locally called Jamuna) joins it at Goalkunda. The united stream of the Brahmaputra and the Ganga beyond Goalkunda continues to flow south east under the name Padma. At Chandpur, 105 km below Goalkunda, the Padma is again joined on the left bank by the Meghna, whose source is in the high mountains, which are subjected to intense rainfall. From this confluence downward, the river known as lower Meghna becomes a very broad estuary, making its exit into the Bay of Bengal. Dacca, the principal city of Bangladesh, stands on the Burhi Ganga, a tributary of Dhaluwari. Apart from the Hooghly and the Meghna, the other distributary streams which form the Ganges delta are as follows: in West Bengal, the Jalangi, and in Bangladesh, the Metabanga, the Bhairab, the Kobadak, the Gorai (Madhumati), and the Arial Khan. The precipitation over the Ganga basin is brought about by the southwest monsoon as well as by cyclones originating over the Bay of Bengal. The average annual rainfall in India varies from 35 cm on the western end of the basin to about 200 cm near the delta. The river drains an area of 106.96 m ha (excluding Tibet) and the average annual flow of the Ganga at Farakka is about 55.01 M ha m.

7.2 TOPOGRAPHY

The Ganga basin comprises of three large topographic divisions of the Indian subcontinent, namely the Himalayan Young Fold Mountains, the Gangetic Plain, and the Central Indian highlands. The Himalayan Fold Mountains comprises the Himalayan ranges including their foot hills with numerous snow peaks rising above 7000 m. Each of these peaks is surrounded by snow fields and glaciers. All the tributaries are characterized by well regulated flows and assured supply of water throughout the year by these glaciers. The Gangetic plains, in which the main stem of Ganga lies, situated between the Himalayas and the Deccan plateau, constitute the most of the sub-basin ideally suited for intensive cultivation. It consists of alluvial formation and is a vast flat depositional surface at an elevation below 300 m. The Central highlands lying to the south of the Great Plains consists of mountains, hills and plateaus intersected by valleys and river plains. They are largely covered by forests. Aravali uplands, Bundelkhand upland, Malwa plateau, Vindhyan ranges and Narmada valley lies in this region.

7.3 PHYSIOGRAPHIC SETUP

The upper Ganga basin has its major part in Lesser Himalayas which is bounded by the 'Central Himalayan Thrust' or Main Central Thrust (MCT) and the 'Main Boundary Fault' from the north and south respectively. It represents typical Synclinal hills and Anticlinal valley topography. The area comprises of part of catchments of Bhagirathi, Alaknanda and Ganga rivers (Kharkwal, 2001). Physiographically, it can be divided into two major units, as shown in Fig.7.1.

- Piedmont/ Flood Plain
- Lesser Himalayan Relief

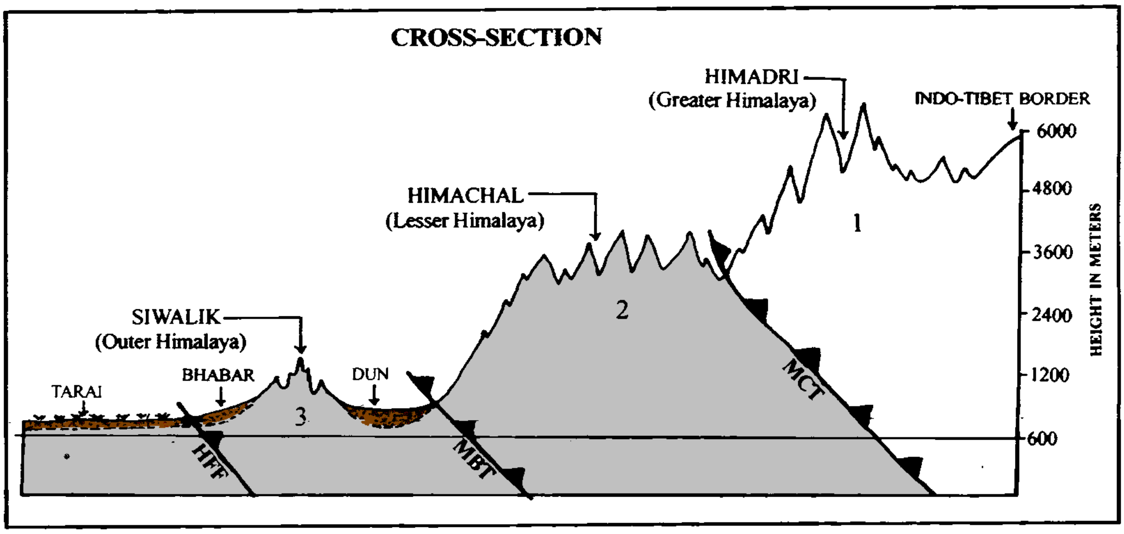


Figure 7.1 Physiographic divisions of upper Ganga basin

Piedmont/ Flood Plain: It consists of approximately 15% of study area towards the west and south-west. It generally consists of gravels and alluvium and is mainly restricted to the west and south west of the study area near Rishikesh. This foothill zone is bordered by hilly/ mountainous areas towards north and east.

Lesser Himalayan Relief: It covers approximately 85% part of the study area. The hill ranges trend mainly northwest-southeast and towards south-west trend changes to north-south direction. The altitude ranges from 1200 to 2270 meters and both sedimentary and metamorphic rocks are found in this zone. The hills are highly dissected making it a very rugged and undulating terrain. Relief in the region varies from low valleys to very high mountains and between these extremes of elevation (high relative relief) are high valleys, narrow plains, foothills and low mountains. Foothill zone forms the geographic boundary in the southwest.

The denudational processes have been very active which have given rise to many fertile valleys. The increased volume of water, combined with the high velocity of rivers in the flood-time, multiplies their erosion and transportation power to an unconceivable extent. The huge boulders and blocks, several meters in diameter, are rolled along their beds, and carried in this manner to distance of 50 km or even 120 km from their source, causing much erosion to the banks and riverbeds. The hilly region abruptly ends close to Rishikesh where fans and fluvial material of Ganga river have formed an alluvial plain with regional slope towards south-west direction (Dey *et al.*, 1991, Kumar *et al.*, 1996).

7.4 GEOLOGY

Geological map of the Ganga basin as obtained from India-WRIS is shown in Fig. 7.2.

(a) Lithology

By virtue of being in Lesser Himalayas, a whole group of rocks from low grade metamorphic to meta-sedimentary, sedimentary and unconsolidated material are present in upper Ganga basin. These have been categorized into different formations (Rupke, 1974), viz. Damta, Chandpur, Nagthat, Blaini, Krol and Tal belonging to Cambrian and pre-Cambrian age. These are overlain by sandstone, shale sequence of Subathu (lower Eocene-tertiary age). The alluvial plain area and narrow valley fills of major rivers are of recent age and mainly composed of gravels, pebbles, sand and silt. Though various names have been given to the rock formations, their main constituents invariably are quartzite, slate, phyllite, limestones and shales.

(b) Structure

Structurally, the Ganga basin comprises of three large divisions of the Indian subcontinent, namely: the Himalayan fold mountains, the Central Indian highlands and the Peninsular shield, and the Gangetic plain. The Himalayan Fold Mountains include numerous snow peaks rising above 7000 meters. Each of these peaks is surrounded by snow fields and glaciers. All the tributaries are characterised by well regulated flows and assured supply of water throughout the year. The Gangetic plain, in which the main stem of Ganga lies, consists of alluvial formation and is a vast flat depositional surface at an elevation below 300 m.

As is known from geological literature, the Himalayas have undergone at least five phases of uplift and mountain building. Therefore the rocks are highly folded, faulted, jointed and fractured. These fold trend NW-SE as per the regional strike of the formation. A minimum of 4 broad plunging synclines separated by narrow, tight anticlines occur in the area. Because of these plunging nature of folds, rock outcrops show closures near Narendranagar, Chamalgaon at the confluence of Ganga and Nayar river. Besides a few major faults also occur in the region, for example, faults trending N-S near Rishikesh, Devprayag (along the course of Bhagirathi and Ganga rivers). Another major fault runs NW-SE partially parallel to Nayar river and partially parallel to Hiyunl river (Dey *et al.*, 1991).

A nappe structure occurs south of Hiyunl river (south) as an isolated (detached) outcrop of low grade metamorphics on the top of Subathu formation (which is one of the youngest formation in the area), due to large scale thrusting from the north. More than 3 sets of joints are seen in brittle rocks, for example, quartzites, limestones. The presence of fractures, lineaments or major joints is inferred from the straight courses of streams/channels at various places.

The Ganga Plain extends from Aravalli-Delhi ridge in the west to the Rajmahal hills in the east; Himalayan foothills (Siwalik hills) in the north to the Bundelkhand Vindhyan plateau - Hazaribag plateau in the south, occupying an area of about 250,000 km^2, roughly between long. 77°E, and 88°E, and Lat. 24°N and 30°N. The length of Ganga Plain is about 1000 km; the width is variable, ranging between ~50-200 km, being wider in the western part and narrower in the eastern part. The southern margin of Ganga Plain is irregular, and shows at many places outcrops of rocks protruding out of the alluvium. The northern margin of the Ganga plain is marked by the exposure of Siwalik rocks.

Most of the rivers in the northern Ganga Plain follow a southeasterly trend; some of the rivers initially flow in the SW direction but then also swing to the southeasterly direction. The rivers of the southern part follow a northeasterly trend; and only those in the axial part follow the easterly slope. The Ganga River is the trunk river of the Ganga Plain into which the large Himalayan rivers join from the north; except for the Yamuna river which meets the Ganga River from the south. Several rivers come from the Peninsular plateau to join the Yamuna or

Ganga River. There are also a number of groundwater-fed streams originating within the alluvium which meet the major streams. The rivers of Ganga Plain show a wide range of channel sizes and channel patterns. The Yamuna River is the axial river of Ganga Plain in the western part; while Ganga River becomes the axial river in the eastern part, after Yamuna Ganga confluence at Allahabad.

From north to south, the Ganga Plain can be identified into four distinctive regions-

(i) Bhabar Belt - This is a 10-30 km wide belt of gravelliferous sediments adjacent to Himalaya with steep slopes and ephemeral streams.

(ii) Terai Belt - This is a 10-50 km wide low-lying area adjacent to the Bhabar Belt with extensive development of swamps, ponds, small sandy rivers.

(iii) Central Alluvial Plain- This represents the major part of Ganga Plain, located between the Bhabar-Terai Belt and the axial river. The drainage is mostly aligned in a SE direction.

(iv) Marginal Alluvial Plain - This is the north-sloping surface, located south of the axial river, and characterized by NE-flowing gravelly to coarse sandy rivers showing entrenched meandering. This area is made up of sediments from Peninsular craton.

However, it is more practical to identify three broad areas in Ganga Plain:

a) Piedmont Zone (It includes both Bhabar and Terai zones).

b) Central Alluvial Plain

c) Marginal Alluvial Plain

These three areas show distinctive landforms, characteristic deposits, and specific tectonic setting. The areas of Bhabar and Terai are closely linked. It appears that in the areas where there is intense fan-building Bhabar is well-developed; while in areas of subdued fan building Terai is well-developed. With changing fan building activity, Bhabar can change to Terai and vice versa. Thus, both are grouped together as Piedmont Zone.

Basement Structure in Ganga Plain: A number of regional geophysical studies have been carried out over the Ganga Plain, including aeromagnetic, seismic, gravity and magnetic surveys. This information has been utilized by several workers to interpret the basement structure and nature of foreland sediment fill. In these studies the basement is taken as the metamorphosed rock succession of Precambrian age. Geophysical information shows that the basement rocks of Ganga Plain exhibit distinctive features. The metamorphic basement exhibits a number of ridges and basins, over which the thickness of sedimentary cover is highly variable. The important basement highs are the Delhi-Hardwar ridge, the Faizabad ridge, the Monghyr-Saharsa ridge, a poorly developed high in the Mirzapur- Ghazipur area; and smaller "highs" of Raxaul, Bahraich and Puranpur. There are two important basins or low areas, namely Gandak and Sarda depressions. There are also a number of basement faults, namely Moradabad fault, Bareilly fault, Lucknow fault, Patna fault, and Maida fault. The southern part of Ganga Plain in Mirzapur area shows E-W and ENE-WSW trending linear magnetic anomaly zones. Seismic studies in the Ganga Plain indicates that the basins and ridges were also active during deposition of Late Proterozoic sediments. However, the foreland sediments (Siwalik and Alluvium) rest on a rather uniform surface dipping towards north. This surface is made up of different type of rocks in different parts. The basement fault recorded in geophysical studies have not affected the foreland fill and also do not show any evidence in geomorphic features.

7.5 GEOMORPHOLOGY

Geomorphologically, the upper Ganga basin can be divided into two regions, in which denudational hills cover most of the area. In some parts where rocks are resistant to erosion, e.g. quartzites of Nagthat formation, structural hills are also present. In smaller scale the structural hills can be named as Cuesta or hog-back respectively depending upon the steepness of the dip of rock formation. Since the apparently flat terrain in Rishikesh and further towards, south and west is dominated by the presence of Ganga river, its alluvial plain covers the major area which merges with the fans/piedmont plain surface towards the hilly region (Pande *et al.*, 1999).

Aspect is an important feature in hilly regions as in the study area, its relation with soil moisture and vegetation is clearly defined. It is seen in the area, that northern slopes are more vegetated, retain more moisture and have thicker soil profile. In contrast, southern slopes are drier¸ have less vegetation and are susceptible to mass wasting processes. Major landslides are seen in the area due to undercutting by river or due to unplanned construction activities of roads, which destabilizes the natural undisturbed slopes in normal equilibrium.

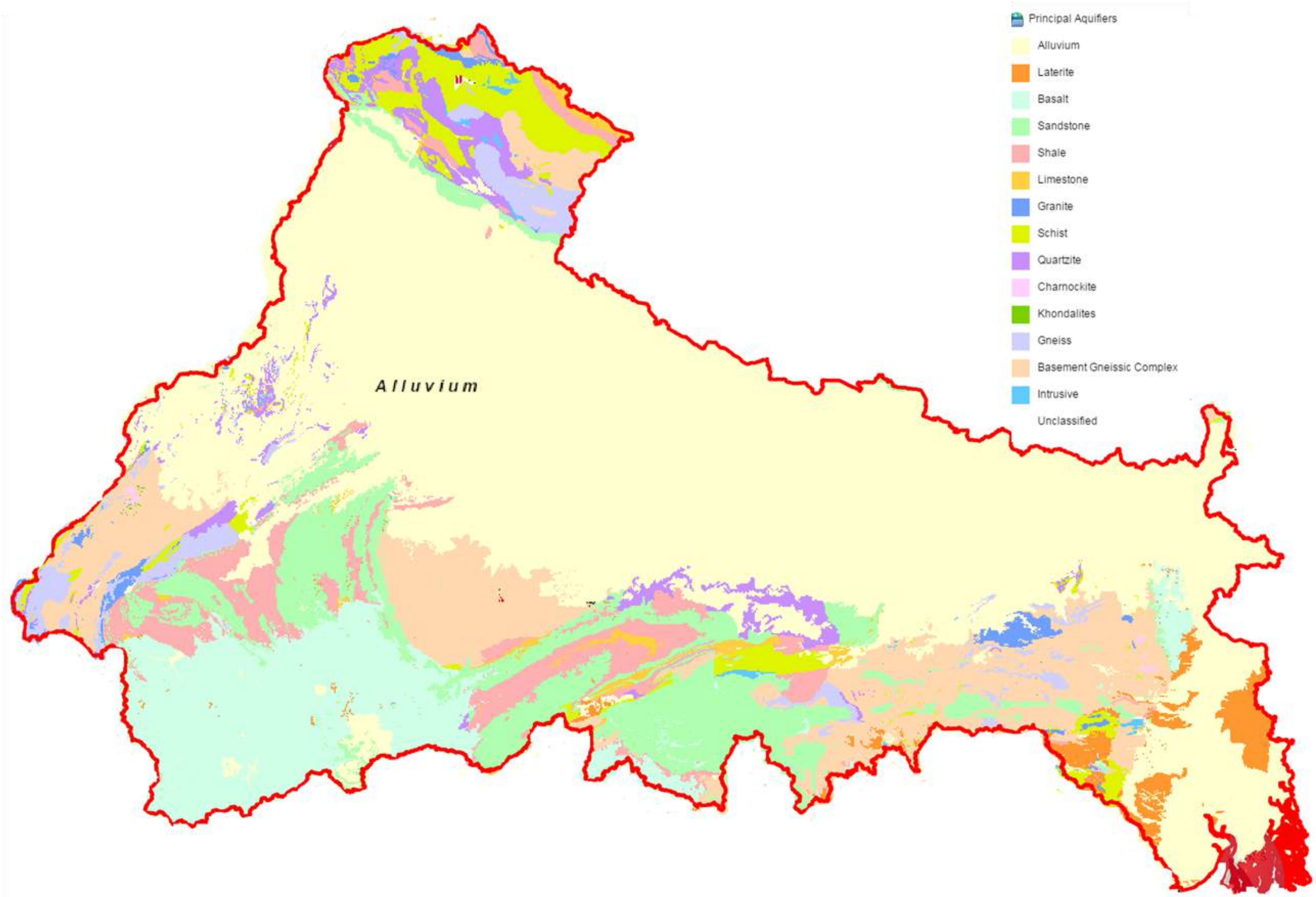


Figure 7.2 Geology of Ganga basin (Source India-WRIS)

Chapter 8 LAND USE CHANGES

8.1 INTRODUCTION

The river Ganga, its tributaries, and the flat and fertile plains through which they flow are one of the world's richest natural resources. For thousands of years, the fertile land and abundant water have provided the foundation for an increasingly civilized society based on agriculture, and have led to the development of one of the world's largest human populations.

Land use is a description of how people utilize the land and socio-economic activity. At any one point or place, there may be multiple and alternate land uses, the specification of which may have a political dimension. Land cover is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. This basin holds a variety of land cover and land use classes.

8.2 LAND USE CHANGES

The forest cover of upper Ganga basin is characterised by mixed vegetation, followed by mountainous terraced agriculture. In general, the major type of forest and other natural vegetation occur in northern aspect of the hill slope, whereas southern slopes are mostly either bare with rock outcrops or under grass cover with scattered Xerophitic and thorny vegetation like Kura, Randia, Carissa. The upper part of the region mainly consists of Pine (*Pinus* species), Teak (*Tectona grandis*) and Sisoo (*Delbergia sisoo*). The common tree species of rest of the region are comprised of Sal (*Shoria robusta*), Babool (*Acassia arabica*), Sisoo along with different shrubs and grasses (Chauniyal, 2001).

The cultivated area is almost devoid of any natural vegetation except some grass species like *Sorghum Helepense, Heteropogun Contrortus* and some bushy broad leaf weeds like *Lantana Camera*. The cultivation is the main occupation of the area, and even the steep hill slopes are extensively taken up for cultivation. Cultivation in steep hill terraces is practiced with fallowing of one year. Mostly Ragi, minor millets and some fodder grasses are cultivated as rainfed crops. Excessive drainage and runoff have caused low fertility of the soil and crop yield is extremely low. Use of fertilizer is very less (Nand and Kumar, 1989).

The cultivation in mountain valleys with moderate slope is taken up more intensively. Due to seepage, the moisture status of the soil is good. Rice and minor millets are commonly cultivated, when non-irrigated. If irrigation facility is available, rice and wheat is cultivated along with ginger and potato. The river terraces are the best cultivated land and irrigation facility is commonly present. Two dominant crops of this region are paddy and wheat. The schematic systems of landforms and land use, and transverse land use profiles are shown in Figs. 8.1 and 8.2, respectively.

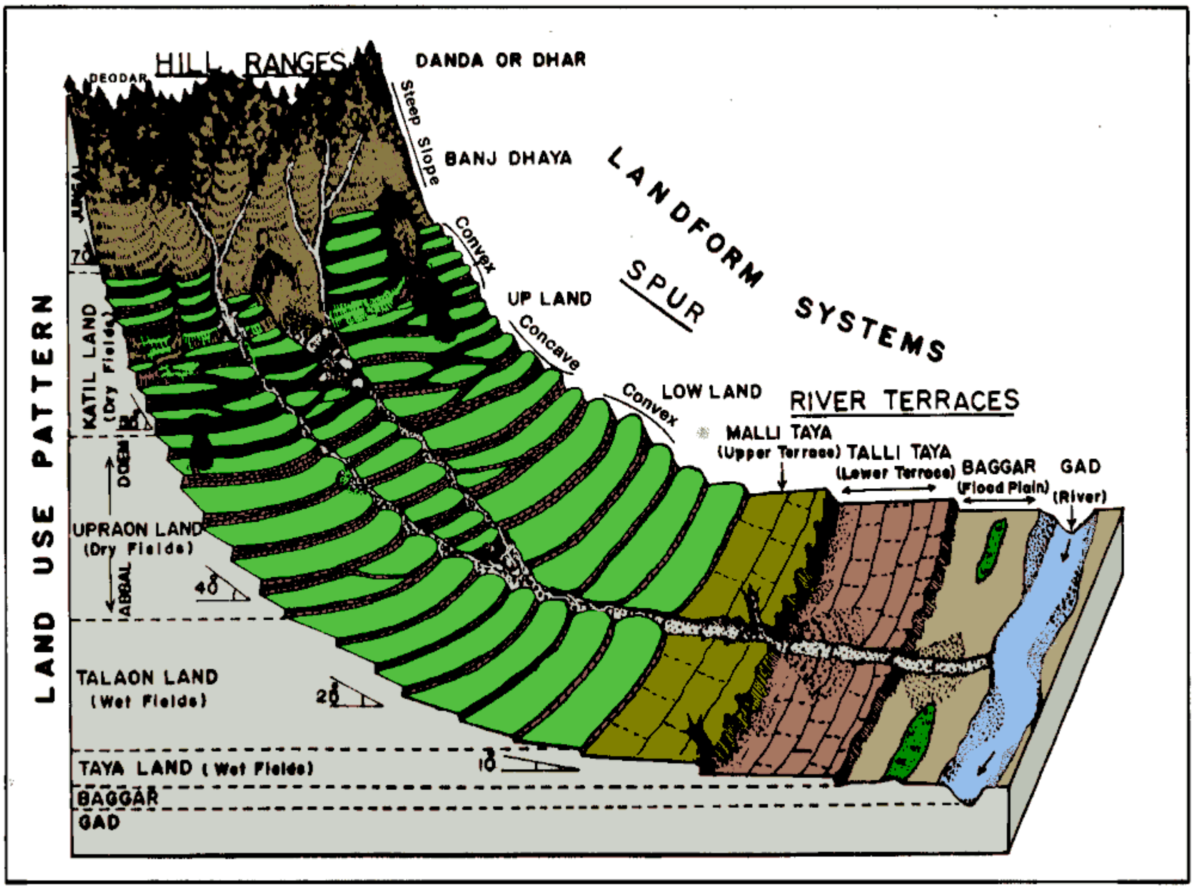


Figure 8.1 Schematic systems of landforms and land use (Source: Chauniyal, 2001; Garg, 2004)

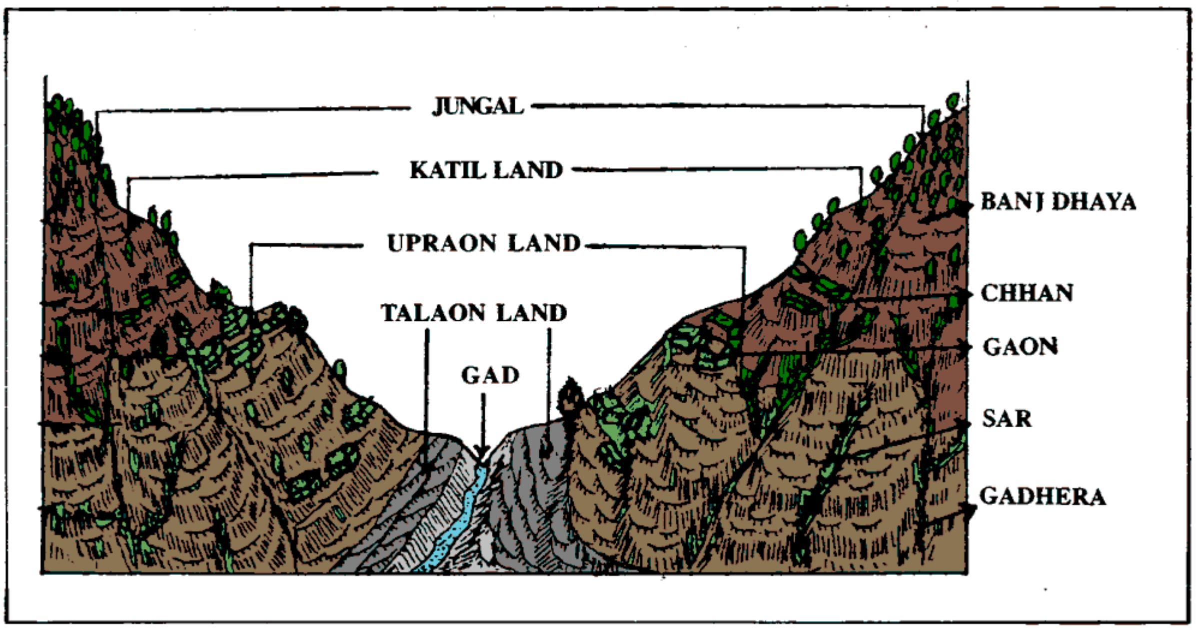


Figure 8.2 Transverse land use profile **(**Source: Chauniyal, 2001; Garg, 2004)

The major part of basin is covered with agriculture accounting to 65.57%. The states falling under Ganga basin are extensively cultivated, constituting approximately about 40% of the total area of the India. Other major land cover is deciduous forest accounting for 16% of the area. The level-I land use/land cover statistics of the Ganga basin for year 2005-06 are shown in the Table 8.1 (India WRIS 2014).

Table 8.1 Land Use /Land Cover Statistics (2005-06) Source: (India-WRIS 2014)

Classes	Area (km^2)	% of Total Area
Agriculture	564866	65.57
Forest	137816.5	16
Wasteland	76603.61	8.89
Built Up Land	36908.24	4.28
Water bodies	29876.51	3.47
Snow/Glaciers	8056.9	0.94
Grassland	7324.27	0.85

The land being the chief resources, has been subject to misuses, which have resulted into several land and associated problems. The distribution of land use/land cover in Ganga basin during 2005-06 is given in Fig. 8.3.

The overgrazing and deforestation in most areas have led to soil erosion and ravine formation on the one hand and have accentuated flooding on the other. For example, particularly the Yamuna and the Chambal have subjected the Yamunanagar district in Haryana to severe ravine-formation. In addition, land not available for cultivation and fallow land class covers a considerable area of the basin. This category of land consists of tracts which cannot be put to agricultural or silvicultural uses at an economic level due to their unproductive nature, as well all lands put to various other economic uses, such as mineral exploitation or construction of human settlements, industrial structures, roads, railways, airports and other civil works needed for providing transport, communication and similar infrastructural facilities for human habitation.

A proportion of the Ganga basin comprises of the non-arable land that is used in urbanization and in construction of homesteads in rural areas, which is one of the thickly populated. The states falling under Ganga basin have only 16.6% of total land areas covered by forest, as compared to India as a whole, which has 21.2% of land under forest cover. In some states, especially Haryana, Delhi, Bihar, Uttar Pradesh, Rajasthan and West Bengal, the forest cover is as low as 0.1 to 13.2% of the geographical area. Most of forest tracts within the Ganga basin are severely degraded because of over exploitation. As a result, the forest ecosystem in the Ganga basin is under severe stress. Even in the states of Uttarakhand (64.7 %), Madhya Pradesh (28.2 %) and Himachal Pradesh (19.8 %) where the forest cover is higher, the proportion of land actually under dense tree cover within the government forest tracts is very low due to extensive clear felling of trees carried out in recent decades.

According to the year 1984 classification, areas in the north of the Upper Ganga (UG) basin (Himalayas) were either barren or covered by snow. The central and northern parts of the catchment were dominated by forests. In the central areas, a combination of dense vegetation and crops was identified along with barren and grassland. Most of the urban and agricultural areas in the basin are located towards the south, in the plains of the UG basin.

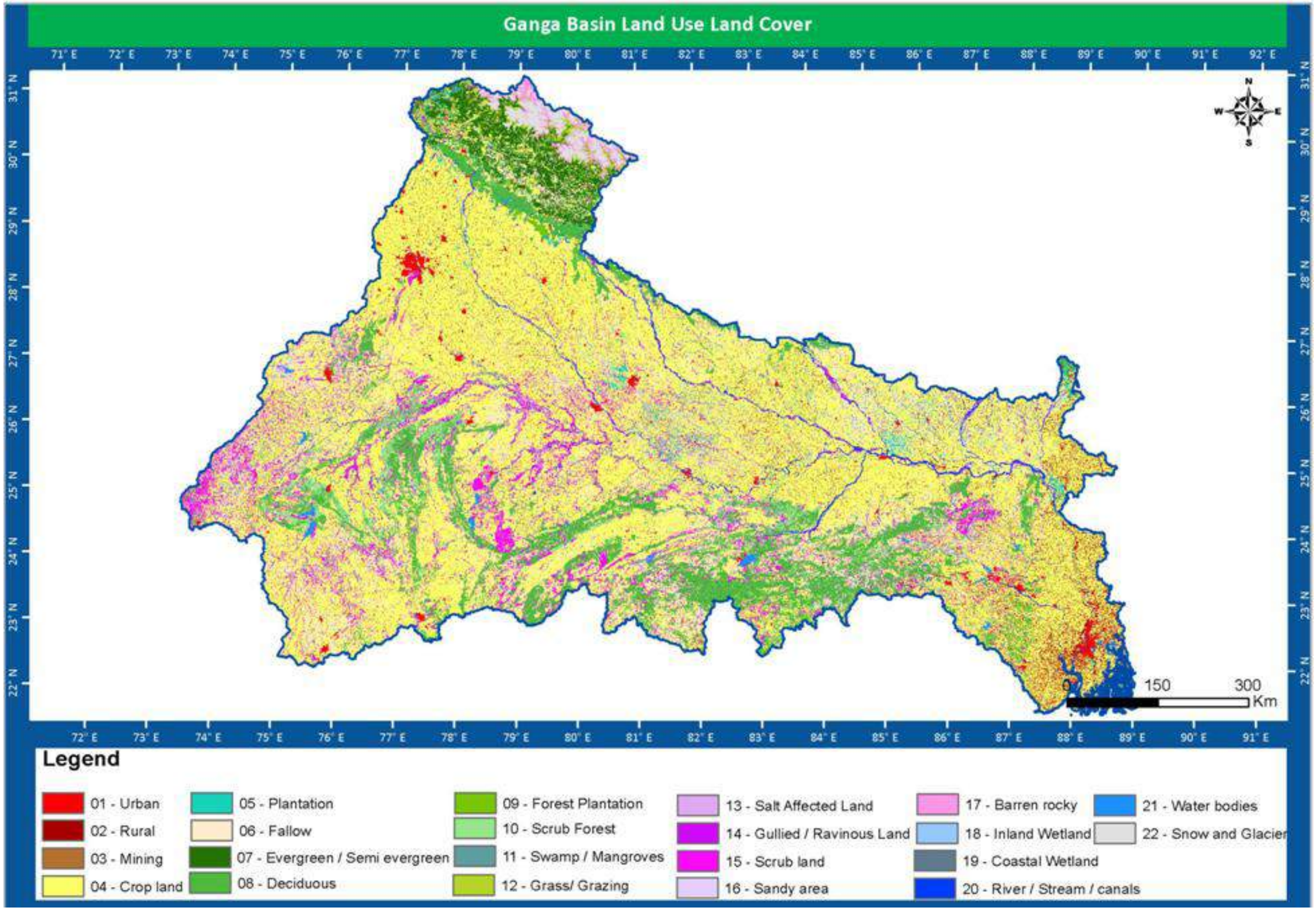


Figure 8.3 Land use/Land cover (2005-06) (Source: WRIS, 2014)

As per the study by Tsarouchi et al. (2014), the changes in land-cover proportions over the periods examined, crops increased from 1984 to 2006 but from 2006 to 2010, they decreased; however, the overall change from 1984 to 2010 was an increase of 1.3% (Table 8.2). The trends observed in the forest proportion follow the opposite direction: forest decreased from 1984 to 1998 but from 1998 to 2010, it increased, achieving a total increase of 4.7% from 1984 to 2010. Shrub coverage increased from 1984 to 2000 but from 2000 onwards, it decreased and showed an overall change of –11.6% from 1984 to 2010. Grass and barren lands did not show a stable trend of increase or decrease in the periods examined between 1984 and 2010; nevertheless, they reduced from 1984 to 2010 by 9.0% and 9.5%, respectively. Urban coverage was expanded from 1984 onwards, and the total increase during the 1984–2010 period was 5.8%.

Table 8.1 Land Use/ Land Cover dynamics of Upper Ganga Basin (1984-2010)
(Source: Tsarouchi et al., 2014)

Image	Water	Forest	Shrubs	Grass	Crops	Urban	Snow	Barren
1984	0.63	16.35	5.41	6.58	62.62	1.39	2.82	4.20
1990	0.60	15.68	6.05	6.84	62.88	1.40	2.72	3.80
1998	0.56	14.83	6.712	7.13	63.06	1.43	2.70	3.58
2000	0.64	14.99	6.72	6.44	63.12	1.43	2.73	3.94
2002	0.64	15.67	6.12	5.55	63.58	1.46	2.93	4.05
2004	0.61	15.90	5.81	5.85	64.78	1.46	2.99	3.60
2006	0.58	16.04	5.47	5.33	64.05	1.46	3.16	3.91
2008	0.60	16.71	5.13	5.56	63.95	1.47	3.14	3.45
2010	0.59	17.12	4.78	5.99	63.42	1.47	2.83	3.80

The Gangetic plains are mostly divided into three parts, Upper Ganga plains, Middle Ganga plains and Lower Ganga plains. The Upper Ganga plain is the part of the Great Plains lying approximately between the Yamuna in the west covering the parts of Uttarakhand and Uttar Pradesh. The region is delimited in the north by 300 m contour which separates it from the Garh - Kum Himalaya west of Sarda while the International boundary of Nepal marks the limit towards the east. In the south the Yamuna demarcates its border with the Bundelkhand. The axis of the topographic trough paradoxically lies nearer the peninsular block or along the

Ganga which traverses the area in a south-southeasterly direction. Thus there is, though not perceptible, a tract adjacent to the foot hills where the slope is higher and has resulted in the preponderance of numerous small streams, assigning a somewhat medium to fine texture to this part. The southern counterparts, particularly north of the Ganga are characterized by the sluggishly-flowing streams like the Ramganga and the Ghaghara studded with ox-bows, sandy stretches (the Bhurs) etc. The topographic diversities produced by the changing river courses are predominantly observed in the Ramganga and the Ghaghara valleys, particularly in their flood plains.

The streams such as the Kali, the Hindan, and the Pandu etc. have to go a long way parallel to their master streams to empty themselves. Distinct, though areally insignificant, in topographic expressions is the Yamunapar or the Yamuna-lower Chambal tract. The deep valley separated by sharp spurs and buttresses are the main features of Upper Ganga Plain. Topographically most significant and complex part of the region is the submontane belt, running at the foot of the Siwaliks from west to east across the area on the northern border consisting of the two parallel strips – the piedmont zone, the Bhabar (the Doab region) and the adjoining relatively gently sloping Tarai belt.

The Middle Ganga Plain is the largest among the three plains of the Ganga. It covers the Bihar plains and the Eastern Uttar Pradesh lying on the entire side of the Ganga and the Ghaghara within the Himalayan and the peninsular ramparts on the north and the south respectively. Structurally the region is the segment of the great Indo-Ganga trough; however it has some marginal portions of the other two major formations that are Siwaliks in the northern part of the Champaran district and the fringes and the projections of the peninsular block in the south. In general, it is below 100 m above the sea level, except that is gradually rises from Domariaganj in Basti up to 130 m in the North West and up to 150 m in the south in cooperating the projections of the southern uplands; in the east the Kosi plain ranges between 30 m in the south to 75 m in the extreme north. A more pronounced relief is occasioned when the plain meets the hilly area in the north bearing the stamp of their loosely-set gravelly nature, particularly in the extreme north, where the surface appears to be broken by large Ganga Basin like the Ghaghara, the Rapti, the Gandak, the Bagmati, the Kosi etc., which comb the region with their affluents in an intricate pattern.

The Lower Ganga Plain includes the Kishanganj district of Bihar, whole of West Bengal excluding the Purulia district and the mountainous parts of Darjeeling district and most of the parts of Bangladesh. The region embraces the area from the foot of the Darjeeling Himalayas in the north to the Bay of Bengal in the south and from the edge of the Chottanagpur Highlands in the west to the border of Bangladesh and Assam in the east. Topographic expressions in the region hardly speak of any well-defined stage of their evolution. The monotonous surface is dissected frequently by the channels of the tributaries or distributaries of the main stream, the Ganga. There are (*i*) the Malda west Dinajpur tract where the inliers of the lateritic alluvium are sufficient to break the general monotony of the plain, (*ii*) the tract bordering the Chottanagpur Highlands, (*iii*) the Midnapore Coast where the sand dunes on the terraces appear to be more significant element of landforms, (*iv*) the Duars of Jalpaigurl and Darjeeling. To the east of the shoreline lies bulge of the Ganga (Sundarbans) where the depositional activity of the stream is prominent and new surface is being continuously added.

8.3 CONCLUSIONS

Following conclusions may be drawn

1. The major part of basin is covered with agriculture accounting to 65.57% followed by forest (16%), Wasteland (8.89%), Buil Up Land (4.28%), Water bodies (3.47%), Snow/Glaciers (0.94%) and Grassland (0.85%).
2. The overgrazing and deforestation in most areas of the Ganga basin have led to soil erosion and ravine formation on the one hand and have accentuated flooding on the other. Most of forest tracts within the Ganga basin are severely degraded because of over exploitation. As a result, the forest ecosystem in the Ganga basin is under severe stress.
3. The changes in land-cover proportions over the periods 2006-2014, crops increased from 1984 to 2006 but from 2006 to 2010, they decreased; however, the overall change from 1984 to 2010 was an increase of 1.3% . The trends observed in the forest proportion indicates an increase of 4.7% from 1984 to 2010. Shrub coverage showed an overall change of –11.6% from 1984 to 2010. Grass and barren lands did not show a stable trend. Urban coverage was expanded from 1984 onwards, and the total increase during the 1984–2010 period was 5.8%.

Chapter 9 RECONNAISSANCE

9.1 INTRODUCTION

This chapter deals with details of the site visit undertaken to various locations of the Ganga river by the team of IIT Roorkee. The observations made during the site visits have been examined in the perspective of the outcomes of the morphological analysis carried out in this study.

9.2 SITE VISIT TO PASHULOK BARRAGE ON 10-12-2016

A team of IIT Roorkee visited the site of Pashulok barrage on December 10th, 2016. This is the first barrage across Ganga river located at Rishikesh. A power canal offtakes from the left side of the river which feeds water to the Chilla hydropower plant. Ganga river near the barrage is characterized as boulders bed and relatively steep slope with well defined banks. The average width of the river and length of the barrage are comparable which indicates no major contraction of the river at the barrage site. No noticeable silting/erosion were noticed in the river near the barrage. Few photographs taken during the site visits are shown in the Figs. 9.1 to 9.4.

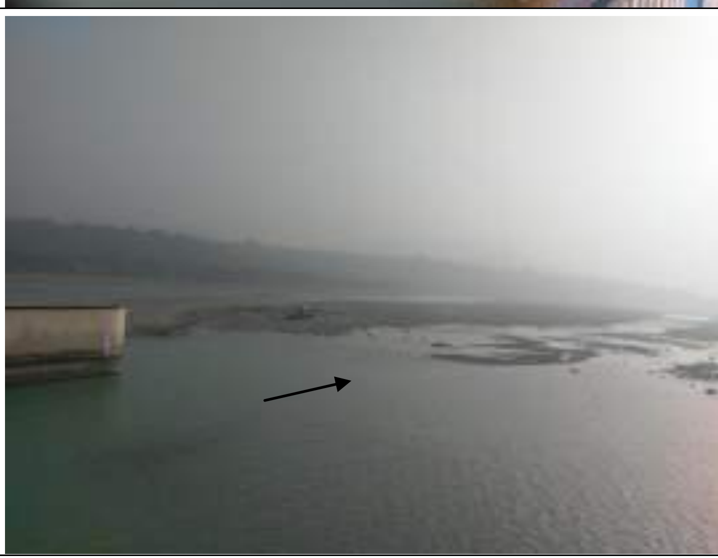
	**Figure 9.1** Upstream view of the Pashulok barrage
	**Figure 9.2** View of the Ganga river upstream of the Pashulok barrage
	**Figure 9.3** Downstream view of the Pashulok barrage

Figure 9.4 View of the Ganga river downstream of the Pashulok barrage

9.3 SITE VISIT TO BHIMGODA BARRAGE ON 10-12-2016

This is the second barrage across the Ganga river at Haridwar. A site visit was undertaken to this barrage on December 10th 2016. Upper Ganga Canal off-takes from the right side while Eastern Ganga Canal off-takes from the left bank. A guide bund is provided towards left side to guide the flow towards the barrage. A series of spurs were also seen towards left side upstream of the guide bund to protect the left bank of the river against erosion. A silted island was noticed towards left side of the river upstream of the barrage.

No noticeable siltation/ erosion were found in the river near to the barrage. However, about 2 km downstream of barrage the river is abutting the right bank which has resulted in its erosion. To protect the right bank against such erosion, a series of spurs have been provided. Photographs taken during the site visits are shown in Figs. 9.5 to 9.7.

	**Figure 9.5** Upstream view of the Bhimgoda barrage
	**Figure 9.6** A small silted island upstream of the barrage towards left side
	**Figure 9.7** Downstream view of the barrage

9.4 SITE VISIT TO CHAUDHARY CHARAN SINGH BARRAGE ON 12-10-2016

Morphology of the Ganga river at the Chaudhary Charan Singh barrage was inspected on 12 Oct. 2016. There was heavy deposition in the river upstream of the barrage with pronounced weeds growth and bushes. It was told by the person associated with the maintenance of barrage that such deposition occurred in the year 2010. Ganga river in the upstream of the barrage was flowing in two channels - major one was towards the left side and minor one was on the right side. In view of water all around the deposit, it has taken a shape of an island. It was told that it does not wash out even during high flood in the river. The size of the islands does not change as the flood water erodes the new deposits, if any. The island got submerged during heavy flood. No dredging is carried out on upstream as well as downstream side of the barrage.

There was deposit in the downstream of the barrage also but it was of low height and got submerged during the flood and also washed out. There was no vegetation, grass on these deposits/islands. The river was mainly flowing towards the right side, downstream of the barrage. The right bank was protected with provision of a solid spur against the erosion.

Few photographs that were taken during the site visit are shown in Figs. 9.8 to 9.11.

Figure 9.8 Chaudhary Charan Singh (C.C.S) barrage

	**Figure 9.9** A spur on right side of the river downstream of the C.C.S. barrage
	**Figure 9.10** Heavy deposits upstream of the C.C.S. barrage (Photo taken from right bank)
	**Figure 9.11** Downstream view of river at C.C.S. barrage

9.5 SITE VISIT TO NARORA BARRAGE ON 12-10-2016

Narora Barrage was also visited on the same day. Two canals namely Lower Ganga Canal and Parallel Ganga Canal off-take from the right side of the river. There was heavy deposition in the river upstream of the barrage in the form of islands with pronounced weeds growth and bushes. The island was stretched over about 60-70% length of the barrage and about 4-5 km long on upstream side. Major flow was towards the right bank of the river. The island doesn't submerge or wash out even in flood time. As per local information, these deposits are there from so many years. It was communicated that one pilot channel was excavated approx. 6-7 years earlier, on upstream side island to erode the island, however, it did not work.

Low height deposits were also seen downstream of the barrage in the mid of the river. Such deposits wash out during the flood time. No protection/training works were provided in the vicinity of the barrage. No dredging is carried out on upstream as well as downstream side of the barrage.

Few photographs taken during the site visit are shown in Figs. 9.12 to 9.14.

Figure 9.12 Heavy deposit upstream of the Narora barrage (Photo taken from left bank)

Figure 9.13 Heavy deposit upstream of the Narora barrage (another view)

Figure 9.14 No major deposit downstream of the Narora barrage (another view)

9.6 SITE VISIT TO LUVKHUSH BARRAGE ON 13-11-2016

A team of IIT Roorkee visited the LuvKhush barrage across Ganga river at Kanpur on 13th November, 2016 and observed the morphology of river in the vicinity of the barrage. Based on the site inspection and discussions held with barrage authorities, the following points have been drawn:

1. Prior to the construction of barrage in the upstream of the barrage, Ganga river was following towards left side, however, after the construction of the barrage river has shifted towards the right side. On the day of the visit, the river was flowing towards left side.

2. There was negligible silt deposition in the upstream of the barrage in the form of islands as it has been seen in other barrages like Farakka, Narora, and Chaudhary Charan Singh barrage.
3. There was silt deposition towards left side in the downstream of the barrage that may be attributed to severe shifting of the river towards right side.
4. All the gates of barrage are being opened during the flood time that may be a reason of negligible siltation in the upstream of the barrage.
5. It was intimated that during the flood of 2010, water level has reached upto 119.8 m and about 5-6 villages located in the upstream of the barrage were got submerged.
6. The design discharge of the barrage is 10,00,000 cusecs, however, till date the maximum observed discharge of 6,47,000 cusecs has passed in the year 2010.

Few photographs taken during the site visit are shown in Figs. 9.15 to 9.20.

Figure 9.15 View of LuvKhush barrage from upstream

	**Figure 9.16** Upstream view of the river relatively towards left side - showing course of the river towards this side
	**Figure 9.17** View of right side of the river upstream of the barrage
	**Figure 9.18** Small silt deposit upstream of the barrage towards left side

Figure 9.19 Silt disposition towards left side downstream of the barrage

Figure 9.20 Severe shifting of river towards right side downstream of the barrage

9.7 SITE VISIT TO GANGA RIVER NEAR THE VARANASI ON 13-08-2016

Various sites on Ganga river near Varanasi were visited during the period 13-14 August, 2016. No noticeable change in the morphology of the Ganga river near the Varanasi was observed. At the Sheetla ghat near Adalpura (25°10'29.90"N, 82°53'28.72"E), the river was too wide and was flowing into two channels. The left channel was not visible from the Sheetla ghat. On the day of visit, the flowing water was containing high sediment load.

At a bridge on NH-2 across Ganga river (25°15'20.00"N, 83° 1'39.30"E), the right bank was higher than the left bank. Mild erosion on right bank was noticed near the bridge. No guide bund or any other training was provided. Left side was heavy habitated.

At Malviya rail-cum-road bridge on Ganga river located at Varanasi (25°19'19.93"N, 83° 2'3.73"E), no guide bund was seen. There was no erosion and deposition near the bridge. The left bank was heavily habitated, however, right bank was thinly habitated. Ghats were noticed on both the banks downstream of the Malviya bridge.

A meeting was held with Er. Rajendra Singh, Chief Engineer (Sone), Irrigation Department, Varanasi and his staff and morphological changes in Ganga river from Allahabad to Ghazipur was discussed. It was intimated that there was no major plan form changes in this reach except at Saidpur and Mirzapur where minor bank erosion has been noticed.

Few photographs taken during the site visit are shown in the Figs 9.21-9.27.

Figure 9.21 Ganga river at Sheetla ghat, Adalpura, Varanasi

	**Figure 9.22** Ganga river at Sheetla ghat, Adalpur, Varanasi view of opposite bank
	**Figure 9.23** Upstream view of Ganga river at Trafi bridge, Varanasi
	**Figure 9.24** Downstream view of Ganga river at Trafi bridge, Varanasi

	**Figure 9.25** Upstream view of Ganga river at Malviya rail-cum-road bridge at Varanasi
	**Figure 9.26** Left bank of the Ganga river upstream of Malviya rail-cum-road bridge at Varanasi
	**Figure 9.27** Right bank of the Ganga river upstream of Malviya rail-cum-road bridge at Varanasi .

9.8 SITE VISIT TO GANGA RIVER TO PATNA AND NEARBY AREAS

Several site visits were undertaken to Patna and its nearby area to examine the morphological change of Ganga river. Such visits were under taken on 25-02-2013, 27-07-2014, 17-12-2014 and 24-7-2016. The IIT Roorkee team visited the Ganga river from its confluence with Ghaghara river at Revelganj (Chhapra) to Patna.

The following points were noticed during the visits-

1. Meandering behaviour of Ganga river was noticed downstream of its confluence with the Ghaghara river. Several sand bars were also noticed at this location.
2. Sone river joins Ganga river near Maner and at this location also the river flow in multiple channels with meandering pattern. Large deposits were noticed in the centre of Ganga river downstream of its confluence with the Sone river
3. No major change in the course of Ganga river was noticed at the Digha ghat. However, it was found through the local enquiry that remarkable changes in the plan form of the Ganga river have occurred both in the upstream and downstream of the Digha ghat. Over the years, the main course of the Ganga river has shifted from left to right upstream of the Digha ghat and from right to left downstream of the Digha ghat.
4. Due to such shifting, Ganga water is not available towards the Patna side over a distance of about 5-6 km downstream of the Digha ghat. To ensure the water availability towards Patna, Water Resource Department excavated a channel in 2015, however due to floods in 2015 and 2016, the channel is silted to a great extent and not serving the purpose for which it was excavated.
5. At the Gandhi Setu, the river is constantly flowing hugging the right bank i.e., Patna side at least from 1970 as image/toposheet before 1970 is/are not available. Further, the river is flowing over a width of about 2.4 km from the Patna side. It. may be concluded that there are no noticeable morphological changes of the river near the Ganga Setu and the river is flowing over a width of about 2.4 km from Patna side from at least year 1970.

   Various photographs taken during the site visits are shown in the Figs. 9.28 to 9.32.

	**Figure 9.28** Upstream view of the Ganga river at Doriganj (Chhapra) (25/2/2013)
	**Figure 9.29** An under-construction bridge at Doriganj (Chhapra) (25/2/2013)
	**Figure 9.30** Digha bridge at Patna (24/7/2016)

Figure 9.31 Downstream view of the channel at its crossing with Gangapath (24/7/2016)

Figure 9.32 Ganga at Patna upstream of the Gandhi setu (27/7/2014)

9.9 SITE VISIT TO GANGA RIVER NEAR SAHIBGANJ-KAHALGAON-SULTANGANJ ON 28-10-2016

Various sites on right bank of Ganga river were visited during the period 27-28 October, 2016.

Sahibganj

No noticeable changes in the morphology of the Ganga river near Sahibganj were observed. At the Feri ghat (25°14'53.6"N, 87°38'26.8"E), Sahibganj, relatively small channel was flowing towards Sahibganj side; the major channel was away from the ghats towards the left bank of the river. Between the two channels, there was a huge deposition of sand and over that vegetation was visible. It was informed by the local persons that there are lot of settlements over the silted area between the two channels. All the silted area along with the settlements got submerged during high flood. Right bank is relatively high, no erosion was noticed in the vicinity of the Feri ghat.

Kahalgaon

At the Ganga Ghat near Kahalgaon (25°15'56.4"N, 87°13'33.7"E) river was too wide, mainly concentrated towards the right bank which is relatively high. Two temples were seen inside the river which wereconstructed on rock outcrop. Minor erosion at right bank was also noticed. River was flowing along and very close to the National Highway-33. On the right side a small river Kartaria was meeting Ganga river just upstream of the Kahalgaon ghat. No protection work was provided towards the right bank, even though there was a little bit erosion.

Bhagalpur

The river was inspected upstream of the Bhagalpur Town. It was too wide and major flow was on right side of the river. The river was flowing along NH-33 and it was very close to the road at some locations. Some small rivers have their confluence with Ganga.

Sultanganj

No noticeable changes in the morphology of the Ganga river near Sultanganj were observed. At the Balua Ghat (25°15'17.7"N, 86°44'24.5"E) river was too wide and major flow was towards the right bank. No erosion was noticed towards right side, rather sand deposits was there downstream of the Mazaar, which was situated on rock outcrop in the river and away from the right bank, and acting as a spur. No protection work was provided towards the right bank side. Heavy silting in the form of island and sandbars was noticed on the downstream of the river.

Medinighat (Near Begusarai)

At the Medini Ghat (25°17'20.1"N, 86°19'11.8"E) river was too wide. A small channel was flowing towards the right side which is named as Kiul river. River was flowing in number of channels and numerous silted islands were noticed. The team went to the middle of the rivers by a motor-boat along with officials of Power Grid, Patna. Two towers of high voltage transmission lines of Power Grid and one tower of Starlite were washed out. On the way, a number of sandbars were noticed. It was told by the local persons that these deposits are not permanent in nature. These got submerged during flood time, and also change their location.

Some of the photographs taken during the site visits are shown in Figs. 9.33-9.38.

	**Figure 9.33** Ganga river at Upstream of Feri Ghat, Near Sahibganj; Huge Deposition on other side is visible.
	**Figure 9.34** Ganga river at Downstream of Feri Ghat, Near Sahibganj; Huge Deposition on other side is visible.
	**Figure 9.35** Ganga river Upstream of Ganga Ghat, Near Kahalgaon; rocky outcrop on river bed is visible.

	**Figure 9.36** Ganga river Downstream of Ganga Ghat, Near Kahalgaon; Deposition on other side is visible.
	**Figure 9.37** Ganga river Upstream of Balua Ghat, Near Sultanganj; Deposition on other side is visible.
	**Figure 9.38** Ganga river downstream of Balua Ghat, Near Sultanganj; Deposition on other side is visible.

9.10 SITE VISIT TO FARAKKA BARRAGE ON 27-10-2016

Morphology of the Ganga river at the Farakka Barrage was inspected on 27th October, 2016. The barrage is 2.45 km long and consisted of 112 gates - out of these 108 are main gates and 4 are fish lock gates. Eleven head regulator gates are provided for diversion of approximately 40,000 cusecs (1035 cumecs) of discharge into the feeder canal. The feeder canal is 40km long and main purpose of the canal to divert adequate quantity of Ganga water to Bhagirathi-Hoogly river system. The maximum observed discharge in Ganga river upstream of barrage in recent time is 17,00,000 cusecs (48,139 cumecs) during flood season of the year 2014. It was seen that some of the barrage gates are under repair.

There is heavy silt deposition upstream of the barrage. Four islands have been formed due to heavy siltation. These islands are at about 400 m upstream of the barrage. Heavy vegetation was seen on the islands. Such islands got submerged during flood time as intimated. The islands were eroded during flood season of year 2014. Silting was also intimated on the downstream of the river. This could be due to the narrow section of the Padma river in the Bangladesh territory.

A meeting was held with Er. A.K. Singh, General Manager and Er. Ashish Kumar Pal, Superintending Engineer of Farakka barrage project. According to them, there is no progressive rise in maximum water level in Ganga river from Buxar to Farakka. They were in opinion that the removal of deposited silt manually or using some mechanical devices could not be a sustainable solution. It was intimated that they succeeded in partial cutting of islands upstream of the Farakka barrage by regulating the barrage gates.

Few photographs taken during the site visit are shown in the Figs. 9.39 to 9.41.

Figure 9.39 Upstream view of the Farakka barrage

Figure 9.40 Heavy silt deposition in the form of islands upstream of the Farakka barrage

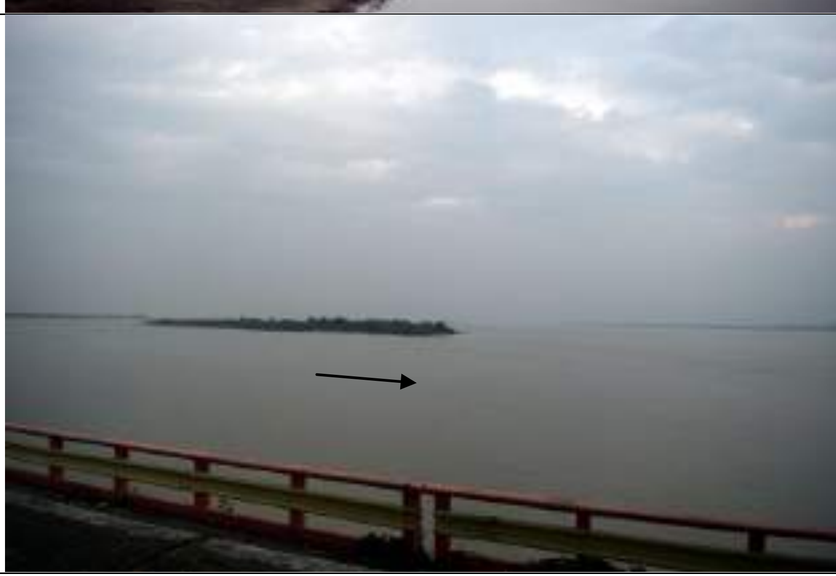


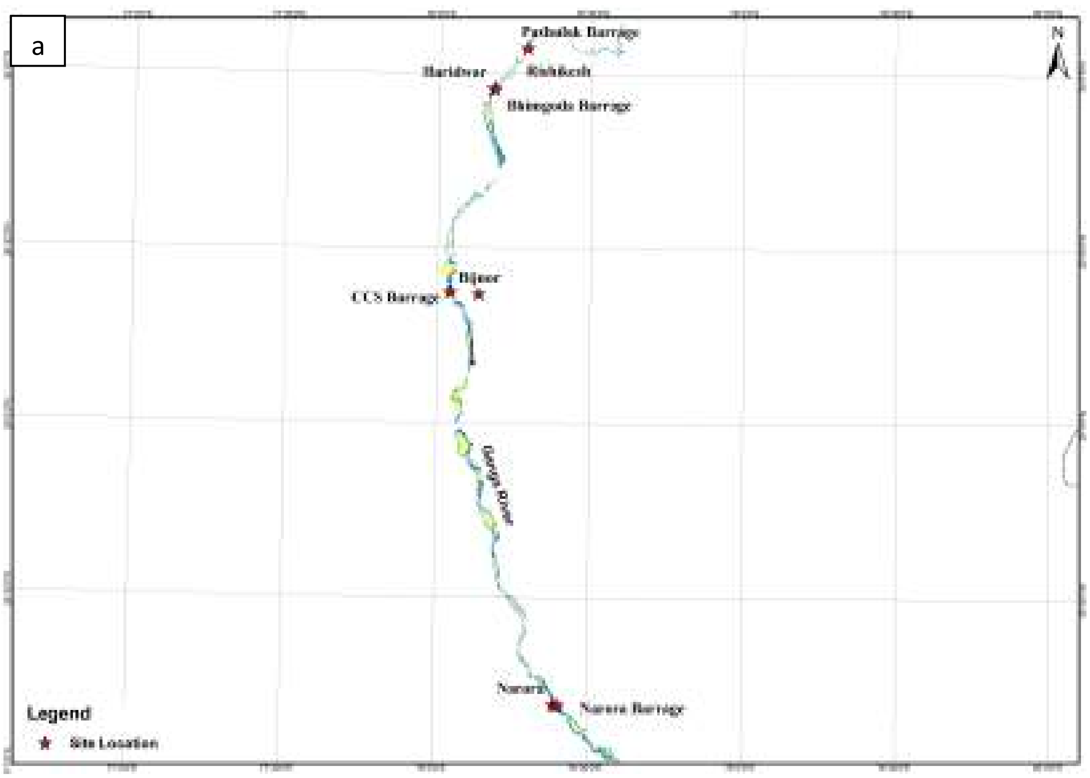
Figure 9.41 View of an island out of four with dense vegetation upstream of the Farakka barrage

9.11 SITE VISIT TO KANAUJ ON 24-06-2017

Bridge across Ganga river on Agra-Lucknow expressway was visited by a team of IIT Roorkee on 24th June 2017. Ganga river was not too wide at that location. The ground level of the right side land was higher than the left side. No guide bunds were provided there for the protection of the bridge. The length of the bridge was lesser than the river width at the bridge site. Both the approach roads were protected with boulder pitching. As such no other training works is required at the bridge site. Few photographs taken during the site visits are shown in the Figs. 9.42 to 9.44.

	**Figure 9.42** Upstream view of the Ganga river
	**Figure 9.43** Higher ground level towards right side

Figure 9.44 Boulder pitched left approach road



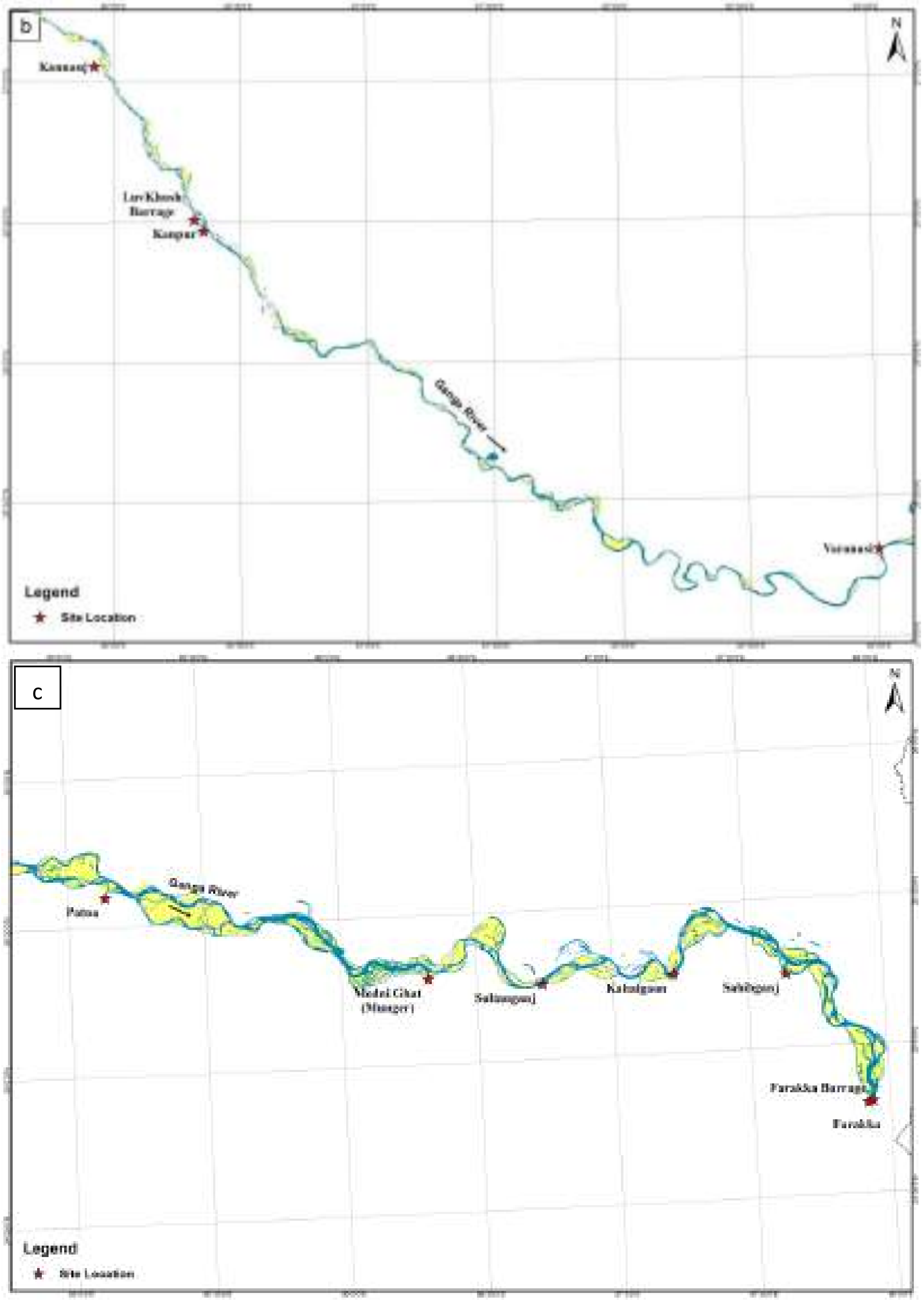


Figure 9.45 a-c Location of the sites of the Ganga river that were visited by the IIT Roorkee team

Chapter 10 RIVER MORPHOLOGY

10.1 DELINEATION/DIGITIZATION OF RIVER BANK LINE

The river bank-line has been identified and delineated from mosaics for all the satellite images of years 1970, 1980, 1990, 2000 and 2010. The identified river bank lines for the left, right and center (main channel) has been digitized using ArcMap software. Left bank, right bank and center line have been prepared for the years 1970, 1980, 1990, 2000 and 2010 (Figs 10.1 to 10.5). The length of arcs of the left bank, right bank and center line for all the above years has been calculated using GIS software. Shifting of center line, left bank, right bank of the river has been evaluated with respect to center line of year 2010.

Figure 10.1 Mosaic of SOI toposheets of Ganga river of 1970 (Scale 1:50,000)

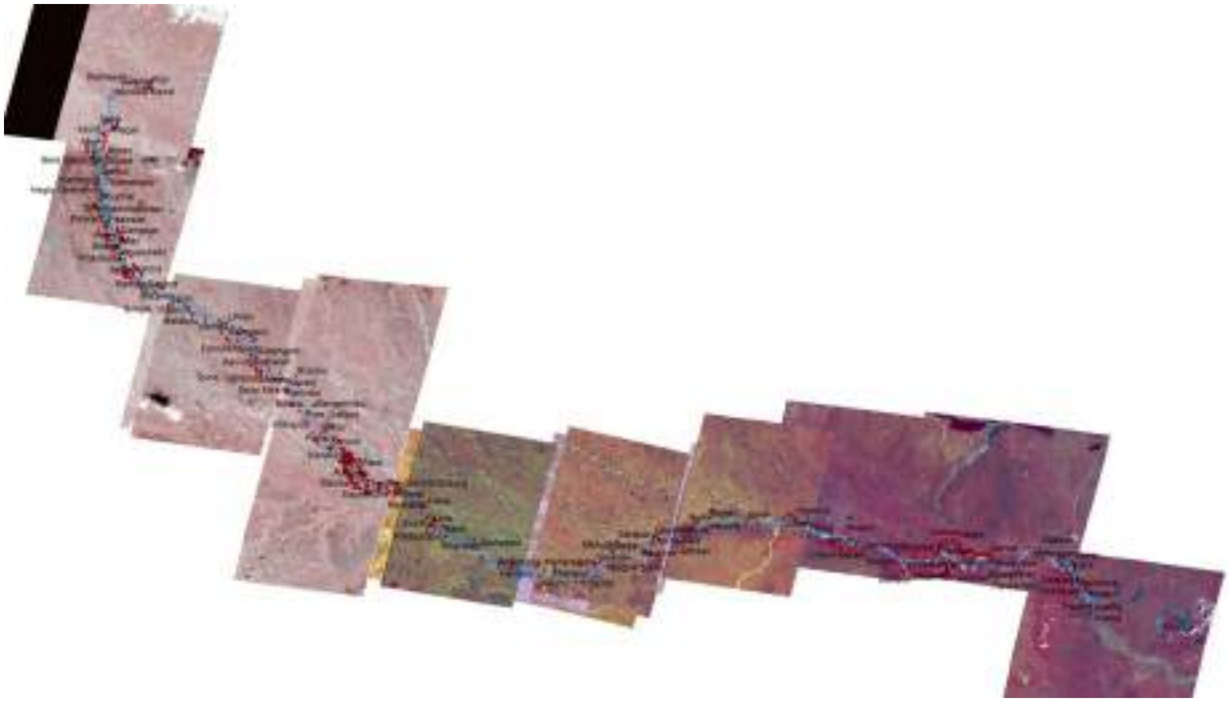


Figure 10.2 Mosaic of FCC of Ganga river of year 1980 (Landsat-MSS Images)

Figure 10.3 Mosaic of FCC of Ganga river of year 1990 (IRS 1A LISS II Images)

Figure 10.4: Mosaic of FCC of Ganga river of year 2000 (IRS 1C LISS III Images)

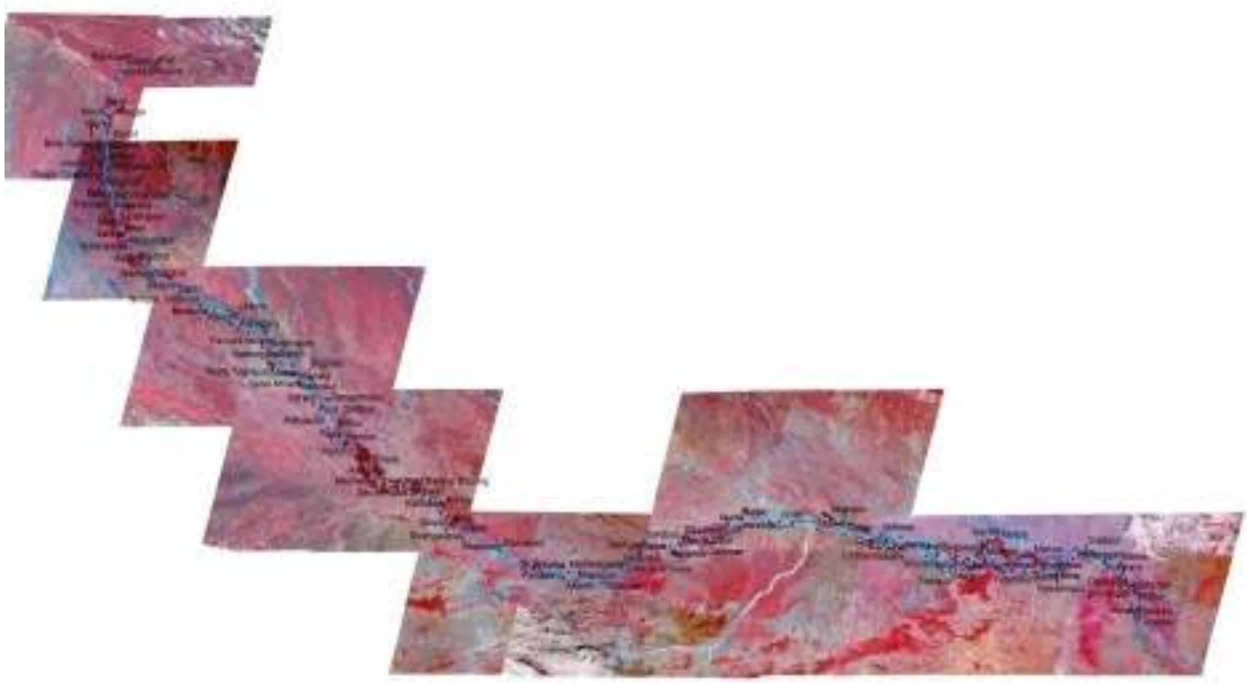


Figure 10.5 Mosaic of FCC of Ganga river of year 2010 (IRS P6 LISS III Images)

The total length of Ganga river from Devprayag to Farraka is 1,824 km. For study and presentation of results, the total length of the river is subdivided into 37 reaches - 36 reaches of 50 km length and the last one is of 24 km length. Details of the reaches are given in Table 10.1.

Table 10.1 Reaches of the Ganga river

Chainage in km	Reaches	Start to End location
0 - 50	Reach A	Farakka to Budhboria
50 - 100	Reach B	Budhboria to Lakshmipur
100 - 150	Reach C	Lakshmipur to Kahalgaon
150 - 200	Reach D	Kahalgaon to Mathurapur
200 - 250	Reach E	Mathurapur to Munger
250 – 300	Reach E	Munger to Khutaha
300 - 350	Reach F	Khutaha to Achauara
350 - 400	Reach G	Achauara to Daudnagar
400 - 450	Reach H	Daudnagar to Dhanaura
450 - 500	Reach I	Dhanaura to Nauranga
500 - 550	Reach J	Nauranga to Arjunpur
550 - 600	Reach K	Arjunpur to Saraia
600 - 650	Reach L	Saraia to Chandipur
650 - 700	Reach M	Chandipur to Mughal Sarai
700 - 750	Reach N	Mughal Sarai to Chunar
750 – 800	Reach O	Chunar to Mirzapur
800 - 850	Reach P	Mirzapur to Katra
850 - 900	Reach Q	Katra to Dumduma
900 - 950	Reach R	Dumduma to Allahabad
950 - 1000	Reach S	Allahabad to Jhangirabad
1000 - 1050	Reach T	Jhangirabad to KotaiyaChitra
1050 - 1100	Reach U	KotaiyaChitra to Daulatpur
1100 - 1150	Reach V	Daulatpur to Kanpur
1150 - 1200	Reach W	Kanpur to Pura
1200 - 1250	Reach X	Pura to Kannauj

1250 - 1300	Reach Y	Daryapur to Saraha
1300 - 1350	Reach Z	Saraha to Kampil
1350 – 1400	Reach AA	Bikrampur to Bsrauna
1400 – 1450	Reach AB	Bsrauna to Bhawanipur
1450 – 1500	Reach AC	Bhawanipur to Talwar
1500 – 1550	Reach AD	Talwar to Bagrasi
1550 – 1600	Reach AE	Bagrasi to Chhuchai
1600 – 1650	Reach AF	NaglaGoshiah to Ganj
1650 – 1700	Reach AG	Bijnor to Nagal
1700 - 1750	Reach AH	Nagal to Haridwar
1750 - 1800	Reach AI	Haridwar to Dabar
1800 - 1824	Reach AJ	Dabar to Devprayag

10.2 PLANFORM PATTERN OF THE RIVER

10.2.1 Sinuosity ratio

Planform of the rivers may be described as straight, meandering or braided. There is in fact a great range of channel patterns from straight through meandering to braided. Straight and meandering channels are described by sinuosity which is the ratio of channel length to valley length or the ratio of valley slope or channel gradient as measured over the same length of valley (Schumm, 1977). A sinuosity ratio of 1.5 was considered by Leopold and Wolman (1957) to differentiate sinuous from meandering. Rivers having a sinuosity of 1.5 or greater refer to meandering, and below 1.5 straight or sinuous. Definition of the sinuosity ratio, as suggested by various investigators, is given in the Table 10.2, however, definition proposed by Leopold and Wolman (1957) is commonly used.

Table 10.2 Definition of sinuosity ratio

S.No.	Sinuosity Ratio	Source
1	$\frac{Thalweg\ length}{Valley\ length}$	Leopold and Wolman, 1957
2	$\frac{Channel\ length}{Length\ of\ Meander\ belt\ axis}$	Brice, 1964
3	$\frac{Stream\ length}{Valley\ length}$	Schumm, 1963

The modified sinuosity parameter, P, as defined by Friend and Sinha (1993) has been used for this study.

$$P = \frac{L_{cmax}}{L_R} \tag{10.1}$$

Where, L_R is overall length of the channel belt reach measured along a straight line, or the valley length, and L_{cmax} is the mid channel length for the same reach or the stream length. The sample map that depicts the computation of river sinuosity is shown in Fig. 10.6a. Figure 10.6b shows channel patterns for different sinuosity ratio.

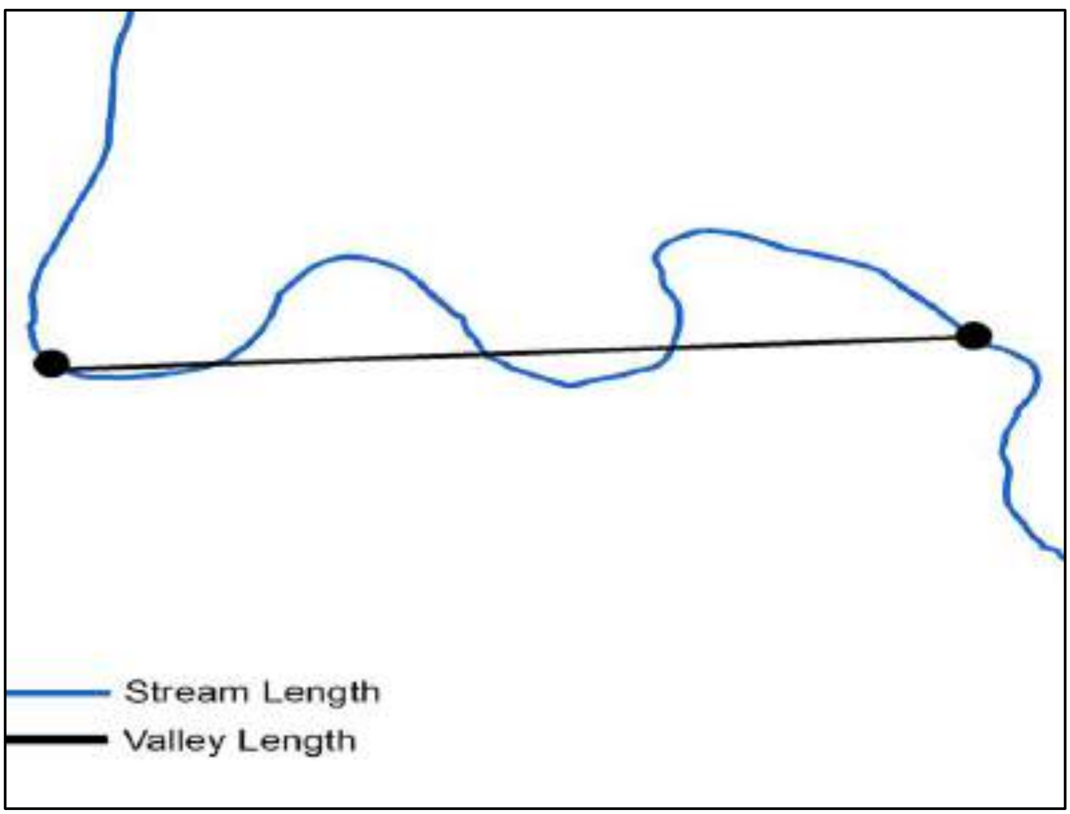


Figure 10.6a Diagram representing the calculation of the sinuosity

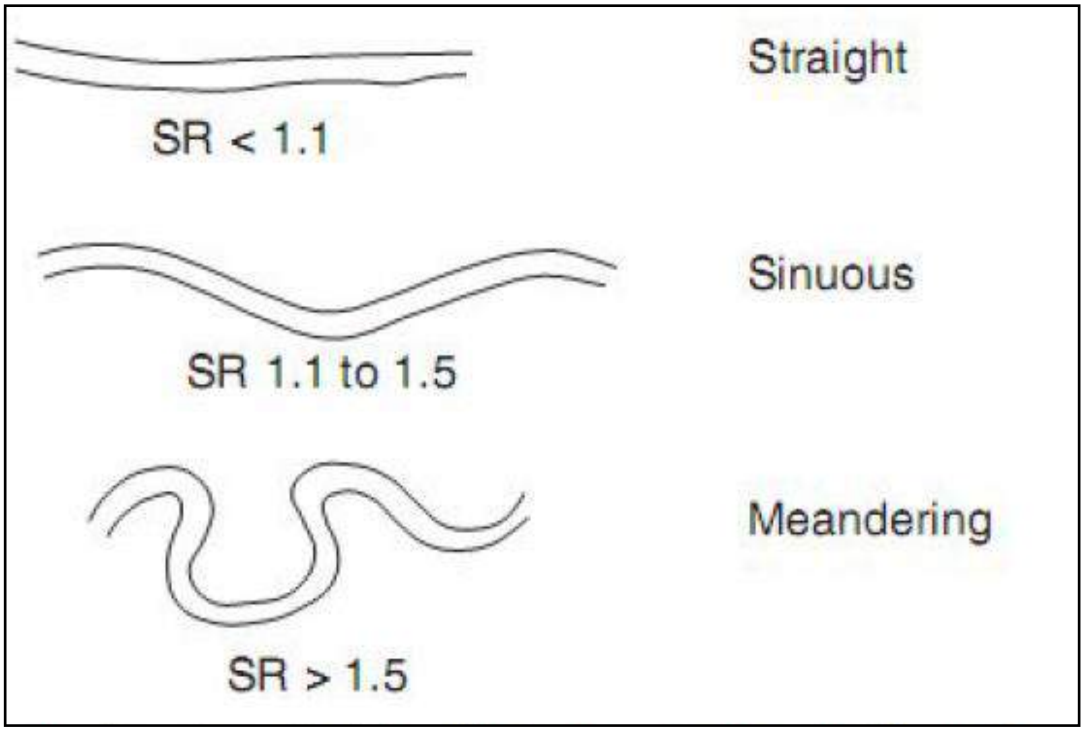


Figure 10.6b Channel patterns for different sinuosity ratio

For calculating sinuosity ratio, Eq. (1) given by Freind and Sinha (1993) has been used. The total length of the river has been subdivided into 37 reaches, out of which 36 reaches are of 50 km length and the last one of 24 km length. The calculated values of sinuosity ratio are given in Table 10.3 and graphically shown in Fig. 10.7.

Table 10.3 Sinuosity ratios for Ganga river of year 1970, 1980, 1990, 2000 and 2010

Chainage	Section	2010			2000			1990			1980			1970		
		L_{cmax}	L_R	SR-2010	L_{cmax}	L_R	SR-2000	L_{cmax}	L_R	SR-1990	L_{cmax}	L_R	SR-1980	L_{cmax}	L_R	SR-1970
0-50	1	50.00	38.68	**1.29**	49.60	38.64	**1.28**	46.34	38.13	**1.22**	410.18	38.23	**1.23**	48.80	310.55	**1.30**
50-100	2	50.00	310.21	**1.34**	46.66	310.82	**1.23**	45.71	310.48	**1.22**	49.57	310.57	**1.32**	48.91	39.18	**1.25**
100-150	3	50.00	33.68	**1.48**	48.50	34.45	**1.41**	45.61	33.97	**1.34**	40.09	34.98	**1.15**	46.49	34.97	**1.33**
150-200	4	50.00	40.26	**1.24**	43.48	39.13	**1.11**	45.95	39.28	**1.17**	46.16	40.88	**1.13**	60.17	40.16	**1.50**
200-250	5	50.00	35.64	**1.40**	63.95	38.10	**1.68**	50.40	310.07	**1.36**	75.44	34.89	**2.16**	75.28	36.04	**2.09**
250-300	6	50.00	41.61	**1.20**	45.37	39.79	**1.14**	44.44	40.33	**1.25**	50.77	42.68	**1.19**	51.14	42.27	**1.21**
300-350	7	50.00	40.90	**1.22**	48.60	41.57	**1.17**	410.41	41.26	**1.08**	50.96	43.73	**1.17**	49.37	42.08	**1.17**
350-400	8	50.00	43.88	**1.14**	51.42	43.14	**1.19**	52.90	43.12	**1.10**	49.42	42.29	**1.17**	49.35	42.91	**1.15**
400-450	9	50.00	44.74	**1.12**	49.09	44.51	**1.10**	61.70	44.62	**1.19**	60.14	44.67	**1.35**	61.27	44.97	**1.36**
450-500	10	50.00	40.80	**1.23**	50.21	41.30	**1.22**	54.47	41.22	**1.50**	51.21	41.52	**1.23**	52.02	41.93	**1.24**
500-550	11	50.00	39.47	**1.27**	50.45	38.99	**1.17**	48.96	39.05	**1.39**	48.48	38.61	**1.26**	49.91	38.42	**1.30**
550-600	12	50.00	38.82	**1.29**	48.98	39.25	**1.16**	49.73	38.48	**1.42**	49.25	38.92	**1.27**	50.29	38.16	**1.32**
600-650	13	50.00	210.43	**1.82**	50.30	210.22	**1.85**	53.54	210.56	**1.78**	50.21	210.32	**1.84**	50.01	210.28	**1.83**
650-700	14	50.00	210.17	**1.84**	50.44	210.08	**1.86**	50.28	210.04	**1.84**	49.24	210.08	**1.82**	50.47	210.06	**1.87**
700-750	15	50.00	39.40	**1.27**	49.86	39.51	**1.26**	50.50	39.57	**1.35**	50.54	39.46	**1.28**	51.22	39.46	**1.30**
750-800	16	50.00	33.83	**1.48**	49.42	33.96	**1.46**	49.19	33.91	**1.48**	410.94	33.84	**1.42**	49.17	33.96	**1.45**
800-850	17	50.00	25.28	**1.98**	50.65	25.23	**2.01**	50.22	25.30	**2.00**	410.88	25.24	**1.90**	50.14	25.24	**1.99**
850-900	18	50.00	28.09	**1.78**	49.79	210.78	**1.79**	49.62	210.54	**1.79**	48.26	210.49	**1.76**	48.89	26.80	**1.82**
900-950	19	50.00	34.77	**1.44**	48.57	33.02	**1.47**	53.42	33.91	**1.48**	51.66	33.45	**1.54**	53.66	34.99	**1.53**
950-1000	20	50.00	42.88	**1.17**	54.79	43.02	**1.27**	56.90	42.45	**1.34**	55.62	42.82	**1.30**	52.60	42.02	**1.25**
1000-1050	21	50.00	40.12	**1.25**	49.77	40.01	**1.24**	52.73	40.02	**1.32**	52.34	40.08	**1.31**	52.10	40.07	**1.30**
1050-1100	22	50.00	40.06	**1.25**	51.54	39.66	**1.30**	51.00	39.84	**1.28**	50.55	39.79	**1.27**	51.97	39.81	**1.31**
1100-1150	23	50.00	410.36	**1.06**	52.82	48.10	**1.10**	51.84	410.46	**1.09**	54.04	410.69	**1.13**	53.41	410.96	**1.11**
1150-1200	24	50.00	42.42	**1.18**	48.26	42.42	**1.14**	48.20	42.41	**1.14**	51.32	42.45	**1.21**	510.03	42.47	**1.34**
1200-1250	25	50.00	41.82	**1.20**	48.22	41.74	**1.16**	46.38	41.79	**1.11**	48.54	41.74	**1.16**	51.01	41.75	**1.22**

1250-1300	26	50.00	42.70	**1.17**	48.04	41.98	**1.14**	51.73	42.02	**1.23**	50.38	43.28	**1.16**	50.22	39.69	**1.27**
1300-1350	27	50.00	40.44	**1.24**	49.19	40.87	**1.20**	44.71	310.93	**1.18**	50.26	38.82	**1.29**	52.39	40.33	**1.30**
1350-1400	28	50.00	41.90	**1.19**	50.35	42.31	**1.19**	53.76	43.24	**1.24**	51.84	42.61	**1.22**	56.33	43.53	**1.29**
1400-1450	29	50.00	42.70	**1.17**	50.90	42.95	**1.19**	52.95	42.52	**1.25**	55.76	42.01	**1.33**	50.55	41.65	**1.21**
1450-1500	30	50.00	42.24	**1.18**	49.87	40.85	**1.22**	48.62	41.97	**1.16**	49.83	41.55	**1.20**	50.48	41.61	**1.21**
1500-1550	31	50.0	41.72	**1.20**	48.47	41.96	**1.16**	50.21	41.11	**1.22**	49.27	41.75	**1.18**	53.25	41.97	**1.27**
1550-1600	32	50.0	40.31	**1.24**	50.67	40.31	**1.26**	53.14	41.19	**1.29**	50.80	40.71	**1.25**	51.94	40.21	**1.29**
1600-1650	33	50.0	310.30	**1.34**	50.92	35.75	**1.42**	45.32	310.04	**1.22**	410.40	310.46	**1.27**	410.15	310.24	**1.27**
1650-1700	34	50.0	35.85	**1.39**	48.87	35.22	**1.39**	46.29	36.86	**1.26**	410.07	36.55	**1.29**	55.73	35.33	**1.58**
1700-1750	35	50.0	41.93	**1.19**	52.87	41.74	**1.27**	51.53	41.01	**1.26**	53.68	40.83	**1.31**	55.96	41.95	**1.33**
1750-1800	36	50.0	210.19	**1.84**	49.30	26.47	**1.86**	49.65	26.58	**1.87**	48.84	26.51	**1.84**	50.01	210.31	**1.83**
1800-1824	37	24.0	11.06	**2.17**	24.22	11.03	**2.20**	24.12	11.06	**2.18**	23.98	11.07	**2.17**	24.33	11.02	**2.21**
Maximum				**2.17**			**2.20**			**2.18**			**2.17**			**2.21**
Minimum				**1.06**			**1.10**			**1.08**			**1.13**			**1.11**
Average				**1.36**			**1.36**			**1.37**			**1.38**			**1.42**

Shaded portion indicates high sinuosity ratio

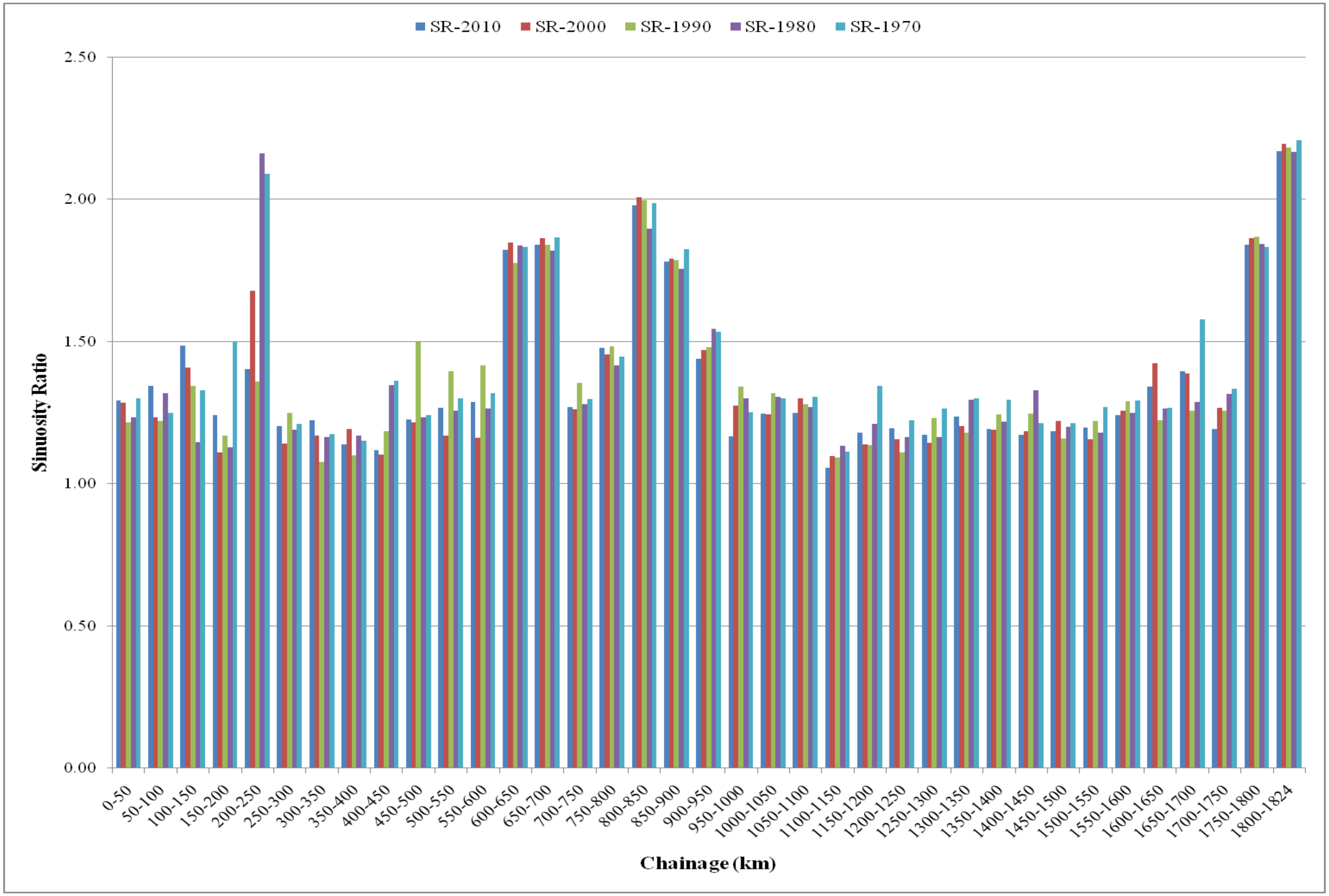


Figure 10.7 Sinuosity ratio of Ganga river of year 1970, 1980, 1990, 2000 and 2010

Following conclusions may be drawn from the calculated values of sinuosity ratio of Ganga river:

1. In the whole reach of the river and for the years 1970, 1980, 1990, 2000 and 2010, the maximum, minimum, and average sinuosity ratios are of the order of 2.2, 1.1 and 1.38 respectively.
2. Sinuosity ratios in the reaches 200-250 km, 600-700 km, 800-900 km and 1750-1824 km are relatively higher than the other reaches. As the average value of the sinuosity ratio for whole reach of the river is 1.38, therefore, the Ganga shall be considered as sinuous river as per the classification laid by Leopold and Wolman (1957) except the reaches identified above which can be classified as meander.
3. A negligible progressive change in the sinuosity ratio has been found from the year 1970 to 2010.

Geometrical parameters of the prominent meanders such as axial wavelength, amplitude and radius of curvature as shown in Fig. 10.8 have been calculated and listed in the Table 10.4. Prominent meanders are numbered as M-1 to M-20 and shown in Figures 10.9 to 10.13.

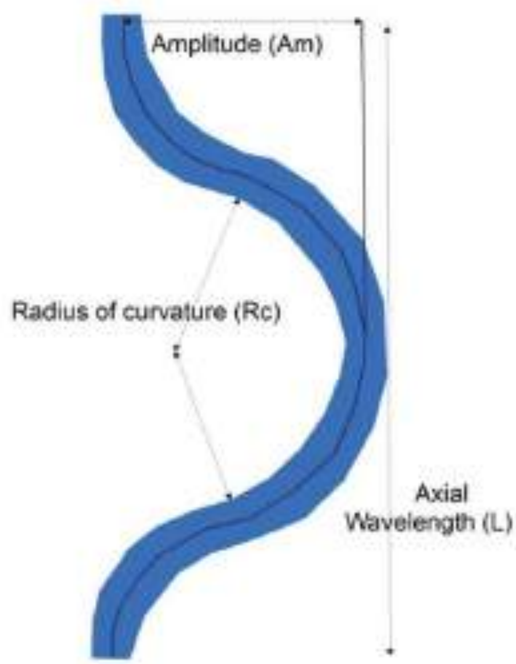


Figure 10.8 Geometrical parameters of a river meander (Sinha 2012)

Table 10.4 Geometrical parameters of the prominent meanders in the Ganga river

Meander No.	Chainage (km)	Location	Year	Axis wave length (km)	Amplitude (km)	Radius of Curvature (km)
M-1	195	D/S of Sultanganj	1970	10	8.5	4.5
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-2	220	U/S of Sultanganj at Fatehpur	1970	14	6.5	3.5
			1980	13.5	6.0	3.5
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-3	240	Munger	1970	14	13	7.5
			1980	14	13	7.5
			1990	10.7	4.5	4
			2000	12	11	3.5
			2010	SR~1.0		
M-4	630	U/S of Ghazipur	1970	17	15	2.5
			1980	17	15	2.5
			1990	17	15	2.5
			2000	17	15	2.5
			2010	17	15	2.5
M-5	680	At confluence point of Gomti river	1970	15.5	11.5	6.0
			1980	15.5	11.5	6.0
			1990	15.5	11.5	6.0
			2000	15.5	11.5	6.0
			2010	15.5	11.5	6.0
M-6	700	D/S of Varanasi	1970	18	10	5.0
			1980	18	10	5.0
			1990	18	10	5.0
			2000	18	10	5.0
			2010	18	10	5.0
M-7	715	At Varanasi	1970	17	6.5	4.5
			1980	17	6.5	4.5
			1990	17	6.5	4.5
			2000	17	6.5	4.5
			2010	17	6.5	4.5
M-8.	725	U/S of Varanasi	1970	15.5	7.0	4.0
			1980	15.5	7.0	4.0
			1990	15.5	7.0	4.0
			2000	15.5	7.0	4.0
			2010	15.5	7.0	4.0
M-9	740	D/S of Chunar	1970	18	5.0	3.0
			1980	18	5.0	3.0
			1990	18	5.0	3.0
			2000	18	5.0	3.0

			2010	18	5.0	3.0
M-10	750	At Chunar	1970	31	10	4.5
			1980	31	10	4.5
			1990	31	10	4.5
			2000	31	10	4.5
			2010	31	10	4.5
M-11	785	D/S of Mirzapur	1970	16	11	4.5
			1980	16	11	4.5
			1990	16	11	4.5
			2000	16	11	4.5
			2010	16	11	4.5
M-12	795	At Mirzapur	1970	12	10	3.5
			1980	12	10	3.5
			1990	12	10	3.5
			2000	12	10	3.5
			2010	12	10	3.5
M-13	815	Near Gopiganj	1970	15	6.0	3.5
			1980	15	6.0	3.5
			1990	15	6.0	3.5
			2000	15	6.0	3.5
			2010	15	6.0	3.5
M-14	830	U/S of Gopiganj	1970	9.5	6.0	2.5
			1980	9.5	5.5	2.0
			1990	9.5	6.0	2.5
			2000	9.5	6.0	2.5
			2010	9.5	6.0	2.5
M-15	840	Kolainpur	1970	9.5	9.0	4.0
			1980	9.5	9.0	4.0
			1990	9.5	9.0	4.0
			2000	9.5	9.0	4.0
			2010	9.5	9.0	4.0
M-16	855	Katra	1970	8.5	15.5	2.0
			1980	8.5	15.5	2.0
			1990	8.5	15.5	2.0
			2000	8.5	15.5	2.0
			2010	8.5	15.5	2.0
M-17	875	Lachhagila	1970	18	9.5	4.5
			1980	18	9.5	4.5
			1990	18	9.5	4.5
			2000	18	9.5	4.5
			2010	18	9.5	4.5
M-18	890	Sirsa	1970	10	5.5	3.0
			1980	10	5.5	3.0
			1990	10	5.5	3.0
			2000	10	5.5	3.0
			2010	10	5.5	3.0
M-19	970	Lalgopalganj	1970	10	5.5	3.5
			1980	10	5.5	3.5

			1990	10	5.5	3.5
			2000	10	5.5	3.5
			2010	10	5.5	3.5
M-20	1010	Manikpur	1970	8.0	4.0	2.5
			1980	8.0	4.0	2.5
			1990	8.0	4.0	2.5
			2000	8.0	4.0	2.5
			2010	8.0	4.0	2.5

From the Table 10.4 and Figures 10.9 to 10.13, it may be concluded that except the meanders M-1(d/s Sultanganj), M-2 (Upstream of Sultanganj) and M-3 (Munger) all other meanders are stable and no noticeable change in their geometry has been noticed from year 1970 to 2010. At the meanders M-1, M-2 and M-3, river has left the meandering route and followed a relatively straight path over the years.

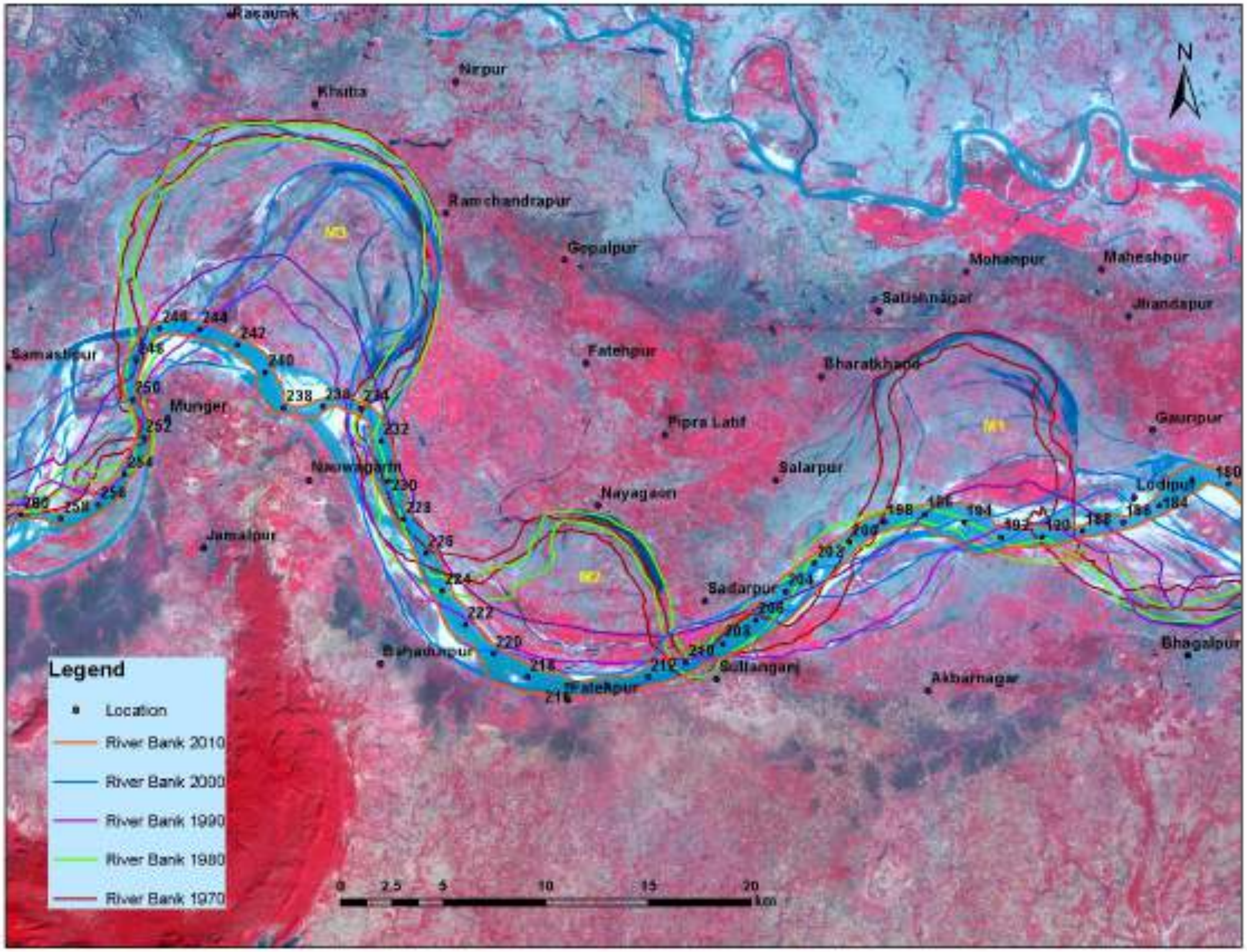


Figure 10.9 Meandering pattern of the Ganga river in the reach from chainage 180 km (Bhagalpur) to 260 km (Munger)

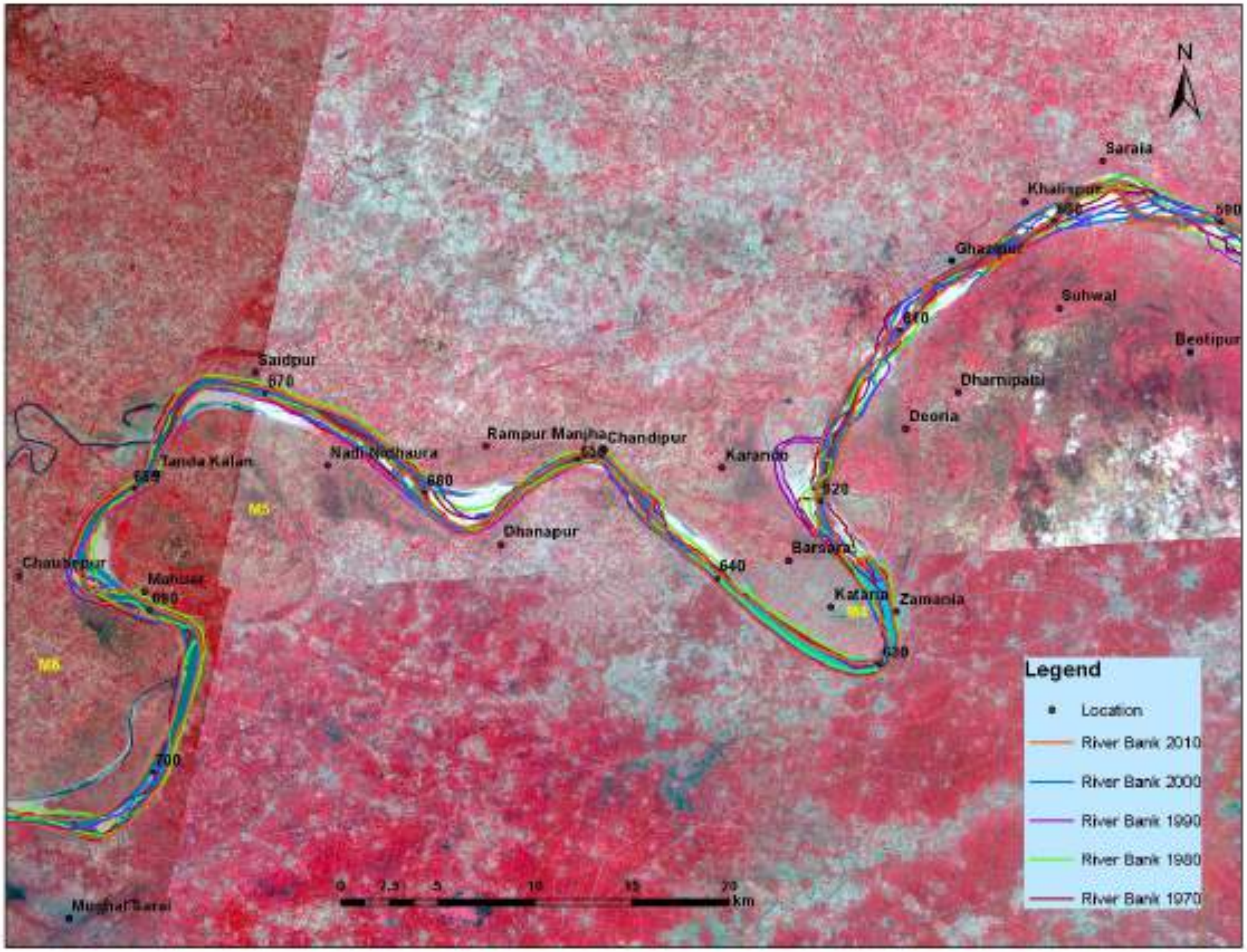


Figure 10.10 Meandering pattern of the Ganga river in the reach from chainage 600 km (Ghazipur) to 700 km (Mughalsarai)

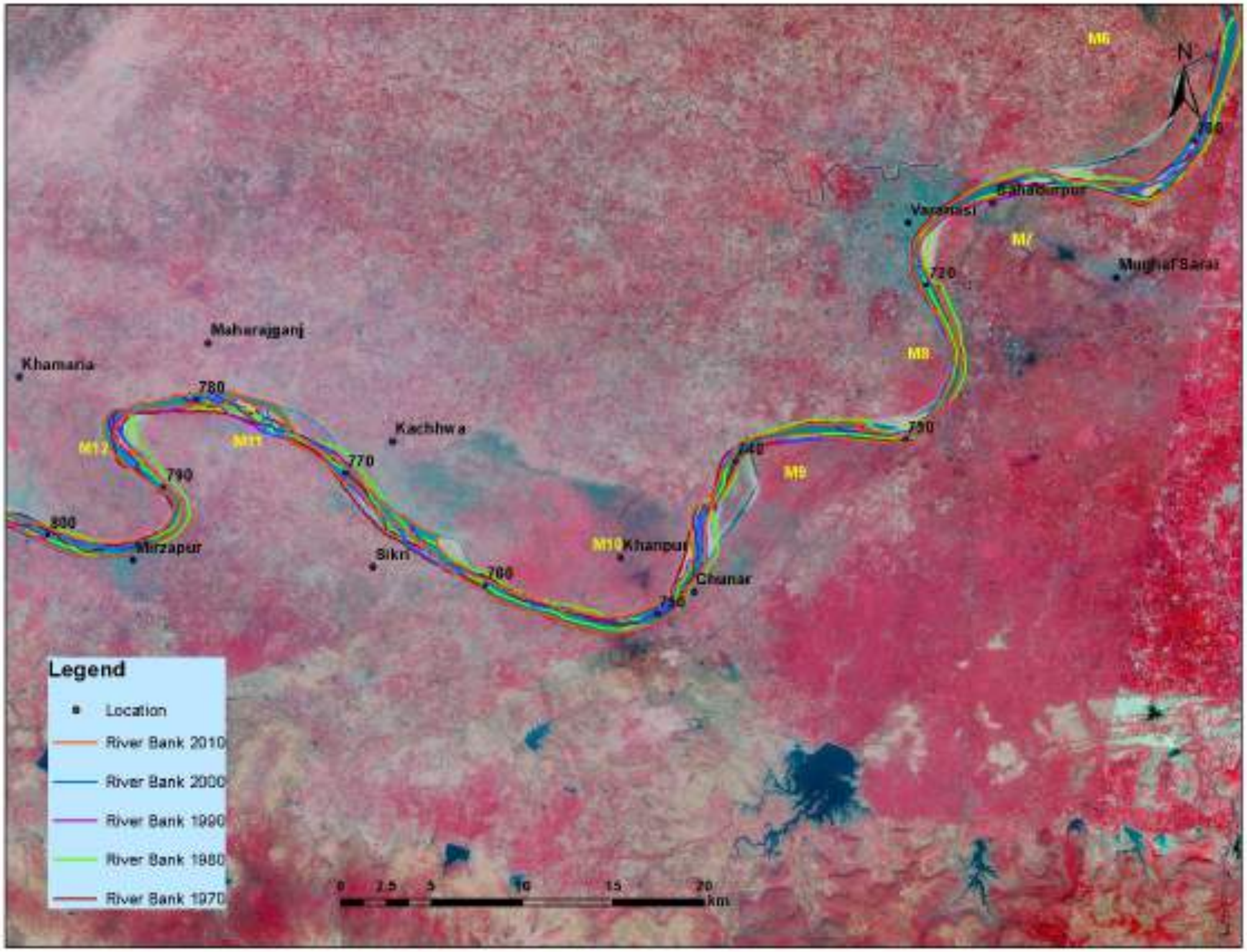


Figure 10.11 Meandering pattern of the Ganga river in the reach from chainage 700 km (Mughalsarai) to 800 km (Mirzapur)

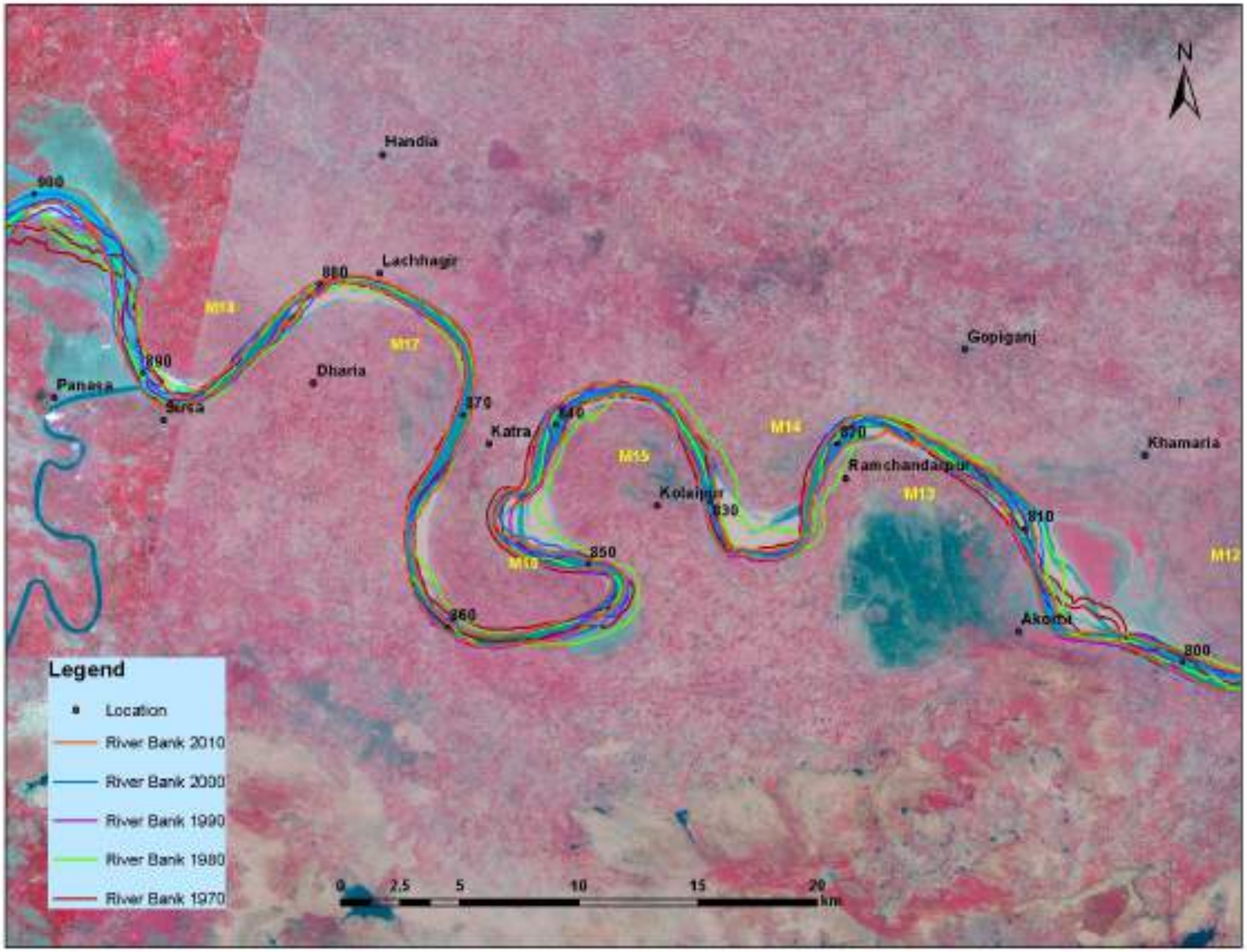


Figure 10.12 Meandering pattern of the Ganga river in the reach from chainage 800 km (Mirzapur) to 900 km (Saidabad)

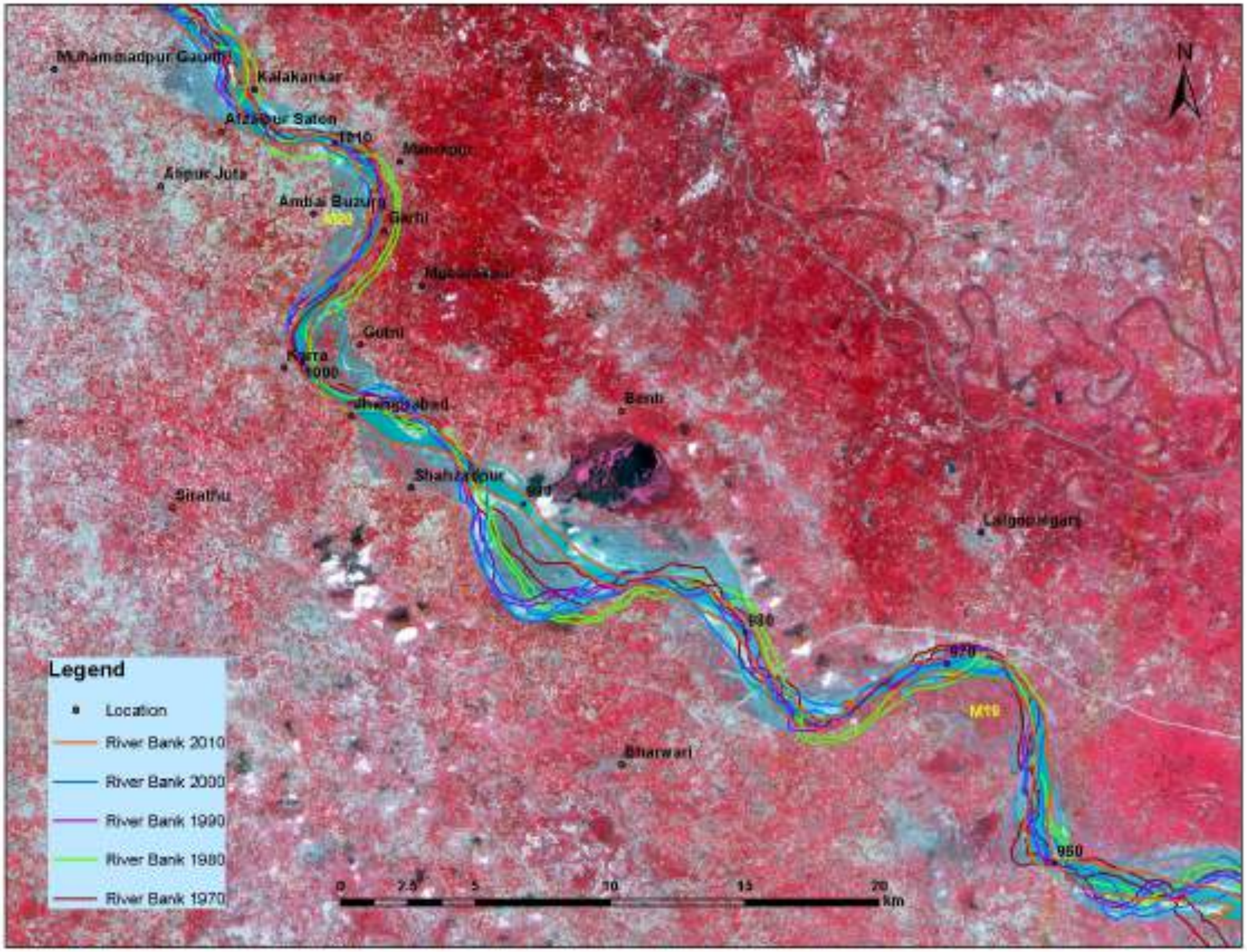


Figure 10.13 Meandering pattern of the Ganga river in the reach from chainage 960 km (Manauri) to 1015 km (Manikpur)

10.2.2 Planform Index

Braiding pattern of the rivers has been characterized in different ways. Three parameters which are mentioned in the literature and commonly being used to characterize the braiding pattern are proposed by Brice (1964), Rust (1978) and Friend and Sinha (1993) (Fig. 10.14).

$$Brice\ Index\ (BI) = 2\frac{\sum L_i}{L_r} \tag{10.2}$$

where $\sum L_i$ is the length of the islands or bars in a reach and L_r is the reach measured midway between the banks of the channel. The factor 2 in the Eq. (10.2) accounts for the total length of the bars.

Braiding parameter as given by Rust (1978) is

$$RI = 2\frac{\sum L_b}{L_m} \tag{10.3}$$

where $\sum L_b$ is the sum of the braid lengths between the channel thalweg divergences and confluences in the reach, and L_m is the average of meander wave lengths in the reach. Friend and Sinha (1993) proposed braid–channel ratio BR as

$$BR = \frac{L_{ctot}}{L_{cmax}} \tag{10.4}$$

where L_{ctot} is the sum of mid-channel lengths of all the segments of primary channels in a reach, and L_{cmax} is the mid-channel length of the widest channel through the reach. The ratio BR is a measure of tendency of the channel belt to develop multiple channels in a reach. If the reach has a single channel, BR will be unity.

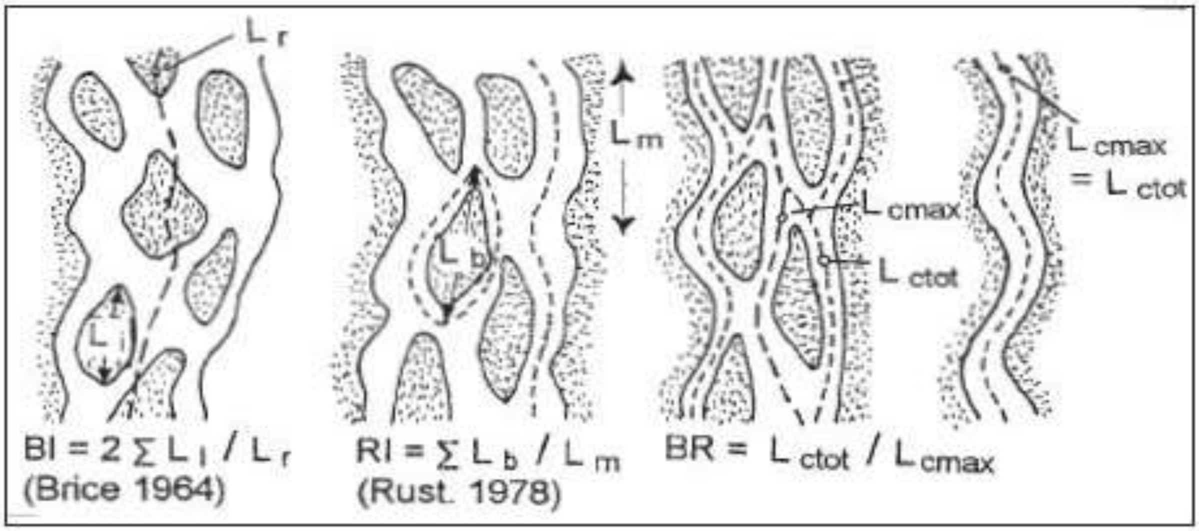


Figure 10.14 Braiding indices

Sharma *et al.* (2004) introduced a Plan Form Index (PFI), Cross-Slope ratio and Flow Geometry Index (FGI) for identifying the level of braiding in a highly braided river. The PFI, Flow Geometric Index and Cross-Slope ratio can be expressed as (Fig. 10.15):

$$\text{Plan Form Index (PFI)} = \frac{\frac{T}{B} \times 100}{N} \tag{10.5}$$

$$\text{Flow Geometry Index} = \left[\frac{\sum d_i\, x_i}{RT}\right] \times N \tag{10.6}$$

$$\text{Cross-Slope ratio} = \frac{\frac{B_L}{2}}{(Bank\,level - Av.\,bed\ level)} \tag{10.7}$$

where, T = flow top width; B= overall width of the channel; N = number of braided channels; R = hydraulic mean depth; d_i and x_i are depth and width of submerged sub-channel, respectively; and B_L = transect length across river width.

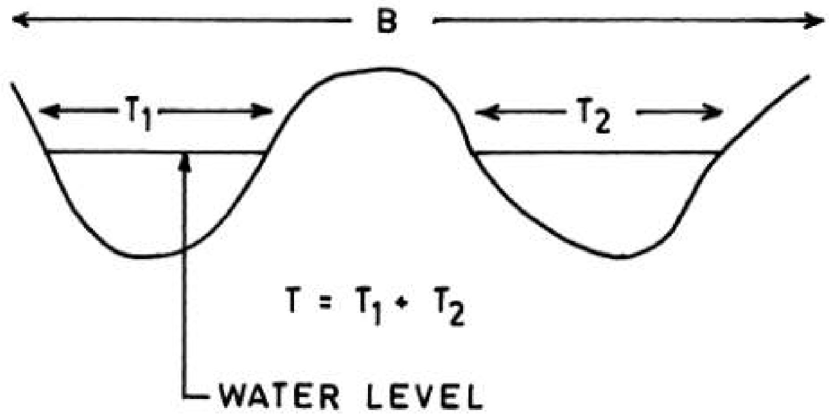


Figure 10.15 Definition sketch of PFI

PFI reflects the river landform disposition with respect to a given water level. Lower value of PFI indicates higher degree of braiding. For the classification of the braiding intensity, following threshold values for PFI are proposed by Sharma and Ashagrie (2012).

Highly Braided:	PFI < 4
Moderately Braided:	19 > PFI > 4
Low Braided:	PFI > 19

PFI of Ganga river is calculated using the formula given by Sharma (2004). For calculating PFI, the 50 km reach of river is further sudivided into 2 km, and the bed width, channel width and number of channels of the river are computed. PFI for each chainage is calculated and the calculated values are given in Table 10.5 and graphical representions are shown in Figs. 10.16a to 10.16j.

Examination of the Table 10.5 and Figs. 7.16a-j reveals that Ganga river is prominently braided downstream of Haridwar, Garhmukhteswar, Ramghat (d/s of Narora), Kachchla bridge, u/s of Farrukhabad, upstream of Allahabad, Balia, Raghopur and Krusela. Braiding pattern of the Ganga river at these locations are shown in Figs. 7.17a-i, respectively, as illustration.

It has been observed that the important variables that affect the braiding of rivers are discharge and its variability, the size distribution of the bed material and the rate and size distribution of sediment load, width, depth, slope, climate and geologic factors (Garde 2006). It is observed on many rivers that a given channel can change in a short distance from a braided to meandering and vice versa; such changes are therefore attributed to the variations in locally independent variables. It is also observed that those rivers dominated by braided as against the meandering channels have on the average a higher flood peakedness, higher total discharge range and higher monthly discharge variability. Braiding is developed by sorting as the stream leaves behind those fractions of the load it is incompetent to transport. If the stream is competent to move all sizes that it is transporting but is overloaded aggradation may take place without braiding (Garde 2006).

Lane (1957) studied plan-forms of a number of streams as well as their history, and concluded that there are two primary causes of braiding; these are (i) overloading i.e., stream may be supplied with more sediment than it can carry and hence part may be deposited; and (ii) steep slopes causing a wide shallow stream in which bars and islands may readily form. All steep slope type braided channels have many characteristics in common in addition to that of multiple channels; these are i) relatively straight course of main channel; ii) steep longitudinal slopes; iii) wide channels; iv) shallow depths; v) sand or coarse bed material; and vi) usually high bed-load. Since braided form can be due to steep slope or due to aggradation resulting from the overloading of stream with sediment, or due to combination of the two, braided streams can be classified into the following five subdivisions as per Lane (1957):

I Braiding due to steep slope:	a) Braiding due to steep slope with degradation
	b)Braiding due to steep slope with approximate equilibrium
II Braiding due to aggradation:	c) Braiding due to steep slope with aggradation
	d) Braiding due to moderate slope with aggradation
	e) Braiding due to low slope with aggradation

High braiding in the Ganga river downstream of the Haridwar, upstream of Allahabad, Krusela etc. is primarily due to aggradation which occurs as the river is incompetent to transport the sediment load that it or tributary is bringing from the relatively steep reach.

Table 10.5 Planform index (in %) for Ganga river of years 1970, 1980, 1990, 2000 and 2010

Highly Braided (PFI<4) — Moderately Braided (19>PFI>4) — Less Braided (PFI>19)

Chainage (km)	1970	1980	1990	2000	2010	Remarks
2	100.00	100.00	100.00	100.00	21.60	Chamogram
4	100.00	100.00	100.00	100.00	22.02	-
6	49.61	100.00	100.00	100.00	25.22	Shikarpur
8	100.00	100.00	100.00	100.00	39.34	Charbabupur
10	100.00	100.00	100.00	39.51	9.76	Gobargari
12	100.00	100.00	100.00	20.15	10.70	Sahibganj
14	100.00	100.00	100.00	32.30	12.56	Phudkipur
16	100.00	100.00	100.00	12.93	22.20	-
18	100.00	36.15	16.39	15.57	11.95	-
20	100.00	23.98	15.86	5.75	10.24	-
22	100.00	100.00	14.18	10.25	10.10	-
24	100.00	100.00	12.05	8.86	10.17	-
26	100.00	100.00	11.29	15.74	9.01	Gopalpur
28	100.00	100.00	11.27	110.80	9.78	Mirpur
30	100.00	100.00	11.66	20.59	12.48	Dharampur
32	100.00	100.00	11.16	18.06	13.84	Ramnagar
34	100.00	100.00	18.21	14.52	10.00	Kamalapur
36	100.00	100.00	100.00	100.00	210.10	Narayanpur
38	28.32	100.00	32.73	32.97	20.92	Rajmahal
40	10.33	29.75	16.06	20.07	13.20	-
42	6.02	13.50	13.54	22.73	13.34	Gidarmari
44	5.96	210.12	13.64	23.00	210.76	-
46	10.04	28.44	13.83	24.19	20.38	Dergama
48	12.53	14.43	20.24	310.01	13.61	Chandipura
50	24.59	23.85	32.43	34.66	18.88	Budhboria
52	41.76	100.00	38.85	22.76	23.86	-
54	48.38	100.00	21.92	56.45	16.69	Harachandrapur
56	100.00	100.00	32.07	24.30	15.52	Maharajpur
58	100.00	100.00	25.50	15.49	8.76	Maharajpur
60	46.55	100.00	18.55	10.70	6.29	Gopaltola
62	32.60	100.00	8.20	50.70	100.00	-
64	28.09	100.00	10.67	9.50	100.00	-
66	100.00	41.80	16.39	8.77	5.28	Dayanandnagar
68	19.94	310.15	100.00	26.22	4.74	Ahmadabad
70	12.96	24.49	16.91	29.62	8.11	Balria
72	35.55	38.99	6.19	18.85	11.07	-
74	100.00	100.00	5.60	210.34	9.17	-
76	100.00	100.00	6.51	16.10	5.48	-
78	100.00	33.06	5.07	13.44	3.93	Shibganj
80	10.40	6.44	13.85	13.82	4.14	Mahadevganj
82	10.26	3.97	12.80	14.13	5.96	-

84	5.96	10.42	10.19	19.06	6.31	-
86	10.85	15.75	11.92	23.07	11.45	Medhipur
88	20.60	110.30	13.12	38.68	11.35	
90	14.19	21.99	9.36	18.95	12.43	Nawabganj
92	19.37	13.64	15.89	16.87	16.47	-
94	9.94	100.00	8.70	20.19	26.34	-
96	12.35	100.00	34.12	20.65	13.84	-
98	13.09	40.30	29.76	30.11	13.23	Lakshmipur
100	100.00	310.01	29.92	38.45	100.00	-
102	100.00	100.00	100.00	100.00	100.00	-
104	100.00	100.00	45.24	100.00	100.00	-
106	36.01	100.00	36.88	100.00	100.00	-
108	9.20	100.00	100.00	100.00	100.00	-
110	9.75	100.00	49.17	30.71	100.00	-
112	110.79	38.92	15.58	16.38	10.69	Kantnagar diara
114	30.07	210.80	19.18	13.32	6.01	Sujapura
116	25.68	13.24	14.17	10.44	4.36	-
118	16.38	11.11	15.37	6.69	8.48	-
120	14.96	6.16	13.63	6.69	5.38	-
122	5.86	6.57	8.02	9.65	5.41	-
124	5.95	11.97	5.26	14.66	3.71	Santoshpur
126	10.76	11.30	23.15	13.63	15.13	
128	8.78	10.47	36.37	8.31	11.56	
130	8.53	12.48	16.36	9.44	11.96	
132	15.92	13.83	18.43	14.23	9.83	
134	20.72	14.45	21.09	12.65	9.43	Rangra
136	19.90	33.95	19.27	21.66	12.44	Jhaludustola
138	410.60	25.09	41.21	100.00	100.00	-
140	46.65	110.09	100.00	100.00	100.00	-
142	100.00	9.62	100.00	40.81	100.00	-
144	100.00	12.30	100.00	100.00	100.00	-
146	100.00	16.81	100.00	100.00	100.00	-
148	100.00	100.00	100.00	100.00	100.00	-
150	40.22	100.00	21.07	20.60	100.00	-
152	41.37	100.00	110.88	13.47	100.00	-
154	100.00	23.96	33.49	22.15	100.00	-
156	100.00	100.00	18.49	15.36	100.00	-
158	100.00	35.87	24.98	110.05	100.00	-
160	100.00	38.21	28.28	10.36	100.00	-
162	56.70	100.00	32.44	9.42	43.36	Dabra(Saidpur)
164	33.06	100.00	21.97	10.74	44.83	-
166	22.70	100.00	39.49	26.06	100.00	-
168	100.00	100.00	100.00	100.00	100.00	-
170	100.00	100.00	10.65	100.00	100.00	-
172	100.00	100.00	33.72	100.00	100.00	-
174	100.00	36.37	100.00	100.00	100.00	-
176	30.72	100.00	9.61	100.00	100.00	-
178	29.23	100.00	10.25	25.54	100.00	-
180	100.00	100.00	13.82	110.61	100.00	-
182	100.00	100.00	5.52	110.94	100.00	-
184	100.00	100.00	10.87	16.24	100.00	-
186	100.00	100.00	11.87	3.02	100.00	-

188	100.00	100.00	20.25	43.75	35.54	Lodipur
190	18.32	11.15	6.48	26.85	100.00	-
192	10.12	5.20	6.15	210.38	100.00	-
194	8.53	5.52	10.46	25.80	100.00	-
196	10.67	5.97	21.61	14.07	9.71	Narayanpur
198	100.00	100.00	11.02	10.99	5.55	Mathurapur
200	100.00	210.68	10.84	23.94	6.34	Salarpur
202	35.23	13.47	11.75	23.15	10.01	
204	22.96	15.10	8.08	110.60	12.74	Sardarpur
206	28.57	100.00	36.95	29.37	16.63	Sultanganj
208	100.00	100.00	100.00	100.00	100.00	-
210	100.00	100.00	100.00	100.00	100.00	-
212	100.00	100.00	100.00	33.06	100.00	-
214	100.00	100.00	100.00	18.40	100.00	-
216	100.00	100.00	100.00	26.28	100.00	-
218	100.00	33.36	100.00	28.62	100.00	-
220	31.79	20.49	210.00	20.60	100.00	-
222	20.78	100.00	25.45	15.21	100.00	-
224	100.00	100.00	28.85	20.48	100.00	-
226	100.00	100.00	28.16	42.23	100.00	-
228	100.00	100.00	100.00	100.00	100.00	-
230	100.00	100.00	32.31	36.90	36.49	Nauwagarh
232	30.80	100.00	20.31	110.18	210.57	Fatehpur
234	18.03	10.99	29.15	15.14	21.93	Gopalpur
236	100.00	5.72	18.02	6.84	100.00	-
238	100.00	49.94	18.41	4.74	18.10	Ramchandrapur
240	100.00	3.09	100.00	6.48	100.00	-
242	100.00	5.15	100.00	100.00	41.19	Tikarampur
244	100.00	6.03	100.00	13.63	100.00	-
246	100.00	9.56	100.00	100.00	100.00	-
248	100.00	100.00	100.00	100.00	19.93	Malhipur
250	100.00	100.00	100.00	310.93	10.25	Munger
252	31.55	63.71	21.88	33.89	8.57	Jafarnagar
254	12.88	28.89	18.48	10.66	6.63	Mahaddipur
256	12.65	12.71	30.65	9.02	10.07	-
258	100.00	10.99	110.24	9.17	22.59	Pharda
260	100.00	8.70	9.58	9.20	31.69	-
261	100.00	100.00	100.00	100.00	10.07	Bahadurnagar
262	10.56	6.51	100.00	13.17	22.06	Hemjapur
264	14.76	18.40	100.00	100.00	19.52	-
266	23.09	100.00	100.00	36.90	13.11	-
268	23.81	100.00	24.47	11.08	8.87	-
270	100.00	100.00	10.55	9.58	9.53	-
272	100.00	100.00	10.42	16.77	15.28	-
274	44.62	100.00	9.45	100.00	18.44	-
276	28.96	100.00	10.85	23.50	30.63	-
278	21.96	100.00	310.16	210.11	32.38	
280	58.66	100.00	100.00	33.25	19.57	Balhapur
282	21.28	100.00	100.00	23.04	19.80	-
284	20.25	100.00	18.67	10.45	10.62	Rampur
286	100.00	100.00	18.85	8.42	12.04	-
288	100.00	100.00	8.35	10.91	10.69	Matihani

290	100.00	15.13	10.52	10.64	5.89	
292	100.00	11.79	9.54	10.84	11.40	Begusarai
294	38.58	11.66	10.91	10.30	10.36	
296	23.59	6.70	6.52	9.55	6.95	-
298	21.61	4.47	10.81	5.56	10.96	-
300	100.00	10.91	23.13	10.46	6.72	Barhiya
302	100.00	11.84	110.50	11.75	16.94	-
304	22.59	100.00	33.13	100.00	100.00	-
306	100.00	100.00	100.00	100.00	100.00	-
308	100.00	100.00	100.00	100.00	100.00	-
310	26.65	56.84	100.00	48.38	100.00	-
312	100.00	32.67	24.05	11.89	210.16	-
314	13.40	110.88	9.45	9.87	16.97	Malhipur
316	21.45	13.57	11.98	11.56	10.36	Bihat
318	10.16	8.24	5.33	8.28	5.10	Makama
320	6.62	3.66	10.41	10.39	8.28	-
322	18.51	5.56	10.03	10.78	6.22	-
324	11.61	6.12	6.47	9.15	8.10	Teghra
326	11.09	14.02	12.14	9.53	11.04	-
328	16.30	4.37	110.31	14.63	21.84	-
330	3.35	2.63	35.37	12.61	16.91	Punarakh
332	5.17	110.57	100.00	10.25	210.87	-
334	21.55	100.00	100.00	9.78	26.54	-
336	14.49	100.00	11.00	14.01	34.34	-
338	19.00	100.00	23.17	100.00	100.00	-
340	11.01	41.99	5.31	45.71	100.00	-
342	100.00	12.52	9.36	100.00	100.00	-
344	100.00	10.98	10.77	100.00	41.65	-
346	5.82	13.42	6.23	39.06	19.01	-
348	8.14	11.59	9.31	18.43	16.74	Daulatpur Chondi
350	5.33	12.93	9.92	210.92	15.44	Achauara
352	11.17	13.92	4.28	12.34	100.00	-
354	13.70	14.91	10.34	85.89	100.00	-
356	14.15	16.54	12.50	100.00	100.00	-
358	6.39	19.43	8.88	49.79	43.38	Chhabbistola
360	11.81	10.92	10.30	21.67	6.91	Mohiuddinnagar
362	4.17	19.09	6.80	8.24	6.45	Harnabhiya
364	4.05	4.73	4.57	8.66	6.67	Bidhipur
366	3.61	3.96	3.03	3.87	6.63	Dhamaun
368	3.25	3.59	4.28	5.60	6.33	-
370	3.48	4.37	2.76	4.88	9.07	Gopalpur
372	2.81	4.12	2.29	4.05	4.57	Alipur
374	6.38	5.83	3.83	10.77	10.35	Mehnar
376	6.25	2.93	3.19	9.17	10.24	Raipura
378	100.00	2.19	3.56	10.07	5.60	Bidhipur
380	100.00	2.88	3.46	10.79	6.19	Jurawan Karari
382	100.00	4.65	100.00	10.25	10.36	Raghopur
384	100.00	9.17	100.00	12.76	5.94	Patuha bazar
386	100.00	5.51	100.00	10.50	8.35	-
388	100.00	2.80	100.00	4.96	4.55	Chechar
390	100.00	3.88	3.60	4.35	4.29	Gopalpur
392	100.00	2.69	2.92	2.74	6.44	Madhurapur

394	100.00	4.94	4.68	6.79	6.14	Biddupur
396	29.80	5.24	8.88	6.50	8.69	Daudnagar
398	12.84	18.22	6.01	9.51	13.78	Shukutarpur
400	100.00	24.47	100.00	12.03	33.08	-
402	100.00	100.00	100.00	100.00	100.00	-
404	100.00	100.00	100.00	100.00	100.00	-
406	100.00	100.00	100.00	100.00	36.06	-
408	100.00	100.00	100.00	11.16	19.14	Hajipur
410	100.00	22.50	110.01	20.57	21.97	
412	100.00	8.55	12.62	26.25	16.64	Sonpur
414	100.00	10.95	10.85	24.13	21.78	
416	100.00	5.63	6.29	10.58	12.16	Khorika
418	100.00	35.01	5.76	5.81	10.88	Patna
420	100.00	100.00	5.74	3.18	100.00	
422	100.00	100.00	3.84	3.78	3.46	Danpur
424	100.00	100.00	4.35	5.51	2.44	Ramsapur
426	100.00	100.00	4.26	4.14	3.00	Akirpur
428	100.00	100.00	4.08	3.20	3.33	Babaganwa
430	100.00	100.00	5.12	11.06	25.11	Ganghara
431	100.00	10.85	100.00	100.00	100.00	Sherpur
432	100.00	9.89	35.94	8.81	35.76	Bhagwanpur
434	100.00	8.30	6.75	5.14	100.00	-
436	100.00	10.71	9.97	31.17	20.18	-
438	100.00	6.92	11.41	5.15	12.64	-
440	100.00	9.25	11.00	6.40	8.55	Manel
442	100.00	19.64	100.00	12.12	9.87	Dhanaura
444	100.00	100.00	100.00	100.00	38.61	-
446	100.00	100.00	100.00	24.32	100.00	-
448	100.00	15.69	14.34	110.34	100.00	-
450	100.00	11.84	10.55	9.04	21.40	Dharmpur
452	100.00	6.12	8.04	9.77	10.63	Kutubpur
454	43.32	24.49	10.24	8.54	4.00	Bishunpura
456	3.76	15.41	5.52	5.82	10.28	-
458	18.54	26.25	100.00	6.70	6.35	-
460	100.00	100.00	100.00	8.79	3.83	Daroga ka Dera
462	100.00	100.00	33.97	15.08	9.93	-
464	21.34	100.00	100.00	22.82	16.33	-
466	21.20	100.00	100.00	35.10	100.00	-
468	100.00	100.00	100.00	100.00	30.86	-
470	100.00	100.00	100.00	100.00	28.64	Barkabaijutola
472	100.00	100.00	100.00	100.00	42.65	Ghazipur
474	100.00	100.00	100.00	100.00	100.00	-
476	100.00	100.00	100.00	100.00	100.00	-
478	100.00	100.00	100.00	100.00	100.00	-
480	100.00	100.00	100.00	13.01	100.00	-
482	54.30	100.00	100.00	12.20	100.00	-
484	45.96	100.00	100.00	110.88	100.00	-
486	43.67	100.00	100.00	43.16	100.00	-
488	100.00	24.02	19.71	100.00	100.00	-
490	21.23	6.45	12.77	35.66	100.00	-
492	100.00	5.67	12.65	5.67	100.00	-
494	12.65	20.19	15.77	100.00	100.00	-

496	16.79	100.00	100.00	43.09	100.00	-
498	15.37	100.00	100.00	8.29	100.00	-
500	100.00	100.00	100.00	100.00	100.00	-
502	100.00	100.00	100.00	100.00	100.00	-
504	100.00	100.00	100.00	100.00	100.00	-
506	100.00	100.00	31.72	100.00	100.00	-
508	100.00	100.00	15.47	100.00	100.00	-
510	100.00	100.00	8.23	100.00	100.00	-
511	100.00	100.00	100.00	24.93	100.00	-
512	36.41	100.00	10.86	100.00	100.00	-
514	100.00	100.00	100.00	100.00	100.00	-
516	100.00	100.00	100.00	100.00	100.00	-
518	100.00	100.00	100.00	100.00	26.74	-
520	100.00	100.00	13.10	110.05	10.72	Deviraidera
522	100.00	21.88	12.07	15.49	9.22	Ramdhani Singhdera
524	100.00	11.86	14.42	100.00	15.14	-
526	100.00	8.26	15.89	100.00	100.00	
528	100.00	23.56	24.42	26.83	100.00	-
530	100.00	21.08	10.59	19.57	100.00	-
532	100.00	10.27	5.45	28.72	100.00	-
534	110.18	4.86	4.45	110.91	100.00	Taranpurdera
536	13.01	2.95	4.94	100.00	100.00	-
538	100.00	6.06	5.30	100.00	100.00	-
540	100.00	15.04	6.26	100.00	100.00	-
542	41.85	100.00	6.88	4.57	100.00	-
544	14.44	11.24	8.08	9.72	100.00	Simri
546	14.54	20.12	8.17	21.40	100.00	Barkagaon
548	6.92	11.67	110.02	21.92	100.00	Dhumri ka Pura
550	100.00	18.72	110.15	16.58	100.00	Manjhariya
552	100.00	100.00	100.00	100.00	100.00	-
554	31.17	100.00	100.00	100.00	100.00	-
556	100.00	100.00	100.00	100.00	100.00	-
558	100.00	100.00	100.00	100.00	100.00	-
560	100.00	100.00	100.00	100.00	100.00	-
562	100.00	100.00	100.00	100.00	100.00	-
564	100.00	100.00	100.00	100.00	100.00	-
566	100.00	100.00	100.00	100.00	100.00	-
568	100.00	100.00	100.00	100.00	100.00	-
570	100.00	100.00	100.00	42.77	100.00	-
572	100.00	100.00	100.00	100.00	100.00	-
574	100.00	100.00	100.00	100.00	100.00	-
576	100.00	100.00	100.00	100.00	100.00	-
578	100.00	100.00	100.00	100.00	100.00	-
580	100.00	100.00	100.00	100.00	100.00	-
582	100.00	100.00	100.00	100.00	100.00	-
584	100.00	100.00	100.00	100.00	100.00	-
586	100.00	100.00	100.00	100.00	100.00	-
588	100.00	100.00	100.00	100.00	100.00	-
590	100.00	35.44	29.49	100.00	100.00	-
592	100.00	100.00	100.00	100.00	25.31	Muhammadabad
594	16.52	100.00	100.00	15.86	9.68	Ghauspur
596	35.16	100.00	15.40	10.38	24.29	Saraia

598	22.49	100.00	110.60	100.00	100.00	-
600	38.29	100.00	20.34	100.00	24.17	Khalispur
602	100.00	100.00	100.00	100.00	32.62	Suhwal
604	100.00	100.00	100.00	100.00	100.00	-
606	100.00	100.00	100.00	18.84	100.00	-
608	25.99	100.00	100.00	18.36	100.00	-
610	75.84	36.04	100.00	100.00	100.00	-
612	100.00	100.00	100.00	28.64	100.00	-
614	100.00	100.00	100.00	110.51	100.00	-
616	100.00	12.45	100.00	40.82	32.15	Deoria
618	100.00	6.28	55.42	100.00	100.00	-
620	14.22	26.52	12.24	16.22	100.00	Jagdishpur
622	15.92	6.07	13.22	59.26	100.00	Tajpur Manjha
624	40.49	100.00	12.88	42.73	100.00	Kalanpur
626	100.00	100.00	29.58	410.21	100.00	Zamania
628	100.00	100.00	100.00	100.00	100.00	-
630	100.00	100.00	100.00	29.56	100.00	-
632	100.00	100.00	100.00	100.00	100.00	-
634	100.00	100.00	100.00	100.00	100.00	-
636	100.00	100.00	100.00	100.00	100.00	-
638	100.00	100.00	100.00	100.00	100.00	-
640	100.00	100.00	100.00	100.00	100.00	-
642	100.00	100.00	100.00	100.00	100.00	-
644	100.00	100.00	100.00	30.30	100.00	-
646	100.00	100.00	100.00	100.00	100.00	-
648	100.00	100.00	100.00	100.00	100.00	-
650	100.00	100.00	100.00	100.00	100.00	-
652	100.00	100.00	100.00	100.00	100.00	-
654	100.00	100.00	100.00	28.48	100.00	-
656	23.65	20.40	100.00	18.10	100.00	Dhanapur
658	100.00	34.04	100.00	11.59	100.00	-
660	100.00	36.24	100.00	35.17	100.00	-
662	100.00	100.00	30.72	100.00	34.26	Nadi Nidhaura
664	100.00	100.00	100.00	45.81	100.00	-
666	100.00	100.00	100.00	100.00	100.00	-
668	100.00	100.00	100.00	100.00	100.00	-
670	100.00	100.00	100.00	100.00	100.00	-
672	100.00	100.00	100.00	29.79	100.00	-
674	100.00	100.00	100.00	32.80	100.00	-
676	100.00	100.00	100.00	100.00	100.00	-
678	100.00	100.00	100.00	100.00	100.00	-
680	100.00	100.00	100.00	100.00	100.00	-
682	100.00	100.00	100.00	100.00	100.00	-
684	100.00	100.00	100.00	100.00	100.00	-
686	100.00	20.26	8.04	43.61	14.84	Chaubepur
688	42.36	56.09	24.84	31.18	100.00	Mahuar
690	100.00	100.00	100.00	100.00	100.00	-
692	100.00	100.00	100.00	100.00	100.00	-
694	32.65	28.12	100.00	100.00	100.00	-
696	44.51	18.81	18.75	100.00	110.43	Ghanshampur
698	100.00	100.00	10.98	100.00	12.56	Markania
700	100.00	10.72	10.02	45.39	22.43	Ramchandipur

702	100.00	12.24	10.40	32.83	18.60	-
704	100.00	9.29	8.16	40.64	18.54	Gokulpur
706	100.00	24.68	14.02	100.00	110.03	Mughal Sarai
708	100.00	100.00	110.51	23.24	20.85	-
710	100.00	15.76	16.80	18.53	64.30	Bahadurpur
712	43.50	100.00	100.00	100.00	100.00	-
714	100.00	100.00	100.00	100.00	100.00	-
716	100.00	100.00	100.00	100.00	100.00	-
718	100.00	100.00	100.00	100.00	100.00	-
720	100.00	100.00	100.00	100.00	100.00	-
722	100.00	100.00	100.00	100.00	100.00	-
724	100.00	100.00	100.00	100.00	100.00	-
726	100.00	100.00	100.00	100.00	100.00	-
728	100.00	100.00	100.00	100.00	100.00	-
730	100.00	36.35	100.00	100.00	100.00	-
732	100.00	100.00	100.00	100.00	100.00	-
734	100.00	100.00	100.00	100.00	100.00	-
736	100.00	100.00	100.00	100.00	100.00	-
738	100.00	100.00	100.00	100.00	100.00	-
740	100.00	36.35	24.10	41.83	110.36	Shivpur
742	110.38	11.22	11.34	15.82	14.82	Sultanpur
744	9.31	24.48	9.88	10.97	21.11	Keshavpur
746	22.60	24.37	14.17	36.46	42.26	-
748	100.00	100.00	100.00	100.00	100.00	-
750	100.00	100.00	100.00	100.00	100.00	-
752	100.00	100.00	100.00	45.99	58.92	-
754	100.00	100.00	100.00	100.00	100.00	-
756	100.00	100.00	100.00	100.00	100.00	-
757	100.00	100.00	100.00	38.10	100.00	-
758	100.00	100.00	100.00	100.00	100.00	-
760	100.00	100.00	100.00	100.00	100.00	-
762	100.00	110.35	100.00	13.41	22.80	Nanhupur
764	100.00	96.02	100.00	43.84	100.00	Kanaura
766	100.00	35.70	100.00	23.08	310.04	Chhatahan
768	100.00	100.00	100.00	33.69	100.00	-
770	100.00	100.00	100.00	100.00	100.00	-
772	46.99	36.43	100.00	100.00	15.13	Kachhwa
774	32.17	39.11	100.00	16.12	13.99	Chapor
776	20.93	26.94	100.00	10.62	19.34	Karhar
778	19.77	23.28	100.00	24.76	32.80	Kolahalpur
780	26.26	100.00	100.00	100.00	100.00	-
782	100.00	100.00	100.00	100.00	100.00	-
784	100.00	29.45	100.00	100.00	100.00	-
786	22.81	21.73	9.43	31.81	100.00	Mujahra Kalan
788	43.01	42.03	33.89	100.00	100.00	-
790	100.00	100.00	100.00	100.00	100.00	-
792	100.00	100.00	100.00	100.00	100.00	-
794	100.00	100.00	100.00	100.00	100.00	-
796	100.00	100.00	100.00	100.00	100.00	-
798	100.00	100.00	100.00	100.00	60.47	Mirzapur
800	100.00	100.00	100.00	35.41	100.00	-
802	28.40	100.00	100.00	100.00	100.00	-

804	100.00	100.00	100.00	20.86	21.84	-
806	18.12	4.85	6.76	16.43	14.87	Akorhi
808	20.06	10.02	4.23	16.97	15.90	-
810	100.00	23.63	5.53	14.74	34.40	Khamaria
812	100.00	38.73	100.00	41.88	100.00	-
814	100.00	100.00	100.00	100.00	100.00	-
816	100.00	100.00	100.00	100.00	100.00	-
818	100.00	100.00	100.00	100.00	52.46	Gopiganj
819	100.00	100.00	100.00	39.99	100.00	-
820	100.00	100.00	100.00	35.96	100.00	-
822	100.00	100.00	100.00	100.00	100.00	-
824	100.00	100.00	100.00	100.00	100.00	-
826	39.27	44.30	100.00	100.00	100.00	-
828	29.39	28.69	100.00	100.00	100.00	-
830	100.00	40.96	12.76	210.01	100.00	-
832	100.00	100.00	100.00	100.00	100.00	-
834	100.00	100.00	100.00	100.00	100.00	-
836	100.00	100.00	100.00	100.00	100.00	-
838	100.00	44.78	100.00	100.00	100.00	-
840	100.00	39.90	11.92	100.00	100.00	-
842	100.00	100.00	100.00	100.00	100.00	-
844	100.00	23.84	100.00	22.62	100.00	-
846	100.00	20.78	100.00	25.75	18.96	Katra
848	100.00	100.00	100.00	100.00	100.00	-
850	100.00	100.00	100.00	100.00	100.00	-
852	100.00	100.00	100.00	100.00	100.00	-
854	48.59	100.00	12.75	45.38	100.00	-
856	100.00	100.00	100.00	100.00	100.00	-
858	100.00	100.00	100.00	100.00	100.00	-
860	100.00	30.01	100.00	100.00	100.00	-
862	100.00	100.00	100.00	100.00	100.00	-
864	100.00	100.00	100.00	100.00	100.00	-
866	100.00	39.94	100.00	100.00	100.00	-
868	100.00	100.00	100.00	100.00	100.00	-
870	100.00	100.00	100.00	100.00	100.00	-
872	100.00	100.00	100.00	100.00	100.00	-
874	100.00	100.00	100.00	100.00	100.00	-
876	100.00	100.00	100.00	100.00	100.00	-
878	100.00	34.66	100.00	100.00	100.00	-
880	100.00	100.00	100.00	100.00	100.00	-
882	100.00	100.00	100.00	100.00	100.00	-
884	100.00	100.00	100.00	100.00	100.00	-
886	100.00	100.00	100.00	100.00	100.00	-
888	100.00	38.33	100.00	100.00	100.00	-
890	100.00	100.00	100.00	100.00	100.00	-
892	100.00	32.34	100.00	30.47	100.00	-
894	42.71	10.79	100.00	33.41	100.00	-
896	100.00	310.83	100.00	100.00	100.00	-
898	100.00	100.00	100.00	100.00	100.00	-
900	100.00	100.00	21.70	26.06	100.00	-
902	100.00	4.69	16.09	6.01	16.44	Dumduma
904	43.54	9.14	14.55	8.77	15.35	Rampur

906	100.00	36.10	4.11	100.00	9.6	Diha
908	100.00	100.00	10.60	41.29	10.69	-
910	100.00	100.00	6.50	100.00	11.20	Mungar
912	100.00	33.44	6.93	34.10	10.47	
914	100.00	11.47	13.01	32.43	13.17	
916	100.00	12.68	15.56	100.00	310.39	
918	100.00	19.78	19.54	23.07	100.00	-
919	100.00	110.39	100.00	100.00	100.00	
920	100.00	100.00	32.05	310.50	100.00	-
921	100.00	100.00	100.00	38.61	100.00	
922	100.00	100.00	100.00	100.00	100.00	
924	100.00	100.00	100.00	100.00	21.39	
926	100.00	100.00	16.86	100.00	100.00	
928	100.00	100.00	6.38	30.97	310.54	Allahabad
930	100.00	23.27	4.18	26.97	20.81	-
932	100.00	42.39	8.07	100.00	100.00	-
933	100.00	100.00	100.00	31.79	100.00	-
934	100.00	30.95	110.57	100.00	100.00	-
936	100.00	15.66	9.16	28.04	21.58	-
938	100.00	24.75	3.05	100.00	9.43	-
940	60.66	13.19	10.03	100.00	12.62	-
942	100.00	9.94	110.45	100.00	6.86	Allahabad
944	100.00	12.98	10.52	100.00	6.55	Kand
946	100.00	9.06	20.24	100.00	9.02	-
948	310.21	10.82	5.79	31.59	15.25	-
950	100.00	9.18	8.19	100.00	100.00	-
952	100.00	15.75	100.00	100.00	100.00	-
954	43.09	100.00	12.56	42.89	25.47	-
956	44.57	25.72	100.00	31.06	26.79	Fatehpur
958	28.78	100.00	14.29	310.70	30.79	-
960	100.00	13.39	100.00	35.78	100.00	Gauspur
962	100.00	18.23	33.06	100.00	33.29	
964	16.43	24.27	15.60	38.46	100.00	-
966	15.54	10.93	100.00	100.00	100.00	-
968	100.00	16.74	32.08	100.00	100.00	-
970	100.00	14.99	14.32	28.92	100.00	-
972	40.63	100.00	100.00	100.00	100.00	-
974	100.00	100.00	100.00	32.27	100.00	-
976	100.00	100.00	100.00	8.48	100.00	-
978	100.00	100.00	26.96	16.58	100.00	-
979	100.00	100.00	100.00	20.36	100.00	-
980	100.00	41.33	100.00	44.71	100.00	-
982	100.00	36.09	11.70	100.00	100.00	-
984	100.00	100.00	10.94	100.00	100.00	-
985	100.00	100.00	100.00	13.13	100.00	-
986	100.00	9.21	3.45	13.90	28.24	Bharwari
988	100.00	10.67	8.45	100.00	10.36	Benti
990	100.00	10.41	16.26	100.00	110.66	Shahzadpur
992	34.23	43.82	100.00	41.39	100.00	-
994	100.00	18.26	100.00	100.00	100.00	-
996	100.00	24.01	100.00	8.41	33.98	Jhangirabad
998	41.53	22.67	100.00	100.00	18.22	Kara

1000	100.00	11.16	100.00	100.00	18.09	-
1002	100.00	10.40	100.00	74.94	11.59	Gutni
1004	100.00	100.00	100.00	39.85	100.00	-
1006	100.00	100.00	100.00	100.00	100.00	-
1008	210.20	11.98	100.00	20.55	26.41	Manikpur
1010	100.00	100.00	28.83	22.67	100.00	-
1012	32.39	33.83	100.00	24.89	35.11	Afzalpur Safon
1014	35.92	29.01	100.00	25.49	100.00	-
1016	30.35	13.80	100.00	22.59	100.00	-
1018	100.00	43.94	100.00	32.18	100.00	-
1020	100.00	12.21	9.44	23.59	100.00	-
1022	100.00	14.54	4.86	10.58	100.00	-
1024	40.23	100.00	10.89	23.56	10.70	Mandwa
1026	100.00	100.00	100.00	25.38	100.00	-
1028	100.00	100.00	100.00	20.08	100.00	-
1030	100.00	11.88	100.00	12.37	100.00	-
1032	100.00	42.40	100.00	110.77	100.00	-
1034	100.00	22.53	100.00	31.83	100.00	-
1036	100.00	100.00	100.00	100.00	100.00	-
1037	100.00	24.82	100.00	100.00	100.00	-
1038	100.00	50.00	100.00	100.00	100.00	-
1040	100.00	21.47	100.00	39.60	100.00	-
1042	21.34	15.31	10.18	26.02	100.00	-
1044	100.00	100.00	100.00	19.33	100.00	-
1046	100.00	20.99	100.00	40.73	100.00	-
1048	100.00	19.68	100.00	110.28	100.00	-
1050	100.00	16.17	100.00	19.83	100.00	-
1052	100.00	100.00	100.00	13.16	100.00	-
1054	41.28	29.78	100.00	24.38	24.50	Mawar
1056	11.83	410.50	100.00	22.51	15.25	Natauli Buzurg
1058	15.26	30.49	21.14	110.33	24.31	Kalyanpur Bainti
1060	13.98	26.96	100.00	30.98	100.00	-
1062	100.00	41.43	100.00	19.61	100.00	-
1064	16.06	23.32	20.73	13.89	26.91	Dalmau
1066	100.00	94.09	52.93	38.54	21.82	Firozpur
1068	100.00	23.50	24.12	30.88	100.00	-
1070	33.18	44.29	15.17	36.10	100.00	-
1072	100.00	41.95	12.37	10.38	11.63	Naugaon
1074	22.61	100.00	39.32	23.29	100.00	-
1076	100.00	100.00	100.00	100.00	100.00	-
1078	100.00	100.00	100.00	100.00	100.00	-
1080	100.00	34.76	100.00	100.00	100.00	-
1082	100.00	38.92	100.00	40.39	210.35	Ahitaura
1084	100.00	20.66	18.34	13.15	12.12	Somanpur
1086	100.00	32.94	10.27	25.79	100.00	-
1088	100.00	100.00	38.71	100.00	100.00	
1090	100.00	100.00	10.40	13.73	22.53	Rampur Kalan
1092	100.00	210.90	6.87	10.19	8.64	Amaura
1094	100.00	26.28	100.00	100.00	40.66	Ghazikhera
1096	100.00	100.00	100.00	100.00	100.00	-
1098	100.00	100.00	100.00	100.00	100.00	-
1099	100.00	100.00	26.27	100.00	25.73	Deomal

1100	100.00	22.34	25.73	26.76	100.00	-
1102	24.34	22.07	11.05	12.95	8.33	Tikwapur
1104	100.00	29.52	13.08	34.99	5.59	Gunir
1106	100.00	10.53	6.29	13.03	10.50	Baksar
1108	100.00	24.63	24.50	24.70	100.00	-
1110	100.00	9.95	28.19	39.69	100.00	-
1111	210.88	100.00	100.00	100.00	100.00	-
1112	100.00	14.70	100.00	100.00	100.00	-
1114	100.00	100.00	100.00	29.59	100.00	-
1116	100.00	32.46	100.00	110.83	100.00	-
1118	100.00	100.00	9.18	22.72	34.19	Raipur
1120	100.00	28.78	100.00	210.57	100.00	-
1122	100.00	30.91	22.11	44.43	100.00	-
1124	100.00	11.96	10.28	29.39	28.86	Domanpur
1126	100.00	310.50	21.27	28.43	100.00	-
1128	100.00	100.00	29.49	15.95	100.00	-
1130	24.58	33.36	22.35	32.45	100.00	-
1131	36.41	100.00	100.00	100.00	100.00	-
1132	100.00	40.64	23.61	100.00	100.00	-
1134	15.27	15.64	10.71	28.77	100.00	-
1136	24.65	100.00	100.00	19.77	21.12	Umarna
1138	100.00	20.91	100.00	12.21	8.02	Manjhara
1140	14.99	16.70	18.21	16.94	21.89	Ghassil Purwa
1142	100.00	18.31	30.63	32.09	11.53	Chharawwakhera
1144	100.00	26.85	22.75	26.63	23.28	-
1146	33.63	100.00	24.11	34.15	100.00	-
1148	14.57	50.54	23.24	26.65	100.00	-
1150	21.57	29.99	80.51	100.00	100.00	-
1152	14.40	19.25	41.27	30.72	100.00	-
1154	100.00	21.09	32.80	32.15	33.52	Aerodrome, Kanpur
1156	100.00	100.00	100.00	100.00	100.00	-
1158	100.00	100.00	14.09	16.91	100.00	-
1160	100.00	62.19	8.09	36.37	100.00	-
1162	100.00	32.76	6.20	100.00	23.18	Karan
1164	100.00	25.44	8.19	100.00	100.00	-
1166	100.00	14.99	10.98	28.94	100.00	-
1168	100.00	10.71	12.22	22.48	100.00	-
1170	100.00	26.17	10.89	210.28	100.00	-
1172	16.97	8.09	18.13	23.20	100.00	-
1174	100.00	100.00	35.32	25.07	100.00	-
1176	100.00	100.00	42.87	35.86	18.68	Bithur
1178	100.00	13.11	13.34	10.20	15.61	Pariar
1180	100.00	15.08	100.00	100.00	100.00	-
1182	100.00	100.00	110.89	100.00	100.00	-
1184	100.00	19.99	100.00	15.73	14.04	Mirzapur
1186	100.00	33.32	100.00	20.70	9.77	Safipur
1188	28.92	100.00	100.00	100.00	100.00	-
1190	4.94	10.73	21.49	23.47	34.21	-
1192	12.06	10.73	4.71	14.46	5.66	Shivarajpur
1194	100.00	10.92	5.93	12.47	8.40	-
1196	6.27	9.12	6.10	13.68	2.80	Kakupur
1198	100.00	11.33	34.83	100.00	100.00	-

1200	40.88	100.00	110.30	100.00	100.00	-
1202	100.00	33.80	100.00	50.00	100.00	-
1204	21.32	100.00	210.78	21.89	100.00	-
1206	22.58	100	100.00	100	22.12	Pura
1208	15.46	100.00	100.00	22.76	39.05	-
1210	100.00	16.96	14.94	100.00	100.00	-
1212	100.00	10.97	5.02	21.85	100.00	-
1214	21.67	4.96	5.06	44.94	25.84	Bilhaur
1216	15.18	8.57	100.00	100.00	6.22	Bangarmau
1218	100.00	13.41	100.00	100.00	31.10	-
1220	100.00	35.75	100.00	100.00	100.00	-
1222	100.00	20.72	100.00	34.58	100.00	-
1224	18.93	34.52	100.00	13.03	15.33	Makanpur
1226	100.00	23.46	100.00	20.96	100.00	-
1228	100.00	23.97	36.55	19.21	100.00	-
1230	100.00	210.68	36.48	34.67	100.00	-
1232	42.08	11.22	10.54	28.09	100.00	-
1234	16.31	9.50	16.64	31.32	19.42	-
1236	19.02	9.50	8.77	19.96	9.15	Sarai Miran
1238	100.00	100.00	100.00	100.00	100.00	-
1240	100.00	29.18	20.69	100.00	100.00	-
1242	16.54	41.33	26.71	510.75	100.00	-
1244	8.42	19.18	12.46	100.00	100.00	-
1246	26.06	19.12	12.95	100.00	16.83	Kannauj
1248	9.48	100.00	8.51	100.00	100.00	-
1250	310.32	100.00	5.52	49.91	100.00	-
1252	100.00	100.00	110.02	11.82	18.54	Rampurwa
1254	10.02	13.03	6.51	100.00	39.11	Bilgram
1255	9.34	100.00	100.00	100.00	100.00	-
1256	6.37	10.61	29.08	35.01	100.00	-
1258	5.89	19.85	18.78	10.92	100.00	-
1260	34.51	24.80	10.35	100.00	23.32	Lalpur
1262	100.00	23.54	100.00	100.00	100.00	-
1264	100.00	100.00	100.00	310.53	15.40	Gorgrapur
1265	10.61	100.00	100.00	100.00	100.00	-
1266	11.16	9.82	100.00	210.15	100.00	-
1268	14.07	36.41	100.00	100.00	100.00	-
1270	100.00	100.00	3.94	100.00	21.20	Srimau
1271	110.43	100.00	100.00	100.00	100.00	-
1272	100.00	100.00	4.49	100.00	210.99	Saunsrapur
1274	100.00	100.00	15.49	100.00	100.00	-
1276	100.00	100.00	100.00	26.75	29.89	Induiagang
1278	100.00	100.00	100.00	11.11	16.51	Khudaganj
1280	100.00	100.00	16.11	20.39	100.00	-
1282	100.00	100.00	34.36	31.87	42.70	Dahilia
1284	10.86	100.00	100.00	100.00	100.00	-
1286	100.00	8.89	100.00	30.33	100.00	-
1288	8.56	23.76	100.00	20.81	100.00	-
1290	4.19	100.00	100.00	310.90	100.00	-
1292	100.00	100.00	100.00	100.00	100.00	-
1294	100.00	18.83	100.00	36.97	100.00	-
1296	100.00	24.15	10.77	22.80	100.00	-

1298	100.00	9.22	41.54	25.90	100.00	-
1300	100.00	9.38	100.00	6.97	22.72	Sarah
1302	100.00	5.29	100.00	100.00	100.00	-
1304	100.00	8.84	100.00	100.00	100.00	-
1306	10.99	25.58	100.00	22.68	100.00	-
1308	100.00	100.00	100.00	100.00	100.00	-
1310	100.00	100.00	100.00	21.20	100.00	-
1312	100.00	100.00	11.72	22.57	100.00	
1314	100.00	13.63	10.88	21.38	100.00	-
1316	100.00	10.76	34.44	100.00	100.00	-
1318	100.00	11.49	2.28	100.00	100.00	-
1320	100.00	5.62	8.47	22.13	100.00	-
1322	4.98	5.76	5.73	100.00	23.78	-
1324	8.04	4.93	8.86	10.41	13.07	-
1326	14.56	100.00	100.00	8.92	4.81	Amritpur
1328	100.00	18.57	100.00	9.02	9.79	-
1330	310.97	12.41	100.00	16.79	9.84	-
1332	100.00	100.00	4.00	100.00	100.00	-
1334	100.00	100.00	14.74	100.00	19.32	Shamsabad
1336	100.00	100.00	4.81	100.00	100.00	-
1338	100.00	12.14	5.63	100.00	100.00	-
1340	100.00	11.80	100.00	100.00	100.00	-
1342	100.00	15.62	100.00	100.00	100.00	-
1344	100.00	14.33	100.00	100.00	100.00	-
1346	18.14	24.67	5.98	16.66	100.00	-
1348	2.47	210.41	1.95	28.41	-	-
1349	100.00	100.00	100.00	100.00	8.40	Lachhmanpur
1350	2.62	22.24	3.48	210.51	-	-
1352	9.10	18.49	1.90	2.65	-	-
1354	3.81	6.85	2.78	3.50	8.28	Bikrampur
1356	5.52	10.79	2.50	3.73	8.20	-
1358	8.77	11.29	10.45	4.03	110.07	Kampil
1360	100.00	100.00	6.52	6.64	100.00	-
1362	100.00	100.00	5.46	13.02	24.47	-
1364	100.00	100.00	110.82	39.83	22.76	-
1366	100.00	100.00	100.00	8.01	110.11	Lilwan
1367	100.00	100.00	100.00	8.34	100.00	-
1368	100.00	100.00	100.00	100.00	100.00	-
1370	100.00	100.00	100.00	100.00	9.63	Katte Saadatganj
1372	100.00	19.67	100.00	6.39	21.11	Khera Jalalpur
1374	100.00	18.70	100.00	5.20	110.80	Sanodi
1376	3.29	5.61	100.00	9.33	100.00	-
1378	5.23	6.32	100.00	10.51	100.00	-
1380	16.66	6.19	100.00	4.58	100.00	-
1382	100.00	8.93	100.00	6.74	100.00	-
1384	100.00	10.79	16.49	10.67	100.00	-
1386	100.00	11.58	25.26	19.78	100.00	-
1388	10.40	21.23	8.56	18.12	100.00	-
1390	3.38	100.00	100.00	39.61	100.00	-
1392	2.73	10.16	100.00	13.73	100.00	-
1394	5.02	10.70	100.00	19.34	100.00	-
1396	100.00	18.07	100.00	100.00	100.00	-

1398	15.88	14.60	6.62	63.15	100.00	-
1400	100.00	210.15	10.91	110.21	100.00	-
1402	16.86	14.00	4.23	16.26	100.00	-
1404	23.77	6.73	3.29	6.41	100.00	-
1406	10.47	5.71	5.99	10.77	100.00	-
1408	10.66	20.34	2.77	3.28	100.00	-
1410	10.20	100.00	100.00	4.52	100.00	-
1412	9.68	3.69	100.00	9.19	100.00	-
1414	12.53	4.17	100.00	15.63	100.00	-
1416	12.33	10.36	100.00	14.32	13.18	
1418	3.20	6.44	29.96	100.00	15.37	
1420	4.04	32.16	9.76	100.00	15.10	Malhanagar
1422	4.62	11.19	10.75	100.00	110.28	
1424	100.00	20.37	4.79	100.00	23.18	Kachhla (Railway Bridge)
1426	6.81	210.56	100.00	4.61	36.92	-
1428	3.61	12.03	8.56	9.02	100.00	-
1430	1.80	11.42	11.04	9.30	100.00	-
1432	3.57	100.00	100.00	30.56	100.00	-
1434	3.29	100.00	22.09	10.88	100.00	-
1436	2.80	100.00	4.49	5.51	100.00	-
1438	5.17	100.00	10.65	32.53	100.00	-
1440	3.95	100.00	9.98	9.68	100.00	-
1442	4.13	100.00	19.56	8.72	100.00	-
1444	4.08	100.00	13.94	8.14	100.00	-
1446	9.62	6.07	12.45	110.43	13.75	-
1448	8.87	15.61	11.60	100.00	8.92	-
1450	4.10	21.52	100.00	3.08	8.33	-
1452	5.37	100.00	4.60	100.00	6.05	Hamunpur
1454	10.43	12.34	12.24	100.00	100.00	-
1456	100.00	14.91	100.00	100.00	100.00	-
1458	2.27	10.13	100.00	100.00	100.00	-
1460	10.52	8.33	100.00	100.00	100.00	-
1462	12.97	14.83	100.00	12.21	29.26	Sankra
1464	4.32	110.16	10.74	12.73	19.10	-
1466	5.69	23.38	110.62	110.75	5.22	Harnath Bhojpur
1468	5.26	14.08	100.00	100.00	6.63	-
1470	4.45	10.85	100.00	3.06	9.85	-
1472	2.23	6.61	18.10	10.53	5.28	-
1474	10.84	11.68	11.95	4.68	6.96	-
1476	5.03	16.42	100.00	8.73	3.98	Jargawan
1478	100.00	9.58	100.00	5.00	8.50	Ramghat
1480	22.98	12.82	10.23	10.87	100.00	-
1482	100.00	28.14	8.51	100.00	5.24	Dabthara
1484	100.00	100.00	100.00	100.00	36.90	-
1486	100.00	24.29	100.00	20.00	100.00	-
1488	100.00	100.00	100.00	100.00	100.00	-
1490	14.67	26.72	26.26	19.47	33.17	Ratanpur
1492	100.00	43.53	100.00	33.37	43.17	Pukhana
1494	14.39	28.42	100.00	23.62	35.81	Deogawan
1496	3.66	100.00	29.89	32.86	100.00	-
1498	100.00	24.16	310.15	16.46	110.18	Mewa Hasnnganj
1500	34.78	100.00	100.00	100.00	100.00	-

1501	0	16.38	100.00	100.00	100.00	-
1502	29.88	100.00	100.00	100.00	100.00	-
1504	20.69	30.67	100.00	43.26	100.00	-
1506	100.00	31.70	110.45	29.19	110.30	Bhapatpur
1508	13.69	8.43	28.06	16.21	12.13	Chaopur
1509	100.00	10.39	100.00	100.00	100.00	-
1510	12.78	28.83	100.00	100.00	100.00	-
1512	12.68	6.78	10.38	44.91	22.68	Anupshahr
1514	8.86	10.01	13.39	100.00	100.00	-
1516	5.07	15.85	14.20	14.47	10.43	Rasulpur
1518	4.86	18.86	100.00	30.33	100.00	-
1520	100.00	15.62	31.63	22.76	100.00	-
1521	100.00	100.00	100.00	30.97	100.00	-
1522	15.80	21.25	100.00	100.00	100.00	-
1524	100.00	16.33	100.00	25.38	100.00	-
1526	100.00	0.00	100.00	34.45	100.00	-
1528	100.00	15.91	100.00	8.75	100.00	-
1530	23.66	100.00	100.00	19.32	100.00	-
1532	100.00	15.31	100.00	310.80	6.87	Aurangabad
1534	11.49	25.78	100.00	9.47	22.79	Phaorara
1536	100.00	100.00	100.00	34.49	20.33	Gangesri
1537	100.00	28.11	100.00	100.00	100.00	-
1538	100.00	100.00	31.68	23.23	100.00	-
1539	100.00	22.12	100.00	100.00	100.00	-
1540	100.00	100.00	100.00	26.75	100.00	-
1542	100.00	34.24	25.66	49.69	100.00	-
1544	100.00	100.00	100.00	21.95	100.00	-
1546	16.82	100.00	19.69	59.01	28.07	-
1548	8.32	6.79	9.09	100.00	100.00	-
1550	4.64	8.38	6.55	18.66	100.00	-
1552	9.91	8.20	16.28	36.04	100.00	-
1554	12.40	10.82	100.00	19.77	15.81	Rukhalu
1556	9.35	14.61	33.94	5.97	6.94	Piplauti
1558	11.90	110.45	16.57	5.07	12.15	Paswara
1560	19.54	13.07	4.43	15.58	2.79	Hasanpur
1562	100.00	6.10	100.00	5.97	3.89	Alipur
1564	3.75	15.11	11.73	8.28	5.35	Rahkera
1566	5.63	100.00	100.00	100.00	8.76	Bijaura
1568	100.00	100.00	100.00	100.00	100.00	-
1570	8.04	15.90	100.00	100.00	100.00	-
1571	100.00	100.00	100.00	9.82	100.00	-
1572	10.90	22.08	32.11	41.77	5.84	Garhmuktesar
1574	3.73	100.00	100.00	310.48	100.00	-
1576	20.33	20.66	100.00	100.00	100.00	-
1578	25.23	14.43	8.18	100.00	100.00	-
1580	2.99	11.92	12.88	10.22	10.16	Papsara Khadar
1582	2.55	8.43	100.00	38.88	14.66	-
1584	2.35	18.02	100.00	44.18	26.08	Jharina
1586	34.42	61.34	100.00	10.84	100.00	-
1588	8.32	4.06	100.00	22.45	41.17	Asilpur
1589	100.00	100.00	100.00	24.05	100.00	-
1590	6.22	12.25	100.00	100.00	8.64	Chhuchai

1592	4.52	8.14	14.49	100.00	100.00	-
1594	9.44	8.41	100.00	25.82	11.45	
1596	10.99	9.68	39.27	31.15	26.21	
1598	100.00	100.00	25.56	11.32	10.45	
1600	29.90	10.56	28.36	100.00	18.79	-
1602	11.24	8.38	24.24	11.34	5.53	Nagla Goshain
1604	9.60	13.12	53.73	100.00	100.00	-
1606	18.74	100.00	100.00	100.00	100.00	-
1608	21.57	9.55	18.27	12.67	100.00	-
1610	20.14	10.64	13.61	9.19	100.00	-
1612	13.98	10.94	10.75	6.85	100.00	-
1614	100.00	10.40	10.31	100.00	100.00	-
1616	8.94	40.33	13.76	100.00	15.74	Kishorpur
1618	100.00	6.60	5.77	4.81	12.38	Khar Rai Dayalpur
1620	34.61	4.68	5.04	100.00	100.00	-
1621	100.00	100.00	100.00	12.03	100.00	-
1622	8.07	8.48	3.33	24.66	46.54	Dudhli Khadar
1624	3.32	22.88	10.78	100.00	100.00	-
1626	20.37	100.00	8.28	40.09	100.00	-
1628	12.83	9.06	100.00	13.75	100.00	-
1630	14.74	12.12	100.00	32.70	41.67	Laftipur
1632	25.06	100.00	100.00	15.00	35.23	Akbarpur
1634	100.00	100.00	38.20	25.37	100.00	-
1636	100.00	100.00	100.00	6.07	100.00	-
1638	100.00	15.59	12.07	100.00	38.90	Jahanabad
1640	100.00	11.13	25.29	16.48	16.13	Ganj
1642	100.00	13.60	100.00	43.93	10.94	Dharanagar
1644	12.42	10.90	28.50	33.73	15.26	
1646	6.50	12.51	100.00	100.00	12.32	
1648	6.94	15.34	100.00	100.00	6.75	Devalpur
1650	10.31	100.00	100.00	100.00	9.88	Jolalpur
1652	10.94	100.00	100.00	33.37	310.97	-
1654	3.10	9.89	100.00	100.00	100.00	-
1656	100.00	9.14	100.00	100.00	10.22	Bijnor
1658	100.00	100.00	100.00	100.00	100.00	-
1660	100.00	100.00	100.00	40.32	100.00	-
1662	100.00	100.00	100.00	100.00	15.40	Bijnor
1664	15.14	8.76	100.00	11.74	10.09	Bera Sadat
1666	2.58	11.36	15.17	11.44	100.00	-
1668	3.37	100.00	310.02	100.00	100.00	-
1670	100.00	100.00	32.99	100.00	100.00	-
1672	100.00	4.70	10.81	12.78	8.63	Muazzampur
1674	12.02	5.67	10.65	100.00	100.00	-
1676	15.69	5.36	5.97	10.27	100.00	-
1678	14.22	6.02	6.38	210.00	100.00	-
1680	28.20	6.07	6.17	34.53	100.00	-
1682	100.00	5.75	8.22	11.66	100.00	-
1684	100.00	10.25	5.95	19.68	100.00	-
1686	33.55	4.90	10.97	15.53	100.00	-
1688	100.00	10.68	20.99	100.00	100.00	-
1689	30.24	100.00	100.00	100.00	100.00	-
1690	100.00	110.32	100.00	14.86	100.00	-

1692	100.00	8.00	100.00	14.19	21.59	Gopalpur
1694	100.00	5.45	20.00	21.73	8.82	Tisotra
1696	12.43	9.20	100.00	42.67	13.01	Lalpur
1698	19.90	4.13	100.00	18.26	16.36	Sofatpur
1700	100.00	4.38	100.00	23.01	100.00	-
1702	100.00	4.48	100.00	33.16	100.00	-
1704	100.00	2.81	100.00	5.91	22.12	Nagal
1706	6.28	5.93	100.00	14.81	19.29	Sarai Alam
1708	100.00	4.87	100.00	6.69	9.33	Shiyamiwala
1710	6.17	4.95	100.00	5.44	8.81	Bhikampur
1712	10.38	3.83	24.24	9.34	14.13	Bhikampur
1714	3.83	4.65	10.13	5.66	4.50	Alawalpur
1716	5.80	4.99	100.00	6.07	3.85	Tilakpur
1718	10.59	5.16	18.50	6.00	10.33	-
1720	6.08	6.92	5.69	4.44	4.23	Bhagpur
1722	10.44	10.91	8.19	4.96	10.00	Shahpur
1724	6.69	13.81	8.11	11.59	9.55	Ramkundi
1726	6.62	10.05	8.81	100.00	6.69	Bishanpur
1728	4.31	5.86	5.93	100.00	4.75	Kotarpur
1730	5.04	10.32	4.67	23.64	10.05	Ajitpur
1732	5.33	11.76	6.72	100.00	4.28	Misarpur
1734	4.46	100.00	10.58	8.52	11.69	Kankhal
1736	4.85	110.83	100.00	6.73	100.00	-
1738	100.00	13.16	100.00	6.53	100.00	-
1740	100.00	16.39	8.45	13.48	100.00	-
1742	100.00	100.00	100.00	100.00	100.00	-
1744	6.36	11.31	4.71	14.11	8.25	Haridwar
1746	9.93	6.79	3.24	100.00	2.03	Haripur
1748	100.00	16.41	2.89	100.00	2.62	Bhopatwala
1750	100.00	11.04	5.47	13.78	4.47	Haridwar
1752	10.94	10.941	4.786	11.27	4.79	Khadri
1754	5.16	20.42	9.338	110.89	3.97	Laokarghat
1756	50.02	24.89	24.64	25.47	28.01	Virbhadra
1758	100.00	100.00	100.00	100.00	100.00	-
1760	100.00	100.00	100.00	100.00	100.00	-
1761	9.45	9.45	10.82	10.029	6.65	Rishikesh
1762	100.00	100.00	100.00	100.00	100.00	-
1764	100.00	100.00	100.00	100.00	100.00	-
1766	100.00	100.00	100.00	100.00	100.00	-
1768	100.00	100.00	100.00	100.00	100.00	-
1770	100.00	100.00	100.00	100.00	100.00	-
1772	100.00	100.00	100.00	100.00	100.00	-
1774	100.00	100.00	100.00	100.00	100.00	-
1776	100.00	100.00	100.00	100.00	100.00	-
1778	100.00	100.00	100.00	100.00	100.00	-
1780	100.00	100.00	100.00	100.00	100.00	-
1782	100.00	100.00	100.00	100.00	100.00	-
1784	100.00	100.00	100.00	100.00	100.00	-
1786	100.00	100.00	100.00	100.00	100.00	-
1788	100.00	100.00	100.00	100.00	100.00	-
1790	100.00	100.00	100.00	100.00	100.00	-
1792	100.00	100.00	100.00	100.00	100.00	-

1794	100.00	100.00	100.00	100.00	100.00	-
1796	100.00	100.00	100.00	100.00	100.00	-
1798	100.00	100.00	100.00	100.00	100.00	-
1800	100.00	100.00	100.00	100.00	100.00	-
1802	100.00	100.00	100.00	100.00	100.00	-
1804	100.00	100.00	100.00	100.00	100.00	-
1806	100.00	100.00	100.00	100.00	100.00	-
1808	100.00	100.00	100.00	100.00	100.00	-
1810	100.00	100.00	100.00	100.00	100.00	-
1812	100.00	100.00	100.00	100.00	100.00	-
1814	100.00	100.00	100.00	100.00	100.00	-
1816	100.00	100.00	100.00	100.00	100.00	-
1818	100.00	100.00	100.00	100.00	100.00	-
1820	100.00	100.00	100.00	100.00	100.00	-
1822	100.00	100.00	100.00	100.00	100.00	-
1824	100.00	100.00	100.00	100.00	100.00	-

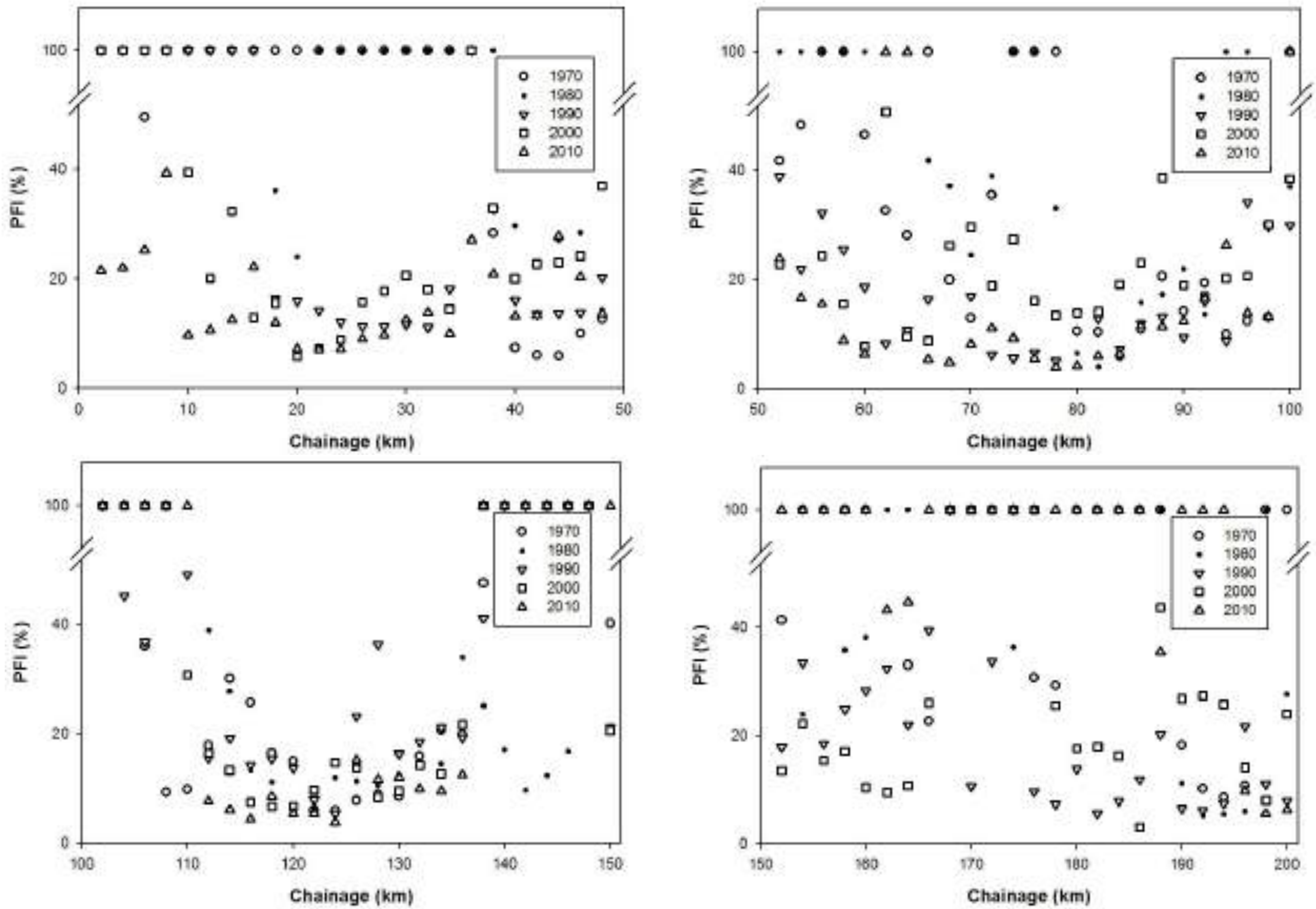


Figure 10.16a Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 0 - 200 km

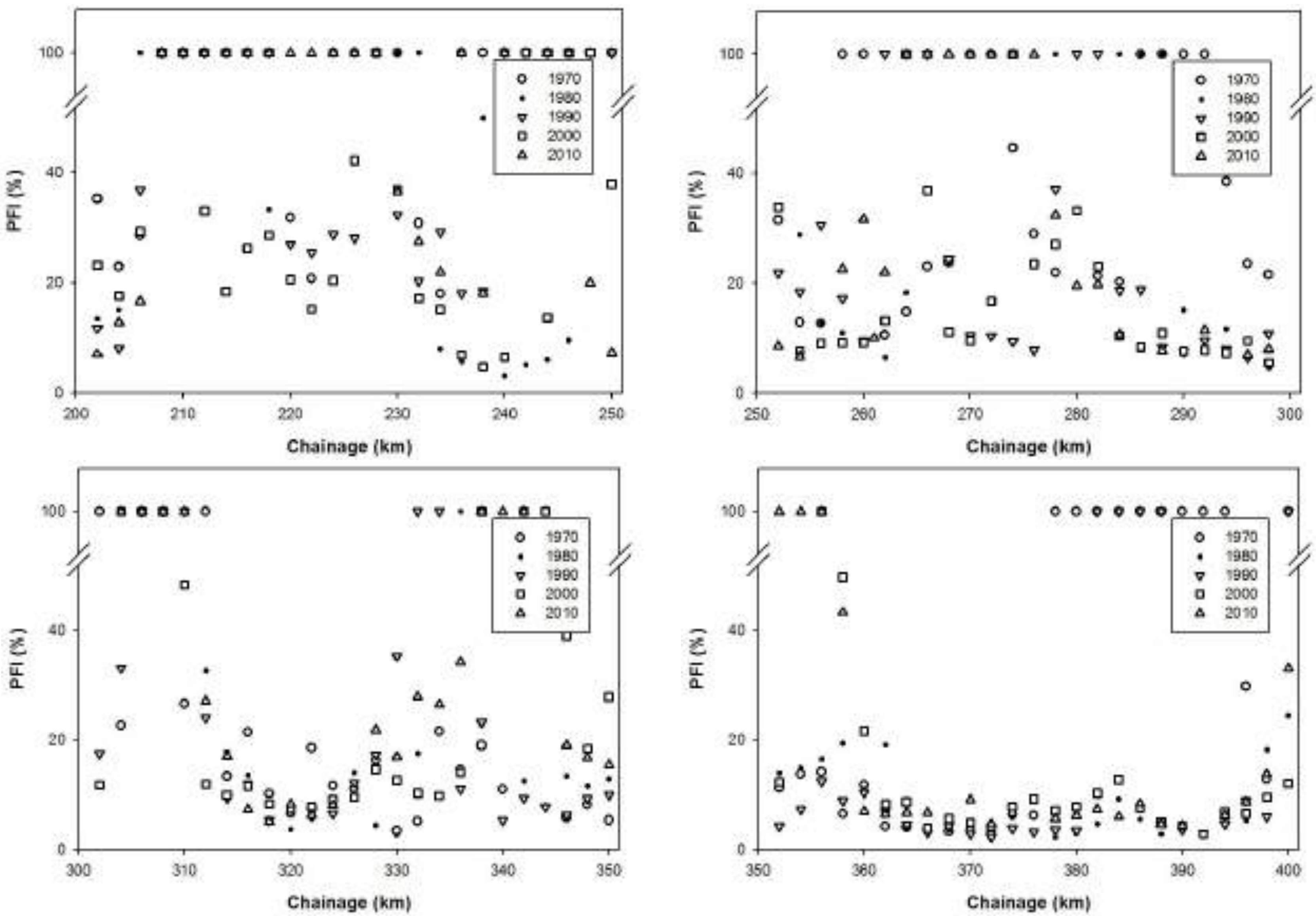


Figure 10.16b Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 200 - 400 km

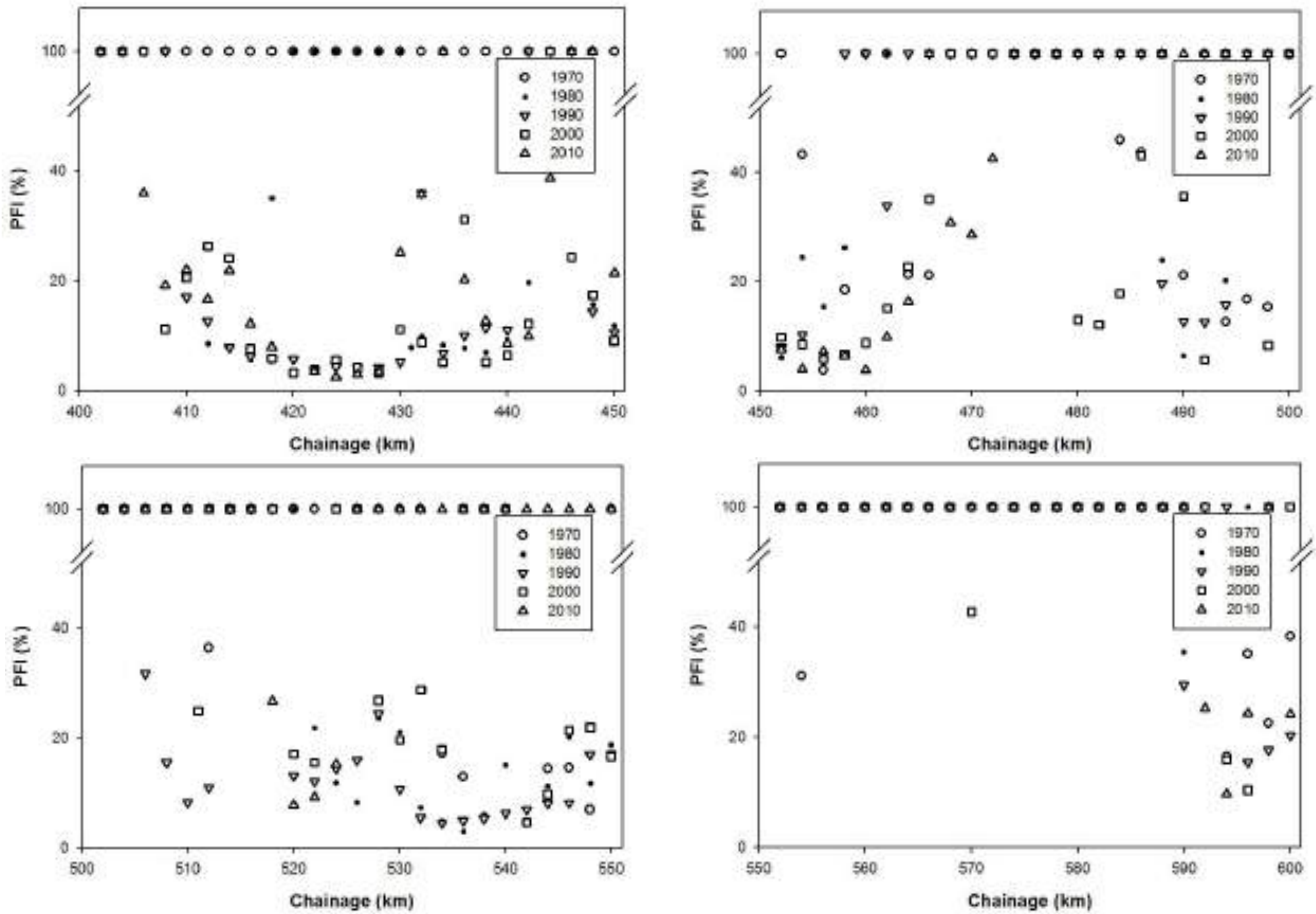


Figure 10.16c Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 400 - 600 km

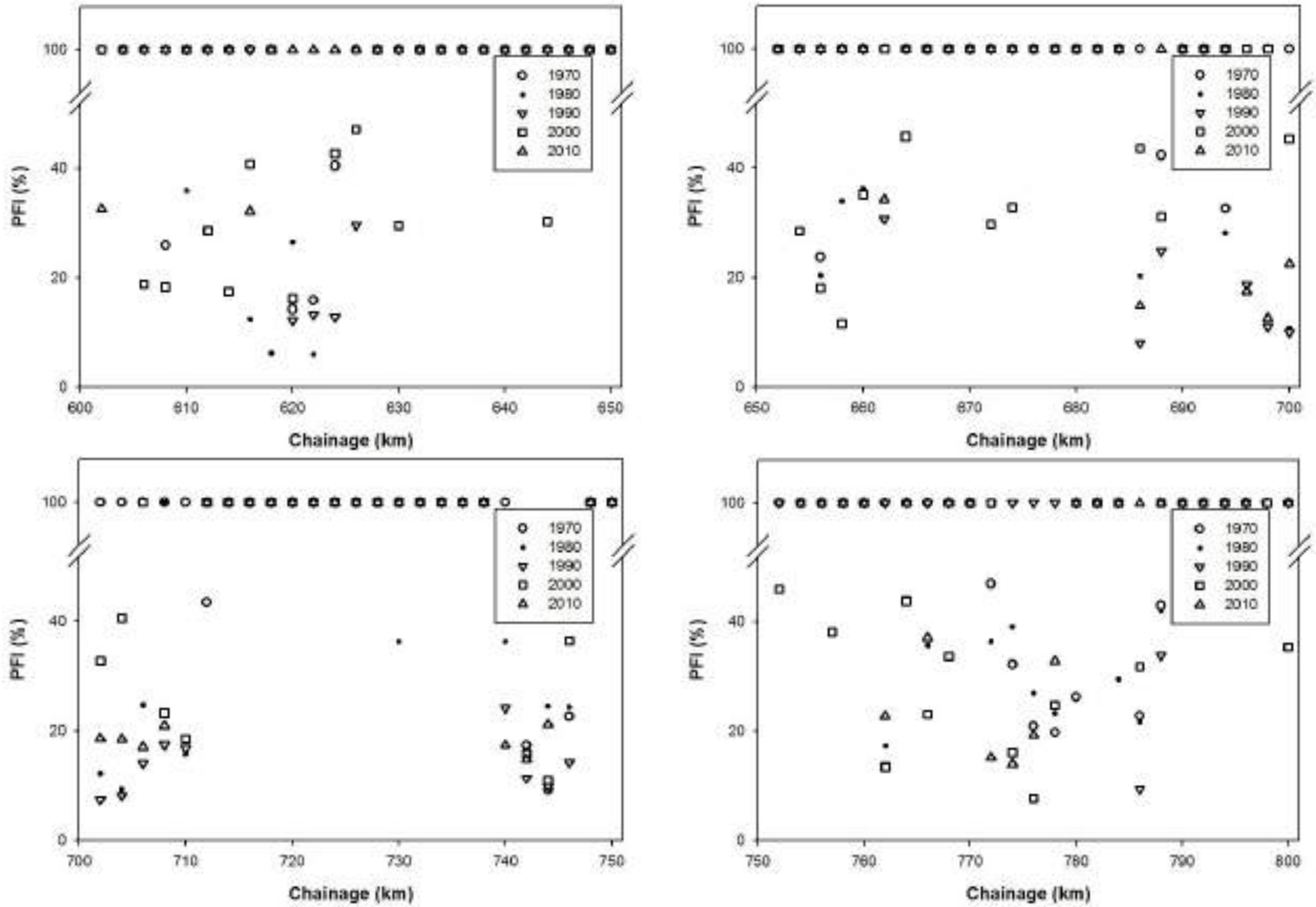


Figure 10.16d Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 600 - 800 km

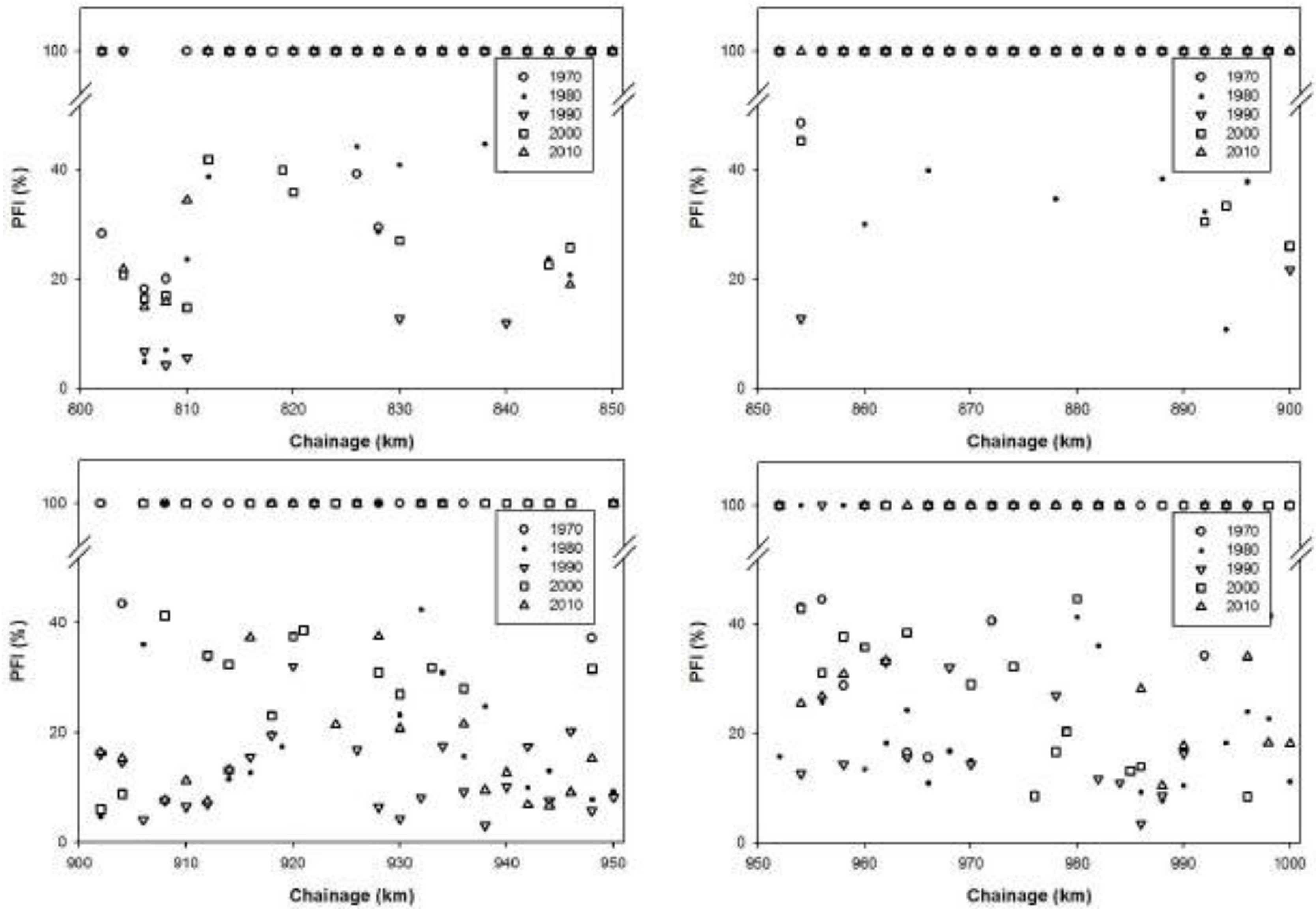


Figure 10.16e Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 800 - 1000 km

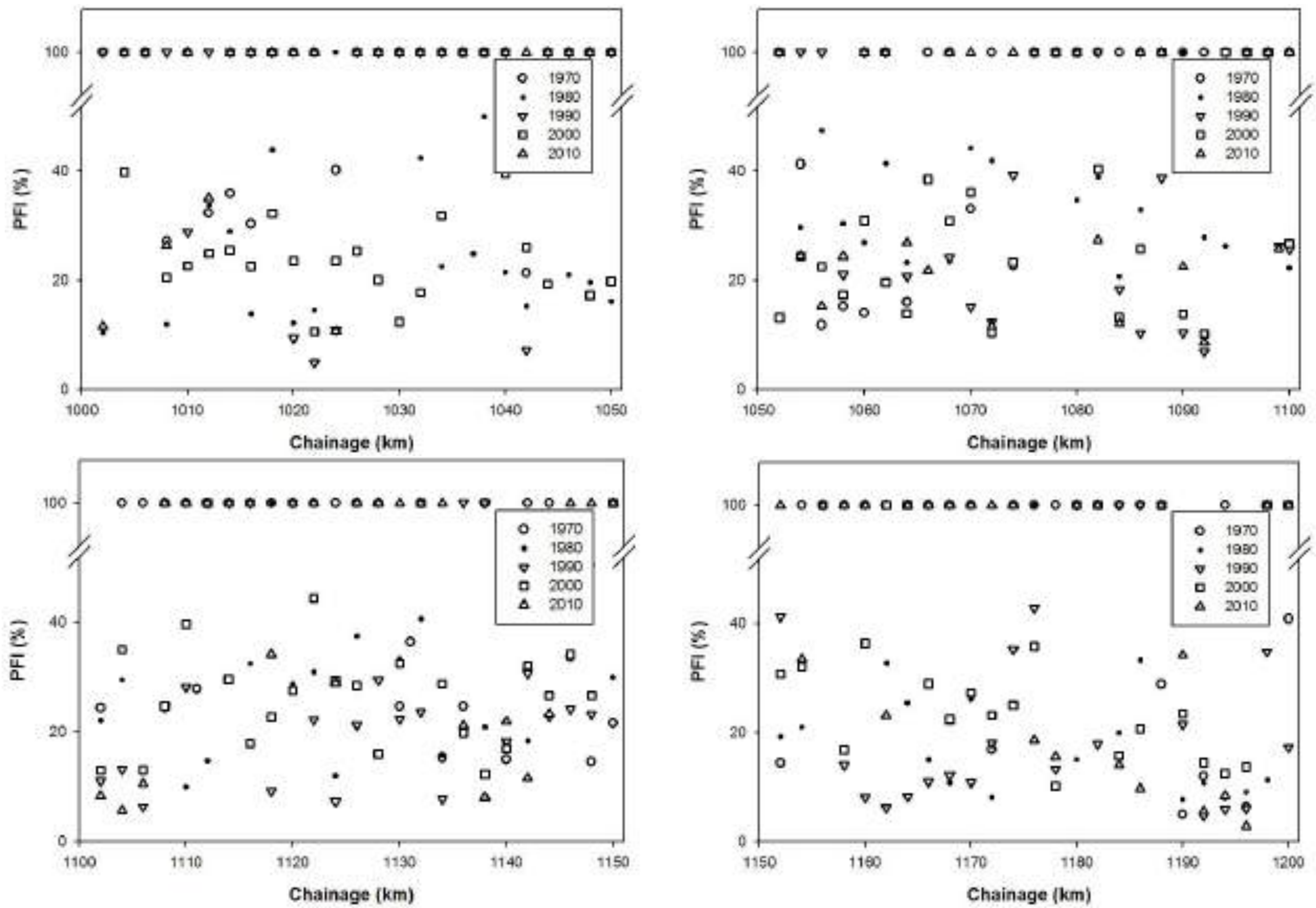


Figure 10.16f Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 1000 - 1200 km

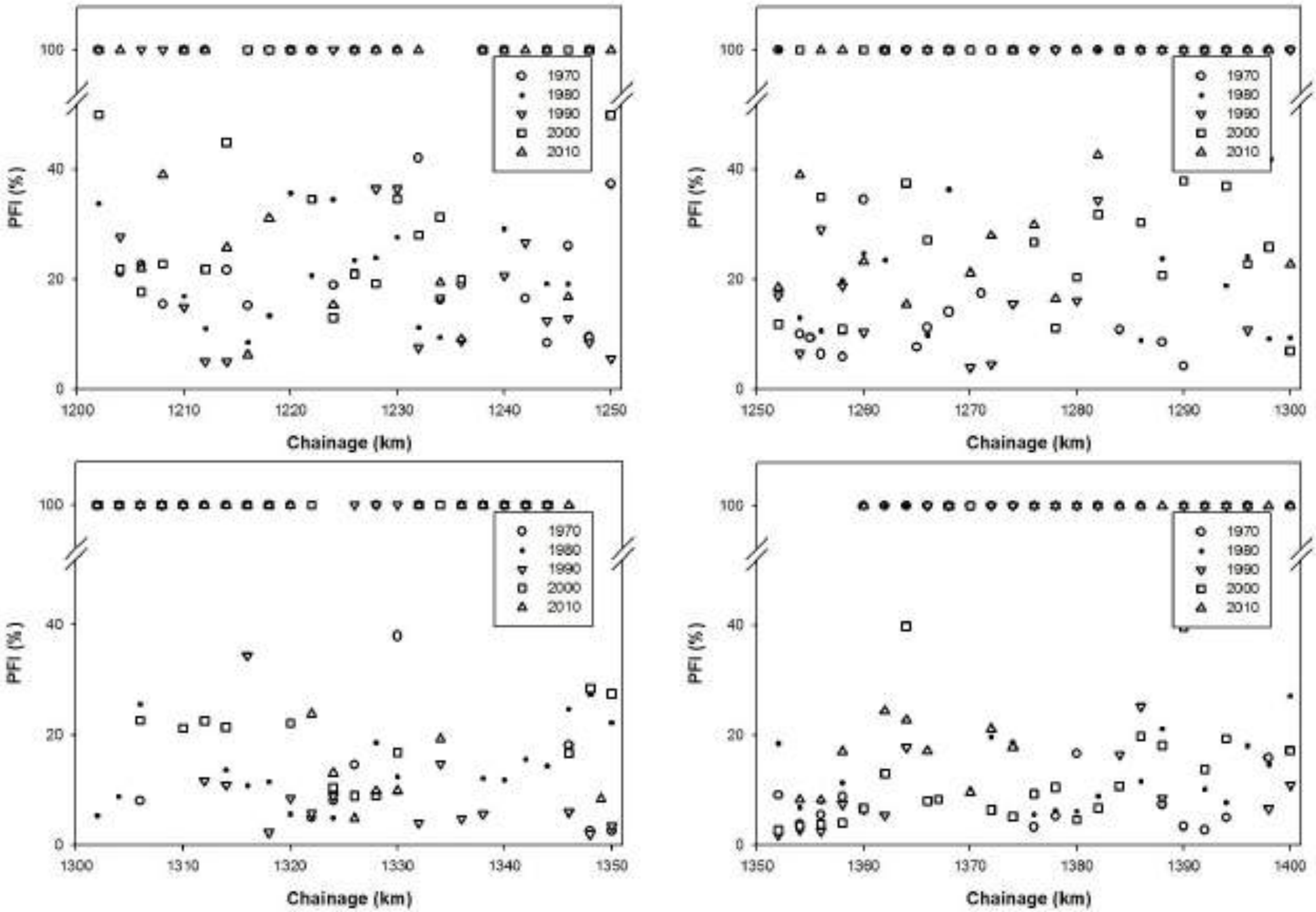


Figure 10.16g Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 1200 - 1400 km

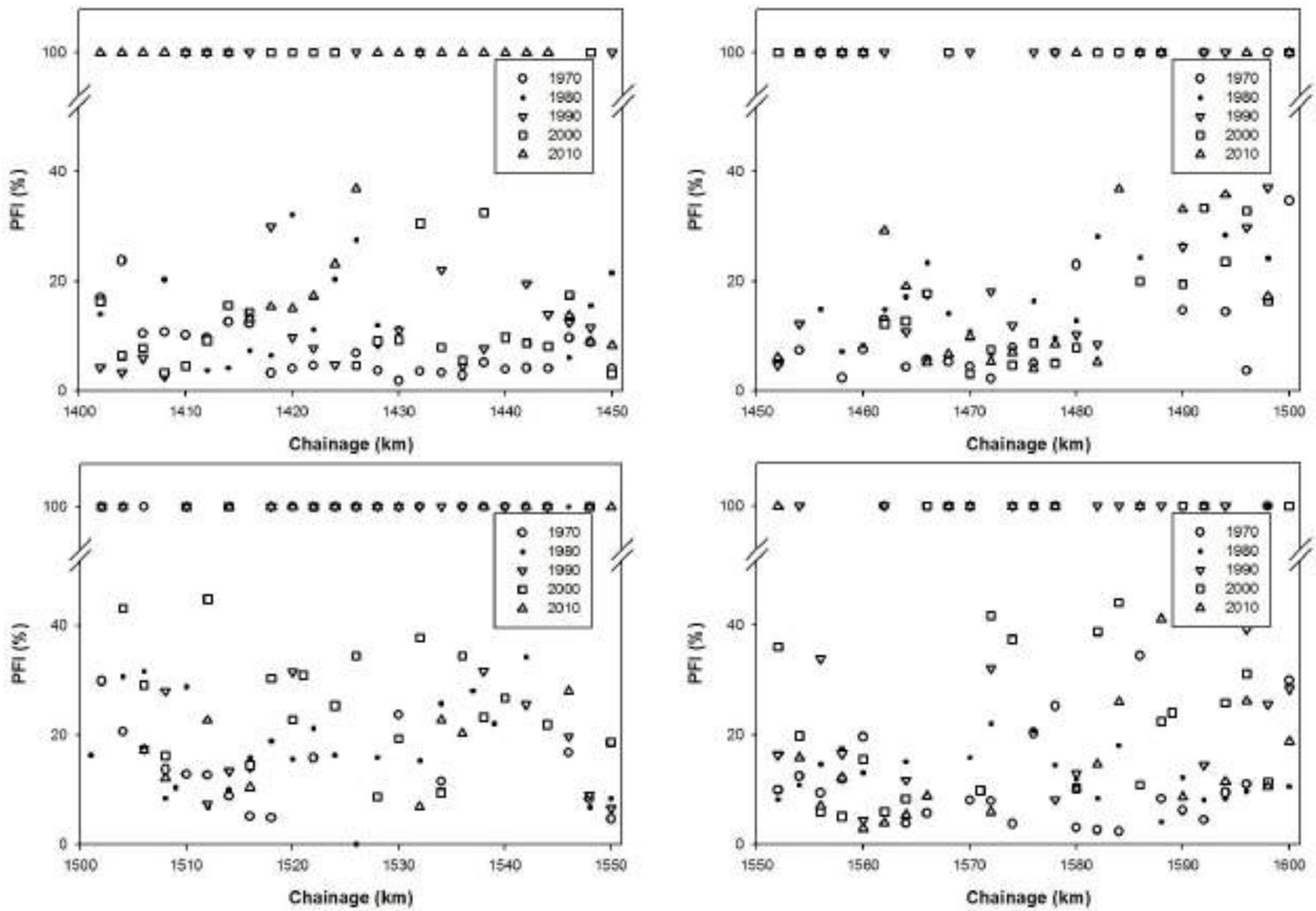


Figure 10.16h Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 1400 - 1600 km

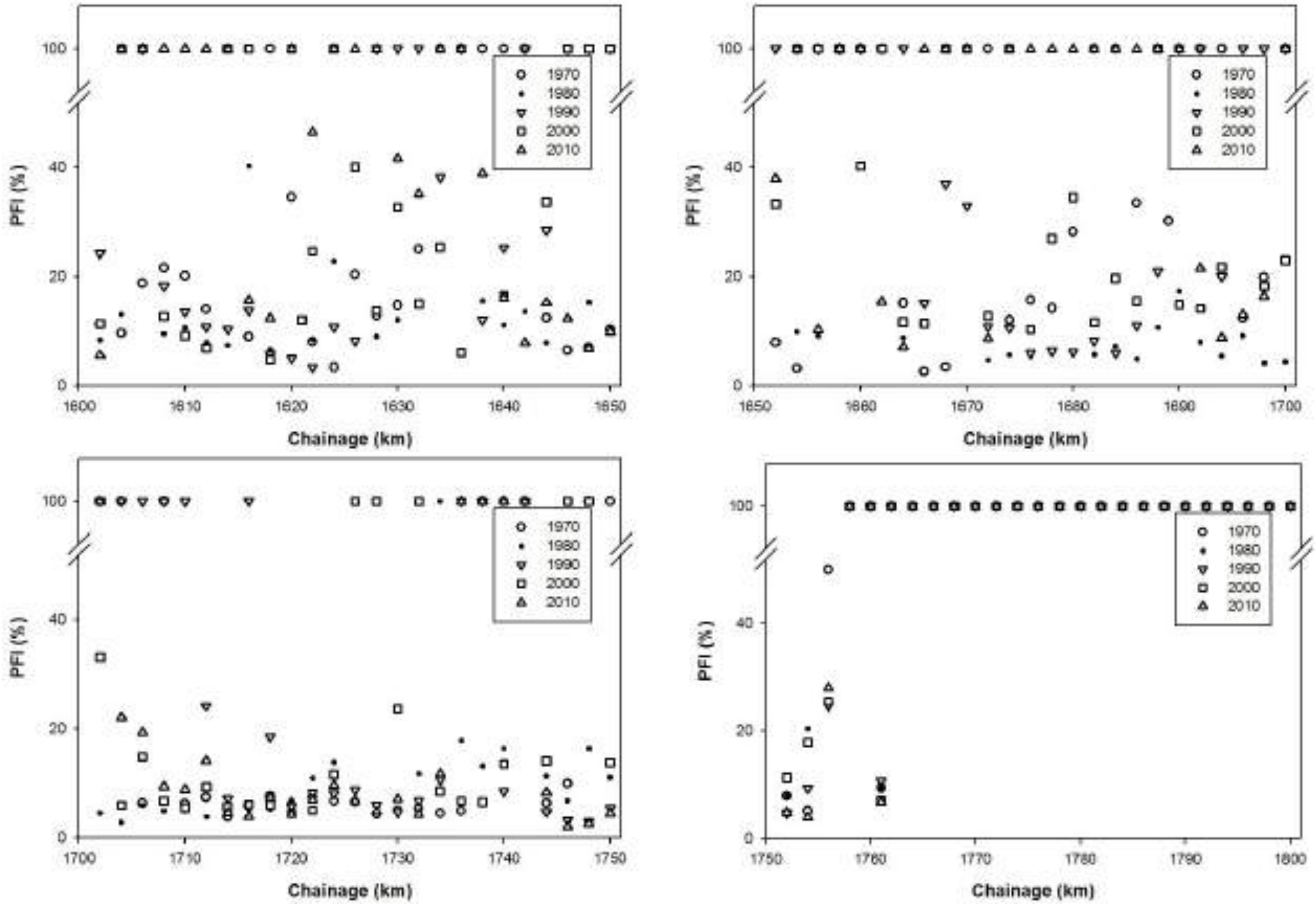


Figure 10.16i Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 1600 - 1800 km

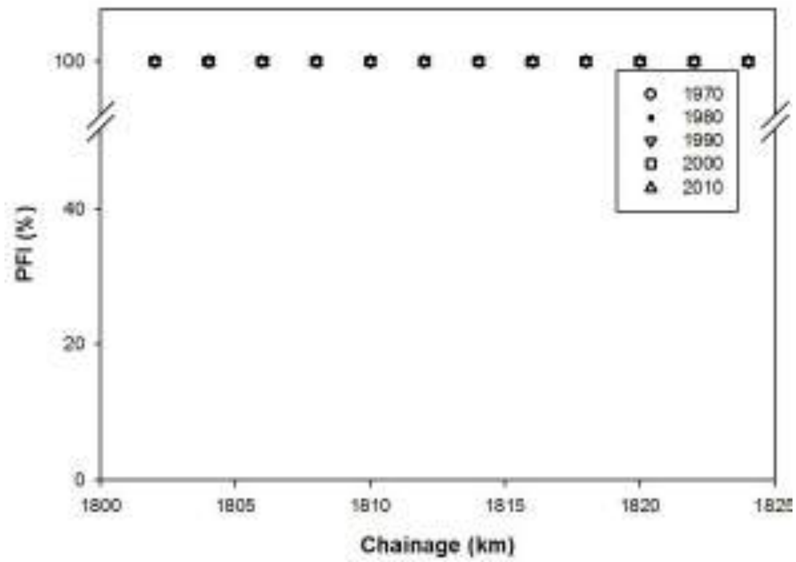


Figure 10.16j Planform Index of Ganga river for the years 1970, 1980, 1990, 2000 and 2010 from chainage 1800 - 1824 km

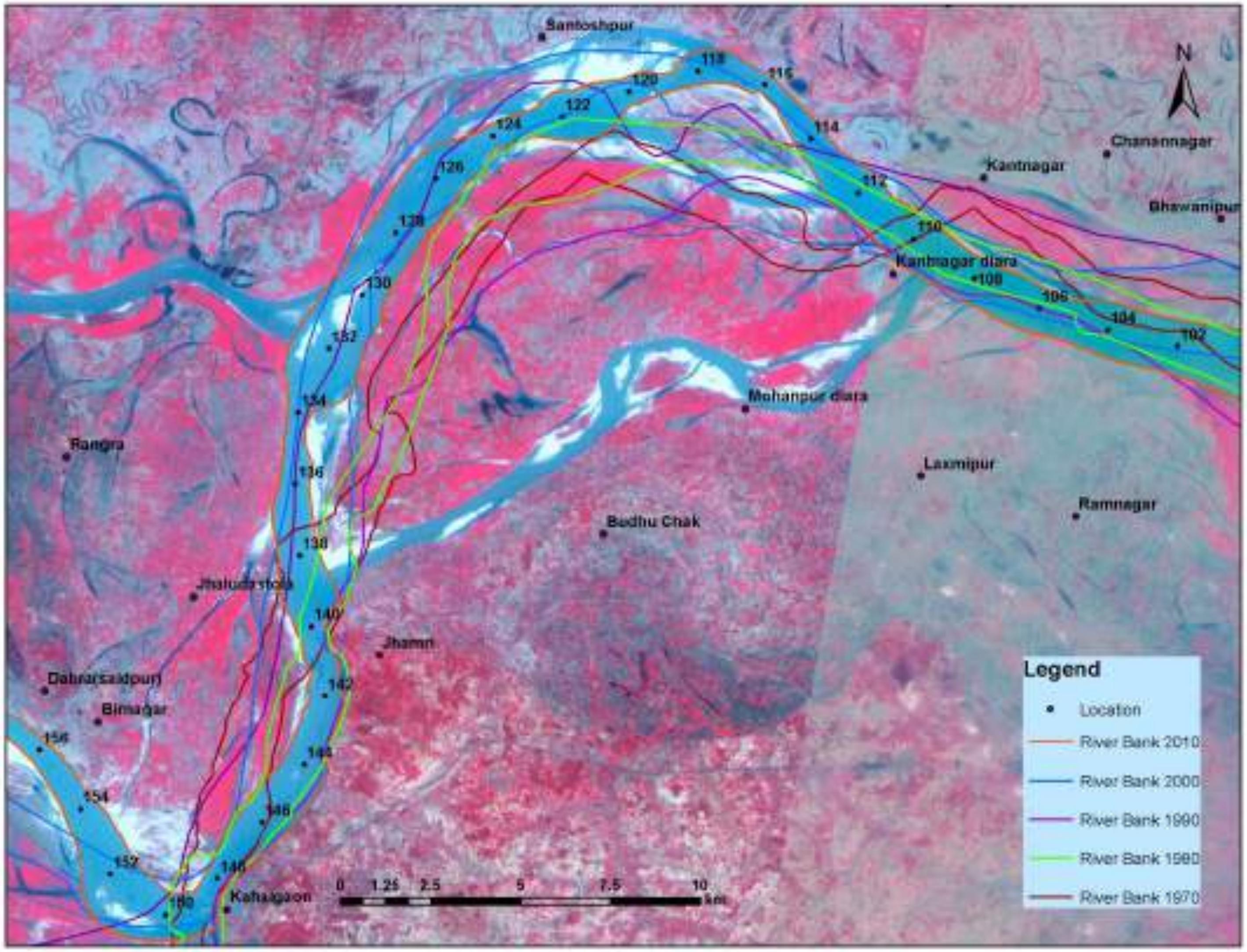


Figure 10.17a Braiding pattern of Ganga river in year 2010 from Chainage 110-140 km near Krusela

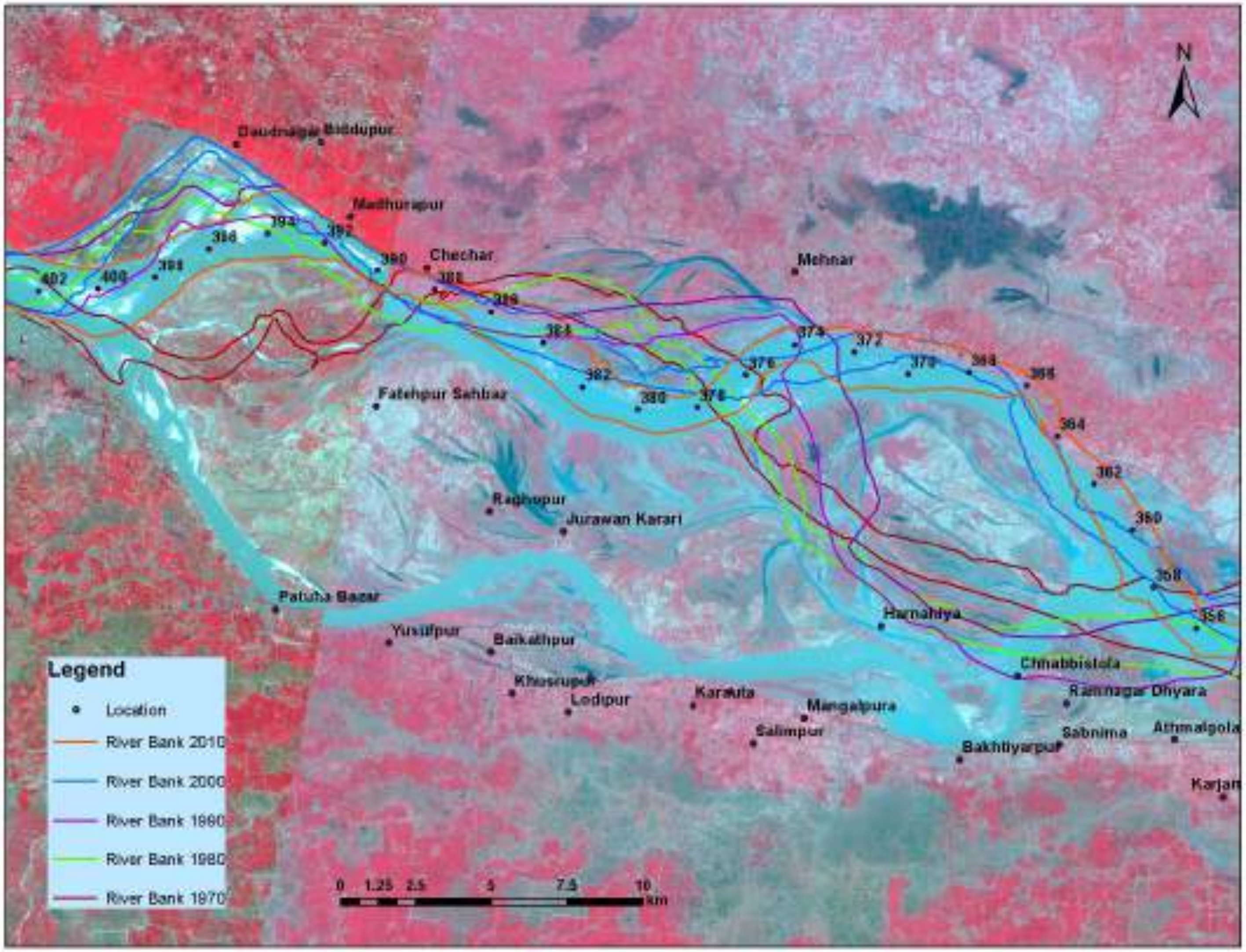


Figure 10.17b Braiding pattern of Ganga river in year 2010 from Chainage 360-400 km near Raghopur

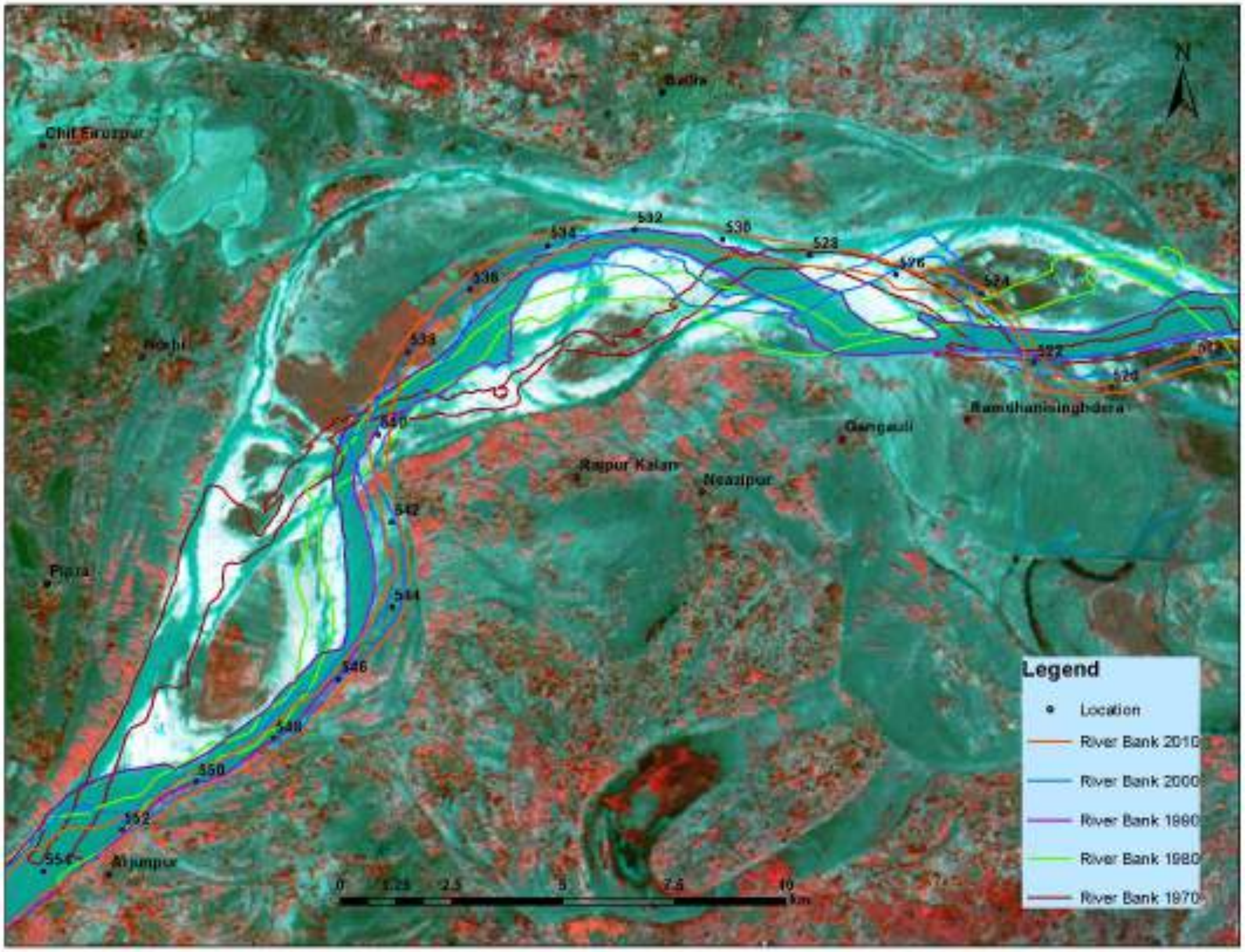


Figure 10.17c Braiding pattern of Ganga river in year 1990 from Chainage 520-550 km near Balia

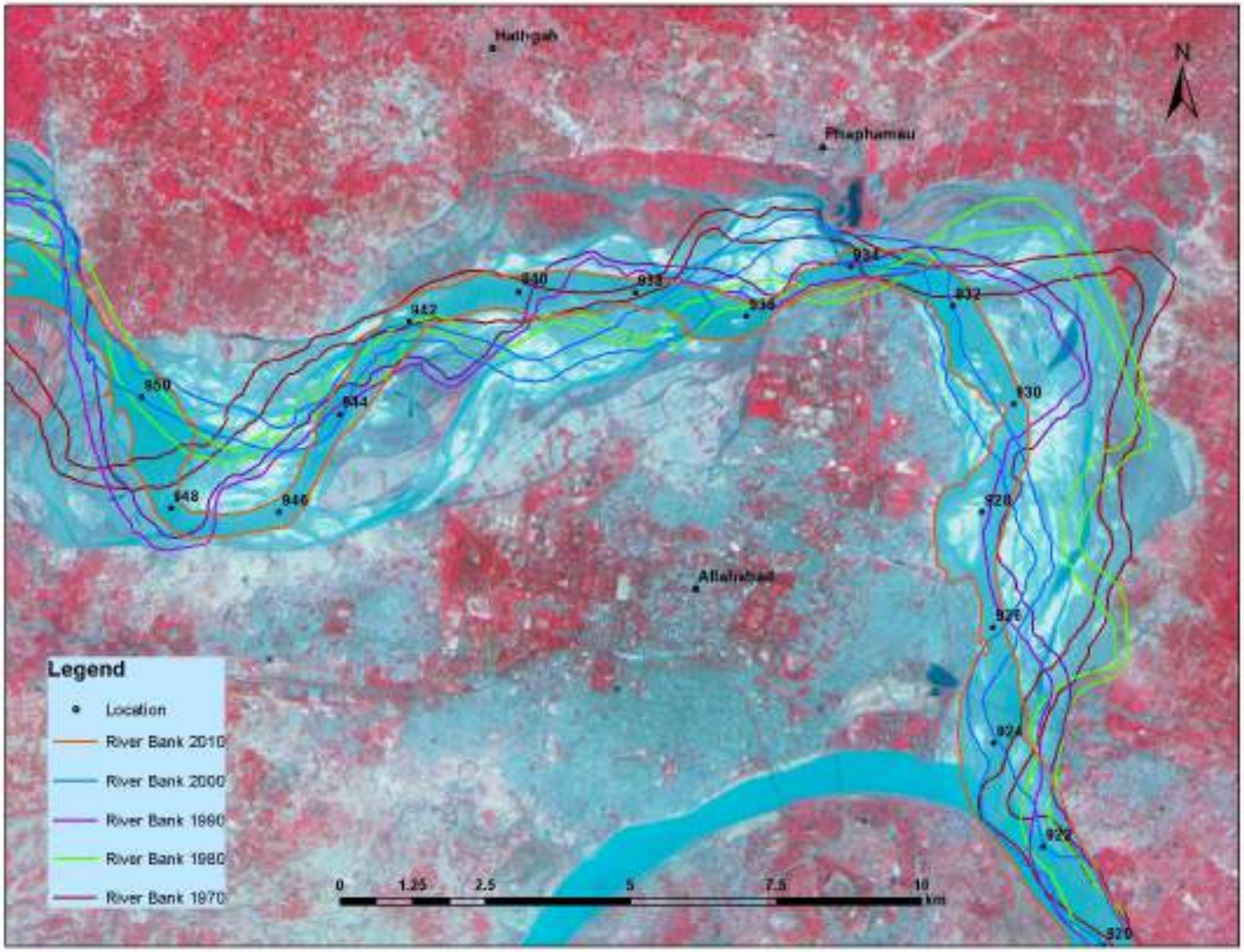


Figure 10.17d Braiding pattern of Ganga river in year 2010 from Chainage 930-950 km u/s of Allahabad

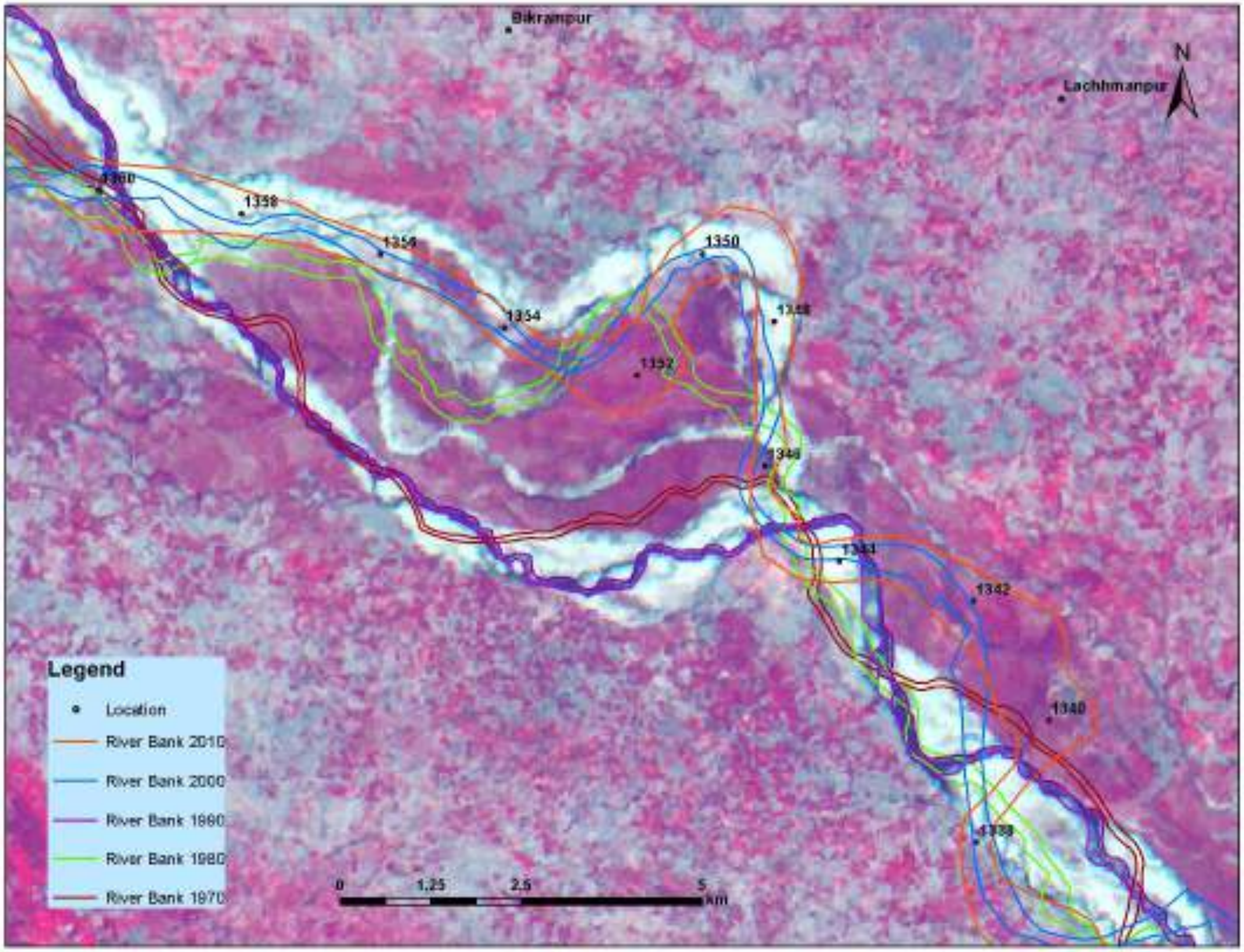


Figure 10.17e Braiding pattern of Ganga river in year 1990 from Chainage 1340-1360 km u/s of Farrukhabad

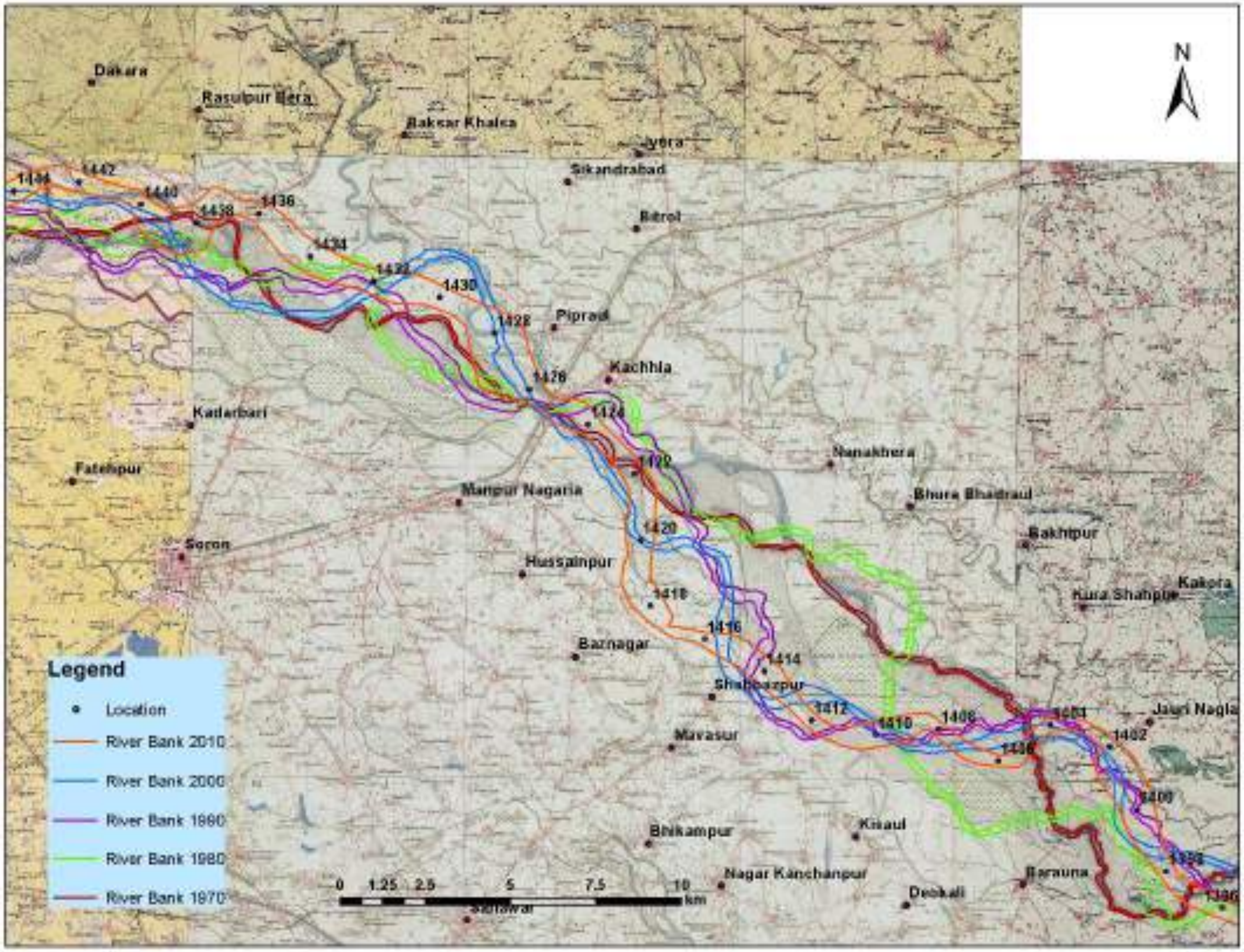


Figure 10.17f Braiding pattern of Ganga river in year 1970 from Chainage 1400-1440 km near Kachhla bridge

Figure 10.17g Braiding pattern of Ganga river in year 1970 from Chainage 1440-1480 km near Ramghat (u/s of Narora)

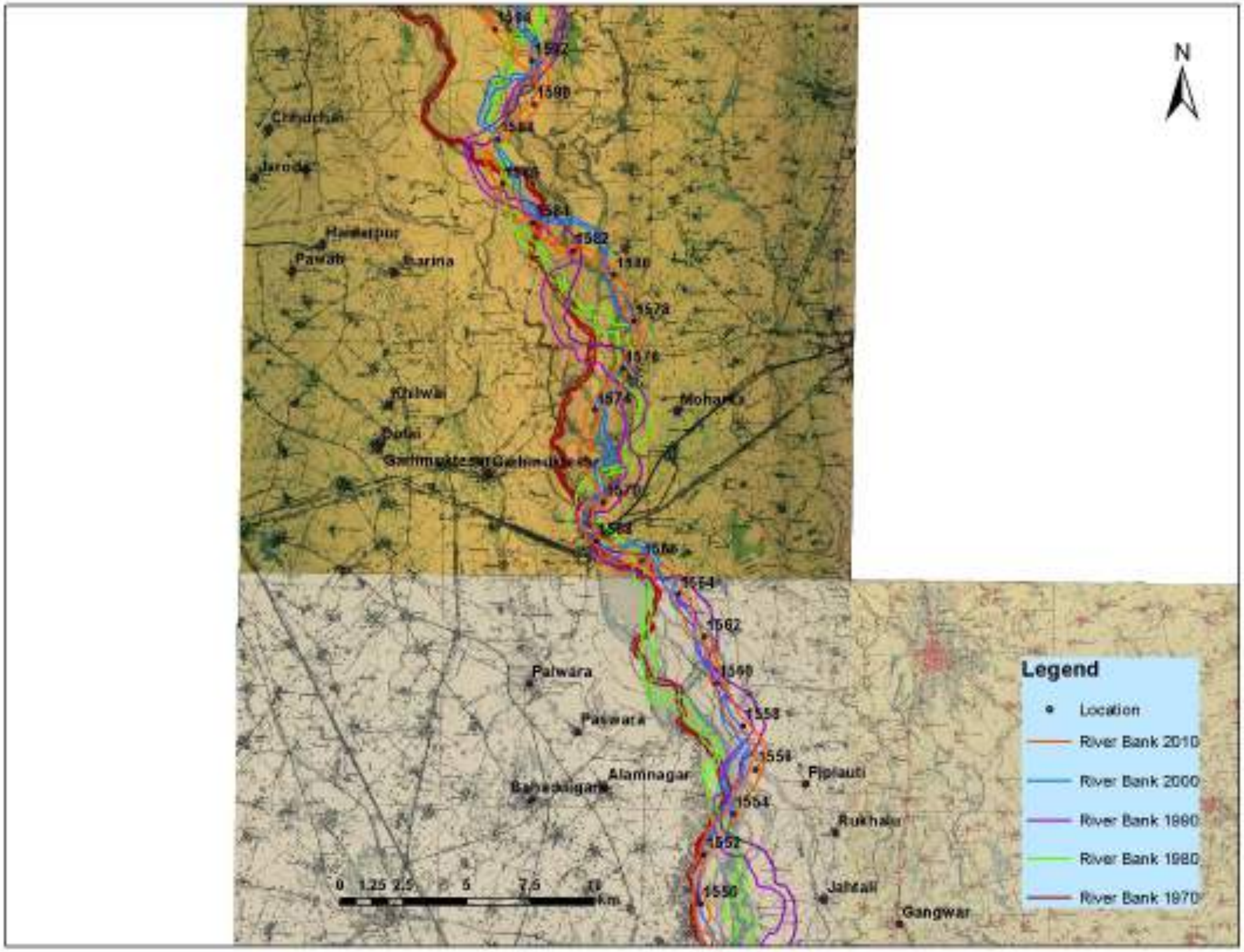


Figure 10.17h Braiding pattern of Ganga river in year 1970 from Chainage 1550-1590 km near Garhmukteswar

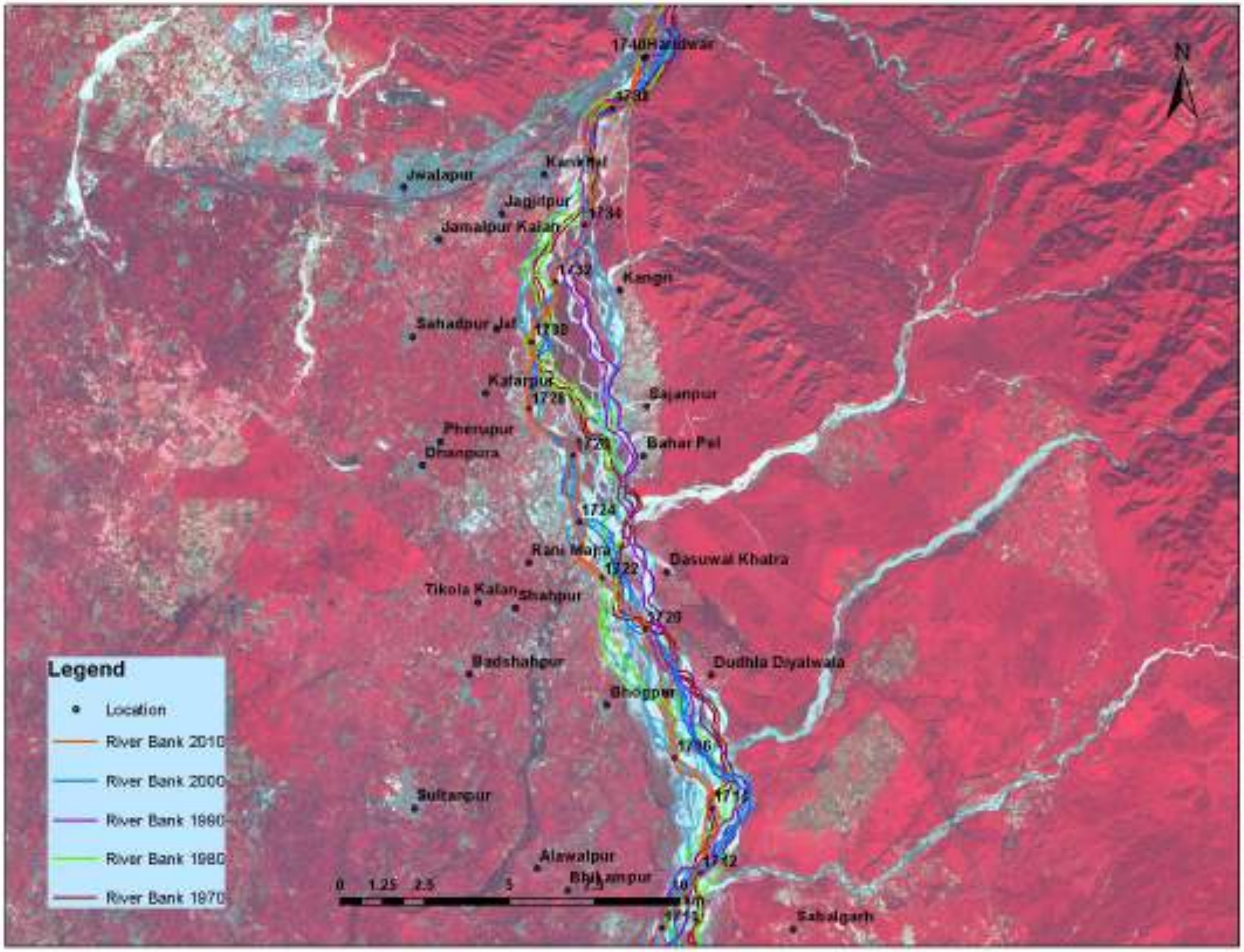


Figure 10.17i Braiding pattern of Ganga river in year 2010 from Chainage 1710-1740 km downstream of Haridwar

10.3 COMPUTATION OF SHIFTING OF MAIN COURSE OF THE RIVER

Shifting of the Ganga river is calculated on the basis of center line of year 2010. Center line of year 2010 is perpendicularly bisected at a regular interval of 2 km. The shift of left bank, right bank and center line in left and right directions has been computed for the years 1970, 1980, 1990 and 2000 with respect to year 2010 in GIS software. The sample map of computation of river shifting is shown in Fig. 10.18 and the database of shifting is given in Table 10.6.

Figures 10.19 to 10.55 show the shifing of center line of river in years 1970, 1980, 1990 and 2000 with respect to year 2010. The 'x' and 'y' scales have been taken as same for all the figures for the ease of comparison and symmetry. Figures 10.56 to 10.92 show decadal change in river course from year 1970 to 2010. The river bank lines have been overlaid on the satellite images of 2010 for the better visualisation.

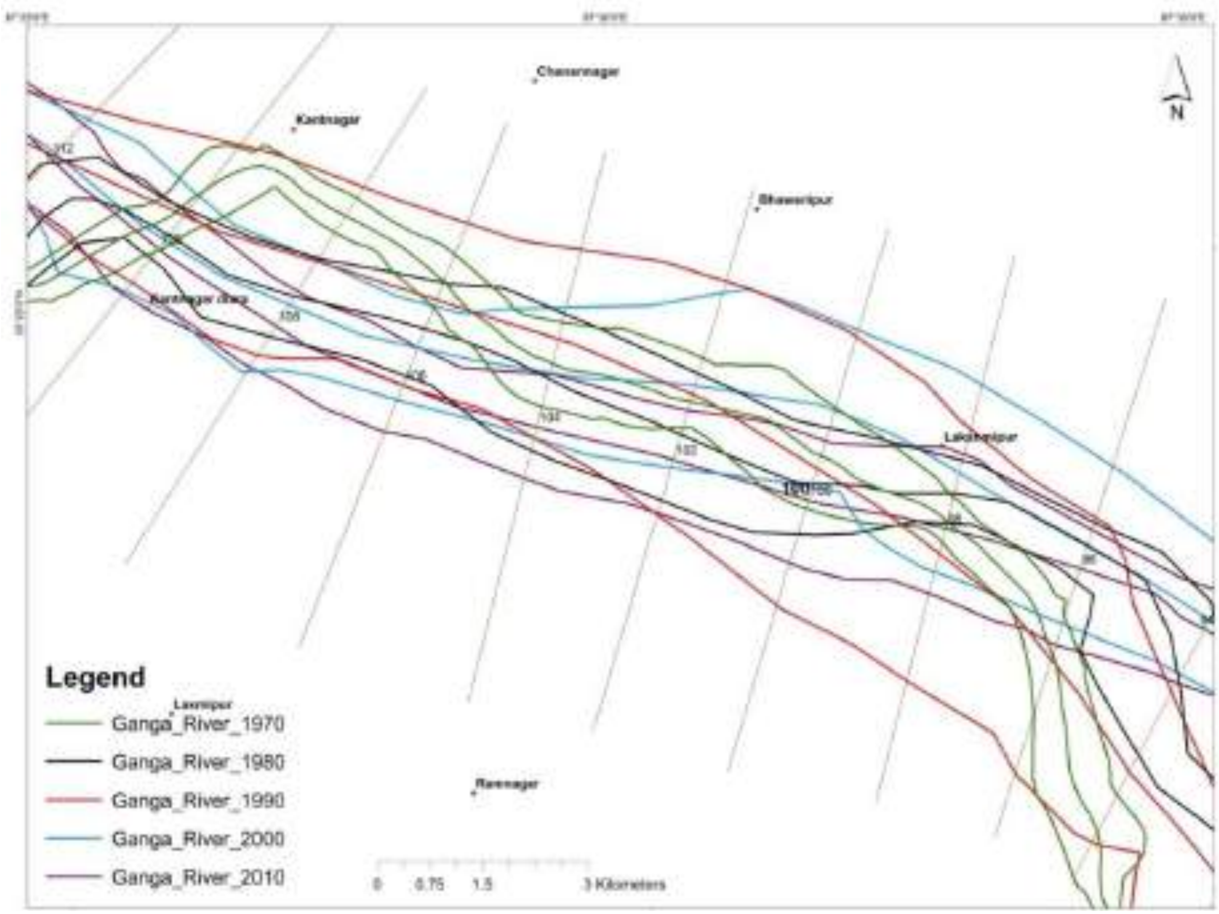


Figure 10.18 Sample procedure map of shifting computation

Table 10.6 Shift in the course of Ganga river of years 1970, 1980, 1990 and 2000 w.r.t. year 2010

	1970			1980			1990			2000		
Chainage (km)	**Left Bank (m)**	**Center Line (m)**	**Right Bank (m)**	**Left Bank (m)**	**Center Line (m)**	**Right Bank (m)**	**Left Bank (m)**	**Center Line (m)**	**Right Bank (m)**	**Left Bank (m)**	**Center Line (m)**	**Right Bank (m)**
0	640.50	330.53	328.64	719.60	670.33	-64.49	123.28	480.16	184.32	-144.07	233.65	-510.26
2	1982.50	2126.06	2112.42	1881.72	1998.97	1542.19	978.33	1275.65	1765.20	68.93	301.29	6210.95
4	4708.49	4150.52	3615.95	2288.40	2869.43	29510.90	844.70	1289.22	1546.49	65.66	306.51	130.75
6	4632.61	3445.91	26310.06	1762.40	1673.70	2504.77	401.96	-795.75	-649.86	-100.61	-9610.56	-1251.92
8	1721.20	1242.18	1472.15	-1320.65	-12910.73	361.45	-2148.95	-2898.45	-3049.88	-2352.74	-2581.16	-2290.58
10	-461.47	-386.23	-390.46	-3359.50	-3283.22	-3215.17	-3073.98	-3029.04	-2940.79	-3354.36	-2919.47	-2513.86
12	-1868.21	-2166.09	-2422.90	-3988.16	-4344.82	-5182.74	-2393.02	-25310.15	-2700.62	-2976.53	-2639.18	-2430.07
14	-1586.47	-2063.85	-3200.22	-3106.90	-3430.83	-42510.17	-1305.54	-12710.01	-1566.38	-1563.45	-1410.28	-1882.28
16	-549.69	-839.08	-663.05	-1552.94	-1692.35	-844.75	-214.41	40.71	-699.96	-298.71	-319.58	-376.18
18	6.84	-153.69	493.24	-3810.44	-621.87	4310.57	-329.10	-8510.77	131.32	-219.46	-1042.76	-821.07
20	-1270.45	582.03	19610.95	-1703.58	213.45	1736.81	-19610.36	-1398.55	-794.28	-32110.28	-3273.76	-3373.42
22	530.04	19410.77	28310.45	365.95	1944.22	2558.81	-1392.35	-1059.07	-494.19	-3476.59	-3578.74	-36010.78
24	3314.99	4182.22	4709.17	31610.43	4100.22	4362.13	1110.75	495.05	921.28	-2128.54	-1892.21	-1744.98
26	4761.88	4948.16	5295.55	4750.67	5056.40	5081.96	1141.56	1446.43	1798.77	-886.57	-421.24	-162.99
28	4742.79	4722.90	5122.00	4595.32	4991.56	4924.75	1284.54	1639.60	1899.92	120.54	5710.45	942.34
30	4302.14	46110.00	48910.75	40510.52	4606.15	4773.61	994.83	11910.79	1578.45	532.73	818.50	1156.80
32	3652.57	3960.24	4505.04	3269.73	3880.31	4311.62	7710.62	962.90	1292.92	965.14	1013.17	1055.02
34	2652.69	2843.11	2843.30	1920.08	2670.27	3238.65	689.34	1040.83	1431.78	899.22	1133.83	1125.05
36	2388.84	21510.50	1852.45	1375.04	1415.10	1763.69	812.42	910.75	1173.30	1036.74	979.89	932.83
38	1531.82	1033.45	729.44	396.60	381.04	366.22	365.65	139.97	233.81	385.43	1310.92	410.12
40	-4610.54	-702.33	-940.05	-1366.47	-955.72	-324.07	-294.93	-154.56	-36.78	-200.67	-69.33	-94.11
42	-1203.84	-1359.76	-1475.02	-2123.88	-1384.85	-653.88	-708.32	-400.37	15.76	-443.24	-205.18	-29.28
44	-1623.60	-1093.61	-1296.80	-884.42	-1195.88	384.09	-561.18	-333.96	26.77	-31.14	-3.12	85.04
46	-2629.39	-2461.04	-2451.96	-1356.55	-896.86	-18.39	-644.61	-2910.43	166.56	9.75	103.90	120.63
48	-3172.71	-3148.27	-3044.48	-1380.32	-1182.95	-4010.26	-1333.63	-775.30	-32.59	-190.82	-60.83	33.56
50	-2734.78	-2159.28	-1639.63	-975.37	-592.16	-345.97	-1398.64	-772.33	-119.38	-26.49	68.11	2.55

52	-682.23	-29.72	410.37	-129.02	104.87	85.78	-1635.43	-980.69	-132.54	-12.56	36.11	233.90
54	2256.97	445.53	1264.60	2055.44	848.48	566.62	-1090.92	-641.79	-79.24	-1196.44	-316.72	255.21
56	1069.74	1370.02	1346.98	41.38	405.18	309.91	-1508.12	-918.08	-362.85	-1812.31	-1272.09	-470.64
58	522.17	595.31	758.67	-810.68	-639.34	-385.37	-2156.36	-1722.87	-1195.20	-2294.67	-1873.98	-1382.06
60	-484.76	-32.25	139.39	-2083.73	-1298.20	-743.37	-3105.35	-2523.56	-1906.79	-3048.63	-2190.02	-1436.32
62	1731.22	611.11	228.43	503.42	16.75	-265.29	-599.41	-1418.00	-1096.70	-242.37	-732.51	-361.47
64	2403.48	23310.33	0.00	1585.63	1944.00	3.59	444.66	559.69	-783.88	941.56	1299.98	31.31
66	2226.92	2092.06	1929.76	2230.03	2504.87	1683.75	748.57	1000.82	1308.10	1292.10	18810.86	24910.54
68	1855.99	2699.00	1756.77	2605.81	14510.55	1886.84	836.03	1094.92	1290.61	950.08	1948.65	2736.23
70	1361.08	926.77	376.06	2490.51	2319.96	12510.38	589.61	7710.24	554.06	374.58	1133.53	2104.48
72	1540.55	1018.38	1114.09	2130.06	2140.62	1684.70	826.76	726.92	412.09	-283.74	-461.92	-176.33
74	1466.13	1772.08	1792.68	1765.67	2055.40	1900.96	-222.47	-66.10	-201.39	-1471.67	-13610.54	-1741.46
76	1614.75	1933.95	2328.08	9410.29	1705.63	2011.10	-2092.16	-1930.36	-1419.02	-2493.39	-2290.97	-2228.79
78	2089.63	1749.72	1613.19	2019.30	2166.58	2838.94	-2926.24	-31010.94	-3254.51	-27410.01	-2666.26	-2639.96
80	26310.69	24610.81	2272.92	3196.95	3060.00	30010.48	-3732.33	-3729.53	-3875.58	-2569.28	-2378.09	-2386.82
82	2549.69	2185.59	1655.79	4090.61	37110.44	32510.84	-3688.40	-3581.95	-3652.95	-859.18	-1105.99	-1275.53
84	3386.41	3202.78	2905.46	5273.16	5281.13	3285.41	-3055.79	-2575.61	-1759.68	-30.54	203.81	291.38
86	4314.61	4271.09	40010.21	3522.14	4974.17	2394.56	-1455.36	-370.96	643.63	80.07	782.04	835.11
88	3419.66	3363.65	31610.52	2108.45	2306.23	2263.17	-191.55	1333.28	3658.66	188.27	922.45	1876.68
90	4676.76	4404.51	4209.07	23510.44	2300.15	2501.94	2203.06	2952.85	5033.46	1088.32	1312.68	1902.54
92	5176.91	4691.38	4173.10	1970.08	1544.02	2195.60	3095.49	33010.78	4646.13	782.62	634.07	494.45
94	3323.88	3246.65	3116.80	356.49	12.12	1155.45	16710.37	2280.65	2555.88	-380.48	-151.89	-129.17
96	1301.14	1278.18	1019.10	54.78	93.46	-949.24	-176.30	1365.14	1894.85	-948.24	-334.47	-3110.95
98	624.48	-103.16	-749.16	729.07	422.92	-1025.20	-370.80	1255.34	1274.51	-10110.92	-809.61	-315.54
100	-492.88	-651.27	-806.39	85.28	5.15	-423.33	-1478.65	671.90	626.94	-1630.79	-1324.41	-1118.69
102	-768.99	-862.77	-1261.29	-1810.20	-188.68	-190.43	-1469.76	-322.48	20.94	-1733.91	-1095.54	-672.65
104	-755.94	-924.60	-1042.31	-412.80	-363.78	-4010.16	-990.40	-10110.95	-591.65	-974.11	-790.39	-588.89
106	-1414.51	-1578.81	-18710.53	-700.10	-725.02	-841.52	-1184.50	-1030.71	-700.78	-629.79	-569.11	-482.66
108	-1565.07	-18410.76	-2255.56	-480.90	-4810.31	-512.90	-12810.99	-908.65	-196.28	-529.26	-3510.38	79.51
110	-1180.44	-10310.40	-774.80	-25.90	-194.71	-525.31	-1103.51	-814.82	-208.06	-296.40	-151.79	-45.79

112	2389.31	1929.70	15210.84	458.19	127.97	-149.20	-123.97	-244.24	59.37	-16.52	-90.56	38.70
114	2526.96	3218.03	2906.39	924.08	784.50	489.94	790.25	601.34	856.10	480.42	4910.51	439.18
116	3338.05	3802.40	4365.61	1745.44	1819.73	1862.06	1452.01	1922.73	2298.81	595.27	1180.57	1754.11
118	3376.13	3589.27	3799.54	2119.60	2076.90	2114.80	2262.96	2491.22	27710.82	269.38	512.23	1064.20
120	1920.84	2423.34	2861.64	1242.35	1668.40	1804.30	2760.78	31410.99	3285.18	-770.12	-682.90	-632.44
122	1714.16	1342.54	1001.22	835.78	1759.81	1513.44	2968.13	2991.86	27310.41	-1039.79	-952.86	-722.35
124	1974.08	1890.71	1799.10	815.60	1623.73	1764.38	26610.76	3039.69	3181.80	-10310.48	-439.27	176.94
126	2712.05	2189.96	1763.92	1726.85	1356.70	917.08	1891.71	2013.41	2421.78	-272.39	-176.69	33.09
128	2489.16	2135.92	1843.64	1914.80	1445.84	1181.98	1655.10	1518.73	2192.19	-290.42	-393.51	-560.09
130	2308.02	19010.66	1715.09	2974.83	2319.11	2034.84	1472.01	1029.18	1959.26	33.90	-345.93	-379.30
132	2471.94	1825.99	12510.40	3350.00	2603.78	1916.22	1435.96	864.59	1286.73	443.60	213.71	-0.89
134	2729.58	2756.07	2971.67	2507.64	2574.60	2764.35	561.15	829.06	20310.06	332.99	831.52	1162.26
136	1963.74	2048.96	2185.20	1638.19	1746.47	1991.90	450.00	754.27	1529.74	303.69	722.59	1224.16
138	-40.05	830.23	1415.20	1127.70	1036.80	876.55	335.95	764.78	1280.84	-155.40	359.98	883.64
140	-816.89	-379.55	270.36	150.10	223.34	172.09	-372.84	-162.69	1310.00	-959.47	-414.02	53.80
142	-17710.25	-1706.85	-1523.73	-779.75	-556.31	-891.43	-1092.95	-552.54	-63.17	-1544.60	-933.92	-30.36
144	-1759.51	-1662.07	-1618.59	-481.96	-3610.62	-881.11	-1120.80	-586.57	-221.30	-1070.24	-470.78	-52.44
146	-1213.20	-1142.77	-534.80	5.03	-99.45	-220.52	-541.15	-291.20	-204.61	-176.94	-150.04	-89.71
148	-574.83	-336.12	-64.59	-615.76	-221.20	710.99	-295.62	-92.62	-80.71	-113.92	-53.31	58.80
150	1702.71	1746.56	18710.05	2296.60	27010.43	2539.33	481.36	1650.85	2354.04	-278.64	-326.52	-364.49
152	5176.26	43910.46	3430.13	5304.30	4421.36	3323.88	4801.42	4238.57	3620.83	912.88	241.25	-253.58
154	6661.82	6706.38	6505.95	56710.83	5744.16	5330.93	5246.65	5476.95	6013.36	1341.24	1405.04	1199.89
156	7876.39	8225.81	8463.27	6499.68	6634.36	6975.00	6210.41	6299.37	62510.08	2062.83	2343.53	2579.48
158	8556.79	89710.82	9469.03	6995.42	7135.54	7264.43	6620.10	6896.63	71310.92	2323.47	2786.17	3364.94
160	8381.07	8398.18	8529.57	6545.85	64110.39	6150.17	6081.66	6202.90	6071.33	2001.93	2150.53	2189.32
162	7044.70	7035.27	7101.62	5278.80	5004.70	4558.06	4482.55	4694.92	4466.48	1035.33	9010.01	710.82
164	5058.89	4941.53	4890.46	3169.61	2989.07	2568.23	2423.77	2705.65	2952.27	-149.01	-2610.86	-645.03
166	3359.45	2848.09	2741.42	1416.49	1151.72	1198.05	525.55	524.49	1159.13	-1162.93	-14010.88	-1264.50
168	642.69	1000.03	1309.83	-323.40	-283.74	-135.89	-1289.37	-916.67	-373.21	-20610.42	-1642.51	-882.35
170	-348.11	-224.23	112.50	-975.59	-10510.12	-1102.01	-1735.61	-1374.44	-1028.36	-2100.02	-1544.35	-1211.27

172	-483.07	-339.37	-126.77	-986.45	-7210.26	-694.84	-1400.15	-1029.59	-898.76	-934.31	-768.62	-766.92
174	708.35	459.96	124.46	4110.23	225.82	126.11	810.47	-100.09	53.38	333.24	1810.56	56.86
176	2789.15	2464.78	2122.90	2221.43	2366.60	2464.93	2910.10	2718.77	2426.93	1261.61	1350.86	1619.44
178	3711.18	36910.41	37410.84	4051.90	4363.45	45910.83	4759.28	4781.46	4785.43	1268.85	1885.02	2451.79
180	5403.09	5595.42	5828.52	5919.73	6098.65	6206.14	6708.57	6695.89	6613.05	1812.44	2351.42	2962.87
182	6126.75	5821.98	5611.59	6746.22	6510.36	6196.96	7354.90	6900.57	6488.61	1384.61	1688.40	22310.47
184	4734.52	4539.57	4459.62	54910.98	5203.73	4988.34	4364.09	5068.10	5183.69	-534.76	-413.95	386.79
186	3521.42	3460.80	3342.56	2605.00	3031.80	3538.53	998.78	1508.85	28210.06	-2013.07	-1811.31	-1545.45
188	1755.03	22710.83	2519.17	1275.00	1363.78	1422.18	-1125.12	-323.28	371.50	-2328.99	-1925.24	-16910.53
190	-8648.75	-8586.83	-98.19	834.47	962.11	840.32	-1959.81	-1604.08	-1148.72	-1155.05	-1270.80	-1210.30
192	-9554.11	-9806.83	-9922.04	723.54	5210.95	338.24	-1844.15	-1468.91	-1031.39	-535.05	-461.38	-345.02
194	-82810.42	-9010.52	-9884.86	798.56	190.87	-446.43	-142.84	-172.38	-710.33	878.19	635.28	144.38
196	-6772.56	-7153.01	-7395.69	39.90	-210.38	-259.57	8010.04	1302.35	1940.73	1260.98	1352.34	1259.31
198	-1249.07	-908.27	-691.64	-910.53	-59.50	109.41	1564.06	1798.83	3679.90	1668.27	1939.09	2109.39
200	389.81	382.95	-1710.98	-5910.03	-500.67	-405.77	1616.34	1696.26	3592.82	1413.95	17710.89	1958.16
202	1426.62	1708.84	1163.65	-493.69	-532.50	-1261.65	1411.78	1665.99	2932.46	665.48	1032.38	928.17
204	2045.19	1879.52	1198.55	192.42	-95.27	-733.59	10110.51	1246.96	2253.32	226.81	148.88	-510.16
206	192.86	750.74	672.10	-273.40	-204.55	-260.66	-10.35	6110.51	1332.97	-462.01	-233.77	-248.83
208	278.06	289.14	-45.68	36.07	132.38	163.69	-545.66	-133.49	34.52	-790.57	-423.21	-39.60
210	-64.23	2710.36	204.44	663.68	281.75	193.68	-981.16	-865.66	-748.36	-1129.86	-588.86	-372.17
212	-6983.65	-7051.85	-6774.18	-7443.58	-7662.61	-7633.05	-1535.00	-1479.53	-1170.01	-145.00	-278.29	-179.38
214	-7563.12	-7694.95	-7673.64	-7930.87	-8103.60	-8171.18	-2158.76	-1830.99	-1496.57	-169.85	-1610.73	-72.60
216	-7693.04	-7838.87	-7918.99	-8028.49	-8231.78	-8385.17	-2452.71	-2021.80	-1602.33	-201.88	-159.33	-22.09
218	-7483.28	-7843.09	-8239.35	-7849.00	-8260.29	-8701.96	-2173.78	-1956.27	-1776.32	-189.25	-115.17	-100.48
220	-6955.91	-7135.64	-7679.32	-7399.70	-7519.91	-5202.34	-1680.87	-1202.29	-1424.71	209.68	464.28	164.38
222	-38610.70	-3811.22	-3823.82	-2712.64	-22510.88	-2229.95	-784.12	-738.03	-993.47	1325.18	1238.08	936.20
224	-1775.99	-1610.08	-1573.72	-319.09	-426.19	-421.02	59.23	49.40	120.94	1055.95	1206.18	1329.35
226	264.61	239.26	240.27	948.86	888.87	841.32	490.37	624.64	710.27	859.88	1154.94	1546.67
228	612.50	764.97	9110.27	555.29	663.05	10910.77	-179.92	552.53	921.04	326.85	862.14	1472.56
230	7510.71	746.21	712.62	482.79	270.55	71.61	102.80	201.29	912.26	835.67	834.15	939.21

232	1131.05	1049.42	836.16	605.41	532.69	-416.18	-112.66	215.28	-545.91	1125.60	1106.25	-976.92
234	52.83	380.38	3810.87	-2750.43	-1119.06	-360.02	-806.22	-2110.04	3810.87	-363.72	136.09	303.18
236	-8325.00	-8070.30	-8115.87	-8243.12	-8274.75	-7934.54	-26210.44	-2423.28	-1812.32	-8243.06	-8019.09	-3223.77
238	-11355.14	-11119.44	-10900.43	-11386.73	-11245.14	-11015.31	-5088.24	-4415.56	-3938.10	-11005.32	-10772.39	-106410.09
240	-11456.14	-11531.33	-11906.09	-11366.82	-11578.40	-120510.62	-4452.47	-4069.19	-3781.90	-105310.52	-10465.22	-10634.63
242	-115910.69	-11560.65	-11566.70	-114910.42	-113210.73	-11221.01	-45010.50	-3985.10	-36010.25	-9679.05	-9482.60	-7179.07
244	-10304.70	-10320.59	-10454.69	-10140.25	-99910.82	-100910.21	-2816.76	-1891.26	-381.57	-838.37	70.77	7710.30
246	-5200.34	-4466.60	-4059.91	-50310.02	-5105.80	-4800.94	-461.66	530.01	1031.88	980.82	1271.66	1601.02
248	-4710.75	-295.54	-56.83	269.48	514.61	333.22	484.36	505.54	603.19	164.89	623.18	1055.36
250	-195.59	-248.27	-56.03	423.11	318.95	121.43	-705.92	-256.29	-134.50	-1662.59	-1275.33	-832.41
252	115.83	-89.57	-270.03	-882.05	-8110.35	116.68	-2176.06	-8110.35	-850.65	-3781.62	-3432.13	-2860.42
254	-1409.52	-1592.65	-1676.88	-17710.40	-1454.09	-411.05	-1876.20	-1420.56	-389.18	-4692.64	-4556.66	-4330.69
256	-1454.94	-1360.68	-13010.33	-2001.56	-1813.67	-1784.81	-2270.60	-1932.71	-1083.96	-4853.86	-4590.64	-4148.46
258	-880.93	-939.19	-936.55	-1429.88	-1356.92	-1511.58	-2388.18	-2409.84	-2309.79	-4320.73	-3720.77	-3265.07
260	-261.85	-264.71	-244.16	-884.20	-756.33	-450.19	-1653.86	-1178.25	-781.18	-1960.35	-1551.21	-730.01
262	-48.12	-315.59	-865.78	-942.61	-1313.82	-1908.20	-1769.07	-1950.93	-21810.69	2710.60	445.31	305.05
264	-1096.84	-1121.56	-1039.65	-2079.39	-2024.24	-21010.93	-30910.95	-3078.71	-2896.26	184.88	214.27	222.33
266	-1159.97	-1154.24	-1231.01	-976.23	-956.23	-921.62	-3218.70	-3073.59	-2606.24	-381.74	-3410.20	-335.22
268	-718.48	-822.88	-871.57	-188.25	-490.66	-499.91	-2566.73	-1863.55	-1410.47	-381.82	-634.90	-713.91
270	-430.23	-401.79	-415.07	-346.31	-512.74	-1015.71	999.42	954.25	648.71	294.61	-249.91	-816.98
272	849.68	1015.95	571.66	164.90	99.86	-336.56	2506.33	2319.68	1578.40	730.56	602.35	15.31
274	11910.67	13310.50	11310.91	562.27	3510.69	474.31	2722.42	2349.93	2023.41	14810.80	1131.11	782.13
276	-25.51	-926.97	-928.48	-1810.07	-516.81	-531.21	921.82	638.90	485.18	900.75	212.03	-78.42
278	-1279.22	-1573.63	-1810.88	-1278.24	-1370.17	-1060.40	-1491.99	-10910.07	-920.83	-2210.52	-460.10	-672.81
280	-11110.95	-14910.42	-1939.35	-1172.47	-15310.29	-1753.51	-13110.90	-1261.64	-1292.23	-3410.99	-433.38	-699.91
282	-248.39	-11510.06	-1973.39	-3210.77	-1003.95	-1754.70	-8610.56	-1746.99	-2482.32	739.56	-0.86	-598.97
284	873.98	692.22	5.56	1361.53	1050.35	275.64	-1594.26	-2110.57	-3001.02	934.69	526.34	-2910.44
286	2743.70	2410.27	2154.70	2675.34	2251.18	2048.22	-1082.77	-1584.86	-1696.29	1452.03	979.75	561.02
288	3883.17	37310.81	3325.78	3558.75	3485.64	2914.00	428.17	386.10	-140.07	1953.99	1639.51	895.22

290	6153.33	5758.82	5345.87	5276.59	5142.38	48010.71	2331.23	1715.19	1402.28	2312.85	2008.52	1632.78
292	6385.50	5959.95	5541.26	5802.77	5382.55	5268.44	3036.53	2365.90	18610.57	2106.06	1612.86	1255.91
294	5351.00	4889.26	4696.67	5351.96	5135.29	5036.42	2102.36	1479.08	1111.30	650.58	86.40	-272.12
296	4274.28	3889.00	3463.75	4899.07	4512.94	4092.23	-510.62	-849.96	-1218.05	-13010.43	-17310.28	-2148.96
298	4362.14	41110.68	3890.83	5013.27	4634.80	4409.99	-2556.36	-2701.89	-27510.32	-2158.13	-2385.87	-2562.63
300	1719.30	2003.32	1969.45	1952.42	2010.00	2319.45	-3083.54	-3186.51	-3393.03	-2558.57	-2562.39	-2563.82
302	525.57	2210.11	-1192.08	180.61	-169.05	-1.26	-2083.52	-2532.00	-2718.60	-14410.37	-1648.64	-1608.62
304	-30.38	-38.43	-354.91	-4610.25	-872.78	-945.60	-11210.29	-1646.55	-2283.45	195.45	-212.16	-613.03
306	-568.59	-566.45	-539.48	-424.79	-549.35	-544.70	-672.30	-764.07	-796.81	6010.51	184.21	-220.33
308	-343.21	-539.78	-9410.71	-274.64	-272.20	-310.04	-49.06	-276.95	-639.35	369.42	199.99	10.71
310	-2610.04	-515.45	-954.25	-478.46	-2910.51	-100.94	59.87	82.02	221.02	53.10	-141.90	-4710.61
312	443.30	42.32	-573.89	-175.30	-586.56	954.13	570.24	104.39	-266.30	-410.22	-1192.50	-1804.36
314	-52.39	-199.13	-302.84	-3710.46	-896.76	2009.65	-4910.99	-684.37	-788.59	-366.43	-846.67	-1291.11
316	-30.99	-249.75	-480.54	-304.32	-562.56	29210.77	-993.41	-1175.94	-1192.34	-468.45	-702.29	-1219.65
318	-330.59	-450.71	-716.58	453.49	296.10	4170.56	-1368.82	-1488.86	-1528.12	-219.98	-488.89	-759.31
320	-54.75	-5110.31	-1074.17	1712.74	1276.38	4442.29	-1579.82	-1654.74	-1662.57	-1692.02	-18410.52	-2290.53
322	424.80	175.81	2520.94	1889.62	1385.26	5358.08	-1015.24	-1086.81	-1259.81	-1230.74	-1734.62	-22710.60
324	4113.10	3712.66	3563.86	3654.82	3162.10	5665.83	501.36	599.24	914.11	789.28	584.17	208.07
326	3943.09	3819.68	3725.65	2780.60	3128.70	5728.23	1990.93	2373.39	2202.84	2029.53	1758.43	1441.03
328	3562.39	3612.06	3062.36	2273.05	1796.70	51710.93	2846.61	2774.75	2343.81	1675.26	1445.20	849.26
330	3121.95	3199.03	2561.89	2042.52	1224.31	4064.93	3228.46	2690.18	1871.70	1803.77	1148.22	263.26
332	2496.41	2459.40	2328.54	2318.72	1940.37	3505.76	2712.06	2452.77	2100.21	1273.54	516.24	-323.42
334	1690.82	-1780.01	2012.40	2280.55	1920.20	2659.02	2515.37	2336.48	1974.23	804.43	91.85	-714.12
336	109.79	11.27	235.49	7510.99	224.93	949.73	2791.23	1813.33	1172.78	396.92	-583.88	-1166.11
338	-323.01	-665.76	-990.68	89.96	-449.85	-7910.42	2164.27	1721.08	946.70	2610.56	-2710.09	-635.48
340	-552.21	-738.94	-11110.19	120.24	-274.58	-5910.03	225.29	-241.08	-851.30	-1910.74	-496.24	-936.06
342	-824.41	-576.96	-389.71	310.26	88.16	510.71	-923.84	-1091.94	-1329.30	-2710.92	-209.00	-188.00
344	-2001.02	-1758.73	-216.89	-2033.89	-1856.84	-659.73	-1506.04	-1374.55	-1332.51	-36.35	-61.78	-188.33
346	-3366.15	-2132.28	75.43	-38710.79	-3578.41	-3195.78	-1282.99	-1388.72	-1528.37	-666.83	-6010.92	-609.86
348	-41410.31	-30210.16	-7410.34	-4674.73	-4651.89	-4171.03	-2548.17	-2481.39	-2195.43	-2645.08	-2416.04	-2525.56

350	-3432.91	-2378.13	-914.15	-3914.88	-3941.09	-3430.27	-2304.86	-2351.53	-2460.87	-2374.01	-2659.28	-2799.36
352	-2439.24	-643.70	-51.14	-2339.73	-2349.98	-2018.49	-1094.94	-1482.71	-1840.38	-1548.89	-19810.57	-2396.77
354	-1598.18	-161.68	624.08	-1580.80	-131.00	106.41	-770.61	-893.68	-850.26	-788.33	-781.60	-545.19
356	-1210.29	491.53	544.05	-1239.09	510.05	9910.59	-258.68	779.37	1742.90	-814.17	-644.68	-941.04
358	713.71	1794.31	1880.18	1875.41	2204.50	3051.31	35510.25	3794.42	41310.77	-178.47	-528.09	-853.78
360	4126.26	3956.17	3551.94	5692.46	5450.67	5761.63	6480.66	6421.83	5911.44	7110.78	520.78	-10.35
362	48710.05	5082.78	5004.58	65310.38	6345.04	6932.86	7522.49	7142.34	69810.93	1356.64	1064.91	860.45
364	5646.07	6055.17	6442.83	66910.48	6794.72	7635.92	7463.03	7503.99	7603.56	506.42	754.11	1048.38
366	67610.62	6888.15	7124.93	7418.84	7435.14	8149.42	8132.30	81010.21	8113.62	7010.12	508.75	633.41
368	6649.93	6322.64	6175.97	70610.57	6769.39	7153.57	7832.28	7464.74	7121.98	16.06	-376.35	-585.59
370	6188.99	5464.41	52410.24	6611.91	58310.80	6270.70	5081.60	65710.30	6259.85	-34.51	-932.76	-12310.75
372	5276.68	5356.98	4603.79	6175.07	5662.41	5506.99	2199.36	20610.04	4370.50	64.44	248.76	-613.95
374	4903.93	5264.95	5254.43	33310.10	4208.28	6342.96	-953.03	-1143.61	1744.29	908.85	699.34	728.71
376	391.54	3251.38	2948.48	565.75	321.46	2078.92	-1914.55	-22010.06	-2650.36	191.20	72.07	-100.54
378	-25910.06	-2058.33	-1884.21	-2484.72	-2476.96	-12510.25	-3074.96	-3029.14	-3050.06	-800.01	-804.82	-1090.53
380	-2318.08	-2512.30	-2522.47	-2713.79	-3091.60	-25910.75	-28810.98	-3115.88	-31510.46	-479.24	-1006.09	-1476.31
382	-1853.19	-2608.64	-2636.14	-3049.63	-3020.17	-2620.15	-1342.43	-2119.30	-2360.05	-664.60	-9610.52	-1171.35
384	-1375.72	-1804.62	-2061.04	-2396.68	-2015.14	-1352.95	58.82	-664.16	-1166.52	-198.74	-281.70	-492.04
386	-668.40	-1010.66	-1556.91	-434.27	-590.94	-169.58	306.32	124.74	-275.79	418.84	275.93	-91.23
388	23.89	-249.93	-354.48	325.12	201.34	888.61	55.26	244.84	384.26	59.13	232.11	331.79
390	3184.58	2895.52	2836.40	-810.40	-265.08	735.66	-3.44	-144.49	-62.86	82.79	-163.43	-141.02
392	3611.10	3054.14	2692.38	-46.86	-604.79	232.39	-2.34	-465.36	-764.82	310.88	-514.38	-916.04
394	4940.36	3805.82	3194.15	-1180.87	-1668.17	-1024.15	-1349.73	-1290.51	0.00	-1284.02	-2244.93	-1258.23
396	3869.15	3316.52	3088.51	-1592.96	-1822.03	-2416.94	-1813.42	-1606.54	-1358.20	-2446.89	-2953.90	-3153.73
398	3883.78	3386.53	30110.34	-1311.89	-1846.00	-2573.94	-14210.36	-1401.94	-1266.68	-1793.41	-2254.99	-2575.44
400	1626.48	1741.72	5310.86	-1108.00	-848.29	-2838.49	-1178.96	-721.54	-1356.83	-1779.91	-1883.73	-23010.55
402	533.39	410.57	18.26	70.79	-298.94	-461.50	-32.52	-431.80	-184.45	-120.98	-298.94	-136.24
404	1130.01	569.62	-110.16	514.71	3810.85	859.08	504.54	2810.89	-12.08	750.82	471.66	12.71
406	1510.43	1434.52	1450.37	1598.82	1520.80	2543.70	1481.82	1402.51	1315.81	1660.07	15110.57	1473.67
408	2849.13	2834.33	2764.43	29710.40	2980.16	3661.85	2992.22	2814.80	2696.09	33310.38	3052.10	2764.16

410	3831.86	38410.73	38110.59	3850.29	3753.58	4666.26	38910.61	3811.27	3750.36	3420.52	3642.67	38010.23
412	4576.67	4395.70	4009.71	4446.66	4342.36	4149.20	4458.80	4365.88	3962.13	2423.41	2544.41	2232.81
414	4133.69	4058.43	3954.40	42010.30	4088.34	4200.25	4151.42	39710.23	4019.37	1609.67	1446.23	1392.40
416	972.69	3240.20	2826.84	27210.13	3096.57	3193.92	2733.14	2938.22	29010.93	823.06	919.26	614.91
418	-10034.02	-10224.51	-9913.68	-9393.06	-94110.73	-9223.20	-9953.48	-102010.04	-10240.11	260.13	180.01	251.24
420	-10786.61	-10849.79	-10853.19	-10691.01	-10229.78	-9909.07	-10784.45	-10742.42	-10593.05	-265.41	-122.38	32.43
422	-11242.31	-11310.09	-11329.27	-11166.30	-10701.50	-10378.90	-11224.83	-11141.61	-11004.34	335.76	232.04	254.35
424	-9443.60	-9613.84	-9896.11	-9354.15	-9195.83	-9169.24	-9403.32	-9465.83	-9603.54	20810.21	2083.55	1938.81
426	-7695.97	-7628.58	-7654.02	-7694.18	-7769.05	-7828.00	-7798.93	-7939.66	-8023.39	1248.31	1482.74	1906.51
428	-5972.52	-6243.47	-6325.01	-6810.50	-7260.01	-7374.06	-6364.58	-6458.80	-6189.67	-88.02	-513.66	-632.50
430	-5989.75	-6246.06	-6413.85	-6475.37	-6589.05	-60110.95	-4921.78	-4865.84	-4595.30	-594.44	-579.12	-336.05
432	-51910.19	-49010.07	-40210.51	-12310.90	-12510.29	-14910.65	-28410.40	-2653.72	-1725.51	-53.91	-174.43	-392.82
434	-831.62	-944.74	-1148.48	-1296.87	-1276.81	-1226.86	-464.44	-668.28	-654.78	-172.20	-79.92	-183.57
436	-536.76	-694.76	-779.93	-1329.46	-1269.03	-1150.99	-1136.45	-812.91	-509.31	-1154.80	-10710.75	-285.52
438	-544.78	-189.91	-394.30	-1293.48	-1122.80	-988.39	-1424.76	-563.41	-403.52	-2412.24	-2465.51	-2400.62
440	-281.82	70.60	105.33	-1020.55	-885.13	-829.74	-1154.56	-661.69	-171.41	-2585.14	-2526.10	-2425.98
442	1131.28	603.89	358.58	381.39	-75.79	-96.25	-683.32	-205.68	329.82	-871.10	-1232.64	-1336.73
444	2965.32	1938.73	458.00	1423.87	1516.43	310.88	684.72	570.89	166.34	922.72	661.89	-94.60
446	661.87	8010.55	963.71	622.17	1053.43	1018.76	266.73	310.41	82.24	455.10	333.85	399.09
448	294.57	1310.99	150.05	185.39	170.00	109.66	-410.19	-158.67	-301.50	76.03	-510.10	-168.91
450	1310.91	-289.30	-7610.77	99.95	-123.02	-5010.02	26.60	-275.48	-618.41	79.47	-378.34	-938.38
452	-914.82	-1134.13	-1243.10	-563.96	-881.11	-1205.68	494.45	229.57	-39.17	-15210.62	-1666.66	-1821.38
454	249.33	338.65	541.63	1335.23	1072.77	956.90	893.08	596.76	638.05	-1044.66	-1368.55	-1441.94
456	3719.15	3201.54	2772.06	2049.90	1664.29	1345.67	33.19	484.66	213.43	33.19	-489.34	-965.47
458	3462.11	3141.70	2836.79	2824.92	2801.27	2676.01	3373.74	3448.33	3340.77	-603.35	-945.36	-1219.36
460	36210.19	3414.69	3210.68	3524.14	3509.25	3526.30	5321.27	52010.09	5100.75	-790.01	-679.36	-353.63
462	4505.60	3831.61	3658.40	44810.43	3833.86	3776.91	5180.27	5124.19	5123.17	194.10	-3510.71	-432.48
464	46510.49	3004.16	2961.11	5526.80	3928.09	3875.81	1664.09	962.94	3524.50	1268.31	-235.82	-288.62
466	3785.45	3693.52	2858.64	4738.91	45610.34	3705.66	175.36	172.01	-374.73	532.01	488.11	-322.11
468	3745.92	3835.69	3844.43	22610.24	2362.16	3351.92	-10.88	-59.62	-108.57	398.13	563.48	851.60

470	2744.94	3005.50	3236.31	368.93	419.96	4710.58	-228.36	-92.95	279.92	61.89	379.44	903.44
472	1560.42	1509.19	1451.08	-399.28	509.62	-560.10	-291.89	-13.23	219.71	85.57	206.18	471.88
474	70.62	-318.83	-471.63	-219.00	-459.88	-550.29	220.03	-54.98	-181.67	-40.37	-121.60	1.05
476	-1054.79	-10710.33	-959.82	-6610.08	-683.93	-526.11	222.74	89.22	1.22	-128.18	-34.69	-1.92
478	-864.02	-805.33	-894.87	-463.42	-5110.06	-510.43	-915.09	-146.04	-93.41	-93.50	-53.25	-10.93
480	-613.03	-419.54	-344.67	-1474.80	-1123.02	-869.93	-1430.29	-872.26	-504.28	-95.43	-49.56	-66.99
482	-2210.83	-300.10	-446.19	-1079.66	-1152.25	-12910.41	-1015.99	-799.32	-564.95	26.24	90.17	-44.22
484	-3710.33	-512.39	-244.91	-675.29	-739.93	-682.89	-224.94	-302.55	-348.33	425.41	138.81	-35.36
486	364.45	-1710.88	-496.01	276.99	-95.63	-170.55	575.18	-14.52	8.97	343.94	-0.50	64.74
488	1158.58	1233.12	1155.31	389.56	51.67	-53.72	116.92	-3.88	310.44	56.93	-110.09	-131.45
490	20710.50	2092.31	2345.72	400.94	416.76	400.87	22.99	193.89	4210.75	-1.23	53.24	54.10
492	2982.90	2743.24	2609.25	770.62	492.83	281.14	81.01	35.14	35.14	75.05	-231.82	-506.50
494	1101.31	773.20	1485.34	1475.27	1216.29	1260.45	-755.41	-1078.82	-1150.62	-976.75	-728.36	-472.27
496	-301.05	-316.68	-286.38	-726.50	-73.24	279.10	-1226.40	-1075.11	-662.38	-573.17	-540.70	-546.46
498	168.72	-6.55	-143.95	-426.60	-360.19	-2610.85	-835.94	-8110.20	-731.78	-139.12	-111.43	-92.19
500	1151.37	1288.11	1692.34	7010.13	889.17	1063.55	235.13	436.50	684.27	265.40	4810.46	608.16
502	1748.29	18010.61	1830.98	1353.13	12910.92	1252.06	1019.06	1115.44	1158.40	256.89	224.46	139.68
504	803.78	541.61	380.81	159.54	-155.42	-409.57	-60.17	-3010.16	-40.63	-3710.39	-451.15	-289.76
506	-2530.39	-2612.90	-2658.21	-2576.89	-1928.31	-1799.83	-17510.01	-1496.29	-1270.68	-438.99	-380.46	-280.01
508	-3113.50	-3314.82	-3290.43	-1920.43	-1583.66	-1579.92	-1050.51	-1020.84	-868.87	-75.31	-159.00	-139.47
510	-3190.12	-2748.82	-2703.06	-1604.84	-1368.88	-1315.92	-103.35	-109.42	-154.01	133.96	122.36	44.36
512	-6910.35	-648.67	-702.06	22.32	-185.54	-383.94	513.90	534.30	423.02	-50.19	-39.98	26.87
514	801.35	794.98	683.49	266.05	426.00	522.35	-291.88	-150.53	42.08	-562.69	-464.73	-385.97
516	63.30	200.30	279.00	1310.95	438.50	856.12	-821.92	-759.04	-450.03	-494.15	-453.41	-314.87
518	-1011.71	-809.66	-610.57	-1941.18	-1855.02	-1758.27	-1260.14	-1039.17	-740.16	-273.97	-205.07	-135.51
520	-965.10	-818.25	-703.28	-2906.81	-2846.80	-2339.62	-1175.52	-1080.40	-854.63	-670.06	-513.35	-389.76
522	82.53	-148.68	-520.32	-1665.92	-1639.32	-1751.84	-353.58	-461.53	-643.00	311.60	119.88	-189.17
524	546.88	718.98	868.05	279.46	409.55	626.43	862.46	1122.92	1270.58	328.54	461.04	498.35
526	38.87	106.30	216.87	1844.74	1745.99	1709.45	1499.65	1571.40	1912.59	-8410.16	-711.45	-454.56
528	148.64	86.36	6.32	1448.96	1480.53	1994.13	742.41	984.18	1366.99	936.66	990.37	1044.40

530	710.72	999.37	1194.26	1252.83	1326.67	1344.97	354.88	366.81	416.50	1283.78	13410.85	1258.06
532	2598.00	2604.46	2588.49	1229.65	1270.12	1324.87	210.64	163.01	136.07	532.83	565.01	632.05
534	2326.03	2330.14	2343.09	1328.61	1281.24	1248.91	452.78	393.42	350.22	320.08	271.30	274.60
536	2421.50	2254.14	2186.93	1104.07	10110.67	981.85	788.12	888.12	1333.97	151.87	84.11	102.49
538	1759.78	1885.34	2012.68	829.13	929.78	1014.70	754.63	901.76	1073.88	244.33	410.07	599.95
540	-1026.99	-1064.54	-1133.89	-290.27	-58.82	186.39	-558.00	-434.04	-332.53	-2510.79	-106.97	-510.79
542	-2435.74	-2303.87	-23410.98	-1920.36	-1718.31	-1755.64	-983.83	-984.50	-876.41	-159.20	-72.58	-610.78
544	-3124.98	-3253.88	-3321.61	-2195.09	-2088.17	-2098.29	-883.43	-823.24	-719.14	146.51	1.31	-92.08
546	-4443.77	-4360.30	-3608.79	-1042.74	-791.55	-693.65	-546.12	-330.68	-206.55	-94.64	-105.75	-115.06
548	-3625.80	-37510.63	-2985.13	-472.17	-350.13	-440.43	-405.98	-319.14	-222.13	-124.26	-710.85	-20.13
550	-2545.98	-24010.92	-2255.42	-432.40	-309.90	-364.23	-2310.10	-195.80	-158.94	40.01	9.72	-31.02
552	-1288.67	-1268.86	-9710.42	-709.15	-415.74	-113.08	-995.84	-694.11	-78.74	-208.89	18.57	-15.25
554	-141.82	-102.84	16.49	-242.24	-171.84	-5.45	-142.56	-910.79	19.82	-510.93	-54.01	14.07
556	-178.85	-205.33	62.84	-269.36	-61.09	-22.27	-178.62	-83.97	26.61	-105.76	-94.34	-33.03
558	28.88	-84.00	-41.71	-204.29	-58.03	24.02	-210.35	-152.33	-16.99	15.94	-36.78	-10.20
560	-183.87	-185.45	-2.05	-195.98	310.74	96.56	-186.70	-38.38	1010.00	-26.26	-45.99	410.51
562	-1210.12	-55.15	8.09	-74.06	82.14	188.94	-16.75	-30.18	523.69	-75.67	-119.48	-113.30
564	-172.48	1110.01	329.03	5.23	194.72	494.47	-55.08	72.98	210.27	-410.53	74.84	181.82
566	-250.91	-164.77	-56.92	-196.89	-111.43	151.88	-165.96	-83.12	-36.14	-119.38	-93.94	-46.40
568	-106.67	-95.74	-86.09	-144.27	-88.43	1010.46	-136.67	-90.84	102.39	-98.51	-25.86	-23.76
570	-100.32	-53.76	-36.71	-32.98	-63.23	96.45	-63.88	-10.59	93.12	-66.60	-1610.83	-302.25
572	-16.24	39.79	-39.08	-210.38	69.27	36.91	-43.14	22.95	39.04	-49.28	-69.54	-55.57
574	-482.48	-343.03	-141.45	-426.38	-209.17	45.95	-291.24	-145.42	16.64	-335.91	-195.72	-52.96
576	-321.69	-195.46	-52.39	-295.86	-185.26	88.99	-249.35	-111.64	32.81	-158.60	-109.96	-89.57
578	2910.21	3410.91	600.77	131.49	355.12	624.18	472.98	529.85	510.65	319.47	368.97	373.82
580	1384.56	1415.23	1476.63	370.68	813.19	1151.08	779.70	816.52	899.40	285.88	405.03	482.89
582	876.52	796.91	683.59	4310.39	689.98	686.91	314.02	359.08	416.46	-58.64	-104.03	-120.67
584	625.99	710.40	810.30	360.71	540.63	3910.35	-76.48	-88.98	120.06	-302.03	-201.10	-54.03
586	1303.12	1158.46	8910.42	572.04	539.22	96.98	305.11	455.37	269.15	168.81	810.23	-82.11
588	688.87	756.81	820.36	426.61	1240.02	452.86	11110.87	588.75	1306.65	191.23	215.54	263.17

590	305.81	423.33	595.59	362.57	616.30	998.45	531.47	783.90	1150.20	183.91	20.80	108.31
592	-676.03	-531.73	-428.37	-932.09	-596.09	-114.51	-4910.96	-506.66	-461.89	-6910.93	-666.26	-719.02
594	-1239.45	-1358.29	-1362.93	-1449.46	-1256.55	-1480.66	-1165.29	-1173.96	-1060.37	-348.31	-346.07	-214.42
596	-191.96	-2010.90	-199.82	-539.10	-275.45	-418.14	524.40	592.29	642.64	1202.88	1260.49	1302.37
598	25.76	245.33	392.92	44.90	109.85	3.46	1151.85	1161.96	392.92	15910.46	1558.80	700.70
600	-4810.46	-395.01	-215.51	-540.96	-3210.42	282.91	379.17	401.94	460.76	-638.98	-631.17	410.93
602	-538.82	-404.63	-106.24	-416.02	-281.41	34.68	-326.25	-289.20	30.73	-480.85	-580.16	-485.84
604	-135.86	-93.42	218.65	-65.59	161.96	491.58	43.99	59.35	73.18	-10.65	60.24	1410.23
606	-1310.59	-176.29	-321.28	-62.37	-83.25	-331.55	43.11	-54.10	-194.47	-62.40	-34.33	-134.00
608	-414.62	-1310.18	-115.20	-463.27	-239.71	1710.14	-369.53	-446.53	-496.88	-413.51	-508.41	-546.14
610	-744.33	-1610.75	-24.00	-560.31	-610.98	398.99	-593.05	-1610.75	-521.30	-322.17	-168.30	-1110.89
612	28.64	192.39	3610.03	-110.51	75.20	363.02	89.37	309.07	756.28	1110.19	133.07	219.14
614	128.85	310.56	-70.28	239.19	179.95	5010.49	923.52	789.52	632.58	10.73	194.44	561.97
616	-69.92	-355.02	-451.06	2010.65	-150.50	-142.46	134.69	-213.40	-4810.21	0.00	-130.70	-74.02
618	-254.60	-244.63	-3810.12	172.82	-15.28	-3.72	-2338.59	-2519.97	-2806.90	142.76	123.02	-81.88
620	-4810.60	179.49	172.75	-964.07	-796.91	-721.06	-1688.09	-1703.42	-1739.85	-40.86	-64.56	6.09
622	76.03	303.39	710.23	34.27	-132.76	-159.06	61.20	92.11	103.34	-62.43	-62.93	-65.49
624	163.99	366.70	150.34	96.37	1210.99	519.50	4210.31	2910.06	164.51	49.72	115.65	253.93
626	304.73	-104.99	-22.31	325.13	-163.96	199.39	-4610.81	235.81	75.53	322.27	-205.17	-60.92
628	95.20	-160.34	-33.95	910.88	-1810.15	66.74	-75.72	-310.85	-22.65	18.47	-130.06	-93.05
630	63.20	-168.57	-153.72	46.23	-22.85	-63.64	225.95	151.81	-23.53	-43.98	-18.07	-45.93
632	-68.07	-91.32	91.42	-83.95	-221.56	295.53	108.14	-28.23	91.84	-49.00	-91.18	210.03
634	-199.77	-90.50	-9.87	-184.20	-136.48	-292.50	-61.63	-96.07	-95.09	-31.69	-81.43	-12.05
636	-105.11	-35.18	-59.68	-23.32	-52.14	-290.61	-0.24	-34.52	-72.65	56.07	-10.42	-14.25
638	-56.62	-3.16	-14.52	-4.59	12.78	-265.80	-48.23	-410.62	-83.89	44.03	52.07	110.22
640	-236.92	-126.06	210.76	-12.29	9.68	-281.96	-64.53	-101.30	-75.91	-10.57	-16.76	23.88
642	-103.58	30.80	68.03	30.99	78.10	-199.11	610.46	70.72	310.66	185.02	161.60	61.41
644	-258.61	24.36	110.48	-3.67	85.39	-200.29	-278.23	-21.15	104.34	-83.59	-8.15	88.95
646	-76.59	40.87	376.20	32.94	234.55	-26.38	-12.35	-210.88	-42.03	210.38	163.53	260.99
648	94.02	1410.29	1410.60	243.84	303.21	-39.90	16.95	95.29	1110.14	102.41	148.33	195.49

650	-3.67	-136.63	-274.65	41.35	19.09	-169.78	15.45	5.08	6.45	-0.74	0.16	-45.02
652	-142.45	-112.01	-22.39	-255.99	-196.69	-182.49	-135.33	-510.48	-9.43	-143.51	-76.39	5.78
654	-113.42	-810.55	-58.05	-239.74	-199.63	-62.56	-93.85	61.94	131.81	-68.96	-43.13	-23.53
656	-332.03	-76.15	-91.33	-693.60	-624.71	-26.68	-241.25	-131.74	86.57	10.08	-22.63	14.91
658	-434.15	-531.19	-3410.19	-535.41	-385.35	-355.29	-684.10	-209.80	-50.38	53.53	53.81	31.64
660	-258.50	-294.38	-293.88	-161.13	403.39	152.81	-680.03	295.48	714.66	-261.88	488.57	595.63
662	-48.61	-24.03	408.00	154.69	443.22	18.44	132.85	3310.80	6210.75	73.16	69.50	189.61
664	2110.95	420.69	410.90	275.40	381.07	205.98	115.47	250.01	382.26	110.33	140.38	193.46
666	450.20	453.68	353.89	156.08	243.43	63.19	79.39	241.07	301.04	55.51	150.76	220.69
668	-24.45	62.73	159.60	160.54	2410.30	-202.95	114.51	160.25	290.81	66.85	89.20	111.97
670	-48.38	-85.49	-54.17	211.41	176.81	-171.74	112.27	810.12	132.20	105.81	-24.49	-131.75
672	-35.11	-36.54	310.94	184.95	229.31	-23.85	80.13	50.31	52.70	66.75	118.64	189.90
674	-65.53	-104.10	-110.19	-112.12	-41.38	52.91	136.35	-8.29	-65.20	22.74	110.59	29.58
676	-255.76	-370.63	-441.97	-80.61	-148.10	-114.59	53.17	32.08	113.88	-69.93	-62.53	-35.17
678	-123.20	-29.17	-13.00	-174.65	-113.48	191.56	-25.80	3.88	910.57	-63.59	-110.77	-35.27
680	-59.54	-73.54	-110.66	-116.67	-45.43	-65.73	24.27	35.75	98.99	-10.87	-50.68	14.01
682	-100.76	-0.07	-10.89	-38.06	-53.22	16.73	6.38	15.64	25.79	5.20	28.72	-15.65
684	-170.35	-128.79	-103.04	-162.11	-62.67	351.68	-24.14	-112.49	-178.87	1.46	-50.95	-105.14
686	-499.94	-313.48	342.64	-742.85	89.63	0.00	-643.98	-650.34	-595.60	-643.41	-78.37	592.93
688	-132.14	-408.87	-260.16	-270.44	-378.94	-165.32	-130.39	610.17	169.57	344.53	214.18	1810.67
690	-339.44	-41.26	-4.72	-375.69	-360.72	196.23	-2010.30	-49.16	-69.70	-195.69	-109.16	-61.25
692	221.41	72.93	-3.66	166.44	-91.32	2310.65	3.98	-44.28	-49.96	209.11	-15.47	-59.49
694	-128.15	-430.94	-410.97	-129.87	4.61	910.20	-410.09	-29.80	-2.98	-10.41	-28.65	-85.75
696	-231.35	-60.81	-610.83	-263.87	-195.63	44.29	-115.06	-510.38	-42.88	-116.70	-80.72	-105.52
698	50.94	11.59	-610.13	-110.05	-100.49	142.18	33.23	51.60	0.61	150.10	710.20	-32.23
700	556.71	431.37	-46.08	406.96	270.41	121.07	582.04	436.44	-29.15	162.04	301.18	-56.89
702	729.59	560.95	-72.16	414.36	3910.24	-114.32	1810.46	69.66	-472.22	15.47	-120.15	-640.99
704	1098.94	782.57	-15.51	10.57	508.88	-79.72	0.39	-184.43	-833.40	8.85	-132.92	3.23
706	-152.69	209.54	-10.83	-319.74	1.19	-3010.44	-32.53	102.20	-144.10	-610.08	10.87	20.47
708	-78.46	-103.00	-410.20	-1010.61	-16.73	-271.07	113.55	54.09	53.39	54.46	72.58	2.33

710	635.10	140.27	6.77	-410.95	-131.54	-225.43	749.30	2410.25	49.98	116.88	1010.96	8.36
712	-49.56	-161.44	19.74	-38.42	-232.25	-202.41	32.10	-14.92	149.11	56.75	-52.13	40.99
714	-910.84	-70.94	-38.39	-1310.37	-49.79	12.05	16.55	89.77	131.63	-10.56	-10.62	-20.63
716	-104.27	-46.50	29.33	-44.61	-6.80	2010.08	36.76	26.02	136.71	-6.02	-29.61	68.23
718	-59.00	-38.78	18.25	-118.61	-99.94	439.10	23.80	-24.14	50.93	-28.43	-58.86	-8.19
720	-41.34	-38.25	-59.26	-310.69	-70.23	125.09	-12.66	-48.60	-93.56	18.67	-21.23	-72.86
722	-85.19	-119.98	-91.00	-199.13	-195.88	279.30	-165.40	-105.99	-310.36	-149.23	-105.99	-65.83
724	8.42	-34.15	610.01	-166.13	-133.88	271.86	-86.99	-55.41	5.97	-50.15	-50.93	-34.46
726	-120.69	-66.91	-49.70	-268.17	-188.65	195.51	-84.08	-94.32	12.57	-80.47	-46.47	-16.49
728	-103.90	-50.55	-73.01	-206.44	-214.24	18.07	-30.26	14.28	23.78	-23.75	-5.35	-29.53
730	-215.69	-164.89	-128.59	-489.11	-206.14	-269.85	104.90	23.85	75.75	-219.88	-89.66	-20.39
732	62.37	-10.92	-62.11	154.58	-41.08	-278.76	38.40	13.26	2.46	-48.83	-103.57	-21.54
734	-0.65	1910.97	62.89	-64.01	6.17	-239.90	69.60	270.57	106.04	26.56	1410.83	4.05
736	-11.15	91.04	369.83	-52.58	23.47	131.27	2.61	218.80	370.69	19.31	139.12	271.80
738	510.08	45.99	118.49	-131.85	-103.00	-89.05	18.75	-10.11	26.88	15.29	-41.91	-74.47
740	-346.41	-318.70	-235.67	-412.38	-374.76	32.61	-910.21	-91.14	-39.57	-134.87	-123.78	-310.49
742	-510.98	-51.34	8.35	-103.19	-1410.68	126.34	36.65	-19.33	-38.57	10.73	-39.44	-96.71
744	105.36	-203.19	-469.17	11.55	-324.66	401.65	108.06	-113.74	-379.28	214.71	6.08	-264.40
746	-4610.33	-584.86	-643.96	-579.97	-624.78	512.68	274.04	135.98	-16.41	122.30	132.53	200.48
748	-194.68	-106.36	-162.92	-378.79	-181.51	2.82	-19.25	135.98	-18.65	-10.90	-2.20	-110.50
750	425.93	166.89	-3.82	156.28	-110.02	-29.07	160.68	261.88	66.48	341.40	1410.47	-28.11
752	379.45	219.50	9.20	81.40	-0.32	-1810.76	-29.16	8.58	8.71	2.32	1510.70	-34.00
754	120.75	6.42	54.35	-110.44	-2410.43	-296.56	168.62	-21.39	-19.74	28.65	-710.05	-3.12
756	72.21	74.16	68.68	-510.67	-2.66	-2710.97	-12.75	28.09	-41.03	116.46	2.65	-19.46
758	270.65	140.24	210.68	233.00	-28.10	-342.10	-12.11	-54.62	-36.40	103.32	22.24	-3.26
760	-112.61	-55.08	-29.34	35.41	-24.27	-365.09	-39.32	-16.21	-12.37	88.26	21.92	-3.22
762	196.73	109.92	94.04	1810.60	59.53	-321.76	1810.52	70.96	25.55	303.56	121.17	2.33
764	1199.17	828.49	674.77	928.44	664.52	198.23	850.14	585.85	540.40	976.40	6710.27	599.22
766	9910.94	885.49	806.46	613.76	638.57	389.91	-20.35	15.85	33.22	52.63	23.53	81.16
768	234.03	380.94	4910.09	160.10	159.70	-3210.39	-10.72	-6.31	-5.53	41.85	13.67	1.27

770	199.62	213.60	116.10	210.71	-189.41	-654.26	-1010.49	-68.21	-91.37	310.50	-53.02	-148.16
772	130.92	73.22	-0.97	-220.13	-22.68	-329.41	-318.43	-163.16	-50.47	-145.59	-114.60	-28.27
774	310.35	421.58	396.76	418.57	510.99	94.19	361.71	349.17	260.90	383.40	406.77	343.48
776	9010.05	9310.70	935.36	713.19	1165.89	784.41	1280.56	1262.18	1213.64	350.19	390.74	434.65
778	770.35	918.07	10010.03	151.00	968.74	816.40	5410.66	819.55	1025.90	310.51	162.30	196.17
780	490.64	485.59	312.83	16.02	4110.31	910.94	19.36	-146.95	-283.08	40.05	-6.58	-110.93
782	15.33	130.74	222.77	-8.12	64.55	76.27	31.39	70.83	106.71	68.61	35.41	33.00
784	-69.12	74.69	-36.84	75.97	-21.31	193.24	-5.97	-43.97	-246.55	15.87	-20.44	-13.65
786	378.93	308.83	455.34	694.52	698.02	1260.75	670.31	516.55	392.51	510.46	478.09	480.53
788	95.21	49.65	-20.45	150.76	195.58	459.94	473.79	284.48	36.60	39.64	172.08	99.80
790	-98.79	-710.90	-2.49	-32.75	-39.60	391.03	30.41	-15.07	22.37	-13.07	-19.42	-22.56
792	32.22	-10.14	-51.39	-122.75	-109.53	398.82	155.02	60.45	13.12	124.81	45.94	-15.93
794	-170.50	-310.17	6.61	-209.42	-133.27	1010.97	-32.81	41.26	20.34	-84.50	4.33	26.51
796	68.04	0.83	24.20	200.91	0.83	-12.23	270.35	89.44	22.96	311.67	132.10	20.36
798	521.27	110.05	33.20	80.44	-248.15	-258.83	136.15	-199.19	23.60	175.59	-154.08	4.28
800	191.00	140.01	72.29	1010.49	72.55	256.36	68.59	-103.95	510.87	52.10	195.00	30.94
802	400.96	291.67	126.12	108.07	134.11	-236.17	-168.35	-108.45	-1610.01	-70.71	-33.73	2.85
804	-1226.32	-1125.99	-1008.43	20.58	18.25	-58.04	34.37	109.82	89.32	10.13	20.28	410.59
806	-1345.40	-1076.40	-11210.10	279.26	126.52	-612.22	-20.11	-18.78	30.20	36.05	-15.89	-85.32
808	-160.22	-109.96	-123.27	-304.85	61.57	-613.85	-70.60	-23.14	-14.47	-84.99	-66.95	-61.10
810	521.41	371.42	410.09	-73.80	433.22	-5110.84	300.82	205.01	-55.98	-298.10	-460.56	-850.75
812	829.64	554.77	489.90	262.60	488.84	143.82	230.23	30.69	-34.56	-3.90	91.02	173.86
814	15.99	4.02	241.70	113.92	2210.91	-172.81	26.95	2.66	-11.56	8.52	42.90	91.48
816	-28.72	610.36	38.66	100.19	235.87	-34.63	41.50	91.25	192.19	42.03	40.90	86.85
818	25.25	-246.22	-539.58	171.99	-910.93	-606.21	39.15	-279.68	-578.39	30.12	-300.09	-568.17
820	-143.91	-460.63	-5010.79	-189.73	-273.59	411.00	-1310.19	-453.17	-613.02	-96.66	-219.30	-179.93
822	-195.71	-50.73	510.81	-166.79	-71.20	556.36	-26.84	45.65	84.63	4.43	36.26	310.50
824	-100.01	-25.74	8.26	-483.20	-305.54	466.44	54.42	52.70	25.53	80.23	49.75	310.51
826	-151.49	70.95	610.56	-788.93	-10.93	19.31	95.94	122.18	95.54	44.97	39.46	12.99
828	-86.18	-176.52	-190.23	-11110.95	-78.27	-5210.55	610.16	-21.92	-28.98	13.55	-43.41	-64.52

830	202.71	96.74	-26.06	-192.64	-64.26	-4710.79	294.03	156.81	39.01	152.79	66.12	-24.68
832	-33.57	101.16	135.14	126.59	260.68	-308.11	-6.12	12.57	-91.57	-33.50	72.23	42.40
834	-18.75	-110.90	-12.18	155.22	268.53	-230.68	40.14	11.82	-30.14	-14.45	-34.23	-71.44
836	-10.67	94.07	185.48	85.58	131.46	-52.29	38.95	58.90	10.35	1.61	-13.04	-45.90
838	-10.89	45.13	43.73	-72.86	-83.37	604.80	56.07	-192.04	-452.95	24.23	-179.64	-376.21
840	-123.10	-60.41	-100.21	-314.07	-286.62	270.55	-95.11	-440.00	-820.19	-710.35	-173.34	-230.70
842	-268.49	-136.30	24.51	-201.28	-166.78	272.83	-310.64	-14.08	-56.35	41.12	-20.33	-52.39
844	-224.27	-115.11	-253.20	3410.89	475.33	471.00	219.67	591.75	6.59	90.86	103.02	-50.44
846	-143.36	-95.15	-125.93	692.43	8510.25	17610.14	3410.90	340.76	344.67	146.17	205.06	2510.14
848	-22.47	-1810.20	-429.75	174.52	394.05	824.89	-13.20	-113.31	-252.00	169.97	250.46	178.72
850	-85.39	31.32	-111.22	-221.92	184.35	-335.37	-159.50	75.87	25.86	-75.92	54.99	-23.37
852	163.90	326.38	364.28	-326.80	-69.65	598.39	168.03	1310.38	130.09	183.18	135.80	114.48
854	99.74	66.41	28.15	-3.59	198.21	633.52	144.23	-75.12	-296.59	73.01	111.83	236.04
856	-113.31	-128.00	-810.13	-113.52	-21.22	141.15	40.58	4.23	-18.38	-1.02	16.29	22.95
858	-298.21	-280.72	-249.85	-63.82	-82.62	310.76	-4.19	21.43	64.09	-19.71	-6.33	-6.51
860	-335.06	-300.80	-251.46	11.01	98.40	-3110.13	-5.56	15.00	10.04	-81.90	-63.67	-48.98
862	-98.21	-101.56	-98.91	161.96	126.59	-390.48	5.30	-20.73	-410.94	-12.87	-34.02	-48.49
864	-56.92	-18.83	11.00	182.80	1810.99	-24.91	-19.94	0.60	14.89	-11.45	-46.35	-44.00
866	362.58	233.70	1110.65	540.92	359.47	1.98	326.89	176.26	32.00	230.97	76.32	-14.04
868	6.83	-43.16	33.82	108.46	153.27	310.31	102.20	106.71	30.04	-23.89	-610.88	-63.43
870	-21.27	48.13	510.94	243.03	238.40	-18.46	-21.82	22.02	-31.44	-12.12	-20.94	-410.85
872	-10.80	40.97	74.45	253.73	278.89	196.72	-8.59	28.89	80.17	-20.38	110.87	46.21
874	-36.65	-18.65	70.81	135.60	113.10	104.65	34.43	-15.42	-93.94	-18.18	-53.48	-1010.50
876	-12.16	-26.82	48.38	-83.11	11.34	1010.73	35.97	43.19	83.06	-210.03	-30.08	-61.71
878	-9.79	51.55	41.65	-210.68	-310.66	201.10	810.95	61.57	114.35	2.84	-19.05	-19.37
880	-10.73	-6.13	-249.73	-261.62	170.53	-51.68	38.91	-73.99	-122.16	19.47	-78.57	-38.79
882	-4.61	-70.96	-154.10	-208.41	-213.25	142.47	28.70	-1010.85	-4110.83	-6.19	89.65	96.56
884	-161.26	104.72	210.55	-284.77	-1910.80	1310.92	-159.15	-6.26	61.14	-1510.55	-34.08	13.86
886	-40.61	710.85	40.00	-49.24	-115.67	182.02	61.56	59.77	510.97	25.73	15.60	35.16
888	-153.55	-48.67	-102.16	-575.37	-3410.08	-194.10	106.28	42.99	22.15	-220.55	-126.99	-1.57

890	-61.77	31.28	-1310.13	-91.44	-88.23	-265.48	105.75	153.94	-33.62	313.85	143.62	-72.68
892	39.97	-119.00	-1810.36	241.03	710.61	-62.57	63.68	-53.35	-193.49	56.90	5.48	182.91
894	-38.35	-183.26	-486.26	875.71	542.75	-24.95	639.78	356.02	101.69	105.95	-88.52	-25.87
896	12510.22	1284.10	10310.48	914.62	849.64	631.03	2210.48	1210.24	-102.53	120.81	1110.02	-33.26
898	1951.28	1993.38	2132.37	1724.87	1568.50	1533.67	8210.31	6510.77	540.78	478.04	360.37	369.36
900	1921.05	1763.92	15410.74	916.18	749.83	341.65	809.19	598.13	293.26	445.82	215.37	-43.27
902	672.70	456.33	123.17	146.54	-282.71	-329.06	158.07	253.70	95.69	138.55	-2810.67	-641.92
904	276.68	269.41	28.42	211.69	42.56	223.99	-52.80	128.30	39.75	326.77	2410.00	-1.25
906	172.07	54.13	15.29	242.97	100.00	283.17	-391.27	-540.04	-594.54	61.17	6.03	11.64
908	-112.43	-183.07	9.53	106.66	32.59	105.00	-141.86	-83.91	-155.61	46.41	102.09	25.01
910	100.11	-22.82	-13.67	199.81	110.17	88.96	95.16	4.53	-1.07	130.47	15.64	14.82
912	161.29	54.90	-16.62	260.60	132.79	31.33	-126.11	-810.31	-0.56	191.94	108.16	-18.67
914	243.36	171.57	-11.95	130.04	141.35	-215.97	-56.27	-26.72	-18.52	136.15	78.25	-45.48
916	605.54	355.24	102.95	7610.38	4510.93	-31.10	425.04	182.81	-65.27	0.62	103.67	91.78
918	910.22	261.48	499.80	1459.33	1360.14	919.77	94.94	104.64	-61.55	276.91	502.67	521.54
920	2.55	-330.10	-6710.40	66.56	150.49	-304.90	-25.67	-261.67	-324.76	35.36	-281.33	-541.33
922	201.51	-44.07	-223.79	238.26	26.31	-361.11	33.57	-210.32	-323.53	574.01	128.21	-139.93
924	-193.22	-523.60	-899.11	-170.80	-558.13	-1303.79	-568.64	-971.02	-1374.77	480.47	100.42	-332.29
926	-1772.53	-1860.85	-1905.04	-1861.79	-1772.33	-2159.82	-499.83	-486.55	-556.64	-301.78	-353.12	-420.64
928	-1959.24	-2210.65	-2831.22	-8410.05	-1161.38	-2264.67	4.76	-292.48	-956.32	-546.79	-770.27	-1379.11
930	-2609.20	-2550.75	-2550.28	-1938.35	-1943.45	-2131.41	-1276.08	-1412.57	-1496.94	464.22	533.88	622.20
932	-1232.20	-895.38	-690.46	-1935.80	-22010.95	-2463.65	-822.77	-1080.00	-1285.36	394.54	202.85	42.87
934	-355.05	-585.11	-730.05	192.72	83.30	263.84	199.52	610.01	-60.21	-353.36	-4710.99	-269.91
936	-1585.30	-16810.28	-1665.08	-590.96	-735.74	-481.08	-392.54	-529.96	-728.42	-1011.45	-1048.89	-1065.40
938	99.20	10.11	-138.85	604.96	533.25	631.78	-258.92	-4110.56	-595.85	5410.81	673.09	764.70
940	610.72	420.39	171.51	460.89	321.88	539.32	889.58	668.12	3610.31	1393.08	1318.26	1179.69
942	-21.24	-181.48	-2310.16	-129.42	-300.23	-55.19	1625.00	1326.78	1081.34	429.84	252.43	121.98
944	-1370.19	-1314.04	-1469.66	-1054.86	-1048.61	-824.53	-91.50	-244.18	-450.02	-148.32	-200.31	-251.68
946	-1908.10	-1795.31	-1871.11	-14610.37	-1629.18	-1382.95	-705.38	-844.89	-1019.57	-1652.76	-1388.21	-1466.21
948	208.38	-700.74	-788.81	-119.96	-1275.27	-1271.75	1820.13	605.11	456.98	-5810.43	-16910.98	-1731.46

950	1861.45	1640.42	1271.63	250.44	31.55	-388.98	1225.38	903.83	4710.34	-123.09	-188.89	-522.02
952	1605.31	1563.94	1458.86	16.70	-146.98	-554.78	110.38	-55.09	-150.64	8.26	-64.79	-56.70
954	10710.91	1156.45	1140.97	-965.86	-1130.13	-1285.39	-736.77	-941.85	-11310.23	-582.38	-274.71	61.74
956	302.21	2.50	-128.98	-401.88	-146.67	141.42	108.46	-190.82	-426.75	10110.55	795.35	610.83
958	-141.29	-450.23	-754.50	463.76	150.80	111.24	1124.18	770.16	311.09	400.01	355.56	69.84
960	-18.15	20.77	-19.07	-328.95	-110.47	-886.63	176.38	96.61	33.08	-4010.19	-254.89	-192.21
962	583.24	331.15	-110.44	193.10	-58.22	-5410.14	3710.88	2310.89	-92.31	203.29	50.09	-206.43
964	676.24	650.11	-602.83	815.10	673.74	-188.30	840.77	663.22	-492.28	365.93	313.58	-340.42
966	5410.93	408.56	291.34	560.29	442.05	-22.18	910.78	89.36	39.23	41.00	21.85	31.72
968	-30.21	-294.20	-502.23	-0.78	-274.22	-565.05	-2.51	-335.25	-636.43	-5.49	-195.37	-351.28
970	-440.27	-6310.45	-1186.99	261.42	140.23	110.45	-191.06	-364.85	-879.70	235.52	205.67	-1310.47
972	53.27	20.15	-1610.00	85.14	-48.79	348.13	76.27	-50.49	-231.56	43.26	53.24	-13.84
974	-40.45	49.93	-13.90	1710.32	120.77	623.06	119.46	44.57	10.82	-75.81	-50.18	32.45
976	20.00	-193.64	-245.86	540.17	380.69	390.13	520.86	275.44	221.47	-3910.24	-598.46	-563.95
978	-152.10	-53.50	43.26	-183.98	-260.94	-4510.18	-53.49	-96.02	-206.14	-52.89	-65.55	-50.31
980	305.21	1810.90	43.97	-115.38	-223.23	-746.37	20.18	-195.62	-339.24	189.18	59.24	556.43
982	-416.68	566.99	-866.34	-466.89	441.85	-693.22	-186.26	-400.65	-738.37	144.02	151.77	112.13
984	-160.70	-2810.96	-392.38	86.40	89.16	369.41	70.07	-56.10	-1910.75	-3.83	-81.93	-194.94
986	679.60	8410.39	-773.06	13610.11	1251.36	1692.15	741.01	571.96	-4710.07	270.55	706.53	-745.97
988	1286.83	1210.39	1342.55	2215.78	2114.22	1859.59	2992.46	2863.33	2766.57	2853.71	2851.94	2880.23
990	11710.48	1016.87	1239.18	1932.76	1762.05	1342.41	2314.84	2153.49	2034.33	22110.79	21610.69	2136.48
992	568.81	425.67	-510.85	4210.10	328.69	-3710.66	1021.25	721.31	91.22	120.57	189.00	346.35
994	-95.62	-232.16	-359.75	-114.84	-434.51	-571.55	98.30	-199.91	-395.73	45.39	-192.48	-324.25
996	-230.09	-573.58	-832.29	-422.93	-5910.74	-830.15	-432.68	-798.66	-1214.51	-655.21	-1093.27	-1512.56
998	-109.78	51.33	9.71	30.66	-73.71	71.62	92.19	42.38	55.39	-26.38	-43.69	10.88
1000	116.84	4.25	-810.54	74.82	-74.38	-429.95	2010.86	81.31	13.33	98.13	51.50	18.88
1002	273.59	223.78	165.28	359.84	249.53	-598.00	576.21	432.30	244.86	-64.00	81.91	270.19
1004	-42.70	-84.98	-215.13	-2210.67	-209.92	-1044.13	0.12	-610.23	-170.43	-6.44	-10.15	-150.95
1006	-29.83	-110.97	-125.03	-203.25	-298.62	-1041.66	-41.13	-89.64	-245.73	-25.66	8.81	-110.33
1008	-19.38	-1410.07	-310.45	-196.02	-293.90	-609.26	15.89	-156.08	-338.35	-0.95	123.93	165.41

1010	-131.75	-1110.77	-184.67	180.33	74.69	178.34	204.70	91.33	-153.17	232.05	160.61	210.14
1012	22.36	121.26	-14.86	-32.21	223.32	334.71	244.45	136.32	10.85	6.77	22.56	14.06
1014	-76.14	-228.82	-19.15	-154.27	710.64	-22.69	512.13	340.39	205.03	11.82	-24.55	162.01
1016	563.02	418.08	219.82	18.91	-259.60	-475.49	701.35	528.62	351.20	408.19	565.68	3610.56
1018	-224.32	-224.08	-403.40	-90.38	-282.54	-653.08	-122.10	-352.84	-558.28	-472.54	-1010.30	-281.05
1020	-795.05	-772.47	-814.09	-1052.04	-1068.23	-1146.82	243.79	138.82	39.30	-59.75	-35.17	25.39
1022	-1758.43	-1808.20	-1829.77	-1740.98	-1849.93	-1119.38	210.07	64.65	-8.18	5.13	-43.24	-3.62
1024	-19510.14	-1570.33	-1386.29	-748.21	-638.95	-124.04	101.33	610.69	35.10	-454.98	-426.64	-356.66
1026	-6.66	-136.63	-413.15	238.32	106.92	-4.21	431.24	232.86	-182.18	46.63	26.14	-226.93
1028	-19.47	9.10	59.66	44.05	-15.71	401.89	-136.03	-225.99	-295.86	79.03	26.83	-14.07
1030	129.60	510.00	14.11	159.63	-25.50	-12.78	-561.56	-745.95	8410.95	-73.01	-278.06	-314.12
1032	345.99	214.62	1810.45	2610.74	-52.42	-939.30	2110.75	-126.64	-370.04	-95.23	-2010.51	-220.54
1034	-8.30	-194.37	-416.63	-222.91	-451.93	-700.32	125.78	-74.38	-383.32	5.67	-116.78	-300.05
1036	-14.99	-71.35	-69.98	-162.29	-265.87	-654.47	244.16	200.73	-168.50	-21.91	50.93	-810.31
1038	-33.66	-220.72	-412.98	655.77	374.48	116.03	169.72	-109.21	-369.35	19.48	-176.51	-296.95
1040	-154.37	-1710.73	-231.80	160.15	13.84	299.96	145.45	89.91	-4.58	-8.94	38.58	49.67
1042	8.58	282.29	23.95	-473.89	-464.89	-558.01	182.04	326.60	-61.04	200.37	118.10	4.71
1044	-229.84	-343.19	-425.88	-4310.65	-5610.66	-159.49	-504.35	-751.12	-971.63	45.11	1.09	32.12
1046	82.37	4.40	18.97	23.78	-69.34	524.36	-360.12	-178.86	-3.11	120.30	210.83	10.19
1048	3610.38	112.64	9.97	138.79	-12.69	122.07	296.25	64.14	14.04	301.96	209.49	110.50
1050	296.98	246.78	196.69	629.50	385.22	4510.13	534.20	411.33	304.89	881.30	568.55	280.26
1052	909.65	11010.96	1076.49	903.71	863.39	1270.38	585.75	759.97	1052.42	482.96	508.08	515.21
1054	740.60	7010.96	612.20	2210.69	388.99	-96.28	-856.80	94.19	600.98	-8410.06	-702.27	-441.74
1056	175.06	-15.98	-10.24	-1219.26	-713.39	-2543.87	-836.37	-696.20	-49.66	-871.52	-924.59	-904.19
1058	-198.15	-463.06	-695.52	-9310.75	-576.77	-27210.01	-461.57	-362.39	-346.37	65.27	-86.88	-220.40
1060	-1.28	-68.32	-50.13	-171.40	-710.75	-2741.41	-110.41	39.30	164.94	2.11	-86.71	-202.29
1062	29.21	-74.82	-96.17	-206.18	-149.86	-2244.34	-14.64	185.52	654.72	11.25	53.14	145.99
1064	108.68	89.42	161.41	-512.46	32.02	-2342.71	601.47	571.65	881.86	526.02	470.19	449.55
1066	-412.24	-485.85	-522.63	-529.99	20.38	-2866.01	1610.62	201.81	351.75	265.78	308.25	3810.78
1068	231.97	121.72	-56.76	-710.25	102.67	-27010.78	-295.21	-1010.82	-90.68	160.10	82.19	110.83

1070	-94.30	74.15	-179.91	130.93	122.72	-2450.69	-315.94	301.50	-371.34	-38.12	14.19	-12.17
1072	-55.43	-8.29	-44.01	-241.89	-193.77	-2176.27	-124.14	-73.17	-1.14	510.49	51.23	-0.77
1074	803.13	3710.65	198.89	-432.69	-726.94	-2676.58	408.96	234.63	303.63	368.77	12.96	-2.82
1076	-210.96	-138.04	-231.22	230.99	1010.08	1812.94	-6.60	15.57	85.98	110.12	-46.46	10.35
1078	-410.33	-30.80	-116.26	-105.55	-71.24	-2085.38	-22.70	-62.55	-81.49	-13.27	-410.36	11.14
1080	55.30	-210.74	-510.07	-233.82	-316.84	-2093.45	-121.41	-144.60	-152.05	-10.70	-5.64	-10.35
1082	74.53	20.15	-41.81	-18.17	99.30	-1543.81	8.51	18.10	15.10	49.71	24.41	1.48
1084	72.76	19.19	-31.94	-201.50	-1510.38	-1779.85	-55.77	-18.85	31.20	-1.96	-10.70	-12.43
1086	-221.00	-173.76	-200.04	-139.74	-111.81	-1408.02	-310.57	-0.78	-9.08	-12.17	12.82	-10.55
1088	-170.35	-2710.86	-404.96	610.84	-108.65	-912.47	-148.41	-212.30	-234.45	-280.40	-172.46	30.47
1090	-1164.94	-1126.21	-10410.16	-1055.84	-1118.90	699.21	-1172.74	-1184.23	-1199.33	-1146.50	-1126.21	-10710.07
1092	-1419.63	-1369.22	-1314.79	-1623.94	-1558.68	-2434.48	-2494.33	-2310.00	-2171.17	-2475.50	-2340.91	-2230.89
1094	196.29	-100.27	-479.14	-105.55	-431.86	-1955.19	-68.00	-306.05	-591.26	-329.38	-314.91	-324.57
1096	196.48	129.64	23.24	-16.54	34.12	-1194.11	235.35	129.88	4.81	82.23	310.05	-3.83
1098	112.95	89.19	86.25	-171.83	-185.55	-1024.64	-321.46	-212.92	4.62	79.73	16.74	13.35
1100	1345.74	1011.57	-53.50	1080.80	5710.57	-1466.38	3810.72	124.62	-9110.38	1603.66	1134.36	9.18
1102	1476.91	1298.13	1160.85	2005.43	1821.53	1030.88	424.60	256.47	113.04	114.84	1188.48	1686.14
1104	1136.36	1124.01	1100.39	516.03	533.98	1010.03	-349.90	-191.95	-710.05	-1058.95	-1014.97	-815.41
1106	1313.99	1095.99	8710.93	-2110.99	-468.51	-1034.55	-6310.77	-784.12	-900.85	450.13	221.06	-22.12
1108	499.54	463.23	736.05	152.28	118.10	-216.35	328.28	345.79	432.00	42.62	-52.67	-76.02
1110	22.84	-1710.88	-354.97	602.53	385.62	310.12	596.50	658.18	630.76	-110.03	-80.39	-69.99
1112	-53.75	-105.73	-190.49	203.83	385.62	288.51	1.46	152.25	235.68	-90.68	2.11	148.35
1114	-761.91	-776.48	-761.16	-1169.59	-1209.04	-875.35	-1368.20	-1454.50	-15410.85	-313.07	-295.43	-184.81
1116	-2203.57	-2301.07	-23710.61	-2088.88	-2304.67	-2381.15	-1570.60	-1676.73	-1762.71	-1010.91	-1083.37	-9810.42
1118	-23410.26	-2606.67	-2812.51	-1701.45	-1823.34	-3250.18	441.63	810.47	-343.66	-1606.85	-1882.58	-1986.74
1120	-991.95	-1069.90	-1036.40	415.46	1210.63	-449.63	-95.49	-1310.47	55.08	435.83	359.84	4810.25
1122	-523.68	-425.82	-460.26	-433.41	-493.80	-616.58	-390.98	-174.21	-141.64	-23.19	53.22	301.89
1124	1095.90	9210.58	532.51	-203.20	-419.50	-726.24	6310.78	563.56	202.08	-13.91	-810.98	-330.20
1126	789.47	385.07	79.06	386.03	-46.94	-738.11	338.22	39.37	-164.48	-10.89	-175.85	-236.48
1128	214.58	58.89	-112.47	431.70	276.07	-178.70	-261.85	-203.14	-182.10	-941.79	-913.57	-875.21

1130	-210.29	-211.91	-510.94	48.63	-11.27	-60.09	45.96	5.68	-18.04	-919.70	-772.06	-628.45
1132	-144.28	-252.06	-366.39	25.30	-108.52	-286.78	342.52	3910.09	360.77	336.19	333.29	3410.10
1134	716.24	579.71	415.94	-443.35	-612.73	-748.33	853.51	724.26	586.48	306.67	452.29	593.44
1136	241.98	95.15	-39.48	-3910.49	-451.42	-674.05	-791.45	-704.45	-588.05	-855.43	-802.74	-435.43
1138	-316.03	-351.27	-338.44	176.46	134.24	-108.07	-965.03	-456.35	-395.92	-1119.65	-1058.80	-942.00
1140	528.19	261.36	-109.17	658.03	415.73	-75.81	136.82	-410.57	-271.03	-102.91	-103.23	-123.13
1142	521.75	312.25	-143.22	-355.74	-515.33	-782.62	43.77	146.22	-196.11	330.93	260.79	-110.64
1144	181.51	-108.96	-634.51	802.26	509.14	-64.52	363.62	146.76	-211.72	391.36	242.36	-105.11
1146	510.72	-85.95	-284.68	144.81	1310.63	-132.45	66.45	-42.00	-168.24	-678.37	-610.14	-515.29
1148	452.00	184.60	-34.62	151.45	-16.52	-710.30	-615.46	-759.13	-812.89	-1063.37	-1041.19	-953.74
1150	459.24	299.24	-46.67	300.59	146.42	-236.05	-276.55	211.36	-291.70	140.10	51.85	-46.89
1152	103.44	64.41	-43.98	-591.65	-629.02	-835.39	-7110.02	-509.80	-273.14	-248.98	-1110.05	-48.05
1154	796.73	529.60	0.97	-28.71	-166.27	-756.09	-102.95	-510.87	-260.85	556.28	400.36	-16.74
1156	475.36	298.53	-3.43	5010.18	293.65	6.47	1410.93	-32.94	-235.59	329.38	179.98	-3.50
1158	-2359.32	-2564.42	-2655.93	-3044.41	-3206.22	-3300.00	-2188.81	-2128.17	-14510.01	-932.43	-803.54	-631.56
1160	-3126.27	-3370.32	-3609.10	-2965.31	-3153.16	-3398.95	-3103.74	-2922.70	-2672.27	-1613.18	-1601.99	-16810.68
1162	-2984.65	-3448.18	-3690.97	-2834.21	-3266.11	-3604.97	-3172.17	-3543.34	-3652.23	-3020.68	-3210.77	-3030.71
1164	-2810.09	-27010.29	-2604.33	-2936.83	-3155.90	-3498.36	-3285.30	-3501.07	-3758.99	-3092.37	-3074.43	-31110.20
1166	-243.60	-645.35	-943.80	-563.73	-912.37	-881.97	-1455.73	-1793.56	-1940.18	-1605.17	-1869.44	-20410.11
1168	1040.19	752.36	476.41	-4.54	-161.96	-423.38	-499.68	-446.90	-3710.95	-401.45	-525.26	-561.53
1170	69.66	-11.06	-22.21	179.50	393.00	310.61	-373.54	-452.12	-578.50	-84.65	201.05	424.09
1172	681.23	5910.48	-22.21	1750.02	1720.66	1584.89	141.92	424.02	638.27	1569.94	1845.26	20210.40
1174	844.55	7610.33	-468.07	910.48	842.41	642.60	1028.55	10310.83	1048.40	1138.86	1286.43	1420.49
1176	1110.70	130.12	659.78	-525.65	-472.74	-6410.73	-62.73	-56.95	-46.74	-342.56	-191.58	-83.93
1178	490.69	599.01	112.21	12.26	16.85	-141.80	518.54	580.15	658.30	11510.16	1166.87	1208.81
1180	-2725.79	-2878.56	-2085.49	-112.81	-119.43	-299.83	-30.33	-186.03	-408.14	-12.56	144.88	250.93
1182	-2698.92	-28010.64	-2880.62	555.53	484.51	150.62	1310.82	200.78	3110.47	4610.94	416.16	393.05
1184	-2173.52	-2205.14	-2348.01	900.69	916.36	749.49	654.04	843.35	912.53	343.28	335.12	2310.83
1186	-942.44	-860.13	-588.77	1556.51	1651.64	1686.92	1242.70	1263.40	1288.92	439.18	5310.88	671.73
1188	3110.21	3210.46	68.24	8210.67	712.86	411.90	270.94	1710.84	41.41	-106.50	-88.74	34.54

1190	-320.57	-326.46	-381.34	-1453.76	-1468.10	-1640.00	-1238.61	-1131.00	-9710.85	-10.42	58.64	62.57
1192	-1438.17	-14910.68	-1538.09	-2759.74	-2724.45	-2631.82	-3408.30	-3244.44	-2786.85	196.32	232.15	2710.06
1194	-17310.39	-1921.39	-2019.95	-2536.70	-2736.24	-2846.25	-3072.78	-3264.18	-3440.04	-115.23	-55.57	41.25
1196	-1073.98	-1054.55	-1091.93	-1646.88	-1426.70	-1119.40	-1735.28	-1675.06	-1634.75	-275.11	-1010.36	15.56
1198	58.46	-1110.75	-288.17	201.00	135.17	-24.29	-34.23	-0.53	44.23	-266.16	-1010.06	54.70
1200	124.64	16.44	-66.64	-28.58	108.31	60.60	-710.79	-21.80	25.73	-111.21	-69.19	210.18
1202	1875.04	1608.38	9510.01	1390.93	1656.88	1175.46	1929.22	1741.19	1885.49	1412.38	14610.42	1448.29
1204	2468.47	24410.38	2466.05	1800.66	2050.44	1611.35	1706.10	1805.78	1885.49	1176.21	1261.11	1448.29
1206	1831.16	1742.64	1628.87	656.02	1165.54	454.56	251.60	356.12	396.61	-1354.62	-1194.00	-812.66
1208	1071.39	828.77	5710.38	631.32	533.44	434.50	-3410.34	-413.24	-458.50	-10610.23	-941.32	-700.24
1210	-535.10	-574.85	-6410.37	-1715.56	-1248.56	-1171.78	-12.97	59.66	132.69	112.11	109.96	51.08
1212	-176.66	-394.39	-695.71	-2179.67	-2185.53	-2489.13	1379.85	1114.99	796.56	278.08	282.21	431.80
1214	-1484.75	-1663.47	-1814.02	-2425.52	-25010.83	-2695.32	9310.18	823.17	685.23	3310.53	685.90	961.02
1216	-360.85	-442.87	-535.78	229.42	213.55	156.81	1300.96	1345.48	1431.47	829.74	1198.28	16610.97
1218	-115.53	-470.65	-1199.57	381.83	179.46	-306.13	894.43	680.79	61.33	620.50	611.81	72.07
1220	-42.30	-176.85	-194.36	1610.02	71.09	78.03	91.69	44.35	65.22	-0.97	-110.63	-0.47
1222	400.40	241.19	710.98	362.07	222.18	103.30	356.32	263.10	166.96	-8810.02	-460.31	-31.46
1224	761.05	784.12	742.01	516.19	630.02	72.81	338.87	465.58	611.28	-1255.63	-1173.70	-1103.47
1226	1236.16	308.33	114.07	1162.28	233.84	92.89	-181.33	-332.89	-510.58	-765.89	-429.36	-26.41
1228	399.26	239.87	-49.40	95.67	74.71	-346.15	-111.67	40.76	85.66	138.85	100.03	-4.34
1230	-101.54	78.28	-31.27	-43.91	-30.85	33.55	-56.10	42.41	55.94	-153.59	-88.81	19.13
1232	-442.77	-346.90	-204.29	70.02	86.99	-81.60	111.22	810.88	49.25	-1180.33	-1053.75	-910.65
1234	272.59	71.69	-910.99	1033.68	924.37	612.56	965.53	9510.24	952.01	15.58	-3.44	69.28
1236	792.30	790.06	782.61	1021.57	1441.62	12410.84	17910.31	1839.55	1916.16	911.59	1083.46	1242.72
1238	85.16	-33.12	-156.44	409.33	5110.48	345.03	834.12	733.06	775.07	399.75	5110.99	731.47
1240	-24.32	-10.70	-10.98	13.56	-0.89	3.68	-444.25	-373.44	-308.39	-354.56	-149.06	2.77
1242	1682.35	1222.80	1710.69	1359.18	1060.15	610.50	722.77	396.83	-486.80	1380.73	1023.19	131.20
1244	3075.11	2860.53	2639.77	2498.14	2345.81	1401.54	1422.15	1395.84	1504.66	1489.79	1569.80	1958.17
1246	2338.05	2279.52	2131.13	936.78	1113.92	1296.28	110.50	366.83	524.62	-936.15	-724.30	-572.47
1248	15210.39	1154.90	203.76	1674.01	1438.32	714.33	945.08	8810.04	205.41	305.61	92.97	-583.66

1250	9310.54	6810.32	565.29	776.38	983.67	1302.50	326.94	1710.00	1010.10	619.63	514.75	521.32
1252	399.52	293.30	202.08	-460.98	-509.73	-3810.46	496.08	542.92	610.69	-108.35	-98.75	-100.87
1254	-964.56	-1156.04	-1285.07	492.41	4410.71	219.09	624.99	5110.11	452.91	-183.21	-64.83	105.68
1256	1359.22	1799.22	1628.06	2633.87	2575.47	2478.40	1086.43	13310.37	1503.50	652.37	784.24	1024.01
1258	2132.25	1554.35	1013.77	1892.96	1426.88	1148.33	1128.10	674.26	2810.98	172.49	-228.43	-540.68
1260	605.62	385.84	143.85	359.70	235.77	71.40	-111.85	-285.59	-444.35	-650.49	-698.08	-805.91
1262	133.98	23.86	-89.66	50.45	-80.81	-183.02	50.43	106.11	110.67	-161.23	-51.00	11.83
1264	-315.17	-393.73	-505.70	-239.90	-178.97	-372.27	33.30	-22.71	-115.86	-662.33	-541.64	-419.48
1266	495.57	318.55	89.19	1178.86	1153.91	853.50	1098.18	1005.61	796.29	-214.32	-243.78	-286.04
1268	1205.64	1045.80	879.05	1164.92	1121.72	1061.42	1305.96	1192.56	1083.03	100.07	51.85	18.98
1270	-699.85	-6910.98	-653.96	-1008.46	-10010.15	-1214.51	-2363.73	-2400.21	-2441.16	-439.16	-460.41	-348.41
1272	-2640.41	-2683.17	-2755.02	-1673.76	-1675.88	-21310.02	-2574.62	-26010.44	-2659.27	-201.18	-261.88	-313.56
1274	-1128.92	-1166.00	-1296.17	-179.79	-2810.44	-655.99	-565.78	-710.44	-881.43	74.77	46.94	-20.21
1276	7810.83	732.87	646.75	533.73	502.61	90.24	449.38	348.85	2110.33	21.22	370.69	5710.63
1278	938.60	780.34	599.39	11310.19	988.54	894.35	10110.34	843.39	610.86	163.99	53.12	-75.16
1280	1155.83	980.90	809.77	1262.13	1103.66	761.06	38.33	-104.53	-244.09	-413.98	-438.17	-401.09
1282	3010.26	154.92	-5.38	311.45	170.73	25.52	89.24	-410.07	-166.32	-198.29	-191.94	-162.30
1284	-421.10	-274.21	-309.40	-361.70	-438.33	-484.99	2510.64	175.05	100.93	44.55	3.85	-22.39
1286	-778.26	-1058.36	-1456.93	416.82	119.95	-464.64	828.74	5210.99	132.51	76.17	-92.60	-365.48
1288	-480.12	-658.55	-846.70	-6.81	-182.86	-559.73	13410.96	1203.69	1063.81	-5610.20	-689.87	-806.77
1290	-42.39	-270.51	-502.29	435.10	270.53	-510.24	-231.88	-405.62	-594.04	-575.59	-6710.45	-742.07
1292	-149.40	-3910.65	-661.44	-882.20	-1048.69	-1715.06	-2810.37	-481.87	-591.34	550.59	406.25	281.33
1294	-3566.11	-36610.74	-3686.26	-2161.66	-2225.86	-2342.20	-1422.48	-1522.32	-1449.98	-281.70	-238.73	-170.91
1296	-1975.42	-2263.16	-3230.12	-139.22	-349.32	-1569.63	226.21	-38.87	-954.84	1136.79	976.05	121.87
1298	-2526.63	-2743.27	-2982.92	1359.40	1315.15	963.91	-630.39	-839.61	-1064.21	735.29	5410.52	421.41
1300	-3416.62	-3505.78	-3583.31	1208.83	1189.65	840.39	-720.05	-743.58	-752.21	-591.10	-588.61	-554.48
1302	-32710.19	-3385.87	-3529.97	1880.56	1880.17	1443.42	735.66	656.97	532.01	285.83	413.65	464.26
1304	-13410.97	-1493.52	-1688.99	1189.19	1248.93	405.85	452.76	319.70	125.50	-33.51	-11.96	-10.72
1306	-591.24	-766.13	-9310.64	5210.39	391.73	90.35	310.87	233.15	120.65	-221.57	-334.68	-414.07
1308	201.49	96.20	20.34	266.34	205.28	102.85	163.49	104.45	39.91	151.15	118.68	75.69

1310	165.31	-15.46	-209.92	259.80	125.19	-315.34	4010.18	1810.61	-31.31	-433.20	-571.29	-669.66
1312	365.89	272.14	159.55	843.50	809.63	470.65	2010.88	143.39	65.79	205.15	234.57	215.13
1314	-1911.77	-2076.24	-2226.78	1710.69	60.01	-543.20	-48.01	-182.07	-285.58	-3310.38	-421.46	-514.79
1316	-762.26	-9710.67	-1525.36	694.80	5110.36	-180.41	249.84	111.28	-329.79	343.65	370.78	-39.73
1318	-661.80	-6910.45	-832.45	1214.32	1152.18	602.51	863.73	794.42	661.66	1152.05	11910.74	1083.21
1320	-955.99	-1413.20	-1663.54	-689.36	-1122.08	-1596.36	-133.22	-593.64	-821.15	-383.89	-805.03	-1003.46
1322	-1291.30	-1352.43	-1425.18	-3341.38	-3390.97	-3636.92	-1493.03	-1510.44	-1541.72	-830.73	-488.02	-414.26
1324	-150.53	-175.32	-181.62	-2079.93	-20810.41	-1810.19	-211.06	-283.85	-3610.51	303.88	360.63	262.75
1326	-241.88	-381.37	-495.65	414.14	268.35	354.97	-295.30	-475.26	-622.25	-1460.48	-1589.86	-16210.12
1328	22110.34	20110.68	1858.22	1762.41	1546.42	1371.43	289.29	-30.19	-285.61	-783.01	-1055.82	-856.59
1330	3278.78	3195.30	3045.55	2758.06	2669.15	26410.85	1875.84	17310.34	15610.93	961.33	1182.81	1338.55
1332	665.48	451.78	310.58	1982.86	1681.72	1789.55	242.33	-810.55	-335.01	1292.87	1110.71	936.40
1334	273.40	18.87	-241.83	-4110.63	-635.72	-562.92	-384.08	-638.13	-901.69	-10110.07	-1235.53	-1462.86
1336	-1266.24	-1799.43	-2204.83	-32.63	-551.99	-806.38	-876.51	-1415.87	-1815.32	366.16	-132.05	-524.41
1338	-1500.33	-16810.88	-18810.70	-462.88	-626.63	-738.62	-11910.97	-1358.76	-1523.01	6.31	-93.09	-188.63
1340	938.64	349.04	-98.92	2126.13	1794.41	1429.20	2484.42	1919.61	1458.25	1541.27	1058.89	641.02
1342	1756.28	1426.29	934.64	2234.10	1921.82	1190.24	2001.43	17410.73	1363.68	445.99	181.91	-210.69
1344	894.19	404.95	85.15	763.31	335.24	123.02	133.14	-349.44	-700.24	1710.63	-182.41	-468.04
1346	748.36	294.04	111.55	403.74	48.26	-6910.04	1971.69	1609.69	1390.06	734.15	433.23	2310.06
1348	3362.52	2644.42	2089.72	1642.84	946.86	789.34	4250.36	3489.35	2938.77	1081.05	405.75	-39.03
1350	42810.40	3803.29	3383.62	1851.59	1366.65	1028.81	5188.44	4704.55	4301.69	459.45	1.30	-355.09
1352	4135.26	2152.92	1659.31	11910.97	-733.69	-1282.59	5006.37	3035.59	2581.74	313.89	-16310.09	-2064.90
1354	2773.54	2591.09	2423.07	1006.87	860.76	1253.21	2781.22	2632.91	2508.00	83.71	-19.83	-116.01
1356	2596.18	2461.33	2341.19	711.94	628.34	-424.72	2575.08	2420.31	2261.15	143.11	80.73	-22.17
1358	1719.12	1430.66	1166.21	340.22	94.55	-322.02	1581.32	1329.47	1091.78	470.96	315.57	-179.38
1360	298.81	-64.87	-469.27	365.86	-11.00	-42.54	-150.68	-432.90	-711.92	126.92	-88.69	-321.22
1362	561.13	343.26	173.90	7710.56	628.18	359.52	-633.53	-852.28	-1046.97	1926.82	1750.70	1624.80
1364	303.52	1510.74	30.32	311.60	192.65	72.13	-92.36	-205.97	-319.94	233.81	282.77	349.90
1366	509.36	400.56	208.80	182.76	84.10	35.16	-604.73	-724.38	-868.02	508.26	422.43	324.84
1368	-894.04	-1369.58	-1792.12	-405.73	-838.55	-544.98	-1732.91	-2210.40	-2640.26	601.90	2010.37	-79.21

1370	-1146.17	-1271.99	-1363.63	-1605.83	-1691.11	-15410.26	-950.14	-1079.66	-1201.68	466.80	359.65	276.19
1372	-2312.31	-2921.25	-35210.95	-1646.78	-2245.72	-2414.97	-24010.51	-29810.35	-3573.75	-362.03	-939.65	-1506.95
1374	-1566.96	-1901.53	-2600.43	-1151.18	-14210.65	-1836.73	-16510.87	-1969.87	-2652.94	-2310.77	-321.73	-779.23
1376	-1771.48	-2015.14	-2240.66	-442.05	-659.14	-621.08	-968.87	-1204.56	-1408.86	-595.72	-780.64	-926.69
1378	-2135.30	-2268.04	-2432.79	-1373.01	-1513.14	-1515.78	-1933.76	-2102.51	-22810.65	-1114.52	-11910.65	-1295.39
1380	724.72	7310.81	451.11	-1206.64	-1478.20	-1875.33	-1243.44	-1529.03	-1842.49	71.99	-160.30	-413.26
1382	4088.51	3833.86	3560.80	72.19	-175.70	-558.52	-230.90	-484.18	-744.63	1306.30	1084.14	864.23
1384	4062.52	3769.13	3330.08	1552.72	1309.08	1233.17	454.02	143.81	-299.84	361.68	143.18	-204.32
1386	3374.19	3104.70	2795.82	12610.76	1050.38	1003.28	350.93	208.67	48.67	-433.02	-460.02	-590.87
1388	115.68	-81.36	-248.38	185.47	54.31	-51.15	-161.46	-335.20	-476.88	-565.21	-5710.86	-619.95
1390	1424.62	1225.75	945.32	148.27	-1.58	-98.68	342.56	205.69	1124.54	683.04	563.77	330.53
1392	118.79	-88.39	-249.61	861.10	660.56	760.61	19110.86	1735.32	15910.56	485.40	350.74	255.63
1394	-1389.56	-1752.13	-20310.03	-344.45	-636.87	-581.11	345.61	34.68	-205.93	-4710.60	-775.56	-10110.55
1396	-893.69	-1032.74	-1220.12	-118.42	-313.83	-266.87	-410.15	-261.29	-5010.91	-988.22	-1145.20	-1343.86
1398	2021.11	1814.80	1615.19	840.28	698.13	501.70	-313.58	-492.25	-6610.63	-626.19	-725.04	-816.58
1400	2009.20	1536.90	11210.33	1312.61	859.26	434.46	600.42	104.85	-332.79	1020.78	609.55	2810.08
1402	2982.34	2786.58	2002.54	2073.51	1896.73	1362.94	9010.27	709.76	-85.33	462.53	282.62	-479.76
1404	2843.22	2952.57	28510.59	2751.12	2551.11	2642.10	-130.90	-294.36	-434.91	286.32	222.96	218.53
1406	-1826.94	-1948.03	-2058.07	1936.12	1839.90	1974.57	-895.39	-981.22	-1076.28	-660.32	-610.06	-560.31
1408	-1670.97	-1820.88	-1974.93	1336.13	1196.74	1136.26	282.96	179.13	74.83	809.70	761.95	681.55
1410	-2114.78	-2562.05	-2961.16	-365.39	-754.81	-1123.88	401.62	-62.75	-515.96	143.18	-233.05	-549.49
1412	-2846.22	-2989.50	-3181.33	-4389.98	-4543.72	-4648.83	609.74	513.68	391.99	-763.57	-873.05	-832.14
1414	-2734.56	-3044.59	-3364.92	-4135.70	-4458.56	-4610.26	904.84	602.70	-309.11	914.85	6610.28	428.60
1416	-3616.58	-3812.19	-4001.81	-4054.29	-4204.35	-4329.41	-1732.84	-1729.78	-1700.81	-885.75	-828.89	-655.17
1418	-3188.37	-3565.20	-3913.88	-3708.35	-3966.53	-3825.14	-18610.96	-2164.20	-2445.87	-2180.67	-2503.93	-2804.89
1420	-1276.87	-1649.50	-1984.07	-1323.08	-16810.82	-1943.31	-1168.40	-1552.57	-1932.87	375.01	0.00	-378.97
1422	1110.76	-181.94	-500.72	-760.76	-1050.81	-1264.84	-705.52	-906.19	-1111.31	871.09	625.35	382.00
1424	602.91	313.88	56.88	-761.07	-975.71	-1059.58	-773.99	-10310.58	-1230.20	655.30	402.70	184.69
1426	926.57	535.72	161.46	10310.23	666.60	399.77	801.90	671.85	492.78	505.07	1810.51	-74.27
1428	1648.41	1022.93	98.70	2086.58	1491.54	651.69	2192.07	1690.56	901.05	314.21	-210.41	-1002.59

1430	932.66	6510.04	356.01	2325.57	2112.94	1832.72	1596.37	1400.46	1231.50	-10610.72	-1311.48	-15710.04
1432	1205.44	951.07	6410.54	73.36	-198.28	-381.31	438.60	232.43	0.34	400.06	299.36	83.63
1434	2204.24	1818.73	13710.12	806.48	4310.29	31.20	1193.78	936.29	654.84	2206.31	1834.56	1444.30
1436	1914.21	1631.51	1368.06	1958.61	1689.53	1388.19	2625.46	23510.68	2118.36	2746.25	26310.38	2450.96
1438	6110.21	-71.45	-834.72	1658.76	895.23	171.27	2111.56	1464.74	756.93	1879.91	1268.97	544.20
1440	919.78	725.35	413.64	1730.74	1518.35	1366.41	22510.95	2090.75	1810.39	424.95	256.53	-210.45
1442	1774.97	1599.47	1444.61	1715.14	1479.42	1220.94	1704.11	1595.16	1534.50	923.14	7110.85	586.90
1444	1473.73	1182.55	889.47	1453.86	1195.86	772.16	850.99	613.00	340.26	355.28	151.68	-59.93
1446	1343.83	1113.08	832.77	15010.56	1292.69	801.16	-676.15	-886.69	-1140.44	116.52	-4.27	-176.89
1448	-1654.80	-1785.99	-1854.92	-1115.32	-1171.92	-1161.80	-1329.28	-1426.17	-1494.00	559.46	486.82	426.52
1450	-2528.72	-2701.76	-2870.24	-2096.62	-2122.75	-2632.81	-852.30	-890.80	-963.16	-1219.77	-1363.93	-1478.82
1452	-2536.69	-2606.88	-2770.15	-840.26	-473.39	-1198.25	-3010.21	-288.97	-291.21	-18710.51	-1806.80	-1718.99
1454	-158.72	-418.42	-946.63	1745.68	1544.98	1106.70	1386.93	1179.67	749.83	666.63	451.95	10.52
1456	1759.09	1665.60	1503.71	1674.00	1632.17	2103.32	905.59	842.11	7910.64	718.16	623.12	553.13
1458	27510.93	2590.62	2382.12	610.81	-65.26	-195.81	102.48	76.76	26.75	2910.16	249.61	163.00
1460	1220.17	604.20	280.26	-660.50	-1372.63	-1638.33	25.71	-663.93	-945.85	1034.48	3110.91	13.07
1462	690.10	528.57	0.00	-926.75	-996.65	-1381.51	-1753.60	-1799.88	-1872.48	-783.29	-821.86	-866.24
1464	420.23	3810.45	356.46	8310.10	779.97	4310.19	-1689.18	-1612.79	-1551.92	-438.11	-498.21	-564.77
1466	-1374.95	-1473.94	-1559.44	-7310.34	-814.80	-811.59	-2773.77	-2669.66	-25910.59	-1709.99	-1715.47	-1683.65
1468	-684.13	-709.26	-753.37	-473.69	-493.79	-432.64	-1751.65	-1669.97	-1538.22	-1445.13	-1412.80	-1369.87
1470	273.12	94.40	-86.53	-983.22	-1106.44	-1470.92	-379.33	-420.78	-501.49	-3400.43	-35110.64	-3630.53
1472	772.98	659.75	5210.09	-9610.86	-1045.59	-959.77	-1109.49	-1180.08	-1272.41	-2330.21	-12410.97	-809.88
1474	199.88	169.59	1005.53	43.96	85.44	-632.26	-1698.53	-1556.53	-1461.85	833.44	1032.39	1233.72
1476	-906.95	-9410.11	-1504.24	-570.03	-559.72	-561.32	-1095.11	-792.23	-580.08	-360.01	-2910.64	-225.77
1478	-1251.80	-1372.15	-1852.57	-2114.90	-2200.71	-2094.34	-552.27	-584.46	-656.50	-323.47	-339.58	-418.07
1480	-11810.07	-13210.56	410.78	-864.68	-981.27	-1766.00	364.55	292.83	126.42	544.20	464.55	-12.10
1482	48.71	-30.85	96.23	1295.11	1293.17	470.18	10410.78	1176.91	1211.97	1399.90	13910.30	1389.17
1484	191.83	115.70	910.11	718.27	676.54	-26.53	185.35	216.47	16.63	411.62	462.87	529.31
1486	182.92	156.96	142.34	278.00	222.64	118.15	-25.79	-2.70	71.53	108.35	71.78	35.45
1488	176.13	169.60	809.37	88.94	149.90	902.82	23.83	44.27	920.08	13.75	210.65	42.31

1490	-341.32	-596.22	-148.29	440.76	222.31	-0.26	-608.48	-765.66	-2810.56	261.52	73.26	-133.67
1492	-100.27	-94.97	-148.29	-116.61	-23.13	-0.26	-323.29	-309.66	-2810.56	162.56	86.49	-22.28
1494	532.22	344.17	1310.42	76.79	59.29	266.82	-276.33	-172.49	-11.90	292.70	171.91	68.44
1496	390.88	48.39	-150.66	39.37	-9.75	-173.59	-292.76	-405.66	-182.02	36.56	-115.34	-102.61
1498	238.25	146.74	-11.07	96.70	72.00	-610.36	265.96	434.13	700.32	232.31	221.73	146.39
1500	2610.91	1910.76	48.48	486.47	398.17	-108.97	74.12	114.84	121.95	223.77	191.87	112.62
1502	588.37	4010.98	153.76	391.32	418.89	-83.73	109.91	104.16	103.99	329.10	291.23	190.27
1504	1308.05	1396.28	1116.50	1312.39	1341.22	1080.61	840.41	1236.62	1110.84	840.41	891.03	699.33
1506	1295.15	976.21	995.73	1138.64	1034.25	922.39	1218.57	904.05	862.12	486.95	151.44	113.47
1508	-579.82	-583.37	-598.66	-129.98	-248.45	-358.20	-1200.91	-1024.52	-965.58	-634.32	-648.03	-640.85
1510	-2253.31	-2311.15	-2354.84	-1358.31	-1324.54	-1339.93	-11810.68	-1010.10	-804.34	-265.92	-314.52	-332.41
1512	-1224.03	-1188.45	-1166.06	-213.68	-182.63	-509.00	-371.73	-275.75	-134.02	-119.35	-44.50	-25.64
1514	-40.96	-290.28	-390.01	159.68	-25.82	258.60	171.56	68.24	140.11	173.90	169.39	324.59
1516	3010.56	312.48	321.93	55.26	76.34	299.61	-79.58	98.16	223.57	-791.51	-701.41	-583.71
1518	-248.01	-346.86	-408.42	899.92	943.06	1235.15	900.37	946.06	1010.28	-226.49	-278.92	-365.22
1520	-794.00	-885.81	-1082.65	-42.63	-144.36	48.36	-202.91	-253.84	349.10	-208.78	-139.37	1610.24
1522	-3410.19	-3910.37	-4410.71	-286.67	-239.07	-392.03	-731.95	-510.03	-260.92	-153.15	-1210.29	-91.13
1524	979.06	879.16	635.15	899.59	8010.21	750.12	969.51	990.64	891.10	1328.08	1293.24	1058.34
1526	1261.33	1204.31	1169.53	1332.91	1353.64	1194.63	1272.92	1225.18	1188.36	565.63	663.56	735.77
1528	1395.77	1320.25	1205.06	485.38	474.40	85.57	-553.52	-486.80	-450.89	-991.70	-912.43	-854.99
1530	138.94	3.32	-226.57	240.66	158.21	-253.61	-982.77	-1000.75	-1076.66	-285.79	-263.67	-375.81
1532	-759.56	-735.24	-749.50	-154.83	-121.04	-65.63	-10.03	56.57	73.27	6210.86	6410.47	700.64
1534	-7910.78	-880.88	-1005.03	-5710.54	-539.67	-1025.96	164.48	124.10	46.58	-172.54	-120.15	-54.05
1536	-462.93	-473.84	-501.66	1121.99	1039.52	746.62	-251.27	49.27	403.27	-648.29	-5710.26	-540.52
1538	380.46	208.93	-28.70	61.19	-210.16	-441.68	-125.26	-80.79	-13.59	153.03	92.02	25.78
1540	-75.16	-84.81	-79.11	-1143.40	-1131.68	-1213.68	-511.52	-279.02	-56.34	-7910.82	-786.77	-761.77
1542	1059.89	950.77	828.55	-8.49	-59.97	-276.89	710.30	689.75	618.08	108.81	124.54	115.08
1544	436.88	418.12	390.52	1500.02	1501.68	1410.30	835.43	1099.27	1323.57	341.69	405.48	485.44
1546	243.96	306.65	312.65	375.13	470.47	1165.18	199.63	395.49	473.45	1310.61	155.34	156.81
1548	873.79	739.14	611.54	-890.48	-888.44	-594.78	-3149.27	-3028.26	-2839.38	346.89	332.98	341.06

1550	339.07	225.06	83.74	-1536.26	-1561.71	-1399.14	-3381.40	-3422.74	-3491.96	215.46	118.22	1.34
1552	332.46	215.44	110.86	-1354.13	-1329.33	-1471.65	-2448.10	-21510.79	-17810.22	710.89	39.15	110.29
1554	729.05	620.53	481.60	905.11	815.69	6410.93	680.74	622.63	550.28	239.72	222.82	190.78
1556	1543.60	1396.65	1230.02	1589.52	1433.27	1811.50	861.06	894.64	1026.80	715.79	765.99	869.00
1558	1965.53	1773.54	1469.35	1860.38	1725.13	1341.72	-553.63	-594.20	-732.68	411.82	2910.19	68.98
1560	1778.50	1684.11	1614.31	1975.84	2064.15	1623.06	-208.36	-224.12	-244.30	-31.82	-36.72	-61.19
1562	2322.01	2265.66	2245.45	3314.81	3284.27	3061.16	-620.22	-145.55	349.80	179.06	243.92	270.44
1564	1183.83	10810.91	9110.12	1394.30	1318.55	12610.61	-4210.53	-269.11	156.18	290.13	231.57	610.82
1566	493.70	423.16	328.51	309.19	295.65	326.03	-88.65	141.35	331.50	-482.78	-499.93	-529.87
1568	294.38	1610.74	68.40	-172.55	-176.50	-302.49	96.25	12.46	-38.44	143.75	39.38	-30.63
1570	951.53	10110.21	798.68	711.26	824.25	773.40	-4810.64	95.82	711.38	171.09	249.98	111.47
1572	853.18	764.86	1051.21	-2499.75	-2221.45	-1873.89	-1709.13	-1691.04	-1634.89	-1013.47	-1033.10	-1114.80
1574	1428.82	1251.36	1045.30	-1771.54	-1944.07	-2050.13	-1735.54	-1619.90	-1386.04	-109.71	-238.04	-374.51
1576	1415.22	1246.88	1073.08	32.73	10.22	-35.50	-410.67	191.03	591.76	-63.93	-94.82	-232.16
1578	1806.55	1709.98	1593.30	983.15	1080.11	1151.24	2526.56	2610.53	2718.68	610.55	69.85	45.86
1580	2244.75	2243.48	2182.54	2060.26	2089.42	19510.73	27210.93	2890.23	3074.57	164.58	224.27	246.13
1582	1625.98	1383.46	1213.42	1582.56	1389.18	1089.30	-10.09	-84.15	-101.41	-868.09	-1086.48	-12010.21
1584	-670.59	-732.15	-849.39	7010.39	635.85	719.53	-552.38	-489.93	-470.90	-226.97	-316.99	-430.36
1586	-889.82	-1000.63	-1192.47	-2.38	-80.35	-203.41	482.41	546.33	464.40	-552.22	-626.10	-762.90
1588	1711.17	20810.21	19610.91	370.25	216.03	75.97	559.71	986.02	952.08	170.53	24.03	-64.34
1590	4529.84	4376.62	4144.39	1796.00	1660.15	1503.22	925.21	894.17	8310.21	2018.80	1982.27	1854.87
1592	4800.30	4449.62	4028.84	1362.01	1078.18	840.38	-658.11	-9210.68	-11210.44	184.97	-118.17	-462.70
1594	2080.57	2124.06	2089.53	-1905.99	-1833.72	-1934.07	-2516.98	-22010.92	-1968.83	-1242.06	-1223.15	-1205.08
1596	2842.56	2654.71	2514.16	-1036.75	-12110.88	-1549.00	-1085.59	-839.69	-1233.62	-209.61	-355.09	-411.12
1598	2189.25	2129.71	2049.96	1093.08	885.97	520.29	213.79	115.91	92.54	684.13	493.84	359.88
1600	-5410.06	-623.57	-774.44	480.86	346.37	158.40	339.30	264.07	163.80	310.68	315.02	3210.49
1602	-1190.99	-1276.09	-1371.63	519.35	440.55	3910.01	592.36	615.82	674.47	930.10	982.58	979.92
1604	-571.54	-714.87	-906.63	222.10	94.16	2510.64	-299.29	-260.40	-191.24	-6910.33	-851.57	-983.31
1606	1363.64	971.33	506.60	1296.00	971.33	844.02	10210.37	772.43	178.75	762.99	419.31	-342.08
1608	2336.14	2196.83	2028.96	641.44	551.46	610.00	-34.98	-94.71	-1910.03	12610.97	1222.92	1130.27

1610	1875.86	1742.90	1618.30	-41.60	-75.92	-1210.74	182.77	218.40	209.60	2155.05	2216.68	2236.45
1612	1836.42	1365.24	749.96	-463.86	-790.88	-1772.95	-130.19	-570.17	1143.56	2045.96	1786.85	1409.15
1614	6.37	-46.27	-122.74	-2129.26	-21510.27	-2472.70	-2705.35	-2676.37	-2633.67	-1612.81	-1653.25	-1689.24
1616	-1269.49	-1285.59	-1302.96	-485.15	-488.67	-565.98	-2524.37	-2511.75	-2522.04	-839.55	-638.35	-484.66
1618	-1550.12	-1681.37	-1695.02	-1353.20	-1402.61	-584.88	-2049.28	-2151.59	-2179.74	971.02	895.75	888.68
1620	-3600.24	-3772.36	-3910.77	-1691.06	-1906.34	-2038.41	-43610.92	-4344.27	-4278.43	-1124.49	-1305.85	-1444.65
1622	-3414.59	-3632.39	-3764.63	-1481.23	-17210.81	-1943.83	-4021.19	-4224.17	-4135.18	314.58	102.72	-8.64
1624	-3910.05	-4052.85	-4302.91	-2050.90	-2184.11	-2246.15	-35610.41	-3481.31	-3556.92	-53.74	-410.88	161.11
1626	-1555.84	-1760.86	-2669.10	-1028.66	-1248.47	-1930.50	-1308.06	-1563.30	-23810.89	63.33	-49.91	842.89
1628	-93.94	-108.29	-160.14	-443.62	-452.65	104.00	705.24	876.71	1061.95	532.61	568.07	611.54
1630	383.70	3010.46	219.53	-1485.12	-1448.32	-1453.66	769.40	816.57	939.23	343.62	268.20	200.83
1632	-769.40	-288.32	-442.00	56.75	-1010.04	-250.57	-451.54	-472.08	-4910.00	49.02	-64.41	-161.67
1634	-959.27	-1071.25	-1175.73	-84.90	-182.68	-253.22	-749.51	-516.36	-234.23	-116.33	-158.43	-212.50
1636	-1111.74	-1141.64	-1169.14	-1392.19	-1429.97	-1393.62	-764.45	-721.78	-679.37	-172.37	-164.76	-168.35
1638	-1713.20	-1905.50	-2094.96	-319.23	-521.25	693.19	-98.40	-1910.21	286.22	5310.77	369.98	198.27
1640	-2310.17	-2512.86	-2609.23	0.73	-145.14	353.21	-13010.56	-1341.08	-1291.88	182.03	13.40	60.38
1642	-1738.48	-1825.25	-1876.44	-14.38	-510.62	95.33	-11710.92	-1171.92	-1132.23	391.27	402.75	4310.30
1644	194.66	62.37	-135.24	578.84	396.83	266.04	816.90	996.90	1005.69	191.85	144.84	95.56
1646	1415.73	1302.23	1118.95	1676.72	1601.38	1335.64	13010.41	1480.38	1603.66	2710.67	315.82	340.21
1648	-80.54	-162.55	-181.93	513.76	4410.75	435.43	-270.30	-1310.99	36.07	-941.23	-862.20	-748.25
1650	-1910.35	-226.86	-251.36	-1710.10	-198.82	-328.50	202.74	886.21	1048.47	-986.92	-931.47	-850.00
1652	412.54	283.37	95.71	183.80	131.99	-214.44	132.33	194.08	150.73	202.20	242.80	179.00
1654	-700.33	-1681.98	-2224.27	-184.25	-1171.34	-1794.44	-1040.90	-1751.35	-1901.69	32.06	-882.43	-13010.85
1656	-23110.27	-2345.54	-2368.30	-13010.52	-1448.46	-1631.40	-2785.41	-26610.90	-2488.20	-1135.29	-1134.68	-1024.29
1658	-356.01	-482.19	622.02	-286.69	-406.80	-578.42	-1249.39	-765.93	632.72	100.82	710.29	46.17
1660	1978.06	1254.25	4910.23	803.17	103.05	459.21	-356.56	-33.72	310.76	-264.87	3310.56	510.76
1662	263.61	371.64	594.57	536.04	421.97	259.20	-1190.08	-791.54	-548.89	-5210.49	-4110.35	-313.51
1664	532.40	456.59	311.06	1352.54	1312.04	1205.22	1446.62	1478.17	1498.40	1182.85	12210.93	12410.75
1666	2678.53	2391.13	2149.83	4148.31	3911.20	3653.69	3446.48	3234.75	3068.97	4390.51	4249.12	4139.46
1668	3658.57	3576.88	3533.41	4801.76	4790.38	4969.99	4565.55	48510.43	5179.80	48210.58	5173.73	5902.08

1670	4021.24	2293.88	1973.85	4040.25	2450.79	2522.19	4000.34	2624.55	2841.43	31510.87	1598.22	1660.45
1672	1410.55	1332.82	1231.80	1422.36	1376.41	1424.09	1009.68	1245.06	1351.70	496.77	645.72	690.43
1674	45510.45	4285.04	4069.93	1739.67	1540.23	1569.94	1290.28	1253.95	1419.20	17610.07	1660.58	1599.53
1676	6523.37	6410.89	62710.80	2596.10	25210.89	25110.00	2194.32	23010.17	2465.46	27510.23	2839.12	2919.44
1678	6604.99	65210.91	6423.76	28310.38	2896.71	2938.91	1398.69	1502.74	1639.78	2228.78	2411.22	2572.61
1680	7020.52	6939.88	6820.86	2274.09	2318.38	2421.23	1662.54	1823.08	2066.37	1731.67	18010.69	1855.67
1682	5770.68	54710.46	50510.77	2545.64	2320.18	2194.80	1243.17	1313.44	1450.57	2443.76	2231.46	1933.61
1684	-329.25	-382.49	-484.47	640.29	332.11	-964.58	645.06	450.50	661.83	671.01	488.85	641.07
1686	1095.80	980.98	754.60	1154.74	1020.73	1066.28	2201.42	2370.25	2411.61	772.12	750.99	666.63
1688	3058.48	2861.08	2653.86	25310.44	2343.07	1568.68	2219.60	2366.75	2486.18	1553.58	1579.33	1611.12
1690	1721.99	1393.17	1170.67	1512.00	1259.62	236.68	-521.92	-76.58	685.05	-1155.39	-1304.15	-1405.88
1692	561.98	-571.29	-5710.46	-583.11	556.73	-373.39	430.21	-284.03	-54.96	-1636.85	-1415.83	-1143.12
1694	126.87	-90.17	-406.18	1194.17	1040.07	276.64	418.93	393.94	349.36	-75.78	68.40	240.98
1696	8510.70	708.20	580.96	289.74	253.04	385.74	23.77	245.52	498.08	54.17	429.77	916.57
1698	-568.49	-684.01	-834.97	25.24	66.43	110.85	803.37	-3810.30	-44.44	-779.80	-740.27	-726.52
1700	-291.15	-572.85	-815.78	1292.86	1079.11	1170.91	749.61	785.08	1049.57	-21.89	-139.80	-180.69
1702	1163.80	1065.00	925.68	2113.06	1999.26	2189.00	1414.63	1425.22	1452.42	6910.13	560.28	4210.31
1704	1079.55	878.40	656.15	823.61	753.51	1171.22	669.01	764.54	850.19	-11.09	-143.50	-300.47
1706	-2166.63	-2226.81	-2368.24	-355.37	-303.60	-1382.72	-381.67	-3310.00	-306.62	-555.27	-5610.94	-608.99
1708	-2449.35	-2526.73	-2538.12	-1482.30	-1498.53	-633.04	-593.41	-3310.88	-114.74	-908.99	-462.22	21.75
1710	-850.93	-898.27	-950.66	-433.91	-3610.88	-471.07	-462.75	-1910.74	-5.76	-334.41	-238.98	-161.11
1712	268.73	205.56	175.89	-346.61	-369.61	3910.58	143.22	135.55	1310.37	119.60	83.75	73.15
1714	139.98	60.50	-1.18	-561.72	-550.54	-509.02	-695.63	-774.98	-852.85	-9810.75	-1062.95	-1104.19
1716	-1408.73	-1446.10	-1459.85	-8810.43	-890.26	-725.69	-1230.52	-10410.18	-805.38	-815.55	-788.34	-723.43
1718	-729.59	-763.72	-830.43	-523.98	-514.24	645.89	-839.25	-772.81	-741.14	-4110.06	-463.88	-522.49
1720	-245.92	-208.27	-205.16	-170.75	-191.63	1322.23	-415.54	-419.41	-413.33	19.56	85.05	138.86
1722	-586.08	-579.50	-548.65	-1296.67	-1328.60	-91.10	-1303.52	-1320.39	-13210.48	-565.45	-529.22	-523.61
1724	-1714.88	-1863.41	-1968.12	-1191.56	-1308.71	-993.69	-1464.34	-15410.70	-1596.38	-63.93	-118.85	-175.92
1726	-996.39	-10210.55	-1043.68	-813.08	-821.93	-1053.28	-1608.30	-1641.44	-1603.96	0.00	75.56	39.31
1728	-1461.50	-1454.58	-1436.56	-1483.13	-1473.79	-1464.11	-2441.30	-2330.25	-22510.85	141.28	14.59	15.07

1730	-306.52	-370.38	-441.20	88.06	-69.48	53.18	-18410.80	-18210.26	-1828.54	-383.40	-428.28	-518.08
1732	516.50	522.48	523.47	1012.53	1068.84	563.51	-502.02	-416.05	-345.33	4.86	11.29	18.67
1734	4810.57	4810.90	518.85	415.57	613.68	984.05	-410.61	-34.53	-110.82	44.11	42.68	60.22
1736	-19.96	51.16	-101.79	130.63	119.05	1210.67	-1.87	65.38	128.74	29.73	75.05	125.34
1738	249.06	154.29	85.26	180.69	154.41	2010.00	65.73	89.67	118.03	510.65	55.86	38.81
1740	-554.98	-575.75	-632.00	41.91	-2.29	63.20	-4210.25	-334.83	-55.59	-394.94	-4210.15	-456.00
1742	-24.23	-51.93	-78.21	110.39	29.37	114.47	-81.88	-58.20	-50.70	-51.02	10.89	25.58
1744	-1018.96	-9810.82	-942.07	-908.93	-829.75	-698.61	-876.15	-849.84	-814.78	-790.27	-752.34	-709.76
1746	-1628.97	-15710.60	-1504.95	-1564.67	-15410.53	-1433.95	-1672.21	-1612.74	-15310.34	-15410.08	-1545.71	-1522.13
1748	476.56	511.95	546.62	-235.01	-250.98	-815.48	-1262.94	-1065.04	-970.77	-749.53	-661.38	-5610.69
1750	-7510.40	-736.22	-694.31	-948.16	-855.17	-679.78	-933.66	-870.17	-795.73	-860.99	-784.66	-670.10
1752	474.26	573.77	504.24	110.48	80.51	410.85	79.10	80.50	72.68	-210.74	114.39	121.14
1754	-109.54	-226.64	-60.18	0.00	0.00	0.00	-102.75	-41.44	44.18	-383.68	-1010.21	0.00
1756	-1810.67	-80.25	-43.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1758	60.00	-34.58	-48.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1760	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1762	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1764	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1766	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1768	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1770	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1772	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1774	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1776	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1778	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1780	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1782	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1784	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1786	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1788	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

1790	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1792	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1794	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1796	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1798	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1800	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1802	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1804	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1806	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1808	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1810	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1812	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1814	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1816	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1818	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1820	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1822	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1824	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: positive (+) value indicates shift towards right side and negative (-) value indicates shift towards left side.

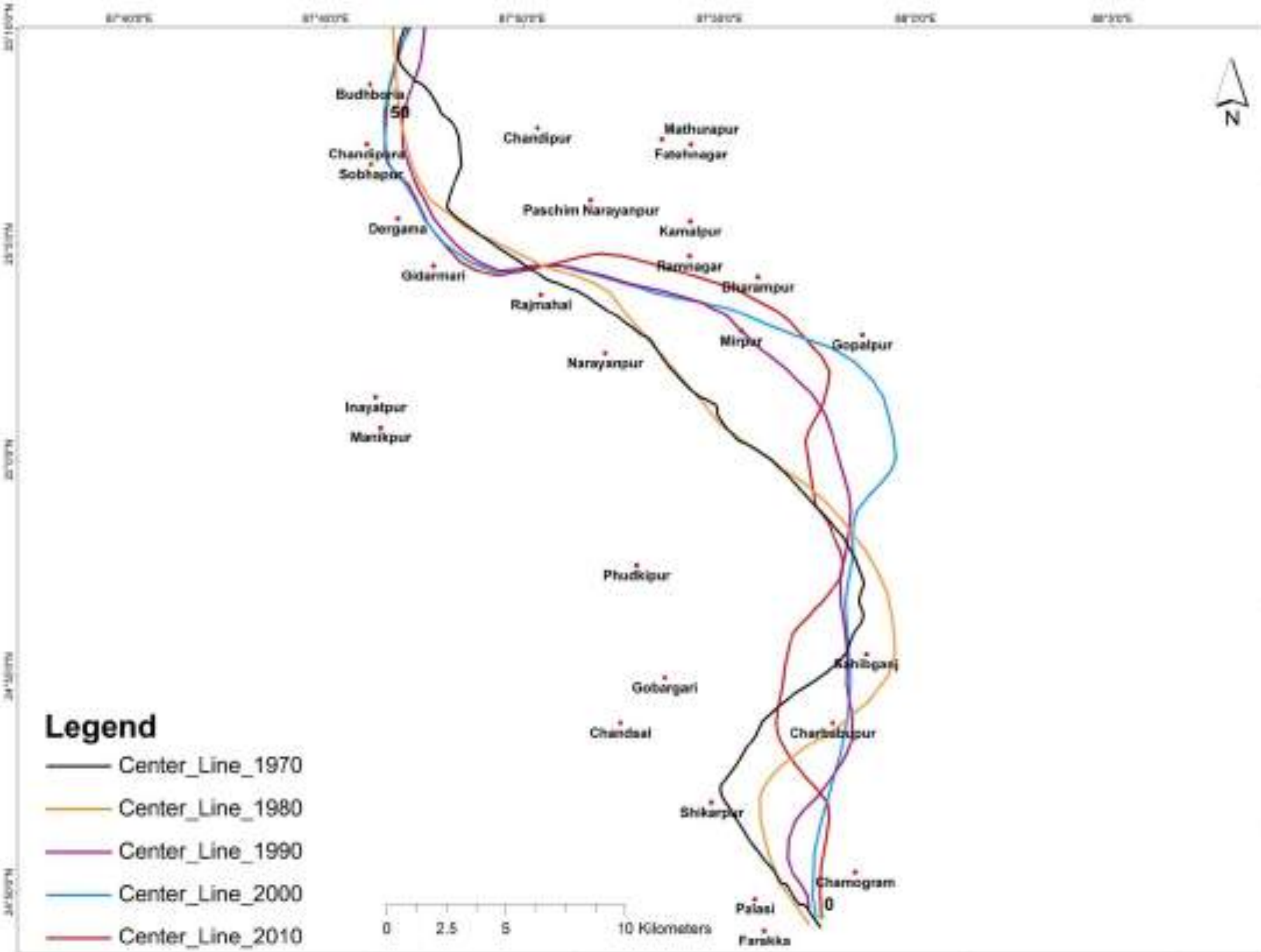


Figure 10.19a Shifting of center line of Ganga river from chainage 0-50 km

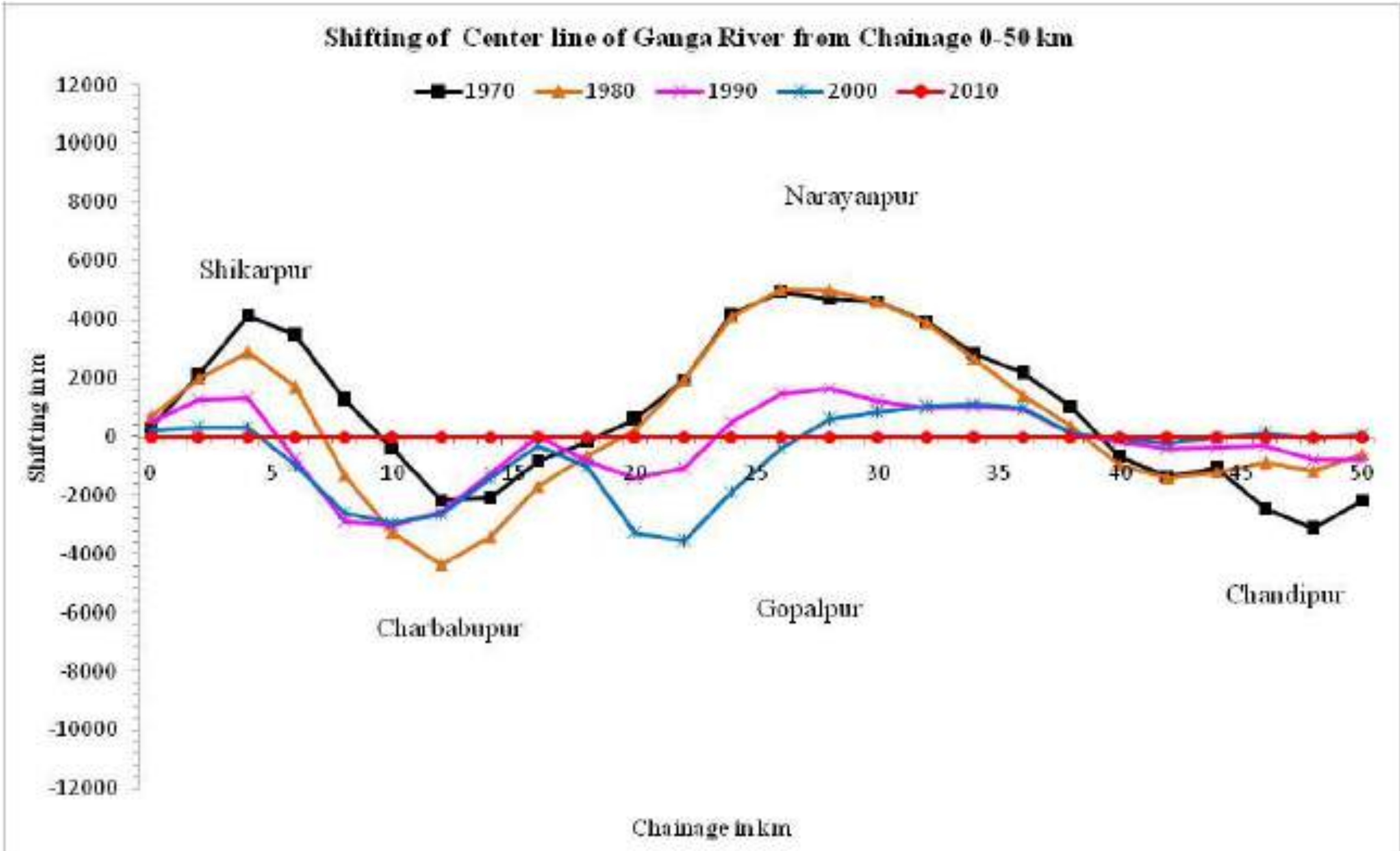


Figure 10.19b Shifting of center line of Ganga river from chainage 0-50 km

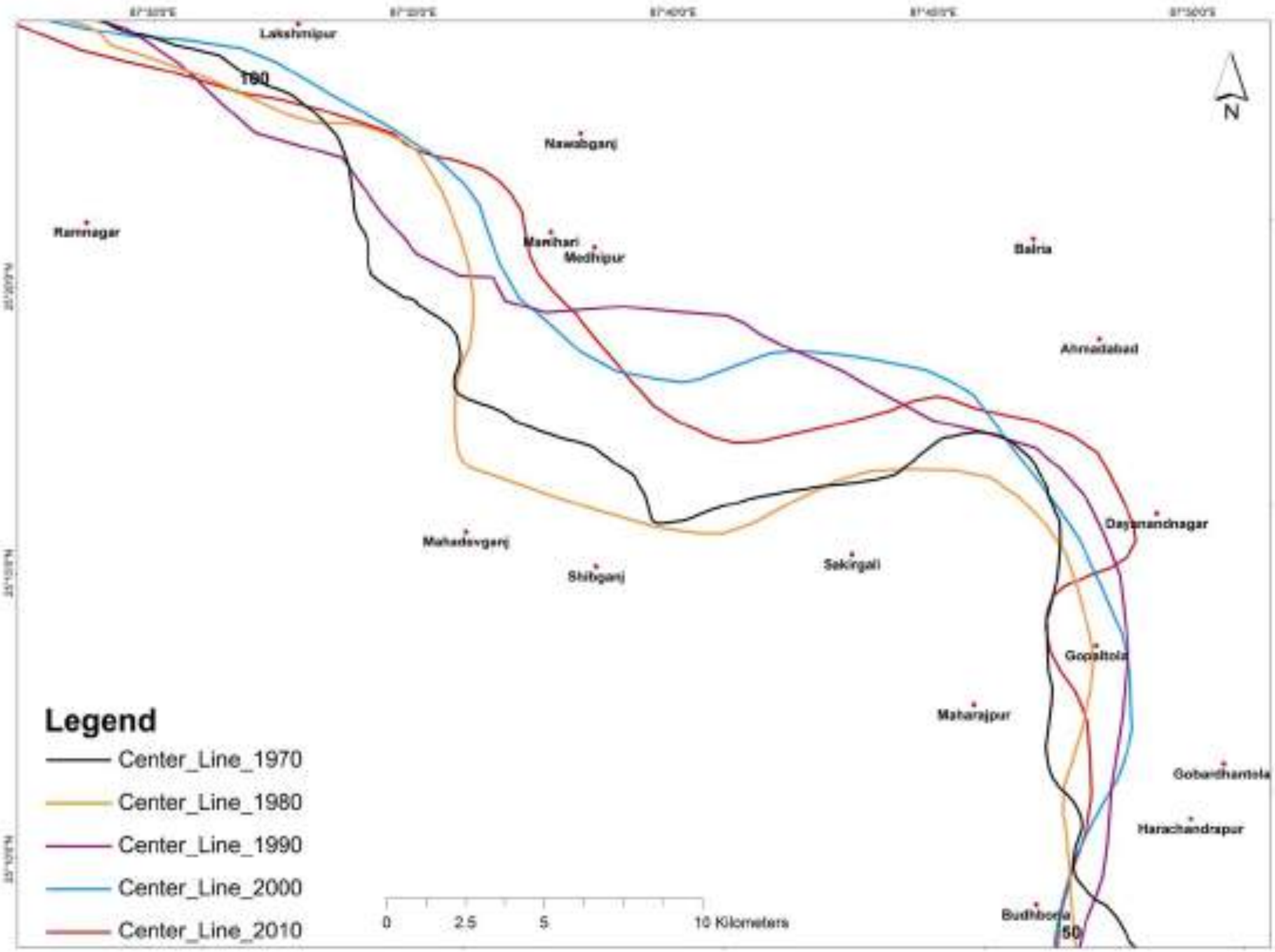


Figure 10.20a Shifting of center line of Ganga river from chainage 50-100 km

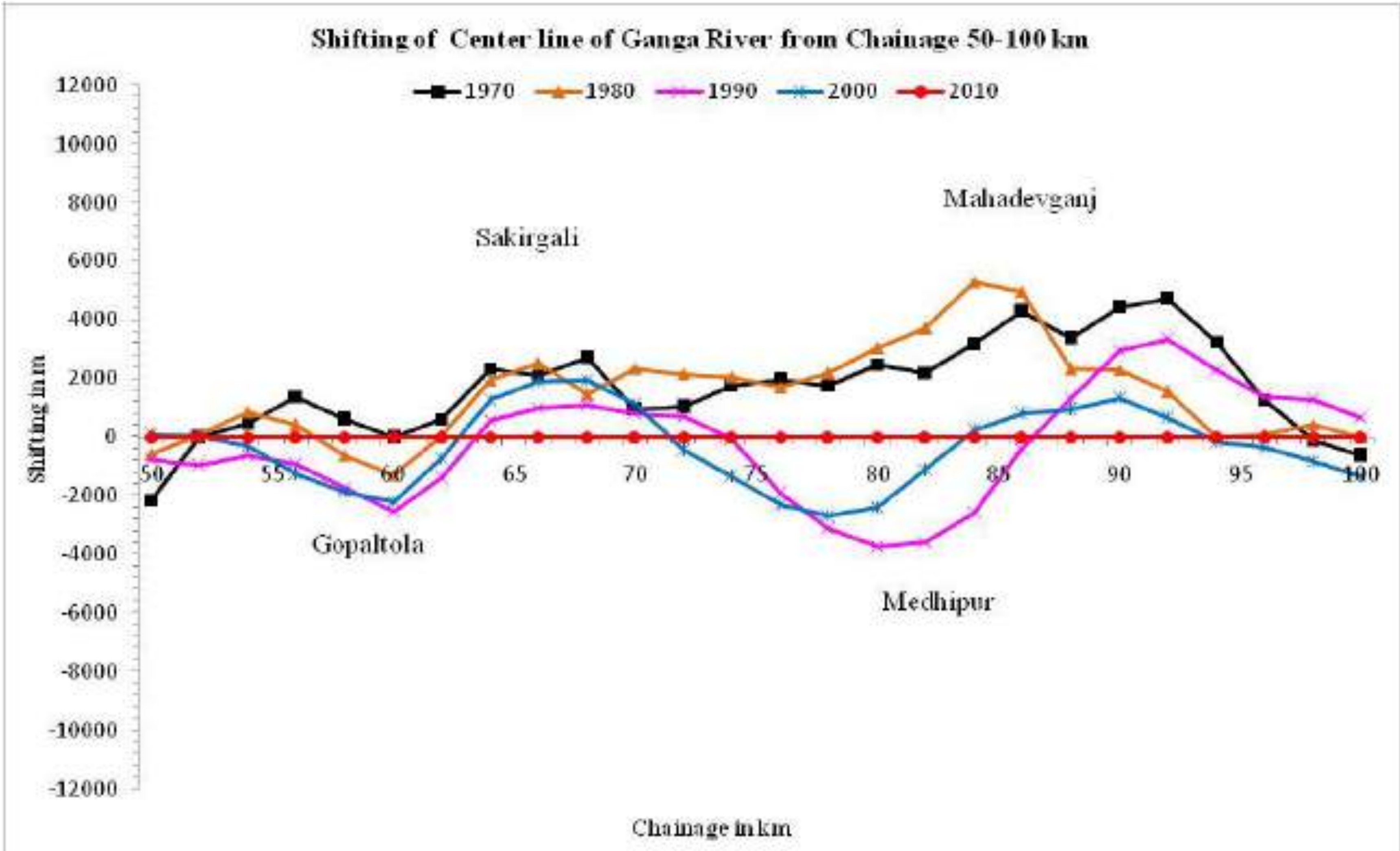


Figure 10.20b Shifting of center line of Ganga river from chainage 50-100 km

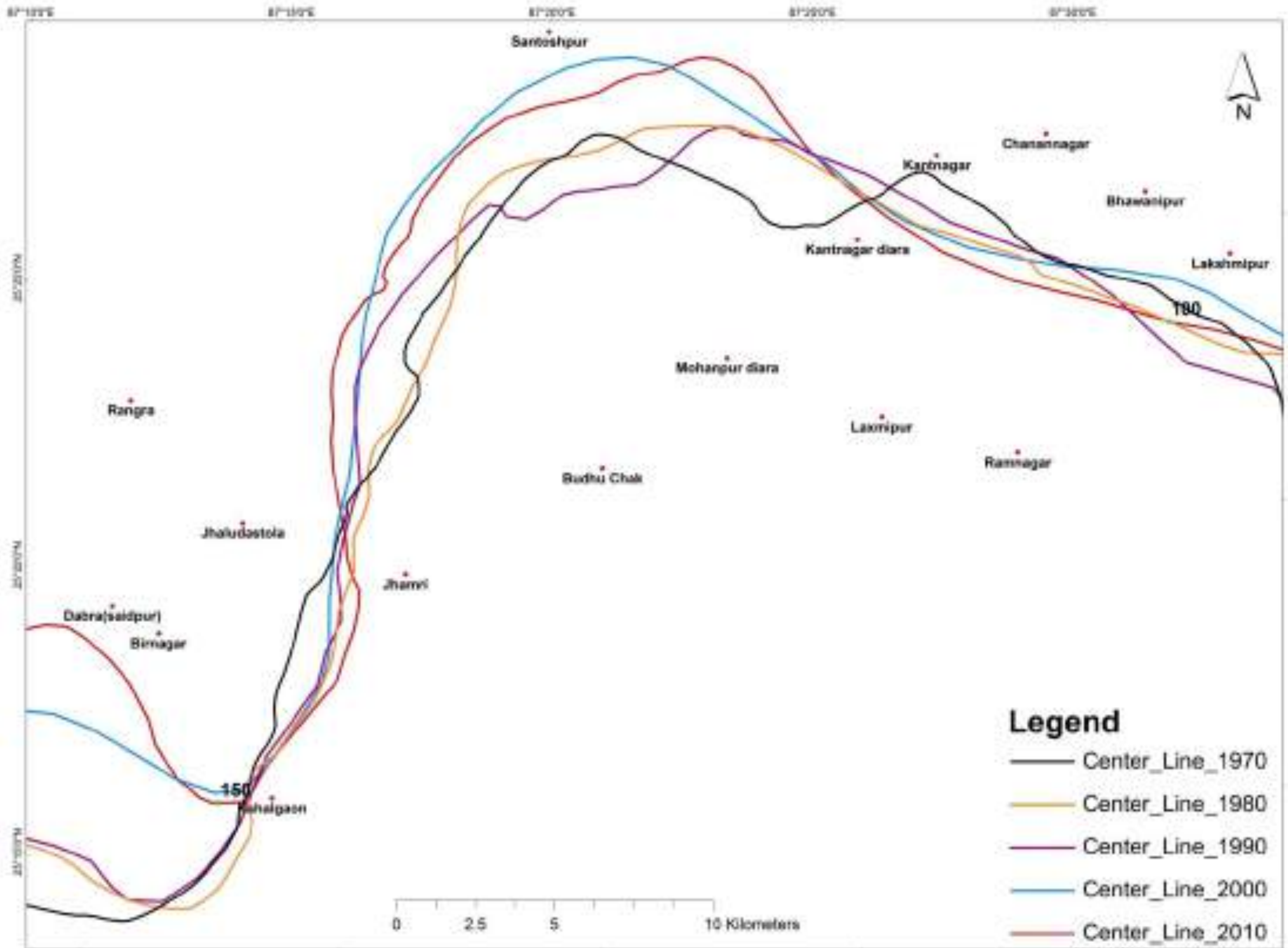


Figure 10.21a Shifting of center line of Ganga river from chainage 100-150 km

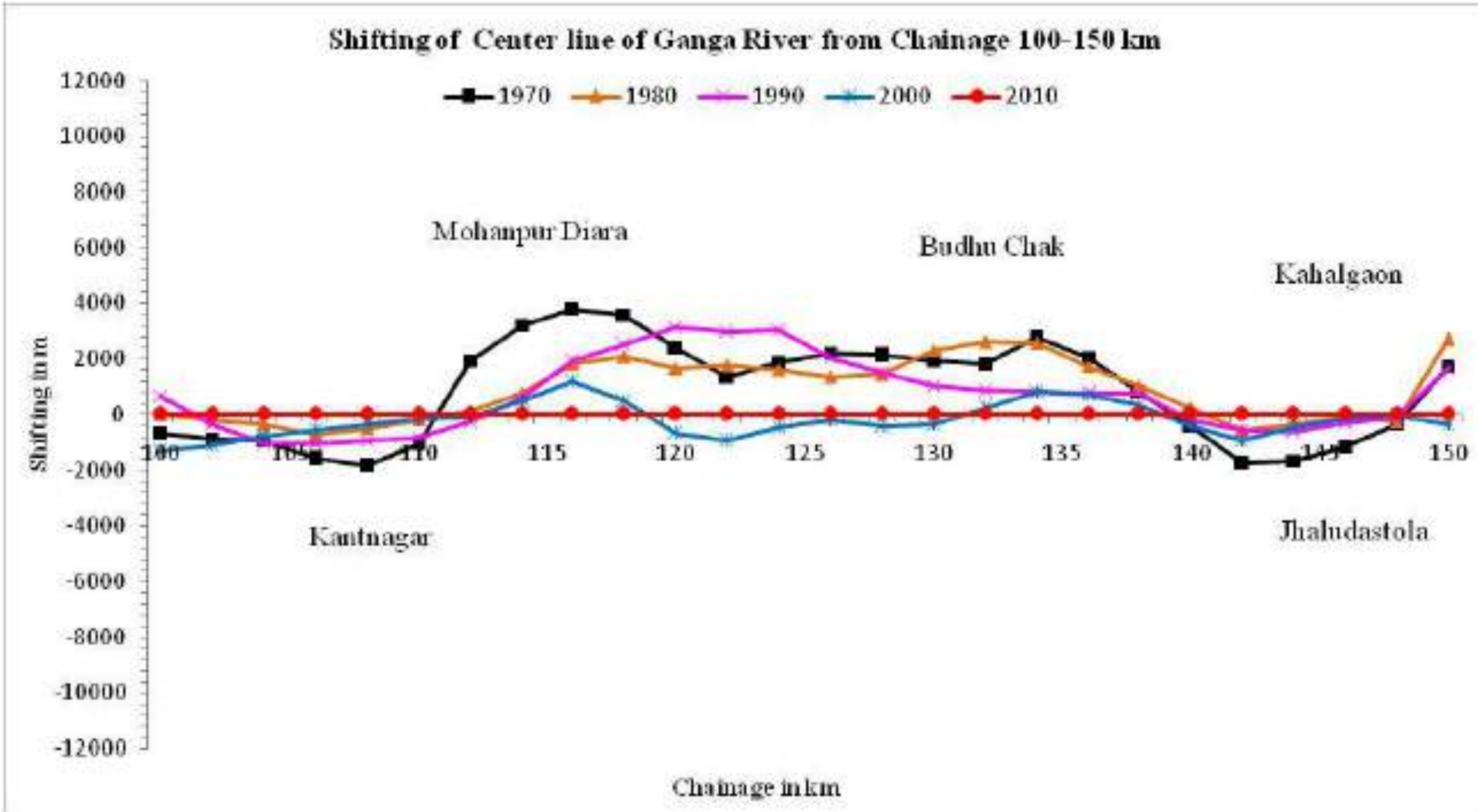


Figure 10.21b Shifting of center line of Ganga river from chainage 100-150 km

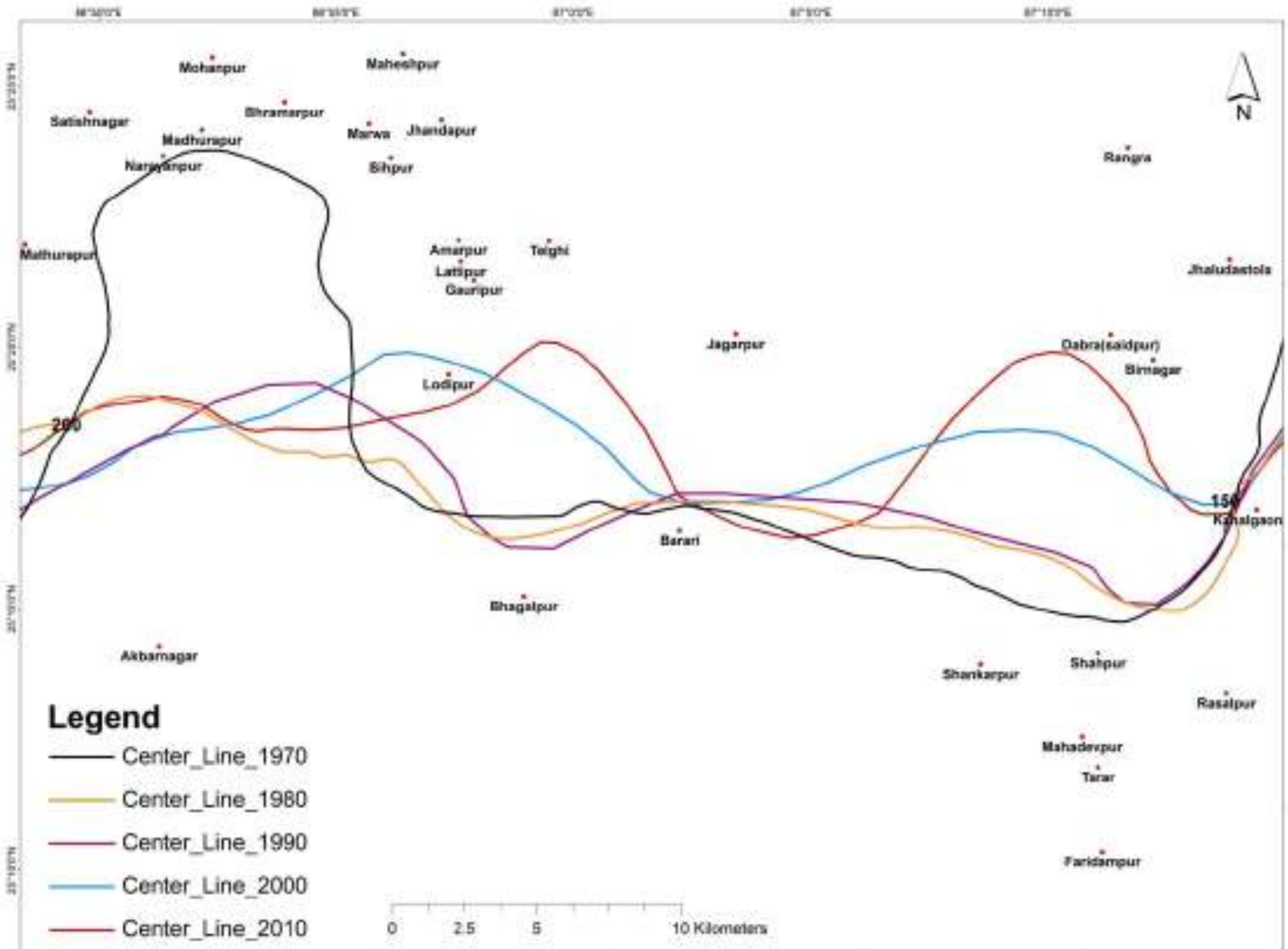


Figure 10.22a Shifting of center line of Ganga river from chainage 150-200 km

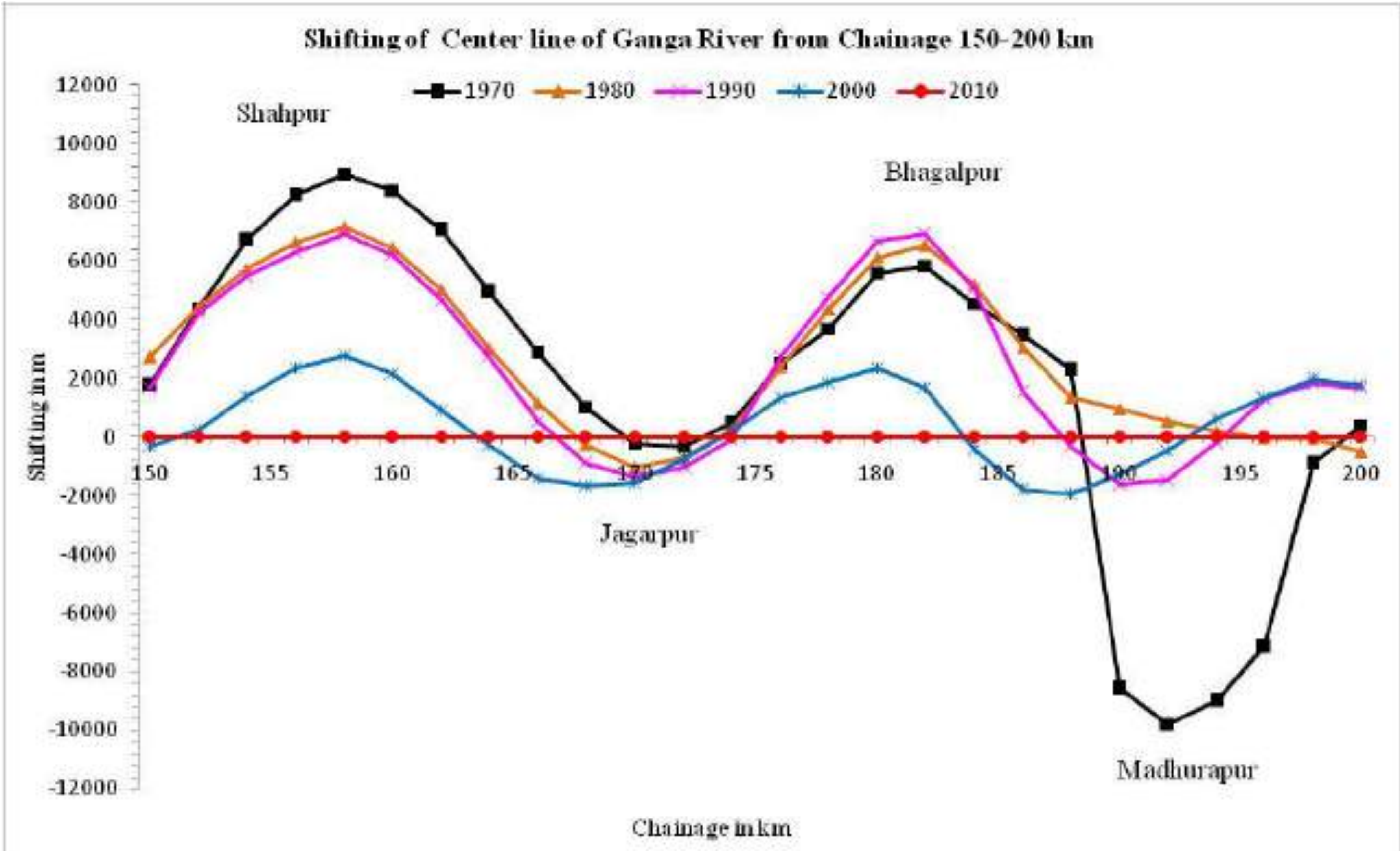


Figure 10.22b Shifting of center line of Ganga river from chainage 150-200 km

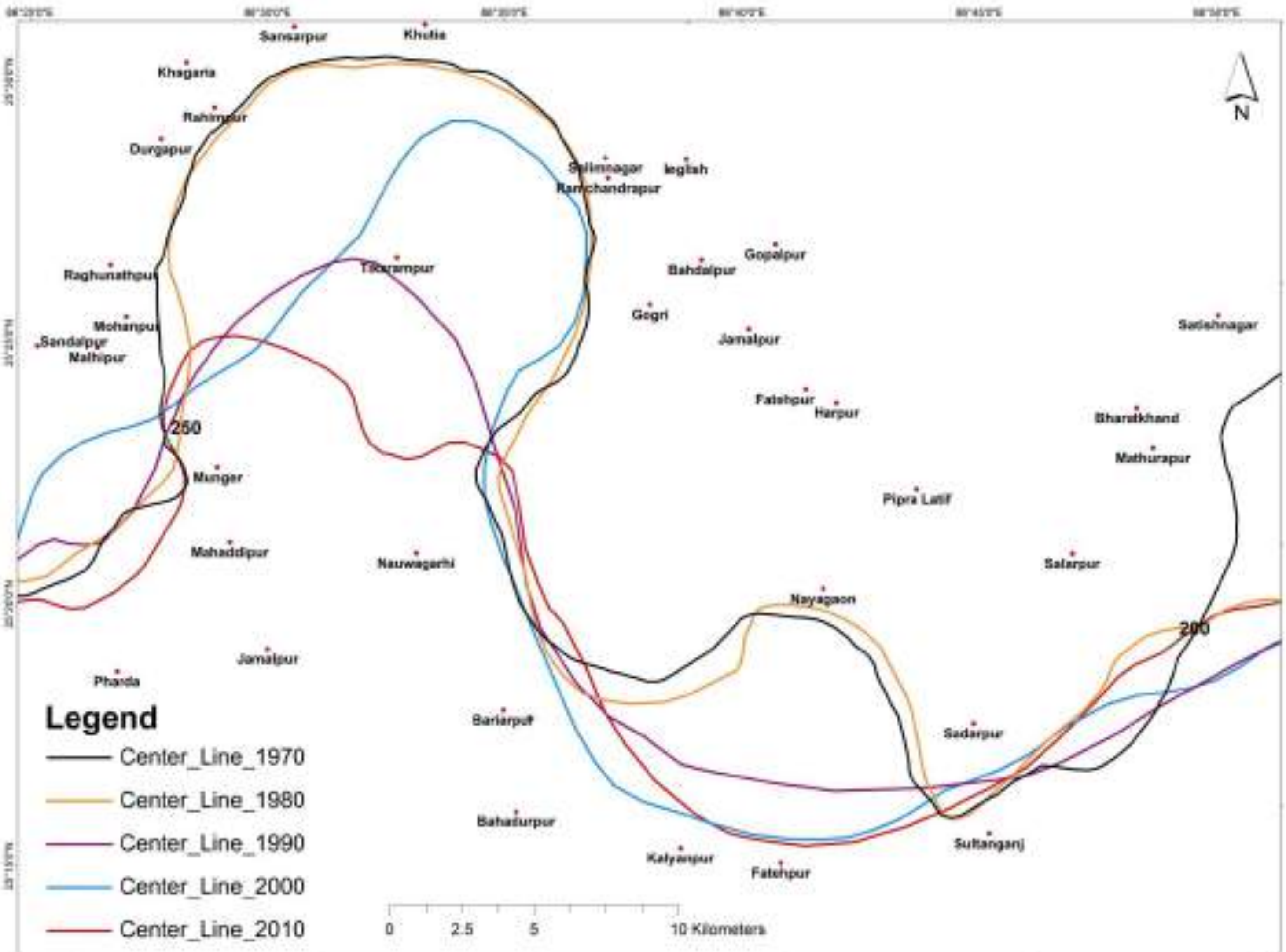


Figure 10.23a Shifting of center line of Ganga river from chainage 200-250 km

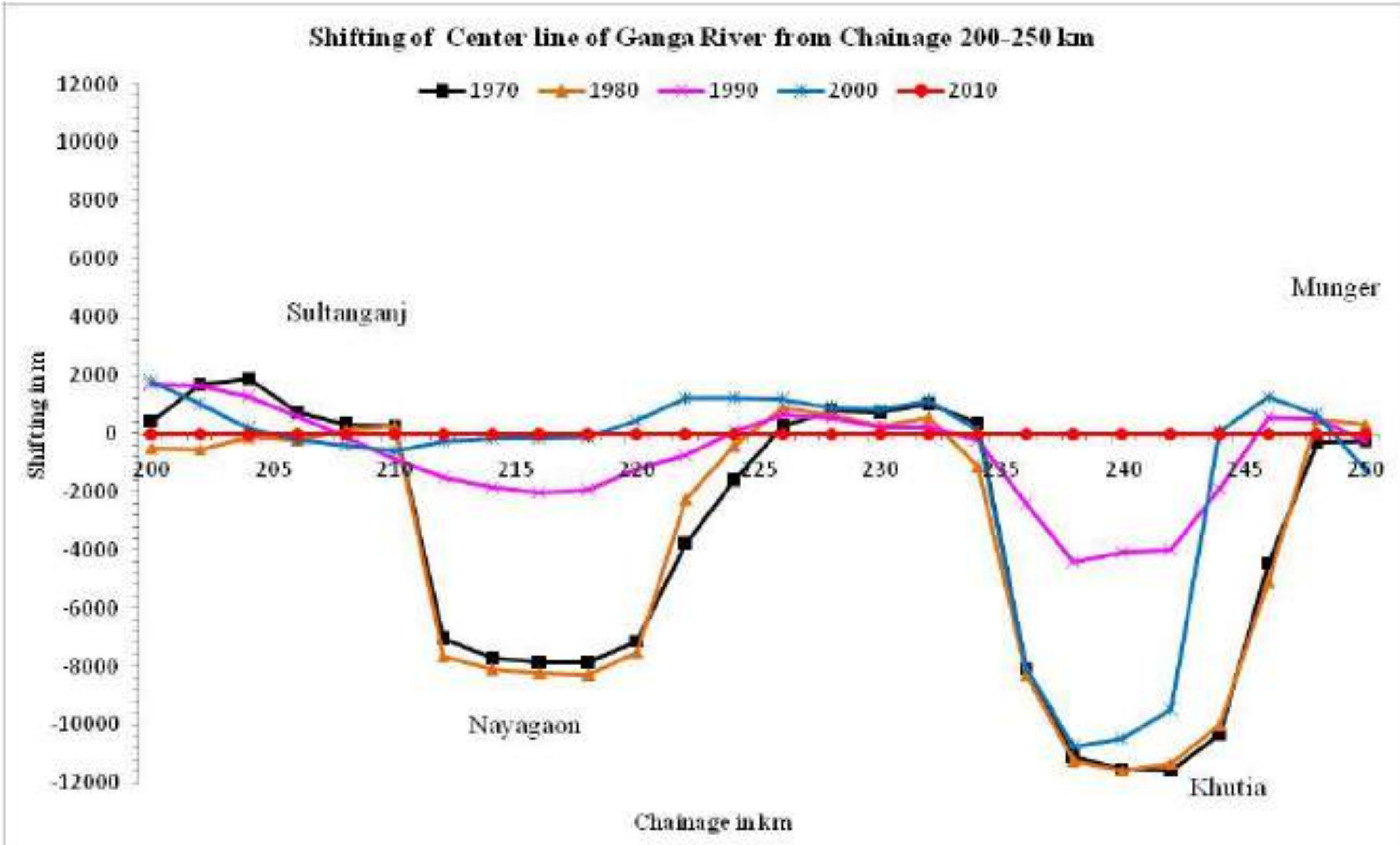


Figure 10.23b Shifting of center line of Ganga river from chainage 200-250 km

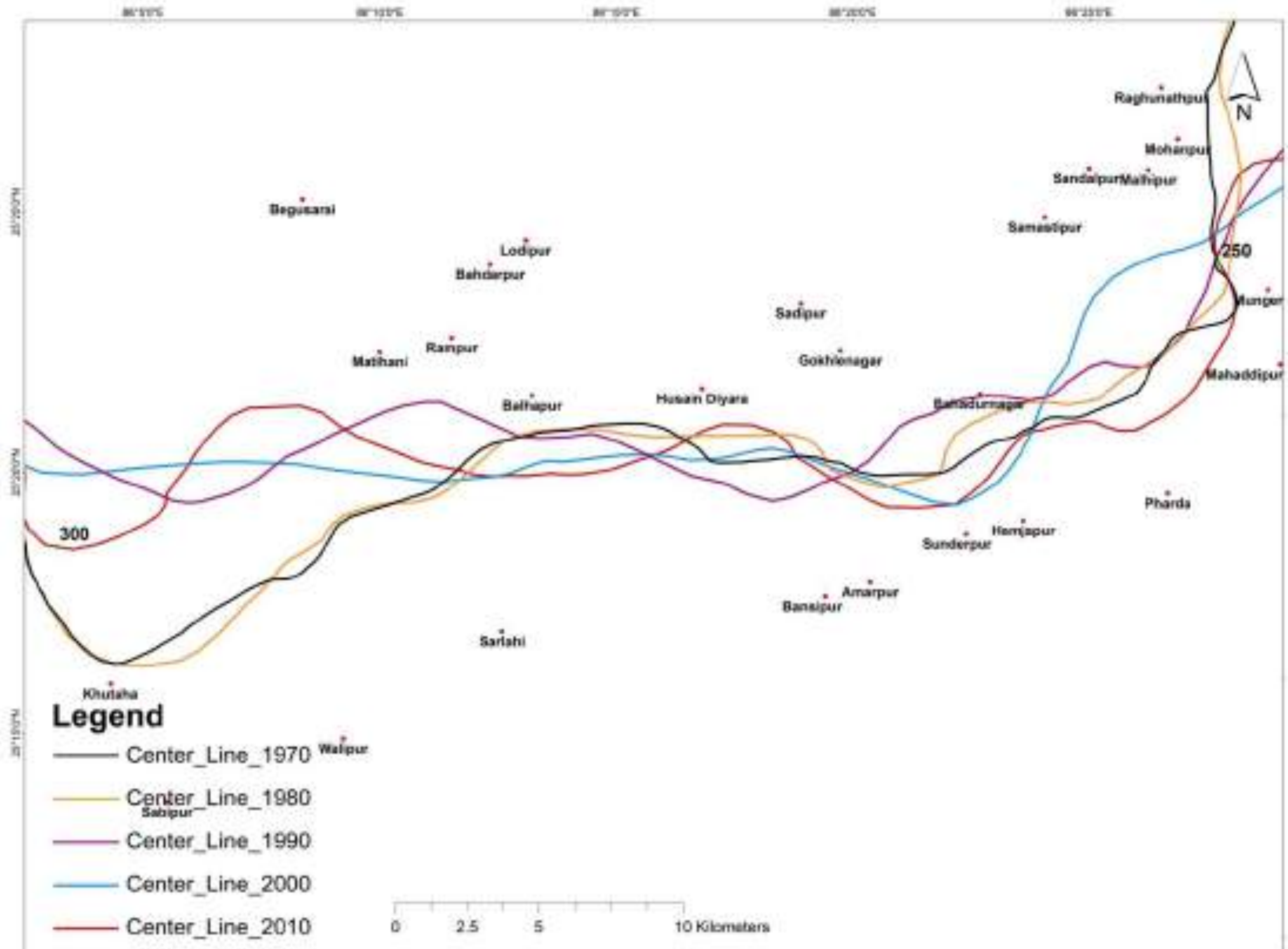


Figure 10.24a Shifting of center line of Ganga river from chainage 250-300 km

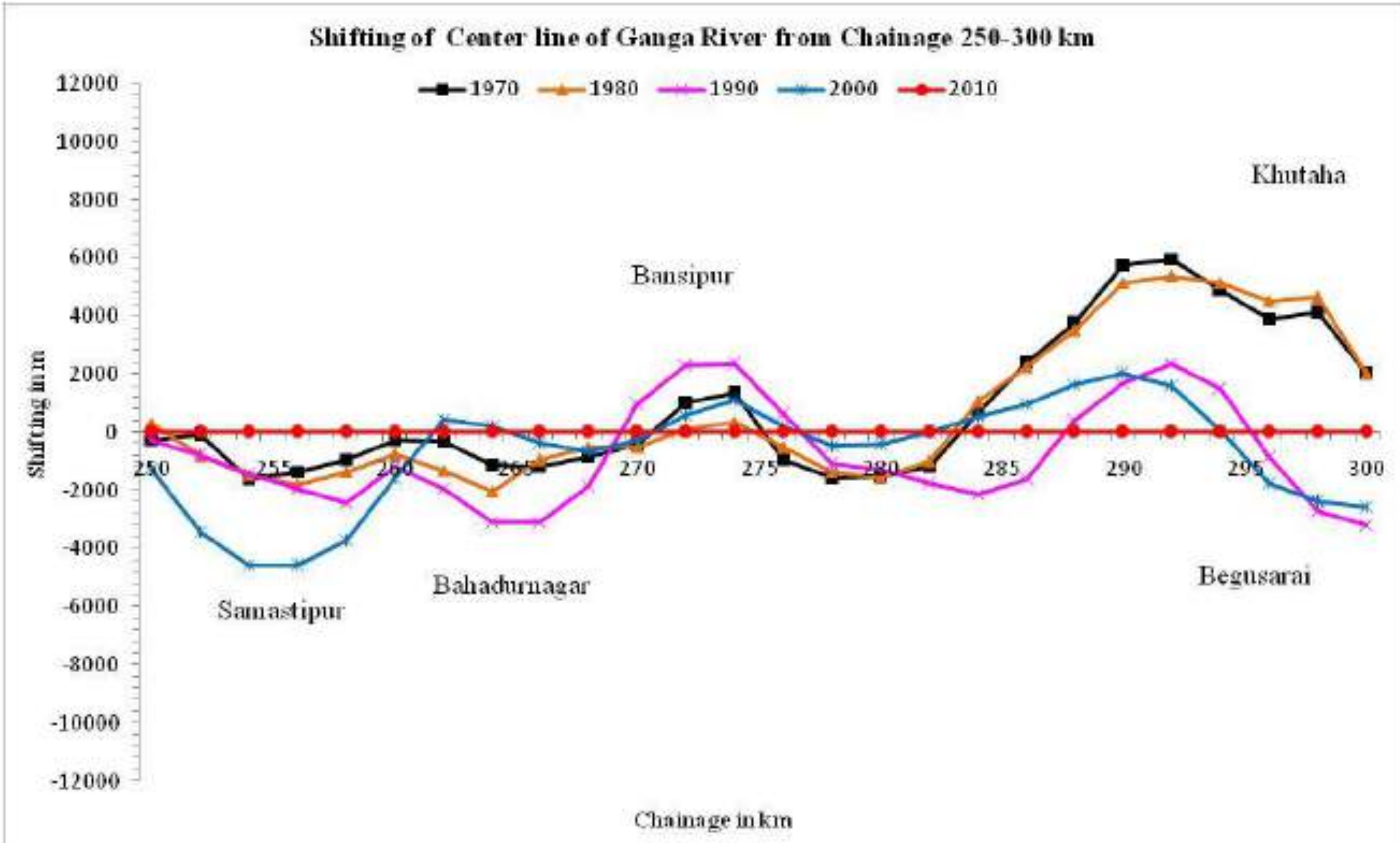


Figure 10.24b Shifting of center line of Ganga river from chainage 250-300 km

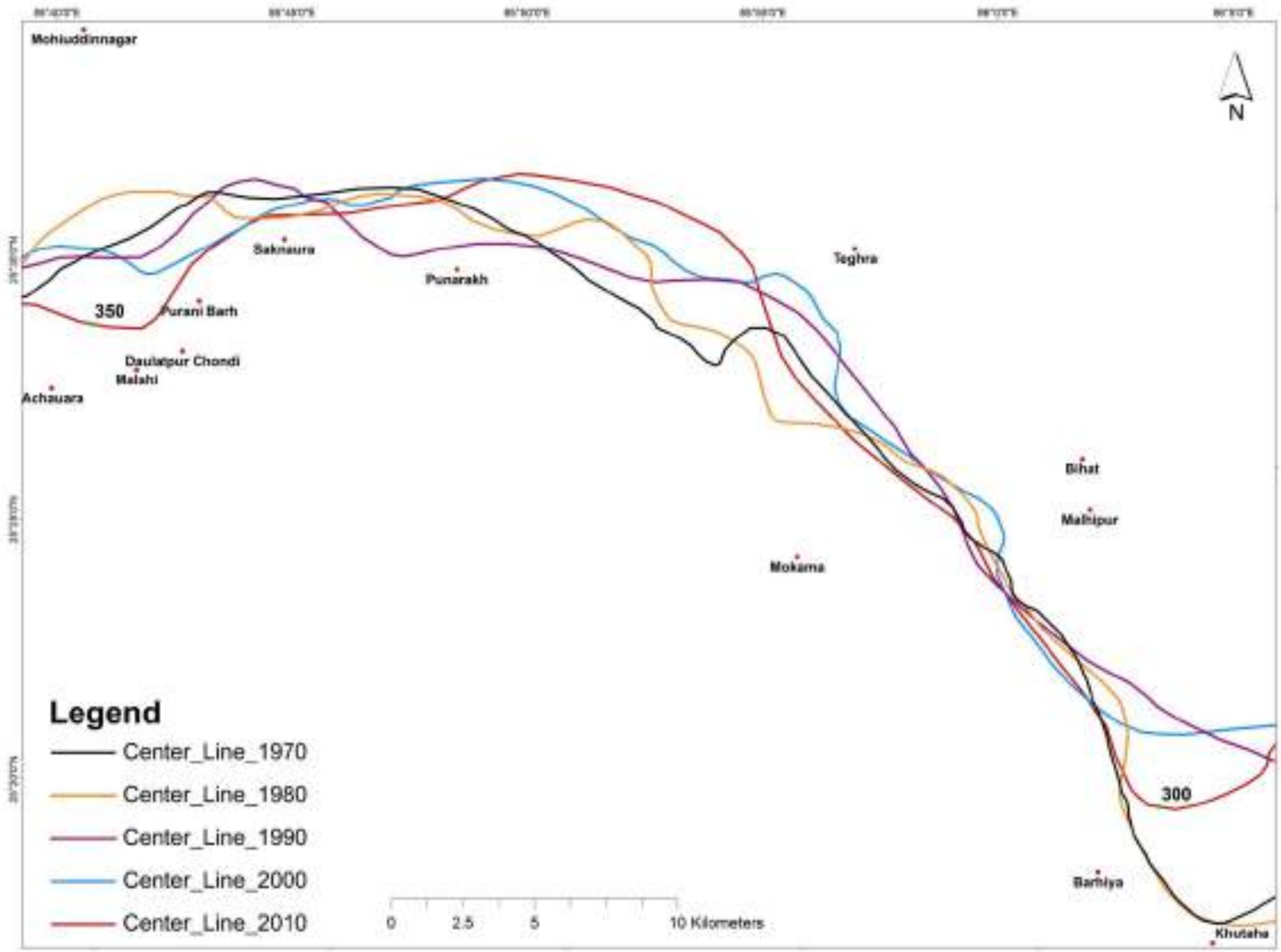


Figure 10.25a Shifting of center line of Ganga river from chainage 300-350 km

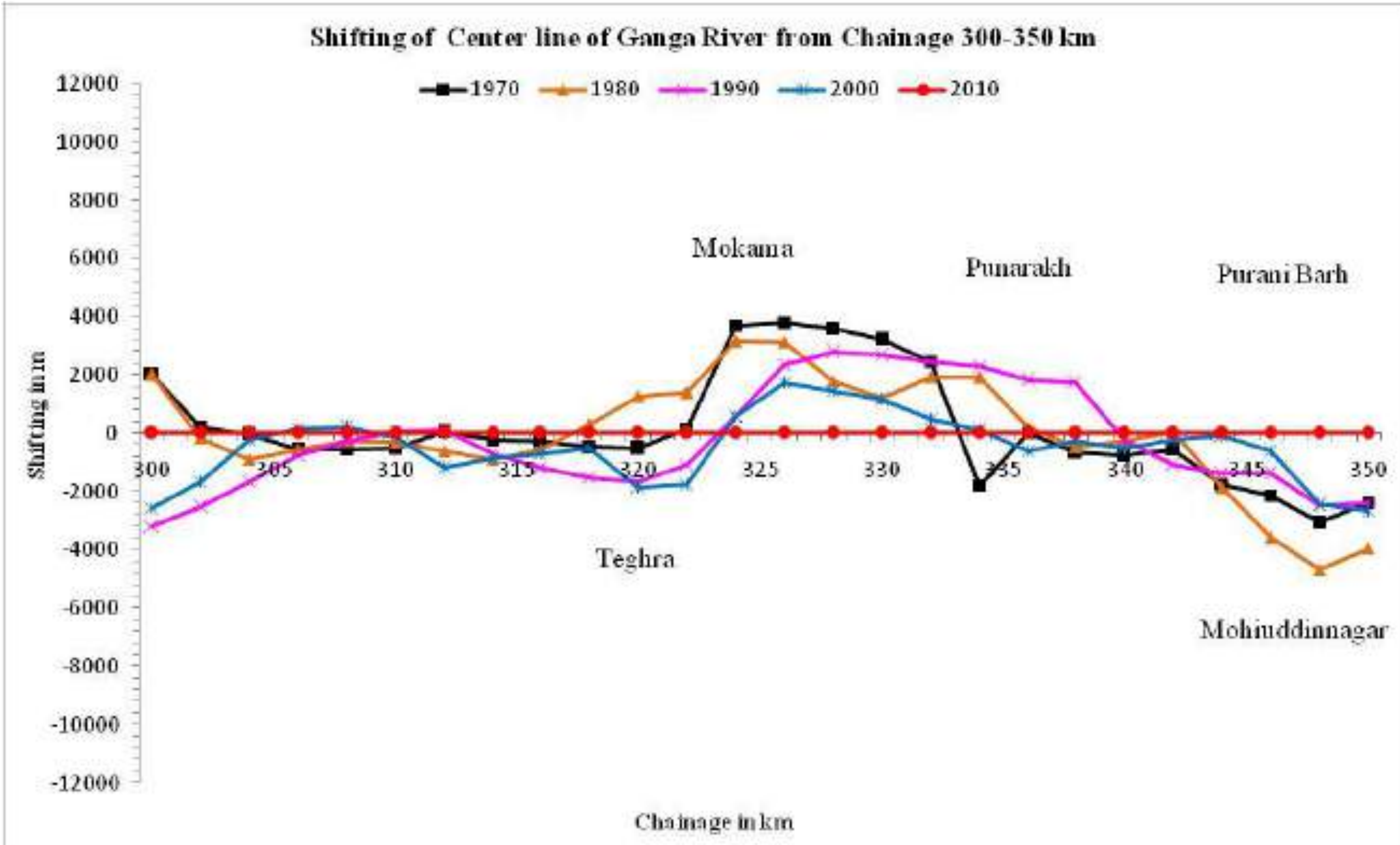


Figure 10.25b Shifting of center line of Ganga river from chainage 300-350 km

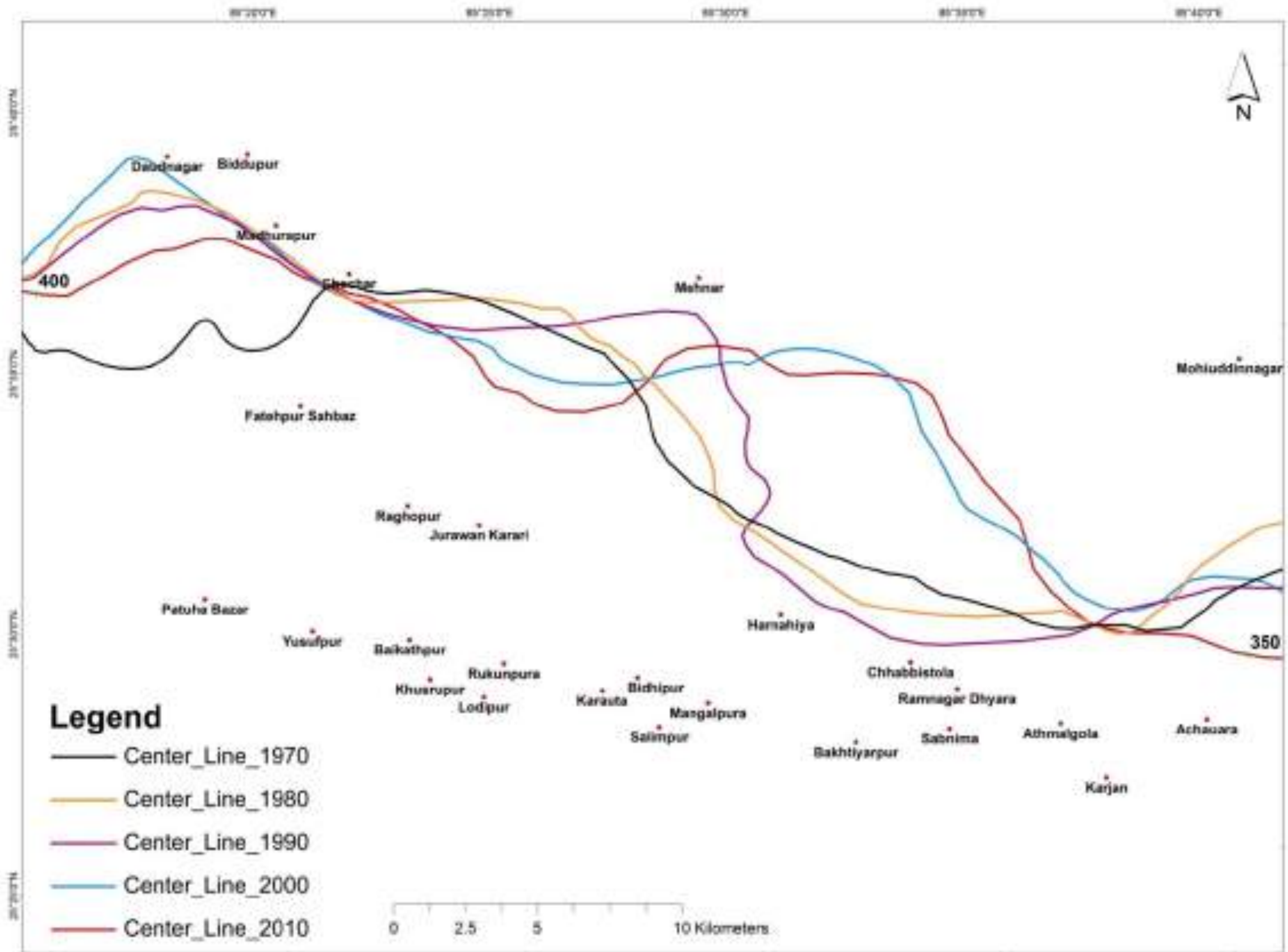


Figure 10.26a Shifting of center line of Ganga river from chainage 350-400 km

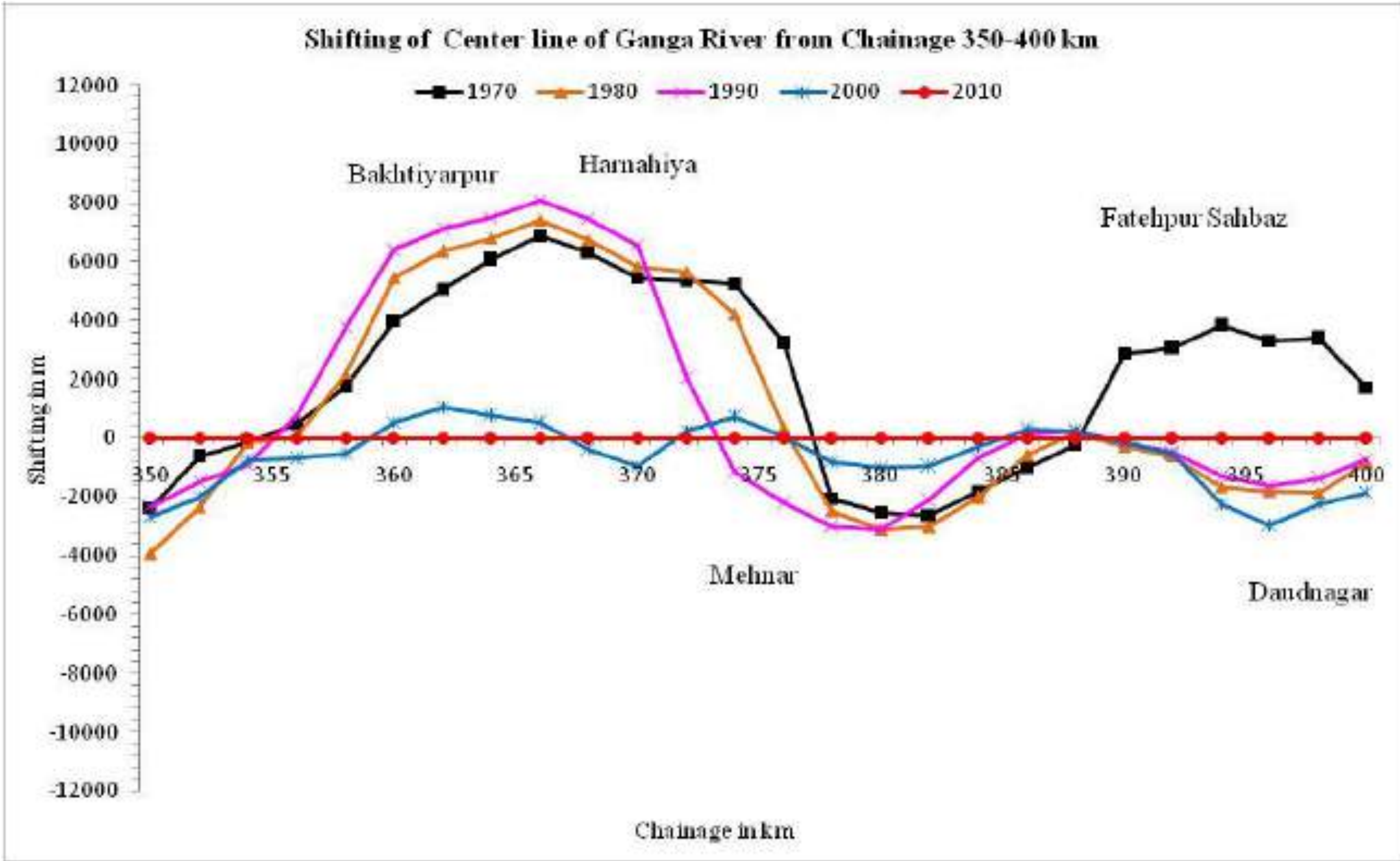


Figure 10.26b Shifting of center line of Ganga river from chainage 350-400 km

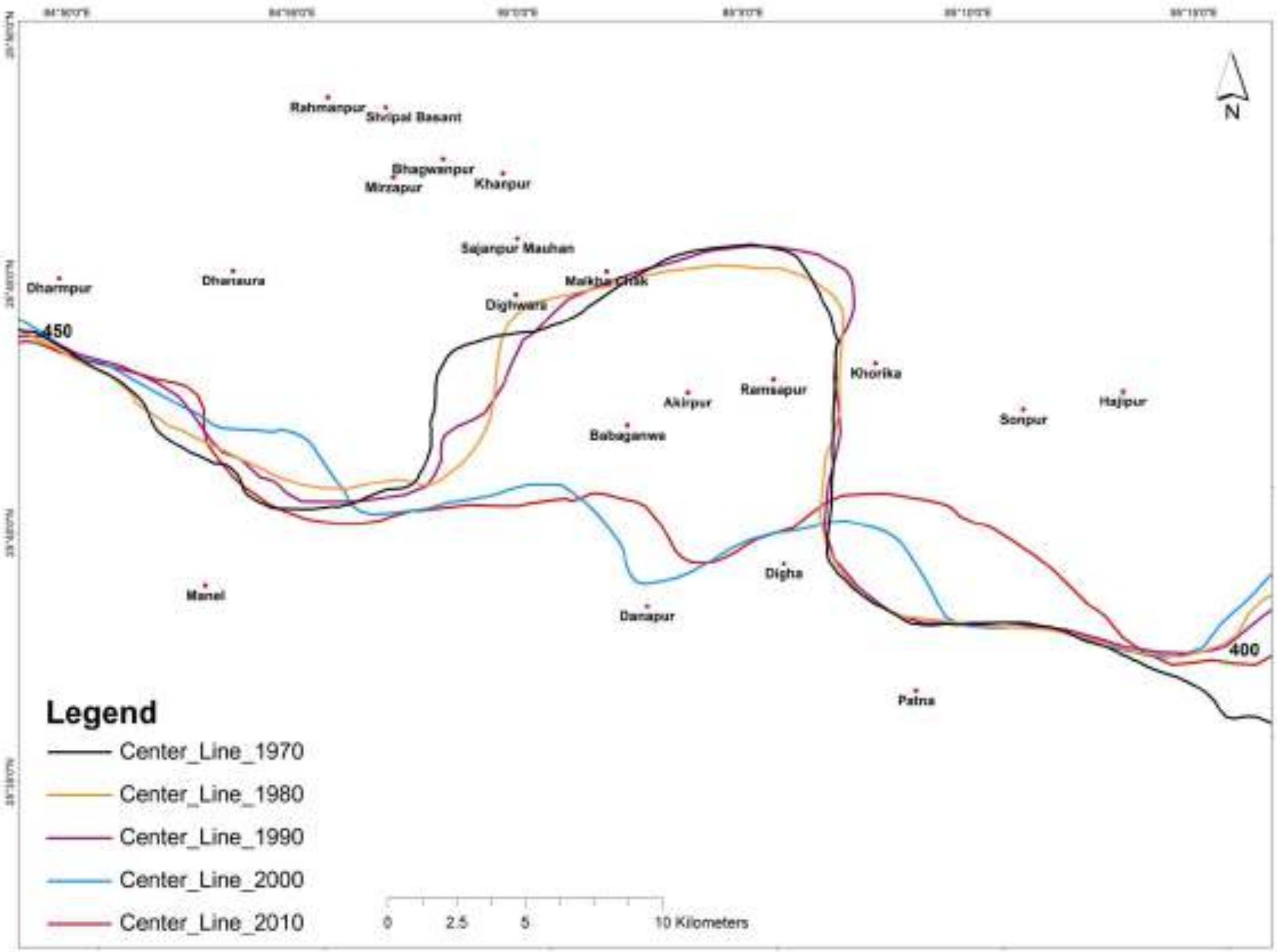


Figure 10.27a Shifting of center line of Ganga river from chainage 400-450 km

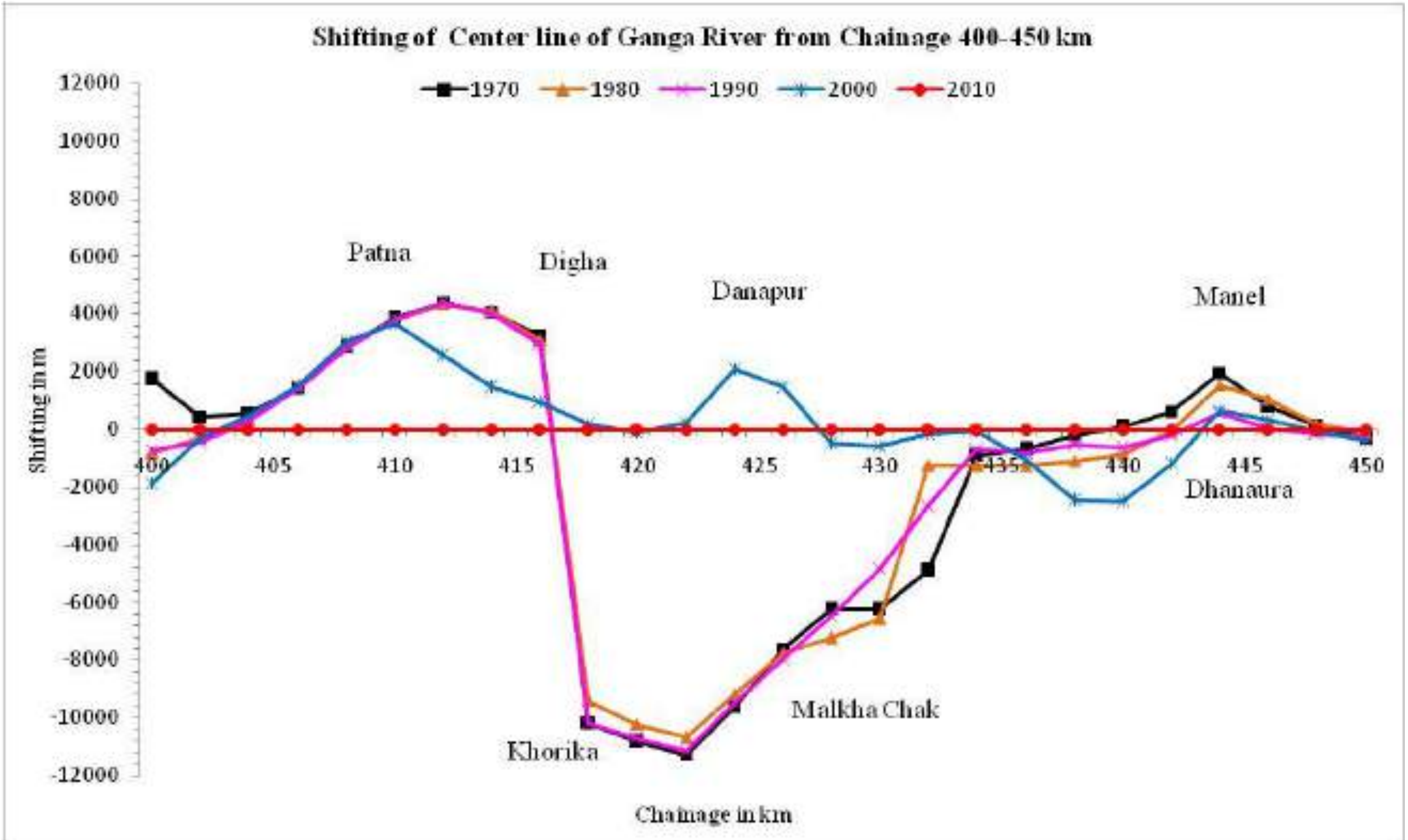


Figure 10.27b Shifting of center line of Ganga river from chainage 400-450 km

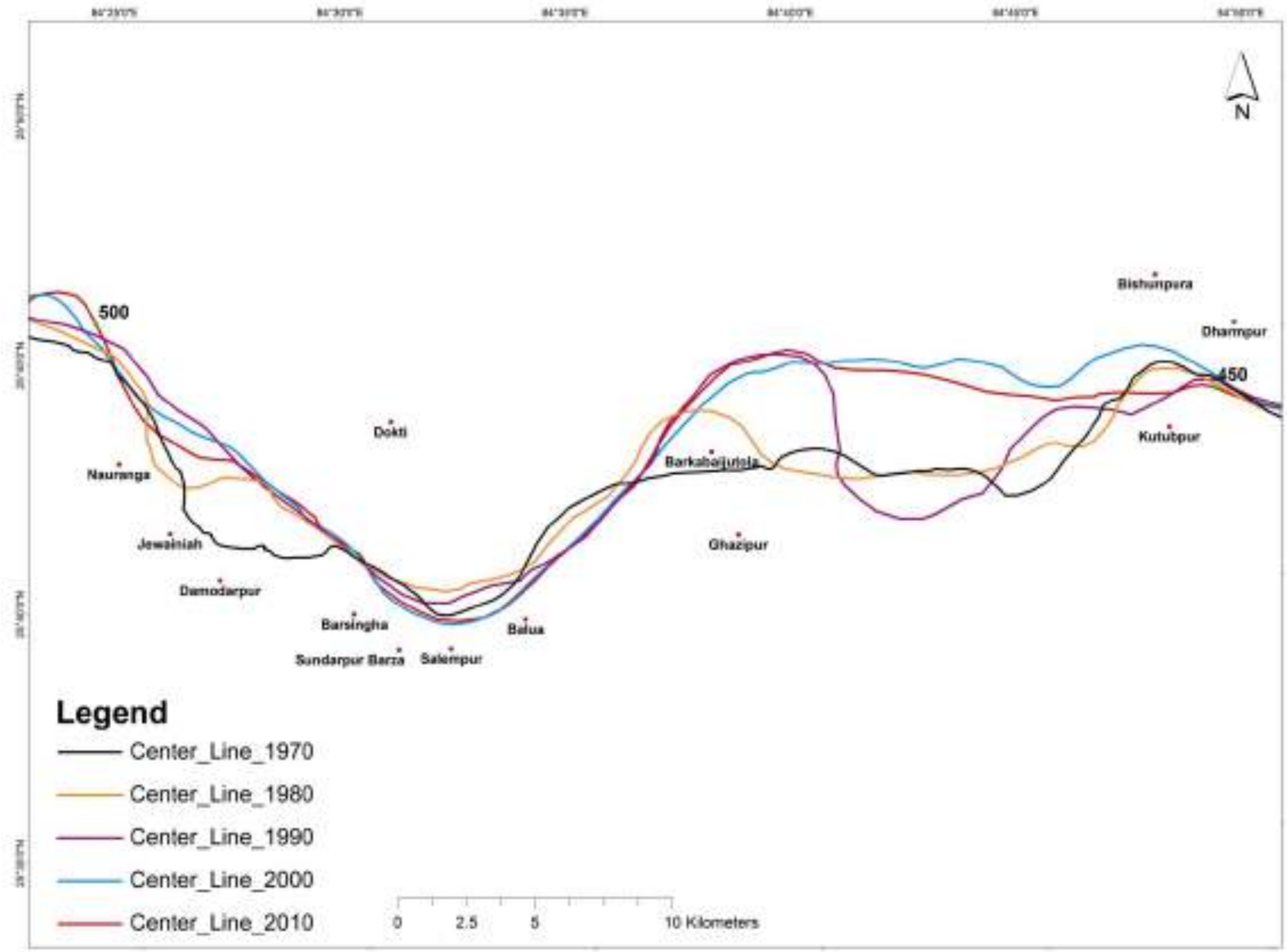


Figure 10.28a Shifting of center line of Ganga river from chainage 450-500 km

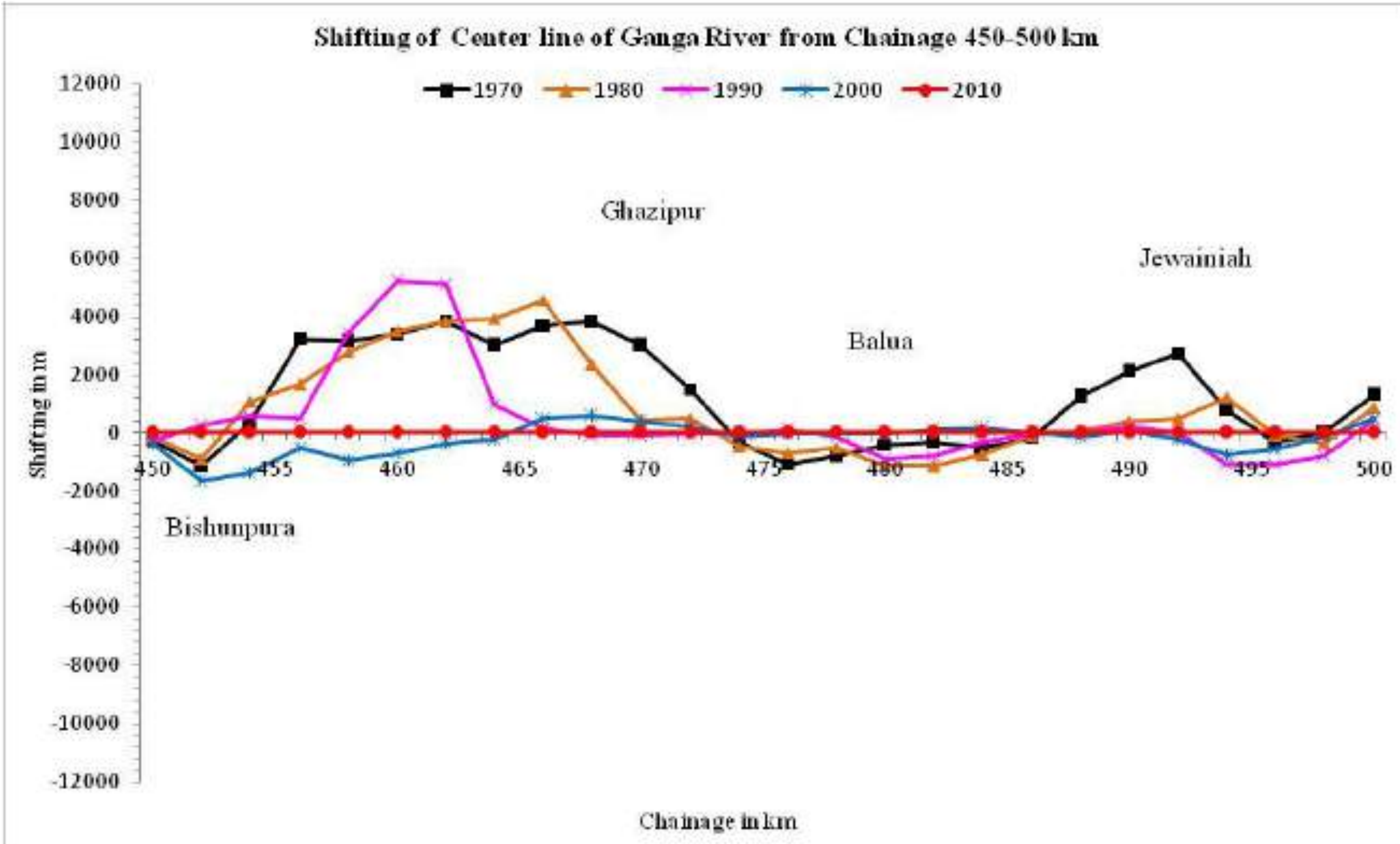


Figure 10.28b Shifting of center line of Ganga river from chainage 450-500 km

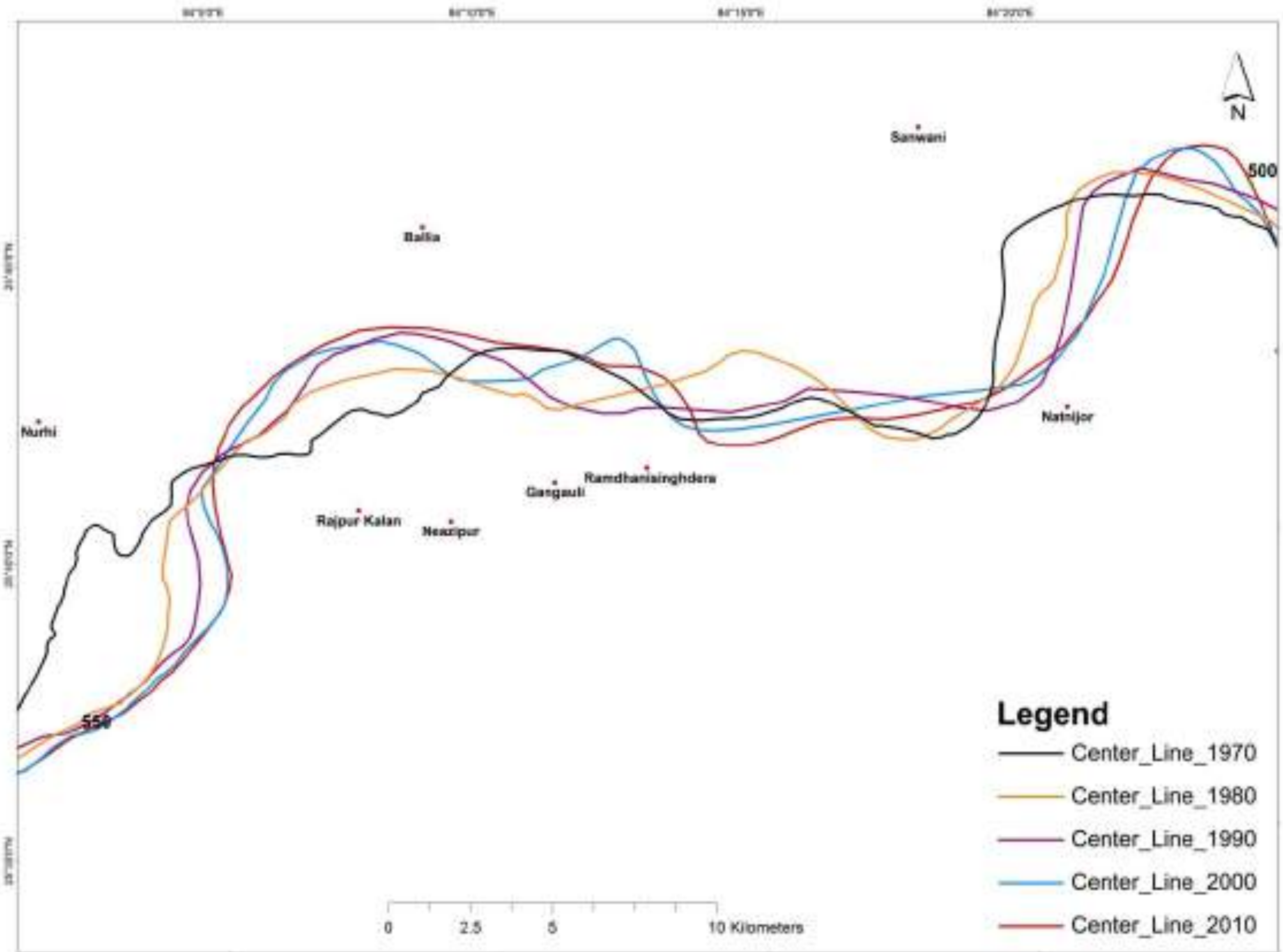


Figure 10.29a Shifting of center line of Ganga river from chainage 500-550 km

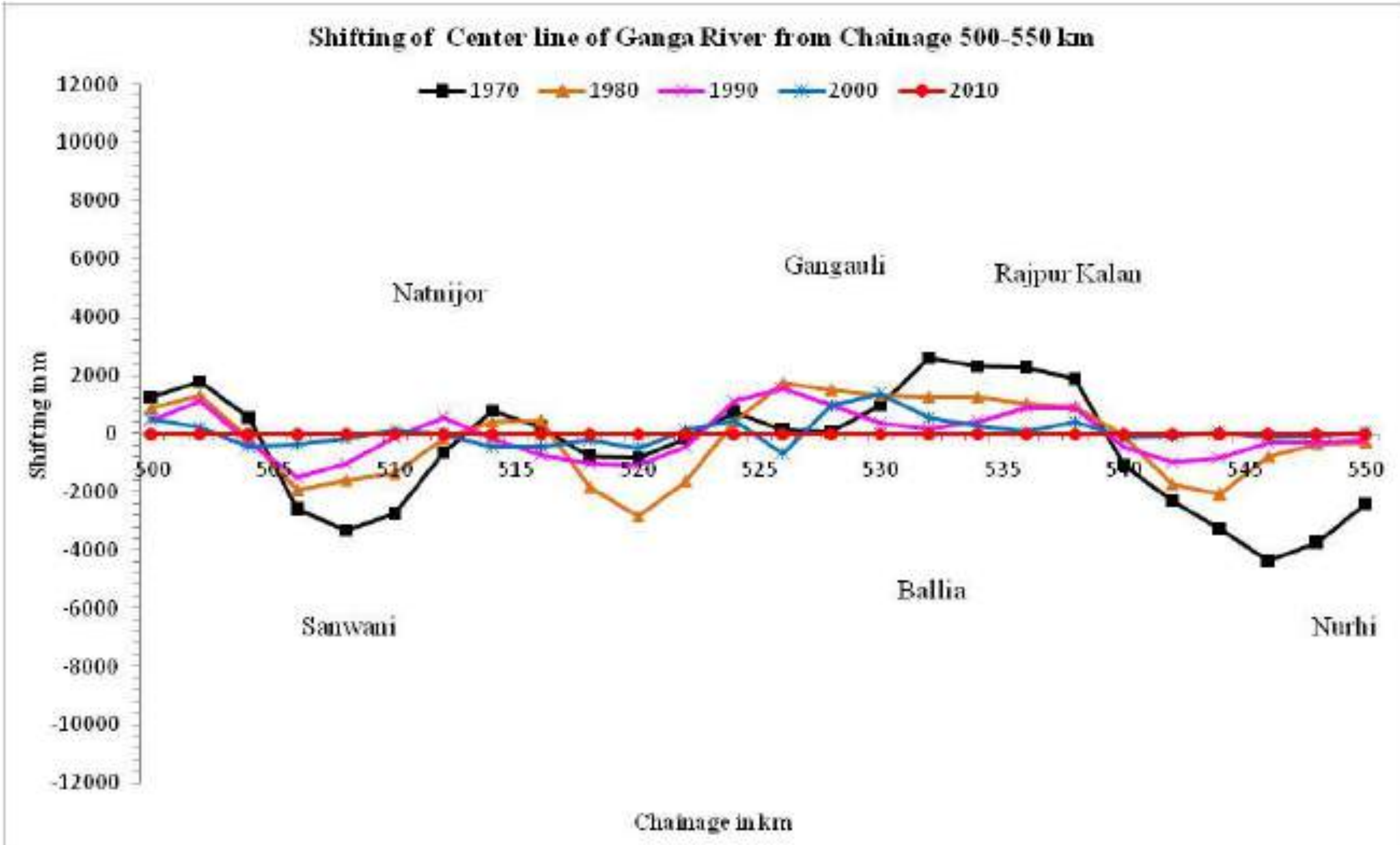


Figure 10.29b Shifting of center line of Ganga river from chainage 500-550 km

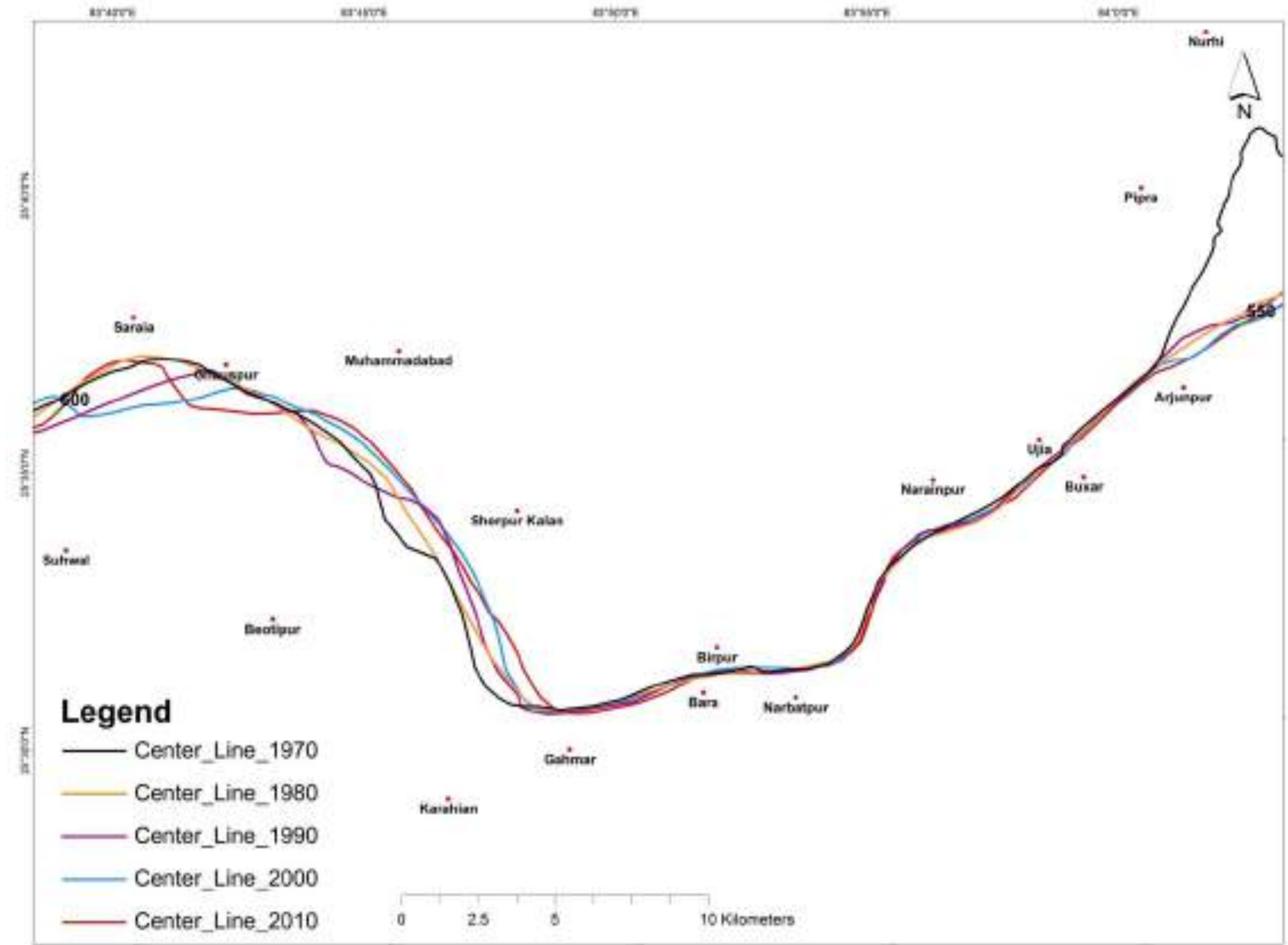


Figure 10.30a Shifting of center line of Ganga river from chainage 550-600 km

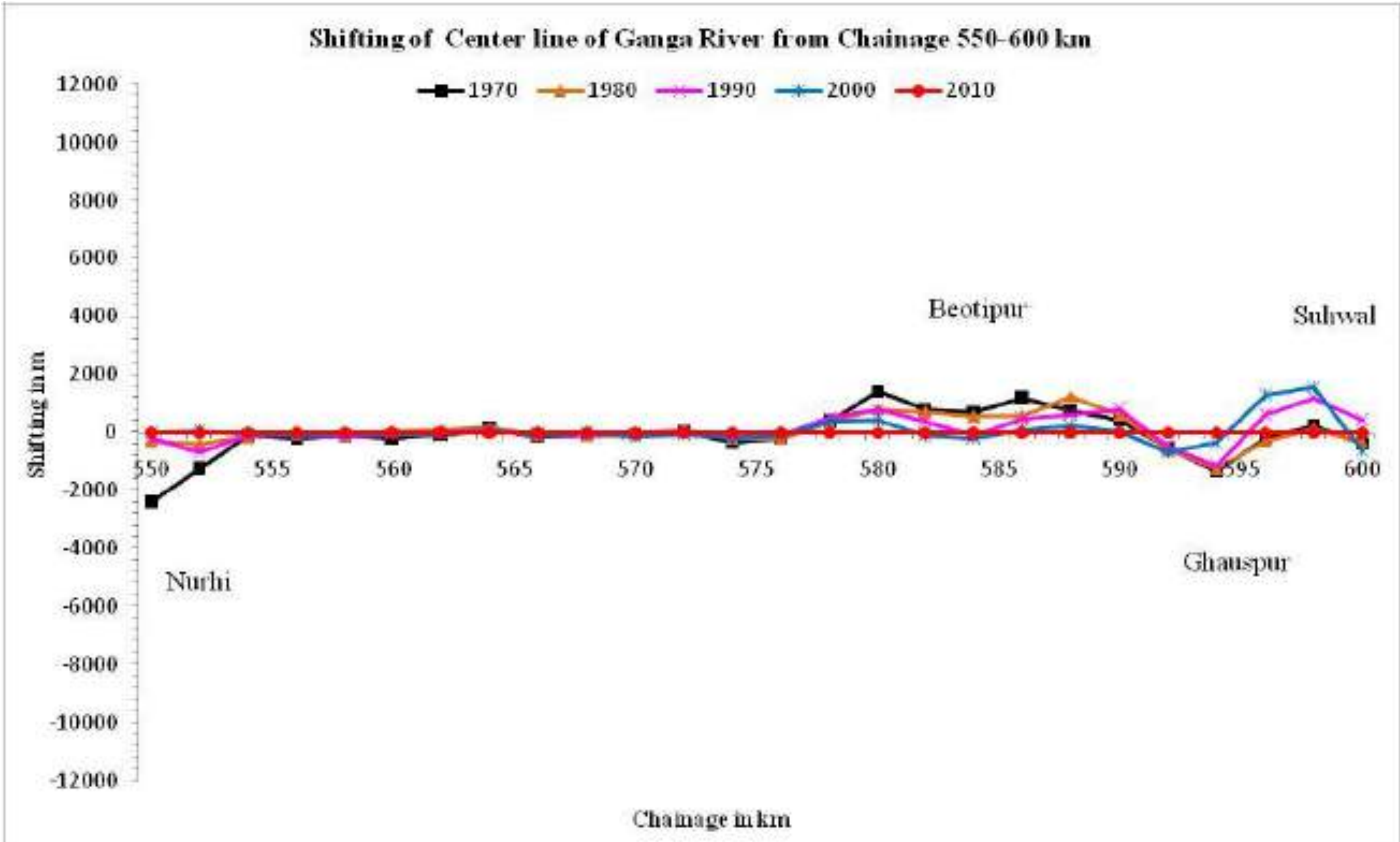


Figure 10.30b Shifting of center line of Ganga river from chainage 550-600 km

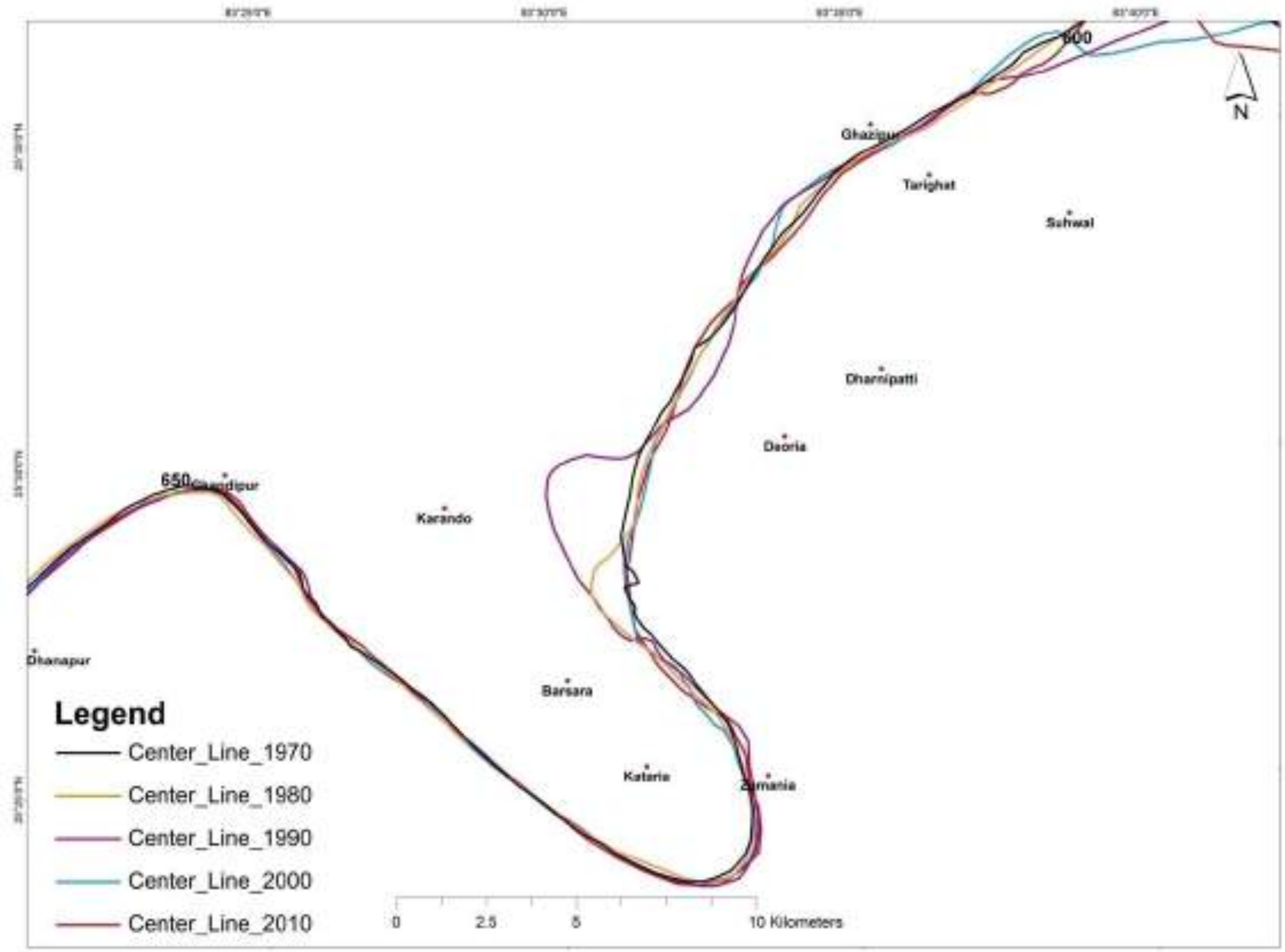


Figure 10.31a Shifting of center line of Ganga river from chainage 600-650 km

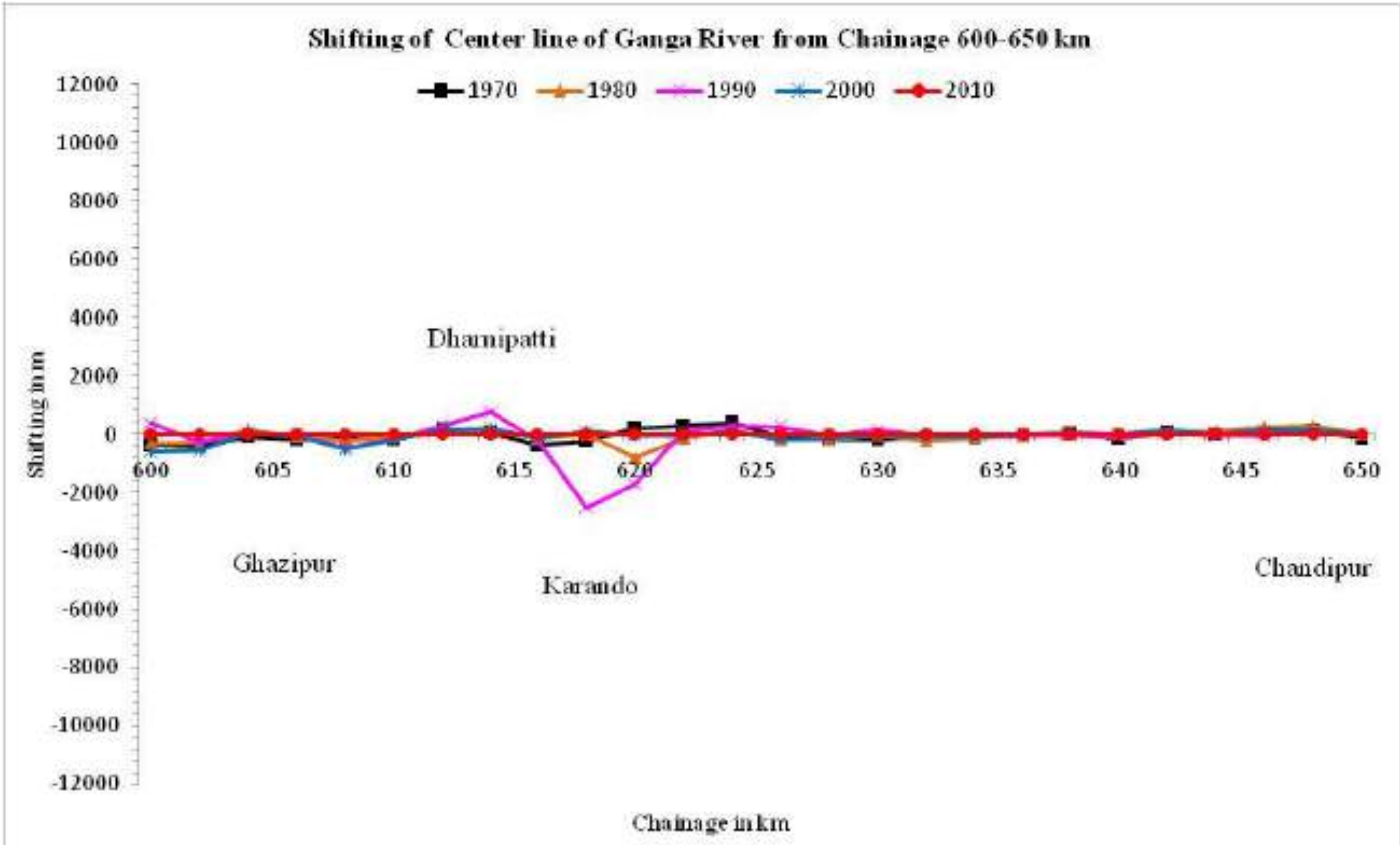


Figure 10.31b Shifting of center line of Ganga river from chainage 600-650 km

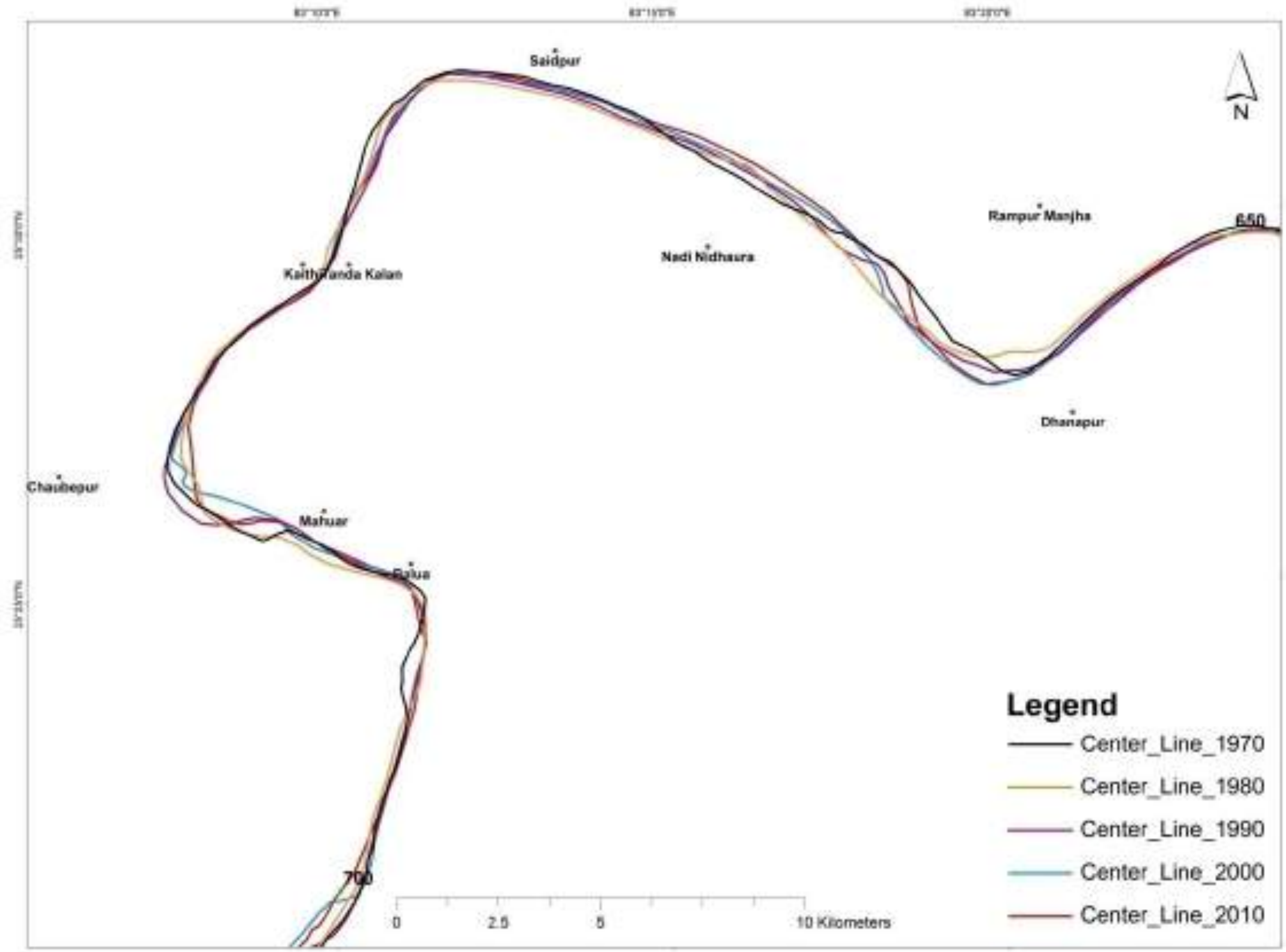


Figure 10.32a Shifting of center line of Ganga river from chainage 650-700 km

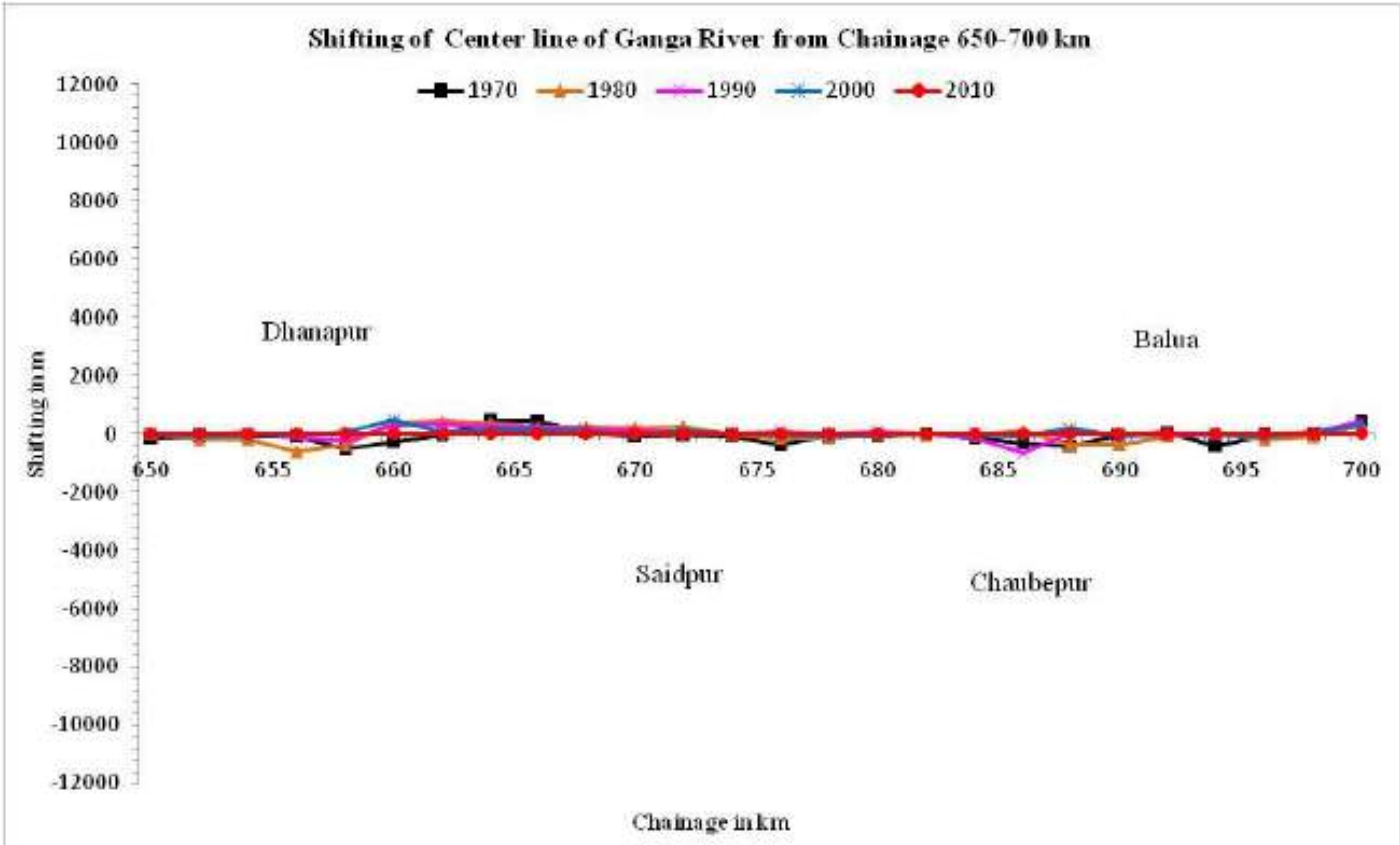


Figure 10.32b Shifting of center line of Ganga river from chainage 650-700 km

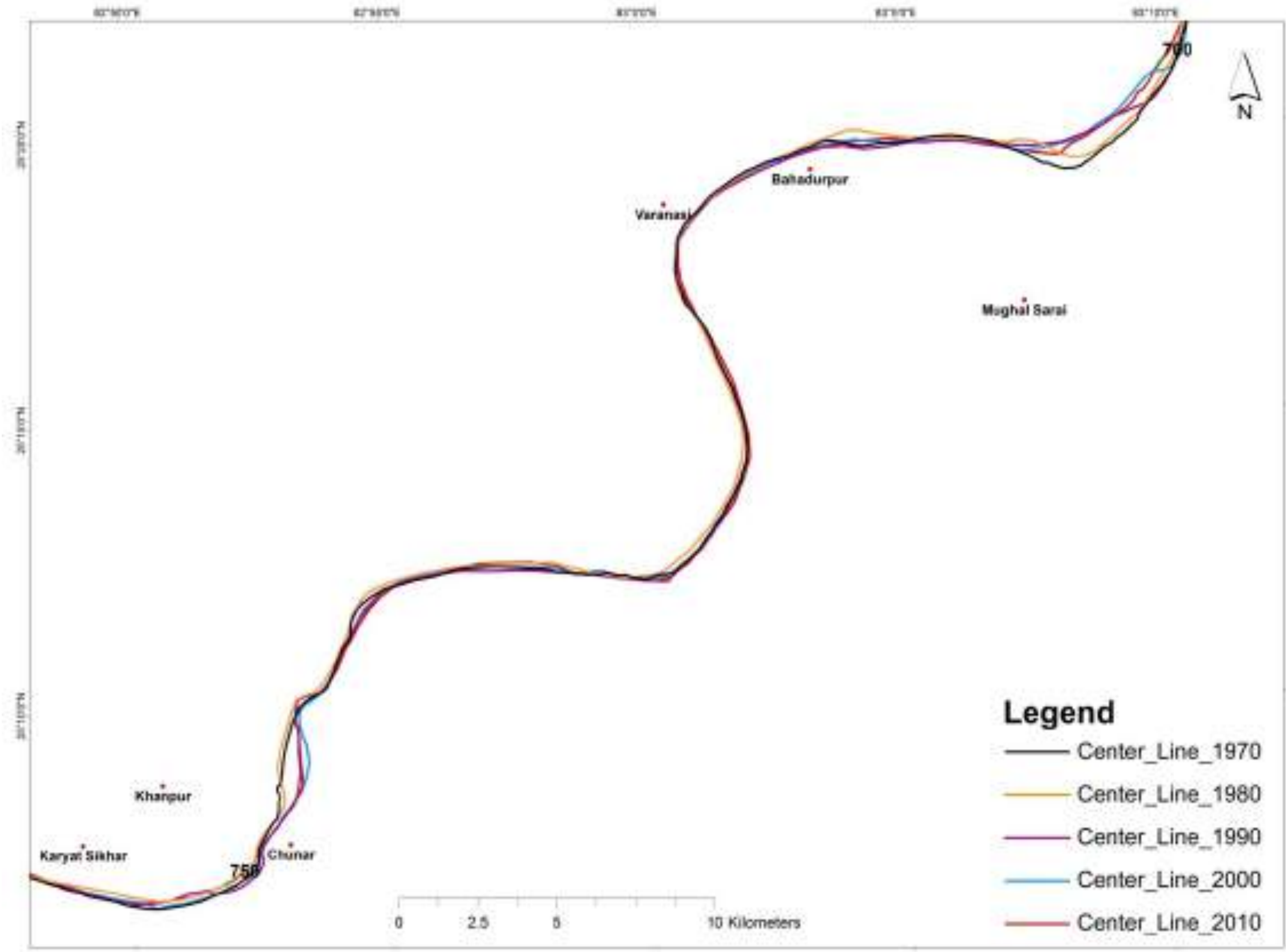


Figure 10.33a Shifting of center line of Ganga river from chainage 700-750 km

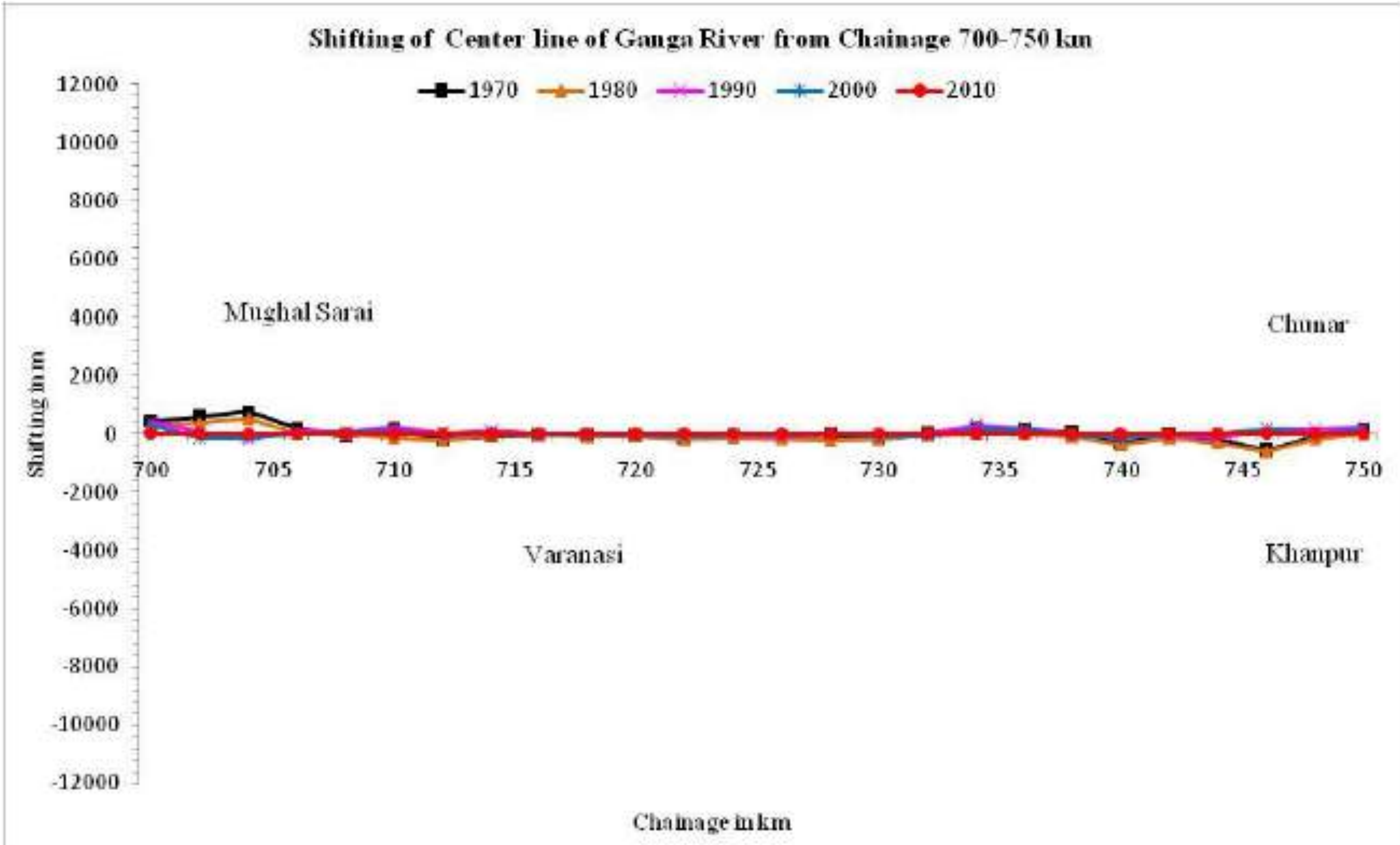


Figure 10.33b Shifting of center line of Ganga river from chainage 700-750 km

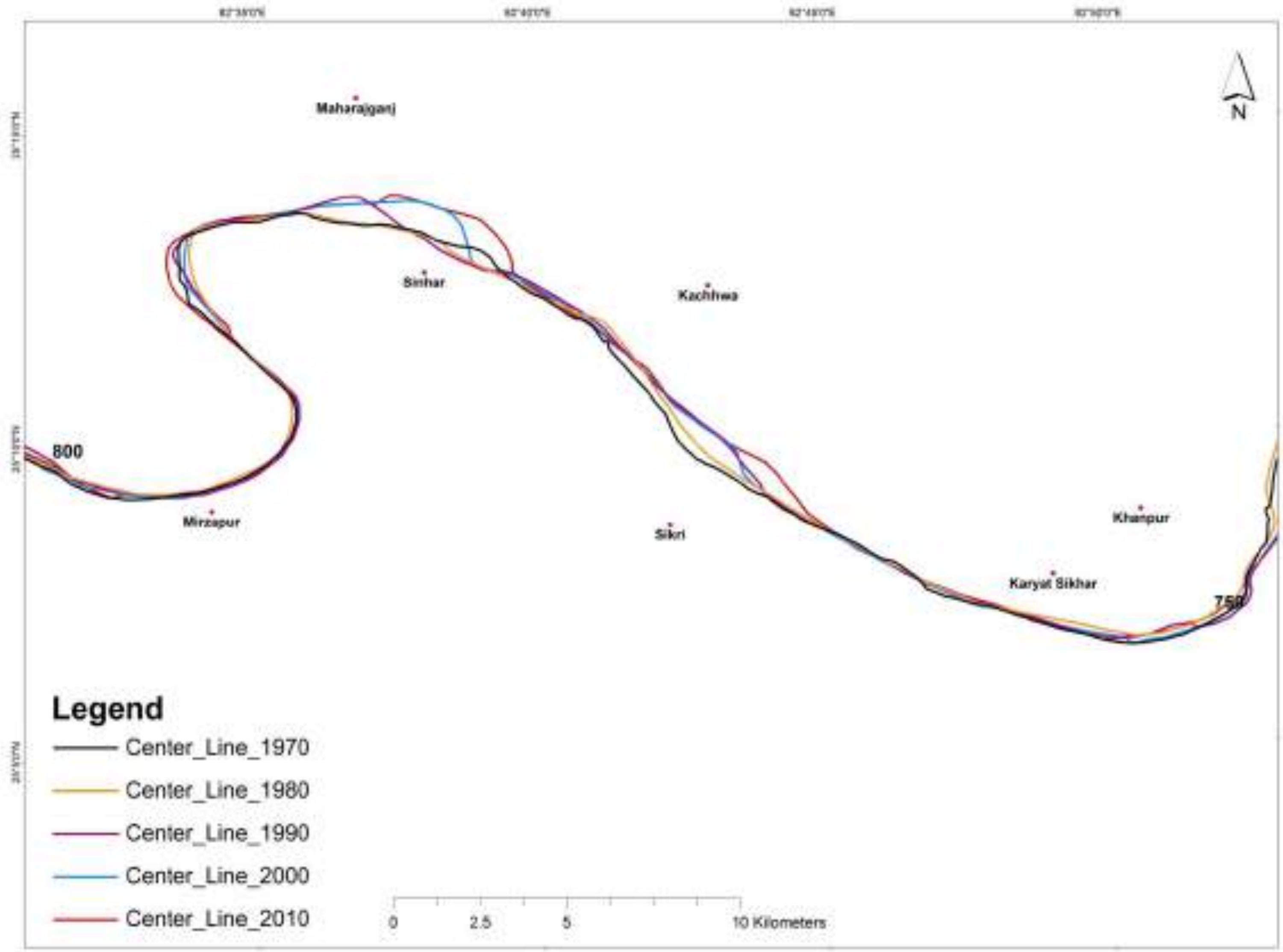


Figure 10.34a Shifting of center line of Ganga river from chainage 750-800 km

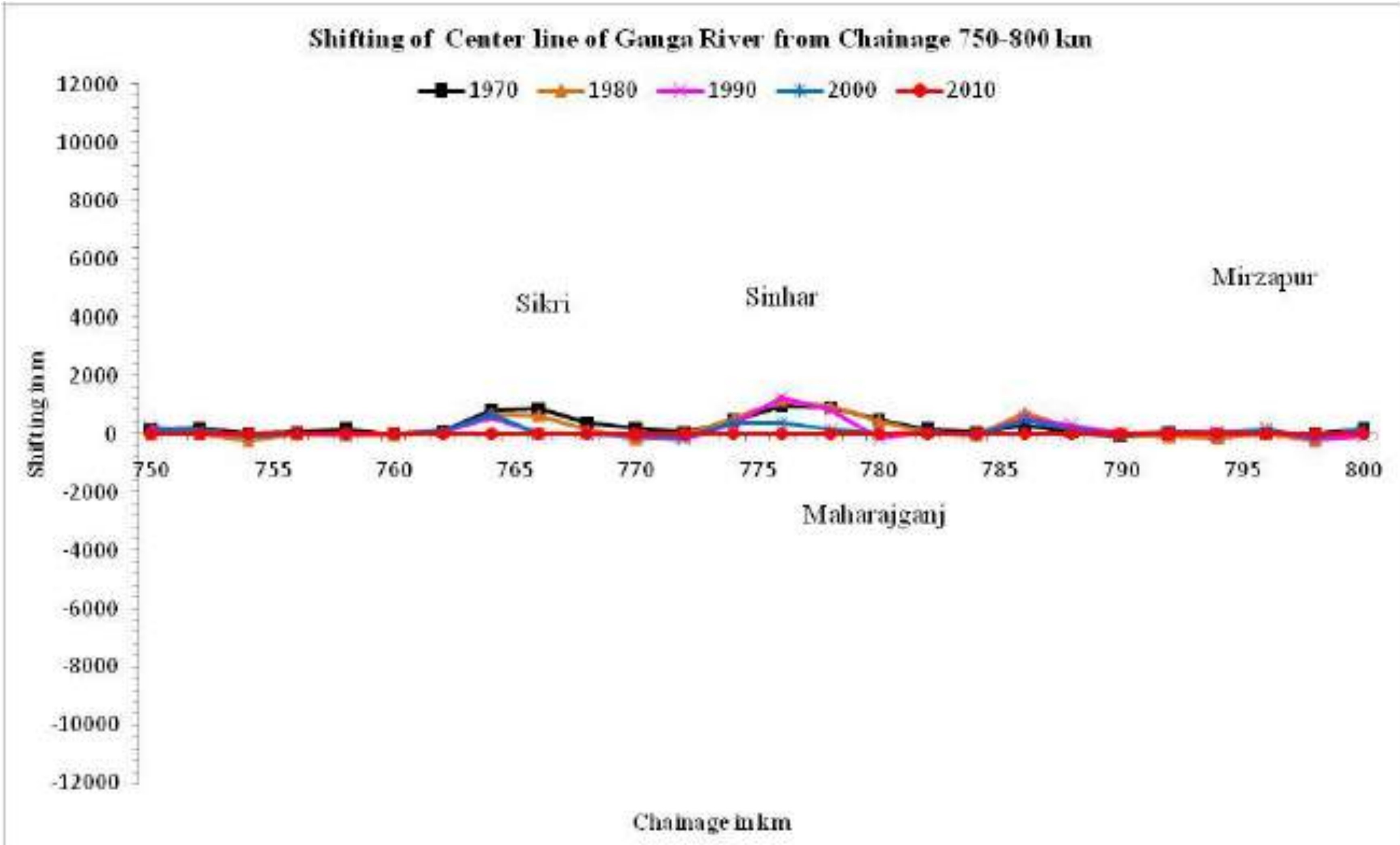


Figure 10.34b Shifting of center line of Ganga river from chainage 750-800 km

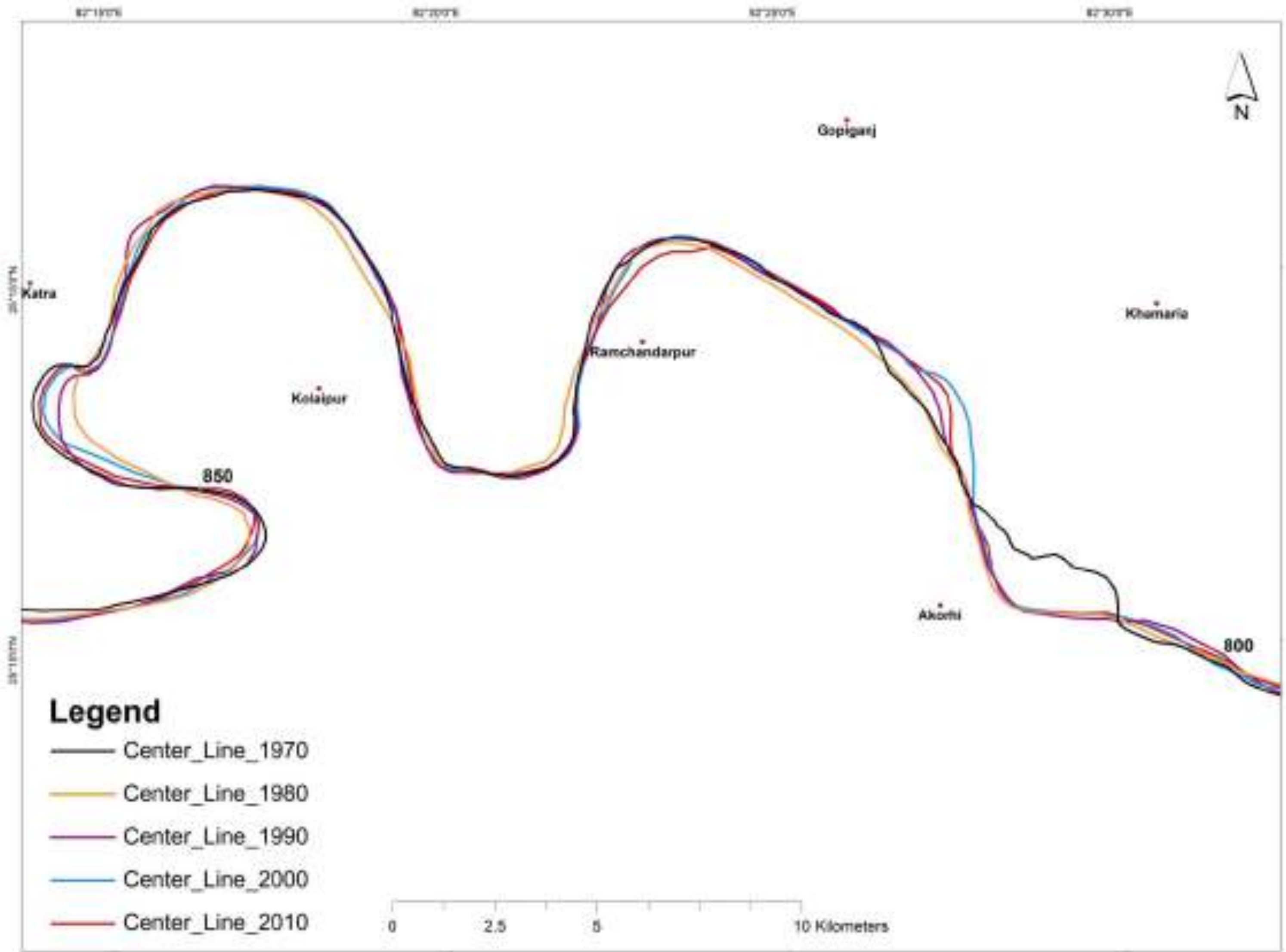


Figure 10.35a Shifting of center line of Ganga river from chainage 800-850 km

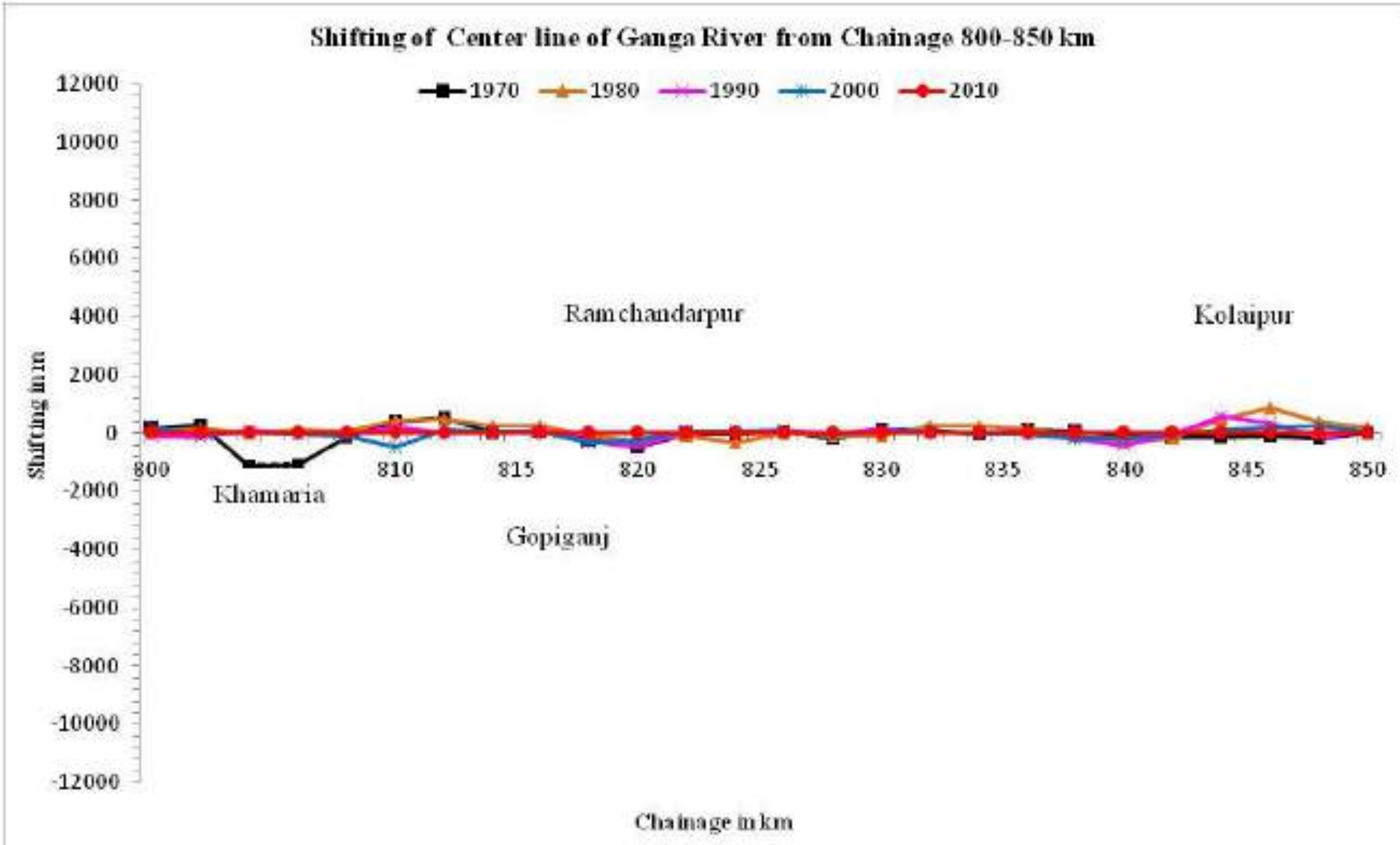


Figure 10.35b Shifting of center line of Ganga river from chainage 800-850 km

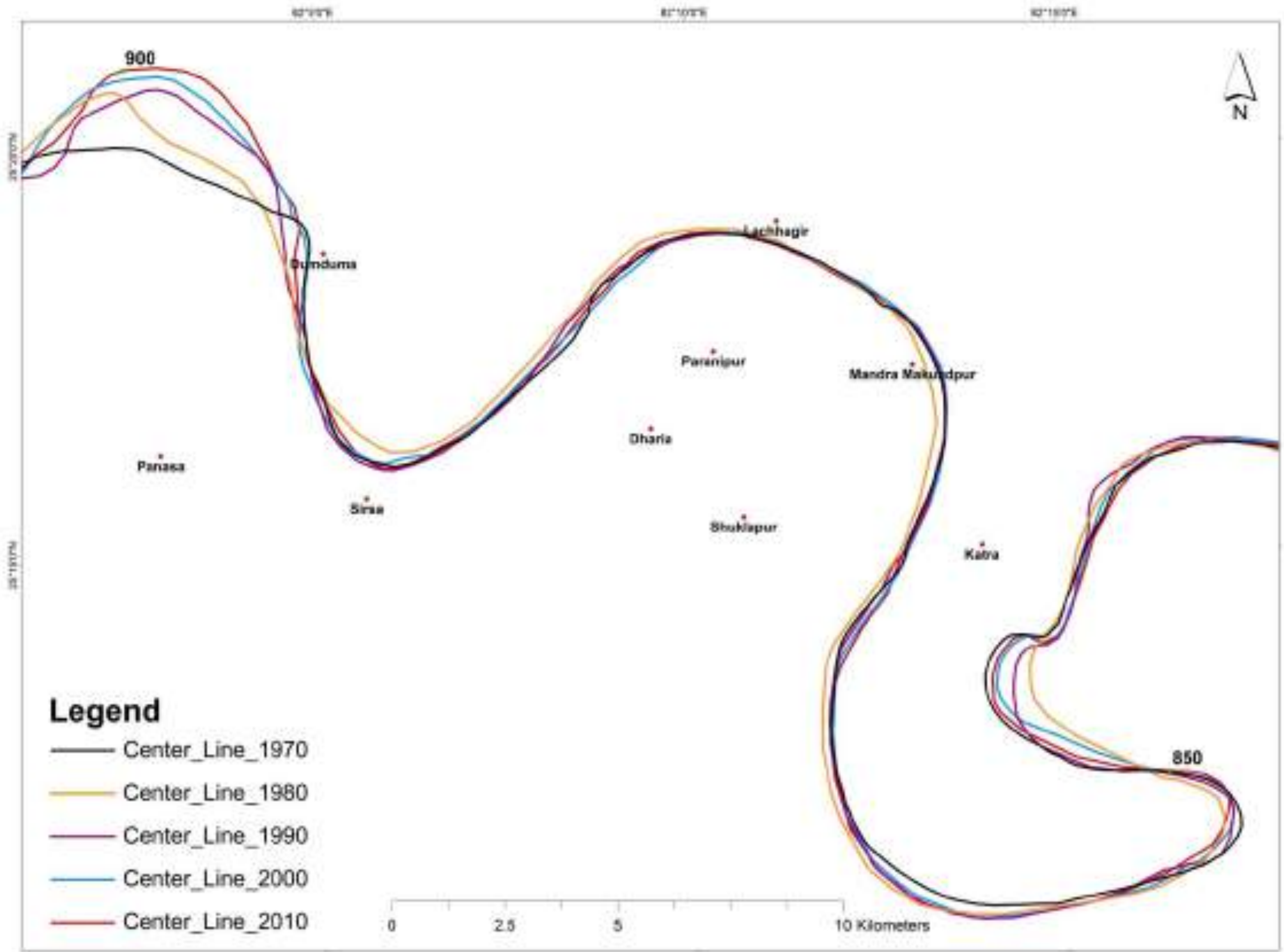


Figure 10.36a Shifting of center line of Ganga river from chainage 850-900 km

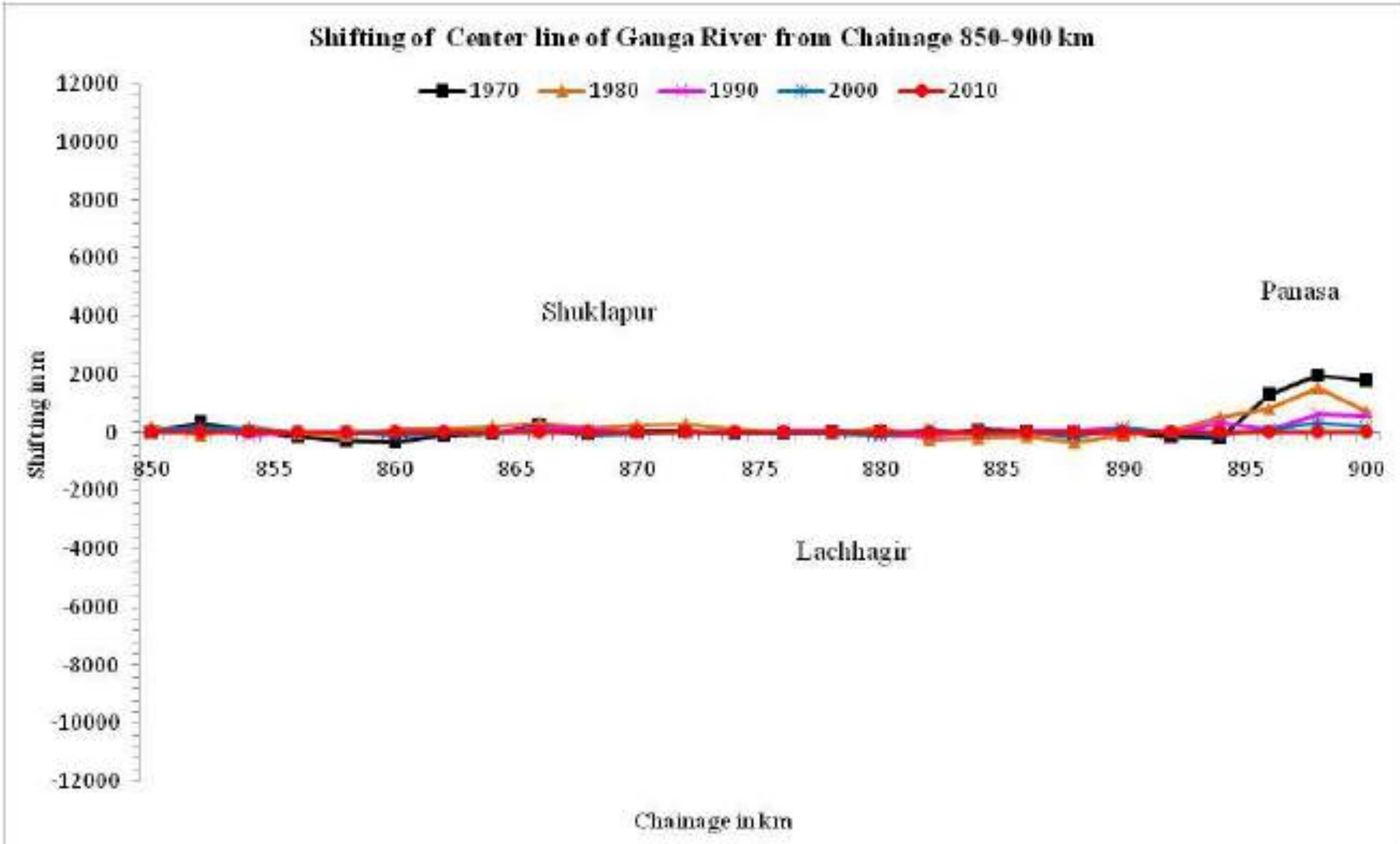


Figure 10.36b Shifting of center line of Ganga river from chainage 850-900 km

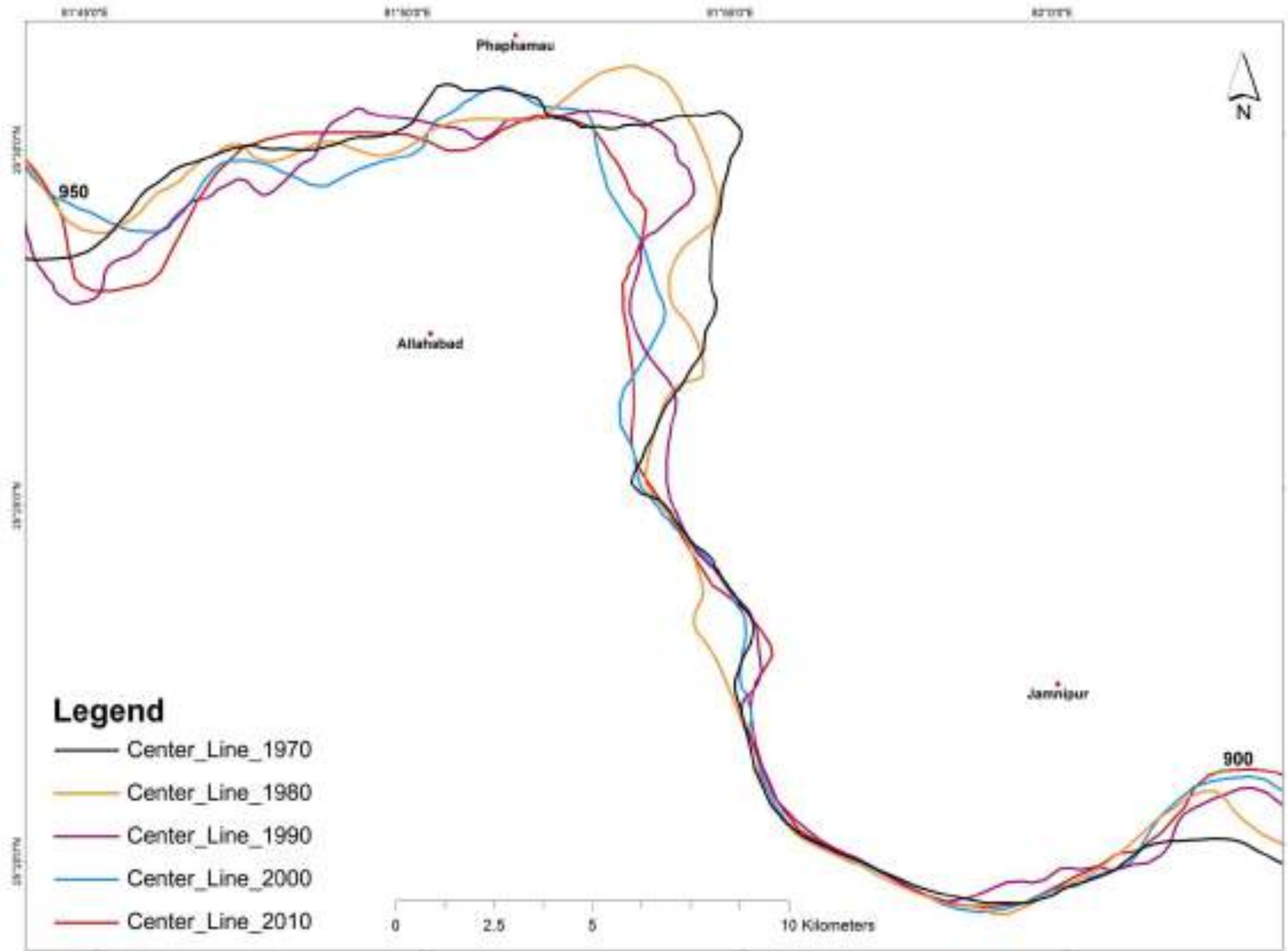


Figure 10.37a Shifting of center line of Ganga river from chainage 900-950 km

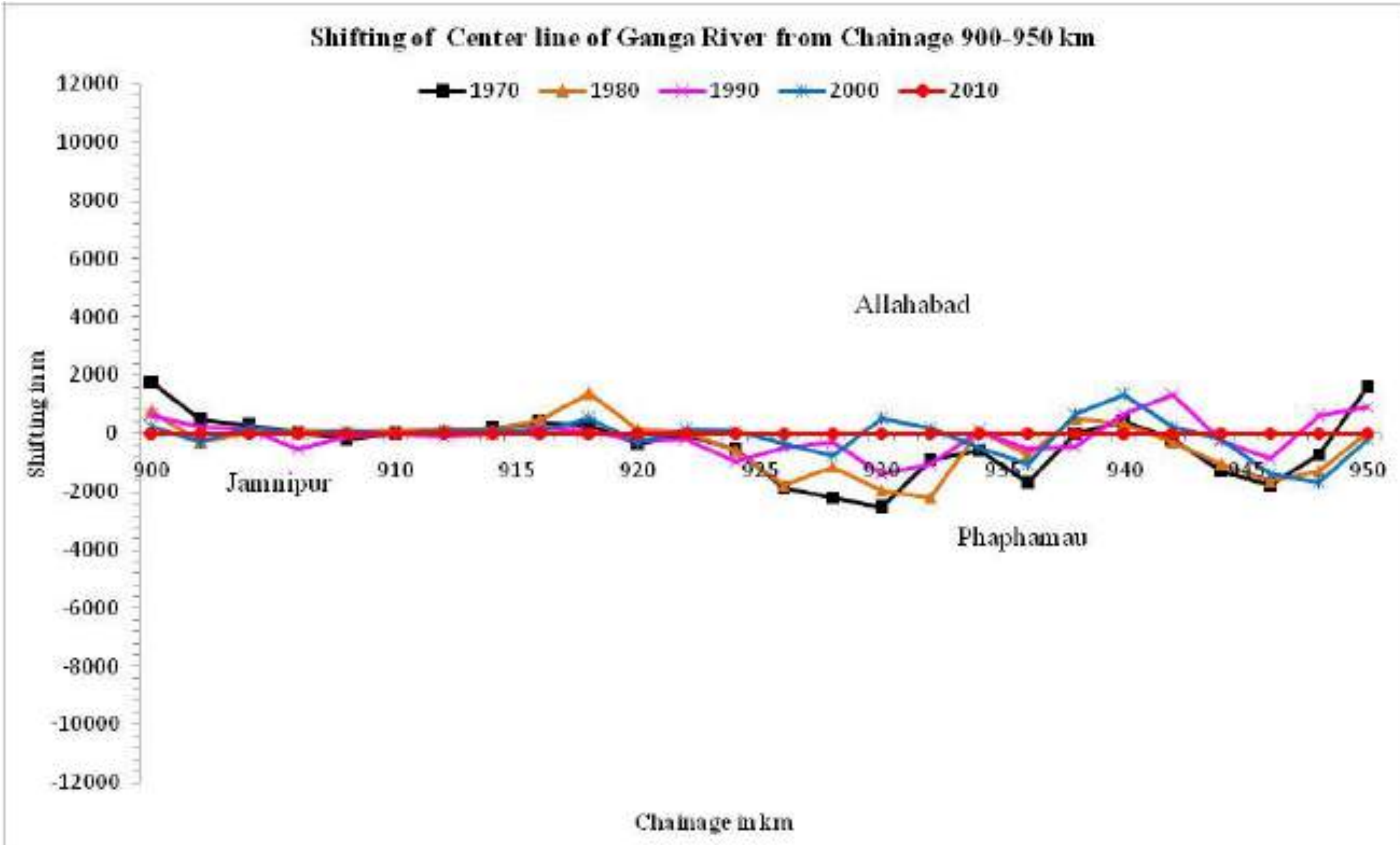


Figure 10.37b Shifting of center line of Ganga river from chainage 900-950 km

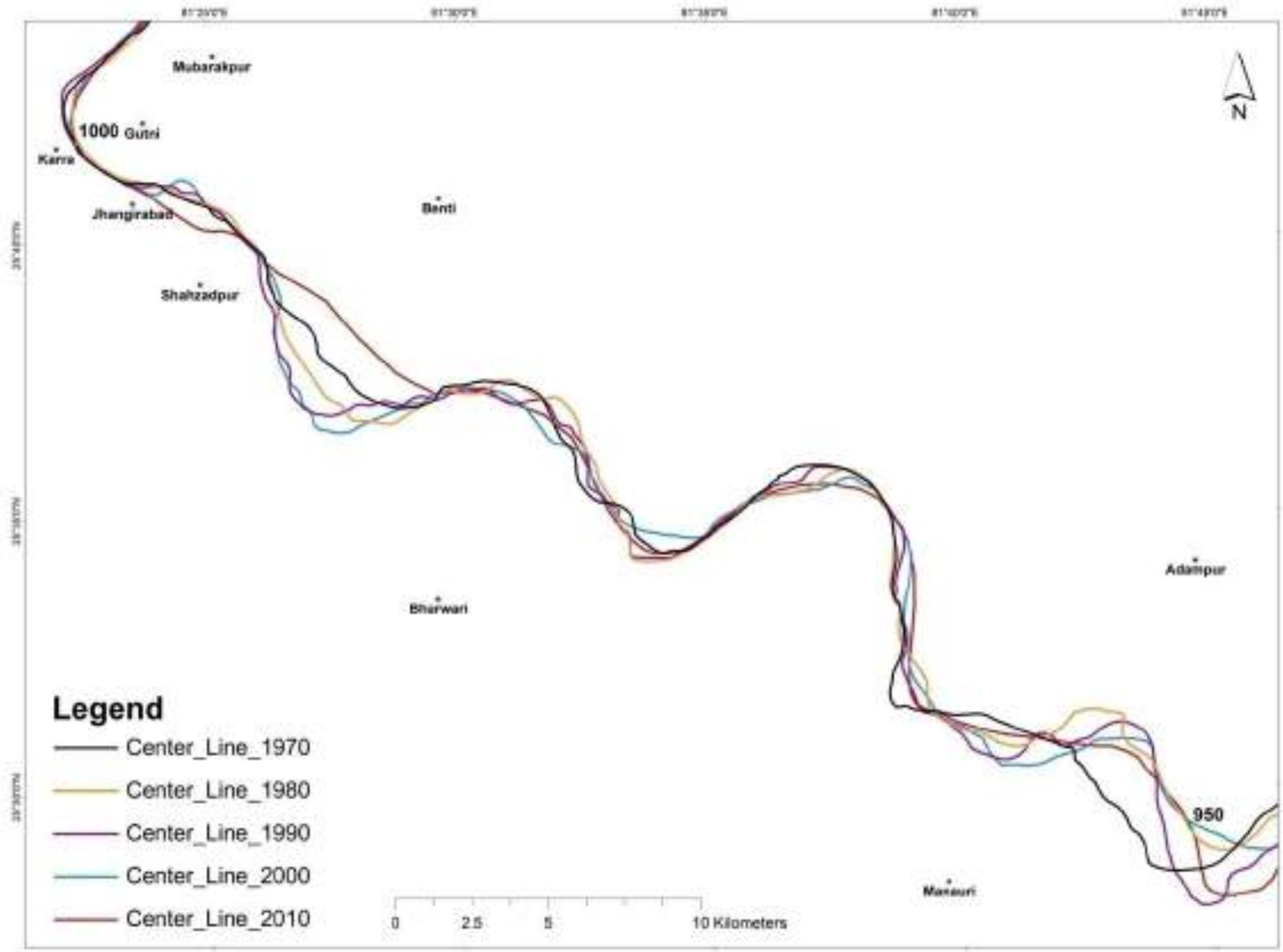


Figure 10.38a Shifting of center line of Ganga river from chainage 950-1000 km

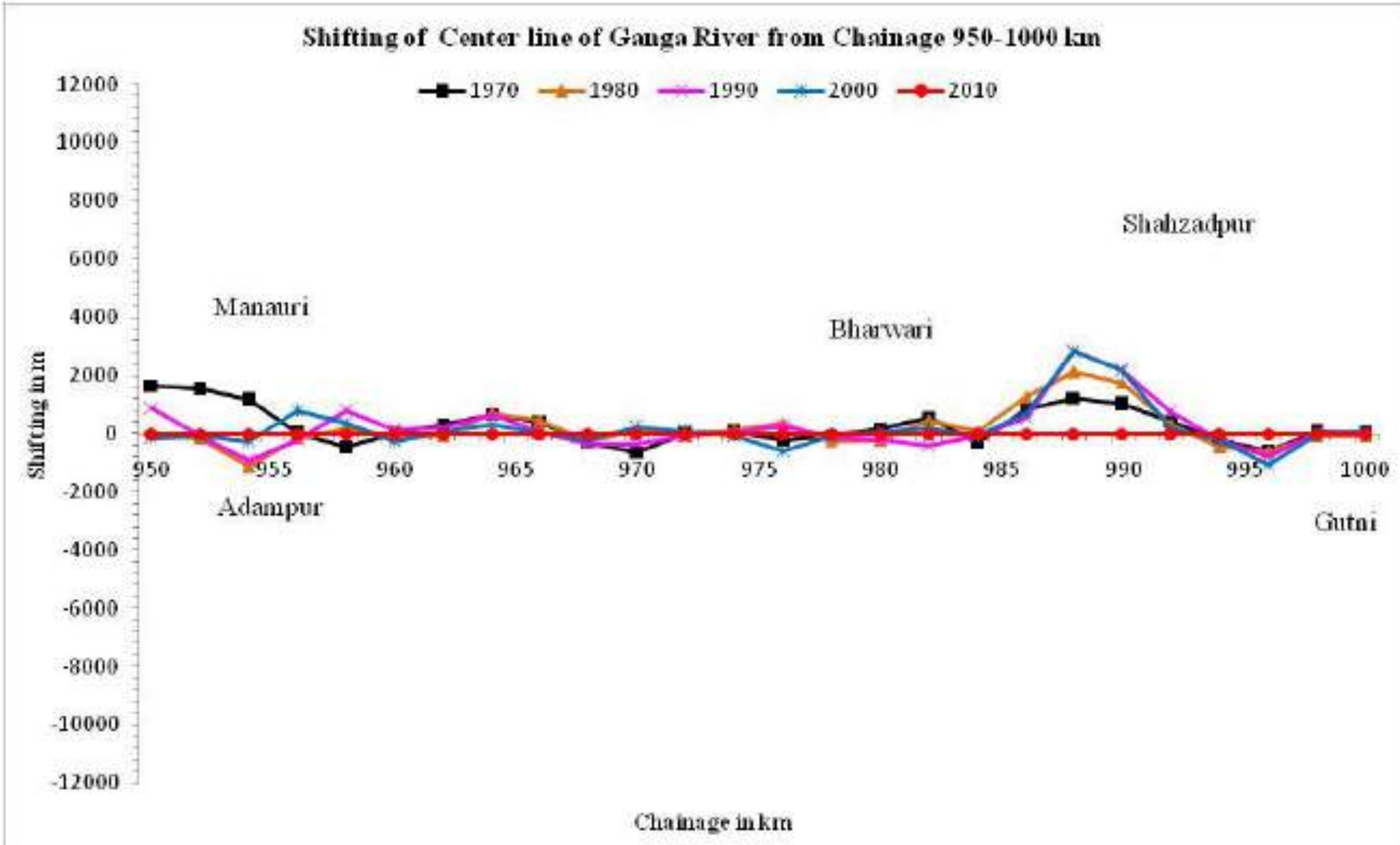


Figure 10.38b Shifting of center line of Ganga river from chainage 950-1000 km

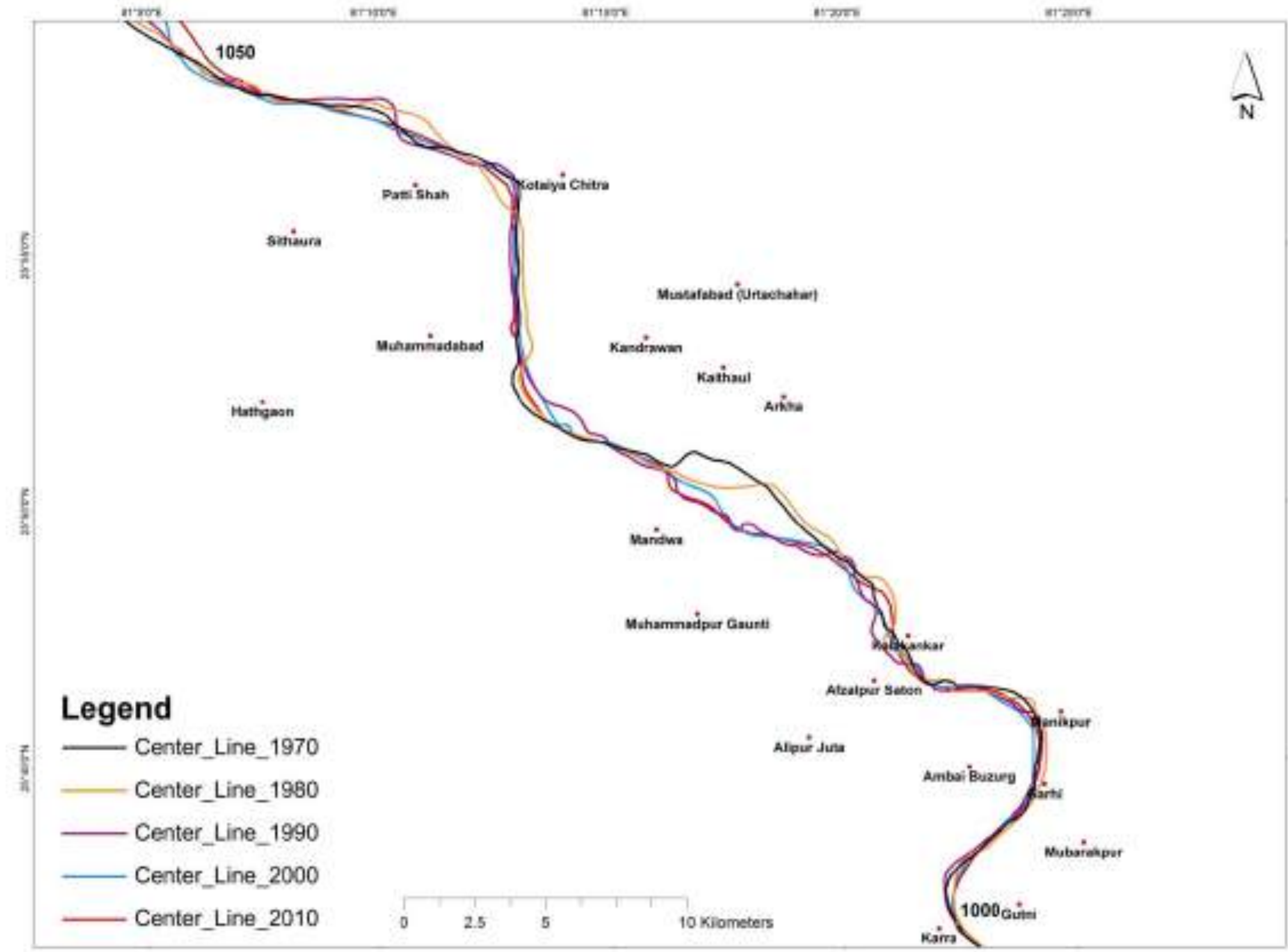


Figure 10.39a Shifting of center line of Ganga river from chainage 1000-1050 km

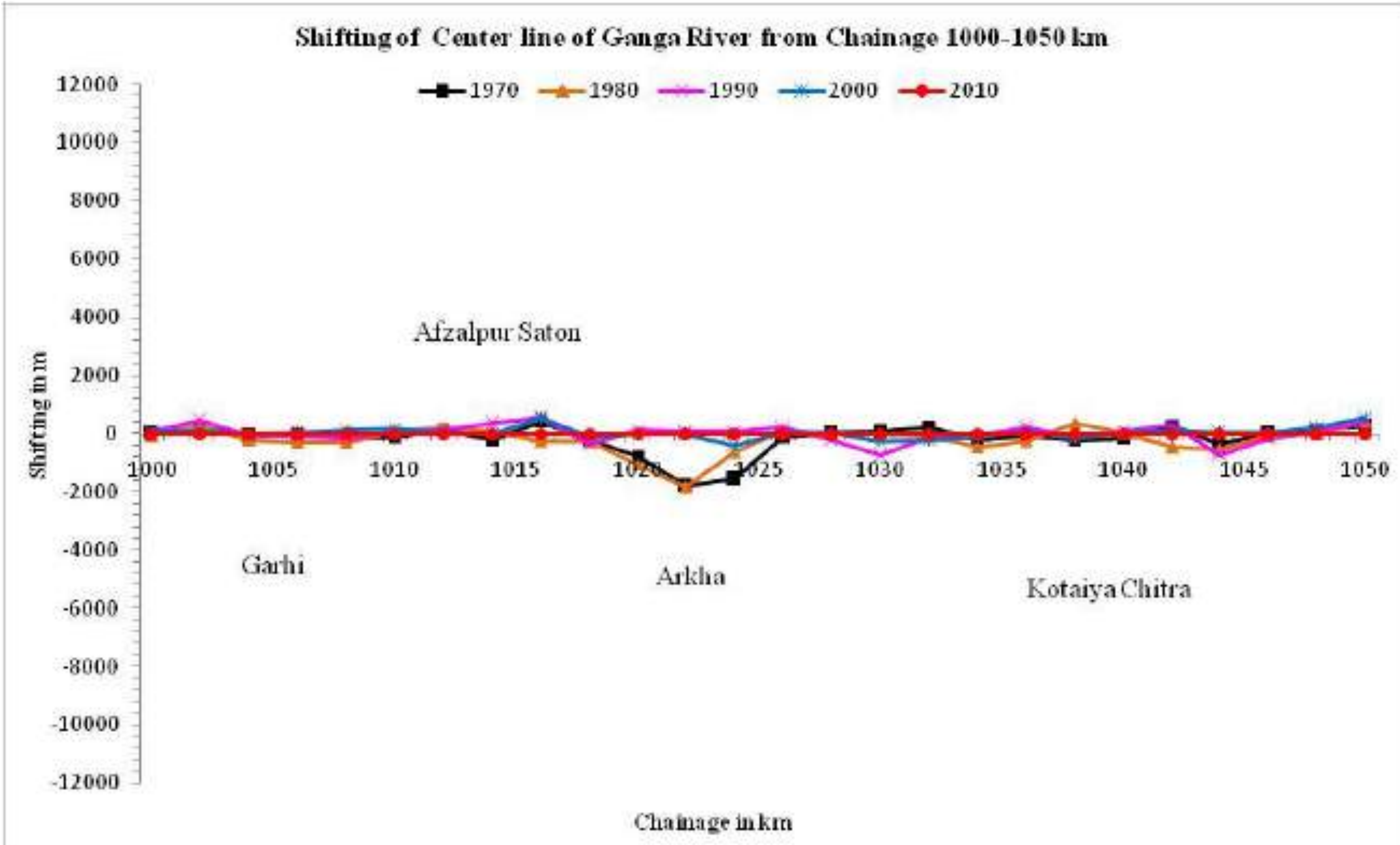


Figure 10.39b Shifting of center line of Ganga river from chainage 1000-1050 km

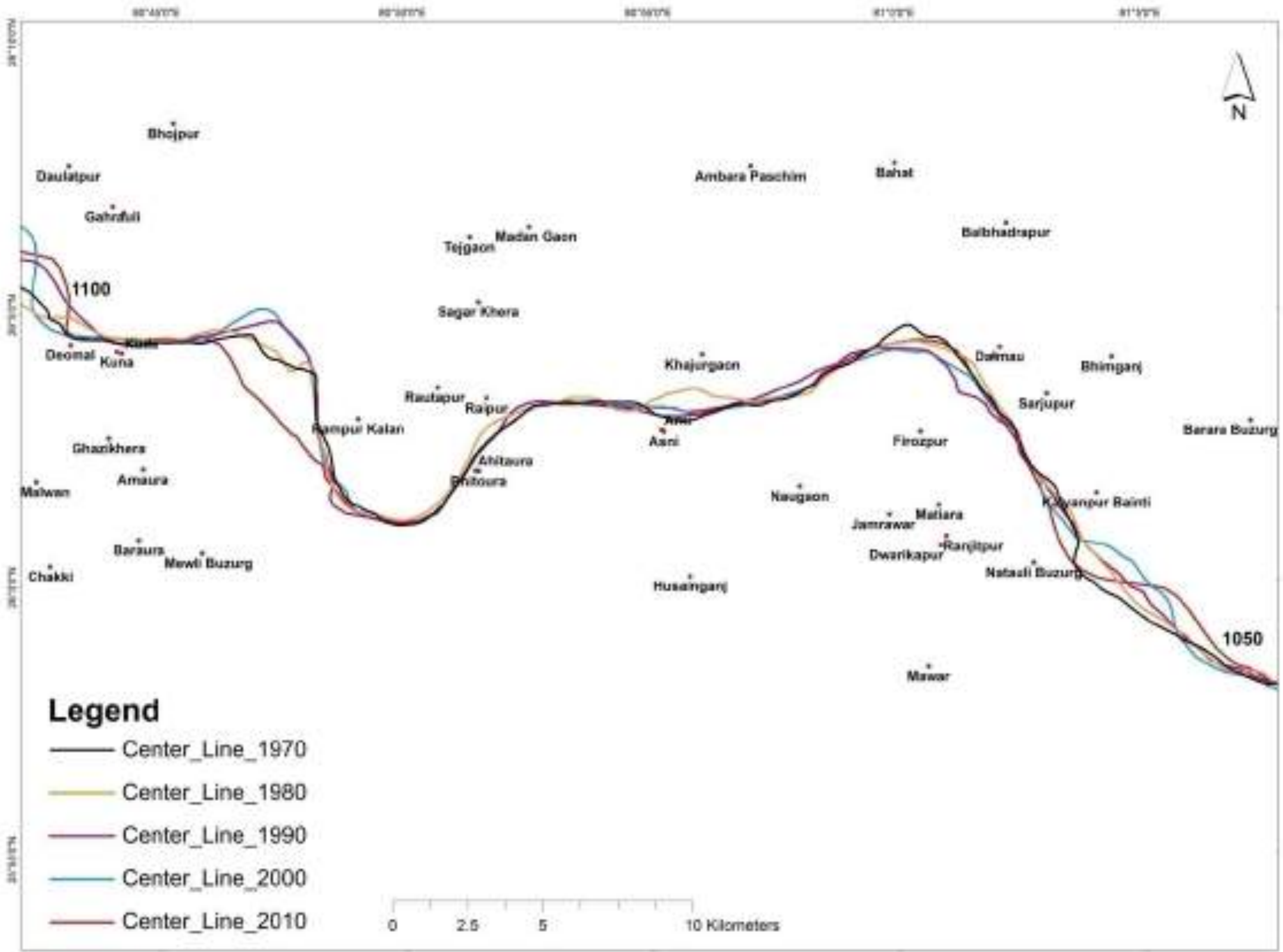


Figure 10.40a Shifting of center line of Ganga river from chainage 1050-1000 km

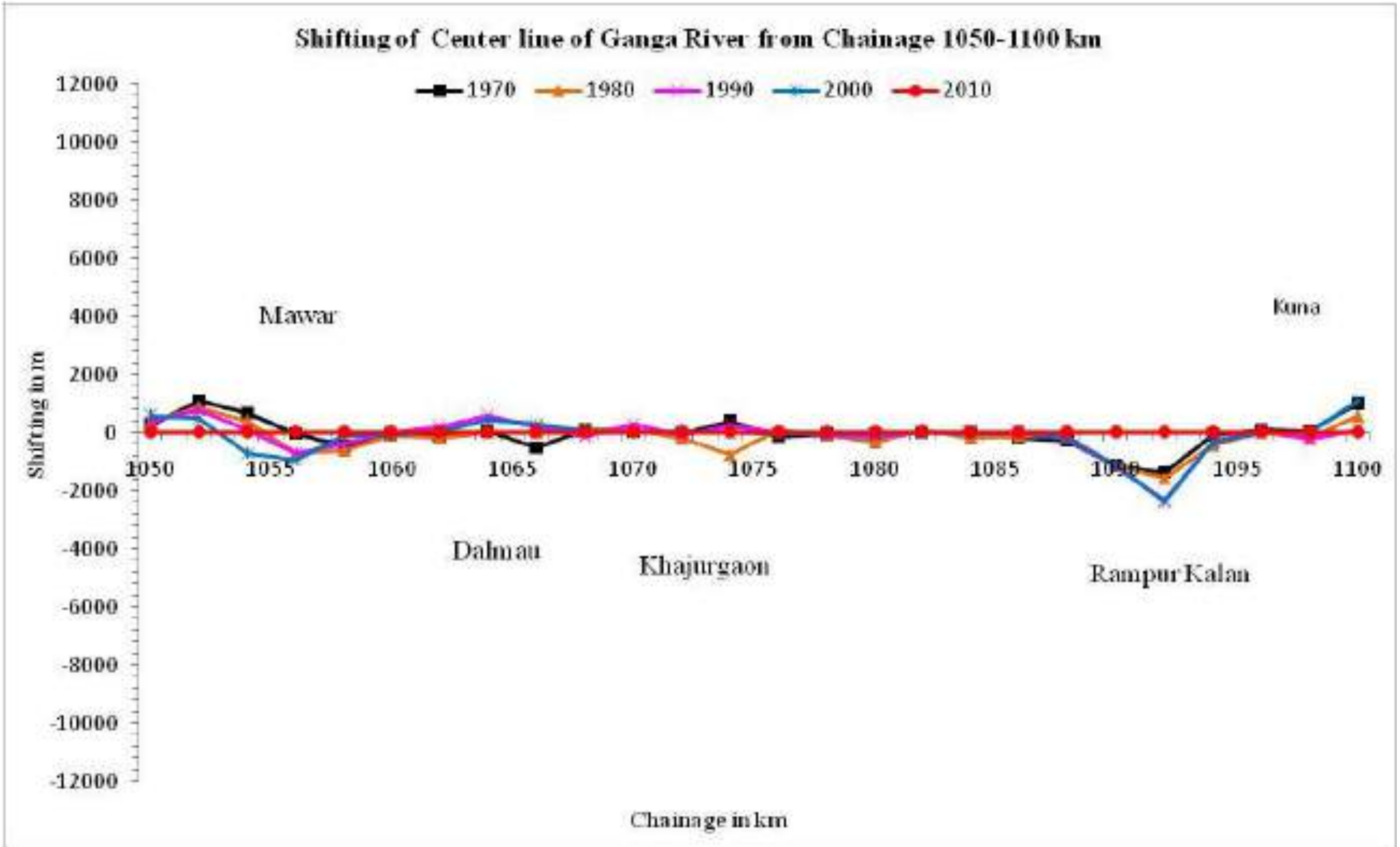


Figure 10.40b Shifting of center line of Ganga river from chainage 1050-1000 km

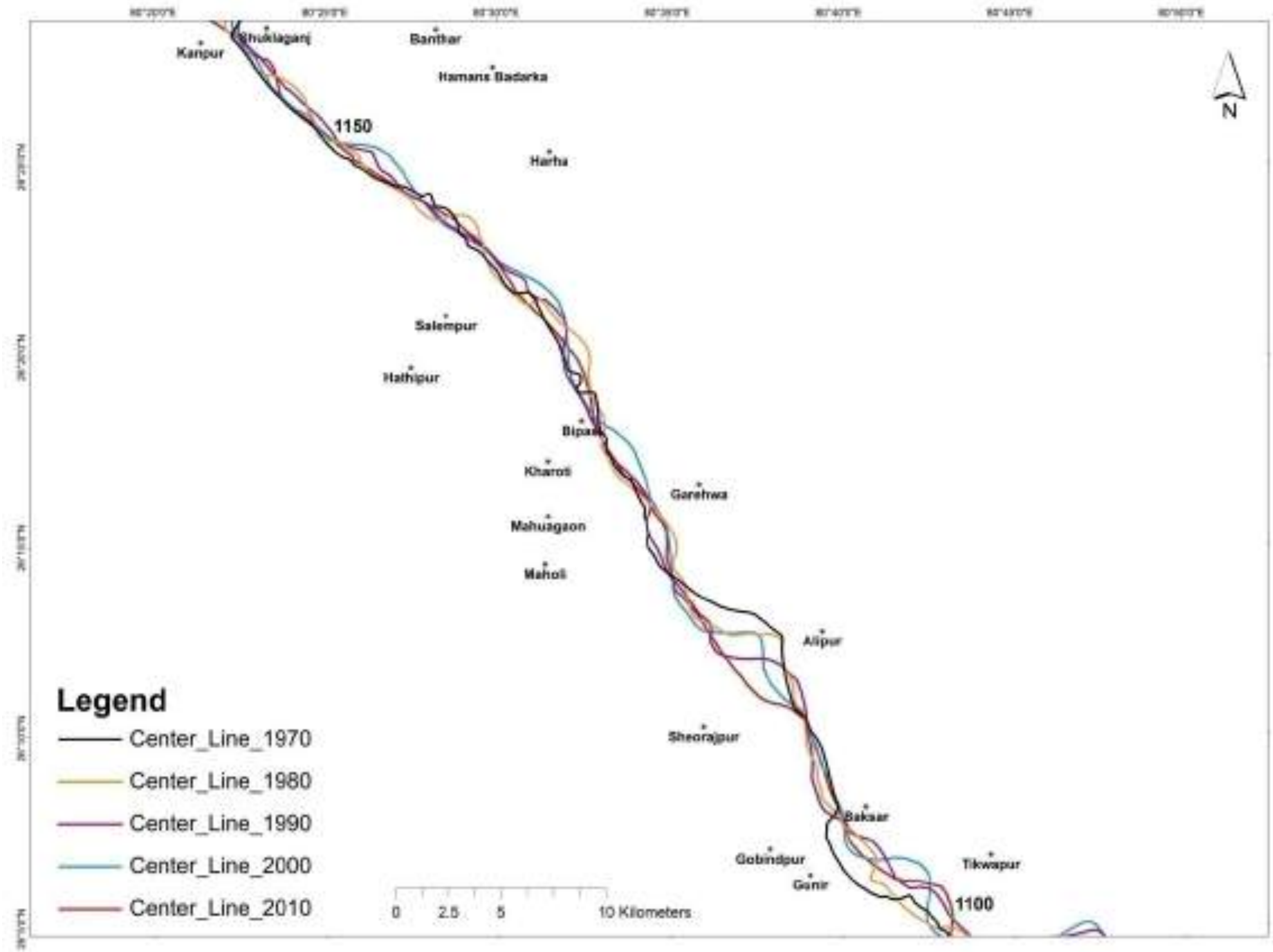


Figure 10.41a Shifting of center line of Ganga river from chainage 1000-1050 km

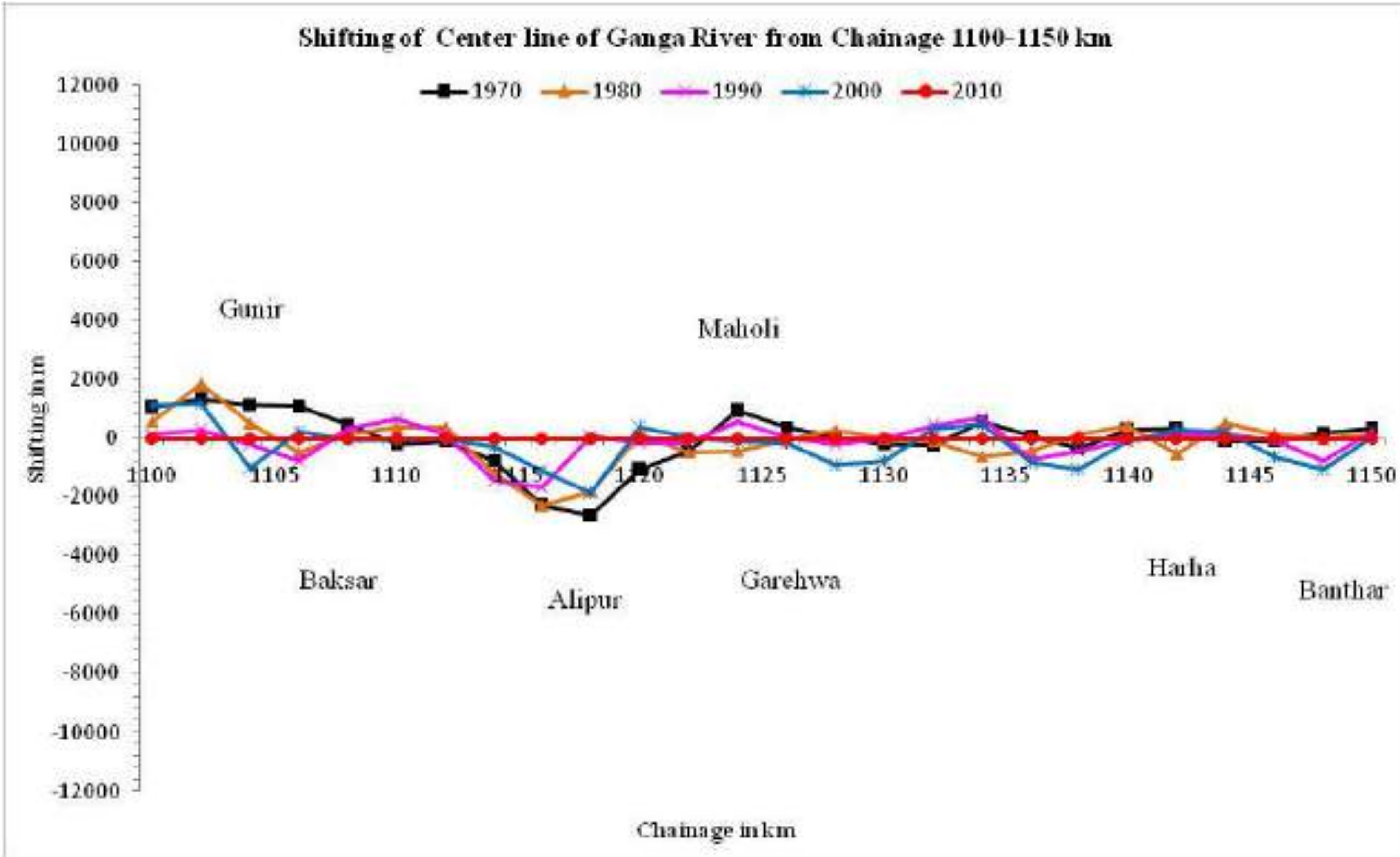


Figure 10.41b Shifting of center line of Ganga river from chainage 1000-1050 km

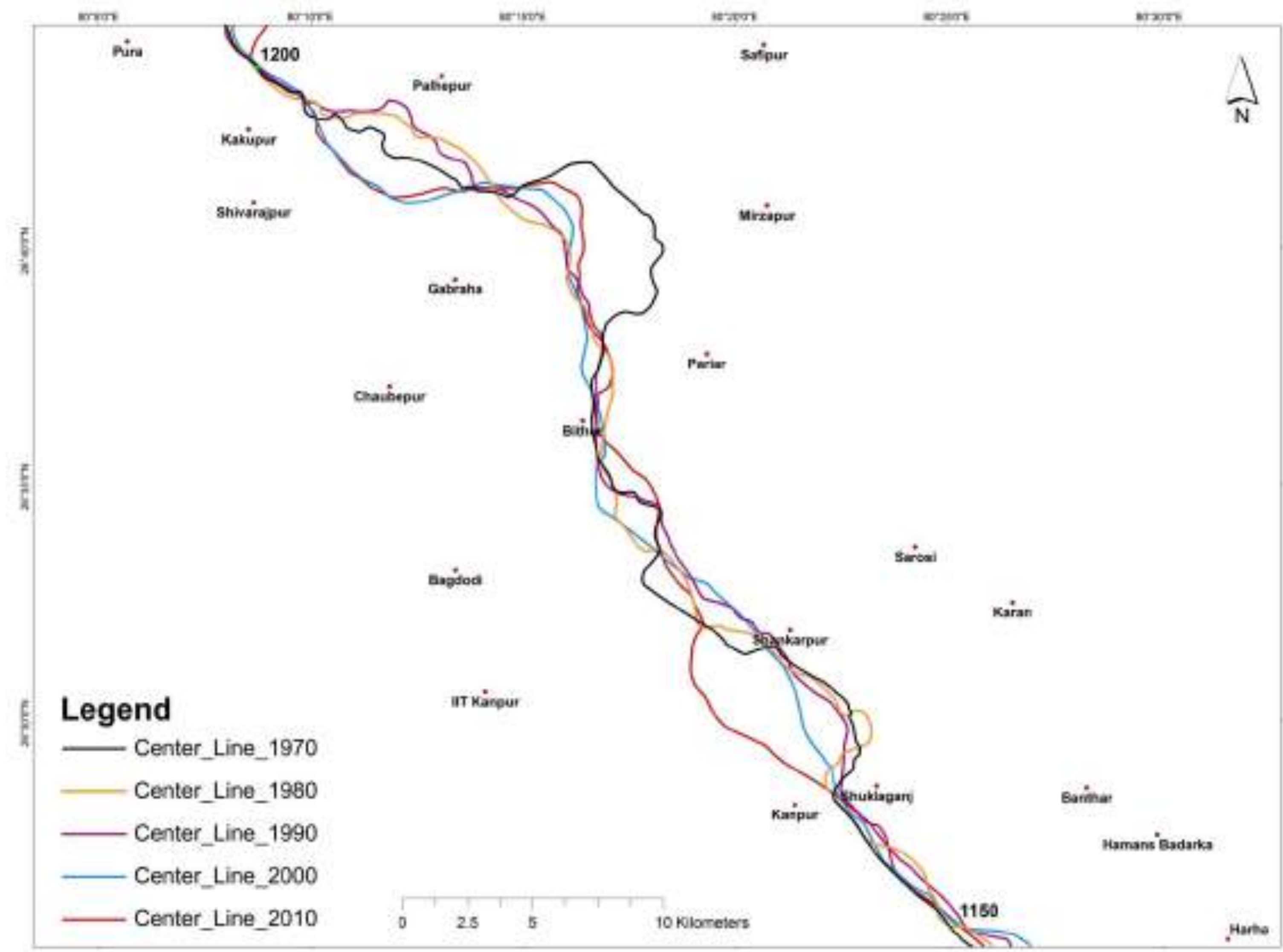


Figure 10.42a Shifting of center line of Ganga river from chainage 1050-1200 km

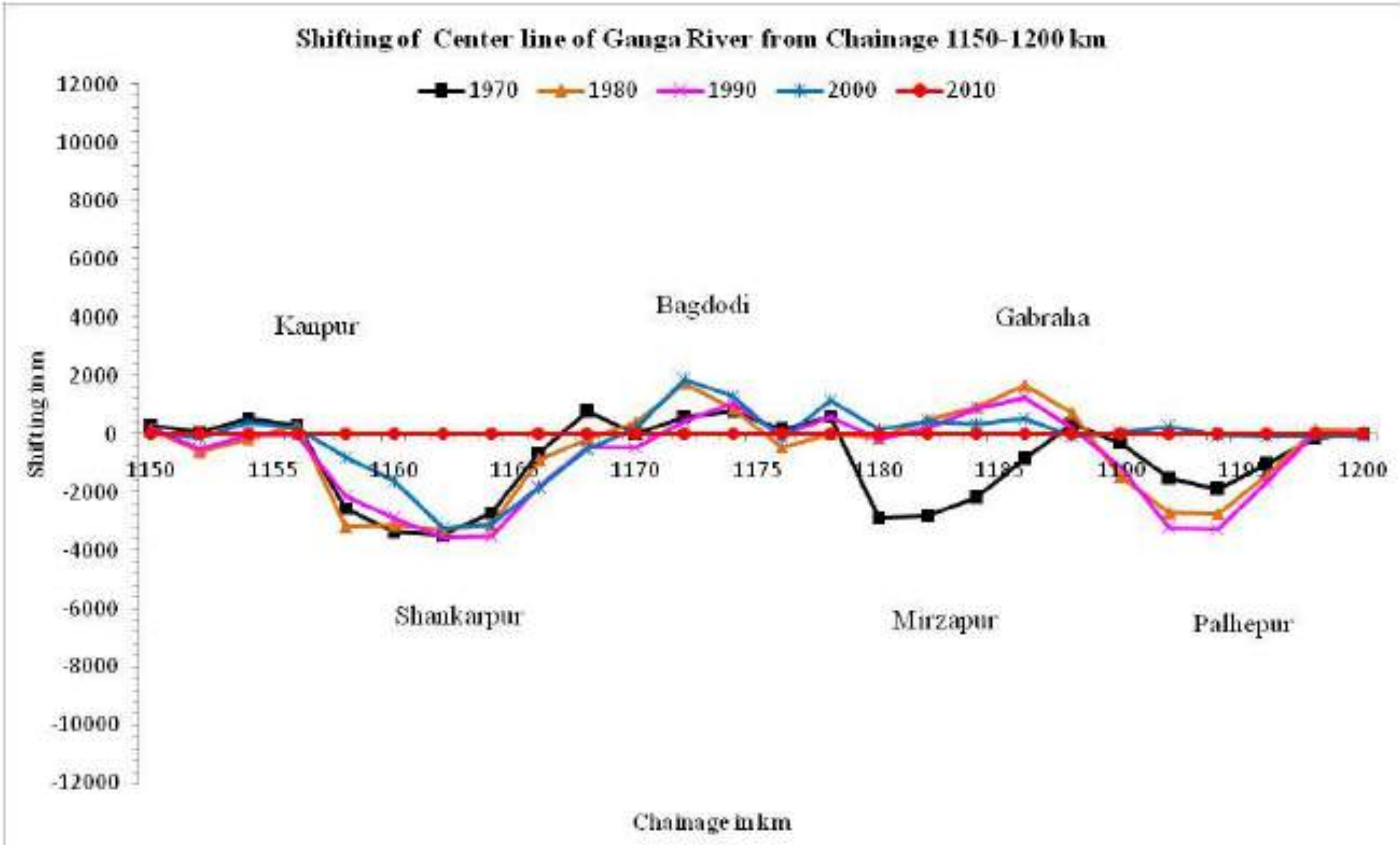


Figure 10.42b Shifting of center line of Ganga river from chainage 1050-1200 km

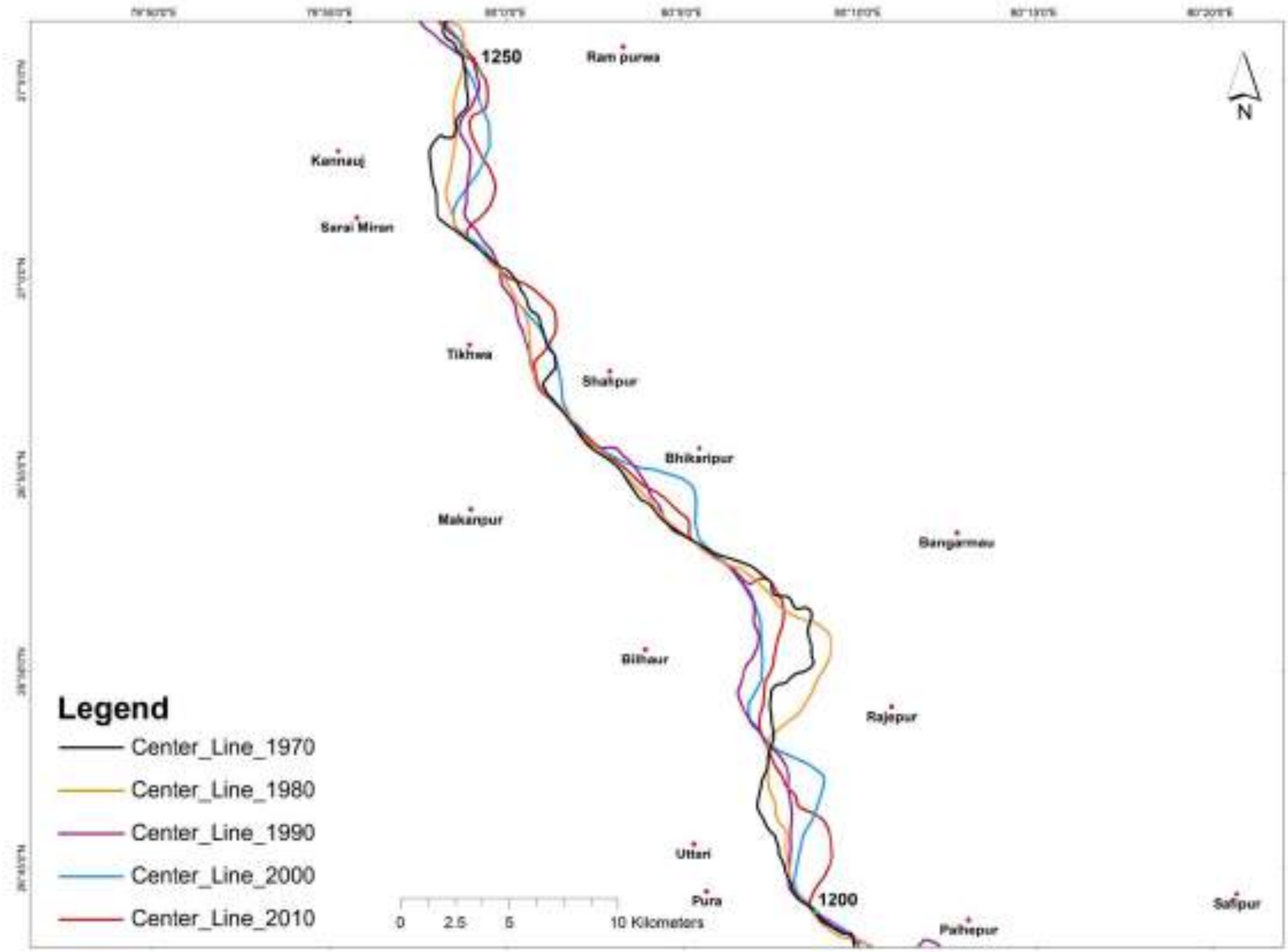


Figure 10.43a Shifting of center line of Ganga river from chainage 1200-1250 km

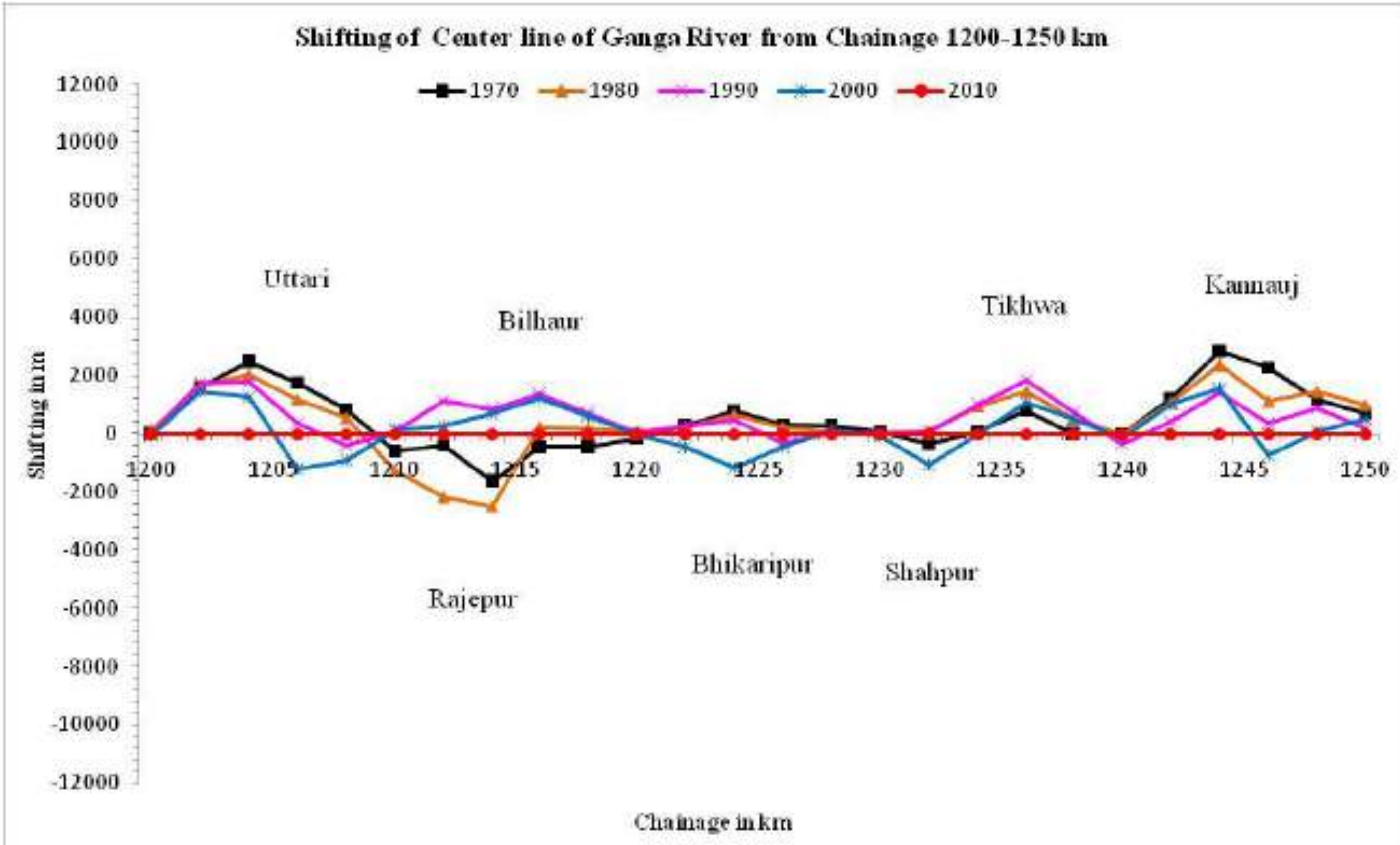


Figure 10.43b Shifting of center line of Ganga river from chainage 1200-1250 km

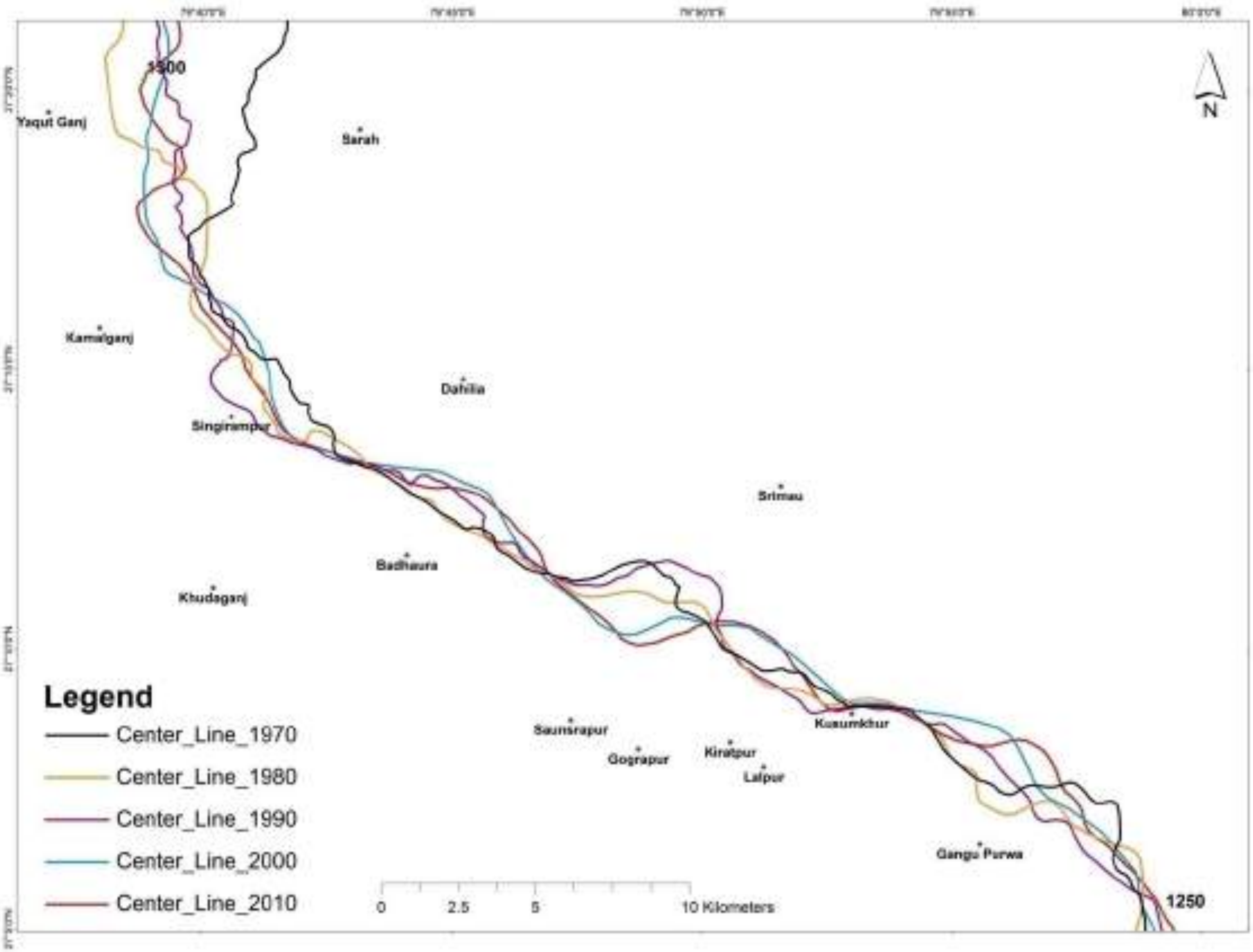


Figure 10.44a Shifting of center line of Ganga river from chainage 1250-1300 km

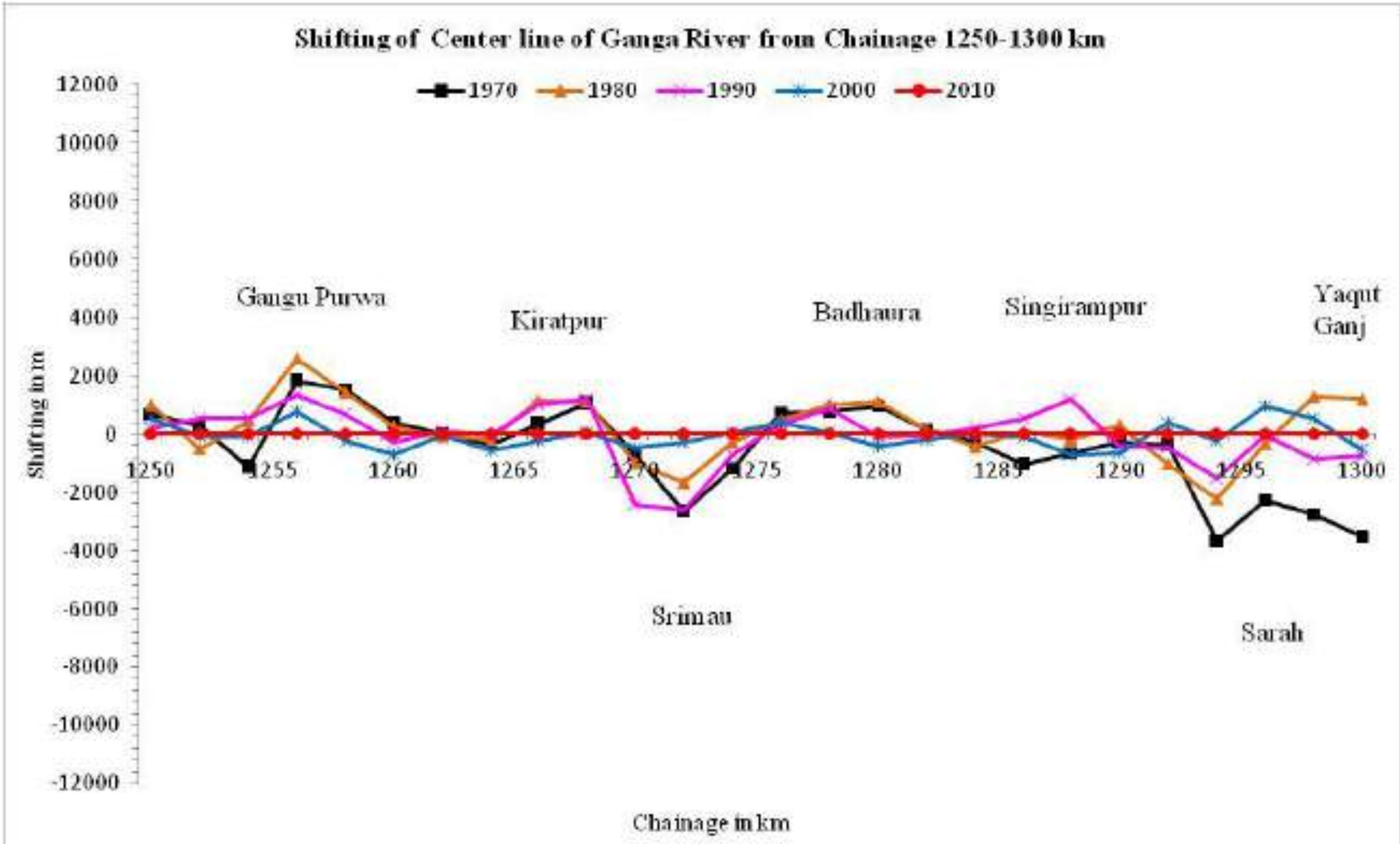


Figure 10.44b Shifting of center line of Ganga river from chainage 1250-1300 km

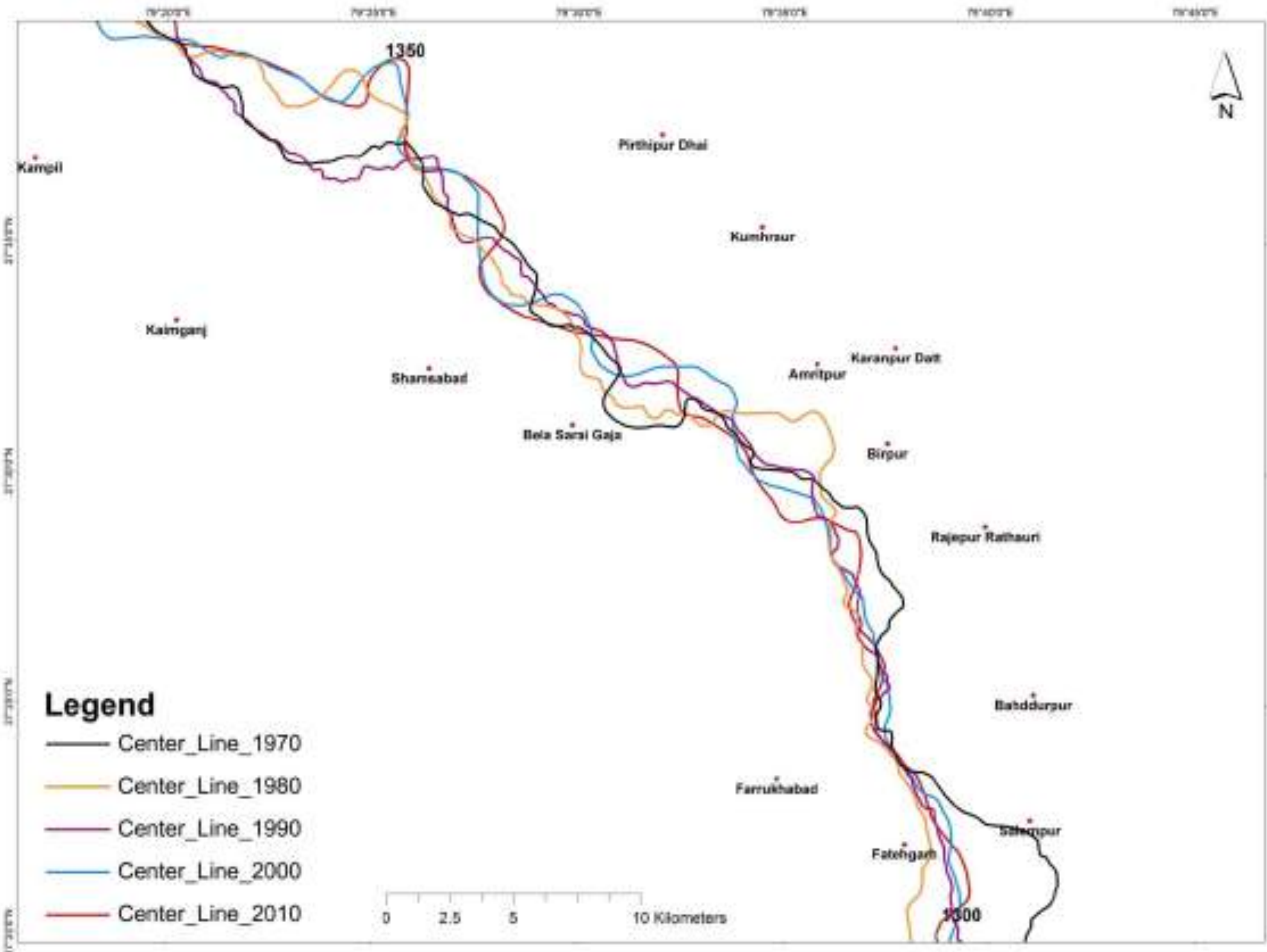


Figure 10.45a Shifting of center line of Ganga river from chainage 1300-1350 km

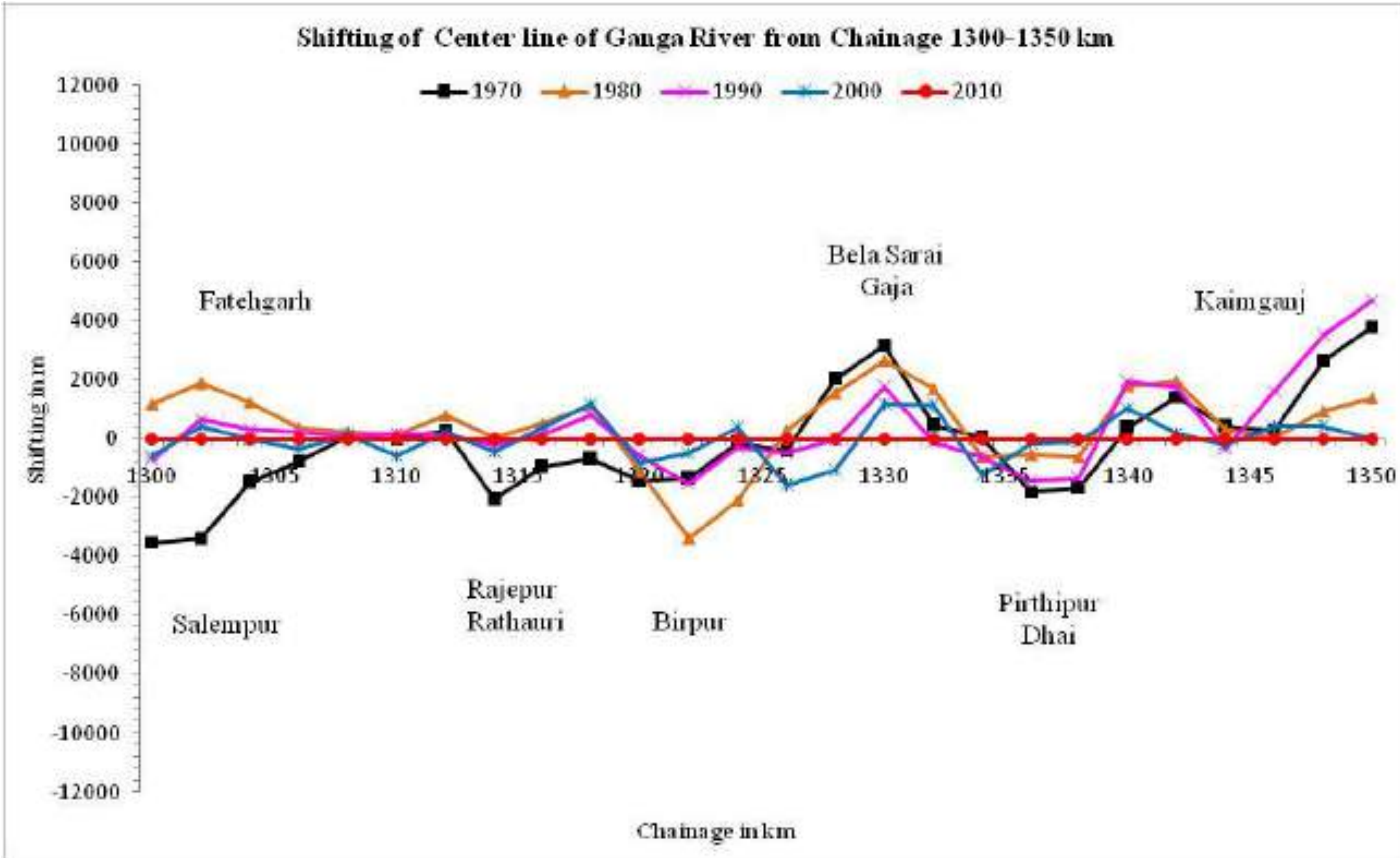


Figure 10.45b Shifting of center line of Ganga river from chainage 1300-1350 km

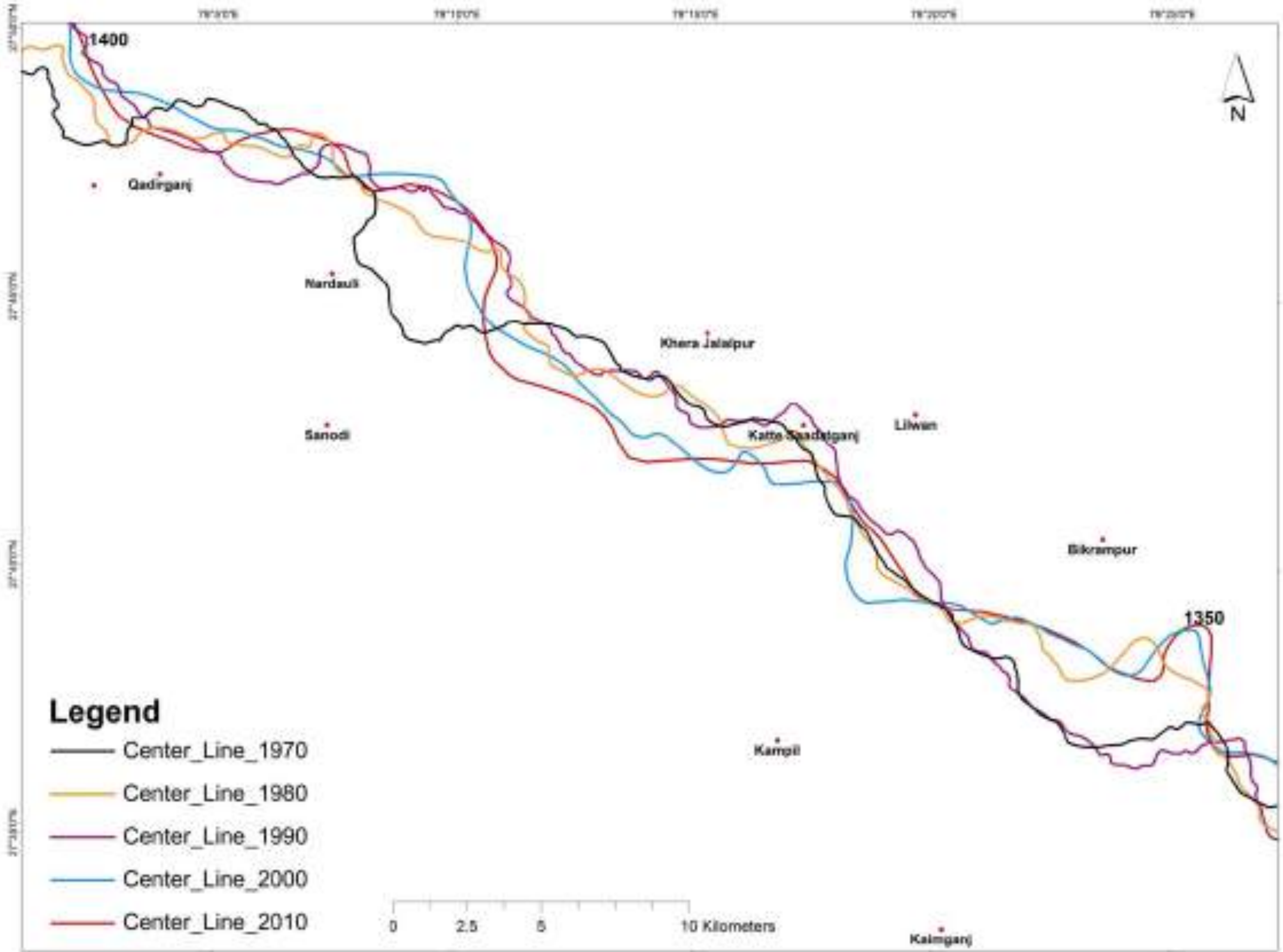


Figure 10.46a Shifting of center line of Ganga river from chainage 1350-1400 km

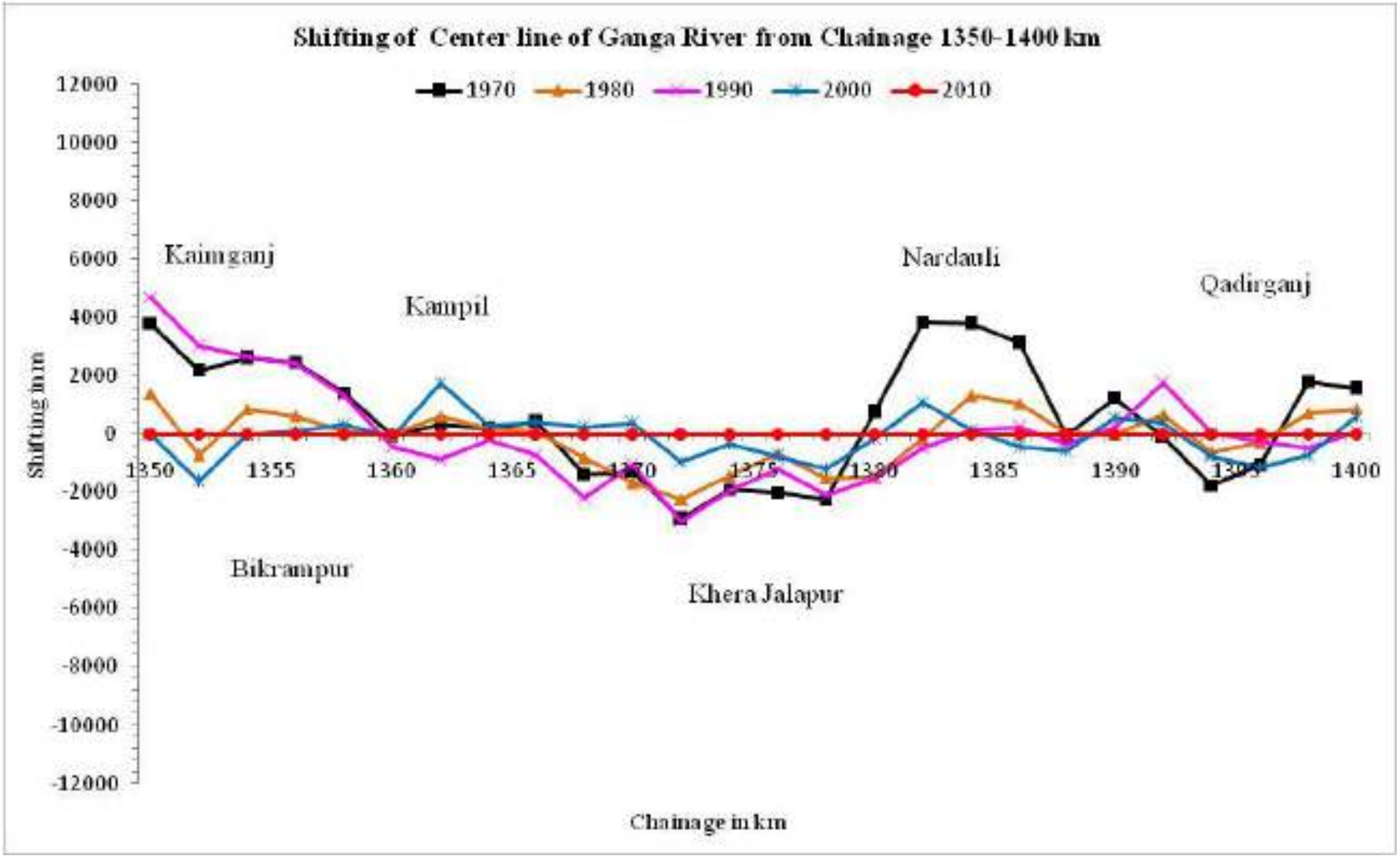


Figure 10.46b Shifting of center line of Ganga river from chainage 1350-1400 km

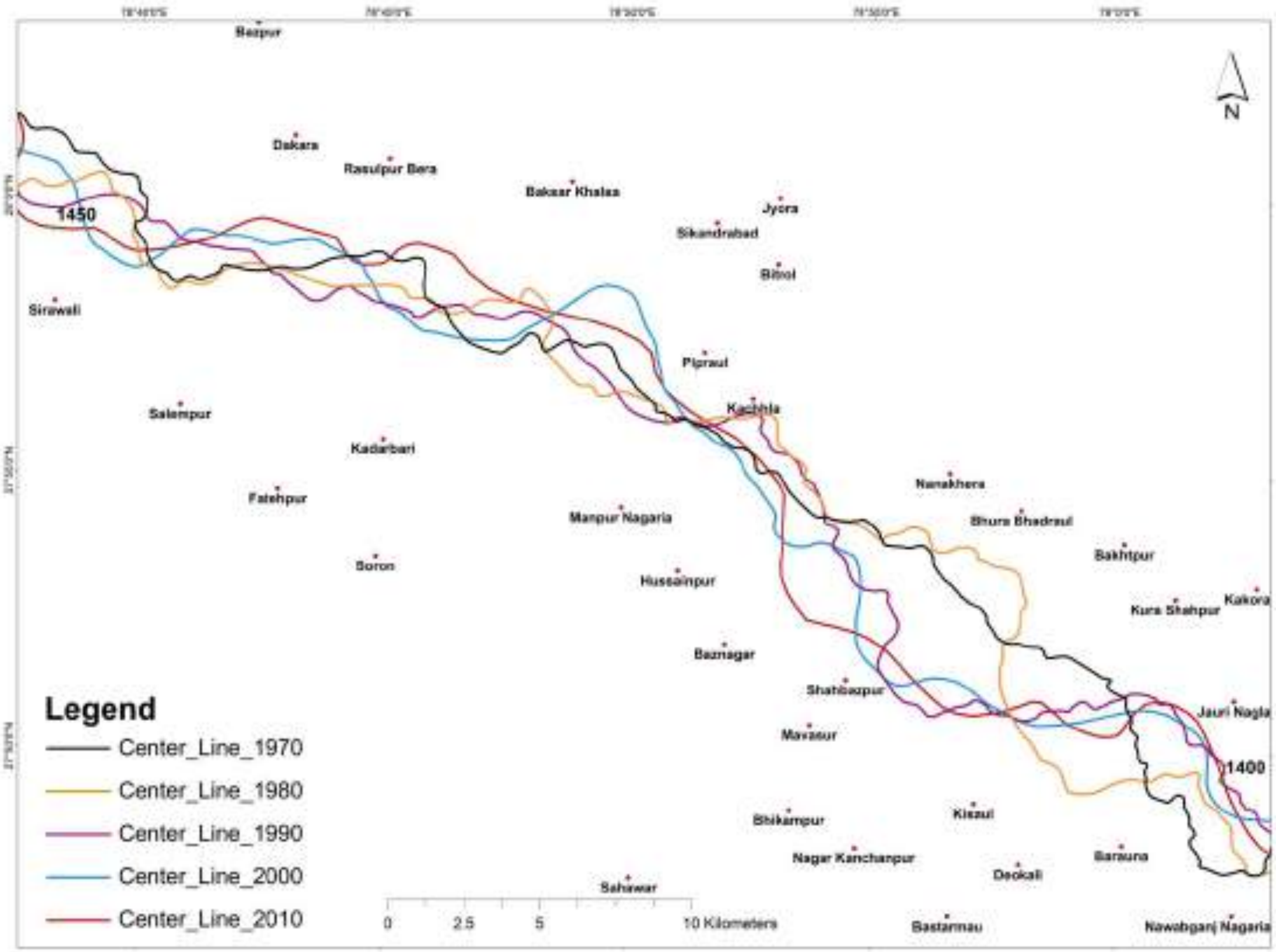


Figure 10.47a Shifting of center line of Ganga river from chainage 1400-1450 km

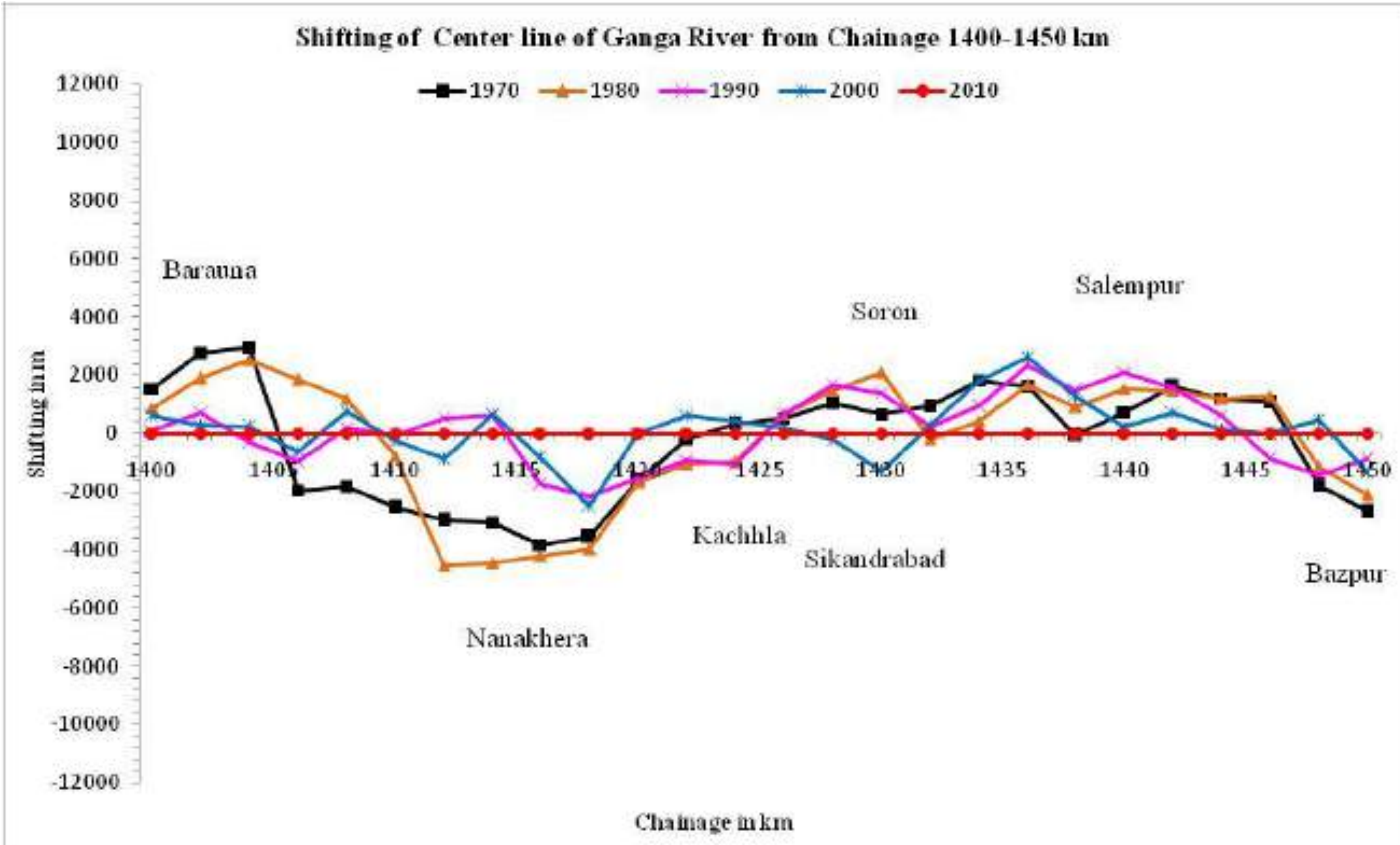


Figure 10.47b Shifting of center line of Ganga river from chainage 1400-1450 km

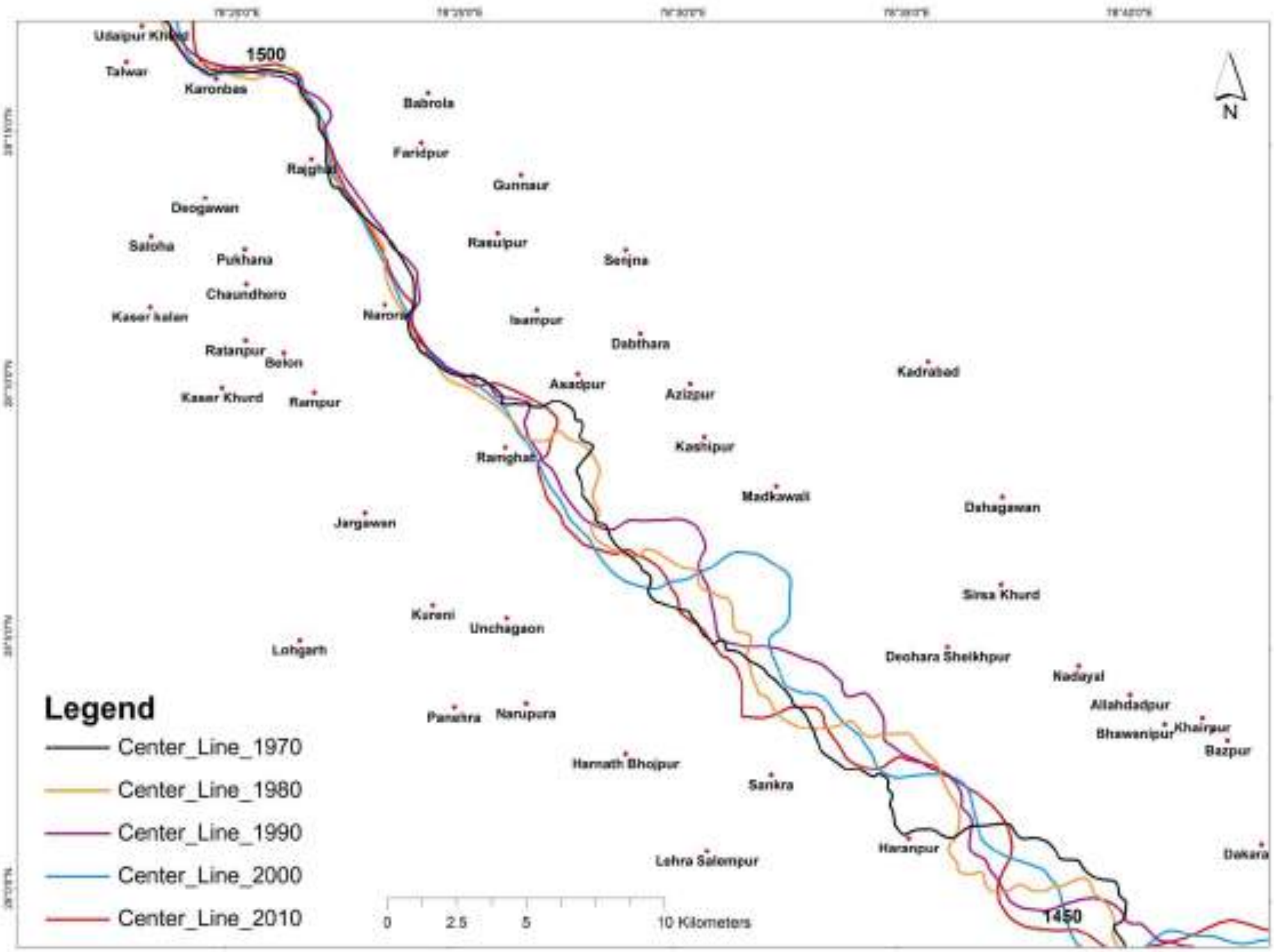


Figure 10.48a Shifting of center line of Ganga river from chainage 1450-1500 km

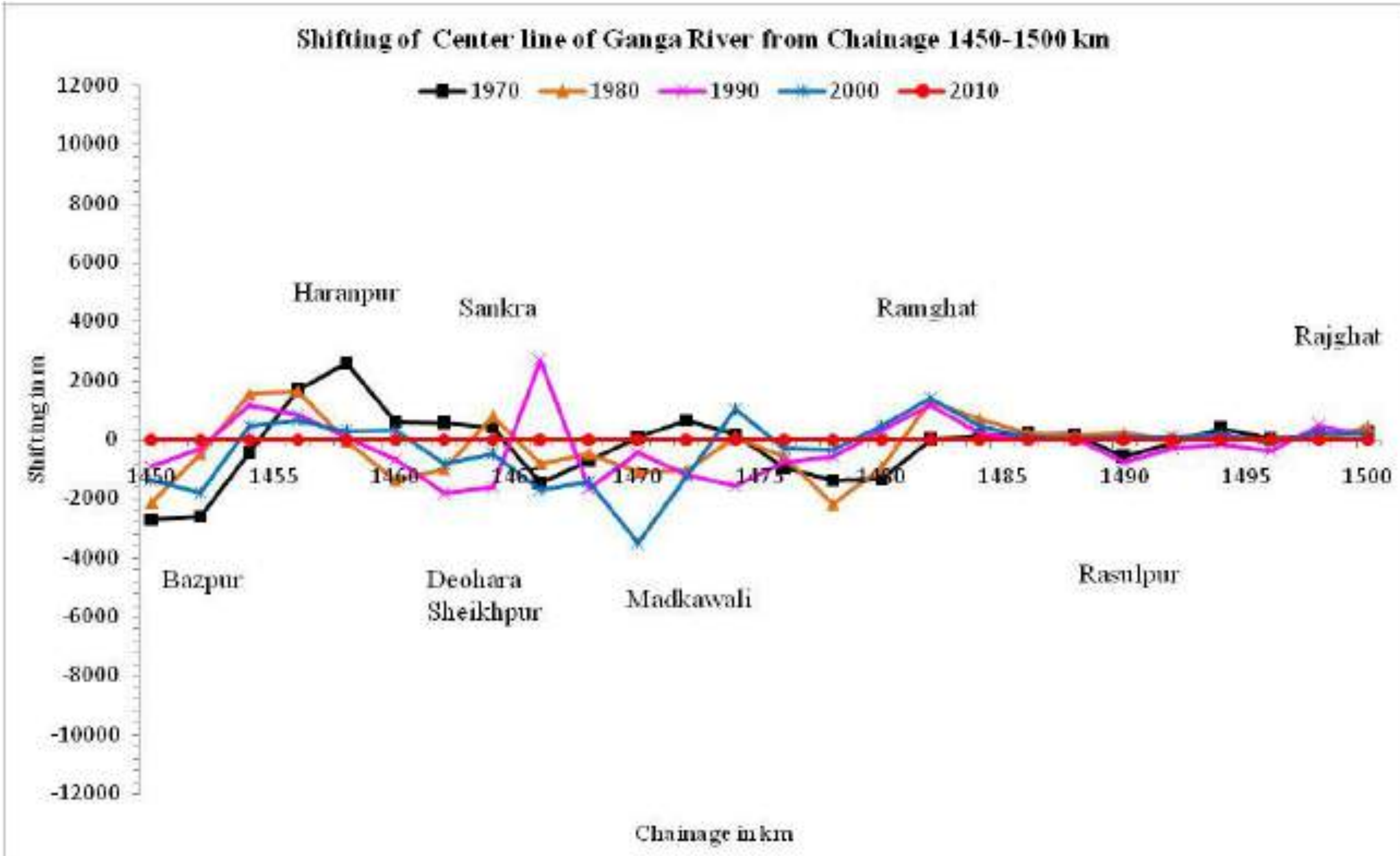


Figure 10.48b Shifting of center line of Ganga river from chainage 1450-1500 km

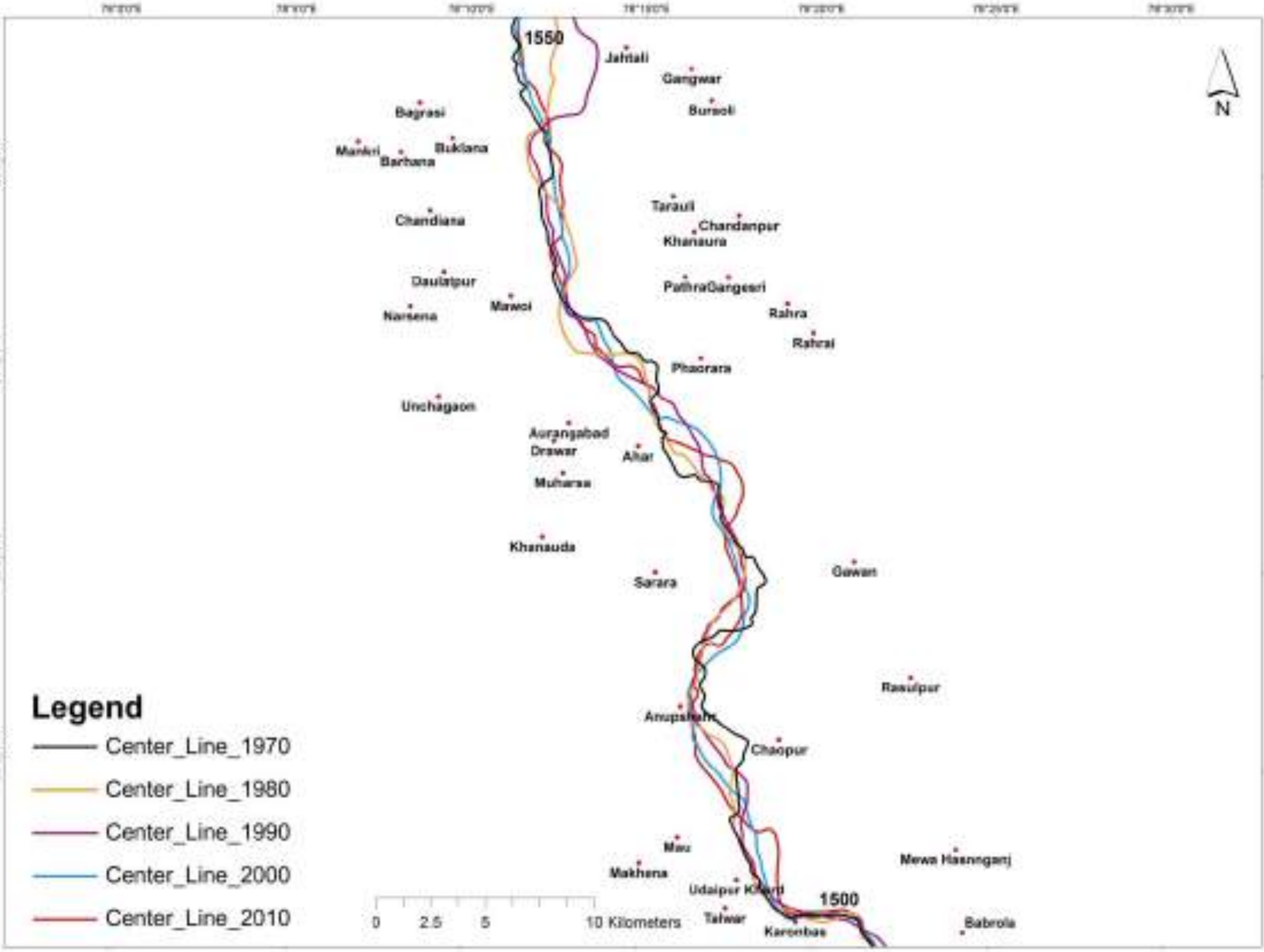


Figure 10.49a Shifting of center line of Ganga river from chainage 1500-1550 km

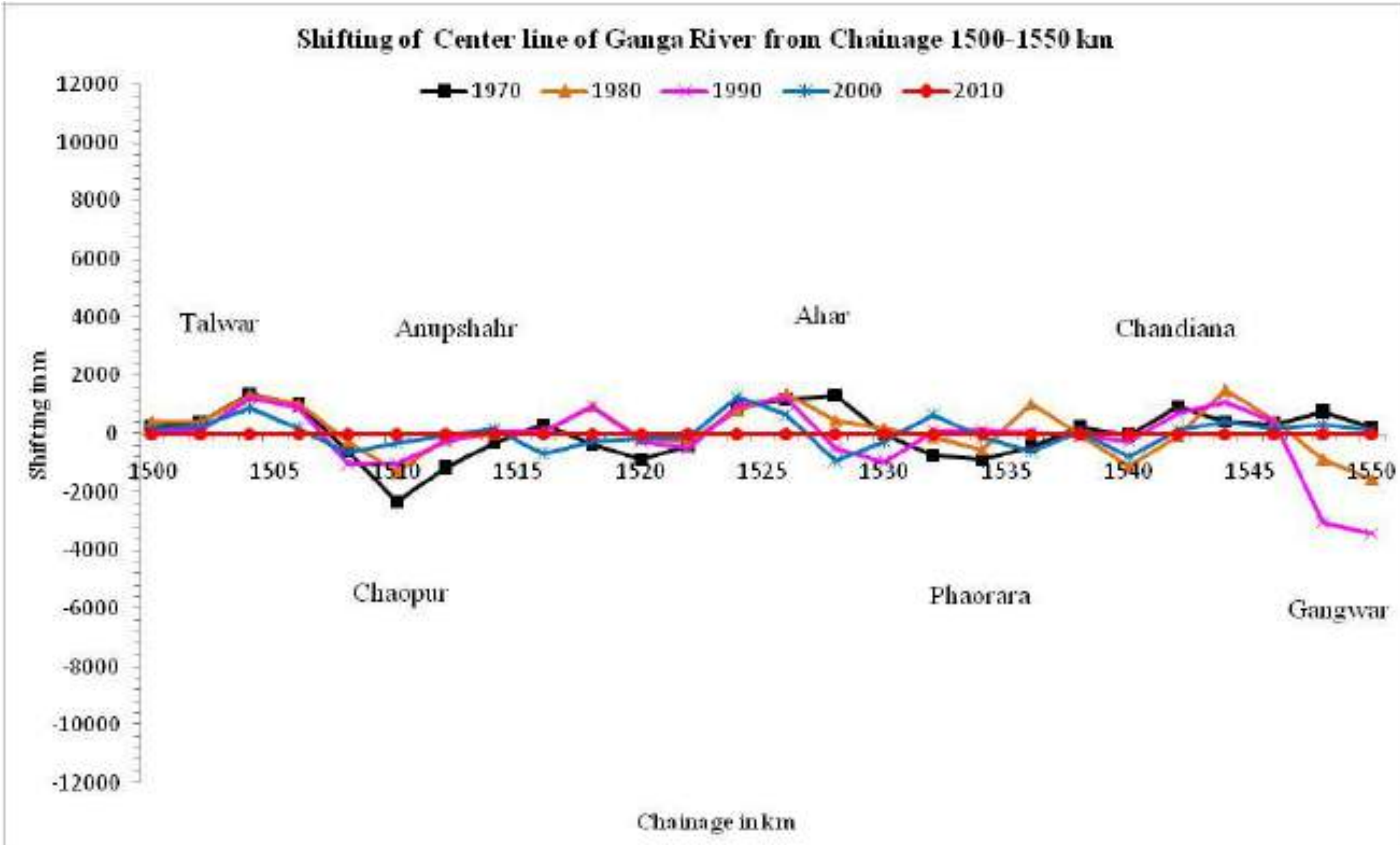


Figure 10.49b Shifting of center line of Ganga river from chainage 1500-1550 km

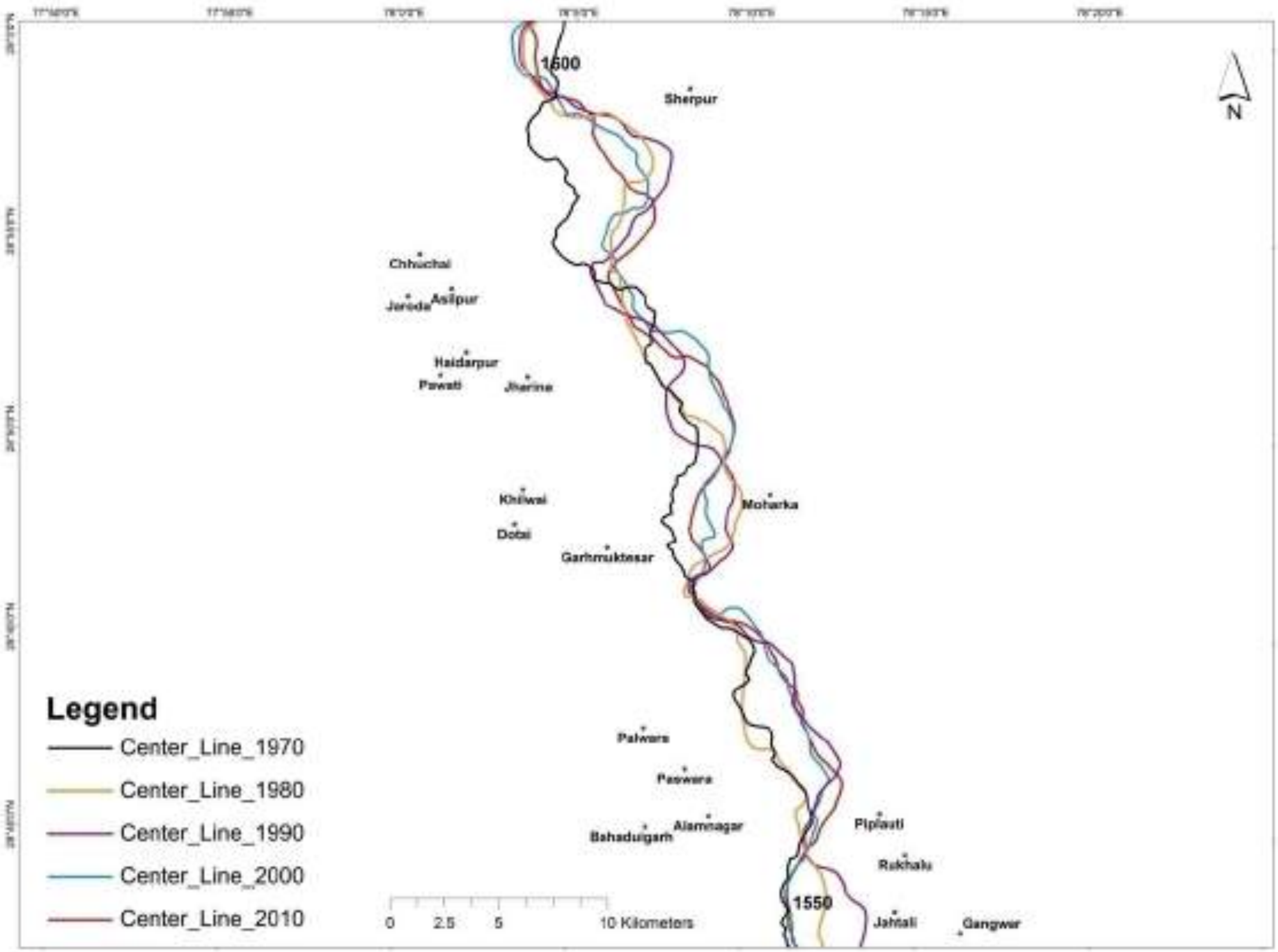


Figure 10.50a Shifting of center line of Ganga river from chainage 1550-1600 km

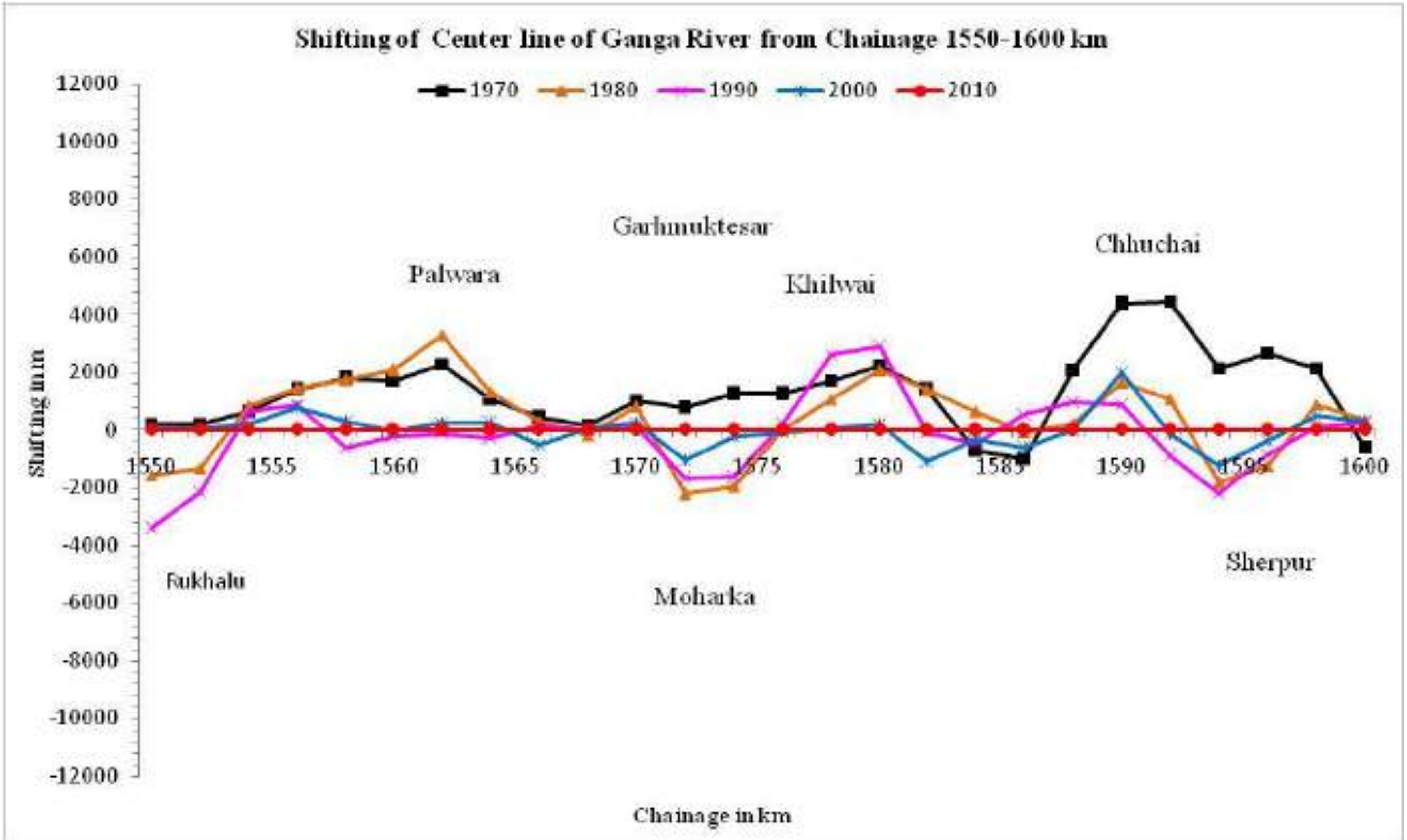


Figure 10.50b Shifting of center line of Ganga river from chainage 1550-1600 km

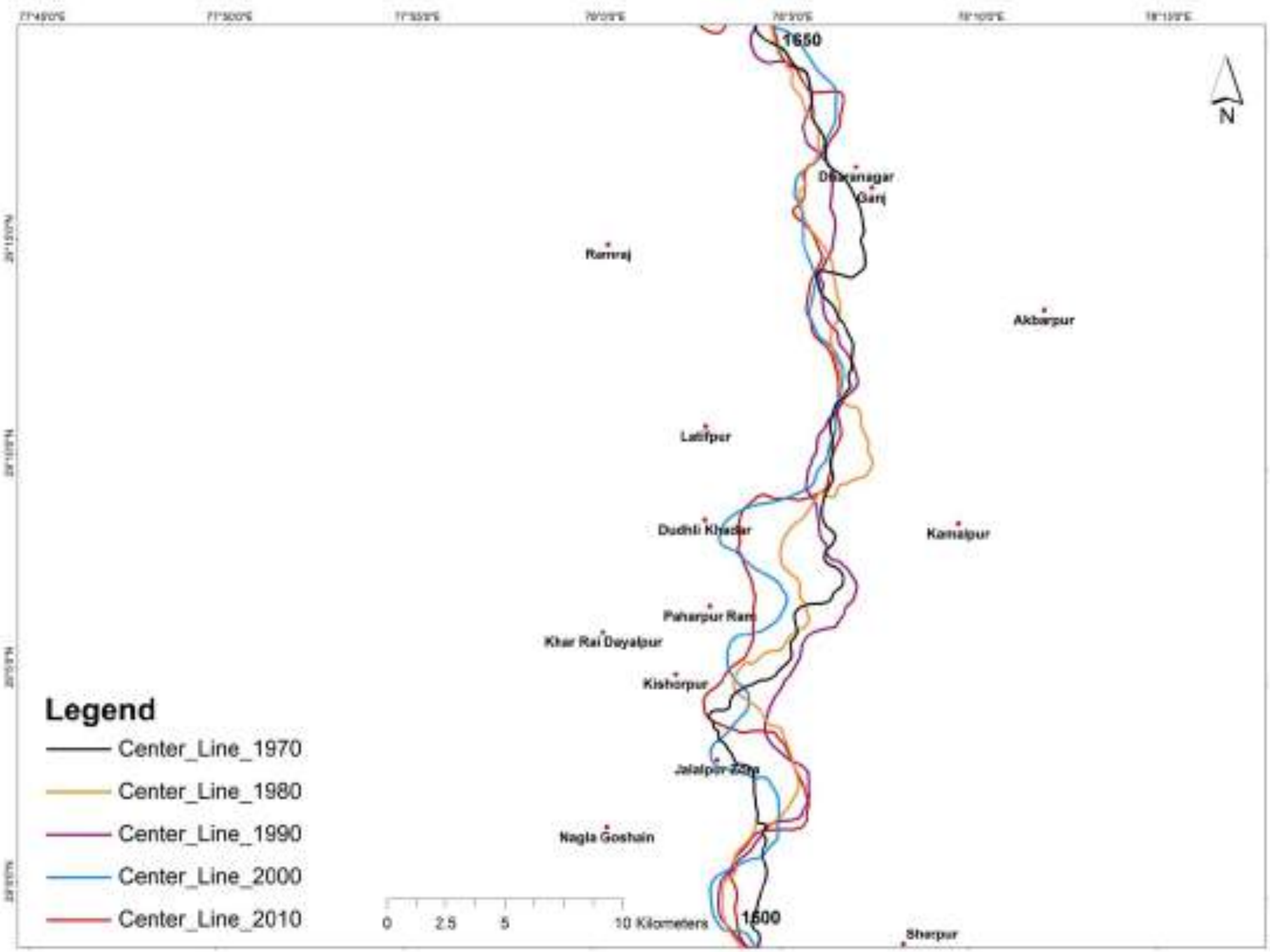


Figure 10.51a Shifting of center line of Ganga river from chainage 1600-1650 km

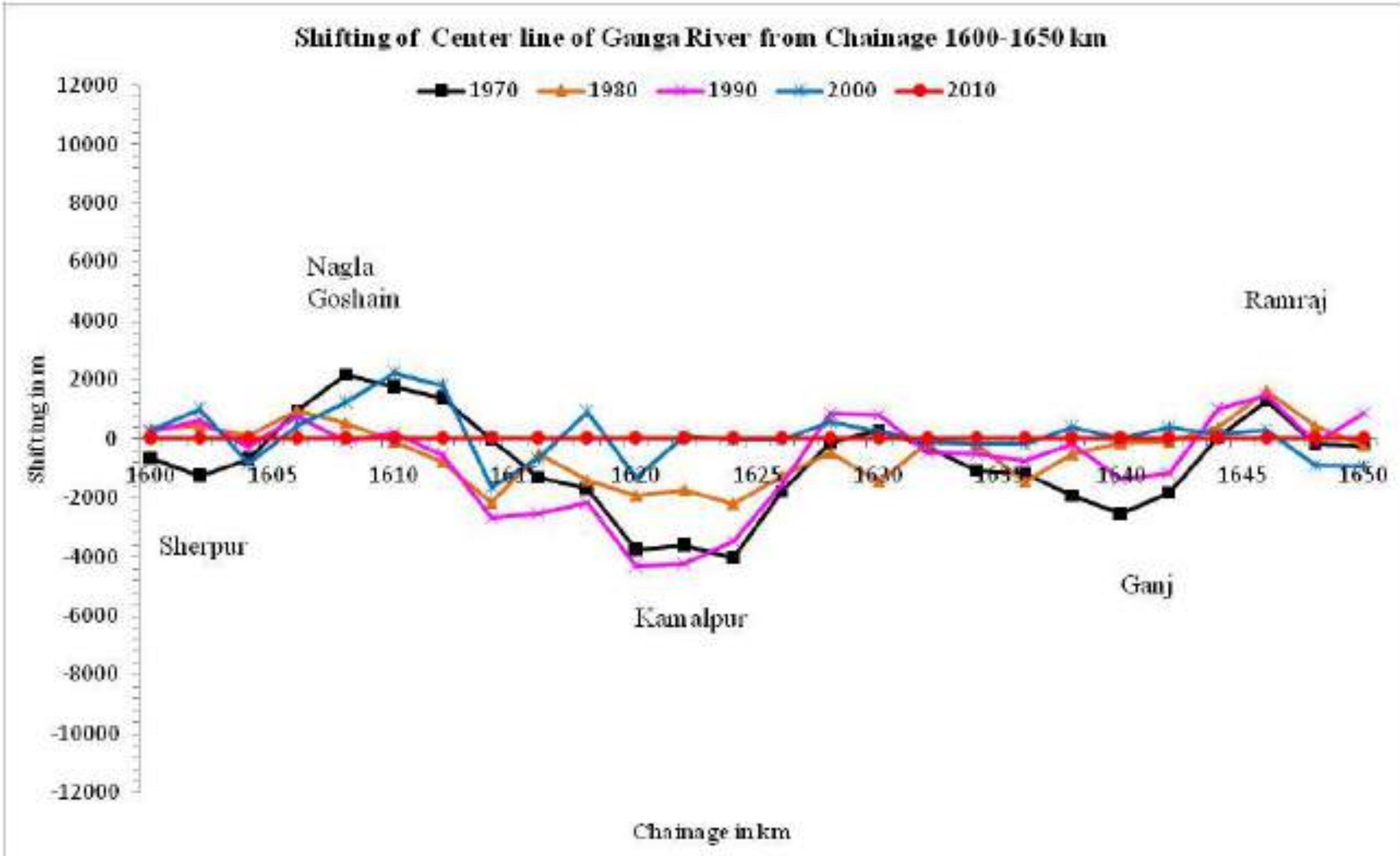


Figure 10.51b Shifting of center line of Ganga river from chainage 1600-1650 km

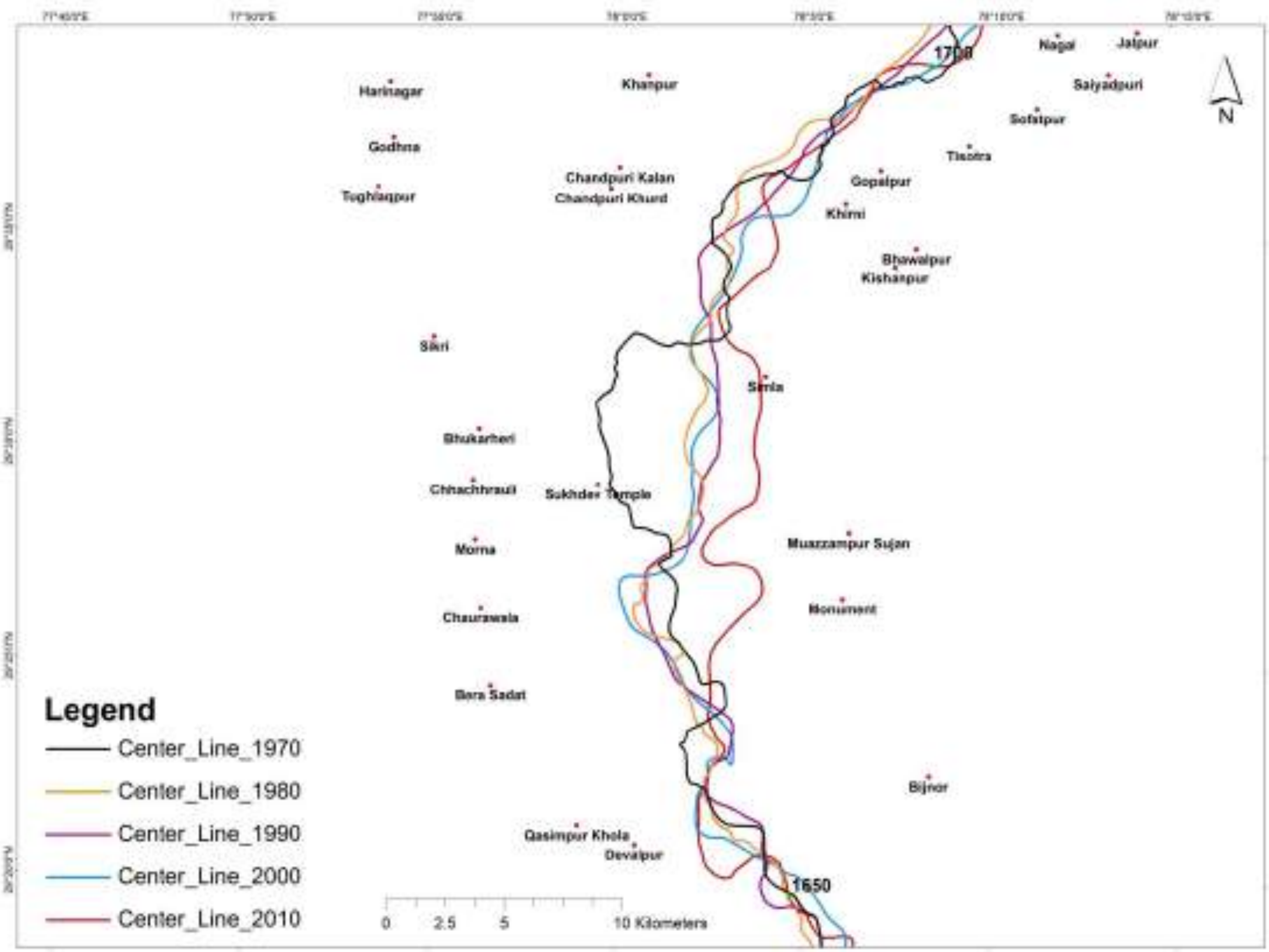


Figure 10.52a Shifting of center line of Ganga river from chainage 1650-1700 km

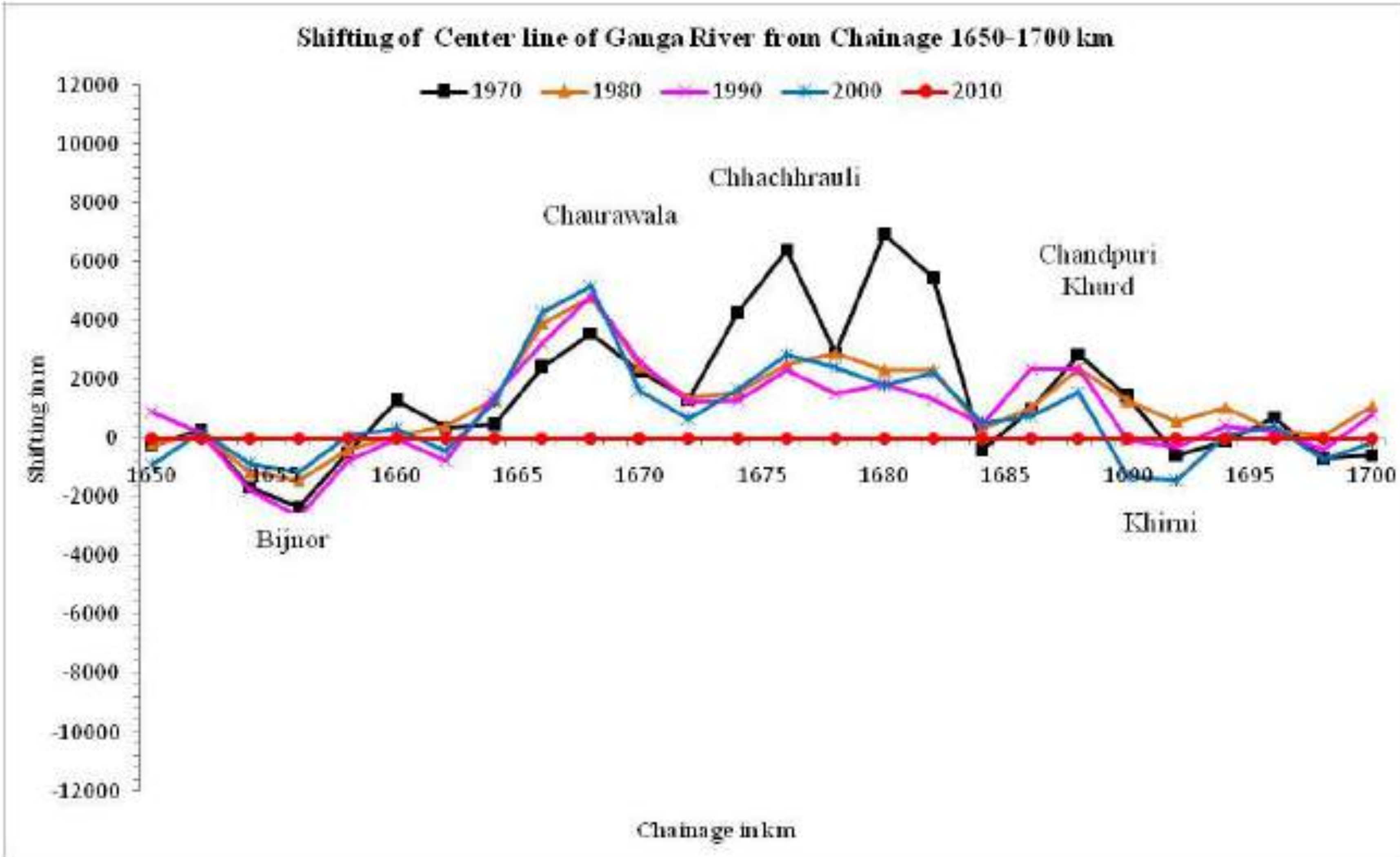


Figure 10.52b Shifting of center line of Ganga river from chainage 1650-1700 km

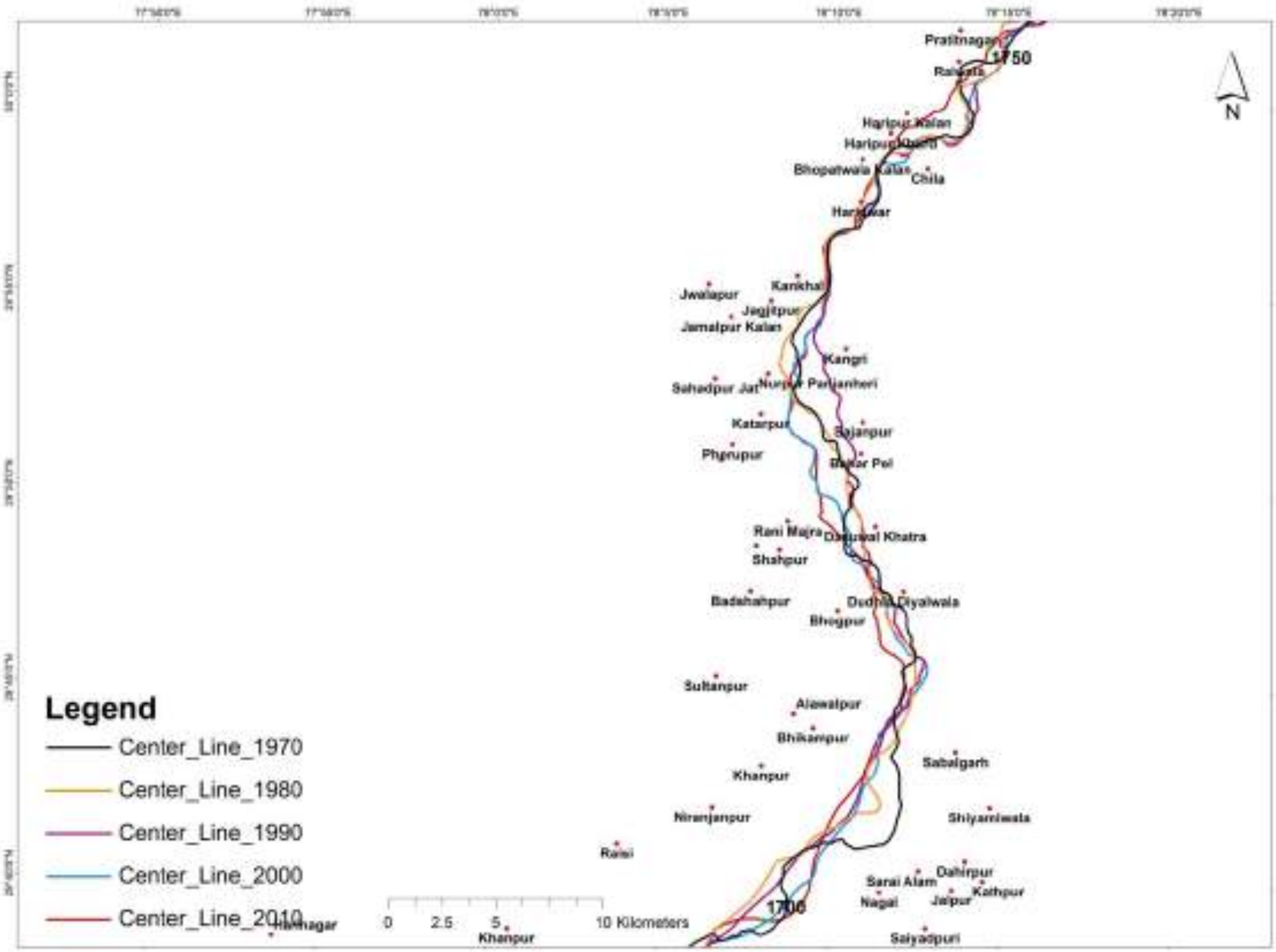


Figure 10.53a Shifting of center line of Ganga river from chainage 1700-1750 km

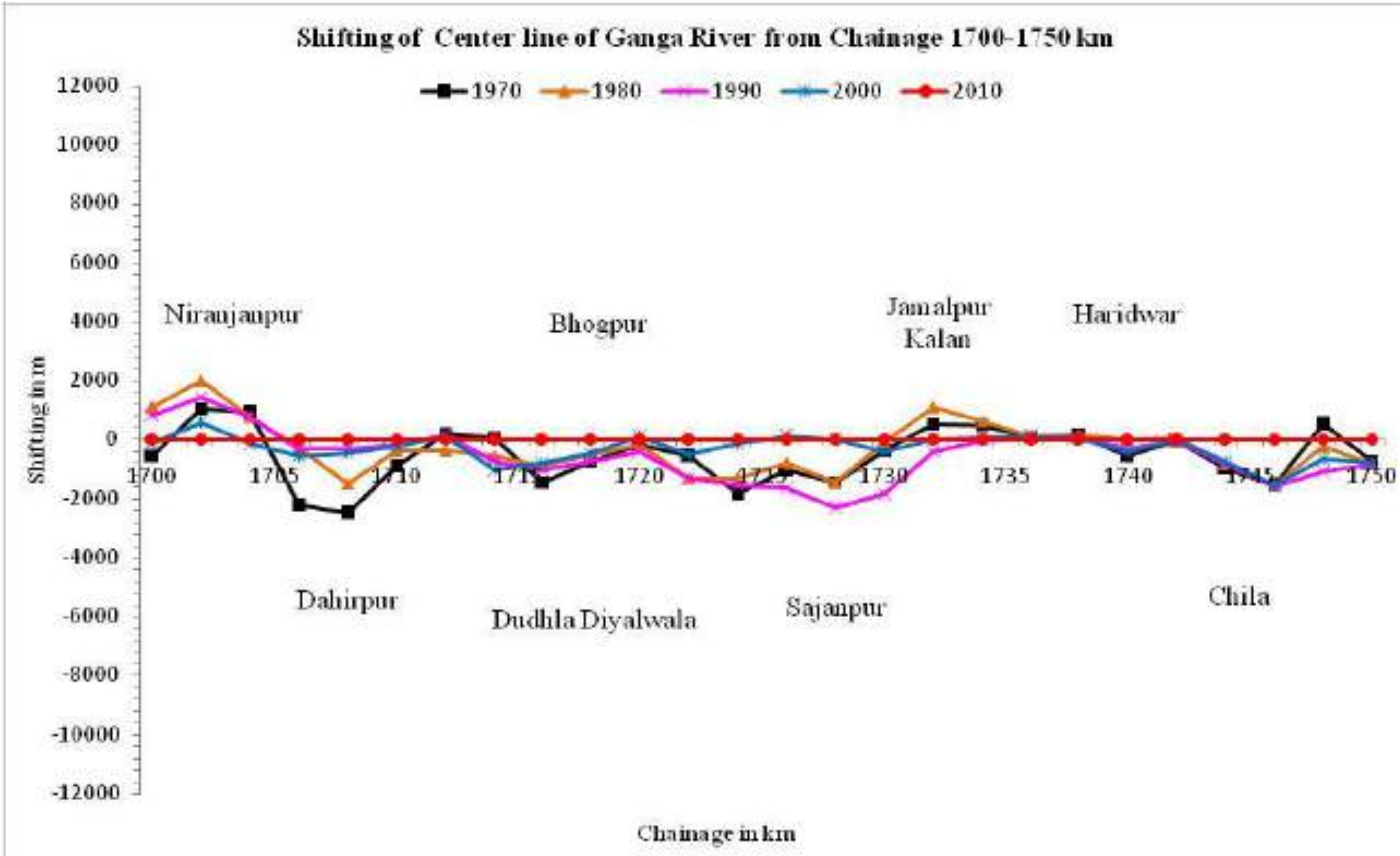


Figure 10.53b Shifting of center line of Ganga river from chainage 1700-1750 km

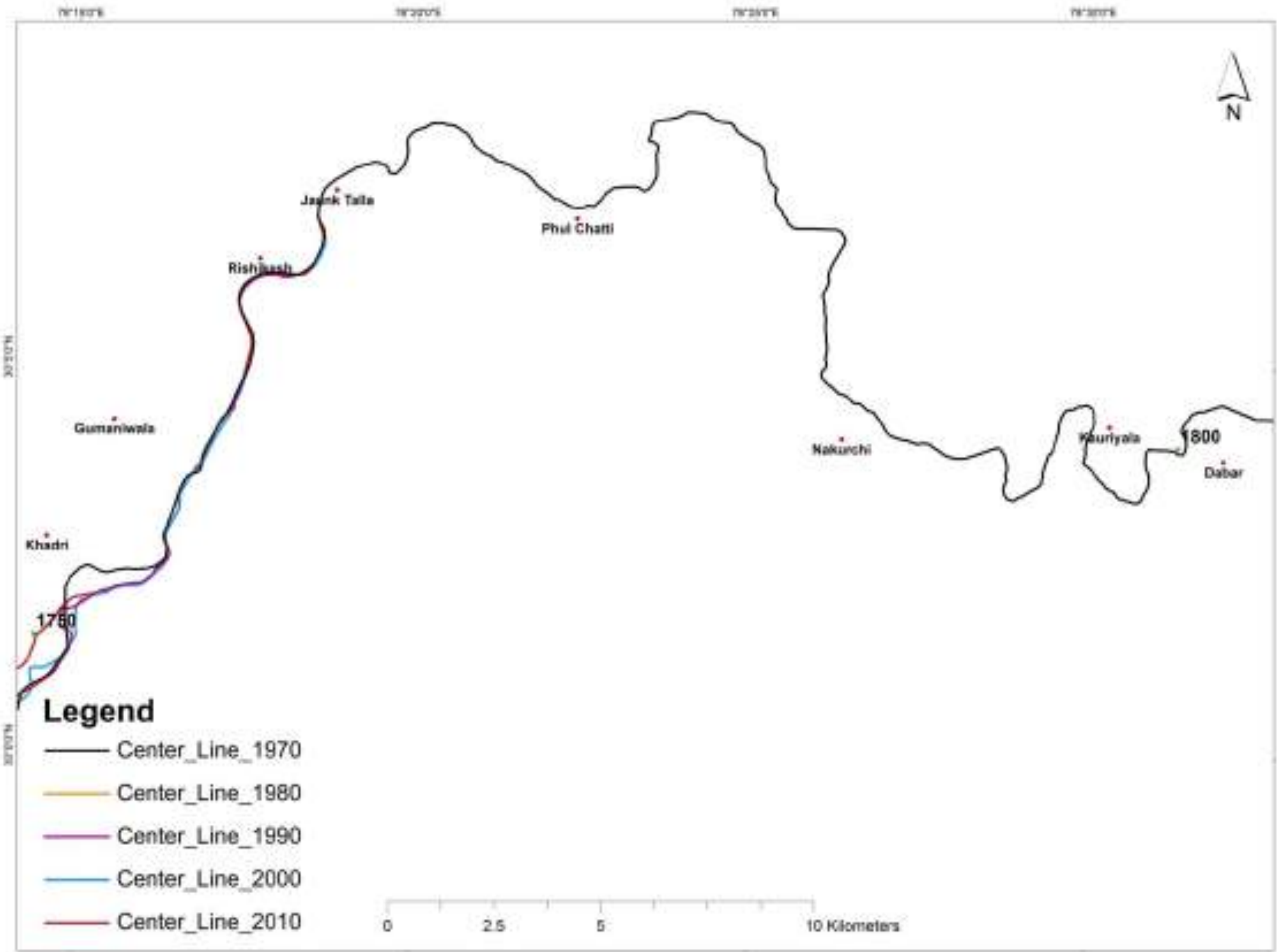


Figure 10.54a Shifting of center line of Ganga river from chainage 1750-1800 km

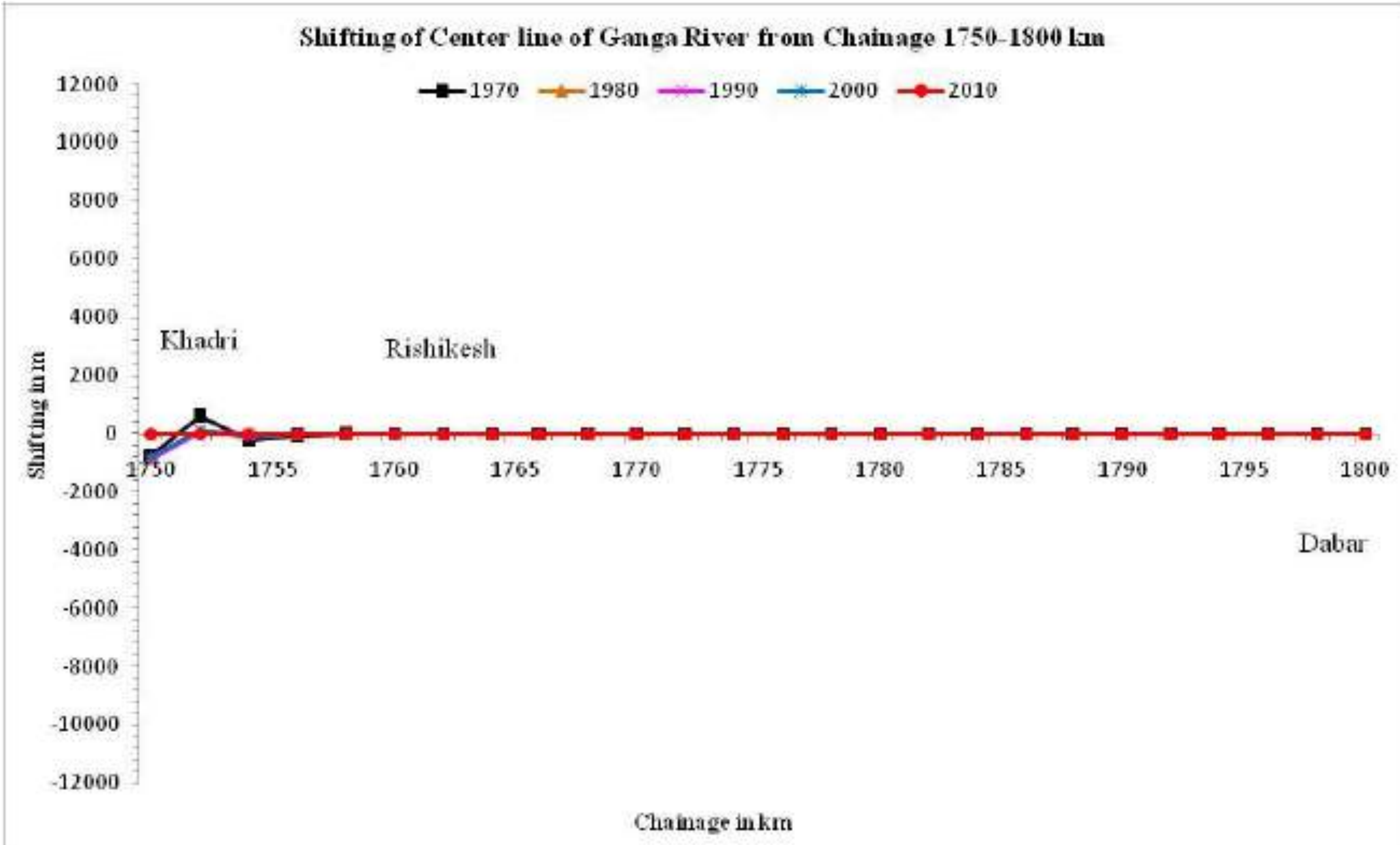


Figure 10.54b Shifting of center line of Ganga river from chainage 1750-1800 km

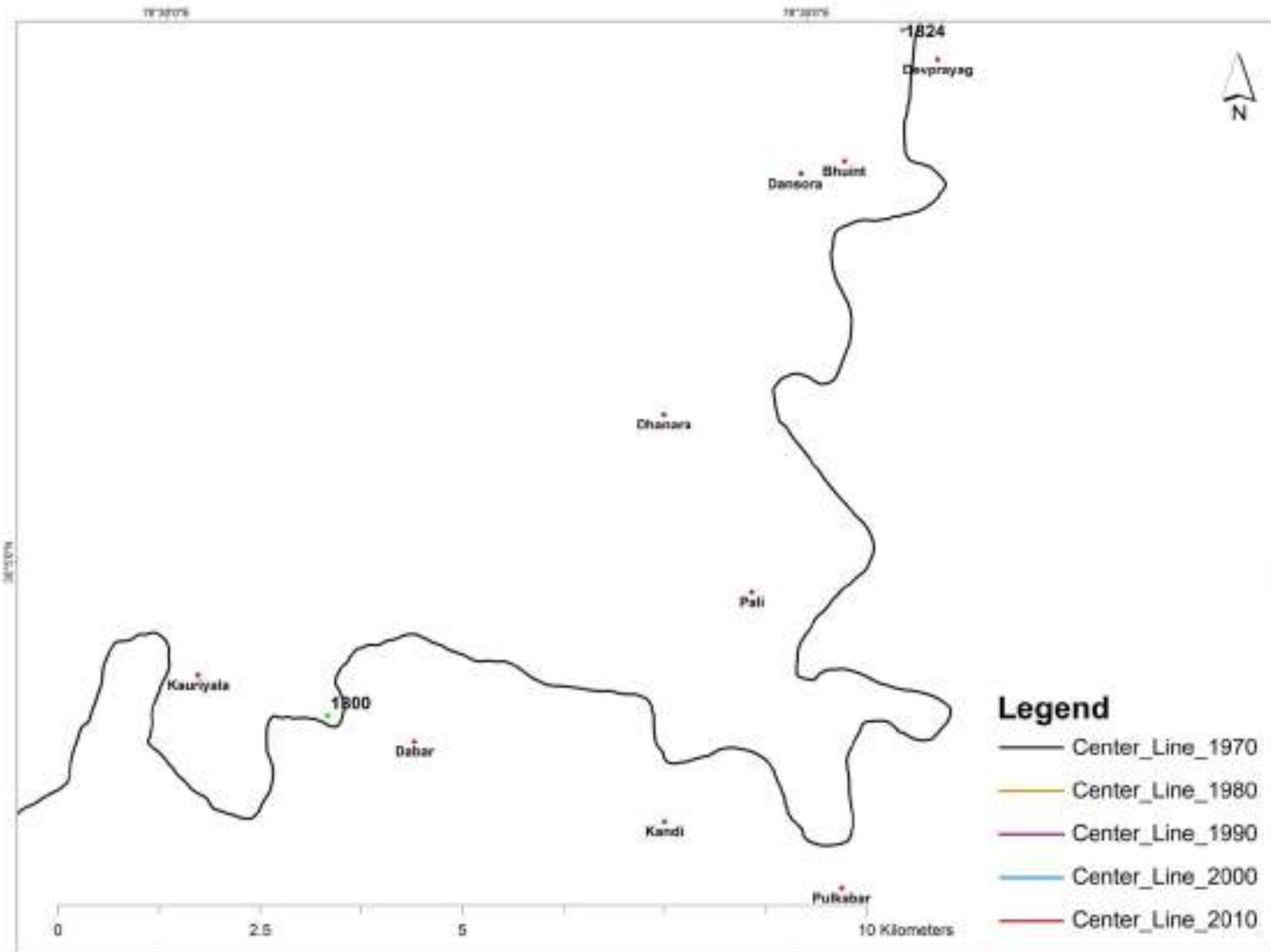


Figure 10.55a Shifting of center line of Ganga river from chainage 1800-1824 km

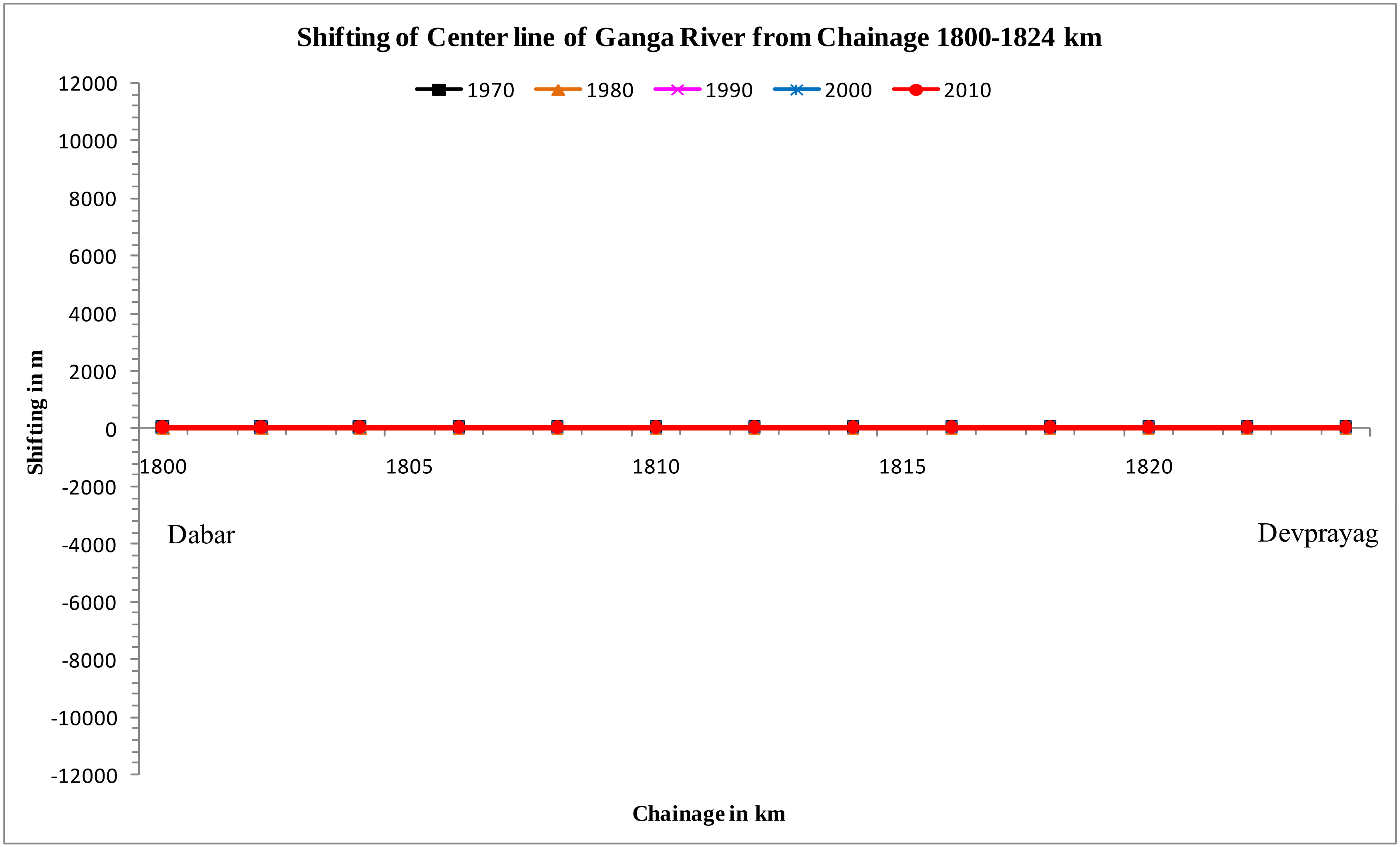


Figure 10.55b Shifting of center line of Ganga river from chainage 1800-1824 km

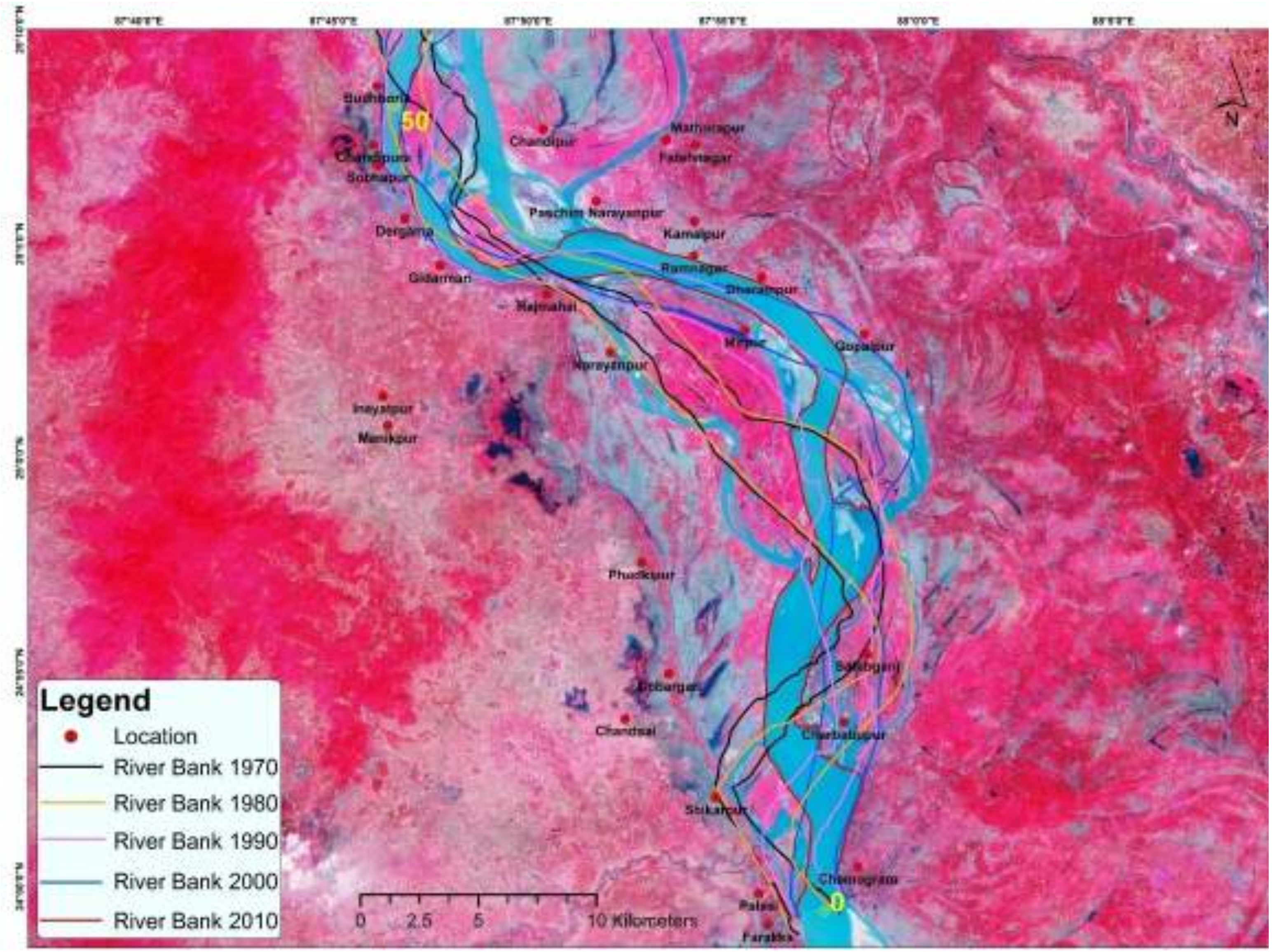


Figure 10.56 Decadal changes in the course of Ganga river from chainage 0-50 km

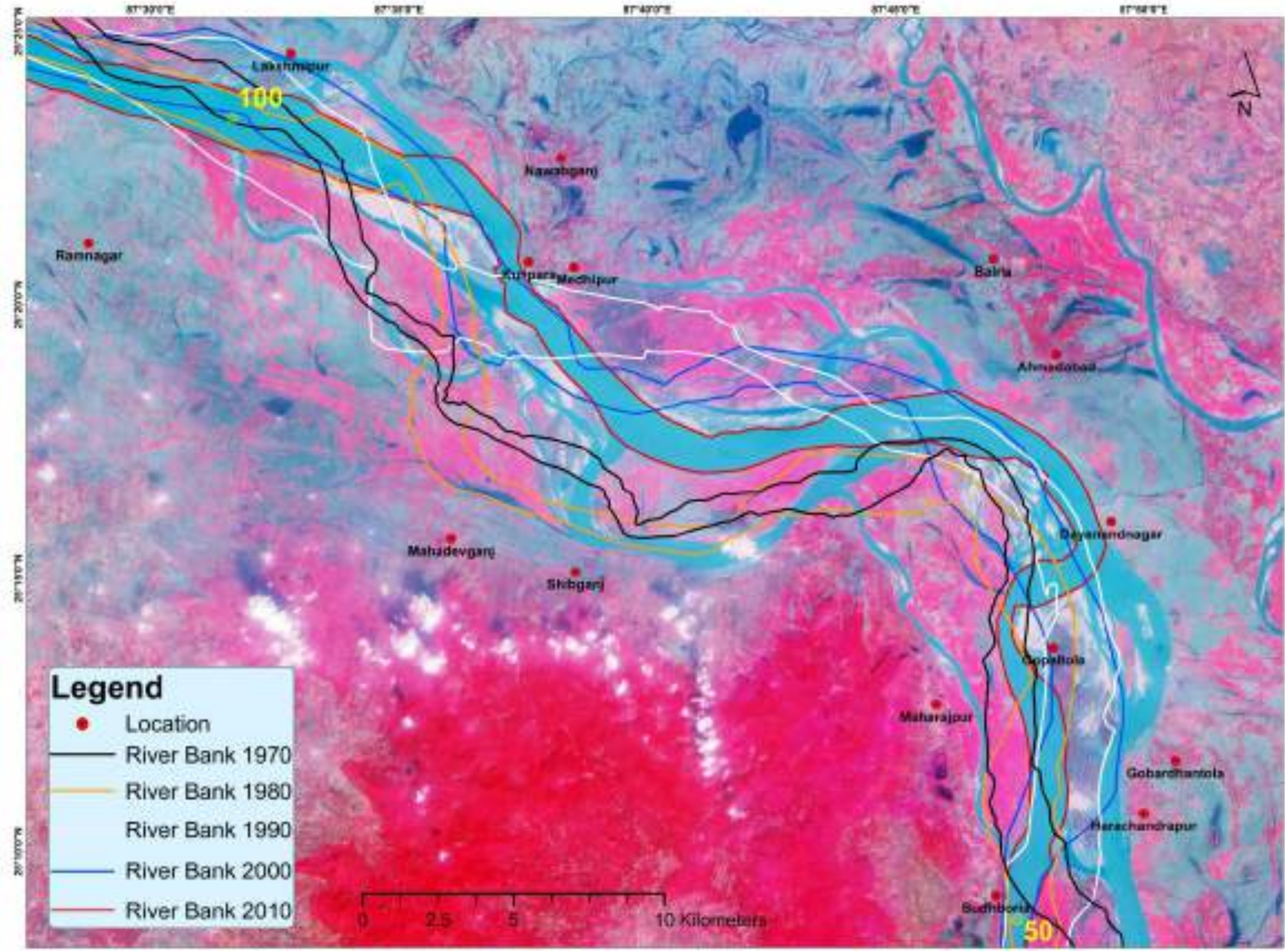


Figure 10.57 Decadal changes in the course of Ganga river from chainage 50-100 km

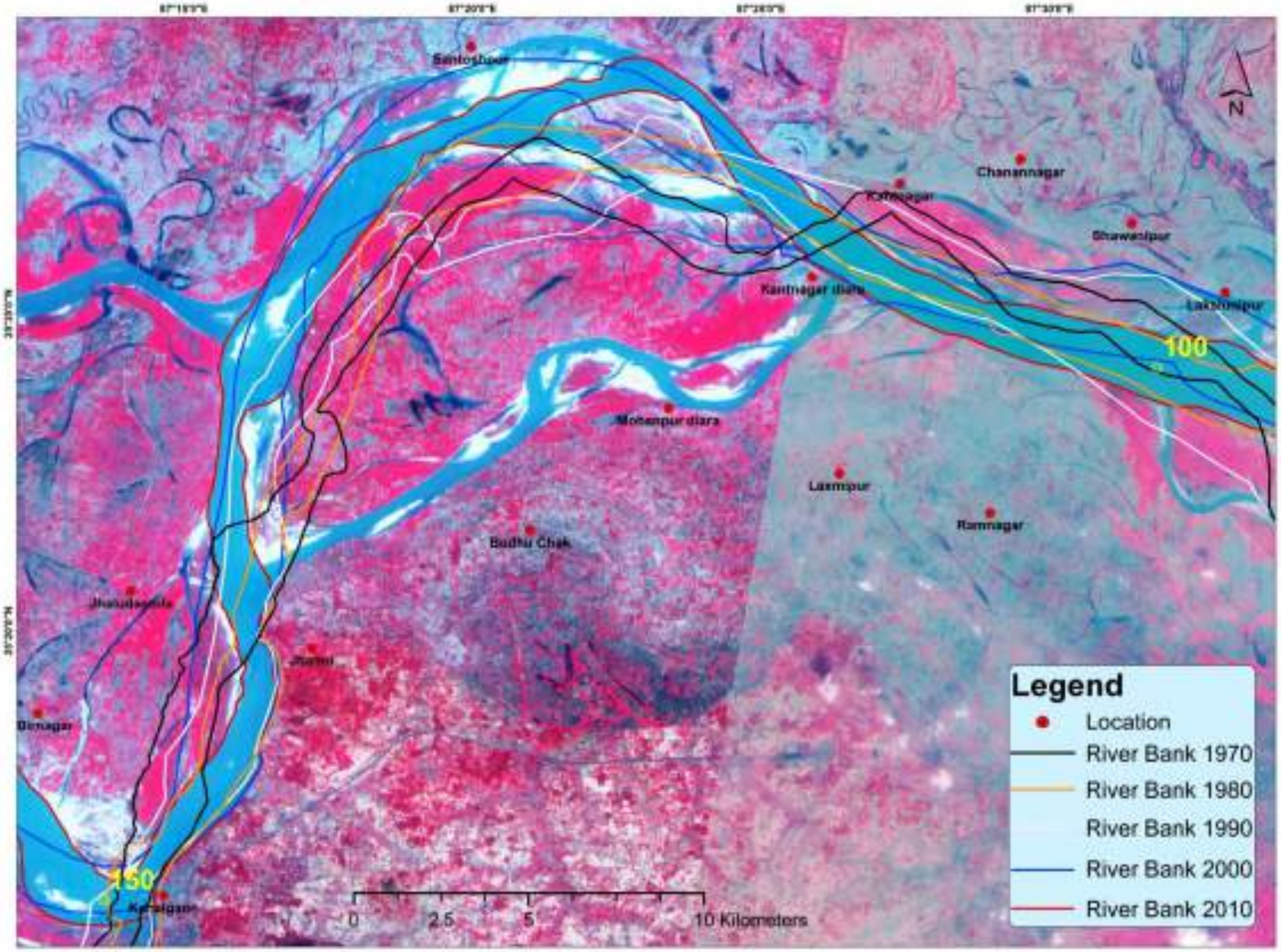


Figure 10.58 Decadal changes in the course of Ganga river from chainage 100-150 km

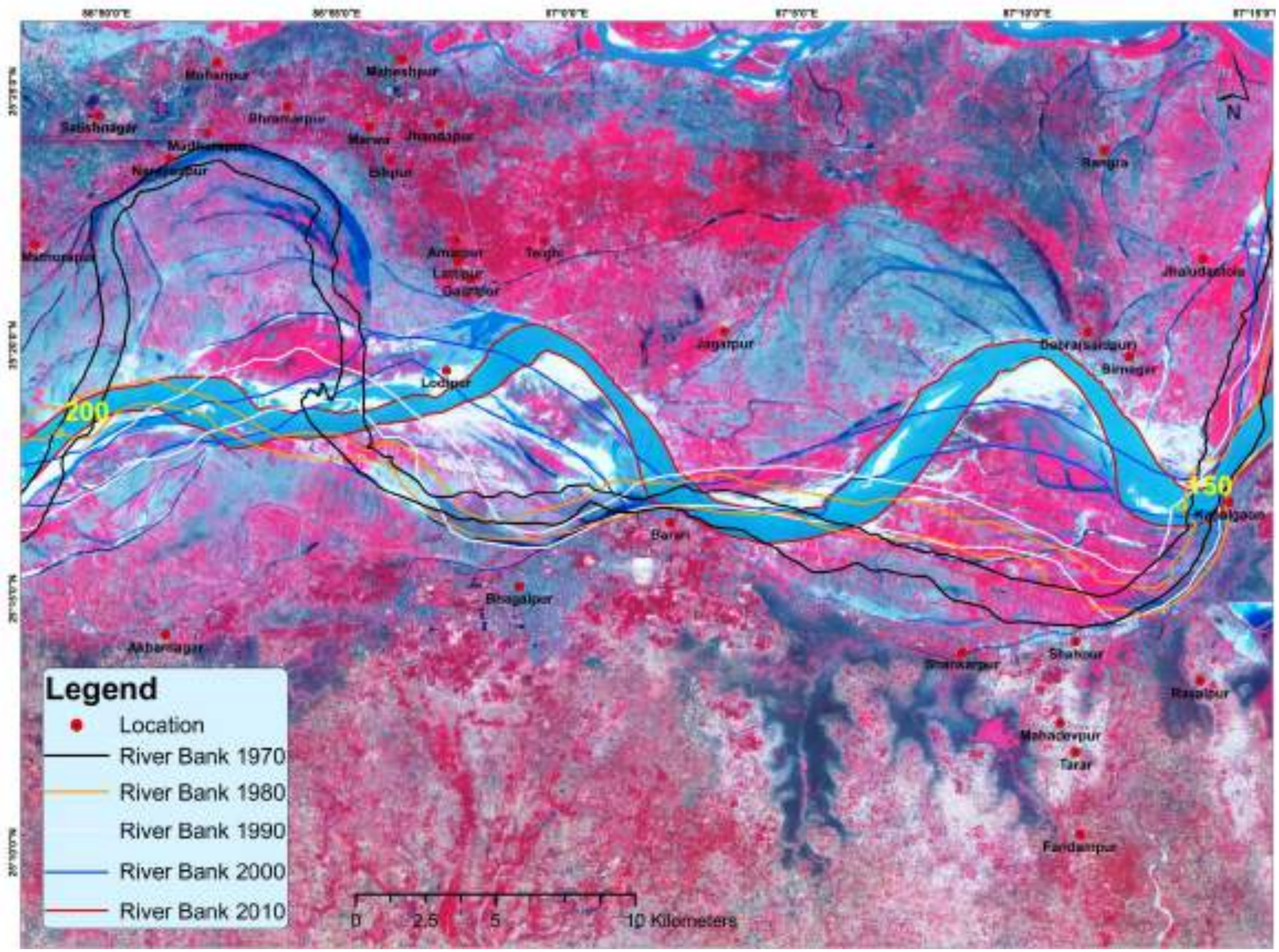


Figure 10.59 Decadal changes in the course of Ganga river from chainage 150-200 km

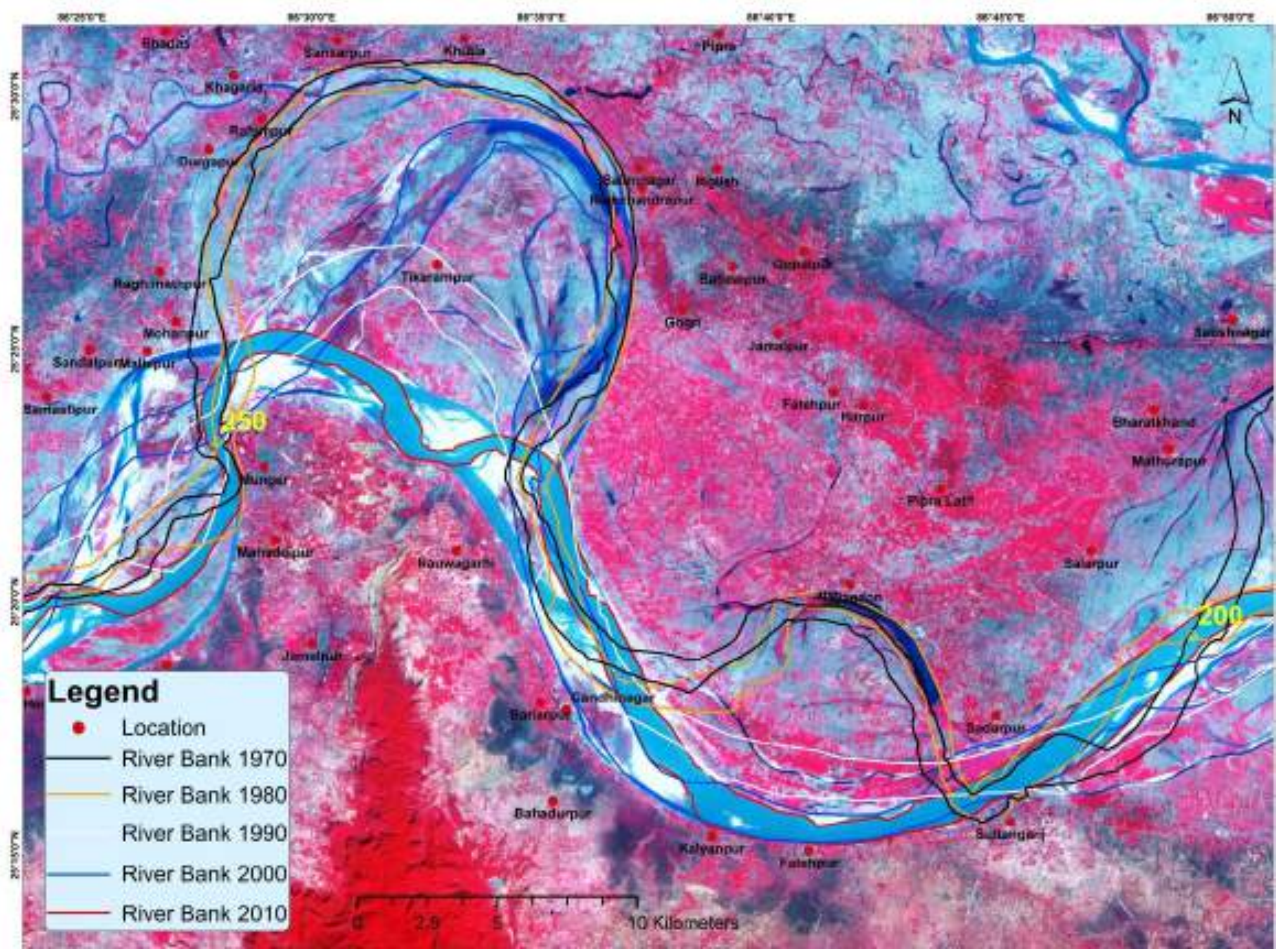


Figure 10.60 Decadal changes in the course of Ganga river from chainage 200-250 km

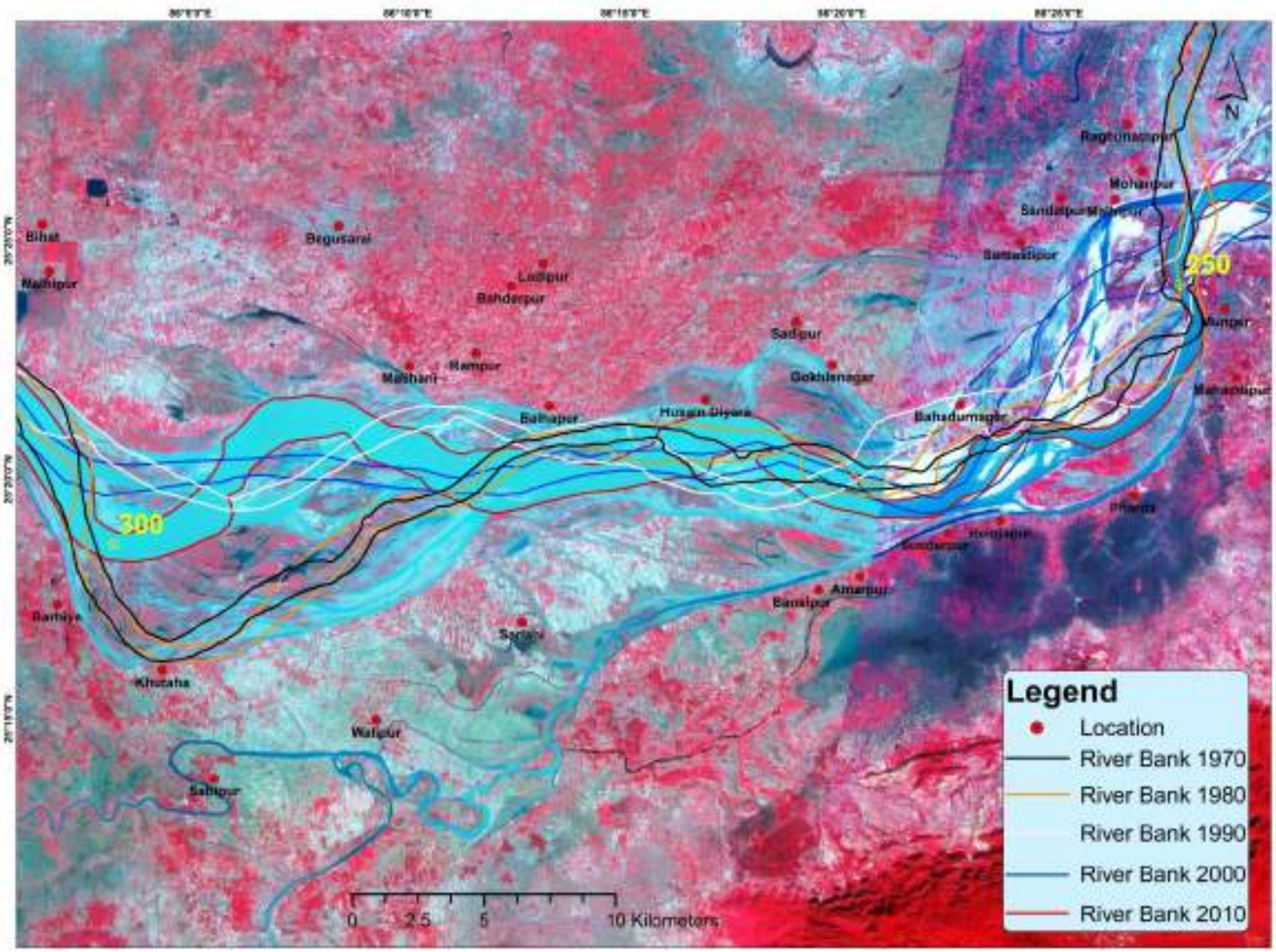


Figure 10.61 Decadal changes in the course of Ganga river from chainage 250-300 km

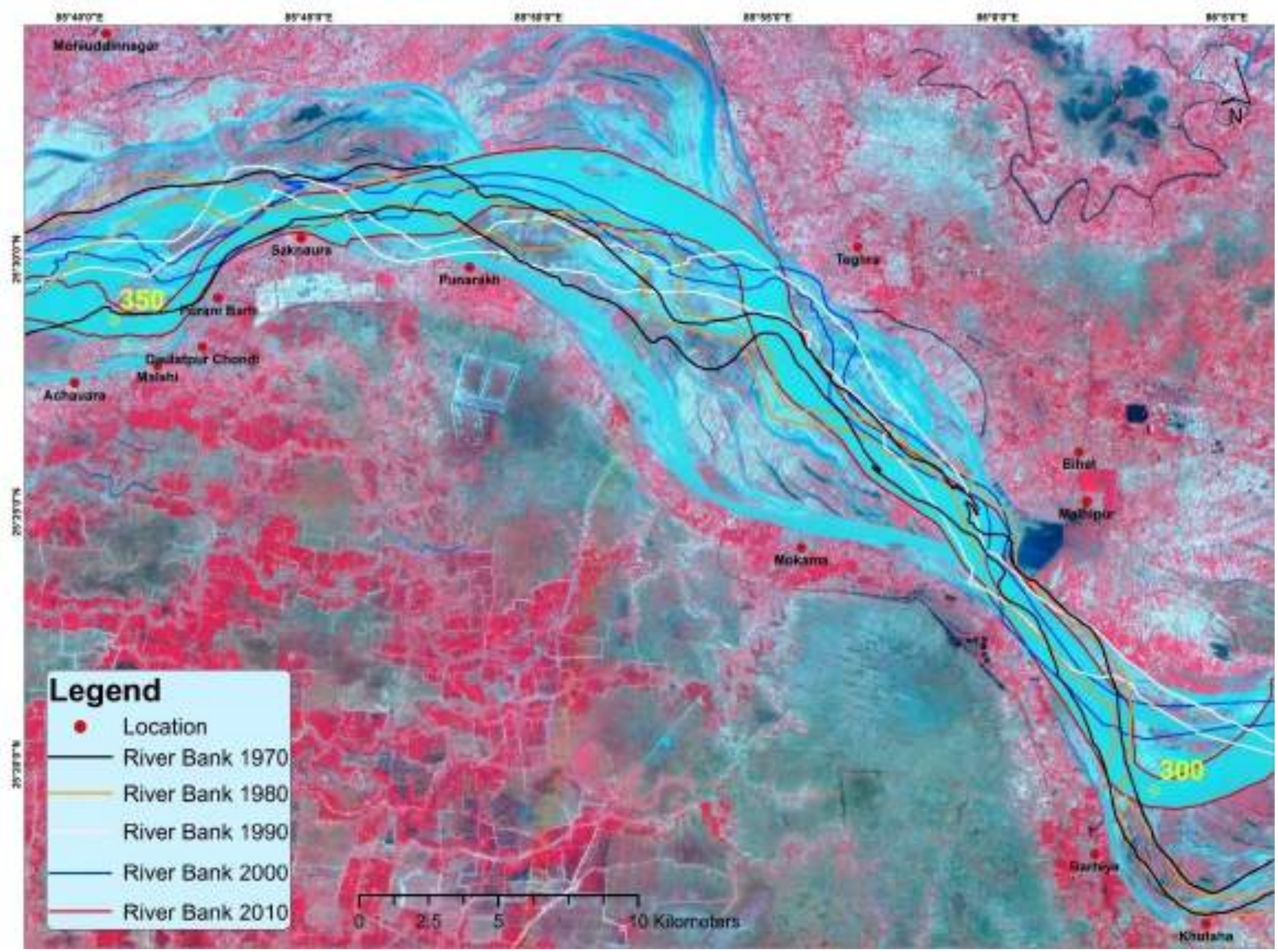


Figure 10.62 Decadal changes in the course of Ganga river from chainage 300-350 km

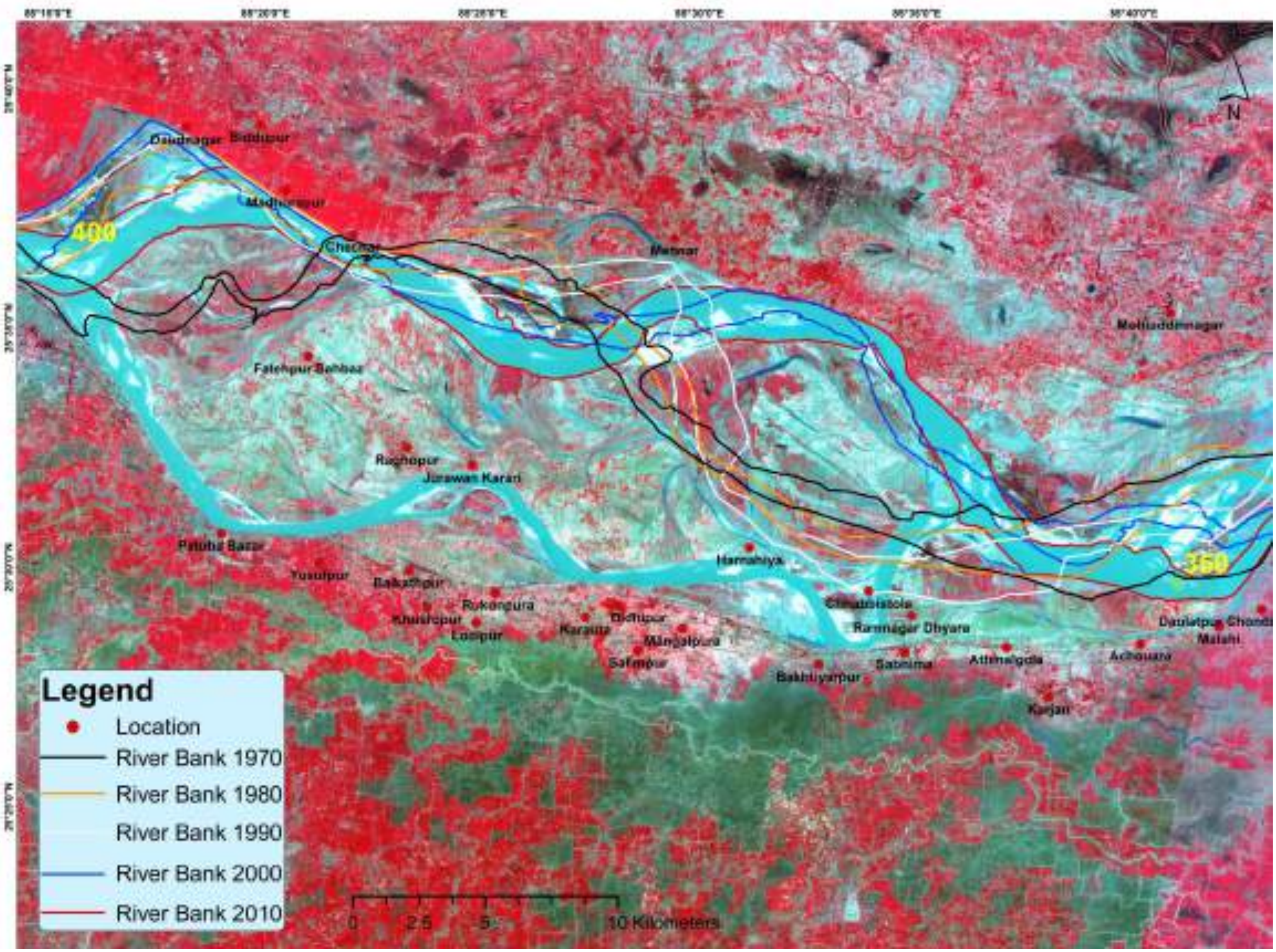


Figure 10.63 Decadal changes in the course of Ganga river from chainage 350-400 km

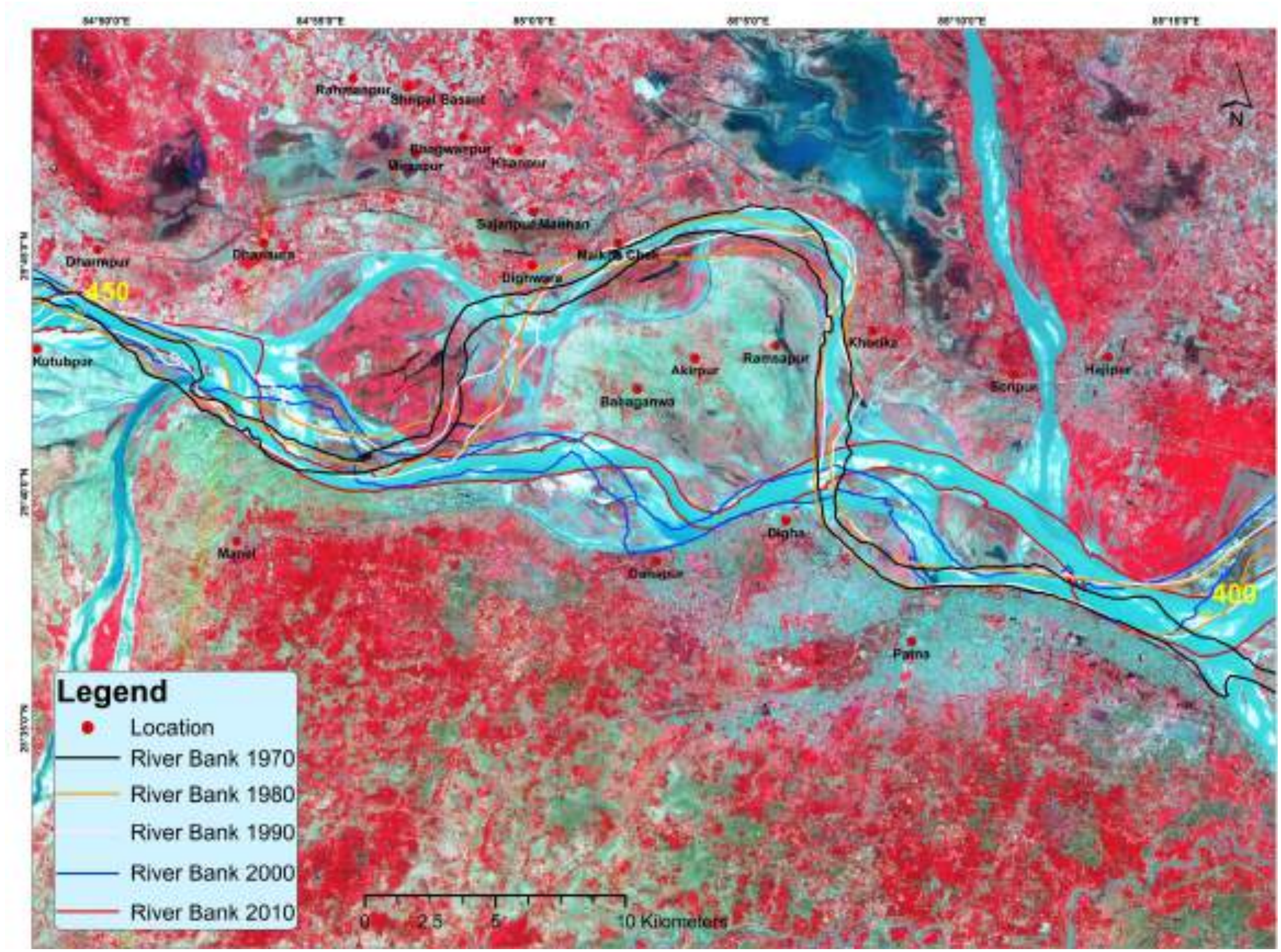


Figure 10.64 Decadal changes in the course of Ganga river from chainage 400-450 km

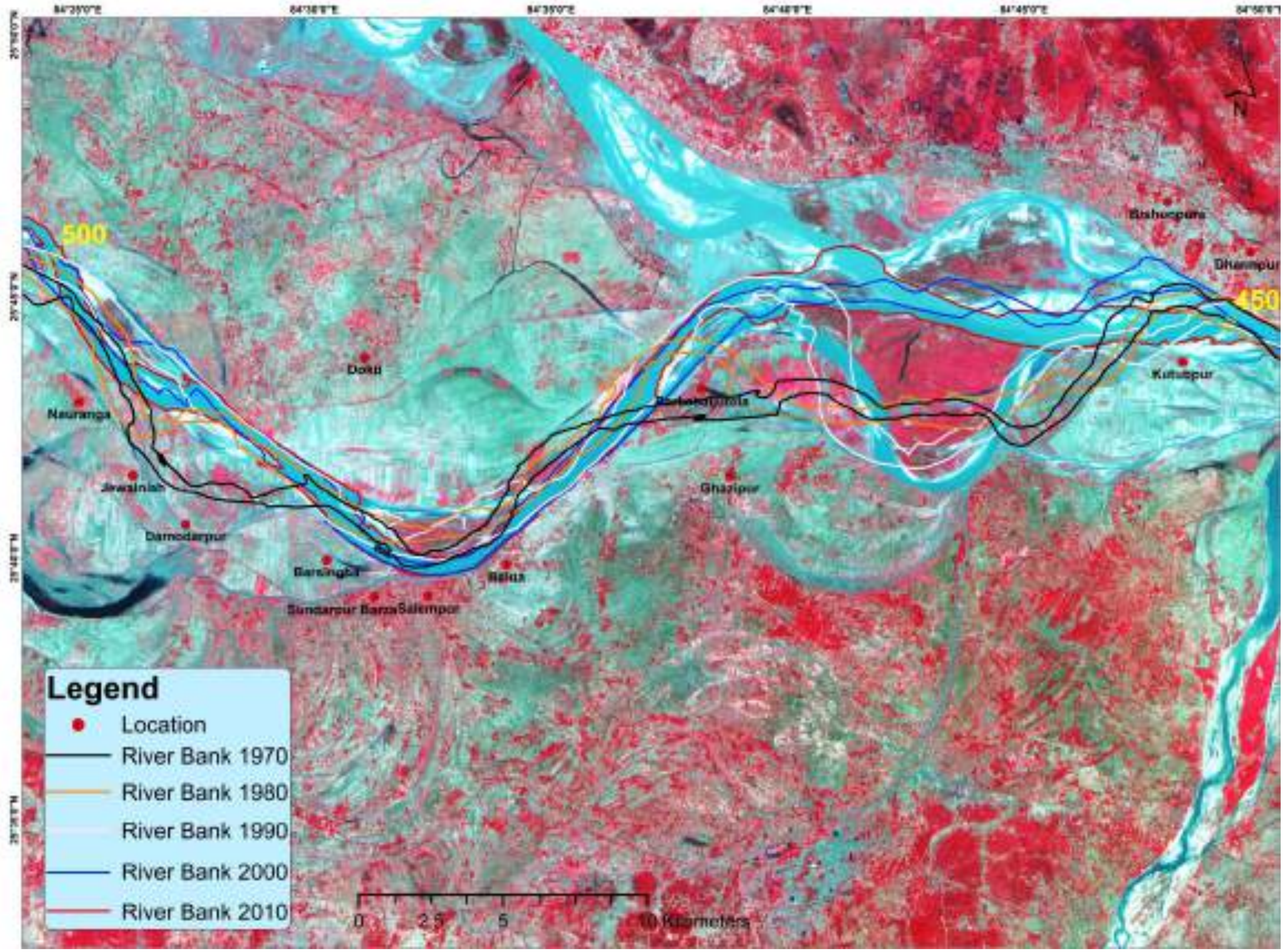


Figure 10.65 Decadal changes in the course of Ganga river from chainage 450-500 km

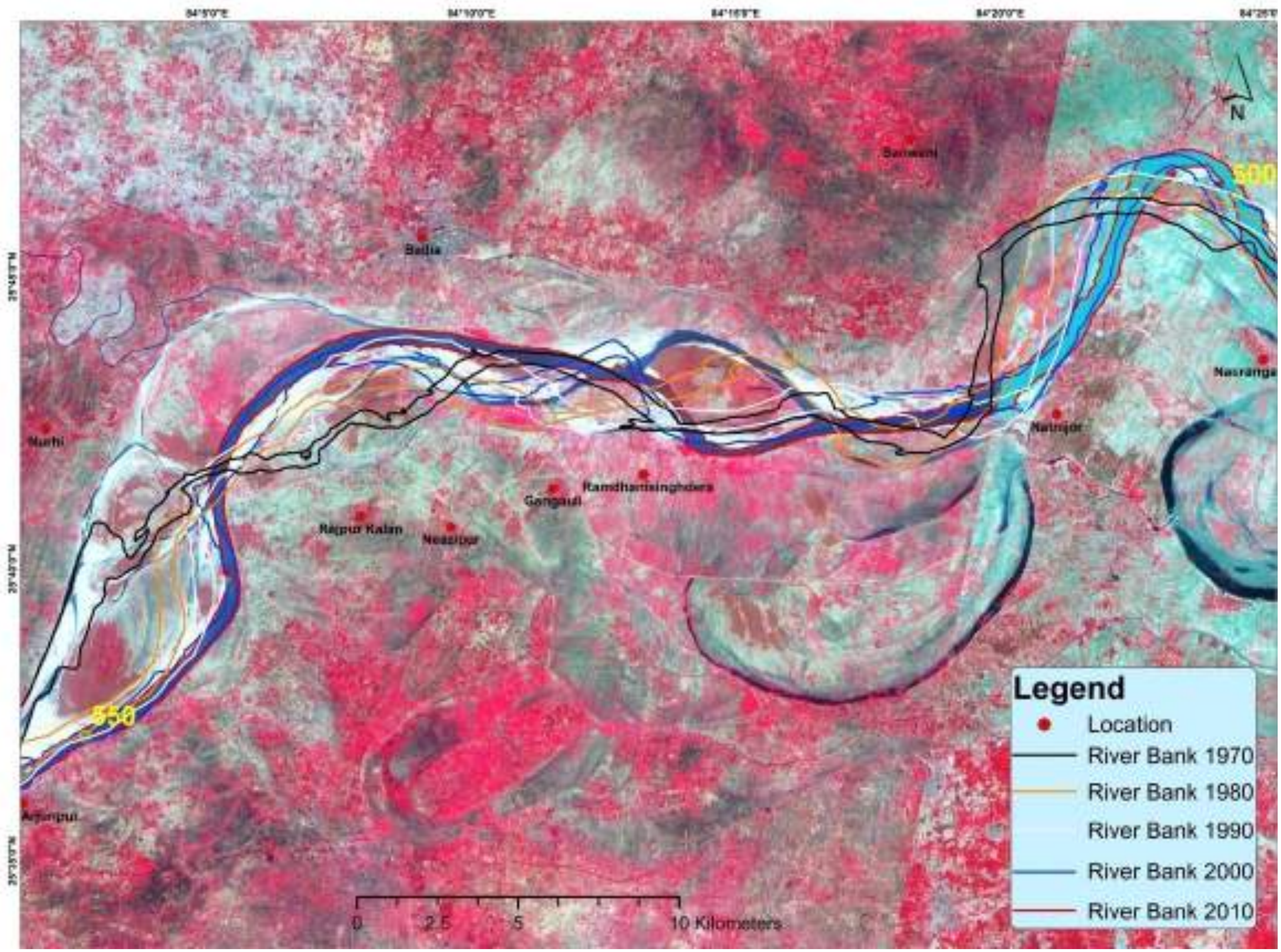


Figure 10.66 Decadal changes in the course of Ganga river from chainage 500-550 km

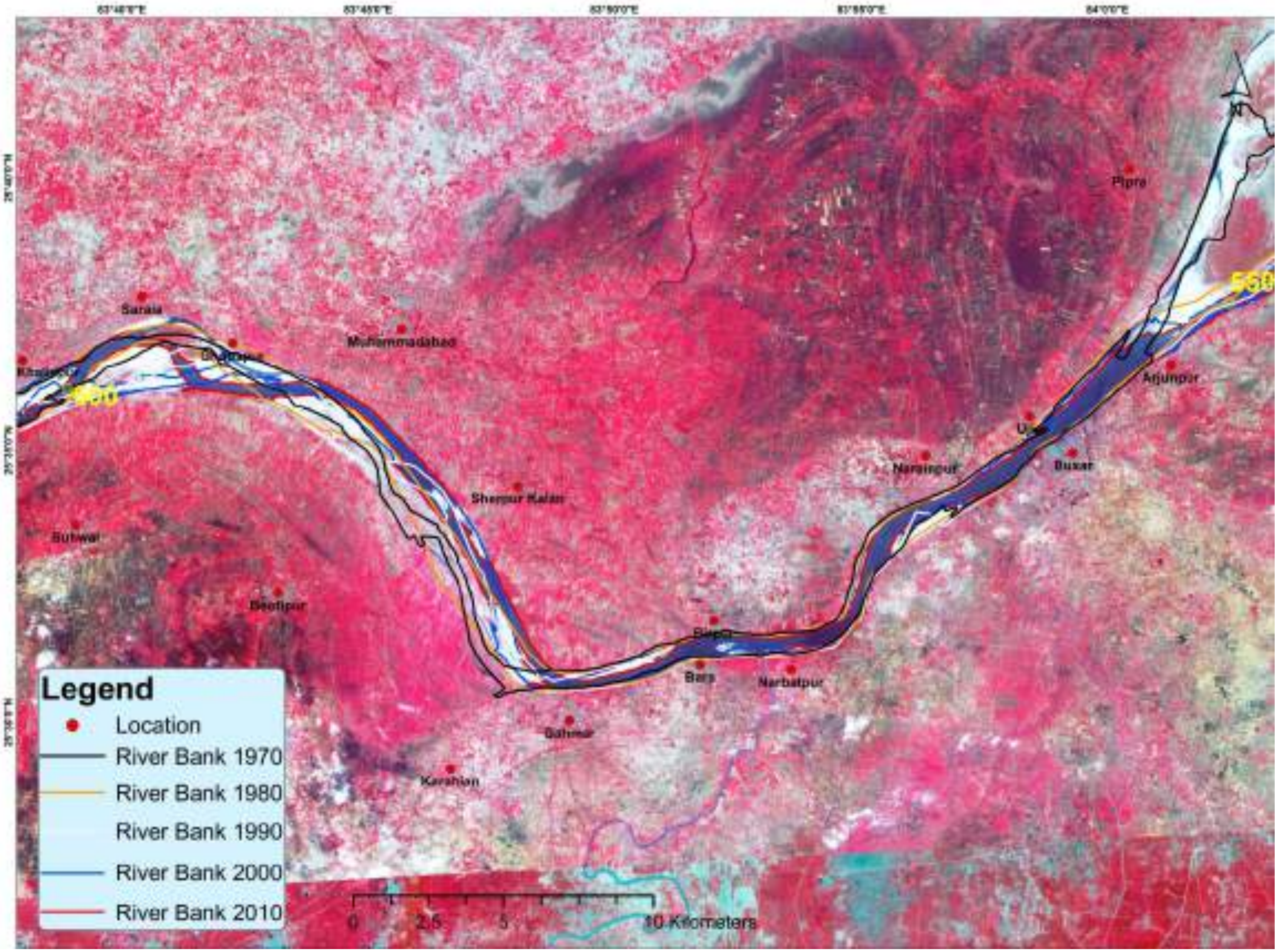


Figure 10.67 Decadal changes in the course of Ganga river from chainage 550-600 km

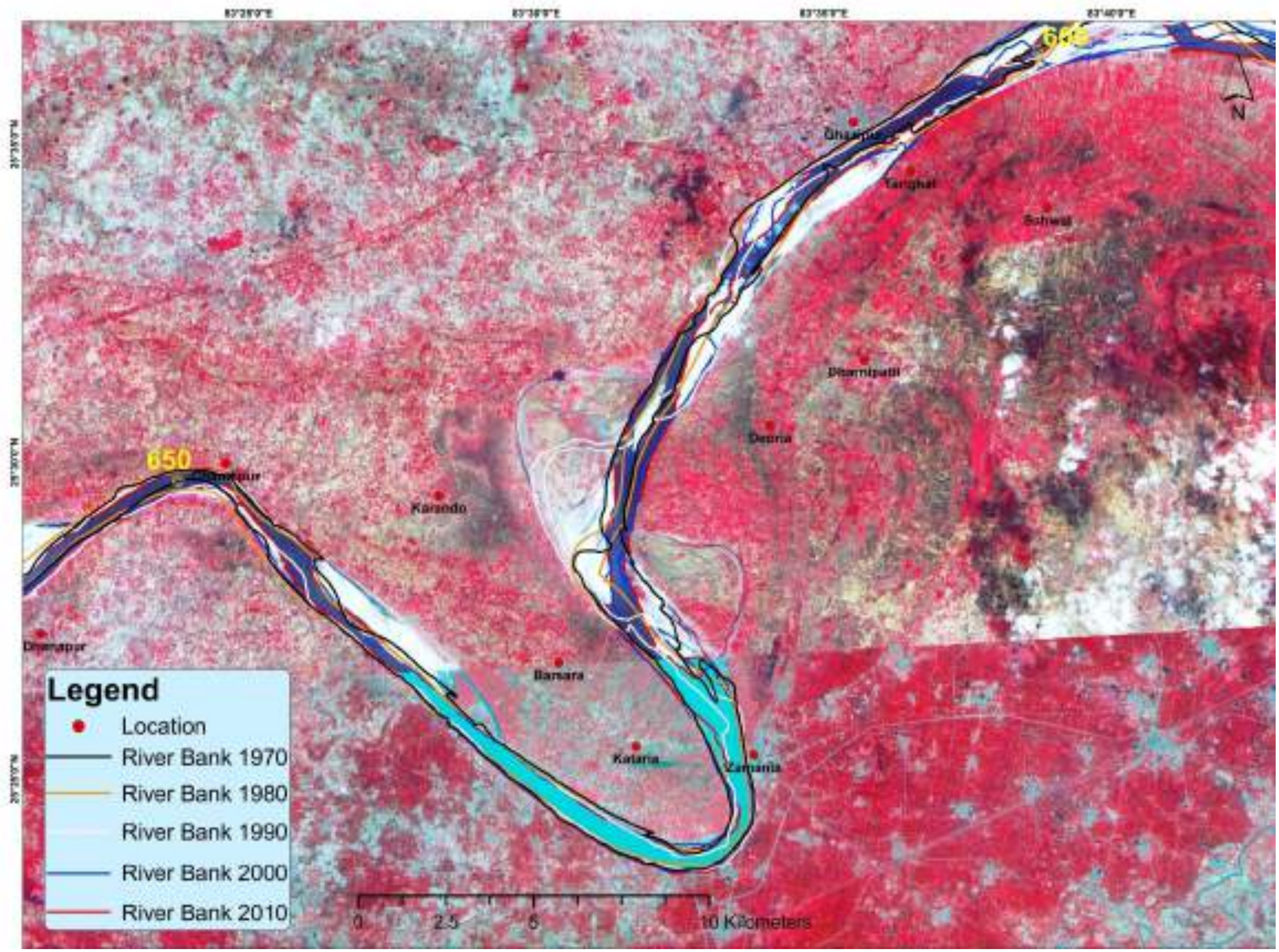


Figure 10.68 Decadal changes in the course of Ganga river from chainage 600-650 km

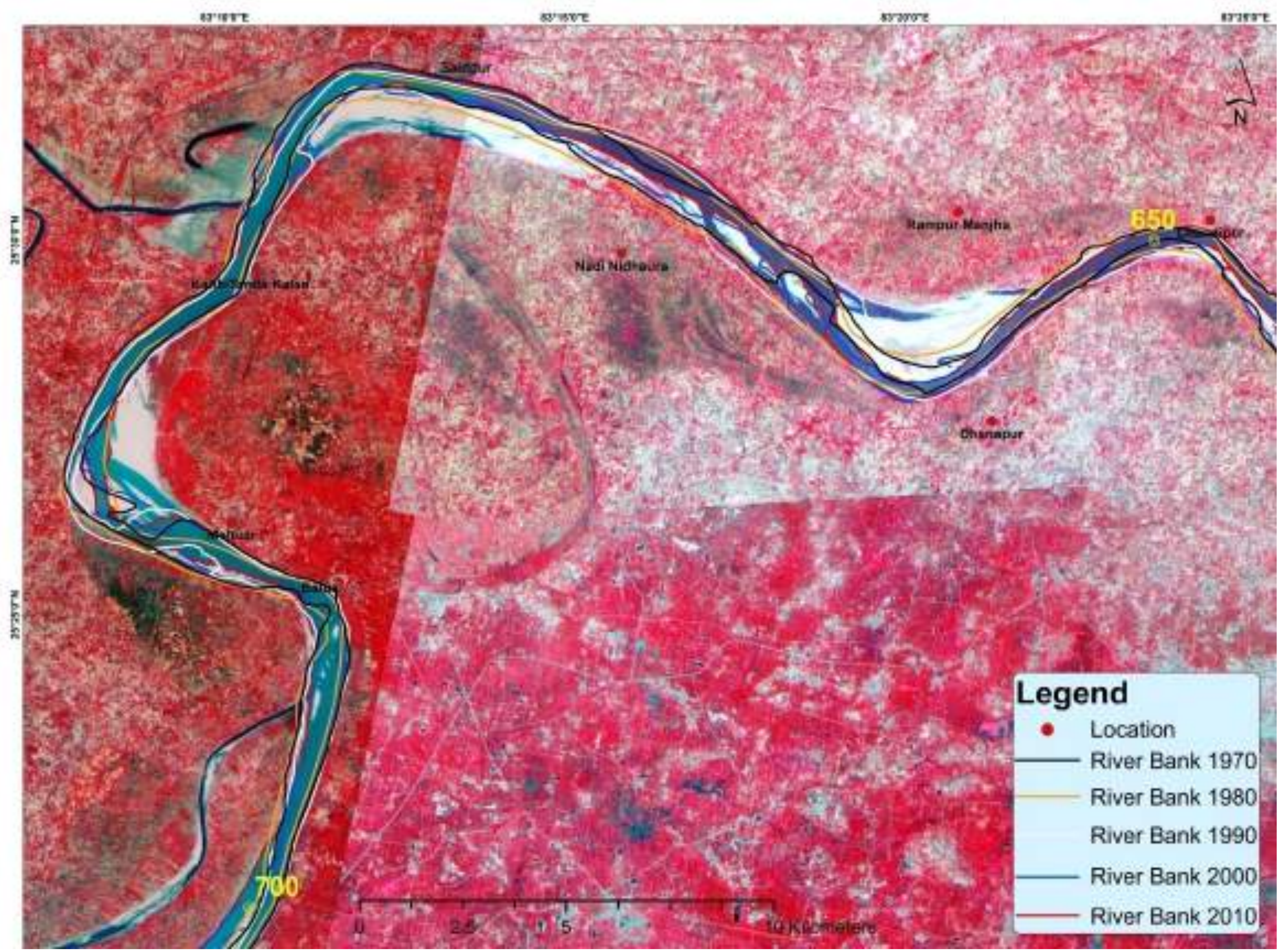


Figure 10.69 Decadal changes in the course of Ganga river from chainage 650-700 km

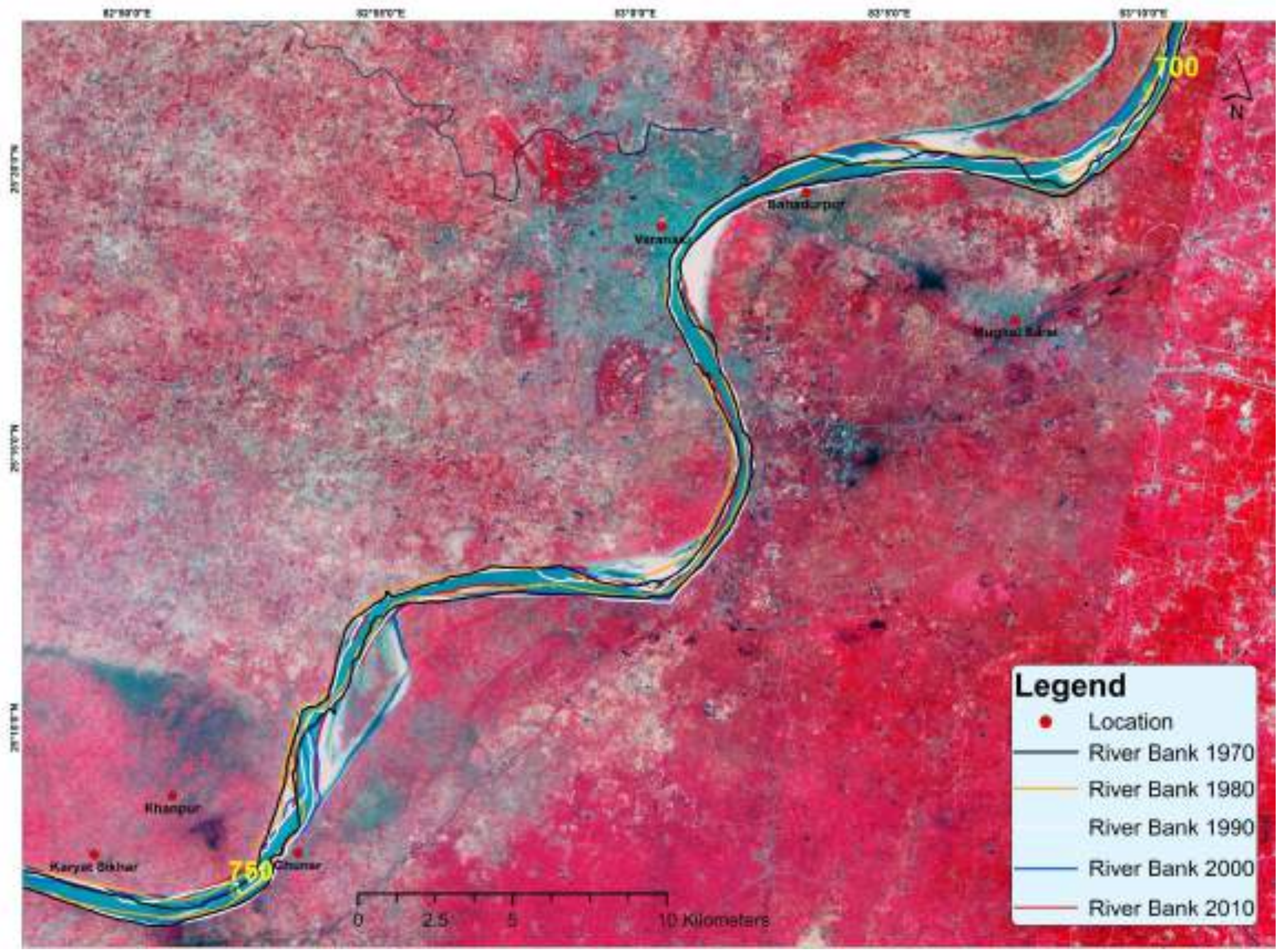


Figure 10.70 Decadal changes in the course of Ganga river from chainage 700-750 km

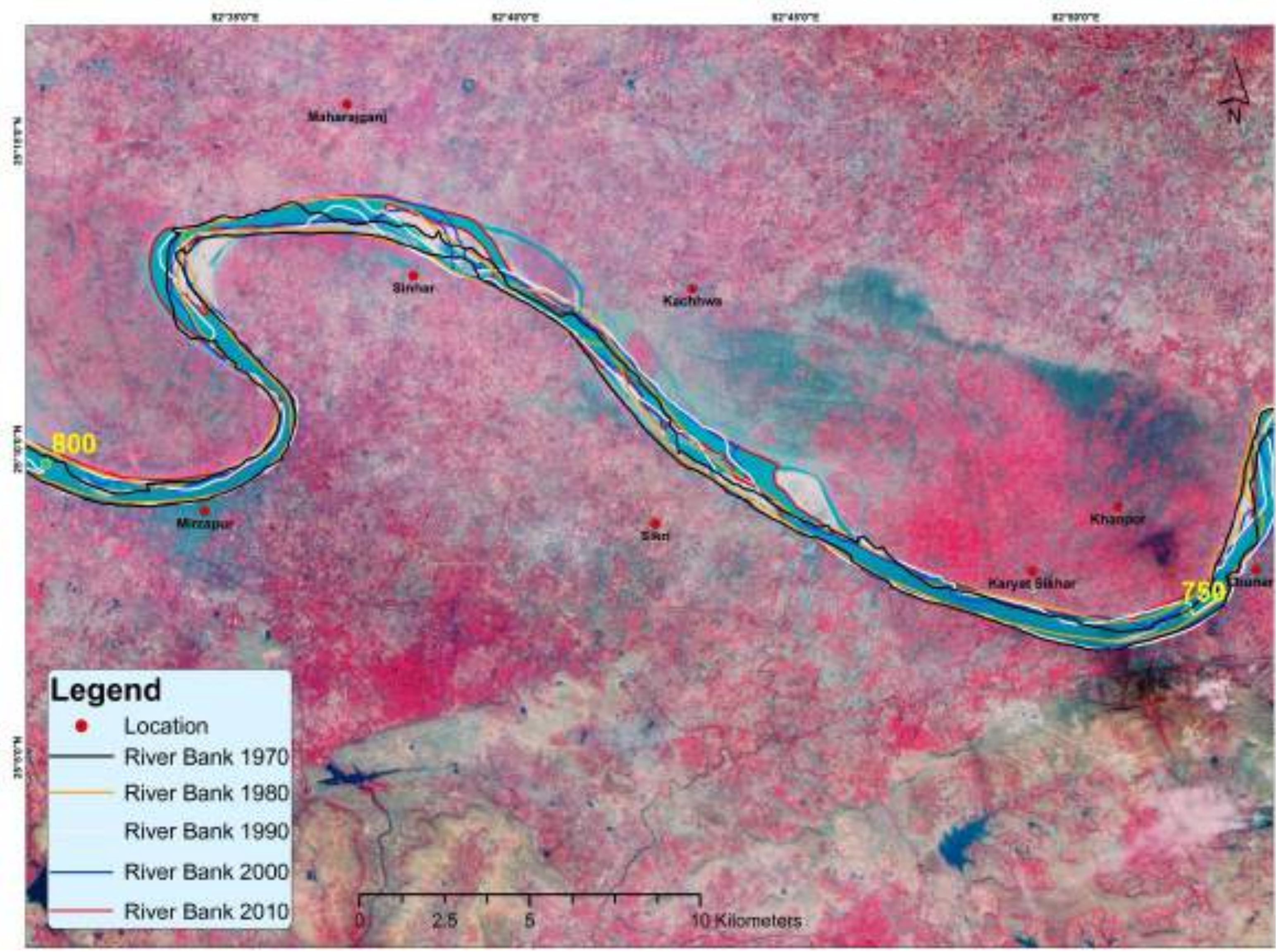


Figure 10.71 Decadal changes in the course of Ganga river from chainage 750-800 km

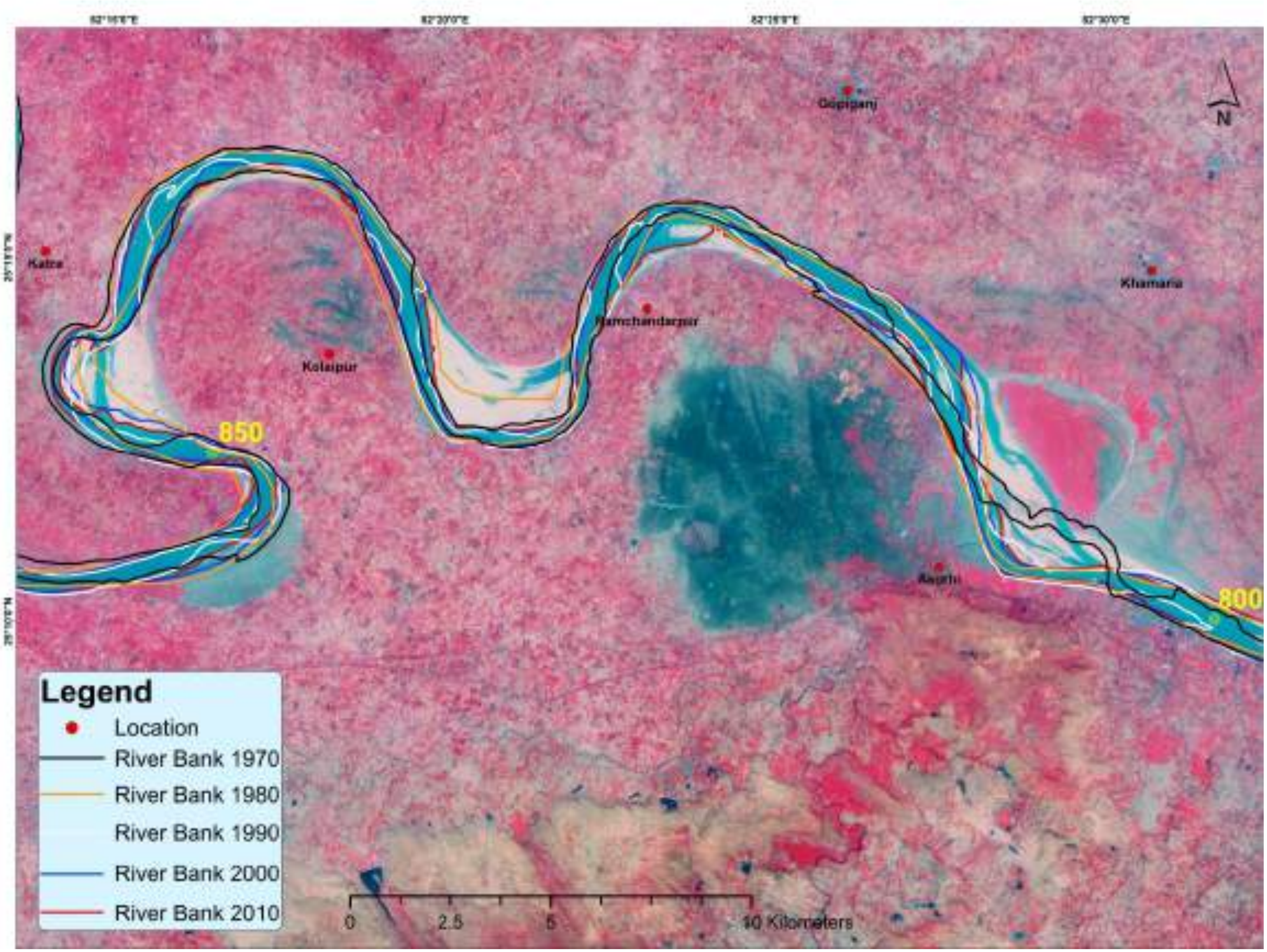


Figure 10.72 Decadal changes in the course of Ganga river from chainage 800-850 km

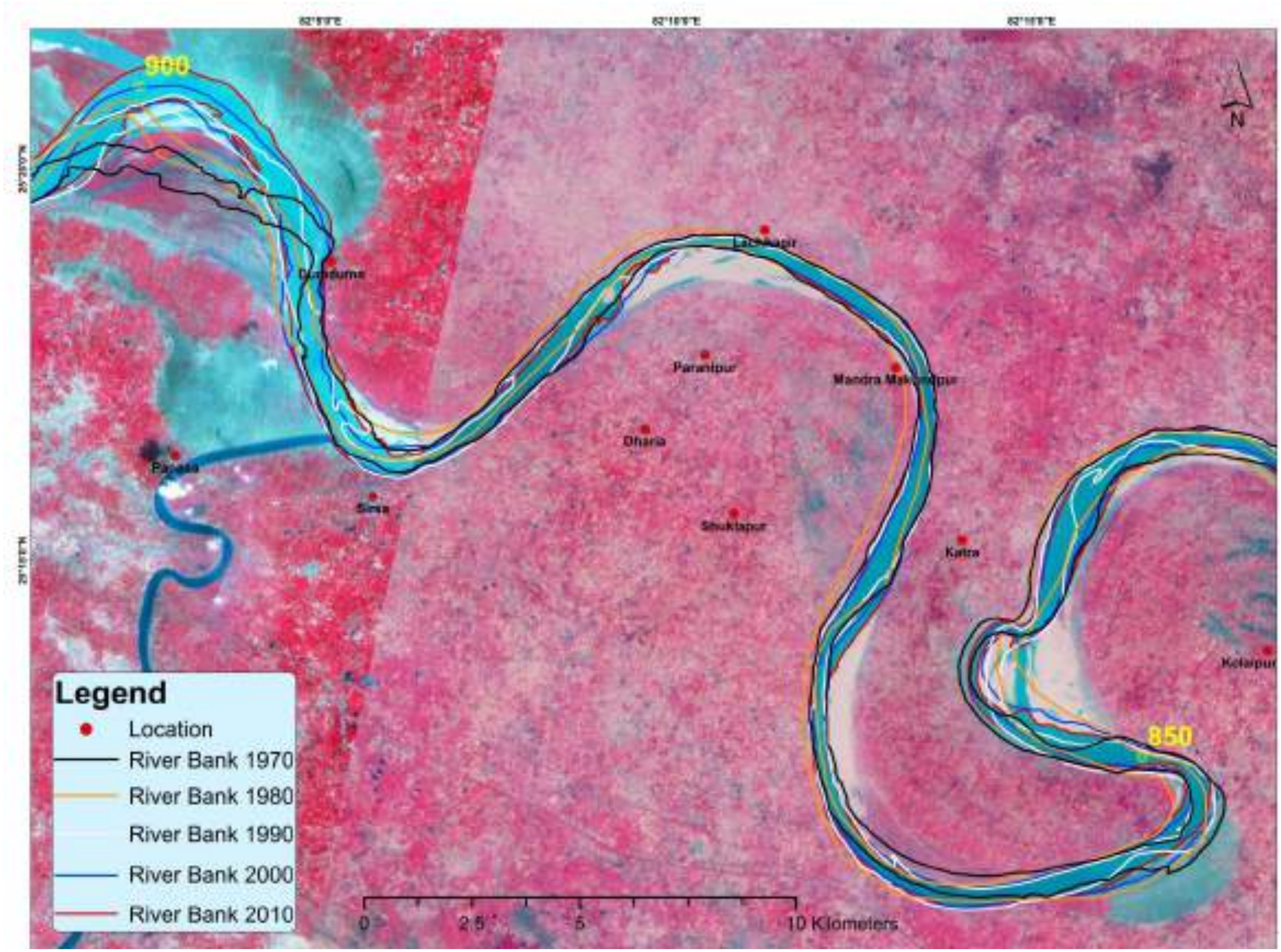


Figure 10.73 Decadal changes in the course of Ganga river from chainage 850-900 km

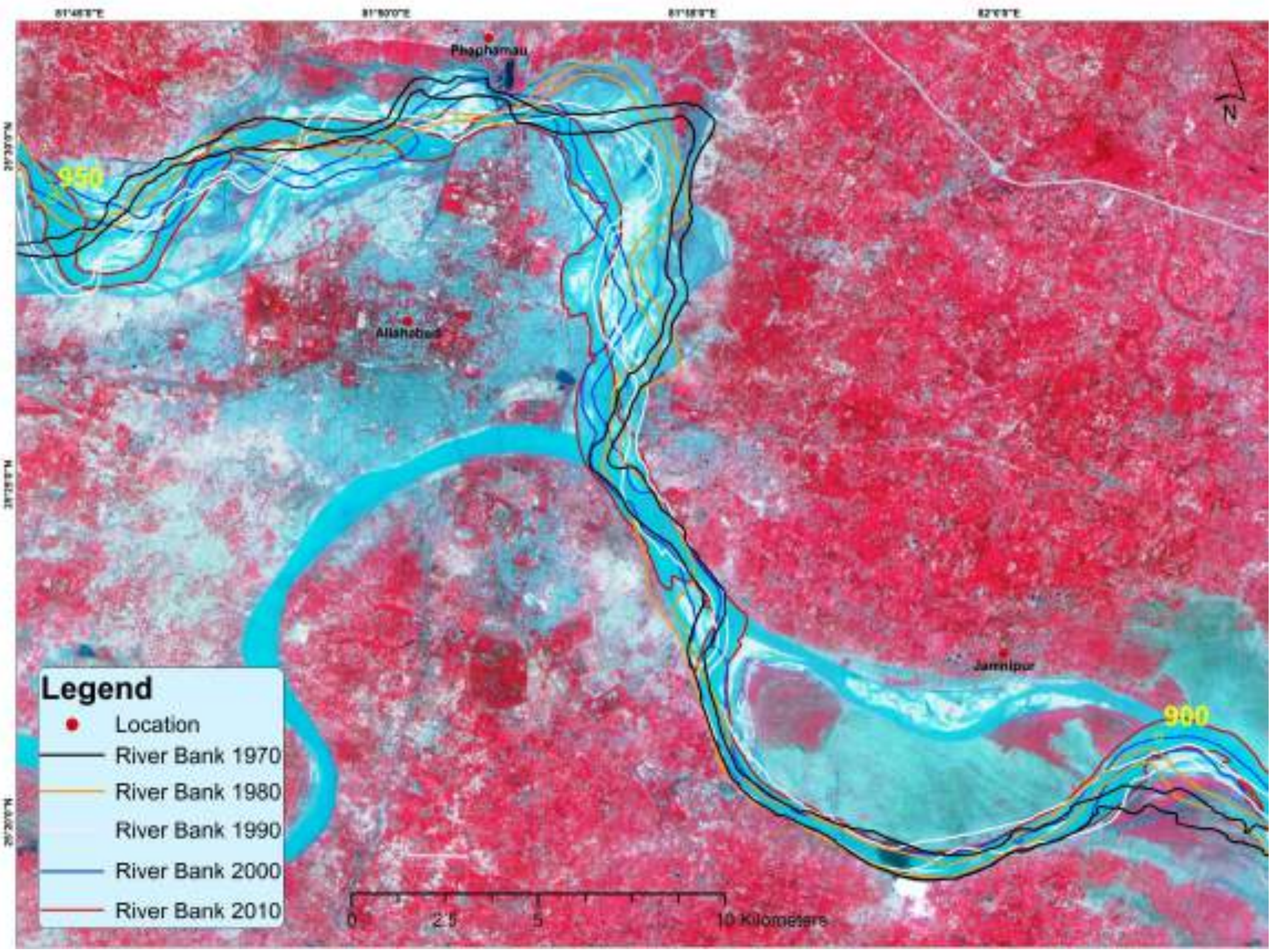


Figure 10.74 Decadal changes in the course of Ganga river from chainage 900-950 km

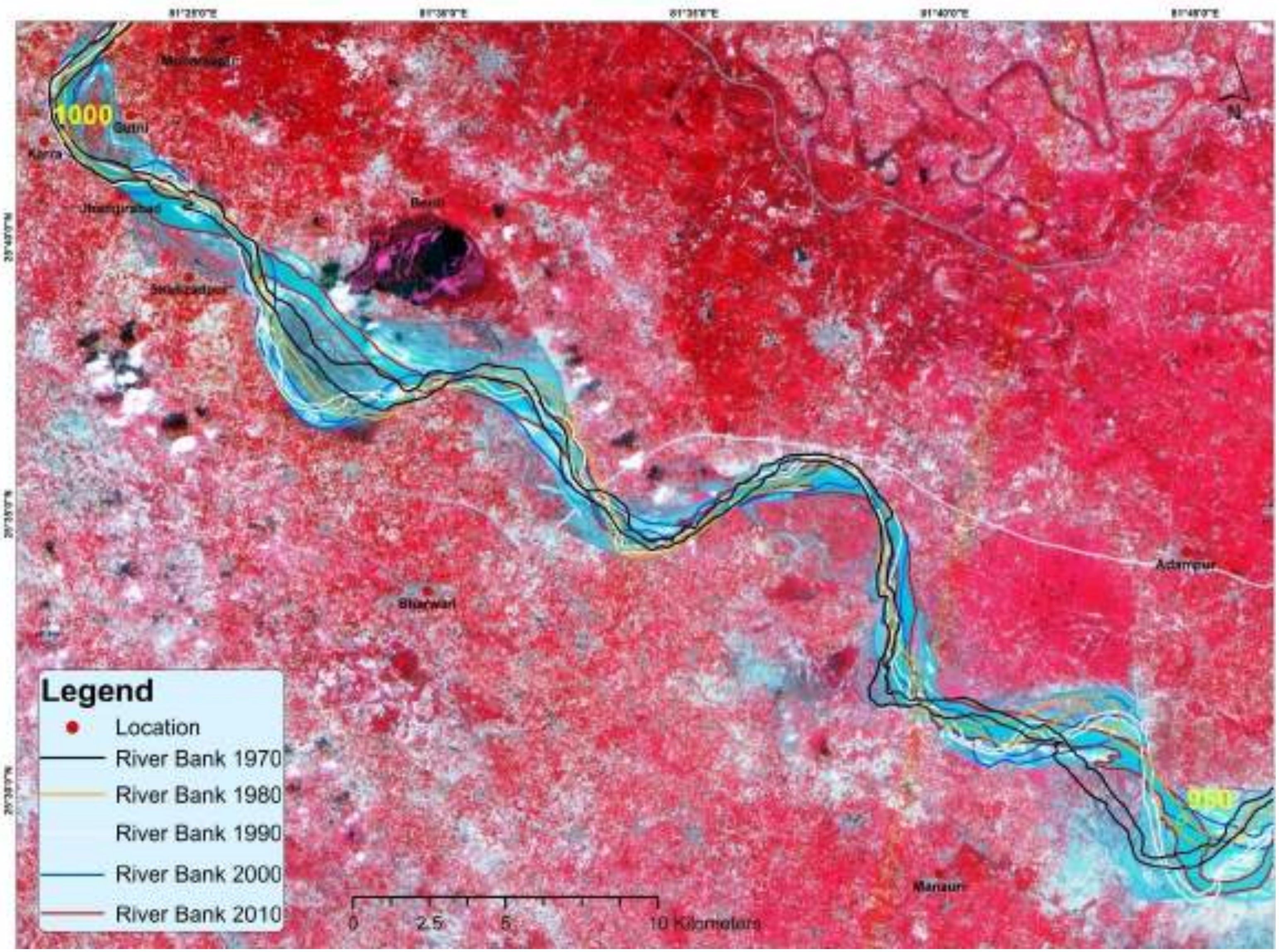


Figure 10.75 Decadal changes in the course of Ganga river from chainage 950-1000 km

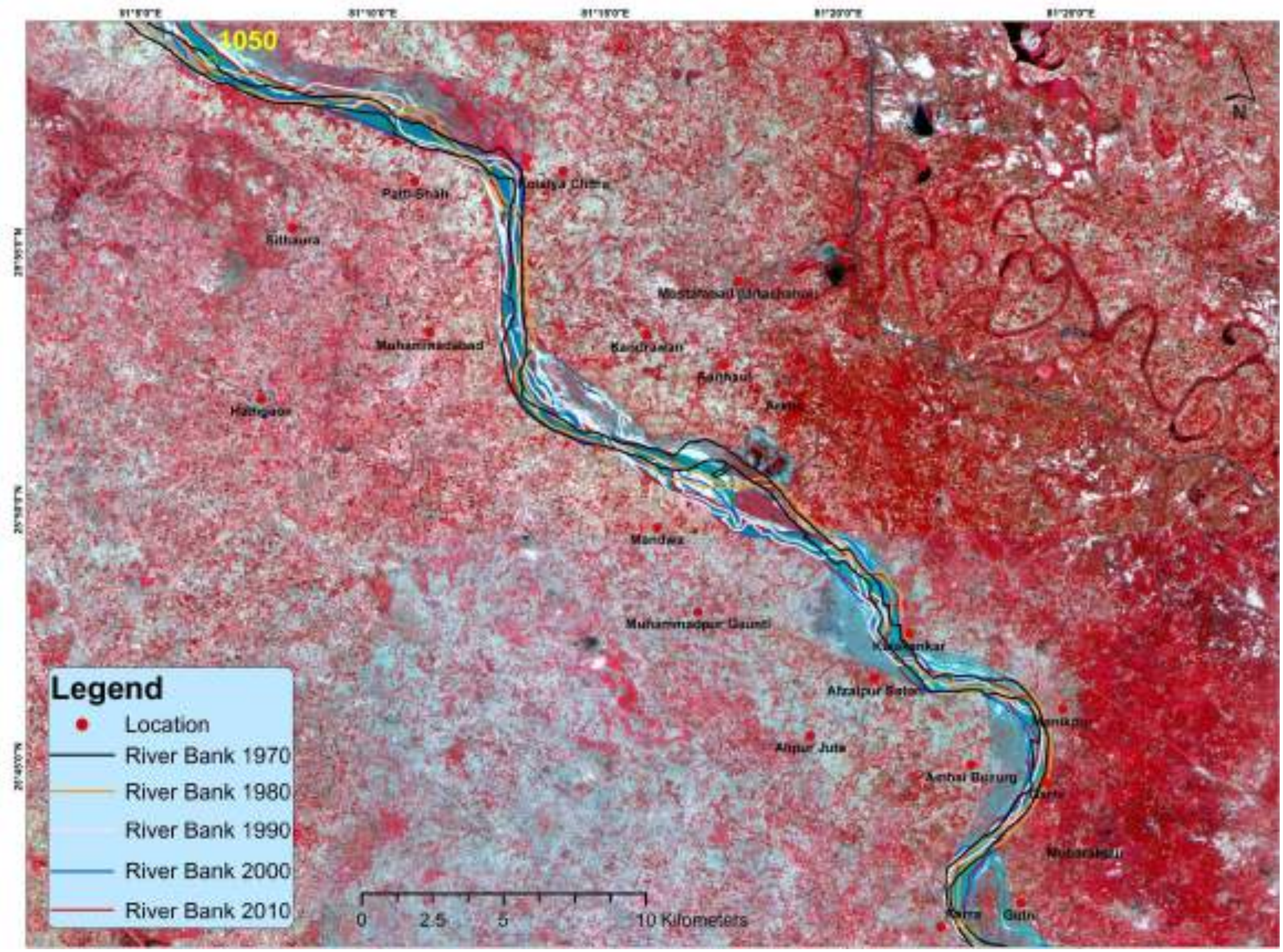


Figure 10.76 Decadal changes in the course of Ganga river from chainage 1000-1050 km

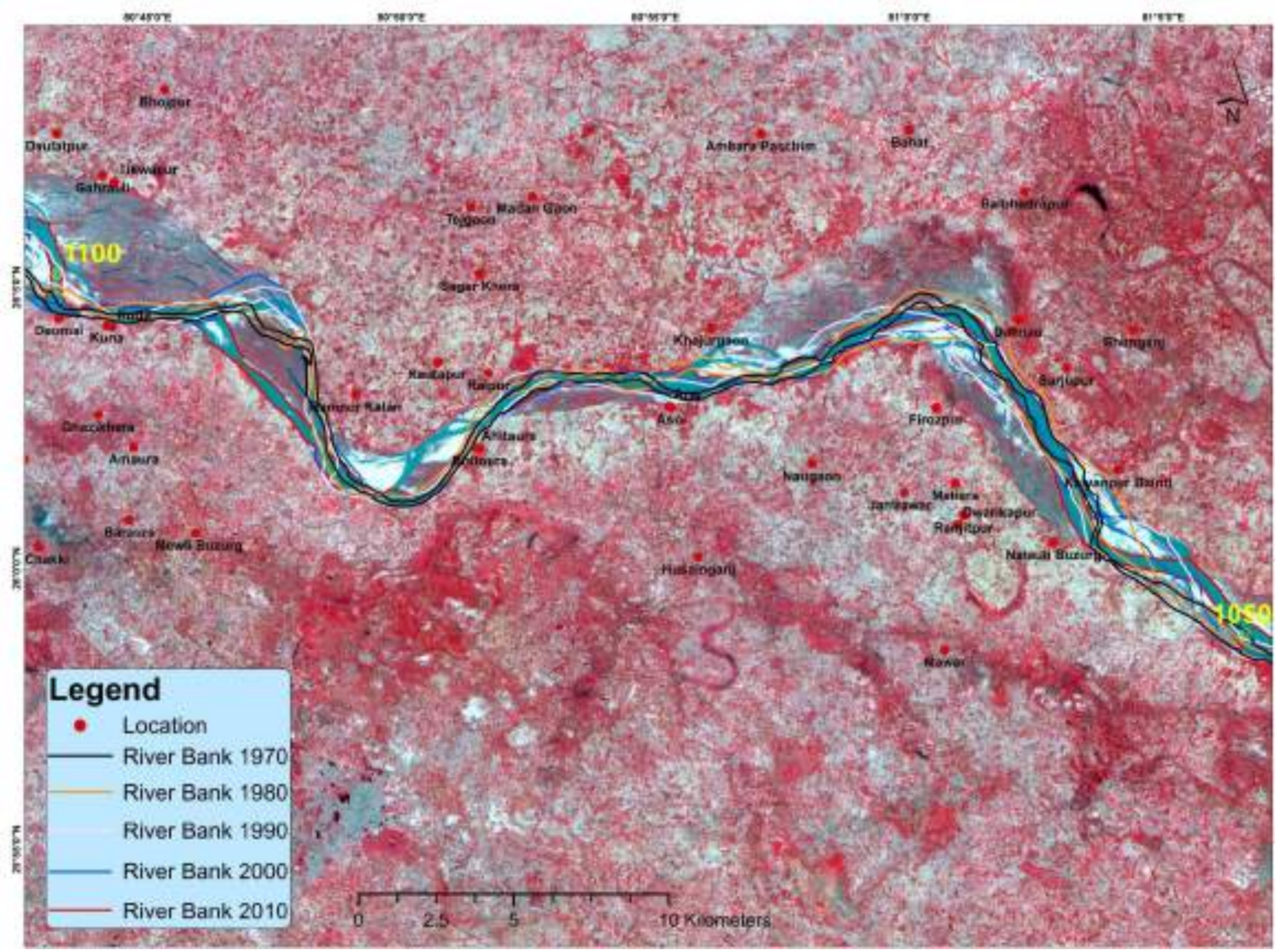


Figure 10.77 Decadal changes in the course of Ganga river from chainage 1050-1100 km

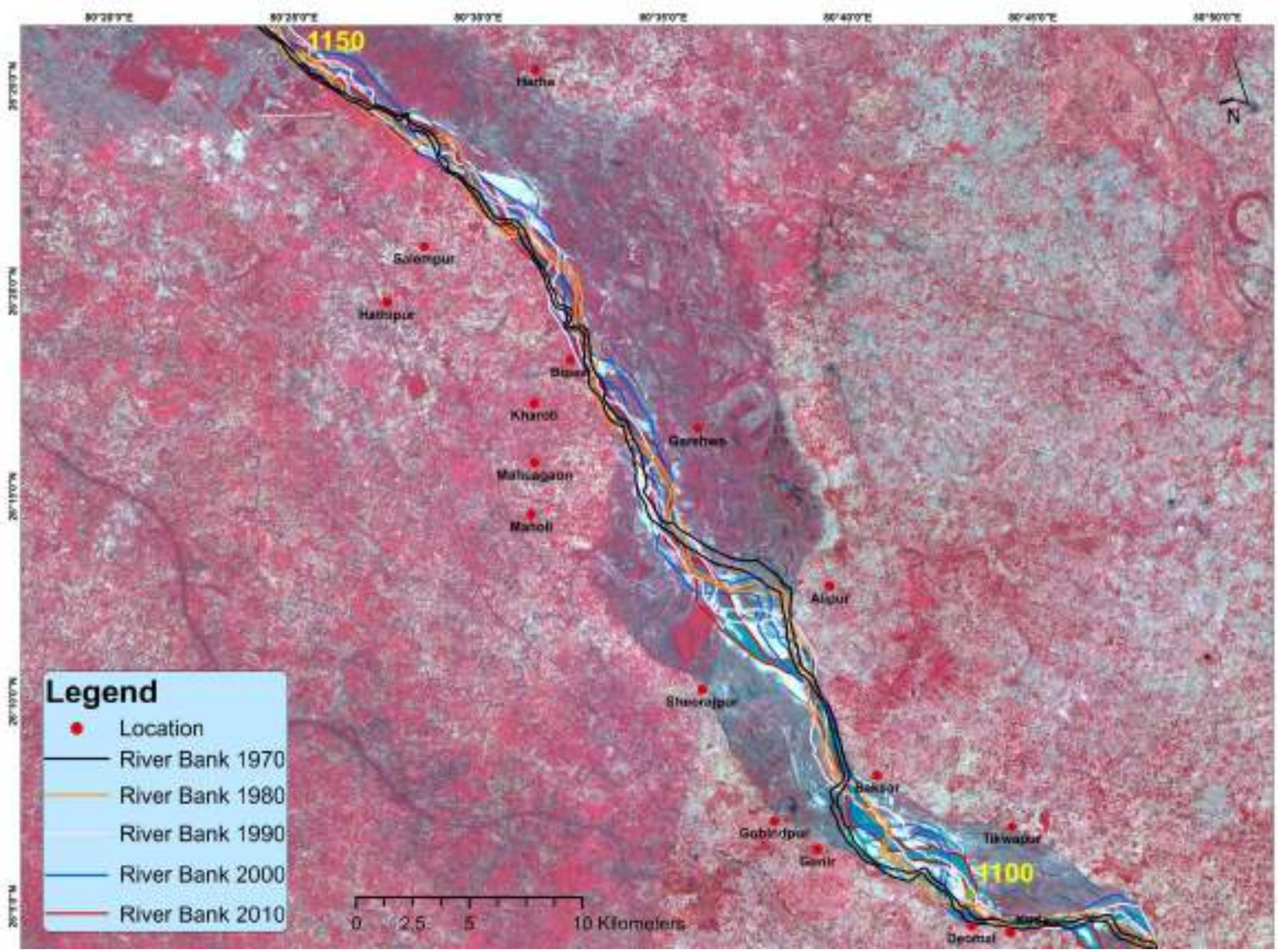


Figure 10.78 Decadal changes in the course of Ganga river from chainage 1100-1150 km

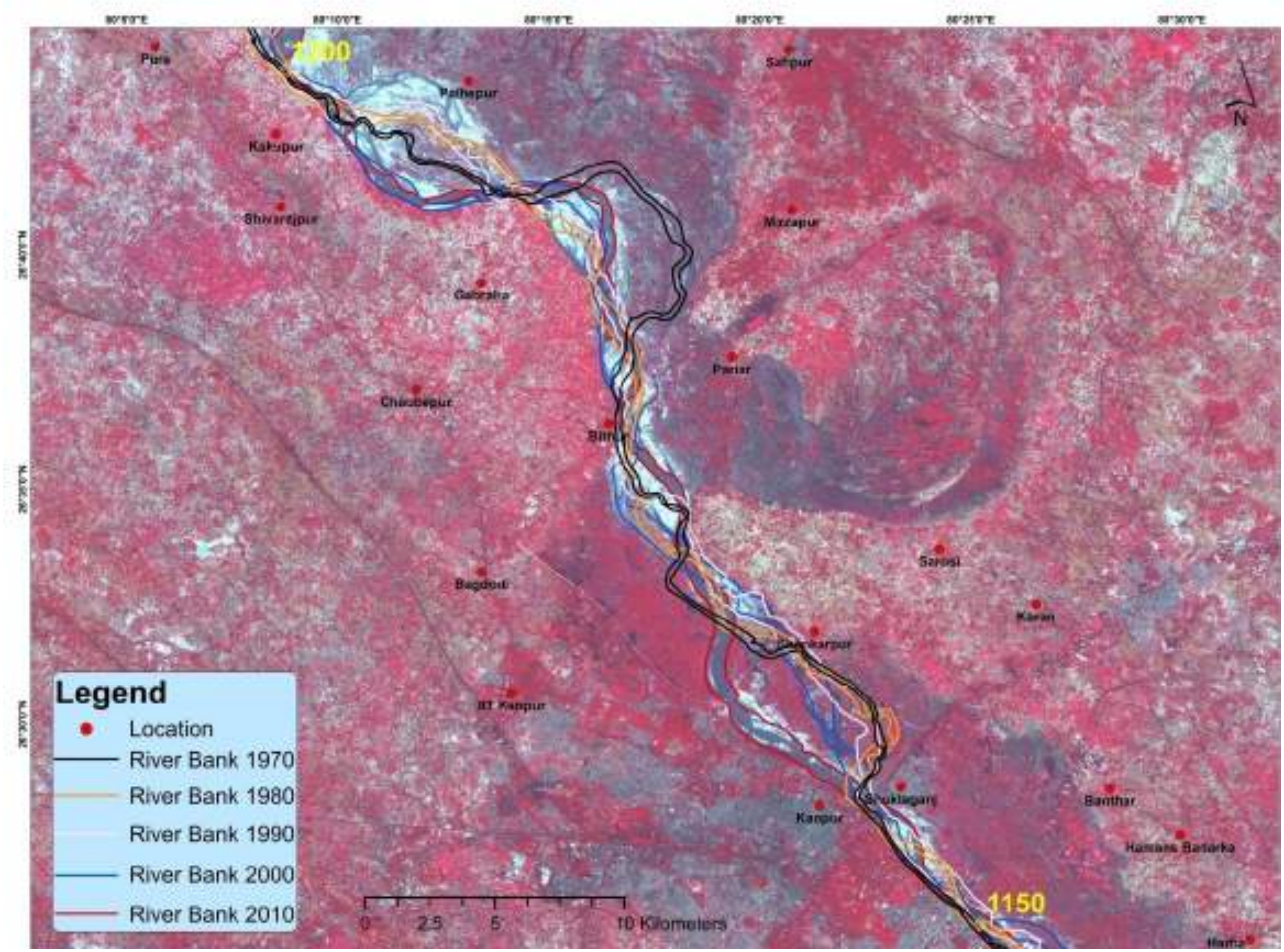


Figure 10.79 Decadal changes in the course of Ganga river from chainage 1150-1200 km

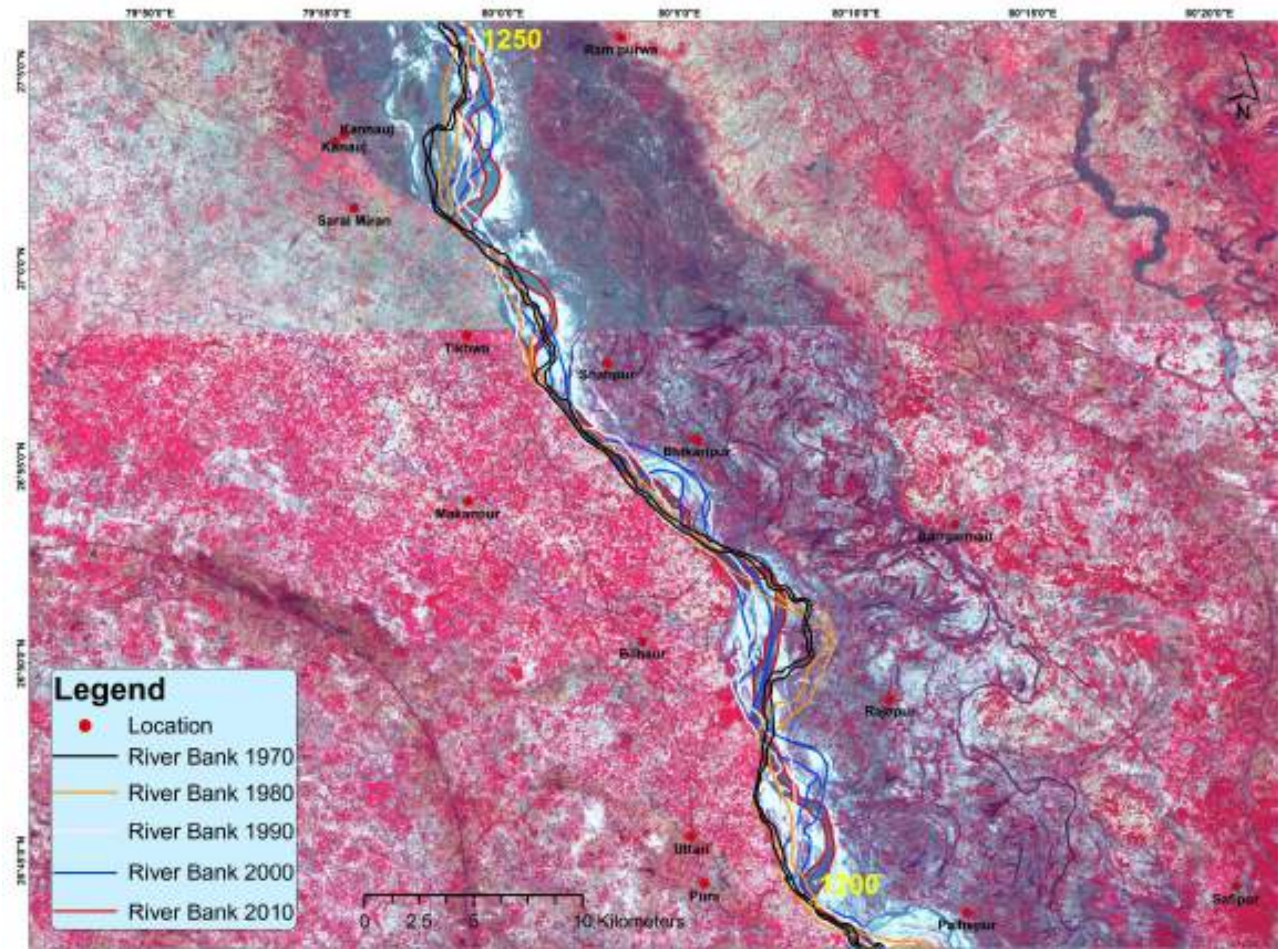


Figure 10.80 Decadal changes in the course of Ganga river from chainage 1200-1250 km

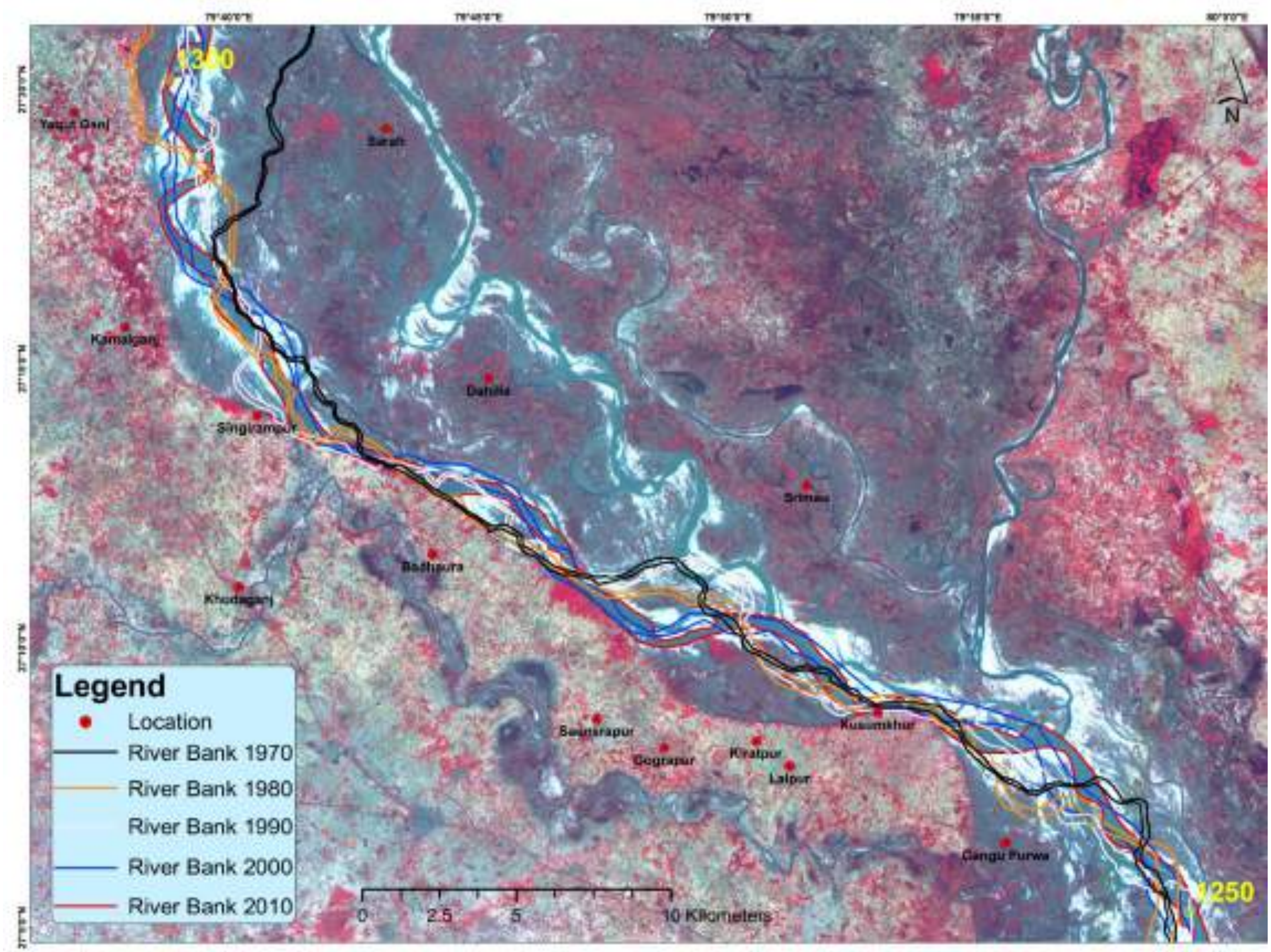


Figure 10.81 Decadal changes in the course of Ganga river from chainage 1250-1300 km

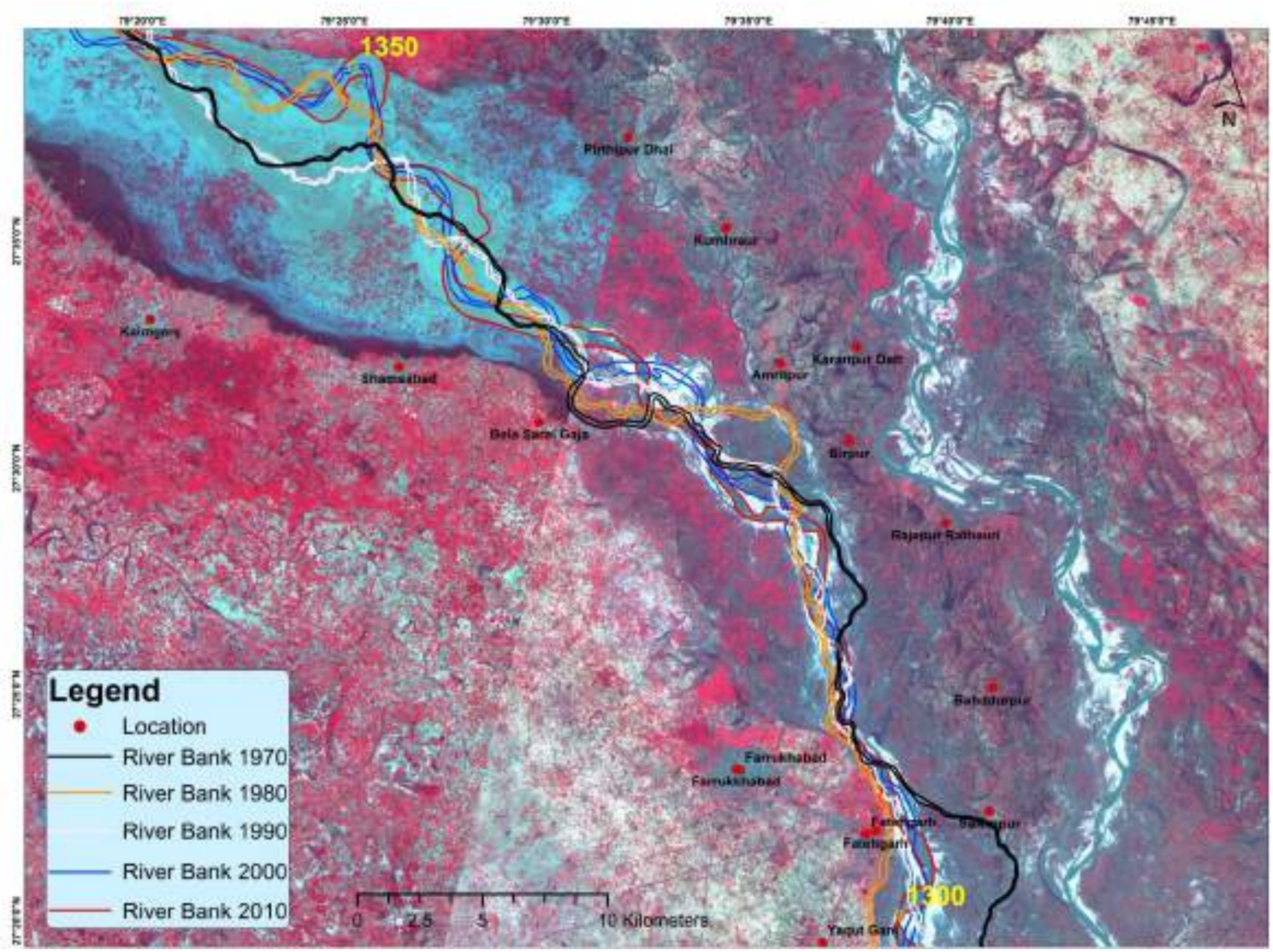


Figure 10.82 Decadal changes in the course of Ganga river from chainage 1300-1350 km

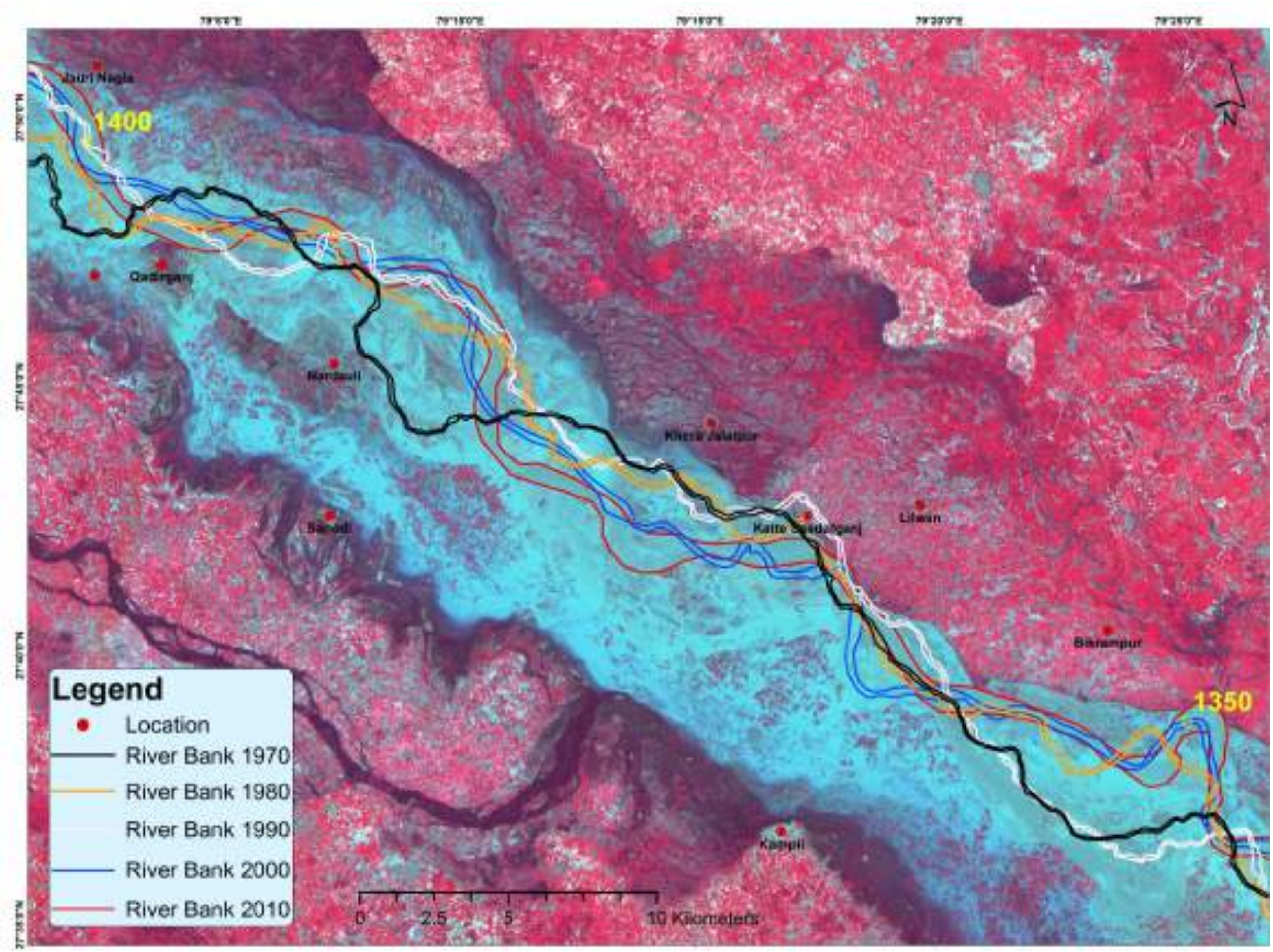


Figure 10.83 Decadal changes in the course of Ganga river from chainage 1350-1400 km

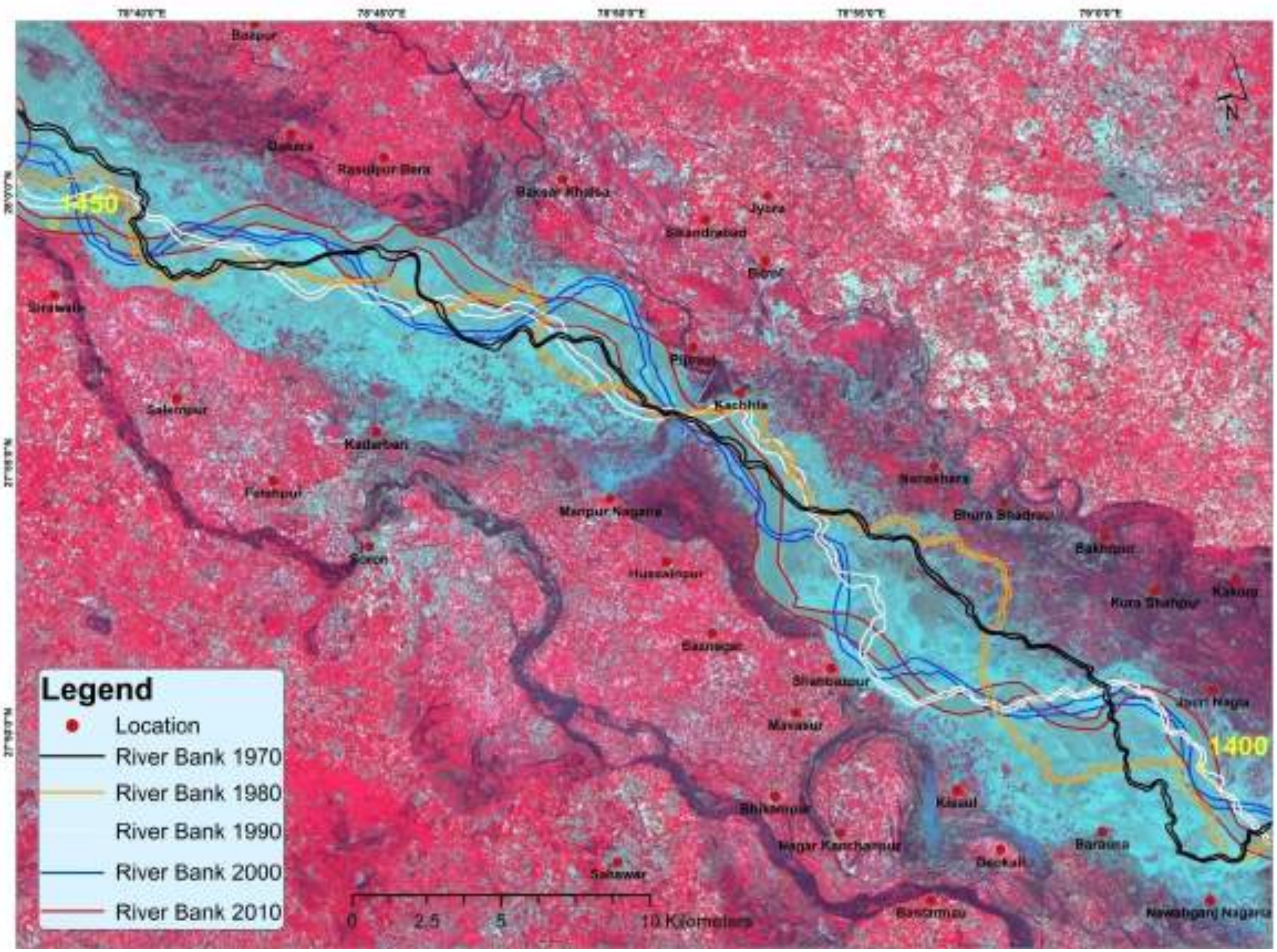


Figure 10.84 Decadal changes in the course of Ganga river from chainage 1400-1450 km

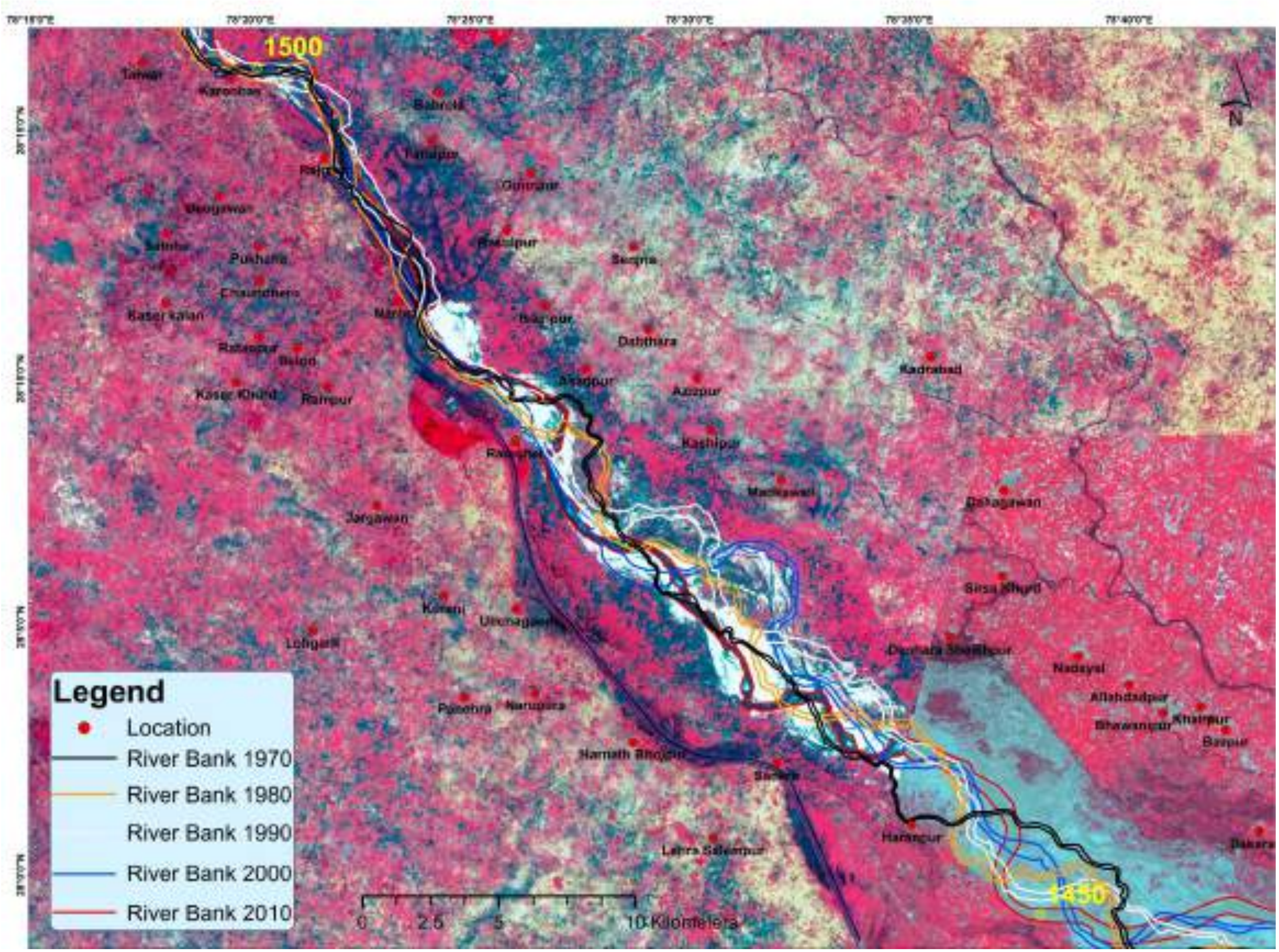


Figure 10.85 Decadal changes in the course of Ganga river from chainage 1450-1500 km

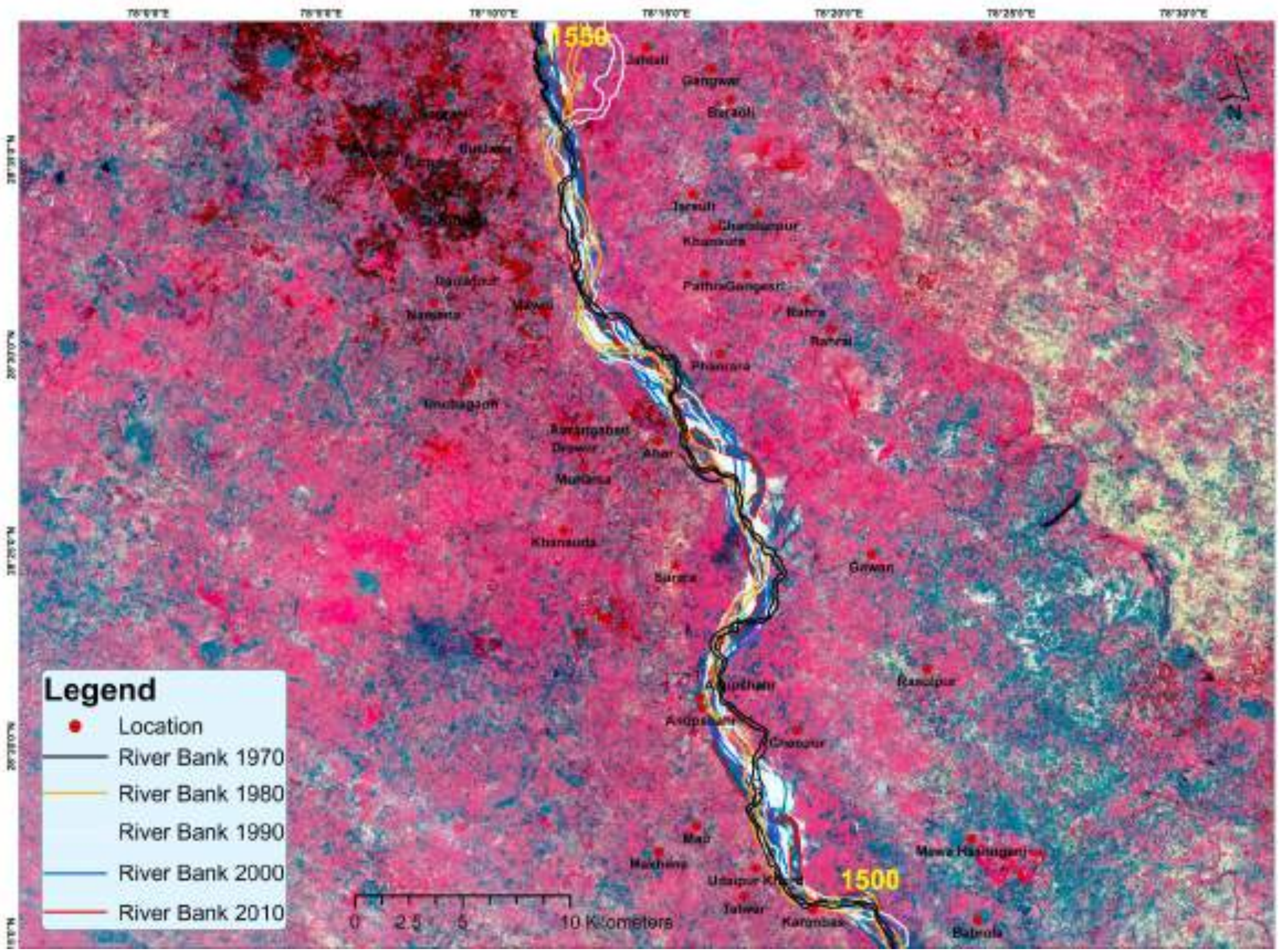


Figure 10.86 Decadal changes in the course of Ganga river from chainage 1500-1550 km

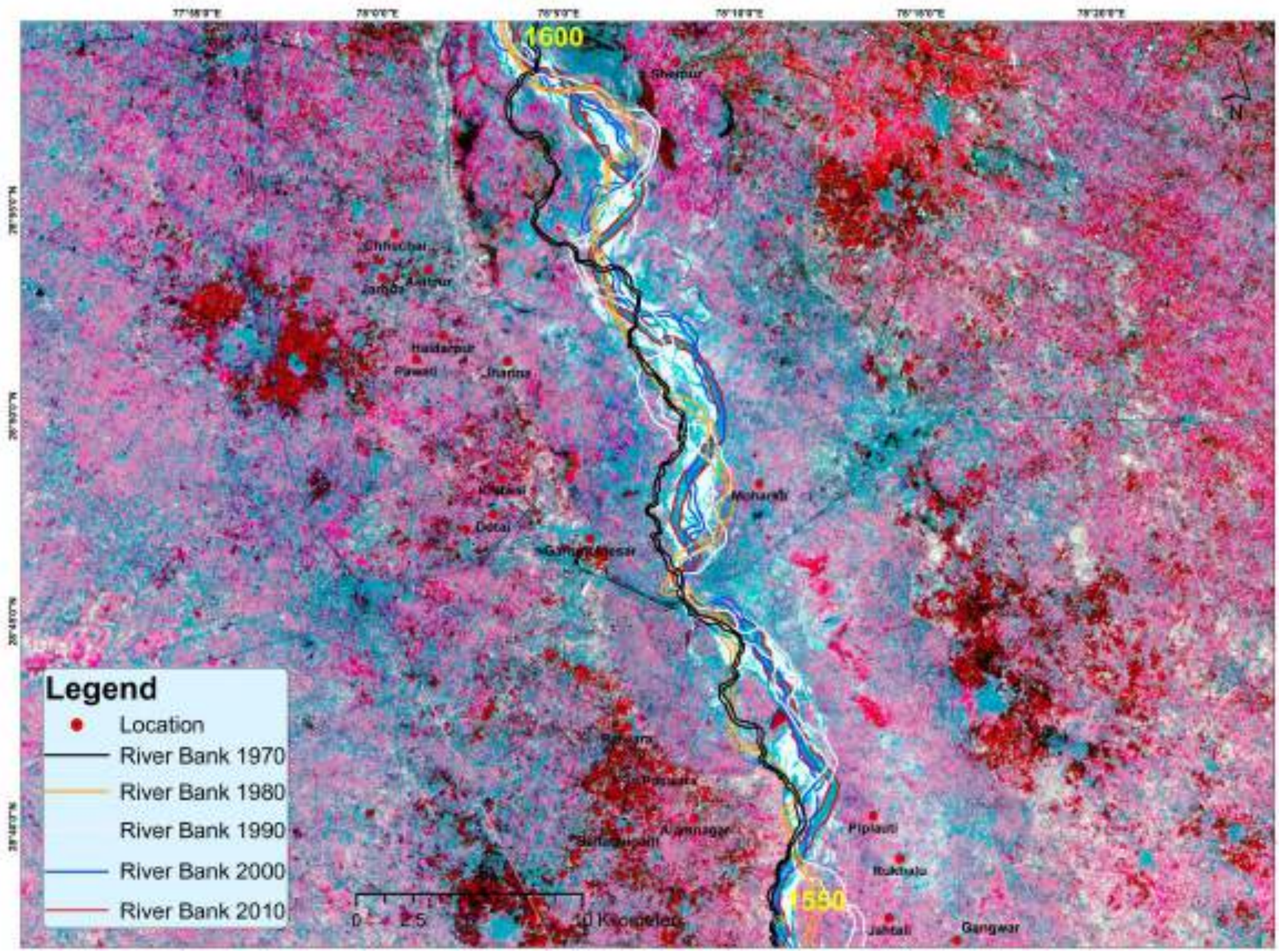


Figure 10.87 Decadal changes in the course of Ganga river from chainage 1550-1600 km

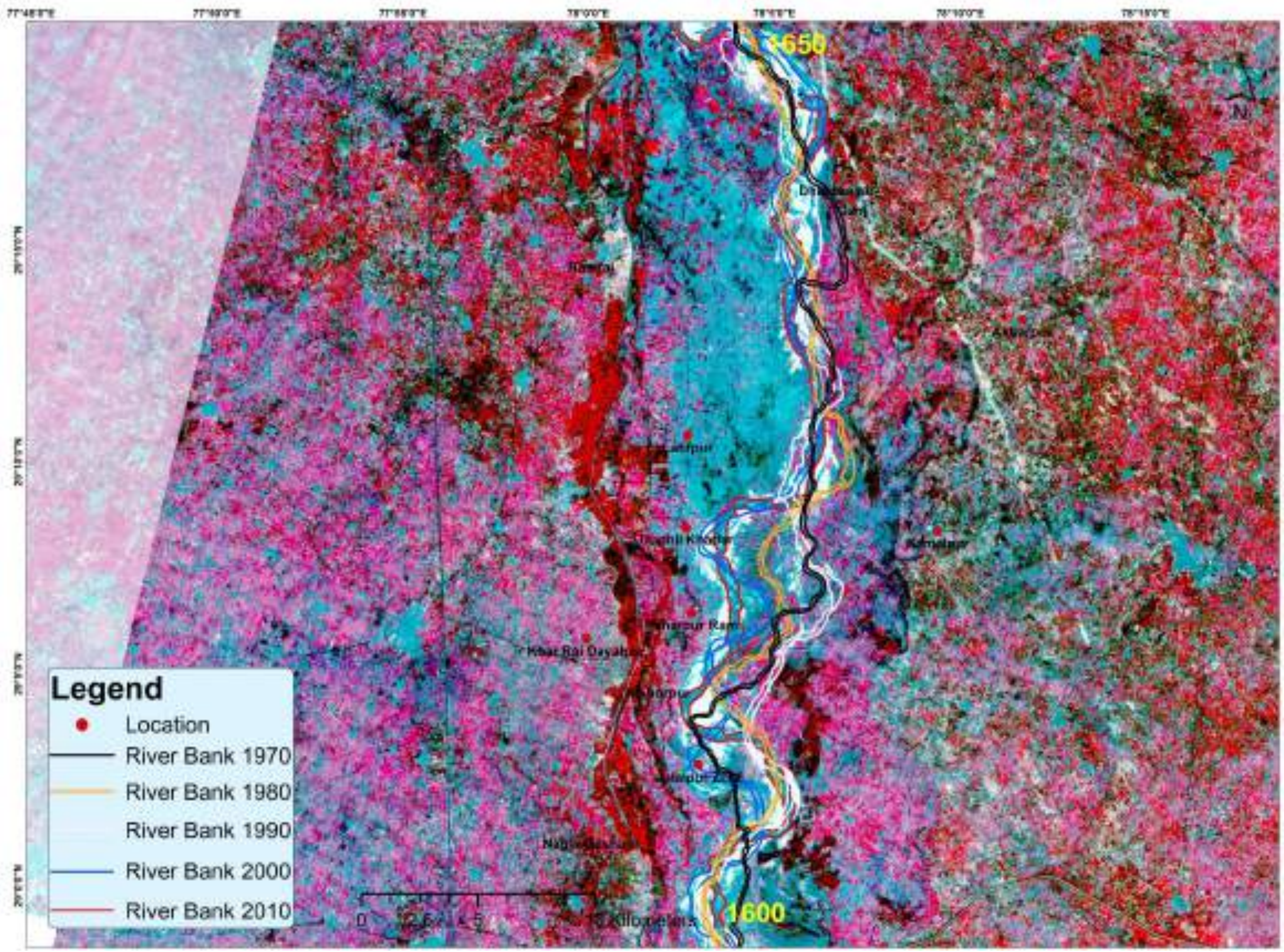


Figure 10.88 Decadal changes in the course of Ganga river from chainage 1600-1650 km

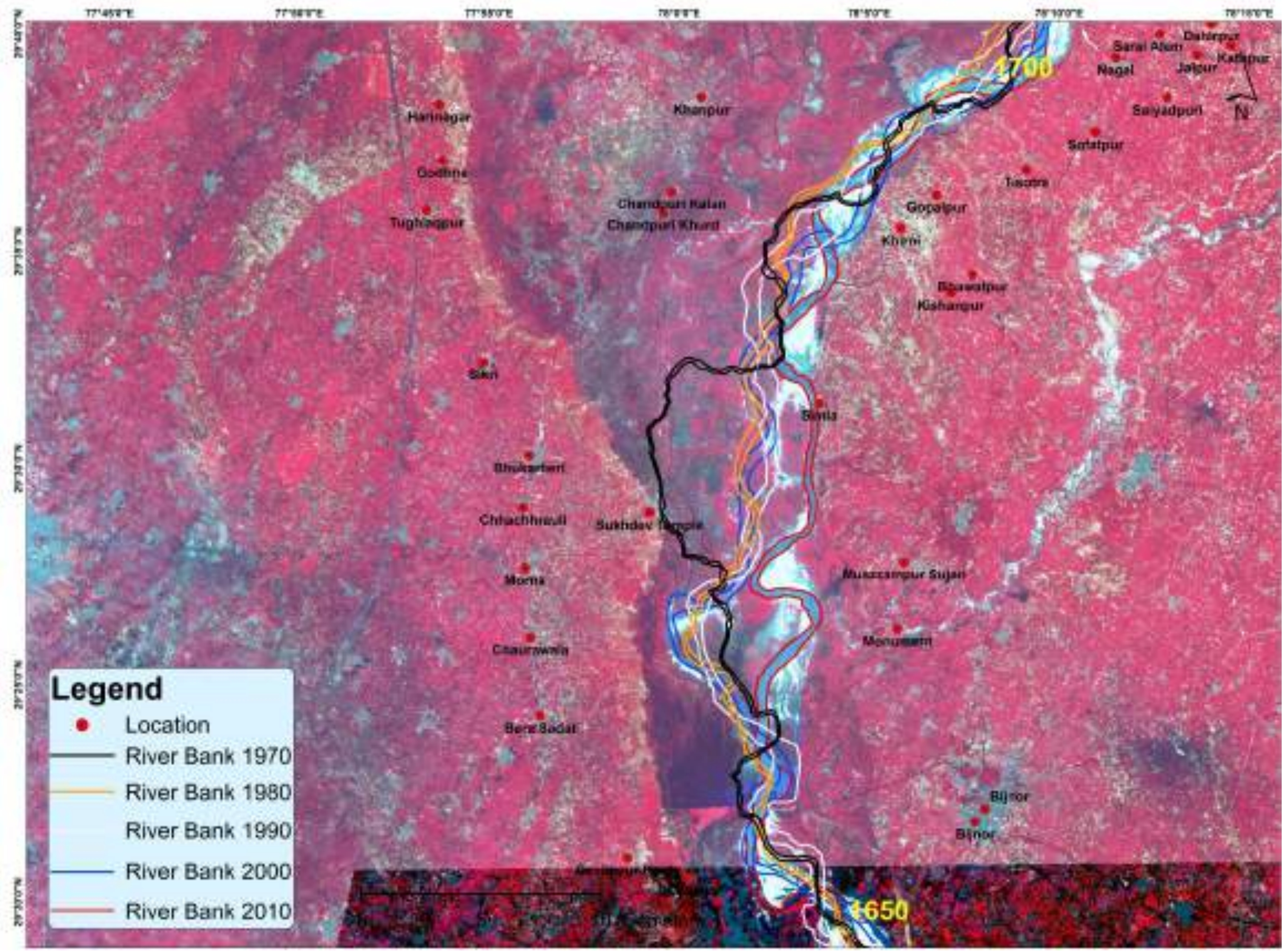


Figure 10.89 Decadal changes in the course of Ganga river from chainage 1650-1700 km

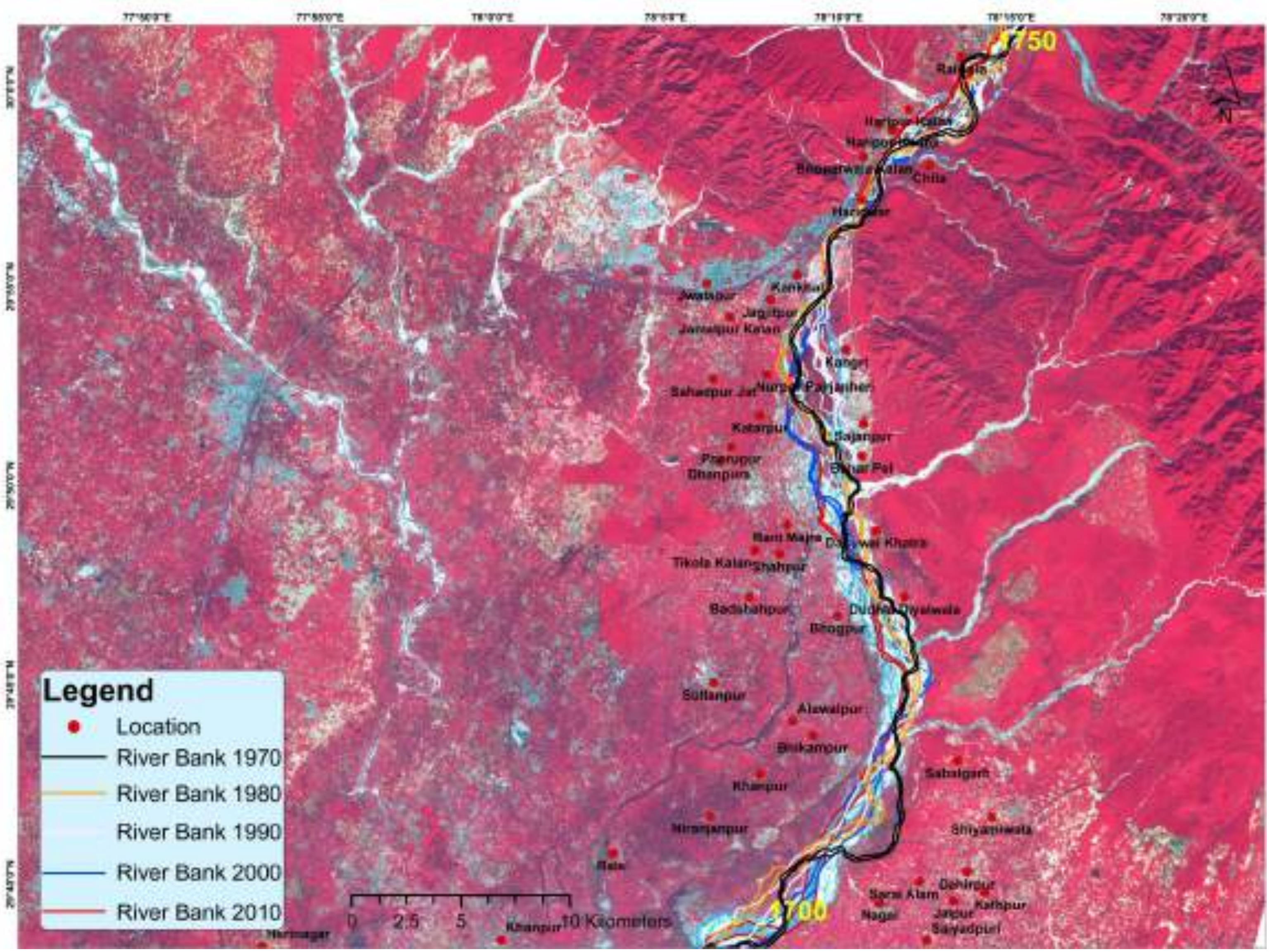


Figure 10.90 Decadal changes in the course of Ganga river from chainage 1700-1750 km

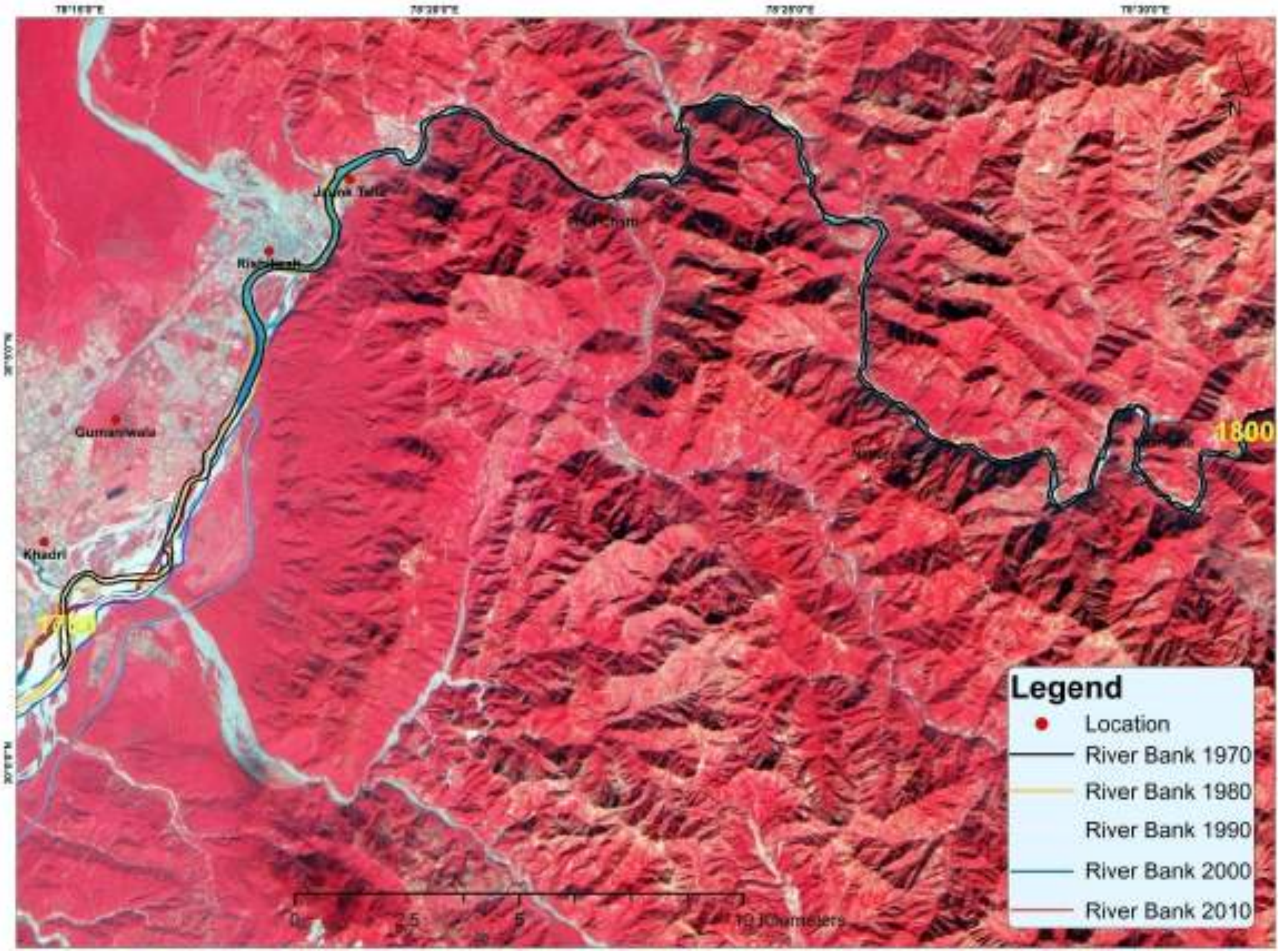


Figure 10.91 Decadal changes in the course of Ganga river from chainage 1750-1800 km

Figure 10.92 Decadal changes in the course of Ganga river from chainage 1800-1824 km

10.4 RIVER WIDTH

The width of the Ganga river has been estimated invoking two approaches. In the first approach, width of active channel has been considered as width of the river and in the second approach, distance between extreme banks of the river has been considered as river width. In the first approach, the river width is estimated using the satellite images of years 1970-2010 by marking the waterlines. However, in the second approach, the same satellite images have been used. But in this case the extent of spread of water towards both sides has been identified by land pattern.

a) Estimation of river width based on active channel: The width of the active channel of the Ganga river during the post monsoon is taken perpendicular to the direction of flow of river. Width of river is calculated in GIS software at the intersection of perpendicular bisector of center line of year 1970, 1980, 1990, 2000 and 2010 at a regular interval of 2 km. The sample map that depicts the computation of river width is shown in Fig. 10.93. The computed width (in meter) of the river of year 1970, 1980, 1990, 2000 and 2010 are given in Table 10.7 and graphically shown in Figs. 10.94 to 10.130.

A comprehensive graph for the width of the river for years 1970, 1980, 1990, 2000 and 2010 for whole the reach of the river is plotted in Fig. 10.131. Figures 10.94 to 10.131 reveal the following:

- There is no definite progressive change in the width of the river over the span of year 1970-2010 in the whole studied reach of the Ganga river.
- From Devprayag to Haridwar average width of the active channel is of the order of 70 m while from Haridwar to confluence of Ramganga river the average width is about 315 m. However, downstream of the confluence of Ramganga river, the width increases downstream non-linearly and reached to about 1636 m at Farraka barrage.

b) Estimation of river width based on extreme banks: The computed width of the river on the basis of extreme left and right banks are shown in Fig. 10.132, which reveals that

- There is no definite progressive change in the width of the river over the span of year 1970-2010 in the whole studied reach of the Ganga river.

- From Buxar to Farakka barrage, the average width is about 4000 m while it is about 900 m from Allahabad to Buxar. From the foothill i.e, Haridwar to Allahabad the average width is about 1150 m. Being in hilly area from Devprayag to Haridwar, the river width is about 130 m.

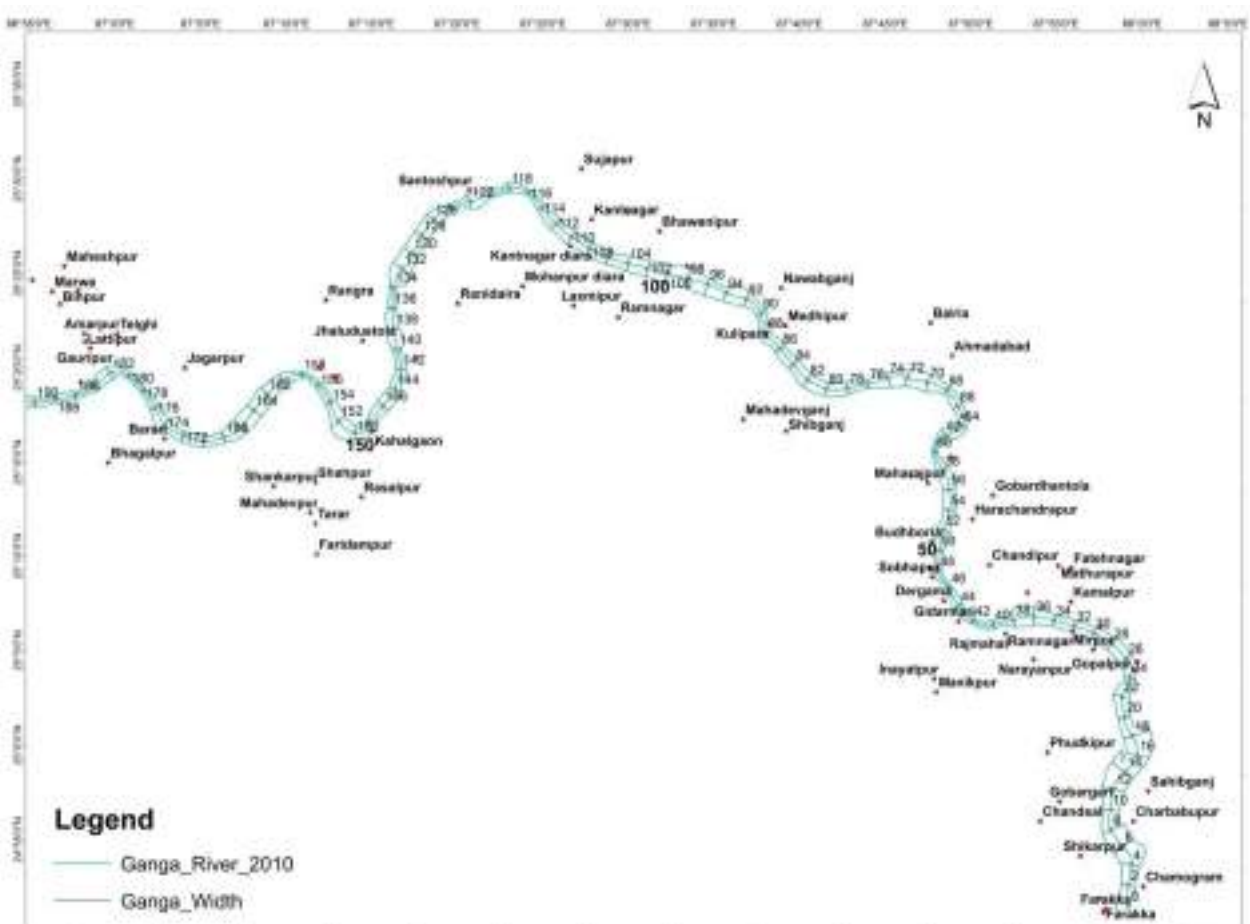


Figure 10.93 Sample procedure map of width computation of Ganga river

Table 10.7 Width (in meter) of Ganga river of years 1970, 1980, 1990, 2000 and 2010

Chainage (km)	2010	2000	1990	1980	1970	Chainage (km)	2010	2000	1990	1980	1970
2	1268.27	1827.60	1892.46	1374.10	1180.87	84	1130.57	1153.09	1454.93	903.80	522.78
4	1874.58	1943.60	2356.84	3010.62	673.61	86	1095.57	1849.78	2282.78	1897.76	770.64
6	2194.47	2261.88	2016.83	3304.18	1417.65	88	906.72	2649.76	2270.06	985.55	632.09
8	2017.76	2465.01	1423.54	2392.20	2153.79	90	1010.23	1839.93	3065.84	901.96	572.86
10	1515.70	2339.21	1579.13	1808.04	1324.92	92	1505.35	1140.17	2932.86	605.72	452.00
12	2064.06	2556.39	1701.78	1304.03	1201.31	94	1528.78	1780.09	2218.18	730.15	1205.94
14	2507.89	2308.15	2342.27	1498.05	1138.48	96	1712.98	2343.26	2862.92	1835.90	761.37
16	2241.90	2164.42	3111.18	2141.50	1900.91	98	2029.06	2731.44	1052.00	1628.53	590.93
18	2619.52	2004.30	2766.62	3212.89	3105.92	100	1801.27	2313.37	1528.77	1498.47	1461.28
20	1209.79	803.76	2403.89	3907.63	4196.82	102	1515.77	2468.11	3195.31	1389.57	1023.46
22	1605.88	1536.80	2546.12	2983.91	3975.41	104	1516.88	1902.10	1913.08	1358.40	1230.51
24	1060.20	1770.24	2188.77	2188.68	2515.19	106	1280.50	1427.63	1771.38	1112.59	762.70
26	1368.08	2411.70	2012.66	1891.83	1895.82	108	1269.28	1878.06	1912.66	1154.99	578.78
28	1412.34	2234.04	2025.24	1928.02	1938.93	110	1462.61	1713.22	2053.11	884.29	849.01
30	1238.28	1862.09	1814.06	2163.38	1833.62	112	1411.28	1392.37	1156.13	438.14	537.34
32	1189.15	1279.15	1704.40	2179.28	1748.60	114	899.59	1133.11	754.09	682.20	1636.59
34	1139.26	1363.11	1880.54	2344.59	1219.73	116	501.89	1489.53	1027.43	524.32	1441.93
36	1737.91	1634.00	2057.53	2323.68	1154.52	118	907.16	1554.80	1448.29	470.16	1160.11
38	1491.91	1078.68	1203.74	1483.62	556.60	120	762.57	881.19	1239.55	455.47	1369.06
40	794.96	913.26	1045.96	1674.72	280.80	122	1383.19	1713.05	1210.68	652.41	682.69
42	604.97	1018.93	1334.49	1860.24	333.79	124	632.18	1850.53	1147.24	939.16	461.14
44	860.26	976.44	1388.38	2083.57	445.23	126	1560.56	1922.63	1185.09	925.04	669.03
46	560.01	670.90	1351.15	1794.48	614.08	128	1484.84	1230.93	1335.47	902.72	855.09
48	712.36	938.46	2025.47	1372.12	842.29	130	1627.98	1218.26	1275.47	870.02	1038.54
50	939.12	968.16	2197.49	1621.40	1549.06	132	2065.67	1549.42	1631.77	508.00	855.59
52	1312.79	1559.25	2843.95	1736.35	2063.59	134	678.31	1511.04	1506.20	491.89	844.72
54	1248.45	2700.11	2246.48	2403.80	1891.57	136	861.26	1781.85	1317.52	1139.79	1082.83
56	1274.62	2616.29	2318.86	2028.75	1551.86	138	1130.53	2047.20	1775.15	883.85	2176.25
58	1093.25	2221.91	2265.70	1474.70	1545.81	140	845.89	1819.29	1323.79	849.01	1677.05
60	502.58	2114.89	1651.24	2012.65	1115.38	142	976.74	2495.85	2075.32	1865.72	1230.25
62	1373.40	2042.87	1396.36	2333.09	838.85	144	1332.13	2349.92	2237.50	1559.83	1473.04
64	961.43	2042.64	1721.70	2356.79	811.06	146	1356.52	1432.33	1650.79	1139.98	1953.19
66	1030.65	2236.09	1600.41	2008.95	753.36	148	678.86	851.58	902.20	1407.20	1189.10
68	1016.64	2713.52	1433.40	1439.83	862.69	150	1414.62	1328.77	1605.01	788.61	1045.21
70	1689.63	2984.95	1617.02	987.58	704.09	152	1729.99	1699.61	1686.93	869.27	866.09
72	1763.87	1330.63	1223.85	1802.71	991.98	154	949.51	1232.91	1281.07	1003.67	1238.80
74	1488.72	1122.98	918.92	1941.76	1645.07	156	600.13	1324.04	712.52	1044.17	1394.26
76	770.85	1005.92	1136.24	1902.24	1368.52	158	568.95	1596.32	909.61	775.42	1467.08
78	1198.69	1322.49	662.64	976.45	739.02	160	1196.50	1577.63	1104.28	917.97	1520.40
80	1305.22	1255.65	1168.12	861.64	807.97	162	1689.43	1554.75	1477.14	1266.86	1608.62
82	1517.17	955.39	1421.75	570.96	625.68	164	1701.32	1478.60	1833.10	1078.59	1422.50
						166	1704.50	1665.38	1725.12	1445.04	952.84

168	1057.71	2242.77	1811.42	1064.02	1655.83	254	692.10	1067.86	2203.56	2193.19	437.17
170	1038.27	1843.36	1729.54	901.28	1487.58	256	764.61	1330.24	1607.51	862.20	709.63
172	1038.80	1044.55	1434.25	1303.36	1339.44	258	642.20	1329.51	864.38	744.01	728.86
174	1315.62	982.36	1083.73	866.31	515.51	260	476.37	1268.63	1357.35	716.06	494.05
176	1017.56	1585.07	533.08	1296.22	633.66	262	1385.91	1254.27	925.18	579.19	618.96
178	528.35	1643.20	521.31	956.92	665.99	264	681.67	769.97	862.21	719.86	789.70
180	652.01	1716.17	547.85	956.04	1133.28	266	744.24	726.08	1300.93	634.24	673.20
182	1334.89	2064.80	581.38	886.42	933.46	268	979.29	708.53	1039.30	571.60	887.53
184	921.48	1935.58	1390.33	656.09	906.73	270	1556.29	435.80	636.27	1386.13	1408.28
186	679.72	1110.92	1300.56	1090.26	464.46	272	943.54	857.60	672.00	893.62	1153.15
188	562.39	1193.59	1212.11	695.27	904.46	274	1595.21	884.42	701.63	1250.24	1332.64
190	1005.33	917.41	1746.59	1012.64	811.50	276	2016.44	837.95	1075.89	1436.17	466.62
192	1117.92	1304.89	1893.45	641.03	671.53	278	1148.53	700.98	1690.17	1095.20	616.86
194	1980.39	1391.48	1890.27	671.28	516.33	280	1349.23	999.57	1358.23	580.75	520.94
196	1157.27	1149.63	1876.92	792.92	504.26	282	2341.84	1003.30	657.25	778.97	616.84
198	867.37	1236.03	1339.47	1051.23	933.57	284	1884.15	624.38	466.71	578.11	736.67
200	984.02	1478.33	1361.25	1059.31	740.55	286	1682.41	758.82	834.59	831.13	857.34
202	1433.48	1508.34	1336.32	673.65	1076.48	288	1328.67	697.95	894.25	833.09	647.13
204	1736.04	1453.67	1249.29	806.72	889.40	290	1573.23	879.38	620.48	1102.76	680.39
206	1502.74	1715.91	1808.92	1501.81	1509.62	292	1691.33	815.27	587.23	1269.00	904.45
208	1205.35	1956.32	1731.40	1178.27	881.60	294	1184.52	667.12	591.96	1314.64	1003.43
210	1073.09	1807.58	1263.64	594.15	829.74	296	1800.36	850.76	627.05	950.92	980.17
212	941.25	914.59	1294.84	586.86	741.01	298	1393.19	972.59	804.90	665.61	930.11
214	809.59	907.82	1468.48	526.07	591.39	300	1102.40	1097.15	752.91	816.89	813.75
216	850.13	1030.15	1701.92	492.83	624.41	302	1342.51	1230.81	744.16	592.81	827.54
218	1347.41	1413.98	1706.50	464.55	546.23	304	1822.49	978.52	612.56	1139.57	1497.95
220	1151.66	1303.47	1583.97	454.22	588.83	306	1729.51	901.66	1583.61	1364.30	1758.61
222	1225.97	848.02	1033.03	1397.52	581.59	308	1545.20	1186.50	929.95	1247.36	940.70
224	1028.89	1299.49	1128.01	685.10	1073.01	310	1172.36	643.10	1305.80	1145.31	485.15
226	1072.98	1759.78	1297.79	935.28	839.23	312	1862.61	468.47	975.47	1338.95	451.98
228	848.72	1900.07	1757.88	1342.40	1153.51	314	1620.27	695.58	1278.44	559.56	1369.81
230	1122.52	1226.06	1103.92	713.08	1077.44	316	1526.32	778.92	1086.17	765.47	1080.57
232	970.30	821.63	1548.61	768.41	675.42	318	1121.75	582.33	966.16	563.19	735.66
234	632.08	1013.99	1793.38	1234.27	636.21	320	1597.02	825.90	1499.93	554.72	577.56
236	572.74	922.15	1528.53	828.84	927.45	322	1596.66	543.35	1150.47	345.91	580.15
238	575.10	745.27	1607.52	699.77	793.11	324	1531.58	788.75	1737.55	525.86	708.22
240	899.29	1168.38	2024.31	549.75	783.97	326	1509.38	921.66	932.35	1256.35	1292.72
242	759.67	1082.20	1777.82	1015.33	805.53	328	1845.49	1018.27	1274.30	759.43	1344.24
244	872.66	1051.59	2024.50	866.45	684.90	330	2449.66	862.71	1095.38	512.08	1800.81
246	666.08	1187.70	1640.37	787.75	810.80	332	2270.88	642.24	1668.83	1042.66	2040.87
248	844.47	1572.65	964.48	1153.06	1206.45	334	2018.42	488.89	1423.25	1087.19	1815.32
250	502.46	1598.22	1513.66	775.71	1065.08	336	2202.24	717.58	549.19	1324.29	1327.12
252	782.77	1484.36	2100.79	1805.63	478.60	338	2079.39	1176.34	748.28	820.61	1367.05

340	1928.96	1190.64	510.23	855.57	1363.97	426	776.47	680.51	506.09	626.84	756.46
342	1218.32	1168.62	758.78	783.23	1394.04	428	1119.14	498.27	925.80	547.02	761.61
344	803.51	651.53	961.72	1107.15	1343.57	430	1118.69	1448.17	904.61	829.82	694.37
346	638.25	767.08	463.12	1249.84	1343.57	432	1004.28	664.55	1588.14	1320.44	669.46
348	861.95	472.83	1217.62	1357.68	1765.00	434	1065.57	1032.59	883.91	1420.81	748.71
350	1139.34	760.18	1043.99	1510.63	1765.00	436	752.21	1067.77	1378.98	1254.80	459.73
352	1408.23	569.08	811.45	1564.82	1765.00	438	638.85	512.19	1717.57	939.96	789.33
354	1221.51	1464.65	1132.78	2553.03	1765.00	440	561.85	573.69	1613.47	786.32	949.00
356	1061.19	856.45	2086.34	2146.16	2259.33	442	1340.93	411.40	2111.21	663.15	566.27
358	1582.24	917.88	1380.45	1373.66	2014.82	444	2747.85	1730.99	2133.92	2039.15	241.00
360	1596.48	752.16	992.68	753.29	999.84	446	1242.47	1186.47	891.13	1772.06	1725.42
362	1265.10	775.36	633.46	898.80	1004.70	448	1058.49	813.54	808.84	947.76	903.71
364	620.25	1072.30	661.58	788.77	1147.51	450	1485.68	459.04	851.99	874.76	580.88
366	671.85	260.98	642.96	667.94	975.38	452	1075.90	782.15	523.62	435.67	747.61
368	1288.86	668.79	562.01	585.23	796.50	454	1178.77	757.09	880.52	560.97	1034.57
370	1719.81	508.64	464.32	539.31	724.84	456	1356.45	337.02	442.11	564.60	320.00
372	1932.87	1200.69	1719.06	543.06	1190.31	458	974.00	338.40	585.38	820.70	269.49
374	1108.21	929.25	696.26	931.72	1120.44	460	851.31	1292.35	510.83	847.55	413.60
376	1180.50	1232.20	787.83	586.77	666.75	462	1303.54	688.32	1100.95	583.78	467.72
378	1032.13	755.75	1055.78	1573.10	1157.87	464	2159.17	571.28	1214.05	517.08	471.12
380	1415.80	418.80	1074.13	1935.00	1211.47	466	1403.03	575.26	785.40	372.55	502.58
382	1890.85	1096.10	955.32	1681.49	1218.34	468	722.67	1018.06	701.52	576.99	816.99
384	1919.24	1507.71	577.86	1748.09	1170.32	470	423.66	1277.44	868.80	482.60	792.60
386	1590.06	1082.40	990.33	778.34	667.16	472	827.34	1224.65	1263.75	674.78	569.25
388	873.71	1086.17	1155.96	548.04	495.33	474	1050.03	1091.45	649.28	672.63	438.87
390	1065.75	859.40	1011.67	750.59	436.86	476	614.85	741.10	393.28	726.19	709.82
392	1376.75	448.22	588.63	526.21	419.34	478	517.17	602.74	1230.23	471.89	486.31
394	2159.68	435.90	1629.00	1341.03	309.62	480	382.88	411.32	1495.69	867.12	651.23
396	1414.27	636.98	1872.62	1110.77	613.58	482	675.04	371.61	1105.60	455.27	456.67
398	1653.35	871.49	1736.42	943.72	686.95	484	797.93	337.15	721.45	769.79	600.09
400	2323.57	1043.63	1758.41	1661.50	1249.41	486	1320.30	1041.10	692.64	816.55	409.74
402	1947.92	2015.13	1836.18	1769.97	1100.73	488	938.85	750.47	844.93	493.96	517.71
404	1858.15	1025.88	1154.81	1235.00	710.99	490	386.68	454.45	806.42	401.62	612.25
406	1109.22	758.69	792.48	791.42	916.23	492	881.22	284.94	815.71	333.26	507.56
408	1086.13	405.37	557.87	656.10	744.93	494	986.00	1490.48	587.29	725.58	614.35
410	846.33	1242.00	592.94	709.32	674.66	496	525.80	552.51	1069.37	1346.66	505.72
412	1305.61	975.96	789.68	802.59	737.44	498	631.68	678.60	734.53	985.82	319.02
414	1007.34	620.24	769.70	783.27	742.71	500	433.04	781.20	749.70	678.36	900.73
416	1057.55	849.19	776.61	531.35	467.30	502	536.73	422.08	683.90	435.84	627.67
418	1112.83	1127.39	837.63	917.54	1256.60	504	798.59	1165.10	538.87	334.12	476.01
420	641.70	957.37	855.63	1420.22	607.10	506	589.44	748.17	1081.09	886.66	292.89
422	662.73	517.41	858.87	1430.97	580.61	508	606.36	522.94	703.15	924.40	435.92
424	520.60	832.63	754.68	1151.06	459.64	510	639.58	525.56	515.30	722.39	560.10

512	921.22	954.90	803.98	499.56	566.53	598	440.68	301.29	431.38	517.56	599.04
514	529.60	694.29	905.79	734.28	384.47	600	333.85	406.18	380.86	986.43	1013.17
516	410.30	561.92	792.17	1090.77	634.04	602	583.57	585.40	960.64	998.55	799.83
518	359.22	487.16	883.54	429.18	757.12	604	465.38	620.27	500.31	835.98	391.81
520	208.54	479.31	526.87	337.90	470.35	606	618.62	498.33	379.96	392.65	763.01
522	435.78	329.35	539.70	633.46	226.04	608	485.31	372.45	331.56	885.24	1270.46
524	271.58	350.57	625.95	480.13	577.54	610	563.51	721.27	609.26	1306.24	727.33
526	451.64	450.88	819.58	221.25	629.15	612	377.74	478.79	885.91	591.38	456.09
528	490.05	547.45	869.87	1037.02	347.73	614	653.78	306.23	354.16	621.94	659.35
530	498.34	495.23	550.04	590.29	573.45	616	1040.49	594.64	321.43	511.55	666.83
532	434.41	498.28	357.62	529.86	411.96	618	804.63	349.44	313.90	323.92	678.62
534	497.59	452.97	392.96	426.44	475.17	620	442.81	739.26	302.53	890.16	599.56
536	444.74	415.54	799.42	322.87	210.19	622	744.21	910.74	325.58	674.90	1130.08
538	394.77	750.40	681.92	508.60	429.48	624	640.44	1105.19	353.84	714.09	746.71
540	437.95	483.79	588.19	774.09	221.25	626	843.85	571.65	452.95	1092.36	447.14
542	324.11	286.47	422.56	587.38	484.34	628	646.24	664.14	546.18	566.31	694.77
544	514.99	273.61	594.72	495.22	305.56	630	670.12	720.43	456.51	400.47	874.32
546	320.98	302.50	656.11	591.00	1034.57	632	705.55	704.05	507.57	634.89	679.80
548	479.60	575.12	670.01	513.71	927.27	634	684.42	564.05	650.83	819.51	567.66
550	417.24	331.14	493.69	490.03	524.66	636	634.38	498.76	562.21	557.48	682.94
552	441.06	589.05	1327.90	936.27	478.63	638	525.56	459.24	489.02	499.51	548.53
554	1033.59	1105.60	1193.62	1221.30	958.61	640	427.78	305.48	415.63	417.45	690.16
556	770.32	841.53	972.46	1052.67	1015.12	642	430.69	517.39	399.74	450.86	353.21
558	526.32	491.02	712.31	614.19	451.90	644	352.99	827.24	746.93	515.85	311.05
560	656.88	748.99	955.31	936.07	832.80	646	574.03	397.50	544.09	981.00	541.07
562	380.69	343.05	674.55	797.60	509.46	648	306.36	561.22	405.60	389.09	410.54
564	692.23	921.59	937.61	1010.89	1139.52	650	584.69	389.98	574.92	485.51	495.24
566	370.70	470.98	506.46	470.52	564.68	652	435.97	434.54	560.56	539.58	435.06
568	584.60	659.35	827.84	677.30	616.52	654	355.18	648.26	577.58	492.70	353.76
570	556.53	320.10	712.77	605.75	753.88	656	256.99	695.24	535.91	896.68	978.58
572	787.50	781.21	878.20	852.08	726.79	658	331.21	831.82	986.51	806.51	789.29
574	385.76	668.71	693.13	833.54	567.33	660	341.22	420.51	1340.67	1107.68	570.32
576	298.03	367.05	580.03	569.21	563.39	662	531.80	309.42	1126.86	798.74	555.04
578	492.63	697.74	695.67	886.12	417.03	664	628.25	489.87	898.57	952.89	541.20
580	336.25	524.10	452.96	1019.02	297.67	666	666.62	588.27	887.12	1060.40	434.53
582	505.68	429.17	600.70	1237.27	481.00	668	375.38	839.95	552.06	601.84	532.42
584	410.39	658.38	315.02	922.07	344.24	670	546.99	499.50	567.87	560.95	652.77
586	767.84	521.54	555.26	605.03	464.12	672	366.71	442.59	336.78	531.56	583.64
588	448.55	397.78	501.18	607.77	715.89	674	580.56	444.77	377.80	714.32	460.30
590	498.91	371.23	958.52	1061.91	680.66	676	838.97	353.24	893.57	517.86	550.19
592	362.37	521.36	506.08	1189.44	239.38	678	471.19	741.26	593.47	544.37	495.93
594	226.66	473.03	451.83	702.73	236.16	680	424.96	565.27	490.56	594.43	680.52
596	332.63	335.65	325.23	616.61	803.44	682	465.63	607.23	484.84	342.13	613.75

684	456.43	535.55	284.54	675.03	873.72	770	718.90	385.03	719.92	213.20	494.99
686	249.37	806.41	274.92	1202.03	544.21	772	329.05	654.15	594.53	588.69	593.19
688	773.82	650.38	903.22	480.64	949.56	774	352.43	348.10	275.78	429.46	466.62
690	475.78	339.26	615.50	705.73	811.54	776	357.83	291.54	283.67	751.73	596.73
692	798.07	618.35	742.54	521.91	412.06	778	226.36	497.64	604.25	1121.36	710.18
694	872.98	477.52	912.86	818.86	365.80	780	712.14	854.61	393.01	1012.52	493.48
696	639.20	1100.83	712.19	706.28	317.81	782	382.09	387.69	467.02	497.36	438.09
698	524.59	650.13	490.98	493.89	195.88	784	394.42	381.48	265.32	237.01	547.51
700	968.16	435.86	354.76	392.99	715.84	786	527.57	486.74	297.40	487.44	667.44
702	1122.54	911.77	460.15	585.99	520.27	788	825.85	413.79	387.18	633.57	393.70
704	1309.64	804.42	418.84	491.17	393.39	790	397.19	669.35	389.71	353.70	736.92
706	562.57	428.09	449.96	924.75	897.32	792	375.72	834.48	379.82	548.89	256.58
708	495.28	389.09	416.54	528.89	497.61	794	521.43	606.53	428.95	555.80	522.40
710	1017.97	286.86	318.75	777.02	617.60	796	711.28	330.82	458.43	440.25	217.83
712	820.18	553.71	932.78	607.59	506.95	798	877.17	338.92	757.77	667.64	393.63
714	438.16	596.15	552.94	584.64	414.24	800	855.62	370.38	585.88	753.21	365.46
716	320.77	362.86	419.15	412.06	477.38	802	532.96	351.68	540.35	539.79	320.35
718	297.50	473.38	322.66	358.95	341.99	804	295.50	840.98	351.50	300.71	861.30
720	645.99	300.54	563.19	549.19	468.45	806	433.33	702.02	522.47	166.99	99.00
722	512.76	589.58	640.86	535.06	482.68	808	354.42	372.47	406.70	691.09	394.86
724	342.38	622.78	437.36	404.55	829.79	810	917.45	275.84	553.14	885.73	309.49
726	409.03	748.38	505.31	506.53	815.82	812	663.21	641.79	396.96	983.95	361.66
728	310.58	690.36	361.88	308.54	430.97	814	660.53	433.22	591.01	770.62	656.81
730	396.18	269.01	352.62	701.56	660.05	816	327.64	277.03	476.30	556.57	433.11
732	595.49	646.70	561.72	268.69	526.09	818	887.26	309.05	256.71	307.23	560.09
734	778.43	352.31	837.82	638.65	258.47	820	726.60	292.86	244.71	763.59	266.88
736	435.11	379.82	812.93	684.14	409.36	822	400.15	389.49	503.52	545.19	13.78
738	369.55	683.89	375.92	428.81	614.58	824	320.05	733.83	295.58	569.08	337.53
740	549.32	614.06	608.82	842.96	463.33	826	341.02	324.15	341.24	1069.99	778.56
742	459.75	523.57	388.97	369.73	457.72	828	370.93	353.59	273.50	949.00	388.40
744	865.42	791.64	361.13	218.04	742.28	830	566.97	212.72	310.97	923.28	596.20
746	607.67	776.90	305.40	372.31	611.48	832	657.93	795.79	572.27	866.78	666.67
748	623.24	476.82	588.60	759.04	470.34	834	381.85	523.08	316.97	546.02	972.03
750	893.08	626.98	752.39	552.69	788.70	836	401.10	5.20	372.67	461.49	909.20
752	827.96	526.61	867.88	530.51	360.81	838	620.33	223.29	111.14	737.72	368.09
754	808.68	177.59	621.23	730.45	314.72	840	949.14	358.65	222.19	967.96	278.69
756	615.00	456.38	578.76	663.88	290.48	842	616.19	656.96	569.14	559.80	240.92
758	724.72	510.48	687.22	363.10	821.79	844	256.10	472.96	311.02	465.89	576.30
760	621.42	518.15	649.02	503.75	626.03	846	264.99	531.85	286.38	698.99	759.84
762	477.56	533.24	299.19	317.76	197.16	848	645.54	715.26	407.17	869.61	464.57
764	864.88	440.75	605.42	426.35	493.08	850	379.69	581.04	511.44	517.66	579.06
766	481.95	348.42	559.31	555.34	386.15	852	600.55	457.06	550.36	792.00	492.22
768	558.73	296.42	549.89	557.42	425.98	854	241.51	402.59	111.41	942.89	443.81

856	557.07	398.63	498.07	694.35	454.81	942	655.47	501.22	108.73	313.64	387.40
858	443.86	297.11	513.38	359.78	397.59	944	586.85	470.28	212.91	457.65	390.78
860	369.66	384.15	385.88	473.38	390.75	946	489.05	432.63	147.63	246.23	582.74
862	421.67	650.00	370.18	390.51	757.38	948	422.79	881.53	268.33	383.09	402.14
864	329.67	559.49	354.80	360.91	665.08	950	996.94	346.89	237.12	526.40	352.39
866	637.25	356.39	342.15	326.21	373.82	952	533.13	795.14	336.06	261.37	231.52
868	695.97	446.46	601.96	988.51	631.26	954	524.20	326.79	170.48	923.15	229.80
870	604.82	362.95	583.35	708.63	458.17	956	788.92	406.15	254.61	755.99	377.86
872	293.16	307.04	382.58	428.22	380.70	958	958.55	480.20	145.66	216.58	224.85
874	526.29	400.06	402.22	451.19	223.87	960	232.10	488.86	86.29	211.66	258.26
876	397.63	856.04	444.85	543.47	621.08	962	830.44	415.25	349.81	225.33	158.99
878	329.26	641.26	356.23	308.41	658.65	964	510.17	576.16	150.92	196.75	389.30
880	467.73	442.12	305.16	477.45	514.95	966	498.44	257.63	436.12	219.71	304.08
882	753.29	696.65	307.02	578.08	527.31	968	761.05	674.00	114.85	252.08	260.97
884	469.84	412.00	698.12	518.10	722.97	970	543.92	497.52	148.82	235.94	404.04
886	432.69	878.07	429.46	345.49	524.72	972	633.25	387.62	321.99	291.18	307.02
888	472.43	1032.91	384.94	676.31	624.96	974	298.79	1028.28	187.36	204.07	305.82
890	798.53	688.02	689.85	692.95	599.59	976	533.26	276.53	215.99	324.93	208.91
892	752.05	527.18	488.78	601.89	820.71	978	365.50	149.92	207.13	226.89	786.54
894	1169.33	440.52	616.97	529.00	556.36	980	571.04	554.18	207.38	321.66	543.56
896	849.04	317.87	493.86	416.26	516.65	982	786.03	326.78	203.60	570.75	617.43
898	638.94	428.86	352.91	392.76	507.25	984	448.75	896.73	176.32	297.16	349.38
900	885.30	574.51	394.02	383.45	472.75	986	537.77	310.84	158.27	199.36	302.72
902	1088.60	700.12	1066.32	277.69	843.47	988	471.00	506.36	240.72	267.92	387.39
904	773.44	450.75	945.35	377.44	452.61	990	536.80	633.30	242.22	231.02	638.97
906	630.11	292.44	370.56	282.02	324.40	992	1054.56	356.53	100.78	273.40	194.82
908	721.52	308.77	651.92	576.67	233.33	994	771.94	612.23	200.33	198.59	445.44
910	566.40	894.80	469.53	433.45	310.62	996	1007.28	530.79	278.53	462.29	284.55
912	503.05	641.68	632.12	263.40	605.25	998	522.51	709.27	481.93	351.84	442.41
914	488.64	485.19	525.82	416.15	771.45	1000	406.03	902.10	209.63	166.22	172.96
916	835.35	478.75	274.24	233.76	400.46	1002	562.54	442.78	216.71	250.63	470.79
918	560.98	327.35	343.29	251.48	259.05	1004	459.91	426.59	193.84	323.91	553.36
920	1065.09	221.87	604.91	1169.01	393.36	1006	497.07	320.19	293.57	252.61	547.64
922	1192.39	426.58	781.71	738.41	236.98	1008	466.93	605.96	108.25	218.73	360.69
924	1172.81	501.15	369.48	383.32	506.41	1010	534.68	247.07	175.68	215.49	449.63
926	410.45	435.73	364.08	405.27	147.61	1012	604.93	353.35	370.90	262.52	302.15
928	1209.74	292.48	279.86	276.28	440.77	1014	502.12	626.16	194.91	686.26	356.74
930	343.18	503.25	118.88	279.73	209.84	1016	740.99	415.05	390.38	238.07	792.73
932	735.34	668.43	195.78	382.76	718.00	1018	710.62	508.76	223.60	282.04	527.87
934	553.10	392.63	280.08	380.37	411.38	1020	364.04	168.35	159.59	260.56	418.62
936	600.28	243.43	238.56	288.86	468.54	1022	428.09	238.84	203.83	247.08	429.32
938	467.52	462.83	128.08	245.48	520.09	1024	221.88	551.86	156.11	404.69	648.54
940	614.21	502.57	80.76	218.77	511.94	1026	880.48	536.16	266.82	318.91	332.67

1028	341.43	639.16	180.75	254.19	355.28	1114	555.50	383.86	420.74	329.71	324.13
1030	594.30	282.68	252.00	271.75	343.24	1116	605.93	734.47	411.37	148.14	289.80
1032	759.20	478.42	168.42	190.37	415.81	1118	1088.46	574.70	230.17	410.25	473.93
1034	727.39	135.06	216.73	181.95	334.28	1120	627.75	425.90	780.61	163.31	174.54
1036	410.07	321.70	328.99	198.92	327.89	1122	506.34	776.99	612.56	351.74	203.46
1038	723.62	647.84	185.07	221.84	393.80	1124	811.25	581.68	306.34	158.52	119.61
1040	493.24	386.22	332.10	215.99	637.27	1126	1059.64	489.03	509.18	162.90	129.01
1042	731.82	372.34	124.45	414.80	468.20	1128	616.86	538.56	665.53	316.90	183.35
1044	652.14	155.04	176.53	326.42	234.77	1130	476.54	507.72	407.42	230.12	265.28
1046	395.79	159.75	771.51	265.43	220.79	1132	396.65	515.05	375.49	220.87	230.48
1048	762.87	500.42	478.02	491.62	189.39	1134	501.09	364.92	218.02	187.64	92.25
1050	737.56	346.79	500.39	225.18	470.34	1136	402.95	396.24	604.77	163.37	68.21
1052	348.75	423.07	815.93	250.44	261.80	1138	260.15	794.68	836.99	184.15	183.13
1054	393.86	640.84	662.16	345.97	490.23	1140	823.25	438.11	401.96	239.97	182.83
1056	459.70	173.33	1245.59	1178.86	242.22	1142	930.25	854.83	602.23	371.07	136.43
1058	689.99	403.83	773.82	1000.26	280.08	1144	1035.74	731.92	461.29	284.56	267.90
1060	519.20	449.68	703.71	725.00	539.01	1146	456.69	531.90	212.68	413.04	191.92
1062	372.27	306.64	1094.12	713.32	243.90	1148	554.35	895.15	352.33	262.36	125.08
1064	441.48	498.50	684.53	1243.39	186.75	1150	695.70	704.84	642.49	248.62	161.27
1066	374.39	275.44	539.25	1171.56	253.19	1152	331.62	508.22	780.85	177.84	246.43
1068	577.66	236.21	798.79	738.47	276.93	1154	941.09	476.18	766.41	234.23	278.96
1070	624.62	189.08	568.44	415.76	382.78	1156	746.09	325.55	360.51	291.21	139.05
1072	232.47	817.60	355.80	285.23	205.00	1158	564.85	966.87	607.43	240.07	362.87
1074	792.88	301.39	649.17	311.33	136.67	1160	608.53	299.14	1011.42	269.10	91.10
1076	456.45	428.62	550.01	265.20	199.17	1162	870.61	356.48	360.46	236.93	230.42
1078	350.63	611.75	292.33	295.82	285.95	1164	756.76	531.54	282.88	277.07	211.91
1080	495.16	427.84	428.20	290.76	324.22	1166	709.62	760.79	508.77	198.66	392.19
1082	323.66	193.94	332.14	175.44	217.98	1168	702.75	355.53	675.12	387.99	183.59
1084	246.16	293.69	328.68	241.13	340.68	1170	454.86	299.45	242.94	253.43	220.67
1086	184.46	260.23	212.69	210.02	237.46	1172	322.96	763.38	704.93	262.06	268.78
1088	523.28	369.52	437.44	220.39	327.80	1174	414.06	406.67	389.20	290.75	374.40
1090	323.34	248.74	222.85	169.43	217.75	1176	222.40	487.00	238.75	257.47	382.57
1092	153.47	374.88	483.15	355.08	284.52	1178	273.90	445.21	396.46	295.36	233.63
1094	944.18	467.93	339.65	237.37	287.71	1180	675.65	992.45	296.96	662.38	126.38
1096	513.91	497.62	282.51	395.76	267.52	1182	407.10	535.73	456.59	324.68	281.82
1098	264.02	672.73	456.99	299.27	201.84	1184	448.19	609.61	627.34	347.38	137.44
1100	398.03	612.81	541.69	177.49	111.57	1186	336.11	867.24	347.91	478.64	205.76
1102	550.65	265.21	236.48	162.22	315.48	1188	631.54	279.94	336.05	274.93	118.31
1104	289.94	796.20	564.89	251.26	311.25	1190	342.25	783.00	581.48	283.78	126.56
1106	734.88	494.95	497.64	262.92	604.08	1192	226.67	412.72	333.55	401.89	247.77
1108	517.47	834.05	440.14	394.64	493.85	1194	601.10	785.63	233.90	230.89	166.58
1110	582.72	611.10	612.66	203.28	412.43	1196	156.80	104.89	204.56	494.27	139.34
1112	259.90	758.97	495.50	330.62	247.87	1198	576.45	216.26	656.25	373.03	297.67

1200	309.60	246.48	405.25	501.79	215.65	1286	809.77	211.23	112.28	103.48	60.07
1202	599.18	1045.52	333.59	984.11	184.33	1288	499.56	221.70	204.54	144.41	70.83
1204	316.87	366.62	483.88	979.55	172.20	1290	520.82	307.80	144.59	242.45	101.06
1206	369.76	1282.23	468.49	1437.23	324.07	1292	586.39	247.25	189.51	171.76	86.02
1208	715.42	475.50	599.27	439.96	287.70	1294	290.24	285.89	68.57	147.14	109.74
1210	407.19	562.09	546.02	872.29	285.51	1296	225.78	283.12	154.32	156.14	127.06
1212	768.93	601.91	168.90	570.49	210.73	1298	521.08	633.50	204.04	207.62	91.08
1214	513.54	613.77	262.80	307.46	323.94	1300	233.29	458.63	205.68	177.91	102.60
1216	349.39	602.59	432.93	392.69	174.86	1302	324.64	212.67	116.04	247.68	98.50
1218	835.01	618.38	578.61	613.45	438.76	1304	446.54	247.38	94.36	228.68	161.41
1220	462.25	618.56	436.25	336.58	346.37	1306	438.81	258.77	258.37	180.46	92.69
1222	376.06	767.06	429.07	279.36	191.28	1308	290.76	585.79	165.64	161.68	134.15
1224	233.77	660.72	411.49	421.64	235.67	1310	510.86	229.86	72.22	207.24	235.26
1226	692.41	648.12	355.23	376.26	246.65	1312	297.81	145.95	145.36	200.21	163.45
1228	624.65	484.30	759.50	484.04	281.90	1314	426.89	158.54	149.90	160.11	196.65
1230	386.32	465.71	491.67	378.07	127.29	1316	494.55	294.51	271.14	186.72	169.10
1232	356.97	619.71	295.22	374.39	199.07	1318	290.34	294.25	95.94	144.13	244.30
1234	320.23	31.58	540.50	425.59	136.40	1320	536.76	251.38	99.07	155.45	79.30
1236	274.06	850.58	319.71	810.61	280.46	1322	265.62	180.00	199.41	148.46	114.37
1238	599.00	495.54	399.48	619.40	261.67	1324	281.75	189.09	118.92	195.19	99.75
1240	261.23	508.64	396.92	240.32	183.59	1326	425.74	233.65	98.28	190.02	127.89
1242	773.13	608.94	431.01	434.38	92.05	1328	380.16	240.42	85.67	176.25	74.05
1244	647.29	489.09	711.89	388.43	61.60	1330	403.66	151.03	93.43	204.68	66.73
1246	358.05	494.70	773.04	563.18	180.23	1332	665.86	241.69	88.07	148.95	102.78
1248	679.54	387.48	501.53	519.37	226.82	1334	597.46	180.20	79.39	164.23	100.33
1250	698.68	271.53	449.91	745.36	97.14	1336	203.87	237.85	120.12	134.77	82.65
1252	459.12	124.57	574.33	429.84	130.96	1338	367.42	283.42	152.08	141.59	80.95
1254	505.62	392.27	268.92	379.51	136.32	1340	231.37	336.44	168.70	254.74	102.39
1256	478.94	260.91	742.30	339.44	200.60	1342	391.01	429.05	218.23	109.06	75.34
1258	761.70	372.16	350.28	260.73	126.61	1344	586.23	198.08	118.77	220.06	114.44
1260	674.12	482.29	323.82	221.56	162.11	1346	164.97	394.76	126.99	190.51	105.24
1262	457.00	257.62	542.47	158.39	170.82	1348	108.17	214.32	89.54	189.82	105.06
1264	294.16	361.78	135.83	313.49	157.85	1350	90.80	268.43	124.82	136.84	100.78
1266	571.12	257.82	224.38	364.66	87.46	1352	111.58	183.81	158.14	144.33	90.59
1268	468.56	346.97	179.99	339.57	148.90	1354	144.84	186.93	145.09	89.56	156.11
1270	243.00	302.72	164.85	217.99	116.02	1356	183.16	532.70	93.14	137.43	107.69
1272	241.22	385.09	137.51	205.78	87.60	1358	197.45	160.23	138.90	176.73	75.35
1274	487.25	221.82	174.63	183.81	91.12	1360	454.75	231.89	149.68	134.01	52.01
1276	345.94	330.78	87.91	282.88	58.13	1362	322.29	203.32	86.91	228.79	130.56
1278	502.94	257.23	84.40	151.12	71.70	1364	240.44	396.68	151.83	146.10	88.93
1280	452.73	489.77	136.08	139.53	87.94	1366	229.75	250.36	109.45	154.97	162.82
1282	461.97	346.54	201.47	170.52	69.63	1368	655.24	329.56	88.86	134.92	89.87
1284	324.57	181.32	167.64	184.04	178.68	1370	388.85	229.03	137.23	198.20	89.84

1372	439.70	172.98	98.08	148.27	74.05	1458	453.15	260.02	367.82	132.05	95.71
1374	334.52	263.10	104.05	174.04	49.54	1460	378.81	598.86	181.50	156.48	109.98
1376	312.90	192.38	70.83	108.14	111.63	1462	466.78	342.04	313.37	252.85	129.14
1378	367.79	202.74	74.87	120.67	80.41	1464	312.85	301.00	457.58	199.95	74.47
1380	356.02	205.53	90.39	165.45	108.88	1466	253.08	142.43	471.29	224.47	123.06
1382	318.00	269.60	170.69	213.35	70.99	1468	167.08	153.28	250.07	158.01	199.19
1384	275.74	251.98	63.65	142.91	122.00	1470	437.61	364.69	293.77	135.97	203.29
1386	402.94	204.29	223.29	188.72	121.81	1472	360.57	217.72	197.76	166.45	125.58
1388	206.83	323.58	119.32	200.67	102.10	1474	197.96	186.59	369.14	172.18	180.53
1390	234.31	426.19	101.72	148.80	100.84	1476	212.65	258.06	736.76	162.41	365.74
1392	312.68	259.65	160.01	167.11	102.81	1478	395.60	273.99	279.44	220.52	114.52
1394	489.25	299.65	171.20	193.59	140.86	1480	273.35	284.66	264.44	175.12	107.78
1396	301.38	237.96	97.82	152.35	88.77	1482	168.10	517.48	209.44	202.10	176.95
1398	334.81	290.81	141.29	238.32	147.18	1484	323.31	326.60	237.27	237.15	241.27
1400	207.38	216.27	98.72	152.83	78.24	1486	291.93	349.54	336.94	199.98	114.84
1402	258.19	211.66	110.39	194.77	106.46	1488	162.27	443.22	206.67	272.41	289.19
1404	277.91	148.82	122.61	74.56	135.76	1490	648.59	219.97	322.34	242.72	215.18
1406	276.36	212.11	149.96	129.62	82.72	1492	458.56	350.24	486.66	679.41	312.62
1408	213.70	201.36	109.92	148.23	136.43	1494	510.91	229.79	772.36	621.99	175.46
1410	264.38	244.34	71.86	201.10	67.94	1496	656.66	273.42	552.94	691.74	165.75
1412	387.22	228.54	213.95	104.50	101.58	1498	448.85	574.45	746.38	332.99	132.26
1414	398.53	175.47	172.71	144.17	98.87	1500	460.69	367.68	488.13	200.70	185.96
1416	328.36	292.64	354.10	146.76	98.43	1502	520.60	275.97	522.27	575.67	200.14
1418	413.06	149.09	254.79	148.78	90.29	1504	302.57	430.21	432.12	347.08	189.14
1420	323.74	236.69	134.82	175.19	62.99	1506	209.16	303.10	163.54	495.60	126.68
1422	430.91	180.91	288.12	128.00	268.22	1508	410.81	462.92	519.00	149.78	197.58
1424	577.62	270.46	189.04	147.61	74.10	1510	298.01	333.71	678.43	449.88	165.78
1426	602.53	279.52	314.60	126.95	238.68	1512	178.83	437.76	354.72	155.41	125.53
1428	342.22	211.53	345.35	149.06	88.11	1514	287.04	182.24	435.79	213.62	183.42
1430	355.30	120.23	307.16	176.08	87.82	1516	212.87	268.06	485.43	250.70	179.99
1432	731.98	392.03	281.51	129.66	152.99	1518	424.17	384.59	528.85	524.31	129.61
1434	266.26	46.47	355.65	145.78	186.87	1520	397.38	448.86	360.65	394.01	266.79
1436	400.04	401.83	128.60	111.06	125.27	1522	246.82	398.08	700.96	322.89	102.33
1438	270.66	437.24	367.99	146.62	157.36	1524	379.33	385.25	452.94	210.10	299.58
1440	539.81	250.25	206.85	95.05	104.86	1526	281.80	374.13	177.05	334.96	164.82
1442	475.92	191.19	353.67	137.34	74.60	1528	321.53	306.40	368.27	757.92	122.63
1444	345.57	294.41	164.02	128.96	103.23	1530	516.56	212.29	458.50	256.92	190.59
1446	343.00	261.48	149.90	147.68	122.33	1532	204.22	336.36	230.65	289.15	76.35
1448	344.46	172.64	180.08	177.37	143.92	1534	336.86	242.20	217.66	294.45	169.54
1450	455.68	344.92	227.36	225.59	118.41	1536	331.41	251.22	331.67	211.08	112.65
1452	354.88	181.07	355.22	264.30	82.51	1538	510.89	360.00	363.67	199.73	159.60
1454	522.87	242.78	297.26	208.33	76.40	1540	319.11	495.54	628.02	546.78	156.49
1456	513.01	160.16	368.44	159.16	78.18	1542	410.38	271.63	306.34	260.31	118.65

1544	170.95	304.58	570.03	198.14	165.55	1630	338.17	439.02	458.28	344.44	148.32
1546	235.20	347.35	339.63	309.49	182.83	1632	492.58	429.08	316.62	211.98	95.11
1548	338.42	228.01	575.27	293.46	154.31	1634	367.79	316.54	869.89	154.35	96.88
1550	456.32	306.26	340.42	325.05	157.98	1636	209.90	340.86	313.41	170.10	179.17
1552	299.87	157.11	411.63	331.31	112.12	1638	613.34	306.56	366.28	171.03	177.55
1554	408.94	239.66	267.63	178.12	216.27	1640	337.07	394.44	501.25	273.38	126.07
1556	451.21	208.26	477.04	177.73	105.18	1642	310.68	662.66	356.81	261.05	164.88
1558	615.86	270.82	318.50	293.45	168.54	1644	509.61	527.93	435.15	165.24	137.57
1560	332.62	158.69	293.98	240.46	128.50	1646	423.43	392.88	651.63	277.03	89.80
1562	299.41	279.50	888.70	277.53	90.34	1648	243.12	429.60	505.30	157.02	135.74
1564	455.72	282.44	420.68	208.77	116.69	1650	207.02	465.04	356.72	137.34	86.13
1566	317.29	143.66	744.55	265.66	137.40	1652	273.99	493.28	427.28	206.22	149.29
1568	340.13	162.00	186.24	359.51	79.87	1654	158.43	484.34	541.98	183.65	138.08
1570	244.47	221.04	747.47	536.05	123.84	1656	428.76	544.56	694.11	141.51	73.28
1572	310.78	154.90	339.60	566.00	140.47	1658	450.38	509.41	513.29	197.26	67.33
1574	456.78	257.70	920.03	232.09	111.22	1660	1001.69	406.09	888.69	153.45	102.08
1576	315.44	336.58	468.16	337.37	119.54	1662	374.46	384.33	876.72	122.57	83.63
1578	303.04	151.04	342.10	345.39	134.48	1664	364.59	433.51	395.48	224.27	107.52
1580	206.05	294.20	538.80	235.25	163.71	1666	354.26	480.06	230.43	170.78	192.22
1582	306.74	196.07	432.98	202.94	195.32	1668	247.68	564.73	437.25	234.28	95.16
1584	373.19	217.44	452.88	149.19	119.30	1670	301.42	581.83	337.87	190.09	87.60
1586	431.72	163.10	300.95	193.43	113.20	1672	329.14	379.25	296.51	161.96	127.90
1588	447.55	166.32	188.42	184.99	94.23	1674	436.85	382.04	634.04	166.28	105.43
1590	358.28	128.23	326.53	175.77	153.60	1676	136.03	442.19	515.01	189.00	95.25
1592	796.50	162.13	252.07	233.83	83.48	1678	251.39	271.61	490.56	305.66	140.70
1594	159.10	137.82	470.85	247.21	91.22	1680	302.35	452.11	648.27	296.44	142.87
1596	369.84	288.07	308.05	192.55	77.27	1682	313.31	200.53	911.16	270.15	111.24
1598	346.38	160.84	362.62	161.91	152.68	1684	263.52	325.61	536.48	287.61	86.40
1600	433.13	331.09	234.38	129.74	123.77	1686	506.76	402.84	753.65	172.75	128.19
1602	270.15	331.44	387.43	132.96	144.34	1688	489.17	258.71	555.69	152.80	193.62
1604	455.94	180.68	565.60	175.71	147.06	1690	451.37	400.80	1388.02	267.23	108.35
1606	279.01	139.87	427.82	123.99	185.64	1692	190.98	529.24	503.64	167.88	114.06
1608	386.59	295.86	228.53	139.02	108.60	1694	642.20	798.22	577.75	215.95	125.98
1610	352.04	285.25	331.17	261.32	239.85	1696	380.74	746.04	835.76	364.31	87.90
1612	293.92	257.33	164.50	216.70	115.72	1698	407.19	344.41	1160.91	356.36	102.47
1614	246.02	195.38	300.82	214.57	146.80	1700	531.95	466.38	1039.17	346.13	116.28
1616	221.98	276.18	218.00	239.29	148.66	1702	549.86	275.60	576.31	439.58	122.90
1618	274.92	267.99	152.91	229.63	133.35	1704	510.08	249.82	688.56	280.43	69.56
1620	512.56	215.58	578.33	137.05	206.93	1706	452.07	138.65	535.64	368.16	153.63
1622	457.64	243.16	125.21	156.09	186.20	1708	299.10	164.43	762.36	295.81	119.00
1624	487.51	235.67	404.97	125.29	145.90	1710	214.13	288.68	676.77	238.46	90.99
1626	433.89	361.98	210.32	218.88	154.12	1712	225.09	270.09	186.54	189.59	127.49
1628	182.71	413.33	543.21	153.78	139.40	1714	267.44	135.22	94.77	270.12	147.73

1716	146.13	293.22	570.08	231.11	110.30	1802	64.98	64.98	64.98	64.98	64.98
1718	210.02	126.80	252.05	189.00	118.02	1804	53.98	53.98	53.98	53.98	53.98
1720	130.92	83.25	127.90	92.05	148.54	1806	70.45	70.45	70.45	70.45	70.45
1722	136.64	180.37	112.02	94.29	166.38	1808	71.50	71.50	71.50	71.50	71.50
1724	323.86	217.33	204.29	137.62	118.87	1810	61.35	61.35	61.35	61.35	61.35
1726	202.98	212.67	184.08	191.70	171.13	1812	79.42	79.42	79.42	79.42	79.42
1728	123.94	152.31	277.35	131.06	104.05	1814	62.77	62.77	62.77	62.77	62.77
1730	245.97	142.93	253.37	146.17	114.79	1816	54.41	54.41	54.41	54.41	54.41
1732	126.64	318.92	279.19	173.60	130.35	1818	60.99	60.99	60.99	60.99	60.99
1734	147.98	220.17	176.12	155.06	54.09	1820	70.49	70.49	70.49	70.49	70.49
1736	193.07	166.81	323.25	204.06	226.85	1822	50.86	50.86	50.86	50.86	50.86
1738	288.93	110.34	329.17	229.83	159.97	1824	31.37	31.37	31.37	31.37	31.37
1740	230.21	228.16	324.43	207.78	146.77						
1742	220.36	160.73	227.28	102.87	127.29						
1744	49.25	119.54	107.76	194.80	147.62						
1746	55.41	146.26	163.09	93.87	160.73						
1748	116.68	123.69	138.97	117.37	114.65						
1750	78.56	249.47	156.26	110.83	110.83						
1752	183.58	220.60	74.96	119.06	119.06						
1754	74.45	328.74	78.84	78.84	78.84						
1756	106.34	124.32	107.88	110.27	110.27						
1758	308.99	308.99	170.26	170.26	170.26						
1760	214.98	184.19	164.97	164.97	164.97						
1762	150.72	112.83	127.72	127.72	127.72						
1764	265.48	133.17	153.85	137.22	137.22						
1766	87.87	87.87	86.96	86.96	86.96						
1768	98.79	98.79	98.79	98.79	98.79						
1770	62.60	62.60	62.60	62.60	62.60						
1772	45.08	45.08	45.08	45.08	45.08						
1774	42.39	42.39	42.39	42.39	42.39						
1776	45.37	45.37	45.37	45.37	45.37						
1778	37.11	37.11	37.11	37.11	37.11						
1780	50.56	50.56	50.56	50.56	50.56						
1782	101.81	101.81	101.81	101.81	101.81						
1784	85.64	85.64	85.64	85.64	85.64						
1786	72.22	72.22	72.22	72.22	72.22						
1788	58.33	58.33	58.33	58.33	58.33						
1790	76.71	76.71	76.71	76.71	76.71						
1792	85.54	85.54	85.54	85.54	85.54						
1794	53.87	53.87	53.87	53.87	53.87						
1796	97.30	97.30	97.30	97.30	97.30						
1798	92.92	92.92	92.92	92.92	92.92						
1800	106.39	106.39	106.39	106.39	106.39						

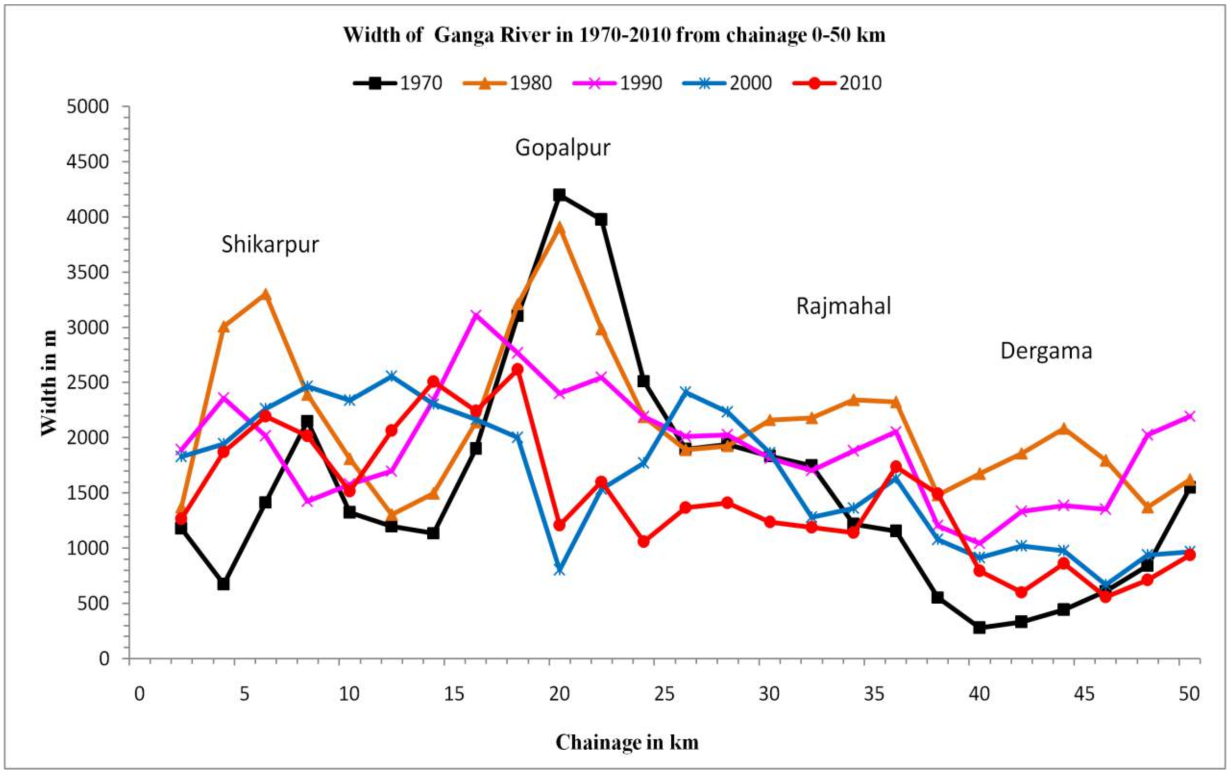


Figure 10.94 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 0-50 km

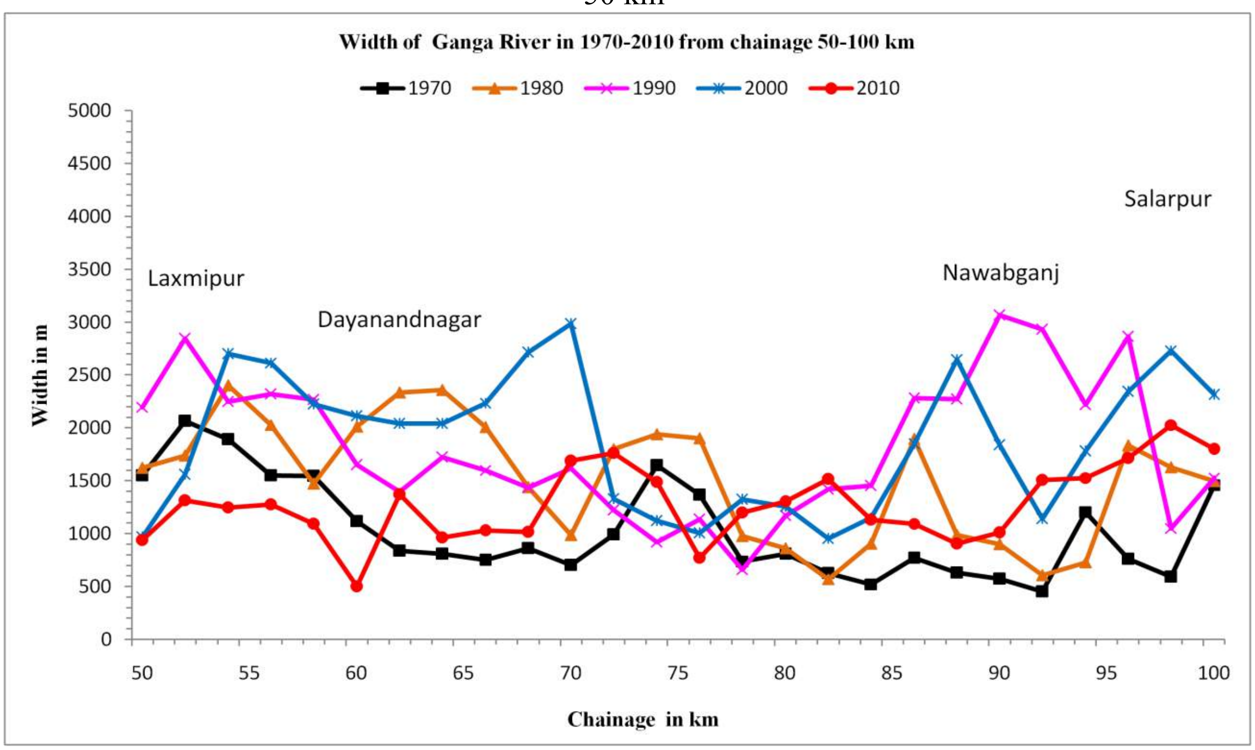


Figure 10.95 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 50-100 km

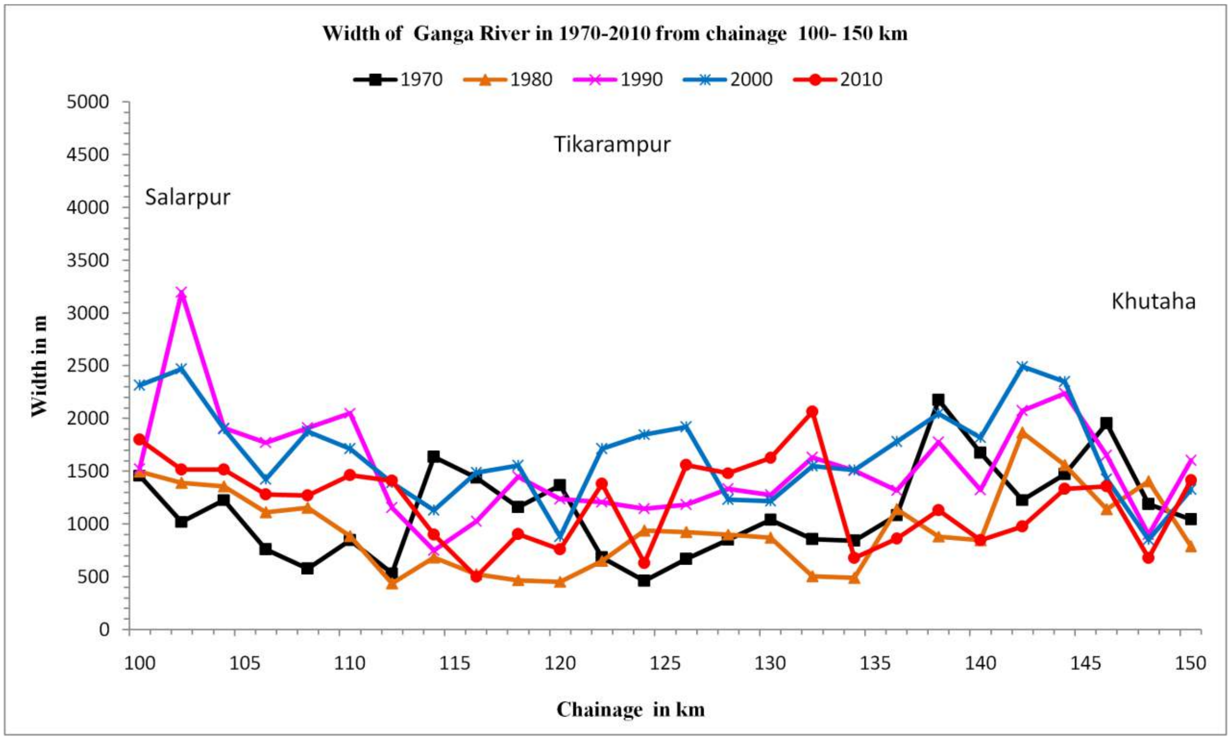


Figure 10.96 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 100-150 km

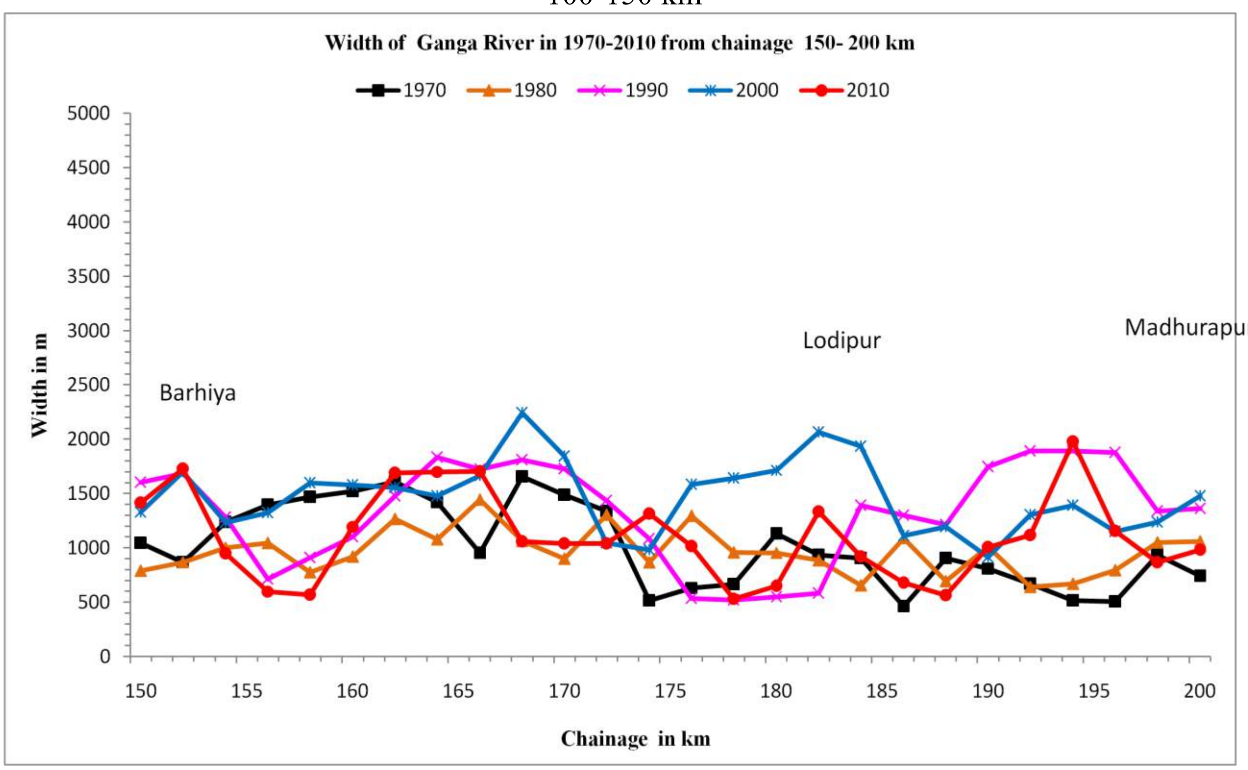


Figure 10.97 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 150-200 km

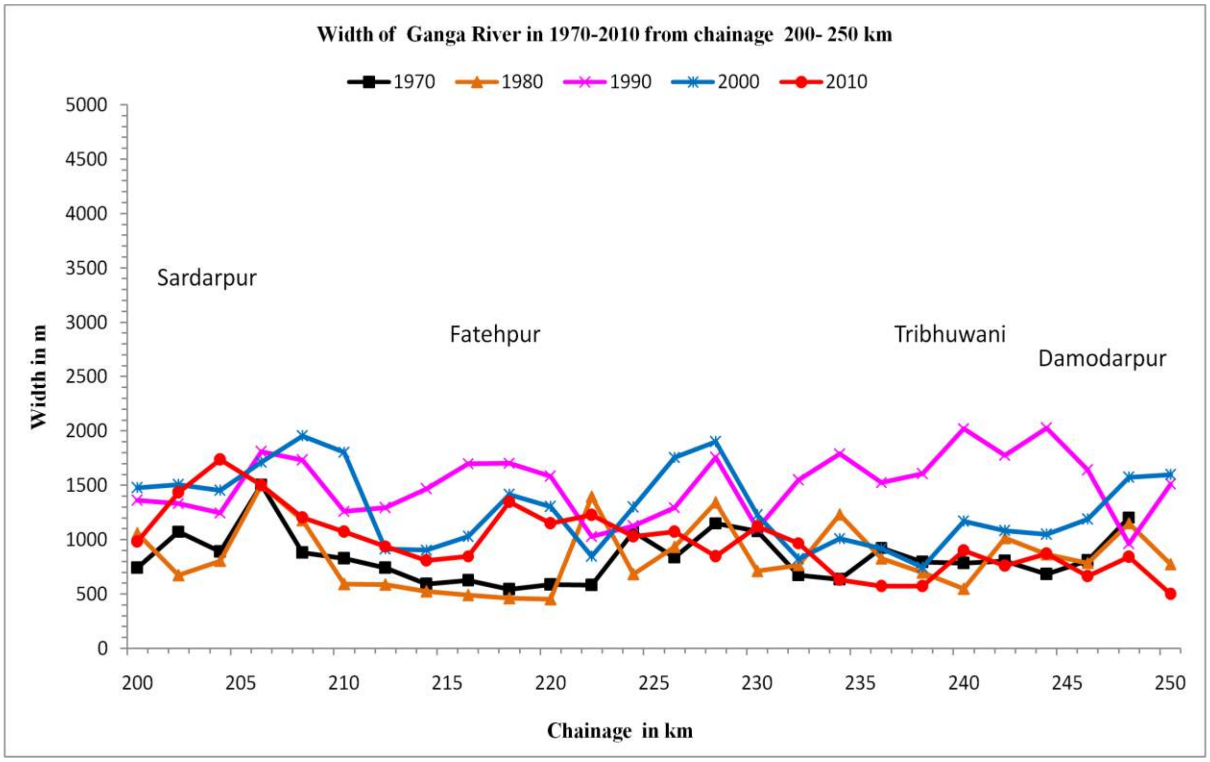


Figure 10.98 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 200-250 km

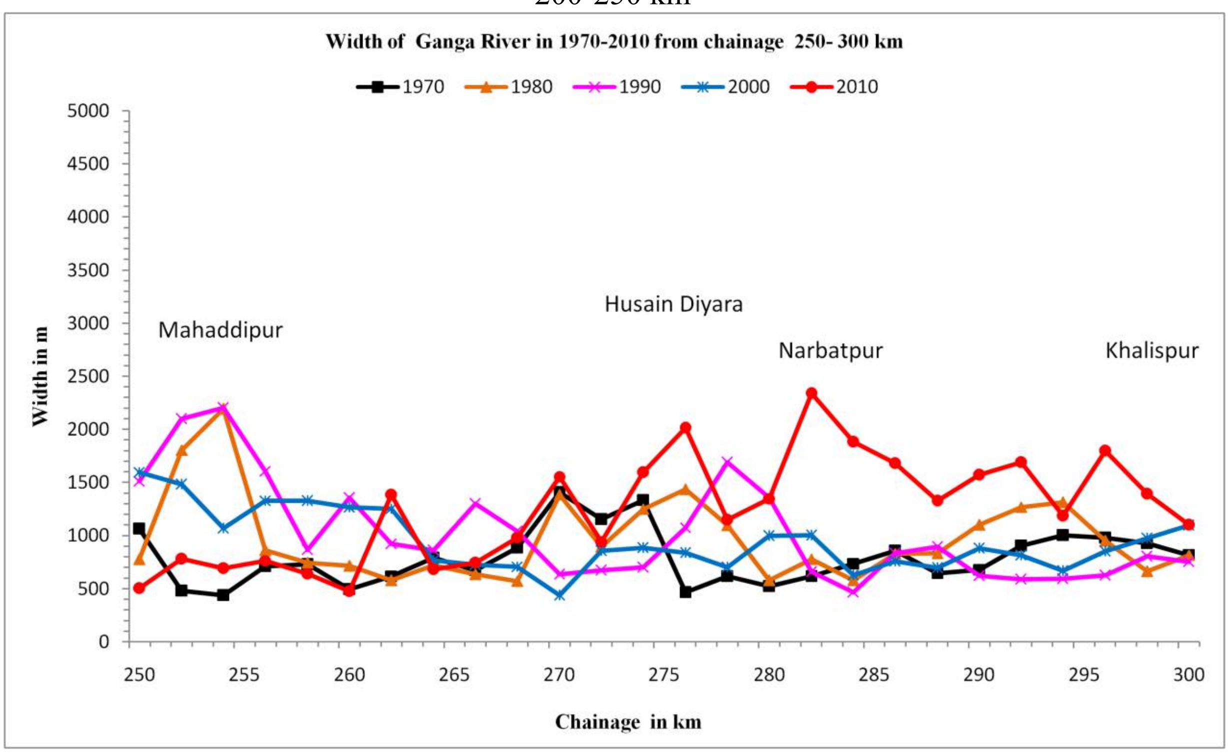


Figure 10.99 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 250-300 km

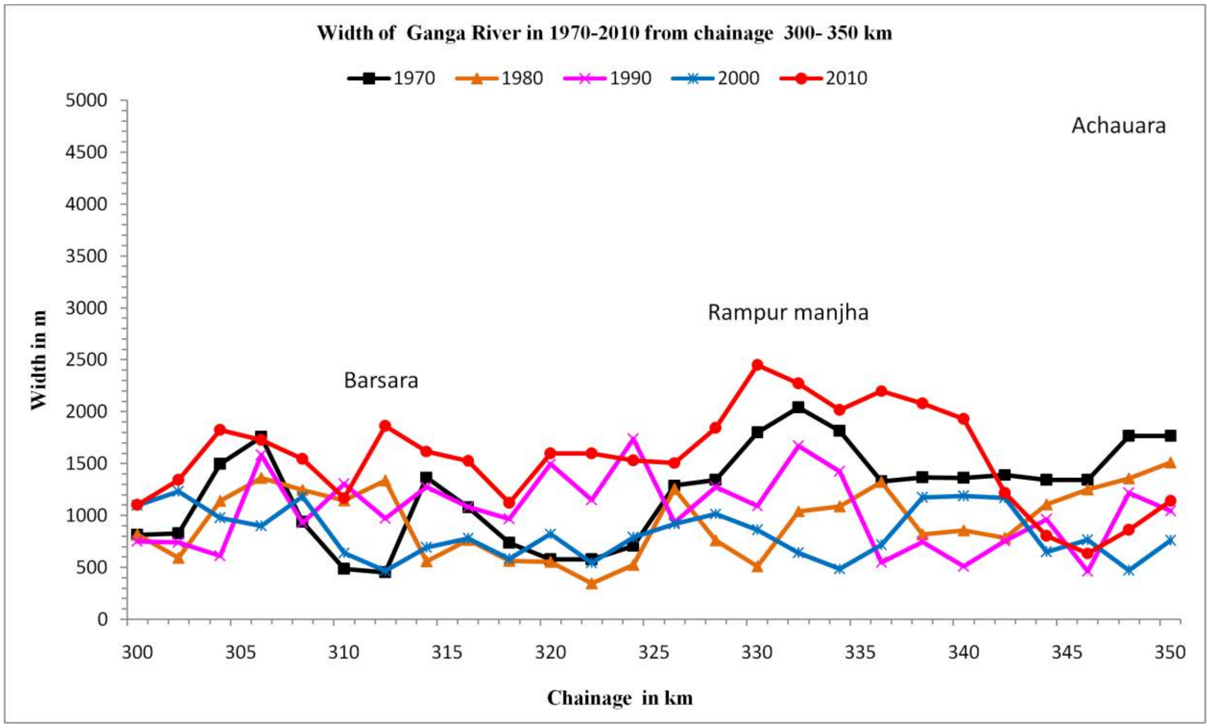


Figure 10.100 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 300-350 km

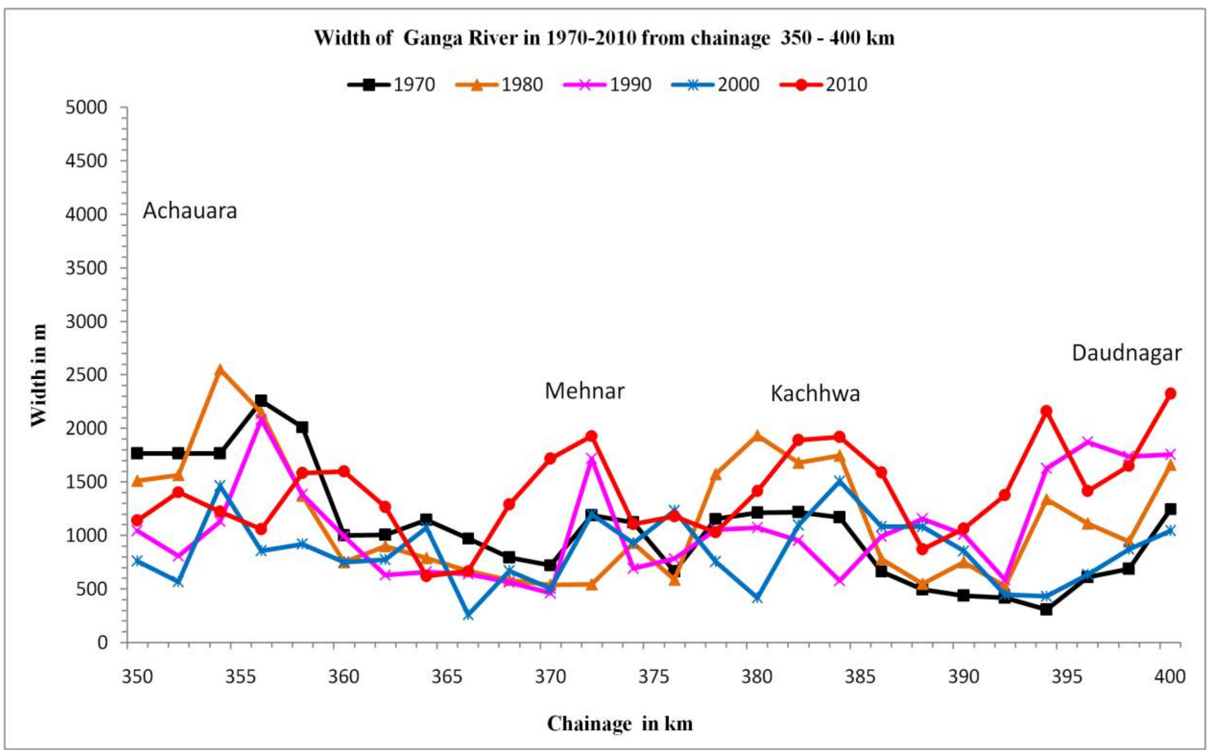


Figure 10.101 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 350-400 km

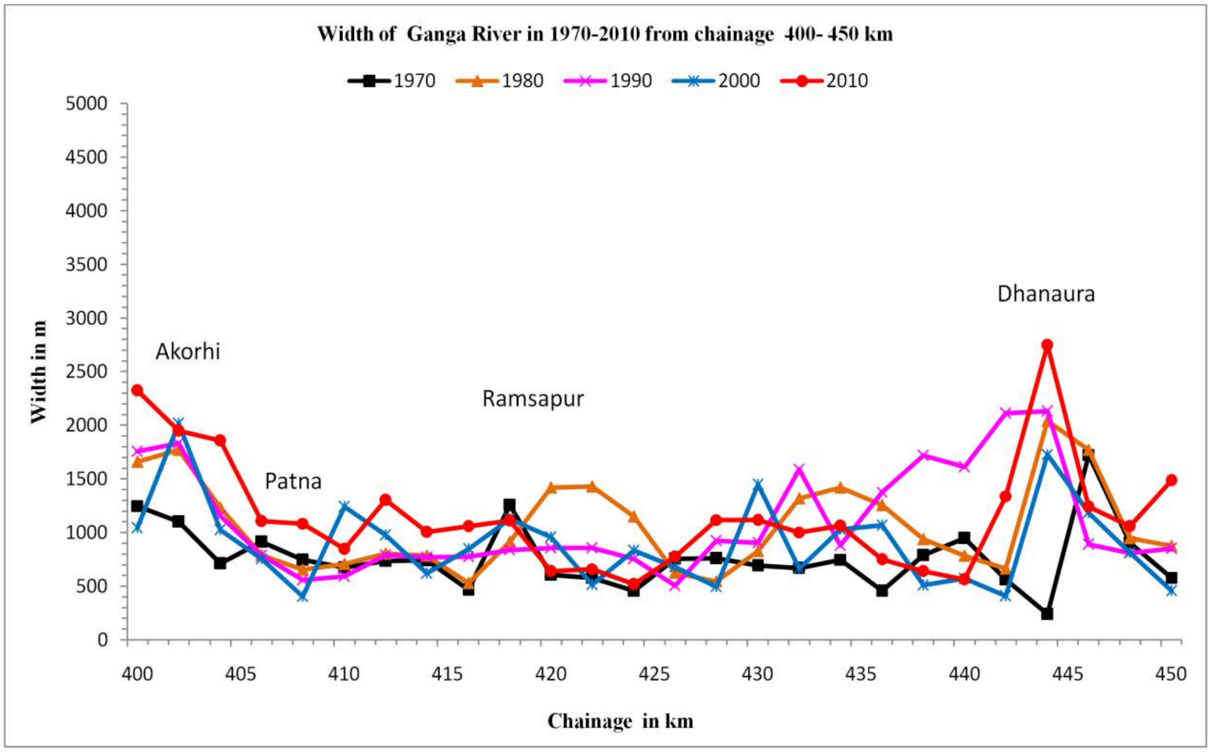


Figure 10.102 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 400-450 km

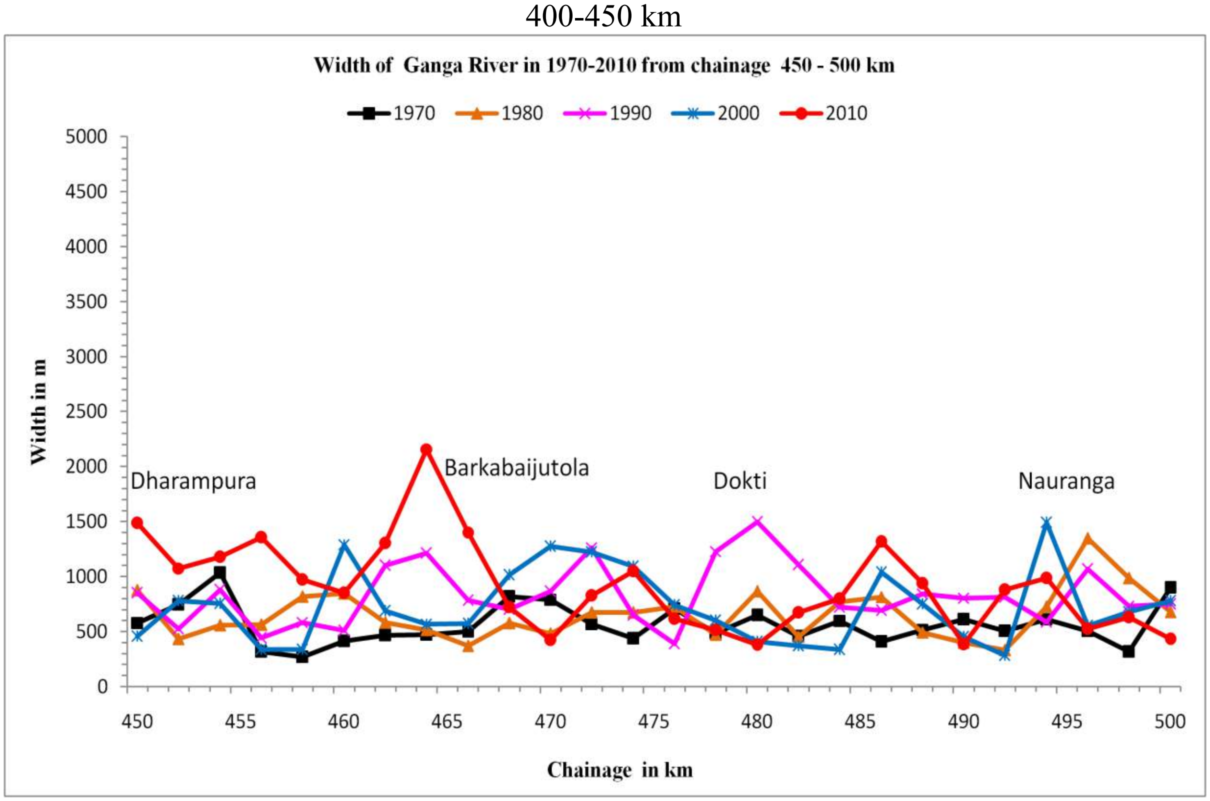


Figure 10.103 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 450-500 km

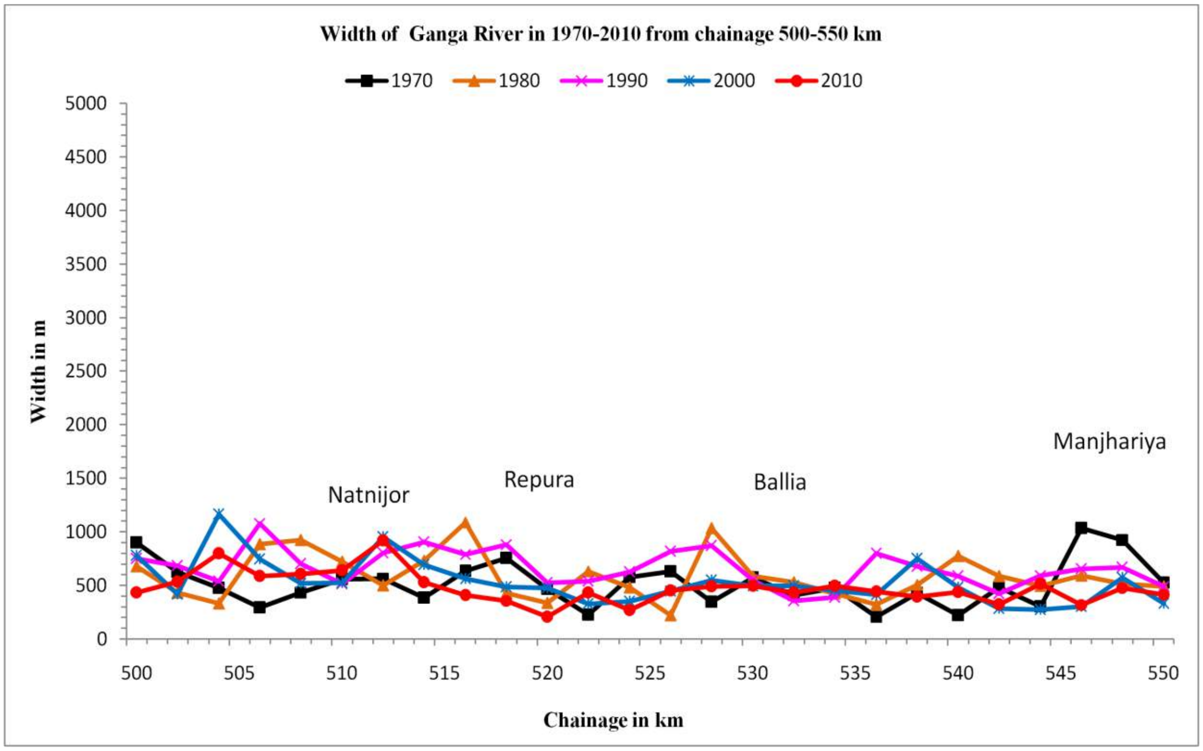


Figure 10.104 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 500-550 km

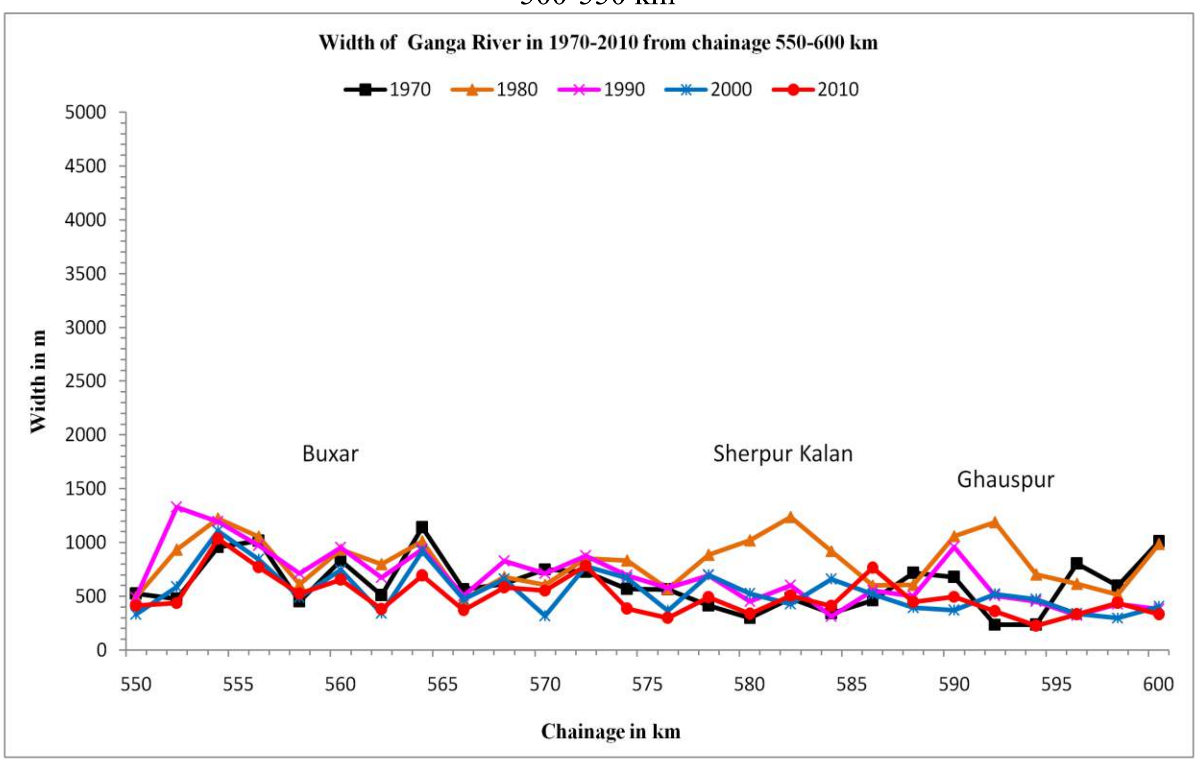


Figure 10.105 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 550-600 km

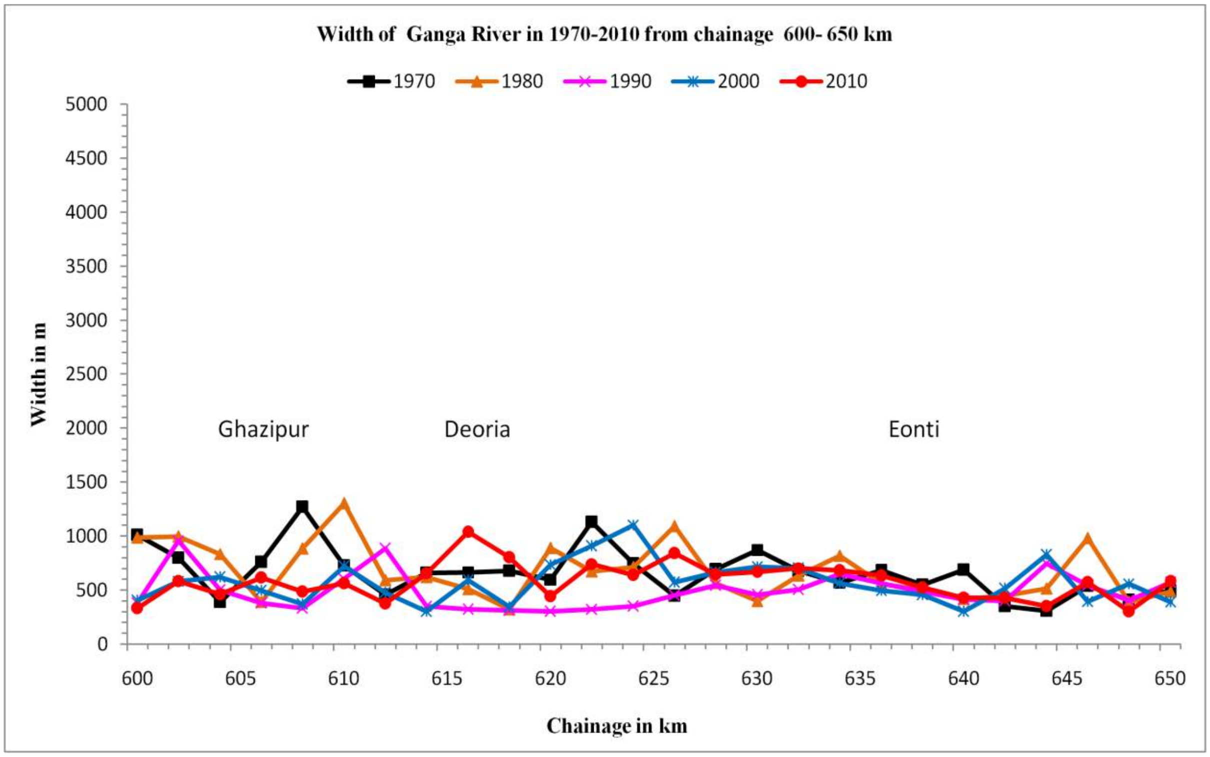


Figure 10.106 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 600-650 km

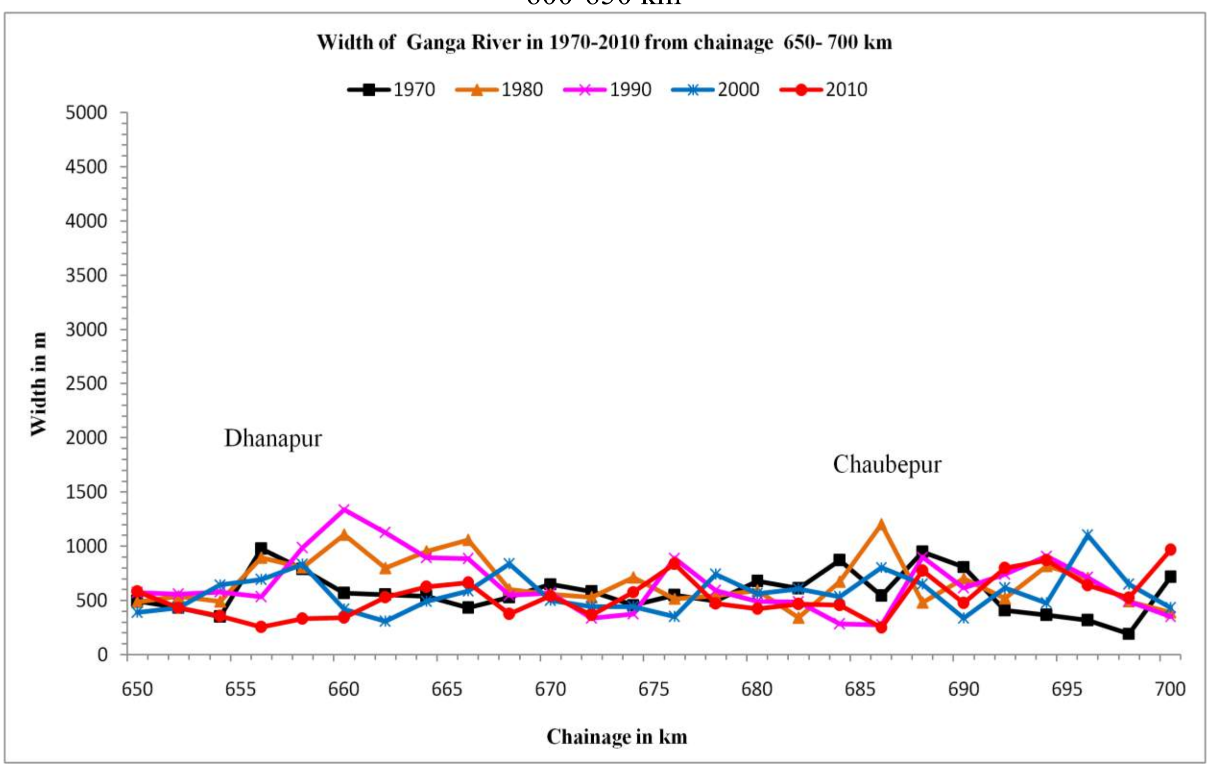


Figure 10.107 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 650-700 km

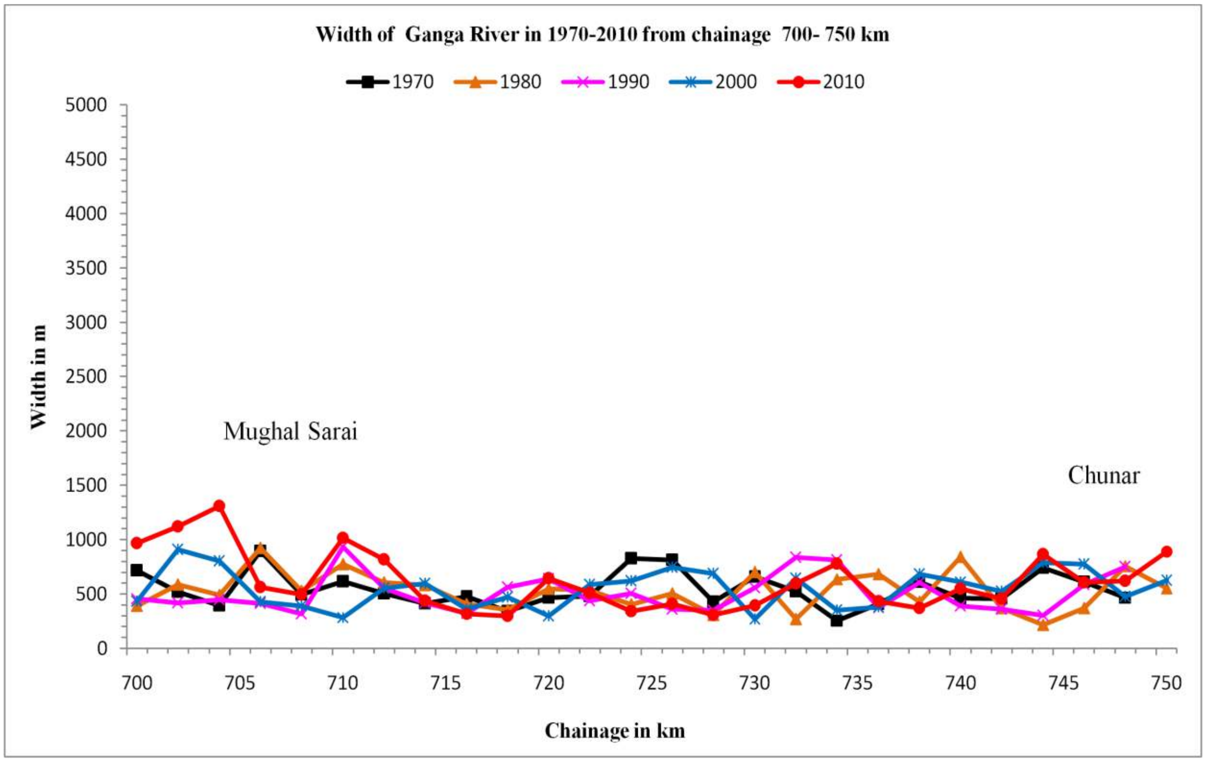


Figure 10.108 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 700-750 km

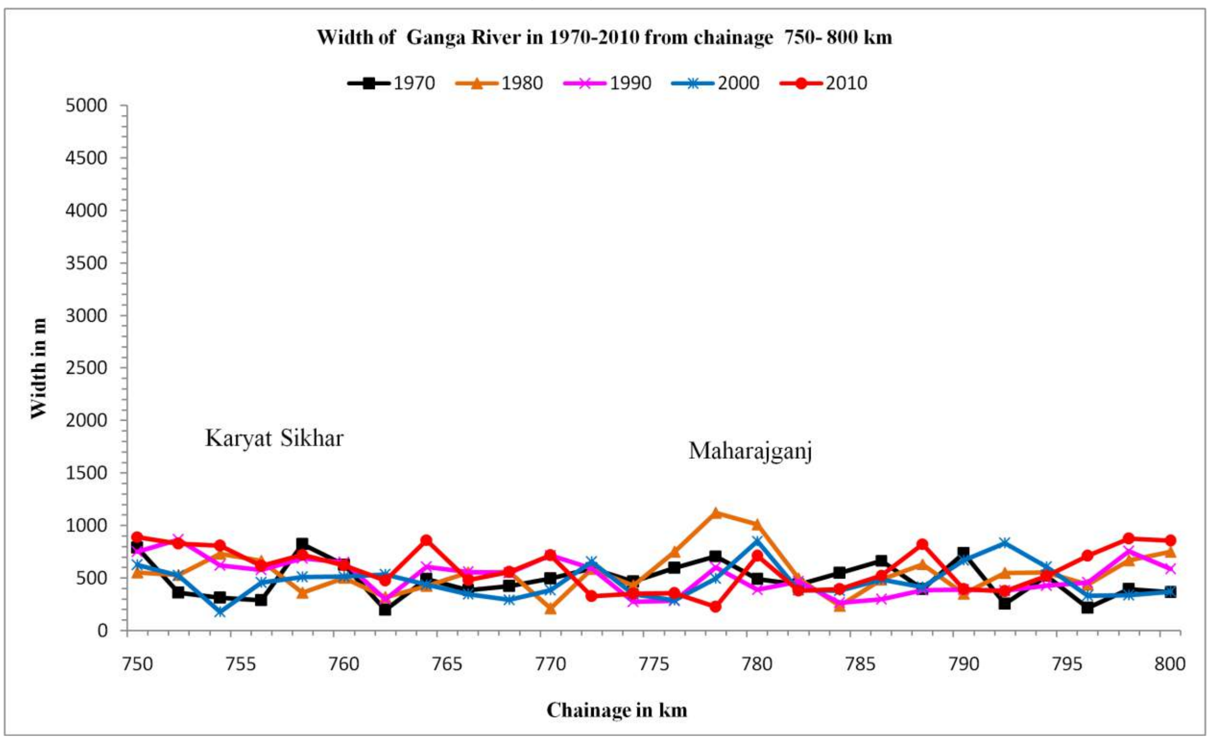


Figure 10.109 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 750-800 km

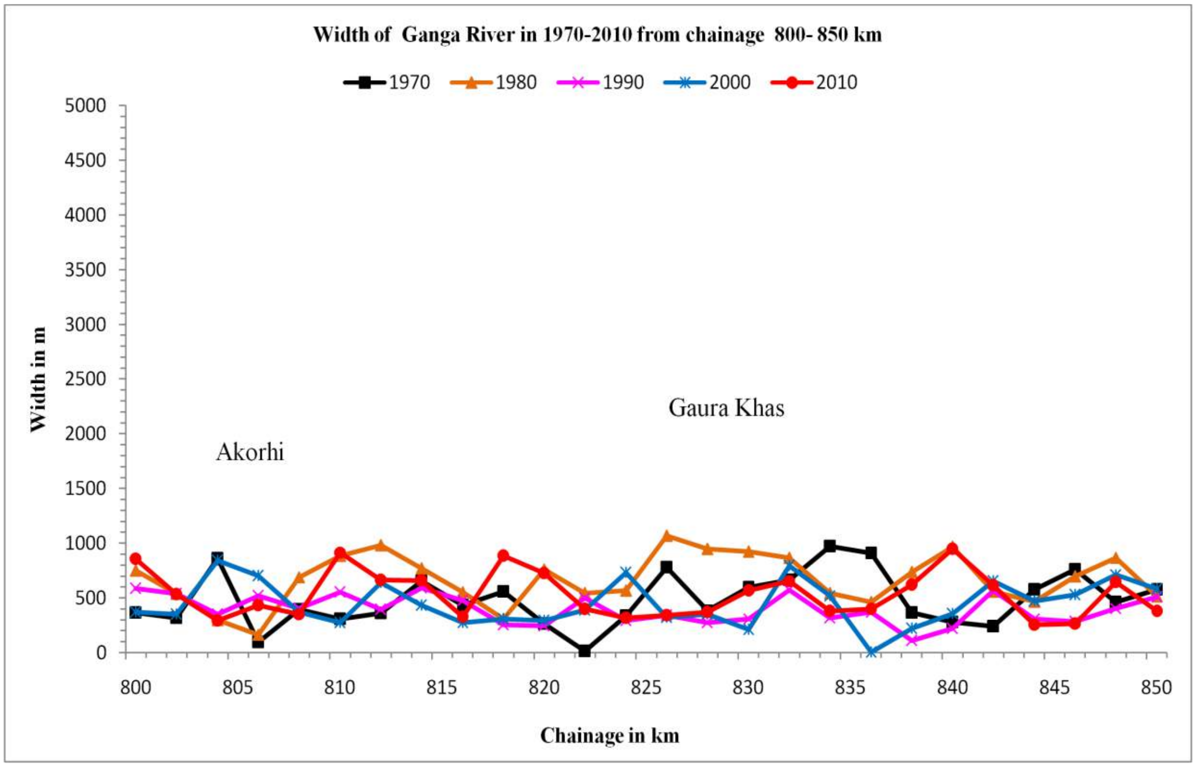


Figure 10.110 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 800-850 km

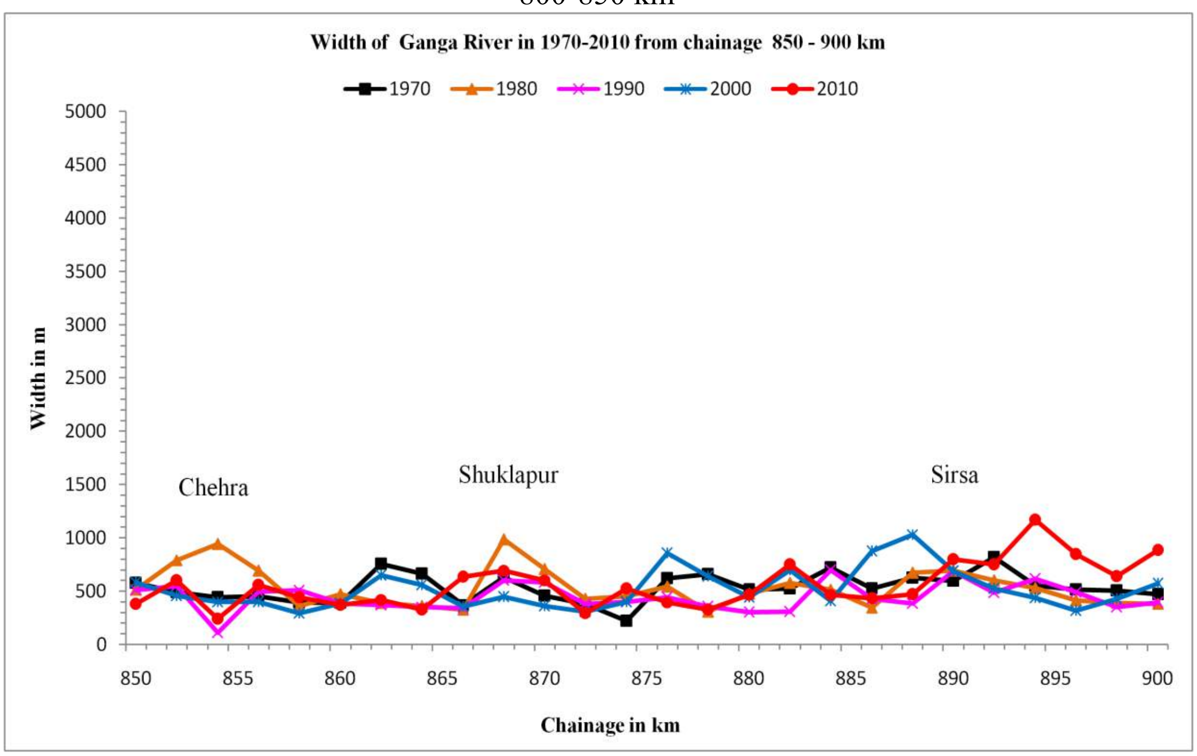


Figure 10.111 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 850-900 km

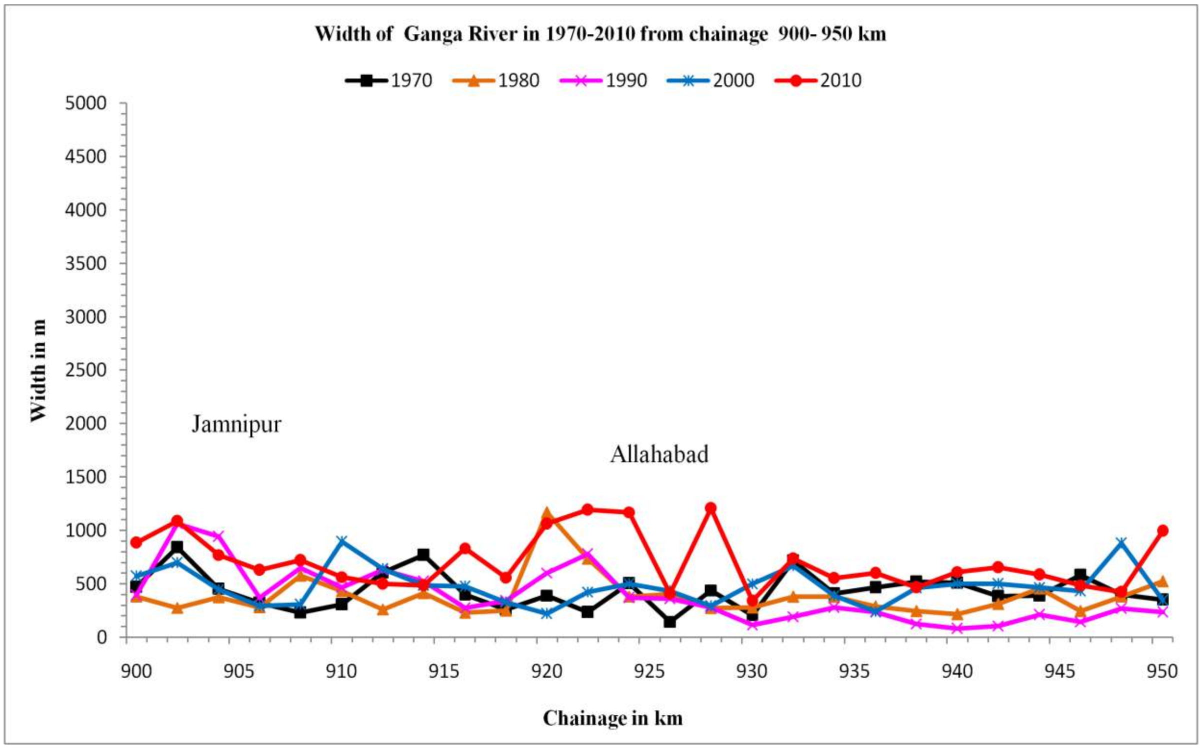


Figure 10.112 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 900-950 km

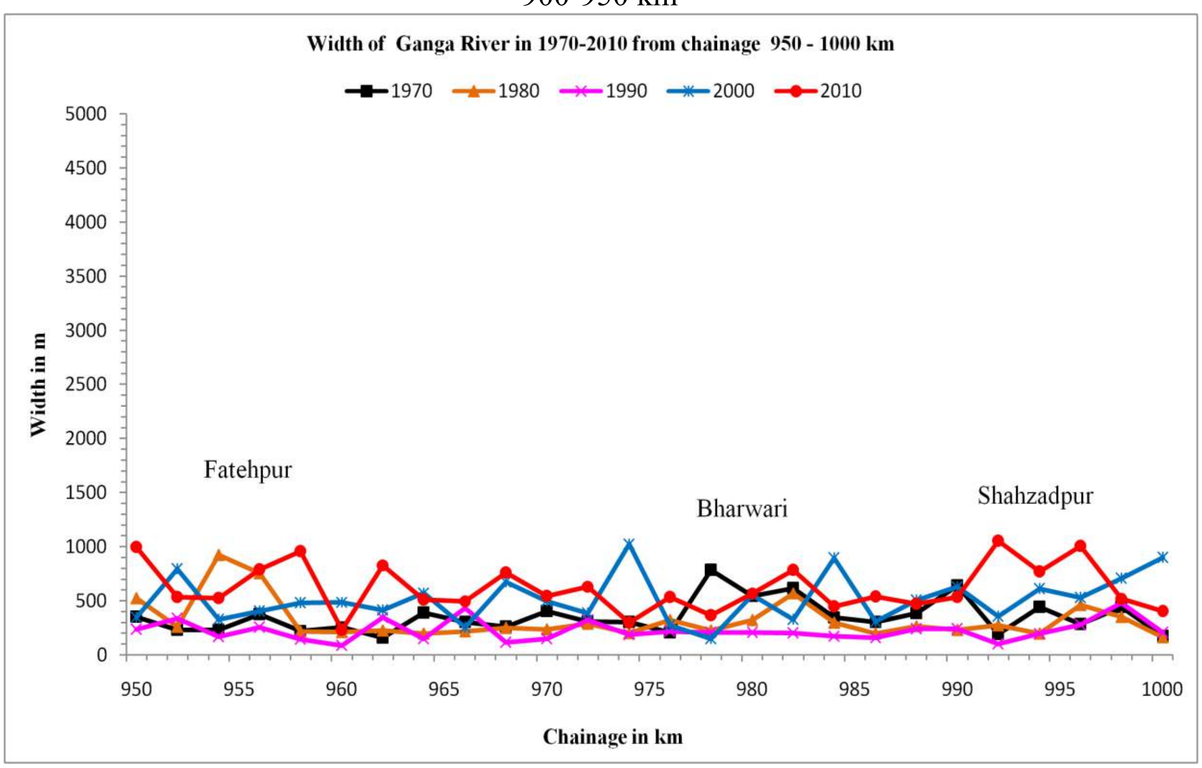


Figure 10.113 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 950-1000 km

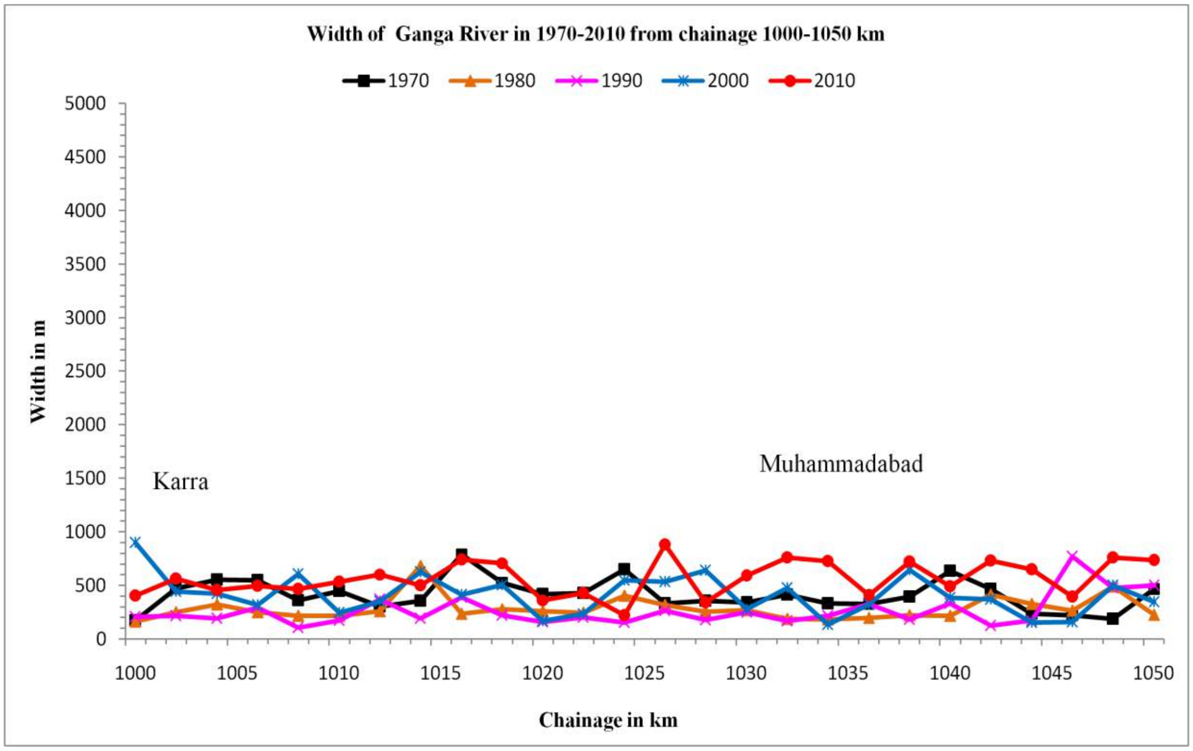


Figure 10.114 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1000-1050 km

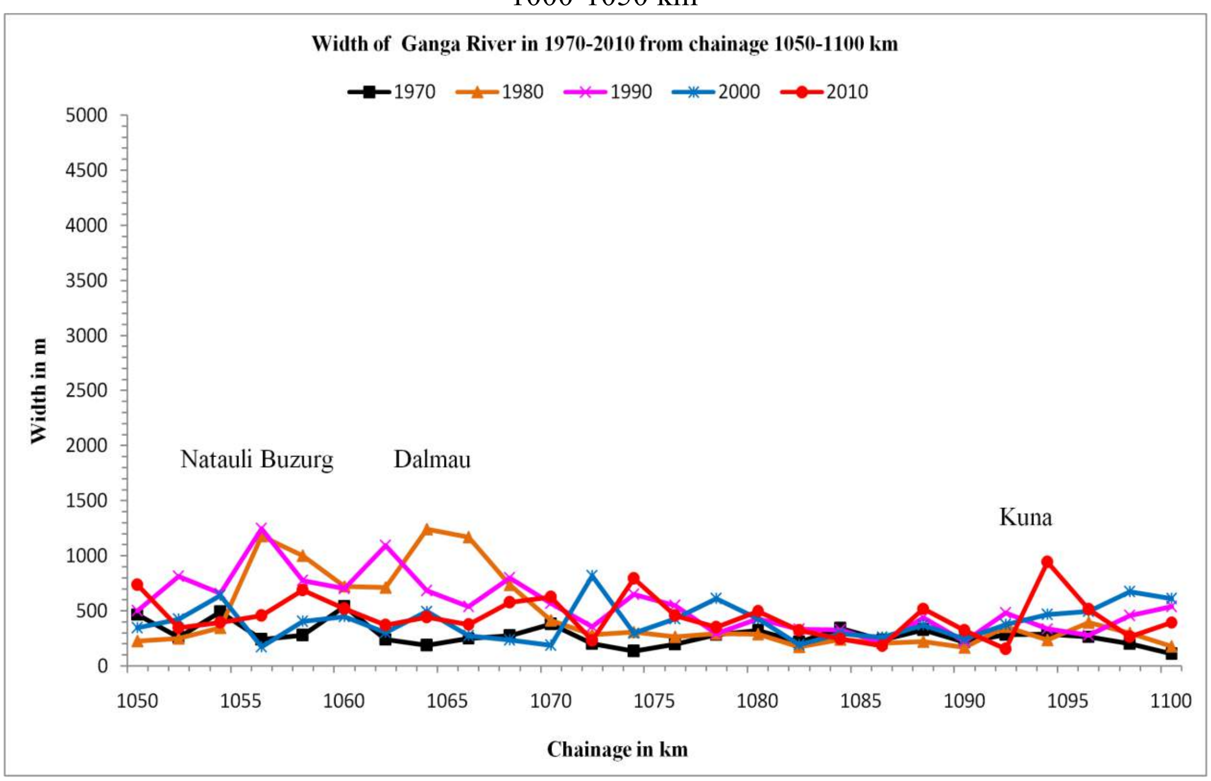


Figure 10.115 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1050-1100 km

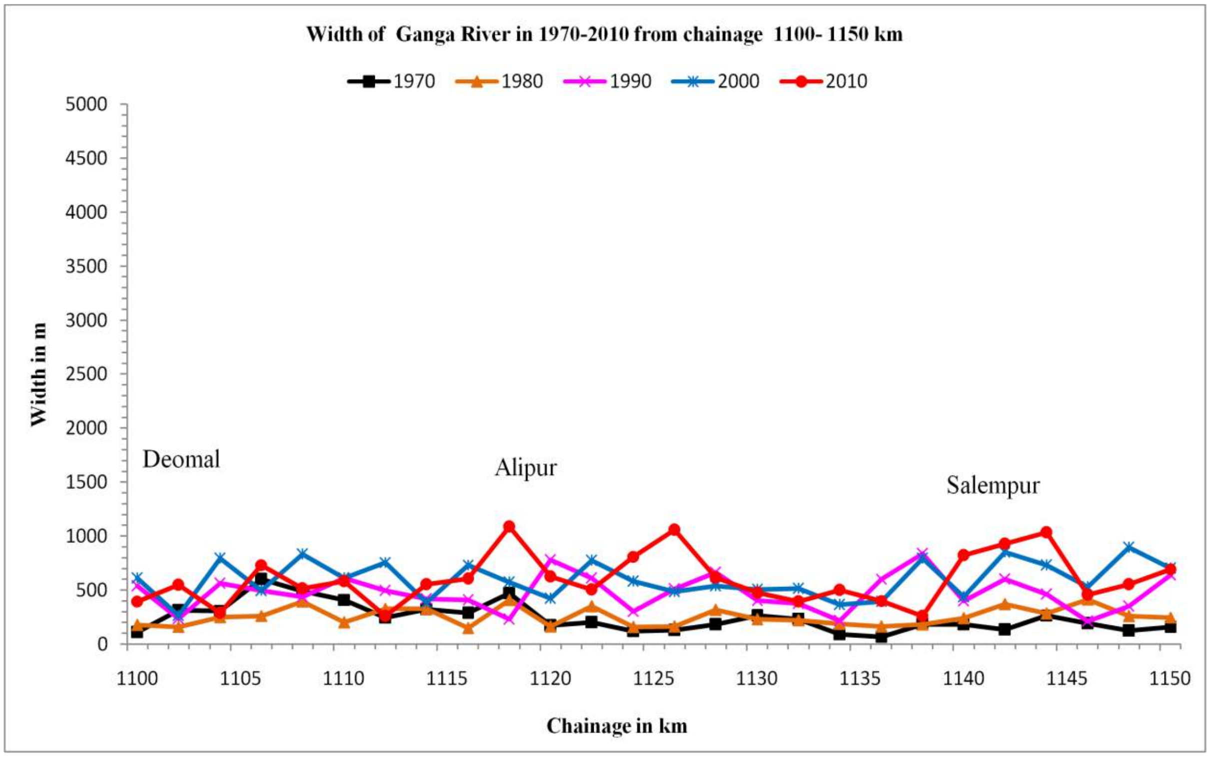


Figure 10.116 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1100-1150 km

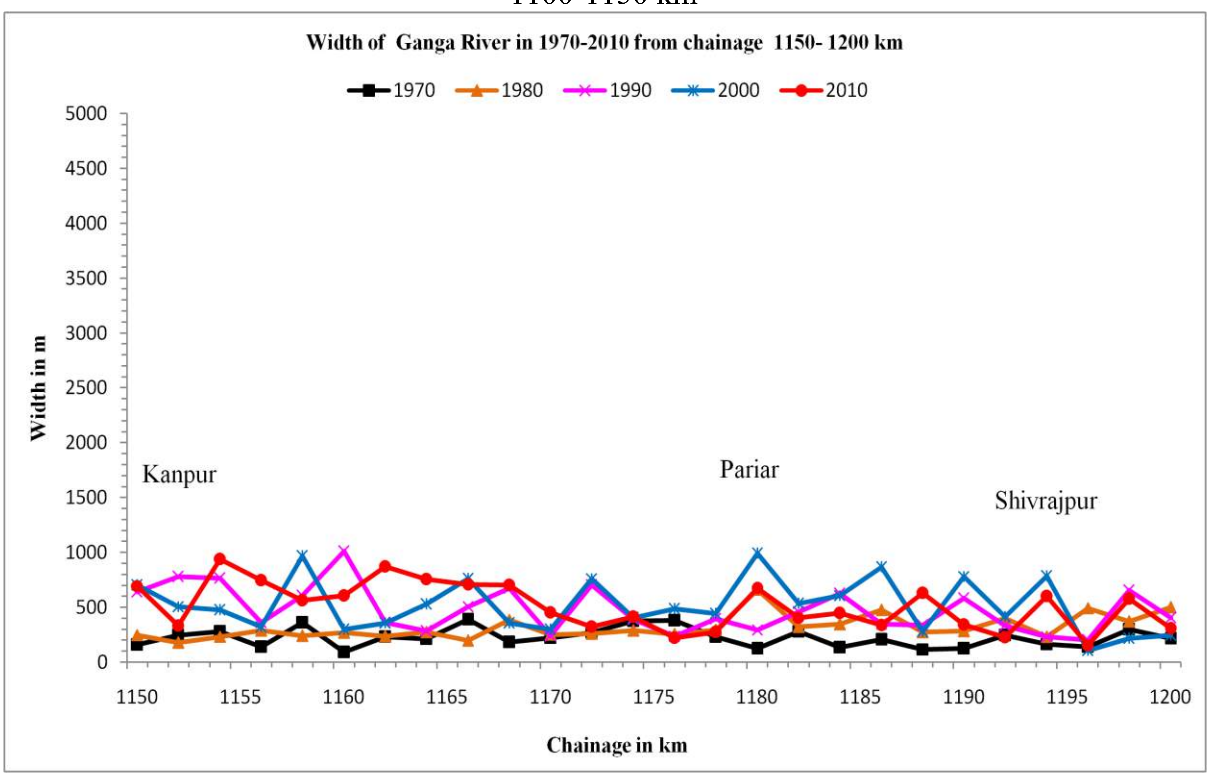


Figure 10.117 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1150-1200 km

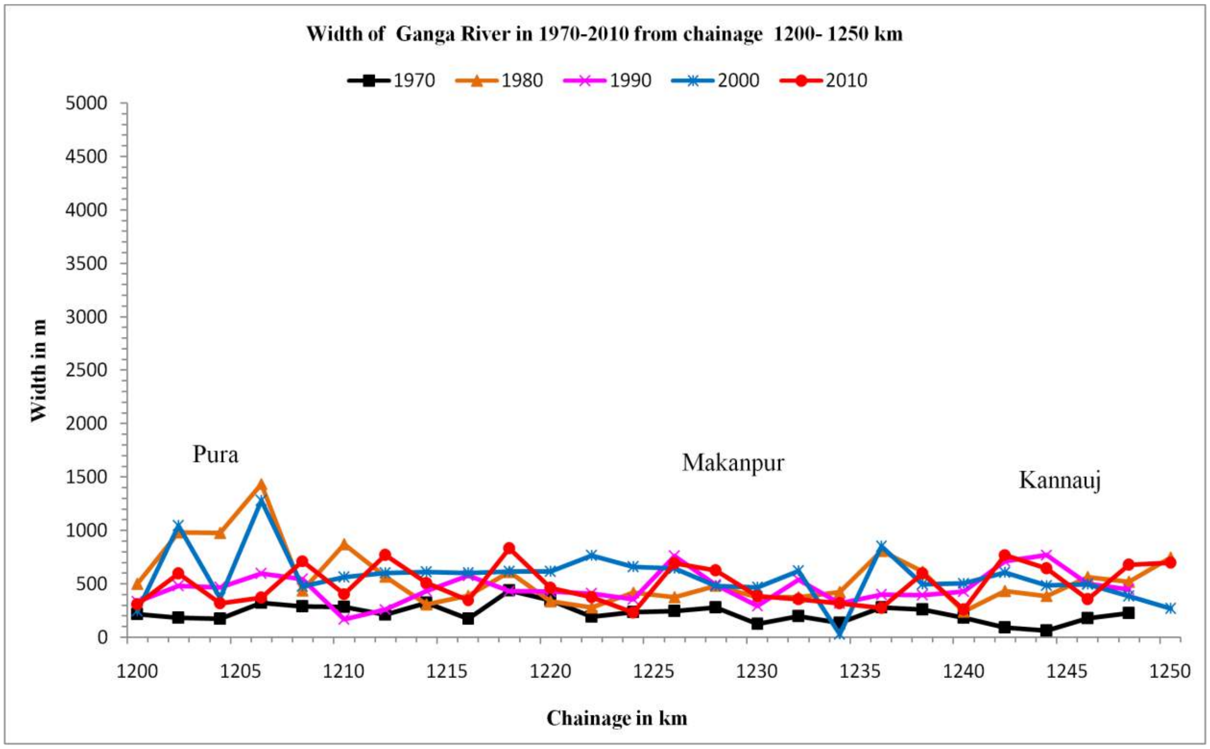


Figure 10.118 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1200-1250 km

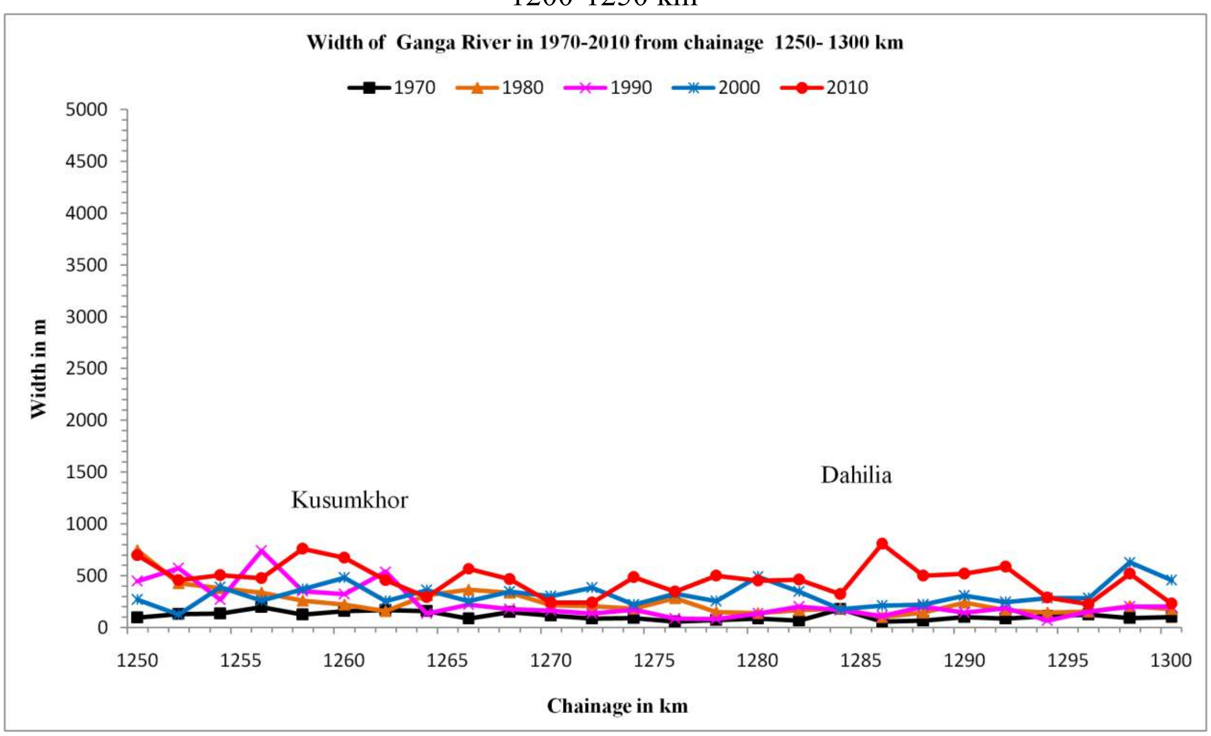


Figure 10.119 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1250-1300 km

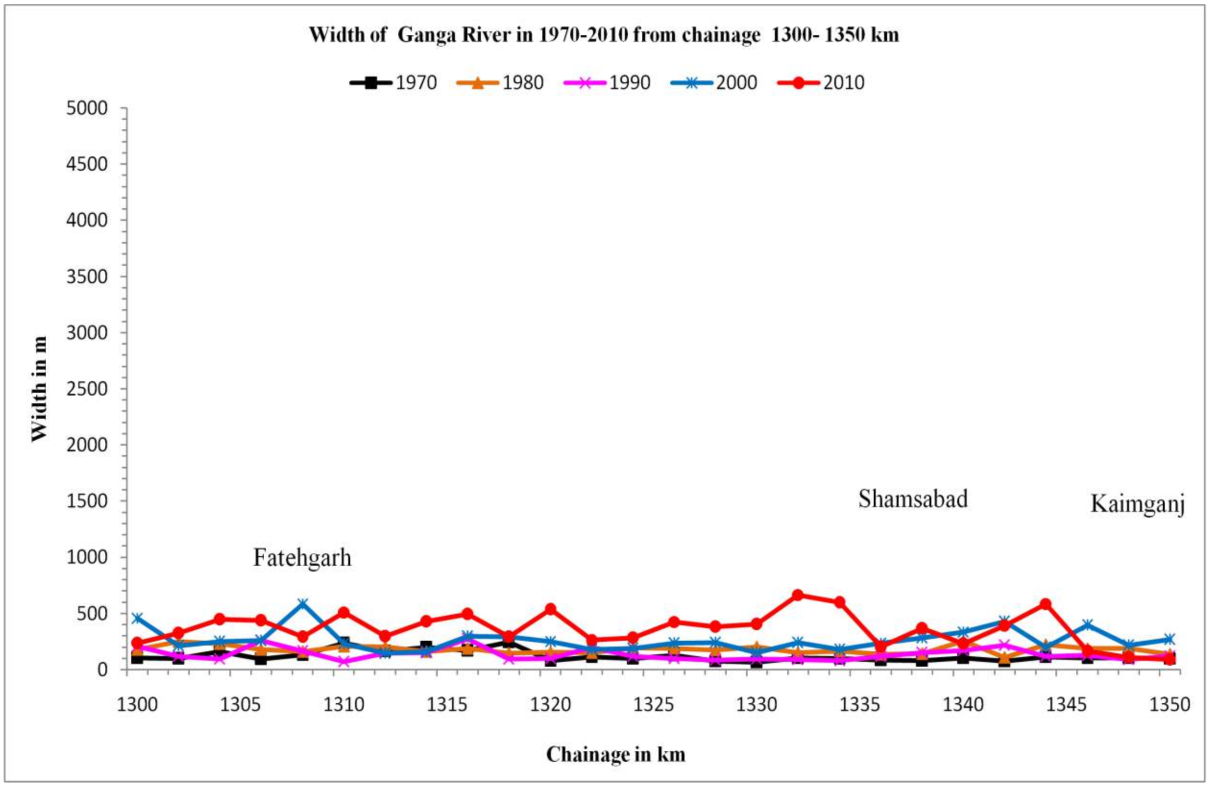


Figure 10.120 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1300-1350 km

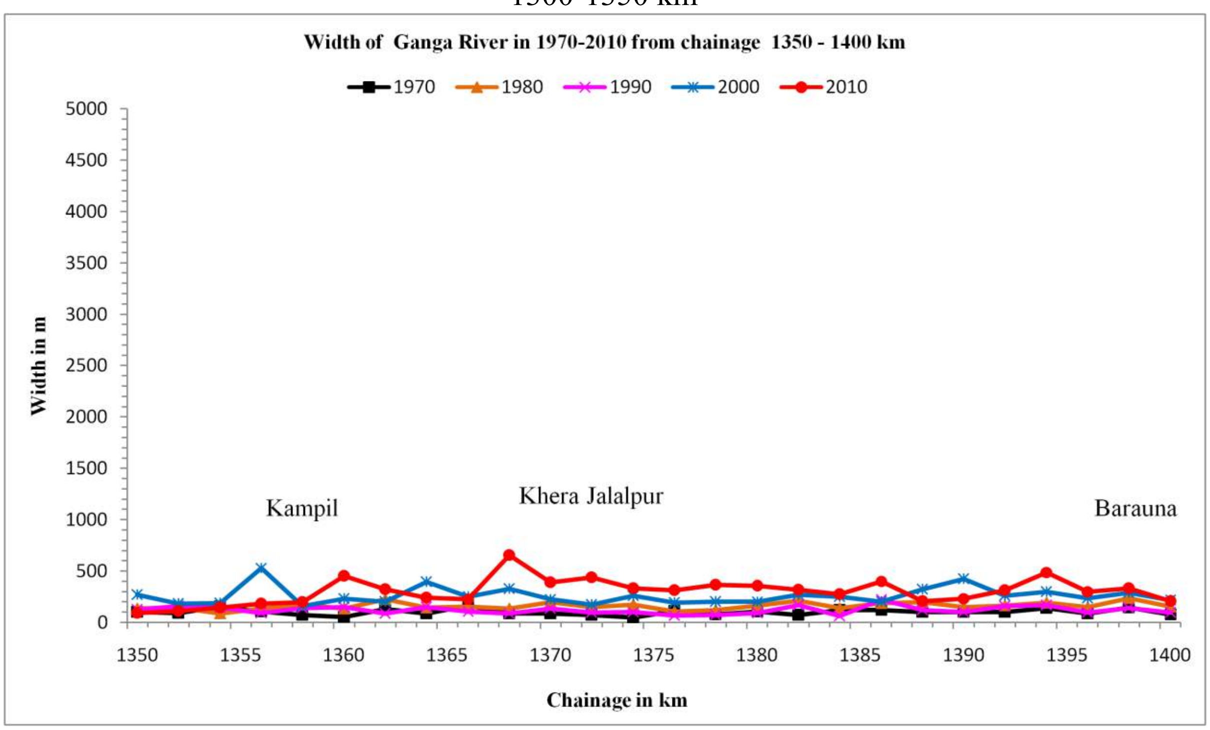


Figure 10.121 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1350-1400 km

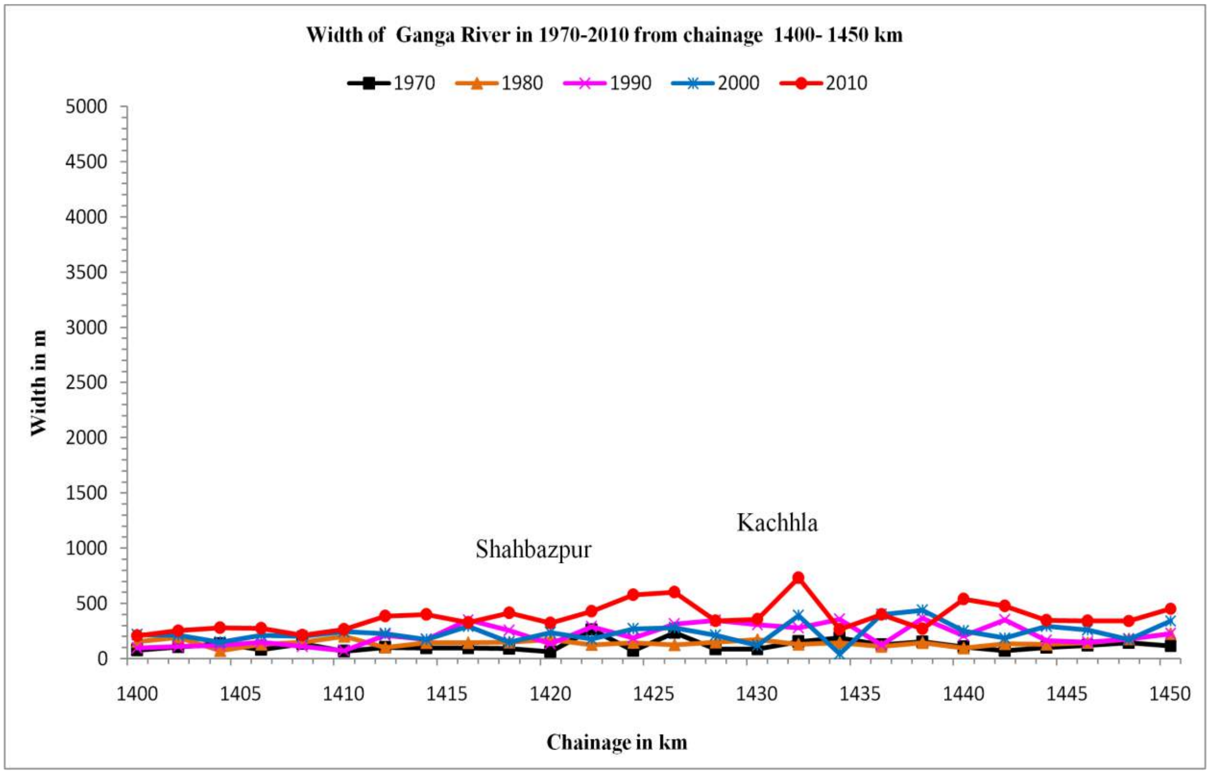


Figure 10.122 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1400-1450 km

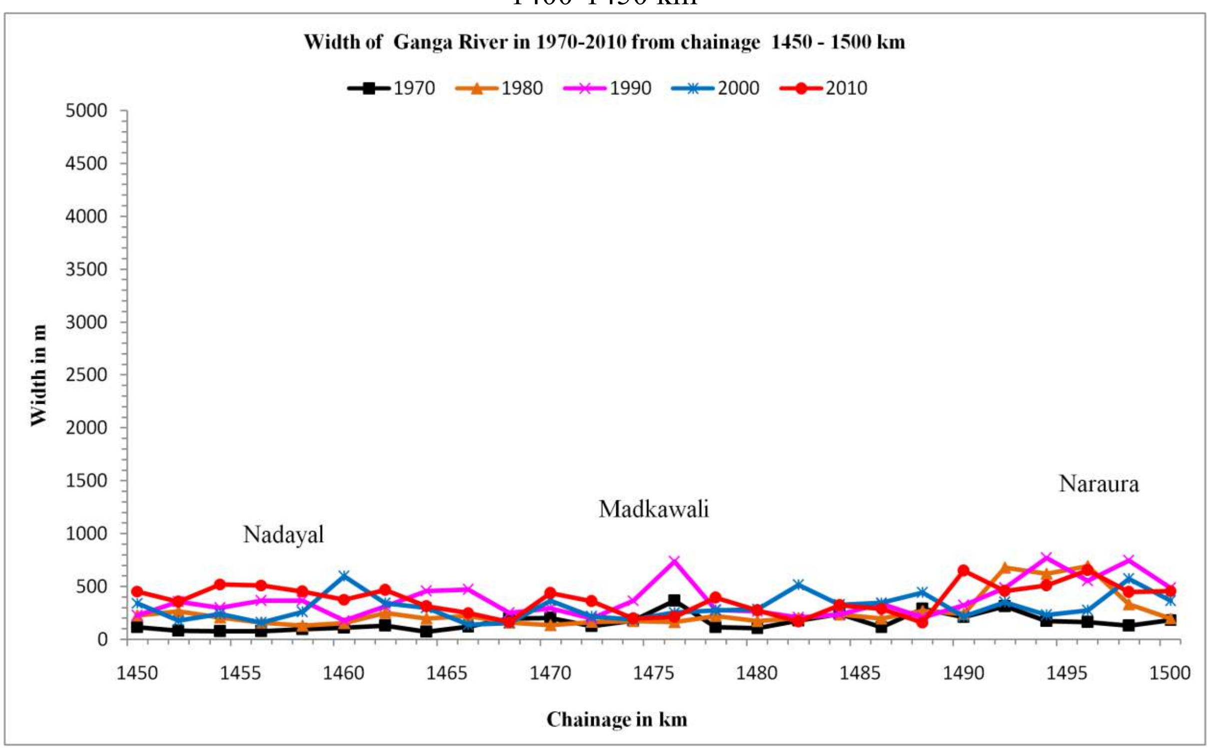


Figure 10.123 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1450-1550 km

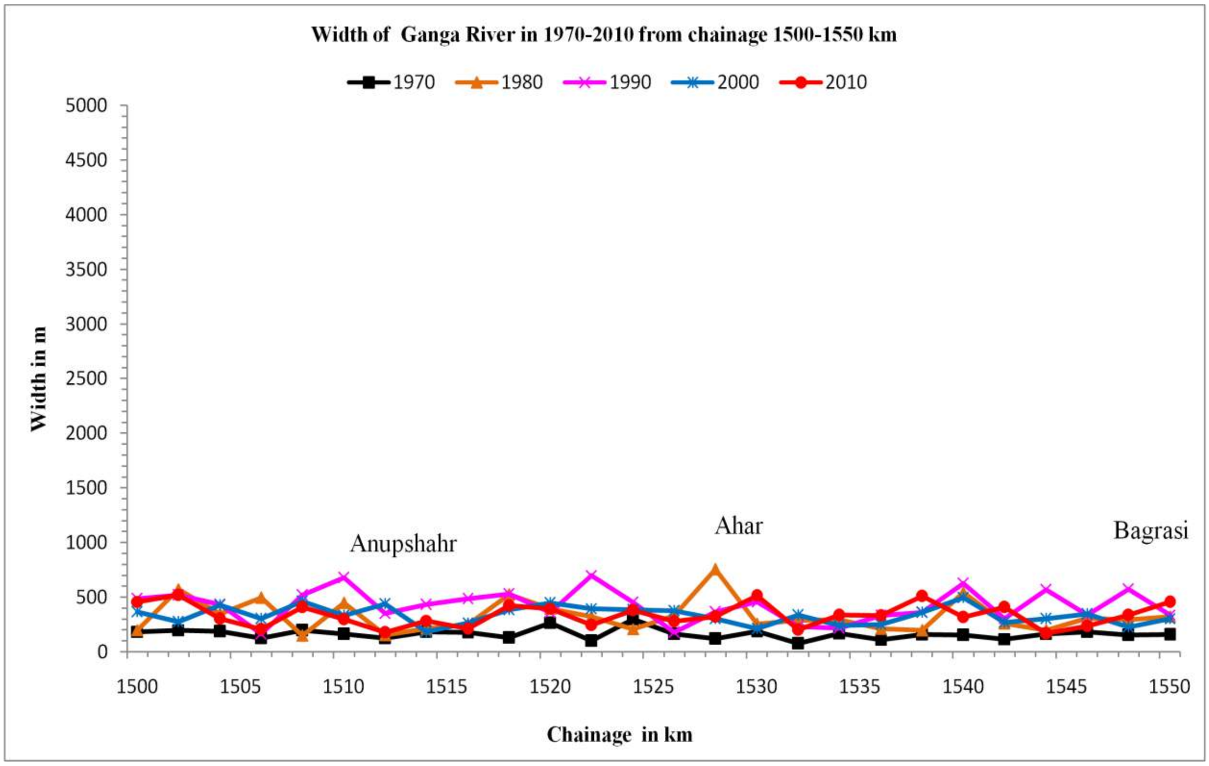


Figure 10.124 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1500-1550 km

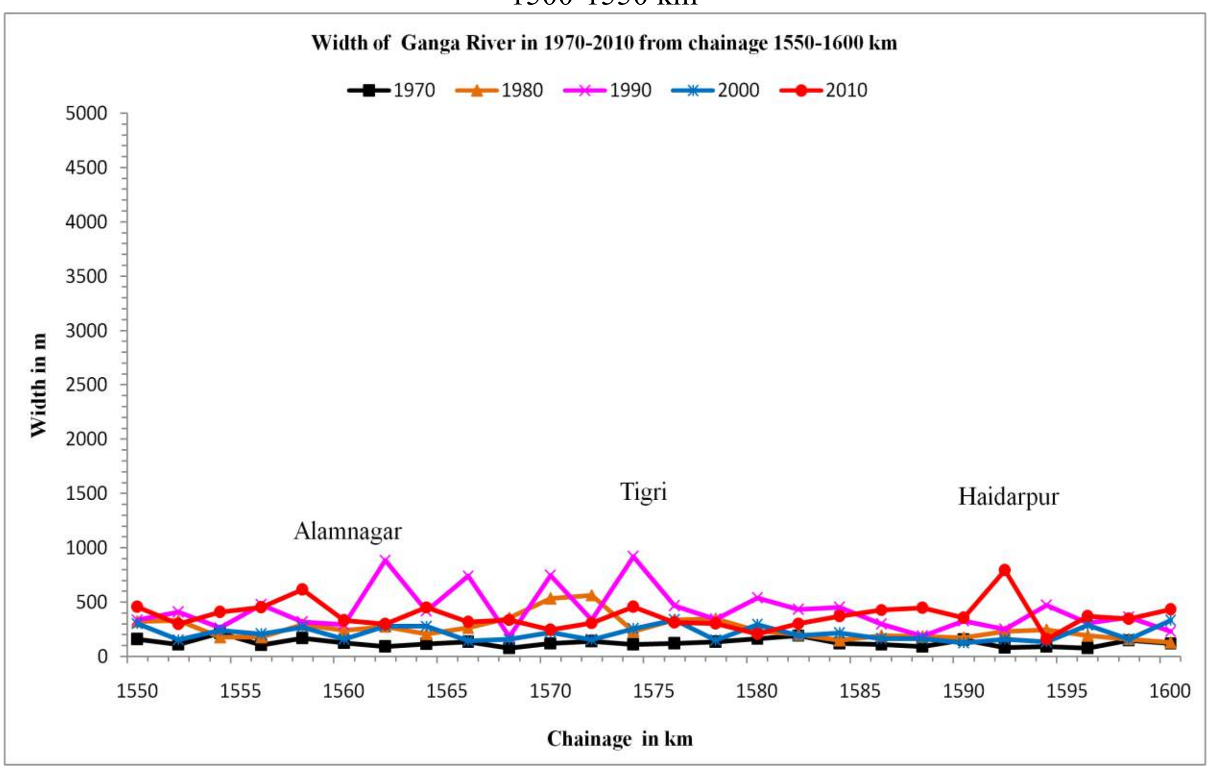


Figure 10.125 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1550-1600 km

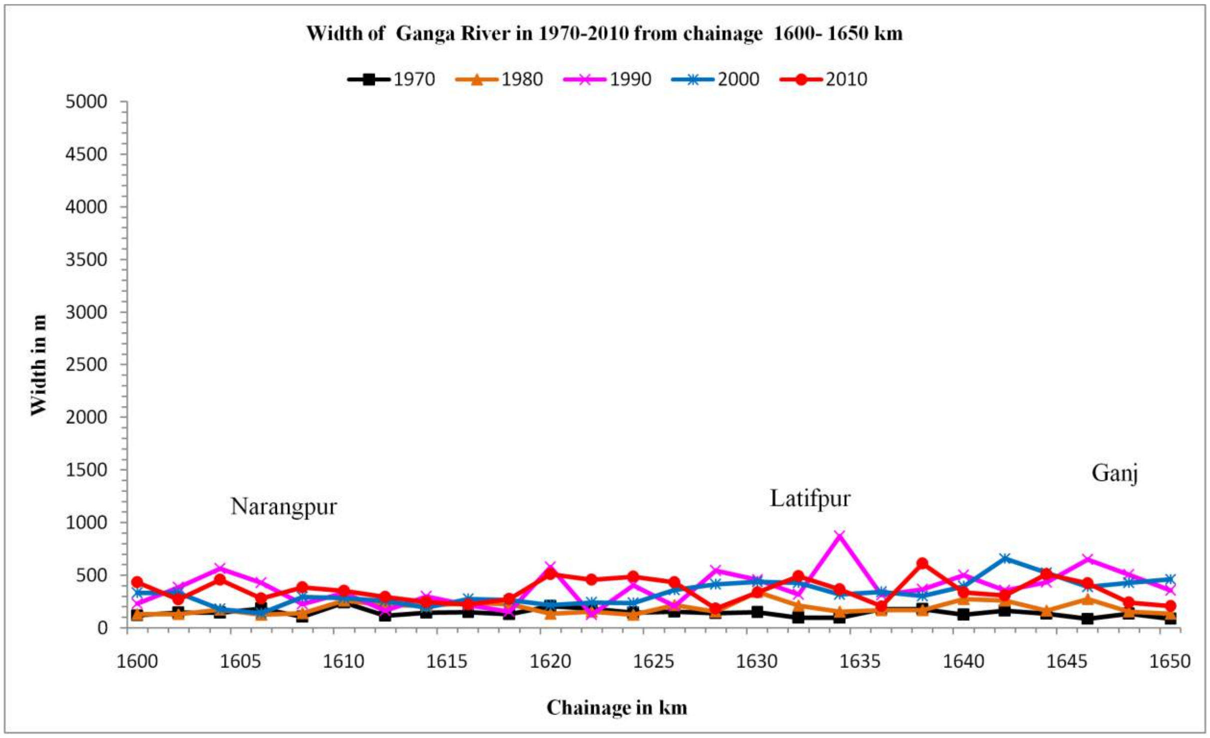


Figure 10.126 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1600-1650 km

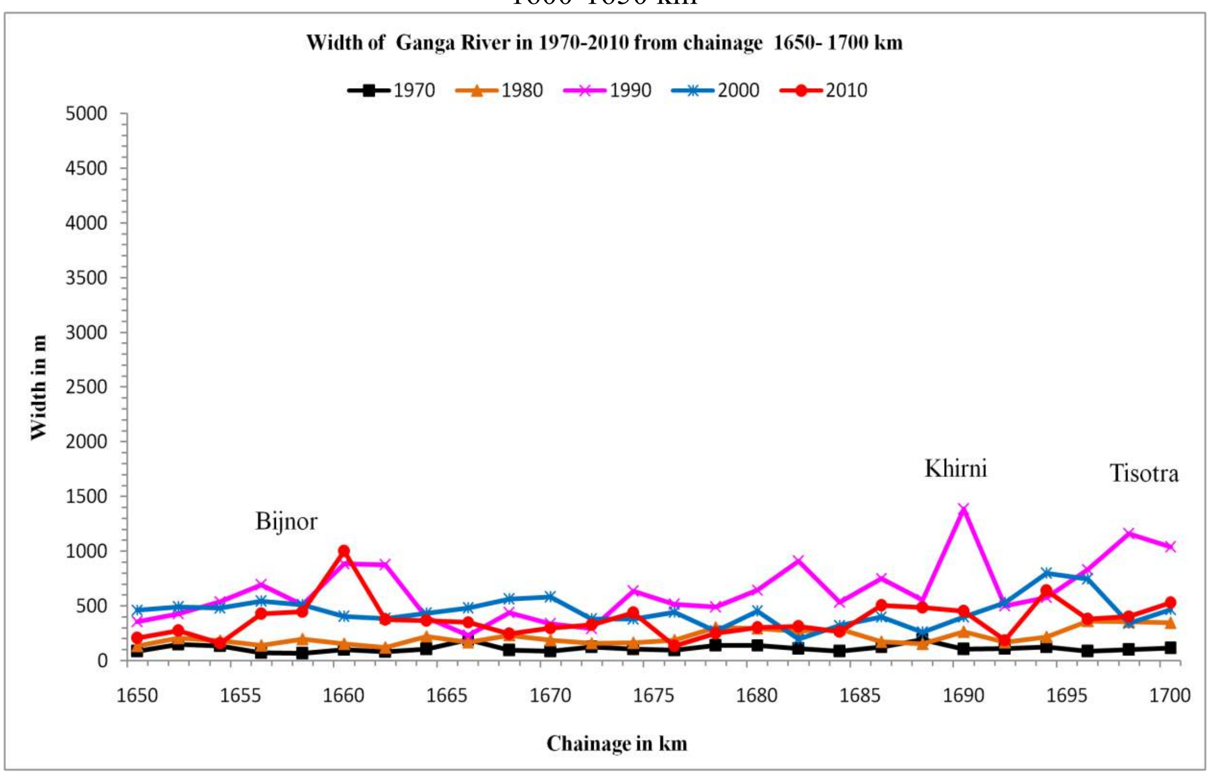


Figure 10.127 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1650-1700 km

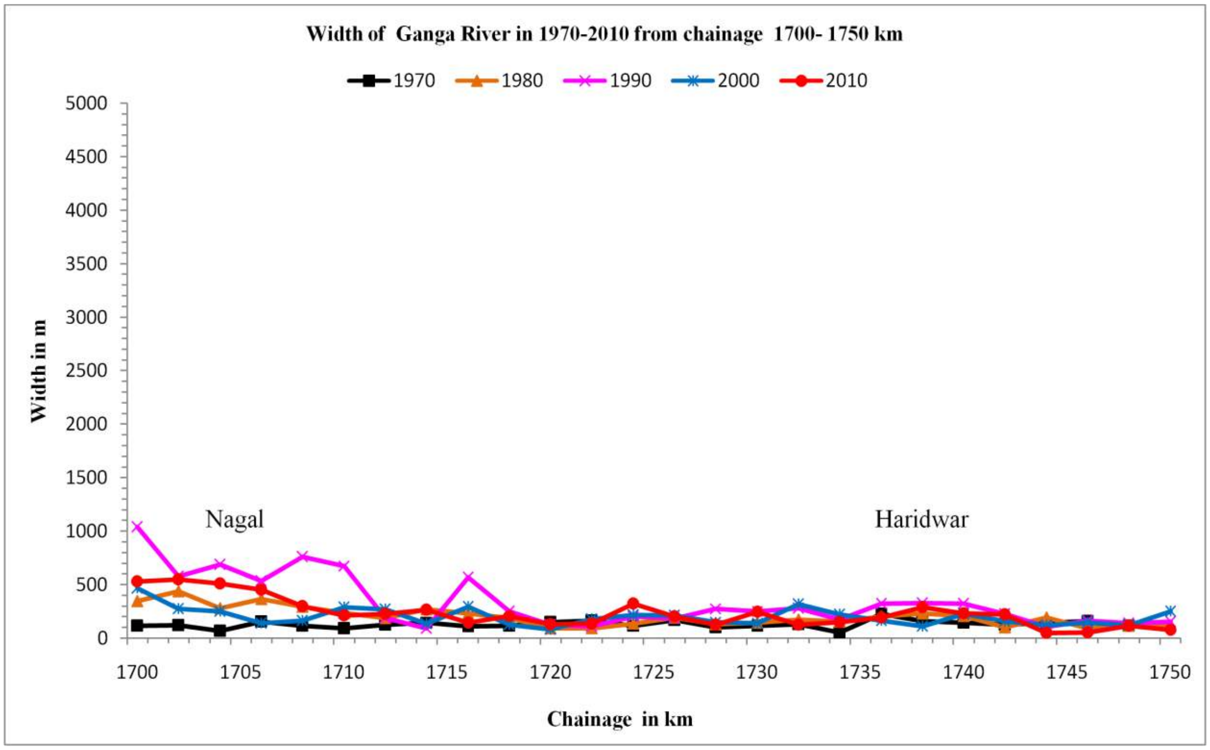


Figure 10.128 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1700-1750 km

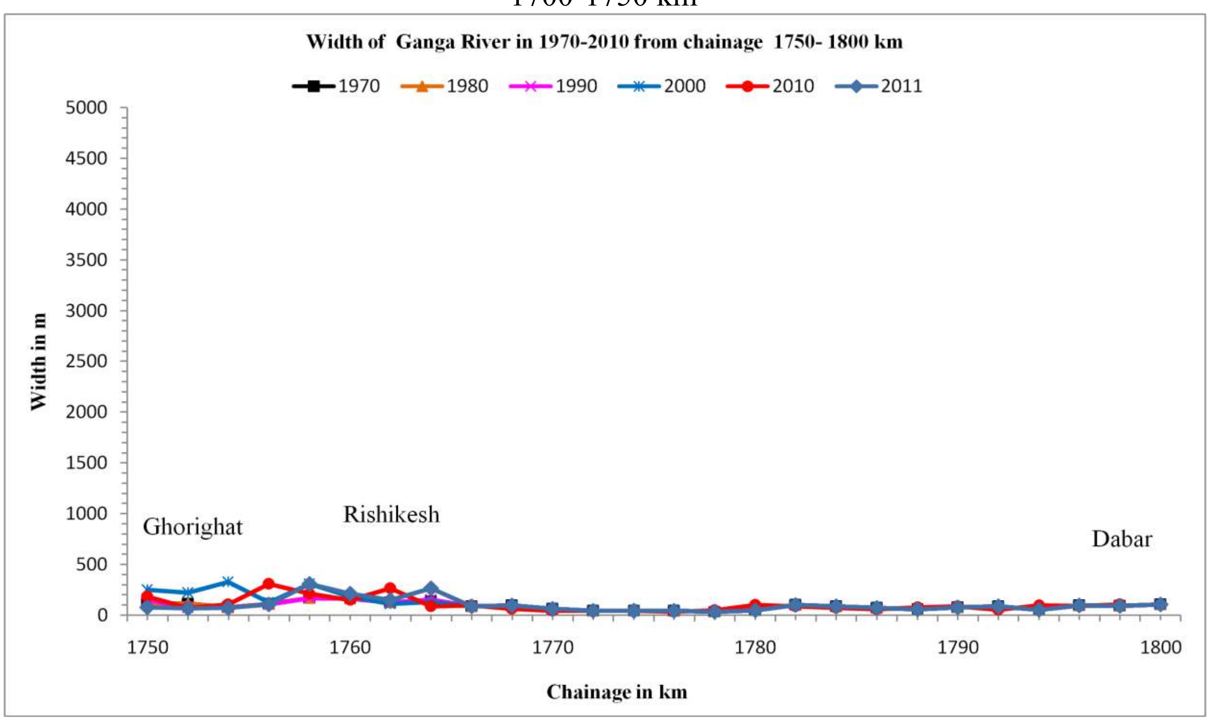


Figure 10.129 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1750-1800 km

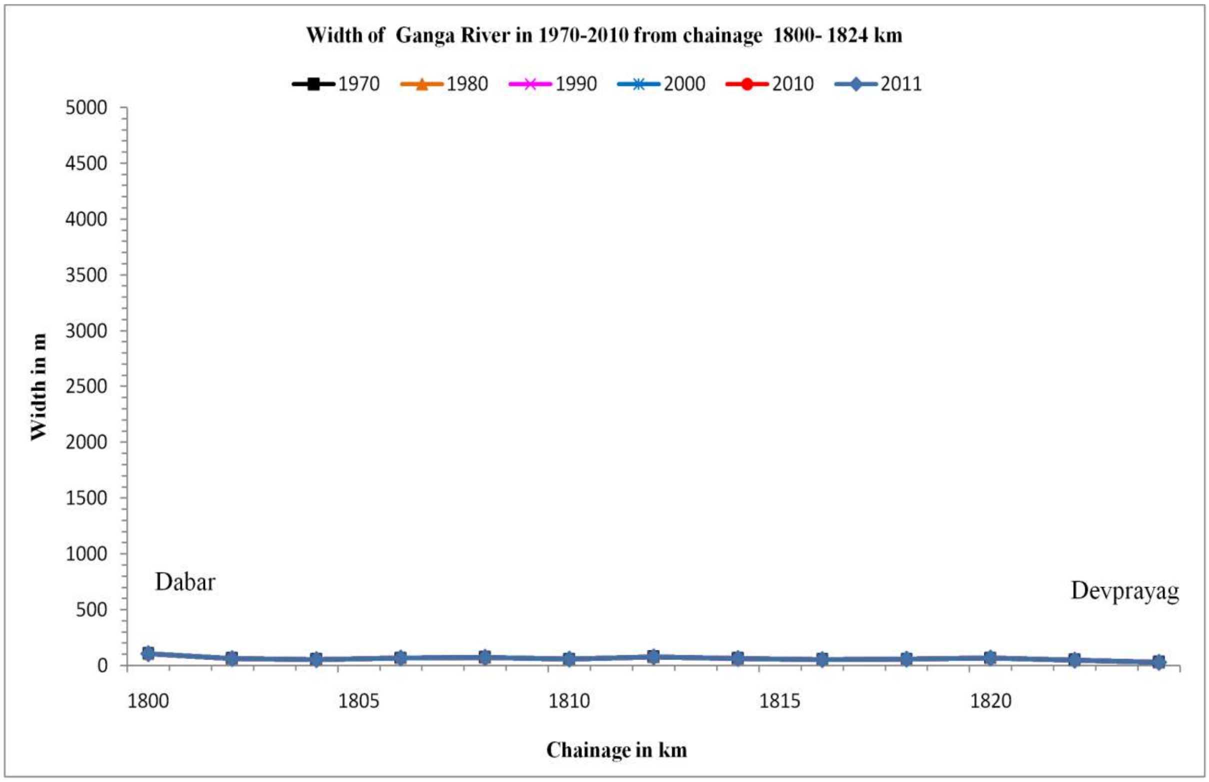


Figure 10.130 Width of Ganga river in years 1970, 1980, 1990, 2000 and 2010 from chainage 1800-1824 km

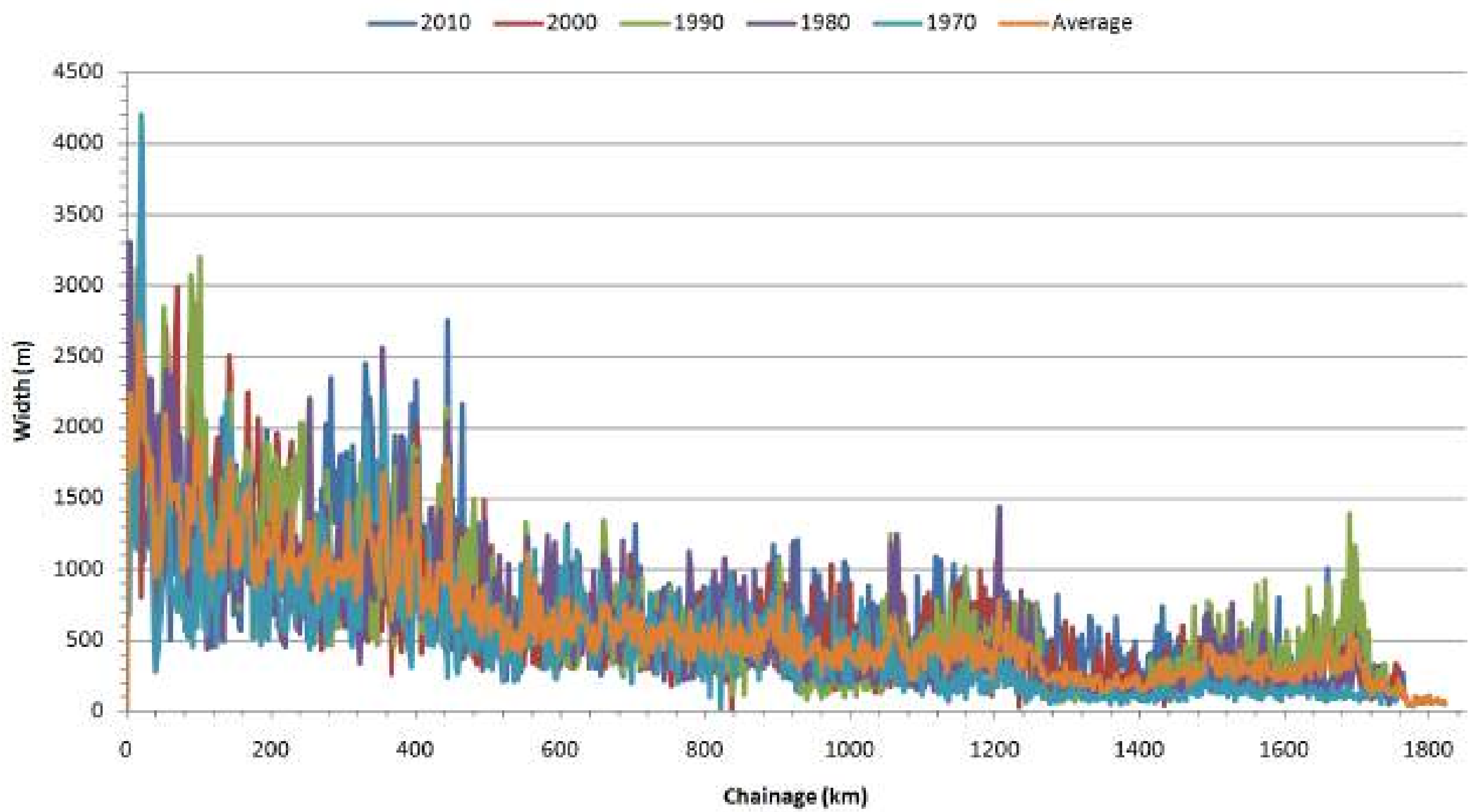


Figure 10.131 Width of the river based on active channel during post monsoon

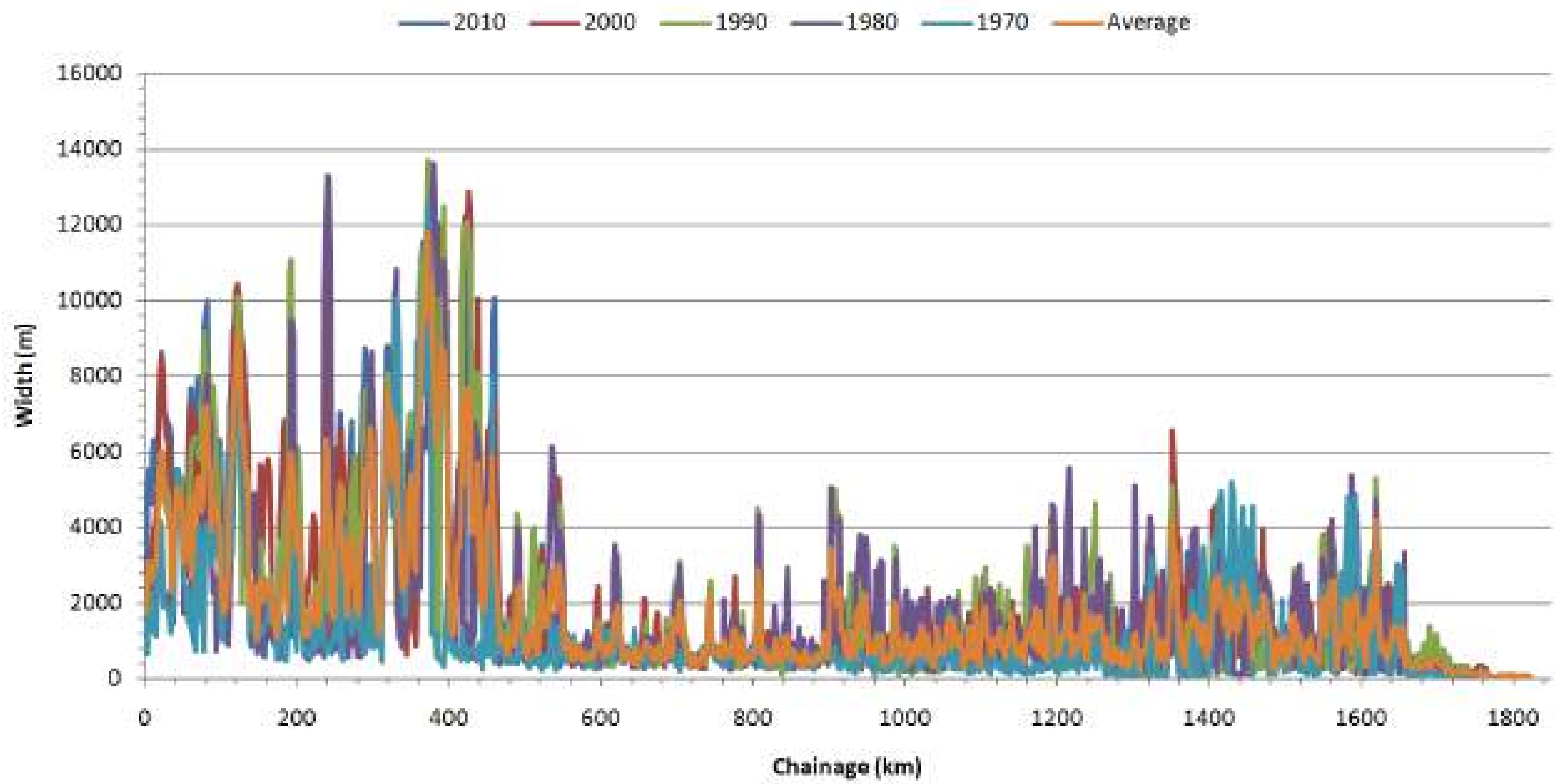


Figure 10.132 Width of the river based on extreme banks

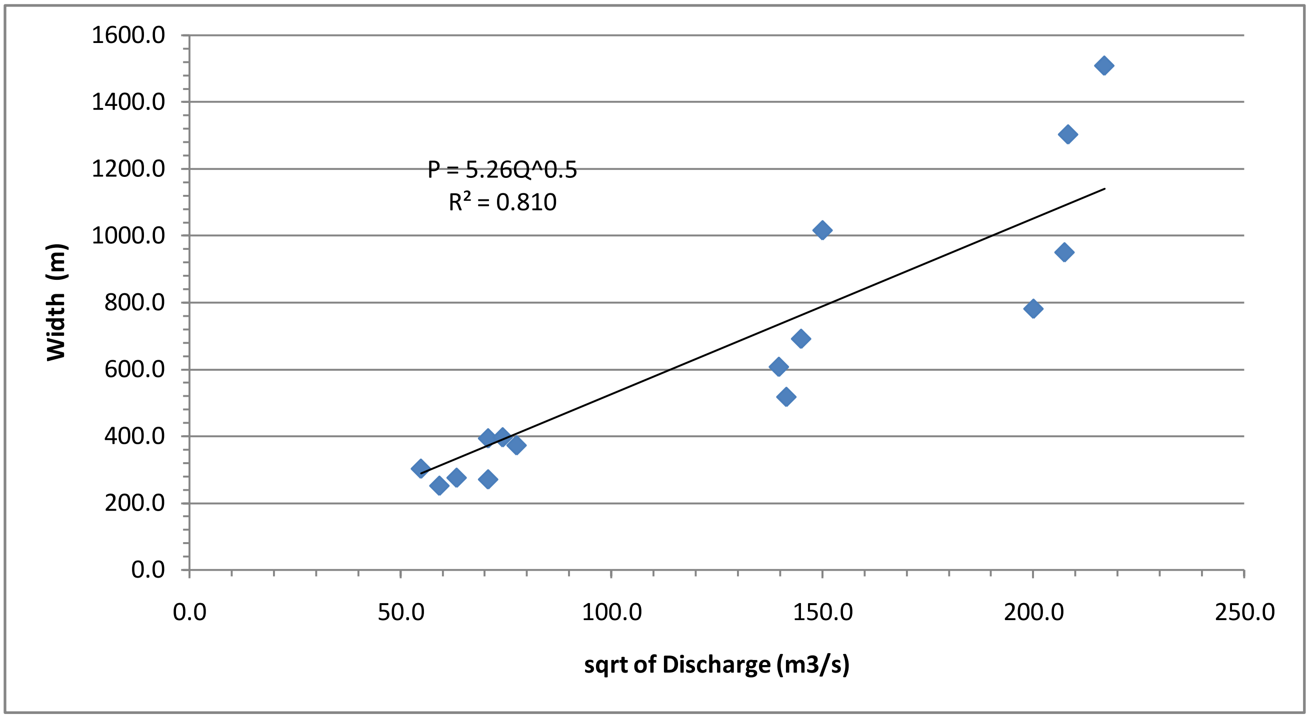


Figure 10.133 A plot between sqrt of two year return period discharge and width of active channel

10.5 SHIFTING OF CONFLUENCE POINTS

There are about 30 major tributaries of Ganga River between Devprayag and Farakka. Details of shifting of confluence points of Ganga river and its tributaries from the years 1970, 1980, 1990, and 2000 to year 2010 are given in Table 10.9. Decadal changes in the location of the confluence point of Ganga and its tributaries for major tributaries or the tributaries whose shifting of confluence point is high are discussed in the following paragraph. Such tributaries are Ramganaga, Garra, Yamuna, Gomti, Ghaghara, Son, Gandak, Burhi Gandak, and Kosi. Figures 10.134 to 10.142 show confluence point of the above rivers with Ganga river in decadal years.

Table 10.9 Shifting of confluence point of Ganga river with its tributaries

S.N.	Tributary	Latitude & Longitude of confluence point						Shifting distance w.r.t 2010 (km)			
			2010	2000	1990	1980	1970	2000	1990	1980	1970
1	Song	N	30.0324	30.0324	30.0324	30.0324	30.0324	0.0000	0.0000	0.0000	0.0000
		E	78.2464	78.2464	78.2464	78.2464	78.2464				
2	Solani	N	29.4450	29.4558	29.4549	29.4546	29.5157	1.3592	1.4382	1.8610	----
		E	77.9990	78.0048	78.0074	78.0127	77.9889				
3	Malin	N	29.4483	29.4465	29.4465	29.4481	29.4472	0.8093	0.8093	0.6825	0.9007
		E	78.0660	78.0589	78.0589	78.0598	78.0579				
4	Baia	N	28.8894	28.9044	28.9044	28.9056	28.8921	2.1259	2.1259	2.3270	0.8613
		E	78.1503	78.1384	78.1384	78.1370	78.1430				
5	Mahawa	N	27.9594	27.9772	27.9701	27.9592	27.9521	3.6292	3.3843	0.3615	1.0518
		E	78.8411	78.8137	78.8126	78.8378	78.8351				
6	Ramganga	N	27.1764	27.1756	27.1942	27.1853	27.1856	0.0865	3.5341	2.2658	2.6067
		E	79.8479	79.8478	79.8216	79.8296	79.8264				
7	Garra	N	27.1409	27.1434	27.0947	27.1020	27.1049	0.8595	6.9828	5.7560	5.2952
		E	79.9443	79.9370	79.9870	79.9786	79.9756				
8	Kali	N	27.0227	27.0227	27.0227	27.0227	27.0227	0.0000	0.0000	0.0000	0.0000
		E	79.9736	79.9736	79.9736	79.9736	79.9736				
9	Isan	N	26.8084	26.8258	26.8324	26.8055	26.8104	2.2172	2.9854	0.6493	0.6443
		E	80.1177	80.1078	80.1055	80.1227	80.1231				
10	Morahi	N	26.2091	26.2091	26.1991	26.2102	26.2102	0.0000	1.1035	0.1316	0.1316
		E	80.6401	80.6401	80.6399	80.6403	80.6403				
11	Pandu	N	26.1206	26.1209	26.1210	26.1233	26.1233	0.2011	0.3265	0.8587	0.8587
		E	80.6644	80.6662	80.6615	80.6572	80.6572				
12	Loni	N	26.0732	26.0746	26.0748	26.0732	26.0725	0.8154	0.5925	0.0000	0.0792
		E	80.9902	80.9830	80.9851	80.9902	80.9903				
13	Duar	N	25.5880	25.5869	25.5868	25.5868	25.5901	0.1656	0.2535	0.2535	0.6515
		E	81.5908	81.5919	81.5928	81.5928	81.5963				
14	Yamuna	N	25.4230	25.4230	25.4185	25.4214	25.4230	0.0000	1.1060	0.4318	0.0000
		E	81.8874	81.8874	81.8962	81.8909	81.8874				
15	Tons	N	25.2753	25.2753	25.2748	25.2752	25.2753	0.0000	0.0687	0.2264	0.0000
		E	82.0847	82.0847	82.0850	82.0867	82.0847				
16	Ojhala	N	25.1551	25.1551	25.1545	25.1562	25.1551	0.0000	0.0694	0.1280	0.0000
		E	82.5305	82.5305	82.5304	82.5304	82.5305				
17	Khajuri	N	82.7006	82.7006	82.7006	82.7006	82.7006	0.0000	0.0000	0.0000	0.0000

		E	25.1716	25.1716	25.1716	25.1716	25.1716				
18	Gomti	N	25.5073	25.5069	25.5069	25.5069	25.5224	0.1127	0.1127	0.1127	1.8351
		E	83.1715	83.1706	83.1706	83.1706	83.1782				
19	Gangi	N	25.5197	25.5200	25.5200	25.5211	25.5200	0.2326	0.2326	0.3790	0.2326
		E	83.5031	83.5010	83.5010	83.5000	83.5010				
20	Besu	N	25.6175	25.6180	25.6172	25.6164	25.6164	0.1093	0.0417	0.2367	0.2367
		E	83.6616	83.6608	83.6614	83.6597	83.6597				
21	Karamnasa	N	25.5140	25.5174	25.5140	25.5144	25.5142	0.5884	0.0000	0.0540	0.1208
		E	83.8777	83.8818	83.8777	83.8773	83.8766				
22	Thora Nala	N	25.5594	25.5585	25.55732	25.5573	25.5573	0.1331	0.2523	0.2523	0.2523
		E	83.9470	83.9463	83.94614	83.9461	83.9461				
23	Chhoti Sarju	N	25.7429	25.7429	25.7429	25.7429	25.7429	0.0000	0.0000	0.0000	0.0000
		E	84.0939	84.0939	84.0939	84.0939	84.0939				
24	Ghaghara	N	25.7573	25.7417	25.7471	25.7363	25.7422	2.8062	1.3487	12.7494	13.7776
		E	84.6790	84.6591	84.6725	84.7918	84.8020				
25	Son	N	25.7049	25.7030	25.7003	25.6993	25.7009	0.2053	0.5019	0.7213	0.7248
		E	84.8631	84.8628	84.8628	84.8596	84.8579				
26	Gandak	N	25.6477	25.6349	25.6264	25.6262	25.6275	1.4786	2.3899	2.4831	2.2445
		E	85.1915	85.1876	85.1883	85.1853	85.1912				
27	Punpun	N	25.5137	25.5135	25.5135	25.5135	25.5133	0.0967	0.0967	0.0967	0.1831
		E	85.3050	85.3059	85.3059	85.3059	85.3066				
28	Burhi Gandak	N	25.4533	25.4533	25.3769	25.4992	25.4992	0.0000	9.0401	13.6254	13.6254
		E	86.6099	86.6099	86.5818	86.4962	86.4962				
29	Kosi	N	25.4101	25.4076	25.3932	25.4214	25.4555	0.4742	1.9355	4.6211	11.2253
		E	87.2596	87.2631	87.2638	87.2996	87.3498				
30	Fulahar	N	25.0905	25.0887	25.0926	25.0955	25.0965	0.9438	0.2456	0.5689	1.0933
		E	87.8441	87.8524	87.8433	87.8451	87.8363				

Ramganga river joins Ganga river from its left side near Chandau Beche which is located upstream of the Kanauj. The confluence point has shifted by about 2.5 km downstream from the year 1980 to 2010, however, since the year 2000, the confluent point is stable. The confluence point of Garra river has moved about 6.6 km upstream from year 1990 to year 2010, and since then the confluence point is stable. Yamuna river joins the Ganga river from right side at Allahabad. No noticeable shifting in the confluence point has been observed over the years.

In year 1970, the Gomti river was joining the Ganga river with a meandering loop from left side, however, it shifted upstream by about 2 km. The confluence point of Gomti river is stable at one location from year 1980. Ghaghra river joins Ganga river from left side near Revelganj, Chhapra. In year 1990, the confluence point shifted upstream by about 12 km and since then it is more and less stable. Son river also join the Ganga river from the right side. No noticeable shifting in the confluence point has been observed except that the point has moved slightly towards the Ganga river in year 2010.

Gandak river joins to the Ganga river from left side at Hajipur. Prior to year 2010, Ganga river was flowing abutting the right bank towards Patna side and Gandak was joining this channel, however, after the year 2000, the main channel of the Ganga river shifted from right to left which forced the confluence point of the Gandak river towards left side. In this way, the confluence point shifted towards north side by about 2.0 km. Prior to year 1980, there was an acute meandering bend in the Ganga river near Munger. The Burhi Gandak was joining with the Ganga river from left side to the developed bend, however, after year 1980 the Ganga river took a straight path by abandoning the bend which resulted in shifting of confluence point of Burhi Gandak downstream by about 13.5 km. This confluence point is stable from year 1990 to till date.

Kosi river joins the Ganga river from left side near Krusela. Figure 1.169 clearly indicates that the confluence point has shifted in the upstream by about 10 km over the years and stable since 1990.

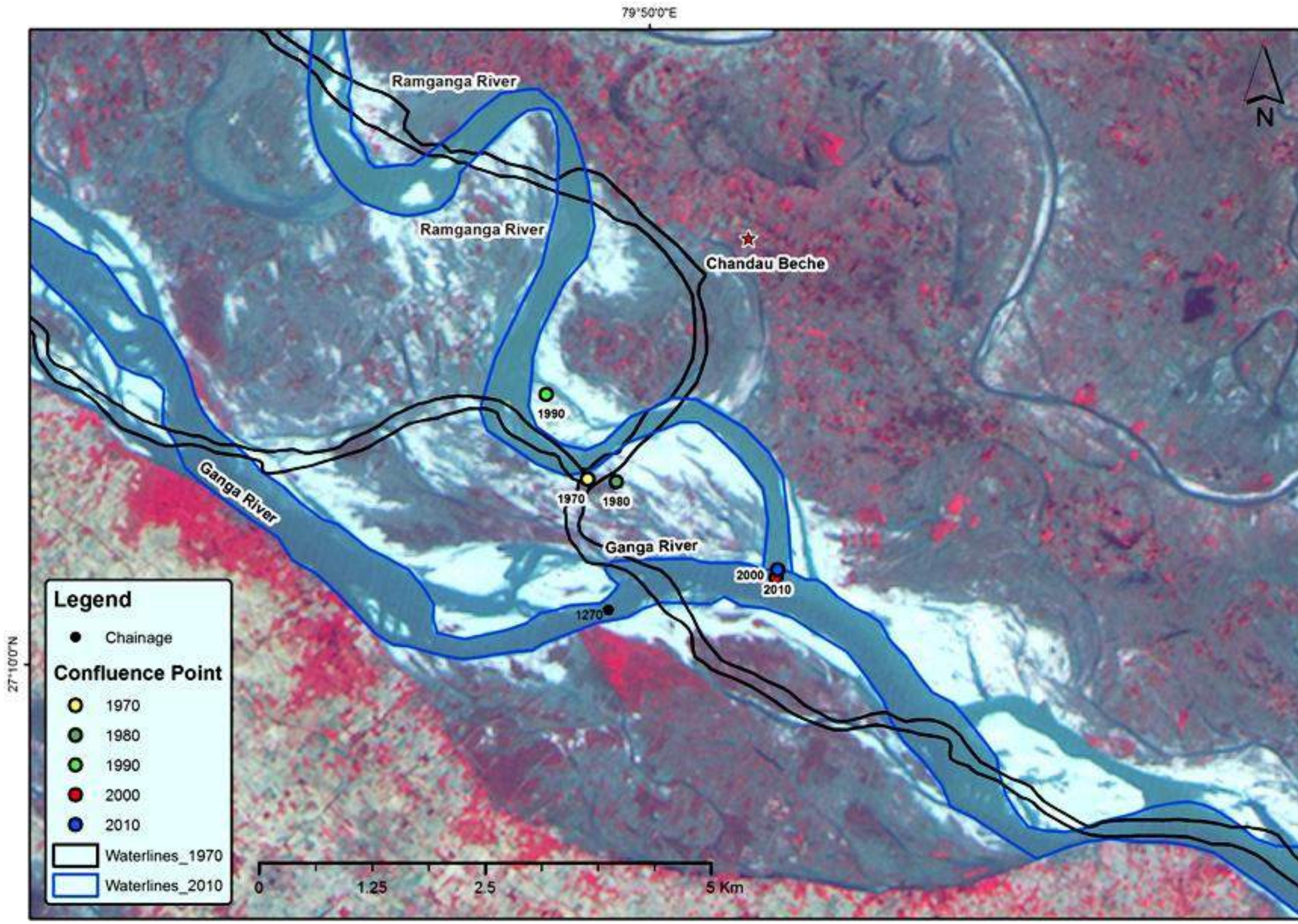


Figure 10.134 Confluence point of Ramganga river with Ganga river

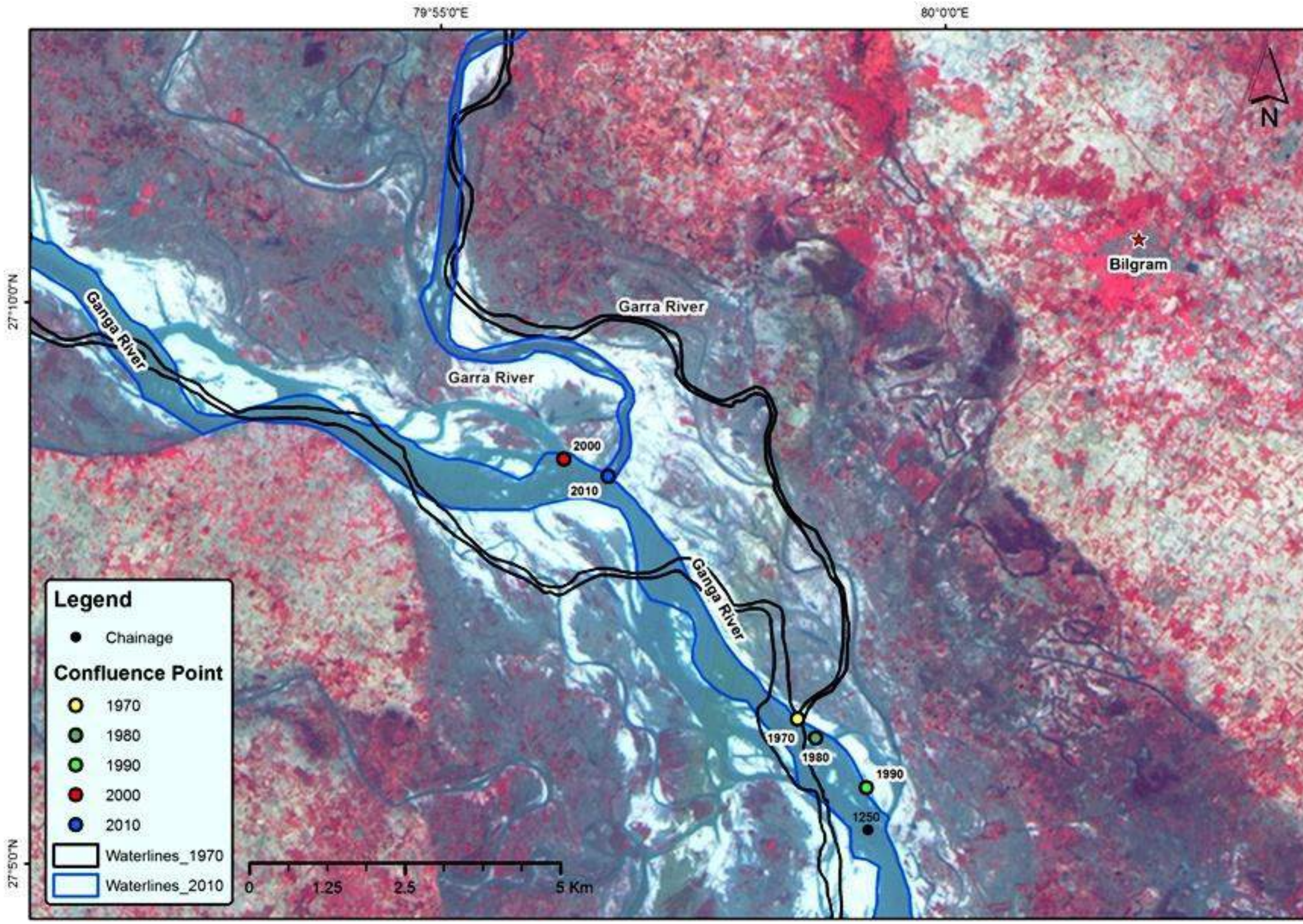


Figure 10.135 Confluence point of Garra river with Ganga river

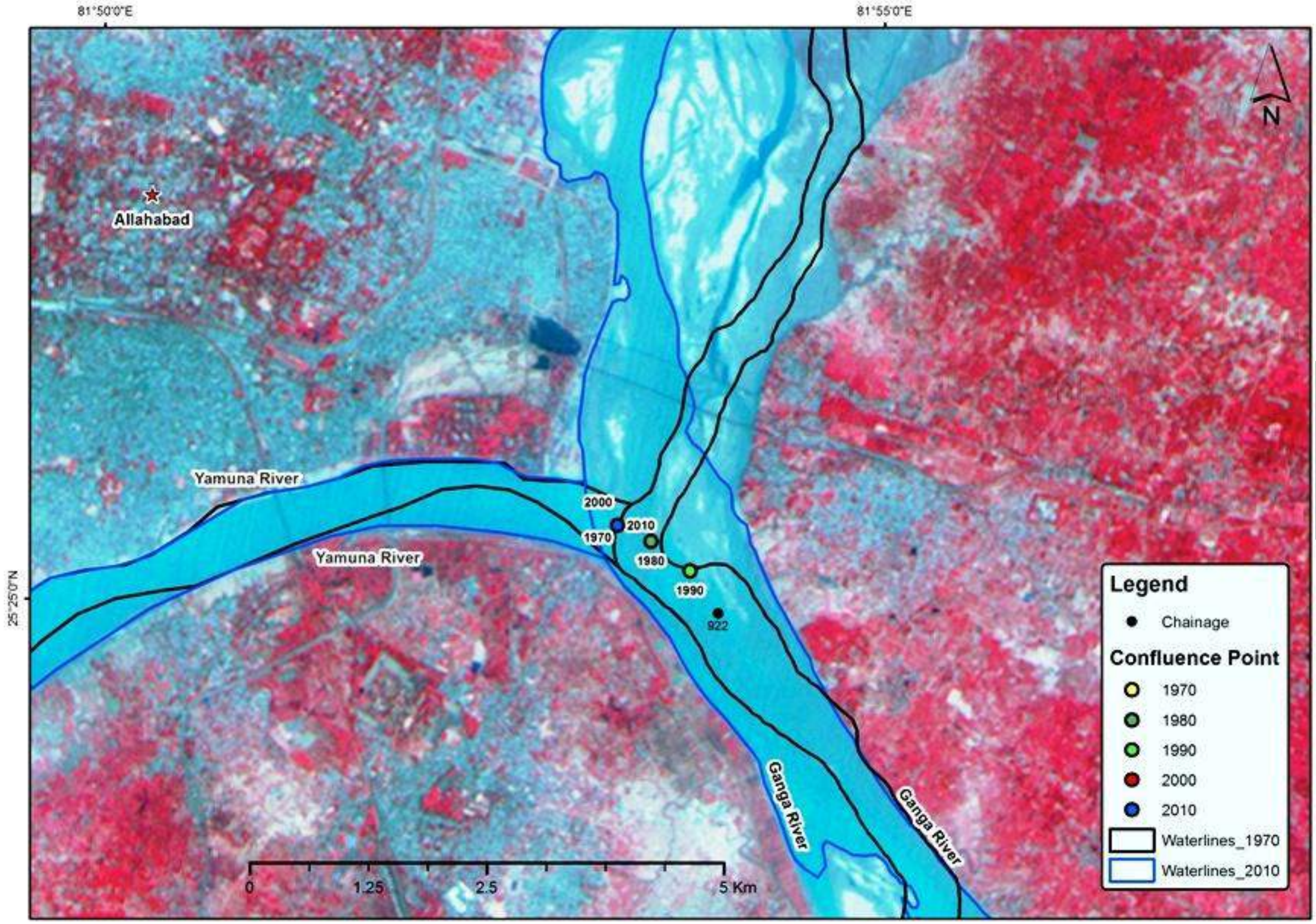


Figure 10.136 Confluence point of Yamuna river with Ganga river

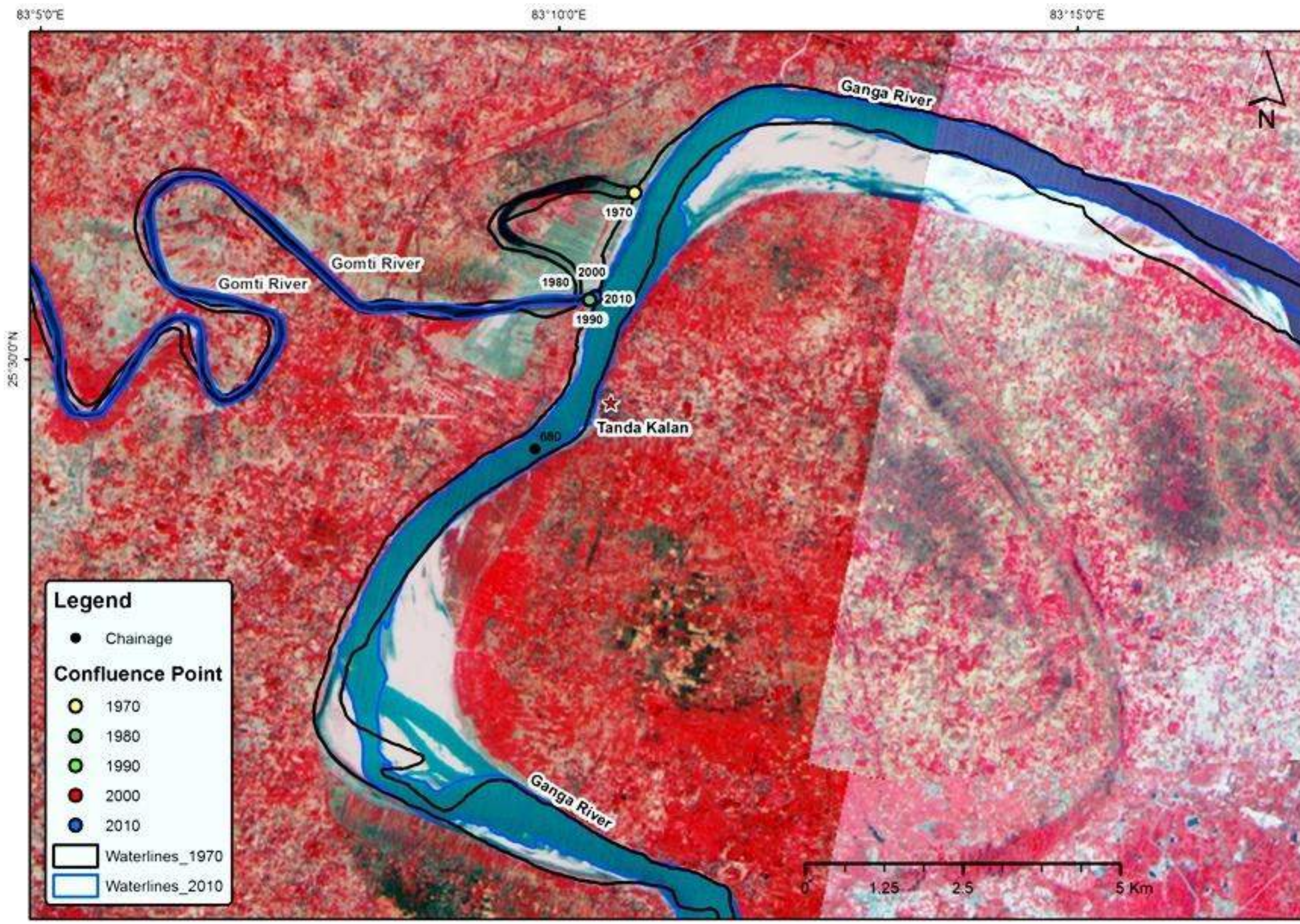


Figure 10.137 Confluence point of Gomti river with Ganga river

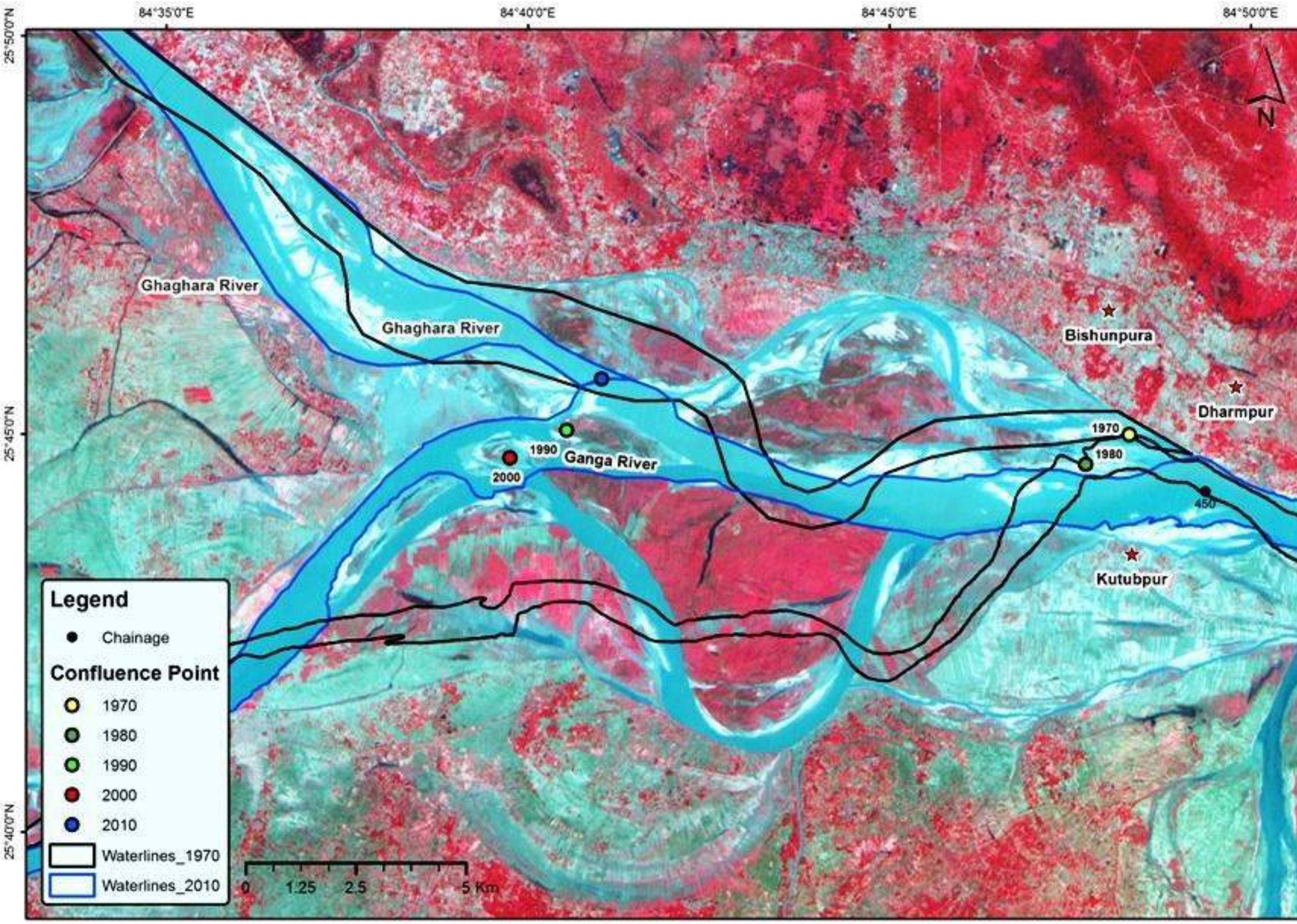


Figure 10.138
Confluence point of Ghaghara river with Ganga river

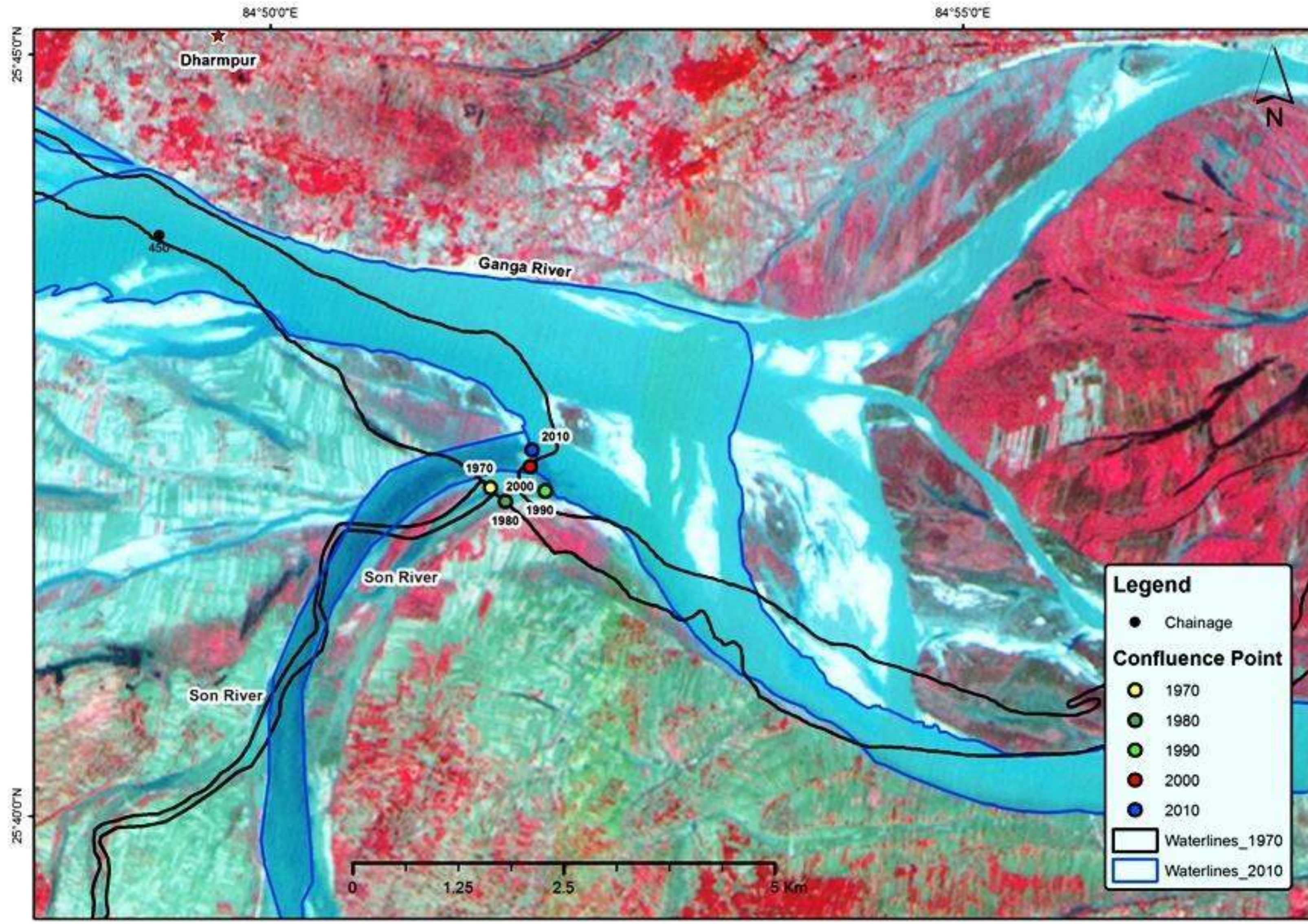


Figure 10.139 Confluence point of Son river with Ganga river

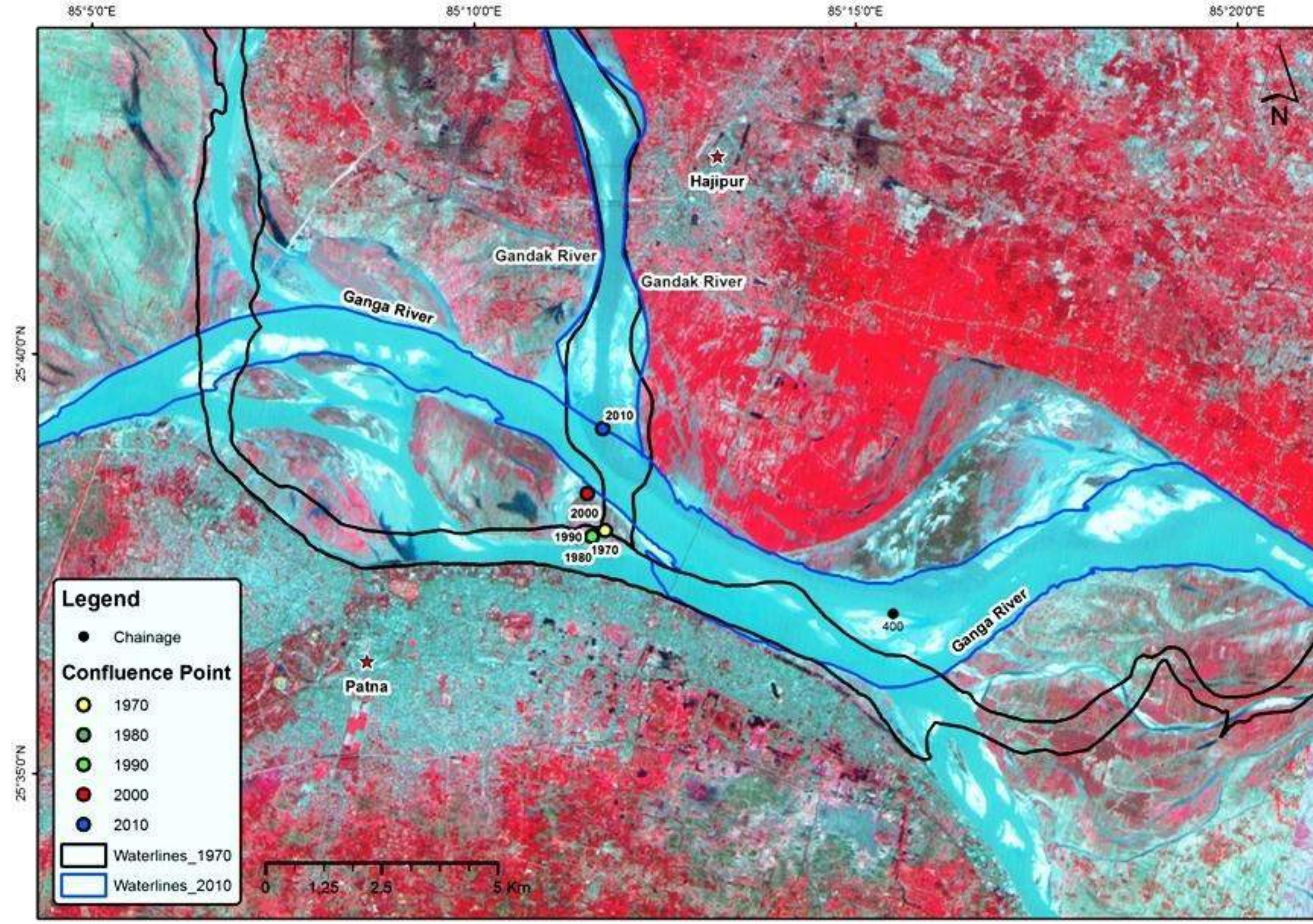


Figure 10.140
Confluence point of Gandak river with Ganga river

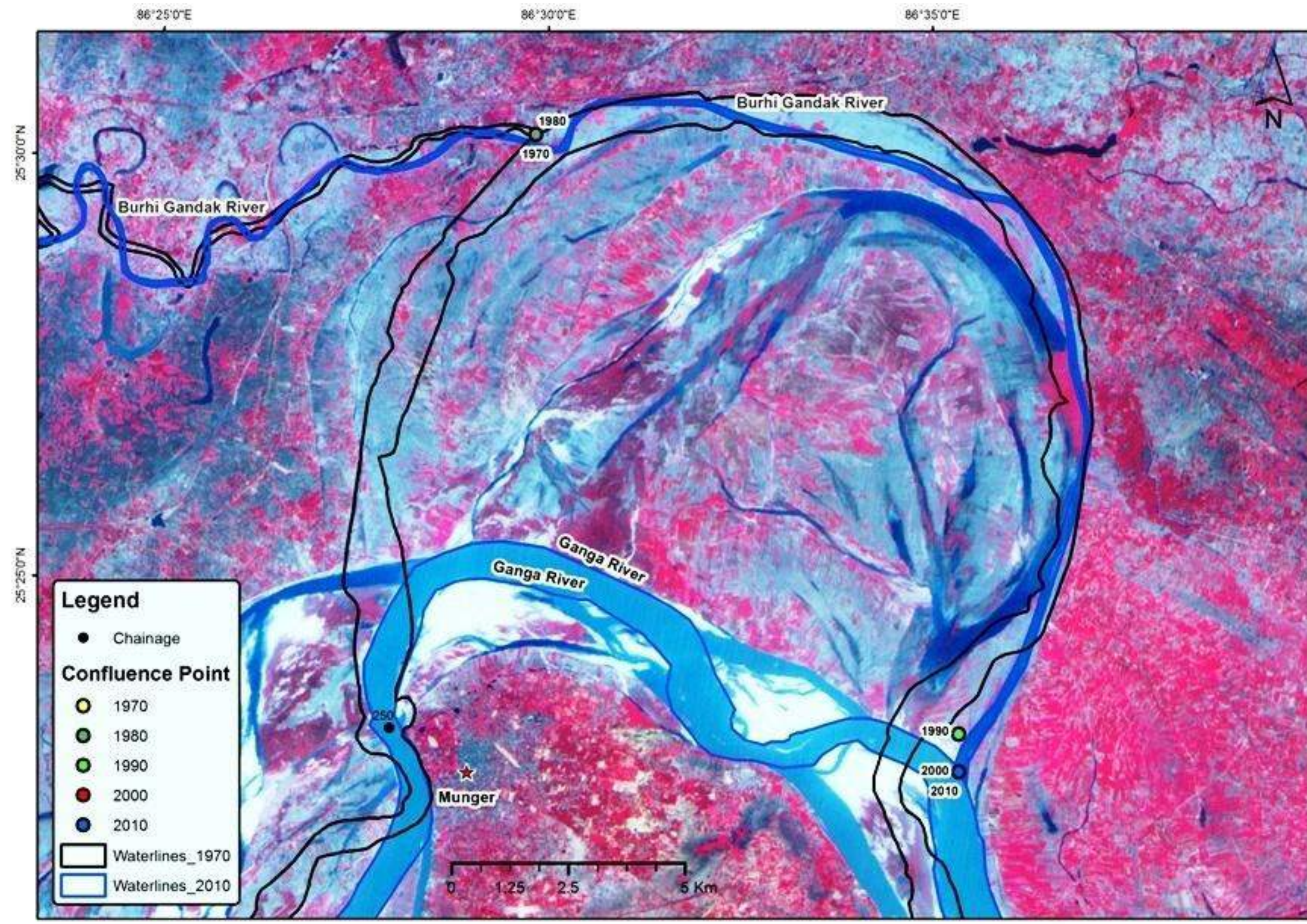


Figure 10.141 Confluence point of Burhi Gandak river with Ganga river

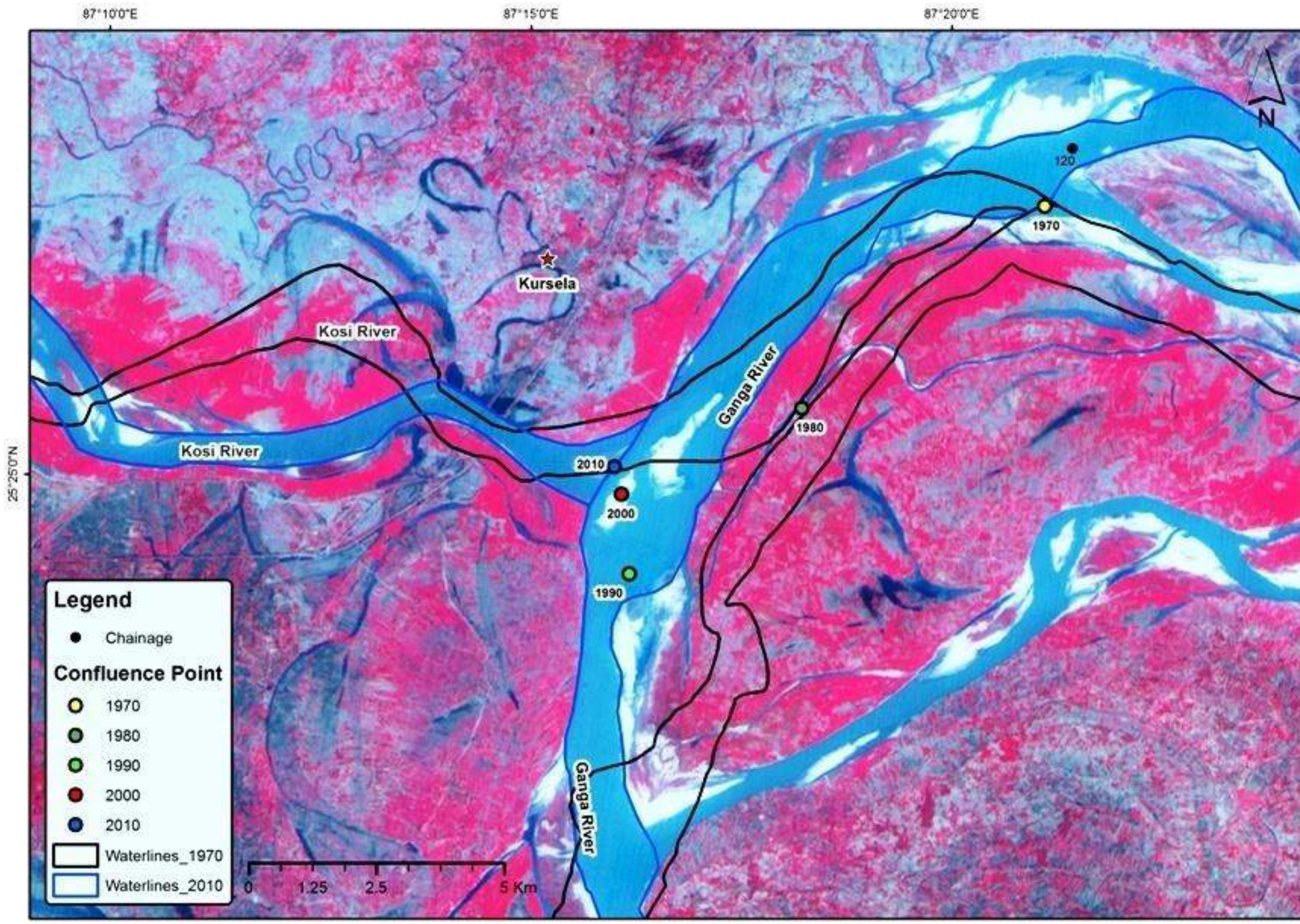


Figure 10.142 Confluence point of Kosi river with Ganga river

10.6 NODAL POITNS

The nodal points along the reach of the river i.e. wherein minimum morphological changes are seen, have been identified and given in Table 10.10 . This will be helpful in planning of structures like bridges and barrages in the future.

Table 10.10 Nodal points of minimum morphological changes

Sl. No.	Chainage (km)	Latitude & Longitude	Location
1.	16	87°57'17.882"E 24°56'20.363"N	Gobargari
2.	38	87°50'35.008"E 25°3'53.034"N	Rajmahal
3.	100-108	87°31'30.369"E 25°23'13.541"N- 87°26'59.499"E 25°24'48.27"N	Ramnagar
4.	140-148	87°15'31.489"E 25°19'59.393"N- 87°13'43.248"E 25°16'11.829"N	Kahalgaon
5.	174	87°1'44.618"E 25°16'33.398"N	Bhagalpur
6.	210	86°43'30.308"E 25°15'15.832"N	Sultanganj
7.	226	86°35'57.653"E 25°18'29.743"N	Bariyarpur (D/S Of Munger)
8.	308	86°0'6.778"E 25°22'9.39"N	Mokamah
9.	342	85°44'26.375"E 25°30'40.089"N	Barh
10.	354	85°38'8.421"E 25°29'13.495"N	Bakhtiyarpur
11.	402-405	85°13'59.42"E 25°36'32.122"N- 85°12'31.399"E 25°37'24.55"N	Patna (Gandhi Setu)
12.	418	85°5'47.66"E 25°39'37.434"N	Digha
13.	448-450	84°50'14.592"E 25°43'24.311"N- 84°49'7.335"E 25°43'48.148"N	Dharmpur
14.	474-486	84°36'3.733"E 25°42'7.008"N- 84°30'12.304"E 25°40'42.591"N	Salempur
15.	498	84°24'46.986"E 25°44'44.123"N	Nauranga
16.	540	84°4'54.674"E 25°41'21.542"N	Rajpur Kalan
17.	554-578	84°0'11.299"E 25°36'2.831"N- 83°48'8.781"E 25°30'42.243"N	Gahmar
18.	600-616	83°38'41.133"E 25°36'6.262"N- 83°31'51.328"E 25°30'23.243"N	Ghazipur
19.	624-682	83°32'9.638"E 25°26'23.967"N- 83°8'38.977"E 25°28'31.137"N	Dhanapur
20.	688-802	83°8'56.677"E 25°26'6.979"N- 82°30'22.596"E 25°10'13.447"N	Varanasi
21.	810-823	82°27'30.62"E 25°12'56.128"N- 82°21'58.481"E 25°13'34.08"N	Ramchandarpur
22.	832--842	82°19'17.388"E 25°14'45.573"N- 82°15'10.289"E 25°14'29.054"N	Kolaipur

23.	848-894	82°15'10.469"E 25°12'27.699"N- 82°4'45.357"E 25°19'0.126"N	Sirsa
24.	918-925	81°55'20.476"E 25°23'7.31"N- 81°53'26.834"E 25°26'26.491"N	Allahabad
25.	934	81°52'1.794"E 25°30'25.624"N	Allahabad
26.	960	81°39'19.217"E 25°31'24.769"N	Manauri
27.	962-980	81°38'57.01"E 25°32'22.04"N- 81°32'21.851"E 25°36'12.704"N	Bharwari
28.	993	81°25'58.463"E 25°39'55.191"N	Shahzadpur
29.	1004-1010	81°23'21.608"E 25°43'42.646"N- 81°23'11.066"E 25°46'21.012"N	Manikpur
30.	1019	81°19'31.403"E 25°49'8.966"N	Muhammadpur Gaunti
31.	1032-1038	81°13'6.305"E 25°52'43.125"N- 81°12'55.888"E 25°55'58.107"N	Muhammadabad
32.	1040-1048	81°12'10.265"E 25°56'43.992"N- 81°7'32.797"E 25°58'7.687"N	Patti Shah
33.	1060-1062	81°2'33.83"E 26°2'18.921"N- 81°1'56.097"E 26°3'15.692"N	Dalmau
34.	1075-1081	80°55'5.334"E 26°3'14.154"N- 80°52'38.847"E 26°3'14.121"N	Arni
35.	1089	80°48'21.813"E 26°2'23.48"N	Rampur Kalan
36.	1095-1098	80°45'38.301"E 26°4'34.097"N- 80°43'41.878"E 26°4'35.747"N	Kuda
37.	1108-1113	80°39'55.524"E 26°7'57.195"N- 80°38'44.707"E 26°10'29.182"N	Gobindpur
38.	1128-1136	80°33'41.744"E 26°16'52.566"N- 80°31'32.731"E 26°20'46.816"N	Bipasi
39.	1142-1157	80°29'10.487"E 26°23'14.559"N- 80°22'31.992"E 26°28'17.322"N	d/s of Kanpur
40.	1170	80°18'10.385"E 26°33'42.684"N	u/s of Kanpur
41.	1176	80°16'41.428"E 26°36'30.152"N	Bithur
42.	1189	80°14'12.706"E 26°41'22.065"N	Gabraha
43.	1198-1200	80°9'44.642"E 26°43'16.079"N- 80°8'45.002"E 26°43'52.918"N	Kakupur
44.	1210	80°7'11.932"E 26°48'31.469"N	Uttari
45.	1220	80°6'4.195"E 26°52'51.403"N	Bilhaur
46.	1228-1230	80°2'35.043"E 26°55'44.286"N- 80°1'43.185"E 26°56'32.628"N	Makanpur
47.	1240	79°59'18.878"E 27°0'39.091"N	Tikhwa
48.	1262-1264	79°53'49.325"E 27°8'59.789"N- 79°52'37.163"E 27°8'56.236"N	Kusumkhur
49.	1275	79°47'12.071"E 27°11'10.252"N	Saunsrapur
50.	1282-1284	79°43'44.06"E 27°13'11.059"N- 79°42'34.106"E 27°13'32.641"N	Khudaganj

51.	1308	79°37'51.013"E 27°23'52.152"N	Farrukkhabad
52.	1333	79°30'3.295"E 27°33'5.225"N	Shamsabad
53.	1345	79°25'51.587"E 27°36'44.545"N	Lachhmanpur
54.	1360	79°20'4.362"E 27°39'20.62"N	Kampil
55.	1364	79°18'28.848"E 27°40'58.7"N	Lilwan
56.	1388	79°8'2.924"E 27°47'5.31"N	Nardauli
57.	1425	78°51'37.529"E 27°55'56.984"N	Manpur Nagaria
58.	1488-1502	78°23'59.842"E 28°11'20.602"N- 78°19'6.671"E 28°16'36.692"N	u/s of Narora
59.	1514	78°16'34.595"E 28°21'59.533"N	Anupshahr
60.	1522	78°17'25.922"E 28°25'39.675"N	Sarara
61.	1538	78°12'43.817"E 28°31'53.353"N	Mawoi
62.	1546	78°12'14.153"E 28°35'58.722"N	Buklana
63.	1553	78°11'49.089"E 28°39'31.573"N	Rukhalu
64.	1568	78°8'43.469"E 28°45'47.374"N	Garhmuktesar
65.	1587	78°6'1.067"E 28°53'49.404"N	Asilpur
66.	1632	78°6'19.933"E 29°11'40.028"N	Latifpur
67.	1659	78°2'21.306"E 29°22'24.769"N	CCS Barrage
68.	1684	78°2'32.519"E 29°33'14.262"N	Kishanpur
69.	1696	78°6'15.568"E 29°38'4.704"N	Balabali
70.	1705	78°9'47.32"E 29°41'4.716"N	Nagal
71.	1712	78°11'57.893"E 29°44'19.775"N	Bhikampur
72.	1738	78°10'9.31"E 29°56'39.409"N	Jwalapur
73.	1742	78°11'17.104"E 29°58'29.568"N	Haridwar
74.	1756-1759	78°16'39.902"E 30°3'32.448"N- 78°17'27.635"E 30°4'58.791"N	Rishikesh
75.	1762-1824	78°18'3.542"E 30°6'2.533"N- 78°35'44.775"E 30°8'40.28"N	d/s of Devprayag

10.7 CONCLUSION & DISCUSSIONS

Following conclusions may be drawn from the morphological study of the Ganga river:

1. Sinuosity ratio of the Ganga river has been calculated from its chainage 0 to 1824 km in an interval of 50 km for the years 1970, 1980, 1990, 2000 and 2010. In the whole reach of the river and for the years 1970, 1980, 1990, 2000 and 2010, the maximum, minimum, and average sinuosity ratios are of the order of 2.2, 1.1 and 1.38 respectively.
2. Sinuosity ratios in the reaches 200-250 km, 600-700 km, 800-900 km and 1750-1824 km are relatively higher than the other reaches. As the average value of the sinuosity ratio for whole reach of the river is 1.38, therefore, the Ganga shall be considered as sinuous river

as per the classification laid by Leopold and Wolman (1957) except the reaches identified above which can be classified as meander.

3. A negligible progressive change in the sinuosity ratio has been found from the year 1970 to 2010.
4. Except the meanders at Sultanganj and Munger, all other meanders are stable and no noticeable change in their geometry has been noticed from year 1970 to 2010. However, river has left the meandering route at Sultanganj and Munger and followed a relatively straight path over the years.
5. Calculated PFI of the Ganga river for the years 1970, 1980, 1990, 2000 and 2010 at an interval of 2 km indicates large variation.
6. The river has high PFI at the locations Shibganj, Santoshpur, Ramchandra Pur, Begusarai, Punarakh, Dhawan, Rajpura, Madhurapur, Akirpur, Bishnupura, Daroga ka Dhera, Mughal Sarai, Akrohi, Rampur, Allahabad, Baksar, Amritpur, Madhonagar, Jargawan, Rasulpur, Hasanpur and Bhopatwala. There is not any definite pattern of the variation of PFI in the whole reach of the river from the year 1970 to 2010.
7. Haridwar (ch. 1740 km) to Devprayag (ch. 1824 km)
   - No noticeable changes in the stream banks shifting is visible in the reach of the river from chainage 1762 km (Rishikesh) to 1824 km (Devprayag). Being in the hilly area, river is also narrow in this reach. However, downstream of Rishikesh upto Haridwar river is relatively wide high and also the river is braided.
   - In this reach, the main course of river has undergone maximum shift near Chila of the order of 1.5 km from left to right side.
8. CCS Barrage, Bijnor (ch. 1660 km) to Haridwar (ch.1740 km)
   - Ganga river highly braided downstream of Haridwar near Sajanpur, which can be attributed to loosening the stream power of the river and deposition of sediments carried out from the hilly areas. Prior to year 1990, the main course of river was towards right side at this location. However, onwards to year 1990, one major stream developed towards left side which is about 2.5 km from main course of river as it was prior to year 1990.
   - A field visit to the site reveals that shifting of river course towards left side near Sajanpur is due to mining towards left side. This area is habitated and is in danger due to shift of river towards left side. Protection majors in form of spurs have been provided to protect the habitated area.

- At chainage 1708 km (Dahirpur), the river has shifted from left to right of the order of 3 km while just downstream of this near Niranjanpur, river has shifted from right to left of the order of 1.5 km.
- Major shifting of course of river has been noticed upstream of CCS barrage. In general, river has shifted from right to left with maximum at Chhachhrauli of the order of 7 km. Such shifting is in a reach of 16 km.

9. Garhmukteshwar (ch. 1568 km) to CCS Barrage, Bijnor (ch.1660 km)

- Major shifting of stream banks has been noticed in this reach. Just downstream of CCS barrage, river has shifted from left to right progressively from year 1970 to 2010 of the order of 3 km.
- At chainage 1622 km (Kamalpur), river has shifted progressively from left to right of the order of 5 km. While at chainage 1610 km (Nagla Goshain), the river has wandered over a width of 3.8 km. In general, it has shifted from right to left.
- At chainage 1594 km (Chhuchai), the river has shifted severely from right to left of the order of 5 km in a reach of 8 km.
- At chainage 1578 km (Khailwai), first river shifted from left to right during year 1970 to 1980 and then shifted right to left of the order of 3 km while downstream of this river has shifted from left to right of the order of 2.25 km near Moharka.

10. Narora (ch. 1488 km) to Garhmukteshwar (ch. 1568 km)

- Major shifting of the river banks in this reach has been noticed at chainage 1562 km (Palwara), 1550 km (Gangwar) and 1510 km (downstream of Anupshahr). Wandering behavior of river has been noticed from chainage 1522 km to 1538 km over a width of 1.8 km.
- Maximum shifting in this reach has been found at Palwara from right to left of the order of 3 km and at Gangwar from left to right of the order of 3.5 km.

11. Farrukkhabad (ch. 1308 km) to Narora (ch. 1488 km)

- Random major shifting of the stream banks has been noticed in this reach with prominent shifting at a) chainage 1470 km (Madkawali) of the order of 3 km from left to right; b) chainage 1458 km (Haranpur) from left to right of the order of 2.5 km; c) chainage 1414 km (Nanakhera) from left to right of the order of 5 km; d) chainage 1384 km (Nardauli) from right to left of the order of 4 km; e) chainage 1350 km (Kaimganj) from right to left of the order of 5 km and f) chainage 1322 km (Birpur) from left to right of the order of 4 km.
- No noticeable meandering and braiding have been identified in this reach.

12. Kanpur Barrage (ch. 1162 km) to Farrukkhabad (ch. 1308 km)

- Major random shifting has been noticed in this reach in particular at chainages 1300 km (Yaqut Ganj), 1245 km (Kannauj), 1214 km (Bilhaur), 1194 km (Palhepur), 1182 km (Mirzapur), and 1162 km (Shankarpur).
- The river is widespread in this reach due to confluence of Ramganga and Garra rivers. No noticeable meandering and braiding have been noticed in this reach.
- At chainage 1300 km (Yaqut Ganj), the river has shifted from left to right of the order of 4.5 km and from year 1980 onwards its course is more or less is stable.
- At chainage 1245 km (Kannauj), Kali river joins the Ganga river from right side. In year 1970, the main course of Ganga river was towards Kannauj side, however, over the years it has shifted towards left side. It was also witnessed during site visit.
- At chainage 1214 km (Bilhaur), the river has wandered over a width of about 4.5 km during year 1970-2010. While at chainage 1194 km (Palhepur), the river has meandering behavior in this reach in past it has wandered over a width of about 4 km.
- At chainage 1182 km (Mirzapur), the Ganga river was following towards Mirzapur side (left side) in year 1970, however, it shifted towards right side by about 3.5 km in 1980. Since then it is more or less stable.
- At chainage 1162 km (Shankarpur) which is just upstream of Kanpur barrage, the river was forced to change its path from left to right side through provision of river training works so that Ganga river should flow through Kanpur barrage.

13. Allahabad (ch. 924 km) to Kanpur Barrage (1162 km)

- No major shifting in the course of Ganga river in this reach has been noticed except the upper reaches.
- Moderate shifting in this reach has been noticed at a) chainage 1118 km (Alipur) - river has shifted from left to right of the order of 3 km; b) chainage 1022 km (Arkha) - river has shifted from left to right of the order of 2 km; c) chainage 990 km (Benti lake) - random wandering behavior of a width of 4 km.
- Before the confluence point with Yamuna river, mild shifting of Ganga river has been noticed.

14. Chainage 465 km (Revelganj) to 924 km (Allahabad)

- From Allahabad to Revelganj (Confluence point of Ghaghara river), Ganga river is almost stable except in the reach from chainage 500 km to 550 km that is near Balia where mild shifting of the river bank has been noticed.

- At chainage 546 km (Nurhi) upstream of Balia, the river was flowing into two channels with major one towards left side. However, over the years the left channel has become the main course at this location.
- River has wandering behavior in this reach most of its meandering pattern are stable.
- At chainage 508 km (Sanwani), river has shifted progressively from left to right of the order of 3.5 km and at chainage 492 km (Jewainiah) from right to left of the order of 2.5 km.

15. Chainage 309 km (Mokamah Bridge) to 465 km (Revelganj)

- At the confluence point of Ghaghara river, Ganga river was flowing towards right side and was meeting with Ghaghara near Kutubpur (Chainge 450 km) in year 1970. However, it has shifted towards left side of the order of 5 km and the confluence point has also shifted upstream by 14 km from year 1970 to 2000. Since year 2000, the course of river and confluence point are stable.
- Sone river joins the Ganga river at chainage 445 km from right side. Confluence point of Sone river with Ganga is more or less stable over the years.
- Upstream of Digha bridge (Chainage 416 km) and up to confluence of Sone river, the Ganga river has meandering pattern and also flowing into two channels. In year 1970,1980 and 1990 the major course of river upstream of Digha bridge was towards the left side and minor channel towards right side. However, year 1990 onwards right channel becomes major channel and a big island is formed between these two channels at upstream of Digha bridge.
- Downstream of the Digha ghat and prior to 1980, the Ganga river was hugging its right bank i.e., Patna side upto Didarganj. On the left side, the left spill of the Ganga river was meeting with Gandak river.
- Downstream of the Digha ghat and from year 1980-1990, the Ganga river was still hugging its right bank i.e., Patna side upto Didarganj. The left spill widened towards the Sonepur side. r.
- Downstream of the Digha ghat and during the period from year 1990-2010, major changes in the morphology of the Ganga river downstream of the Dighaghat occurred. The right channel deflected from the Dighaghat towards the left side resulting in its separation from the right bank of the river in a length of about 6 km downstream of the Dighaghat. The maximum shifting of the right channel of the river was of the order of 2.5 km at about 3 km downstream of the Dighaghat. The separated channel was joining the right bank of the river towards Patna side at about 6 km downstream of the Dighaghat.

- Downstream of the Ganga Setu, no noticeable changes in the morphology of the a river has occurred. At about 5 km downstream, the Ganga river bifurcates - one channel goes towards left bank and another towards right bank of the river. In between these two channels, there is huge deposit of sand which has taken a shape of an island. The two channels rejoins near Bakhtiyarpur (Chainage 356 km). Left channel is constantly flowing as major channel. However, upstream of Bakhtiyapur river has shifted by 8 km from right to left from year 1990 to 2000.
- Upstream of Mokhmah bridge, the river flows into two channels. The right channel was major in year 1970, however onwards to year 1980, the left channel has become the major channel. Ganga river is wide and braided both upstream and downstream of the Mokhmah bridge. The width of the river in the upstream is of the order of 7.5 km while in the downstream it is about 5 km. The river has been channelized near the bridge by constructing a left guide bund.

16. Chainage 210 km (Sultanganj) to 309 km (Mokamah Bridge)

- Major shifting of river course has been noticed downstream of Mokamah bridge near Khutha. In year 1970 and 1980, the river was flowing towards right side (Khutha), however from year 1980 onwards it has shifted towards left side of the order of 9 km. Near this location, river has followed relatively straight path over the years.
- Upstream of Munger (Chainage 250 km) river has wandered over a width of about 6 km over the years. However, overall it has shifted towards right side over the years.
- Major change in the river bank shifting has been noticed from Munger to Sultanganj. In general, the river has abandoned the meandering path and followed relatively straight path.
- At Munger in year 1970 and 1980, the river was flowing in an acute meander touching Khutia towards left side. However, its course shifted progressively from left (Khutia) to right (Munger) of the order of 12 km. At present, river is flowing abutting the Munger township.
- In year 1970 and 1980, Burhi Gandak was meeting with Ganga river near Khutia, however, it's confluence has shifted towards downstream near Nauwa Garhi over the years.
- Upstream of Sultanganj, the river was following a meandering path towards left side (Naya Gaon) in year 1970 and 1980. However, it has shifted progressively towards right side (Fatehpur) of the order of 8 km.

17. Kahalgaon (ch. 148 km) to Sultanganj (ch. 210 km)

    - Major changes in the river course has been noticed in this reach. In year 1970, the river was flowing through an acute bend downstream of Sultanganj near Madhurapur. However, onwards to year 1970, it has shifted from left to right side of the order of 10 km. Onwards to year 1980, no major shifting of river bank has been noticed at this location.
    - Near Bhagalpur, the river has progressively shifted from right to left side of the order of 7 km. However, downstream of Bhagalpur near Barari there is no change in the course of river from year 1970 to 1980.
    - Upstream of Kahalgaon near Shahpur, the river was flowing in a relatively straight path towards right side in year 1970. However, in year 2010, it has shifted from right to left progressively of about 9 km and also followed a meandering path.

18. Rajmahal (ch. 40 km) to Kahalgaon (ch. 148 km)

    - No major shifting in the river course has been noticed in this reach. However, river is flowing over a wide width in this reach. Downstream of Kahalgaon near Budhu Chak the river is flowing into two channels with an island in between. The major channel is flowing towards left side and minor towards right side. Kosi river joins the left channel of the Ganga river near Krusela.
    - Near Mahadevganj, Ganga river has wandered randomly over a width of 7 km. In the respect of year 1970, the river has shifted by about 3 km from right to left in the year 2010.

19. Farakka (ch. 0) to Rajmahal (ch. 40 km)

    - At about 5 km upstream of the barrage, river has progressively shifted towards left side by about 4 km from year 1970 to 2010 at Chamogram. At about 12 km upstream of the barrage, the river has shifted towards right side at Sahibganj. The maximum shift of river towards right side was about 5 km in year 1980 with respect to center line of river in 2010.
    - At about 27 km upstream of barrage river has shifted towards left side from yea 1970 to 2000. The maximum shift towards left side is in the order of 5 km at Gopalpur.
    - Fulahar river joins the Ganga river from left side near Rajmahal.

20. There are 30 major tributaries of Ganga river between DevPrayag and Farraka. Major shifting of confluence points of Ramganga, Garra, Gomti, Ghaghra, Gandak, Buri Gandak and Kosi rivers has been observed in the period 1970-2017.

Concluding Remarks

From the consideration of river bank shifting, the Ganga river from Devprayag to Farakka barrage may be divided into following five reaches:

a) Devprayag (ch. 1824 km) to Haridwar (ch.1740 km):- Being in hilly area, the river bank shifting is very low in this reach except for upstream of Bhimgoda barrage (chilla) where river has shifted right side of the order of 1.5 km.

b) Haridwar(ch.1740 km) to Allahabad (ch. 924 km):- Noticeable shifting of the river bank in the period of 1970 to 2010 has been noticed primarily at Sajanpur (Downstream of Haridwar), Dahirpur, Niranjanpur, Chhachhrauli, upstream and downstream of CCS barrage. Kamalpur, Nagla Goshain, Chhuchai, Khailwai, Moharka, Palwara, Gangwar, downstream of Anupshahr), Madkawali, Haranpur, Nanakhera, Nardauli, Kaimganj, Birpur, Yaqut Ganj, Kannauj, Bilhaur, Palhepur, Mirzapur, Shankarpur, Alipur, Arkha, and Benti lake

c) Allahabad (ch.924 km) to Revelganj (ch. 465 km):- The river is more or less stable in this reach except for 50 km reach of Ganga river near Balia where mild shifting of river bank has been noticed.

d) Revelganj (ch. 465 km) to Mokamah(ch. 310 km):- The river is too wide and stable except at upstream and downstream of Digha bridge and upstream of Mokamah bridge, where major shifting of the river has been noticed.

e) Mokamah(ch. 310 km) to Farakka barrage (ch. 0):- Major shifting of river bank upto 12 km has been noticed in this reach. The river is also too wide and having meandering pattern at some locations. Prominent river bank shifting has been noticed at Khutha, Munger, Fatehpur, Madhurapur, Bhagalpur, Shahpur (upstream of Kahalgaon) and upstream of Farakka barrage.

Chapter 11 ISLANDS IN GANGA RIVER

11.1 INTRODUCTION

A river island or diyara is landmass or fluvial landform that forms within a river. This forms primarily due to morphological changes of the river. Such morphological changes may be attributed to various factors, like meandering, braiding, formation of spill channel, erosion and siltation, construction of structures, river training works, confluence of highly sedimented river, geology of the river, sediment yield from the catchment, etc. In case of meandering, when a cutoff channel develops across a meandering bend, it forms an island encompassing with meandering channel and cutoff channel. An island can also be formed between two channels of a braided river. Formation of a spill channel that originates from the main channel of the river and joins it in the downstream also forms an island. Spill channel forms due to local depression, loose soil, breach in an embankment, deployed river training works etc. Inability of the river to carry high sediment load results in its deposition en-route may also form an island. Lowering the velocity of the flow due to construction of barrage, dams etc. are also liable of forming islands. Once a river of high sediment load meets with another river which geometry and flow are not capable of carrying the injected sediment from the former river, island forms in the latter river near the confluence.

After the formation of the island due to river action, vegetation develops over it that poses high resistance to the flowing water during the flood time. In general, such island are used by the farmers for the agricultural purpose, however, prolonged existence of the island attracts habitations. The resistance posed by the highly vegetated and habitated island to the flow is high, which results in major morphological changes in the river at that location in the form of erosion, shifting of the main course, rise in water level, inundation in nearby areas during flood etc. Thus, such habitation with *pucca* structure is not to be encouraged.

11.2 IDENTIFFIED ISLANDS IN GANGA RIVER

The formed islands/diyaras in Ganga river from Devprayag to Farakka barrage have been identified using historical satellite images of years 1980, 1990, 2000, 2010 and 2015 and SOI toposheet of year 1970. Some of the islands are permanent in nature with different degree of settlement - such islands can be seen on each image and thus have been easily identified. Some islands are temporary in nature and can be seen on images with limited duration only. In view of ephemeral nature of such type of islands, it is difficult task to deals with all the islands that were formed from the year 1970 to 2015. In view of this, only those islands that were formed in year 2015 in the Ganga river from Devprayag to Farakka barrage have been identified and discussed. The locations of the identified islands are shown in Figs. 11.1a-g. Also, the list of the islands is given in Table 11.1.

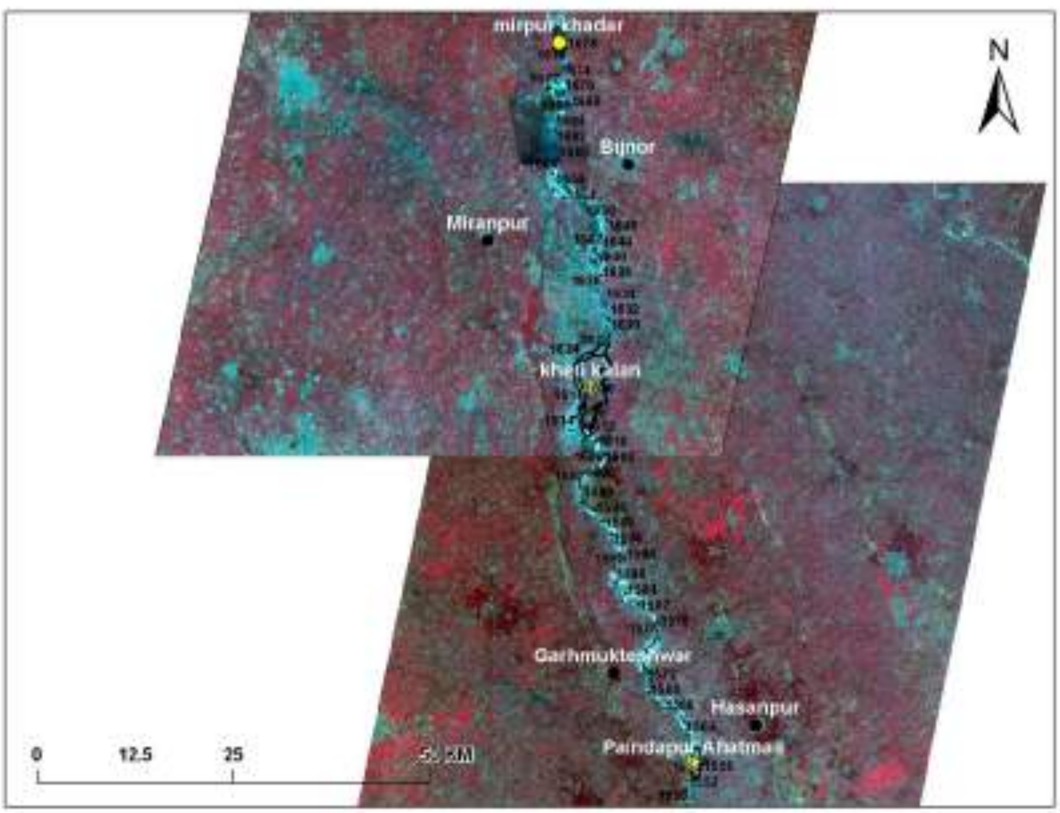


Figure 11.1a Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

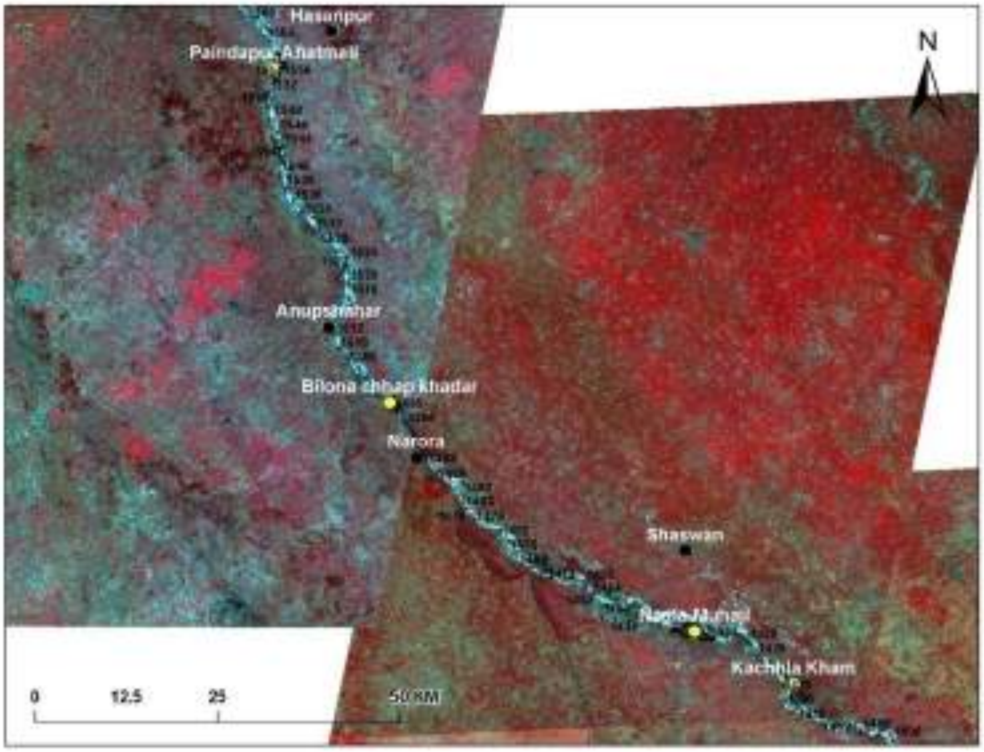


Figure 11.1b Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

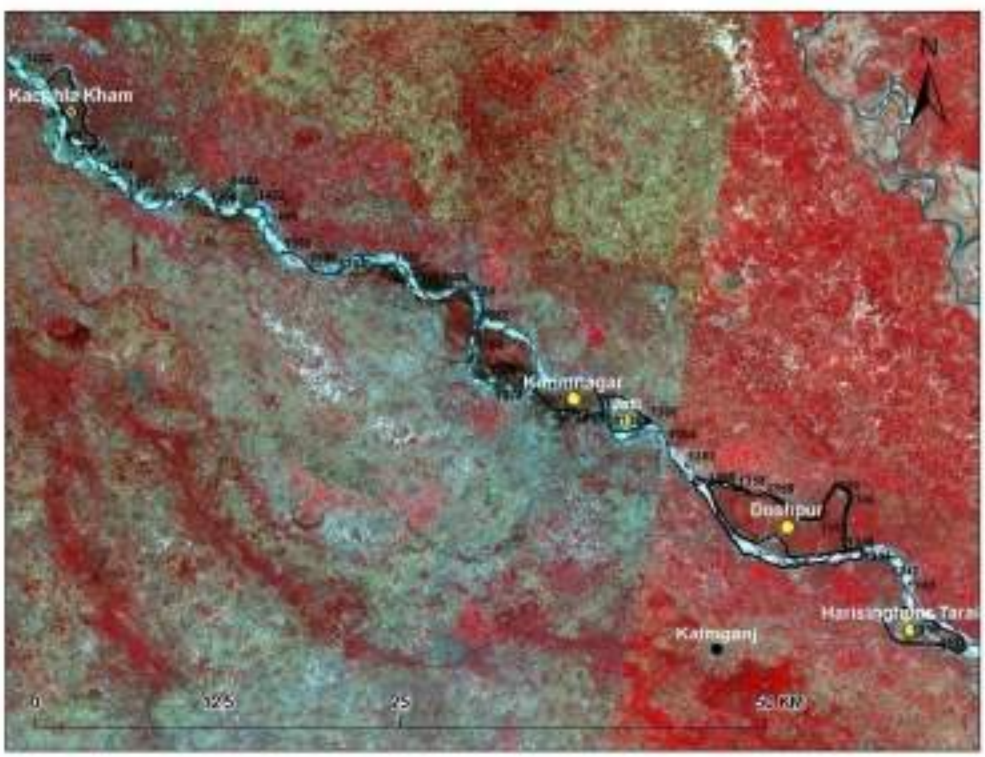


Figure 11.1c Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

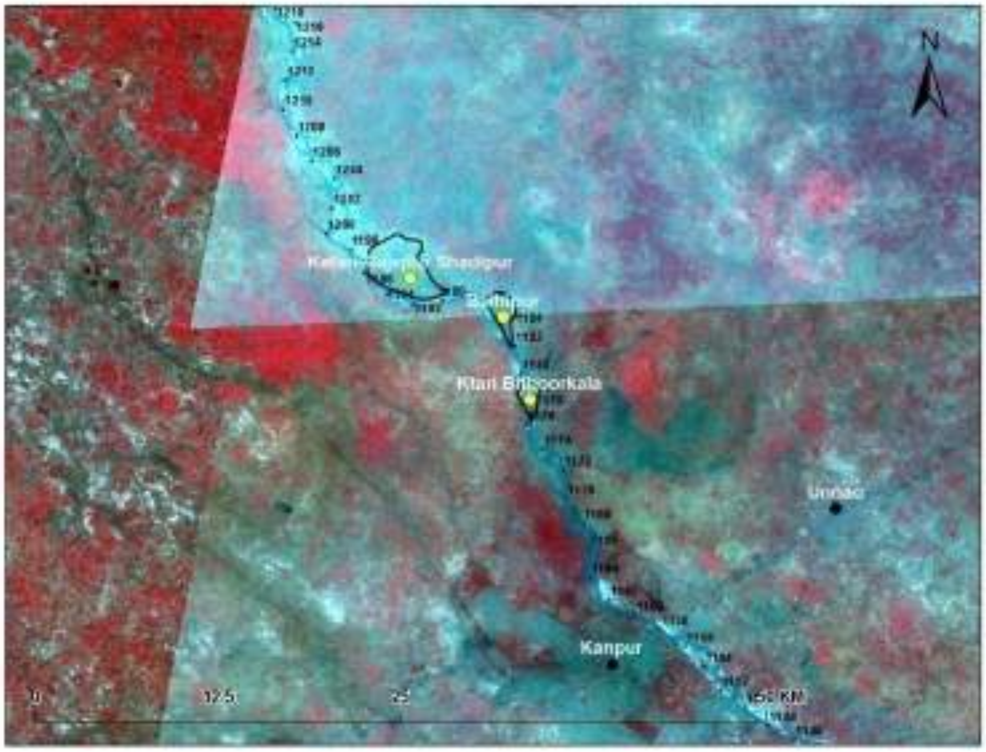


Figure 11.1d Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

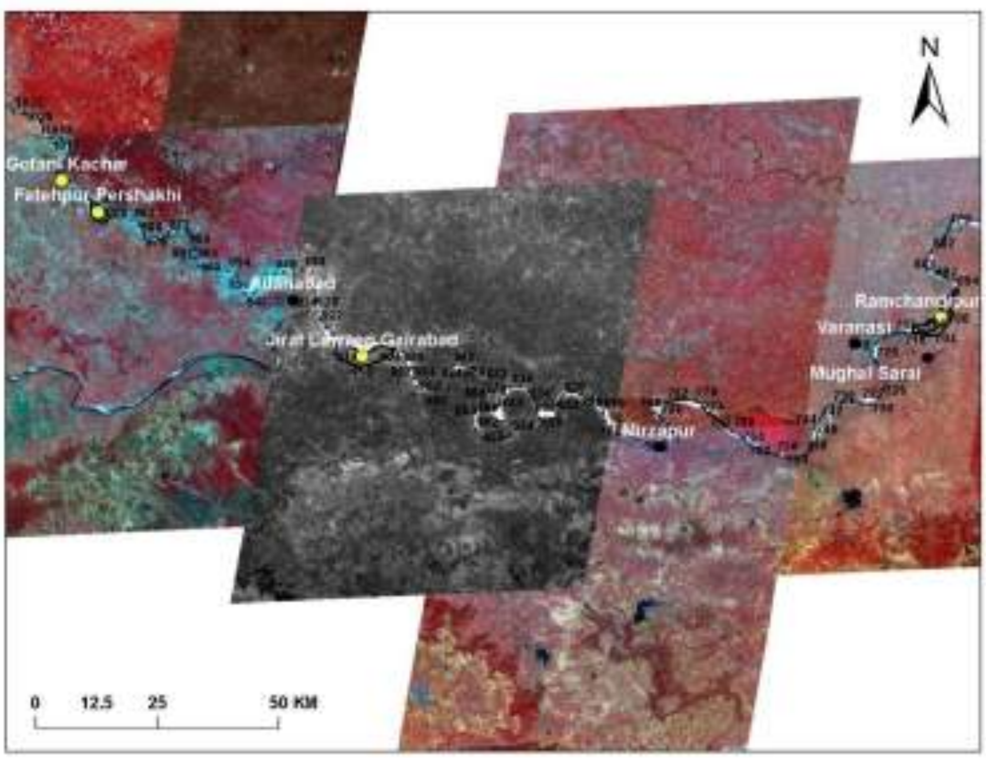


Figure 11.1e Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

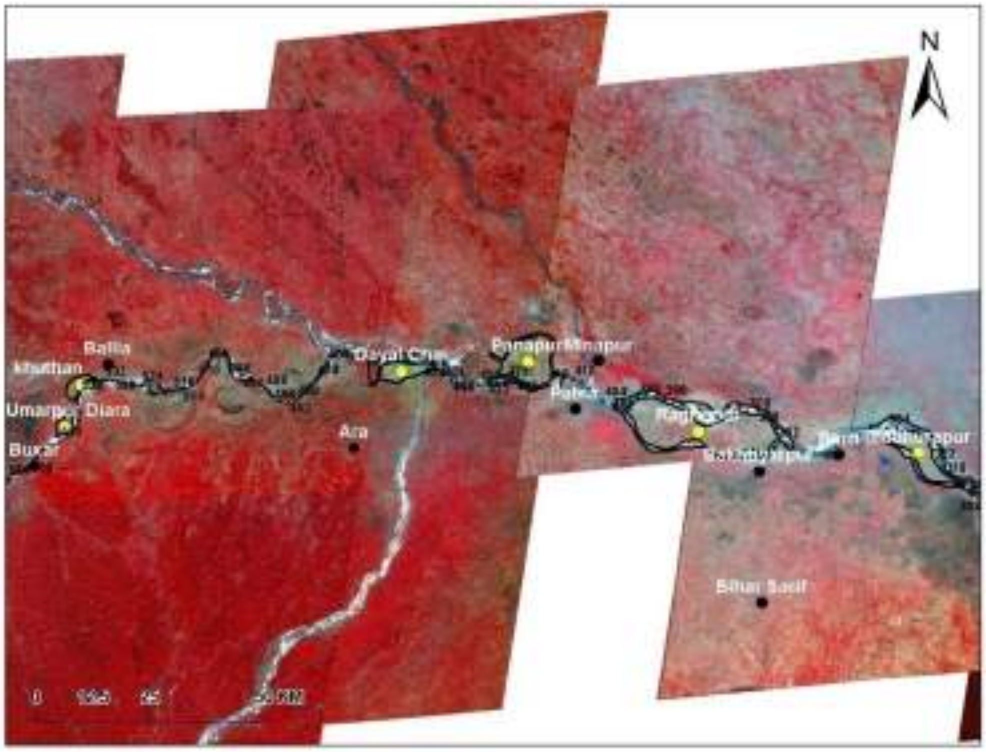


Figure 11.1f Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

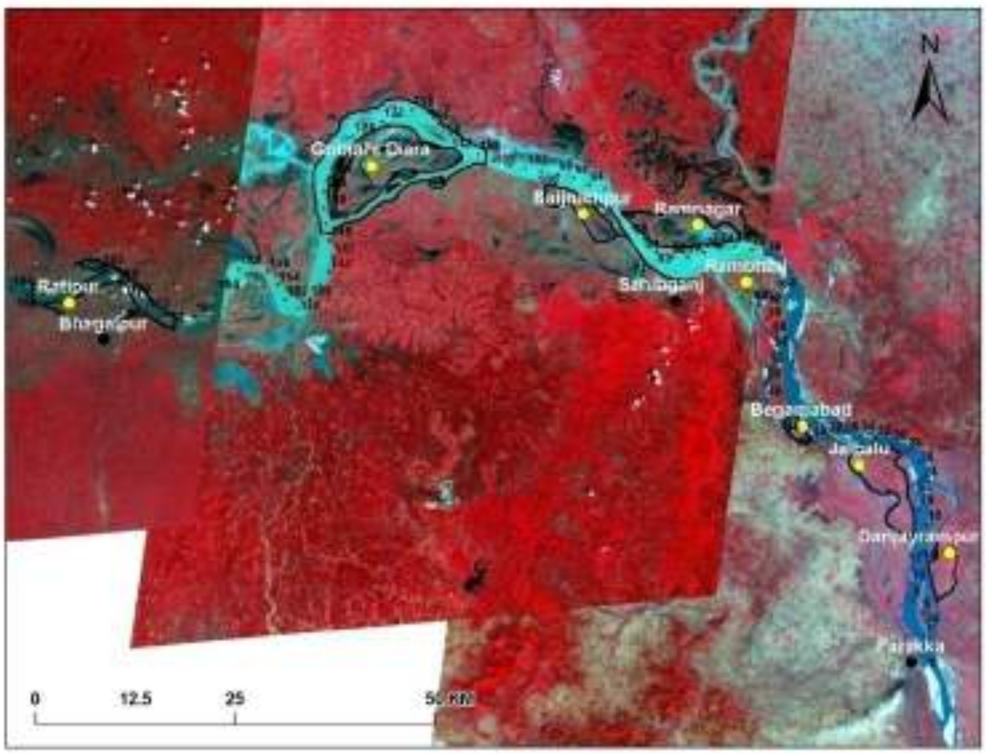


Figure 11.1g Locations of the identified islands in the reach from Chainage 1552 km to 1680 km

Table 11.1 Identified islands/diyaras in the Ganga river from Devprayag to Farakka barrage

Sl No.	Island Location	Lat	Long	Chainage (km)	Habitation Status in year 2015	Area (km^2) in year of study						Remarks
						1970	1980	1990	2000	2010	2015	
1.	Mirapur Khadar (u/s of Bijnor)	29.51277	78.04973	1679	No	0	0	0	0	4	4	Temporary
2.	Kheri Kalan (Near Hastinapur)	29.11542	78.07954	1620	Yes	0	0	24	24	22	19	Temporary
3.	Paindapur Ahatmali (d/s of Gadrhmukteshwar)	28.67849	78.20042	1555	No	0	0	0	1	1	3	Temporary
4.	Bilona Chhap Khadar (u/s of Narora Railway bridge)	28.26216	78.3503	1497	No	0	0	0	2	2	1	Temporary
5.	Nagla Mahaji (u/s of Kachhla bridge)	27.96899	78.76591	1435	No	0	0	3	6	6	5	Temporary
6.	Kachhla Kham (d/s of Kachhla bridge)	27.89968	78.90173	1420	No	4	4	5	9	12	7	Temporary
7.	Karimnagar (Near Patiyali)	27.71242	79.24446	1371	No	0	0	0	5	8	8	Temporary
8.	Jati (Near Patiyali)	27.69778	79.28013	1367	No	0	0	3	3	2	4	Temporary
9.	Doshpur (d/s of Jati)	27.62858	79.38924	1354	No	14	19	22	26	24	26	Temporary
10.	Harisinghpur Tarai (Near Shamsabad)	27.56267	79.47305	1336	No	0	0	0	0	0	8	Temporary
11.	Ktari Rajepur Shaidpur (Near Shivrajpur)	26.70131	80.20261	1193	No	6	10	10	12	13	15	Temporary

12.	Balhipur (u/s of Kanpur)	26.67507	80.26495	1184	No	0	1	1	3	4	5	Temporary
13.	Katri Baithoorkala (u/s of Kanpur)	26.62367	80.28079	1178	No	0	0	1	1	1	1	Temporary
14.	Gotani Kachar (Near Sirathu)	25.69322	81.38512	999	No	4	5	5	4	3	5	Moderately permanent
15.	Fatehpur Pershakhi (Near Kunda)	25.63231	81.4558	989	No	8	10	9	11	10	10	Moderately permanent
16.	Jirat Lawaen Gairabad (d/s of Allahabad)	25.34099	81.97835	908	No	24	26	23	32	29	30	Moderately permanent
17.	Ramchandaepur (d/s of Varanasi)	25.35173	83.15456	701	Yes	12	13	12	14	14	14	Permanent
18.	Umarpur Diyara (d/s of Buxar)	25.64274	84.05085	547	No	4	5	5	9	12	17	Moderately permanent
19.	Khuthun (u/s of Balia)	25.72307	84.09338	536	No	25	23	21	19	17	15	Moderately permanent
20.	Panapur (u/s of Digha Bridge)	25.70796	85.08138	423	Yes	105	115	86	96	92	93	Permanent
21.	Dayal Chak (Near Chhapra -Doriganj Bridge)	25.71735	84.80074	452	Yes	31	28	32	34	32	33	Permanent
22.	Raghopur (d/s of Patna)	25.53447	85.38387	380	Yes	256	248	265	252	234	228	Permanent
23.	Madhurapur (d/s of Barh)	25.46563	85.88448	323	No	36	39	54	71	62	56	Permanent
24.	Ratipur (Near Bhagalpur)	25.28979	86.93505	187	Yes	0	0	0	37	43	36	Temporary

25.	Gobrahi Diyara	25.41073	87.31901	125	Yes	41	51	57	65	86	80	Permanent
26.	Baijnathpur	25.33548	87.57103	92	Yes	0	0	6	17	20	21	Temporary
27.	Saidpur, Ramnagar (Sahibganj)	25.31116	87.70926	80	Yes	0	0	11	20	37	38	Temporary
28.	Rambani (Maharajpur)	25.24246	87.76134	65	Yes	0	22	30	31	29	42	Temporary
29.	Begamabad (u/s of Rajmahal)	25.07755	87.81182	43	Yes	0	0	23	13	5	5	Temporary
30.	Jalbalu (d/s of Rajmahal)	25.02814	87.87683	30	Yes	0	0	21	40	43	40	Temporary
31.	Darijayrampur (u/s of Farakka Barrage)	24.92143	87.97593	14	Yes	0	0	6	7	9	10	Temporary

11.3 DESCRIPTION OF THE ISLANDS

1. Mirapur Khadar (Upstream of CCS barrage)

It is located 15 km upstream of CCS barrage at Bijnor. The major channel of the river is flowing towards left side while the minor stream is flowing towards right side. There is no habitation on this island, however, it is covered with vegetation. Historical images indicate high dynamic behavior of the river with its main channel keeps on wandering in a wide width. It may also be concluded from the past images that this is not a permanent island. Prior to year 2010, the major channel was flowing towards right side and a minor channel towards left side. Images before year 2000 indicate no sign of island at the same place. At the outset, it can be concluded that it is not a permanent island and may be washed away in future. The island as in year 2015 is shown in Figure 11.2.

Figure 11.2 View of Mirapur Khadar upstream of the CC barrage on LISS IV image of year 2015

2. Kheri Kalan (Near Hastinapur)

It is located 30 km downstream of CCS barrage near Hastinapur. At present, the major channel of the river is flowing towards right side while a small creek is flowing towards left side. This is partially habitated island with only one village with an area of 0.06 km^2, however, it is partially covered with vegetation. On the recent image, footage of past river channels can be seen. It is relatively narrow and long temporary island. The behavior of river is highly dynamic at this location with frequent lateral shifting of main course. Prior to year 1990, the main channel was flowing towards left side and minor towards right side. Prior to year 1980, the island did not exist. At the outset, it can be concluded that it is highly unstable island. The island as in year 2015 is shown in Figure 11.3.

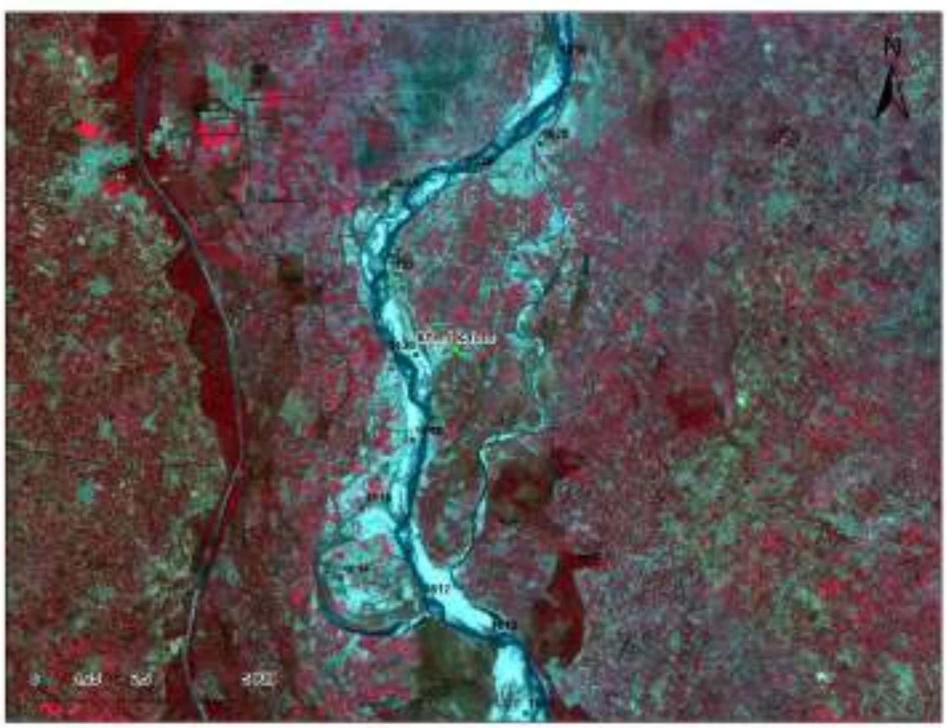


Figure 11.3 View of Kheri Kalan island downstream of the CC barrage on LISS IV image of year 2015

3. Paindapur Ahatmali (Downstream of Garhmukteshwar)

It is located 10 km downstream of Garhmukteshwar. It is relatively small island with major channel of the river is flowing towards right side where a small creek is flowing towards left side. There is no habitation on this island and partial vegetation can be seen. Prior to year 2000, the island did not exist. This is a temporary island as it washes away frequently. The island as in year 2015 is shown in Figure 11.4.

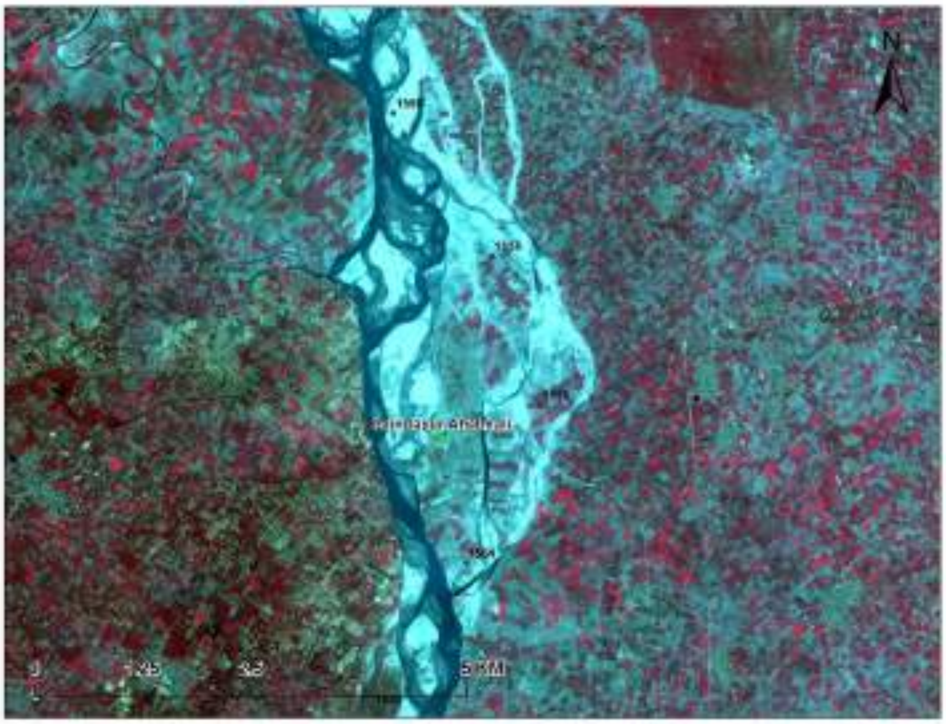


Figure 11.4 View of Paindapur Ahatmali island on LISS IV image of year 2015

4. Bilona Chhap Khadar (Upstream of Narora Railway bridge)

This island is located 2.5 km upstream of Narora Railway bridge. At present, both the channels that encompass the island are of the same order at this location. There is no habitation, however, partial vegetation can be seen on this island. Historical images indicate that earlier, the river was flowing in only one channel towards left side from the present condition of the island. However, in year 2010 another channel was flowing towards right side. Prior to year 1990, the island did not exist. This is a highly unstable island. The island as in year 2015 is shown in Figure 11.5.

Figure 11.5 View of Bilona Chhap Khadar island on LISS IV image of year 2015

5. Nagla Mahaji (Upstream of Kachhla bridge)

It is located about 9 km upstream of Kachhla bridge. At present the major channel of the river is flowing towards left side whereas a small creek is flowing towards right side. There is no habitation and vegetation on this island. Prior to year 1980, the island did not exist. Historical images indicate that this is a temporary island which frequently washes away. The island as in year 2015 is shown in Figure 11.6.

Figure 11.6 View of Nagla Mahaji island on LISS IV image of year 2015

6. Kachhla Kham (Downstream of Kachhla bridge)

It is located 5 km downstream of Kachhla bridge. At present major channel is flowing towards right side while a small spill creek is towards left side. No habitation and sparsely vegetation is present on the island. Historical images indicate that river possess extremely dynamic behavior at this location which has resulted in frequent lateral shifting of main course of river in a wide width. The area of this island in year 1980 and 1970 was very less. The island is temporary and unstable which washes out frequently. The island as in year 2015 is shown in Figure 11.7.

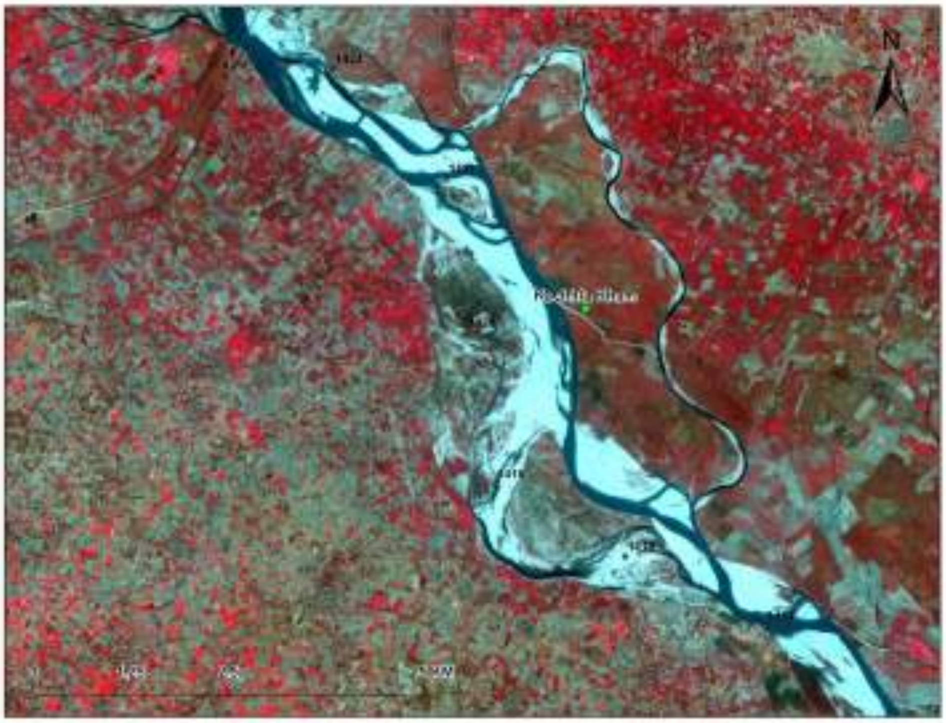


Figure 11.7 View of Kachala Kham island on LISS IV image of year 2015

7. Karimnagar (Near Patiyali)

It is located 52 km downstream of Kachhla bridge. At present, the river is flowing in multiple channels at this location. The major channel is flowing towards left side. Habitation is in small area (200 m × 200 m) on this island. In year 1990, there was no such island at this location. However, in year 2000 an island can be seen and that island even existing today. This island is existing from last 20 years but it gets submerged even in moderate flood. The island as in year 2015 is shown in Figure 11.8.

Figure 11.8 View of Karimnagar island on LISS IV image of year 2015

8. Jati (Near Patiyali)

It is located just downstream of Krimnagar island. This island has formed due to meandering behavior of the river. At present, river channel is flowing towards right side and a small creek is on the left side. There is no habitation and vegetation on this island. Historical images indicate that main course of the river was towards left and a small creek was towards right in the year 2010. The island was not there in years 1970 and 1980. This is highly unstable island as river keeps on changing the path at this location. The island as in year 2015 is shown in Figure 11.9.

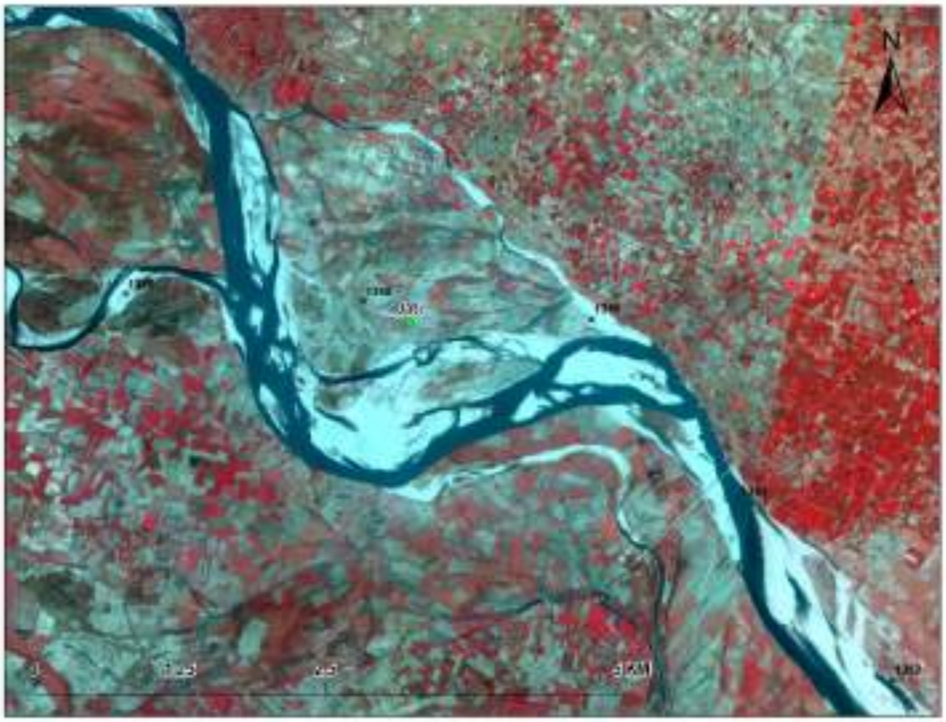


Figure 11.9 View of Jati island on LISS IV image of year 2015

9. Doshpur (Downstream of Jati)

It is located near Karimganj in Uttar Pradesh. This is a relatively big island. At present, the major channel is flowing towards right and a small creek towards the side. There is no habitation and major vegetation on this island. Footage of the channel of the river channel can be seen on the recent image of the island. Historical images as shown in Fig. 11.10a-f clearly indicate that this is a temporary island as river keeps on shifting laterally.

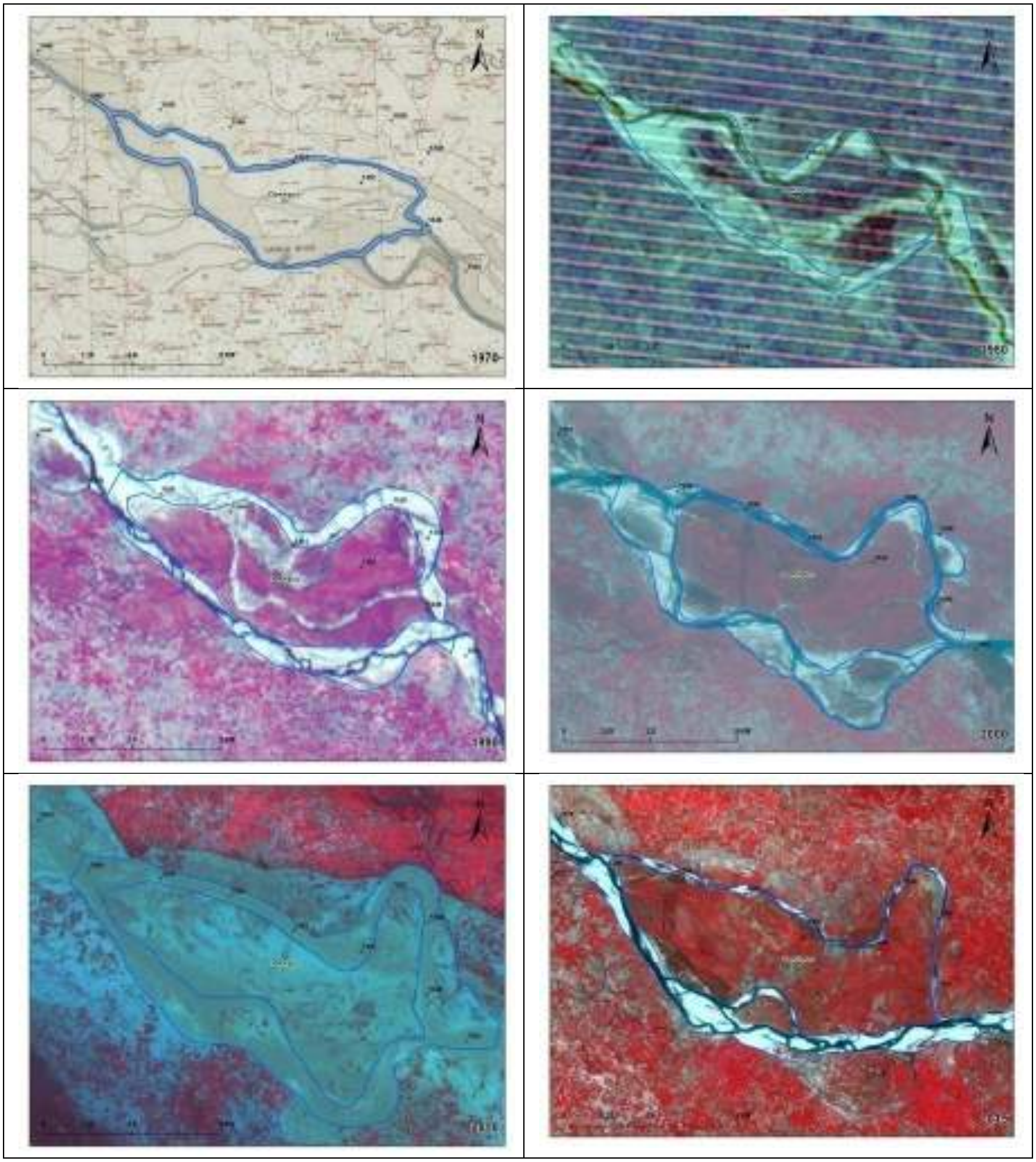


Figure 11.10a-f View of Doshpur island on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

10. Harisinghpur Tarai (Near Shamsabad)

It is a small island located about 10 km downstream of Doshpur. It can be seen on the image of the year 2015 only. Prior to year 2015, this island did not exist. There is no habitation and major vegetation on this island. The island as in year 2015 is shown in Figure 11.11.

Figure 11.11 View of Harisinghpur Tarai island on LISS IV image of year 2015

11. Katri Rajepur Shaidpur (Near Shivrajpur)

It is located about 25 km upstream of Kanpur near Shivrajpur. There is no habitation but partial vegetation on this island can be seen in the recent image. Main channel is flowing towards right side and multiple small channels are towards left side. Historical images indicate that the main course of river was towards right side till year 2000, but image of year 1990 indicates that main course of river was on left side. Footage of past river path can be seen on the recent imagery. This is a temporary island and gets submerged during flood. The island as in year 2015 is shown in Figure 11.12.

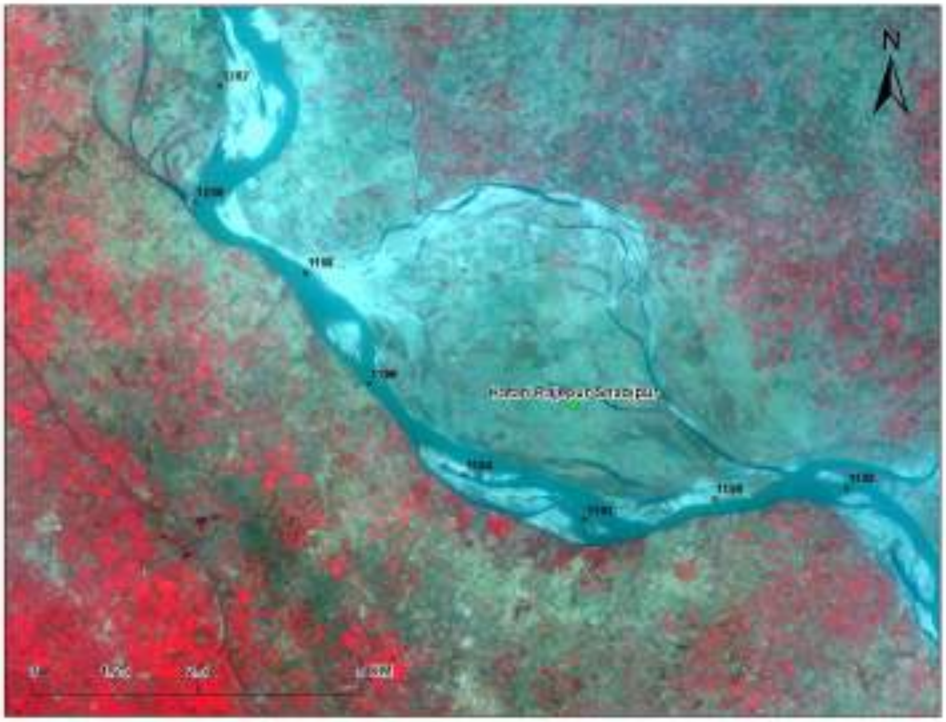


Figure 11.12 View of Katari Rajepur Shadipur island on LISS IV image of year 2015

12. Balhipur (Upstream of Kanpur)

It is located just downstream of Katri Rajepur Shaidpur island. It is relatively a small island where main channel is flowing towards right and a small creek is flowing towards left side. There is no habitation and no major vegetation on this island. Historical images show highly dynamic behavior of river at this location. In year 1980, island was seen at slightly downstream from the present position. This is a temporary island with no habitation. It recent image can be seen in Fig. 11.13.

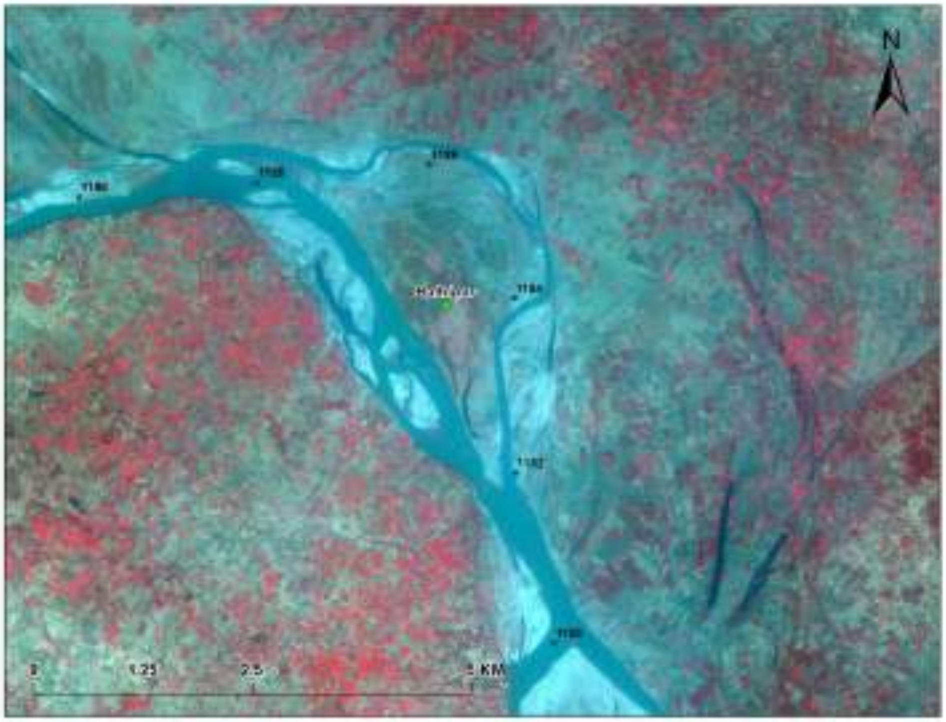


Figure 11.13 View of Balhipur island on LISS IV image of year 2015

13. Ktari Baithoorkala (Upstream of Kanpur)

It is located 13 km upstream of Kanpur barrage near Ktari Baithoor Khurd. At present, river is flowing in two major channels encompassing this island. It is a small island of maximum area of one km^2. There is no habitation but some seasonal agricultural activity can be seen on the image. Historical images show that river had flowed in multiple channels in past at this location. There was no island in year 1980 and year 1970 at this location. At the outset, we can conclude that the island is not stable and gets washed away. It recent image can be seen in the Fig. 11.14.

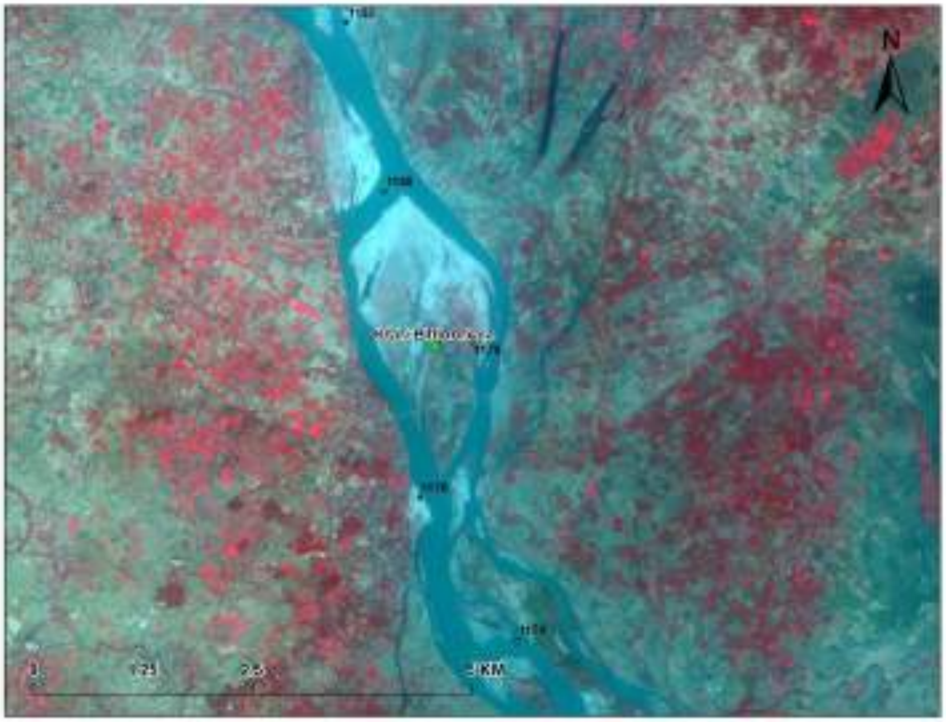


Figure 11.14 View of Ktari Bithoorkala island on LISS IV image of year 2015

14. Gotani Kachar (Near Sirathu)

It is located about 70 km upstream of confluence of Yamuna river and Ganga river at Allahabad. The major channel of river is flowing towards right and a minor channel is flowing towards left side of the island from very long time. There is no habitation on this island. It is a relatively stable island and does not wash away completely. Its recent image can be seen in Fig. 11.15.

Figure 11.15 View of Gotani Kachar island on LISS IV image of year 2015

15. Fatehpur Pershakhi (Near Kunda)

It is located about 60 km upstream of Allahabad near Benti lake. At present, the main river channel is flowing left side and a small channel is flowing towards right side of the island. There is no habitation but sparse vegetation can be seen in the recent of the island. Footage of past channels can be seen on the recent image. This island is there in one form or the other from long time and gets submerged during flood. Its recent image can be seen on Fig. 11.16.

Figure 11.16 View of Fatehpur Pershaki island on LISS IV image of year 2015

16. Jirat Lawaen Gairabad (Downstream of Allahabad)

It is located downstream of Allahabad. At present, river is flowing in two channels encompassing the island. It is not habitated and vegetated. Historical images indicate that there is not much change in the course of river and the island exists from a long time. In year 1980, there was dense vegetation on this island. Recent image of the island is shown in Fig. 11.17.

Figure 11.17 View of Jirat Lawaen Gairabad island on LISS IV image of year 2015

17. Ramchandipur (Downstream of Varanasi)

It is located about 10 km downstream of Varanasi. At present, river is flowing in two channels encompassing the island. The main channel is flowing towards right side and minor channel is flowing towards left side. This island is highly habitated and partially vegetated. Historical images as shown in Figs. 11.18a-f indicate no major change in the shape and size of island over the years. It is relatively narrow and long. In year 1980, this island was covered with dense vegetation. It can be concluded that this island is stable as no major change has been noticed throughout the study period.

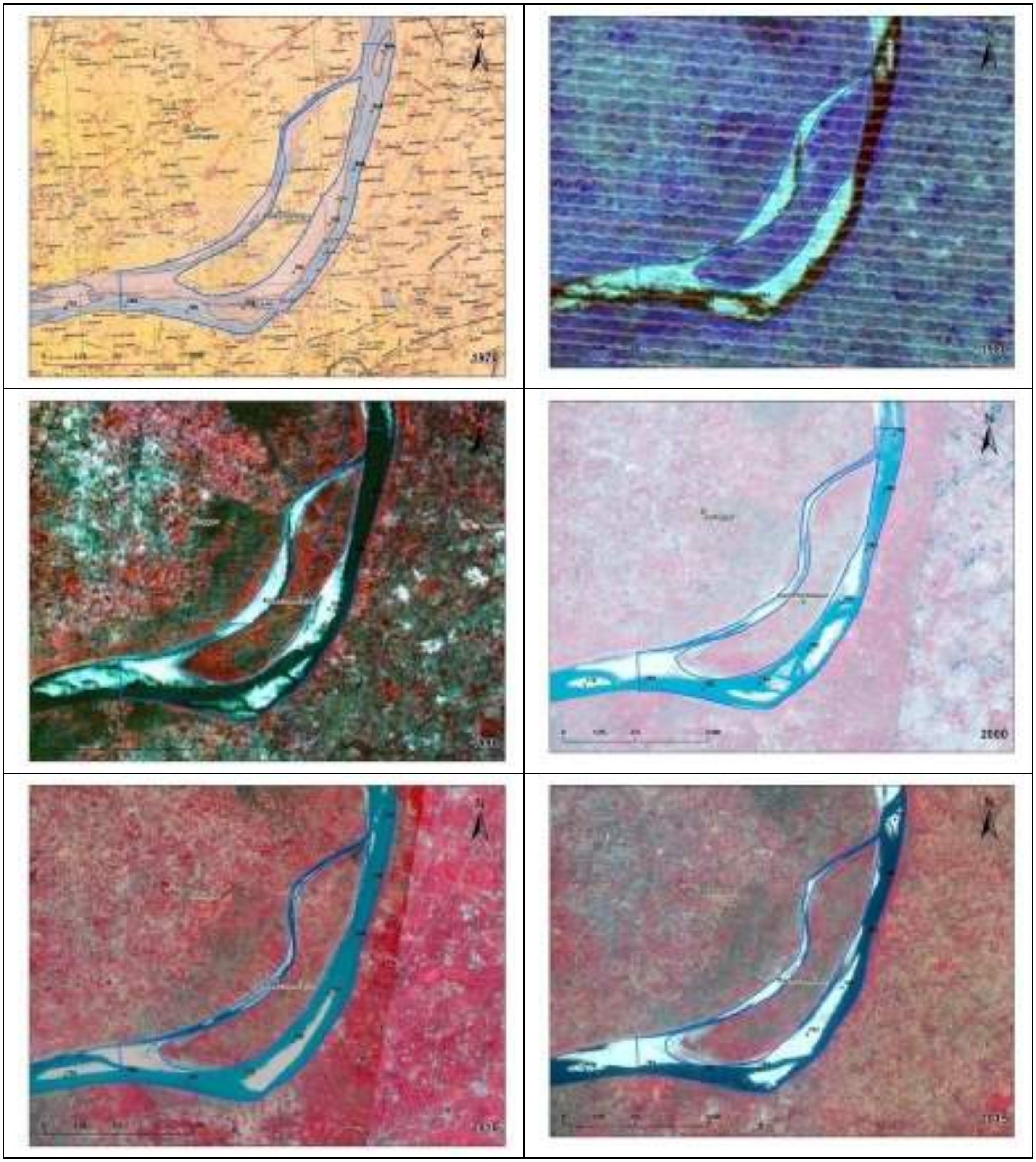


Figure 11.18a-f View of Ramchandipur island on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

18. Umarpur Diyara (Downstream of Buxar)

It is located about 8 km downstream of Buxar. At present, the main channel of river is flowing towards right side and a minor creek is flowing towards left side. There is no habitation and major vegetation on this island. Historical images indicate the river path is almost same from year 1970 to 2015. There is no major change in path of river channels. The island exists from a long time, however, it shape and size has changed. Growth in the area of the island with time may be seen. It is relatively a stable island. Further, this island gets submerged during the flood time. Its recent image can be seen in the Fig. 11.19.

Figure 11.19 View of Umarpur island on LISS IV image of year 2015

19. Khuthun (Upstream of Balia)

This island is located downstream Umarpur Diyara and upstream of Balia. Major channel of river is flowing towards right side and a minor channel is towards left side. There is no habitation and vegetation on the island. This island is present there from a long time, however, it gets submerged during flood time. Recent image of this island can be seen in Fig. 11.20.

Figure 11.20 View of Khutum island on LISS IV image of year 2015

20. Dayal Chak (Near Chhapra -Doriganj Bridge)

This island is located downstream of confluence of rivers Ganga and Ghaghra near Babura (Bihar). At present, the major channel is flowing towards left side and a small creek is towards right side. Two bridges are constructed across these two channels with embankment in between these two bridges. This island is sparsely habitated and vegetated. The HFL in Ganga river is of the order of 54 m at this location while the ground level of the island level is of the order of 52.5 m. This island gets submerged during flood in the Ganga river. Sone river joins the Ganga river just downstream of this island. Historical images as shown in Figs. 11.21a-f clearly indicate existence of major channel constantly towards left side. Erosion and siltation have been noticed in this island. However, this island is relatively stable from long time with minor changes in its shape and size.

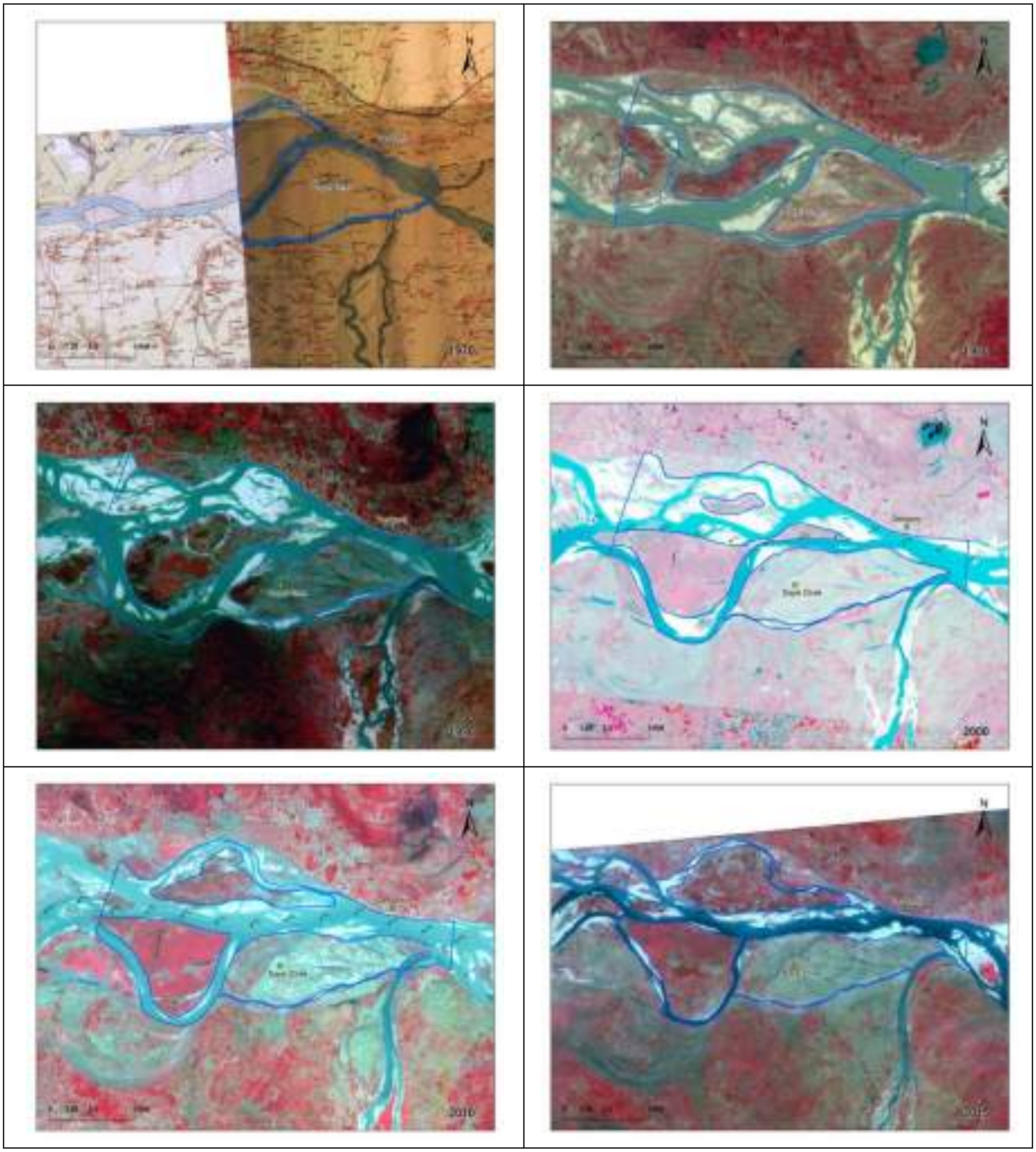


Figure 11.21a-f View of Daiyal Chak on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

21. Panapur (Upstream of Digha Bridge)

This island is located just upstream of the Digha bridge at Patna. At present, the major channel is flowing towards right side and a minor channel is towards left side. This is densely populated and also has vegetation. Prior to year 2000, this island was divided into two parts with a channel of the river passing through it. However, after year 2000, the channel passing through island diminished and it becomes one island. There is no habitation in upper part of this island.

Prior to year 1980, the main course of the Ganga river was flowing towards left side and was passing through Goraipur, Dighwara, Sitalpur etc., before its arrival to Dighaghat. The Ganga river was attacking to its right bank almost normally at Dighaghat. In period 1980 to 2000, the left channel widened while the right channel narrowed down. The major concentration of the flow was in the right channel.

The lower part of island which is just upstream of Digha bridge is more or less stable with minor changes in its shape and size. The area of the island has decreased over the years. However, it gets submerged during flood time as evident from the land pattern of the past images as shown in Figs. 11.22a-f.

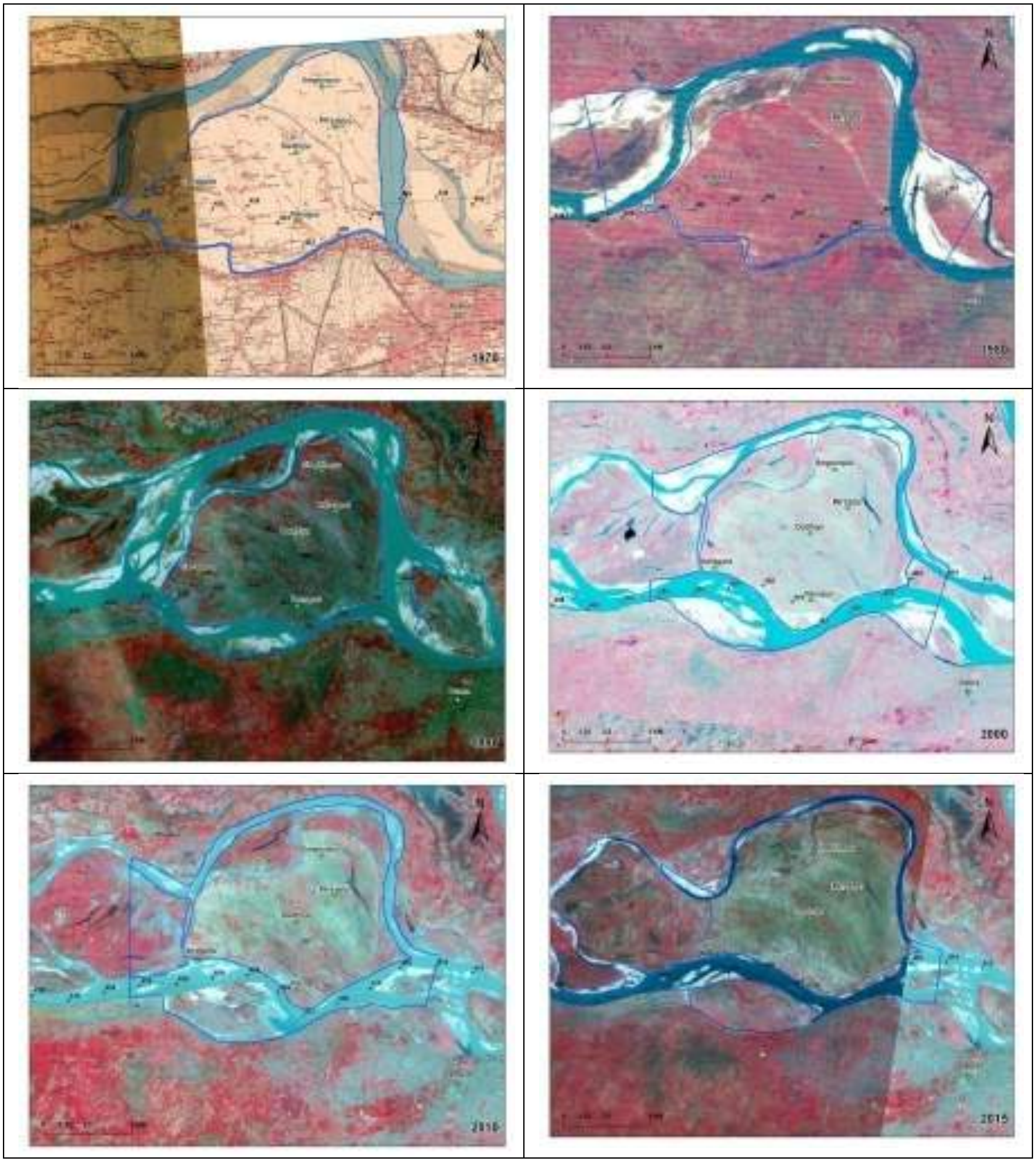


Figure 11.22a-f View of Panapur island on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

22. Raghopur (Downstream of Patna)

It is located about 10 km downstream of Gandhi setu at Patna. This island is highly habitated and vegetated. Ganga river bifurcates at about 8 km downstream of *Gandhi setu* into two channels of more or less same order of size. These two channels after running individually about 32 km re-join again near Bakhtiyarpur. This tendency of the river has formed this island which is about 32 km long and about 7.5 km width and having at an area of 228 km^2. Footage of the channels near its upper and lower parts may be seen on the recent image. A narrow channel of the order of 12 km long can be seen on the recent image which divides the upper portion of the island into two parts. This channel is not active during the lean flow season. A bridge of length 9.7 km connecting *kachi dargah* (Didarganj) towards Patna side and Bidurpur towards left side of Ganga is under construction at this site. The HFL at this location is about 50 m while the average ground level of the island is about 48 m. As evident from the ground survey and the levels, this island gets submerged frequently. It is the largest island in terms of area in the Ganga river. Image of year 2000 indicates that multiple channels were active near its upper and lower parts. A channel passing through Birpur near downstream of island had divided the island into two part. In the year 1990, the area of island has shrunk with multiple channels in upper and lower parts. Image of years 1970 and 1980 (Figs. 11.23a-f) indicate that the left channel was major while right was minor. Major changes in the dynamics of river has been noticed at this location which has resulted in severe erosion and siltation on this island time to time except the core area of the island.

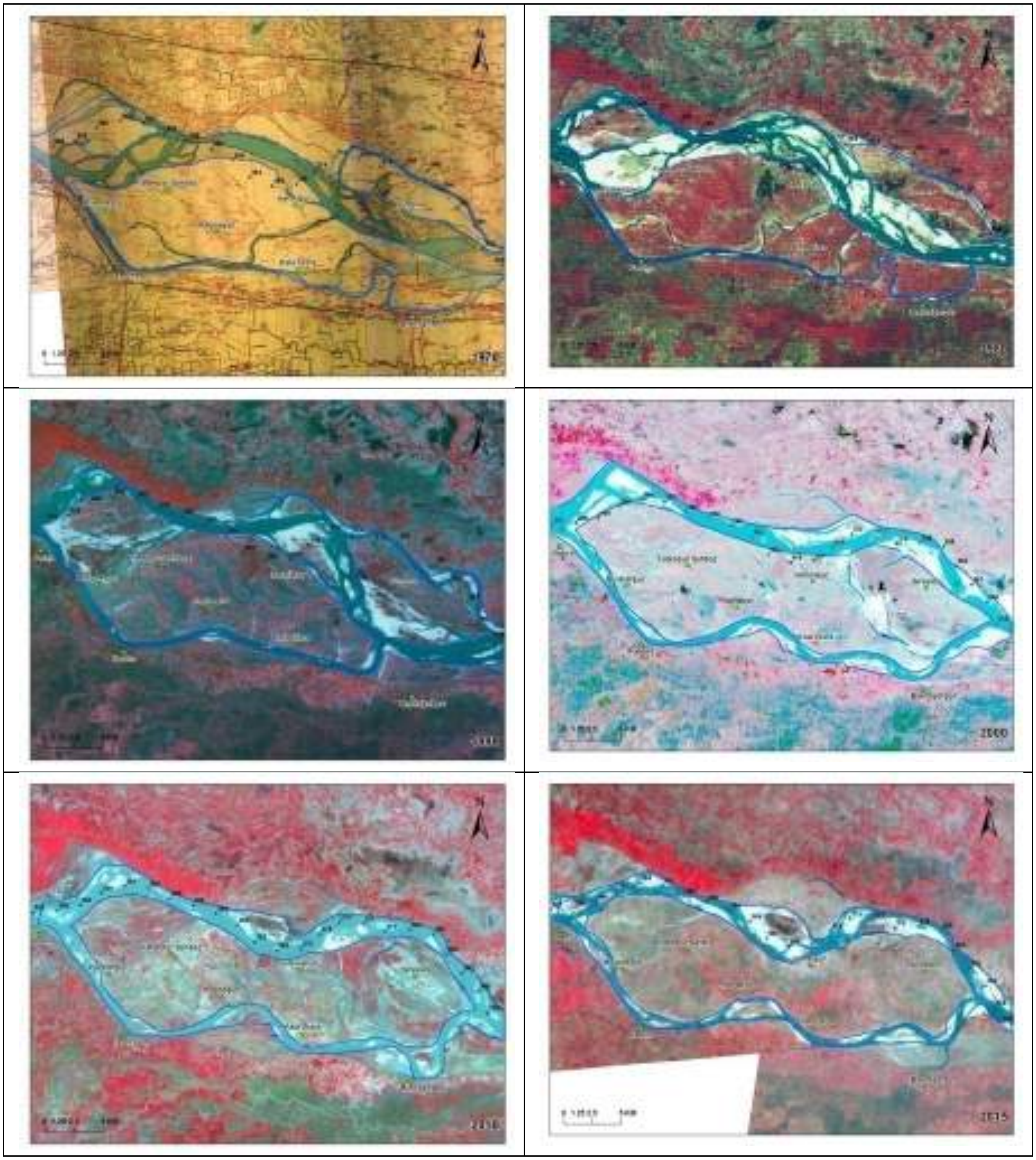


Figure 11.23a-f View of Raghopur island on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

23. Madhurapur (Downstream of Barh)

It is located upstream of Mokama bridge. At present two channels of almost equal size are flowing towards left and right sides of this island. Footage of the river on the recent image indicated that in past the river was flowing through this island. This is not habitated, however, there is sparse vegetation over this island. The river width is narrowed down to about 1.6 km at Mokamah bridge by deploying a guide bund towards left side. The back water induced with these constrictions in the flow may be the root cause of the formation of this island. There is no remarkable change in its shape and size from year 2010 to 2015 (Figs. 11.24a-f). However in year 2010, upper part of the island was a part of deep section of the river. In year 1990, a channel that starts from upstream of the island and going through mid of the island was joining the right channel of the river. SOI toposheet of 1970 and satellite images of year 1980 also indicate existence of this island. The land pattern as depicted by satellite images indicates that this island gets submerged during the flood. It may also be noticed that the area of this island has increased over the years.

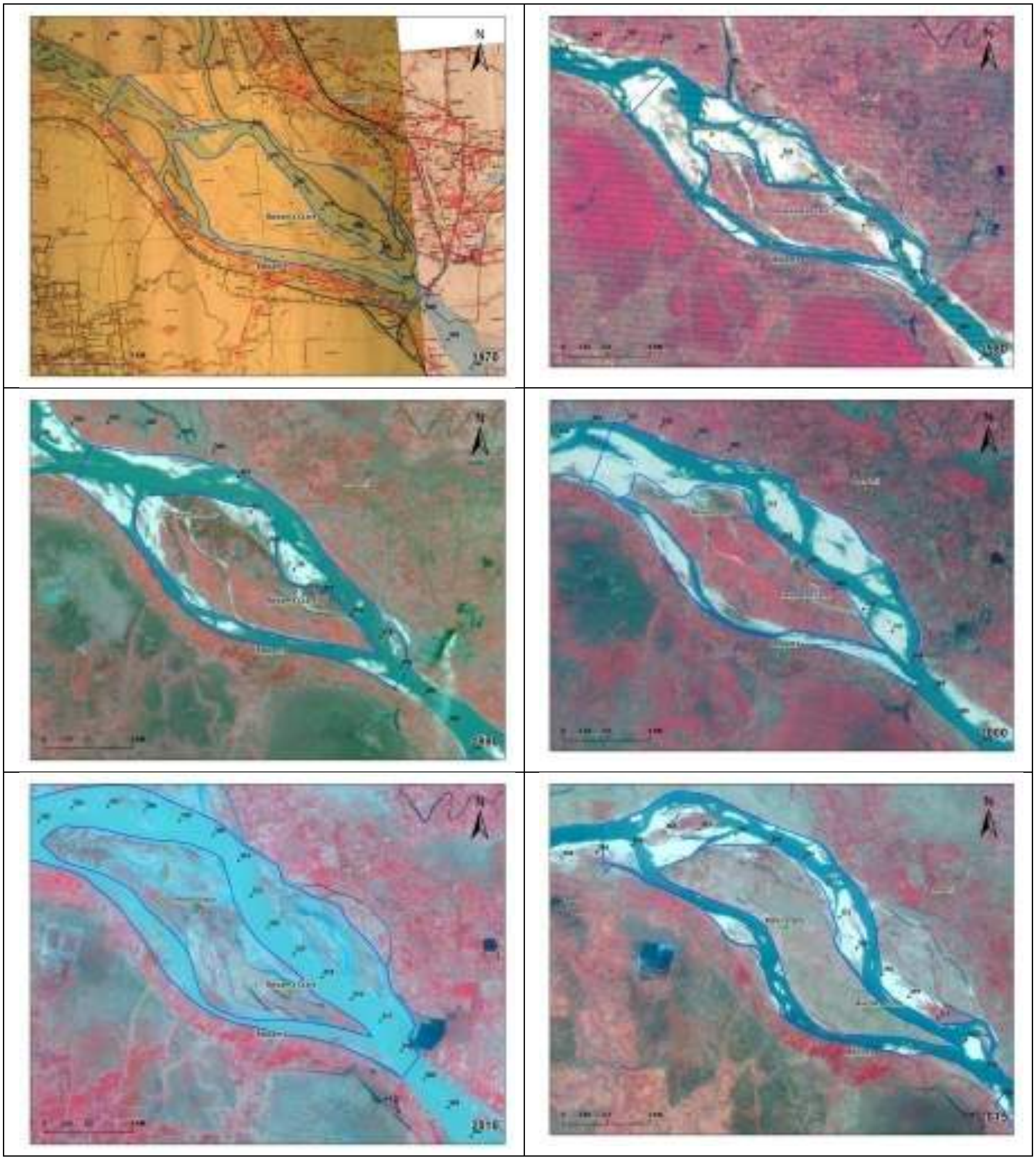


Figure 11.24a-f View of Madhurapur island on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

24. Ratipur (Near Bhagalpur)

It is located near Bhagalpur. At present major channel is flowing towards left side and multiple minor channels in form of spill channel may be seen towards right side. This island is sparsely habitated and vegetated. Footage of multiple channels passing through almost all the area of island can be seen on the recent image. Footage of the multiple channels over this island is more prominent on the image of year 2010. The shape and size of island was almost same as it is today, however, this island did not exist before the year 1990. The major channel of this river was its right side. This is a temporary island which shape and size changes over the year and also washes out. It is recent image is shown in Fig. 11.25.

Figure 11.25 View of Ratipur island on LISS IV image of year 2015

25. Gobrahi Diyara (Near Kursela)

This is located downstream of confluence of Kosi river with Ganga river near Kursela. Formation of this island may be attributed to dumping of the sediment load at the confluence point by Kosi river which brings lot of sediment from its catchment. At present, river is flowing into two channels. One channel is towards left side and another is towards right side. Kosi river joins the left side channel of the Ganga river at upstream of this island. This island is densely habitated and vegetated. Satellite image of year 2010 (Figs. 11.26a-f) indicates there were multiple channels that are flowing towards left side in addition to the main channel. There is no remarkable change in the shape and size of the island from year 2000 to 2010. However, in year 1990 the area of island was relatively less and major concentration of flow was towards left side. SOI toposheet of year 1970 and satellite image of year 1980 indicate existence of this island in those years. As evident from historical images river, the river had shown its dynamism at this location with channel passing through the island.

It may be concluded that the island exists at this location from long time, however shape and size of the island keep on changing with the action of flow.

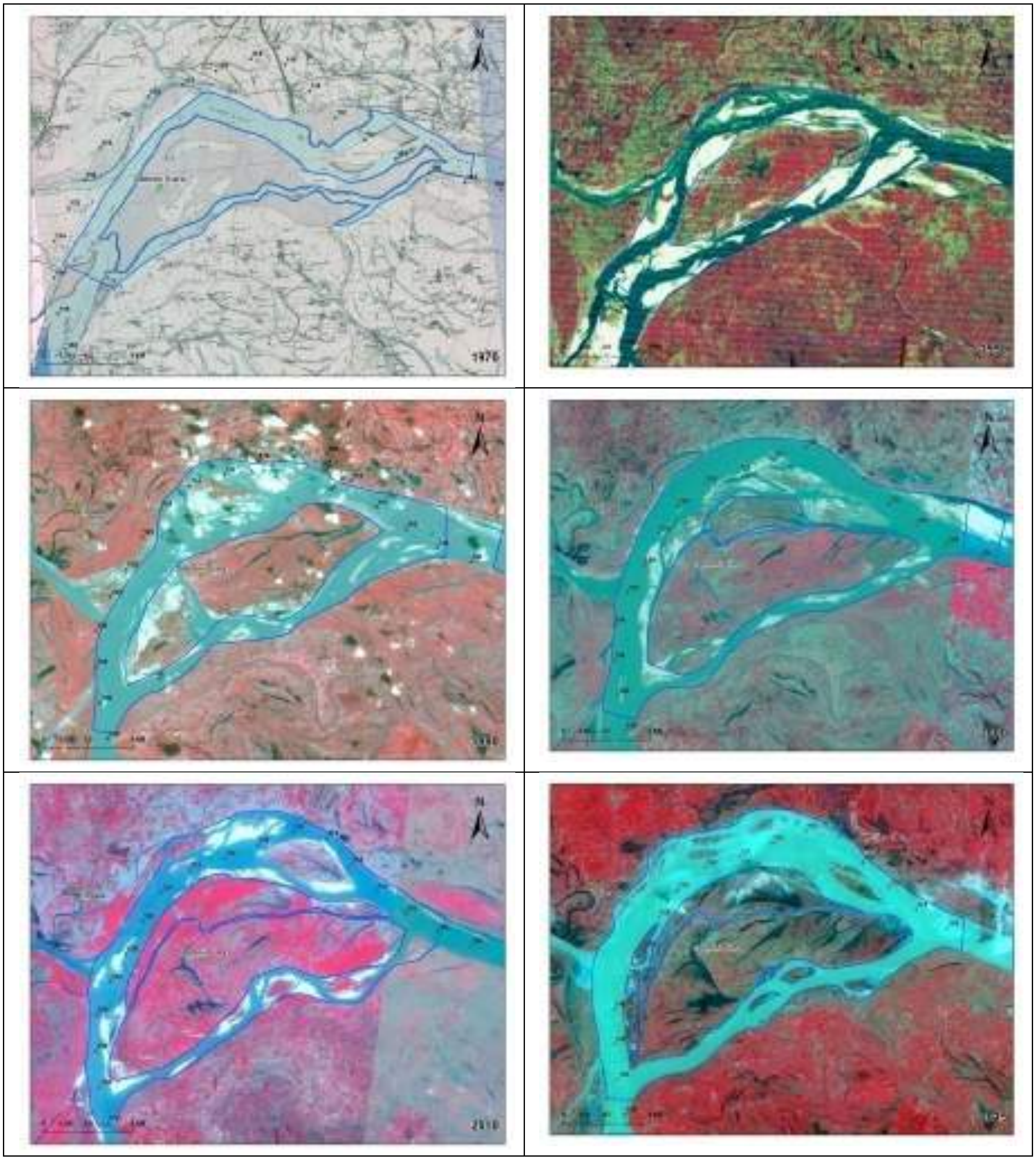


Figure 11.26a-f View of Gobrahi island on LISS IV image of year a) 1970; b)1980; c) 1990; d) 2000; e) 2010 and f) 2015

26. Baijnathpur (Near Manihari)

It is located on the other side of Manihari. At present, major channel is flowing towards left side and a minor spill channel is towards right side of this island. This island is having habitation mainly along a road which runs NW-SE direction. Sparse vegetation may also be seen on this island. In year 2010, the right channel was active and was also passing lean flow discharge as evident from recent images (Fig. 11.27). In year 2000, a channel was dividing the island into two parts. The channel off take from the left channel and joins the right cannel. The island did not exist prior to year 1990. As evident from past images, the river has dynamic behavior at this location. This is a temporary island and washes out frequently.

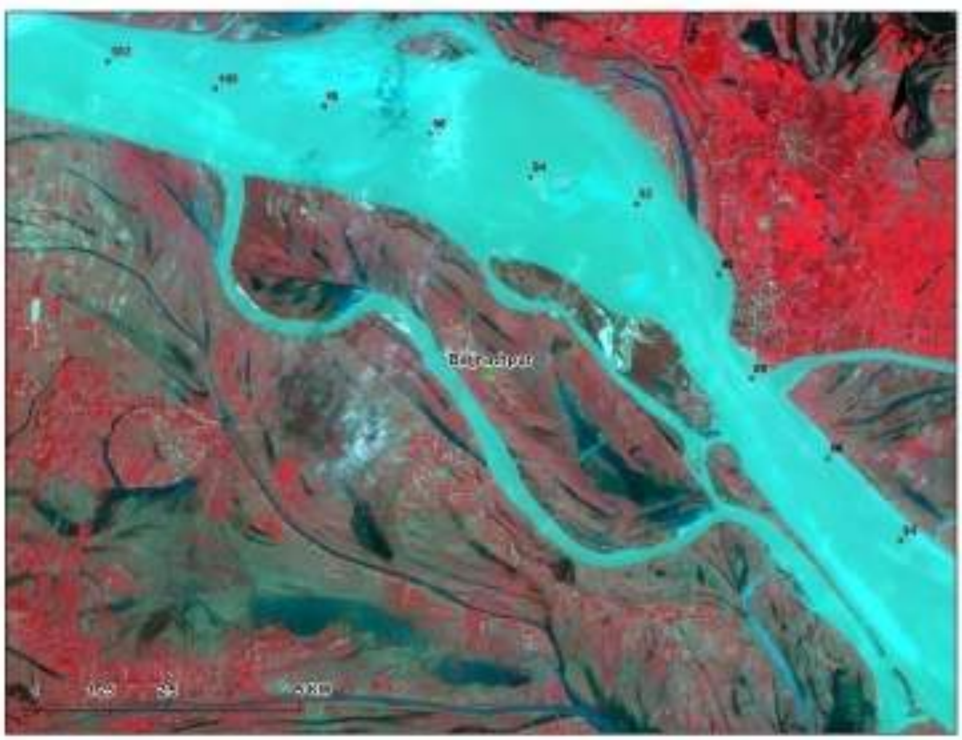


Figure 11.27 View of Baijnathpur island on LISS IV image of year 2015

27. Saidpur, Ramnagar (Sahibganj)

At present this is located other side of Sahibganj. Major channel is flowing towards right and a small channel is flowing towards left side. Sparse habitation can be seen on this island. The river has very dynamic behaviour at this location as evident from the past images. River keeps on changing its path in random way at this location. The island is temporary and washes out frequently. Its recent image may be seen in Fig. 11.28.

Figure 11.28 View of Saidpur island on LISS IV image of year 2015

28. Rambhari (Maharajpur, Sahibganj)

It is located downstream of Sahibganj towards right side near Maharajpur. This is sparsely habitated and there is no major vegetation on this island (Fig. 11.29). At present, major channel is flowing towards left side. Footage of the multiple channels can be seen on the island. Historical images indicate that there is remarkable change in the shape and size of the island over the year. It is existing in one form or other from year 1980, however, it did not exist in year 1970.

Figure 11.29 View of Rambhari island on LISS IV image of year 2015

29. Begamabad (Upstream of Rajmahal)

It is a small island upstream of Rajmahal. A small habitation and almost no vegetation can be seen on this island. River is flowing in multiple channels at this location. Fulahar river joins towards left side to Ganga river at this location. In year 2000, the area of island was bigger than its area in year 2010 and year 2015 (Fig. 11.30). In year 1990, the river was flowing towards right side and the island was attached with land between Fulahar and Ganga river. It did not exist in years 1980 and 1970. This is an unstable and temporary island and its gets submerged during flood as evident from the past satellite images.

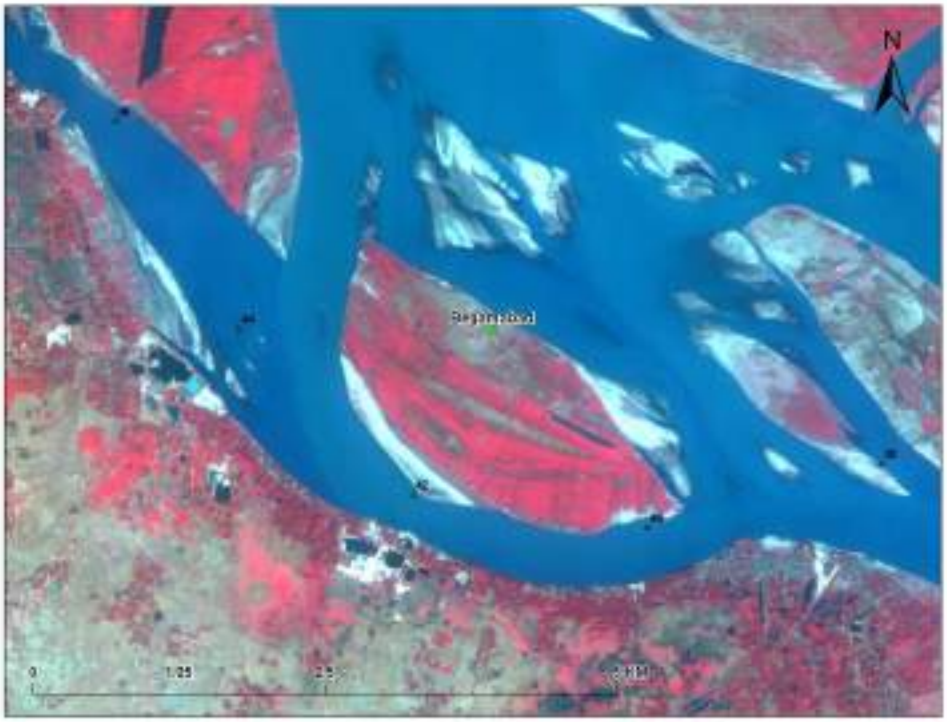


Figure 11.30 View of Begamabad island on LISS IV image of year 2015

30. Jalbalu (Downstream of Rajmahal)

This island is located downstream of Rajmahal. Main channel is towards left and minor channel is towards right side. Footage of multiple channels may be seen on the recent image of the island (Fig. 11.31). There is a small habitation at upper part of this island. sparse vegetation can be seen on the recent image. In year 2010, the shape and size of island was almost same as it is today. However, in year 2000 the right channel was relatively wide. In year 1990, the area of island was low due to dynamism of river. Prior to 1980 it did not exist. It is concluded that it is a temporary island which gets submerged during flood and its area changes frequently.

Figure 11.31 View of Jalbabu island on LISS IV image of year 2015

31. Darijayrampur (Upstream of Farakka Barrage)

It is located 10 km upstream of the Farakka barrage. River is flowing towards right side and a small creek in the form of spill channel is flowing towards left side. This is sparsely habitated and vegetated. A small spill is flowing in the centre of the island and runs almost parallel to the left channel. Footage of river channel can be seen on the recent imagery (Fig. 11.32). It is found that such footage were dominant in year 2010. Image of year 2000 indicates that the area of island was low in that year as river was flowing through major part of this island. In year 1990, it was a very small island surrounded by major channels. The island did not exist in year 1970 and 1980 as evident from the images. It is concluded that this is a temporary island, and river is dynamic in nature at this location.

Figure 11.32 View of Darijayrampur island on LISS IV image of year 2015

11.4 CONCLUDING REMARKS

a) Governing factors of formation of islands are river meandering, braiding, formation of spill channel, erosion and siltation, construction of structures, river training works, confluence of highly sedimented river, geology of the river, sediment yield from the catchment, etc.

b) Some of the islands are permanent in nature with different degree of settlement, while some islands are temporary in nature and can be seen on images for limited duration only.

c) Out of 31 identified islands in Ganga river from Devprayag to Farakka barrage six islands, namely Ramchandipur, Dayalchak, Panapur, Raghopur, Madhurpur and Gobrahi are permanent in nature at least from year 1970. Other islands, like Gotani Kachar, Fatehpur Pershakhi, Jirat Lawaen Gariabad, Khuthun and Umarpur Diyara are moderately stable. Habitated islands are Kheri Kalan, Ramchandipur, Dayalchak, Panapur, Raghopur, Ratipur, Gobrahi Diyara, Baijnathpur, Saidpur Ramnagar, Rambari, Begamabad, Jalbalu and Darijayrampur.

d) Habitated islands pose major resistance to the river flow due to construction of the pucca houses which protrude significantly and results in major obstruction to the flow. Major morphological changes in the river occur near such islands in the form of erosion, shifting of the main course, rise in water level, inundation in nearby areas during flood etc. In view of this, it is recommended that habitation shall not be allowed on the islands that have formed in the rivers irrespective of whether they are permanent or temporary in nature. However, such island can be used for the agricultural purpose with crops of low height.

Chapter 12 EROSION AND SILTATION

12.1 CHANNEL EVOLUTION ANALYSIS

Channel evolution analysis describes the status of the river channel that includes channel dimension, pattern and longitudinal profile identifying distinct river reaches i.e. channel in upper reaches, channel in flood plain, aggradation and degradation, bank erosion etc. Such study is carried out from a field reconnaissance.

The evolution sequence provides an understanding that reaches of a stream may differ in appearance, but channel form in one reach is associated with other reaches by an evolving process. The channel evolution analysis helps in understanding a stream's response to downstream as well as upstream disturbances in the form of morphological changes.

In the present study, the quantification of bank erosion and deposition has been carried out from the satellite images and toposheets. Year 1970 has been considered as base year and the changes have been plotted graphically.

12.2 EROSION AND SILTATION

Erosion and siltation studies have been carried out for the Ganga river from Devprayag to Farakka using the remote sensing techniques. The toposheets and post-monsoon images of years 1970 and 2010 have been used, and the study has been carried out to quantify sediment erosion and deposition for a duration from year 1970 to year 2010. The erosion and deposition have been expressed in the terms of area in km^2.

The extreme left and right banks have been identified based on the sand deposit and vegetation and based on the shifting of these banks, the erosion and siltation have been estimated in the different reaches of the Ganga river.

Suspended sediment load at the various observational sites of the Ganga river has abeen quantified in the terms of metric tonne. Accounting for the sediment inflow from the tributaries between Buxar to Farakka, erosion siltation study in this reach has been carried out based on the mass balance concept.

12.3 RESULTS AND ANALYSIS

Estimation of erosion and deposition have also been carried out in the view of shifting of extreme left and right banks which are being identified on the basis of sand deposit and vegetation. Details of the computed eroded and silted area and also area that were eroded and subsequently silted or otherwise in the period 1970 to 2010 are given in Table 12.1 and also shown in Fig. 12.1. Net erosion and deposition in the each reach of 50 km are shown in Fig. 12.2.

Table 12.1 Erosion and deposition of Ganga river on the basis of shifting of extreme left and right banks

Chainage (km)	Erosion (ha)	Deposition (ha)	Erosion + Deposition (ha)	Net Erosion/Deposition (ha)
0-50	-4289.32	724.00	3402.12	-3565.32
50-100	-5381.91	4658.13	4093.43	-723.78
100-150	-4145.91	10973.13	3769.99	6827.22
150-200	-3004.61	13231.59	5450.95	10226.98
200-250	-2118.45	9999.95	4741.05	7881.50
250-300	-1404.24	1063.55	4103.81	-340.69
300-350	-1580.38	5653.20	1314.52	4072.82
350-400	-1044.42	2161.91	1150.81	1117.49
400-450	-1628.96	1136.23	2727.92	-492.73
450-500	-2527.75	3941.74	4106.60	1413.98
500-550	-1506.72	4675.85	2309.24	3169.13
550-600	-899.28	1694.85	690.36	795.57
600-650	-345.87	1764.76	178.24	1418.88
650-700	-229.89	936.23	28.98	706.35
700-750	-236.53	492.82	215.15	256.29

750-800	-263.38	553.54	25.69	290.16
800-850	-227.29	471.58	14.83	244.30
850-900	-654.12	1298.49	104.22	644.37
900-950	-391.39	1376.94	314.72	985.55
950-1000	-706.26	947.45	1511.31	241.20
1000-1050	-197.71	361.38	414.49	163.67
1050-1100	-165.76	361.311	351.58	195.55
1100-1150	-1063.71	871.722	910.69	-191.99
1150-1200	-525.05	2864.53	1154.23	2339.48
1200-1250	-1152.82	455.92	2314.63	-696.90
1250-1300	-889.097	1210.67	1264.6871	321.57
1300-1350	-414.813	4096.74	1131.719	3681.93
1350-1400	-1325.17	2360.23	2797.689	1035.06
1400-1450	-1044.87	7105.65	1650.489	6060.78
1450-1500	-622.398	3782.85	489.5068	3160.46
1500-1550	-662.921	2399.16	1293.3263	1736.25
1550-1600	-698.62	2399.16	1287.407	1700.55
1600-1650	-1409.39	2495.08	2864.4	1085.70
1650-1700	-1169.68	6602.27	3113.245	5432.59
1700-1750	-745.495	1816.87	999.016	1071.38
1750-1800	-26.13	149.78	61.71	123.65
1800-1824	-0.62	4.3	1.636	3.68
Total	**-44700.92**	**107093.60**	**62354.38**	**62392.68**

* '-' indicates erosion and '+' indicates deposition

1 ha = 0.01 km^2

From the above table, it can be summarized that the total eroded area = 44,700.92 ha, total deposited area = 1,07,093.6 ha and total eroded and deposited area = 62,354.4 ha. Net deposited area is 62,392.7 ha during the period 1970-2010.

Total drainage area of Ganga river is 1.08 million km^2. Thus deposited area per km^2 catchment area = 623.92/1080000 = 0.06 %.

Based on the shifting of extreme left and right banks, erosion deposition maps for each reach have been prepared and the same are shown in the Figs 12.3 to 12.39.

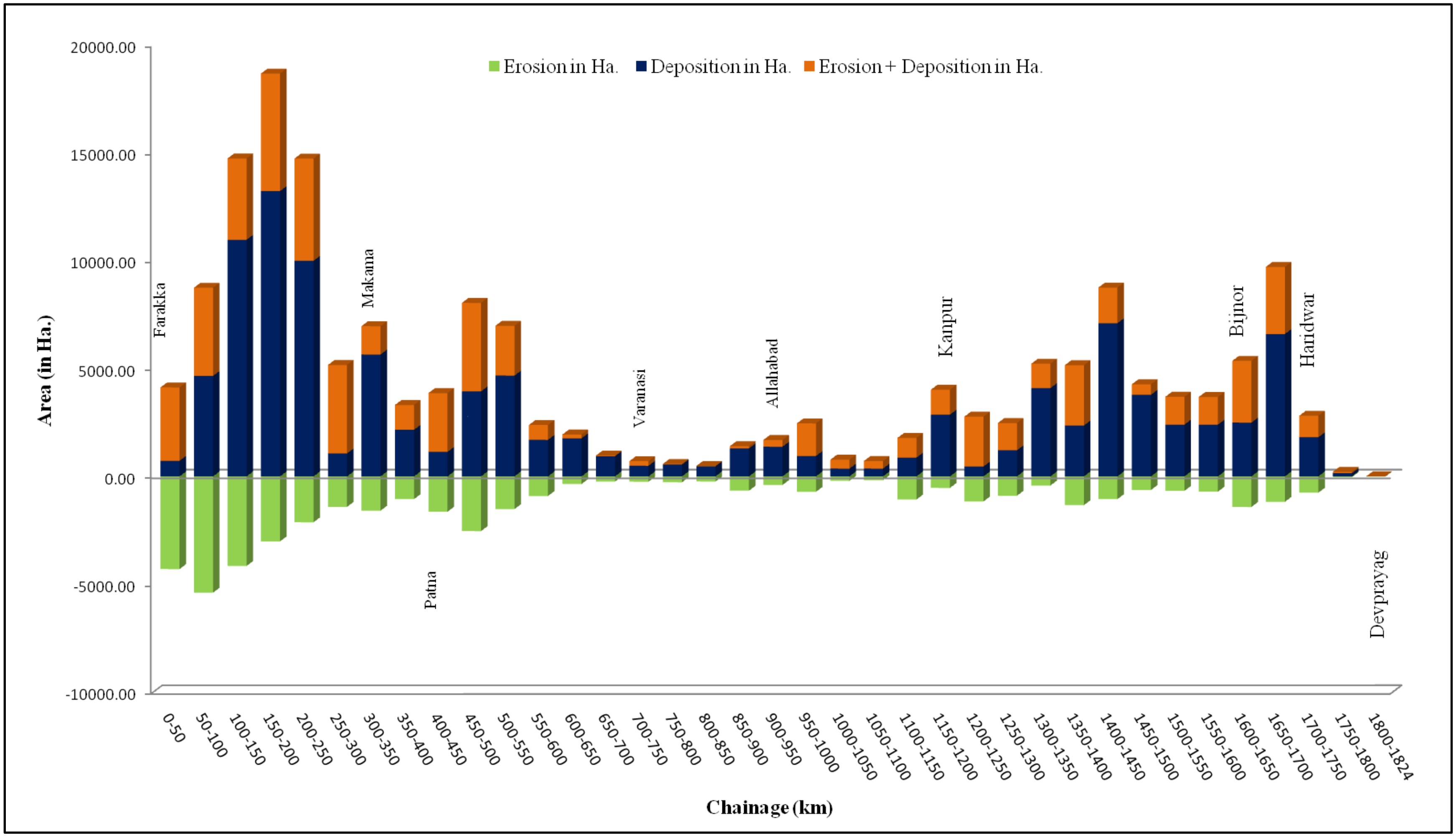


Figure 12.1 Erosion and deposition in Ganga river based on shifting of extreme right and left banks during the period 1970 to 2010

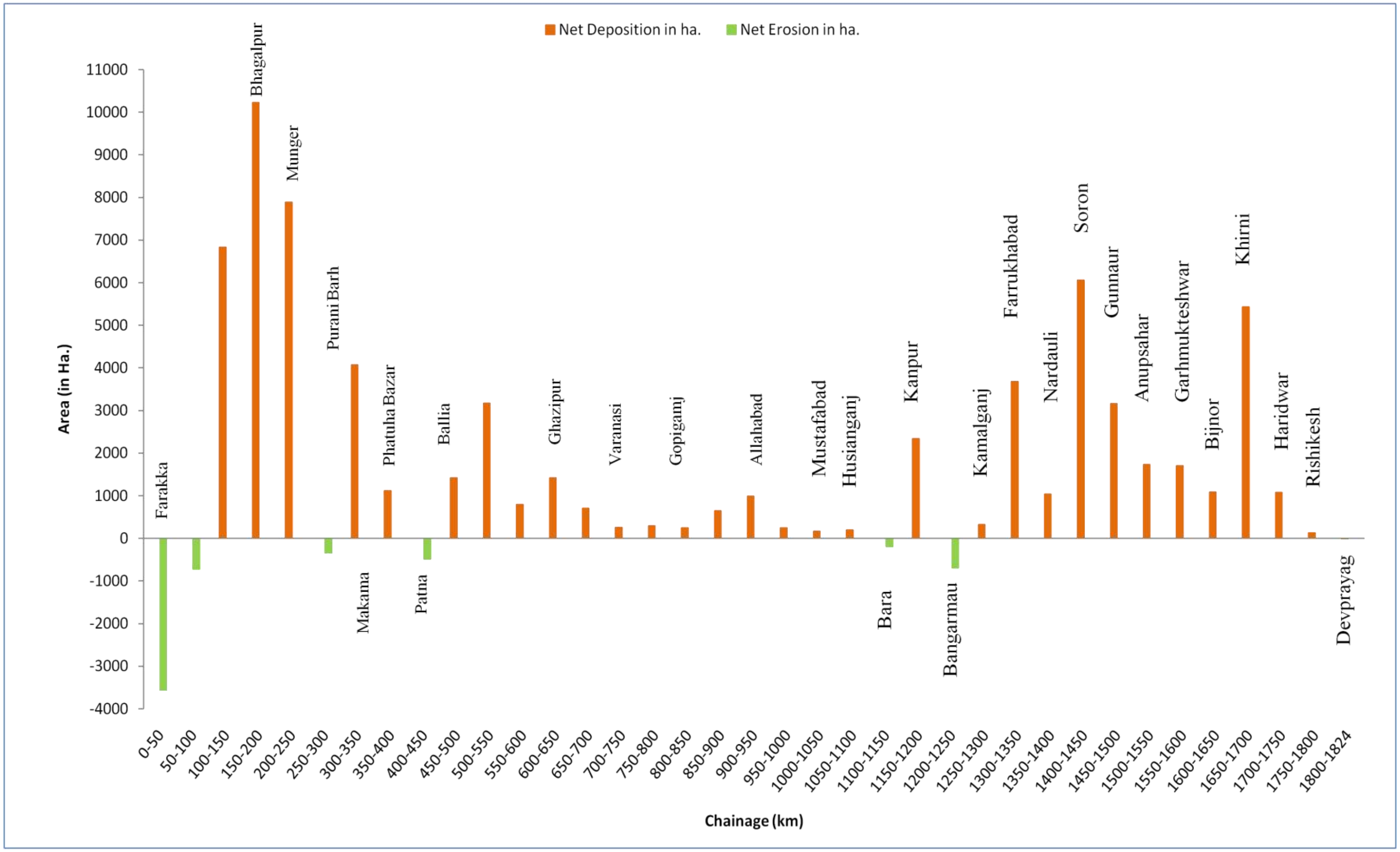


Figure 12.2 Net erosion and deposition in Ganga river during the period 1970 to 2010 based on shifting of extreme right and left banks during the period 1970 to 2010

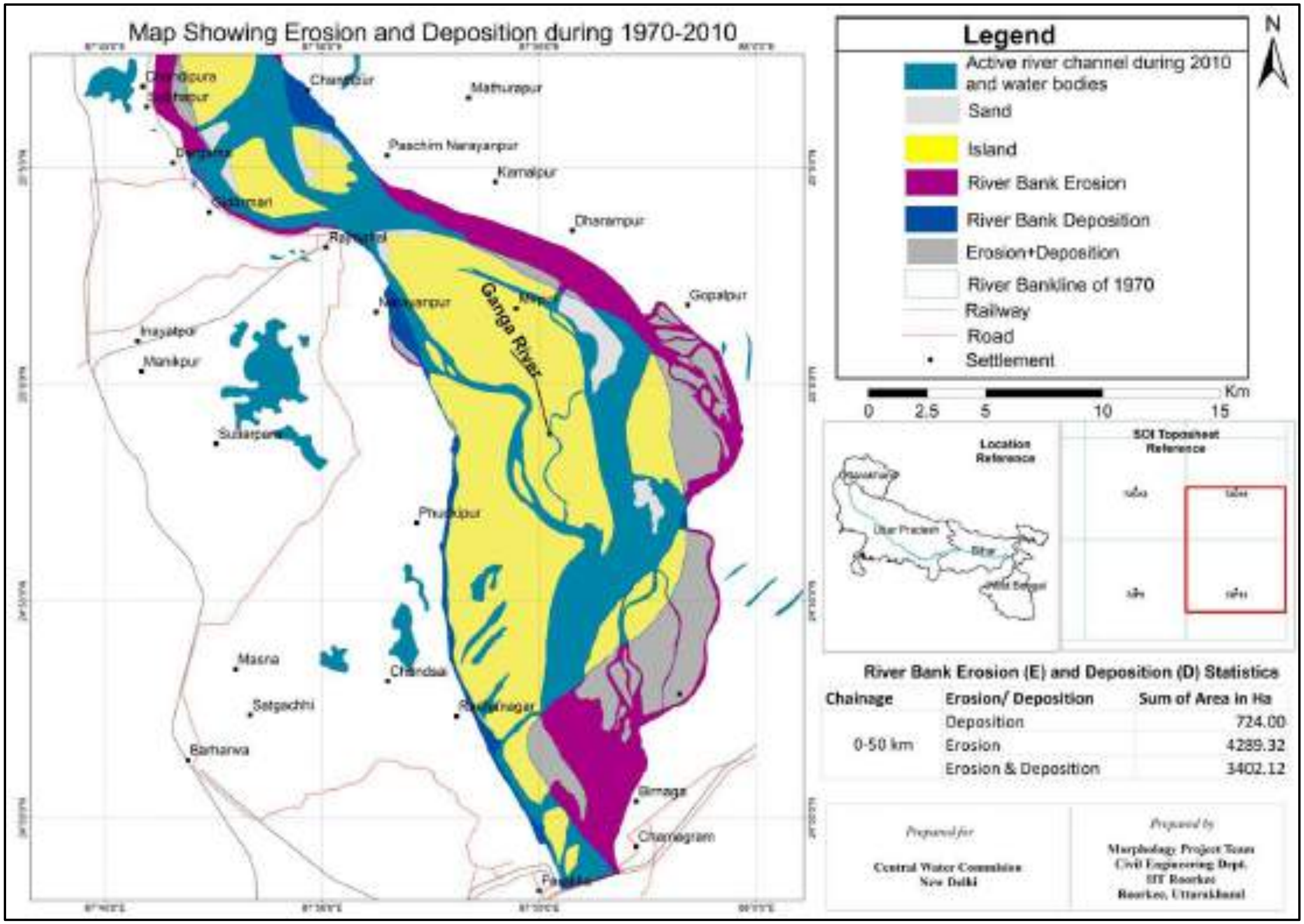


Figure 12.3 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 0-50 km

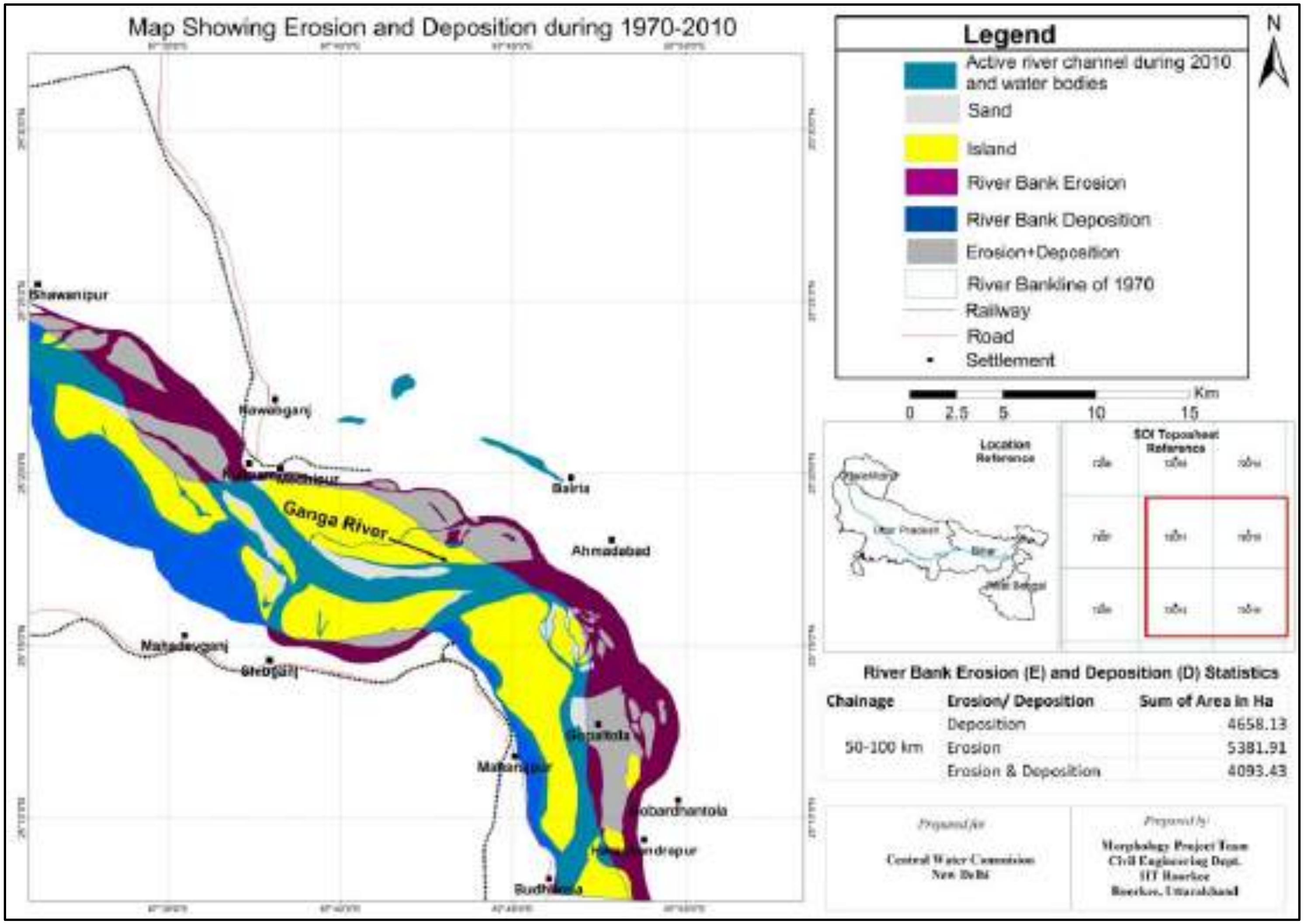


Figure 12.4 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 50-100 km

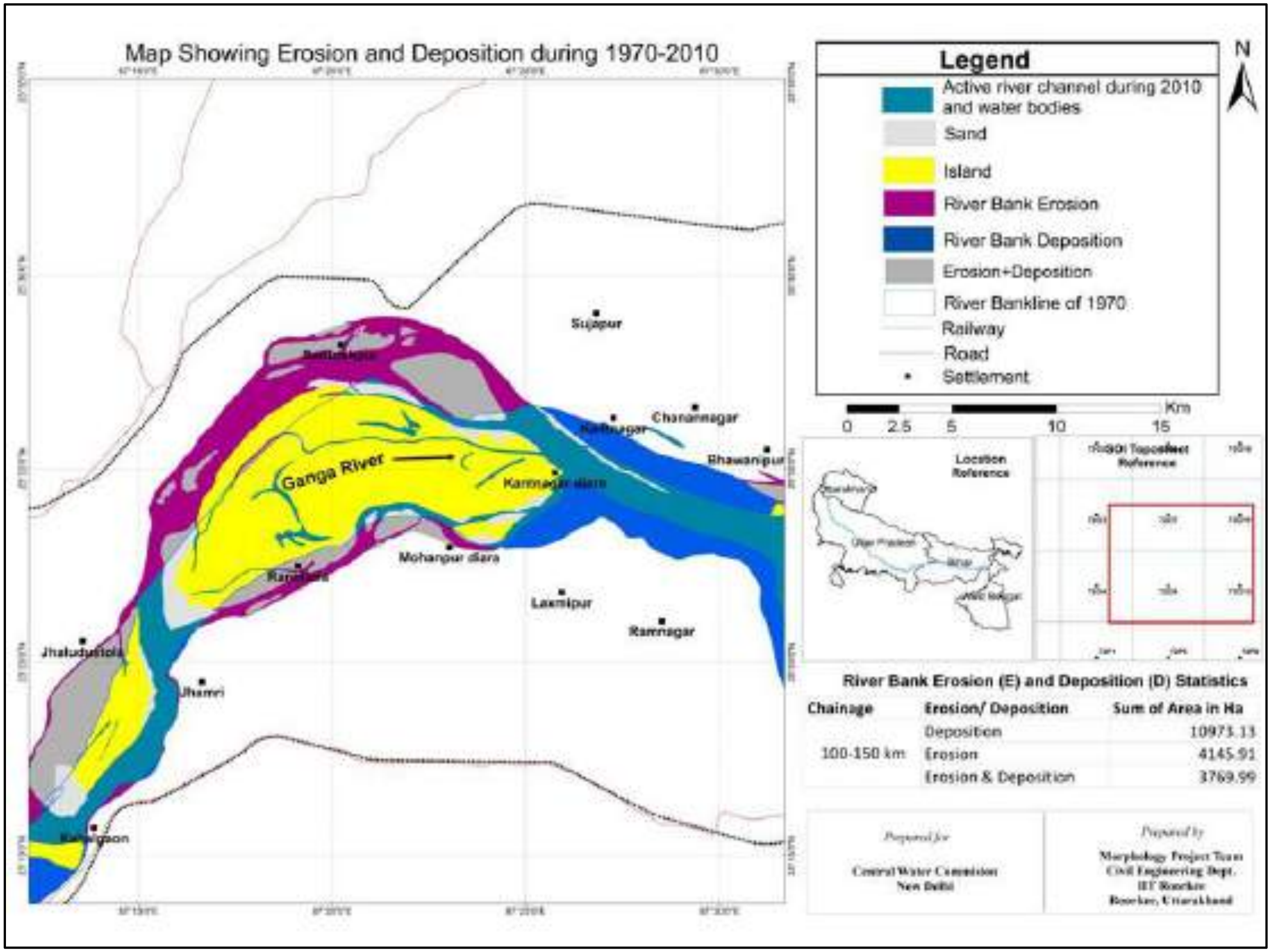


Figure 12.5 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 100-150 km

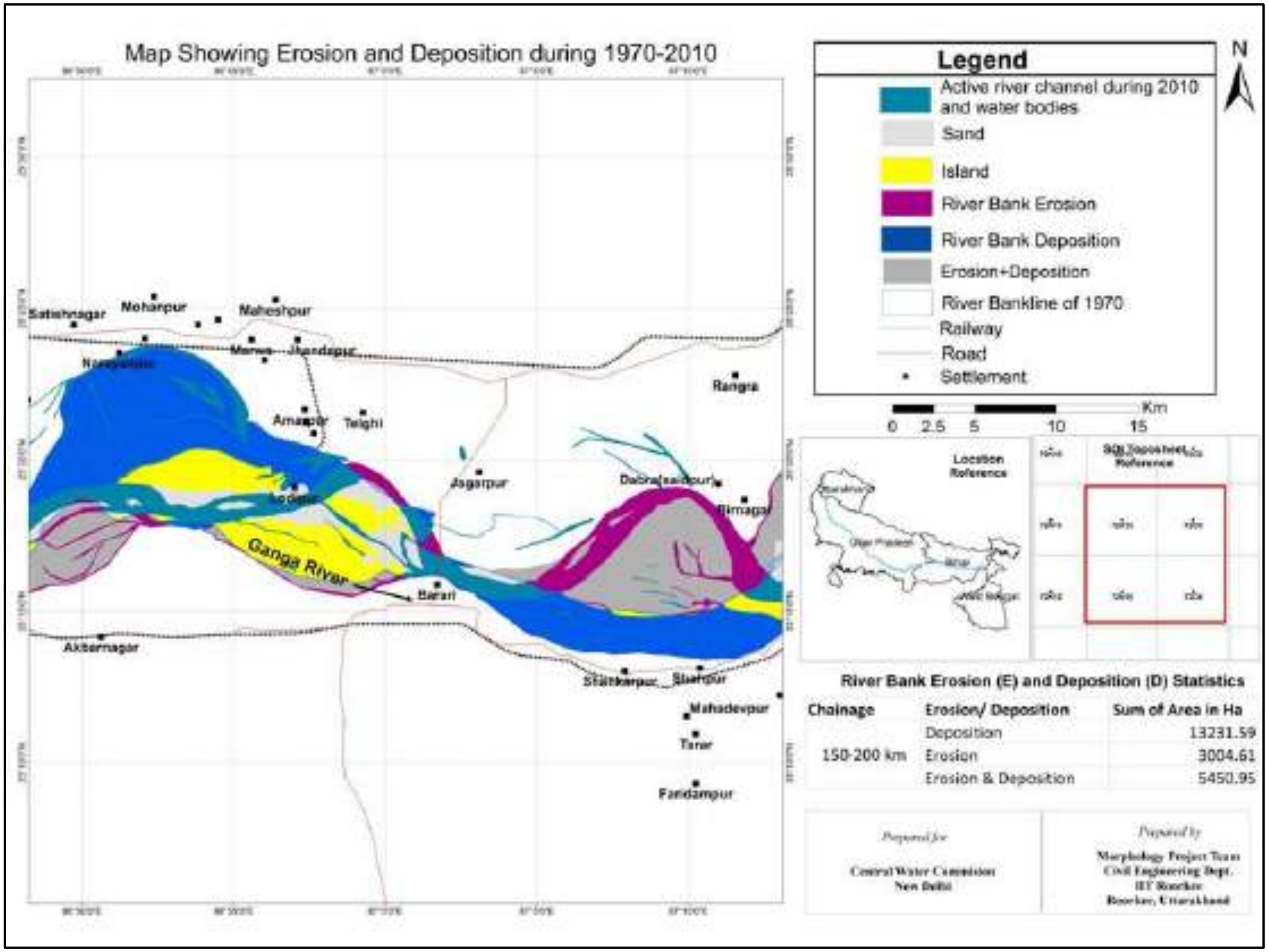


Figure 12.6 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 150-200 km

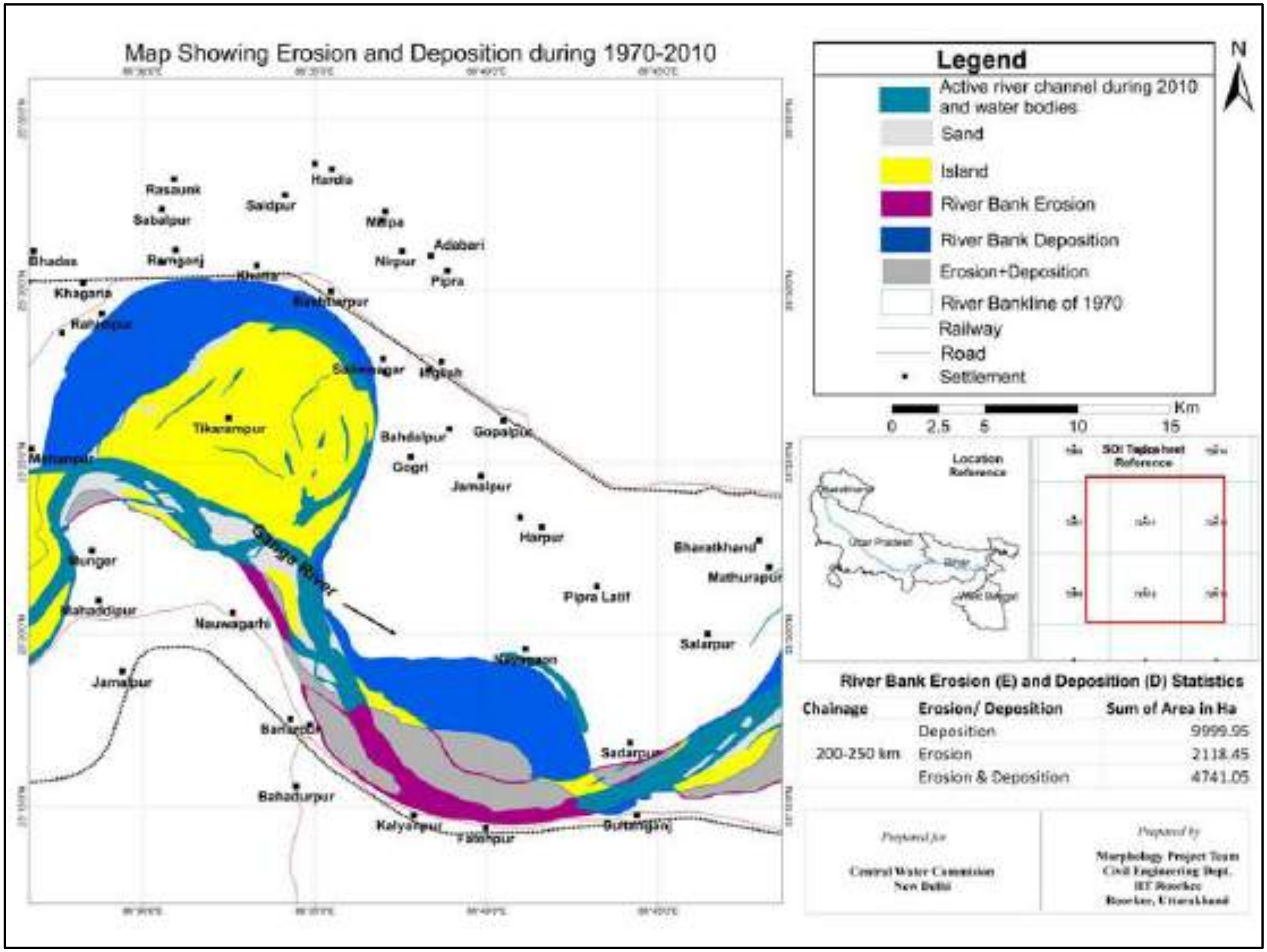


Figure 12.7 Erosion and map deposition map of Ganga river for period 1970-2010 from chainage 200-250 km

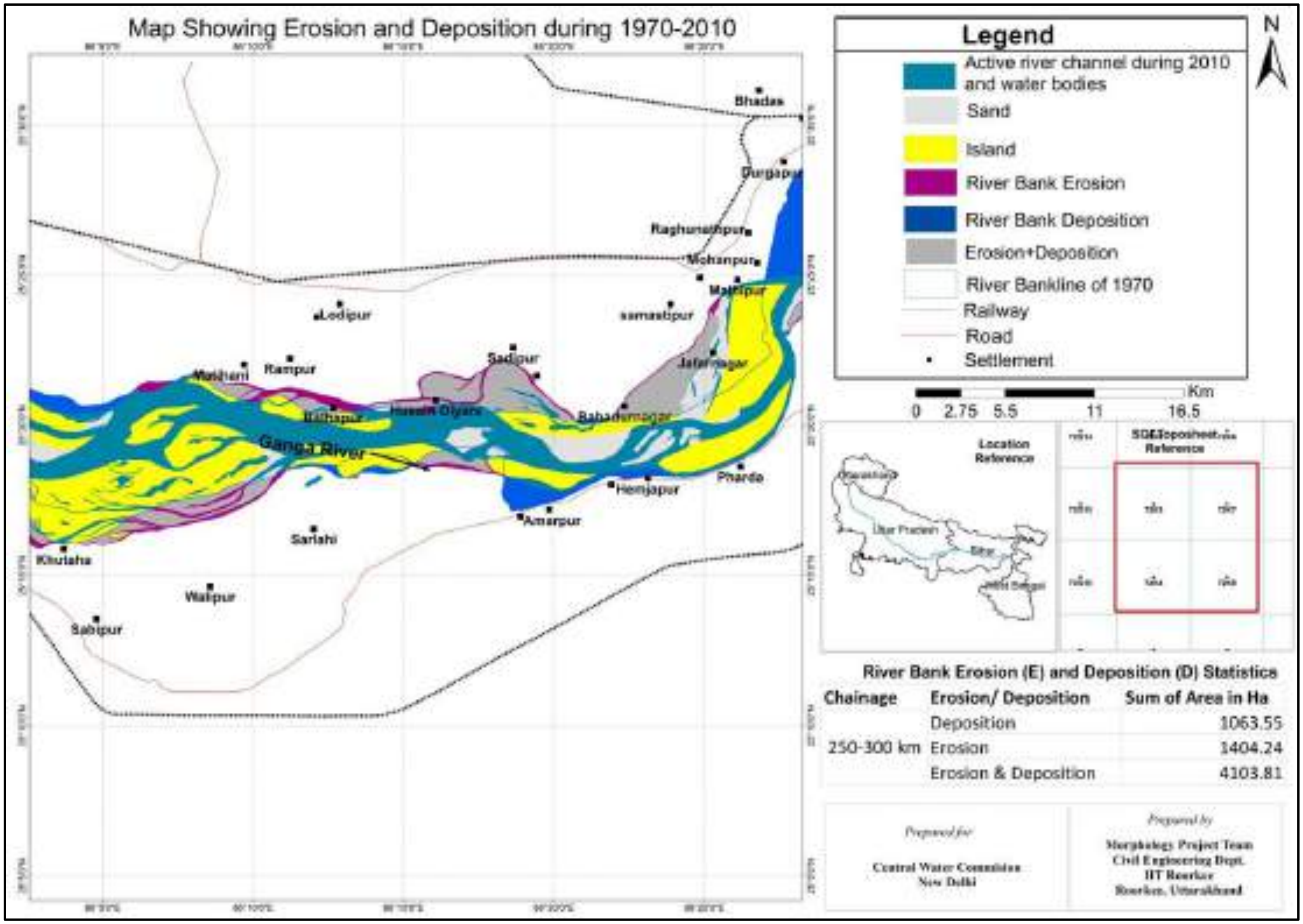


Figure 12.8 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 250-300 km

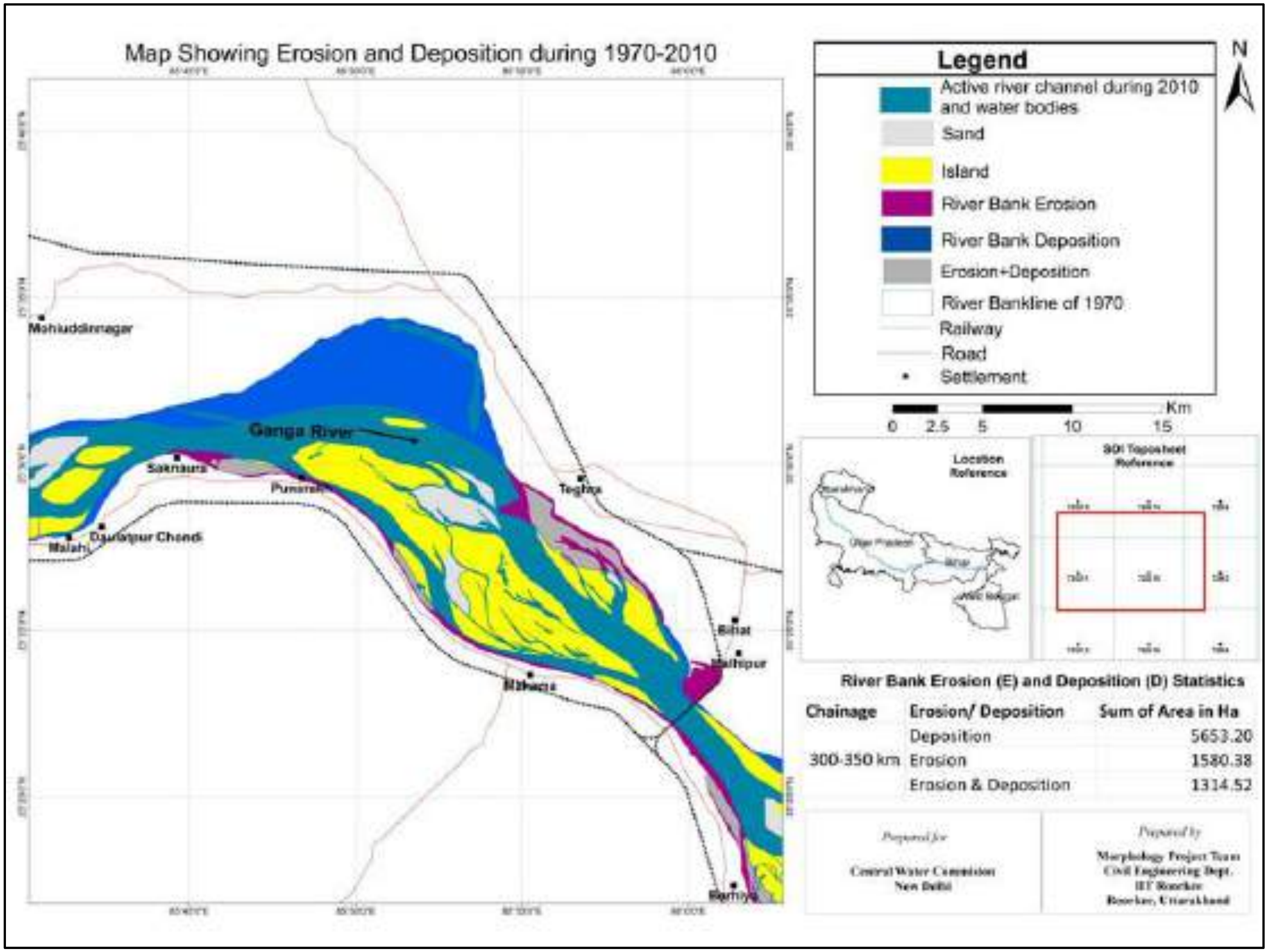


Figure 12.9 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 300-350 km

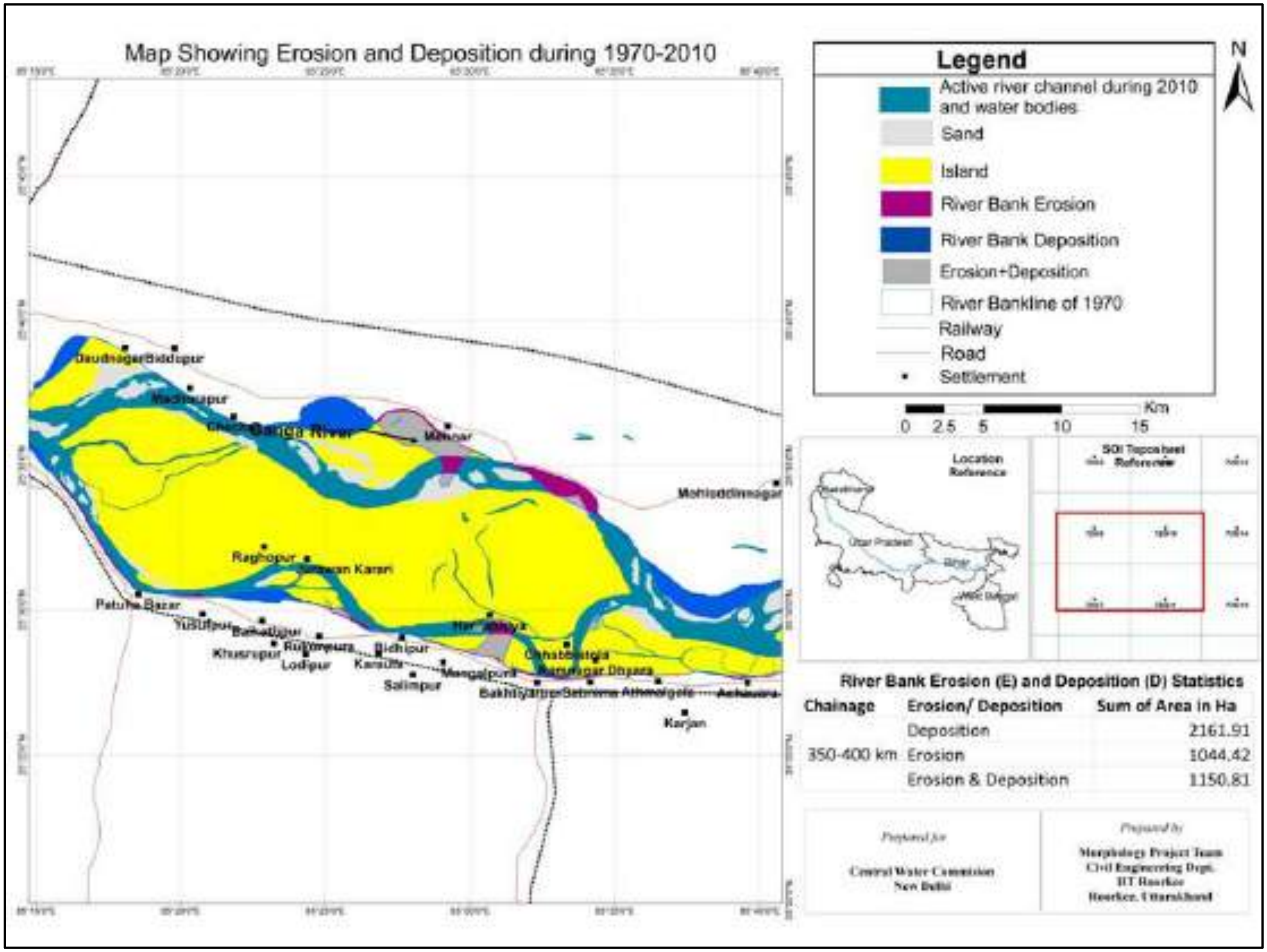


Figure 12.10 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 350-400 km

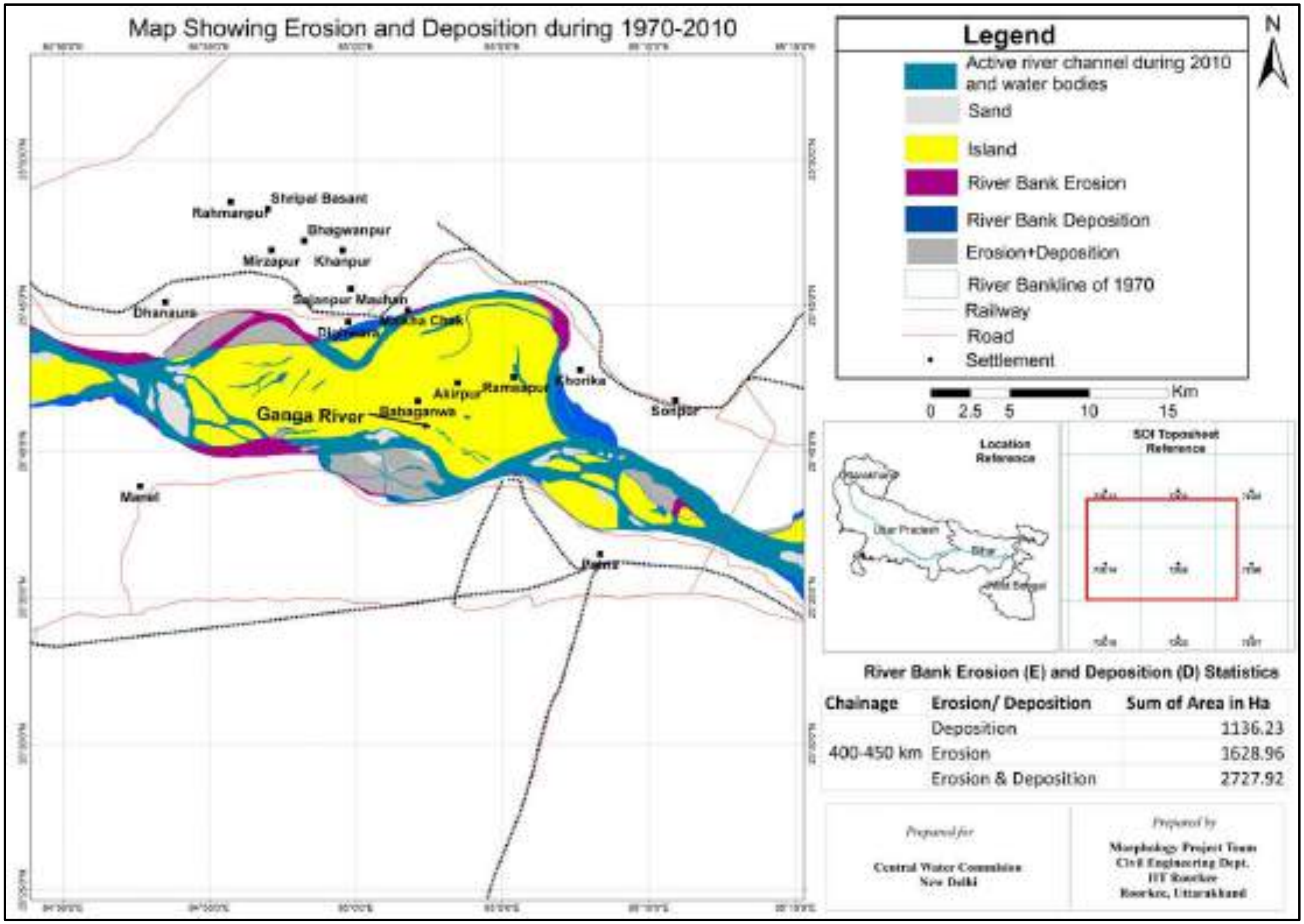


Figure 12.11 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 400-450 km

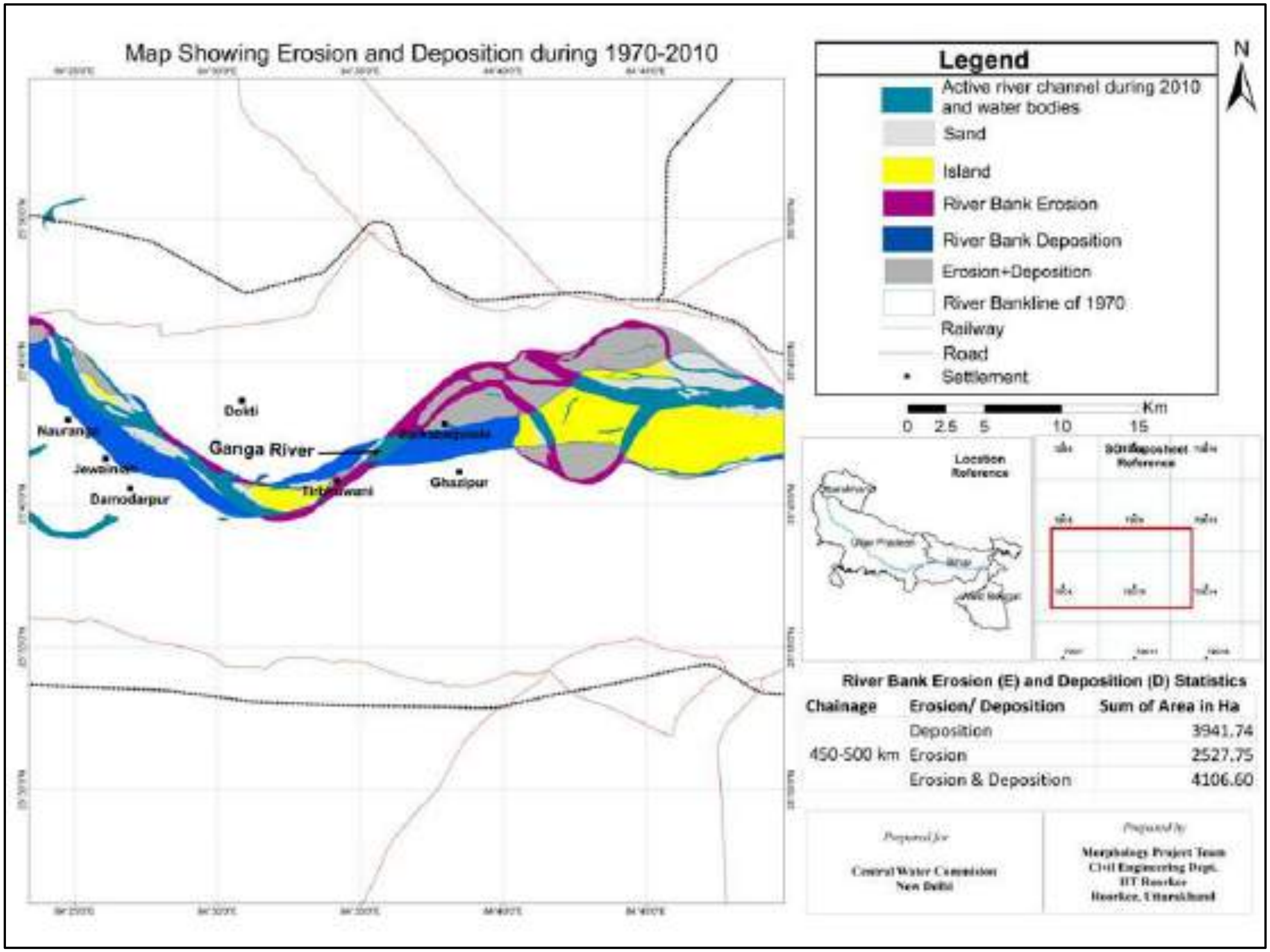


Figure 12.12 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 450-500 km

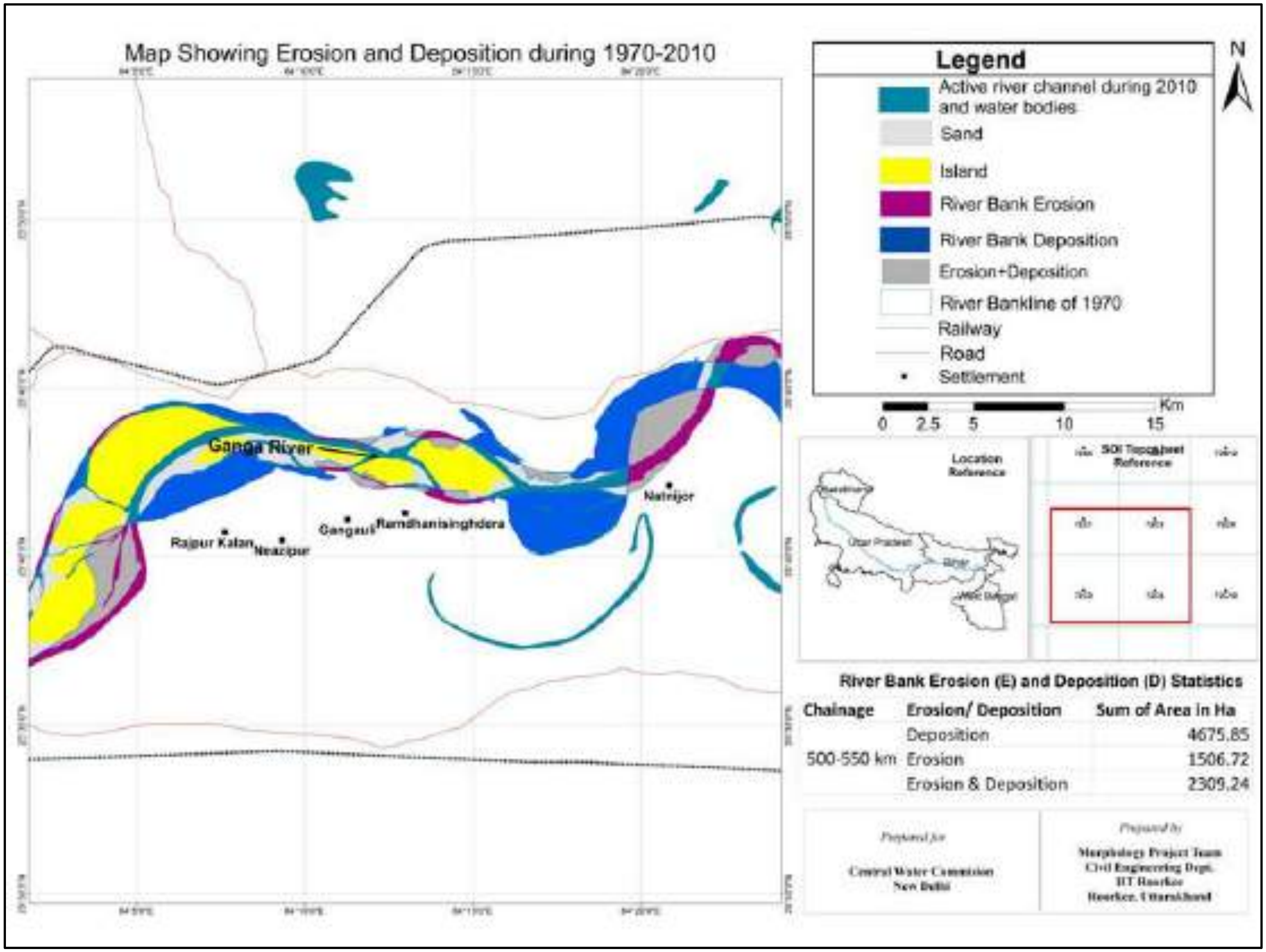


Figure 12.13 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 500-550 km

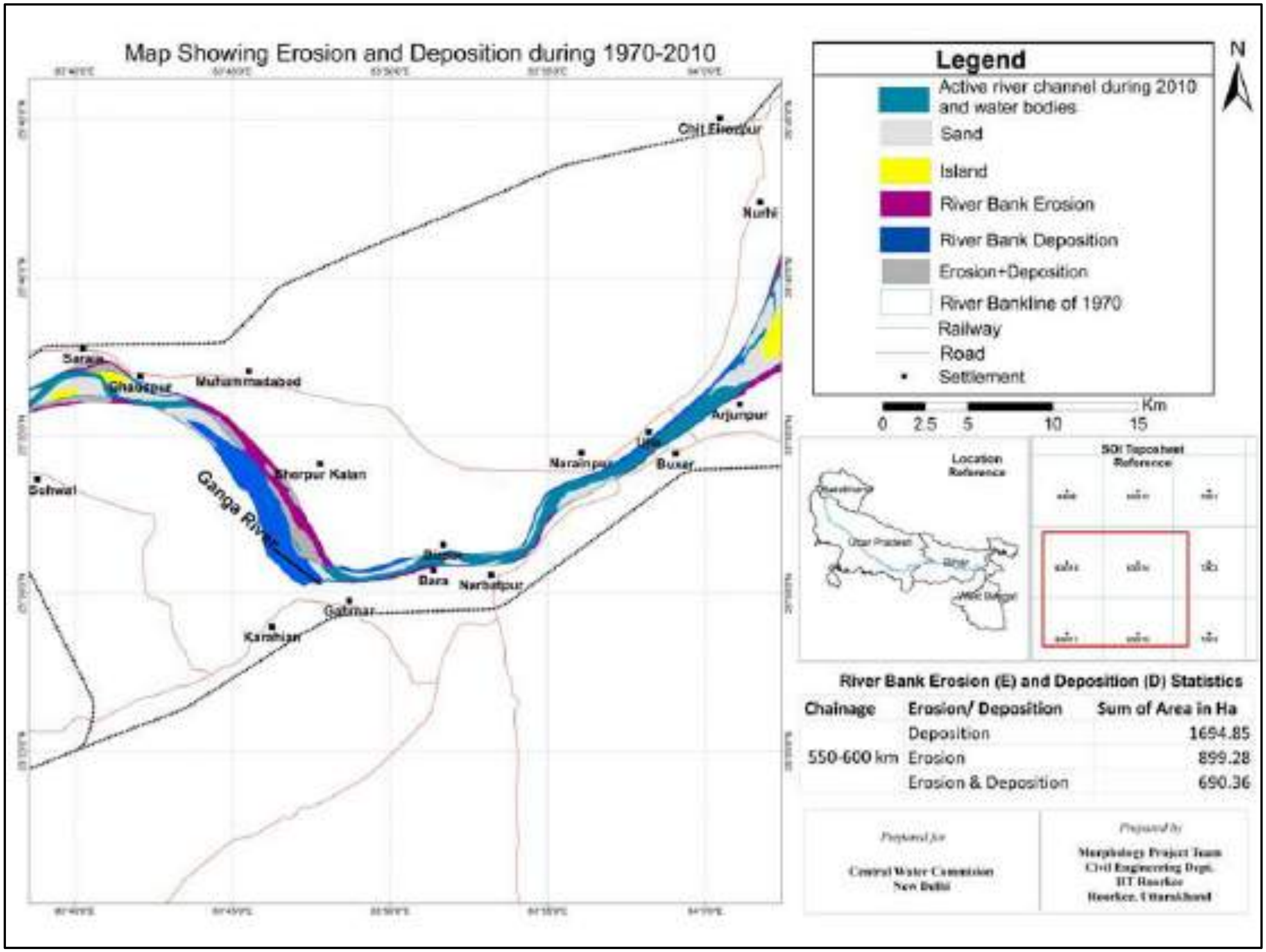


Figure 12.14 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 550-600 km

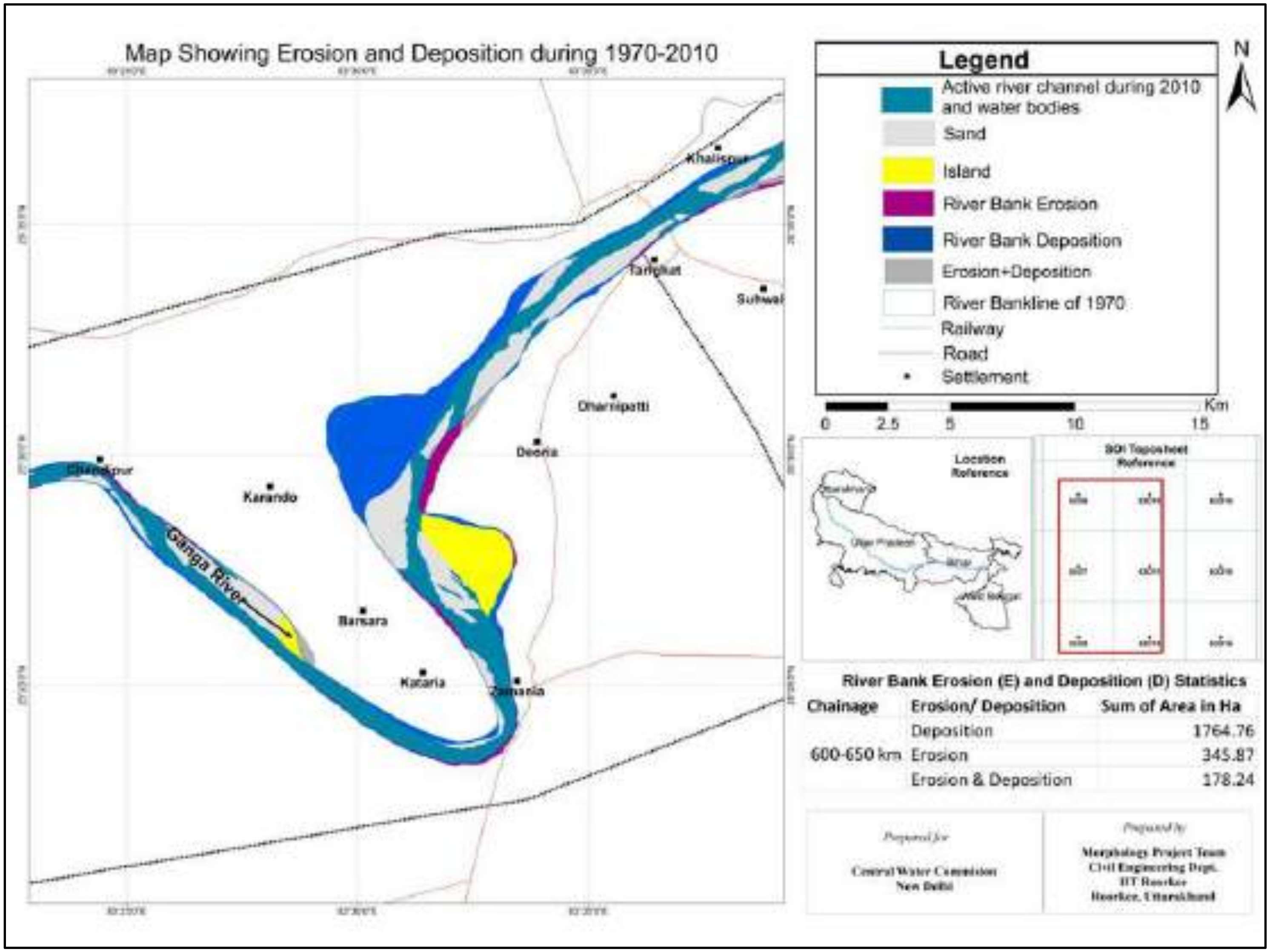


Figure 12.15 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 600-650 km

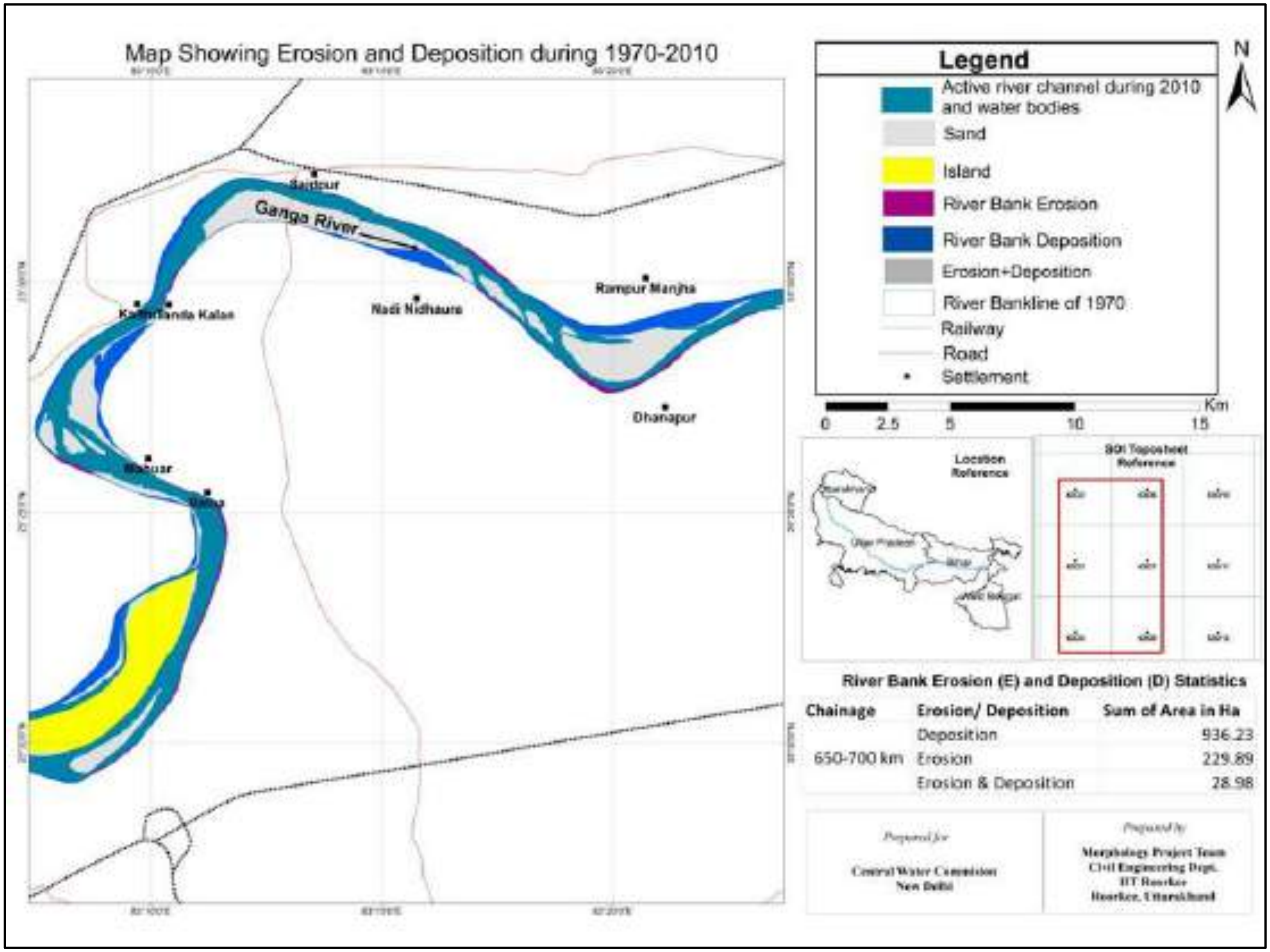


Figure 12.16 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 650-700 km

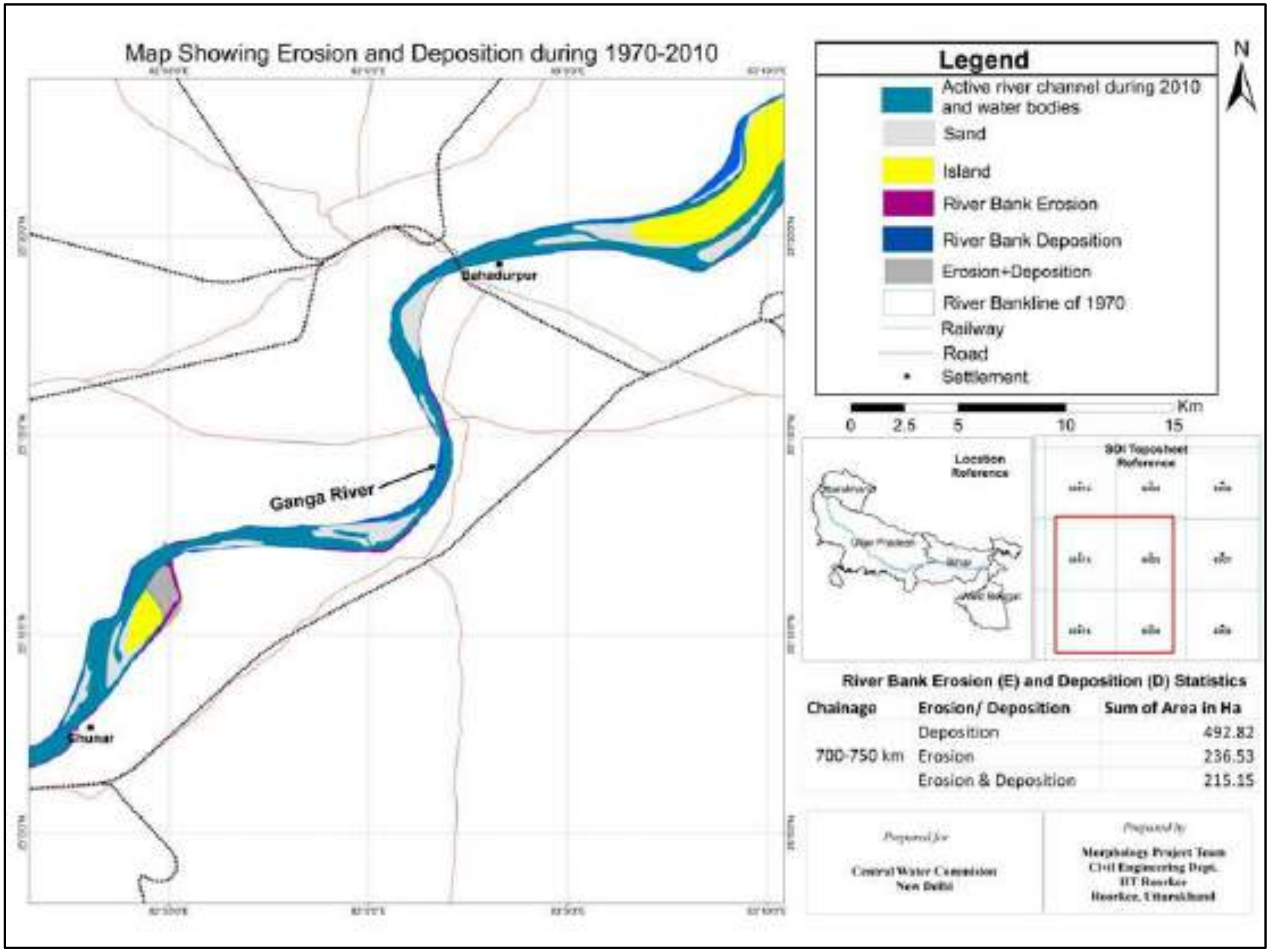


Figure 12.17 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 700-750 km

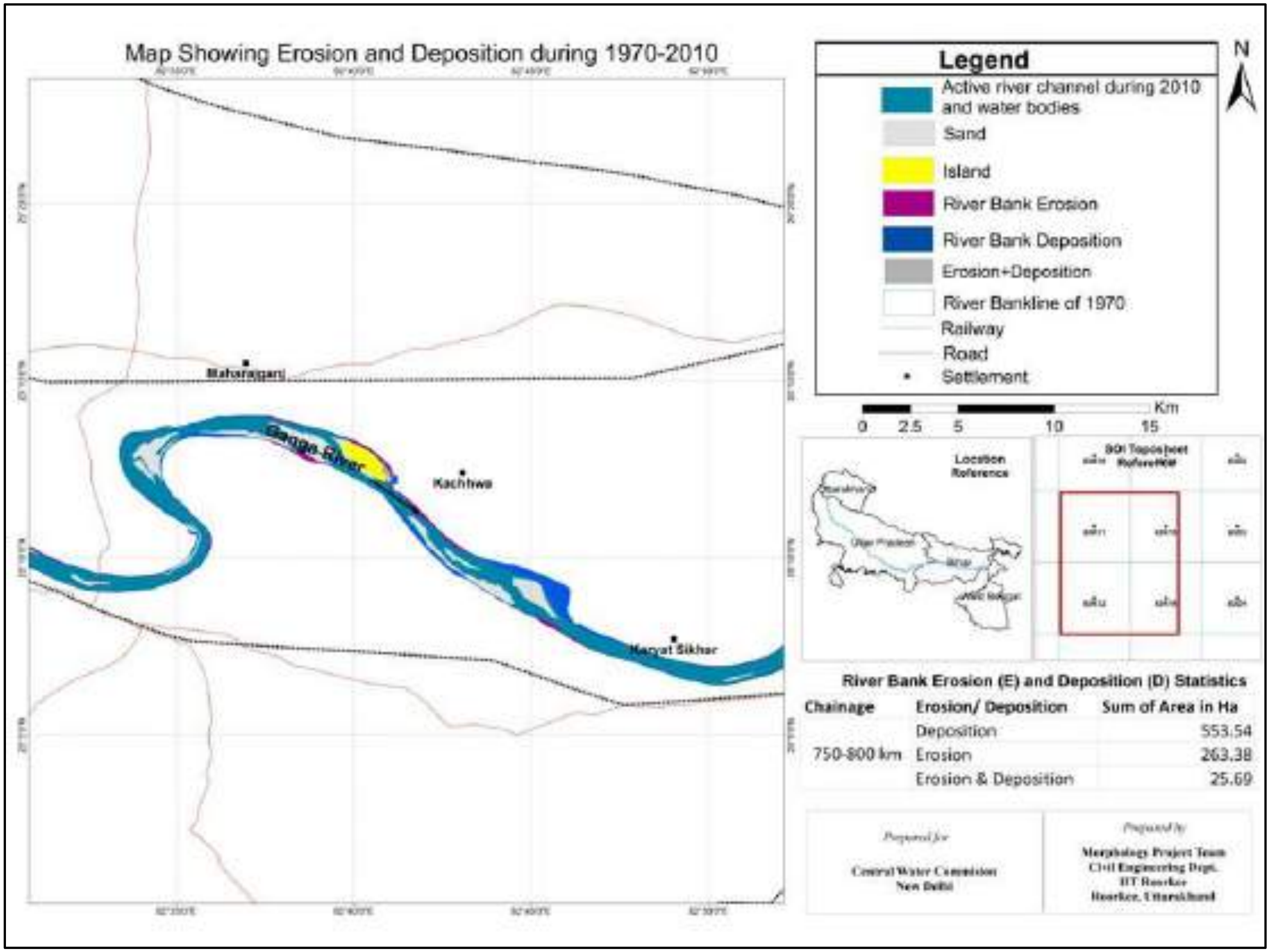


Figure 12.18 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 750-800 km

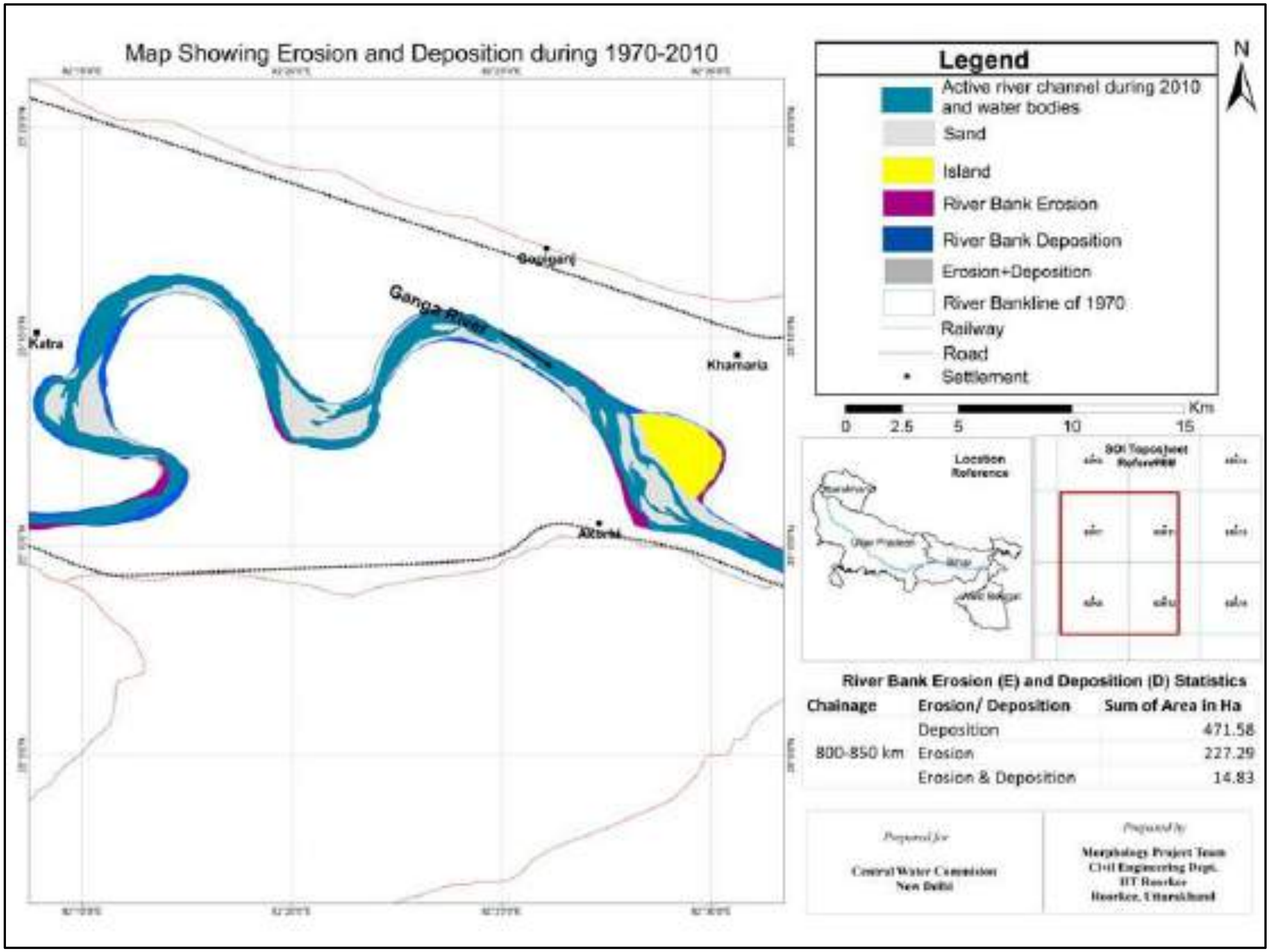


Figure 12.19 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 800-850 km

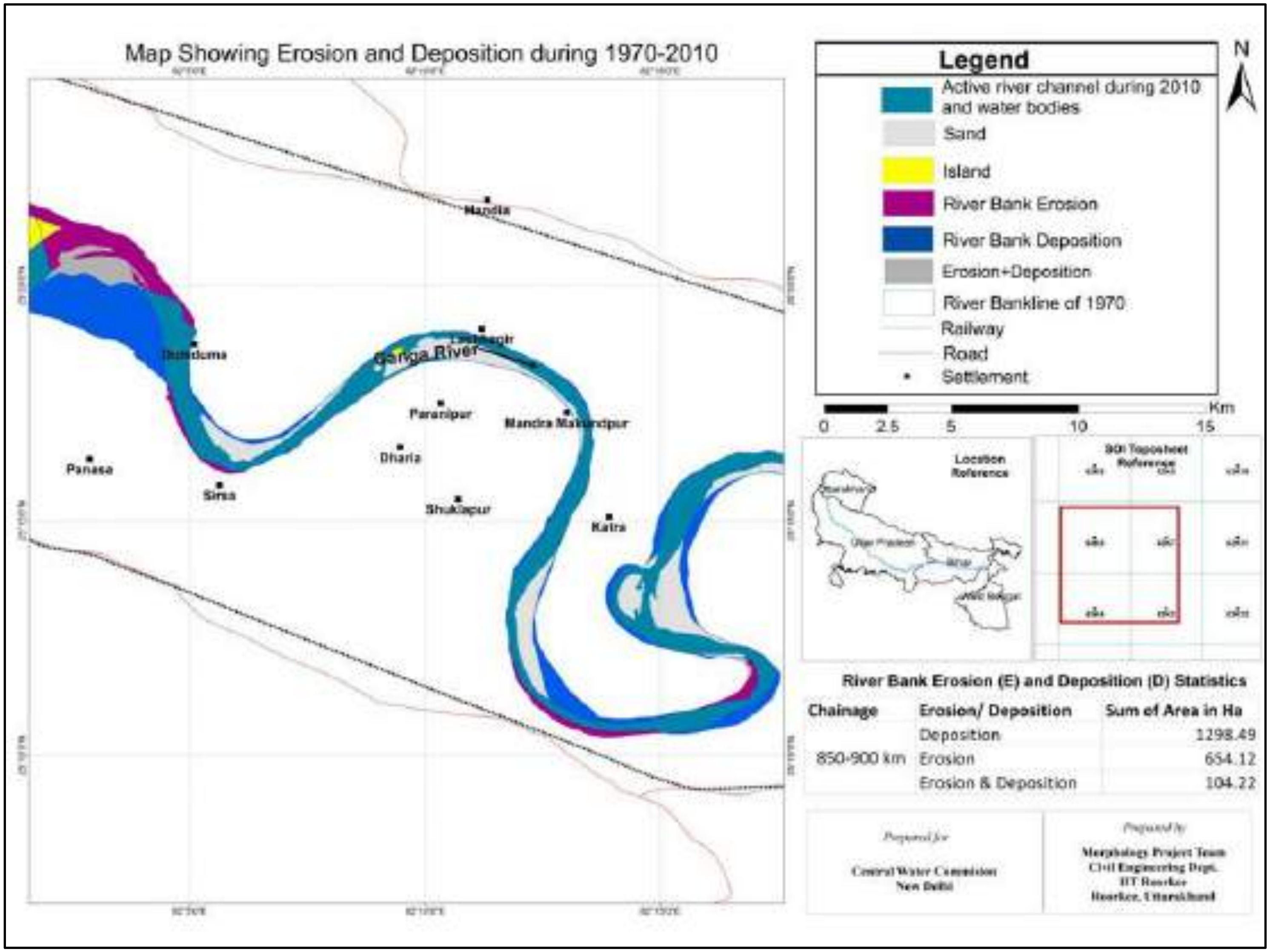


Figure 12.20 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 850-900 km

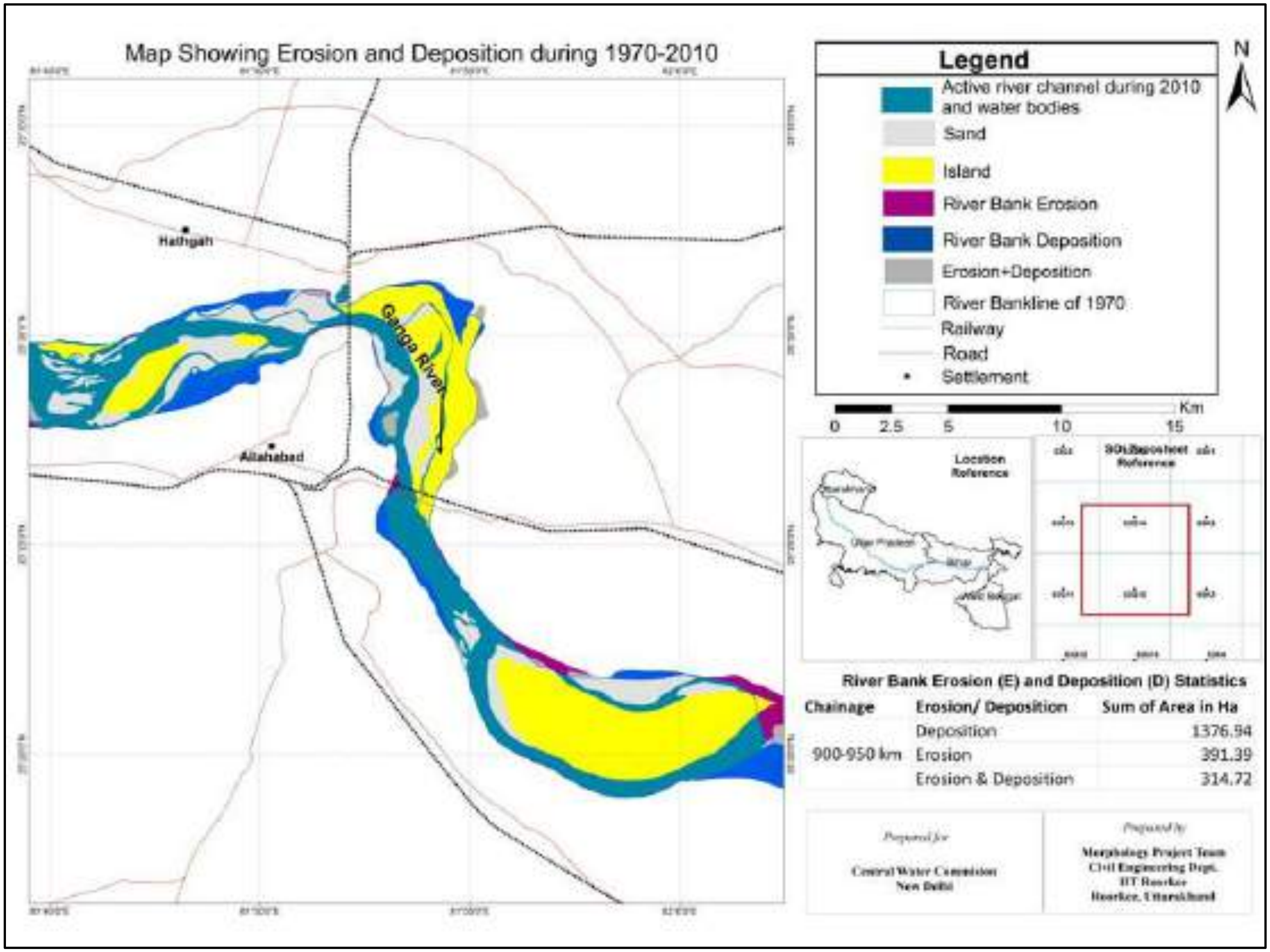


Figure 12.21 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 900-950 km

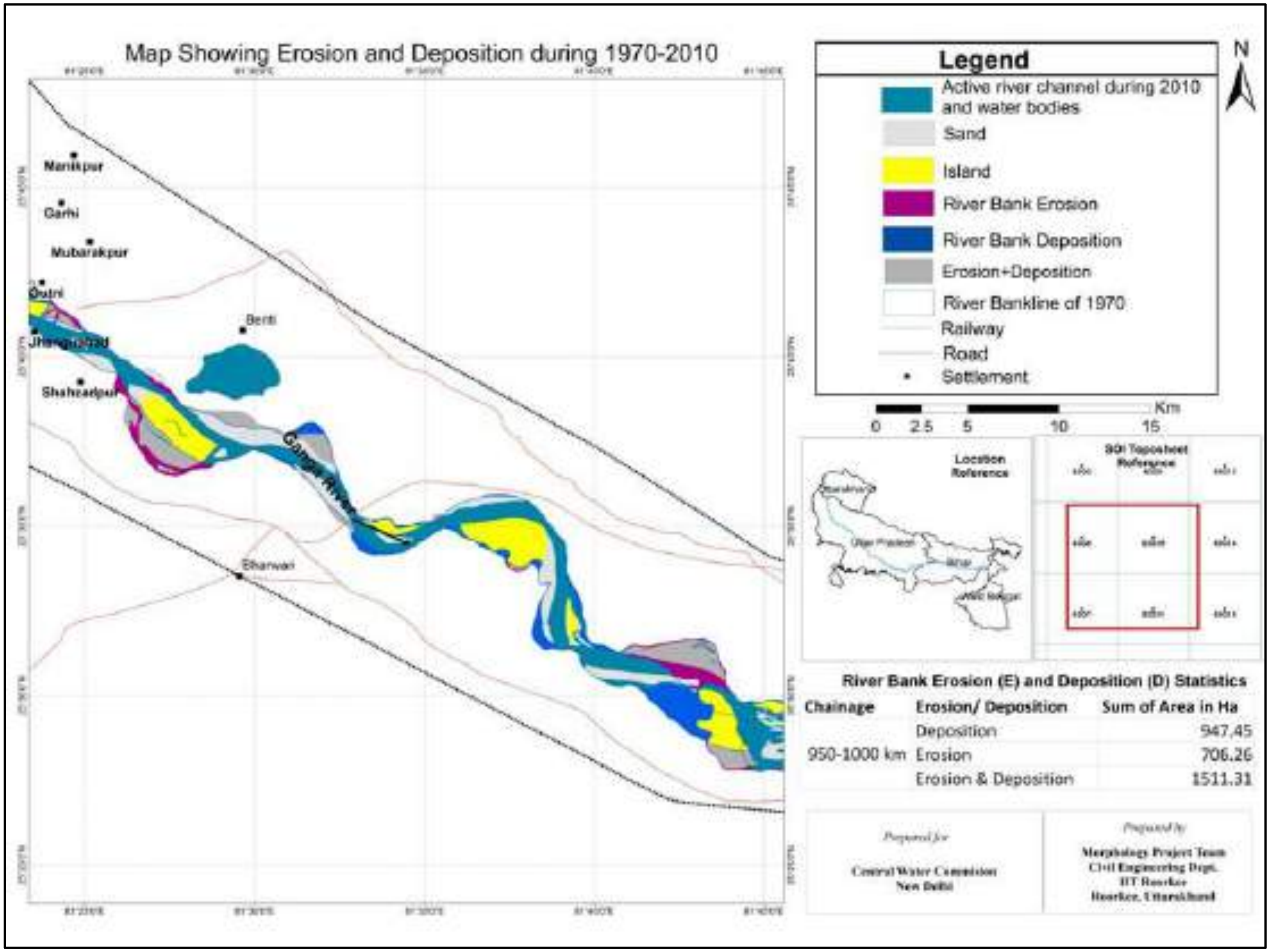


Figure 12.22 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 950-1000 km

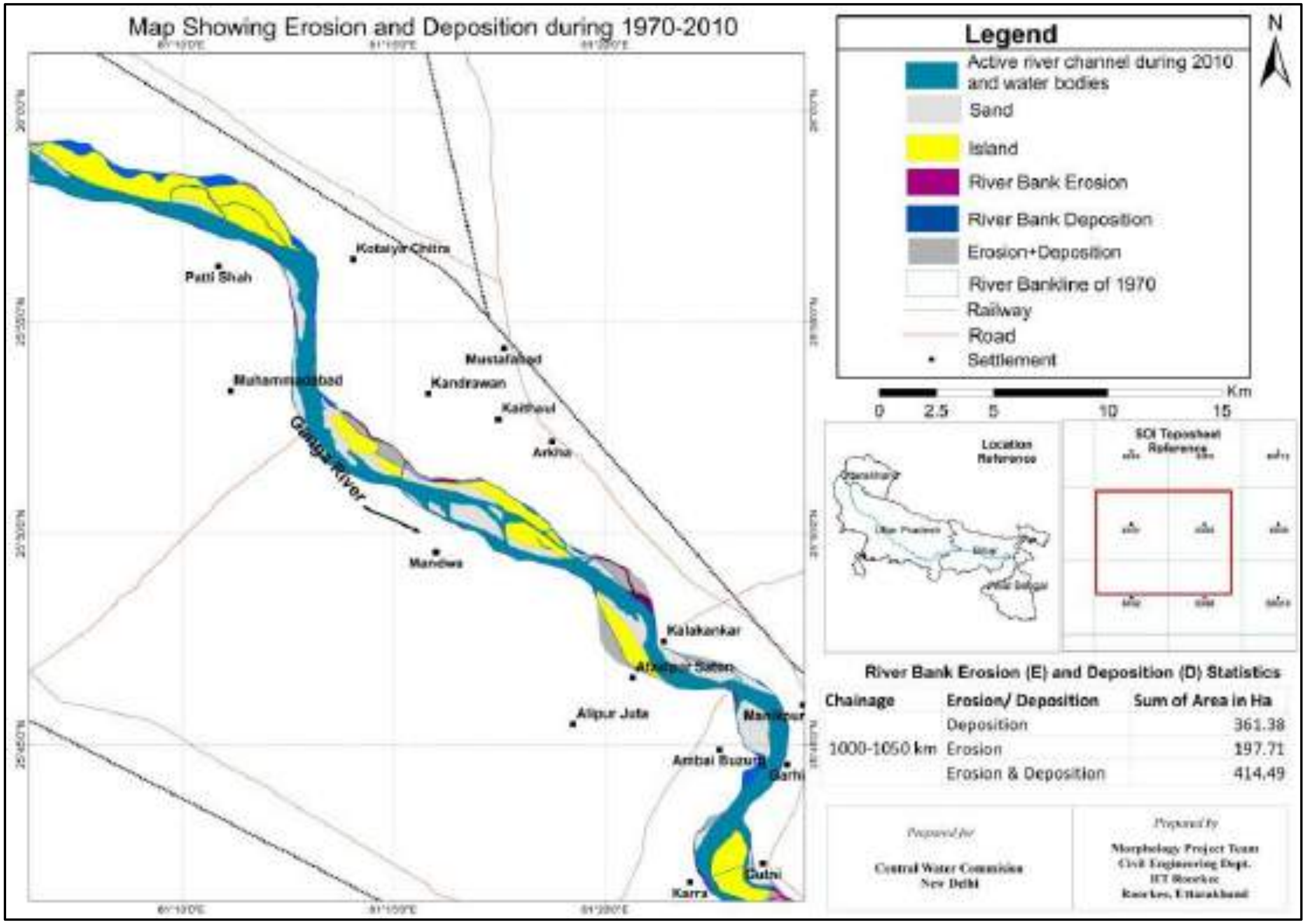


Figure 12.23 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1000-1050 km

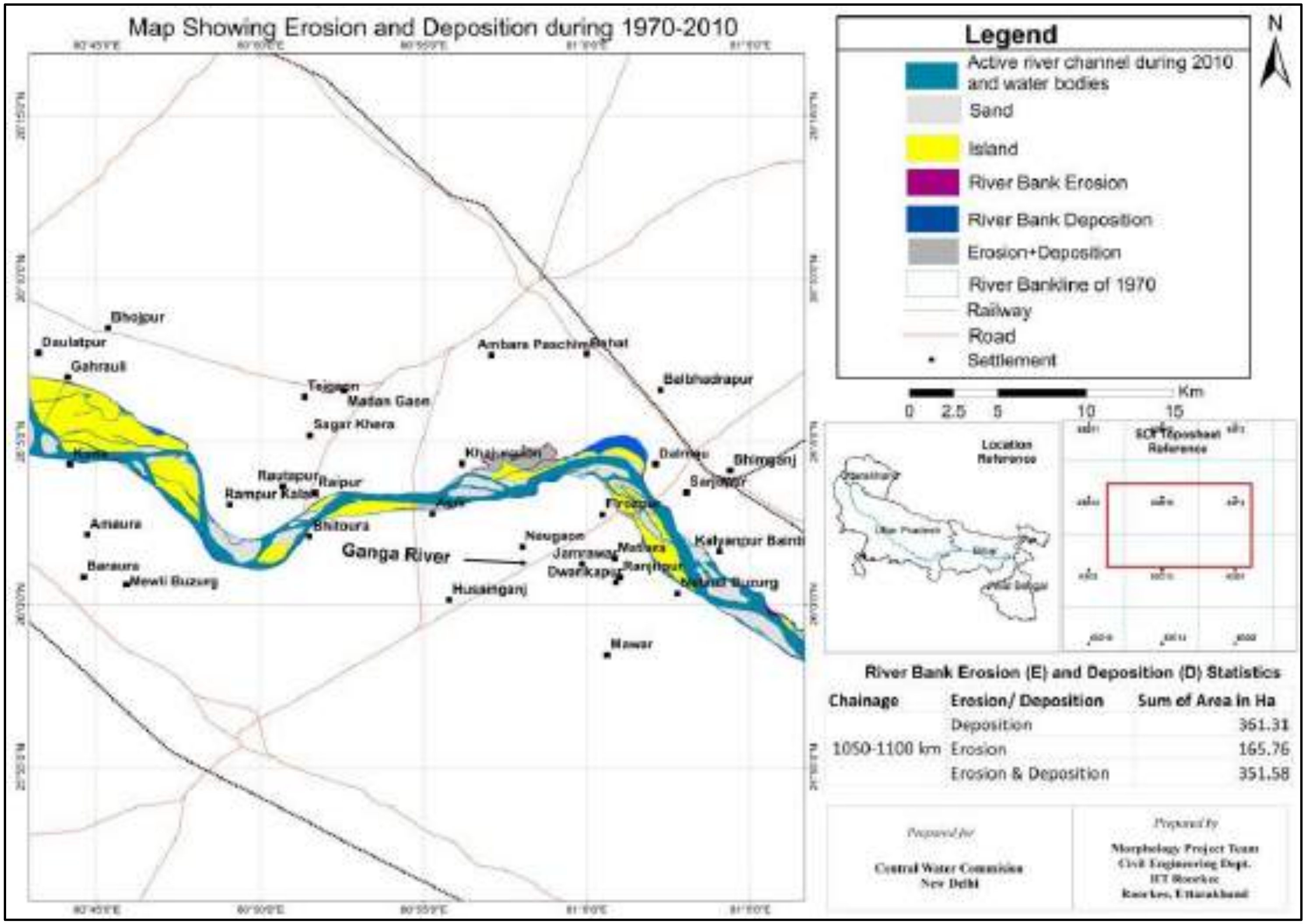


Figure 12.24 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1050-1100 km

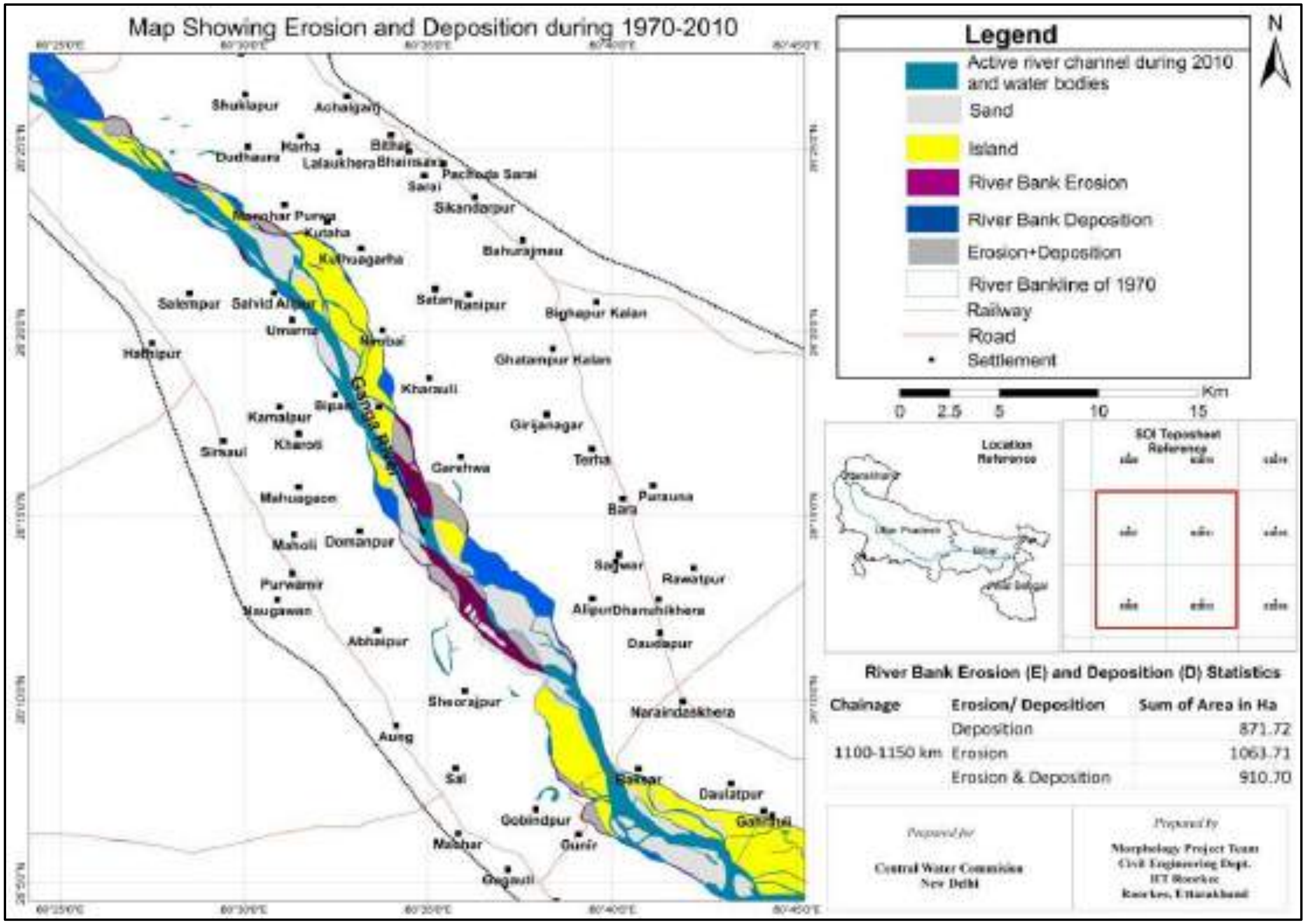


Figure 12.25 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1100-1150 km

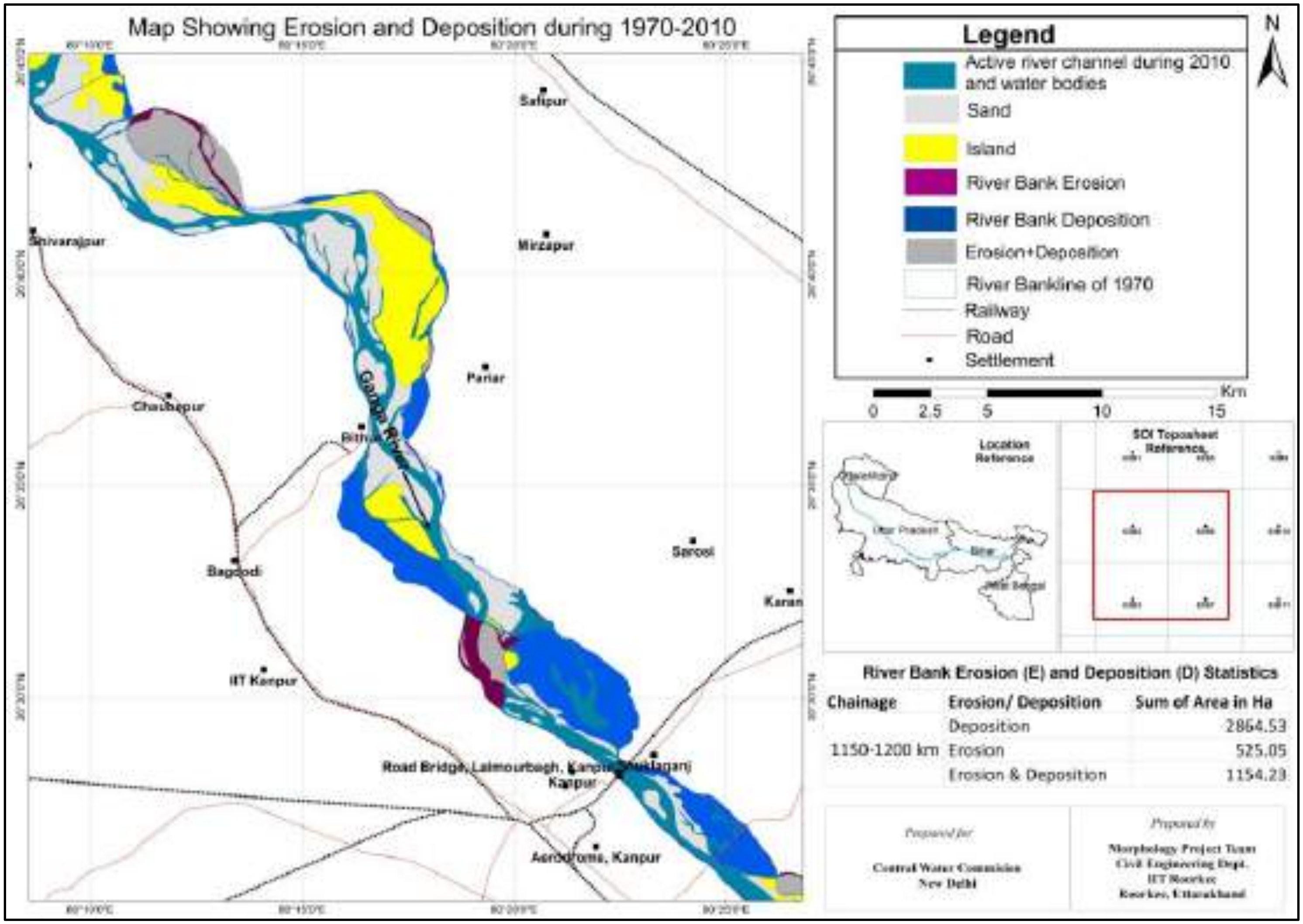


Figure 12.26 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1150-1200 km

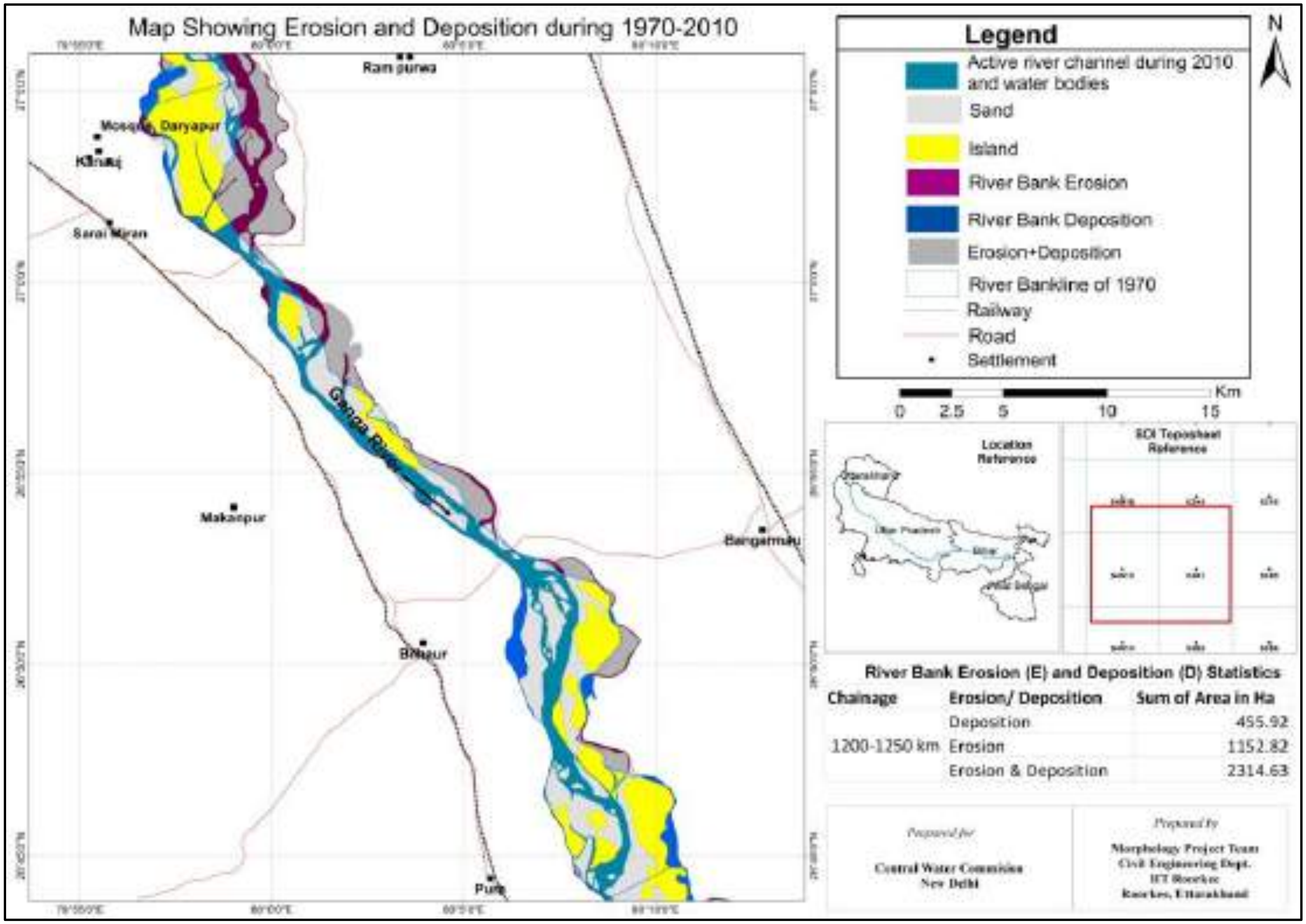


Figure 12.27 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1200-1250 km

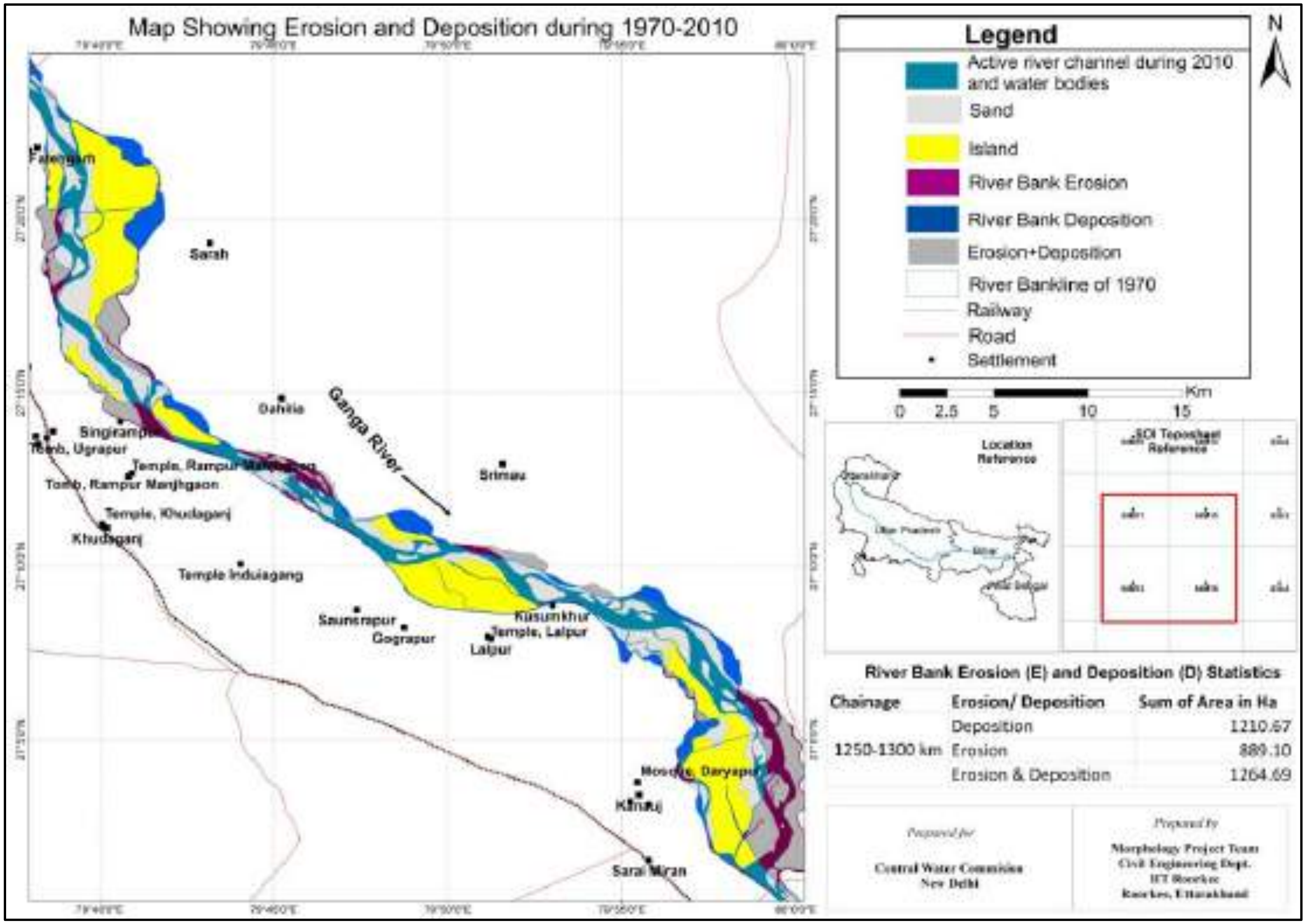


Figure 12.28 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1250-1300 km

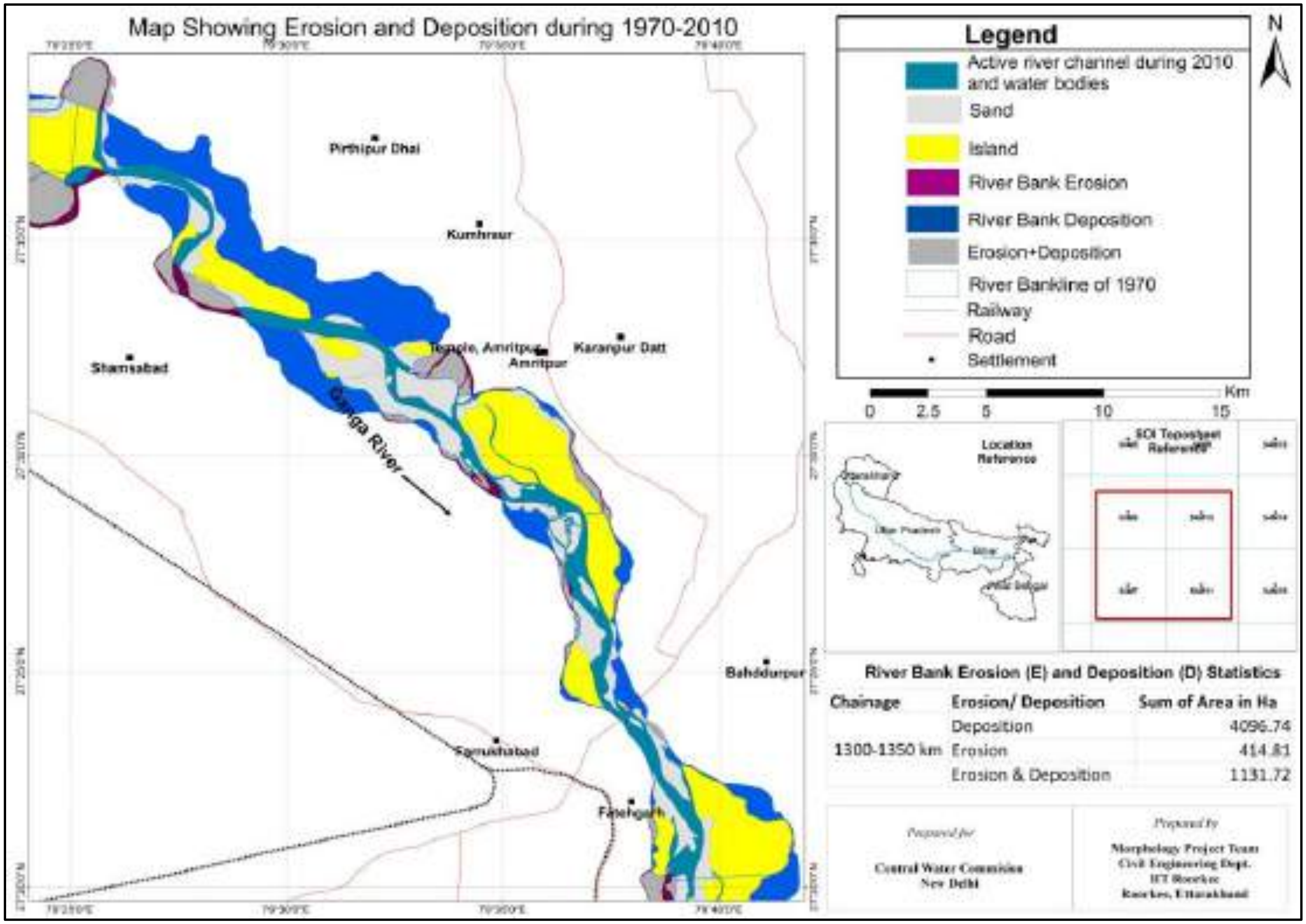


Figure 12.29 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1300-1350 km

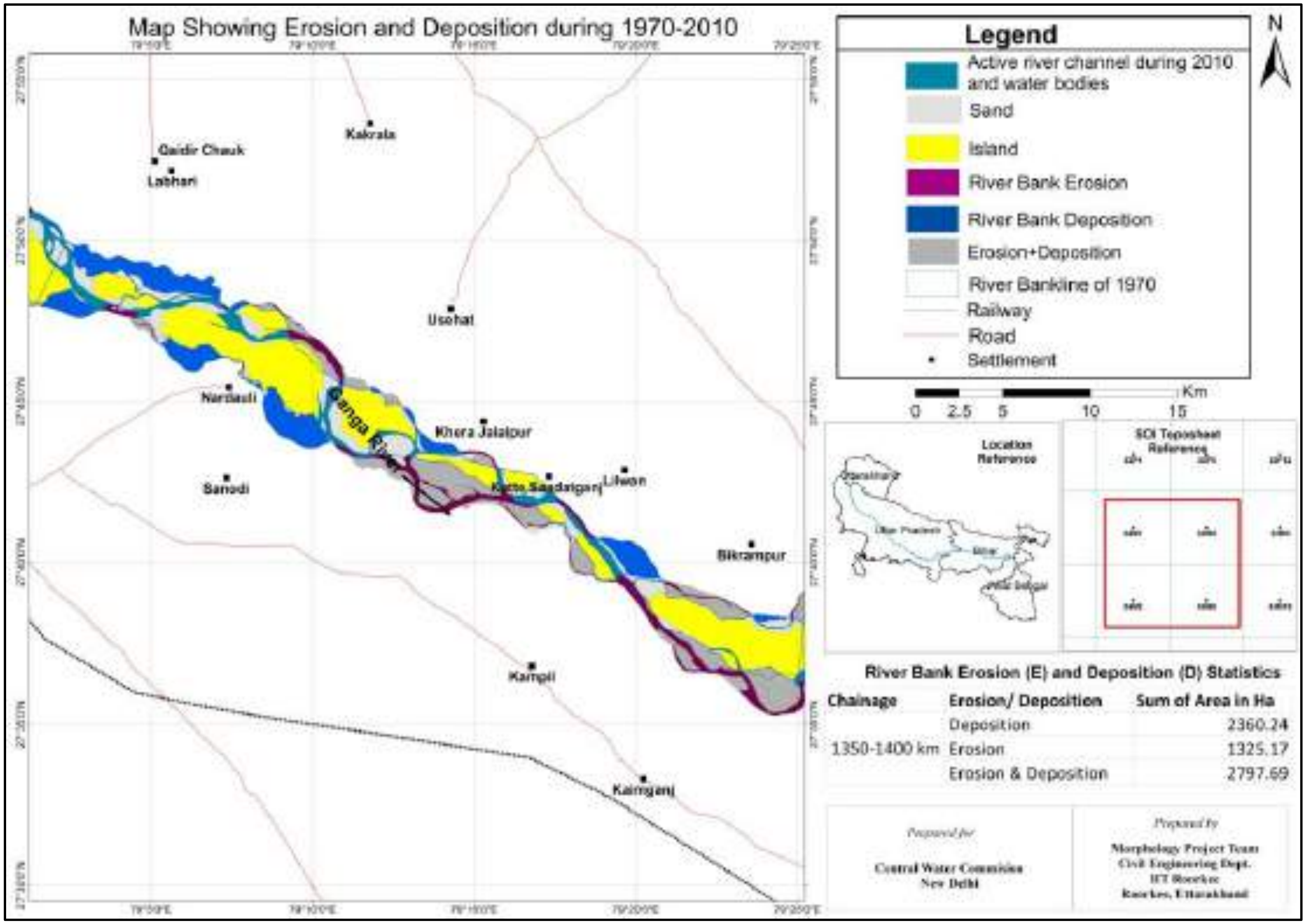


Figure 12.30 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1350-1400 km

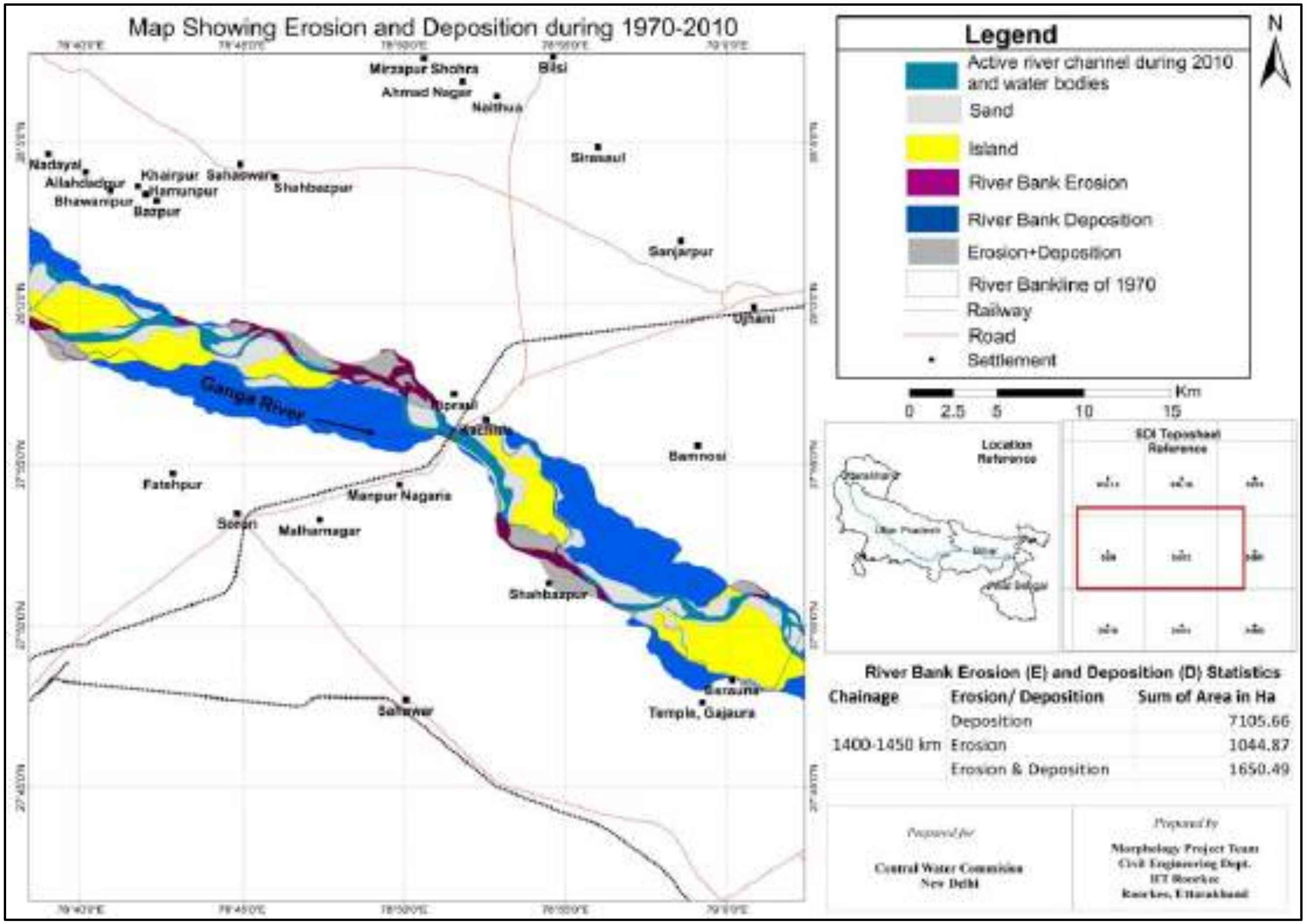


Figure 12.31 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1400-1450 km

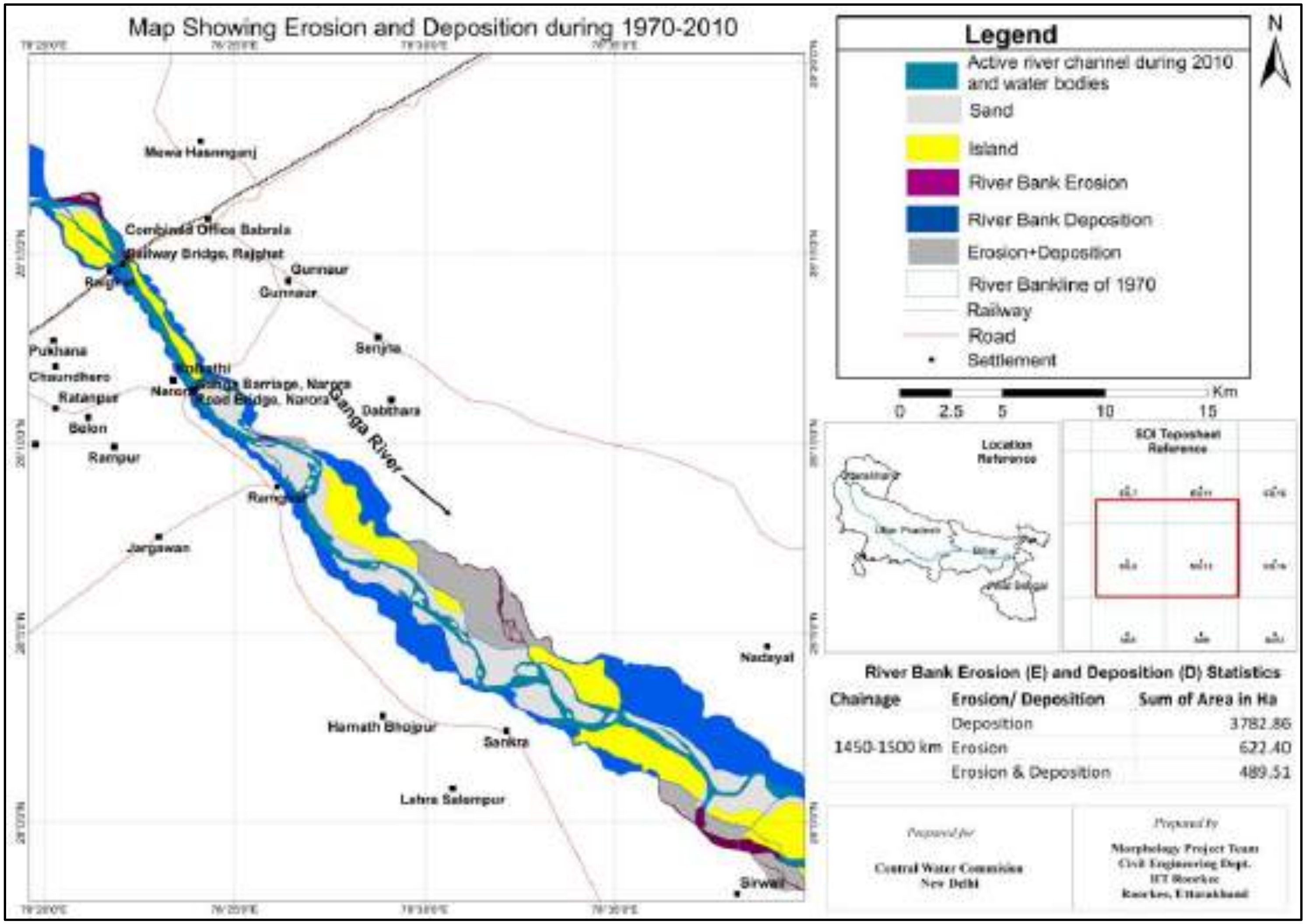


Figure 12.32 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1450-1500 km

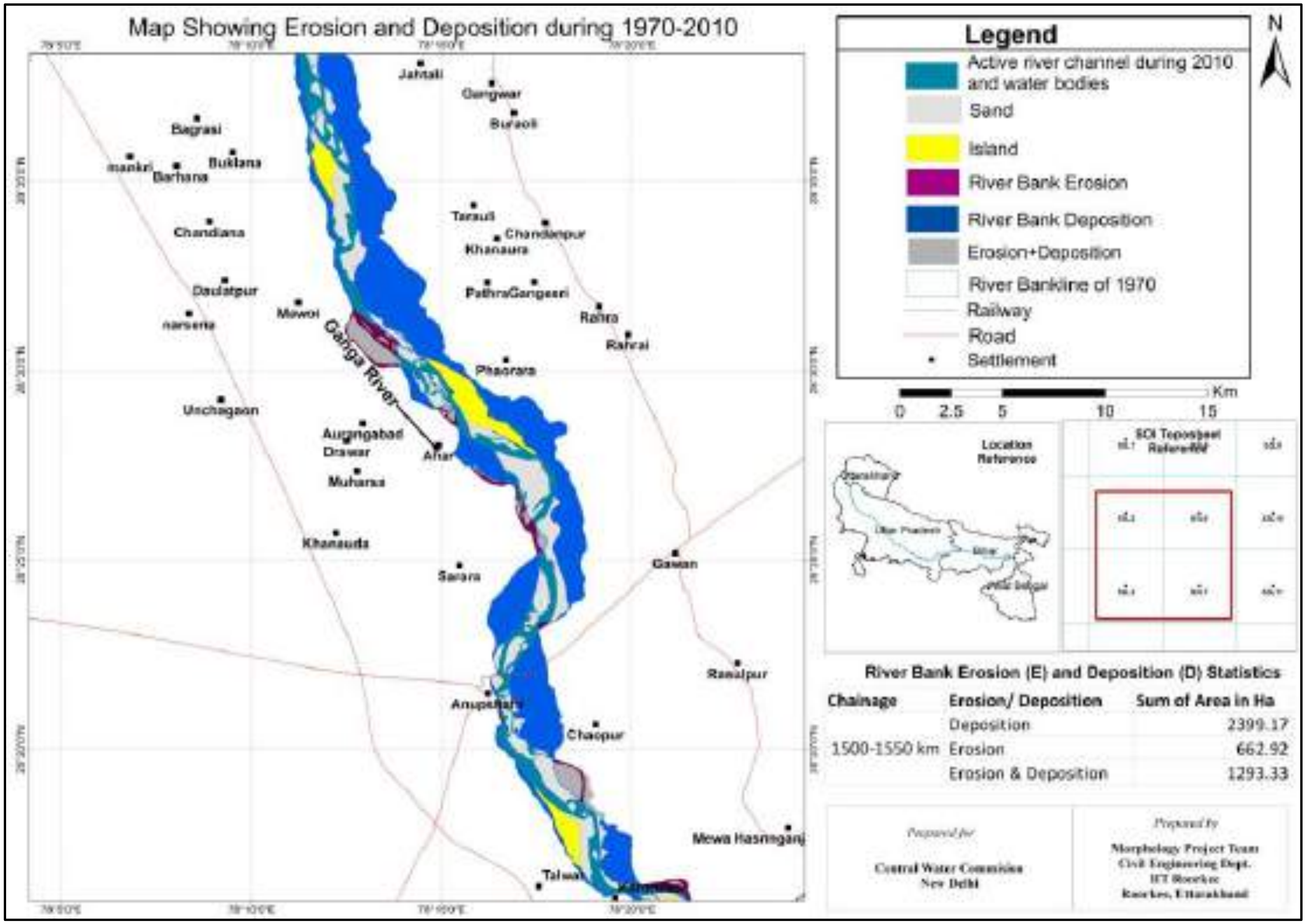


Figure 12.33 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1500-1550 km

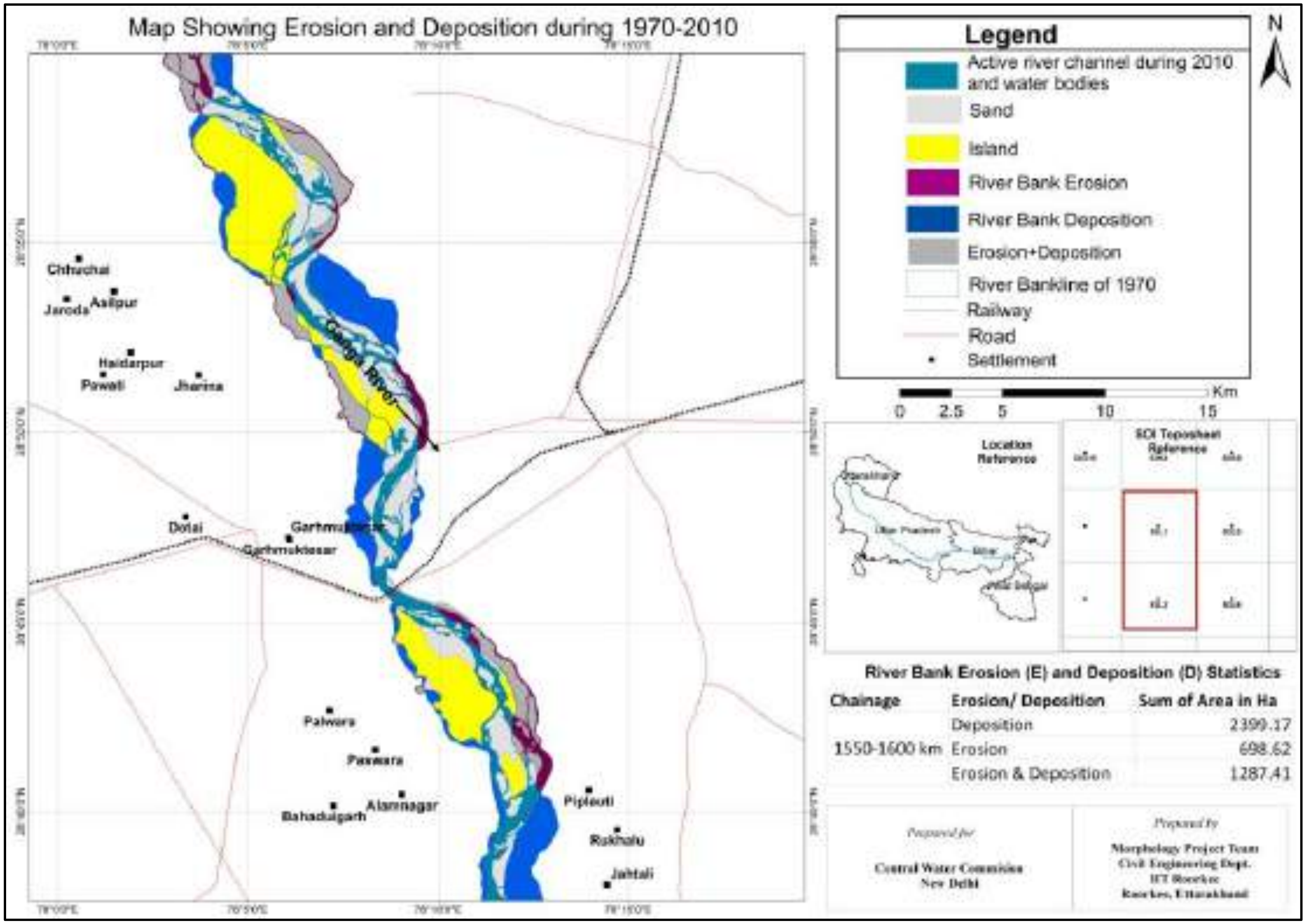


Figure 12.34 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1550-1600 km

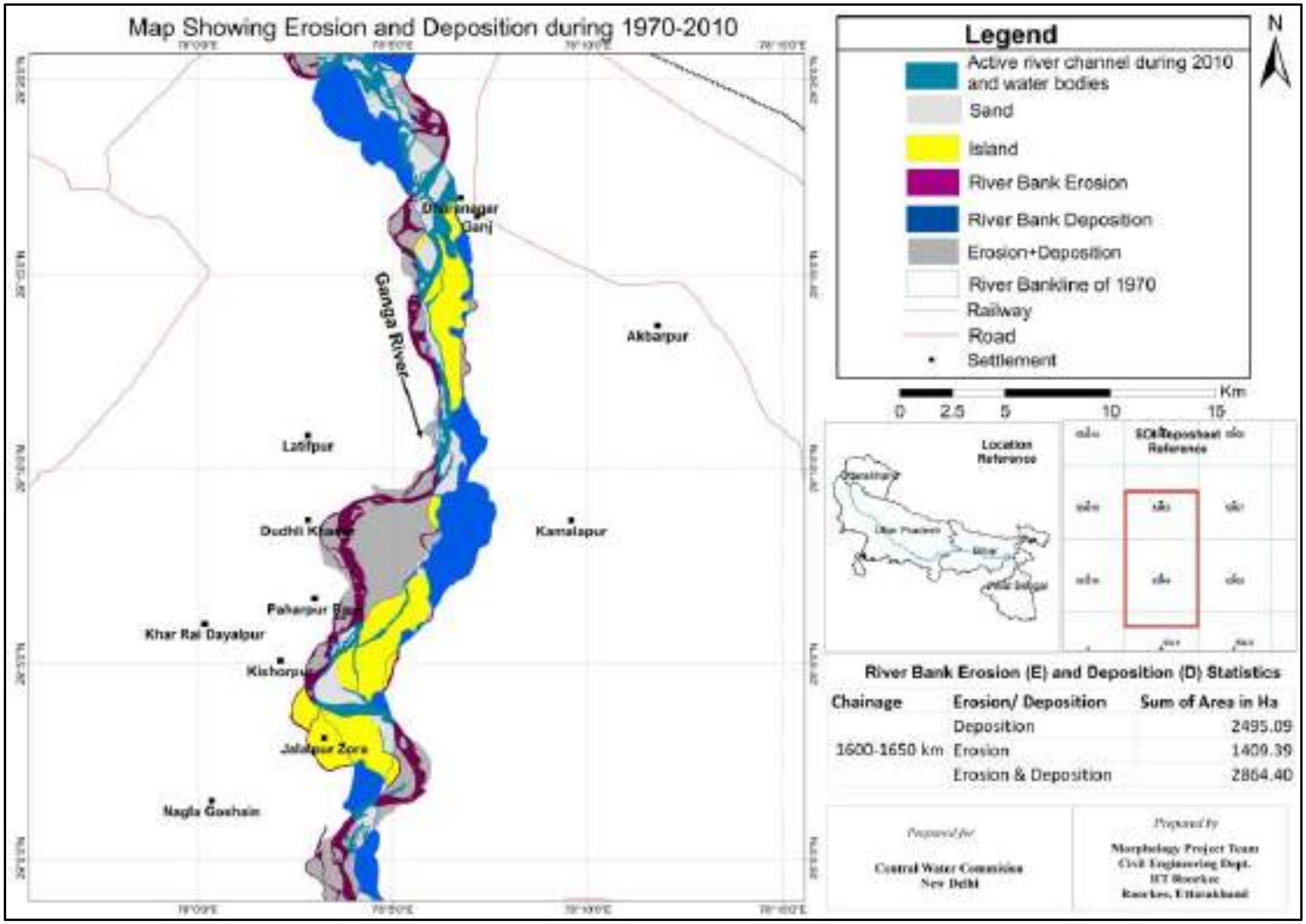


Figure 12.35 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1600-1650 km

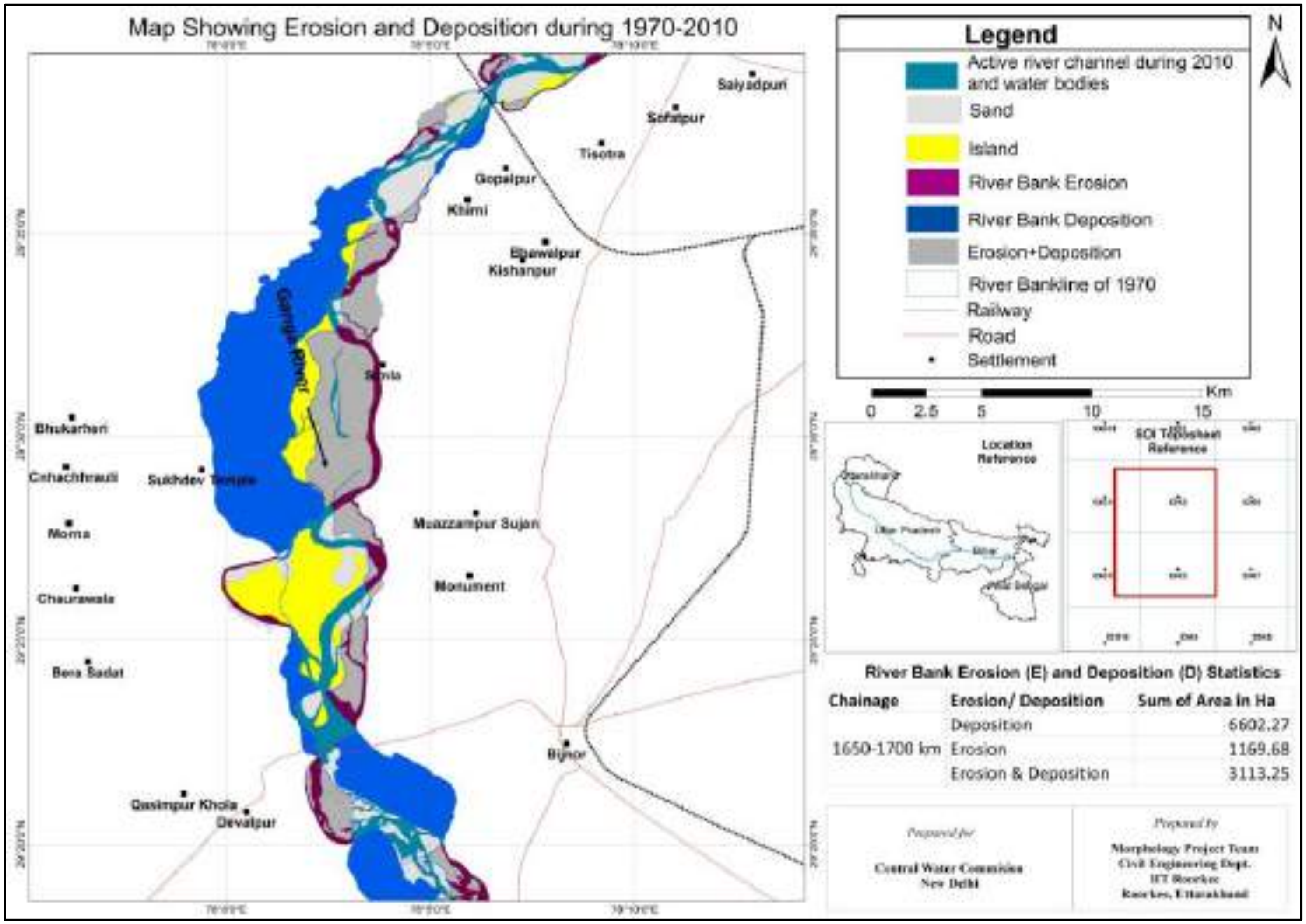


Figure 12.36 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1650-1700 km

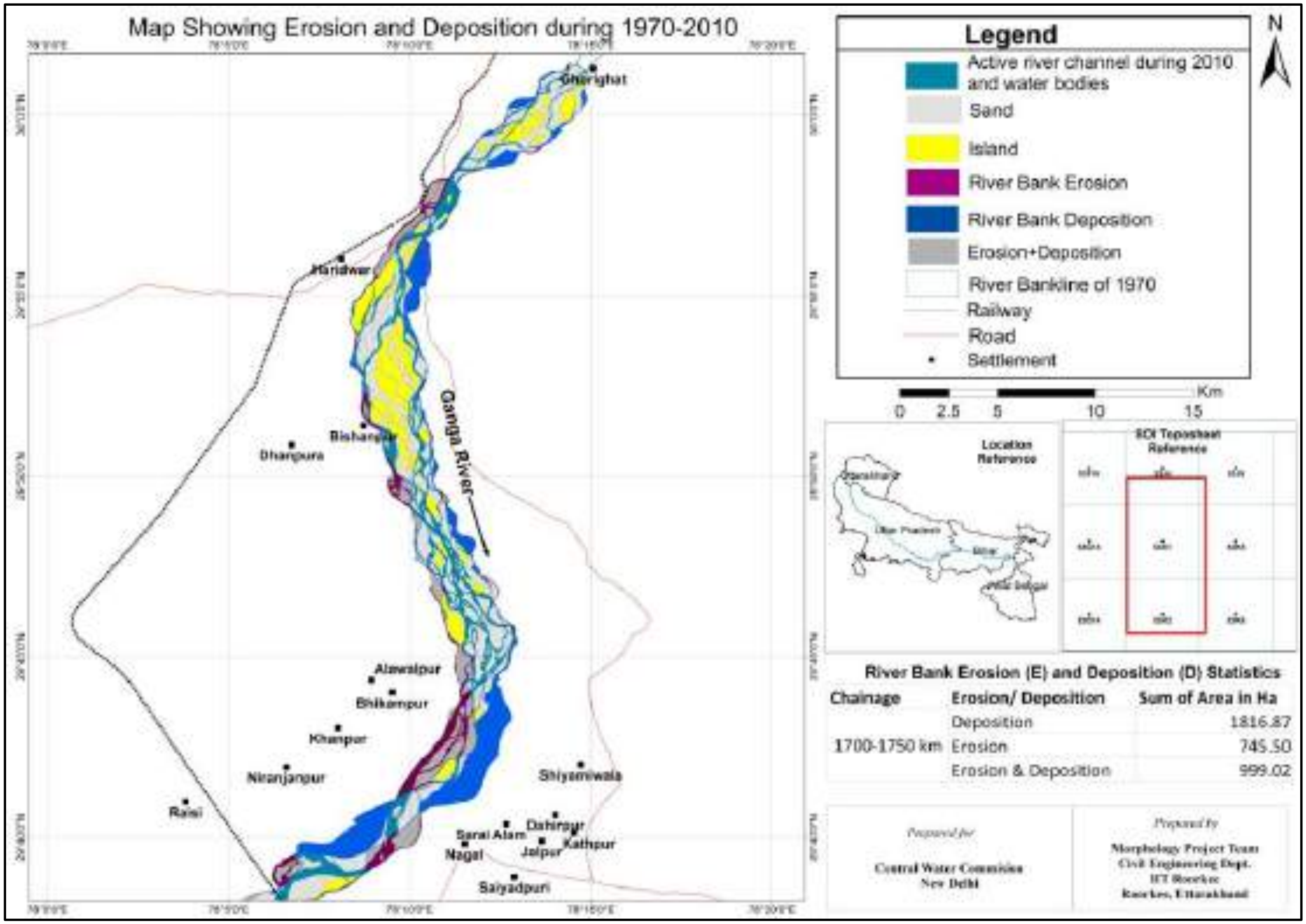


Figure 12.37 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1700-1750 km

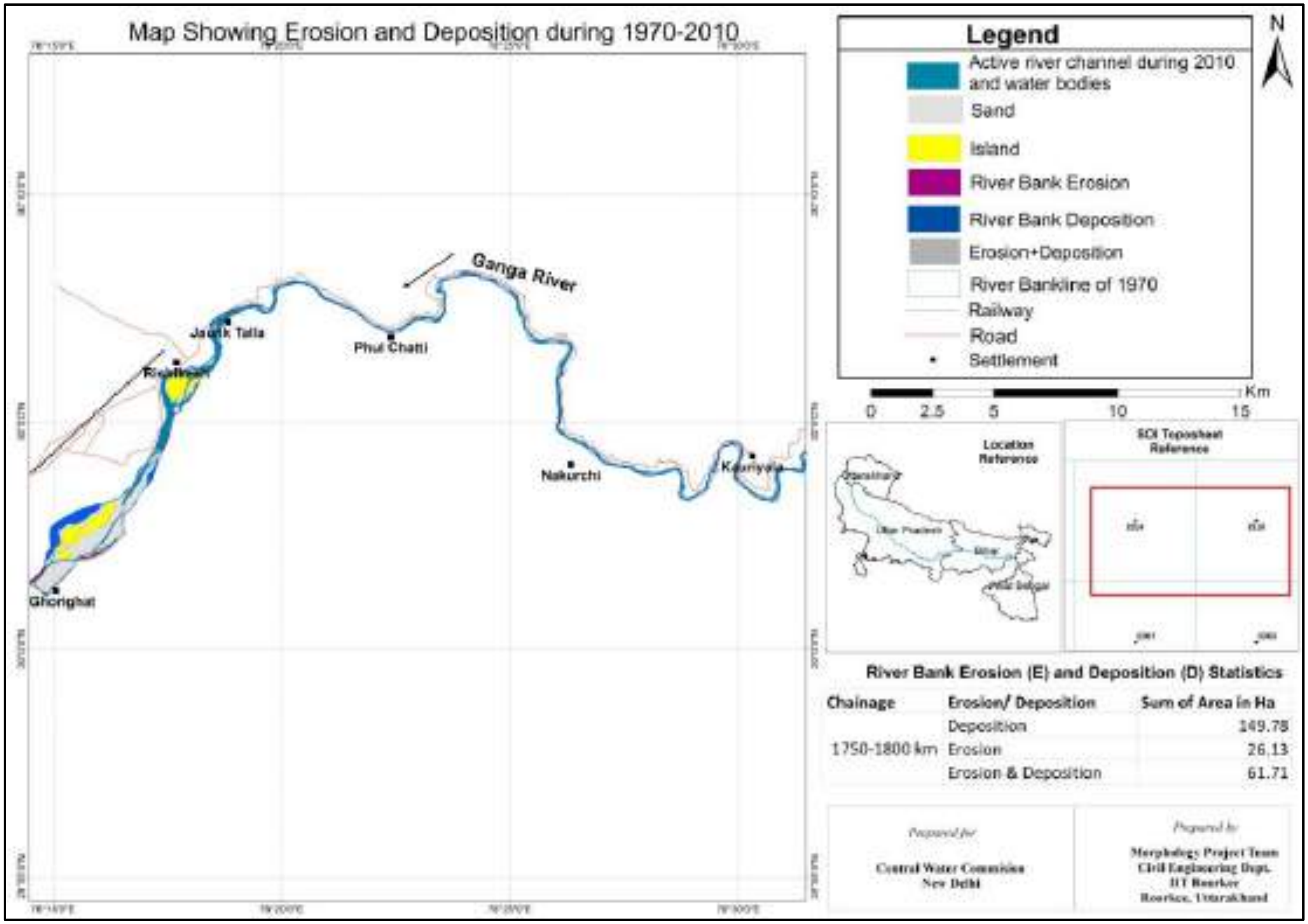


Figure 12.38 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1750-1800 km

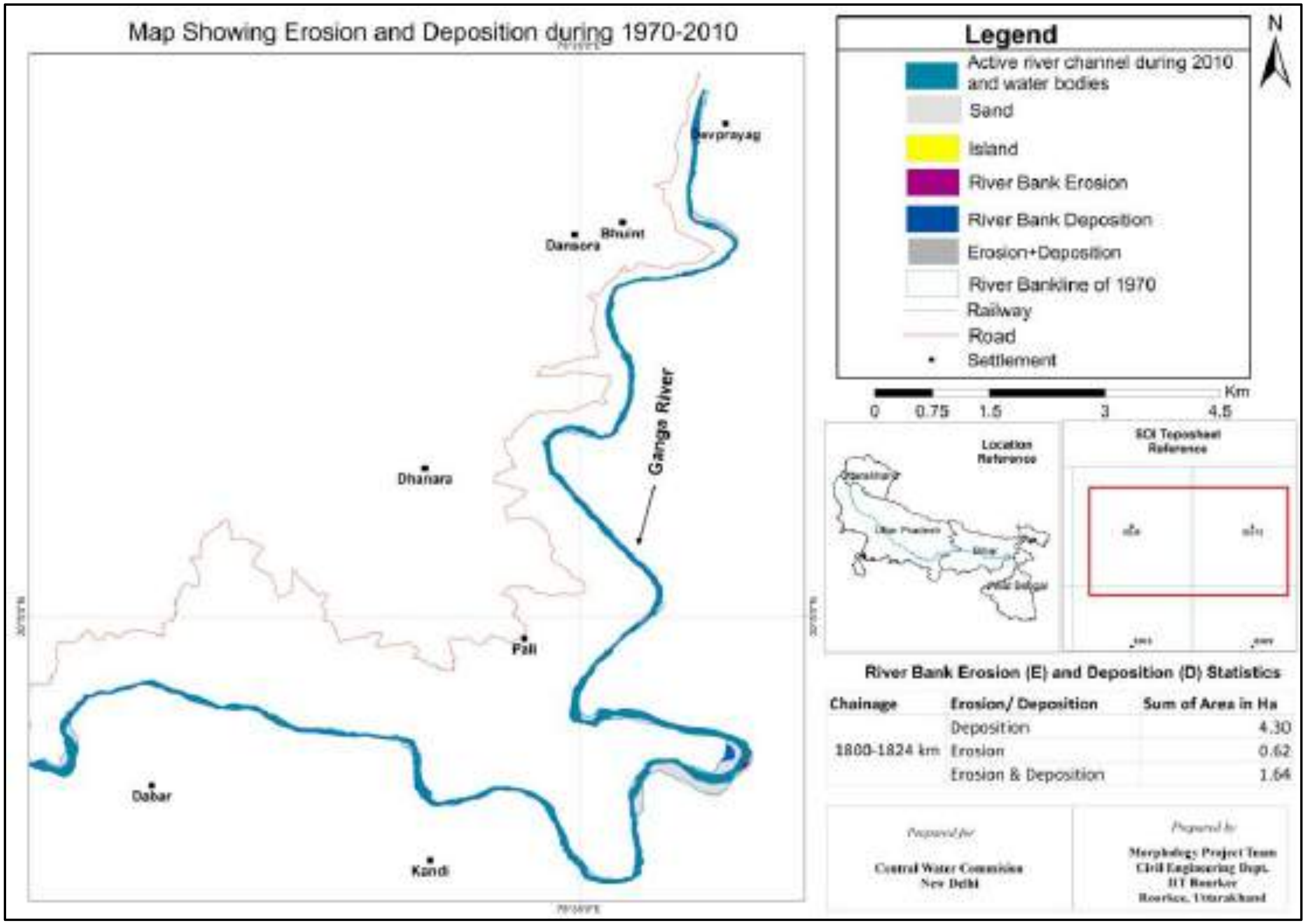


Figure 12.39 Erosion and deposition map of Ganga river for period 1970-2010 from chainage 1800-1824 km

12.4 DISCUSSION ON THE RESULTS

The following points have been noted considering erosion and siltation based on the shifting of extreme left and right banks.

1. In the reach 0-50 km, the total eroded area, the total deposited area and the total eroded & deposited area are 4289.32 ha, 724.00 ha and 3402.12 ha respectively. Net erosion in this reach is 3565.32 ha. In this reach, river has eroded the left side between Chamagram & Paschim Narayanpur. Spreading of river may be due to construction of Farakka Barrage.
2. In the reach 50-100 km, the total eroded area, the total deposited area and the total eroded & deposited area are 5381.91 ha, 4658.13 ha and 4093.43 ha respectively. Net erosion in this reach is 723.78 ha. There is erosion towards left bank near Ahmadabad village and Nawabganj. On the other hand, deposition has occurred towards left bank near Harchandrapur and right bank side near Mahadevganj. The possible reason behind this is lateral shifting of the river.
3. In the reach 100-150 km, the total eroded area, the total deposited area and the total eroded & deposited area are 4145.91 ha, 10973.13 ha and 3769.99 ha respectively. Net deposition of this reach is 6827.22 ha. Deposition has occurred towards both the banks near Ramnagar; on the other hand major erosion has occurred towards left bank near Santoshpur.
4. In the reach 150-200 km, the total eroded area, the total deposited area and the total eroded & deposited area are 3004.61 ha, 13231.59 ha and 5450.95 ha respectively. Net deposition in this reach is 10226.98 ha. There is erosion towards left bank near Dabra (Saidpur), on the other hand deposition is towards left bank near Narayanpur and towards right bank near Shahpur. The erosion and deposition may be due to changes in the river.
5. In the reach 200-250 km, the total eroded area, the total deposited area and the total eroded & deposited area are 2118.45 ha, 9999.95 ha and 4741.05 ha respectively. Net deposition of this reach is 7881.5 ha. There is erosion towards right bank near Kalyanpur on the other the hand deposition has occurred near Khutia and Nayagaon on the left bank.
6. In the reach 250-300 km, the total eroded area, the total deposited area and the total eroded & deposited area are 1404.24 ha, 1063.55 ha and 4103.81 ha respectively. Net

erosion in this reach is 340.7 ha. Erosion and deposition have occurred along both the banks of the river due to lateral shifting.

7. In the reach 300-350 km, the total eroded area, the total deposited area and the total eroded & deposited area are 1580.38 ha, 5653.20 ha and 1314.42 ha respectively. Net deposition in this reach is 4072.82 ha. There is erosion towards left bank near Teghra on the other hand, deposition has occurred near Punarakh on the right bank. The deposition may be due to shifting of course of the river.
8. In the reach 350-400 km, the total eroded area, the total deposited area and the total eroded & deposited area are 1044.42 ha, 2161.91 ha and 1150.81 ha respectively. Net deposition in this reach is 1117.49 ha. There is erosion towards left bank near Mehnar. Deposition has occurred near Mohiuddin nagar and Chechar on the left bank and near Raghopur on right bank. The possible reason behind this is lateral shifting of the river.
9. In the reach 400-450 km, the total eroded area, the total deposited area and the total eroded & deposited area are 1628.96 ha, 1136.23 ha and 2727.92 ha respectively. Net erosion in this reach is 492.73 ha. There is erosion on left bank near Dhanaura & Khorika and on right bank near Manel. Deposition has occurred near Dighwara & Khorika on the left bank. The possible reason behind this morphological changes is lateral shifting of the river.
10. In the reach 450-500 km, the total eroded area, the total deposited area and the total eroded & deposited area are 2527.75 ha, 3941.74 ha and 4106.60 ha respectively. Net deposition in this reach is 1413.98 ha. Noticeable amounts of erosion and deposition is visible in this reach. There is erosion on left bank near Barkabaijutola and on right bank upstream and downstream of Ghazipur. Deposition has occurred on left bank near Dokti and on right bank near Nauranga and Ghazipur. The possible reason behind this is braiding nature and/or lateral shifting of the river.
11. In the reach 500-550 km, the total eroded area, the total deposited area and the total eroded & deposited area are 1506.72 ha, 4675.85 ha and 2309.24 ha respectively. Net deposition in this reach is 3169.13 ha. Noticeable amounts of erosion and deposition on both the banks of river are noticed in this reach. The possible reason behind this is lateral shifting of the river.

12. In the reach 550-600 km, the total eroded area, the total deposited area and the total eroded & deposited area are 899.28 ha, 1694.85 ha and 690.36 ha respectively. Net deposition in this reach is 795.57 ha. There is erosion on left bank near Sherpur Kalan, and deposition near Karahian on the right bank. The possible reason behind this is lateral shifting of the river.
13. In the reach 600-650 km, the total eroded area, the total deposited area and the total eroded & deposited area are 345.87 ha, 1764.76 ha and 178.24 ha respectively. Net deposition in reach is 1418.88 ha. Erosion and disposition have occurred in this reach. Major deposition area is identified near Karando due to abandoning of the active channel by the river.
14. In the reach 650-700 km, the total eroded area, the total deposited area and the total eroded & deposited area are 229.89 ha, 936.23 ha and 28.98 ha respectively. Net deposition in reach is 706.35 ha.. The river has eroded right bank near Dhanapur and upstream of Balua. Deposition has occurred at the major places along left bank and right bank near Nadi Nidhaura and Rampur Manjha due to lateral shifting.
15. In the reach 700-750 km, the total eroded area, the total deposited area and the total eroded & deposited area are 236.53 ha, 492.82 ha and 215.15 ha respectively. Net deposition in reach is 256.29 ha. Erosion and deposition have occurred in this reach due to lateral shifting of the river.
16. In the reach 750-800 km, the total eroded area, the total deposited area and the total eroded & deposited area are 263.38 ha, 553.54 ha and 25.69 ha respectively. Net deposition in this reach is 290.16 ha. Erosion and deposition have occurred in this reach due to lateral shifting of the river. Major deposition area is identified downstream of Kachhla. No major morphological changes have been found in this reach.
17. In the reach 800-850 km, the total eroded area, the total deposited area and the total eroded & deposited area are 227.29 ha, 471.58 ha and 14.83 ha respectively. Net deposition in reach is 244.43 ha. Erosion and deposition have occurred in this reach towards both the banks due to lateral shifting of the river.
18. In the reach 850-900 km, the total eroded area, the total deposited area and the total eroded & deposited area are 654.12 ha, 1298.49 ha and 104.22 ha respectively. Net

deposition in reach is 644.37 ha. Erosion and deposition have occurred in this reach. Major erosion has been identified on left bank and deposition on right bank near Dumduma due to lateral shifting.

19. In the reach 900-950 km, the total eroded area, the total deposited area and the total eroded & deposited area are 391.39 ha, 1376.94 ha and 314.72 ha respectively. Net deposition in reach is 985.5 ha. Deposition has occurred along both the banks. River has eroded left bank downstream of Allahabad.
20. In the reach 950-1000 km, the total eroded area, the total deposited area and the total eroded & deposited area are 706.26 ha, 947.45 ha and 1511.31 ha respectively. Net deposition in reach is 241.20 ha. There is erosion on left bank near Gutni and right bank downstream of Shahzadpur; on the other hand, deposition is found near Benti & Mainapur on the left bank and near Bharwari & Fatehpur on the right bank.
21. In the reach 1000-1050 km, total eroded area, total deposited area and total eroded & deposited area are 197.71 ha, 361.38 ha and 414.486 ha respectively. Net deposition in this reach is 163.67 ha. River has eroded left side near Kalakankar and Kaithaul. On the other hand, deposition has occurred towards both sides near Garhi followed by deposition on left side upstream of Kotaiya Chitra. No other major changes have been seen.
22. In the reach 1050-1100 km, total eroded area, total deposited area and total eroded & deposited area are 165.76 ha, 361.31 ha and 351.58 ha respectively. Net deposition in this reach is 195.55 ha. There is erosion towards left bank near Dalmau. No other major changes have been seen.
23. In the reach 1100-1150 km, total eroded area, total deposited area and total eroded & deposited area are 1063.71 ha, 871.72 ha and 910.70 ha respectively. Net erosion of this reach is 192 ha. River is severely eroded and deposited near Garehwa. Deposition has occurred towards left bank side near Alipur.
24. In the reach 1150-1200 km, total eroded area, total deposited area and total eroded & deposited area are 525.05 ha, 2864.53 ha and 1154.23 ha respectively. Net deposition in this reach is 2339.48 ha. There is erosion towards right bank near Kanpur on the other hand, heavy deposition along left bank near Shuklaganj and along right bank near Bithur

has been found. Major erosion and deposition has been occurred due to construction of Kanpur barrage across Ganga river. Before the construction of the barrage, the river was flowing towards left side which was diverted towards right side through excavation of a pilot channel.

25. In the reach 1200-1250 km, total eroded area, total deposited area and total eroded & deposited area are 1152.82 ha, 455.92 ha and 2314.63 ha respectively. Net erosion in this reach is 696.90 ha. The river has eroded left bank near Bangarmau and Ram Purwa. On the other hand, deposition has occurred near Bithaur and Daryapur on the right bank - this deposition may be due to change in course of the river.

26. In the reach 1250-1300 km, total eroded area, total deposited area and total eroded & deposited area are 889.10 ha, 1210.67 ha and 1264.69 ha respectively. Net deposition in this reach is 321.57 ha. Deposition has occurred towards right bank near Lalpur and towards left bank near Srimau and Sarah. On the other hand, erosion has been noticed towards left bank near Dahillia and towards right bank near Singirampur.

27. In the reach 1300-1350 km, total eroded area, total deposited area and total eroded & deposited area are 414.81 ha, 4096.74 ha and 1131.72 ha respectively. Net deposition in this reach is 3681.93 ha. There is heavy deposition in the upstream of Amritpur towards both the banks of river; erosion towards left bank near Amritpur and towards right bank near Shamsabad.

28. In the reach 1350-1400 km, total eroded area, total deposited area and total eroded & deposited area are 1325.17 ha, 2360.24 ha and 2797.69 ha respectively. Net deposition in this reach is 1035.06 ha. There is major erosion towards right bank near Kaimganj and Kampil followed by erosion towards left bank near Usehat. On the other hand, deposition near Bikrampur and Labhari on the left bank and near Nardauli in right bank. The possible reason behind this is lateral shifting of the river

29. In the reach 1400-1450 km, total eroded area, total deposited area and total eroded & deposited area are 1044.87 ha, 7105.66 ha and 1650.49 ha respectively. Net deposition in this reach is 6060.78 ha. There is erosion in right bank near Shahbazpur and left bank upstream of Kachhla bridge. Heavy deposition towards left bank near Bamnosi and right

bank near Bsrauna & Fatehpur has been noticed. The possible reason behind this is lateral shifting of the river.

30. In the reach 1450-1500 km, total eroded area, total deposited area and total eroded & deposited area are 622.40 ha, 3782.86 ha and 489.51 ha respectively. Net deposition in this reach is 3160.46 ha. Noticeable deposition are visible in this reach. There is erosion towards left bank near Mowa Hasanganj and towards right bank near Sirwali. Deposition in this reach can be attributed to low velocity.

31. In the reach 1500-1550 km, total eroded area, total deposited area and total eroded & deposited area are 662.92 ha, 2399.17 ha and 1293.33 ha respectively. Net deposition in this reach is 1736.25 ha. Noticeable amounts of deposition on the both banks of river has been noticed. There is erosion towards left bank downstream of Chaopur and right bank near Mawoi. Deposition in this reach can be attributed to low velocity.

32. In the reach 1550-1600 km, total eroded area, total deposited area and total eroded & deposited area are 698.62 ha, 2399.17 ha and 1287.41 ha, respectively. Net deposition in this reach is 1700.55 ha. There is erosion towards left bank near Piplauti and upstream of Garhmukteswar. Deposition may be seen near Rukhalu (left bank), upstream of Garhmukteswar (right bank) and upstream of Jharina (left bank). The possible reason behind deposition in this reach is lateral shifting of the river.

33. In the reach 1600-1650 km, total eroded area, total deposited area and total eroded & deposited area are 1409.39 ha, 2495.09 ha and 2864.40 ha respectively. Net deposition in reach is 1085.70 ha. Noticeable amounts of erosion and deposition are visible in this reach due to lateral shifting. Major eroded and deposited areas are identified near Kamalapur and Dharannagar which can be attributed to the shifting of the main course of the river.

34. In the reach 1650-1700 km, total eroded area, total deposited area and total eroded & deposited area are 1169.68 ha, 6602.27 ha and 3113.25 ha respectively. Net deposition in reach is 5432.59 ha. Noticeable amounts of erosion and deposition are visible in this reach. Major eroded and deposited areas are identified near Bijnor and Bhukarheri which could be due to shifting of main course of the river.

35. In the reach 1700-1750 km, total eroded area, total deposited area and total eroded & deposited area are 745.50 ha, 1816.87 ha and 999.02 ha respectively. Net deposition in reach is 1071.38 ha. Major eroded and deposited areas are identified near Niranjanpur and Haridwar which could be due to lateral shifting of main course of the river.
36. In the reach 1750-1800 km, total eroded area, total deposited area and total eroded & deposited area are 26.13 ha, 149.78 ha and 61.71 ha respectively. Net deposition in the reach is 123.65 ha. Deposition towards right bank near Ghorighat has been noticed. No other major changes have been found in this reach due to river being in hilly terrain.
37. In the reach 1800-1824 km, total eroded area, total deposited area and total eroded & deposited area are 4.30 ha, 0.62 ha and 1.64 ha respectively. Net deposition in the reach is 3.68 ha. No other major changes have been found in this reach as the river is flowing in hilly terrain.

12.5 AGGRADATION AND DEGRADATION

Available measured cross sections of the Ganga river at the gauging stations Garhmukteshwar, Kachhlabridge, Fatehgarh, Ankinghat, Kanpur, Bhitaura, Shahjadpur, Allahabad, Mirzapur, Varanasi, Buxar, Gandhighat, Hathidah, Azmabad and Farakka barrage have been used to study the aggradation and degradation in the river bed. As the cross section are available only at gauging stations, which are located at large distances, it would not be appropriate to draw inferences from the cross sections of gauging stations for aggradations and degradation in Ganga river from Garhmukteshwar to Farakka barrage. However, such cross sections shall indicate aggradation and degradation process in vicinity of the gauging stations.

Figures 12.40-12.54 show measured cross sections of the Ganga river for different years at gauging stations Garhmukteshwar, Kachhla Bridge, Fatehgarh, Ankinghat, kanpur, Bithaura, Shahjadpur, Allahabad, Mirzapur, Varanasi, Buxar, Gandhighat, Hathidah, Azmabad and Farakka barrage, respectively. At the stations where more cross sections are available, cross section of approximately 5 years interval are considered for studying the aggradation and degradation of river over the time.

Following inferences may be drawn from the plotted cross sections of the river as shown in Figs. 12.40-12.54.

a) Chainage 1572 km : Garhmukteshwar

Only two cross sections of the Ganga river of pre and post monsoons of the year 2010 are available at this station (Fig. 12.40). No change in cross section has been noticed which reflect no aggradation and degradation.

b) Chainage 1425 km : Kachhlabridge

Two cross sections of the Ganga river at this station of pre and post monsoons of the year 2010 indicate that river has degraded towards left side over a length of 300 m (Fig. 12.41). The maximum degradation is of the order of 2.25 m. Practically, there is no aggradation or degradation of the river bed has occurred towards right side.

c) Chainage 1309 km : Fetehgarh

Cross sections of the Ganga river at Fetehgarh are available of pre and post monsoon of the year 2010 (Fig. 12.42). Remarkable aggradation and degradation has been noticed. Towards left side, aggradation has occurred while towards the right side, river has degraded by about 3.5 m. Net aggradation and degradation at this section is negligible.

d) Chainage 1224 km : Ankinghat

Pre and post monsoons cross sections of the year 2010 are available at Ankinghat. Such cross sections indicate existence of a deeper channel of depth of 6 m and width 50 m towards right side (Fig. 12.43). Bed has degraded in the flood of year 2010 in the deeper channel. No aggradation or degradation has been noticed in the flood plain area. However, in the flood of the year 2010, a small deep channel has developed towards the left side.

e) Chainage 1156 km : Kanpur

Pre and post monsoons cross sections of the year 2010 are available at this section (Fig. 12.44). Such cross sections clearly indicate that river bed has degraded by about 4 m in the flood of the year 2010.

f) Chainage 1083 km : Bhitaura

Pre and post monsoons cross sections of the year 2010 are available at this section. Deeper section of the river is towards left side and has degraded by 1.5 m (Fig. 12.45). No remarkable aggradation or degradation has been noticed in other parts of the cross section of the river.

g) Chainage 992 km : Shahjadpur

Cross sections of post monsoon of the year 1984, 1991, 1997, 2005, 2010 and 2014 indicate that there is no definite pattern of aggradation or degradation of river bed at this location of the river (Fig. 12.46).

h) Chainage 920 km : Allahabad

Post monsoon cross sections of the year 1981, 1991, 1998, 2004 and 2014 indicate that the river bed has degraded over the time at this station (Fig. 12.47). The maximum degradation is about 4 m from the year 1981 to 2014. River is flowing in well defined channel at this location with deeper section towards the left side.

i) Chainage 798 km : Mirzapur

Post monsoon cross sections of year 1998, 2004, 2009 and 2014 indicate that river is channelized at this station (Fig. 12.48). The width of the channel is of the order of 900 m and depth is of the order of 14 m. There is no progressive trend of aggradation or degradation at this location.

j) Chainage 714 km : Varanasi

The deeper section of the river which is about 600 m wide and 30 m deep is towards left side (Fig. 12.49). There is no progressive trends of aggradation or degradation of the river bed. However, the elevation of the river bed of deeper section has changed by 8 m in the period of year 1980 to 2014.

k) Chainage 555 km : Buxar

There is no definite pattern of aggradation or degradation of river bed at this location, however; aggradation has occurred towards left side of the river (Fig. 12.50). There is no change in bed level of the river towards the right side over a period of year 2002 to 2015. The maximum temporal variation in the bed level is of the order of 5 m.

l) Chainage 407 km : Gandhighat

There is no definite pattern of aggradation or degradation of river bed at this location, however; the deeper section of the river has shifted towards the right bank over the years (Fig. 12.51). The maximum temporal variation in the bed level is of the order of 10 m in the period of year 1988 to 2013.

m) Chainage 310 km : Hathidah

Aggradation of the order of 10 m has occurred in the deeper section of the river at this station (Fig. 12.52). Beyond the deeper section, degradation has occurred in the river towards both side. On the right side, the river has degraded by about 10 m in the period 1994 to 2015.

n) Chainage 140 km : Azmabad

There are two deeper sections of the river at this site, and degradation has occurred in both the channels over the years (Fig. 12.53). Aggradation has occurred in other parts of the river section. The maximum temporal variation in the bed level is of the order of 5 m in the period 1995 to 2013.

o) Chainage 0 km : Farakka barrage

Post monsoon cross sections of the year 2006, 2009, 2012 and 2015 at this station indicate that degradation of deeper section of the river (Fig. 12.54). The order of degradation in the deeper section is 8 m from the year 2006 to 2015. However, aggradation has occurred towards the left side of the section over the time. Average variation of the river bed from the year 2006 to 2015 at this location is of the order of 4 m.

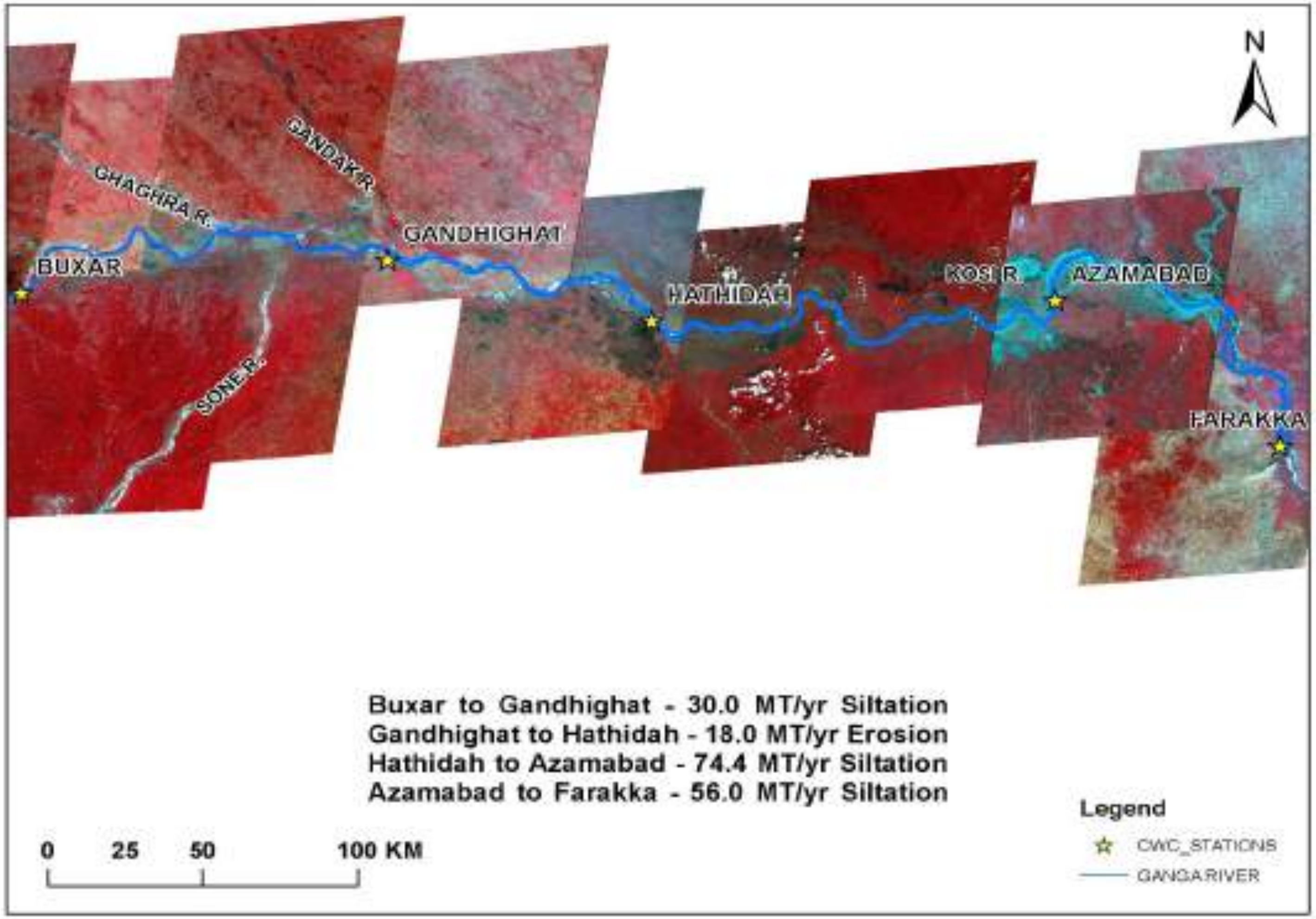


Figure 12.59 Erosion and siltation in different reaches of Ganga river from Buxar to Farakka

12.7 CONCLUSIONS

Following conclusions may be drawn from the study of erosion and siltation in the Ganga river:

1. The total eroded area in the Ganga river from Devprayag to Farakka barrage in the period 1970-2010 is 447 km^2 while the total deposited area in extreme left and right banks shifting is 1070.94 km^2. The total eroded plus deposited area during the said period is 623.54 km^2.
2. During the period 1970-2010, the Ganga river is subjected to deposition in almost whole reach. The deposition is pronounced and is of the order of 2000 ha per 50 km length of the river upstream of the Kanpur. From Kanpur to Mokamah, the deposition is of the order of 800 ha per 50 km. In the lower reach of the Ganga i.e., chainage 50 - 250 km, heavy sediment deposition of the order of 6000 m^3 per 50 km reach has been estimated.
3. There is no progreessive aggradation or degraddation in the river bed of the Ganga river from Garhmukteshwar to Farrage barrage. However, remarkable changes in the river bed over the years have beben noticed at many stations. Deepeer section of the river has subjected to degraddation at most of the stations of the Ganga river except at Hathidah where aggrdation has occurred in the deeper section over the years.
4. From the consideration of the suspended sediment load, Ganga river may be divided into three distinct reaches a) Devprayag to Allahabad, b) Allahabad to Buxar, and c) Buxar to Farakka. Average suspended sediment load in the monsoon period in these reaches are 26, 108 and 189 MT/yr, respectively. Maximum SSL has been observed at Gandhighat which can be attributed to inflow of sediment from Ghaggra, Sone and Gandak rivers to Ganga river upstream of the Gandhighat.
5. Ghaggra river contributes about 130 MT/yr sediment to the Ganga river - about three times more sediment than the Kosi river. Gandak river contributes about 35 MT/yr sediment to Ganga river which is comparable to Kosi river.
6. Siltation has been observed in the Ganga river from Hathidah to Farakka. This may be due to low sediment carrying capacity of the river which can be attributed to wideness and shallowness of the river in this reach. Siltation in the upstream of the Farakka barrage up to its pondage fetch may be due to back water effect of the barrage, however, this aspect is to be investigated through modelling. Total siltation of the sediment in the reach from Buxar to Farakka is estimated as 250 MT per year. Siltation of the order of 30, 000 ha has also been obtained in this reach based on the shifting of left and right banks of the Ganga river.

Chapter 13 MAJOR STRUCTURES & THEIR IMPACT ON THE MORPHOLOGY

13.1 IDENTIFICATION OF MAJOR STRUCTURES

Major structures such as railway & road bridges and barrages from Devprayag to Farakka on Ganga River have been identified using Google Earth and WRIS website and are mentioned in Table 13.1.

Table 13.1 Major structures located on Ganga river

ID	Name	Nearby Place	Length (m)	Type	Long. (degree)	Lat. (degree)
1	Road Bridge	Devprayag Pauri Road	160	Road	78.59659	30.14062
2	Road Bridge	Tilwal Gaon	122	Road	78.58673	30.11712
3	Road Bridge	Naugaon	82	Road	78.58723	30.08037
4	Road Bridge	Bachhali khal	100	Road	78.56675	30.06155
5	Road Bridge	Chandpur	145	Road	78.51399	30.05837
6	Road Bridge	Koudiyla	108	Road	78.49090	30.06705
7	Road Bridge	Mala	102	Road	78.43423	30.08585
8	Road Bridge	Nilkhanth Bridge, Haldogi	200	Road	78.35359	30.12723
9	Pedestrian Bridge	Lakshman Jhula	120	Pedestrian	78.33002	30.12631
10	Pedestrian Bridge	Ram Jhula	215	Pedestrian	78.31450	30.12314
11	Pashulok Barrage	Rishikesh	320	Barrage/Road	78.28839	30.07428
12	Bhimgoda Barrage	Haridwar	453	Barrage/Road	78.18047	29.95643
13	Road Bridge (NH 74)	Haridwar	498	Road	78.16695	29.94349
14	Old Railway Bridge (Laksar-Balawali)	Laksar	881	Railway	78.10420	29.63896
15	Railway Bridge (Laksar-Balawali)	Laksar	873	Railway	78.10481	29.63857

16	C.C.S. Barrage (SH 12)	Jansath	583	Barrage/Road	78.03766	29.37337
17	Railway Bridge 1	Mohamadabad Atamali	1217	Railway	78.14395	28.76326
18	Railway Bridge 2	Mohamadabad Atamali	693	Railway	78.14422	28.76305
19	Road Bridge (NH24)	Brijghat	692	Road	78.14512	28.76209
20	Pontoon bridge	Ahar	89	Road	78.25963	28.47915
21	Road Bridge	Aligarh byepass Rd	1063	Road	78.27105	28.36451
22	Railway bridge	Rajghat, Narora	912	Railway	78.36559	28.24469
23	Narora Barrage	Narora	913	Barrage/Road	78.39992	28.19171
24	Railway bridge	Kachhla	637	Railway	78.85683	27.93344
25	Road Bridge (SH 33)	Kachhla	677	Road	78.85818	27.93276
26	Pontoon bridge	Dhakia Shobha	76	Road	79.47679	27.57281
27	Road Bridge (SH 43)	Fatehgarh	624	Road	79.62952	27.40100
28	Pontoon Bridge	KatriUmrauli	162	Road	79.88594	27.15031
29	Road Bridge (SH 21)	Mehandipur	797	Road	79.98768	27.01196
30	Road Bridge (SH 40)	Alamnagar	721	Road	80.10000	26.88116
31	Pontoon Bridge	Katripanka	178	Road	80.15335	26.72487
32	Ganga Barrage (NH 91)	Kanpur	635	Barrage/Road	80.31847	26.50966
33	Road Bridge (SH 58)	Shuklaganj	842	Road	80.37439	26.47188
34	Railway Bridge	Shuklaganj	800	Railway	80.37477	26.47145
35	Road Bridge	Shuklaganj	824	Road	80.37646	26.47003
36	Road Bridge (NH 25)	Asharfabad	710	Road	80.40948	26.43595
37	Road Bridge (NH 25)	Ashafabad	701	Road	80.40977	26.43570
38	Road bridge (Baksar Muradpur Road)	Baksar	820	Road	80.66275	26.13611
39	Road Bridge	Alampur Narhi	1047	Road	80.90953	26.05495

	(SH 13)					
40	Road Bridge (SH 13A)	Fatehabad	1013	Road	81.03155	26.05342
41	Pontoon Bridge	Mubarakpur	257	Road	81.36759	25.70697
42	Road Bridge (Allahabad Bypass)	Dhheemi	1002	Road	81.54537	25.58729
43	Road Bridge (Allahabad Bypass)	Dhheemi	1003	Road	81.54553	25.58717
44	Road Bridge (Chandra Shekhar Azad Bridge)	Rangpura	959	Road	81.86591	25.50758
45	Road Bridge (Lord Curzon Bridge)	Rangpura	1022	Road	81.86673	25.50761
46	Railway bridge	Rangpura	981	Railway	81.86772	25.50740
47	Railway bridge (Near Daraganj)	Daraganj	1903	Railway	81.89236	25.43884
48	Road Bridge (Shastri Bridge, NH 2)	Daraganj	2056	Road	81.89280	25.43530
49	Pontoon Bridge	Rasauli	407	Road	82.22190	25.28332
50	Pontoon Bridge	Dhantulasi	491	Road	82.24540	25.17718
51	Pontoon Bridge	Bairaja	513	Road	82.41742	25.24807
52	Road Bridge (PakkaPul, SH 5)	Mirzapur	986	Road	82.54462	25.15489
53	Pontoon Bridge	Bhatauli	459	Road	82.67369	25.20095
54	Pontoon Bridge	Mundipur	529	Road	82.87444	25.13042
55	Road Bridge (NH 2)	Salhupur	1283	Road	83.02771	25.25576
56	Pontoon Bridge	Salhupur	674	Road	83.01823	25.27096
57	Rajghat Bridge (NH 7)	Suzabad	1205	Road/ Railway	83.03467	25.32208
58	Pontoon bridge	Ramchandipur	475	Road	83.13235	25.34755
59	Pontoon Bridge	Sapsaul	364	Road	83.18025	25.42054

60	Road Bridge (NH 97)	Mednipur	1003	Road	83.60733	25.58424
61	Road Bridge (NH 84)	Babanagare	1097	Road	83.98596	25.59028
62	Digha Bridge	Digha	4780	Road/ Railway		
63	Road Bridge (NH 19)	Alamganj (Patna)	5575	Road	85.20874	25.62499
64	Bridge (NH 31)	Hathidah	1700	Road/ Railway	86.45587	25.40005
65	Road Bridge (SH 58, Vikramshila Setu Road)	Basgarha	4400	Road	87.02710	25.27371
66	Farakka Barrage, (NH 34)	Farakka	2249	Barrage/Road/ Railway	87.93106	24.80396

Information of six major barrages on Ganga river from Devprayag to Farakka is as follows

1. Pashulok/ Rishikesh barrage

The Pashulok barrage, also known as Rishikesh barrage, is located on the Ganga river in south of Rishikesh in Dehradun district, Uttarakhand, India. The main purpose of the barrage is to divert water into a canal located on the east bank of the river which feeds water to the Chilla power plant downstream at 29°58′34″N 78°13′11″E, and 4 km upstream of Haridwar. The power station contains four 36 MW Kaplan turbine-generators for an installed capacity of 144 MW. Elevation between the plant's intake and tailrace

Salient Features	
Name of the Structure	Vibhadra / Rishikesh Barrage
Nearest city	Dehra Dun
District	Dehradun
State	Uttarakhand
Name of River	Ganga
Basin	Ganga
Year of completion	1980
Purpose	Hydroelectric
Mean annual rainfall (mm)	
Total annual yield of catchment (MCM)	
Length of Barrage and Anicut (m)	312
Height upto crest (m)	11.5
No. of bays (i.e. number of openings)	15

provides a hydraulic head of 32.5 m. The design discharge of the plant is 560 m^3/s.

Type of spillway gate	Others
Spillway gates - Number	12
Spillway gates - Size (m)	10.15 ×18
Crest Level (m)	325.5
Pond level (m)	337
Under sluice bay - Size (m)	11.5 m × 18 m
Gates for under sluice - Number	3
Status of BWA Construction	Completed

2. Bhimgoda barrage

The Bhimgoda barrage, also referred to as the Bhimgoda Weir or Bhimgoda Head Works, is a barrage on the Ganga river at Har ki Pauri near Haridwar in Haridwar district, Uttarakhand, India. Built as the headworks of the Upper Ganga Canal, an initial barrage was completed by year 1854 and replaced twice; the final one completed in1983. The primary purpose for the barrage is irrigation but it also serves to provide water for hydro-electric power production and control the floods. The area behind the barrage is known as the Neel dhara bird sanctuary and is a popular destination for various water birds and tourists. Design discharge is 19,300 m^3/s as per wikipedia and 17,400 m^3/s as per India-WRIS.

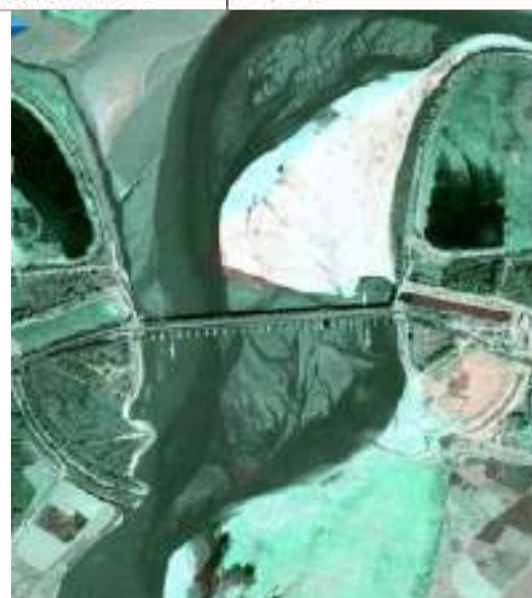
Bhimgoda Barrage	
Location of Bhimgoda Barrage	
Country	India
Location	Haridwar
Coordinates	[illegible]
Status	Operational
Construction began	1979
Opening date	1983

Dam and spillways	
Length	454 m (1,490 ft)
Spillway capacity	19,300 m^3/s (681,573 cu ft/s)
Reservoir	
Catchment area	23,000 km^2 (8,880 sq mi)
Power station	
Operator(s)	Uttaranchal Jal Vidyut Nigam Ltd.
Commission date	Pathri: 1955 Mohammadpur: 1952
Turbines	Pathri: 3 x 6.8 MW Kaplan-type Mohammadpur: 3 x 3.1 MW Kaplan-type
Installed capacity	Pathri: 20.4 MW Mohammadpur: 9.3 MW

3. Chaudhary Charan Singh barrage

Madhya Ganga barrage also known as Chaudhary Charan Singh barrage as located near Jansath, Muzaffarnagar, Uttar Pradesh. The barrage has a length of 621 m.

Salient Features	
Name of the Structure	Madhya Ganga Barrage (Chaudhary Charan Singh Barrage)
Nearest city	Jansath
District	Muzaffarnagar
State	Uttar Pradesh
Basin	Ganga
Purpose	Irrigation
Design flood (Cumec)	17500
Length of Barrage and Anicut (m)	621
No. of bays (i.e. number of openings)	28
Width of Bay (m)	18
Type of spillway gate	Others
Pond level (m)	221.8
Under sluice bay - Number	6
Status of BWA Construction	Completed



4. Narora barrage

Narora barrage is next to Narora and is located in Uttar Pradesh, India. Narora barrage has a length of 922.43 m.

Salient Features	
Name of the Structure	Narora Barrage
Nearest city	Anupshahr
District	Bulandshahr
State	Uttar Pradesh
Name of River	GANGA
Basin	Ganga
Year of commencement	1963
Year of completion	1966
Purpose	Irrigation
Design flood (Cumec)	14166
Length of Barrage and Anicut (m)	922.43
Length of upstream divide wall (m)	67.05
No. of bays (i.e. number of openings)	54
Width of Bay (m)	7.51
Type of spillway gate	Others
Spillway gates - Number	54
Thickness of Pier (m)	1.52
Thickness of Intermediate Pier (m)	2.44
Pond level (m)	178.9
Under sluice bay - Number	7
Means for dissipating energy (Hydraulic)	STILLING BASIN WITH FLOOR BLOCKS
Status of BWA Construction	Completed

5. LuvKhush barrage

LuvKhush barrage also known as Ganga barrage across the Ganga is located near Azad Nagar-Nawabganj in Kanpur.

Construction started in 1995 and inaugurated in May 2000. The total length is 621 m and it serves as a four lane highway bypass for NH 91.

Ganges Barrage	
Official name	Lav Khush Barrage
Location	Kanpur, INDIA
Coordinates	26.5078°N 80.3169°E
Construction began	1995
Opening date	May 2000
Construction cost	Rs. 303.14 crore
Dam and spillways	
Impounds	Ganges River
Length	621 m
Website	
Ganges Barrage	

6. Farakka barrage

Farakka barrage is a barrage across the Ganga River, located at Chapai Nawabganj District of West Bengal, roughly 16.5 km from the border of India and Bangladesh. Its construction was started in 1961 and completed in 1975 at a cost of Rs. 156.49 crore. Operations began on April 21, 1975. The barrage is about 2,240 m long. The feeder canal from the barrage to the Bhagirathi-Hooghly river is about 40 km long.

The purpose of the barrage is to divert 1100 m^3/s of water from the Ganga river to the Hooghly river for flushing out the sediment deposition from the Kolkata harbour without the need of regular mechanical dredging. After commissioning the project, it is found that the diverted water flow from the Farakka barrage is not adequate to flush the sediment from the river satisfactorily. In addition, there are regular land/bank collapses into the Ganga river due to the high level back water of the Farakka barrage. Substantial high land is already converted in to low level river bed causing displacement of huge population. The water diverted from the Farakka barrage is less than 10% of Ganga river water available at Farakka. Indian government is contemplating to cement line/widen /deepen the Farakka feeder canal to increase the flow.

Salient Features	
Name of the Structure	Farakka Barrage
Nearest city	Jangipur
District	Murshidabad
State	West Bengal
Name of River	Ganga
Basin	Ganga
Year of commencement	1961
Year of completion	1975
Purpose	Irrigation
Spillway capacity (Cumec)	1100
Length of Barrage and Anicut (m)	2240
Type of spillway gate	Others
Spillway gates - Number	123
Status of BWA Construction	Completed

13.2 IMPACTS OF THE MAJOR STRUCTURES ON THE MORPHOLOGY OF THE GANGA RIVER

13.2.1 Impacts of the barrages

There are six barrages on the ganga river, namely Pashulok (near Rishikesh), Bhimgoda (in Haridwar), Chaudhary Charan Singh (near Bijnor), Narora (in Narora), Luvkhush (near Kanpur) and Farakka (in Farraka). Impacts of construction of such barrages on the morphology of river have been studied herein with the use of historical toposheets and satellite images. Changes in the morphology have also been witnessed through visits to the various sites of the barrages.

1. Pashulok barrage (Rishikesh)

To study the impact of the Pashulok barrages on river morphology, the decadal satellite images and geospatial datasets have been examined. Figure 13.1 shows major course of Ganga river of years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs. 13.2 (a-f) show images of years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

Pashulok barrage also known as Rishikesh barrage is constructed across Ganga river at Rishikesh, Uttrakhand. This is the first barrage across Ganga river and is constructed in 1980 to divert water into a power channel from its left side which feeds water to Chilla power plant for the power generation of 144 MW. The length of barrage is 312 m and its design discharge is 13200 cumecs. The catchment area of Ganga river at this location is 21,000 km^2.

Protection walls are provided upstream of the barrage along left side in a length of 180 m and towards right side in a length of 117 m to protect the banks against erosion. Downstream of the barrage wing walls followed by ghats are provided. Being in the hilly area, no noticeable change in the morphology of the river has been noticed.

The width of the Ganga river near the barrage is 340 m and over the time from 1970 to till date negligible changes in the bed width have been observed. Near the barrage, the river is straight, however, about 1.8 km upstream of the barrage, river is flowing in two channels over a length of about 1.5 km. No remarkable changes in the shape and size of the river upstream of the barrage have been noticed during the period 1970 - 2015.

Figure 13.1 GIS layers of the Ganga river for the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015 at the Pashulok barrage

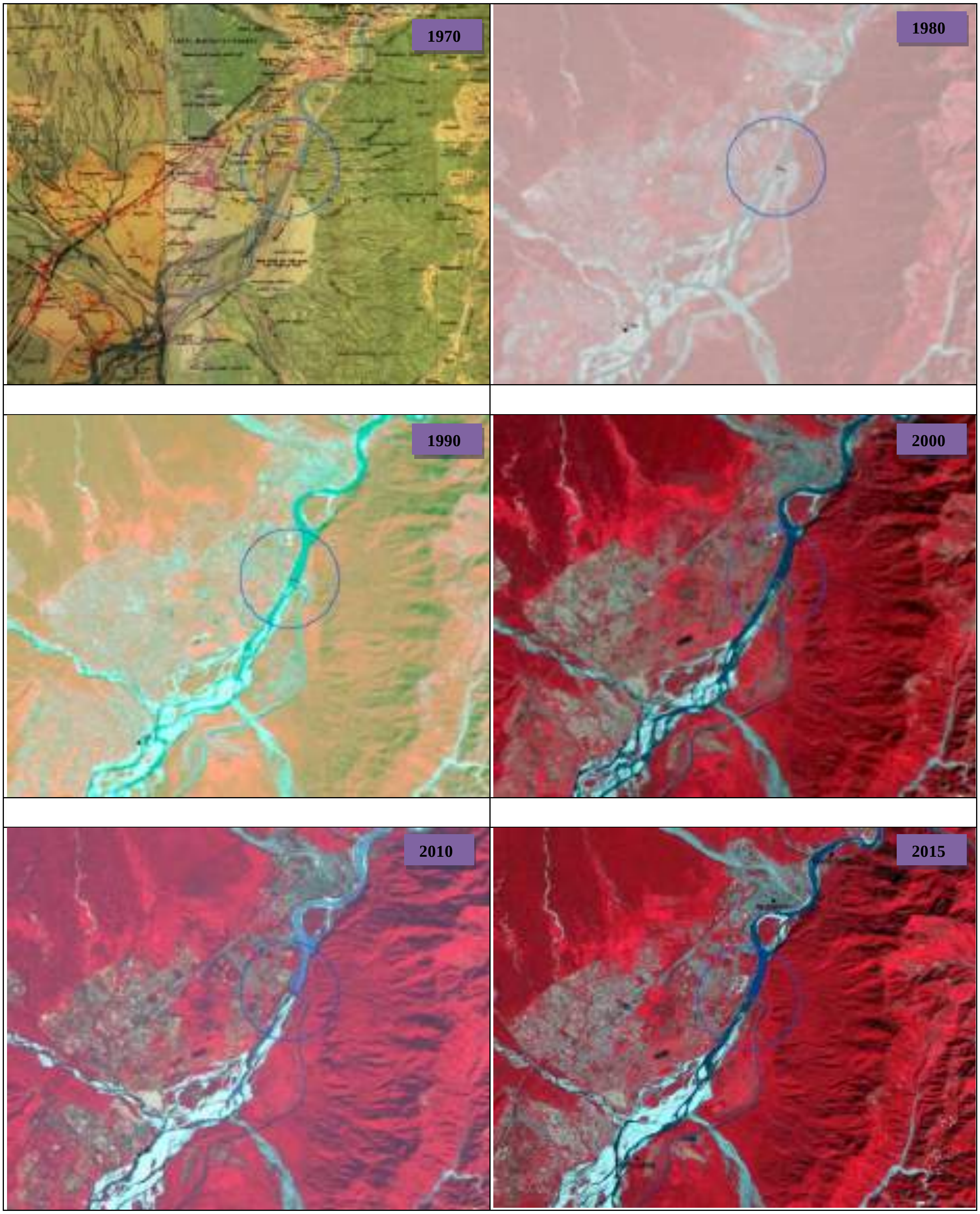


Figure 13.2 (a-f) Images of Ganga river of the year 1970, 1980, 1990, 2000, 2010 and 2015 at the Pashulok barrage

About 2.5 km downstream of the barrage, braiding in the river in the form of 3-4 channels has been observed. No remarkable changes in the braiding pattern over the year from 1970 to 2015 have been seen from SOI toposheet and satellite images.

Based on the analysis carried out in this study, it can be concluded that there is negligible impact of Pashulok barrage on the plan form of the Ganga river in its vicinity. Site visit to the barrage which was undertaken on December 10th 2016 and discussions held with barrage authority also reveal that no noticeable changes in the morphology and erosion & deposition haave occurred in the vicinity of barrage.

Upstream and downstream view of the barrage are shown in Figs. 13.3 (a) and 13.3 (b), respectively.

Figure 13.3a Upstream of the Pashulok barrage

Figure 13.3b Downstream of the Pashulok barrage

2. Bhimgoda barrage (Haridwar)

To study the impact of the Bhimgoda barrage on river morphology, the decadal satellite images and geospatial datasets have been examined. Figure 13.4 shows major course of the Ganga river for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs. 13.5 (a-f) show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

Bhimgoda barrage is located on Ganga river in Haridwar (which is located at foothills) at about 17 km downstream of the Pashulok barrage. The length of the barrage is 453.5 m and its design discharge is 17,400 cumecs (India-WRIS). The catchment area of the Ganga river at this location is 23,000 km^2. Built as the headworks of the upper Ganga canal, earlier barrage was completed by 1854 and replaced twice, the final one was completed in 1983. Two canal systems offtake from this barrage - the upper Ganga canal which design capacity is 10,500 cusecs offtakes from the right side, while, eastern Ganga canal offtakes from left bank and its design discharge is 8,385 cusecs.

Elliptical guide bund of length 535 m is provided towards left side. A series of spurs have been provided towards left side at about 700 m upstream of the barrage to protect the erosion of the left bank over a length of 900 m.

The Survey of India (SOI) toposheet for year 1970 and satellite images for years 1980, 1990, 2000, 2010 and 2015 reveal that there was an island upstream of the barrage of area of 0.33 km^2 approximately in 1970, however, it is eroded by the flowing water which has resulted in gradual decrease in area of the island as evident from the Figs. 13.6 & 13.7. Presently, the area of the island is just 0.06 km^2. As the first barrage was constructed in 1854 and subsequently replaced by new one in 1983, it is difficult to draw any conclusion in respect of impact of barrage on the morphology of the Ganga river as images are not available for the years prior to 1970.

No noticeable changes in the plan form of the Ganga river upstream of barrage have been noticed from 1970 to 2015 except reduction in the area of the island.

After passing through the barrage in the downstream, the flow strikes to the left bank at about 1.2 km and takes turn towards right side which has resulted in erosion of the right bank. To control such erosion, concerned department has constructed a series of spurs along the bank in a length of about 2 km. This pattern of flow is prevailing since 1970. Severe braiding in the river has been noticed at about 5 km downstream of the barrage.

No major changes in the plan form of the river have been seen from 1970 to till date. As barrage is there in one form or other from year 1854 and no image is available for the years prior to 1970, therefore, it is hard to draw conclusion respect of impact of barrage on the morphology of the Ganga river.

Figure 13.4 GIS layers of the Ganga river for the years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015 at the Bhimgoda bararge

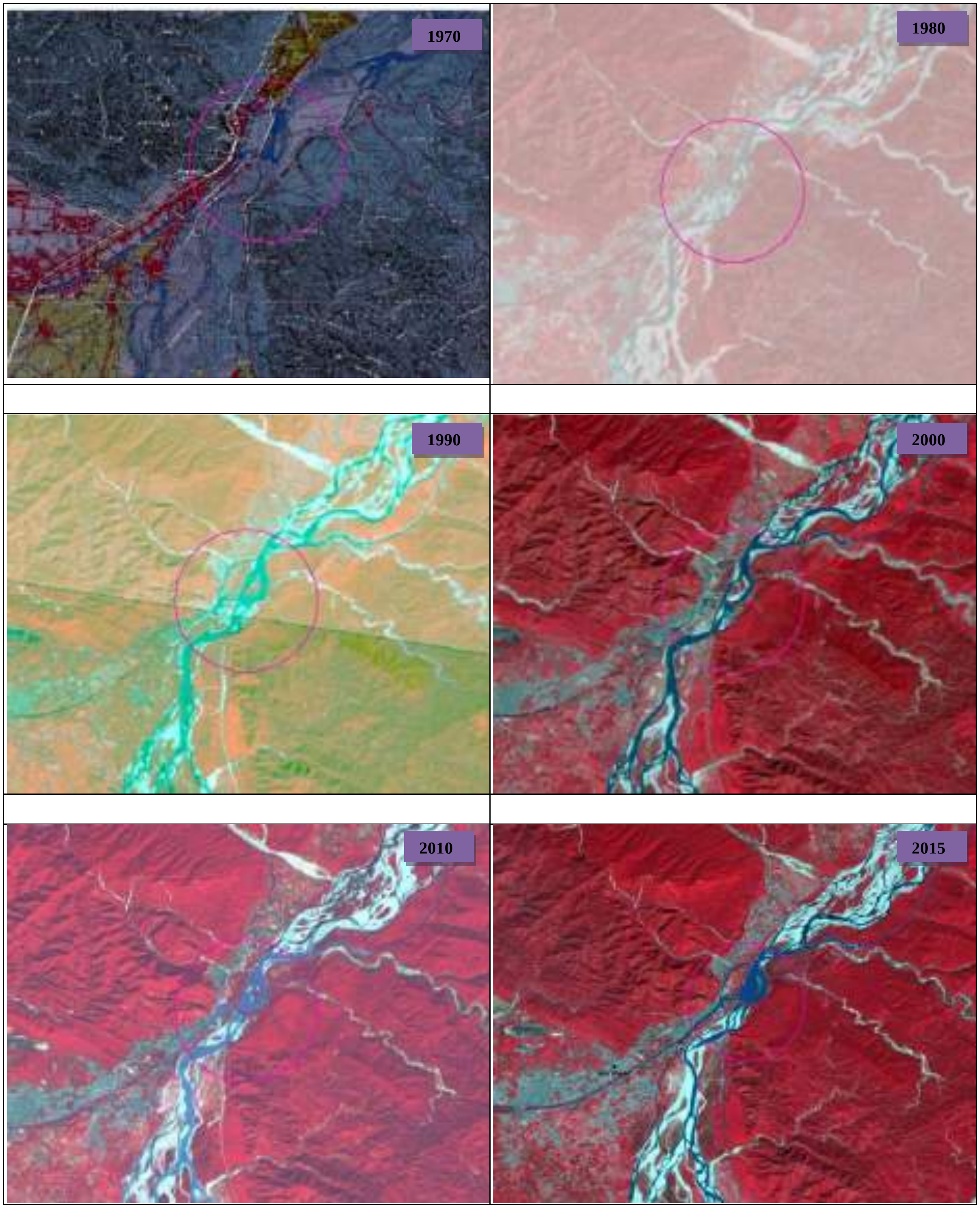


Figure 13.5 (a-f) Images of Ganga river for the year 1970, 1980, 1990, 2000, 2010 and 2015 at the Bhimgoda barrage

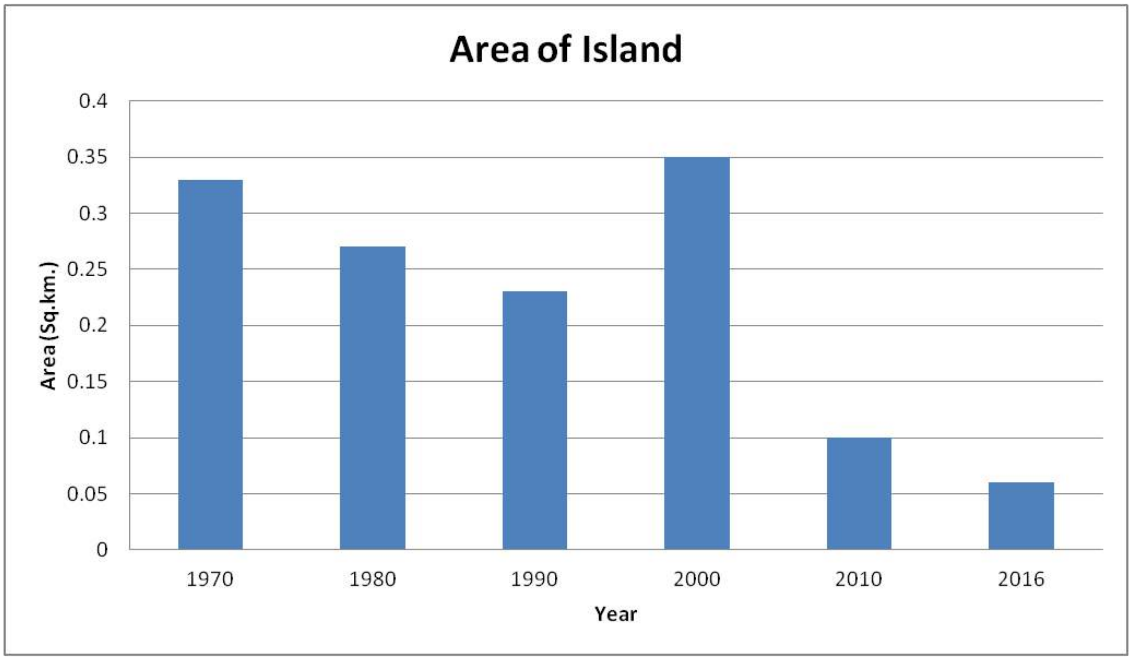


Figure 13.6 Temporal variation of area of island formed upstream of the barrage

Figure 13.7 A small silted island upstream of the Bhimgoda barrage

3. Chaudhary Charan Singh Barrage (Bijnor)

To study the impact of the Chaudhary Charan Singh Barrage (CSS) on river morphology, the decadal satellite images and geospatial datasets are examined. Figure 13.8 shows major course of Ganga river for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs. 13.9 (a-f) show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively

The CCS barrage is constructed across Ganga river near Jansath (Uttar Pradesh) probably in 1984. The length of barrage is 621 m, while the design discharge is 17,600 cumecs. The barrage is constructed to feed Ganga water into two canals namely Madhya Ganga Canal (MGC) Phase-I (right) and MGC Phase-II (left). MGC Phase-I is functional, however, construction of the MGC Phase-II is underway. Due to large width of the river at barrage site, elliptical type guide bunds are provided on both the sides of the river. In addition to this, an embankment of length of about 8 km is provided towards left side. Ganga-Pushta road is constructed over this embankment. A solid spur is provided at right bank downstream of the barrage to control the bank erosion. No other river training works have been provided near the barrage except for the above mentioned protection works.

In year 1970, the river at the location of CCS barrage was spread over a width of about 2.15 km with its major course towards right side. The main course of the river shifted towards left side in year 1980 and even today, the main course of river is flowing towards left side. At about 1 km upstream of the barrage, river was severely abutting the left bank till year 2000, however, in year 2010 onwards, the main course moved away from the left embankment.

No remarkable changes in the morphology of the Ganga river has been noticed on the basis of analysis of SOI toposheets & satellite images, site visit and discussion held with barrage authorities.

Major changes have been noticed in the shifting of main course of the river at about 7 km upstream of the barrage. At this location, in year 1970 to 2000, the river was flowing towards right side, however, in year 2010 it shifted towards left side of the order of about 5 km. Such shifting resulted in heavy erosion and deposition in the upper reaches of the barrage.

The Lacey perimeter for the design discharge (17,600 cumecs) of barrage is 630 m against 621 m length of the barrage. Thus the looseness factor of the barrage is close to unity.

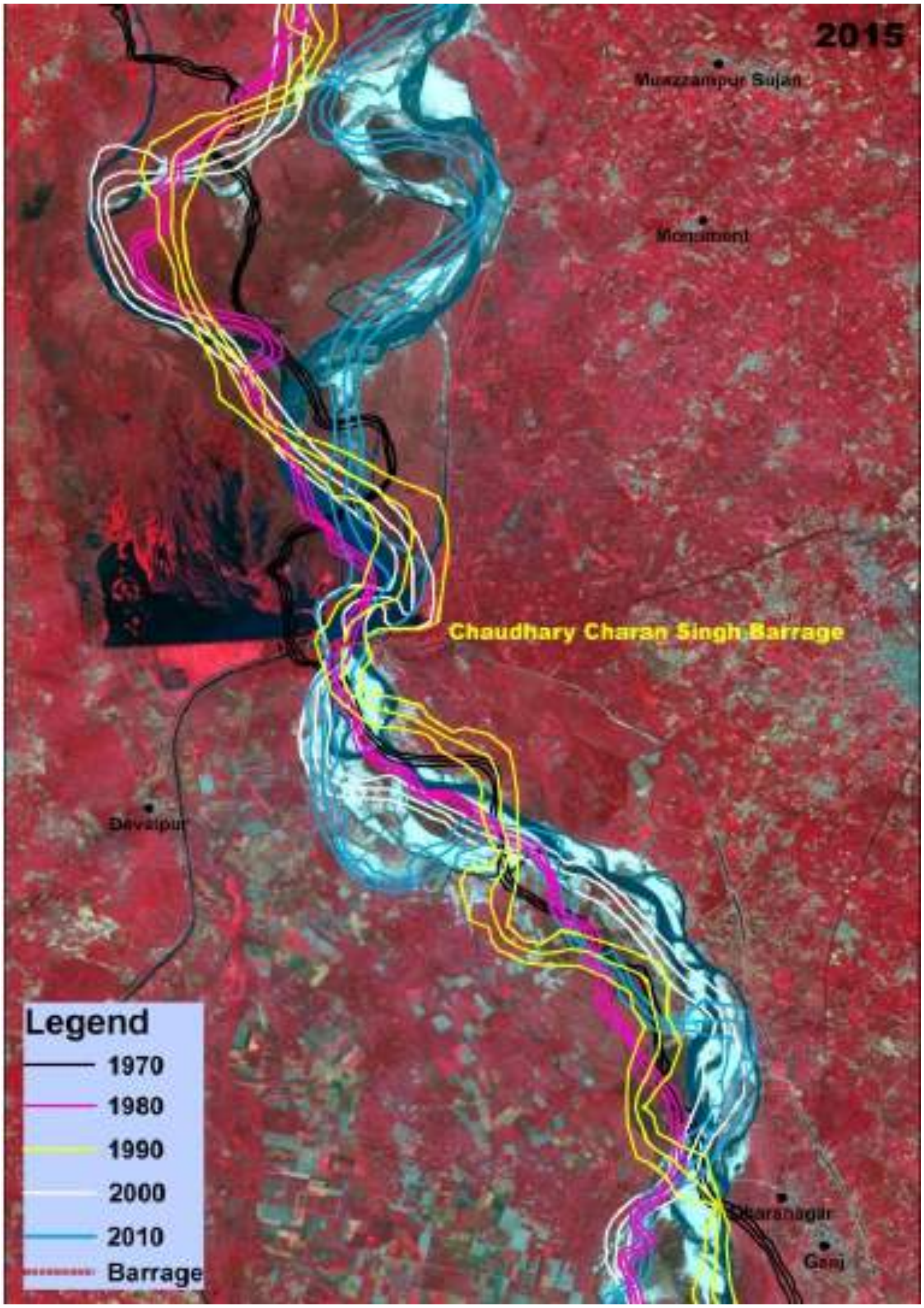


Figure 13.8 GIS layers of the Ganga river for the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015 at the CCS barrage

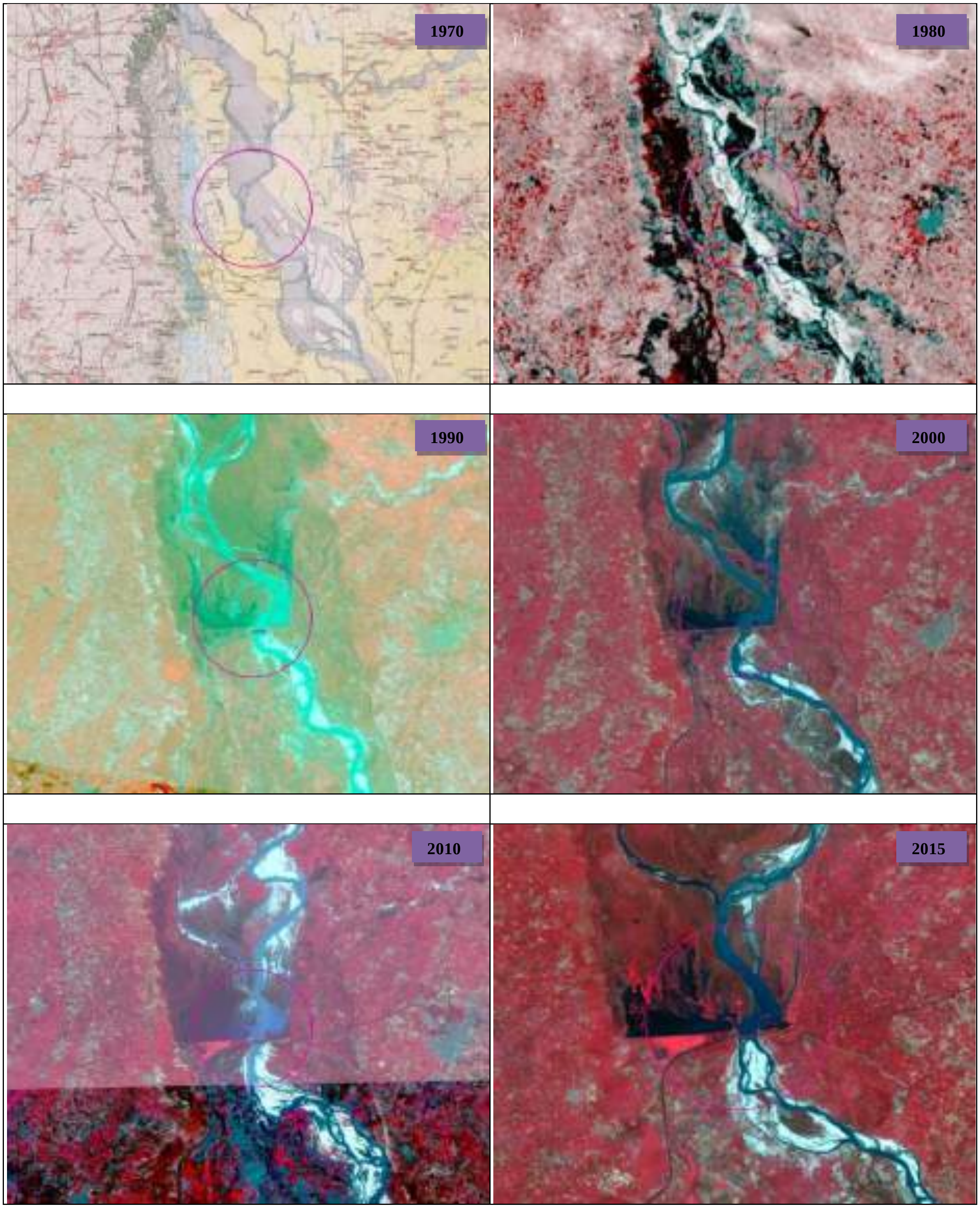


Figure 13.9 (a-f) Images of Ganga river for the year 1970, 1980, 1990, 2000, 2010 and 2015 at the CCS barrage

During the site visit undertaken on 12th October 2016, sand deposits upstream of barrage at about 600 m was seen and it was interpreted that such deposits were due to construction of the barrage. After analysing the SOI toposheets of 1970 and satellite images of years 1980 to 2015, it was found that so called deposits were actually the land which had never been part of the river. Such land appesred as deposits due to shifting of main course of river from right to left over the years.

At the outset, it may be concluded that there are no remarkable changes in the morphology of Ganga river due to construction of the barrage. It may also be concluded that, no noticeable silting has occurred due to almost unity looseness factor of the barrage.

Upstream and downstream view of the barrage is shown in Figs. 13.10a and 13.10b, respectively.

Figure 13.10a Upstream of the CCS barrage

Figure 13.10b Downstream of the CCS barrage

4. Narora Barrage

To study the impact of the Narora barrage on the river morphology, the decadal satellite images and geospatial datasets are examined. Figure 13.11 shows major course of Ganga river for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs. 13.12 (a-f) show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively

Narora barrage is constructed across Ganga river near Anupshahr (U.P.) to divert water into two canals namely parallel Ganga canal and lower Ganga canal. Both canals offtake from right side of the river. Construction of the barrage commenced in year 1963 and completed in 1966. The length of the barrage is 922.43 m and design discharge is 14166 cumecs. It has 54 numbers of bays, out of which 7 bays are of under sluice type.

Only left guide bund is provided at the barrage. Land towards right side of the barrage is relatively on higher elevation compared to the left side. The river is jacketed by constructing embankment and series of spurs from barrage to about 6.5 km upstream (railway bridge). Beyond 6.5 km upstream, only left bank embankment is provided over a length of 30 km. Embankment and series of spurs arrangement are also provided along right side of the river downstream of the barrage over a length of 25 km.

Close examination of the SOI topsheets of 1970 and satellite images of year 1980 to 2015 reveals that the deployed river training works (guide bund, embankment, spurs) are performing satisfactorily. With the provision of embankments and spurs upstream of barrage, river has been channelized in a width of about 900 m. In the presence of deployed river training works, no remarkable shifting of river from about 12 km upstream of the barrage to about 25 km downstream of barrage has been observed. However, river width is wide and of the order of 2 km downstream the barrage.

Huge deposition in the form of island from barrage to upstream railway bridge which is located about 6.5 km upstream has occurred that is evident from SOI toposheets of year 1970 and satellite images of years 1980 to 2015. The island starts from about 100 m upstream of the barrage. In the upstream of the barrage, the width of river is of the order of 1 km, out of which island covers about 600 m width. Thus, it can be concluded that out of the total width of the river, about 60% is blocked by heavy silt deposition.

The Lacey perimeter for design discharge of barrage is 565 m. However, provided length of barrage is 922.43 m. The looseness factor of the barrage comes out to be 1.63. Heavy silting upstream of barrage upto railway bridge can be attributed to high looseness factor of the barrage and also wide jacketed width of the river.

Temporal variation of area of the deposited island from year 1970 to till date has been examined and found that it varies from 1 km^2 to 2.68 km^2. Precisely island areas were 2.68 km^2, 1.4 km^2, 1.0 km^2, 2.5 km^2, 2.22 km^2, 2.2 km^2 in the year 1970, 1980, 1990, 2000, 2010 and 2015, respectively. In year 1970, there were two islands in the upstream of the barrage upto the railway bridge. Length of both the islands was of the order of 3.2 km each. In year 1980, the island was just upstream of barrage and was spread over a length of 1.8 km in upstream. In year 1990, the length of the island was of order of 1.4 km just upstream of barrage, however, in year 2000, 2010 and 2015 the length of island was of the order of 6.5 km.

Temporary island is formed downstream but does not last for long period. Site visit was undertaken on 12th October 2016 and heavy deposits upstream of the barrage were witnessed. Low height deposits were seen downstream of the barrage which were partially washed out during the flood time. No dredging of island is carried out; however, further enlargement in area of island is controlled by operation of the barrage gates.

A pilot channel of length 5.5 km was excavated, sometime before 2010 in the island located upstream of the barrage. The purpose of excavation of the pilot channel was to help in eroding the island through its widening due to concentrated flow during flood in the channel. However, the available Google Earth images of year 2010 (Figures 13.13a-b) onwards and LISS IV images of 2015 clearly indicates that channel is not serving the purpose, for which it was excavated as no increase in it's width has been seen, rather deposition in pilot channel has been noticed.

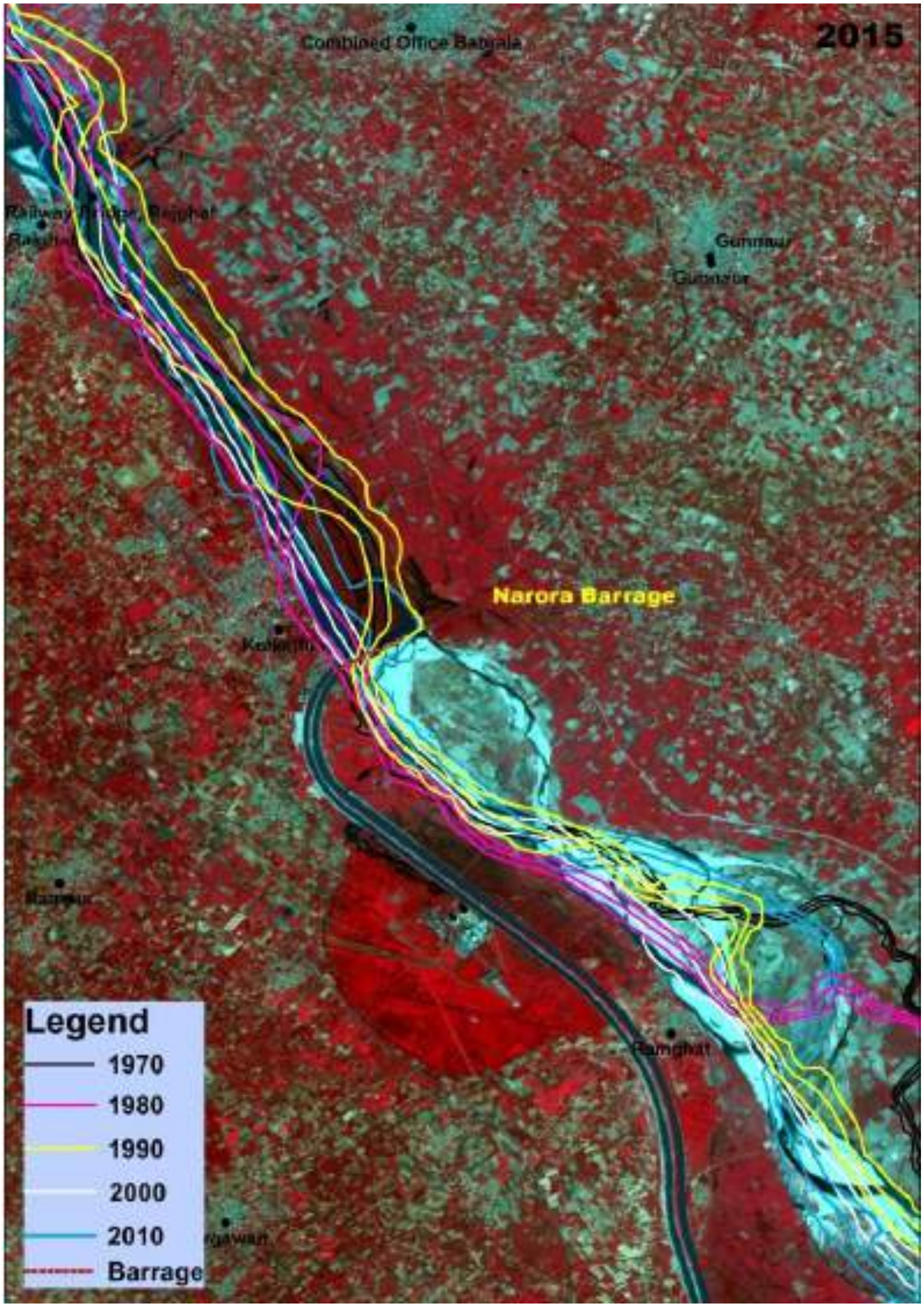


Figure 13.11 GIS layers of the Ganga river for the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015 at the Narora barrage

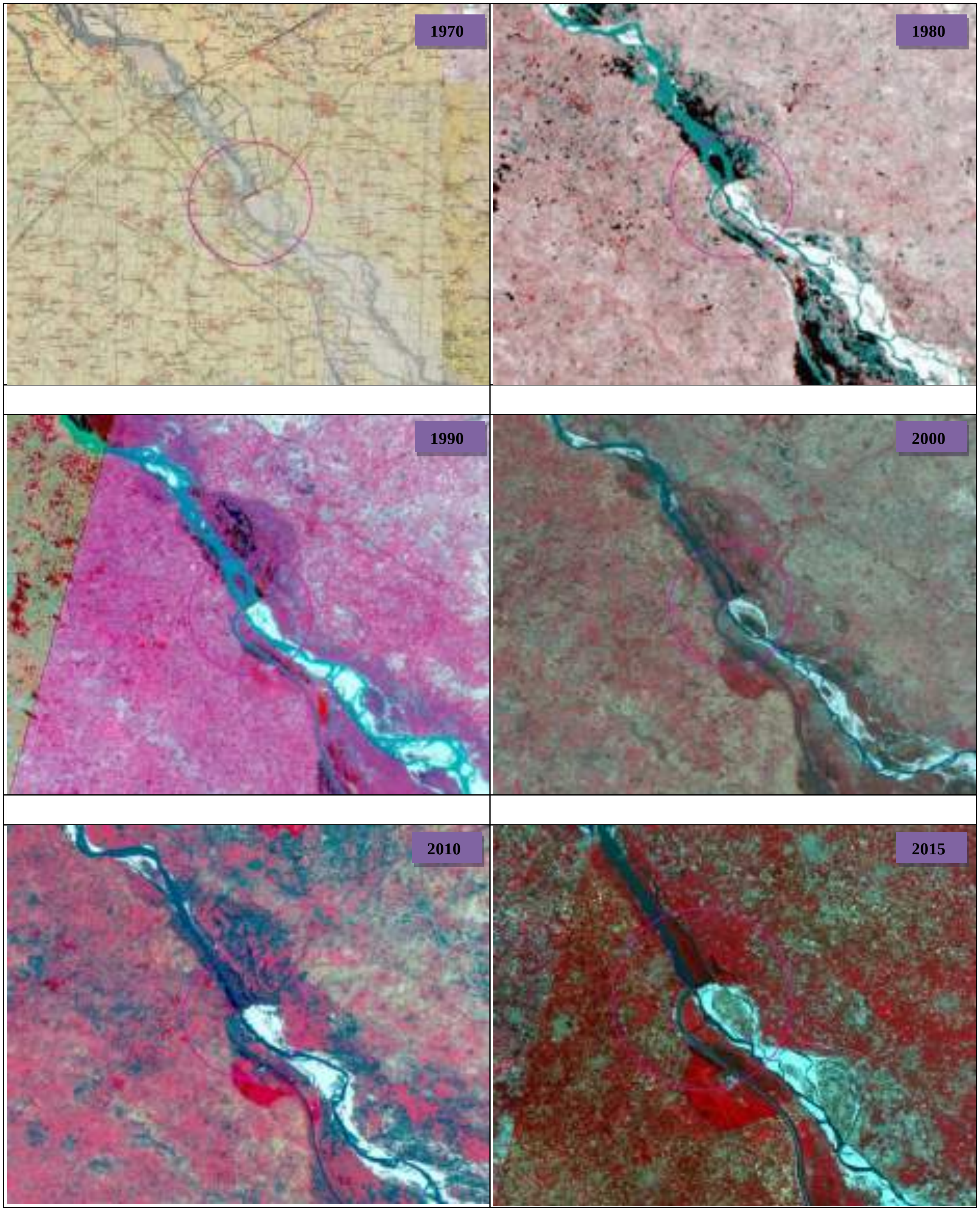


Figure 13.12 (a-f) Images of Ganga river for the year 1970, 1980, 1990, 2000, 2010 and 2015 at the Narora barrage

Figure 13.13a A pilot channel upstream of the barrage in year 2010

Figure 13.13b Silted pilot channel in year 2015

As no image is available prior to construction of the barrage in 1966, it is difficult to draw any conclusion in respect of impact of the barrage on the morphology of Ganga river. But it is apparent that jacketing of river that maintains large width of river higher than the Lacey perimeter and long length of the barrage have resulted in heavy deposition in the form of island from railway bridge to the barrage in a length of 6.5 km.

Upstream and downstream views of the barrage are shown in Figs. 13.14a and 13.14b, respectively.

Figure 13.14a Silted island upstream of the Narora barrage

Figure 13.14b Downstream of the Narora barrage

5. Kanpur barrage

To study the impact of the Kanpur barrage on river morphology, the decadal satellite images and geospatial datasets are examined. Figure 13.15 shows major course of Ganga river for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs. 13.16 (a-f) show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

LuvKhush barrage also known as Ganga barrage is constructed across Ganga river at Nawabganj, Kanpur, Uttar Pradesh. The construction of barrage was started in 1995 and completed in May 2000. The purpose of barrage was to supply water to Kanpur city for domestic uses, in addition to bring the main course of Ganga river towards the main township of Kanpur.

The LuvKhush barrage is 621 m long and designed for discharge of 28,370 cumecs. It consisted of 30 gates.

Elliptical type guide bund of a length of 1 km including curve length is constructed at the left side, however, a straight guide bund of length 700 m including its curve length is provided towards its right side. A marginal bund is provided towards right side on which metallic road is constructed (NH 91 bypass). Left approach road to the barrage (NH 91 bypass) is also in the form of high embankment. At present, no other river training/ protection works have been provided. The main course of the river is towards left side in upstream of barrage, however, in the downstream it is towards right side.

SOI toposheet of year 1970 indicates that the main course of the river was about 2 km away from the barrage towards left side and 3 km away from the main township of Kanpur. At the location of the constructed barrage, there was not even a spill channel. Nearby spill channel was at about 1 km towards left side of the barrage.

The main course of the river was joining the right bank (township of Kanpur) in the upstream of railway bridge which is about 7 km downstream of the barrage. Images of the years 1980 and 1990 indicate, no remarkable changes in the plan form of the river which was in 1970 except movement of mouth of cited spill channel further upstream and its widening.

Construction of the barrage was completed in year 2000 and the construction was carried out in dry condition, as no channel of river was passing through the barrage. Guide bunds were also constructed alongwith the construction of barrage in year 2000. Subsequently, a marginal bund towards right side was constructed as evident from the Google Earth image (Fig. 13.17).

To divert main course of the river towards the constructed barrage, a pilot channel of length 12.5 km was excavated from upstream (26˚32´52.91˝N, 80˚18´50.45˝E) to the barrage (Google Earth image of 2003, Fig. 13.17).

Subsequently, embankment was constructed towards left side of the barrage to block the main course of the river, so that pilot channel can be activated and water can be diverted through the pilot channel. As a result, pilot channel became wider and the main course of river has shifted to the pilot channel. After passing through the barrage, the river was flowing abutting its right bank towards Kanpur township as evident from Google Earth images of years 2005, 2007 and 2008 (Fig. 13.18). Over the years, silting occurred in upstream and downstream of the blocked earlier channel. Currently the planform of main course has stabilized and no major changes have been noticed.

A visit to site of the barrage was undertaken on 14th November 2016. During the site visit, it was noticed that the main course of river is towards left side upstream of the barrage, however, in the downstream of the barrage, the main channel has shifted towards the right side and passing abutting the Kanpur township. No deposition was noticed in the upstream of the barrage, however, there was deposition towards left side in the downstream of the barrage. This is also evident from the recent satellite images of years 2010 and 2015 as shown in Figs. 13.16a-f.

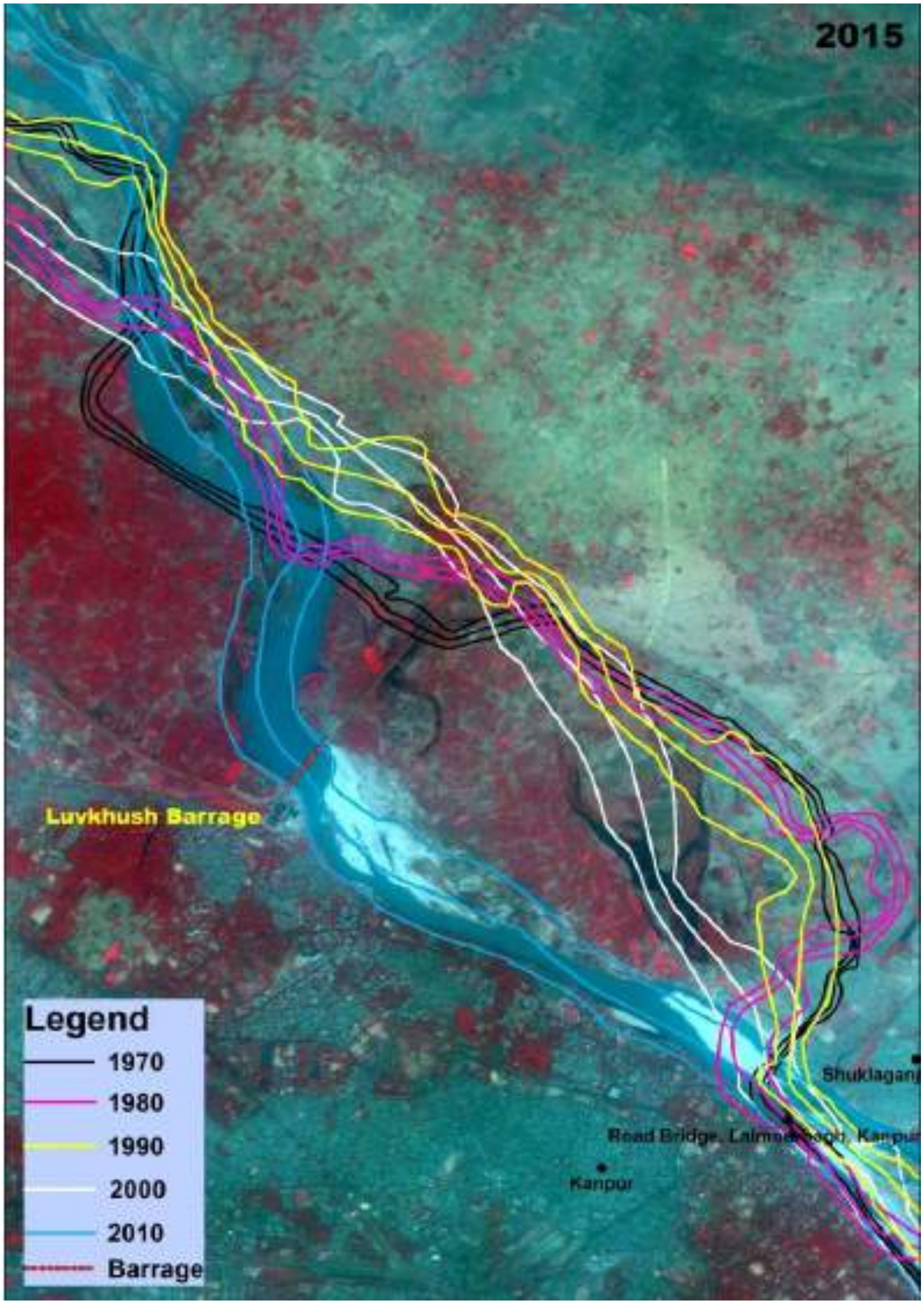


Figure 13.15 GIS layers of the Ganga river for the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015 at the Luvkhush barrage

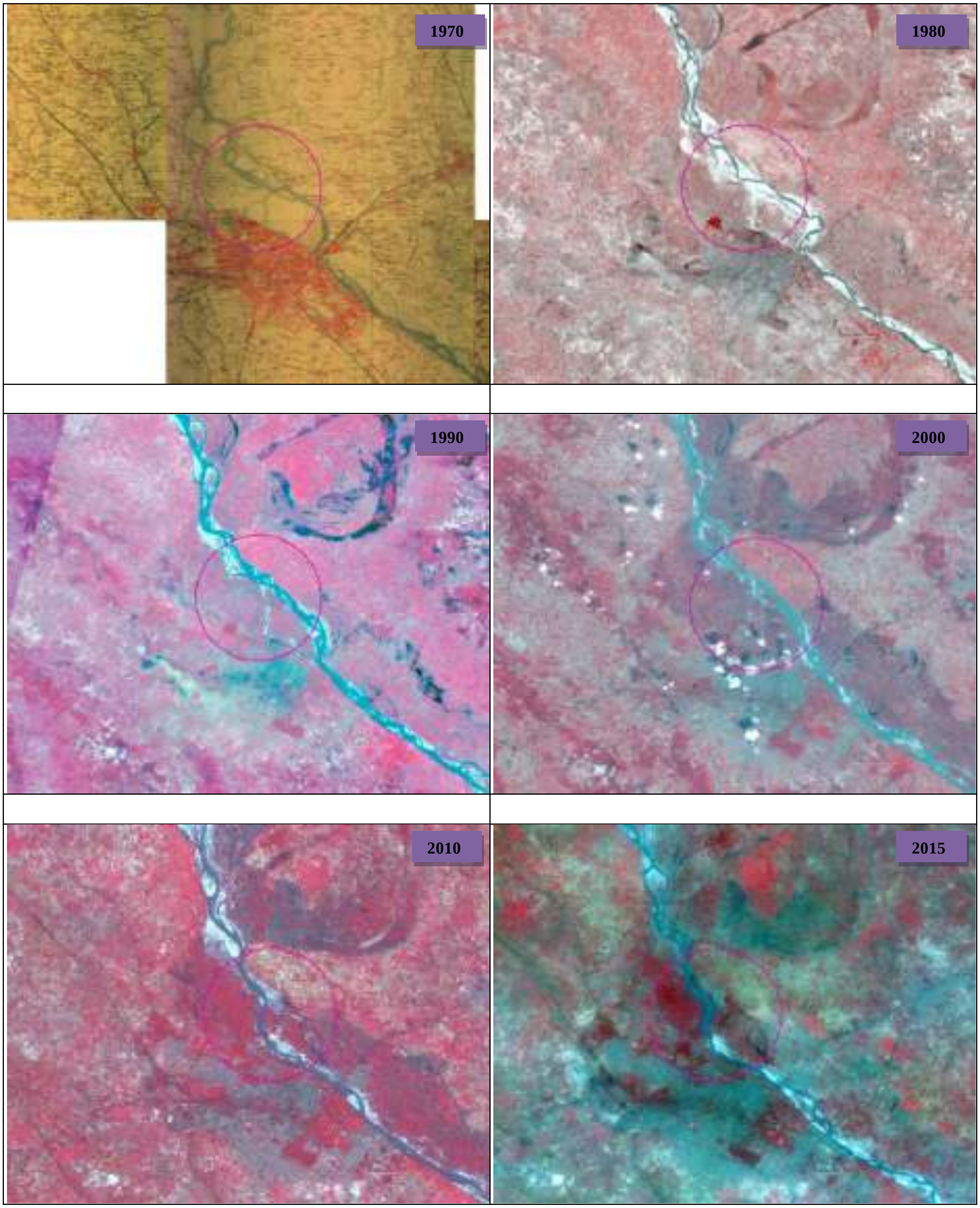


Figure 13.16 (a-f) Images of Ganga river for the year 1970, 1980, 1990, 2000, 2010 and 2015, respectively at the Luvkhush barrage

Figure 13.17 Google Earth image as on 26/3/2003 showing marginal bund and pilot channel near the Luvkhush barrage

8/12/2005 21/3/2006 01/12/2007

Figure 13.18 Google Earth images in year 2005, 2006 and 2007

The barrage was constructed in year 2000 at location where there was not even a spill channel. Subsequently, with the provision of pilot channel and blockage of main course of the river, which was about 2 km away from the barrage towards left side, the river diverted successfully towards the barrage along the pilot channel. The role of construction of barrage in changing the morphology of river is negligible. After the diversion of river towards the barrage, no major morphological changes in Ganga river have been noticed. Negligible silting upstream of the barrage in the form of island may be attributed to the looseness factor less than unity. At the outset, it may be concluded that there is negligible impact of construction of LuvKhush barrage on the morphology of the Ganga river.

Upstream and downstream views of the barrage are shown in Figs. 13.19a and 13.19b, respectively.

Figure 13.19a Silted island upstream of the Luvkhush barrage

Figure 13.19b Downstream of the Luvkhush barrage

6. Farakka barrage

To study the impact of the Farakka barrage on river morphology, the decadal satellite images and geospatial datasets are examined. Figure 13.20 shows major course of Ganga river for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs. 13.21 (a-f) show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respevtibey at the Farakka barrage.

Farakka barrage is constructed across Ganga river at about 16.5 km upstream of the border of India-Bangladesh. Nearest city to the barrage is Jangipur in the district of Murshidabad, West Bengal. The construction of the barrage was started in 1961 and completed in 1975. It was made functional on April 21st 1975. The length of barrage is 2.24 km and number of the spillway gates are 123. The design discharge of the barrage is 27,00,000 cusecs (76,455 m^3/s). A canal named as feeder channel off takes from the right side of the barrage which is 40 km long and its designed discharge is 40,000 cusec. It feeds water from Ganga river to Hooghly river for flushing out the sediment deposition from the Kolkata harbour to avoid frequent mechanical dredging. However, after the operation of the feeder canal, it has been found that diverted flow from the Farakka barrage is not adequate to flush the sediment from Hooghly river satisfactorily.

An elliptical guide bund of a length of 2 km including curve path is provided towards left side of the barrage. No other river training works have been provided in the upstream and downstream of the barrage except localized protection to the bank against its erosion.

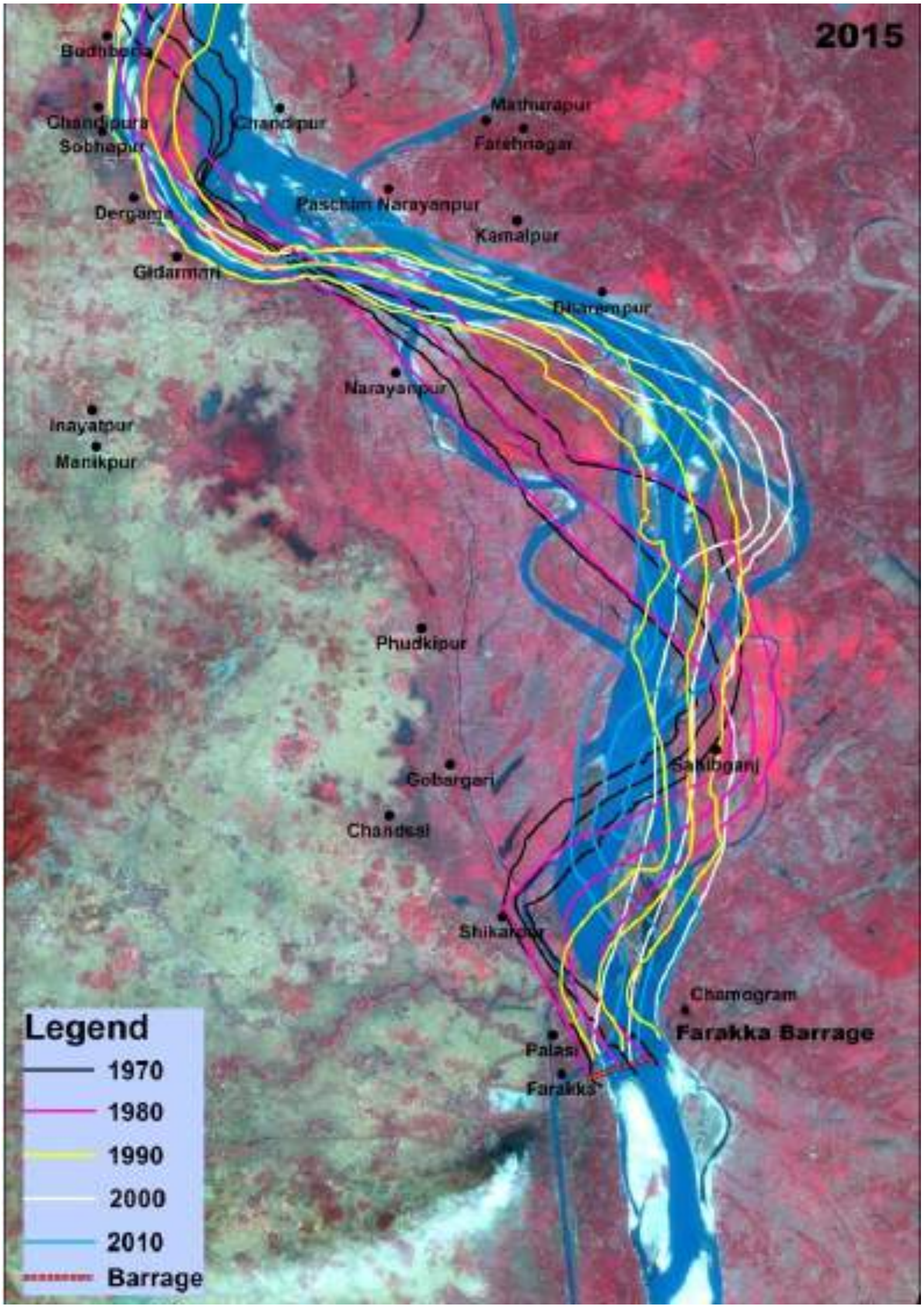


Figure 13.20 GIS layers of the Ganga river for the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015 at the Farakka barrage

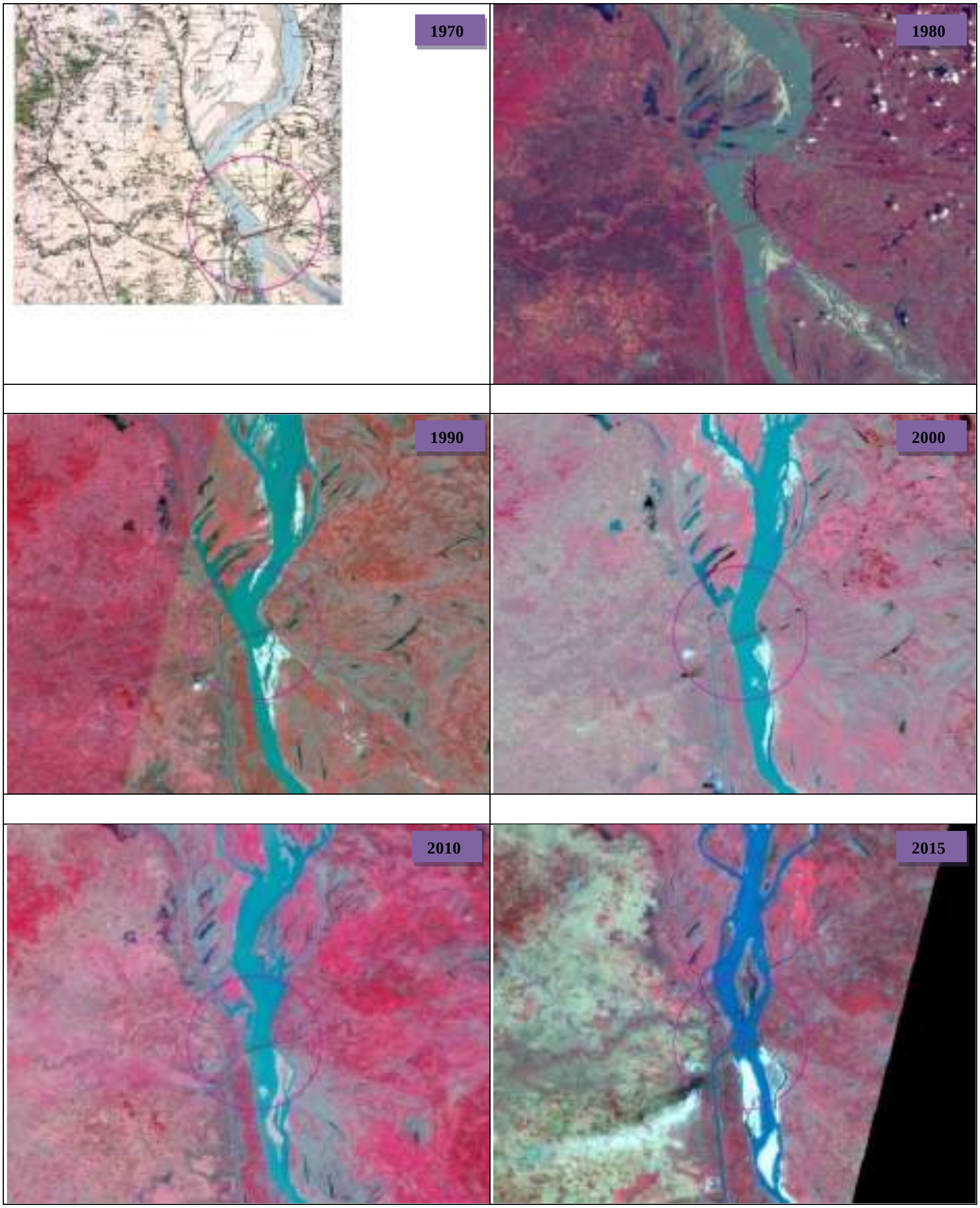


Figure 13.21 (a-f) Images of Ganga river for the years 1970, 1980, 1990, 2000, 2010 and 2015 at the Farakka barrage

To study the impact of barrage on the morphology of river, a length of 140 km of Ganga river from barrage to Krusela is being considered. Krusela is located 138 km upstream of the barrage. The centerline shifting of the river in this reach with respect to year 2010 is shown in Fig. 13.22. At about 5 km upstream of the barrage, river has progressively shifted towards left side by about 4 km from 1970 to 2010 at Shikarpur. At about 12 km upstream of the barrage, the river has shifted towards right side at Charbabupur. The river was towards left side by about 5 km in year 1980 with respect to center line of river in 2010. However, in years 1970, 1990, 2000 the river was towards left side by about 2.25 km with respect to center line of the river in year 2010. At about 27 km (Narayanpur) and 85 km (Mahadevganj) upstream of the barrage, the river has shifted towards left side from year 1970 to 2010 by about 5 km.

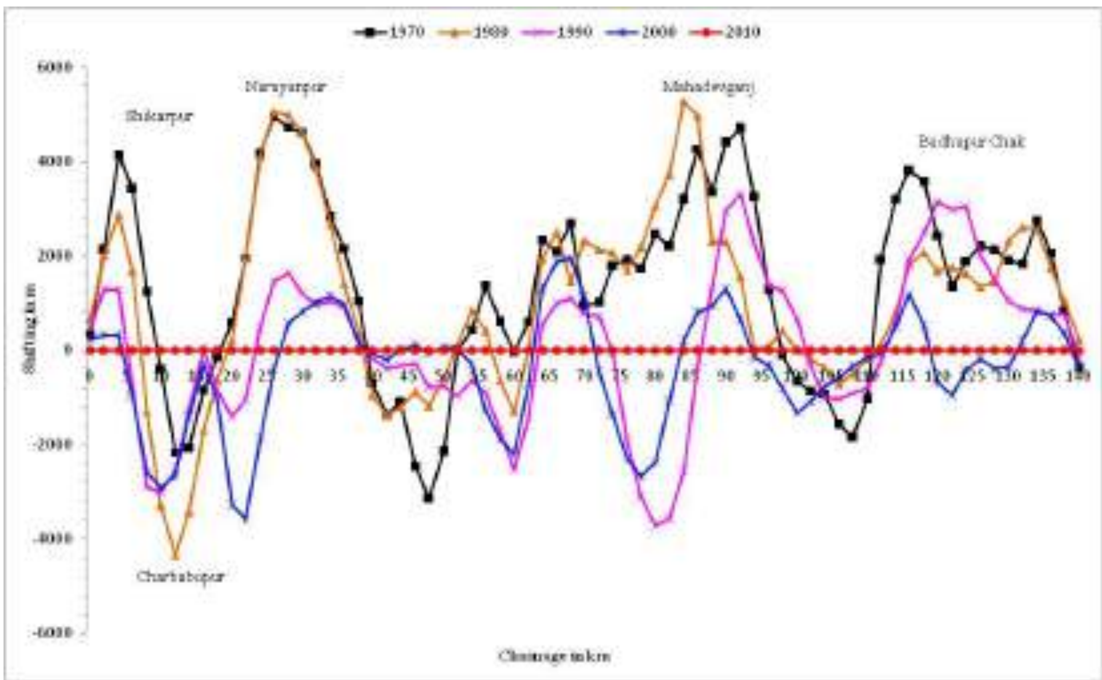


Figure 13.22 Shifting of center line of the river from Farakka barrage to Krusela

Temporal variation of width of deeper channel of Ganga river and extreme banks from barrage to Krusela has also been studied and such variation is shown in Fig. 13.23a-b, respectively. In general, width of the deep channel and width based on the extreme banks have increased from year 1970 onwards. The range of temporal variation of the width of the deep channel in this reach varies from 500 m to 3000 m with average width of about 1.5 km. In particular, no remarkable change in the width of the of river based on the extreme banks has been noticed from 1970 to 2010 just upstream of the barrage.

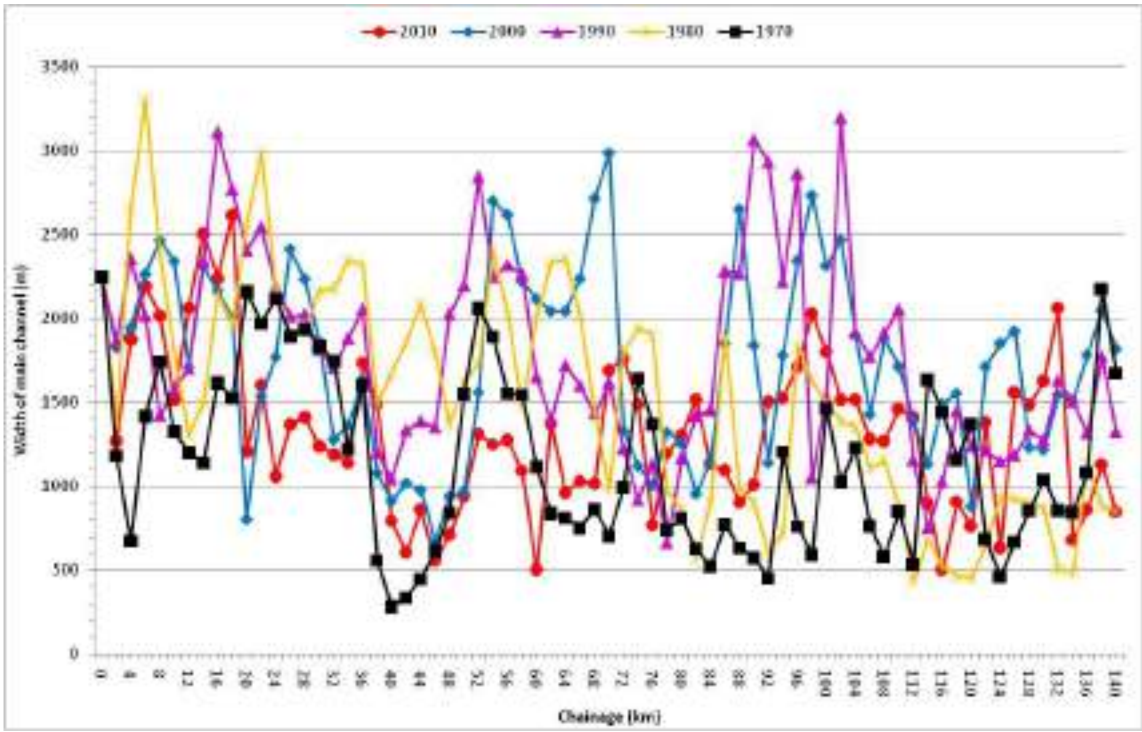


Figure 13.23a Temporal variation of width of deep channel of Ganga river from Farakka barrage to Krusela

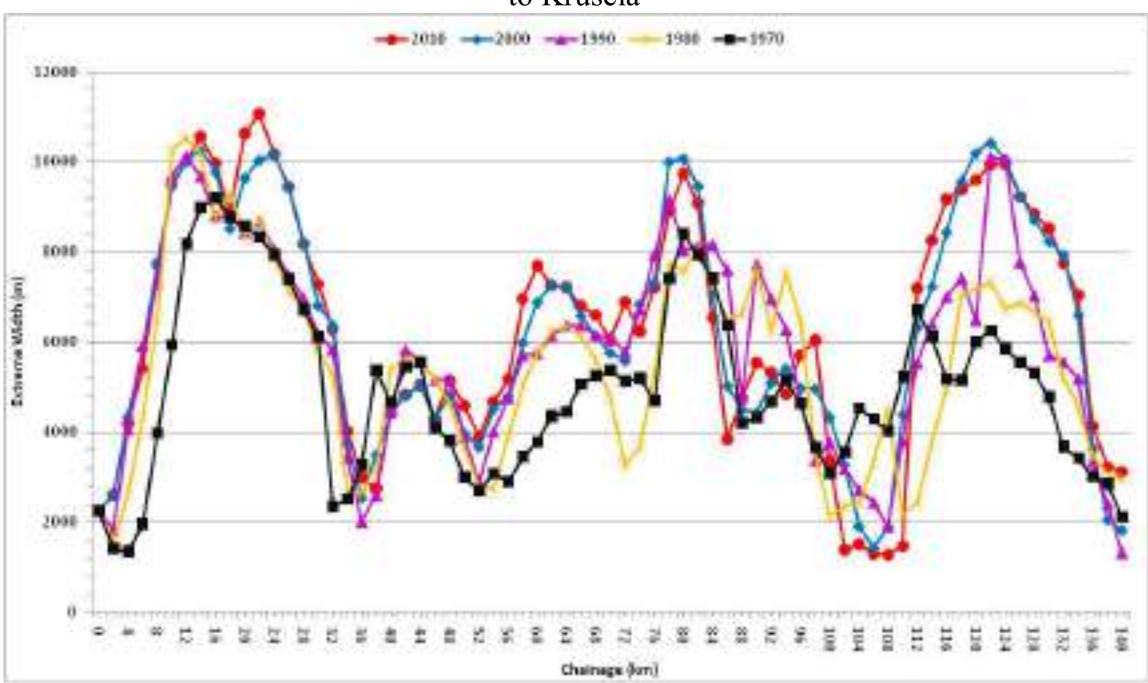


Figure 13.23b Temporal variation of width of Ganga river based on extreme banks from Farakka barrage to Krusela

Temporal variation of area of islands formed between barrage to Krusela is shown in Fig. 13.24. It is apparent from this figure that there is progressive increases in the area of islands in this reach that may be attributed to severe shifting of river from year 1970 to 2010.

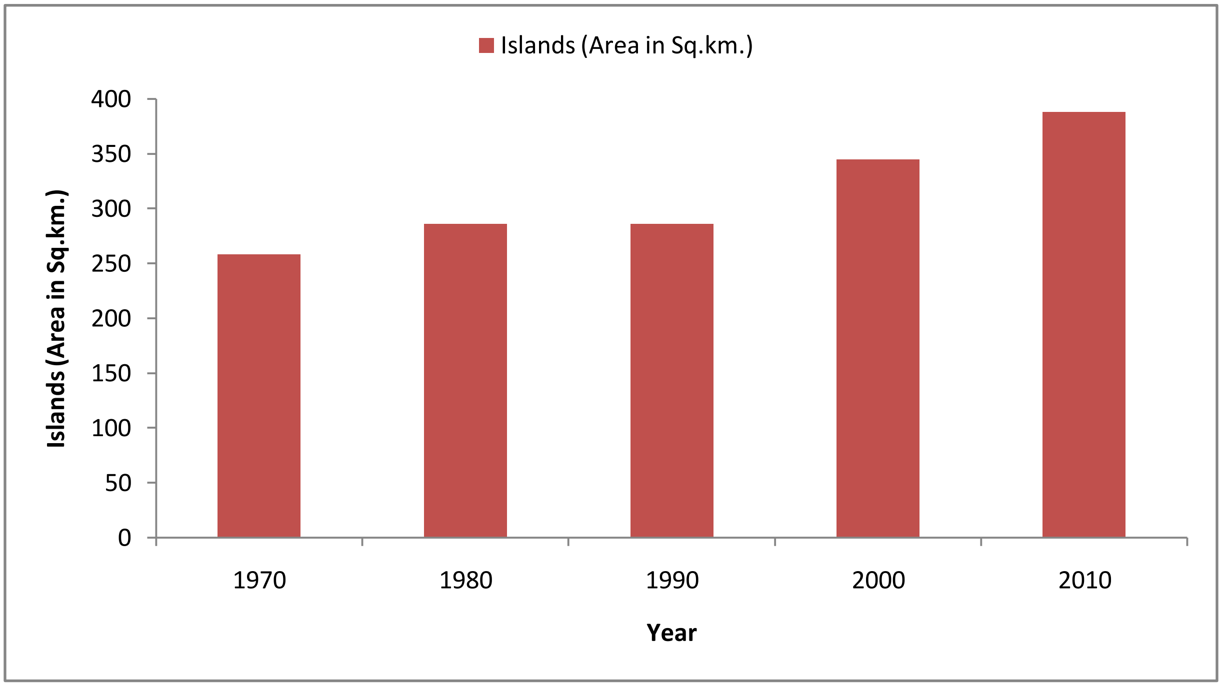


Figure 13.24 Temporal variation of area of Islands from Farakka barrage to Krusela (Ch. 138 km)

At present, there are two islands upstream of the barrage; one is towards right side and about 0.5 km upstream of barrage and having an area of 2 km^2. The area of this island in 2010 was 0.5 km^2 which indicates increase in the area by 4 times from 2010 to 2015 (Figs. 13.25a-b). Another island towards left side is currently at about 2.5 km upstream of barrage and having an area of 12 km^2. This island was not existing till 2010 (Figs. 13.26a-b).

Figure 13.25 Images of the right side island located at 0.5 km upstream of the Farakka barrage as in year 2010 and 2015

A site visit was undertaken on 22nd October 2016 and such islands were witnessed during the visit. As conveyed by authorities of the Farakka barrage, they succeeded in the partial removal of formed islands upstream of the barrage by regulating the barrage gates. Over the time, the Ganga river has shifted towards right side downstream of the barrage.

As satellite images/ SOI toposheets prior to construction of barrage are not available, therefore, it is difficult to draw any conclusion in respect of impact of Farakka barrage on the morphology of Ganga river. Silting has occurred upstream of barrage from 1970 to till date. Severe lateral shifting of river has been observed in this period. However, there are no remarkable changes in the width of deeper section of river over the period 1970 to 2010.

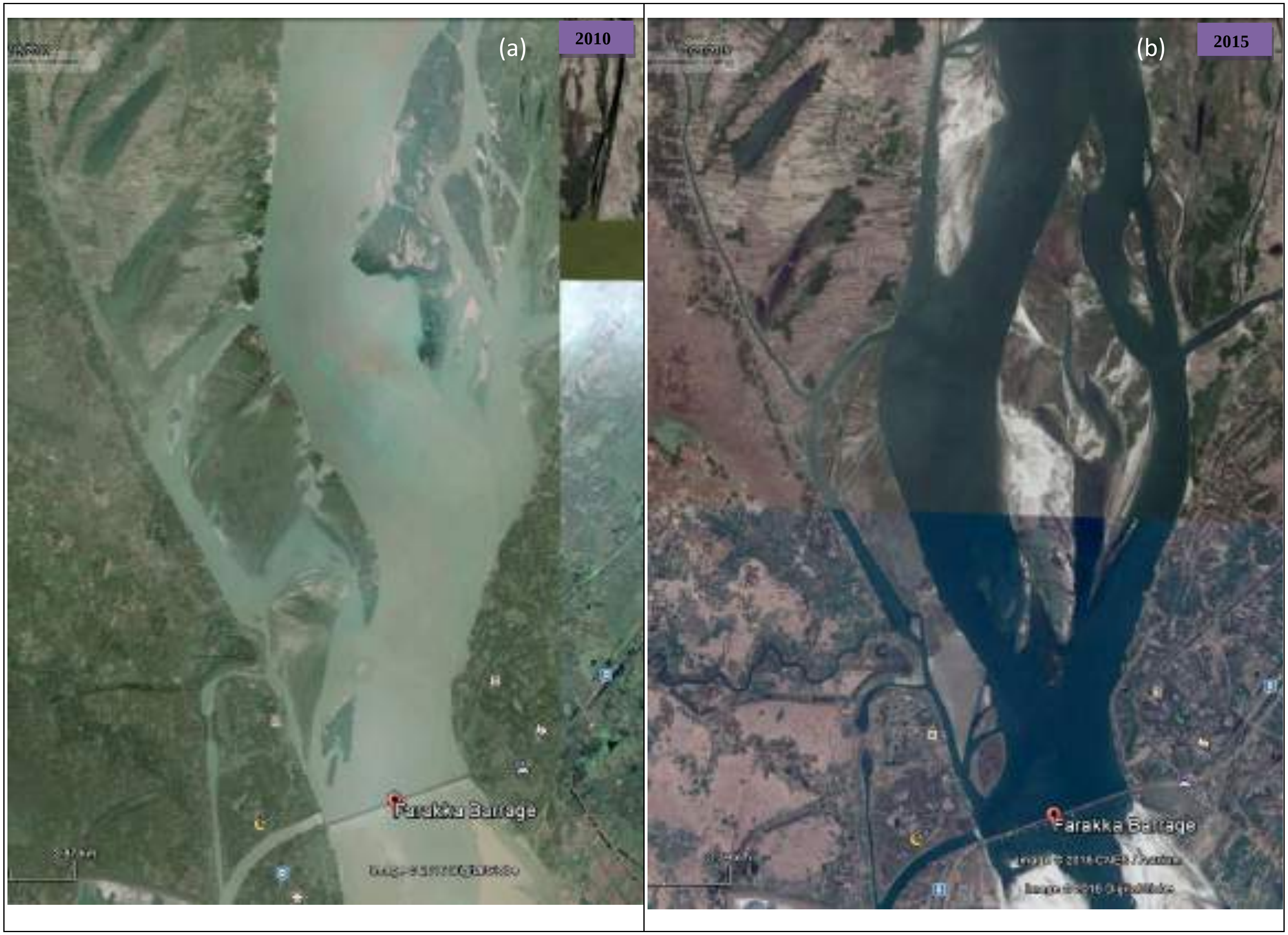


Figure 13.26 Images of the left side island as in year 2010 and 2015

13.2.2 Impacts of the Bridges

There are about 49 bridges on the Ganga river from Devprayag to Farakka barrage. Impacts of such bridges on the morphology of the Ganga river are summarised in the Table 13.2. Morphological changes in the river have been noticed near some of the bridges. Even though river training works have been provided at such bridges which are working satisfactorily, it is recommended to provide suggested river training works to train the river.

Table 13.2 Impacts of the bridges on the river morphology

S.No.	**Name of Bridge**	**Chainage** (km)	**Nearby Place**	**Length of Bridge** (m)	**Average Width of the River** (m)	**Remarks**
1.	Road Bridge	1823.6	Devprayag Pauri Road	160	80	• Located on relatively straight reach of the river • At present, no RTW is required.
2.	Jhulla Bridge	1820	Tilwal Gaon	122	82	• Located on relatively straight reach of the river • At present, no RTW is required.
3.	Jhulla Bridge	1814.5	Naugaon	82	75	• Located on relatively straight reach of the river • At present, no RTW is required.
4.	Jhulla Bridge	1807.7	Bachhali khal	100	100	• River takes right turn downstream of the bridge • At present, no RTW is required.
5.	Jhulla Bridge	1798.2	Chandpur	145	145	• Located on relatively straight reach of the river

						• At present, no RTW is required.
6.	Jhulla Bridge	1793.3	Koudiyla	108	108	• Wide river downstream of the bridge • At present, no RTW is required.
7.	Jhulla Bridge	1784.7	Mala	102	85	• Hard rock on both the sides • At present, no RTW is required.
8.	Road Bridge	1770	Nilkanth Bridge, Haldogi	200	125	• No contraction of the river near the bridge • Located on relatively straight reach of the river • At present, no RTW is required.
9.	Road Bridge	1766.8	Lakshman Jhula	120	120	• No contraction of the river near the bridge • Widening of river downstream of the bridge • At present, no RTW is required.
10.	Road Bridge	1765.1	Ram Jhula	215	215	• No contraction of the river near the bridge • At present, no RTW is required.
11.	Road Bridge (NH 74)	1737.7	Haridwar	1250	600	• Erosion on right bank -series of spurs provided which are performing well • These spurs are to be watched in future and be repaired if required
12.	Old Railway Bridge (Laksar-Balawali)	1696.5	Laksar	881	2250	• Guide bund on both sides are provided without proper nose. Length of right guide bund = 550 m Length of left guide bund = 440 m • Suggested to provide nose to each guide bund
13.	Railway Bridge (Laksar-	1696.4	Laksar	873	2250	

	Balawali)					• Boulder revetment be provided to the right embankment of the railway track over a length of 1.5 km
14.	Railway Bridge 1	1568	Mohamadabad Atamali	1217	2000	• Guide bund on both sides with proper nose - working satisfactory Right guide bund = 900 m left guide bund = 1100 m • At present, no RTW is required.
15.	Railway Bridge 2	1568	Mohamadabad Atamali	693	2000	
16.	Road Bridge (NH 24)	1567.9	Brijghat	692	2000	
17.	Road Bridge	1513.9	Aligarh bye pass Road	1063	1000	• Guide bunds on both sides - performing well. Upstream right guide bund = 550 m-joined with embankment Left guide bund = 800 m-proper nose • At present, no RTW is required.
18.	Railway bridge	1495.1	Rajghat, Narora	912	1000	• Guide bund on left side without nose Length of left guide bund = 530 m • Jacketing of river using series of spurs downstream of the bridge. • Suggested to provide nose to the left guide bund
19.	Railway bridge	1425.3	Kachhla	637	1600	• Guide bunds on both sides with truncated nose. • Left and right guide bunds = 630 m • Both guide bunds should be extended downstream
20.	Road Bridge (SH 33)	1425.2	Kachhla	677	1600	

21.	Road Bridge (SH 43)	1308.2	Near Fatehgarh	624	800	• No guide bund on right side however guide bund of 950 m length with nose provided on left side • Flow is attacking right bank • Should be watched and suitable measures be provided, if required in future
22.	Road Bridge (SH 21)	1240	Mehandipur	797	1400	• No guide bund on the right side • Guide bund on left side = 450 m with nose • Series of spurs provided towards right side both upstream and downstream of the bridge
23.	Road Bridge (SH 40)	1220	Bilhaur	721	1155	• No guide bund on the right side • Length of left guide bund = 680 m with proper nose • Right bank shall be watched and if required anti erosion works be provided in future
24.	Road Bridge (SH 58)	1156.6	Shuklaganj	842	1250	• Bank protection provided on both upstream and down stream • At present no RTW is required
25.	Railway Bridge	1156.5	Shuklaganj	800	1250	
26.	Road Bridge	1156.3	Shuklaganj	824	1250	
27.	Road Bridge (NH 25)	1151.1	Asharfabad	710	1250	• No guide bund on right side • Length of left guide bund = 690 m with proper nose • Right bank shall be watched and if
28.	Road Bridge	1151	Ashafabad	701	1250	

	(NH 25)					required anti erosion works be provided in future
29.	Road bridge (Baksar Muradpur Road)	1108.3	Baksar	820	680	• Widening of river downstream of the bridge • No protection work provided • Negligible morphological changes at bridge site • Should be watched and RTW be provided, if required in future
30.	Road Bridge (SH 13)	1075.4	Tanda	1047	1300	• River is straight near the bridge • Negligible morphological changes at bridge site • At present no RTW is required
31.	Road Bridge (SH 13A)	1062	Dalmau	1013	1500	• Curved path of the river upstream of the bridge • River is stable at bridge location • At present no RTW is required
32.	Ganga Bridge Road	1010.5	Manikpur	967	1372	• Located on curved path of the river • River is stable at bridge location • At present no RTW is required
33.	Road Bridge (Allahabad Bypass)	978.08	Dhheemi	1002	1250	• Embankments on both sides of the river near the bridge • Located on relatively straight reach of the river • At present no RTW is required
34.	Road Bridge (Allahabad Bypass)	978.06	Dhheemi	1003	1250	

35.	Road Bridge (Chandra Shekhar Azad Bridge, SH38)	933.8	Rangpura (Allahabad)	959	3000	• Left guide bund of length 720 m with nose and also marginal bund • Dense habitations towards right side • Wide spread both upstream and downstream • Located on relatively curved reach of the river • At present no RTW is required
36.	Road Bridge (Lord Curzon Bridge)	933.7	Rangpura (Allahabad)	1022	3000	
37.	Railway bridge	933.6	Rangpura (Allahabad)	981	3000	
38.	Railway bridge	925	Daraganj (Allahabad)	1903	2100	• Wide spread upstream of the bridges • Dense settlement on both sides • Located upstream of confluence of Yamuna river • At present no RTW is required
39.	Road Bridge (Shastri Bridge, NH 2)	924.5	Daraganj (Allahabad)	2056	2100	
40.	Road Bridge (SH 5)	797.5	Mirzapur	986	1000	• Settlements towards both sides of the river near the bridge • Meandering pattern of the river near the bridge • Stable river near bridge site • At present no RTW is required
41.	Road Bridge (NH 2)	724	Salhupur (Varanasi)	1283	640	• Channelized river near the bridge • Dense settlement towards both sides • At present no RTW is required
42.	Road cum Rail Rajghat Bridge (NH 7)	714.2	Suzabad (Varanasi)	1205	720	• Channelized river near the bridge • Dense settlement towards both side • At present no RTW is required

43.	Road Bridge (NH 97)	604	Mednipur (Ghazipur)	1003	1400	• Channelized river near the bridge • Settlement towards both side • Located on relatively straight reach • At present no RTW is required
44.	Road Bridge (NH 84)	556	Babanagar (Buxar)	1097	1000	• Channelized river near the bridge • Dense settlement towards right side • Located on relatively straight reach • At present no RTW is required
45.	Ara-Chhapra Bridge	450	Doriganj (Chhapra)	4000	2500	• Major morphological changes upstream of the bridge • River is stable near the bridge • Sone river joins Gaga river downstream of the bridge from right side • There is a spill towards right side of the bridge • A truncated guide bund may be provided towards right side • Right bank u/s of bridge is to be protected to control the shifting of the river
46.	Rail cum Road Bridge (Digha)	418.1	Digha	4780	4000	• Elliptical left guide bund of length = 1250 m • River is flowing in two channels both upstream and downstream of the bridge • River is stable near bridge site-at

						present no RTW is required
47.	Road Bridge - Gandhi Setu (NH 19)	404.8	Gulzarbagh (Patna)	5540	4000	• River flows mainly towards right side (Patna) • River has widen towards downstream of the bridge and flowing in two channels • Suggested to repair washed out portion of launching apron towards Hajipur side
48.	Rail cum Road bridge (NH 31)	308.7	Hathidah (Mokamah)	1700	7000	• Wide spread river both upstream and downstream and flowing in multiple channels • Left guide bund of length = 1700 m with proper nose -performing well • At present no RTW is required
49.	Road Bridge (SH 58) Vikramshila Setu Road)	174	Bhagalpur	4400	3000	• Wide spread at upstream of the bridge • Skewed bridge with respect to direction of flow of the river • At present no RTW is required

RTW= River Training Works

13.3 CONCLUDING REMARKS

Following conclusions may be drawn:

1. There is a negligible impact of Pashulok barrage on the morphology of the Ganga river in its vicinity. No noticeable erosion and deposition has occurred in the vicinity of the barrage.
2. No major changes in the plan form of the river have been seen from 1970 to till date near the Bhimgoda Barrage. As the barrage is there in one form of other from year 1854 and no image is available of the years prior to 1970, therefore, it is difficult to draw any conclusion in respect of impact of barrage on the morphology of the Ganga river. There was an island upstream of the barrage of area of 0.33 km^2 approximately in 1970, however, it is eroded by the flowing water which has resulted in gradual reduction in the area of the island.
3. There is no remarkable changes in the morphology of Ganga river due to construction of the C.C.S Barrage. No noticeable silting/deposition has occurred near the barrage that may be attributed to its unity looseness. Major changes have been noticed in the shifting of main course of the river at about 7 km upstream of the barrage. Such shifting has resulted in heavy erosion and deposition in the upper reaches of the barrage.
4. As no image is available of the year prior to the construction of the Narora barrage in 1966, it is difficult to draw any conclusion in the respect of impact of the barrage on the morphology of the Ganga river. However, it is apparent that jacketing of river between railway bridge and Narora barrage, which has resulted in wide width of the river have resulted in heavy deposition in the form of island in a length of 6.5 km. The deployed river training works i.e., guide bund, embankment and spurs near the barrage are performing satisfactorily. Looseness factor of the barrage is 1.63 - this high value of the looseness factor has aggravated the problem of silting upstream of the barrage.

5. The LuvKhush barrage was constructed in year 2000 at a location where there was not even a spill channel. Subsequently, with the provision of pilot channel and blockage of main course of the river, the river was diverted successfully towards the barrage through pilot channel. The role of construction of barrage in changing the morphology of river is negligible. After the diversion of river towards the barrage, no major morphological changes in Ganga river have been noticed. Negligible silting upstream of the barrage may be attributed to the looseness factor less than unity. At outset, it may be concluded that there is negligible impact of construction of LuvKhush barrage on the morphology of the Ganga river.
6. As satellite images/ SOI toposheets prior to construction of the Farakka barrage are not available, therefore, it is difficult to draw any conclusion in respect of impact of Farakka barrage on the morphology of Ganga river. It is to be noted that silting has occurred upstream of barrage from 1970 to till date. Severe lateral shifting of the river upstream of the barrage has been observed in this period, however, there are no remarkable changes in the width of deeper section of river in the period 1970 to 2010. Silting in upstream of the barrage may also be attributed to high looseness factor of the barrage which is equal to 1.7.
7. There are about 49 bridges on the Ganga river from Devprayag to Farakka barrage. Morphological changes in the river have been noticed near some of the bridges. Even though river training works have been provided at such bridges which are working satisfactorily, it is recommended to provide suggested river training works to train the river.
8. It is recommended to plan hydraulic structures like barrage, bridge etc. at the identified nodal points (wherein minimum morphology of the river has occurred) on Ganga river to avoid outflanking of the river and to minimize protection works

Chapter 14 RIVER FLOOD AFFECTED AREAS

14.1 INTRODUCTION

India is one of the most flood prone countries in the world. The Indo-Gangetic and Brahmaputra river basins are the most chronic flood prone areas and are regarded as the worst flood affected region in the world (Agarwal and Sunita, 1991). Every year states like Assam located in Brahmaputra basin and Bihar, Uttar Pradesh and West Bengal located in Indo-Gangetic basin face severe flood problems due to the huge amount of discharge and large volume of sediments brought down from the Himalayan Rivers and their tributaries during the monsoon season. The recurring floods cause loss of life, destruction and damages to existing infrastructure, including roads, bridges, embankments and agricultural land and stress the need for identification of flood prone areas in the country. Identification of flood prone areas is one of the most important non-structural measures for mitigation of floods (Jain *et.al.* 2005).

With limited information available during 1970, Rashtriya Barh Aayog assessed the flood prone area of India to be about 40 Mha. Various Expert Groups for Flood Management have expressed strong need for adopting scientific approach for arriving at reliable flood affected area in the country (NRSC, 2014).

Flood hazard zonation facilitates appropriate regulation and development of floodplains thereby reducing the flood impact. The recurrent flood events at frequent intervals demand the need for identification of flood hazard prone areas for prioritizing appropriate flood control measures. In this context, satellite remote sensing plays an important role in delineating such flood hazard zones.

14.2 FLOOD AFFECTED AREAS

The active floodplain for the river Ganga from Haridwar to Farakka is shown in Fig. 14.1. As per Tare *et al.,* 2010, the active floodplain from Haridwar to Farakka does not show any uniformity. At some sites, the floodplain is broad and at some other site it is narrow. In some cases, there is total absence of floodplain on one bank.

Based on the distribution of active floodplain, Tare et al. (2010) divided the Ganga River into four distinct reaches between Haridwar and Farakka (the reaches upstream of Haridwar have not been mapped yet):

(i) Haridwar to Narora: As soon as Ganga leaves the mountainous part and enters the plains downstream of Haridwar, the floodplain is quite wide (~28 km). Around Bijnor (latitude 29°22′ N and longitude 78°8′ E) the floodplain width narrows down to ~10 km. Further downstream, it becomes even narrower and at Narora barrage (latitude 28°13′ N and longitude 78°23′ E) it is only about 5 km wide.

(ii) Narora to Kanpur: Downstream of Narora barrage the floodplain starts widening and at the confluence with Ramganga it attains a maximum width of ~28 km. Further down the floodplain starts narrowing again and at upstream of Kanpur maximum width is ~15 km and downstream of Kanpur it is ~9 km.

(iii) Kanpur to Buxar: The floodplain starts narrowing down downstream of Kanpur to a minimum of about 1 km. As the river approaches Allahabad, the flood plain starts widening again and at Allahabad (latitude 25°28′ N and longitude 81°52′ E) it is about 7.5 km. This width is more or less maintained with little variation till Buxar (latitude 25°33′ N and longitude 83°59′ E) after which the floodplain becomes very wide.

(iv) Buxar to Farakka: Downstream of Buxar, the floodplain reaches the maximum width in the whole of the basin and just downstream of Munger (latitude 25°23′ N and longitude 86°28′ E) the width is about 42 km and at Farakka (latitude 24°48′ N and longitude 87°55′ E) about 26 km.

NRSC initiated a study to scientifically assess the flood prone area. Using the available historical satellite datasets acquired during the flood season (more than 100 historical satellite datasets) from Indian Remote Sensing Satellites (IRS) and foreign satellites, aggregated extent of flood inundated areas were generated. Only those datasets corresponding to either high flood situation or unprecedented floods were used. Presented herein the

Generation of the flood hazard zones was done by NRSC based on the analysis of multi-temporal satellite data acquired during the floods of 2003-2013. Three major steps are involved in preparation of flood hazard zonation maps.

i. **Satellite data Planning and Acquisition**: Data from Indian Remote Sensing Satellites (IRS) and Landsat satellites was acquired during the floods. The water levels observed at different gauge stations were closely monitored during floods and attempts were made to program the satellite data during peak/near peak situations.

ii. **Rectification**: The acquired satellite datasets were geo-rectified to Lambert Conformal Conic projection system with Modified Everest Datum for achieving positional accuracy.

iii. **Flood inundation layer preparation**: Using image processing classification algorithms, water layer was extracted from the satellite data and integrated with the pre-flood river and water bodies layer to derive flood inundation layer

Aggregated flood map of Ganga Basin so developed by NRSC from 2003-2013 is shown in Fig. 14.2. While figures 14.3 to 14.11 show the flood hazard flood in the reaches a) Devprayag to Bijnor, b) Bijnor to Narora, c) Narora to Farrukhabad d) Farrukhabad to Kanpur, e) Kanpur to Allahabad, f) Allahabad to Varanasi, g) Varanasi to Arrah, h) Arrah to Munger, and (i) Munger to Farakka, respectively. Following inferences may be drawn from these maps:

a) No inferences can be drawn in the respect of flood hazard area in the reach of Ganga river from Devprayag to Balawali, as the flood hazard map of Uttarakhand is not developed by NRSC.

b) From Shukratal (about 15 km upstream of CCS barrage) to Asifabad (about 10 km upstream of Garhmukhteshwar), the flood hazard zone is spread over a width of about 7 km with low to moderate intensity of flood.

c) Low to moderate intensity of flood has been found near Farrukhabad and its downstream area along the river that can be attributed to confluence of Ramganga river downstream of Farrukhabad.

d) From Farrukhabad to Kanpur, the width of flood hazard zone is of the order of 10 km with low and moderate intensity of flood.

e) As such there is no remarkable flood hazard area from Kanpur to Ghazipur.

f) From Ghazipur to Buxar, flood hazard area of the width 10 km and low to moderate flood intensity may be seen.

g) Downstream of Arrah to Munger, the flood hazard zone is widely spread towards both the sides of the river with low to high intensity of flood.

h) From Munger to Sahibganj, the flood hazard area is limited as compare to reach Arrah to Munger, however, the near the confluence of Kosi river at Krusela and along the Kosi river upstream, flood of very high intensity can be seen.

i) Very high hazard zone can also be seen towards south of Katihar between Ganga and Fulahar rivers.

14.3 CONCLUDING REMARKS

The flood hazard area is limited to maximum width of ~ 10 m with low to moderate intensity of the flood upstream of the Arrah. Near the confluence of the Ramganga river to the Ganga river downstream of the Farrukhabad, the flood hazard area is relatively large.

From the confluence point of the Ghaghra river at Doriganj (Chhapra) to Farakka, the flood hazard zone is severely wide spread with high intensity of the flood. Near the confluence point of the Kosi, the flood hazard zone is of very high intensity. This is also true in the area between Fulahar river and Ganga river near to Katihar. Such very high intensity of flood in these areas may be due aggradation of the bed of the Kosi and Fulahar rivers and also siltation in the flood plain which has reduced the water carrying of the river and resulted in high inundation.

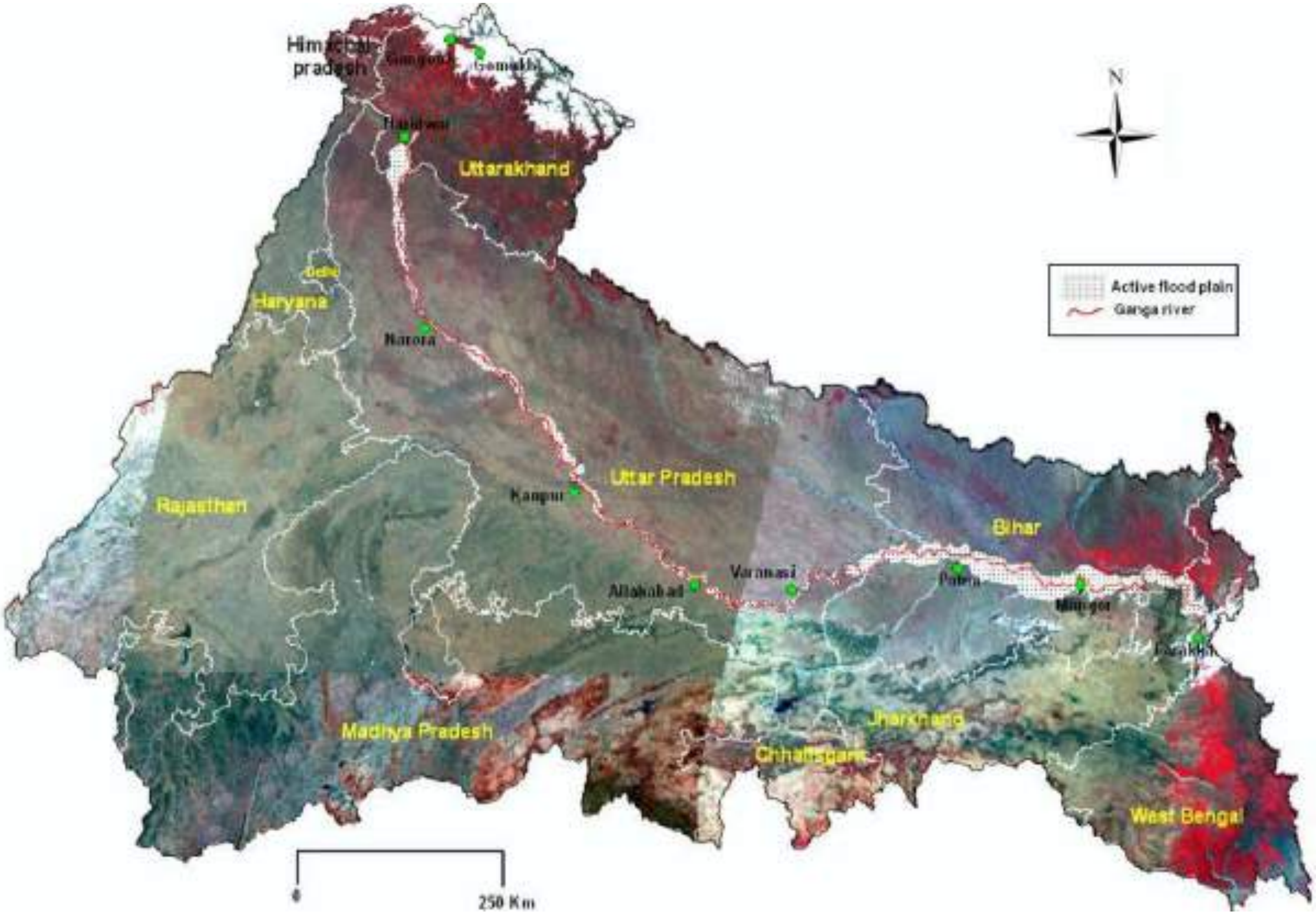


Figure 14.1 Active floodplain area of Ganga river basin (Tare et al., 2010)

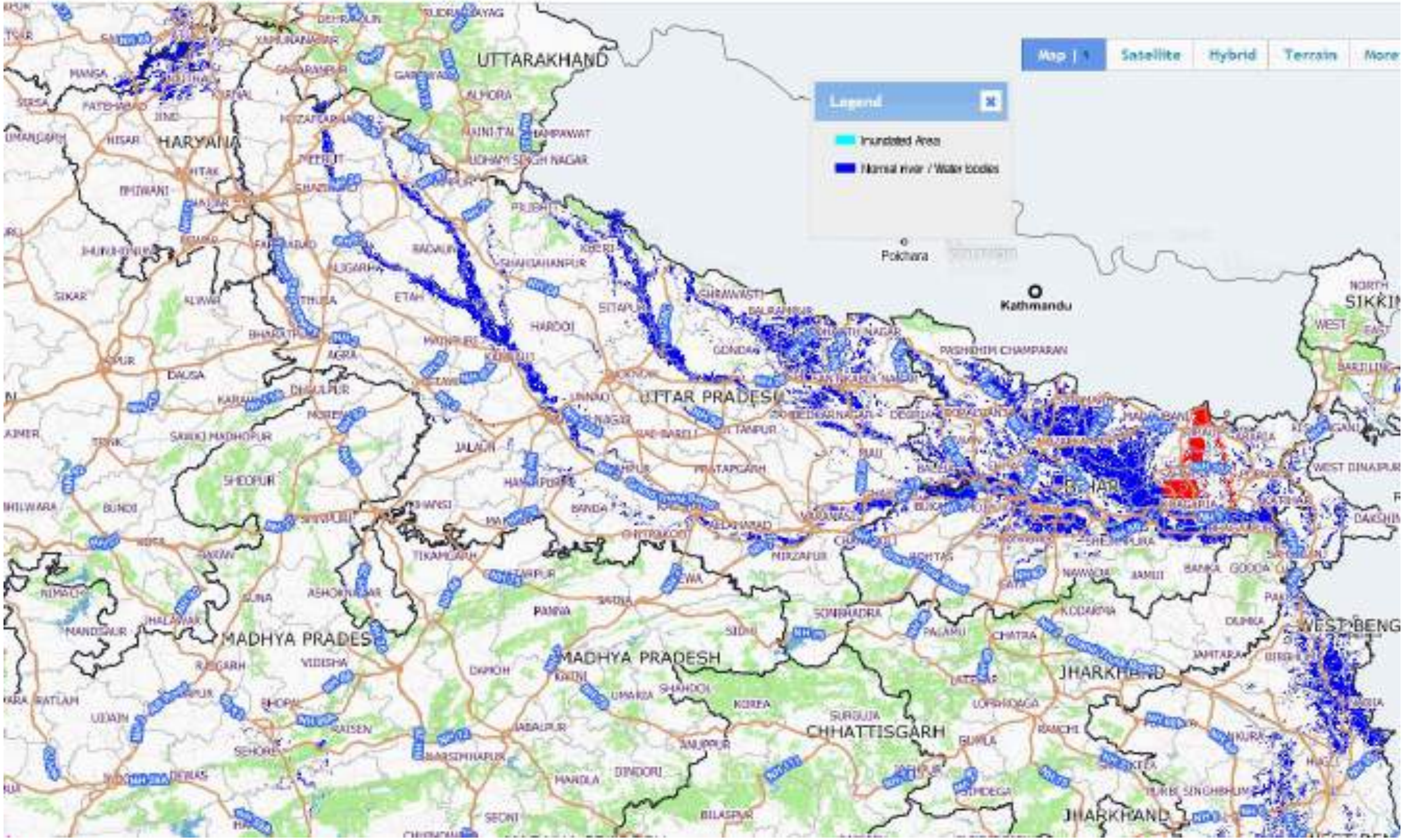


Figure 14.2 Aggregated flood map of Ganga Basin from 2003-2013 (Source: NRSC Portal)

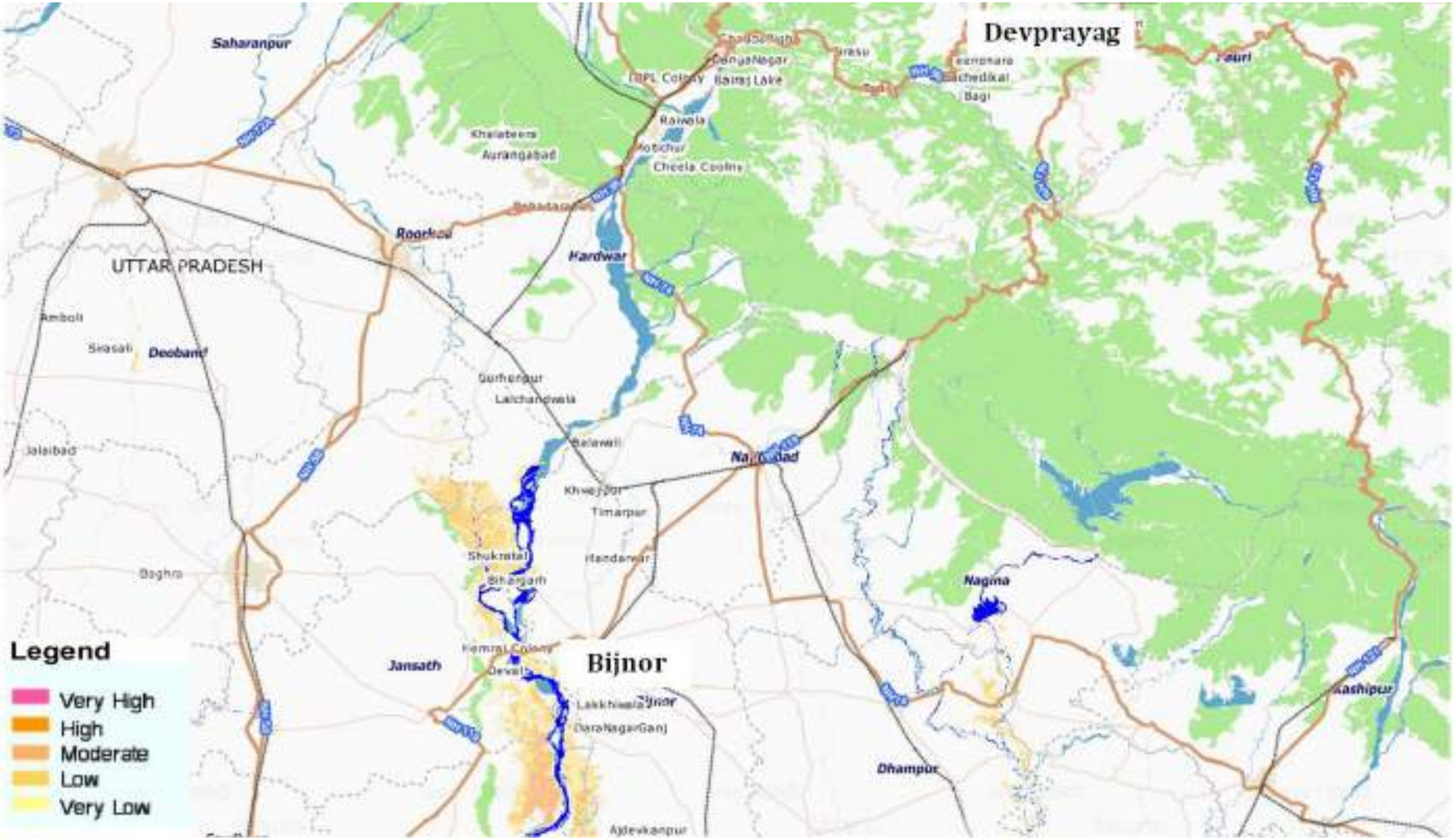


Figure 14.3 Flood Hazard Zone Map of Ganga river from Devprayag to Bijnor (Source: NRSC Portal)

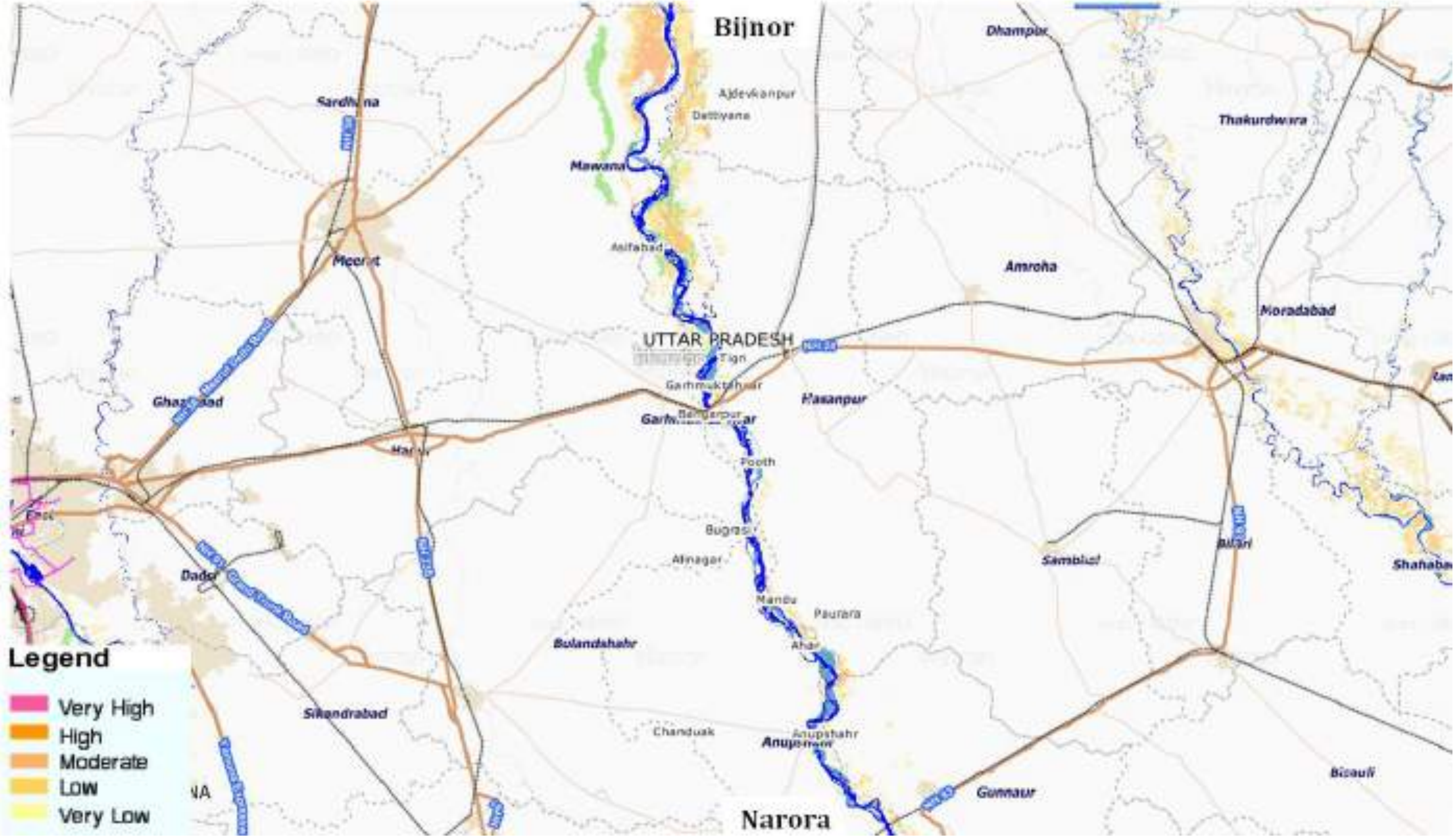


Figure 14.4 Flood Hazard Zone Map of Ganga river from Bijnor to Narora (Source: NRSC Portal)

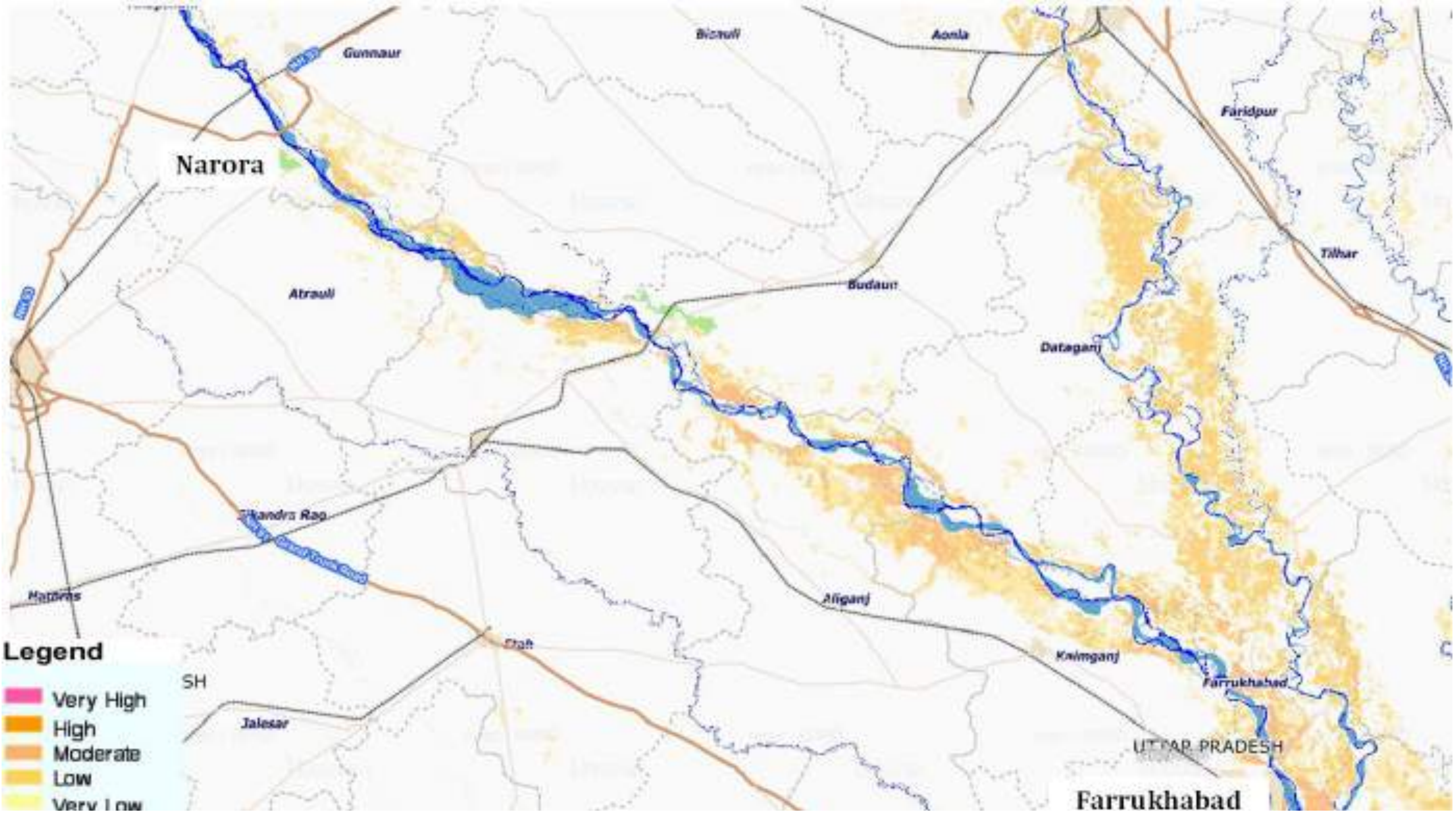


Figure 14.5 Flood Hazard Zone Map of Ganga river from Narora to Farrukhabad (Source: NRSC Portal)

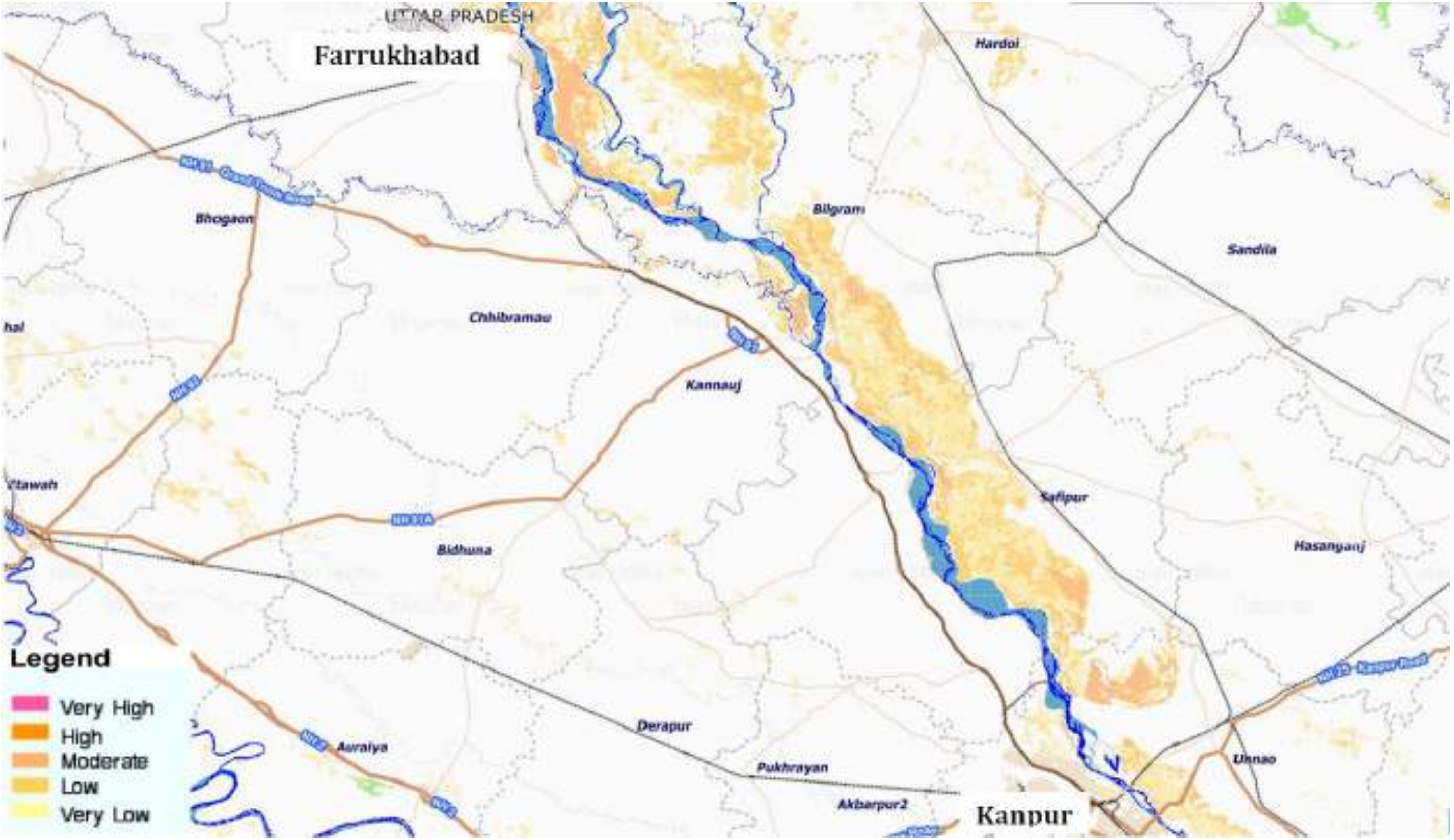


Figure 14.6 Flood Hazard Zone Map of Ganga river from Farrukhabad to Kanpur (Source: NRSC Portal)

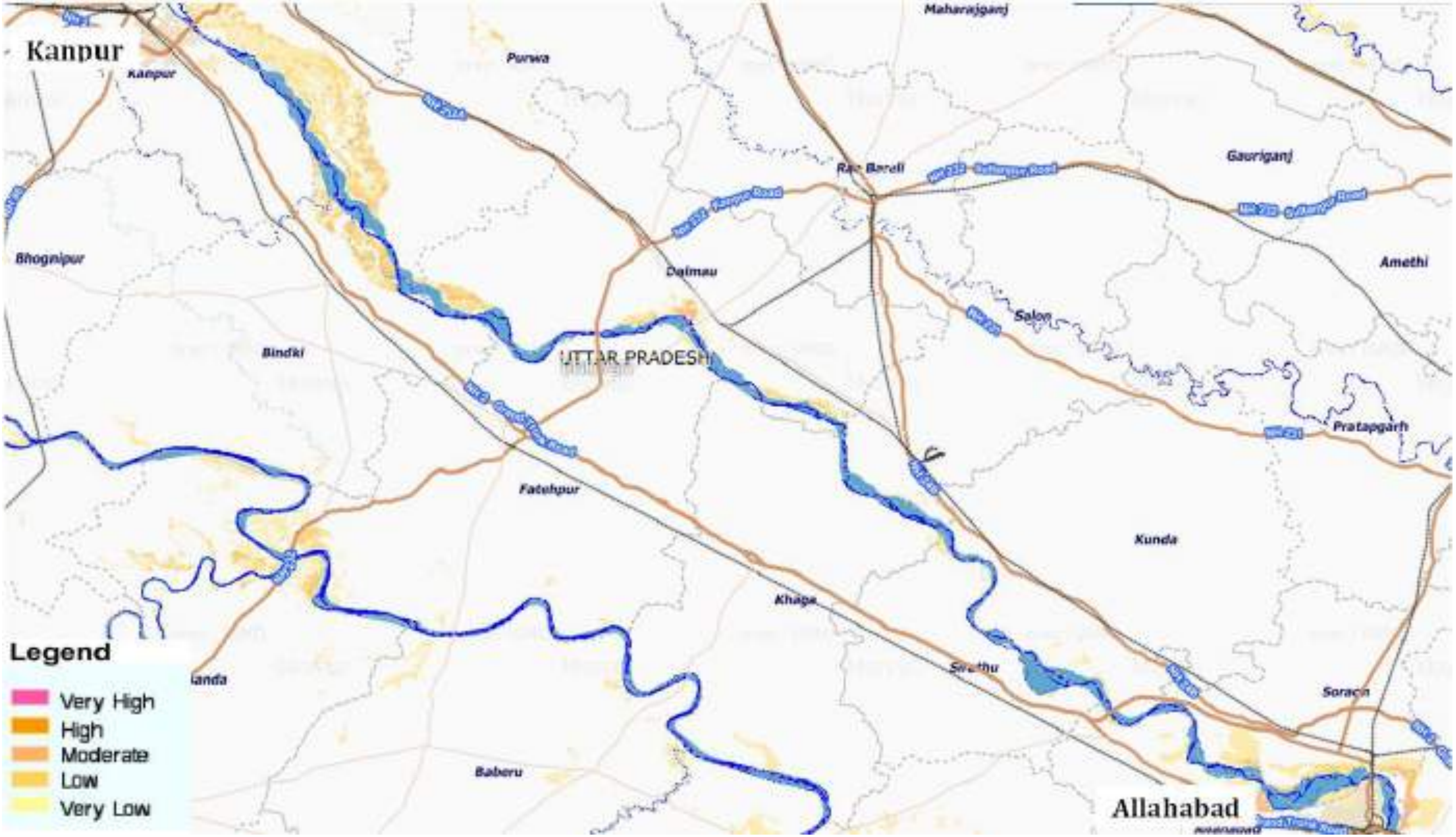


Figure 14.7 Flood Hazard Zone Map of Ganga river from Kanpur to Allahabad (Source: NRSC Portal)

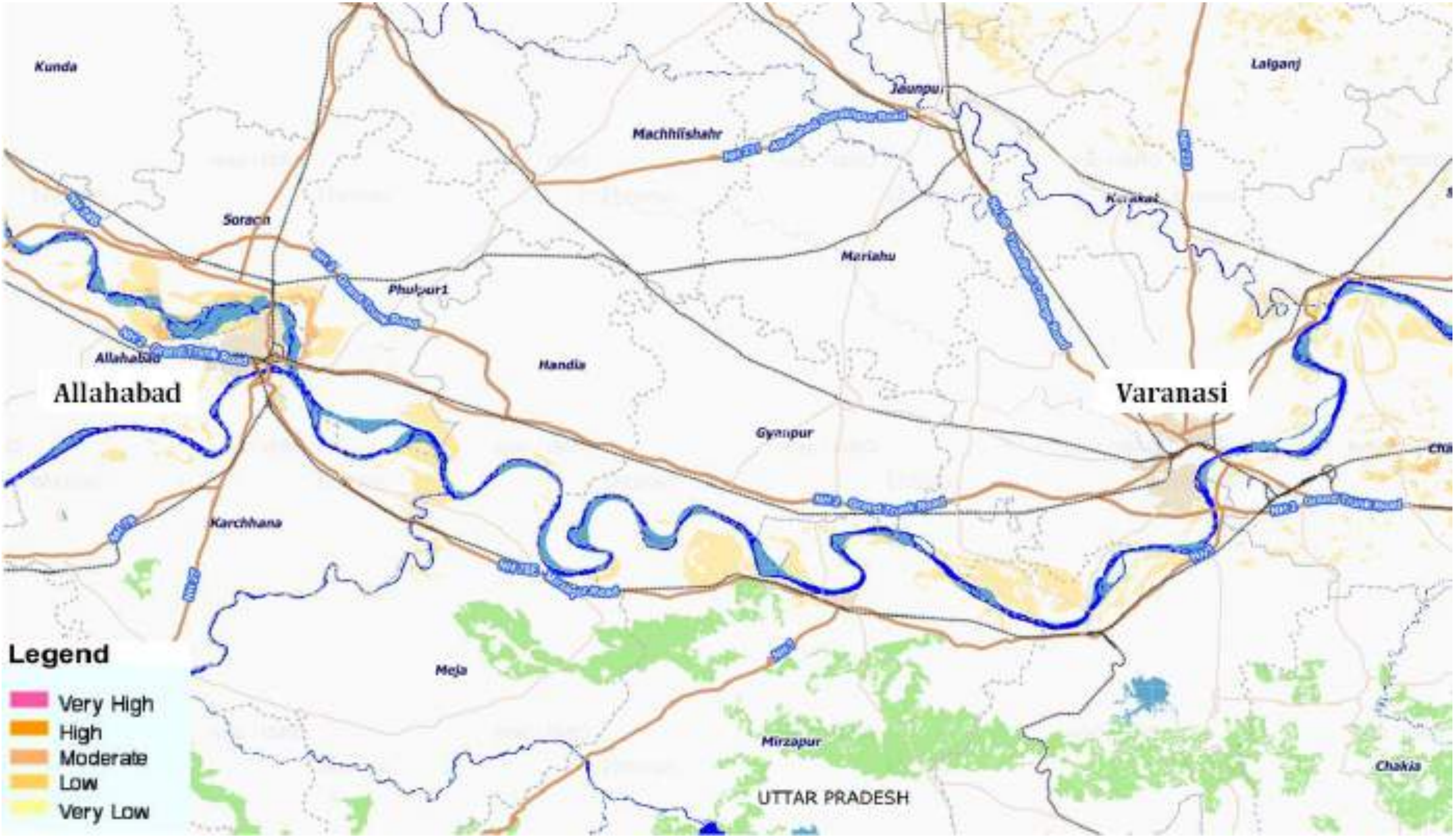


Figure 14.8 Flood Hazard Zone Map of Ganga river from Allahabad to Varanasi (Source: NRSC Portal)

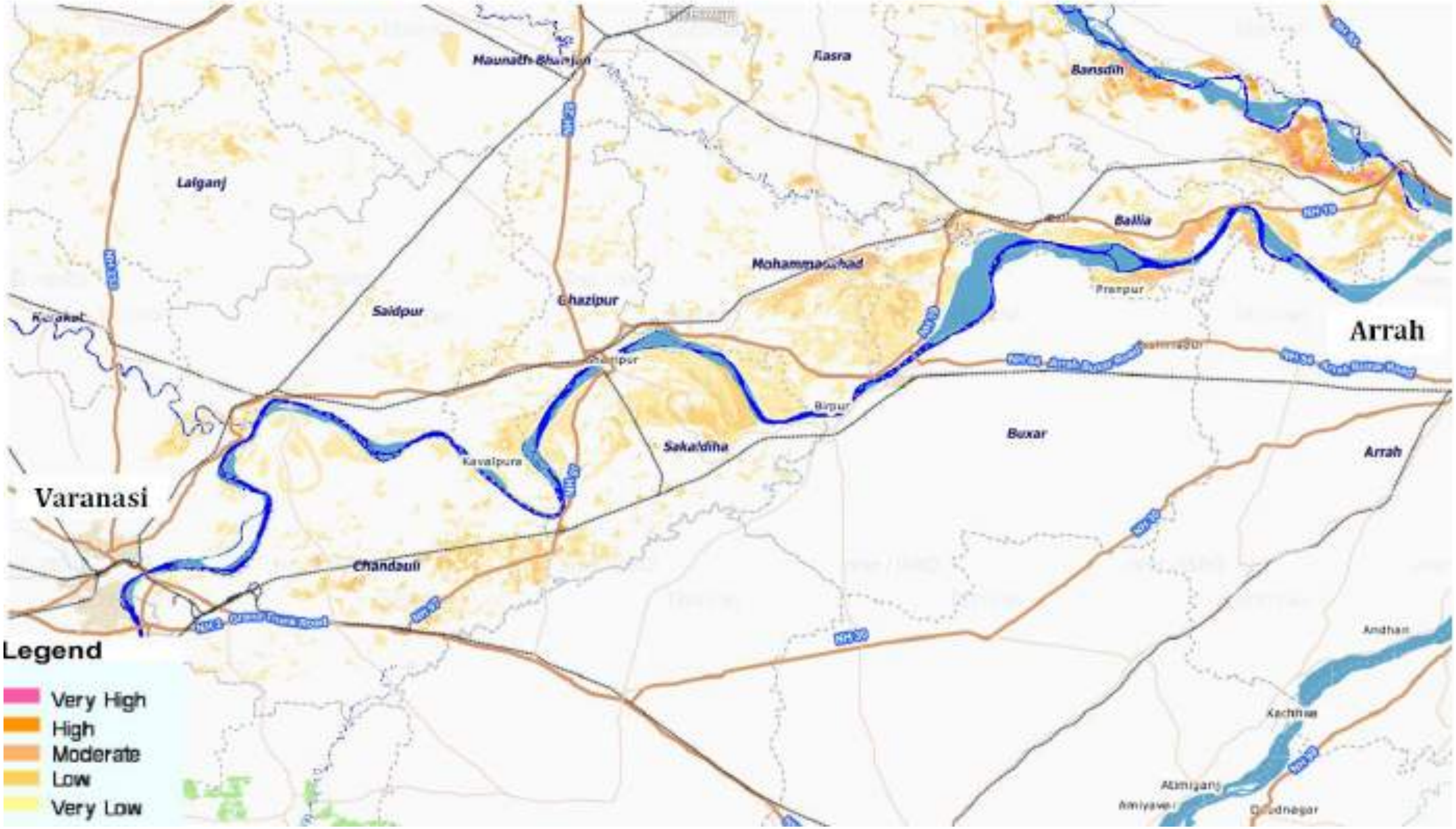


Figure 14.9 Flood Hazard Zone Map of Ganga river from Varanasi to Arrah (Source: NRSC Portal)

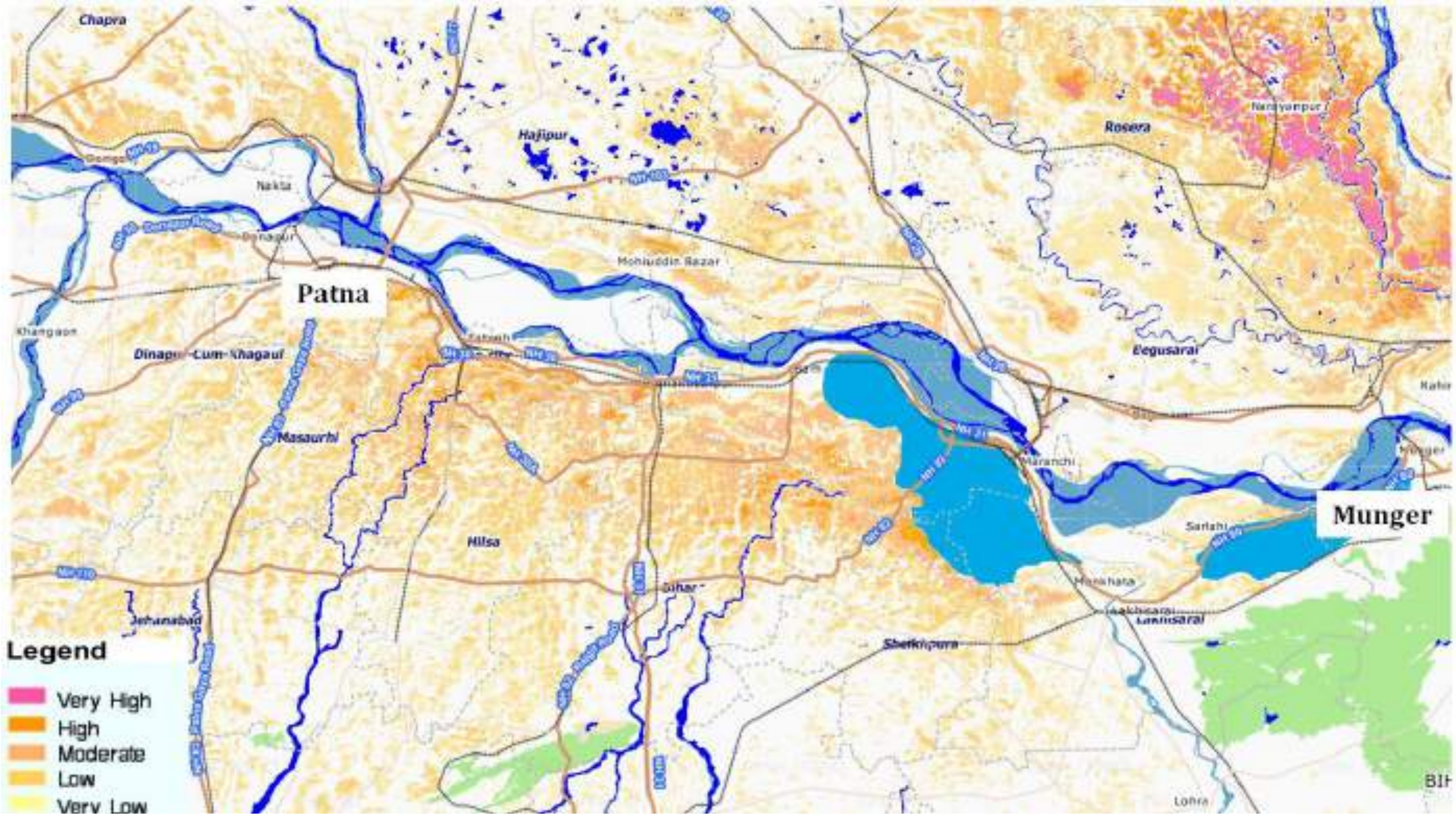


Figure 14.10 Flood Hazard Zone Map of Ganga river from Patna to Munger (Source: NRSC Portal)

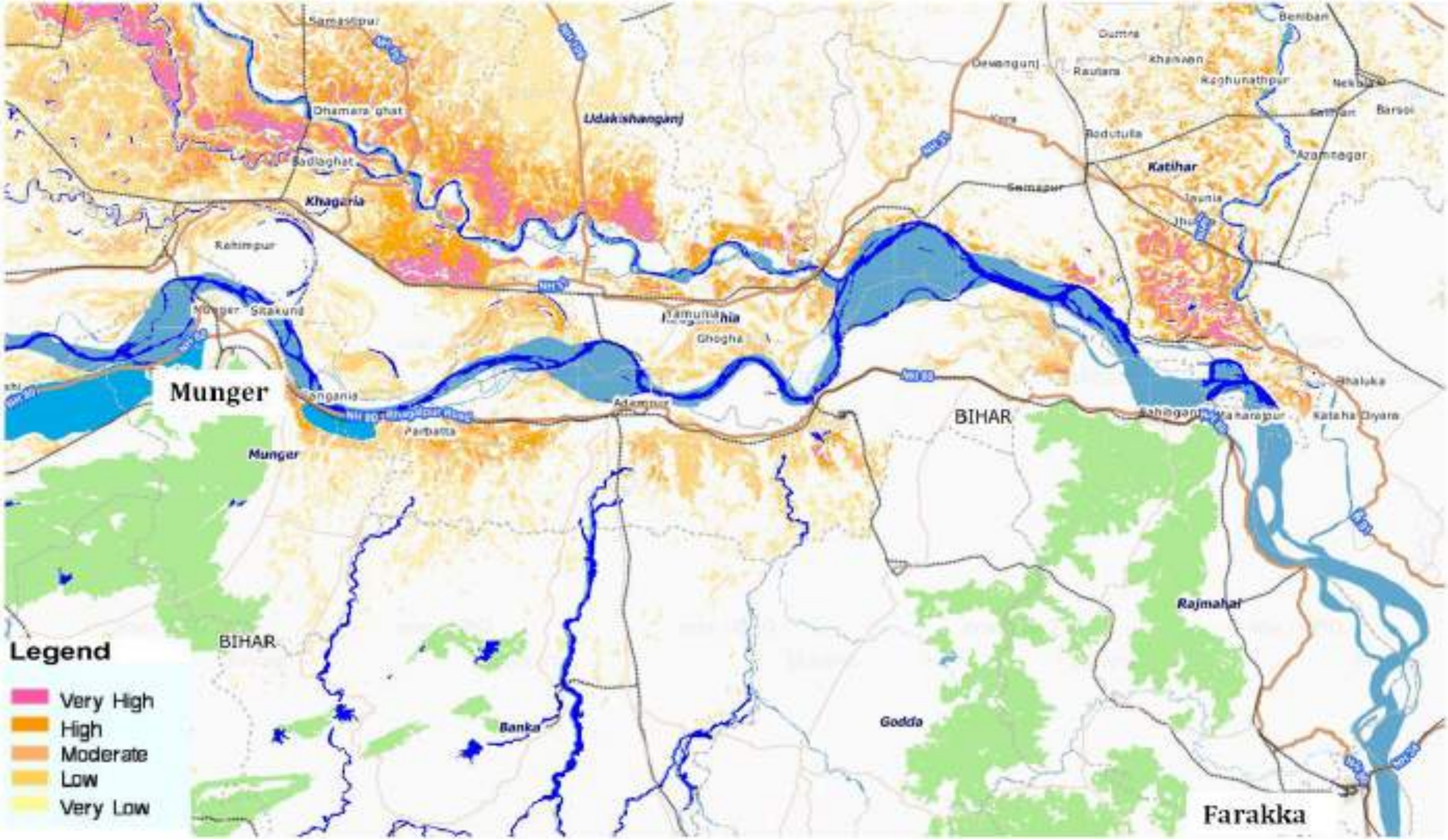


Figure 14.11 Flood Hazard Zone Map of Ganga river from Munger to Farakka (Source: NRSC Portal)

Chapter 15 IDENTIFICATION OF CRITICAL REACHES & RIVER TRAINING WORKS

15.1 IDENTIFICATION OF THE CRITICAL REACHES

Methodology for the plan form changes of the river in the terms of bank line shifting, sinuosity, plan form index etc. has been discussed in the Chapter 7. For fulfilling the objectives of the study regarding identification of the critical reaches and provision of river training works thereof, suitable basis has been evolved and that are discussed here.

The proposed basis for the identification of the critical reaches are as follows:

a) The reach of the river that has been progressively shifting towards either sides from the base year 1970 shall be considered as critical. This is due to the fact that such progressive shifting of the course of river causes severe erosion of the agricultural areas, which results in loss of the agricultural land.

b) Localized erosion of the either banks in the habitated/ settlement areas, as such erosion causes displacement of the houses to the new locations, inundation of pricey areas etc.

(c) In agricultural land, where the river is wide and the width is much higher than regime width of the channel even though there is no progressive shifting of river course in the either directions. Such frequent shifting of the river in wide width of the land causes loss of the crops and agricultural land. Thus there is a need to confine the width of the river so that spread of the flood water which is causing huge inundation can be controlled.

The above basis has been adopted in this study for the identification of critical reaches of the Ganga river.

As per the IS code 12094:2000, the spacing between the embankments/levees for the containment of the river should not be less than 3 times Lacey's wetted perimeter for the design flood discharge. In no case should an embankment be placed at a distance less than one or one and half times Lacey's wetted perimeter from the river bank.

Lacey's perimeter for the alluvial river may be obtained by

$$P = 4.75\sqrt{Q} \tag{15.1}$$

Where P is in m and Q in cumecs.

Invoking the methodology/criteria discussed in the above section, the identified critical reaches of the Ganga river are given in Table 15.1. Justification of the identifiedof reaches as critical is also mentioned in the Table 15.1. In total, thirty five reaches/locations are identified as critical in Ganga river out of which 27 reaches have already been protected using spurs, embankments etc. and for remaining eight critical reaches/locations, protection measures are suggested.

Figures 15.1 to 15.7 show satellite images of the Ganga river of year 2015 from Devprayag to Farakka. In these figures, the extreme left and right banks of the river that was attained by the Ganga river in the period 1970 to 2010 are marked. In addition to this, lines of three times the Lacey perimeter are also marked on the image of year 2015. The existing embankments are also shown in the Figs. 15.1 to 15.7.

Lacey perimeter for 50 years return period discharge is computed at various gauging sites along with three upper barrages i.e., Pashulok barrage, Bhimgoda barrage and CCS barrage. The computed Lacey perimeter at different locations are given in Table 15.2, which reveals that Lacey perimeter of the Ganga river varies from 472 m at Garhmukteshwar to 1425 m at Farakka barrage.

Table 15.1 Critical reaches of the Ganga river and suggested protection measures

S. No.	Chainage	Location	Behavior of River/Justification	Remarks
1	1752-1754 km	4.4 km downstream of the Pashulok barrage	Left bank under erosion	Provided series of spurs are adequate
2	1745-1749 km	5 km upstream of the Bhimgoda barrage near Haripur Kalan	Left bank under erosion	**Series of spurs are recommended for the protection of left bank in a length of 4.15 km to control the cutting of the forest area (see Fig. 15.8)**
3	1740.5-1741 km	Just upstream of the Bhimgoda barrage	Left bank under erosion	Provided series of spurs are adequate
4	1725-1731 km	8 km downstream of the Bhimgoda barrage near Kangri village	Left bank under erosion and same may be attributed to mining activity; there is dense habitation towards left side. Right side is also protected with series of spurs	**Series of spurs are provided, some more spurs are required in a length of 6 km towards left (see Fig. 15.9)**
5	1699-1703 km	2.5 km upstream of the Balawali railway bridge near Laksar	Left bank under erosion	No habitation towards left side - mainly agricultural land, protection works may not be required
6	1664-1674 km	7.5 km upstream of the C.C.S barrage	Wandering behavior of main course of the river, maximum shift is of the order of 6 km during period of 1970-2015	Being agricultural area, river training works may not be required
7	1610-1628 km	Near Kishanpur, Hastinapur	Wandering behavior of river with maximum shift of around 5 km	Being agricultural area, river training works may not be required
8	1464-1495 km	Upstream of the Narora	River channelized by jacketing with	No measure required

		barrage	embankment and spurs	
9	1436 km	Sidholia Kham	River attacking the left existing embankment	**Spurs are suggested to be provided along with existing embankment in a length of 0.6 km at chainage 1436 km (see Fig. 15.10)**
10	1446 km	Saharpur Makanpur Kham	River attacking the left existing embankment	**Embankment along with spurs are suggested to be provided in a length of 1.0 km at chainage 1446 km (see Fig. 15.11)**
11	1346-1360 km	About 36 km upstream of the Farukkhabad road bridge	Wandering behavior of river with maximum shift of about 5 km	No measures required
12	1157-1168 km	Kanpur	River was forced to divert its path towards right side through Kanpur barrage by deploying pilot channel and embankment	No measures required
13	1092-1108 km	Downstream of Baksar-Muradipur road near Gunir	Wide spread over about 5 km width, deep channel towards right side which has habitation	**Protection to right bank is required in a length of 14.5 km using boulder revetment and/or provision of series of spurs (see Fig. 15.12)**
14	986-992 km	Near Shahzadpur	Wide width of river of about 5 km	Embankment provided on the left side, No other measure required
15	942-952 km	Upstream of Allahabad	Wide width of river of about 4 km, no progressive shifting	No measure required
16	926-932 km	Downstream of Lord	River is progressively shifting towards	Series of spurs are provided towards

		Curzon bridge	right side	right side and the same are functioning satisfactory, No other measure required
17	902-916 km	Downstream of confluence of Yamuna river near Allahabad	Flowing in two channels with a big island in between having width of about 3 km and area of 30 km^2	No measure required
18	696-710 km	Downstream of Varanasi	Flowing in two channels with an island in between having width of 1.4 km and area of 16.5 km^2	No measure required
19	614-620 km	Upstream of Ghazipur	River is wide spread with maximum width of about 4.5 km	No measure required
20	472-550 km	Near Ballia	No major morphological changes in the main stream of Ganga river, however, spreading of flood water in this reach is very large	No measure required
21	464 km	Confluence of Ghaghara river with Ganga	River is wide and shifted from right to left of the order of 5 km	No measure required
22	418 km	Digha rail cum road bridge	Upstream of the bridge, river width is of the order of 12 km and main channel has shifted from left to right over the years, however, downstream of bridge the width of river is about 5 km and river has shifted from right to left	No measure required
23	360-400 km	Downstream of Patna	River is flowing in two channels which	No measure required

			form an island of width of 10 km and with an area of 240 km^2	
24	312-336 km	Upstream of Mokamah bridge	River is flowing in two channels which has formed an island of width of 4 km and with an area of 65 km^2	No measure required
25	298 km	Near Khutha	River is wide and shifted from right to left of the order of 4 km over the years	No measure required
26	245 km	Munger	Remarkable change in the morphology of the river. Major course of the river has shifted around 12 km from left to right, at present river is flowing towards Munger side.	River has severe tendency of its shifting, however, at present river is flowing towards city side (Munger), thus no measure required
27	210 km	Upstream of Sultanganj	Remarkable change in the morphology of the river noticed, Main course of river has shifted about 8 km from left to right in past	As river is flowing towards right side from year 2000 onwards and is also stable, no measure required
28	194 km	Downstream of Sultanganj (Akbarnagar)	Remarkable change in the morphology of the river noticed, main course of river has shifted about 9 km from left to right	River is stable towards right side from year 1980, no measure required
29	180 km	Bhagalpur	River has moved progressively away from Bhagalpur city over the year, left bank under erosion	**Protection measures in the form of embankment with boulder revetment and launching apron be provided near Raghopur area over a length of about 4 km (see Fig. 15.13) to control lateral shifting towards left side**

30	158 km	Upstream of Kahalgaon	River has progressively shifted from right to left by about 9 km	Embankment with series of spurs are provided along the left bank and their performance is satisfactory, no additional measure is required
31	122 km	Downstream of confluence of Kosi river	River is flowing in two channels which has formed an island of width of 6 km and an area of 90 km^2, Left channel has further tendency of its movement towards left	Embankment with series of spurs are provided in the left bank and their performance are satisfactory, No additional measure is required
32	80 km	Sahibganj	Wandering behavior of main channel with maximum shift of about 8 km, presently flowing towards Sahibganj side	No measure required
33	36-78 km	Rajamahal to Maharajpur	River has shifted towards left side and eroding the left bank in this reach	**Embankment along with launching apron may be provided to control the erosion of left bank in this reach in about 33 km length (see Fig. 15.14) and lateral shifting towards left side**
34	24-34 km	Near Manikchak	River is shifting towards left side in this reach	**Embankment along with launching apron may be provided to control the erosion towards left side in this reach in about 10 km length (see Fig. 15.15) and lateral shifting towards left side**
35	2 km	Upstream of Farakka barrage near Jagannathpur	Left side eroded by the river in past	Presently relatively stable left, thus no protection work is required

Table 15.2 Peak discahrges for different return periods and Lacey perimeter for 50 years return period discharge

Station	Chainage (km)	Peak Discharge (m^3/s) Return period 25 yr	50 yr	100 yr	Lacey Perimeter (P) for 50 years return period discharge $P = 4.75\sqrt{Q}$ (m^3/s)
Farakka	0	82174.75	90055.21	97877.48	1425
Azamabad	140	85030.47	93790.17	102485.18	1455
Hathidah	310	75412.03	82165.96	88870.02	1362
Gandhighat	407	80300.70	89531.20	98693.54	1421
Buxar	555	47752.24	53049.12	58306.90	1094
Varanasi	714	49944.38	55895.72	61803.10	1123
Mirzapur	798	59480.42	67785.67	76029.60	1237
Allahabad	920	62344.22	71158.86	79908.42	1267
Shahjadpur	992	15030.53	17293.20	19539.17	625
Bhitaura	1083	16174.75	18744.09	21294.47	650
Kanpur	1156	14755.19	16741.24	18712.61	615
Ankinghat	1224	12588.28	14225.48	15850.60	567
Fatehgarh	1309	9241.50	10544.59	11838.07	488
Kachla bridge	1425	10369.15	11685.10	12991.33	513
Garhmukteshwar	1572	8727.63	9879.49	11022.85	472
C.C.S. barrage	1660		17600.00		630
Bhimgoda barrage	1740		17400.00		626
Pashulok barrage	1758		13200.00		546

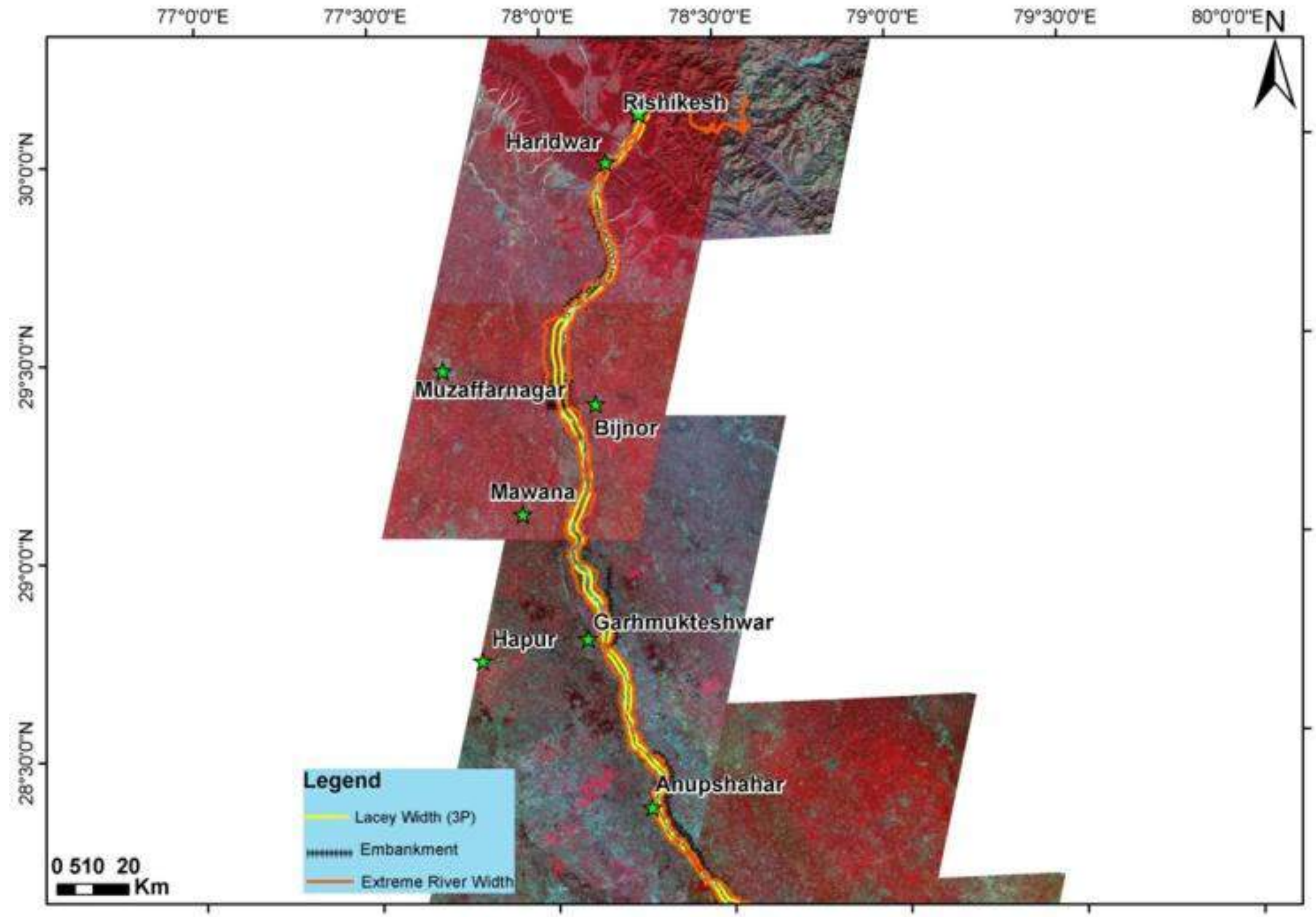


Figure 15.1 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 1500-1824 km

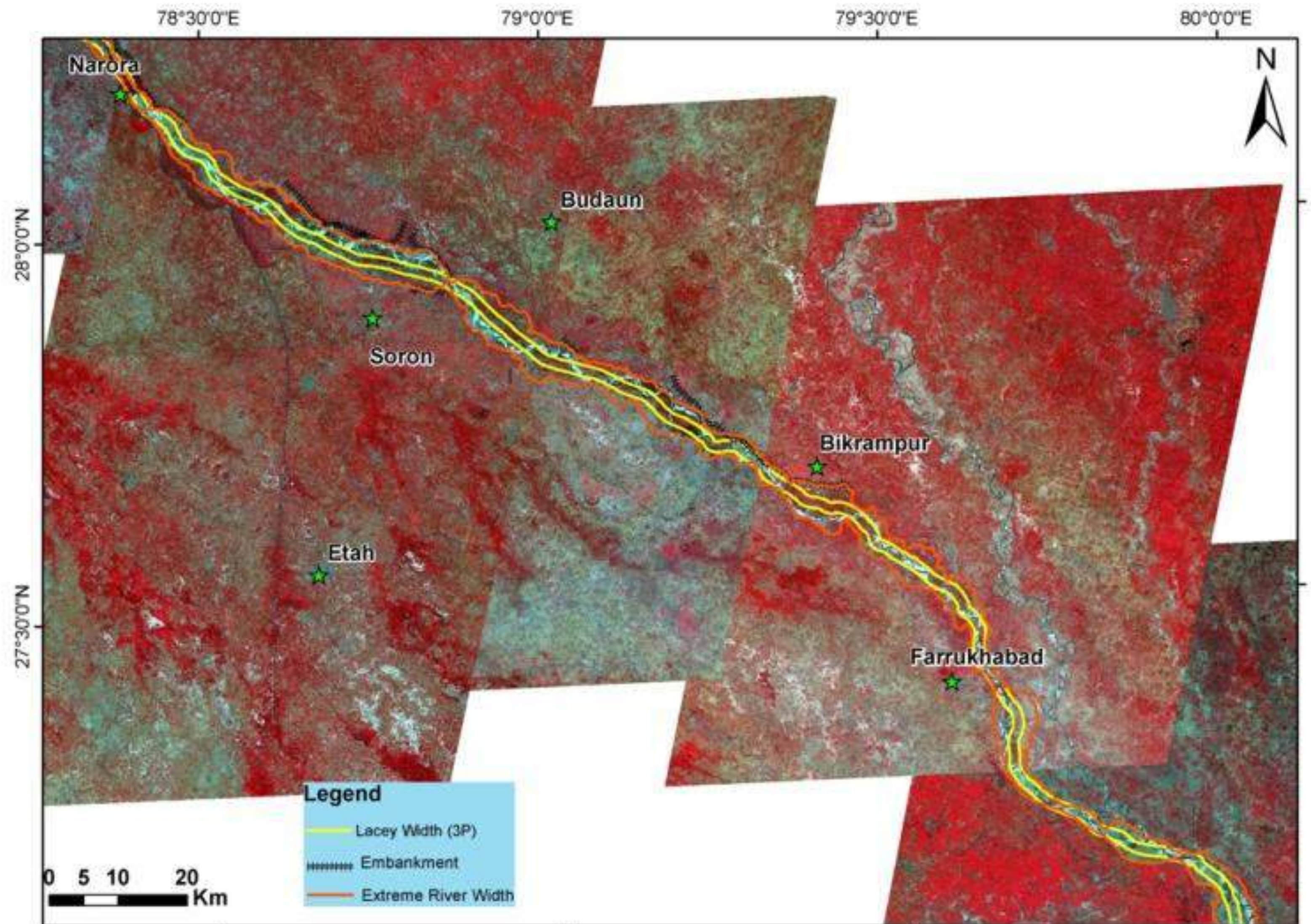


Figure 15.2 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 1250-1500 km

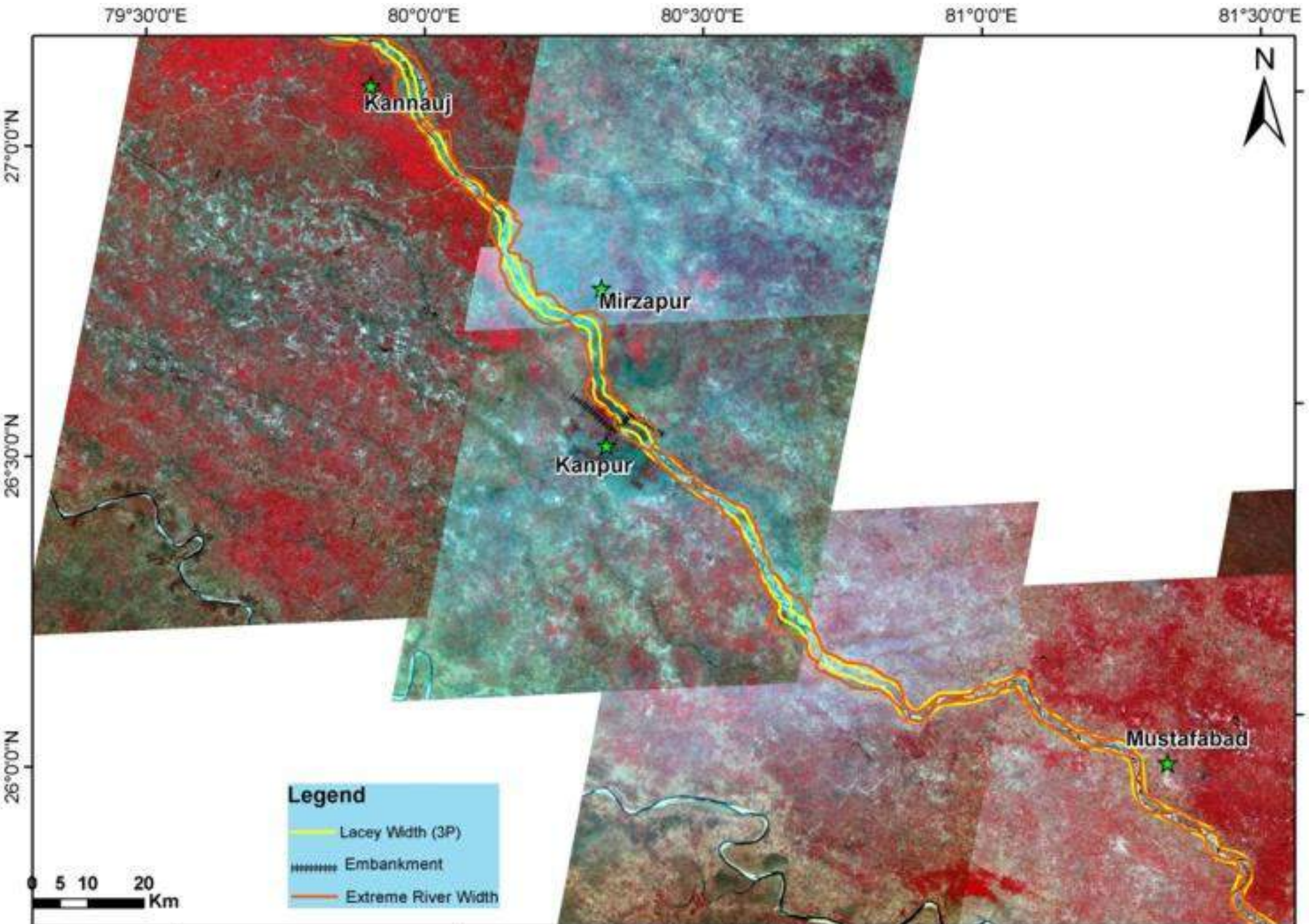


Figure 15.3 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 1000-1250 km

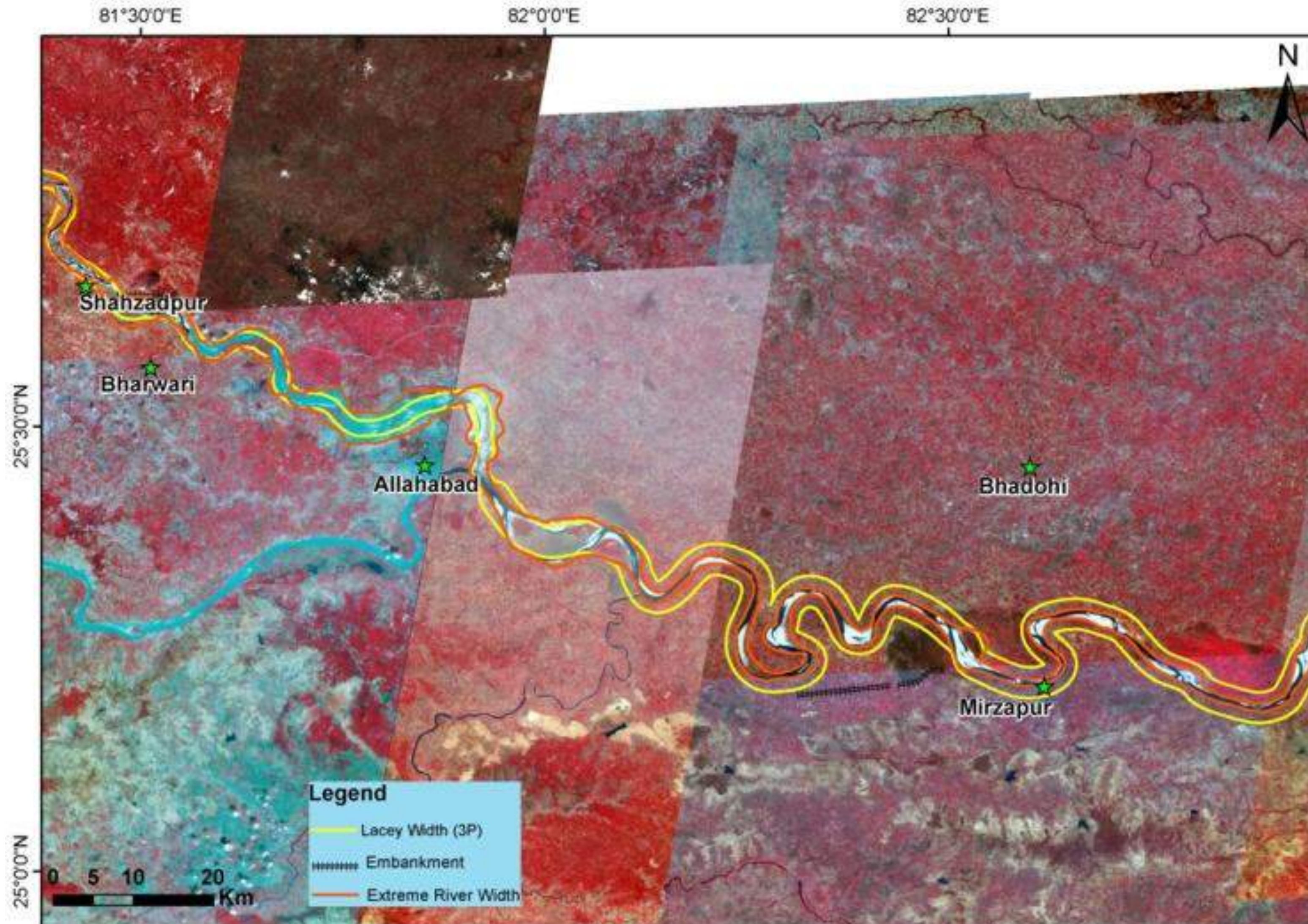


Figure 15.4 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 750-1000 km

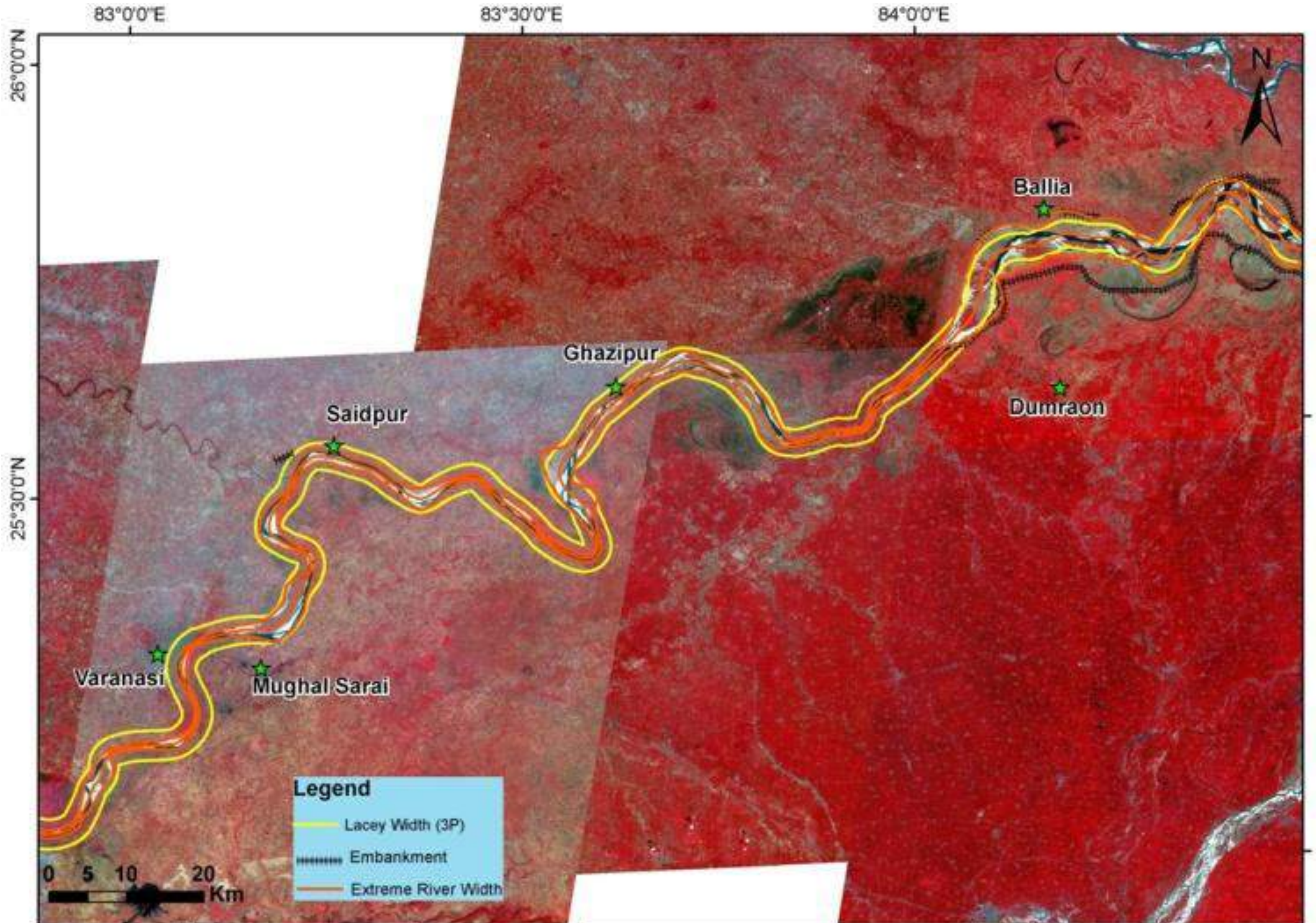


Figure 15.5 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 500-750 km

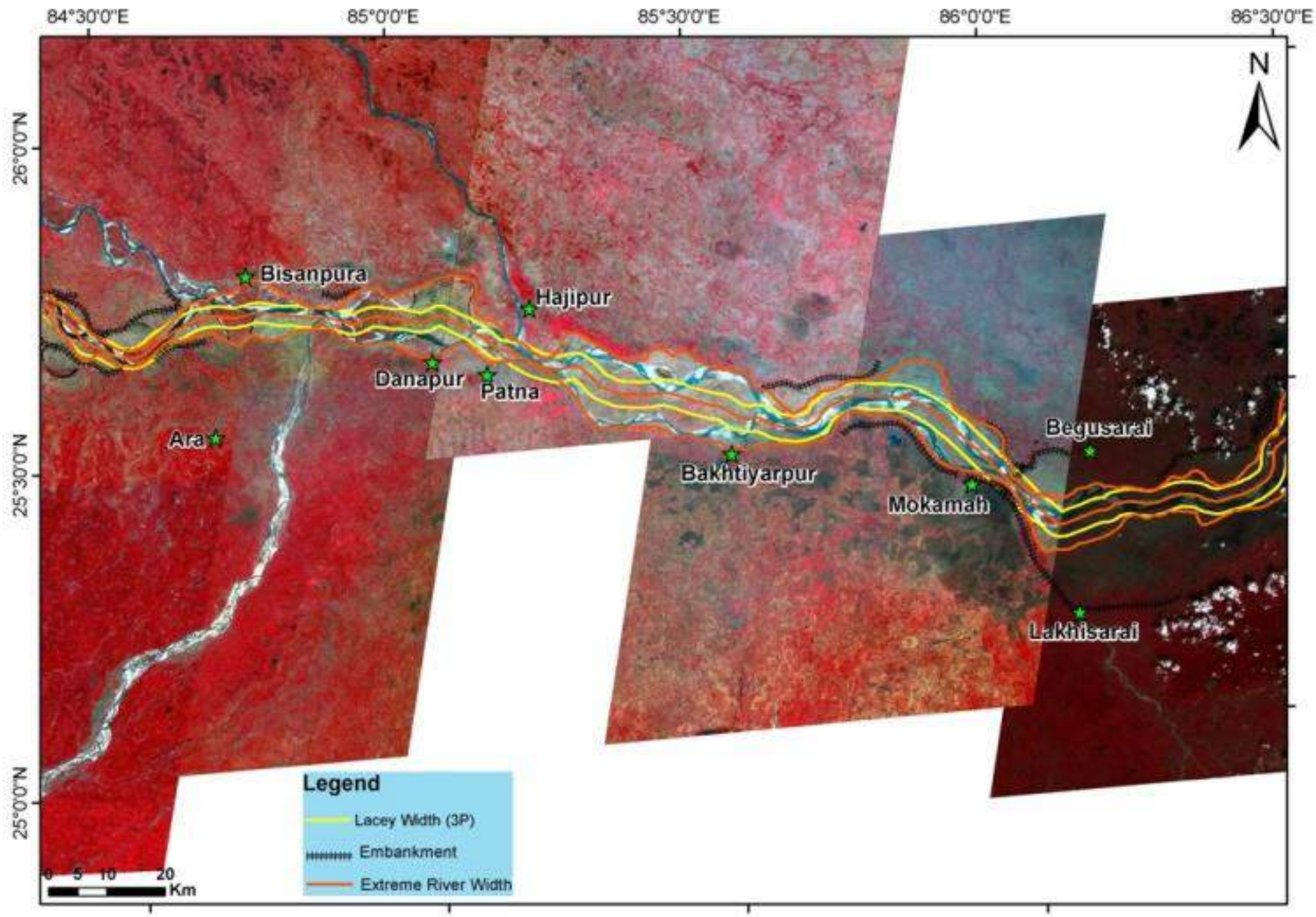


Figure 15.6 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 250-500 km

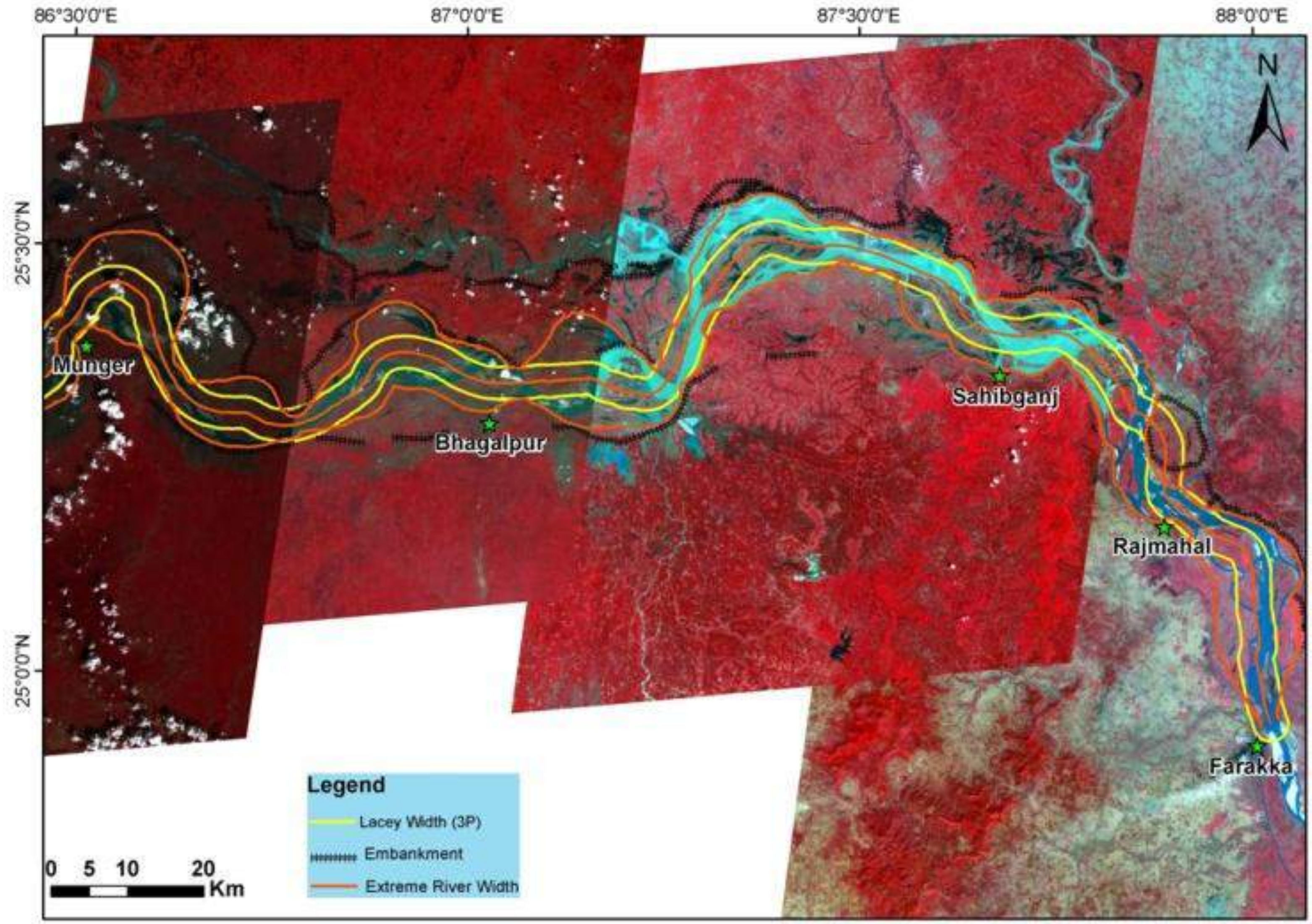


Figure 15.7 Marked Lacey width (3P), existing embankment and extreme banks of the Ganga river on satellite image of year 2015 in the reach of Chainage 0-250 km

15.2 PROPOSED RIVER TRAINING WORKS

Design methodologies of various river training works like guide banks, spurs, pilot channels etc., are given in Annexure - A. Such methodologies have been compiled from the relevant IS and IRC codes and also from relevant literature.

In total, thirty five reaches/locations are identified as critical in Ganga river. However, in twenty seven critical reaches of the Ganga river either the river is protected using spurs, embankments etc. or being in agricultural area, protection works are not required. At the remaining eight critical reaches/locations near Haripur Kalan, Kangri, Sidholia Kham, Saharpur Makanpur Kham, Gunir, Bhagalpur, Rajmahal to Maharajpur and Manikchak, protection measures are suggested as given in the Table 15.1. Such suggested measures are mainly series of spurs and/or embankment with boulder revetment. Alignment and location of the suggested measures are shown in the Figs. 15.8 to 15.15.

In addition to the above, the river training works shall also be provided near the following bridges:

1. Railway Bridge, Balawali, Laksar (Ch. 1696.5 km): a) Suggested to provide nose to each guide bund and b) boulder revetment be provided to the right embankment of the railway track over a length of 1.5 km.
2. Railway bridge, Rajghat, Narora (Ch. 1495.1 km): Suggested to provide nose to the left guide bund.
3. Railway & Road bridges, Kachhla (Ch. 1452.2 km). Both the guide bunds should be extended downstream.
4. Ara-Chhapra road Bridge, Doriganj, Chhapra (Ch. 450 km). a) A truncated guide bund be provided towards right side and b) right bank u/s of bridge is to be protected to control the shifting of the river.
5. Road Bridge - Gandhi Setu (NH 19) (Ch. 404.8 km). Suggested to repair washed out portion of launching apron towards Hajipur side.

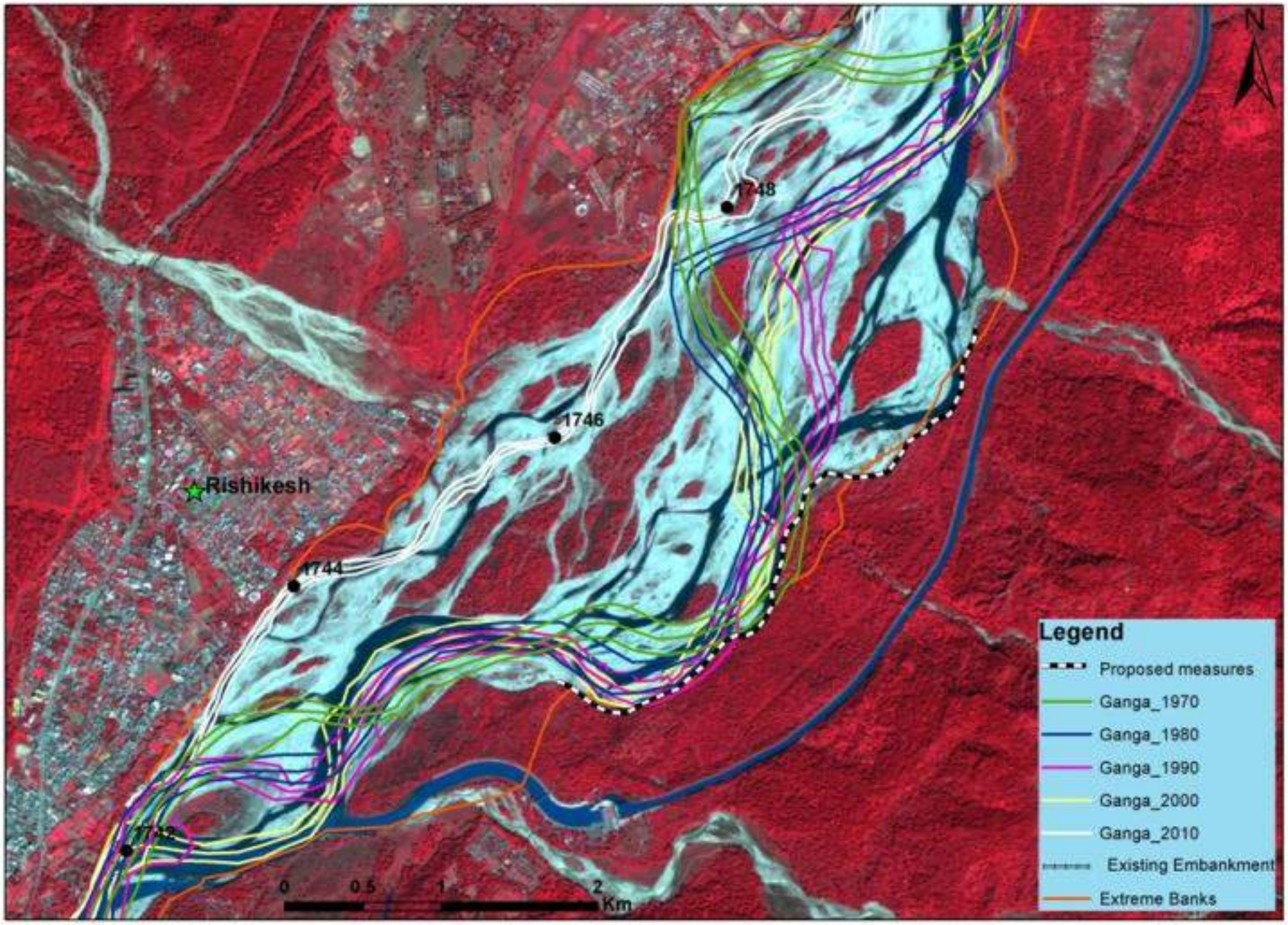


Figure 15.8 Proposed river training works in the reach of Chainage 1745-1749 km

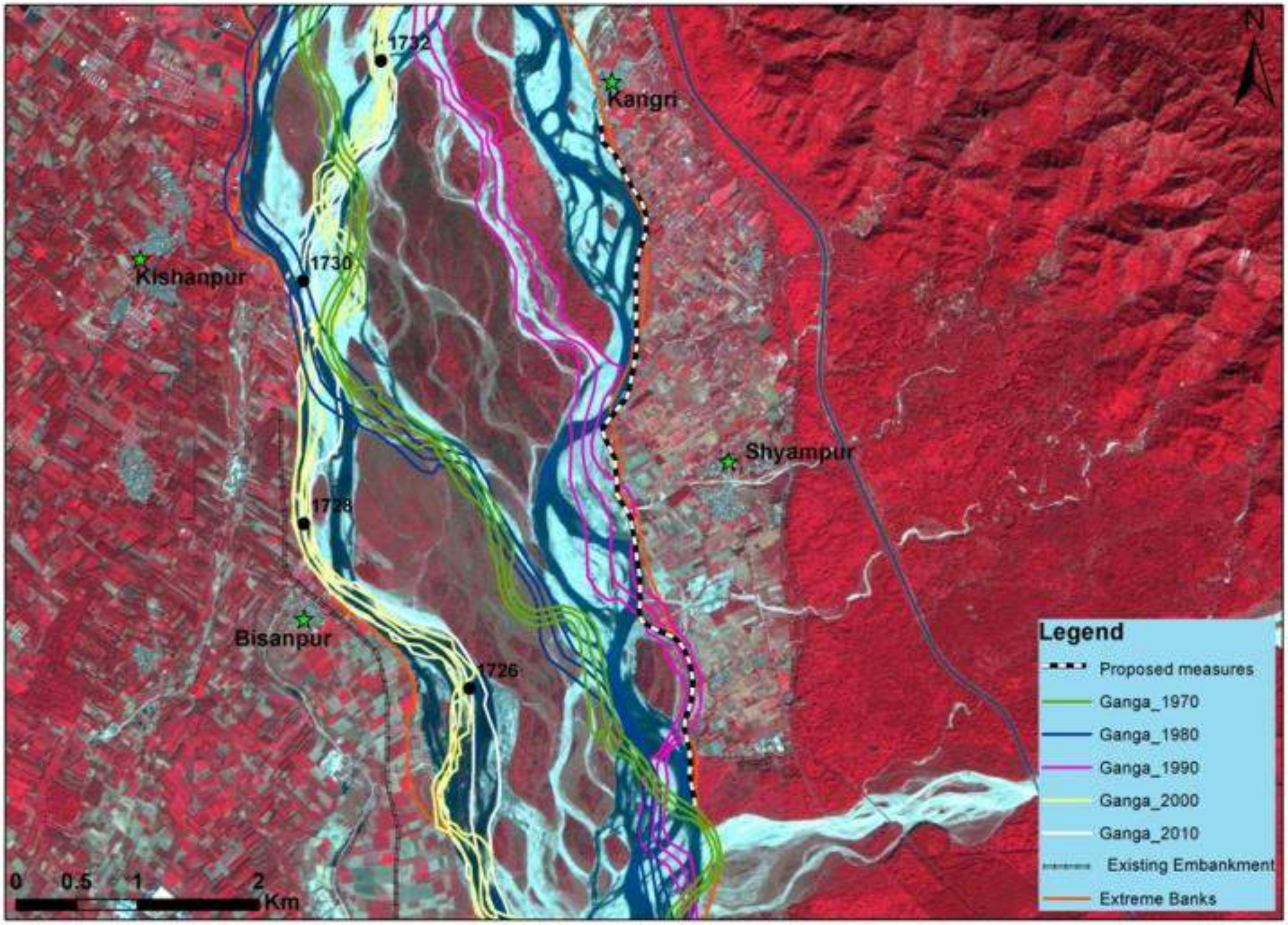


Figure 15.9 Proposed river training works in the reach of Chainage 1725-1731 km

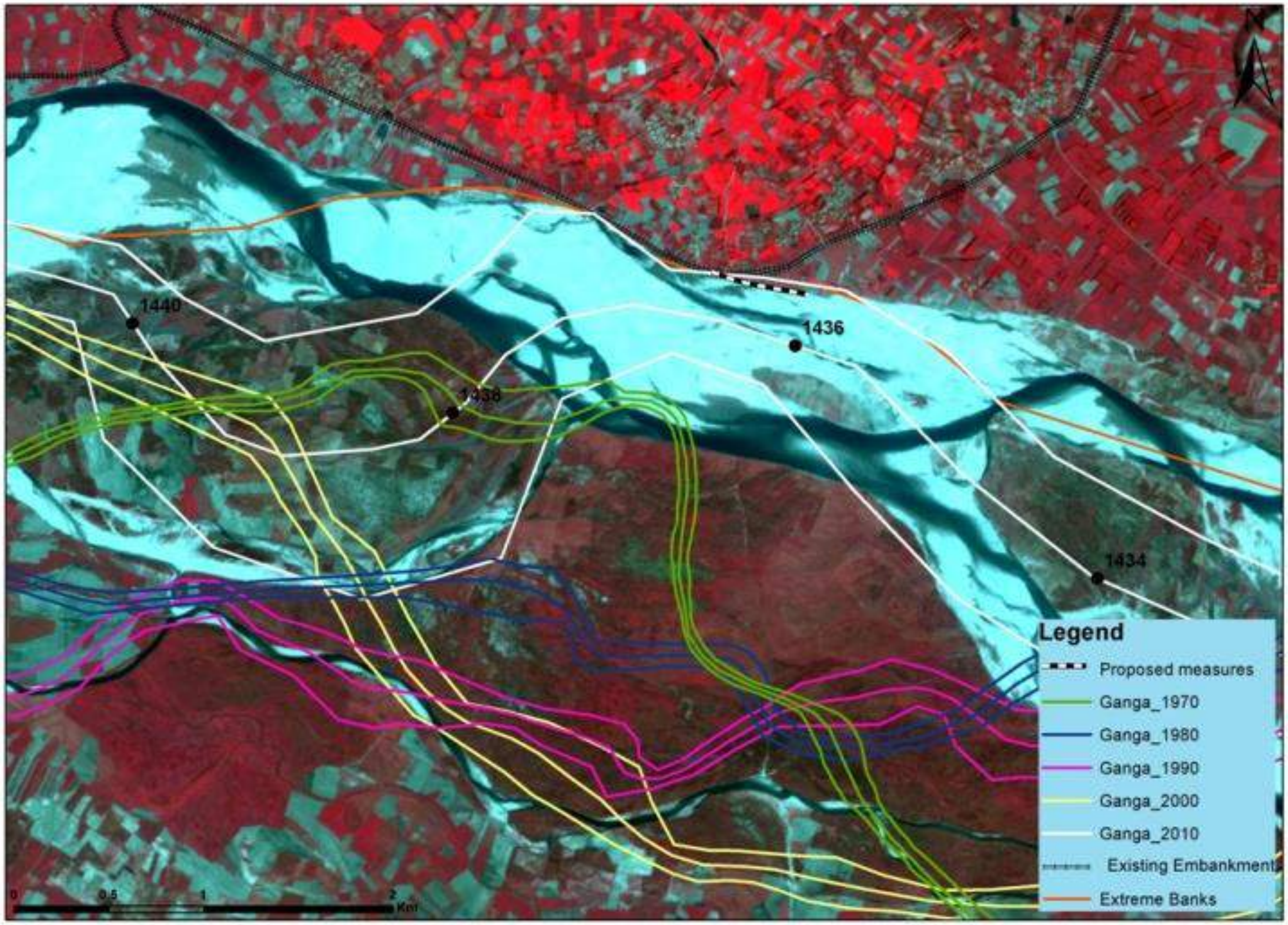


Figure 15.10 Proposed river training works near the Chainage 1436 km

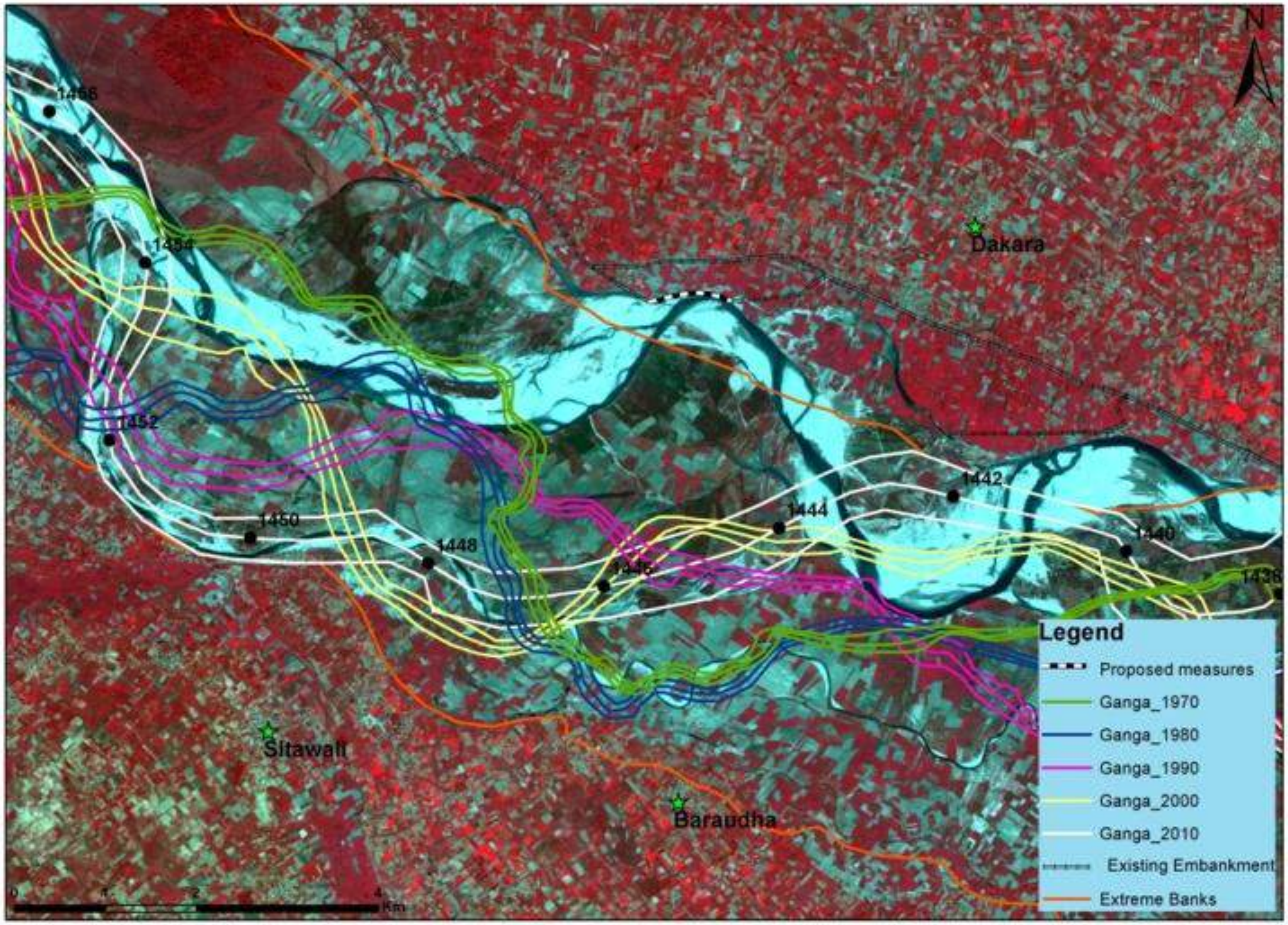


Figure 15.11 Proposed river training works near the Chainage 1446 km

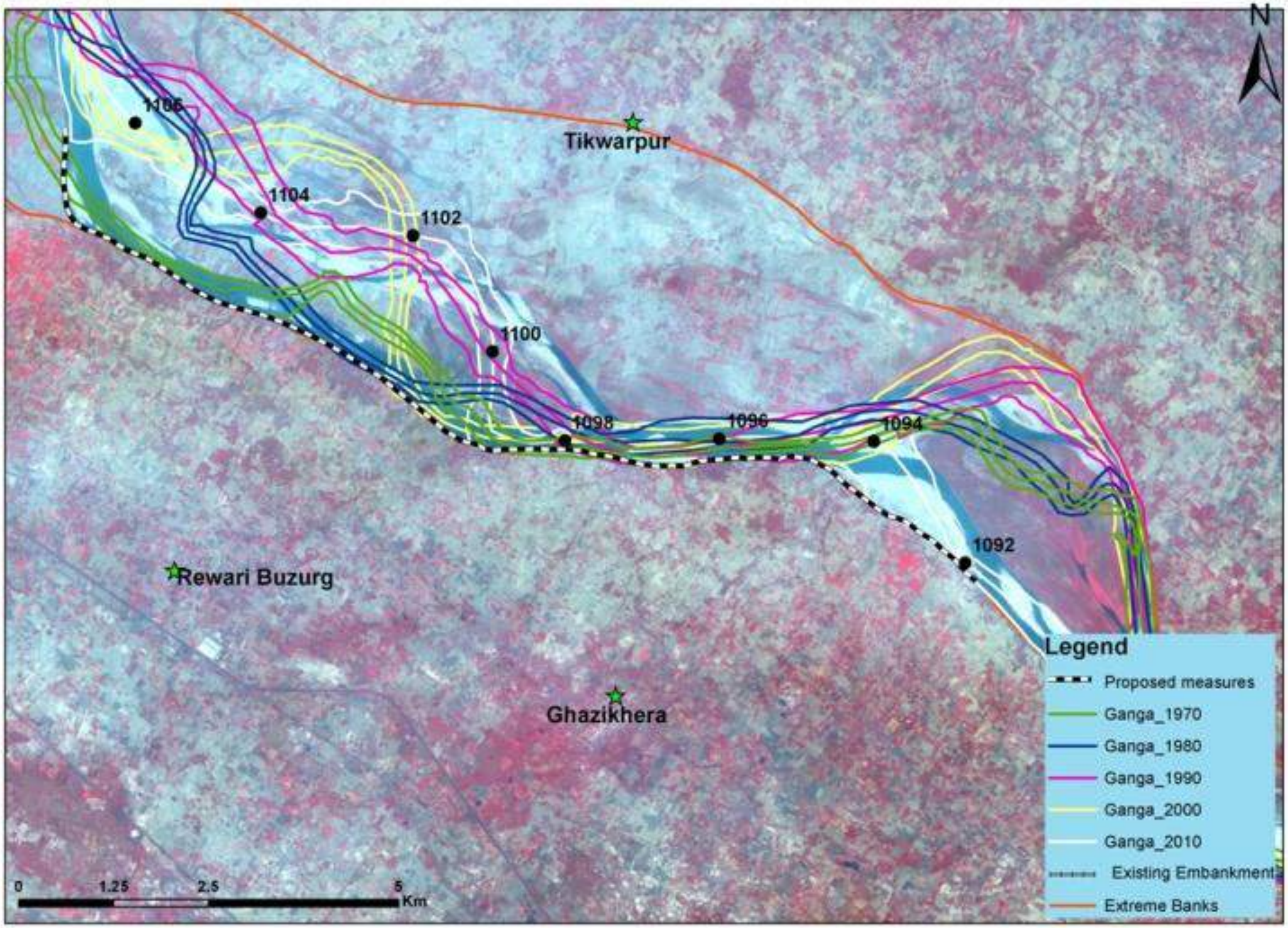


Figure 15.12 Proposed river training works in the reach of Chainage 1092-1108 km

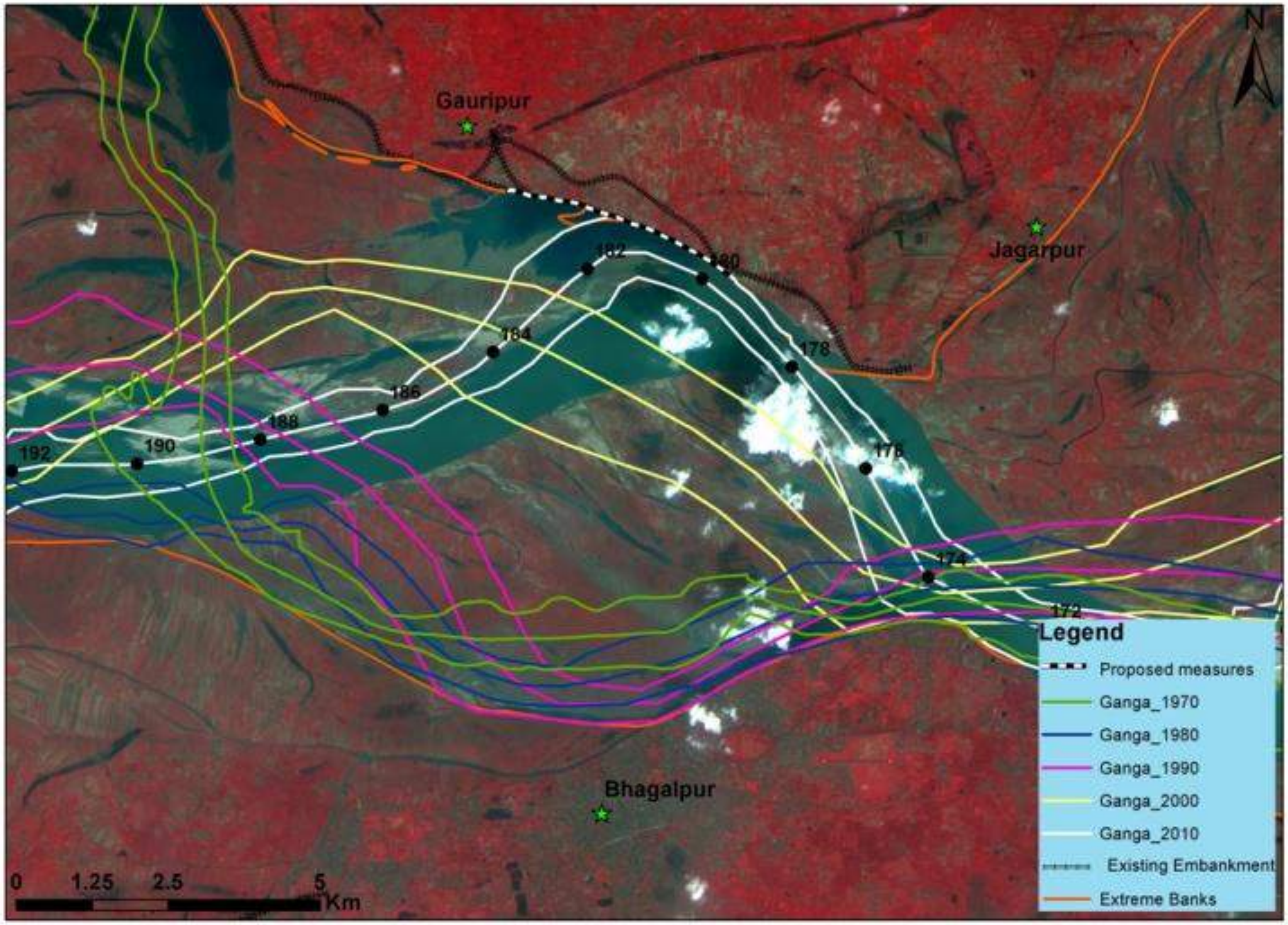


Figure 15.13 Proposed river training works near the Chainage 180 km

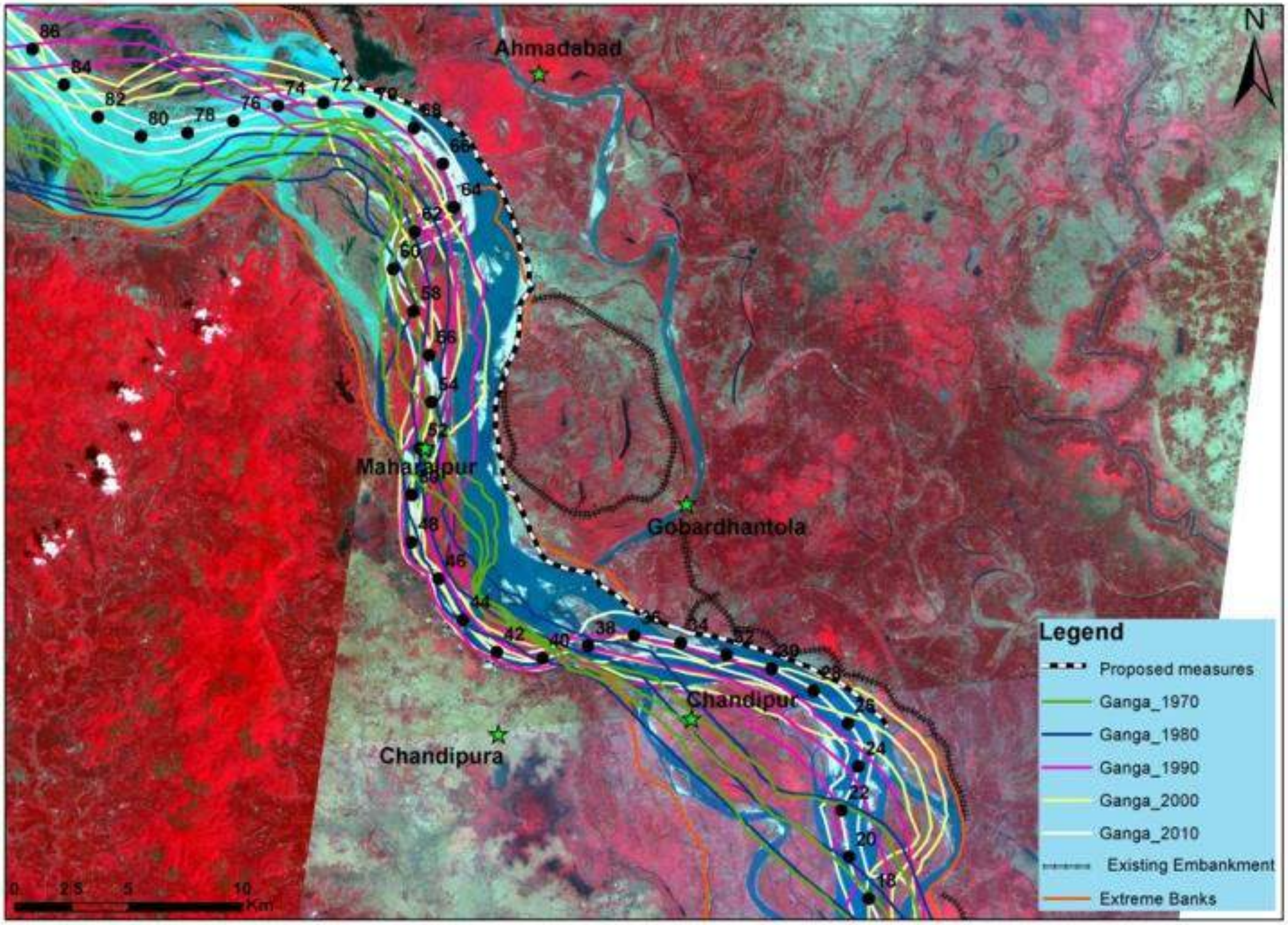


Figure 15.14 Proposed river training works in the reach of Chainage 36-78 km

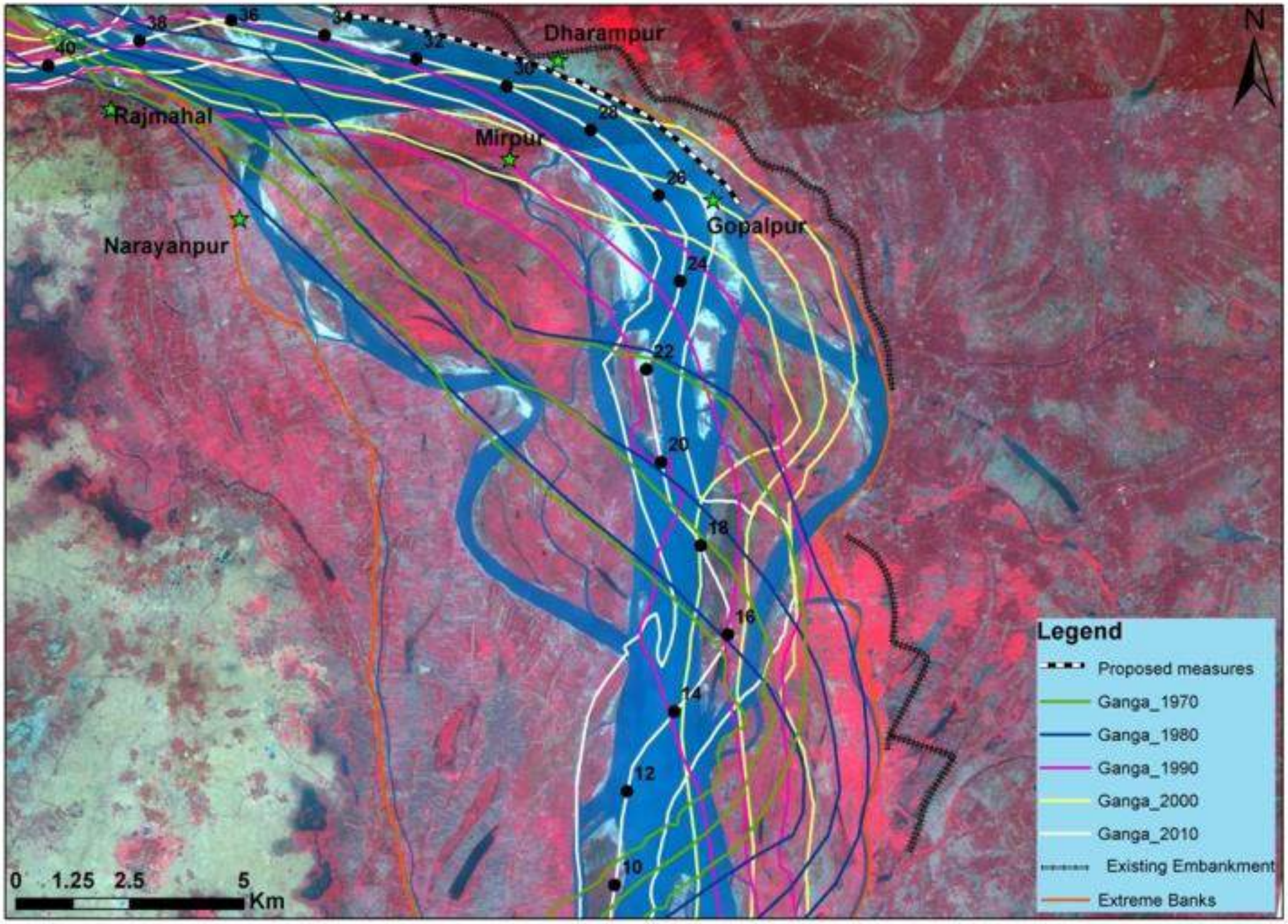


Figure 15.15 Proposed river training works in the reach of Chainage 24-34 km

15.3 EXISTING RIVER TRAINING WORKS

Earthen embankments are mostly provided from Haridwar to Kanpur and from Buxar to Farrakka barrage. Out of about 33 embankments as listed in the Table 15.3 and shown in Figs. 15.16a-15.16s, major embankments are located towards right side downstream of the Haridwar; towards left side upstream of the Garhmukteswar, Narora barrage, and Farrukhabad; downstream of Buxar towards right side; towards left side downstream of the Mokama and confluence of Burhi Gandak; and downstream of the Krusela towards left side. In the lower Ganga basin, the embankments are mostly provided along left bank as evident from the Figs. 15.16a-15.16s.

Details of the provided river training works on the Ganga river are given in Table 15.4. Such river training works are generally in the form of series of spurs and guide bunds and provided mostly to protect the bridges and barrages.

Table 15.3 Details of the existing embankments provided on Ganga river

Sl. No.	Location	Lat/Long of the starting point	Lat/Long of the end Point	Chainages of the starting & end points (km)	Provided along bank	Length of the embankment (km)
1.	D/S of Haridwar	78° 3' 1.428" E 29° 36' 2.232"N	78° 8' 34.666" E 29° 52' 18.550" N	1690-1729	Right	37.76
2.	U/S of CCS Barrage	78° 2' 37.285" E 29° 22' 31.281" N	78° 4' 3.927" E 29° 26' 45.586" N	1660-1668	Left	8.88
3.	U/S of CCS Barrage	77° 59' 53.298" E 29° 22' 21.920" N	78° 2' 12.432" E 29° 22' 30.624" N	1668	Right	3.71
4.	U/S of Garhmuktesar	78° 8' 56.275" E 28° 46' 4.831" N	78° 9' 47.047" E 28° 57' 58.460" N	1568-1594	Left	24.27
5.	U/S of Narora Barrage	78° 16' 31.323" E 28° 29' 33.778" N	78° 28' 40.902" E 28° 9' 10.620" N	1480-1530	Left	51.31
6.	D/S of Narora Barrage	78° 37' 15.679" E 28° 4' 23.251" N	78° 40' 53.495" E 28° 0' 45.298" N	1446-1458	Left	8.93

7.	D/S of Narora Barrage	78° 41' 26.685" E 28° 0' 44.613" N	78° 47' 43.169" E 28° 0' 58.037" N	1435-1445	Left	12.52
8.	U/S of Kachhla Bridge	78° 48' 12.844" E 27° 55' 22.565" N	78° 50' 54.095" E 27° 55' 11.124" N	1425-1429	Right	4.87
9.	U/S of Kachhla Bridge	78° 48' 38.385" E 28° 0' 24.150" N	78° 51' 46.546" E 27° 56' 29.782" N	1425-1434	Left	11.07
10.	D/S of Kachhla Bridge	79° 1' 18.423" E 27° 51' 27.167" N	79° 2' 30.883" E 27° 50' 11.094" N	1401-1404	Left	3.15
11.	U /S of Farrukhabad	79° 10' 55.292" E 27° 48' 12.677" N	79° 26' 6.009" E 27° 38' 48.964" N	1349-1386	Left	33.84
12.	U/S of Kanpur Barrage	80° 14' 14.088" E 26° 33' 50.047" N	80° 19' 6.500" E 26° 30' 26.051" N	1164-1174	Right	10.43
13.	D/S of Kanpur Barrage	80° 20' 16.684" E 26° 31' 48.825" N	80° 23' 54.488" E 26° 29' 48.218" N	1164-1155	Left	7.07
14.	U/S of Allahabad Bypass	81° 27' 49.096" E 25° 38' 37.541" N	81° 31' 47.498" E 25° 38' 37.599" N	982-989	Left	6.85
15.	U/S of Ballia	84° 3' 51.895" E 25° 43' 34.660" N	84° 4' 52.467" E 25° 44' 18.578" N	536-538	Left	2.15
16.	D/S of Buxar	84° 0' 18.315" E 25° 35' 44.599" N	84° 31' 2.137" E 25° 39' 16.023" N	484- 554	Right	65.02
17.	U/S of confluence of Ghagra river	84° 24' 44.543" E 25° 46' 27.337" N	84° 24' 44.543" E 25° 46' 27.337" N	471-501	Left	29.33
18.	U/S of Arrah Chhapra Bridge	84° 34' 20.823" E 25° 39' 49.300" N	84° 39' 32.872" E 25° 41' 16.372" N	469-479	Right	9.44
19.	U/S of Arrah Chhapra Bridge	84° 40' 59.990" E 25° 41' 17.074" N	84° 43' 9.066" E 25° 40' 42.126" N	459-464	Right	3.83
20.	U/S of confluence of Sone river	84° 44' 6.746" E 25° 40' 45.402" N	84° 48' 53.153" E 25° 40' 18.136" N	450-458	Right	9.48
21.	D/S of Raghopur Diara	85° 35' 14.198" E 25° 32' 45.768" N	85° 47' 25.216" E 25° 34' 37.570" N	336-362	Right	22.24
22.	D/S of Mokama Bridge	86° 24' 10.620" E 25° 24' 4.847" N	85° 57' 49.614" E 25° 28' 1.462" N	258-319	Left	54.69
23.	D/S of confluence of Burhi Gandak river	86° 36' 37.801" E 25° 28' 57.022" N	86° 51' 5.841" E 25° 23' 51.427" N	196-240	Left	51.61
24.	D/S of Madhurpur	86° 54' 5.517" E	86° 58' 29.484" E	182-196	Left	10.67

		25° 23' 41.733" N	25° 20' 10.364" N			
25.	D/S of Madhurpur	87° 0' 1.475" E 25° 19' 25.405" N	87° 1' 45.232" E 25° 18' 23.131" N	177-180	Left	3.70
26.	D/S of confluence of Koshi river	87° 7' 31.094" E 25° 18' 57.388" N	87° 11' 48.328" E 25° 17' 45.308" N	154-162	Left	8.40
27.	D/S of Kursela	87° 16' 34.075" E 25° 28' 22.560" N	87° 19' 13.024" E 25° 28' 43.355" N	123-127	Left	4.58
28.	D/S of Kursela	87° 19' 32.252" E 25° 28' 32.956" N	87° 31' 41.712" E 25° 27' 38.037" N	100-123	Left	27.17
29.	U/S of Nawabganj	87° 37' 0.121" E 25° 22' 14.262" N	87° 37' 0.121" E 25° 22' 14.262" N	91-101	Left	13.50
30.	D/S of Nawabganj	87° 44' 8.841" E 25° 19' 29.649" N	87° 46' 29.493" E 25° 17' 10.151" N	70-75	Left	6.05
31.	U/S of confluence of Fulahar river	87° 49' 4.037" E 25° 10' 9.304" N	87° 49' 4.046" E 25° 10' 9.380" N	46-58	Left	26.71
32.	D/S of confluence of Fulahar river	87° 53' 15.667" E 25° 6' 12.600" N	87° 59' 43.768" E 24° 58' 57.316" N	20-38	Left	19.37
33.	U/S of Farakka Barrage	87° 57' 46.376" E 24° 51' 54.906" N	87° 58' 51.373" E 24° 57' 27.416" N	6-18	Left	13.41

Table 15.4 Details of the river training works (other than embankments) provided on Ganga river

Sl No.	Location	Lat/Long	Type of Works	Provided on/along	Length (m)
1.	Near Chilla Hydro power Plant	78°13'34.645"E 29°59'5.361"N	Series of Spurs	Left Bank	Left bank=700
2.	Upstream of Bhimgoda Barrage, Haridwar	78°11'14.818"E 29°57'34.911"N	Series of Spurs	Both Banks	Left bank=500 Right bank= 920
3.	Downstream of Bhimgoda Barrage, Haridwar	78°10'11.606"E 29°56'37.981"N	Series of Spurs	Both Banks	Left bank= 4600 Right bank =4000
4.	Downstream of Bhimgoda Barrage, Kangri, Haridwar	78°10'15.341"E 29°53'34.538"N	Series of Spurs	Both Banks	Left bank= 4000 Right bank =2000

5.	Downstream of Bhimgoda Barrage, Bisanpur, Haridwar,	78°9'15.698"E 29°50'56.073"N	Series of Spurs	Right Bank	Right bank =7000
6.	Balawali Bridge	78°6'24.642"E 29°38'16.569"N	Guide Bund	Both Banks	Left bank =550 Right bank =440
7.	Downstream of Balawali Bridge	78°3'41.19"E 29°32'42.035"N	Series of Spurs	Left Bank	Left bank =1200
8.	Upstream of CCS Barrage	78°3'52.101"E 29°26'29.532"N	Series of Spurs	Left Bank	Left bank =760
9.	CCS Barrage	78°2'23.832"E 29°22'28.431"N	Guide Bund	Both Banks	Left bank =850 Right bank =800
10.	Hastinapur	78°3'24.895"E 29°7'36.845"N	Series of Spurs	Right Bank	Right bank =900
11.	Garhmukteshwar	78°8'43.463"E 28°45'50.916"N	Guide Bund	Both Banks	Left bank =1100 Right bank =900
12.	Upstream of Anupshahar (Aligarh Bypass Road)	78°16'29.098"E 28°21'56.126"N	Guide Bund	Both Banks	Left bank =800 Right bank =550
13.	Rajghat Rail Bridge	78°22'5.61"E 28°14'48.939"N	Guide Bund	Left Bank	Left bank =530
14.	Rajghat to Narora Barrage	78°23'9.646"E 28°13'23.66"N	Series of Spurs	Both Banks	Left bank =5200 Right bank =4000
15.	Narora Barrage	78°24'6.085"E 28°11'37.051"N	Guide Bund	Left Bank	Left bank =1100
16.	Downstream of Narora Barrage	78°26'23.813"E 28°7'32.517"N	Series of Spurs	Right Bank	Left bank =17000
17.	Upstream of Kachhla Bridge	78°50'16.338"E 27°58'18.866"N	Series of Spurs	Left Bank	Left bank =1100
18.	Kachhla Bridge	78°51'25.93"E 27°56'1.09"N	Guide Bund	Both Banks	Left bank =630 Right bank =630
19.	Upstream of Kaimganj	79°15'39.734"E 27°43'18.941"N	Series of Spurs	Left Bank	Left bank =1070
20.	Upstream of Kaimganj	79°17'46.122"E 27°42'0.242"N	Series of Spurs	Left Bank	Left bank =2050

21.	Farrukhabad (NH-93)	79°37'47.561"E 27°23'57.033"N	Guide Bund	Left Bank	Left bank =1250
22.	Downstream of Kannauj (SH-21)	79°59'51.108"E 27°1'3.415"N	Guide Bund Series of Spurs	Left Bank Right Bank	Left bank =450 1000
23.	Bilhaur (SH-40)	80°6'8.708"E 26°52'55.879"N	Guide Bund	Left Bank	Left bank =680
24.	Kanpur Barrage	80°19'22.287"E 26°30'46.774"N	Guide Bund	Both Banks	Left bank =680 Right bank =1000
25.	Ganga Bridge, Kanpur (NH-25)	80°24'40.041"E 26°26'7.567"N	Guide Bund	Left Bank	Left bank =690
26.	Lord Curzon Bridge, Allahabad	81°52'4.501"E 25°30'26.917"N	Guide Bund	Left Bank	Left bank =720
27.	Upstream of Didarganj Rail Bridge, Allahabad	81°52'43.359"E 25°28'10.477"N	Series of Spurs	Left Bank	Left bank =1500
28.	Ghazipur	83°35'29.947"E 25°34'47.549"N	Series of Spurs	Left Bank	Left bank =2000
29.	Downstream of Balia	84°23'8.814"E 25°46'35.239"N	Series of Spurs	Left Bank	Left bank =3000
30.	Rajendra Bridge, Hathidah (NH-31)	85°59'52.797"E 25°22'35.179"N	Guide Bund	Left Bank	Left bank =1700
31.	Downstream of Bhagalpur	87°9'28.675"E 25°19'13.668"N	Series of Spurs	Left Bank	Left bank =8000
32.	Downstream of Kursela	87°21'2.122"E 25°29'3.652"N	Series of Spurs	Left Bank	Left bank =11200
33.	Farakka Barrage (NH-34)	87°56'14.44"E 24°48'31.855"N	Guide Bund	Left Bank	Left bank =1600

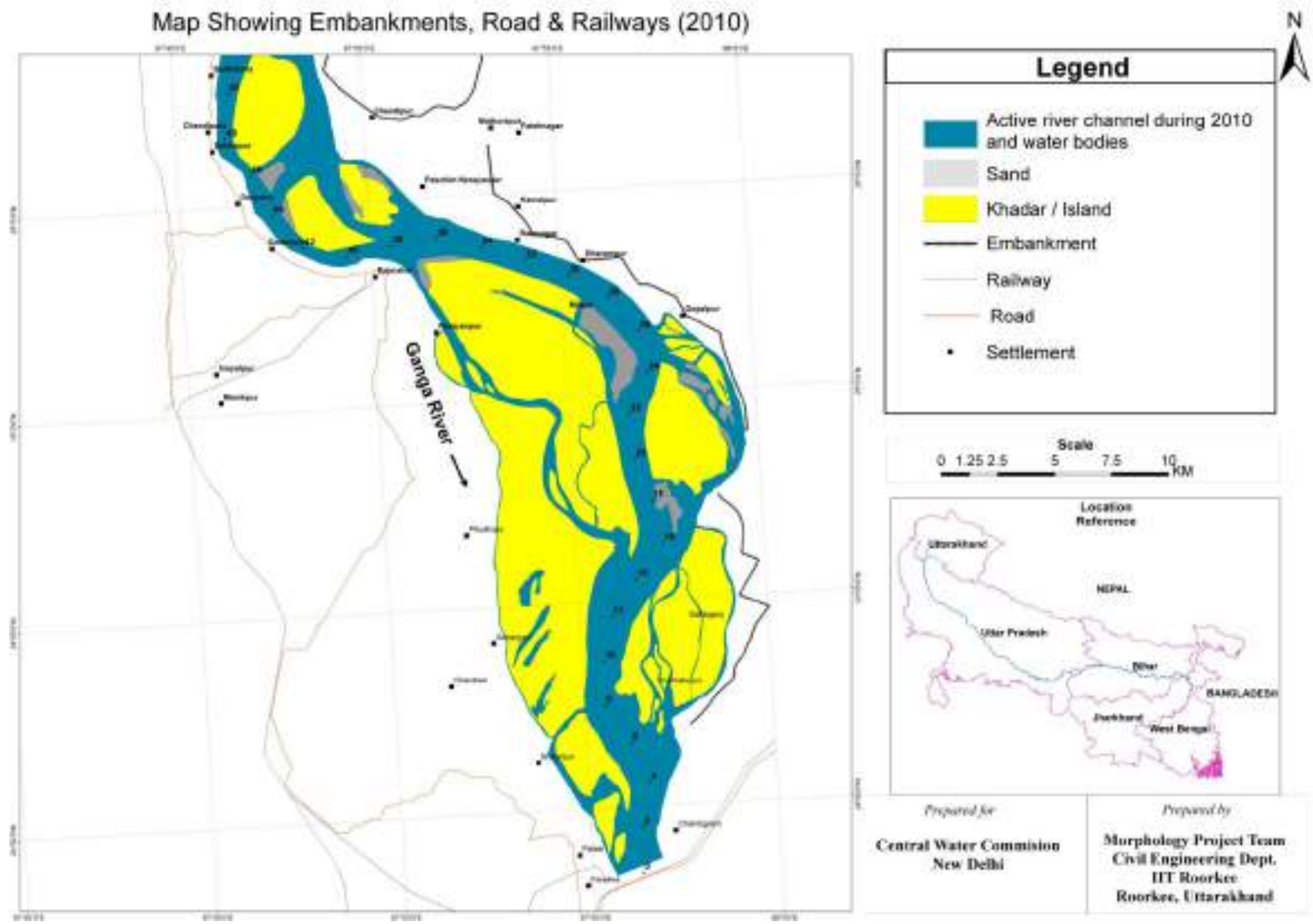


Figure 15.16a Existing embankments on Ganga river from chainage 0-50 km

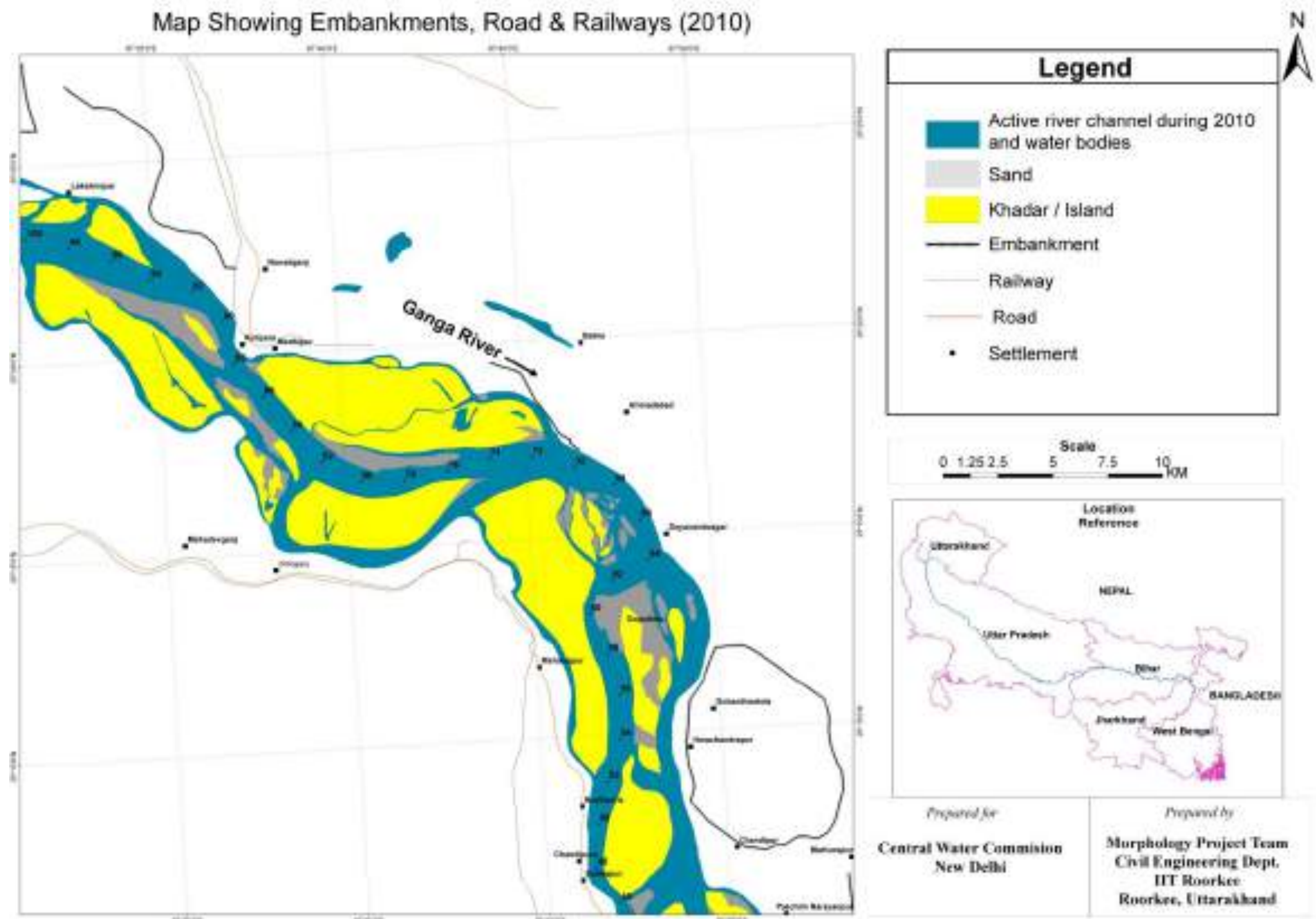


Figure 15.16b Existing embankments on Ganga river from chainage 50-100 km

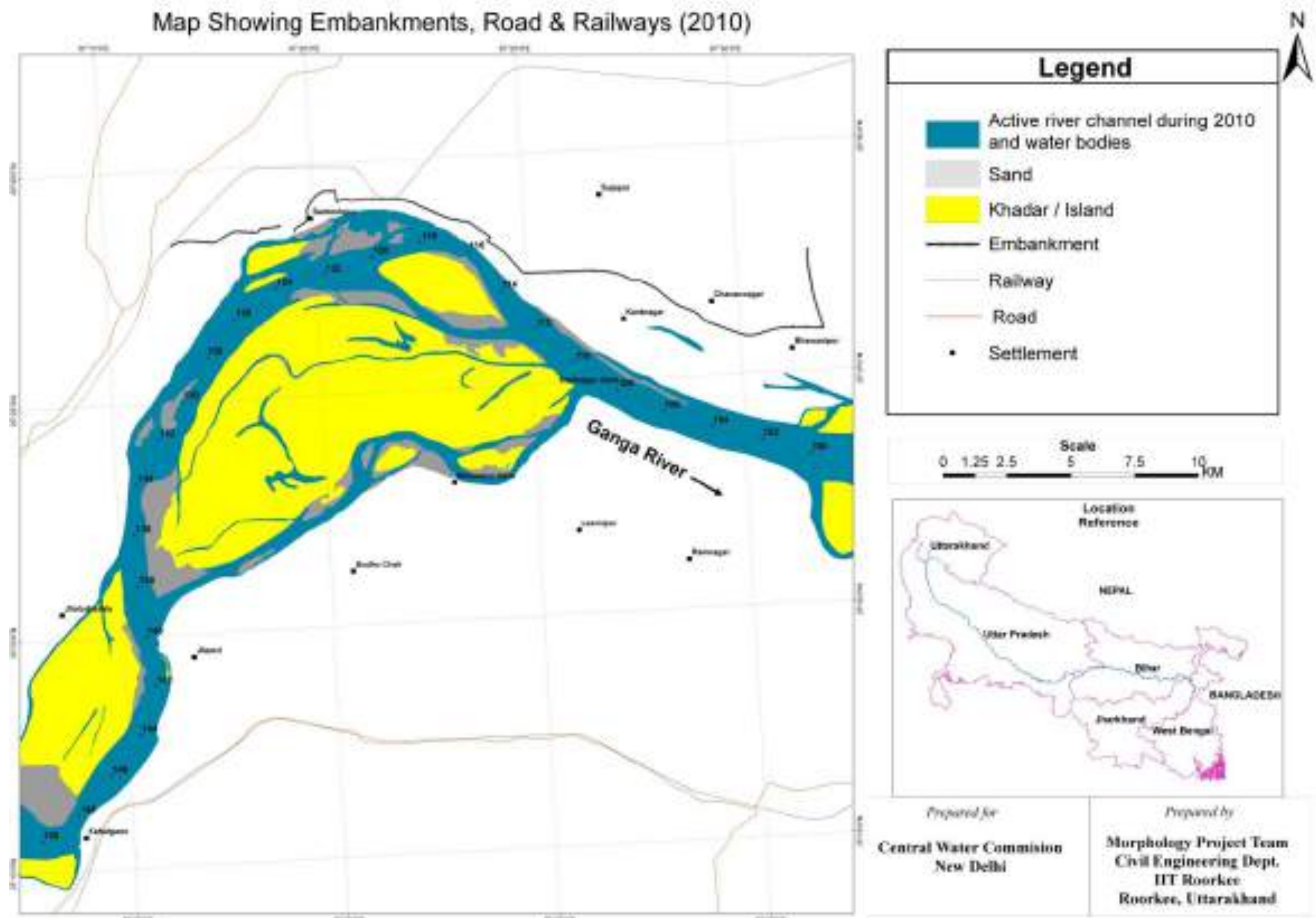


Figure 15.16c Existing embankments on Ganga river from chainage 100-150 km

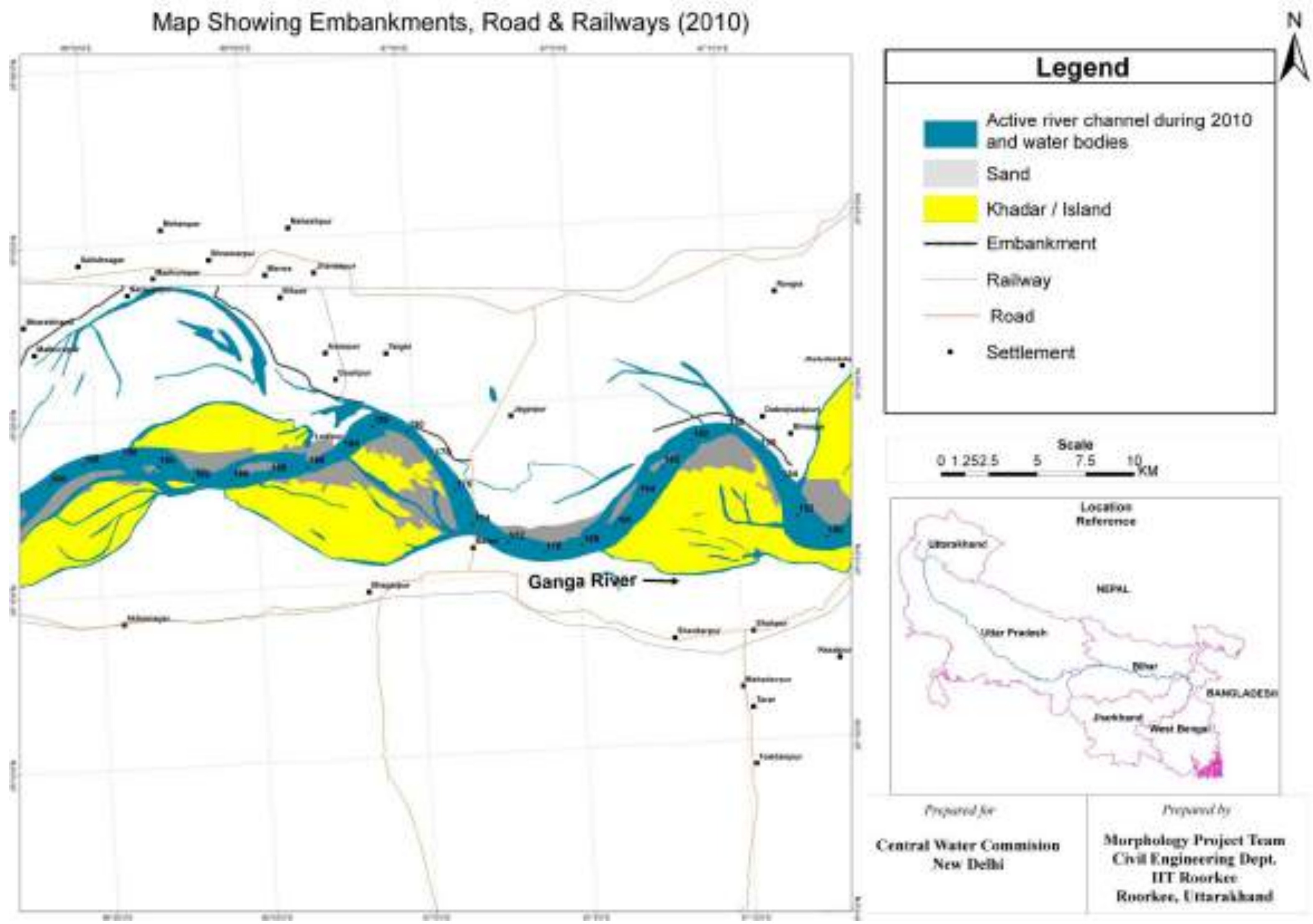


Figure 15.16d Existing embankments on Ganga river from chainage 150-200 km

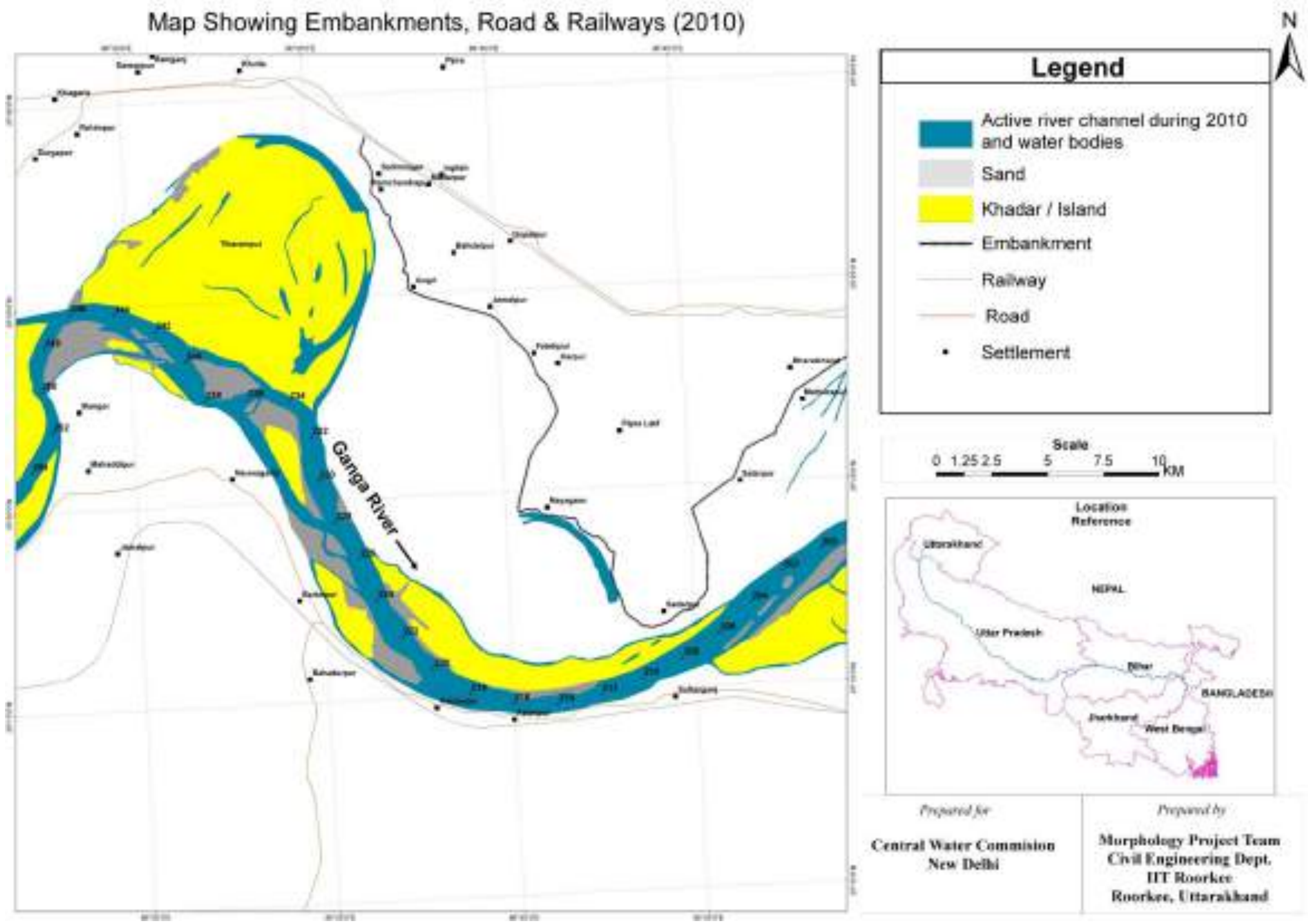


Figure 15.16e Existing embankments on Ganga river from chainage 200-250 km

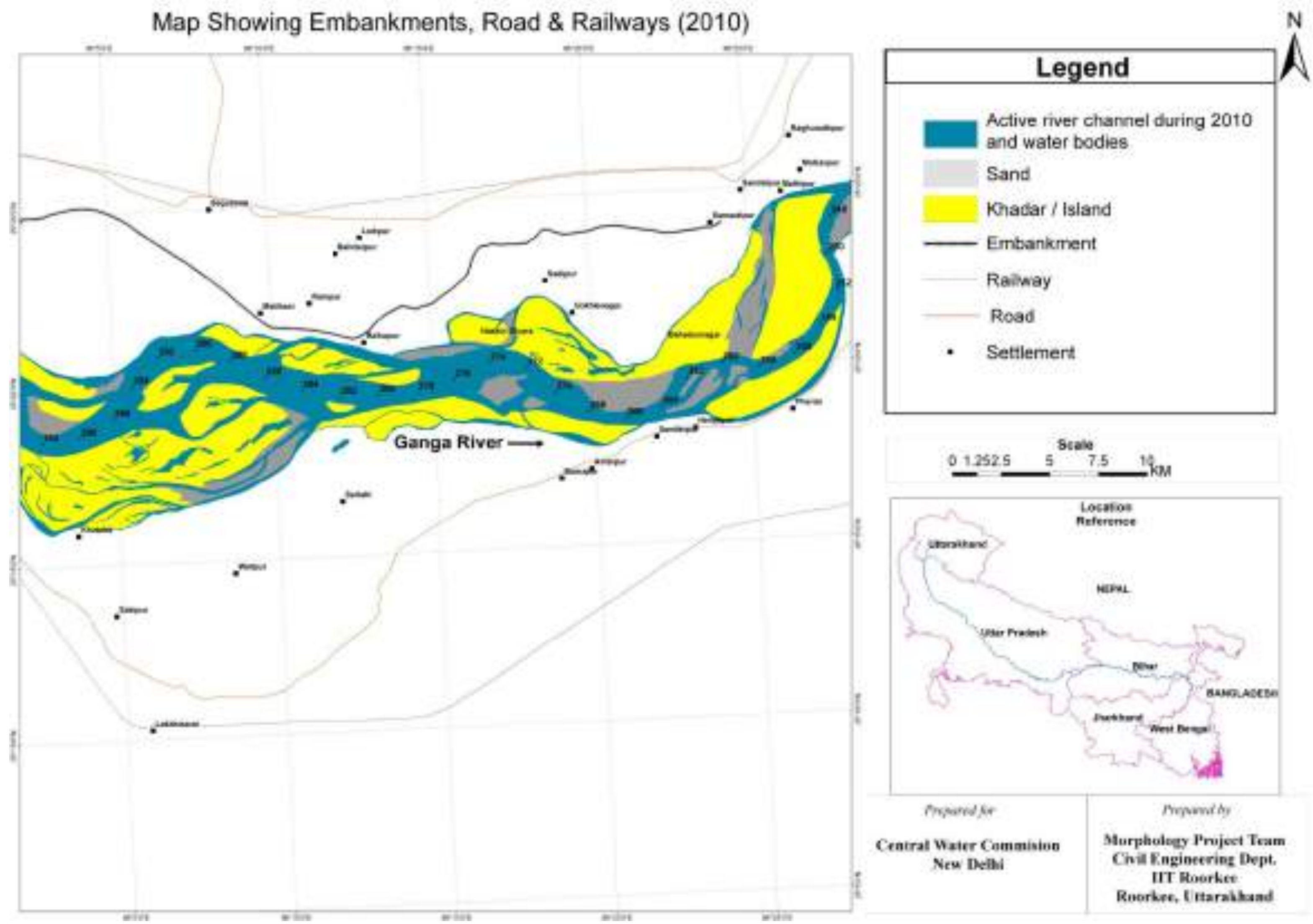


Figure 15.16f Existing embankments on Ganga river from chainage 250-300 km

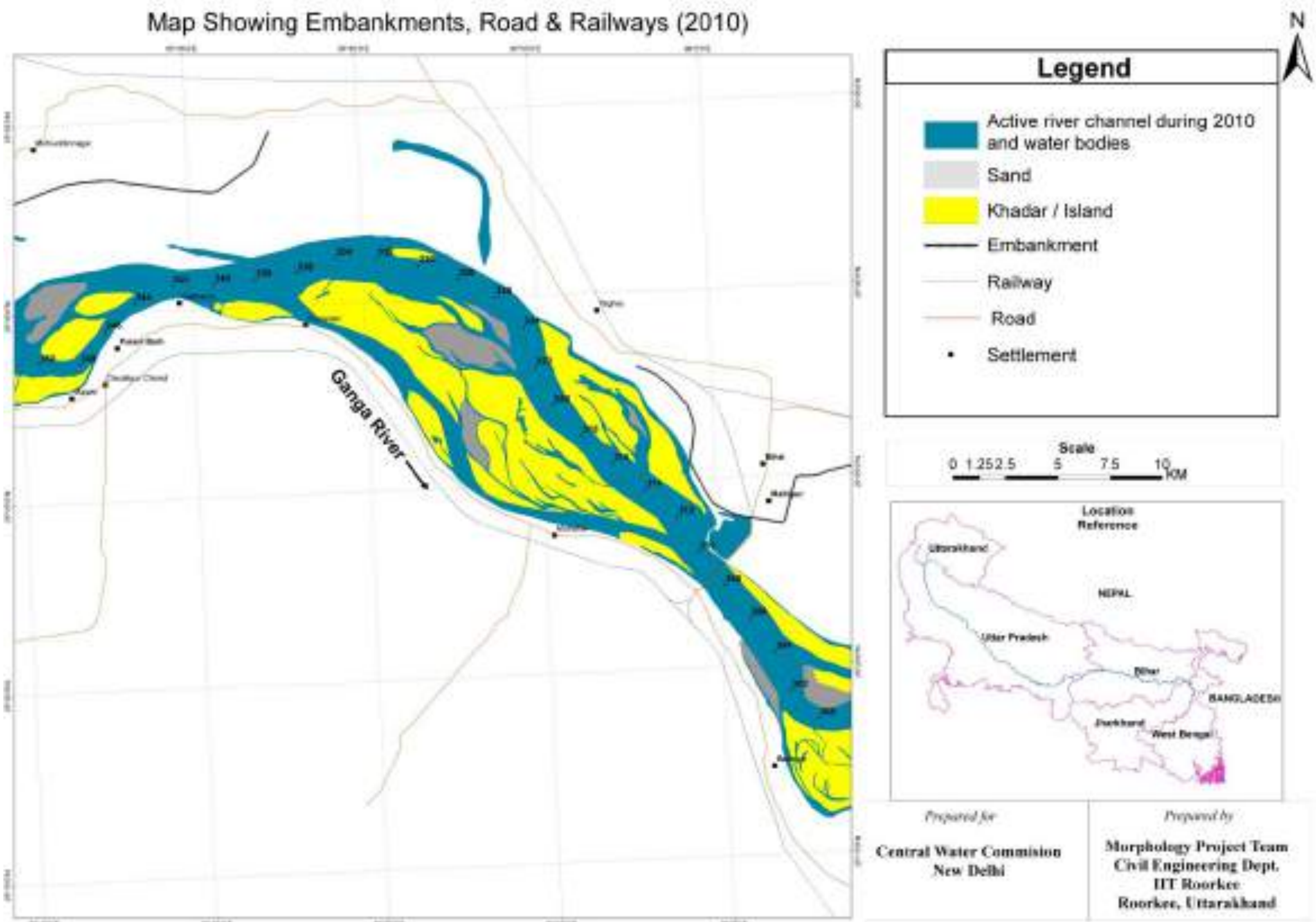


Figure 15.16g Existing embankments on Ganga river from chainage 300-350 km

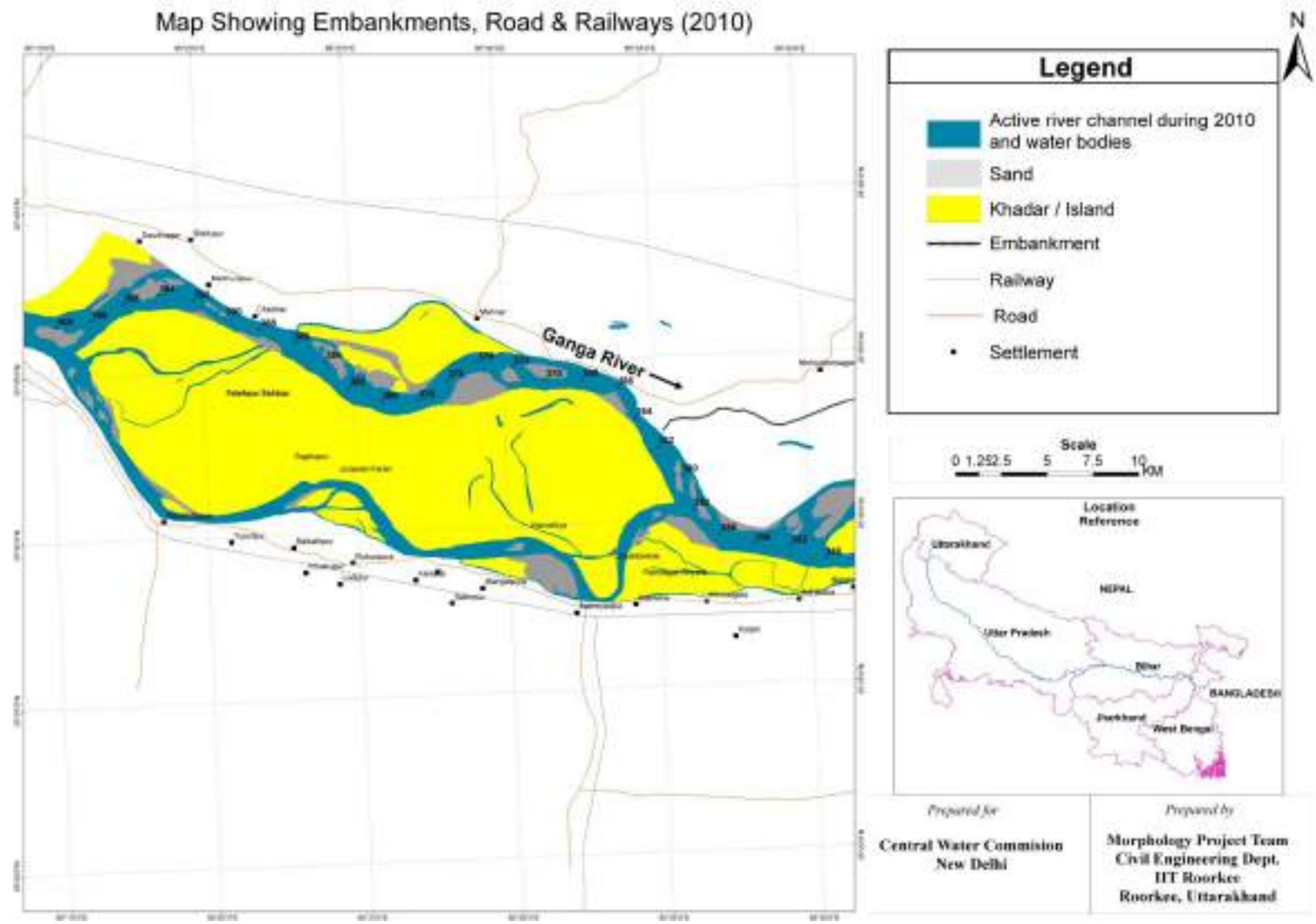


Figure 15.16h Existing embankments on Ganga river from chainage 350-400 km

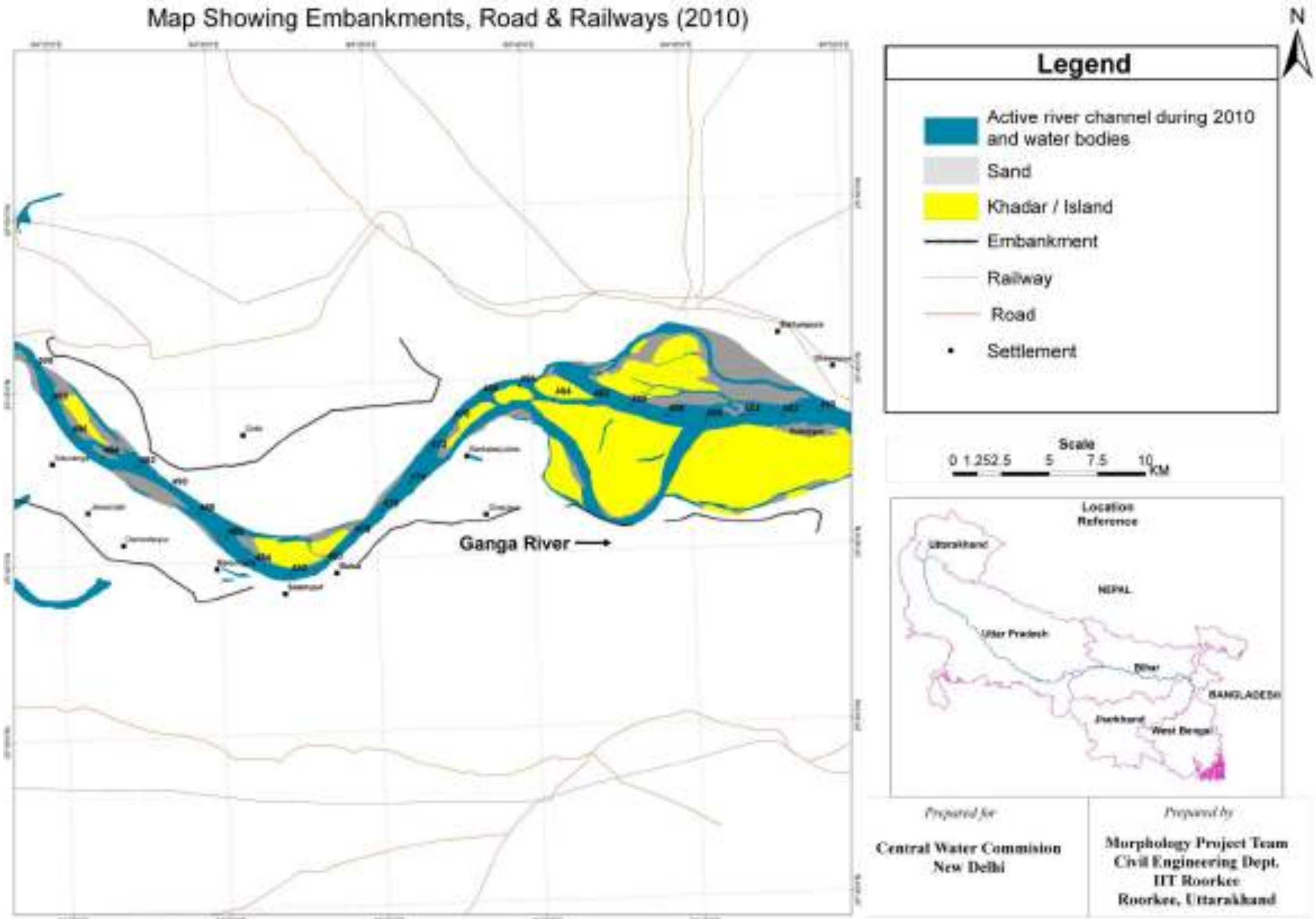


Figure 15.16i Existing embankments on Ganga river from chainage 450-500 km

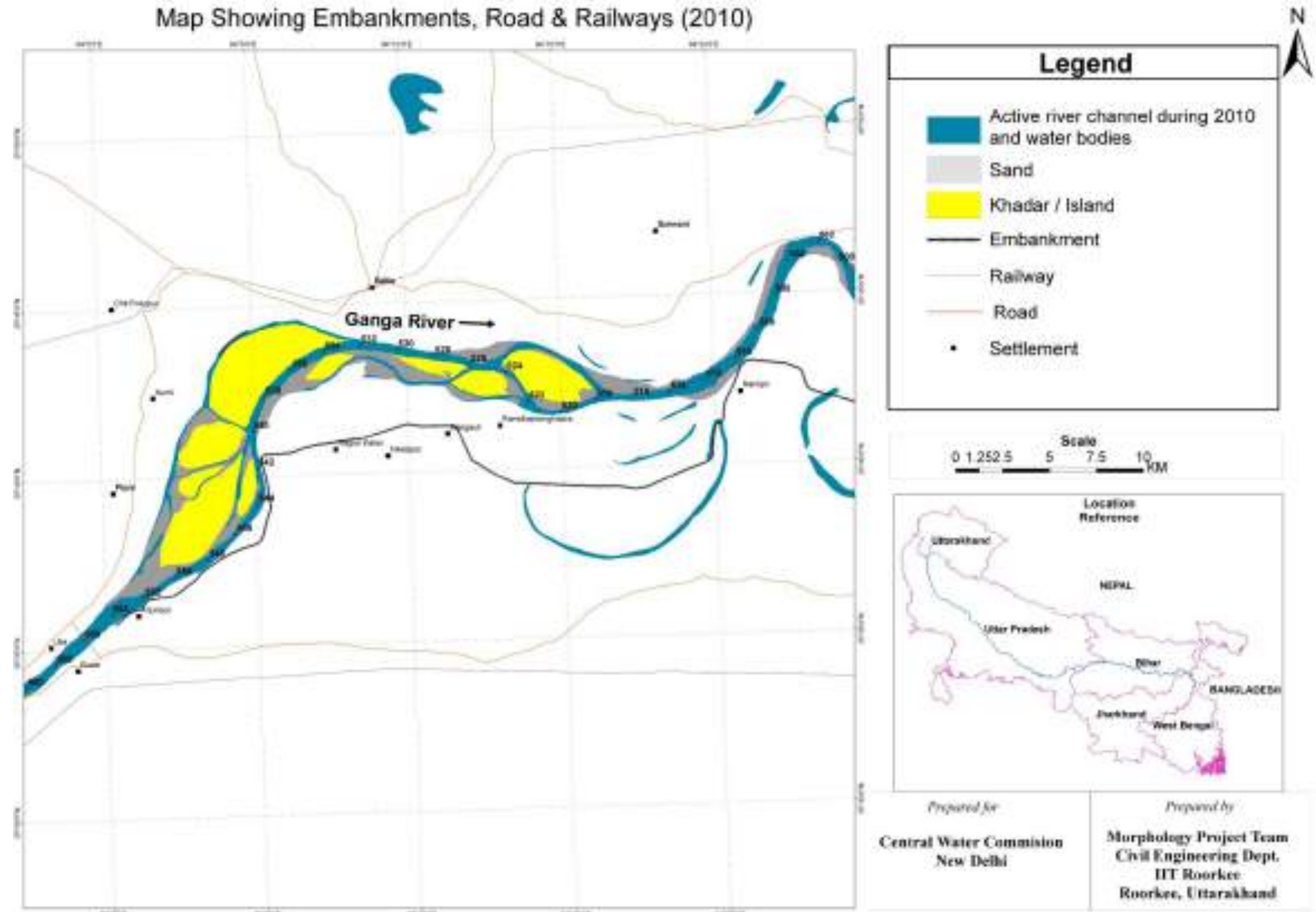


Figure 15.16j Existing embankments on Ganga river from chainage 500-560 km

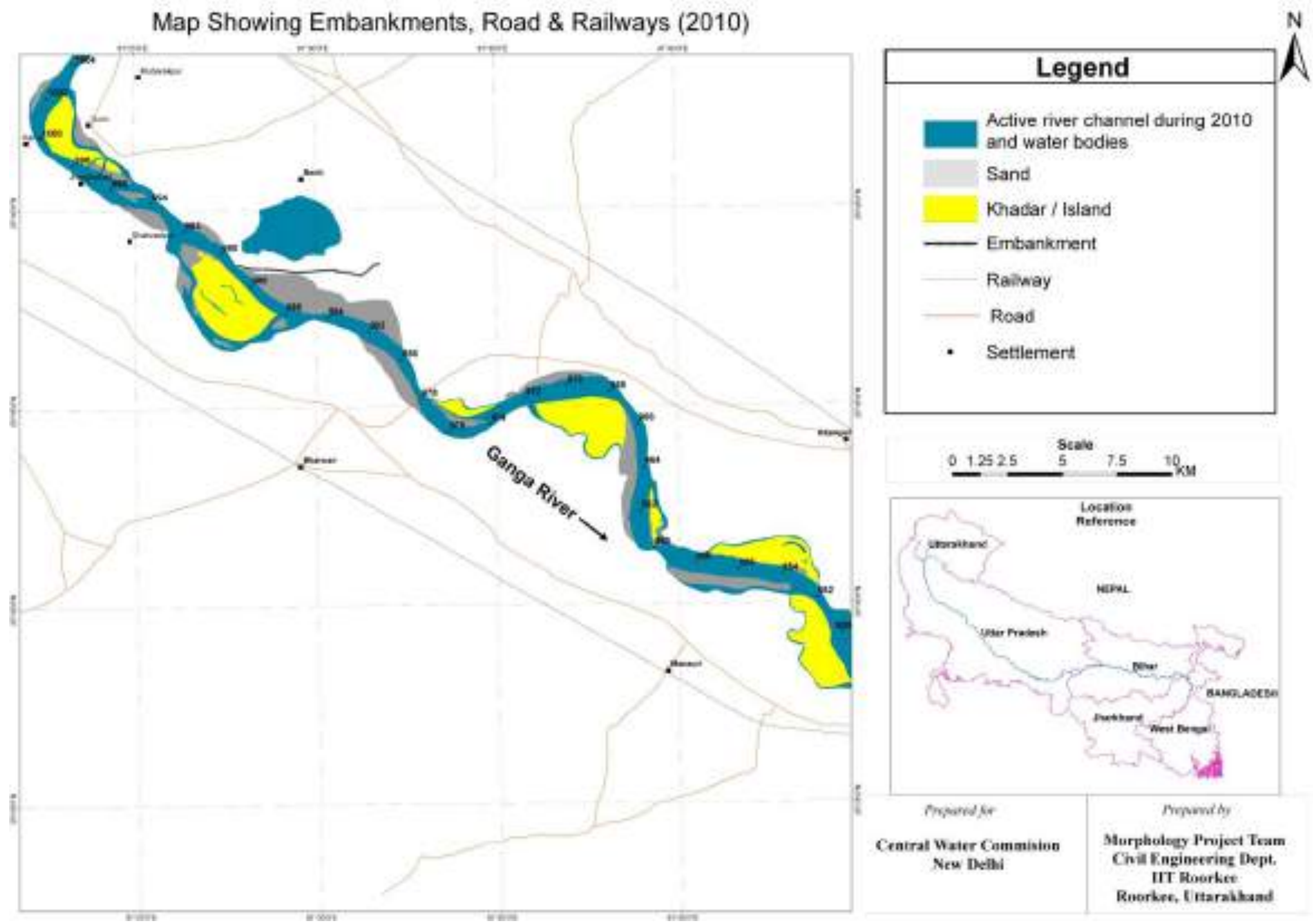


Figure 15.16k Existing embankments on Ganga river from chainage 950-1000 km

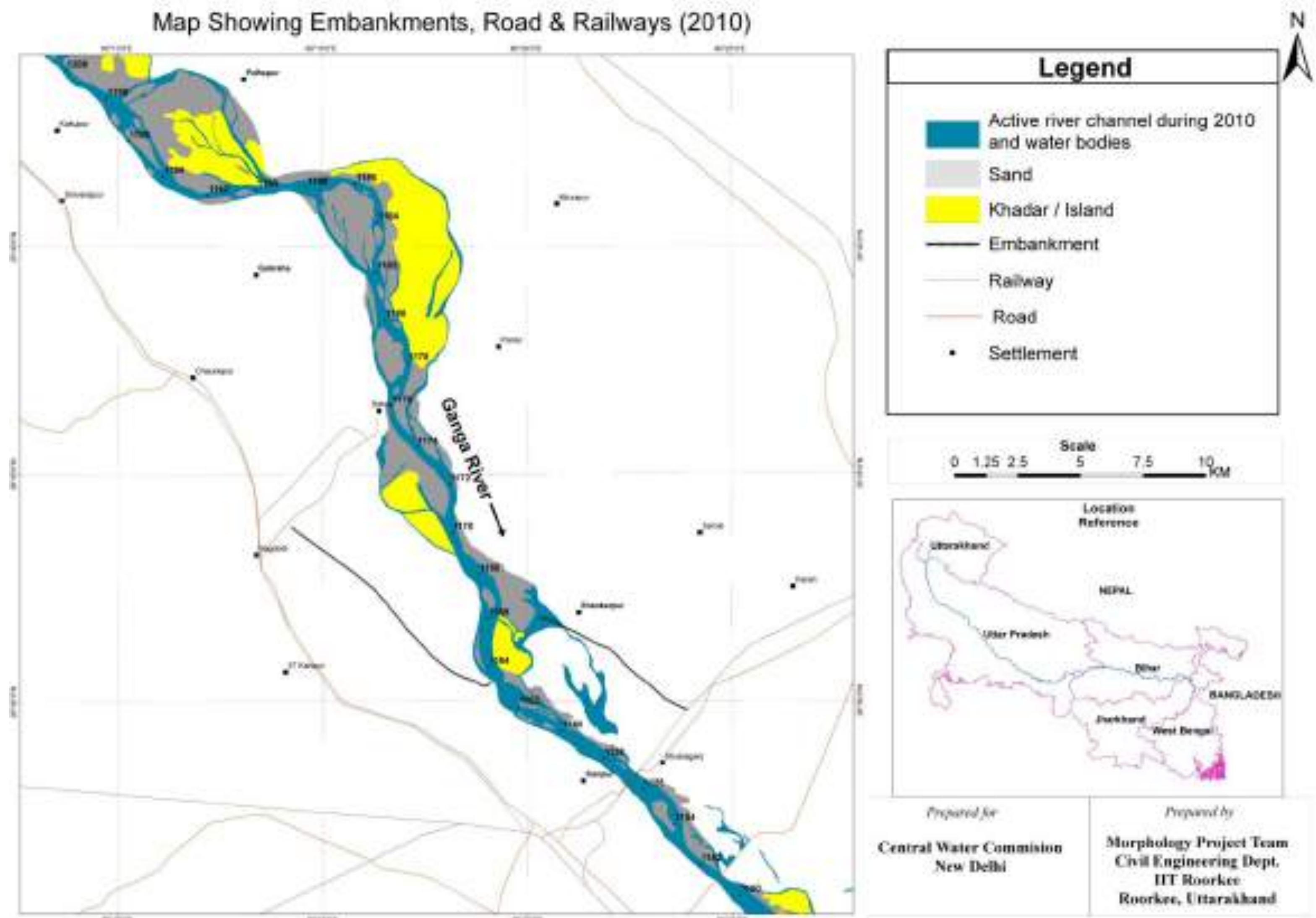


Figure 15.16l Existing embankments on Ganga river from chainage 1150-1200 km

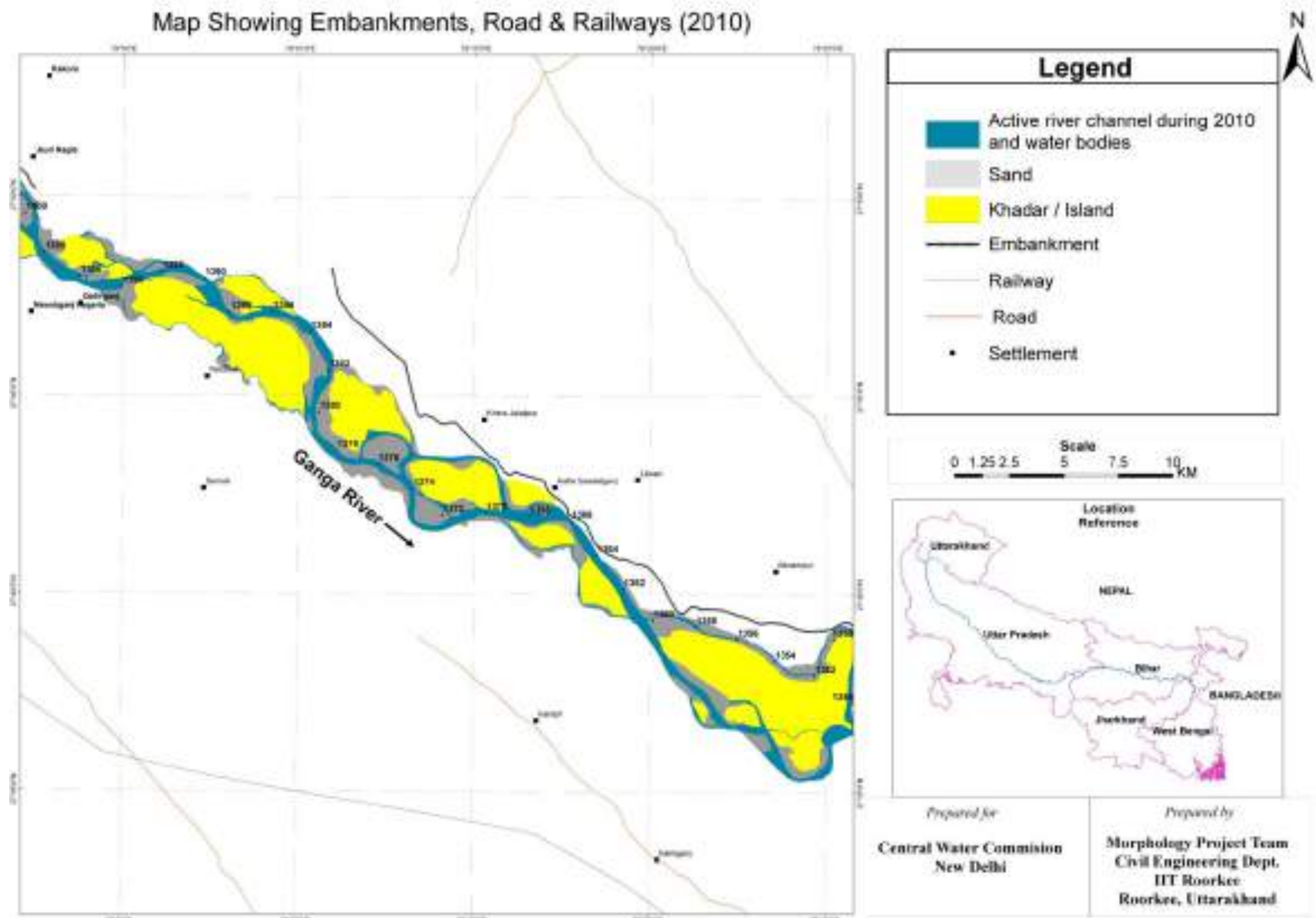


Figure 15.16m Existing embankments on Ganga river from chainage 1350-1400 km

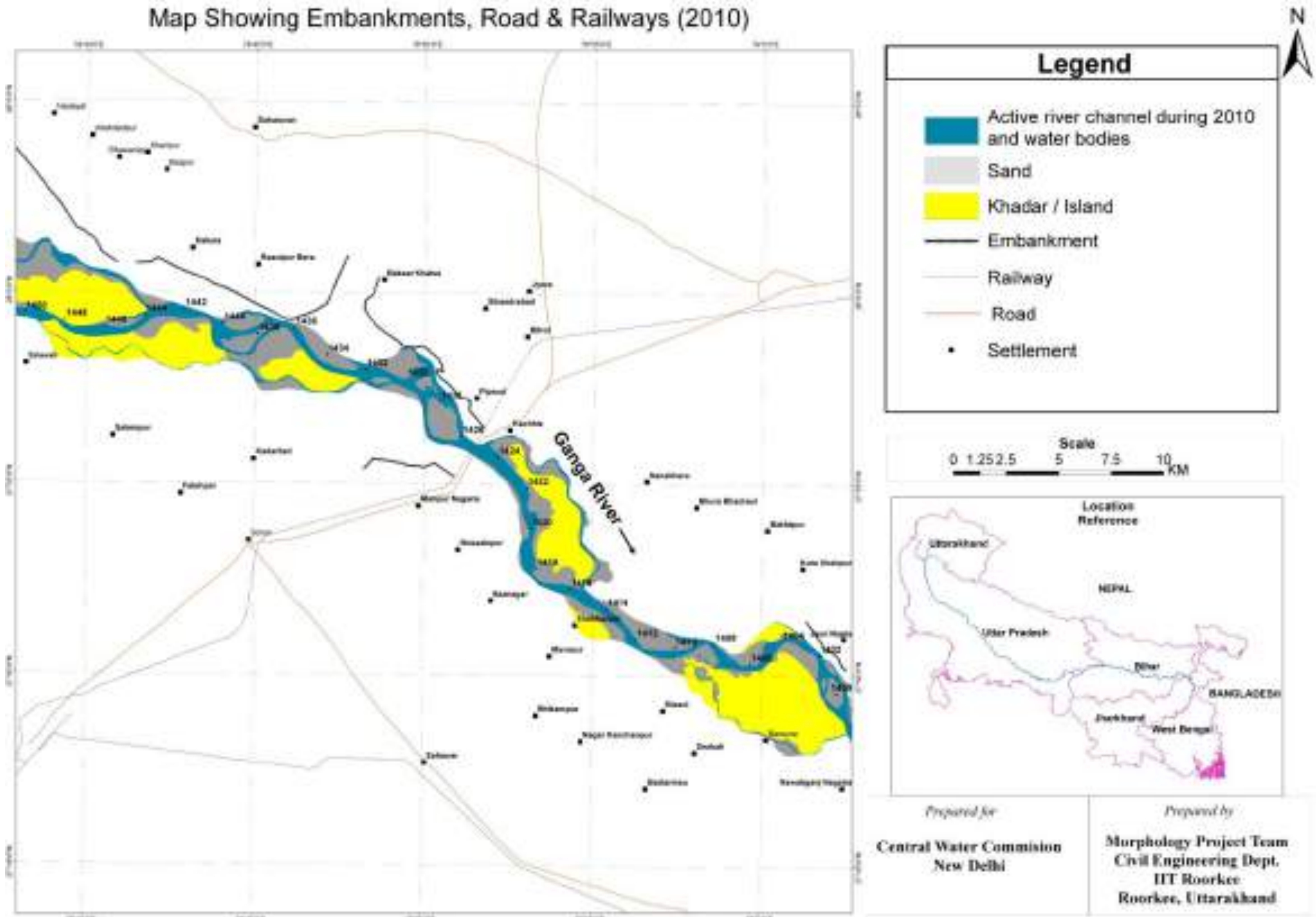


Figure 15.16n Existing embankments on Ganga river from chainage 1400-1450 km

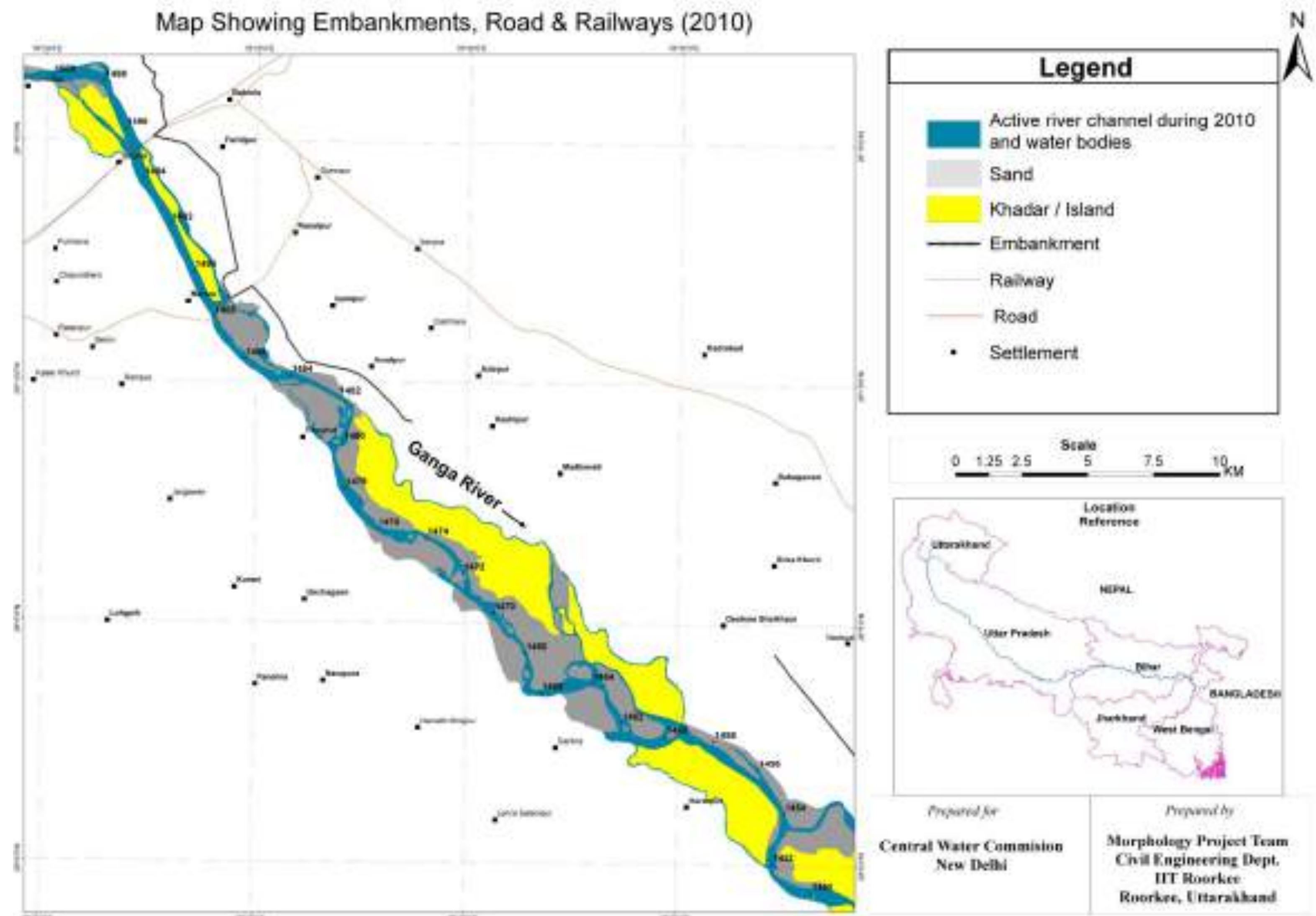


Figure 15.16o Existing embankments on Ganga river from chainage 1450-1500 km

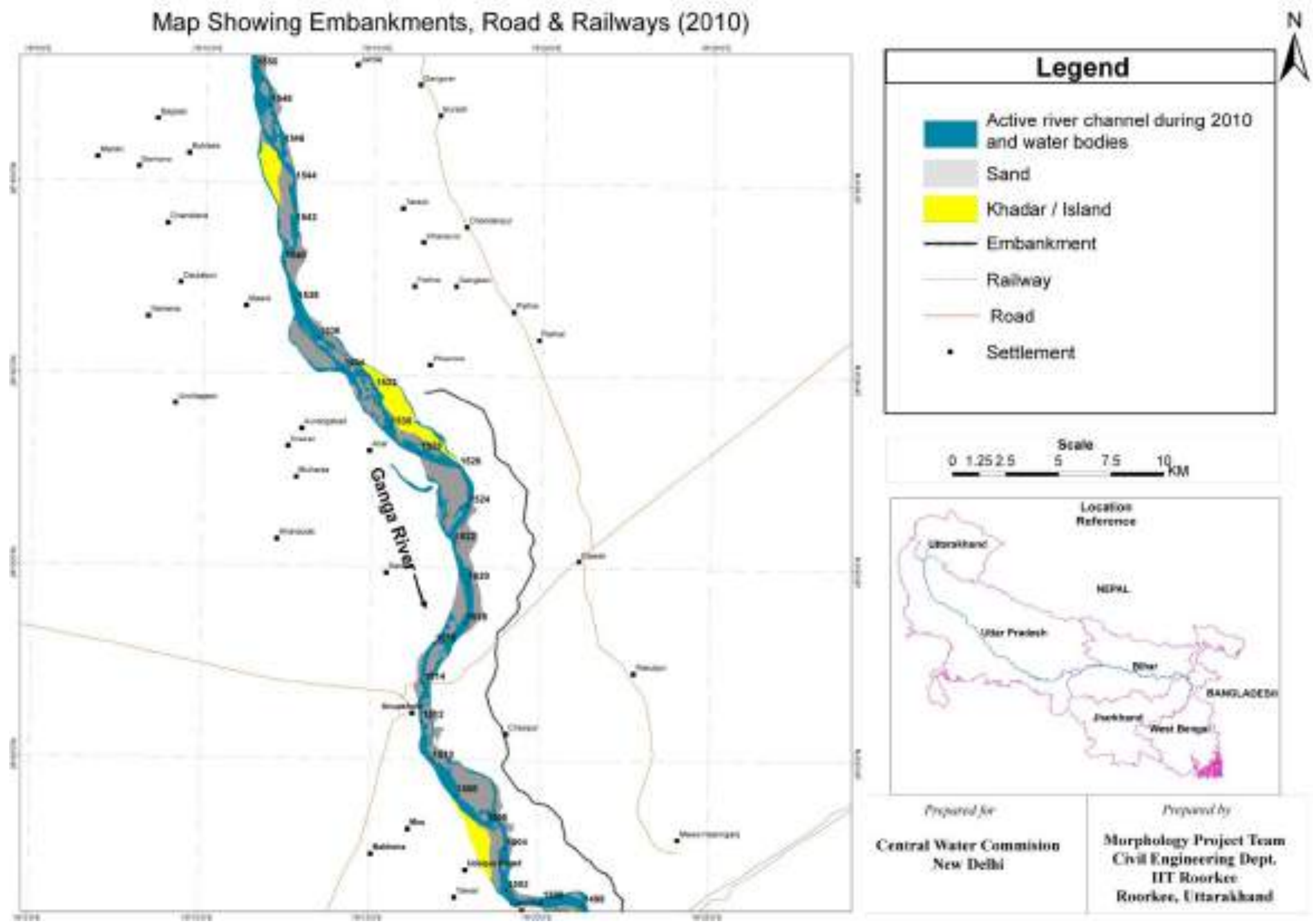


Figure 15.16p Existing embankments on Ganga river from chainage 1500-1550 km

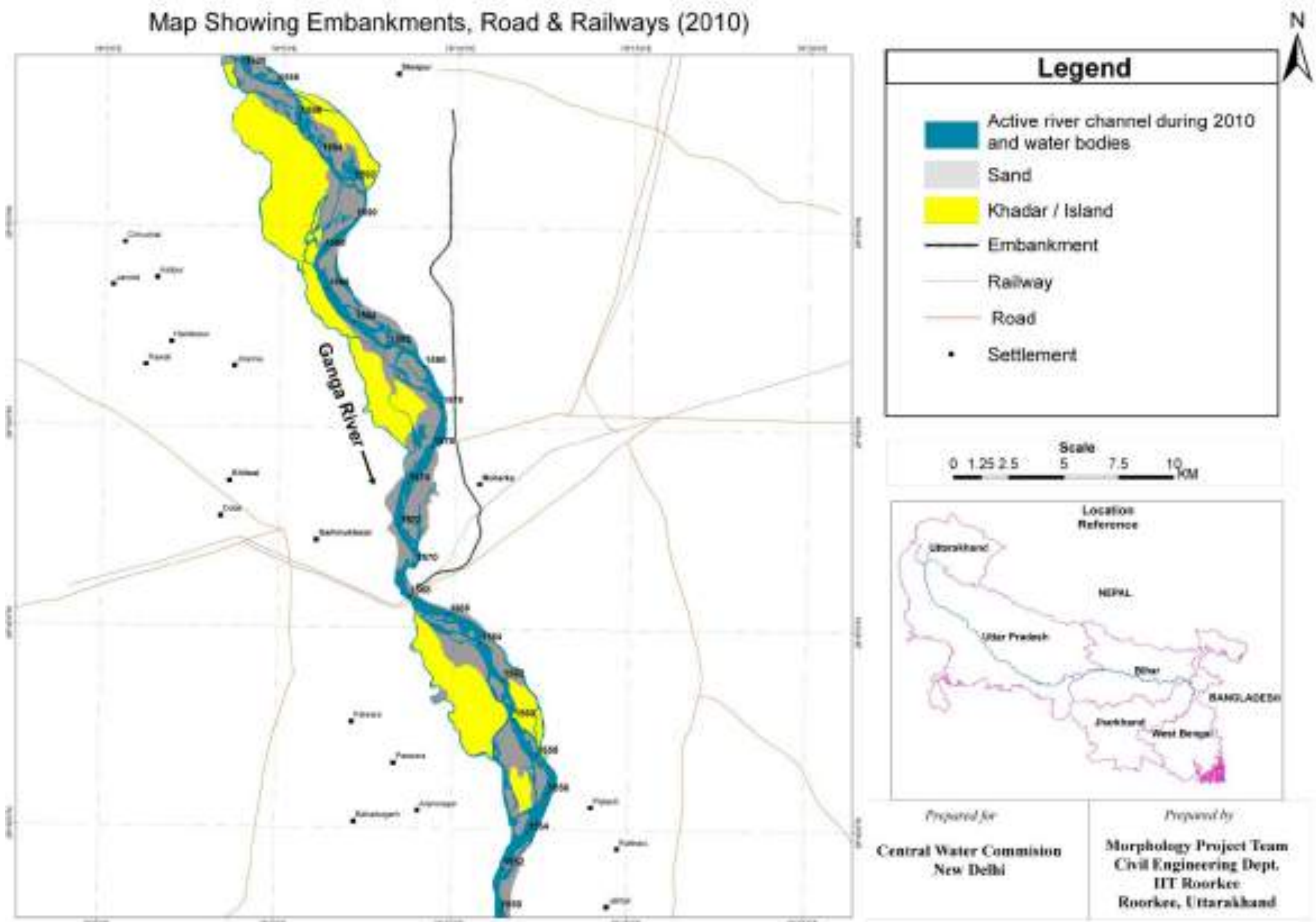


Figure 15.16q Existing embankments on Ganga river from chainage 1550-1600 km

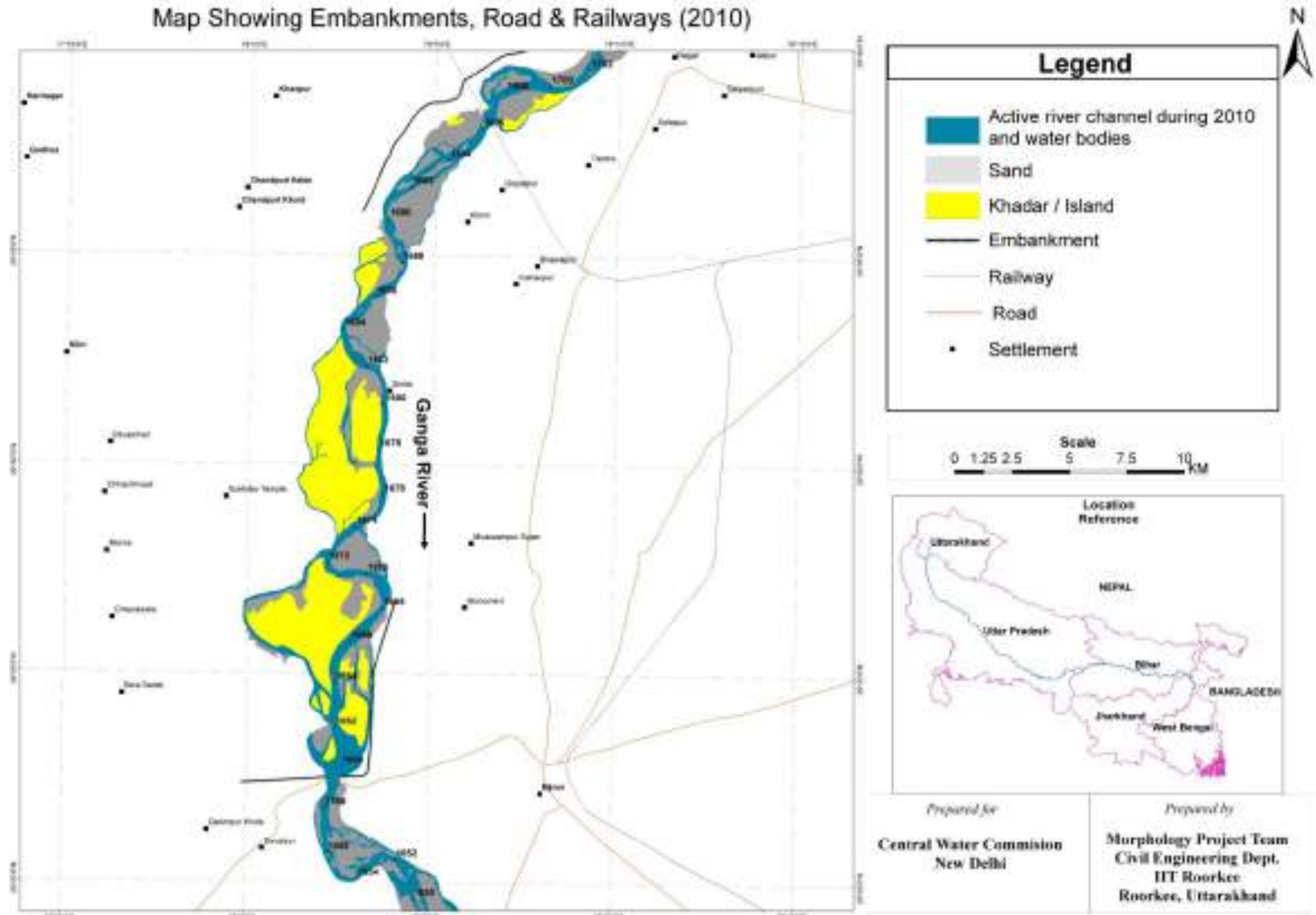


Figure 15.16r Existing embankments on Ganga river from chainage 1650-1700 km

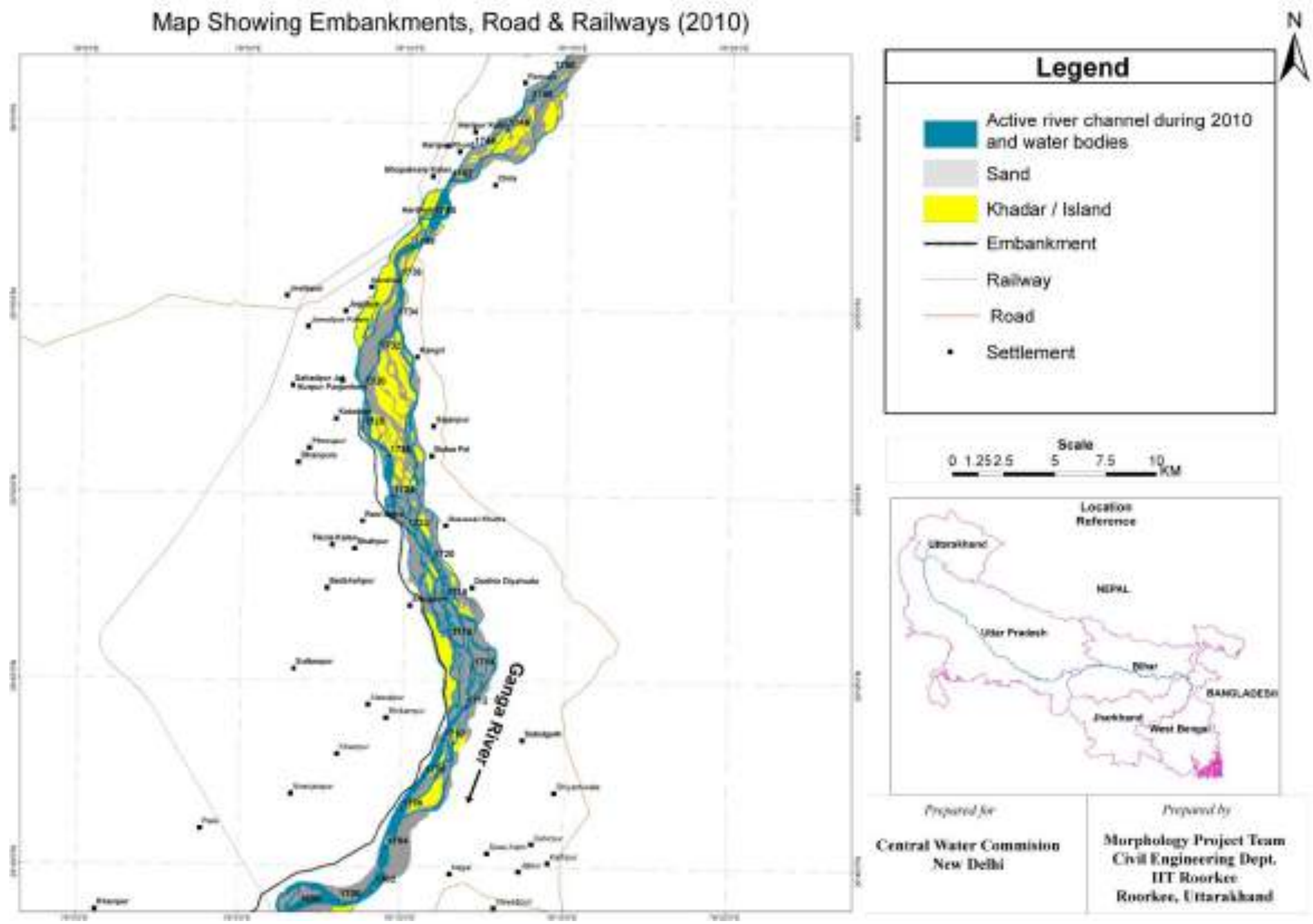


Figure 15.16s Existing embankments on Ganga river from chainage 1700-1750 km

15.4 DESIGN EXAMPLES

Three sample design of river training works have been carried out in this section on the basis of some assumed data. It is recommended that other suggested measures shall be designed after acquiring detailed data and invoking the methodology described in the Annexures-A and B.

15.4.1 Design of a Truncated Right Guide Bund for Ara-Chhapra Road Bridge, Doriganj, Chhapra (CH. 450 KM)

Guide bund has been designed as per methodology given by Springs (Garde and Ranga Raju, 2000) and in IRC:89-1997 and IS:10751:1994 using the following data.

Design discharge	= 60,000 m^3/s
Silt factor	= 1
Length of the bridge	= 4000 m
HFL	= 54 m
NSL	= 52 m

The following sections give the details of this design.

a) Plan Form of the Guide Bund

According to Springs (Garde and Ranga Raju, 2000), the straight length of the guide bund L_1 from the bridge axis on the upstream side is 1.1 L, while on the downstream side this length L_2 is 0.25L, where L is the total length of the bridge between the abutments. For L= 4000 m the values of L_1 and L_2 are

$L_1 = 1.1\times 4000 = 4400$ m

$L_2 = 0.25\times 4000 = 1000$ m

However, a nominal 250 m length on upstream and 75 m on downstream is proposed. The radius of the upstream mole head R_1 is given by

$$R_1 = 2.2\sqrt{Q} \quad \text{in SI units} \qquad (1)$$

in which Q is the design flood discharge.

$$R_1 = 2.2\sqrt{60000} = 538.89 \text{ m}$$

The radius of the downstream mole head R_2 is given by

$R_2 = 1.1\sqrt{Q}$ in SI units (2)

$R_2 = 1.1\sqrt{60000}$ = 269.44 m

However, as per IRC:89-1997, R_1=0.4 to 0.5 L and R_2=0.3 to 0.5 R_1, further R_1 should not be less than 150 m. For L=40000 m, R_1=0.4×4000 = 1600 m and R_2= 0.4×R_1= 0.4×1600 = 640 m. Let us adopt R_1=550 m and R_2=270 m.

The upstream mole head is extended to subtend an angle of 120^0 to 145^0 at its centre, while the downstream mole head subtends an angle of 45^0 to 60^0. The values of these angles for the upstream and downstream mole heads adopted in the present design are 120^0 and 45^0, respectively.

b) Cross- section of the Guide Bund

It is proposed to keep the top width of guide bunds as 7.0 m in its straight portion while 9.0 m in the mole head portion. Further, the top level of the guide bund is proposed at 55.80 m to provide an adequate freeboard of 1.8 m over HFL of 54.0 m. Side slopes of 1V: 2H are suggested for the sloping banks of the guide bund as shown in Fig. 15.17.

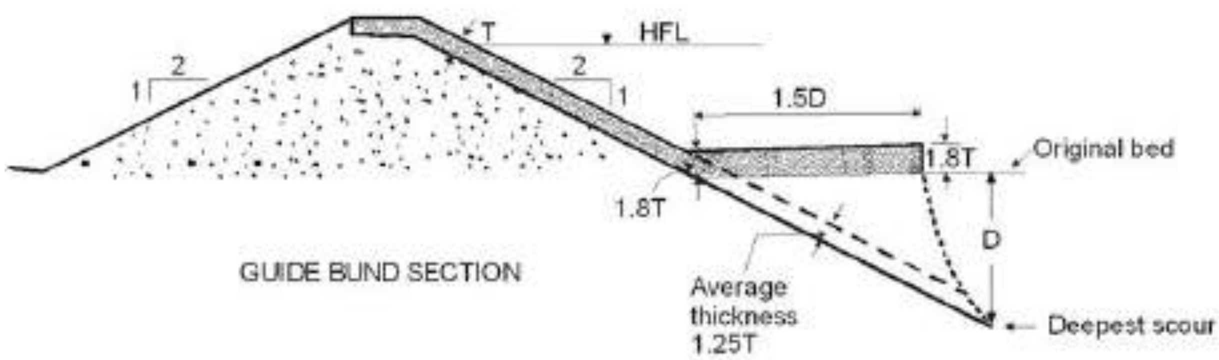


Figure 15.17 A typical sketch of guide bund & launching apron

c) Bank Revetment on Guide Bund

The thickness T required for the bank revetment is related to high flood discharge by the following empirical equation of Inglis (Garde and Ranga Raju, 2000):

T = 0.04 to 0.06 $Q^{1/3}$ in SI units (3)

The value of T for the design discharge Q equal to 60000 m^3/s is

T = 0.04 $(60000)^{1/3}$ = 1.57 m

For stones of relative density 2.65, the minimum size of stone is given by (Garde and Ranga Raju, 2000):

$$d_{min} = 0.023 \text{ to } 0.046\ U^2_{max} \quad (4)$$

in which d_{min} is expressed in m, and U_{max} is the maximum velocity of flow (in m/s) in the vicinity of the guide bund.

As per IRC:78-2000, to provide for an adequate margin of safety, the design discharge for scour depth estimation is increased over the given flood discharge depending on the catchment area. Since the catchment area of the river at the location of the proposed bridge is more than 40000 km², the increase in discharge is 10%.

The average velocity U during flood is

$$U = \left(\frac{Qf^2}{140}\right)^{1/6} \quad (5)$$

Here Q is 1.1 times the given flood discharge i.e. Q = 1.1 × 60000 = 66000 cumecs.

For the given data Q = 66000 cumecs and f =1.0, the Eq. (5) gives U = 2.78 m/s. Taking U_{max} as 1.25 times the average velocity U, U_{max} is 3.75 m/s. Taking the value of the coefficient as 0.0345 in Eq. (4), the value of d_{min} is calculated as

$$d_{min} = 0.0345\ (3.75)^2$$

$$\text{or } d_{min} = 0.48\text{m}$$

A geosynthetic filter or a conventional sand gravel filter of 0.30 m thickness may be placed on the sloping bank of the guide bund facing river flow to prevent washing out of fine material from the sub-grade or backfill and the revetment may be provided over this filter. For the revetment, three layers of boulders of size 0.40 m to 0.50 m are suggested. These boulders are to be placed in a closely packed formation between 0.30 m thick masonry walls along the slope at spacing of 6.0 m. Details of bank revetment are shown in Fig. 15.17.

Alternatively

Reno mattress may also be provided on the sloping surface in the place of boulder revetment. Required thickness of the mattress as per FHWA, Hydraulic Eng. Circular No. 11 and given in Table 15.5 is 12 inch (30 cm) for bank slope 1:2 and velocity of 3 m/s for base material silt and sand.

As per Maynord (1995) (see Table 15.6), the gabion thickness for 1:2 bank slope, toe depth (scour depth) of 3.05 m and velocity 3 m/s and for straight bank may be taken 30 cm.

As in this case, the velocity is of the order of 3 m/s and scour depth is much higher than 3.05 m, a 30 cm thick mattress on the sloping surface is suggested as per the recommendation of FHWA circular and Maynord (1995). The maximum size of stone should not exceed the thickness of individual mattress units. The stone should be well graded within the sizes available, and 70 percent of the stones, by weight, should be slightly larger than the wire-mesh opening.

A geosynthetic filter shall be placed below the mattress on the sloping bank of the embankmant facing to river flow to prevent washing out of fine material from the sub-grade or backfill.

Table 15.5 Criteria for gabion thickness (FHWA)

Bank Soil Type	Maximum Velocity (ft./sec.)	Bank Slope	Min. Required Mattress Thickness (inches)
Clays, heavy cohesive soils	10	< 1:3	9
	13 - 16	< 1:2	12
	any	> 1:2	≥ 18
Silts, fine sands	10	< 1:2	12
Shingle with gravel	16	< 1:3	9
	20	< 1:2	12
	any	> 1:2	≥ 18

c) Launching Apron

Figure 15.17 shows the general arrangement of a launching apron that is generally provided at the mole head and the straight portion of the guide bund to prevent undermining of the bank revetment and consequent failure of the guide bund. It is assumed that the launching apron placed on the river bed would launch into the scour hole to take a slope of 1V: 2H with an average thickness of 1.25T. To ensure this volume of boulder material, the average thickness of the launching apron on the river bed comes to 1.86T = 1.86 × 1.57 = 2.91 m say 3.0 m. This launching apron is placed on the river bed over a length equal to 1.5 times D, where D is the scour depth measured below the river bed.

The design of the launching apron, therefore, requires the estimation of the maximum scour below the river bed level that is likely to occur at the mole head and straight reach of the guide bund.

Table 15.6 Gabion bank protection thickness and rock size versus limiting average channel velocity, 1V:2H side slope and angular stone (after Maynord, 1995)

Gabion thickness		Limiting Average Channel Velocity					
		Toe depth = 1.52 m	Toe depth = 5 ft	Toe depth = 3.05 m	Toe depth = 10 ft	Toe depth = 6.10 m	Toe depth = 20 ft
cm	in.	(m/s)	(ft/sec)	(m/s)	(ft/sec)	(m/s)	(ft/sec)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(*a*) Natural channel bend, $R/W = 3$							
15.2	6	2.1	6.8	2.2	7.3	2.4	7.8
22.9	9	2.4	8.0	2.6	8.6	2.8	9.2
30.5	12	2.7	9.0	2.9	9.6	3.1	10.3
45.7	18	3.2	10.5	3.4	11.3	3.7	12.1
(*b*) Straight channel, $V_{ss} = V_{avg}$[b]							
15.2	6	3.3	10.9	3.5	11.6	3.8	12.5
22.9	9	3.9	12.8	4.2	13.7	4.5	14.7
30.5	12	4.4	14.4	4.7	15.3	5.0	16.4
45.7	18	5.1	16.8	5.5	18.0	5.9	19.3

Note: D_m = 1/2 of gabion thickness.

[a]Depth at V_{ss} = 80% of toe depth.

[b]In straight channels having gabions on both the bottom and side slope, the designer should also check the stability of the bottom gabions where depth-averaged velocities equal 10–20% greater than V_{avg}.

Here R = centreline bend radius of main channel flow and W = water surface width of main channel flow. D_m = size of stone.

d) Estimation of maximum scour depth D below river bed level

According to IS Code: 10751:1994, the maximum scour depth D_{se} measured from the high flood level at different portions of the guide bund is KR, where K is 2.0 to 2.50 for upstream mole head, 1.50 for straight or shank portion and 1.5 to 1.75 for downstream mole head, in which R is Lacey's normal scour depth also measured from high flood level. The value of R is given by

$$R = 0.48(Q/f)^{1/3} \quad \text{in SI units} \qquad (6)$$

In Eq. (6) f is Lacey's silt factor having a value of 1.0 in the present case.

For Q = 66000 m^3/s i.e. discharge adopted for the scour computations as per IRC: 78-2000 and f = 1.0, Eq. (6) gives

$$R = 0.48(66000 / 1.0)^{1/3}$$

$$= 19.12 \text{ m}$$

Adopting K = 2.25 for the upstream mole head, 1.5 for the straight portion and 1.75 for the downstream mole head, the maximum scour depths D_{se} measured from HFL at different locations are:

For upstream mole head, D_{se} $= 2.25 \times 19.12 = 43.02$ m

For straight portion, D_{se} $= 1.5 \times 19.12 = 28.68$ m

For downstream mole head, D_{se} $= 1.75 \times 19.12 = 33.46$ m

High flood level (HFL) in the river being 54.0 m, the levels of deepest scour holes at different locations of the guide bund are given in Table 15.7.

Table 15.7 Levels of Deepest Scour at Different Locations of the Guide Bund

Location	Level of deepest scour (m)
Upstream mole Head	10.98
Straight Portion	25.32
Downstream mole Head	20.54

It is suggested that the information given in Table 15.7 be used to estimate the scoured bed levels at these locations of the guide bund. The launching apron may be placed over a length equal to 1.5 times the scour depth D at each of these places. With average bed level of the river 52.0 m, the values of D at different places of the guide bund are

Upstream mole head D = 41.02 m; length of apron = 61.53 m; provide 61.5 m

Straight portion D = 26.68 m; length of apron = 40.02 m; provide 40.0 m

Downstream mole head D = 31.46 m; length of apron = 47.19 m; provide 47.0 m

It is proposed that 6-7 layers of boulders of 0.4 m to 0.50 m sizes be placed in the launching apron to provide the required thickness of 3.0 m. Wire crates of suitable sizes be used to place different layers of boulders. This is to ensure that boulders are not moved during flood.

Alternatively

Reno/gabion mattress may be provided in the launching apron in place of loose boulders. As per FHWA, Hydraulic Eng. Circular No. 11, the thickness of the mattress used as launching apron should always exceed 12 inch (30 cm). The typical range is 12 to 20 inch.

Maynord (1995) proposed the following equation for the minimum size of the stone to be placed in the horizontal apron of mattress

$$\frac{D_m}{d} = C_s \left[\sqrt{\frac{\gamma_w}{\gamma s - \gamma_w}} \frac{V}{\sqrt{gd}} \right]^{2.5} \qquad (7)$$

Where C_s = stability coefficient =0.1

D_m = average filling rock diameter in mattress

d = flow depth

V = depth average velocity

γ_m = unit weight of water

γ_s = unit weight of stone

g = acceleration due to gravity

For V =2.78 m/s

d =R = 19.12 m

$$\frac{V}{\sqrt{gd}} = \frac{2.78}{\sqrt{9.81 \times 19.12}} = 0.20$$

From Eq. (7), D_m =0.0204 m = 2.04 cm

Thickness of the Mattress = $2D_m$ = 4 cm, it is too low to be adopted.

As per recommendation of Escarammia (1995), a 30 cm thick mattress can sustain 4 to 5 m/s velocity of the flow. To the knowledge of the writers, only in the FHWA, Hydraulic Eng. Circular No. 11, the thickness of the mattress used as launching apron is being addressed. Thus in the present case, higher thickness i.e. 20 inch (50 cm) is recommended in view of Ganga river being a large river.

Thus, it is recommended that 30 cm thick mattress shall be provided on the sloping surface of the embankment towards the Ganga river side. The slope protection shall be followed by a launching apron in form of Reno/gabion mattress of thickness 0.50 m.

Figures 15.18-15.20 show location, plan layout and sections of the guide bund.

Figure 15.18 Location of the Ara-Chhapra bridge

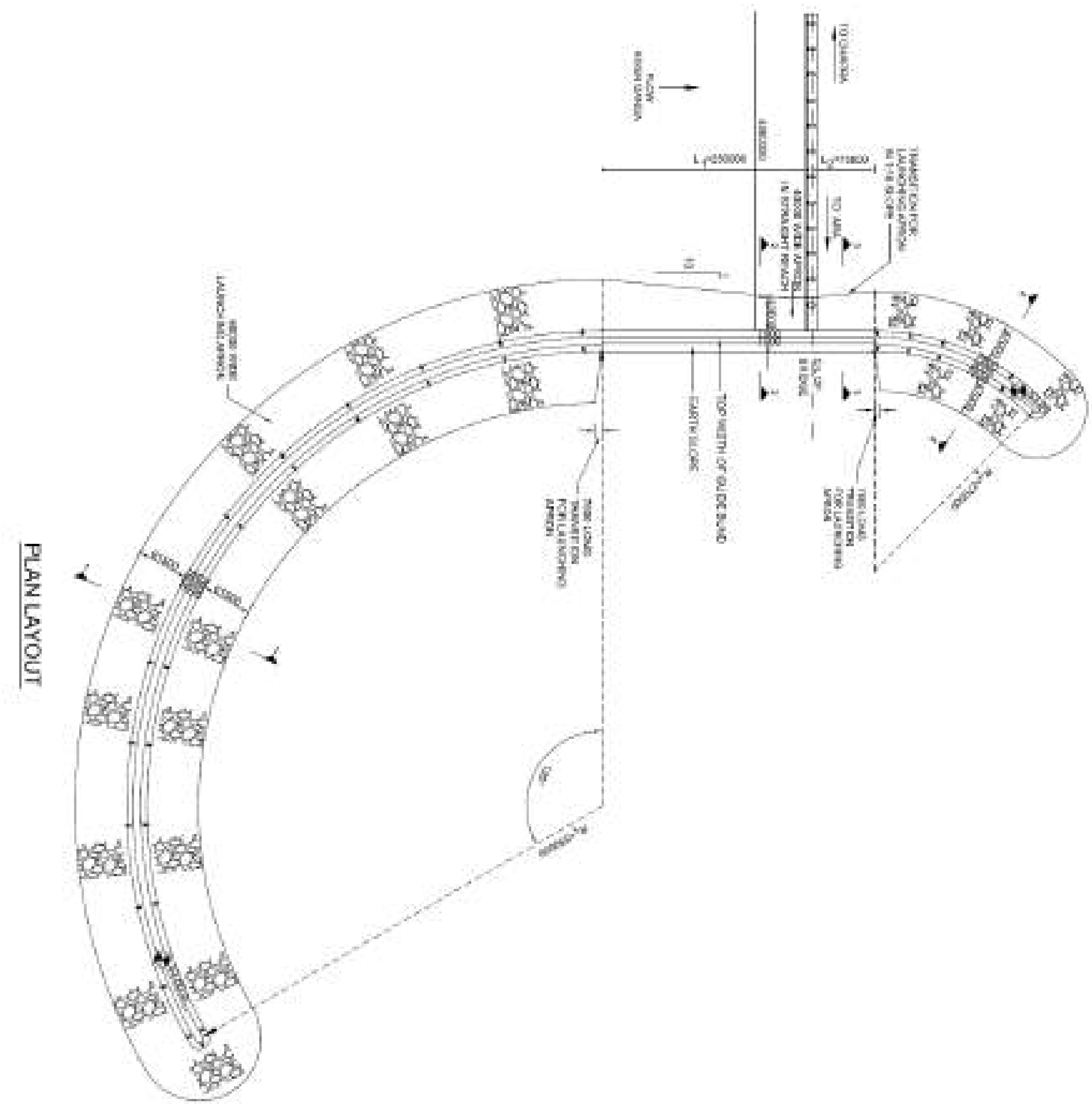


Figure 15.19 Plan layout of the Guide bund

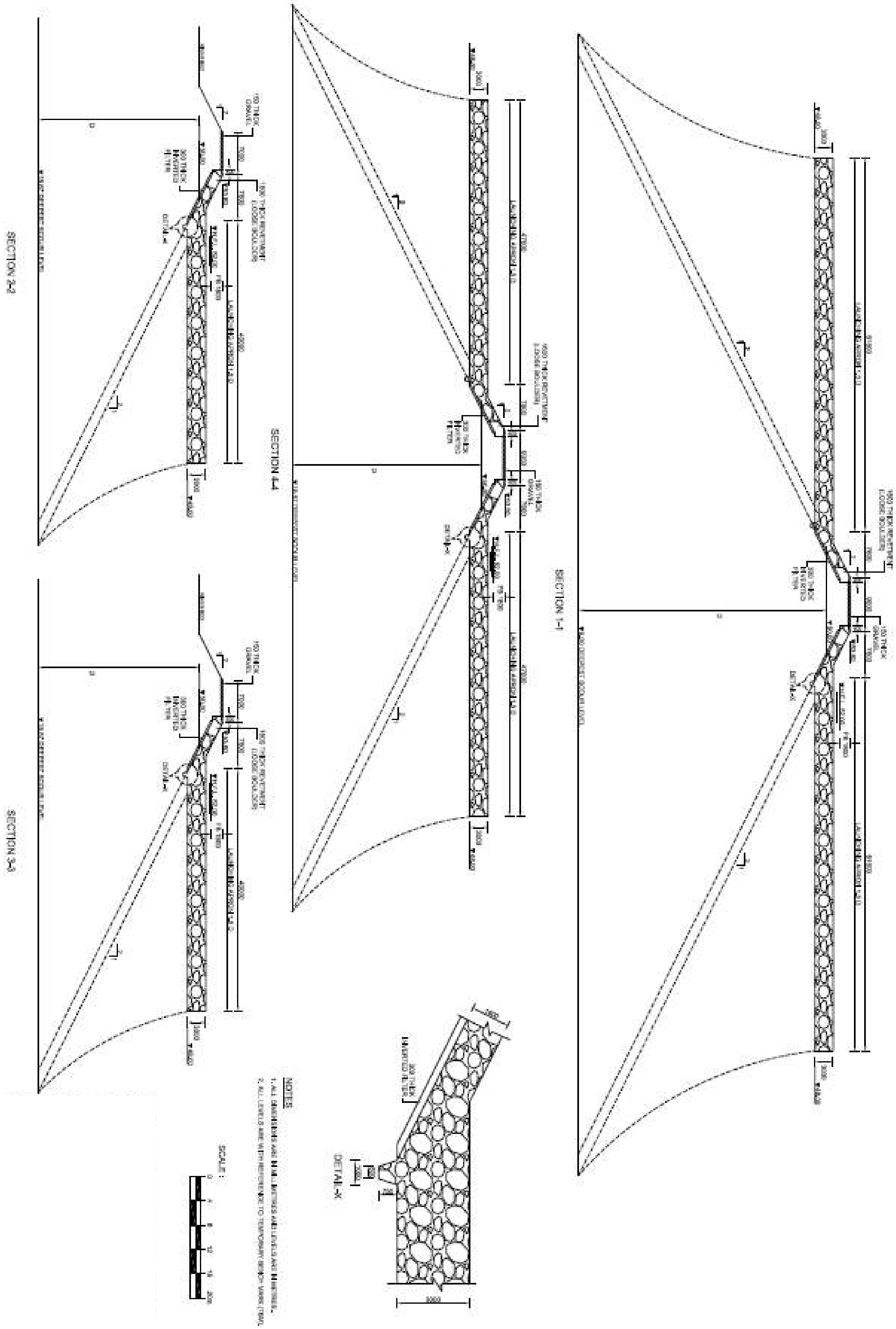


Figure 15.20 Sections of the Guide bund

15.4.2 Design of a Spur at Chainage 1446 km near Saharpur Makanpur Kham (U/S Of Kachla Bridge)

This site is about 21 km upstream of the Kachla bridge. Discharge for 50-year return period at Kachla bridge is 11685 m^3/s while ever maximum recorded water level = 162.765 m. As the site is close to the Kachla bridge, let take design discharge = 11685 m^3/s. Assuming water surface slope =0.1 m/km, the estimated HFL at the site = 162.765+0.1×21 = 164.865 m. Assume silt factor = 1 for the design of spur. Also let assume NSL=163 m.

Bank Revetment

The thickness T required for the bank revetment is given by

$$T = 0.04\, Q^{1/3} \quad \text{in SI units}$$

The value of T for the design discharge Q equal to 11685 m^3/s is

$$T = 0.04\, (11685)^{1/3} = 0.91 \text{ m}$$

Minimum size of stone

$$d_{min} = 0.023 \text{ to } 0.046\ U_{max}^2$$

in which d_{min} is expressed in m, and U_{max} is the maximum velocity of flow (in m/s) in the vicinity of the guide bund.

The average velocity U during flood is

$$U = \left(\frac{Qf^2}{140}\right)^{1/6}$$

For Q = 11685 m^3/s and f=1, U = 2.09 m/s

Taking U_{max} as 1.25 times the average velocity U, U_{max} is 2.61 m/s. Taking the value of the coefficient as 0.0345 in Eq. (2), the value of d_{min} is calculated as

$$d_{min} = 0.0345\ (2.61)^2 = 0.23 \text{ m}$$

A geosynthetic filter or a conventional sand gravel filter of 0.30 m thickness may be placed on the sloping bank of the guide bund facing river flow to prevent washing out of fine material from the sub-grade or backfill and the revetment may be provided over this filter. For the revetment, three layers of boulders of size 0.30 m to 0.40 m are suggested, the bottom layer of hand-placed boulders with joints staggered followed by second and third layers of dry random rubble masonry. All the joints of this boulder revetment are to be filled with bajri.

As per the IRC-89: 1997, thickness of revetment for various sloping face of the spur as shown in Fig. 15.21 shall be as follow:

a) At nose of the embankment, thickness = T = 0.91 m, adopt 0.90 m thickness - three layers of boulders of size 30-40 cm.

b) Straight and curve path of the embankment on the upstream sides, thickness = T = 0.91 m, adopt 0.90 m thickness- three layers of boulders of size 30-40 cm.

c) Upto 60 m length of spur from the nose on the downstream side, thickness =2/3T = 0.61 m, adopt 0.60 m thickness – two layers of boulders of size 30-40 cm.

d) Beyond 60 m length of spur from the nose on the downstream side, thickness =0.30 m – one layers of boulders of size 30-40 cm.

Launching Apron

Launching aprons shall be provided at the curve, straight and nose of the spur on the upstream side and upto 60 m length from nose on downstream side to prevent undermining of the bank revetment and consequent failure of the spur. It is assumed that the launching apron placed on the river bed would launch into the scour hole to take a slope of 1V:1.5H with an average thickness of 1.25T. To ensure this volume of boulder material, the average thickness of the launching apron on the river bed $=1.5T$. This launching apron is placed on the river bed over a length equal to 1.5 times D, where D is the scour depth measured below the river bed.

According to IRC-89:1997, the maximum scour depth D_s measured from the high flood level at different locations of the spurs are as follow:

(i) At nose Ds=2R to 2.5R adopt Ds=2R

(ii) Transition from nose to shank and shank in upstream Ds=1.5R

(iii) Transition from nose to shank and 30 m straight length of shank in downstream Ds=R

Scour depth

$$R = 0.48(Q/f)^{1/3} = 0.48\times(11685/1)^{1/3} = 10.86 \text{ m}$$

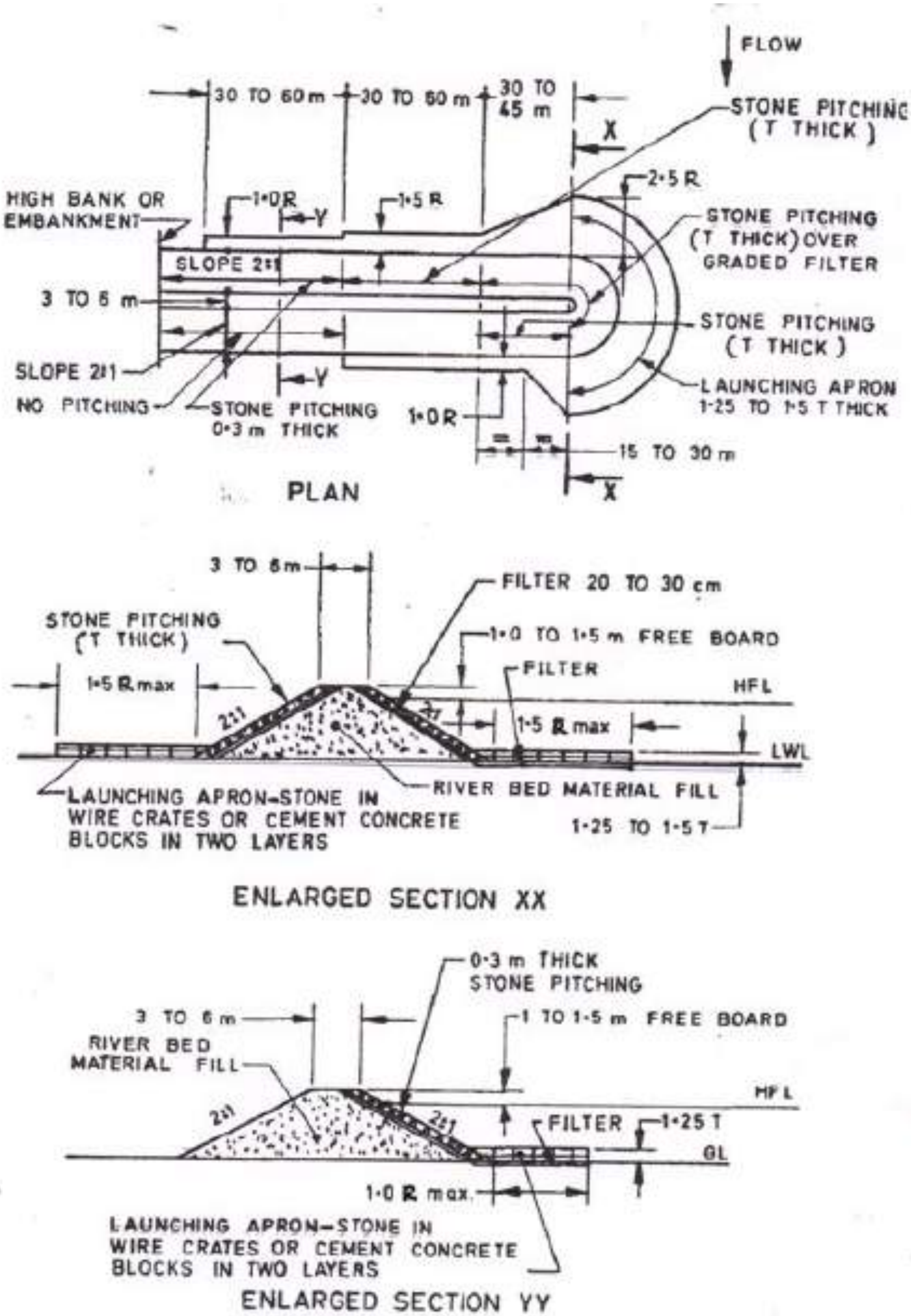


Figure 15.21 Layout of a typical spur

(a) At Nose

$Ds = 2R = 21.72$ m

Level of deepest scour = upstream HFL-Ds

Level of deepest scour = HFL-Ds = 164.865 -21.72 = 143.145 m

Depth of scour below river bed level D = 163.0-143.145 = 19.86 m

Length of launching apron =1.5D = 1.5×19.86 = 29.78 m, adopt 28 m

Thickness of the launching apron = 0.90 m in wire crates

(b) Transition from nose to shank and shank in upstream

$Ds = 1.5R = 15.18$ m

Level of deepest scour = HFL-Ds = 164.865-15.18 m = 149.685 m

Depth of scour below river bed level D = 163.0-149.685= 13.315 m

Length of launching apron =1.5D = 1.5×13.315 = 19.97 m, adopt 18 m

Thickness of the launching apron = 0.90 m in wire crates

(c) Transition from nose to shank and 30 m straight length of shank in downstream

$Ds = R = 10.86$ m

Level of deepest scour = HFL-Ds = 164.865-10.86 m = 154.01 m

Depth of scour below river bed level D = 154.01-151.08= 2.925 m

Length of launching apron =1.5D = 1.5×2.925 = 4.39 m, adopt 4 m

Thickness of the launching apron = 0.90 m upto 30 m straight shank and beyond that 0.30 m

It is proposed that four layers of boulders of 0.30 m to 0.40 m sizes be placed in the launching apron to provide the required thickness of 0.90 m. Wire crates of suitable sizes be used to place different layers of boulders. This is to ensure that boulders are not moved during flood.

Length of the spur should be of 50 m and they are to be placed at spacing of 200 m.

15.4.3 Design of Embankment near Bhagalpur

It is proposed to keep the top width of the embankment of 3 m and side slope 1V: 2H. The top level of the embankment shall be 1.5 m higher than the highest flood level. Further, it is proposed to provide Biomac blankets which are also known as Rolled Erosion Control Protection (RECPs) mats and are used for surface erosion protection (Fig. 15.22). Placed onto top soiled and seeded slopes, Biomac supports the establishment of vegetation. As the mat biodegrades over time, the protection function is maintained by the vegetation. The Biomac are made with a mixture of fully biodegradable fibres properly integrated during manufacturing. The fibre mat is reinforced with a fine polypropylene scrim netting securely stitched on both sides during manufacturing.

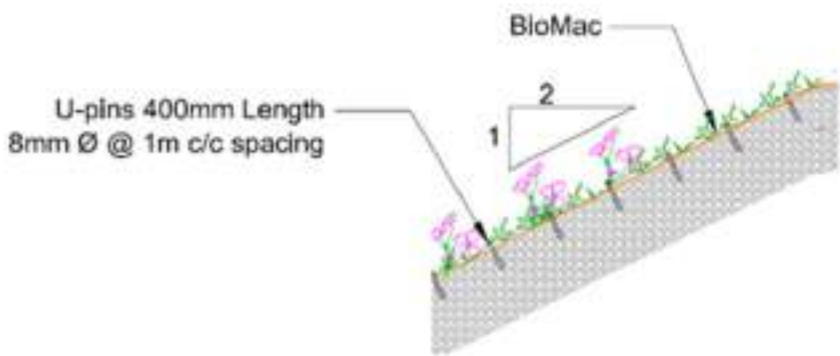


Figure 15.22 Details of BioMac

The site is about 50 km upstream of the Azamabad hydrological station. Peak discharge for 25 years return period at Azamabad is estimated as 85030 m^3/s and ever maximum recorded water level at this station is 32.915 m. Let adopt these data for the design of the embankment.

As such, no revetment on the sloping surface of the levees and launching apron are required, however, it is suggested that river behaviour shall be watched and if river has tendency to come close to levees, slope protection and launching apron be provided as per detail below:

Slop protection

It is proposed geo-bags for the control of erosion of the slope. Annexure-B may be seen for the details of flexible system including geo-bags.

Size of Bags: Weight of bags shall be calculated by

$$W = \frac{0.02323\, S_s}{K\,(S_s - 1)^3} V^6 \qquad (7)$$

$$K = \left[1 - \frac{\sin^2\theta}{\sin^2\phi}\right]^{\frac{1}{2}} \qquad (8)$$

where, W - weight in kg

V – velocity in m/s

Ss - Specific Gravity of protection material (adopted between 1.5 to 1.8)

θ - Angle of sloping bank

φ - Angle of repose of protection material

The average velocity U during flood is given by Lacey equation

$$U = \left(\frac{Qf^2}{140}\right)^{1/6}$$

For Q = 85030 m^3/s and f = 1, the above equation yields V = 2.91 m/s

let assume $\varphi = 30^0$

$\theta = \tan^{-1}(1/2) = 26.565^0$

K = 0.45

Let take $S_s = 1.7$

W = 91.39 kg, let provide bags of size 1.1m x 0.7m x 0.15m (weight around 126 kg) as per Nomograph given in IS-14262.

Thickness of Pitching: Thickness should be more than that calculated as under:

$$T = \frac{V^2}{2\,g\,(S_s - 1)} \qquad (9)$$

T - thickness in m

V – velocity in m/s

Ss - Specific Gravity of protection material (adopted between 1.5 to 1.8)

g - Acceleration due to gravity (9.81 m/s^2)

For the data in the present case, Eq. (9) yields T =0.62 m

Pitching may be provided in four layers of geo-bags (in loose).

Launching Apron

Let assumed that the launching apron placed on the river bed would launch into the scour hole to take a slope of 1V: 2H (Fig. 15.16). This launching apron is placed on the river bed over a length equal to 1.5 times D, where D is the scour depth measured below the river bed.

According to IS Code: 10751:1994, the maximum scour depth D_{se} measured from the high flood level at the toe of straight part of the embankment 1.5R, in which R is Lacey's normal scour depth also measured from high flood level. The value of R is given by

$$R = 0.48(Q/f)^{1/3} \quad \text{in SI units}$$

where f is Lacey's silt factor, let assume f = 1.

For Q = 85030 m^3/s i.e. discharge adopted for the scour computations as per IRC: 78-2000 and f = 1.0, Eq. (5) gives

$$R = 0.48(85030\ /1.0)^{1/3}$$

$$= 21.10 \text{ m}$$

Maximum scour depths D_{se} at the toe of the embankment measured from HFL at different locations = 1.5R = 31.65 m

Ever maximum recorded water level at Azamabad = 32.916 m

The site is about 50 km upstream of the Azamabad. Let us take water level slope = 0.10 m/km. Thus HFL at site = 32.916+0.1×25 =35.416 m

Deepest scour level = 35.416-31.65 = 3.766 m

Bed level of the river = 32 m (assumed)

Scour below bed level D = 32-3.766 = 28.23 m

Length of the launching apron = 1.5D = 42.35 m , provide 40 m

Thickness of launching apron = 1.8T = 1.8×0.62 = 1.116 m, let provide 1.0 m thick geo-bags in 5-6 layers.

Disclaimer: ***The above are sample design and based on the gross assumed data. Thus this should not executed in the present form. It is suggested to collect detailed data and design shall be carried out as per the above procedure.***

15.5 CONCLUSIONS

Following conclusions have been drawn from the study carried out in this report:

a) In total, thirty five reaches/locations are identified as critical in Ganga river, however, in twenty seven critical reaches of the Ganga river either the river is protected using spurs, embankments etc. or being in agricultural area, protection works are not required. At the remaining eight critical reaches/locations near Haripur Kalan, Kangri, Sidholia Kham, Saharpur Makanpur Kham, Gunir, Bhagalpur, Rajmahal to Maharajpur and Manikchak, protection measures are suggested.

b) Summary of the protection measures in the critical reaches are given below

Sl. No.	Chainage	Location	Suggested River Training Works
1	1745-1749 km	5 km upstream of the Bhimgoda barrage near Haripur Kalan	Series of spurs are recommended for the protection of left bank in a length of 4.15 km to control the cutting of the forest area
2	1725-1731 km	8 km downstream of the Bhimgoda barrage near Kangri village	Series of spurs are provided, some more spurs are required in a length of 6 km towards left (see Fig. 15.9)
3	1436 km	Sidholia Kham	Spurs are suggested to be provided along with existing embankment in a length of 0.6 km at chainage 1436 km (see Fig. 15.10)
4	1446 km	Saharpur Makanpur Kham	Embankment along with spurs are suggested to be provided in a length of 1.0 km at chainage 1446 km (see Fig. 15.11)
5	1092-1108 km	Downstream of Baksar-Muradipur road near Gunir	Protection to right bank is required in a length of 14.5 km using boulder revetment and/or provision of series of spurs
6	180 km	Bhagalpur	Protection measures in the form of embankment with boulder revetment and launching apron be provided near Raghopur area over a length of about 4 km (see Fig. 15.13) to control lateral shifting towards left side
7	36-78 km	Rajamahal to Maharajpur	Embankment along with launching apron may be provided to control the erosion of left bank

			in this reach in about 33 km length (see Fig. 15.14) and lateral shifting towards left side
8	24-34 km	Near Manikchak	Embankment along with launching apron may be provided to control the erosion towards left side in this reach in about 10 km length (see Fig. 15.15) and lateral shifting towards left side

In addition to the above, the river training works shall also be provided near the following bridges:

1. Railway Bridge, Balawali, Laksar (Ch. 1696.5 km): a) Suggested to provide nose to each guide bund and b) boulder revetment be provided to the right embankment of the railway track over a length of 1.5 km.
2. Railway bridge, Rajghat, Narora (Ch. 1495.1 km): Suggested to provide nose to the left guide bund.
3. Railway & Road bridges, Kachhla (Ch. 1452.2 km). Both the guide bunds should be extended downstream.
4. Ara-Chhapra road Bridge, Doriganj, Chhapra (Ch. 450 km). a) A truncated guide bund be provided towards right side and b) right bank u/s of bridge is to be protected to control the shifting of the river.
5. Road Bridge - Gandhi Setu (NH 19) (Ch. 404.8 km). Suggested to repair washed out portion of launching apron towards Hajipur side.

Earthen embankments are mostly provided from Haridwar to Kanpur and from Buxar to Farrakka barrage. Major embankments are located towards right side downstream of the Haridwar; towards left side upstream of the Garhmukteswar, Narora barrage, and Farrukhabad; downstream of Buxar towards right side; towards left side downstream of the Mokama and confluence of Burhi Gandak; and downstream of the Krusela towards left side. In the lower Ganga basin, the embankments are mostly provided along left bank. Existing river training works are generally in the form of series of spurs and guide bunds and provided mostly to protect the bridges and barrages.

Chapter 16 CONCLUSIONS & RECOMMENDATIONS

16.1 CONCLUSIONS

Following conclusions have been drawn from the study carried out in this report:

a) General

1. Study reach of the Ganga river starts from Devprayag and ends at Farakka barrage. The total length of the reach is 1,824 km and elevation varies from 500 m to 35 m. Ganga river is in hilly area from Devprayag to Haridwar with an average bed slope of 3 m/km. However, the reach from Haridwar to Farakka is flat with an average slope of 0.14 m/km.
2. The tropical zones and subtropical temperature zones are most dominant in the entire Ganga basin. The tropical zone in the basin has a mean annual temperature over 24°C and mean temperature of the coldest month over 18°C and subtropical temperature zone has a mean annual temperature over 17°C - 24°C and mean temperature of January between 10°C - 18°C.
3. The major part of basin is covered with agriculture accounting to 65.57% followed by forest (16%), Wasteland (8.89%), Built Up Land (4.28%), Water bodies (3.47%), Snow/Glaciers (0.94%) and Grassland (0.85%).
4. The overgrazing and deforestation in most areas of the Ganga basin have led to soil erosion and ravine formation on the one hand and have accentuated flooding on the other. Most of forest tracts within the Ganga basin are severely degraded because of over exploitation. As a result, the forest ecosystem in the Ganga basin is under severe stress.
5. The changes in land-cover proportion over the period 2006-2014, crops increased from 1984 to 2006 but from 2006 to 2010, they decreased; however, the overall change from 1984 to 2010 was an increase of 1.3% . The trend observed in the forest proportion indicates an increase of 4.7% from 1984 to 2010. Shrub coverage showed an overall change of –11.6% from 1984 to 2010. Grass and barren lands did not show

any stable trend. Urban coverage was expanded from 1984 onwards, and the total increase during the 1984–2010 period was 5.8%.

6. The hydrologic cycle in the Ganga basin is governed by the southwest monsoon. About 84% of the total rainfall occurs in the monsoon from June to September. Consequently, stream flow in the Ganga is highly seasonal and the seasonality of flow is so acute that it even causes flood situation in the plains.
7. Annual and monsoon season precipitation, evapotranspiration, surface water availability (surface runoff) have declined in the period 1948-2012 compared to the period 1901-1947, while temperature has risen.
8. Changes in mean monsoon season water budget components during the 1948-2012 periods with respect to 1901-1947 period are as follows:
    i. Precipitation = -5.0%
    ii. Air Temperature = 0.1 ^{0}C
    iii. Evapo-transpiration = -2.1 %
    iv. Total runoff/surface water availability = -7.9 %

b) Hydrological Analysis

1. Exceedance probability curves at various stations on Ganga river have been prepared and flow for 1.5 and 2 years return period have been estimated. Flood discharge for 25, 50 and 100 years return period have been estimated using Gumbel's Extreme Value Distribution method, Log Pearson Type III Distribution method and Log Normal Distribution method. Abrupt and prominent increase in the discharge at Allahabad and Gandhighat (Patna) is due to confluence of the Yamuna & Tons rivers at Allahabad and confluence of Ghagra, Sone and Gandak river upstream of the Patna, respectively.
2.
3.
4. Upstream of the Allahabad, the minimum flow in the Ganga river is very low. This could be due to diversion of major lean flow of Ganga river to various canal system through barrages.

c) Morphological Changes

1. Sinuosity ratio of the Ganga river has been calculated from its chainage from 0 to 1824 km in an interval of 50 km for the years 1970, 1980, 1990, 2000 and 2010. In the whole reach of the river and for the years 1970, 1980, 1990, 2000 and 2010, the maximum, minimum, and average sinuosity ratios are of the order of 2.2, 1.1 and 1.38 respectively.
2. Sinuosity ratios in the reaches 200-250 km, 600-700 km, 800-900 km and 1750-1824 km are relatively higher than the other reaches. As the average value of the sinuosity ratio for whole reach of the river is 1.38, therefore, the Ganga shall be considered as sinuous river as per the classification laid by Leopold and Wolman (1957) except the reaches identified above which can be classified as meander.
3. A negligible progressive change in the sinuosity ratio has been found from the year 1970 to 2010.
4. Except the meanders at Sultanganj and Munger, all other meanders are stable and no noticeable change in their geometry has been noticed from year 1970 to 2010. However, river has left the meandering route at Sultanganj and Munger and followed a relatively straight path over the years.
5. Calculated PFI of the Ganga river for the years 1970, 1980, 1990, 2000 and 2010 at an interval of 2 km indicates large variation.
6. The river has high PFI at the locations Shibganj, Santoshpur, Ramchandra Pur, Begusarai, Punarakh, Dhawan, Rajpura, Madhurapur, Akirpur, Bishnupura, Daroga ka Dhera, Mughal Sarai, Akrohi, Rampur, Allahabad, Baksar, Amritpur, Madhonagar, Jargawan, Rasulpur, Hasanpur and Bhopatwala. There is no definite pattern of the variation of PFI in the whole reach of the river from the year 1970 to 2010.
7. Haridwar (ch. 1740 km) to Devprayag (ch. 1824 km)
    - No noticeable changes in the stream banks shifting is visible in the reach of the river from chainage 1762 km (Rishikesh) to 1824 km (Devprayag). Being in the hilly area, river is also narrow in this reach. However, downstream of Rishikesh upto Haridwar river is relatively wide high and also it is braided.
    - In this reach, the main course of river has undergone maximum shift of the order of 1.5 km from left to right side near Chila.
8. CCS Barrage, Bijnor (ch. 1660 km) to Haridwar (ch.1740 km)
    - Ganga river is highly braided downstream of Haridwar near Sajanpur, which can be attributed to loosening the stream power of the river and deposition of sediments carried out from the hilly areas. Prior to year 1990, the main course of river was towards right side at this location. However, year 1990 onwards, one major stream developed towards left side which is about 2.5 km from main course of river as it was prior to year 1990.

- A field visit to the site reveals that shifting of river course towards left side near Sajanpur is due to mining activity towards left side. This area is habitated and is in danger due to shift of river towards left side. Protection majors in form of spurs have been provided to protect the habitated area.
- At chainage 1708 km (Dahirpur), the river has shifted from left to right of the order of 3 km while just downstream of this near Niranjanpur, river has shifted from right to left of the order of 1.5 km.
- Major shifting of course of river has been noticed upstream of CCS barrage. In general, river has shifted from right to left with maximum at Chhachhrauli of the order of 7 km. Such shifting is in a reach of 16 km.

9. Garhmukteshwar (ch. 1568 km) to CCS Barrage, Bijnor (ch.1660 km)

- Major shifting of stream banks has been noticed in this reach. Just downstream of CCS barrage, river has shifted from left to right progressively of the order of 3 km from year 1970 to 2010.
- At chainage 1622 km (Kamalpur), river has shifted progressively from left to right of the order of 5 km. While at chainage 1610 km (Nagla Goshain), the river has wandered over a width of 3.8 km. In general, it has shifted from right to left.
- At chainage 1594 km (Chhuchai), the river has shifted severely from right to left of the order of 5 km in a reach of 8 km.
- At chainage 1578 km (Khailwai), firstly river shifted from left to right during year 1970 to 1980 and then shifted right to left of the order of 3 km while downstream of this river has shifted from left to right of the order of 2.25 km near Moharka.

10. Narora (ch. 1488 km) to Garhmukteshwar (ch. 1568 km)

- Major shifting of the river banks in this reach has been noticed at chainage 1562 km (Palwara), 1550 km (Gangwar) and 1510 km (downstream of Anupshahr). Wandering behavior of river has been noticed from chainage 1522 km to 1538 km over a width of 1.8 km.
- Maximum shifting in this reach has been found at Palwara from right to left of the order of 3 km and at Gangwar from left to right of the order of 3.5 km.

11. Farrukkhabad (ch. 1308 km) to Narora (ch. 1488 km)

- Random major shifting of the stream banks has been noticed in this reach with prominent shifting at a) chainage 1470 km (Madkawali) of the order of 3 km from left to right; b) chainage 1458 km (Haranpur) from left to right of the order of 2.5 km; c) chainage 1414 km (Nanakhera) from left to right of the order of 5 km; d) chainage 1384 km (Nardauli) from right to left of the order of 4 km; e) chainage 1350 km (Kaimganj) from right to left of the order of 5 km and f) chainage 1322 km (Birpur) from left to right of the order of 4 km.

- No noticeable meandering and braiding has been identified in this reach.

12. Kanpur Barrage (ch. 1162 km) to Farrukkhabad (ch. 1308 km)

    - Major random shifting has been noticed in this reach in particular at chainages 1300 km (Yaqut Ganj), 1245 km (Kannauj), 1214 km (Bilhaur), 1194 km (Palhepur), 1182 km (Mirzapur), and 1162 km (Shankarpur).
    - The river is widespread in this reach due to confluence of Ramganga and Garra rivers. No noticeable meandering and braiding has been noticed in this reach.
    - At chainage 1300 km (Yaqut Ganj), the river has shifted from left to right of the order of 4.5 km and from year 1980 onwards its course is more or less is stable.
    - At chainage 1245 km (Kannauj), Kali river joins the Ganga river from right side. In year 1970, the main course of Ganga river was towards Kannauj side, however, over the years it has shifted towards left side. It was also witnessed during the site visit.
    - At chainage 1214 km (Bilhaur), the river has wandered over a width of about 4.5 km during year 1970-2010. While at chainage 1194 km (Palhepur), the river has meandering behavior in this reach. In past it has wandered over a width of about 4 km.
    - At chainage 1182 km (Mirzapur), the Ganga river was following towards Mirzapur side (left side) in year 1970, however, it shifted towards right side by about 3.5 km in 1980. Since then it is more or less stable.
    - At chainage 1162 km (Shankarpur) which is just upstream of Kanpur barrage, the river was forced to change its path from left to right side through provision of river training works so that Ganga river could flow through Kanpur barrage.

13. Allahabad (ch. 924 km) to Kanpur Barrage (1162 km)

    - No major shifting in the course of Ganga river in this reach has been noticed except the upper reaches.
    - Moderate shifting in this reach has been noticed at a) chainage 1118 km (Alipur) - river has shifted from left to right of the order of 3 km; b) chainage 1022 km (Arkha) - river has shifted from left to right of the order of 2 km; c) chainage 990 km (Benti lake) - random wandering behavior of a width of 4 km.
    - Before the confluence point with Yamuna river, mild shifting of Ganga river has been noticed.

14. Chainage 465 km (Revelganj) to 924 km (Allahabad)

    - From Allahabad to Revelganj (Confluence point of Ghaghara river), Ganga river is almost stable except in the reach from chainage 500 km to 550 km that is near Balia where mild shifting of the river bank has been noticed.

- At chainage 546 km (Nurhi) upstream of Balia, the river was flowing into two channels with major one towards left side. However, over the years the left channel has become the main course at this location.
- River has wandering behavior in this reach; most of its meandering pattern are stable.
- At chainage 508 km (Sanwani), river has shifted progressively from left to right of the order of 3.5 km and at chainage 492 km (Jewainiah) from right to left of the order of 2.5 km.

15. Chainage 309 km (Mokamah Bridge) to 465 km (Revelganj)

- At the confluence point of Ghaghara river, Ganga river was flowing towards right side and was meeting with Ghaghara near Kutubpur (Chainge 450 km) in year 1970. However, it has shifted towards left side of the order of 5 km and the confluence point has also shifted upstream by 14 km from year 1970 to 2000. Since year 2000, the course of river and confluence point are stable.
- Sone river joins the Ganga river at chainage 445 km from right side. Confluence point of Sone river with Ganga is more or less stable over the years.
- Upstream of Digha bridge (Chainage 416 km) and up to confluence of Sone river, the Ganga river has meandering pattern and also flowing into two channels. In year 1970,1980 and 1990 the major course of river upstream of Digha bridge was towards the left side and minor channel towards right side. However, year 1990 onwards right channel becomes major channel and a big island is formed between these two channels at upstream of Digha bridge.
- Downstream of the Digha ghat and prior to 1980, the Ganga river was hugging its right bank i.e., Patna side upto Didarganj. On the left side, the left spill of the Ganga river was meeting with Gandak river.
- Downstream of the Digha ghat and from year 1980-1990, the Ganga river was still hugging its right bank i.e., Patna side upto Didarganj. The left spill widened towards the Sonepur side.
- Downstream of the Digha ghat and during the period from year 1990-2010, major changes in the morphology of the Ganga river downstream of the Dighaghat occurred. The right channel deflected from the Dighaghat towards the left side resulting in its separation from the right bank of the river in a length of about 6 km downstream of the Dighaghat. The maximum shifting of the right channel of the river was of the order of 2.5 km at about 3 km downstream of the Dighaghat. The separated channel was joining the right bank of the river towards Patna side at about 6 km downstream of the Dighaghat.
- Downstream of the Ganga Setu, no noticeable changes in the morphology of the a river has occurred. At about 5 km downstream, the Ganga river bifurcates - one

channel goes towards left bank and another towards right bank of the river. In between these two channels, there is huge deposit of sand which has taken a shape of an island. The two channels rejoins near Bakhtiyarpur (Chainage 356 km). Left channel is constantly flowing as major channel. However, upstream of Bakhtiyapur river has shifted by 8 km from right to left from year 1990 to 2000.

- Upstream of Mokhmah bridge, the river flows into two channels. The right channel was major in year 1970, however year 1980 onwards, the left channel has become the major channel. Ganga river is wide and braided both upstream and downstream of the Mokhmah bridge. The width of the river in the upstream is of the order of 7.5 km while in the downstream it is about 5 km. The river has been channelized near the bridge by constructing a left guide bund.

16. Chainage 210 km (Sultanganj) to 309 km (Mokamah Bridge)

    - Major shifting of river course has been noticed downstream of Mokamah bridge near Khutha. In year 1970 and 1980, the river was flowing towards right side (Khutha), however from year 1980 onwards it has shifted towards left side of the order of 9 km. Near this location, river has followed relatively straight path over the years.
    - Upstream of Munger (Chainage 250 km) river has wandered over a width of about 6 km over the years. However, overall it has shifted towards right side over the years.
    - Major change in the river bank shifting has been noticed from Munger to Sultanganj. In general, the river has abandoned the meandering path and followed relatively straight path.
    - At Munger in year 1970 and 1980, the river was flowing in an acute meander touching Khutia towards left side. However, its course has shifted progressively from left (Khutia) to right (Munger) of the order of 12 km. At present, river is flowing abutting the Munger township.
    - In year 1970 and 1980, Burhi Gandak was meeting with Ganga river near Khutia, however, it's confluence has shifted towards downstream near Nauwa Garhi over the years.
    - Upstream of Sultanganj, the river was following a meandering path towards left side (Naya Gaon) in year 1970 and 1980. However, it has shifted progressively towards right side (Fatehpur) of the order of 8 km.

17. Kahalgaon (ch. 148 km) to Sultanganj (ch. 210 km)

    - Major changes in the river course has been noticed in this reach. In year 1970, the river was flowing through an acute bend downstream of Sultanganj near Madhurapur. However, year 1970 onwards, it has shifted from left to right side of the order of 10 km. Onwards to year 1980, no major shifting of river bank has been noticed at this location.

- Near Bhagalpur, the river has progressively shifted from right to left side of the order of 7 km. However, downstream of Bhagalpur near Barari, there is no change in the course of river from year 1970 to 1980.
- Upstream of Kahalgaon near Shahpur, the river was flowing in a relatively straight path towards right side in year 1970. However, in year 2010, it has shifted from right to left progressively of about 9 km and also followed a meandering path.

18. Rajmahal (ch. 40 km) to Kahalgaon (ch. 148 km)
    - No major shifting in the river course has been noticed in this reach. However, river is flowing over a wide width in this reach. Downstream of Kahalgaon near Budhu Chak the river is flowing into two channels with an island in between. The major channel is flowing towards left side and minor towards right side. Kosi river joins the left channel of the Ganga river near Krusela.
    - Near Mahadevganj, Ganga river has wandered randomly over a width of 7 km. In the respect of year 1970, the river has shifted by about 3 km from right to left in the year 2010.
19. Farakka (ch. 0) to Rajmahal (ch. 40 km)
    - At about 5 km upstream of the barrage, river has progressively shifted towards left side by about 4 km from year 1970 to 2010 at Chamogram. At about 12 km upstream of the barrage, the river has shifted towards right side at Sahibganj. The maximum shift of river towards right side was about 5 km in year 1980 with respect to center line of river in 2010.
    - At about 27 km upstream of barrage river has shifted towards left side from yea 1970 to 2000. The maximum shift towards left side is in the order of 5 km at Gopalpur.
    - Fulahar river joins the Ganga river from left side near Rajmahal.
20. There are 30 major tributaries of Ganga River between DevPrayag and Farraka. The highest shifting of confluence point is observed in Solani, Baia, Pandu, Chhoti Sarju, Ghaghara, Buri Gandak and Kosi rivers from the years 1980-2010 w.r.t year 1970.
21. It is recommended to plan hydraulic structures like barrage, bridge etc. at the identified nodal points (wherein minimum morphology of the river has occurred) on Ganga river to avoid outflanking of the river and to minimize protection works

d) Islands in Ganga River

1. Governing factors of formation of islands are river meandering, braiding, formation of spill channel, erosion and siltation, construction of structures, river training works, confluence of highly sedimented river, geology of the river, sediment yield from the catchment, etc.
2. Some of the islands are permanent in nature with different degree of settlement, while some islands are temporary in nature and can be seen on images for limited duration only.
3. Out of 31 identified islands in Ganga river from Devprayag to Farakka barrage six islands, namely Ramchandipur, Dayalchak, Panapur, Raghopur, Madhurpur and Gobrahi are permanent in nature at least from year 1970. Other islands, like Gotani Kachar, Fatehpur Pershakhi, Jirat Lawaen Gariabad, Khuthun and Umarpur Diyara are moderately stable. Habitated islands are Kheri Kalan, Ramchandipur, Dayalchak, Panapur, Raghopur, Ratipur, Gobrahi Diyara, Baijnathpur, Saidpur Ramnagar, Rambari, Begamabad, Jalbalu and Darijayrampur.
4. Habitated islands pose major resistance to the river flow due to construction of the *pucca* houses which protrude significantly and results in major obstruction to the flow. Major morphological changes in the river occur near such islands in the form of erosion, shifting of the main course, rise in water level, inundation in nearby areas during flood etc. In view of this, it is recommended that habitation shall not be allowed on the islands that have formed in the rivers irrespective of whether they are permanent or temporary in nature. However, such island can be used for the agricultural purpose with crops of low height.

e) Erosion and Siltation

Following conclusions may be drawn from the study of erosion and siltation in the Ganga river:

1. The total eroded area in the Ganga river from Devprayag to Farakka barrage in the period 1970-2010 is 447 km^2 while the total deposited area in extreme left and right banks shifting is 1070.94 km^2. The total eroded plus deposited area during the said period is 623.54 km^2.
2. During the period 1970-2010, the Ganga river is subjected to deposition in almost whole reach. The deposition is pronounced and is of the order of 2000 ha per 50 km length of the river upstream of the Kanpur. From Kanpur to Mokamah, the deposition is of the order of 800 ha per 50 km. In the lower reach of the Ganga i.e., chainage 50 -

250 km, heavy sediment deposition of the order of 6000 m^3 per 50 km reach has been estimated.

3. There is no progreessive aggradation or degraddation in the river bed of the Ganga river from Garhmukteshwar to Farrage barrage. However, remarkable changes in the river bed over the years have beben noticed at many stations. Deepeer section of the river has subjected to degraddation at most of the stations of the Ganga river except at Hathidah where aggrdation has occurred in the deeper section over the years.
4. From the consideration of the suspended sediment load, Ganga river may be divided into three distinct reaches a) Devprayag to Allahabad, b) Allahabad to Buxar, and c) Buxar to Farakka. Average suspended sediment load in the monsoon period in these reaches are 26, 108 and 189 MT/yr, respectively. Maximum SSL has been observed at Gandhighat which can be attributed to inflow of sediment from Ghaggra, Sone and Gandak rivers to Ganga river upstream of the Gandhighat.
5. Ghaggra river contributes about 130 MT/yr sediment to the Ganga river - about three times more sediment than the Kosi river. Gandak river contributes about 35 MT/yr sediment to Ganga river which is comparable to Kosi river.
6. Siltation has been observed in the Ganga river from Hathidah to Farakka. This may be due to low sediment carrying capacity of the river which can be attributed to wideness and shallowness of the river in this reach. Siltation in the upstream of the Farakka barrage up to its pondage fetch may be due to back water effect of the barrage, however, this aspect is to be investigated through modelling. Total siltation of the sediment in the reach from Buxar to Farakka is estimated as 250 MT per year. Siltation of the order of 30, 000 ha has also been obtained in this reach based on the shifting of left and right banks of the Ganga river.

f) Major Structures & their Impact on the Morphology

1. There is a negligible impact of Pashulok barrage on the morphology of the Ganga river in its vicinity. No noticeable erosion and deposition has occurred in the vicinity of the barrage.
2. No major changes in the plan form of the river have been seen from 1970 to till date near the Bhimgoda Barrage. As the barrage is there in one form or other from year 1854 and no image is available of the years prior to 1970, therefore, it is difficult to draw any conclusion in respect of impact of barrage on the morphology of the Ganga river. There was an island upstream of the barrage of area of 0.33 km^2 approximately in 1970, however, it is eroded by the flowing water which has resulted in gradual reduction in the area of the island.

3. There is no remarkable changes in the morphology of Ganga river due to construction of the C.C.S. barrage. No noticeable silting/deposition has occurred near the barrage that may be attributed to its unity looseness. Major changes have been noticed in the shifting of main course of the river at about 7 km upstream of the barrage. Such shifting has resulted in heavy erosion and deposition in the upper reaches of the barrage.

4. As no image is available of the year prior to the construction of the Narora barrage in 1966, it is difficult to draw any conclusion in the respect of impact of the barrage on the morphology of the Ganga river. However, it is apparent that jacketing of river between railway bridge and Narora barrage which has resulted in wide width of the river have resulted in heavy deposition in the form of island in a length of 6.5 km. The deployed river training works i.e., guide bund, embankment and spurs near the barrage are performing satisfactorily. Looseness factor of the barrage is 1.63 - this high value of the looseness factor has aggravated the problem of silting upstream of the barrage.

5. The LuvKhush barrage was constructed in year 2000 at a location where there was not even a spill channel. Subsequently, with the provision of pilot channel and blockage of main course of the river, the river was diverted successfully towards the barrage through pilot channel. The role of construction of barrage in changing the morphology of river is negligible. After the diversion of river towards the barrage, no major morphological changes in Ganga river have been noticed. Negligible silting upstream of the barrage may be attributed to the looseness factor less than unity. At outset, it may be concluded that there is negligible impact of construction of LuvKhush barrage on the morphology of the Ganga river.

6. As satellite images/ SOI toposheets prior to construction of the Farakka barrage are not available, therefore, it is difficult to draw any conclusion in the respect of impact of Farakka barrage on the morphology of Ganga river. It is to be noted that silting has occurred upstream of barrage from 1970 to till date. Severe lateral shifting of the river upstream of the barrage has been observed in this period, however, there are no remarkable changes in the width of deeper section of river in the period 1970 to 2010. Silting in upstream of the barrage may also be attributed to high looseness factor of the barrage which is equal to 1.7.

7. There are about 49 bridges on the Ganga river from Devprayag to Farakka barrage. Morphological changes in the river have been noticed near some of the bridges. Even though river training works have been provided at such bridges which are working satisfactorily, it is recommended to provide suggested river training works to train the river.

g) Flood Affected Areas

1. The flood hazard area is limited to maximum width of ~ 10 m with low to moderate intensity of the flood upstream of the Arrah. Near the confluence of the Ramganga river to the Ganga river downstream of the Farrukhabad, the flood hazard area is relatively large.
2. From the confluence point of the Ghaghra river at Doriganj (Chhapra) to Farakka, the flood hazard zone is severely wide spread with high intensity of the flood. Near the confluence point of the Kosi, the flood hazard zone is of very high intensity. This is also true in the area between Fulahar river and Ganga river near to Katihar. Such very high intensity of flood in these areas may be due to aggradation of the bed of the Kosi and Fulahar rivers and also siltation in the flood plain which has reduced the water carrying of the river and resulted in high inundation.

h) Critical Reaches and River Training Works

1. In total, thirty five reaches/locations are identified as critical in Ganga river, however, in twenty seven critical reaches of the Ganga river either the river is protected using spurs, embankments etc. or being in agricultural area, protection works are not required. At the remaining eight critical reaches/locations near Haripur Kalan, Kangri, Sidholia Kham, Saharpur Makanpur Kham, Gunir, Bhagalpur, Rajmahal to Maharajpur and Manikchak, protection measures are suggested.
2. Summary of the protection measures in the critical reaches are given below

Sl. No.	*Chainage*	*Location*	*Suggested River Training Works*
a)	1745-1749 km	5 km upstream of the Bhimgoda barrage near Haripur Kalan	Series of spurs are recommended for the protection of left bank in a length of 4.15 km to control the cutting of the forest area
b)	1725-1731 km	8 km downstream of the Bhimgoda barrage near Kangri village	Series of spurs are provided, some more spurs are required in a length of 6 km towards left
c)	1436 km	Sidholia Kham	Spurs are suggested to be provided along with existing embankment in a length of 0.6 km at chainage 1436 km
d)	1446 km	Saharpur Makanpur Kham	Embankment along with spurs are suggested to be provided in a length of 1.0 km at chainage 1446 km
e)	1092-1108 km	Downstream of Baksar-Muradipur road near Gunir	Protection to right bank is required in a length of 14.5 km using boulder revetment and/or provision of series of spurs

f)	180 km	Bhagalpur	Protection measures in the form of embankment with boulder revetment and launching apron be provided near Raghopur area over a length of about 4 km to control lateral shifting towards left side
g)	36-78 km	Rajamahal to Maharajpur	Embankment along with launching apron may be provided to control the erosion of left bank in this reach in about 33 km and lateral shifting towards left side
h)	24-34 km	Near Manikchak	Embankment along with launching apron may be provided to control the erosion towards left side in this reach in about 10 km length and lateral shifting towards left side

3. River training works shall also be provided near the following bridges:
   a) Railway Bridge, Balawali, Laksar (Ch. 1696.5 km): a) Suggested to provide nose to each guide bund and b) boulder revetment be provided to the right embankment of the railway track over a length of 1.5 km.
   b) Railway bridge, Rajghat, Narora (Ch. 1495.1 km): Suggested to provide nose to the left guide bund.
   c) Railway & Road bridges, Kachhla (Ch. 1452.2 km). Both the guide bunds should be extended downstream.
   d) Ara-Chhapra road Bridge, Doriganj, Chhapra (Ch. 450 km). a) A truncated guide bund be provided towards right side and b) right bank u/s of bridge is to be protected to control the shifting of the river.
   e) Road Bridge - Gandhi Setu (NH 19) (Ch. 404.8 km). Suggested to repair washed out portion of launching apron towards Hajipur side.
4. Earthen embankments are mostly provided from Haridwar to Kanpur and from Buxar to Farrakka barrage. Major embankments are located towards right side downstream of the Haridwar; towards left side upstream of the Garhmukteswar, Narora barrage, and Farrukhabad; downstream of Buxar towards right side; towards left side downstream of the Mokama and confluence of Burhi Gandak; and downstream of the Krusela towards left side. In the lower Ganga basin, the embankments are mostly provided along left bank. Existing river training works are generally in the form of series of spurs and guide bunds and provided mostly to protect the bridges and barrages.

16.2 RECOMMENDATIONS

1. It is recommended to implement the suggested measures in the identified eight critical reaches of the Ganga and in the vicinity of the identified bridges. It is further suggested that such reaches/locations be studied in more details based on ground survey and analysis of high resolution satellite data.
2. Suggested measures are prioritized as follow:
   a) Railway Bridge, Balawali, Laksar (Ch. 1696.5 km): a) Suggested to provide nose to each guide bund and b) boulder revetment be provided to the right embankment of the railway track over a length of 1.5 km.
   b) Railway bridge, Rajghat, Narora (Ch. 1495.1 km): Suggested to provide nose to the left guide bund.
   c) Railway & Road bridges, Kachhla (Ch. 1452.2 km). Both the guide bunds should be extended downstream.
   d) Ara-Chhapra road bridge, Doriganj, Chhapra (Ch. 450 km). a) A truncated guide bund be provided towards right side and b) right bank u/s of bridge is to be protected to control the shifting of the river.
   e) Road Bridge - Gandhi Setu (NH 19) (Ch. 404.8 km). Suggested to repair washed out portion of launching apron towards Hajipur side.
   f) About 8 km downstream of the Bhimgoda barrage near Kangri village (Ch.1725-1731 km): Series of spurs are provided, some more spurs are required in a length of 6 km.
   g) About 5 km upstream of the Bhimgoda barrage near Haripur Kalan (Ch.1745-1749 km): Series of spurs are recommended for the protection of left bank in a length of 4.15 km to control the cutting of the forest area
   h) Bhagalpur (Ch. 180 km): Protection measures in the form of embankment with boulder revetment along with launching apron be provided near Raghopur area over a length of about 4 km.
   i) Sidholia Kham (Ch.1436 km) & Saharpur Makanpur Kham (Ch. 1446 km): Spurs are suggested to be provided along with existing embankment in a length of 0.6 km at chainage 1436 km and 1.0 km at chainage 1446 km
   j) Downstream of Baksar-Muradipur road near Gunir (Ch.1092-1108 km): Protection to right bank is required in a length of 14.5 km using boulder revetment and/or provision of series of spurs
   k) Rajamahal to Maharajpur (Ch. 36-78 km): Embankment along with launching apron may be provided to control the erosion of left bank in this reach of about 33 km length.
   l) Near Manikchak (Ch. 24-34 km): Embankment along with launching apron may be provided to control the erosion towards left side in this reach of about 10 km length.
3. It is recommended to site hydraulic structures like barrage, bridge etc. at the identified nodal points (wherein minimum morphology of the river has occurred) on the Ganga river to avoid outflanking of the river and to minimize protection works.

4. Large scale de-silting from the rivers is not recommended. Efforts shall be made to manage the sediment in the river through deploying suitable river training works. However, from the utility consideration like siltation at water intake, minimum draft requirement for navigation, skewed distribution of flow across bridges/barrages etc., it is recommended to desilt the sediment from that location.
5. Habitation shall not be allowed on the islands/diyaras that have formed in the rivers irrespective of whether they are permanent or temporary in nature. However, such islands may be used for the agricultural purpose with crops of low height.
6. Adoption of high looseness factor in the design of the barrages leads to siltation upstream of the barrage as it is noticed for the Narora and Farakka barrages. Therefore, it is recommended that looseness factor close to unity shall be adopted to control silting upstream of the barrage.
7. Formation of the Madhurapur diyaras upstream of the Mokama bridge may be attributed to backwater effect resulted due to high afflux caused by the construction of the bridge by narrowing down the width of the river to 1.6 km by deploying a guide bund towards left side. Therefore, it is recommended that length of the bridge shall be fixed keeping nominal afflux.
8. It is suggested that from Haridwar to Revelganj (Chhapra), the length of the bridge/spacing of embankment should be close to three times the Lacey parameters, however, in the reach from Revelganj to Farakka, it should be from bank to bank. Final decision in this regard is to be taken considering other factors and site conditions.
9. River training works or any other structure shall be designed in such a way that it should not encroach the flood plains of the river or it should not delink the lakes, depressed areas, wetlands etc. as such bodies provide additional storage to the river and that results in lowering the peak discharge that controls the flood.
10. Sediment management in the vicinity of a barrage shall be explored by operation of the barrage gates. For an example, gates of the barrages shall be operated such that incoming sediment can be passed downstream during the flood time, to maintain the sediment equilibrium. Further, it should be ensured that the concentrated sediment flux passed downstream should not cause major morphological changes in the downstream reaches.
11. It is further suggested that a detailed survey of the area and data collection/analysis is to be carried out before implementing the recommendations, so as to incorporate the current ground conditions and river behaviour.

16.3 SUGGESTED FURTHER STUDY

1. Unauthorized, unscientific and unplanned mining of sand and gravel from the river has resulted in major morphological changes in river in the terms of stream bank shifting, bed degradation, bank erosion, disrupting the sediment mass balance, danger to the hydraulic structures etc. It has been seen downstream of Haridwar where Ganga river has shifted towards left side due to excessive mining. Therefore, there in a need to carry out replenishment study so that quantity of the sand and gravel to be mined can be estimated and morphological changes can be controlled.
2. Erosion and siltation in the Ganga river has been studied herein on the basis of the shifting of the banks of the river except in the reach from Buxar to Farakka in which study has been carried out based on sediment mass balance approach. This approach of the study is an indicative and does not provide the eroded/silted sediment in the terms of volume/weight. In view of this, it is suggested that the eroded/silted sediment shall be quantified on the basis of the sediment mass balance study i.e., quantity of eroded/silted sediment in a reach of the river is equal to mass of the sediment entered into the reach minus mass of the sediment gone out from the reach during a period. Collected sediment and flow data of the Ganga river and its tributaries by CWC at its H.O. can be used for this study and some data in this respect should also be collected.
3. Flood zones of the river should be identified and delineated along both the banks of river. Based on flood zone boundaries, habitation and development activities may be prohibited in such areas.
4. This study indicates that silting has occurred in almost whole the reach of Ganga river from Devprayag to Farakka barrage. This has resulted in formation of sand bars, islands, etc. and also aggravated the problem of flood. It is suggested that appropriate study should be carried out in generic basis or case to case basis to dredge out such islands/bars through non-structural measures like pilot channel, channelization etc.
5. In future, morphological studies are required to be carried out using 3D data of the terrain, as topography and slope of the region play an important role to study the morphological behavior and flood situation of the river. Laser based surveying and mapping techniques are now available which can provide 3D data with greater accuracy and speed to identify the critical regions affected by the flood due to meandering of the river.

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Annexure-A

DESIGN METHODOLOGY FOR VARIOUS RIVER TRAINING WORKS

A1. GUID BANKS (IS 10751:1994)

General

The alignment should be such that the pattern of flow is uniform with minimum return currents. The guide banks can be straight or elliptical with a circular or multi-radii curved head (Fig. A1). Elliptical guide banks have been found more suitable in case of wide flood plain rivers for better hydraulic performance. In case of elliptical guide banks, the ratio of major axis to the minor axis is generally in the range of 2 to 3.5.

Length of Guide Banks

Upstream Length

The general practice is to keep the upstream length of guide banks as 1.0 L to 1.5 L, where L is the length of structure between the abutments. For elliptical guide banks, the upstream length (that is semi major axis a) is generally kept as 1.0 L to l.25 L. This practice is generally applicable where the waterway is within the close range of L that is, Lacey's waterway.

For wide alluvial belt, the length of guide banks should be decided from two important considerations, namely (a) the maximum obliquity of current (it is desirable that obliquity of flow to the river axis should not be more than 30^0), and (b) the limit to which the main channel of the river can be allowed to flow near the approach embankment in the event of the river developing excessive embayment behind the guide bank. The radius of worst possible loop should be ascertained from the data of acute loops formed by the river during past. In case of river where adequate past surveys are not available, the radius of worst loop can be determined by dividing the average radius of loop worked out from the available surveys of the river by 2.5 for river having a maximum discharge up to 5000 m^3/s and by 2.0 for discharging above 5000 m^3/s. The above considerations are illustrated in Fig. A2. The limit to which the main channel of the river can be allowed to flow near approach embankment has to be decided based on importance of structure and local conditions.

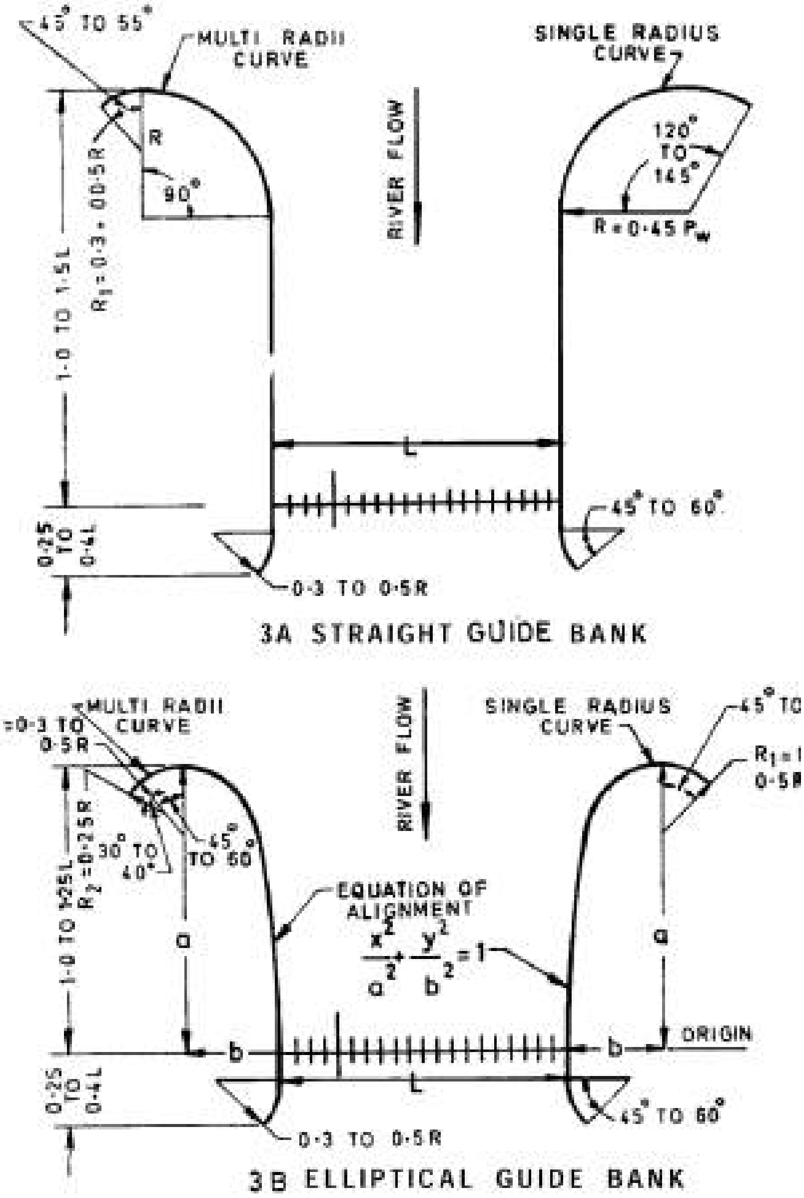


Figure.A1 A) Straight guide bank, and B) Elliptical guide bank

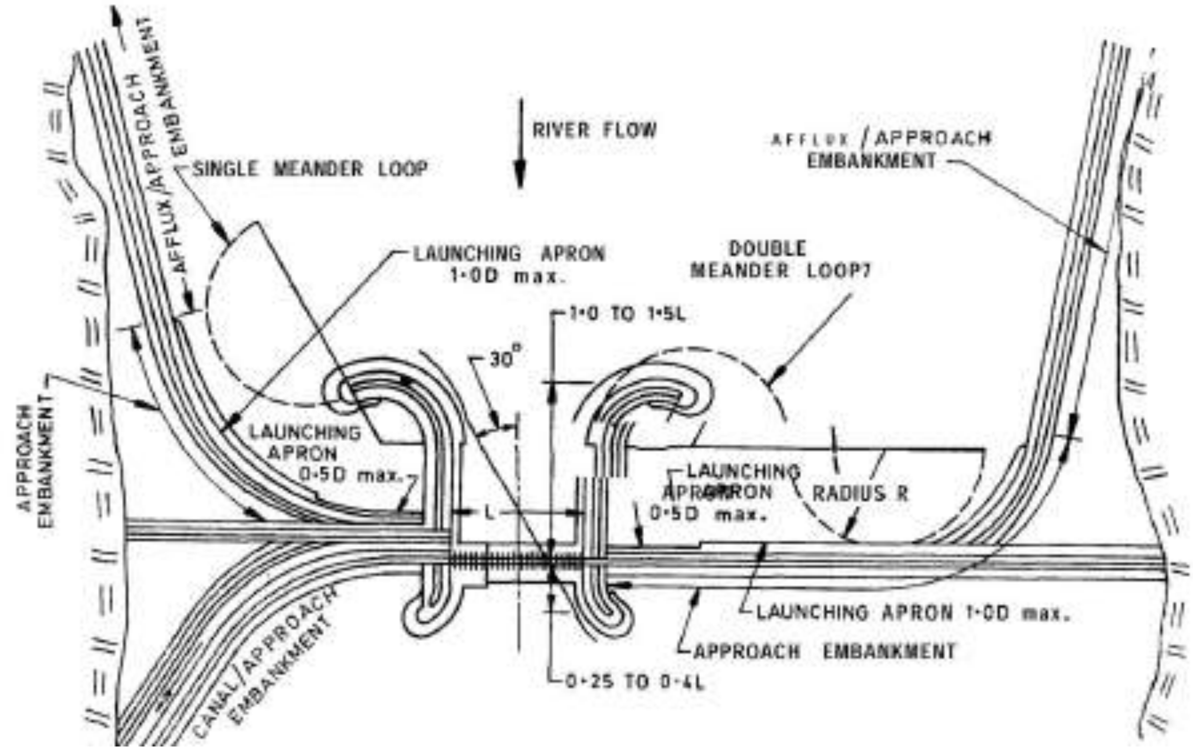


Figure. A2 Typical layout of the guide bank

Downstream Length

On the downstream side the river tries to fan out to regain its natural width. The function of guide bank is to ensure that the river action does not adversely affect the approach embankment. The downstream length will therefore, has to be determined so that swirls and turbulence likely to be caused by fanning out of the flow downstream the guide bank do not endanger the structure and its approach. The length of 0.2L to 0.4L is recommended.

Radius of Curved Head and Tail

Radius of curve head equal to 0.45L has been found to be satisfactory. Radius of curved tail may be 0.3 to 0.5 times the radius of curved head.

As per IRC: The radius of upstream mole head should not be less than 150 m nor more than 600 m unless indicated otherwise by model studies.

The radius of the upstream mole can also be estimated by

$$R_1 = 2.2\sqrt{Q} \quad \text{in SI units}$$

in which Q is the design flood discharge.

The radius of the downstream mole head R_2 is given by

$$R_2 = 1.1\sqrt{Q} \quad \text{in SI units}$$

Sweep Angle

The sweep angle is related to the loop formation. For curved head the angle of sweep may range from 120^o to 145^o according to river curvature. For curved tail it varies from 45^o to 60^o. As per IRC: 89-1997.

Design of Guide banks

Material

Guide banks may be made of locally available materials from river bed, preferably silt, sand or sand-cum-gravel.

Top Width

The top width should be 6 to 9 m to permit transport of material. At the nose of guide banks, the width may be increased suitably to enable vehicles to take turn and for stacking stones.

Free board

A free board of 1.0 m to 2.0 m may be provided above the design flood level. Where heavy wave action is apprehended and/or aggravation is anticipated, a higher free board may be provided. As per IRC: 89-1997: The minimum free board to top of guide bank above the pond level is generally kept as 1.5 m to 1.8 m.

Side slope

It depends on the angle of repose of the material of guide banks and the height. Side slope of 2H:1V to 3H:1V are generally recommended.

Protection of structures

Curved head is prone to damage due to concentration of discharge caused by collection of over bank flow and direct attack of current obliquely. The shank is subjected to attack by parallel/oblique flow. The curved tail is subject to attack by fanning out of current.

Toe Protection

Launching apron should be provided for protection of toe and it should form a continuous flexible cover over the slope of the scour hole in continuation of pitching up to the point of deepest scour.

Bank Revetment

Thickness of pitching on slope should be equal to two layers of stones of size given by Eq. (A1) in the case of free dumping of stones.

The weight of the stones required on sloping surface to withstand erosive action of flow may be determined using following relationship

$$W = \frac{0.02323 G_s}{K(G_S - 1)^3} V^6 \tag{A1}$$

$$K = \left[1 - \frac{\sin^2\theta}{\sin^2\phi}\right]^{\frac{1}{2}} \tag{A2}$$

where W = weight of stone in kg, G_s = specific gravity of stones, ϕ = angle of repose of protection material, θ = angle of sloping bank, and V = velocity in m/s.

Alternatively, the thickness of the bank revetment can be estimated by the following empirical equation of Inglis (Garde and Ranga Raju, 2000):

$$T = 0.04 \text{ to } 0.06\, Q^{1/3} \quad \text{in SI units} \tag{A3}$$

As per IRC 89, the thickness of stone pitching computed from the above formula shall be subject to an upper limit of 1.0 m and lower limit of 0.3 m.

In the case of crates, the thickness of crates be decided for negative head created due to velocity from following formula:

$$t = \frac{V^2}{2g\left(G_s - 1\right)} \tag{A4}$$

Where, t = thickness in m; V in m/s; g in m/s^2. The crate openings should not be larger than the smallest size of stone used. Shape of crates or blocks should be as far as possible cubical. Crates may be made of G.I. wire or nylon ropes of adequate strength and should be with double knots and close knits.

Size of stone

The stones used for slope protection and launching apron must be heavy enough to stay in place against the force of the current. For stones of relative density 2.65, the minimum size of stone is given by (Garde and Ranga Raju, 2000):

$$d_{min} = 0.023 \text{ to } 0.046\ U^2_{max} \tag{A5}$$

in which d_{min} is expressed in m, and U_{max} is the maximum velocity of flow (in m/s) in the vicinity of the guide bund.

As per IRC 89, the size of stone required for slope protection and launching apron to resist mean design velocity (average velocity) is given by the formula:

$$V = 4.893\ d^{1/2} \qquad \text{(A6)}$$

Where, V = mean design velocity in m/s and d = equivalent diameter of stone in m.

For velocities up to 5.0 m/s, the size and weight of stone is given in Table A1 below.

Table A1. Minimum size and weight of stone for slope protection

Mean design velocity in m/s	**Minimum size and weight of stone**			
	Slope 2:1		**Slope 3:1**	
	Diameter (cm)	**Weight (kg)**	**Diameter (cm)**	**Weight (kg)**
Upto 2.5	30	40	30	40
3.0	30	40	30	40
3.5	35	59	30	40
4.0	45	126	35	59
4.5	57	257	55	118
5.0	71	497	54	218

Launching Apron

Figure A3 shows the general arrangement of a launching apron that is generally provided at the mole head and the straight portion of the guide bund to prevent undermining of the bank revetment and consequent failure of the guide bund. It is assumed that the launching apron placed on the river bed would launch into the scour hole to take a slope of 1V: 2H with an average thickness of 1.25T. The slope of launched apron may be taken as 1.5H:1V for concrete blocks or stones in wire crates. To ensure this volume of boulder material, the average thickness of the launching apron on the river bed comes to 1.86T. This launching apron is placed on the river bed over a length equal to 1.5 times D, where D is the scour depth measured below the river bed.

The design of the launching apron, therefore, requires the estimation of the maximum scour below the river bed level that is likely to occur at the mole head and straight reach of the guide bund. The extent of scour depends on angle of attack, discharge intensity, duration of flood and silt concentration, etc.

The regime depth R may be determined as given below:

$$R = 0.473\left(\frac{Q}{f}\right)^{1/3} \quad \text{(A7)}$$

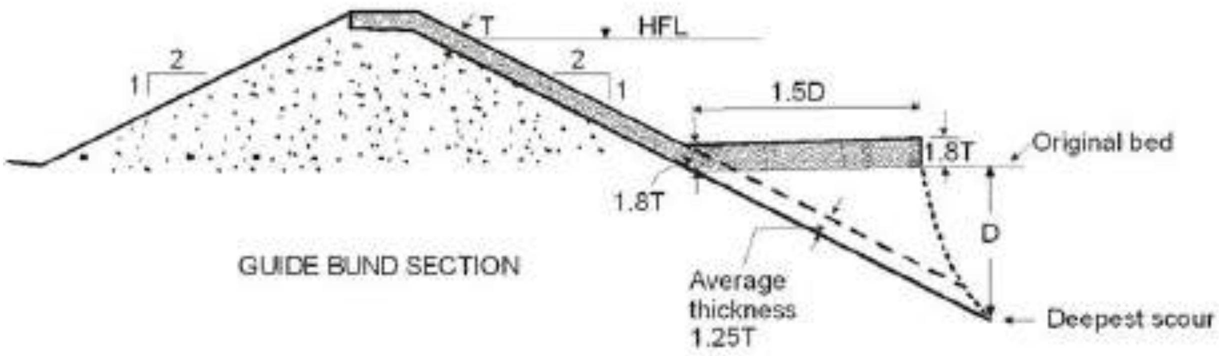


Figure. A3 A typical sketch of guide bund & launching apron

For waterway equal to or more than Lacey's waterway. In case where the waterway is less than Lacey's waterway and also the flow is non-uniform, D may be calculated as:

$$R = 1.35\left(\frac{q^2}{f}\right)^{1/3} \quad \text{(A8)}$$

Where R =scour depth in m, f = silt factor $=1.76\sqrt{d}$ where d is the mean diameter of river bed material in mm, Q = discharge in m^3/s, q = intensity of discharge in $m^3/s/m$.

The depth of design scour for different portions of the guide banks may be adopted as below:

Location	**Design Scour Depth to be adopted (R×Scour factor)**
Upstream curved head of guide bank	2.0 R to 2.5 R
Straight reach of guide bank to nose of downstream guide bank	1.5 R
Downstream curved tail of guide bank	1.5 R to 1.75 R

However, as per IRC: 89-1997

Location	**Maximum scour depth to be adopted**
Upstream curved mole head of guide bank	2-2.5 R
Straight reach of guide bank including tail on the downstream of guide bank	1.5 R

Slope Protection

The river side earthen slope of guide banks are protected against river action by covering them with dumped or hand placed stones and concrete blocks. This pitching is intended to remain in its laid position.

The rear slopes of guide banks are not subjected to direct attack of river and may be protected against wave splashing by 0.3-0.6 m thick cover of spawls or by turfing, In case however, a parallel or back flow leading to erosive action is likely as evident from model studies at the rear face, suitable pitching may be necessary.

The thickness of pitching should be equal to the size of stone determined from the velocity consideration from Eq. (A1) for hand placed pitching. For dumped stone pitching the thickness may be two times the size of stone. In general the following guidelines are followed:

a) Brick on edge can be adopted up to an average velocity of 2 m/s,
b) Quarried stones of size 350 mm and/or weighing 40-70 kg should be used up to an average velocity of 3.5 m/s, and
c) For higher velocity cement concrete blocks/crated stone could be used.

As per IRC 89, rear slopes of guide banks are not subjected to direct attack of the river and may be protected against ordinary wave splashing by 0.3- 0.6 m thick cover of clayey or silty earth and turfed. Where moderate to heavy wave action is expected slope pitching should be laid up to a height of 1 m above the pond level.

Drainage Arrangement

A system of open paved drains (Chutes) along the sloping surface terminating in longitudinal collecting drains at the junction of berm and slope should be constructed at 30 m center to drain the rain water. The drains are to be formed of stone pitching or with precast concrete section.

A2. DESIGN OF SPURS (IS 8408:1994)

General

Spurs may be aligned either normal to the dominant flow direction or at an angle pointing upstream or downstream. Spurs serve one or more of the following functions:

(a) Training the river along the desired course to reduce the concentration of flow at the point of attack,

(b) Protecting the bank by keeping the flow away from it,

(c) Creating a slack flow with the object of silting up the area in the vicinity of the river bank, and

(d) Improving the depths for navigation purpose.

Classification of Spurs

(a) The methods and materials of construction, namely permeable, impermeable and slotted;

(b) Height of spur with respect to water level, namely submerged, non-submerged and sloping (partially and/or submerged);

(c) Action, namely deflecting, attracting and repelling (see Fig. A4); and

(d) Special shapes, namely T-headed, hockey type or Burma type, kinked type, etc.

For repelling spur the angle upstream varies from 60^o to 80^o with the bank while in attracting spur the angle is usually 60^o with the bank.

In case of deep and narrow rivers or rivers carrying considerable suspended sediment, permeable spurs are preferred. Following type of permeable spurs are generally in use:

(a) Pile spurs

(b) Tree spurs

(c) Porcupine spurs

Design of spurs

The design discharge for the spur should be equal to that for which any structure in close proximity is designed or 50 year flood whichever is higher.

Length and Spacing of spur

Normally the effective length of spur should not exceed $1/5^{th}$ of width of the flow in the case of single channel. In case of wide, shallow and braided rives, the protrusion of the spur in the deep channel should not exceed the length over the bank. The spacing of the spur is normally 2 to 2.5 times its effective length.

Shorter length may also cause bank erosion upstream of the spur whereas too long spur may dam up the river. Normally spur should not obstruct more than 20% of the channel width at ordinary flood level.

As per IRC 89, in a straight reach the spacing is about 3 times the length of spur. Spurs are spaced further apart (with respect to their length) in a wide river than in a narrow one, if their discharges are nearly equal. In a curved reach a spacing of 2 to 3.5 times the length of spur is recommended. Larger spacing (3 to 3.5 times) can be adopted for concave banks and smaller spacing (2 to 3 times) can be adopted for convex banks.

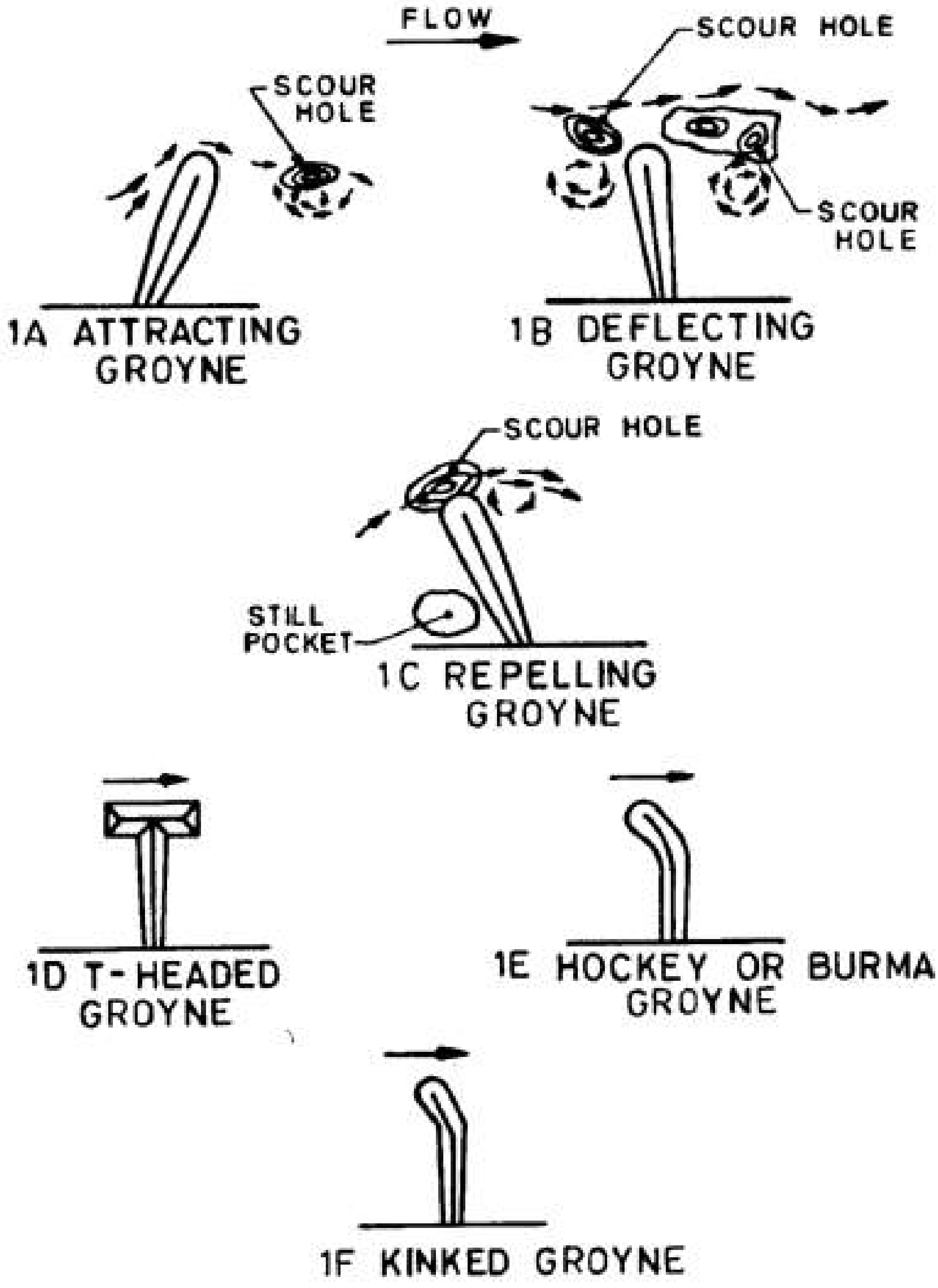


Figure. A4 Types of spurs

Top level and Top width of spur

In case of non-submerged spurs the top level should be above design flood level with a free board of 1 to 1.5 m. The top width of spur should be 3 to 6 m as per requirements.

Side slopes

Slopes of the sides and nose of the spurs would be between 2H:1V and 3H:1V depending upon the material used.

A typical layout of the spur is shown in Fig. A5. Methodology for the bank protection and Launching apron discussed in the design of Guide banks shall be adopted for the spur also. However, scour depth at different locations of the spur shall be taken as

S.N.	Location	Maximum Scour Depth to be Adopted
(i)	Nose	2.0 R to 2.5 R
(ii)	Transition from nose to shank and first 30 to 60 m in upstream	1.5 R
(iii)	Next 30 to 60 m in upstream	1.0 R
(iv)	Transition from nose to shank and first 15 to 30 m in downstream	1.0 R

A3. PILOT CHANNEL /ARTIFICIAL CUT OFF

In order to divert the flow and reduce pressure on the protection works, wherever feasible, pilot channels are provided. It is made is initially constructed of small cross-section so as to carry 8 to 10% of the flood discharge. This channel is then allowed to develop by itself and sometimes such gradual development is assisted by dredging.

The following points are worth considering for the design and execution of the pilot channels (Garde and Ranga Raju, 2000).

1. The pilot channel should be tangential to the main direction of river flow approaching and leaving the cut.
2. The pilot channel is usually made on a slight curve, the curvature being less than the dominant curvature of the river itself.

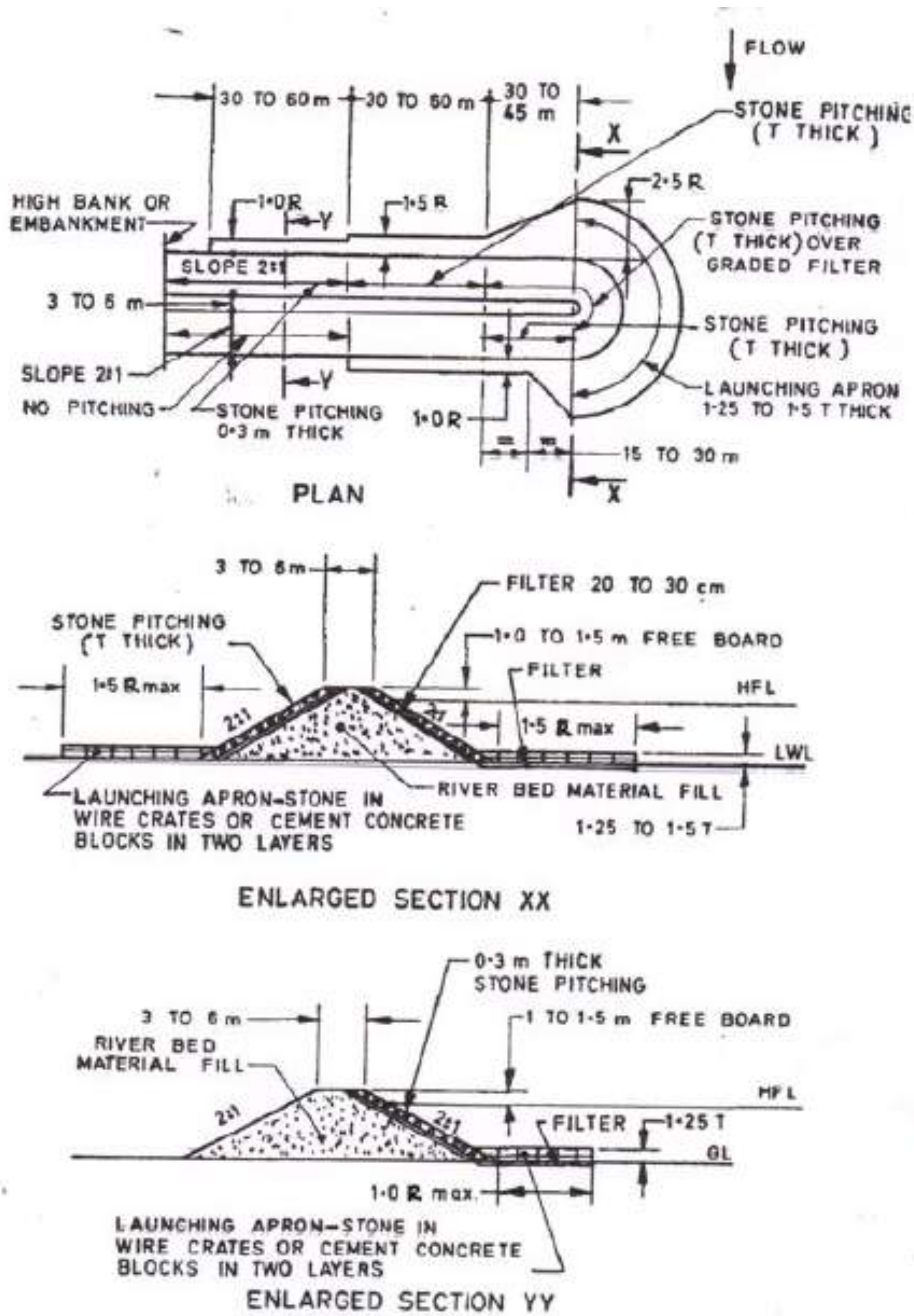


Figure. A5 Layout of a typical spur

3. Entrance of the pilot channel is made bell-mouthed. Such transition at the exit is considered unnecessary because the cut develops first at the lower end and works progressively upstream.
4. The cut, when unlikely to develop because of coarseness of the material or of low shear stress, should be excavated to mean river cross-section.
5. The width of the pilot channel is unimportant as the cut ultimately widens due to scouring, Hence, in practice, the width is determined by consideration of the type and size of the dredging equipment used.
6. When a series of cutoff is to be made, the work should progress from downstream to upstream.

It is desirable that the dimensions of this pilot channel should be such that with flow in it, the actual shear stress is much more than the critical shear stress required to move the bed material. It is hypothesized that with this excess shear stress, the channel will develop on its own during the period when discharge increases in the main river.

Let consider a pilot channel having

Length	= 1000 m
Upstream bed level	= 97.0 m
Downstream bed level	= 96.0
Channel slope	=1/1000
Base width	= 10 m
Side slopes	= 1V:2H

For a depth of flow of 1.0 m provided in the pilot channel, the values of flow area, A and hydraulic radius, R for this channel are 12.0 m^2 and 0.829 m, respectively. Using Manning's equation with n = 0.025, the discharge in the pilot channel may be calculated as -

$$Q = \frac{1}{0.025} \times 12 \times 0.829^{2/3} \times (10^{-3})^{1/2} \quad = 13.40 \text{ m}^3/\text{s}$$

The average shear stress τ_o in this channel is given by

$$\tau_o = \gamma_f \, R \, S = \quad 9810 \times 0.829 \times 10^{-3} \quad = 8.132 \text{ N/m}^2$$

The critical shear stress τ_c as per Yalin-Karahan (Garde and Ranga Raju, 2000) for the average size of 0.32 mm comes out to be 0.19 N/m^2.

Thus, the proposed pilot channel has an average shear stress on its boundary much more than the critical shear stress and this would help in the development of this channel during the flood. And once this happens, this channel would carry a much higher discharge than the calculated discharge of 13.40 m^3/s, giving relief to its tendency to move in bend.

A4. DESIGN OF RIVER EMBANKMENTS (LEVEES) (IS 12094:2000)

General

Embankments/Levees are used for the containment of spread of the flood water. These are designed for a flood of 25 years frequency in the case of predominantly agricultural areas and for flood of 100 years frequency for works pertaining to protection of town, important industrial and other vital installations. It would better consider flood of a particular frequency based on the benefit-cost ratio.

In general, embankment should be aligned on the high ridge of the natural banks of a river, where land is high and soil suitable for the construction of embankments. Their alignment has to be determined in such a way that the high velocity flow is sufficiently away from them. Where it is not possible to avoid high velocity flow, protection in the form of spurs and revetments is necessary.

Embankment should be aligned so that important towns and properties along the river bank are left outside the embankment. Where it is not possible to set back embankments to avoid the high velocity flow, some form of protection is necessary. Protrusions and sudden changes in the alignments and forming kinks should be avoided as far as possible.

The spacing between the embankments in jacketed reach of river should not be less than 3 times Lacey's wetted perimeter for the design flood discharge. In no case should an embankment be placed at distance less than Lacey's wetted perimeter from the river bank or one and a half times the Lacey's wetted perimeter from the midstream of the river.

Length of embankment directly depends upon the alignment. However, it is to be ensured that both ends of the bund are tied up to some high-ground or existing highway or railway or any other embankment nearby conforming to the design height of the embankment.

Design of Embankment

Embankments can be classified into two types as given below:

a) *Homogeneous Embankment*

b) *Zoned Embankment*

The essential requirements for design of the embankment are design high flood level (HFL), hydraulic gradient, free board, side slopes, top width etc. The stability of the structure should be checked under all stages of construction, condition of saturation and drawdown. Typical cross-sections of the homogenous and Zoned embankments are shown in Figs. A6, and A7, respectively.

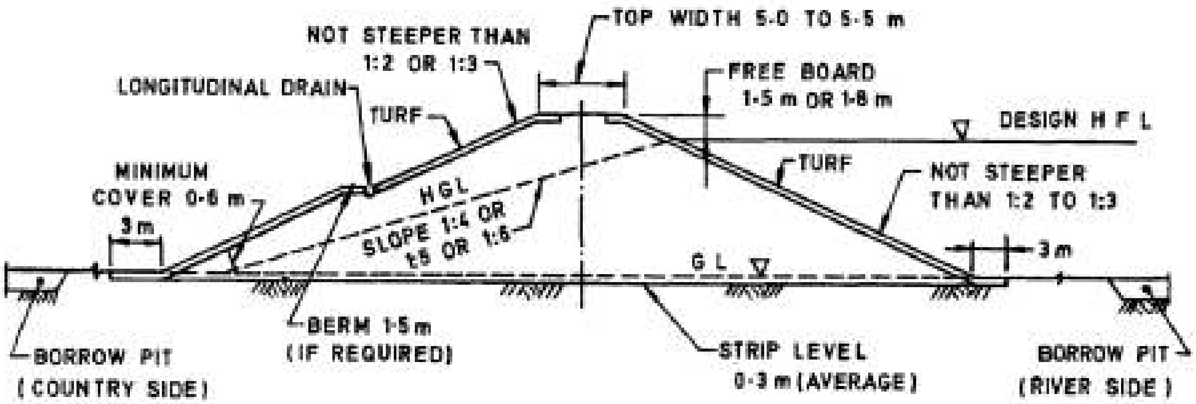


Figure. A6 Typical cross-section of Homogeneous embankment

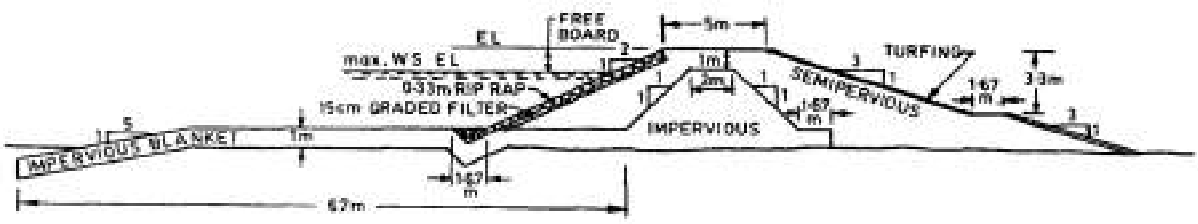


Figure. A7 Typical cross-section of Zoned embankment

Design discharge & HFL: To be obtained from the hydrological analysis.

Free Board: As a guideline, minimum free board of 1.5 m over design HFL including the back water effect, if any, should be provided for the river carrying design discharge up to 3000 m^3/s. For higher discharges or for flashy rivers, the minimum free board should be of 1.8 m. This should be checked also for ensuring a minimum of about 1.0m of free board over HFL corresponding to 100 years frequency flood.

Top width : The top width of the embankment should be of 5.0 m. The turning platforms, 15 to 30 m long and 3.0 m wide with side slope 1:3 along the countryside of the embankment should be provided at every km (Fig. A8).

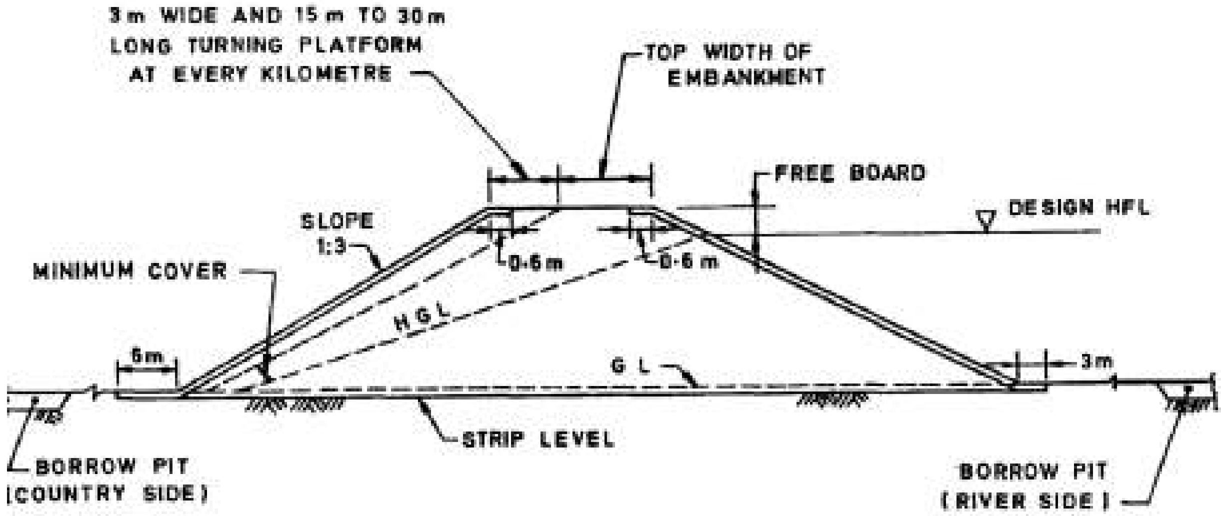


Figure. A8 Typical cross-section showing turning platform

Hydraulic Gradient :

Type of fill	Hydraulic Gradient
Clayey soil	1V: 4H
Clayey sand	1V:5H
Sandy soil	1V:6H

River Side Slope: The river side slope should be flatter than the underwater angle of repose of the material used in fill. Up to an embankment height of 4.5 m, the slope should not be steeper than 1 in 2 and in case of higher embankments slopes should not be steeper than 1 in 3, when soil is good and to be used in the most favorable condition of saturation and drawdown.

a) In case of higher embankment protected by rip-rap, the slope of embankments up to 6 m high may be 1 in 2 or 1 in 2.5 depending upon type of slope protection.
b) If the construction material is sandy, the slope should be protected with a cover of 0.6 m thick good soil.

c) It is usually preferable to have more or less free draining material on the river side to take care of sudden drawdown. In case of high and important embankment stone rip-rap either dry dumped or hand placed and concrete pavements/ concrete blocks with open joints are adopted to protect the embankment against drawdown and/or erosive action of the river; in less important embankments where rip-rap is costly, willow mattress can be used.

Countryside Slope: A minimum cover of 0.6 m over the hydraulic line should be provided.

a) For embankment up to 4.5 m height, the countryside slope should be 1 in 2 from the top up to the point where the cover over HG line is 0.6 m after which a berm of suitable width, with the countryside slope of 1 in 2 from the end of the berm up to ground level should be provided.
b) For embankment of height between 4.5 to 6.0 m, the corresponding slopes with respect to above point (a) should be 1 in 3. Berm should be of width of 1.5 m normally.
c) For embankments of height more than 6.0 m detail design should be made.

A5. PITCHED ISLAND

The device of a pitched island is a recent innovation in the armoury of river training hydraulics. The basic principle underlying the behavior of a pitched island, used as a river training measure, is its ability to cause re-distribution of velocity and tractive force. The tractive force near a pitched island begins to increase rapidly after the construction of the island, with the result that deep scour begins to form round the island and gradually draws the, main river channel into itself and ultimately holds it permanently. Because of this property, the pitched island can be used, either singly or in series for the following purposes:

(i) Correcting oblique approach upstream of weirs, barrages and bridges by training the river to be axial.

(ii) Rectification of adverse curvature for effective sand exclusion.

(iii) Redistributing harmful concentration of flow for relieving attack on marginal bunds, guide banks and river bends.

(iv) Training the river in the reach away from control points.

(v) Improve channel for navigation.

Generally, pitched island consist of a sand core pitched with boulders along its side slopes and protected at the toe by a falling boulder apron. As deep scour occurs round the pitched island creating heavy concentration of flow in its vicinity, the boulder pitching and apron have to be designed for the maximum scour under worst condition, generally taken equivalent to 2R (Lacey).

The general shapes adopted are triangular, elliptical or egg-shaped. Scour at the toe of a steeper slope is deeper that the toe of a flatter slope. The steeper slope, usually 2:1 is adopted on the side on which a concentration of flow is desired, while the flatter slope is given on the side where a throw-off becomes necessary.

A6. DESIGN OF PORCUPINES

According to IRC: 089-1997 and River Behavior Management and Training Volume-I (CBIP, 1989), these is one particular type of permeable spurs which help to induce siltation along the banks. These are made of steel, bamboo or timber and are provided on a scouring bank in a line normal to the flow. These spurs increase the roughness of the channel thereby deflecting the eroding current away from the bank. In course of time, vegetation within the jacks and action of spur is enhanced further.

One type of porcupine, known as Kellner Jack comprises of three steel angles about 5 m long bolted together at the center with the wire string between the legs (Fig. A9).

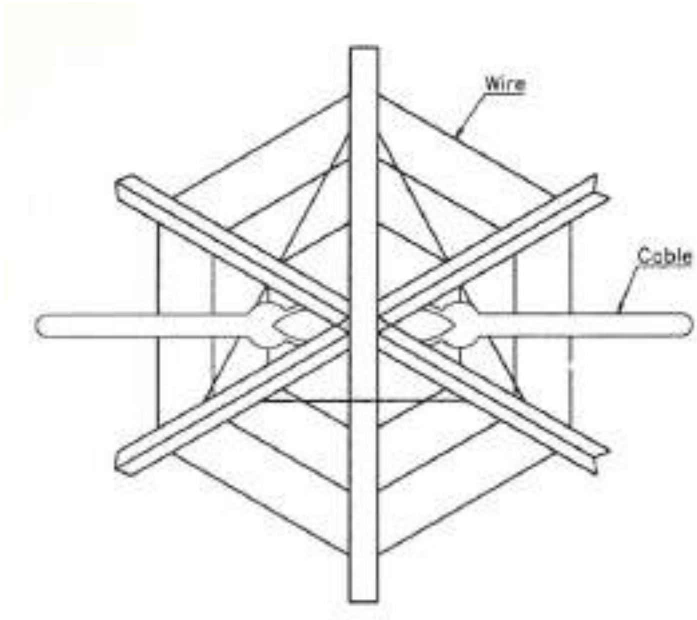


Figure. A9 Kellner Jack type porcupine

Other type of porcupine used for similar purpose is made of bamboo (Fig. A10). These are made of 3 to 6 m long bamboo of 75 mm diameter tied together at the center in the form of a space angle and are weighed down by tying boulder stones packed in wire cage at the center.

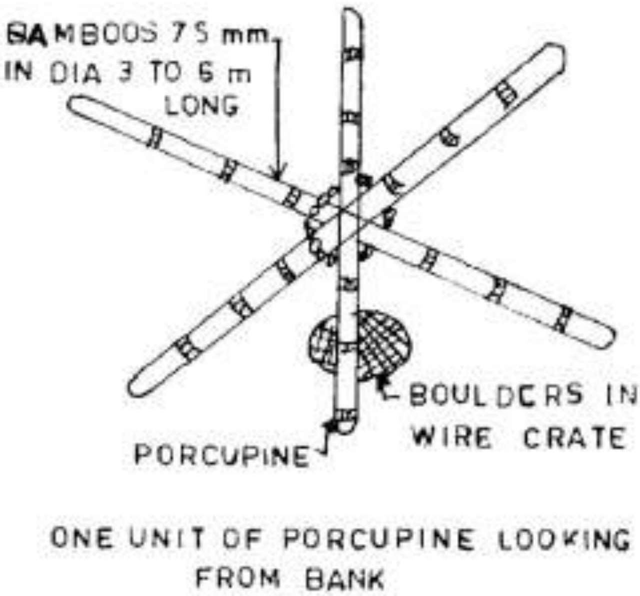


Figure. A10 Bamboo type porcupine

The spacing between the two consecutive units of porcupines will depend upon the desired permeability varying from 30 to 50 %. The spacing of two consecutive rows of porcupines varies from 3L to 4L, where L is the length of spur.

Cribs

These are similar to porcupines with the difference that the ballies/bamboos from a pyramid type structure with a box at the bottom for holding stones for the stability of individual units. The spacing between the consecutive cribs and the consecutive rows of cribs will be similar to that of porcupines.

Balli/bamboo frames

A framed structure made with driven poles of bamboos/shawls with longitudinal, cross and diagonal bracing is constructed across the flow.

Willow/brushwood spurs

Willow is a type of bush available in plenty across the country, has sufficient rigidity and strength are not easily decomposed. These or other brushwood available locally are filled and weighted by heavy stones in alternate layers within the framed structures. Such spurs, however, entrap sediments and lose their initial permeability and eventually behave like impermeable spurs with deep scour near their noses.

Submergence of spurs

Unlike impermeable spurs which are un-submerged with freeboard, permeable spurs may be either un-submerged or submerged. The submergence up to 50% is acceptable for porcupines, 20% for cribs and 5% to 10% for tree and willow spurs with framed structure.

A7. SUBMERGED VANES

Introduction

Recently at Iowa Institute of Hydraulic Research (IIHR) a new technique using submerged vanes has been suggested to alleviate the above sediment problems. The vanes are small submerged flow-training structures or foils designed to modify the near-bed flow pattern and redistribute the flow and sediment transport within the channel cross-section at relatively lesser cost (Fig. A11). Number, size and layout of these vanes depend on the channel, flow and sediment parameters. Vanes stabilize a channel reach without inducing changes upstream or downstream of that reach. Vanes may not be visible at times as they become buried by depositing sediment and assist streams by redistributing the flow energy to produce a uniform cross-section without an appreciable increase in the energy loss through the reach. The vanes function by generating secondary circulation in the flow. The circulation alters magnitude and direction of the bed shear stresses and causes a change in the distribution of velocity, depth, and sediment transport in the area affected by the vanes. As a result, the riverbed aggrades in one portion of the channel cross-section and degrades in another.

The available laboratory and field studies on the submerged vanes reveal that these vanes have broad range of applications in (a) changing the cross-sectional profile of the bed of a straight laboratory channel, (b) protecting the river bend against erosion, (c) reducing the bed load from entering into the water intake, (d) controlling the scour at vertical wall abutments and (e) Checking the shoal formation at pump station intake. To the knowledge of the writers, the vane technique has not been used in India for the sediment management so far in spite of its great potential for the same. However, some laboratory study related to the performance of the submerged vanes in two-meanderings channels and scour near the nose of the vanes have been conducted at IIT Roorkee.

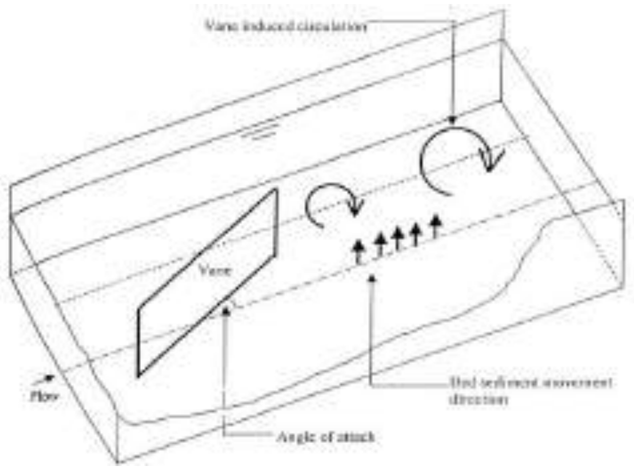


Figure. A11 Definition sketch of a submerged vane

On the basis of theoretical and physical model studies, Odgaard and Kennedy (1983), and Odgaard and Spoljaric (1986) have proposed that short vertical submerged vanes, installed with small angle of incidence to the channel axis in the outer half of a river bend channel, significantly reduce the secondary currents and also the high velocity attack on the outer bank. In addition, these vanes do not increase the local channel roughness as much as other traditional methods do when used for reduction of near bank velocity. On the basis of theoretical studies in a curved channel Odgaard and Wang (1991a, b) have shown that vanes having height equal to 0.2–0.4 times the local water depth and installed at an angle of attack within 15^0- 25^0 with the flow are quite successful in straight as well as meandering channels. Their findings also reveal that by introducing relatively small changes in the bed shear stresses, array of vanes could generate local changes in the bed elevation of the order of vane height. Odgaard and Mosconi (1987) carried out laboratory tests and found that the vane system does not interfere with the overall sediment balance and stability of channel while protecting the bank. Experimental work of Johnson et al. (2001) using rock vanes, angled to the flow and embedded into the stream bed such that the tip of the vane is submerged even during low flow, also clearly demonstrates the effectiveness of vanes for preventing scour at vertical wall abutments. Sinha and Marelius (2000) have shown that the optimal angle of attack close to 40^0 produces strongest vane-induced circulation. Islam et al. (2003) carried out experiments on both straight and curved reaches and have shown that for straight reach, increasing the angle of attack in a vane array results in increasing the navigation depth.

Laboratory study of Barkdoll et al. (1999) shows that submerged vanes placed at the diversion entrance admits only a negligible rate of bed-sediment entry into the water intake when the ratio of unit discharge in the diversion to unit discharge in the main channel q_r is less than about 0.2. Beyond this value, the effectiveness of the vanes diminishes.

The performance of vanes for sediment control can be enhanced in several ways. One is to use of a skimming wall in conjunction with the vanes and this is effective for values of q_r up to about 0.3. Another way is to widen the diversion entrance such that at the entrance q_r does not exceed about 0.3. Further enhancements like modified vane shape, uniformity of flow distribution into the diversion, and increased flow velocity into the diversion are not effective.

Figures A12a and A12b show a system of submerged vanes used by Odgaard and Mosconi (1987) to protect the bank erosion of a bend of Wapsipinicon River, Iowa. Fig. A12(a) shows vanes being installed in the bend in the summer of 1988 during low-flow, and the condition of the same bend two years later; Fig. A12(b). Substantial deposition of sediment induced by these vanes can be clearly seen in Fig. A12(b), thus demonstrating the capacity of these vanes in preventing the scour along the river bend.

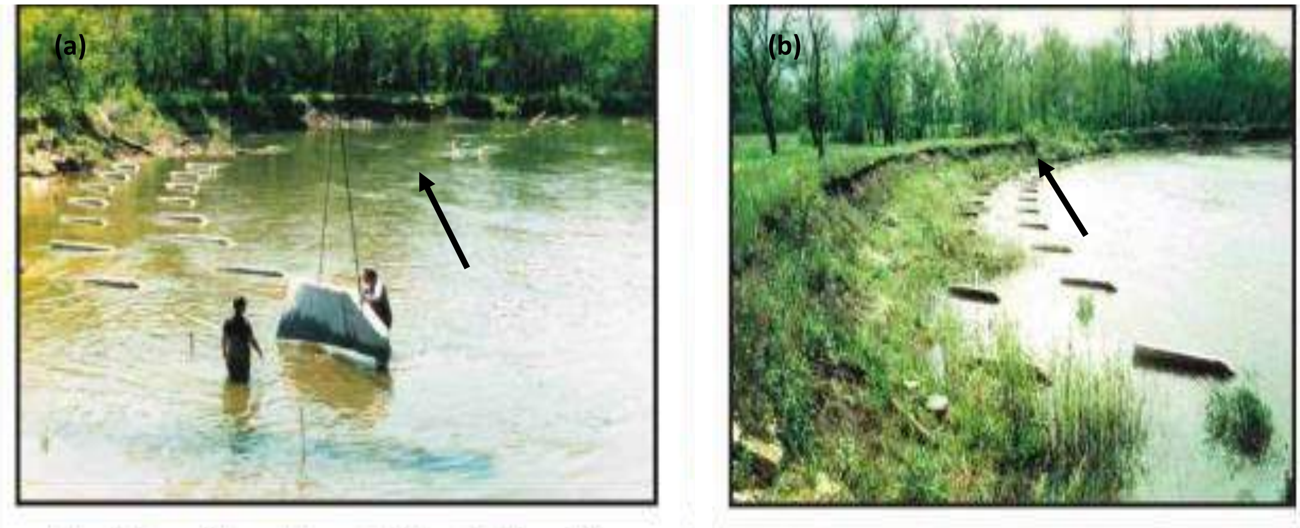


Figure. A12 Installation of Iowa Vanes in Wapsipinicon river bend
(a) During low flow in the Summer of 1988 (b) Low flow, May 10, 1990

Submerged vanes installed outside a water intake on Kosi River in Nepal is shown in Fig. A13. The vane system prevents sediment from being entrained into the intake (left). Each vane is 6 m long and 1.5 m-tall (with 0.8 m of vane below average bed level). Longitudinal spacing varies between 30 m and 40 m; lateral spacing is 5 m.

2. Design of a Submerged Vane System

The design variables of a vane system are shown in Fig. A14. The design procedure generally consists of selecting values of vane height H_0, vane length L, angle of incidence α, vane submergence T, vane spacings δ_n and δ_s, and vane-to-bank distance δ_b using the following known values: (a) the average depth of flow prior to the vane installation, d_0; (b) the velocity in the channel u_0; (c) the resistance parameter m; (d) the channel's width-depth ratio b/d_0; (e) the radius of bend-width ratio r/b; and (f) the sediment Froude number F_D, defined as $F_D = u_0 / \sqrt{gD}$ where g = acceleration due to gravity; and D = median grain diameter. The resistance parameter, m is defined as $m = \kappa\sqrt{8/f}$, where f = friction factor and κ =Karman's constant taken as 0.4.

Figure. A13 Vanes installed at a water intake on Kosi river, Nepal

To facilitate design, Odgaard and Wang (199a,b) prepared a number of graphs relating maximum changes in depth of flow $d_0–d_v$, as a function of vane, flow and sediment parameters where d_0 = maximum pre-vane flow depth; and d_v = vane induced flow depth. These graphs were prepared for arrays with one, two, and three vanes arrangement; relative vane submergence of T/d_0=0.5, 0.7, and 1.0; Froude numbers F_D = 5, 15, and 25; aspect ratio of H_0/L=0.3; angle of incidence $\alpha = 20^0$; and resistance parameter m = 4 and 3. Further these graphs were for vane spacing of $\delta_n = 3H_0$ and $\delta_s = 15H_0$ and $30H_0$, and for channels with depth-width ratio of 0.03. In these graph the values of $(d_0–d_v)/d_v$ were shown as function of width/radius of river bend (b/r). For a straight channel, radius of the bend can be considered as infinity. Therefore, width/radius tends to zero. For this value of b/r ,i.e, for straight channel the value of $(d_0–d_v)/d_v$ was found to be zero for T/d_0 = 1. This shows that for straight channels, vanes will not have any effect on bed level variation if relative submergence is close to unity. The design chart as proposed by Odgaard and Wang (1991a) can be reproduced in a tabular form as shown in Table A2.

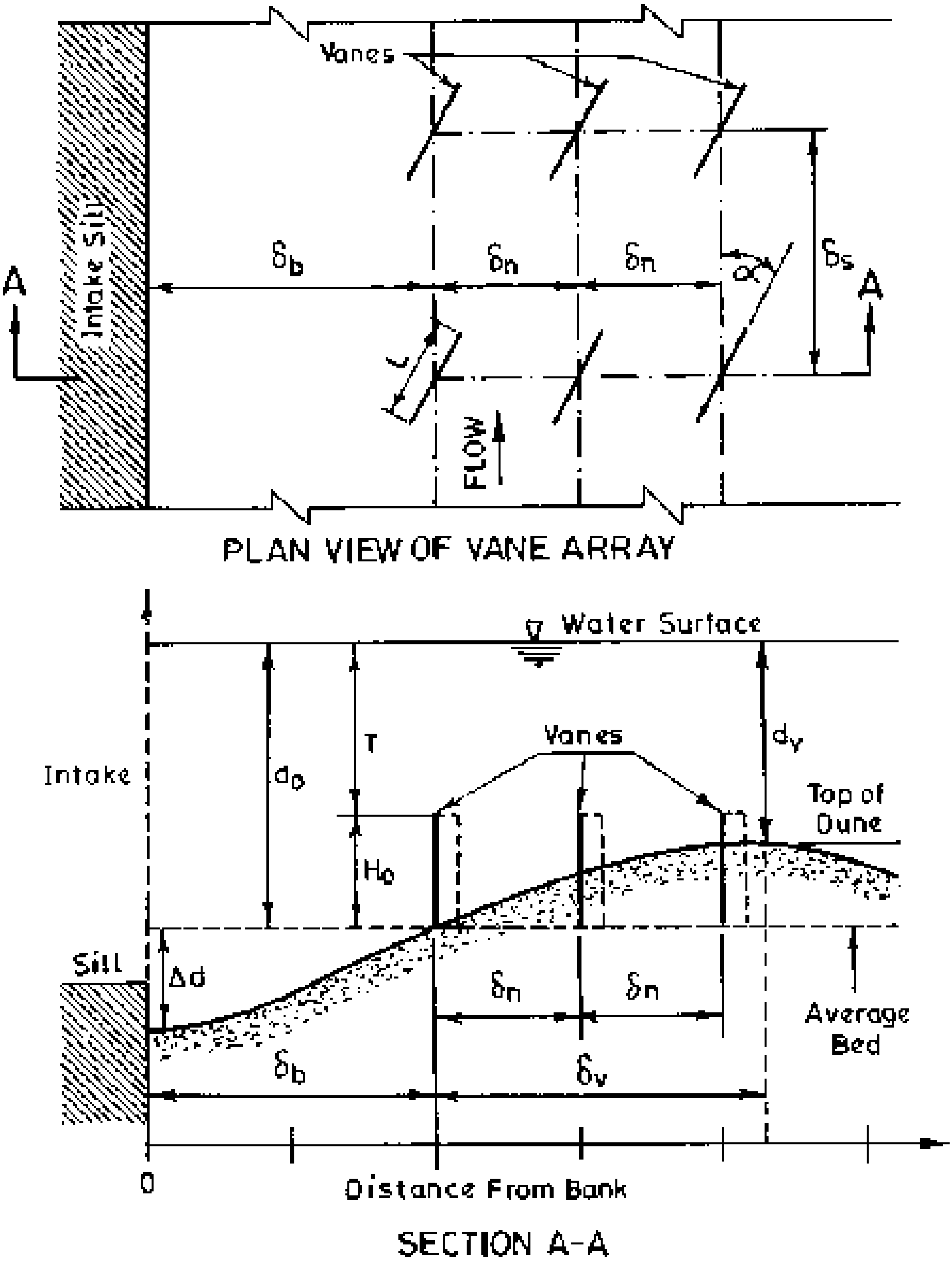


Figure. A14 Design variables of a submerged vane system

Table A2 Vane induced maximum increase in bed level along the bank of a stream.

F_D	m	$(d_0-d_v)/d_0$											
		Three vanes array				Two vanes array				One vane array			
		T/d_o=0.5 $\delta s/H_o$= 15	0.5 30	0.7 15	0.7 30	0.5 15	0.5 30	0.7 15	0.7 30	0.5 15	0.5 30	0.7 15	0.7 30
5	4	0.20	0.20	0.18	0.15	0.16	0.15	0.12	0.10	0.10	0.09	0.07	0.05
5	3	0.25	0.20	0.20	0.16	0.20	0.16	0.14	0.11	0.12	0.10	0.08	0.05
15	4	0.46	0.40	0.30	0.27	0.36	0.34	0.25	0.23	0.24	0.2	0.17	0.13
15	3	0.50	0.45	0.30	0.28	0.45	0.38	0.30	0.25	0.26	0.22	0.2	0.15
25	4	0.50	0.50	0.30	0.28	0.50	0.45	0.30	0.30	0.4	0.34	0.25	0.22
25	3	0.50	0.50	0.30	0.28	0.50	0.50	0.30	0.30	0.41	0.35	0.30	0.30

3. Design Procedure

At the design stage, the depth of the flow d_0, bed slope of the river S, velocity in the channel u_0, and median size of sediment D are known. If the vane system is to be designed for a river bend, the radius of the bend r is also known. However, for the installation of vane in straight channel like in the case of water intake, radius of the bend will be equal to infinity. Assuming the channel to be wide, calculate $\sqrt{8/f} = u_o/\sqrt{(gSd_o)}$ and then the channel's resistance parameter $m = \kappa\sqrt{8/f}$. Also calculate the sediment Froude number from the median diameter of the sediment. Odgaard and Wang (1991a) and Odgaard and Kenedy (1983) recommended that the height of vane H_0 should be equal to 0.2 -0.4 times the depth of flow. Choose some value of T/d_0 out of 0.5, 0.7 and 1.0. Calculate the length of vane L keeping the aspect ratio H_0/L=0.3. Take $\delta_n = 3H_0$ and $\delta_s = 15H_0$ or $30H_0$. Now corresponds to known values of T/d_0, m, δ_s/H_0, F_D, b/r and number of vanes per array, read $(d_0–d_v)/d_0$ from the Table 1. Finally, one can calculate the vane-induced depth of flow d_v. It is to be noted that a number of alternate designs are possible for a specific problem.

A8. FLOOD RETAINING WALL

There a several types of floodwalls, including gravity, cantilever, buttress and counter fort. The gravity and cantilever floodwalls are the more commonly used types.

Gravity Floodwalls

As its name implies, a gravity floodwall depends upon its weight for stability. The gravity wall's structural stability is attained by effective positioning of the mass of the wall, rather than the weight of the retained materials. The gravity wall resists overturning primarily by the dead weight of the concrete and masonry construction.

Frictional forces between the concrete base and the soil foundation generally resist sliding of the gravity wall. Soil foundation stability is achieved by ensuring that the structure neither moves nor fails along possible failure surfaces. Gravity walls are appropriate for low walls or lightly loaded walls. They are relatively easy to design and construct. The primary disadvantage of a gravity floodwall is that a large volume of material is required. As he required height of a gravity floodwall increases, it becomes more cost-effective to use cantilever wall.

Cantilever Floodwall

A cantilever wall is reinforced-concrete wall that utilizes cantilever action to retain the mass behind the wall. Stability of this type of wall is partially achieved from the weight of the soil on the heel portion of the base. A comfortable safety factor is taken when considering the unpredictability of the flood. Backfill can be placed along the outside face of the wall to keep water away from the wall during flooding conditions.

Buttressed Floodwall

A buttressed wall is very similar to a counterfort wall. The only difference between the two is that the transverse support walls are located on the side of the stem, opposite the retained materials. The counterfort wall is more widely used than the buttress because the support stem is hidden beneath the retained material, whereas the buttress occupies what may otherwise be usable space in front of the wall.

Counterfort floodwall

A counterfort wall is similar to a cantilever retaining wall except that it can be used where the cantilever is long or when very high pressures are exerted behind the wall. Counterforts or intermediate traverse support bracing, are designed and built at intervals along the wall and reduce the design forces.

Floodwall design

(i) Determine wall height and footing depth

(a) Determine wall height based on the highest flood level (HFL) plus 1.5 m of freeboard.

(b) Determine minimum footing depth based on the Lacey scour depth. Take depth of foundation at $1.5d_{sm}$, where d_{sm} mean depth of scour

(ii) Assume dimensions

Based on the following guidelines or reference to engineering handbooks, assume dimensions for the wall thickness, footing width and footing thickness.

(a) The choice of wall thickness depends on the wall material, the strength of material and the height of the wall. Typical wall thicknesses are 8, 12 and 16 inches for masonry, concrete or masonry/concrete walls.

(b) The footing width depends on the magnitude of the lateral forces, allowable soil bearing capacity, dead load and wall height. Typically, the footing is located under the wall in such a manner that 1/3 of its width forms the toe and 2/3 of the width forms the heel of the wall. Typical footing thickness is based upon strength requirements.

(iii) Calculate forces

There are two types of forces acting on all and its footing: lateral and vertical.

(a) Vertical forces: The vertical forces are buoyancy and the various weights of the wall, footing, soil and water acting upward on the floodwall.

Lateral forces: These forces are mainly the hydrostatic and differential soil/water forces on the heel side of the wall and the saturated soil force on the toe side of the wall.

Annexure-C

A BRIEF REPORT ON WORKSHOP ON "MORPHOLOGICAL STUDY OF RIVERS GANGA, SHARDA AND RAPTI USING REMOTE SENSING TECHNIQUE" HELD AT LIBRARY BUILDING, CWC, NEW DELHI DURING 18-19 SEPT. 2017

Indian rivers experience large seasonal fluctuations in discharge and sediment load resulting in significant changes in their morphology. Shifting of the river course is generally accomplished by erosion of habitated and pricey agricultural area that causes tremendous losses. The sediments deposited and eroded in the river have a tremendous effect on river cross-section, gradient, intensity of water flow and its discharge. Understanding of changes in the morphology of the rivers is required in all engineering projects for their planning, design and execution. With this in mind, CWC, New Delhi desires to carry out morphological study of the major Indian rivers. In this direction, CWC awarded a project entitled "Morphological study of rivers Ganga, Sharda and Rapti using remote sensing techniques" to IIT Roorkee. Accordingly, IIT Roorkee carried out the morphological study of Ganga river from Devprayag to Farakka barrage; Sharda river from Tanakpur to its conflunece with Ghaghra river and Rapti river from Nepalgunj to Patana ghat near confluence of Ghaghra river for the period 1970 to 2010. The broad objectives of the study were hydrological aspects of flow and sediment; stream bank shifting; plan form changes; erosion & siltation; impacts of major hydraulic structures on the river morphology; vulnerable reaches and suggestion for training/protection works; morphology of islands; recommendations in the respect of actionable points & suggestions for the further study.

For the dissemination of outcomes of the study carried out under the cited project to the potential users, a workshop on *Morphological Study of Rivers Ganga, Sharda and Rapti Using Remote Sensing Technique* was organized by Indian Institute of Technology Roorkee in association with Central Water Commission at Library building, CWC, New Delhi during 18-19 Sept. 2017.

The workshop was inaugurated by Hon'ble Union Minister of State, Water Resources, River Development & Ganga Rejuvenation and Parliamentary Affairs Shri Arjun Ram Meghwal. Prof. A K Chaturvedi, Director, IIT Roorkee; Shri Narendra Kumar, Chairman, CWC; Shri Pradeep Kumar, Member (RM); Shri N.K. Mathur, Member (D&R); Shri S Masood Husain, Member, (WP&P); Shri Ravi Shankar, CE (P&D), Prof. C S P Ojha, Head Civil Eng., IIT Roorkee; Prof. P K Garg, Professor, IIT Roorkee & Vice Chancellor, UTU; Shri P N Singh, Project Director, DRIP were also present.

Prof. Z Ahmad, Org. Secretary presented the gist of the study in the inaugural session. Shri Meghwal emphasizes the importance of water and its conservation. He also stressed upon the study on morphology of the rivers prior to the independence subject to availability of the required data.

The workshop was attended by more than 160 participants from various Institutions, organizations, Public & private sectors, NGO etc. like CWC, New Delhi; IMD, New Delhi; IWAI, Noida; GFCC, Patna & Lucknow; NMCG, MoWR, RD & GR, New Delhi; NDMA, New Delhi; BSRDCL, Patna; CWPRS, Pune; RITES Ltd., New Delhi; DHI, India; C2S2, New Delhi; PWD, Uttarakhand; JNU, New Delhi; AMU, Aligarh; MANIT, Bhopal; Wildlife Inst. of India, Dehradun; Myway Education Charitable Trust, New Delhi; MGCGVV, Satna (MP); GEU, Dehradun.

Prof. Z. Ahmad, Prof. P K Garg, and Dr. R D Garg presented the outcomes of the morphology of the Ganga, Sharda and Rapti rivers before the participants which were well responded by them. Details of the delivered talks are as follow:

18 October 2017: Ganga River

- Introduction covering scope of study, basin, study reach, data, methodology, geology, Land use land pattern, flood affected area, reconnaissance etc. : Prof. Z Ahmad
- Analysis of hydrological data - Exceedance curve, Frequency Analysis, Trend Analysis : Prof. Z Ahmad
- River Morphology : Planform (Meandering & Braiding), Shifting of course of river, Width of river & Shifting of confluence points : Prof. P K Garg, Dr. R D Garg & Prof. Z Ahmad
- River Morphology - Islands in Ganga river : Prof. Z Ahmad
- Erosion and Siltation (including aggradation & degradation): Prof. P K Garg & Dr. R D Garg
- Major structures & their impacts on the morphology: Dr. R D Garg & Prof. Z Ahmad
- Critical reaches and suggested training works : Prof. Z Ahmad
- Panel discussion

19 October 2017: Rapti River

- Introduction covering scope of study, basin, study reach, data, methodology, geology, Land use land pattern, flood affected area, reconnaissance etc. : Prof. Z. Ahmad
- Presentation of outcomes of the hydrological data - Exceedance probability curves, peak discharge for different return periods & trend analysis: Prof. Z. Ahmad
- River Morphology: Planform (Meandering & Braiding), Shifting of course of river & Width of river : Prof. P K Garg, Dr. R D Garg & Prof. Z Ahmad
- Erosion and Siltation (including aggradation & degradation) : Prof. P K Garg & Dr. R D Garg Major structures & their impacts on the morphology: Prof. Z Ahmad
- Critical reaches and suggested training works : Prof. Z Ahmad

19 October 2017: Sharda River

- Introduction covering scope of study, basin, study reach, data, methodology, geology, Land use land pattern, flood affected area, reconnaissance etc. : Prof. Z. Ahmad
- Presentation of outcomes of the hydrological data - Exceedance probability curves, peak discharge for different return periods & trend analysis: Prof. Z. Ahmad

- River Morphology : Planform (Meandering & Braiding), Shifting of course of river & Width of river, Erosion and Siltation (including aggradation & degradation) : Prof. P K Garg & Dr. R D Garg
- Major structures & their impacts on the morphology and Critical reaches and suggested training works : Prof. Z Ahmad
- Panel Discussion

Shri Pradeep Kumar (CWC), Prof. M K Mittal, Shri Ravi shankar; Shri R K Sinha (CWC), Shri Sanjay Kumar (BSRDCL), Shri NN Rai (CWC), Shri Arun Kaumar (GE Univ.), among others actively participated in the discussion. The work of the IIT Roorkee was well appreciated by the participants.

After deliberation, the following actionable points were suggested for enhancing the scope of the study from the consideration of its wide usage :

1. The 10-daily discharge and sediment data of terminal sites of river Ghaghra, Gandak, Sone, Burhi Gandak and Kosi may be considered and the effect of sediment brought by tributaries, on sedimentation of main stem of Ganga may be studied.
2. The reach between Farraka to Revalganj (0-450kms) may be divided into two considering geology and probable broad reasons for morphological changes occurring there may be identified.
3. It has been observed that there is progressive increase in the area of islands from Farakka barrage to Krusela. It may also be analyzed if the other diaras are also increasing. A correlation in increase of sizes of islands may be found out.
4. In context of many islands, participants in the conference from various State Organizations suggested that with time these islands have become highly habitated and vegetated. Road networks are coming up in Raghopur diara. This is likely to disturb the natural nesting sites for wildlife. Further, these diaras are likely to be submerged frequently during floods. Hence, as a recommendation in the report encroachment of these areas should be strictly prohibited. Flood Plain Zoning should be encouraged.
5. State Governments may share the success stories (if any) of how people are living with the floods in highly flood prone areas of these diaria regions. This may help CWC to come up with non-structural solutions for flood protection.
6. In total, thirty five reaches/locations have been identified by IIT Roorkee as critical in Ganga river, however, in twenty seven critical reaches of the Ganga river areas are either protected by using spurs, embankments etc. or being in agricultural area, protection works are not required. At the remaining eight critical reaches/locations near Haripur Kalan, Kangri, Sidholia Kham, Saharpur Makanpur Kham, Gunir, Bhagalpur, Rajmahal to Maharajpur and Manikchak, protection measures are suggested. The critical locations may further be prioritized so that suggested river training works may be taken up on the selected reaches on pilot basis.
7. Other critical locations near major structures like Bridges etc. may also be highlighted.

8. Some key economical flood management structures which may be suitable for these reaches as available globally may also be indicated along with the report. An economical flood protection work scheme which may try to utilize locally available silt / sand in the river for protection through geo bags & geo tubes, etc. for immediate relief, a suitable design of this tentative proposal may also be included in the report. Similar globally adopted structures may also be indicated. Non conventional method of flood control in critical areas may also be discussed.
9. The trends of aggradations/degradation in the river may be established and certain conclusions be drawn from it.
10. The suggested future studies by IIT Roorkee may be prioritized according to the need and importance. Further, similar small studies if carried out by IIT Roorkee in past in form of Phd or M. Tech. thesis may be shared with CWC.
11. The dates corresponding to the remote sensing images used to determine the width of the river may be provided, so that discharge corresponding to the same day may be provided. The same may be used to infer, if possible some relationship between water level, discharge and the width of the river.
12. The existing embankments on the Ganga River may be marked in GIS environment and included in the final report.
13. The trend analysis of hydrological parameters like discharge etc. carried out by IIT Roorkee may result in wrong interpretations due to lack of complete daily hydrological data; hence the same may not be included in the final report. However frequency analysis may be published in the final report.
14. The nodal points along the reach of the river i.e. wherein minimum morphological changes are seen in the river be identified. This will be helpful in planning of structures like bridge in the future.
15. Where ever possible Disclaimers may be provided for more clarification.
16. Effect of vegetation on both sides of river and Existing Embankment on river morphology may be discussed.

Few photographs of the workshop are as follow:

Annexure-B

FLEXIBLE SYSTEM IN FLOOD CONTROL AND MITIGATION PLAN

I. Use of Geo-Textile Filters in Flood Management Works

For better performance of embankments, retaining walls, pavements and other structures, drains are provided to relieve hydrostatic pressure by allowing passage of water while preventing loss of soil. Traditionally granular filters are provided to serve these two functions. In last 25 years or so, geo-textile filters have emerged as a better alternative to traditional granular filter but since long term experience is limited, geo-textiles should not be used as a substitute for granular filter within or on the upstream face of earth dams or within any inaccessible portion of the dam embankment. Caution is advised in using geotextiles to wrap permanent peizometers and relief wells where they form part of the safety system of a water retaining structure.

During monsoon period, rivers undergo bank and bed erosion at many stretches. Traditionally anti-erosion works to protect river bank and bed consists of a granular filter below the revetment and also below apron at Low Water Level (LWL). This anti-erosion work provides a good protection against erosion by preventing excessive migration of soil particles, while at the same time allowing water to flow freely through the filter layer. But this granular filter is often difficult to obtain, expensive to purchase, time consuming to install and segregates during placement, thus compromising its filtration ability. While the launching elements slide easily over the subsoil, they do not do so over each other. The falling apron, therefore, results in an about one-layer thick coverage. This layer is not stable and prone to loss of fines through the gaps in the protection. Many of the shortcomings of traditional filter can be overcome using geotextiles. Specially, a single layer of geo-textile fabric can replace a graded filter comprising of two or three layers. Geo-textiles are easy to install, especially, working underwater becomes much easier because the filter system can be assembled above the water and lowered into position. On negative side, geotextiles are sensitive to UV exposure and punching. Due care, therefore, must be taken while the installation of geo-textiles. Geo-textiles are comparatively costlier but more effective with longer serviceability.

Design of Bank Protection/ Anti-Erosion/ River Training works using Geo-textile Filters

Geo-textiles are frequently used in armoured erosion control and drainage applications. Geo-textiles are used to retain soil particles while allowing liquid topass freely. Designing with geo-textiles for filtration is essentially the same as designing graded granular filters.

Mechanism of Filtration

A filter should prevent excessive migration of soil particles, while at the same time allowing liquid to flow freely through the filter layer. Filtration is therefore summarized by two seemingly conflicting requirements:

1. The filter must retain soil, implying that the largest size of filter pore spaces or openings should be smaller than a specified maximum value; and
2. The filter must be permeable enough to allow a relatively free flow through it, implying that the openings of the geo-textile filter are sufficiently large enough and in large number to allow water flow while preventing clogging.

Design Philosophy

The design philosophy includes the estimation of scouring potential of river which is a function of the discharge intensity and Lacey's scour depth. The fineness of riverbed material is indicated in terms of silt factor which along with discharge intensity governs the Lacey's scour depth. The thickness of sloped bank pitching is determined on the basis of velocity of flow along the bank. Thickness and length of launching apron is determined once the scour depth, High Flood Level (HFL), and Low Water Level (LWL) are known. Proper drainage arrangement behind revetment is necessary. A suitable filter is also provided below the sloped pitching and launching apron to prevent fine soil particles from being removed. The provisions regarding Design of revetment and design of apron are available in IS 14262 and IS 10751, respectively.

Design of Geo-textile Filter

Before the introduction of geo-textiles, granular materials were widely used as filters for geotechnical engineering applications. Drainage criteria for geo-textile filters are largely derived from those for granular filters. The criteria for both are, therefore, similar. In addition to retention and permeability criteria, several other considerations are required for geo-textile filter design. Some considerations are noted below:

1. Retention: Ensures that the geo-textile openings are small enough to prevent excessive migration of soil particles.
2. Permeability: Ensures that the geo-textile is permeable enough to allow liquids to pass through without causing significant upstream pressure build up.
3. Anti-clogging: Ensures that the geo-textile has adequate openings, preventing trapped soil from clogging openings and affecting permeability.
4. Survivability: Ensures that the geo-textile is strong enough to resist damage during installation.
5. Durability: Ensures that the geo-textile is resilient to adverse chemical, biological and ultraviolet (UV) light exposure for the design life of the project.

The specified numerical criteria for geo-textile filter requirements depends on the application of the filter, filter boundary conditions, properties of the soil being filtered, and construction methods used to install the filter. These factors are discussed in the following step-by-step geo-textile design methodology.

Design Methodology

The proposed design methodology represents years of research and experience ingeo-textile filtration design. The approach presents a logical progression through seven steps.

Step 1: Determine Soil Retention Requirements
Step 2: Define Boundary Conditions
Step 3: Define the Application of Filter Requirements
Step 4: Determine Permeability Requirements
Step 5: Determine Anti-Clogging Requirements
Step 6: Determine Survivability Requirements
Step 7: Determine Durability Requirements

STEP 1: DETERMINE SOIL RETENTION REQUIREMENTS

Analysis of the soil to be protected is critical to proper filtration design. The particle-size distribution of the soil to be protected should be determined using test method ASTM D 422. The grain size distribution curve is used to determine parameters necessary for the selection of numerical retention criteria.
The maximum allowable opening size (O95) of the geo-textile is one that will provide adequate soil retention. It is also known as the geo-textile’s Apparent Opening Size (AOS) and is determined from test procedure ASTM D 4751. AOS can often be obtained from manufacturer’s literature.

STEP 2: DEFINE BOUNDARY CONDITIONS

Confining Stress: The confining pressure is important for several reasons:
1. High confining pressures tend to increase the relative density of coarse grained soil, increasing the soil’s resistance to particle movement. This affects the selection of retention criteria.
2. High confining pressures decrease the hydraulic conductivity of fine grainedsoils, increasing the potential for soil to intrude into, or through, and thegeo-textile filter.
3. For all soil conditions, high confining pressures increase the potential for thegeo-textile and soil mass to intrude into the flow paths. This can reduce flow capacity within the drainage media, especially when geo-synthetic drainagecores are used.

Flow Conditions: Flow conditions can be either steady-state or dynamic. Defining these conditions is important because the retention criteria for each are different. Examples of applications with steady-state flow conditions include standard dewatering drains, wall drains and leachate collection drains. Inland waterways and shoreline protection are typical examples of applications where waves or watercurrents cause dynamic flow conditions.

STEP 3: DEFINE THE APPLICATION OF FILTER REQUIREMENTS

Geo-textile filters are used between the soil and drainage or armoring medium. Typical drainage media include natural materials such as gravel and sand, as well as geo-synthetic materials such as geo-nets and cuspated drainage cores. Armoring material is often Revetment/ foundation or concrete blocks. Often, anarmoring system includes a sand bedding layer beneath the surface armour. The armoring system can be considered to act as a “drain” for water seeping from the protected slope.

Drainage Material: The drainage medium adjacent to the geo-textile must be identified. The primary reasons for this include:

1. Large voids or high pore volume can influence the selection of the retention criterion
2. Sharp contact points such as highly angular gravel or rock will influence the geosynthetic survivability requirements

STEP 4: DETERMINE PERMEABILITY REQUIREMENTS

Soil Permeability (*ks*): The soil permeability should be lab measured using representative field conditions in accordance with test procedure ASTM D 5084.
Minimum Allowable Geo-textile Permeability (*kg*): The requirement of geotextile permeability can be affected by the filter application, flow conditions and soil type. The following equation can be used for all flow conditions to determine the minimum allowable geo-textile permeability (Giroud, 1988):

$kg \geq is.ks$; where:

kg= minimum allowable geo-textile permeability

ks= the soil permeability

is= desired hydraulic gradient (based upon the filtration application)

Permeability of the geo-textile can be calculated from the permittivity test procedure (ASTM D 4491). This value is often available from manufacturer’sliterature. Geo-textile permeability is defined as the product of the permittivity, Ψ, and the geo-textile thickness, tg:kg= Ψ.tg

STEP 5: DETERMINE ANTI-CLOGGING REQUIREMENTS

To minimize the risk of clogging, one should follow the provisions of IS 14262.

STEP 6: DETERMINE SURVIVABILITY REQUIREMENTS

Minimum strength properties of the geo-textile fabric should be specified that fit with the severity of the installation procedure, to ensure construction survivability.

STEP 7: DETERMINE DURABILITY REQUIREMENTS

During installation, if the geo-textile filter is exposed to sunlight for extended periods, high carbon black content and UV stabilizers are recommended for added resistance to UV degradation. Polypropylene is one of the most durable geo-textiles today. It is inert to most naturally occurring chemicals in civil engineering applications.

However, if it is known that the geo-textile may exposed to adverse chemicals (such as in waste containment landfill applications), use test method ASTM D5322 to determine its compatibility.

BIS Specifications (IS 14262):

Geo-textile filters may be recommended because of ease in installation and their proven effectiveness as an integral part of protection works. A 15 cm layer of sandis provided over filter fabric to avoid its mechanical rupture by protection material. The following criteria, depending on the gradation of bed material, may be used to select the correct filter fabric:

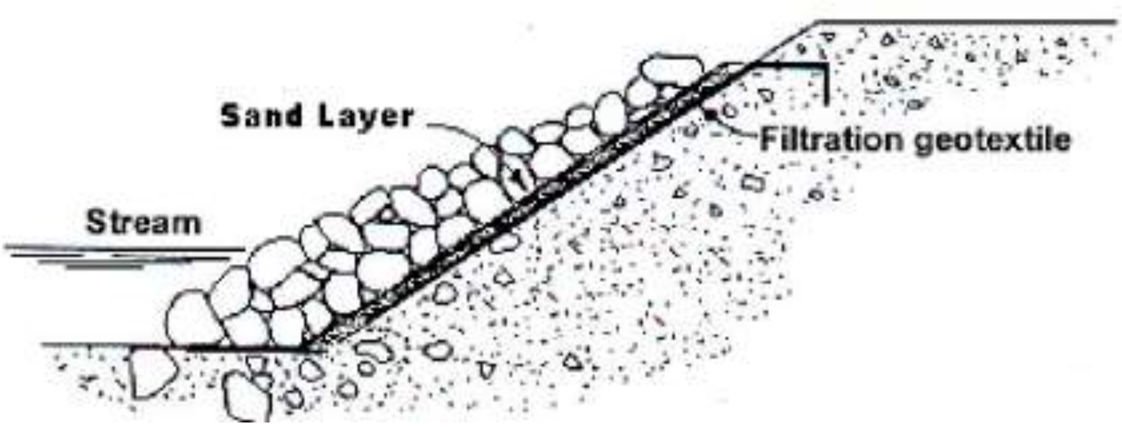
a) For granular material containing 50 percent or less fines by weight, the following ratio should be satisfied:

$$\frac{85\%\ passing\ size\ of\ bed\ material\ (mm)}{Equivalent\ opening\ size\ of\ bed\ of\ fabric\ (mm)} \geq 1$$

In order to reduce the chances of clogging, no fabric should be specified with an equivalent opening size smaller than 0.075 mm. Thus the equivalent opening size of fabric should not be smaller than 0.149 mm and should be equal to or less than 85 percent passing size of the bed material.

b) For bed material containing at least 50 percent but not more than 85 percent fines by weight, the equivalent opening size of filter should not be smaller than 0.149 mm and should not be larger than 0.211 mm.

c) For bed material containing 85 percent or more of particles finer than 0.074 mm, it is suggested that use of non-woven geo-fabric filter having opening sizeand permeability compatible to the equivalent values given in a) above may be used.



Typical Layout

II. Use of Geo-bags/ Geo-textile in Flood Management Works/ Anti-Erosion Works

Erosion is caused by a group of physical and chemical processes by which the soil or rock material is loosened, detached, and transported from one place to another by flowing water, waves, wind, moving ice, or other geological sheet and bank erosion agents. Clayey soils are less erodible than fine sands and silts.

Boulders are used conventionally for revetment / apron in the country. It is neither cost effective (at location where its availability is less) nor environmental friendly. Transporting and handling the material to work site is also difficult. Geo-Bags is a appropriate alternative; which are cost effective in long term. Bags can be transported long distance and filled at site and also the handling the Geo-Bags is easier than boulders. They are also sufficiently durable if not exposed to sunlight. Geo-bags are flexible armour system made of Geo-textile, fabricated in form of bags. They can be designed in any size and shape depending on site requirement and can be filled with locally available material (local earth). Geo-bags are well proven system of erosion control across the world. Geo-textile bags are made of woven or non woven geo-textile fabrics which are specially designed for good soil tightness and high seam efficiency. Geo-textile bags range in volume from 0.05 m^3 to around 5 m^3, and are pillow shaped, box shaped or mattress shaped depending on the required application. Geo-textile bags have also been used as revetment, breakwaters, etc to build erosion protection measures.

Design of anti-erosion works using Geo-Textile

Geo-textile bags as protective elements have to satisfy four main criteria

1. Stability against flow and wave attack
Field Experience and Physical Modeling indicated that bags of 126 Kg are stable to depth-avg. velocity of 3 m/s and that only very few bags would displace at high velocities of 4.5 m/s.

2. Filtration

Geo-textile in the Bags also to act as filter for preventing loss of fines between bags, this type of failure is called as winnowing failure. This can be prevented by using multiple layer coverage.

3. Launching

4. Longevity
- UV stability
- Abrasion resistance

Design steps
- Application evaluation
- Obtain soil samples from the site
- Evaluate armor material and placement
- Calculate anticipated reverse flow through erosion control system.
- Determine geo-textile requirements
  - Retention criteria
  - Permeability criteria
  - Clogging criteria
- Estimate costs
- Prepare specifications
- Obtain samples of the geo-textile before acceptance.
- Monitor installation during construction and control drop height. Observeerosion control systems during and after significant storm events.
-

The provisions regarding design of revetment and design of apron are available in IS 14262 and IS 10751 respectively. All structural parameter need to be designed similar to revetment/ spur using boulders.

Size of Bags

- For velocity up to 3 m/s, bags of size 1.1m x 0.7m x 0.15m (weight around 126 kg) may be used.
- For higher velocity, weight should be more than that calculated as under:

$$W = \frac{0.02323\ S_s}{K\,(S_s - 1)^3} V^6$$

$$K = \left[1 - \frac{\sin^2\theta}{\sin^2\phi}\right]^{\frac{1}{2}}$$

where

W - weight in kg

V – velocity in m/sec

Ss - Specific Gravity of protection material (adopted between 1.5 to 1.8)

θ - Angle of sloping bank

φ - Angle of repose of protection material

- The geo-synthetic material should be safe against the UV rays and abrasion.

Thickness of Pitching

- Thickness should be more than that calculated as under:

$$T = \frac{V^2}{2\,g\,(S_s - 1)}$$

T - thickness in m

V – velocity in m/sec

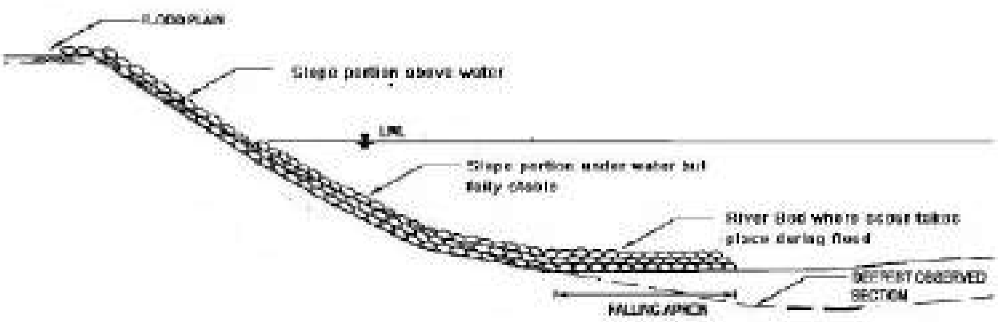
Ss - Specific Gravity of protection material (adopted between 1.5 to 1.8)

g - Acceleration due to gravity (9.81 m/s^2)

- Pitching may be provided in double layers of geo-bags (in loose) and single layer (encased with nylon/polypropylene ropes)

Filter

- A layer of Geo-textile filter may be provided under Geo-Bags.



Typical layout

III. Use of Geo-tubes/ Geo-textile in Flood Management Works/Embankments

Geo-tubes are basically containment systems in tubular forms filled with locally available sand which are formed in-situ on land or in water to protect shore and marine environments. It is in tubular shape made of geo-textile and is generally filled with sand or dredged material. These tubes are generally about 1 m to 3 m in diameter, though they can be customized to any size depending on their application. Today, geo-textile tubes ranging in diameters from 1.5 m to 5.0 m are used in many coastal and flood protection applications.

Earthen embankments are constructed for Flood Protection. Availability of good quality earth is a major bottle neck in ensuring the quality of embankment. Embankment quality can be substantially improved by the use of geo-tubes. Use of geo-tubes also provides enhanced security against breach and hence reduces investment on anti-erosion measures. Geo-tubes are very effective in breach closure without back shifting.

Quite often, conventional construction techniques will not allow dikes or levees to be constructed on very soft foundations because it may not be cost effective, operationally practical, or technically feasible. Nevertheless, geo-tube reinforced dikes have been designed and constructed. Geo-tubes used in those dikes alleviated many soft-ground foundation dike construction problems because they permit better equipment mobility, allow expedient construction, and allow construction to design elevation without failure. Embankments constructed on soft foundation soils have a tendency to spread laterally because of horizontal earth pressure acting within the embankment. These earth pressures cause horizontal shear stresses at the base of the embankment which must be resisted by the foundation soil. If the foundation soil doesn't have adequate shear resistance, failure can result.

Design of Embankments using Geo-Tube

The cross section of the embankment made using Geo-tube is to be designed as per usual earthen embankment. The Geo-Tubes are placed in the core of such embankment generally in a pyramid shape. As with ordinary embankments on soft soils, the basic design approach for reinforced embankment is to design against failure. To successfully design a dike on a very soft foundation, three potential failure modes must be investigated:

- Horizontal sliding and spreading of the embankment and foundation.
- Rotational slope and/or foundation failure.
- Excessive vertical foundation displacement.

The geo-tube must resist the unbalanced forces necessary for dike stability and must develop moderate-to-high tensile forces at relatively low-to moderate strains. It must exhibit enough soil fabric resistance to prevent pullout. The geo tube tensile forces resist the unbalanced forces, and its tensile modulus controls the vertical and horizontal displacement of dike and foundation. Adequate development of soil-geo-tube friction allows the transfer of dike load to the geo-tube.

Developing geo-tube tensile stresses during construction at small material elongations or strains is essential. In addition, potential creep of the reinforcement must also be considered. Because the most critical condition for embankment stability is at the end of the construction, the reinforcement only has to function until the foundation soils gain sufficient strength to support the embankment.The cross section of the embankment made using Geo-Tube is to bedesigned as per usual earthen embankment. The Geo-Tubes are placed in the core of such embankment generally in a pyramid shape. Double layer of sheets of woven textiles is also used for added UV protection for a prolonged life and sufficient abrasion resistance.

Design Steps

The following is a step-by-step procedure for design of reinforced embankments.

STEP 1 Define embankment dimensions and loading conditions

A. Embankment height, H
B. Embankment length
C. Width of crest

D. Side slopes, b/H

E. External loads
- Surcharges
- Temporary (traffic) loads
- Dynamic loads

F. Environmental considerations
- Frost action
- Shrinkage and swelling
- Drainage, erosion and scour

G. Embankment construction rate
- Project constraints
- Anticipated or planned rate of construction

STEP 2 Establish the soil profile and determine the engineering properties of the foundation soil

A. From a subsurface soils investigation, determine
- Subsurface stratigraphy and soil profile.
- Groundwater table (location, fluctuation)

B. Engineering properties of the sub-soils
- Undrained shear strength, cu, for end of construction
- Drained shear strength parameters, c' and Φ', for long-term conditions.
- Consolidation parameters (Cc, Cr, cv, σP ')

- Chemical and biological factors that may be detrimental to the reinforcement

C. Variation of properties with depth and areal extent.

STEP 3 Obtain engineering properties of embankment fill materials

- Classification properties
- Moisture-density relationships
- Shear strength properties
- Chemical and biological factors that may be detrimental to the reinforcement.

STEP 4 Establish minimum appropriate factors of safety and operational settlement criteria for the embankment. Suggested minimum factors of safety are as follows

- Overall bearing capacity: 1.5 to 2
- Global (rotational) shear stability at the end of construction: 1.3
- Internal shear stability, long – term: 1.5
- Lateral spreading (sliding): 1.5
- Dynamic loading: 1.1
- Settlement criteria: dependent upon project requirements

STEP 5 Check bearing capacity

A. When the thickness of the soft soil is much greater than the width of theembankment, use classical bearing capacity theory : $q_{ult}= \gamma_{fill}*H = cuNc$; Where Nc, the bearing capacity factor, is usually taken as 5.14 – the value for a strip footing on a cohesive soil of constant un-drained shear strength, cu, with depth.This approach underestimates the bearing capacity of reinforced embankments.

B. When the soft soil is of limited depth, perform a lateral squeeze analysis.

STEP 6 Check rotational shear stability

Perform a rotational slip surface analysis on the unreinforced embankment andfoundation to determine the critical failure surface and the factor of safety againstlocal shear instability.

A. If the calculated factor of safety is greater than the minimum required, then reinforcement is not needed. Check lateral embankment spreading (Step 7).

B. If the factor of safety is less than the required minimum, then calculate the required reinforcement strength, Tg, to provide an adequate factor of safety where :

$$T_g = \frac{FS\ (M_D) - M_R}{R\ \cos(\theta - \beta)}$$

STEP 7 Check lateral spreading (sliding) stability

Perform a lateral spreading or sliding wedge stability analysis

A. If the calculated factor of safety is greater than the minimum required, thenreinforcement is not needed for this failure possibility.
B. If the factor of safety is inadequate, then determine the lateral spreading strength of reinforcement, Tls required. Soil/geo-synthetic cohesion, Ca should be assumed equal to 0 for extremely soft soils and low embankments. A cohesionvalue should be included with placement of the second and subsequent fills in staged embankment construction.
C. Check sliding above the reinforcement.

STEP 8 Establish tolerable geosynthetic deformation requirements and calculatethe required reinforcement modulus, J, based on wide width (ASTM D4595) tensile testing.

Reinforcement Modulus: $J = T_{ls} / \epsilon_{geosynthetic}$
Recommendations for strain limits, based on type of fill soil materials and for construction over peats, are:
Cohesonless soils: $\epsilon_{geosynthetic}$ = 5 to 10%
Cohesive soils: $\epsilon_{geosynthetic}$ = 2%
Peats: $\epsilon_{geosynthetic}$ = 2 to 20%

STEP 9 Establish geosynthetic strength requirements in the embankment’s longitudinal direction (i.e. direction of the embankment alignment).

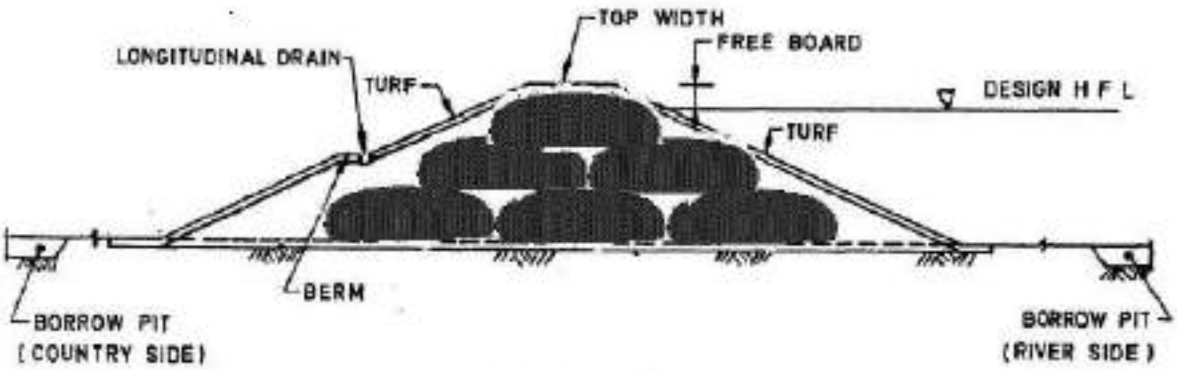
A. Check bearing capacity and rotational slope stability at the ends of the embankment (Steps 5 and 6)
B. Use strength and elongation determined from Steps 7 and 8 to control embankment spreading during construction and to control bending following construction.
C. As the strength of the seams transverse to the embankment alignment control strength requirements, seam strength requirements are the higher of thestrengths determined from Steps 9A or 9B.

STEP 10 Establish geosynthetic properties.

A. Design strengths and modulus are based on the ASTM D 4595 wide width tensile test. This test standard pewits definition of tensile modulus in terms of:
(i) initial tensile modulus; (ii) offset tensile modulus; or (iii) secant tensile modulus. Furthermore, the secant modulus may be defined between any two strain points. Geosynthetic modulus for design of embankments should be determined using a secant modulus, defined with the zero strain point anddesign strain limit (i.e., 2 to 10%) point.
B. Seam strength is qualified with ASTM D 4884 test method, and is equal to the strength required in the embankment's longitudinal direction.
C. Soil-geosynthetic friction, Φsg , based on ASTM D 5321 with on-site soils. For preliminary estimates, assume $\Phi sg = 2/3\Phi$; for final design, testing is recommended.
D. Geo-textile stiffness based on site conditions and experience.
E. Select survivability and constructability requirements for the geosynthetic based on site conditions, backfill materials, and equipment.

STEP 11 Estimate magnitude and rate of embankment settlement- Use conventional geotechnical procedures and practices for this step.
STEP 12 Establish construction sequence and procedures.
STEP 13 Establish construction observation requirements.
STEP 14 Hold preconstruction meetings- Consider a *partnering* type contract with a disputes resolution board.
STEP 15 Observe construction.

Geo-textile tubes fabric undergoes several stress cycles during its installation as well as during its life cycle. Theoretically the tube fabric is subjected to maximum stresses, both in circumferential and axial, directions at the time of filling. The Geo-textile skin of the Tube and it's component parts should have adequate tensile strength to resist the various forces generated during filling as well as during the life time of the structure. The required Ultimate Tensile Strengthof the Geo-textile Tube Fabric is: [Tu]c>= FS [Tu]c
The FS must account for factors such as Geotextile Tensions, Creep, seam factors and Durability. If any specific analysis is not undertaken a minimum FS of 4-5 shall be applied. With this the required fabric strength should be 150 N/mm^2.



Typical layout

IV. Use of Gabion Revetments as Anti-Erosion Works

Wire-enclosed rock, or gabion, revetments consist of rectangular wire mesh baskets filled with rock. These revetments are formed by filling pre-assembled wire baskets with rock, and anchoring to the channel bottom or bank. Wire-enclosed rock revetments are generally of two types distinguished by shape:

The primary advantages of wire-enclosed rock revetments include:

- Their ability to span minor pockets of bank subsidence without failure.
- The ability to use smaller, lower quality, and less dense, rock in the baskets.

Besides its use as a general bank revetment, wire-enclosed rock in the form of either mattresses or blocks is also used as bank toe protection. In some instances the wire-enclosed rock is used alone for protection of the bank also. In other cases, the wire-enclosed rock is used as toe protection along with some other bank revetment.

Design Guidelines for the Gabion Revetments:-

Components of a rock and wire mattress design include layout of a general scheme or concept, bank and foundation preparation, mattress size and configuration, stone size, stone quality, basket or rock enclosure fabrication, edge treatment, filter design. Design guidance is provided below in each of these areas.

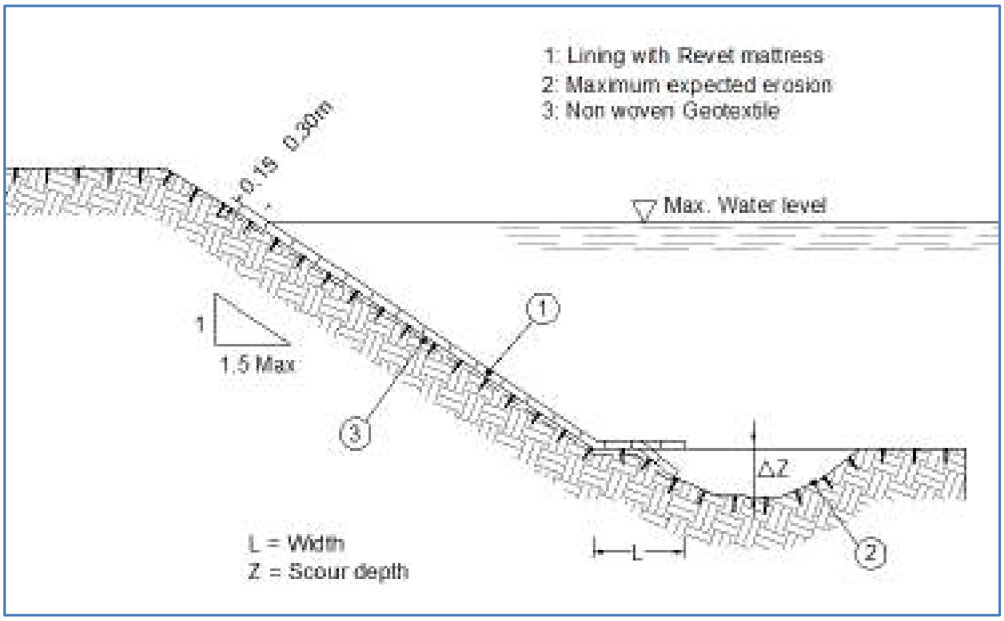
Rock and wire mattress revetments can be used to protect either the channel bank or the entire channel perimeter. When used for bank protection, rock and wire mattress revetments consist of two distinct sections: a toe section and upper bank and toe protection.

Bank and Foundation Preparation: Channel banks should be graded to a uniform slope. The graded surface, either on the slope or on the stream bed at the toe of slope on which the rock and wire mattress is to be constructed, should not deviate from the specified slope line by more than 150 mm. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed.

Large boulders near the outer edge of the toe and apron area should be removed. The thickness of the mattress is determined by three factors:

1. The erodability of the bank soil
2. The maximum velocity of the water, and
3. The bank slope.

The mattress thickness should be at least as thick as two overlapping layers of stone. The thickness of mattresses used as bank toe aprons should always exceed 150 mm. The typical range is 150 to 510 mm. The maximum size of stone should not exceed the thickness of individual mattress Units. The stone should be well graded within the sizes available and 70 percent of the stone, by weight, should be slightly larger than the wire-mesh opening.



Typical Layout

Note: This chapter is contributed by Mr. Dheeraj Kumar, Maccaferi Pvt. Ltd. and edited by Prof. Z Ahmad