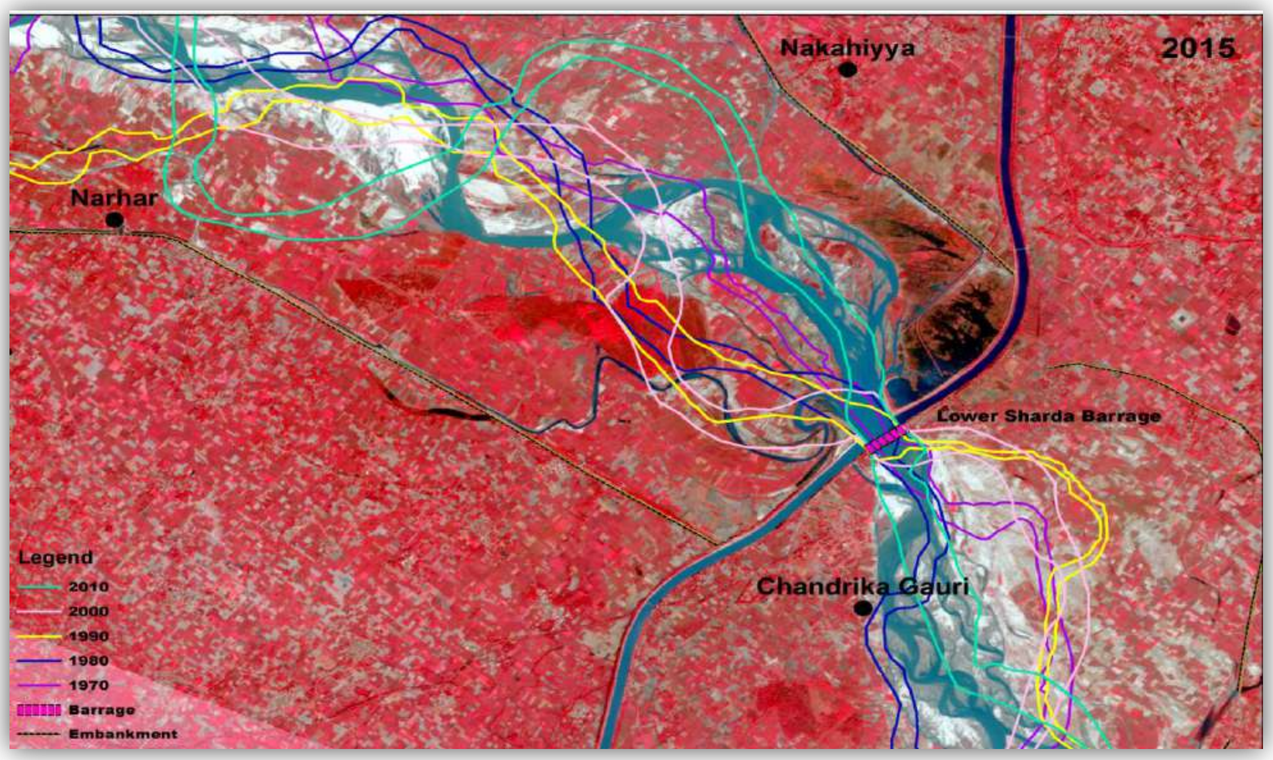
FINAL REPORT

MORPHOLOGICAL STUDY OF SHARDA RIVER USING REMOTE SENSING TECHNIQUES



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April 2018

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 causes 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*

   a) Compilation of river drainage map in GIS; changes in Land use/Land cover, flood affected areas, rainfall-runoff, geology etc.

   b) Hydrological analysis: Probability curve and flow rates corresponding to return period of 1.5 year and 2 years.

   c) Decadal stream banks shifting and also changes in its Plan form (Sinuosity & Plan form Index) from the base year 1970 to till 2010.

   d) Work out erosion and siltation based on the banks shifting.

   e) Evaluate the impacts of major hydraulic structures on the river morphology.

   f) Identification of critical and other vulnerable reaches and to suggest suitable river training/protection works.

   g) Reconnaissance survey for ground validation of outcomes of the study.

   h) Recommendations in the respect of actionable points.

   i) Suggestions for the further study.

3. Sharda river, a river of northern India and western Nepal, rises as the Kali River in northern Uttarakhand and then flows towards south-west, where it constitutes the border between Uttarakhand and Nepal. Descending from the mountains, it enters the Indo-Gangetic Plain at Barmdeo Mandi (Nepal). Downstream of this point, it is known as the Sharda River which continues to flow south-eastward into India through northern Uttar Pradesh state before joining the Ghaghara River - southwest of Bahraich. Drainage area of the river in India is 5132.81 km^2. Important tributaries of the Sharda river

in the reach of present study are Bamni, Ghaghi, Jagbura, Old Chauka. Important habitations near the Sharda rivers are Tanakpur, Banbasa, Palia Kalan, Nighasan and major water resources projects are Tanakpur Barrage, Banbasa Barrage, Lower Sharda Barrage and Sharda canal. The reach of the river Sharda which is studied herein is from Tanakpur to confluence point of Sharda and Ghaghra which lies between longitudes 80°00' E to 81°20' E and latitudes 27°36' N to 29°10' N. The area is entirely an alluvial plain and the land is highly fertile. The total length of the Sharda river studied in this report is 283 km.

4. Various aspects of the Sharda basin related to topography, soil, climate, geology, meteorological stations, land use land cover, flood map etc. are compiled in this report from the different sources like, GSI, WRIS, NRSC. Like most of northern India, Sharda basin has an extreme humid subtropical with dry winter type of climate. Summers are hot with temperatures rising up to 40°C. Geologically, the Sharda river basin may be divided into three zones: (i) The northern mountain zone or Shiwalik Himalaya, (ii) The tarai zone, and (iii) The plain zone. The studied area is mainly in plain zone. Geological map of the Sharda river indicates that it is consisted of fluvial. Land use and land cover map of the basin indicates that it is dominated by crop land followed by forest plantation. Scrub land can be seen along the Sharda river. Flood hazard zone map of Sharda river indicates moderate flooding in the areas along the river flow.

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.

7. 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.

8. Sharda river behaves as sinuous from Tanakpur to its confluence with Ghaghra river except from Chainage 200-225 km near Sampurnnagar in which it had behaved as meander river before year 1990. The meanders of

the river are not stable and keep on changing. The river has followed a relatively straight path over the years in the reaches 0-80 km and 210-240 km while meandering has increased in the reaches 100-140 km and 170-200 km. Axial wave length, amplitude and radius of curvature of the meanders are of the order of 4 km, 3 km and 1.5 km, respectively.

9. Sharda river may be considered moderately braided river in its major length from Tanakpur to its confluence with Ghaghra river. However, near Jagdispur, downstream of Banbasa barrage and Dodhara braiding of the river is high. At other locations, like Chandrika Gauri and Ghosiyana, it was highly braided in past. High braiding in the Sharda river in its upper reach i.e, Tanakpur, Banbasa, Dodhara is primarily due to aggradation which occurs as the river is incompetent to transport the sediment load that it is bringing from the relatively steep reach.

10. For the computation of shifting of course of the river, center line of the river as in year 2010 is perpendicularly bisected at a regular interval of 2 km and shift of left bank, right bank 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. Remarkable shifting of the course of the Sharda river from 1970 to 2010 has been noticed. The maximum shift is of the order of 7 km at some locations. The confluence point of Sharda and Ghaghra rivers has shifted 15 km downwards in year 2010 w.r.t. year 1970.

11. Width of the active channel of the river and river width based on the extreme banks have been estimated using the satellite images of years 1970-2010. There is no definite progressive change in the width of the active channel of the river over the span of year 1970-2010 in the whole studied reach of the Sharda river. From chainage zero to 225 km, the average width of the river is almost constant and is equal to about 300 m, however, in the upper reach i.e., Chainage 225 km to 248 km, the average width is about 240 m.

12. Erosion and siltation studies have been carried out for the Sharda river from Tanakpur to its confluence with Ghaghra river using SOI toposheets and post-monsoon decadal satellite images from years 1970 to 2010. 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 deposition have been estimated for duration from year 1970 to year 2010 and is expressed in the terms of area in km^2.

13. In the studied reach of the Sharda river, the total eroded area is 7544.79 ha, total deposited area is 21426.02 ha and total eroded and deposited area is 25513.79 ha on span of year 1970 to 2010, while net deposited area is 13881.23 ha.

14. Erosion and siltation are noticeable throughout the entire reach of Sharda River from Tanakpur to the confluence point (Durgapur). This is due to shifting and meandering nature of the river course. Noticeable amount of siltation has occurred near Tanakpur and Durgapur - the starting and ending points of the river. In addition to the above locations, major silting has also taken place near Nai Ratauli, Jamdari, Gudaria, Baleha, Ghosiyana, Tirkaulia, Mallaha Purva, Madhotanda and Tanakpur while erosion has taken place at Nandura, Mohammadpur, and Ramnagar Kalan due to frequent shifting of the river course in these areas. Major erosion plus deposition has occurred in the reach 50-250 km on the span of year 1970-2010 especially at Nauwapur, Bhadpur, Baleha and Ramnagar Kalan.

15. Available measured cross-sections of the Sharda river at the gauging stations have been used to study the aggradation and degradation in the river bed. Measured cross sections of the Sharda river for different years at gauging station of Palian Kalan, indicate no progressive aggradation or degradation, however, adjustment in the cross-sections of different years may be seen.

16. There are three barrages, namely Tanakpur, Banbasa, and Lower Sharda at chainages 277 km, 269 km and 92 km on Sharda river, respectively. A road cum Rail Bridge which connects Bhira and Palia Kalan is constructed across Sharda River at chainage 168 km. Another road bridge (SH26) of length 590 m is constructed across Sharda River at chainage 57 km.

17. The river was wide spread upstream and downstream of the Tanakpur barrage even before its construction in year 1992. During the years 2000 to 2010, no noticeable changes in the planform of the river near barrage have been noticed. However, after year 2010, siltation in upstream of the river has occurred. In year 2015, the main river was flowing in two channels with siltation in between these two channels upstream of the barrage.

18. Banbasa barrage was commissioned in year 1920. No remarkable changes in the water course of Sharda river have occurred. There is no sign of siltation upstream of the barrage. Lower Sharda barrage was commissioned in year 1974. Remarkable changes in the water course of Sharda river near the barrage have occured. The river has shifted right to left over the years upstream of barrage and right to left downstream of barrage.

19. The river course wanders both upstream and downstream of the bridge at chainage 168 km (Palia Kalan). There are no specific progressive shifting of the river near the bridge. At road bridge (SH26), river flows mainly in two channels upstream of the bridge. Performance of the guide bunds are satisfactory as no damage to the guide bunds and approach roads have been seen.

20. Four reaches of the Sharda river have been identified as critical. These reaches are at chainages 213-230 km (Mustafabad), 167-202 km (Dhakka Ghat), 143-160 km (Ramnagar Kalan and Bhanpur) and 53-87 km (Chandrika Gauri). In the three reaches i.e., 213-230 km, 167-202 km and 53-87 km, river has been wandering within wide width even though there is no progressive shift in the either directions. However, in the reach 143-160 km, historical images of the river indicate its progressive shift from left to right.

21. The following training works are suggested for the critical reaches

    a) Chainages 213-230 km — Embankment/ Levees
    b) Chainages 167-202 km — Guide banks, Spurs, Levees
    c) Chainages 143-160 km — Levees
    d) Chainages 53-87 km — Embankment/ Levees

22. At Road (SH 90) cum Railway Bridge at Palia Kalan, it is suggested to repair the washed out upstream mole of the right guide bund. At road bridge (SH 26) (chainage 57 km), it is suggested to protect the embankment of the road by boulder pitching or provision of series of spurs.

23. 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. A sample design of levees using flexible system is also mentioned in the report.

24. Field reconnaissance survey was conducted at various locations like Tanakpur Barrage, Banbasa Barrage, Lower Sharda Barrage, PaliaKalan 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:

(i) It is recommended to repair the washed out upstream mole of the right guide bund at Road (SH 90) cum Railway Bridge at Palia Kalan. At road bridge (SH 26) (chainage 57 km), it is suggested to protect the embankment of the road by boulder pitching and/or provision of series of spurs.

(ii) Recommended to implement the suggested measures in the identified four critical reaches of the Sharda river. It is further suggested that such reaches be studied in more details based on ground survey and analysis of high resolution satellite data.

(iii) Suggested measures are prioritized as follow:

a) Repair of washed out upstream mole of the right guide bund at Road (SH 90) cum Railway Bridge at Palia Kalan.

b) Protection of the embankment of the road by boulder pitching and/or provision of series of spurs at road bridge (SH 26) (chainage 57 km).

c) Provision of Guide banks, Spurs, Levees in the reach at Chainages 167-202 km

d) Provision of embankment/ Levees in the reach at Chainages 213-230

e) Provision of embankment/ Levees in the reach at Chainages 143-160 km

f) Provision of embankment/ Levees in the reach at Chainages 53-87 km

(iv) 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 the Sharda river to avoid outflanking of the river and to minimize protection works.

(v) Large scale de-silting from the rivers are 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.

(vi) Detailed survey of the area and data collection/analysis is proposed before implementing the recommendations, so as to incorporate the current ground conditions and river behaviour.

(vii) 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.

(viii) 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 in such a way that incoming sediment can be passed downstream during the flood time to maintain the sediment equilibrium.

Suggested Further Study

(i) 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 is suggested 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.

(ii) Erosion and siltation in the Sharda river has been studied herein on the basis of the shifting of the banks of the river. 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.

(iii) 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.

(iv) 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 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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Acknowledgements

On behalf of the project team of IIT Roorkee, I would like to acknowledge the support and help extended by the various organizations for carrying out this study. It is worth mentioning some of them like Morphology and Climate Change Directorate, CWC, New Delhi; Himalayan Ganga Division, CWC, Dehradun; Chief Engineer (UGBO), CWC, Lucknow; Chief Engineer (LGBO), CWC, Patna; Water Resources Dept., Patna; Irrigation Dept. UP; BSRDC, Patna; IWAI, Noida; Irrigation Dept., UK; Chief Engineer (Sone), Irrigation Department, Varanasi; General Manager and SE of Farakka barrage project; Director (R&D), MoWR, RD & GR, New Delhi; Director, Remote Sensing Directorate, CWC, New Delhi; GFCC, Patna; Brahmaputra Board; Executive Engineer, Irrigation Department, Roorkee.; Survey of India, Dehradun; NRSC, Hyderabad; NIH, Roorkee; AHEC, Roorkee; Faculty of Civil Eng., IIT Roorkee; Macafferri Pvt. Ltd.
Financial support received from Central Water Commission under the Plan Scheme "Research & Development Program in Water Sector", Ministry of Water Resources, Govt. of India for carrying out this study is greatly acknowledged.
We would like to thank all members of the "Consultancy Evaluation cum Monitoring Committee (CEMC)" whose valuable inputs and constructive comments improved the contents of the project.

We indebted to Hon'ble Union Minister of State, Water Resources, River Development & Ganga Rejuvenation and Parliamentary Affairs Shri Arjun Ram Meghwal for inaugurating the workshop and delivering motivating lecture.

We heartily thank Prof. A K Chaturvedi, Director, Prof. M. Parida, Dean (SRIC), and Prof. C S P Ojha, Prof. & Head, Dept. of Civil Eng, IIT Roorkee for their encouragement and support.

We owe deep gratitude to 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), Shri P N Singh, Project Director, DRIP; Shri, Shri. A K Sinha, Director, Morphology & CC Directorate for their encouragement, support and guidance. We would not forget to remember other officials of CWC, New Delhi who helped us in carrying out this study.

We are grateful to Prof. M. K. Mittal, Retd. Prof., IIT Roorkee for his timely advice for carrying out the study. Thanks to Shri Mahavir Prasad, Retired SE, UP Irrigation who accompanied us during the visit to Rapi river at its various locations.

And finally, I would like to extend my sincere esteems to Prof. Deepak Kashyap, Prof. P K Garg, Dr. R D Garg, Dr. P K Sharma and other project staff who assisted me in timely completion of the project work.

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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 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 braid. 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). 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 arrange 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; and 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).

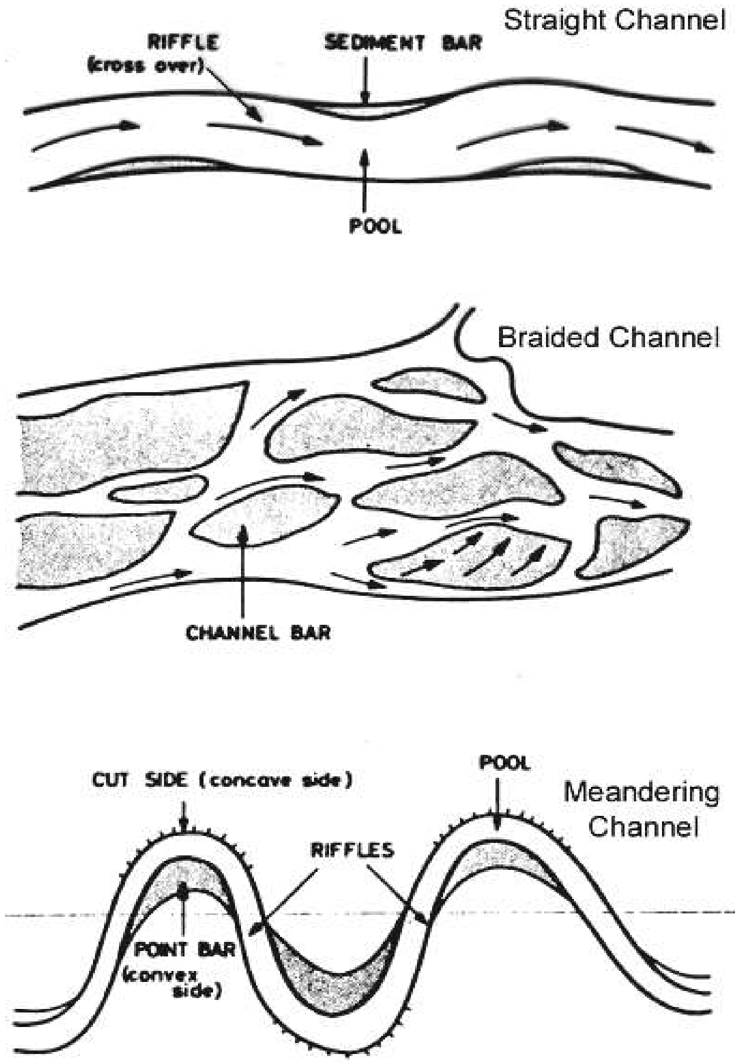


Figure 1.1 Channel Patterns

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 term of erosion length & erosion area w.r.t. base year at 50 km interval.

vi. Assess 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 LIS-I, LIS-II, LIS-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, LIS-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 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 alongwith 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 Bihar. It include 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. The 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.

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 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 southern western part of the island. Increases 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 flood plain 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 the 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 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 (1993) and recently in 2008 but in comparison of pre barrage operations year 1977 and 1990 where Plan Form Index (PFI) values have shown an increasing trend in most of the reaches indicating less braiding of the river planform. 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.

Tiwari (2000) studied the land use changes in Himalaya, rapid growth of population and large-scale deforestation. He concluded that the irrational land transformation process has not only disrupted the ecological balance of the Himalayan watersheds through reduced groundwater recharge, increased run-off and soil erosion, but has also adversely affected the ecology and economy of the adjoining Indo-Gangetic plains by recurrent floods and decreased irrigation potential. In order to assess the environmental impact of mountain land-use changes on adjoining plains ecosystem, detailed studies in the principal river basins, in Bhabar and Tarai tracts, were carried out. Four parameters were taken into account for the environmental impact assessment. These parameters are (a) rise in the river beds due to siltation, (b) loss of irrigation potential due to reduced water-generating capacity in the mountains, (c) increase in area affected by recurrent floods, and (d) increase in cultivated land devastated by floods. The process of siltation is also alarming in Sharda (26 cm/yr), Kosi (25 cm/yr) and Nandhur (24 cm/yr). But the magnitude of siltation is comparatively lower in the Ramganga (West) river. On an average, the land under irrigation has declined by 1.3% in Sharda, 3.1% in Dabka, 4.3% in Ramganga (Wests), 6.3% in Nandhaur, 7.3% in Gola and as much as 8.7% in Kosi basin of the region during the period 1970-1995. The rise in agricultural area damaged by recurrent floods ranges between 10.3% in Nandhaur valley and 47.3% in Sharda basin.

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 Ganges River, from the India–Bangladesh border and the Padma, and 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 banks 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 al., 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. Large scale morphological features of large river systems such as the Majuli Island of the Brahmaputra.

River support human populations 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 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 characterised 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 year 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 percent of which is accounted for by bicarbonate ions only.

Shukla and Asthana (2005) studied the inter linking of river in India. The interlinking river project was separated into two primary components that is Himalayan and Peninsular Rivers. The Himalayan Component proposes fourteen canals and the Peninsular Component sixteen. 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 Krishna entails pumping 1,200 cusecs of water over a crest of about 116 m. 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 6×106 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 orogenic 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.

Schwenk et al. (2016) studied the planform changes of large, active meandering rivers at high spatio-temporal 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.

Midha and Mathur (2010) evaluated channel changes in the Sharda River and their implications on an area of high biodiversity value and conservation significance. They also described river channel changes and determined their effects on swamp deer habitat and on floodplain pattern from year 1948 to 2001, and constructed a probability model of channel configuration during the timeframe of the assessment period to assist managers in assessing channel stability in the study area and risk of channel encroachment to Jhadi *taal*. Results showed the instability and continuous shift of Sharda River channel towards Jhadi *taal.* This instability brought the west bank line closer to Jhadi *taal* by 100 m in 2001 and was posing a potential threat to it.

Midha and Mathur (2013) used multi-temporal satellite imagery and geographic information system analysis to assess the planform dynamics along a 60 km length of the Sharda River between 1977 and 2001 to understand the altered dynamics and its plausible causes in this data-poor region. Analyses revealed that the Sharda River has undergone significant change corresponding to enhanced instability in terms of increased number of neck cut-offs and consistent occurrence of avulsions in subsequent shorter assessment periods. The Sharda River has migrated toward the east with its west bankline being more unstable. The maximum channel shifting was approximately 2.5 km in all the assessment periods.

2.2 CONCLUDING REMARKS

Review of the available literature related to morphology of the rivers indicates that various investigators have investigated the morphology of the rivers in the 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 Sharda river is not available in the literature. In view of this gap, this study has been taken up.

Chapter 3 RIVER BASIN

3.1 SHARDA RIVER BASIN

Sharda river originates from the greater Himalayas at an altitude of 3600 m, in the Pithoragarh district of Uttarakhand, India, and joins with the Gori Ganga at Jauljibi, which in turn joins the Saryu River at Pancheshwar.

The river borders the Nepalese Mahakali river zone and the Indian state of Uttarakhand. The river flows in a gorge section in the upper region. The Mahakali river after it descends into the plains into India is known as Sharda river, which meets the Ghaghra river (Karnali in Nepal) in Indian Territory at about 323.5 km from the existing Upper Sharda barrage at Banbasa as shown in Fig. 3.1. Mahakali River flows for a length of 223 km length in Nepal and 323.5 km in India up to its confluence with Ghaghra River. Figure 3.2 shows a sample map of Sharda river basin layers procured from WRIS.

There are five factors such as parent material, climate, topography, organism and time involved in the soil formation. These factors vary across the Sharda river basin. Thus, the major soils of the basin are as: red, tarai and alluvial soil.

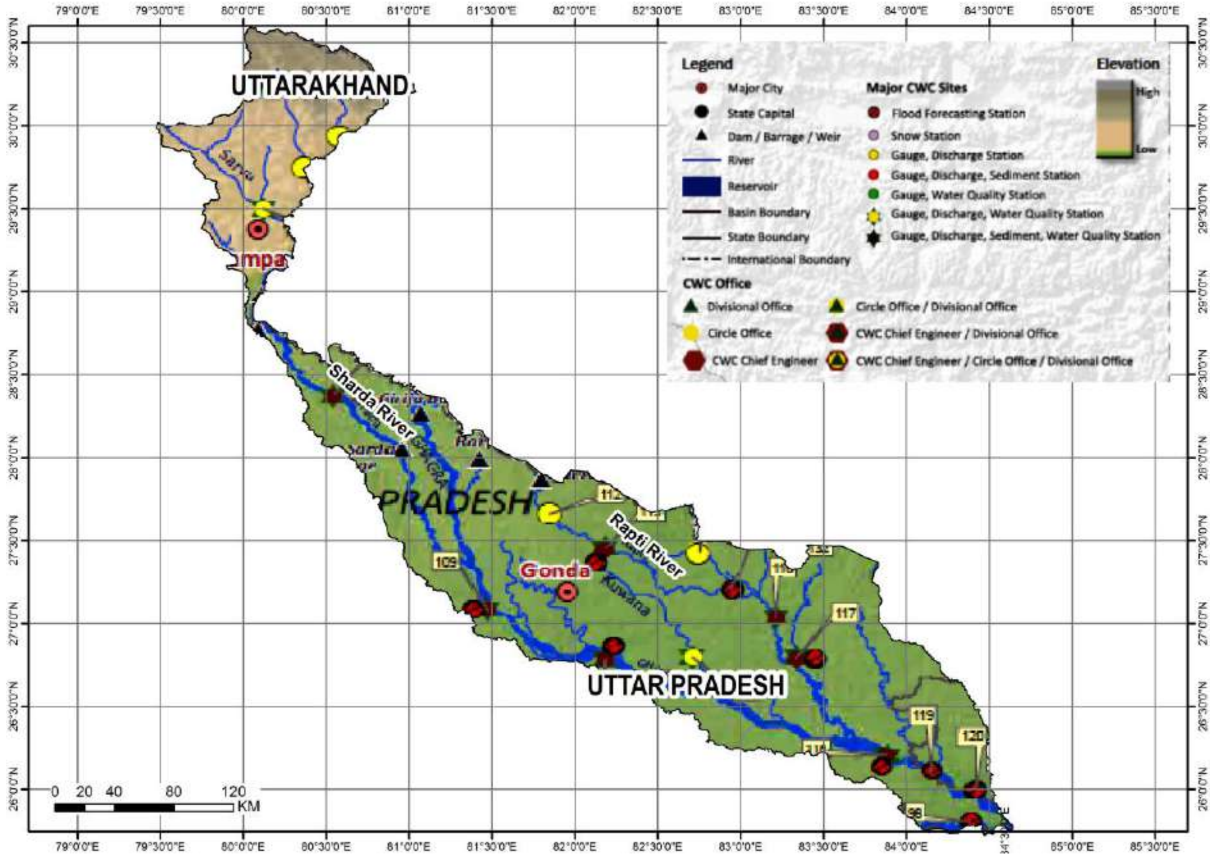


Figure 3.1 River basin map of Rapti - Sharda - Ghaghra Basin (Source: WRIS)

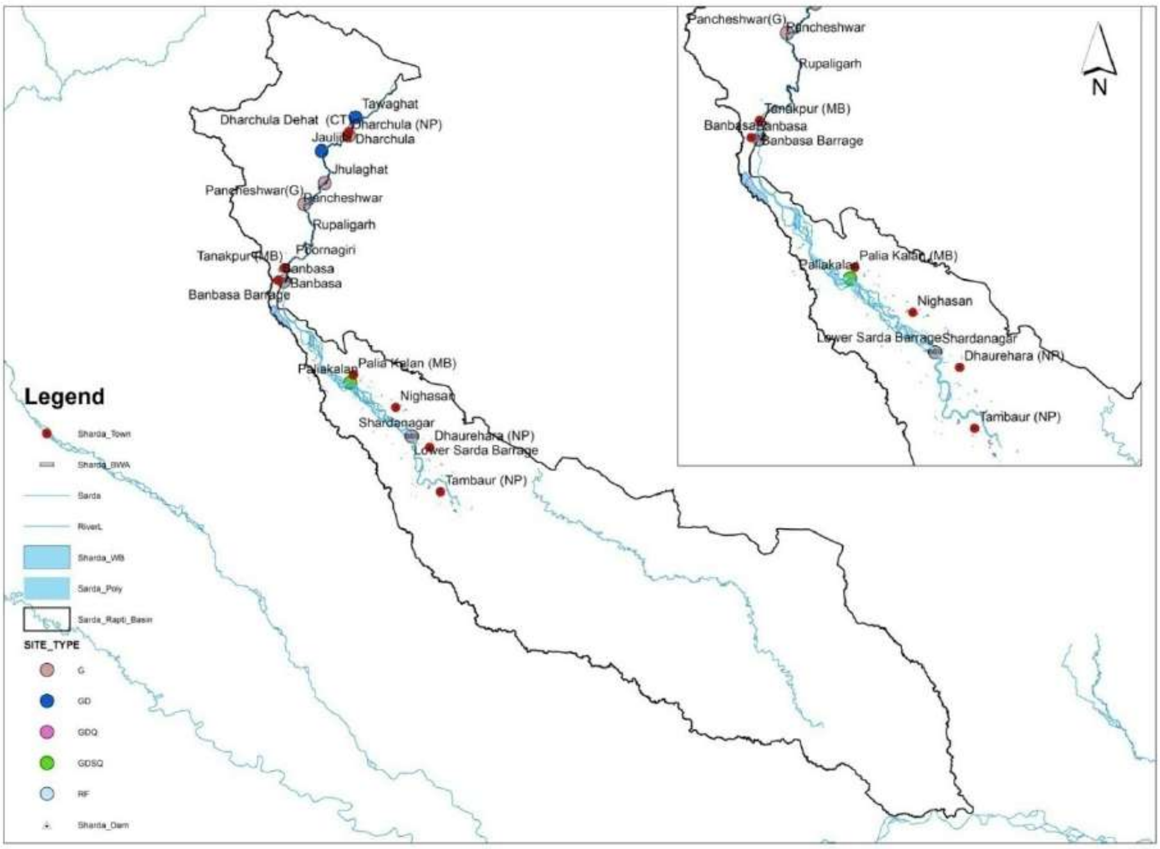


Figure 3.2 Sharda river basic layers (Source: WRIS)

3.2 CLIMATE

Due to difference in altitude, the Sharda river basin has two distinct climatic regions, the temperate climate prevails in the mountainous region while the plain has subtropical climate.

Like most of northern India, Sharda Basin has an extreme Humid Subtropical with dry winter type of climate. Summers are hot with temperatures rising up to 40 °C. During winters from mid-October to mid-March, temperatures hover between 20 and 30 °C. Prevalent winds are westerly. The hot wind *'Loo'* blows strongly from mid-April up to end of May. Monsoon starting in mid-June and lasting up to September accounts for 90% of the rainfall of 150 cm. Temperatures range between a minimum of 9 °C in winter to a maximum of up to 45 °C in peak summer.

3.3 METEOROLOGICAL STATIONS

Meteorological sites (rain gauge sites) of the Indian Meteorological Dept. located in the basin of the Sharda river are shown in Fig. 3.3.

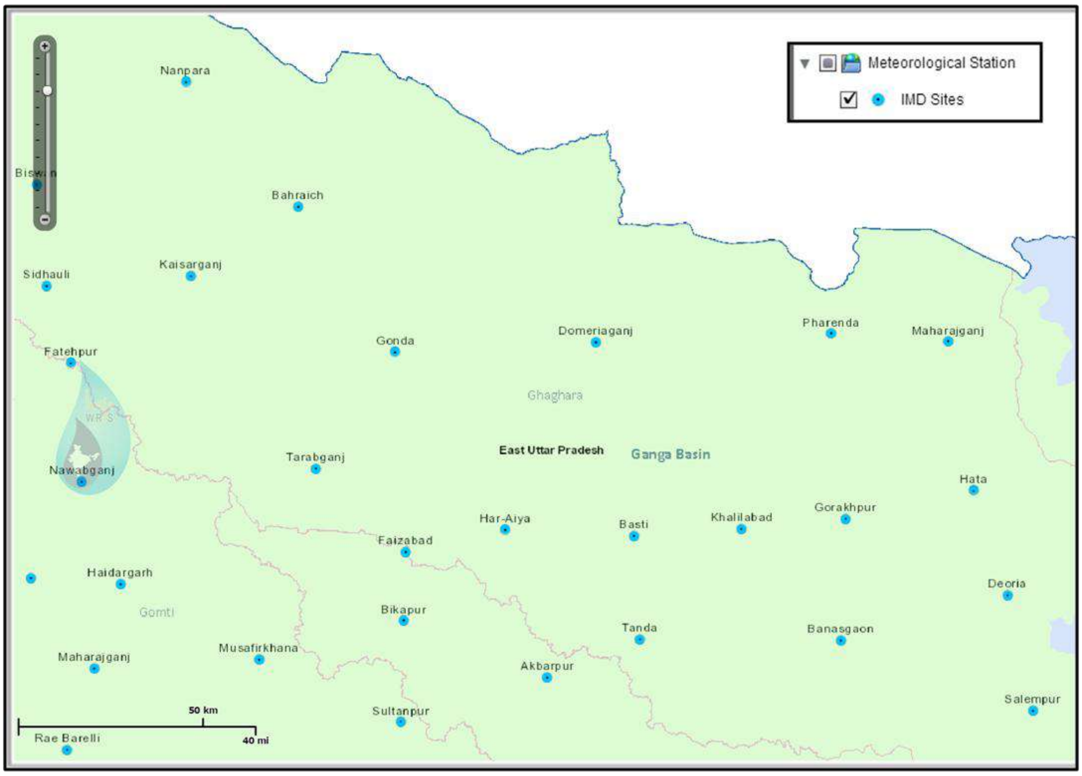


Figure 3.3 Rain gauge stations in Sharda Basin (Source: WRIS)

3.4. BASIN GEOLOGY

Geologically, the Sharda river basin may be divided into three zones:

- The northern mountain zone or Shiwalik Himalaya,
- The *tarai* zone, and
- The plain zone.

The Northern Mountain Zone or Shiwalik Himalaya: It forms the foothills of the Himalayan Range and is essentially composed of Miocene to Pleistocene molassic sediments derived from the erosion of the Himalaya. These molasse deposits, known as the Muree and Siwaliks formations, are internally folded and imbricated. The sub Himalaya is thrust along the Main Frontal Thrust over the Quaternary alluvium deposited by the rivers coming from the Himalaya (Ganges, Indus, Brahmaputra and others), which demonstrates that the Himalaya is still a very active orogeny.

The Tarai Zone: The Tarai is crossed by the large perennial Himalayan rivers Yamuna, Ganges, Sharda, Karnali, Narayani and Kosi that have each built alluvial fans covering thousands of square kilometres below their exits from the hills. Medium rivers such as the Rapti rise in the Mahabharat Range. The geological structure of the region consists of old and new alluvium, both of which constitute alluvial deposits mainly of sand, clay, silt, gravels and coarse fragments. The new alluvium is renewed every year by fresh deposits brought down by active streams, which engage themselves in fluvial action. Old alluvium is found rather away from river courses, especially on uplands of the plain where silting is a rare phenomenon.

The Plain Zone: The reduction in slope as rivers exit the hills and then transition from the sloping Bhabhar to the nearly level Tarai causes current to slow and the heavy sediment load to fall out of suspension. This deposition process creates multiple channels with shallow beds, enabling massive floods as monsoon-swollen rivers overflow their low banks and shift channels. Many areas show erosion in the form of gullies. This area consists of highly fertile and is arable land.

Geology of Rapti - Sharda - Ghaghra Basin as obtained from GSI is shown in Fig. 3.4.

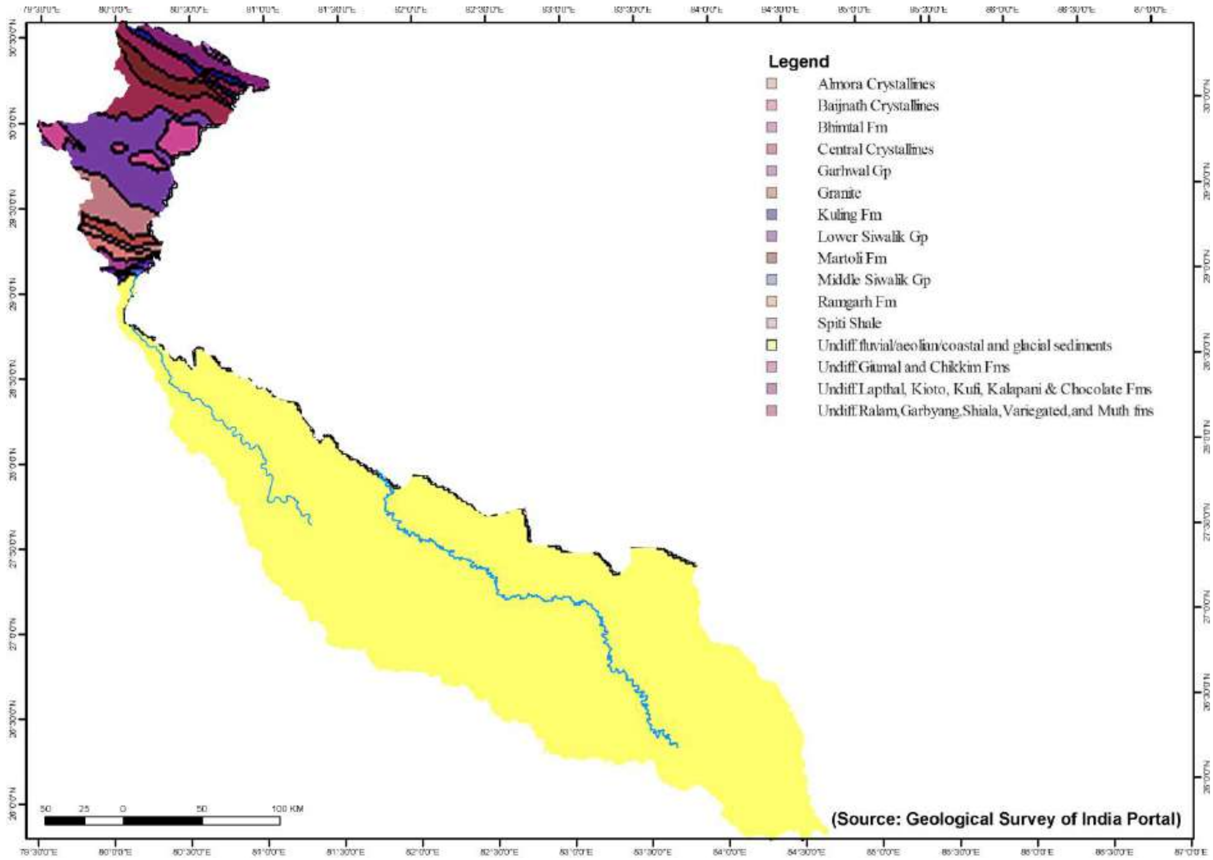


Figure 3.4 Geology of Rapti - Sharda - Ghaghra Basin (Source: GSI)

3.5 LAND USE & LAND COVER

Land use land cover map of Rapti - Sharda - Ghaghra Basin as obtained from WRIS is shown in Fig. 3.5, while Fig. 3.6 shows land use land cover map of Sharda basin explicitly.

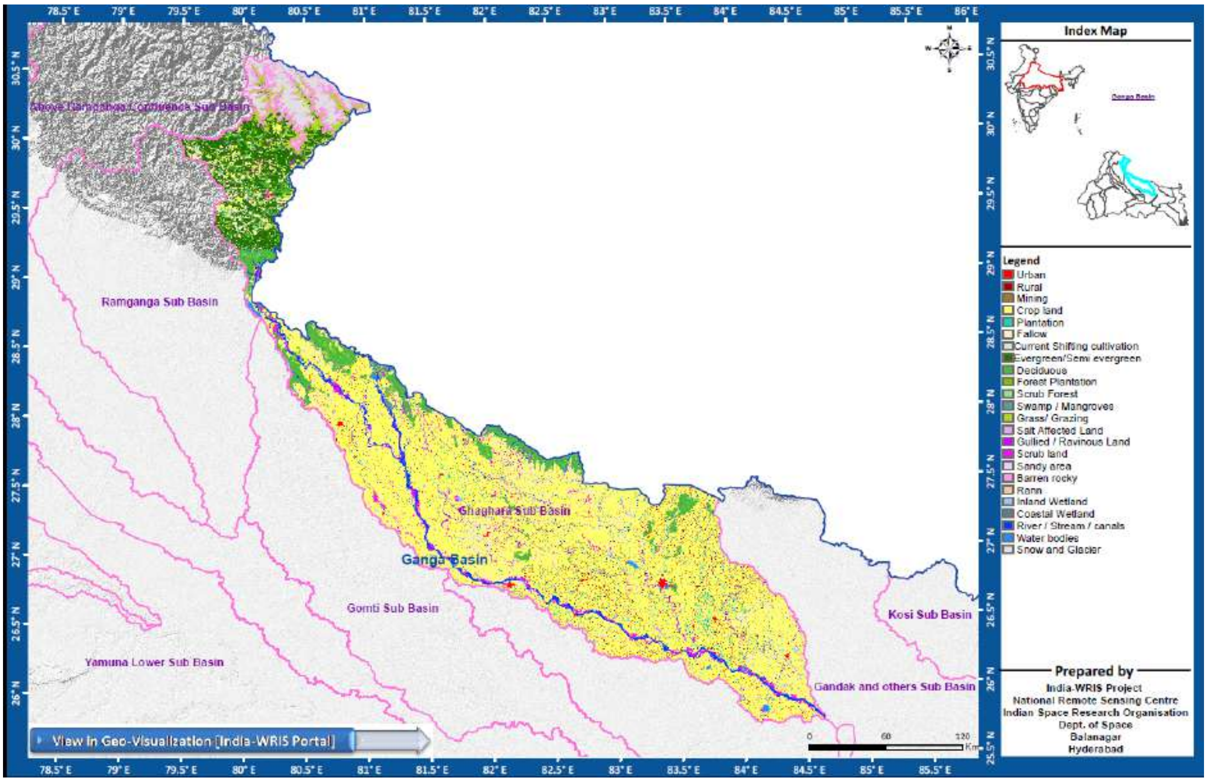


Figure 3.5 Land Use Land Cover Map of Rapti - Sharda - Ghaghra Basin (Source: WRIS)

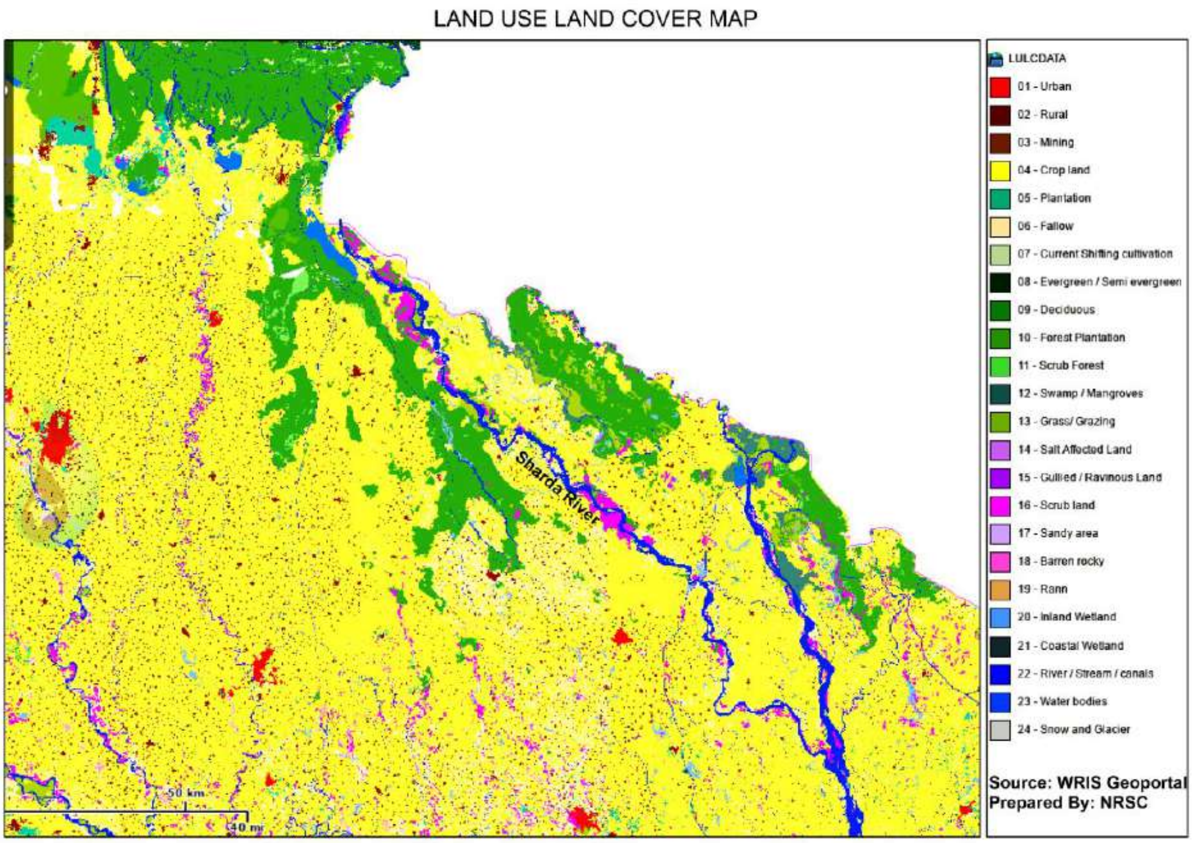


Figure 3.6 Land Use Land Cover Map of Sharda Basin (Source: WRIS)

3.6 FLOOD AFFECTED AREA

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).

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.

Generation of the Flood hazard zones was done 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.

Flood hazard zone map of Rapti - Sharda - Ghaghra Basin as obtained from NRSC is shown in Fig. 3.7, while Fig. 3.8 shows flood hazard zone map of Sharda basin explicitly.

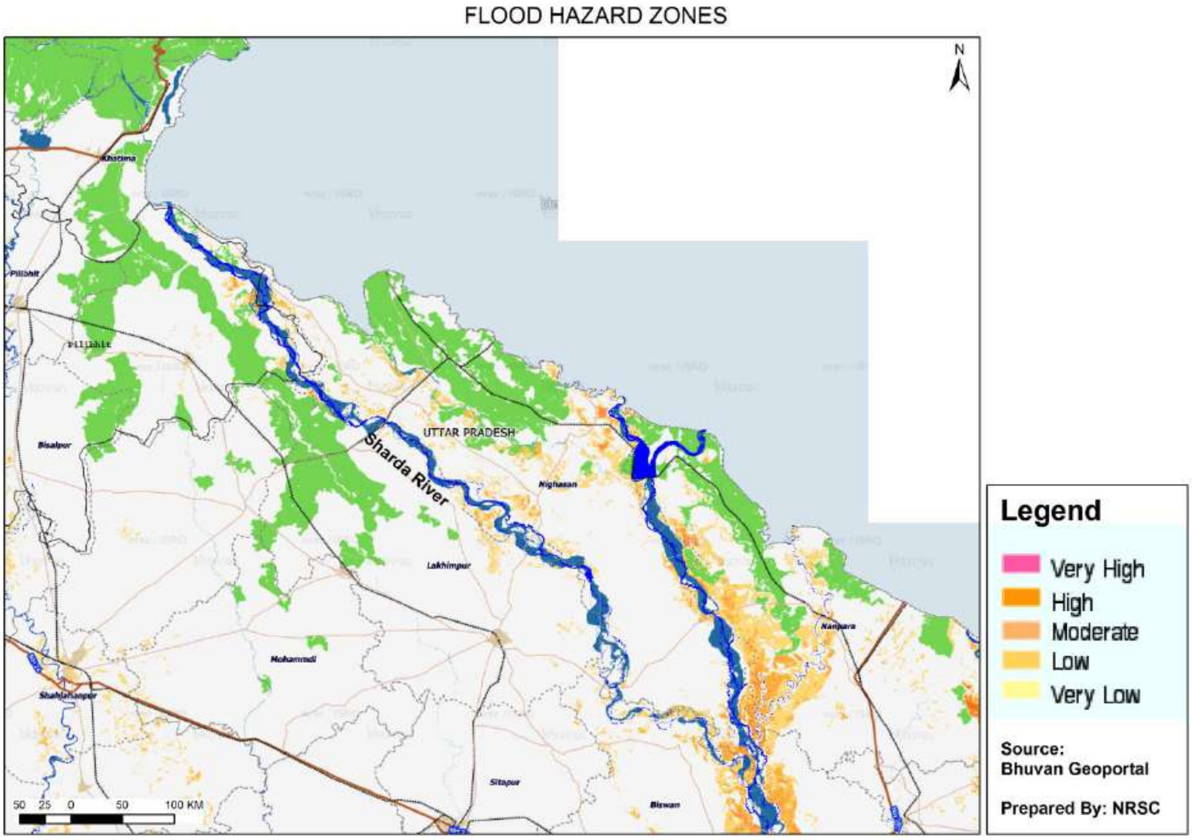


Figure 3.7 Flood Hazard Zone Map of Sharda - Ghaghra Basin (Source: NRSC

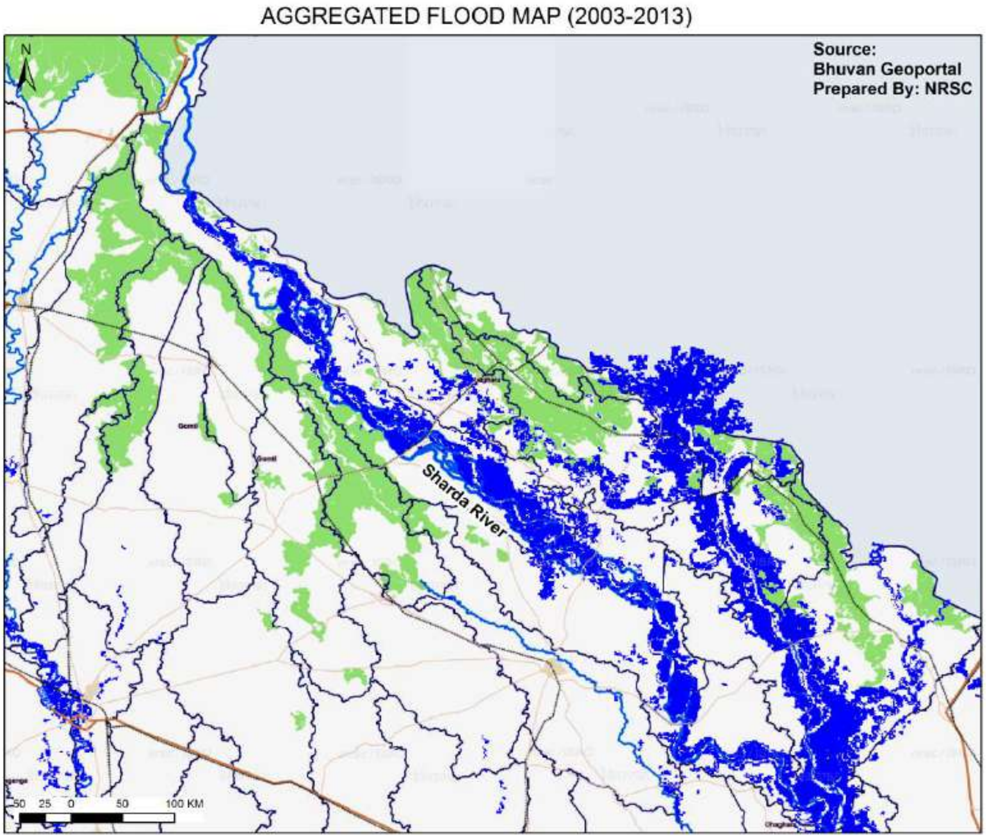


Figure 3.8 Aggregated flood map of Sharda Basin from 2003-2013 (Source: NRSC)

Sunita and Dinkar (2015) estimated the inundated areas near Sharda Rivers based on satellite data of previous flood and hydrological data that is water level. The maximum flood was observed with respect to rise in water level at three gauge stations of Sharda River during year 2009 from the observation of all the graphs based on flood inundated areas and water level and inundation maps and their corresponding information about area of the districts, blocks and villages:

i. The water level at Banbasa gauge station was 220.35m, the maximum flood was observed and 2394.70 ha area was affected due to flood.

ii. The water level at Paliyakala gauge station was 154.62m., the maximum flood was observed and 6248.57 ha area was affected due to flood.

iii. The water level at Sharda Nagar gauge station was 136.10m., the maximum flood was observed and 10589.97ha area was affected due to flood.

iv. Based on satellite data of previous flood and hydrological data, the flood inundated areas along Sharda River were estimated.

The area of flood inundation in downstream of each gauge station of Sharda River during year 2008 and 2009 iare shown in Figs. 3.9 and 3.10, respectively.

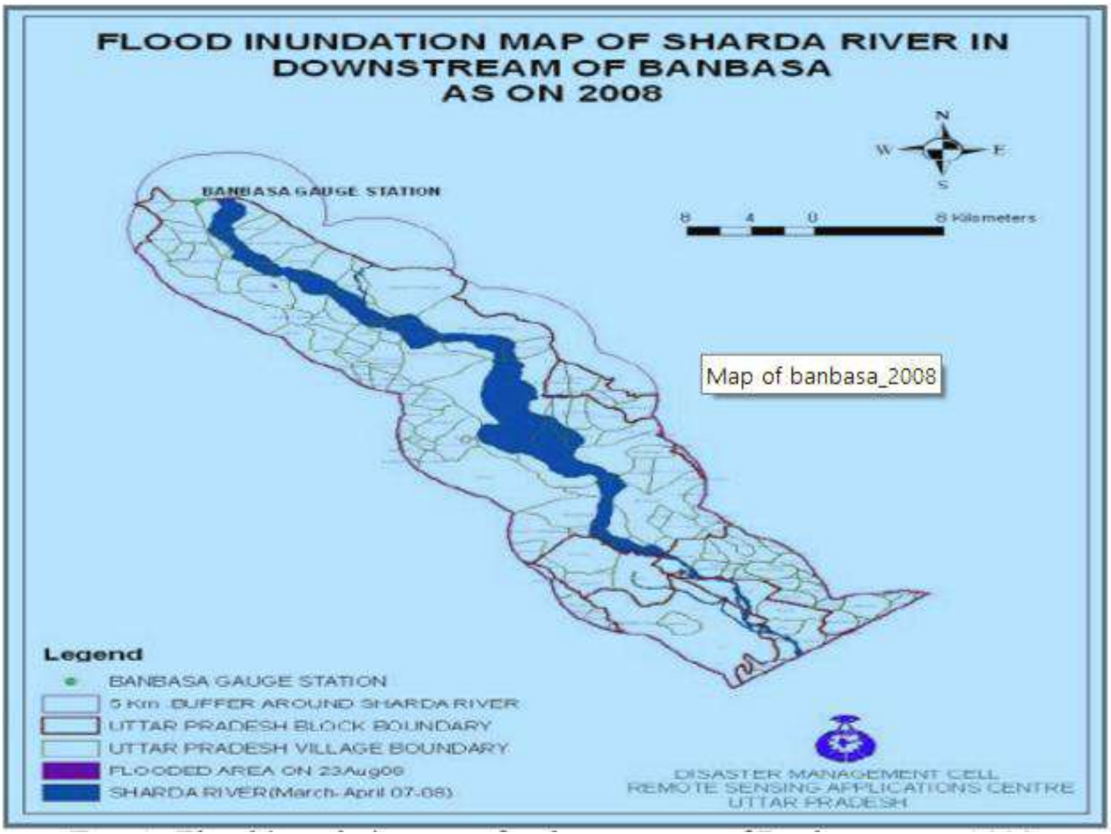


Figure 3.9 Flood inundation map for downstream of Banbasa as on 2008 (Sunita and Dinkar 2015)

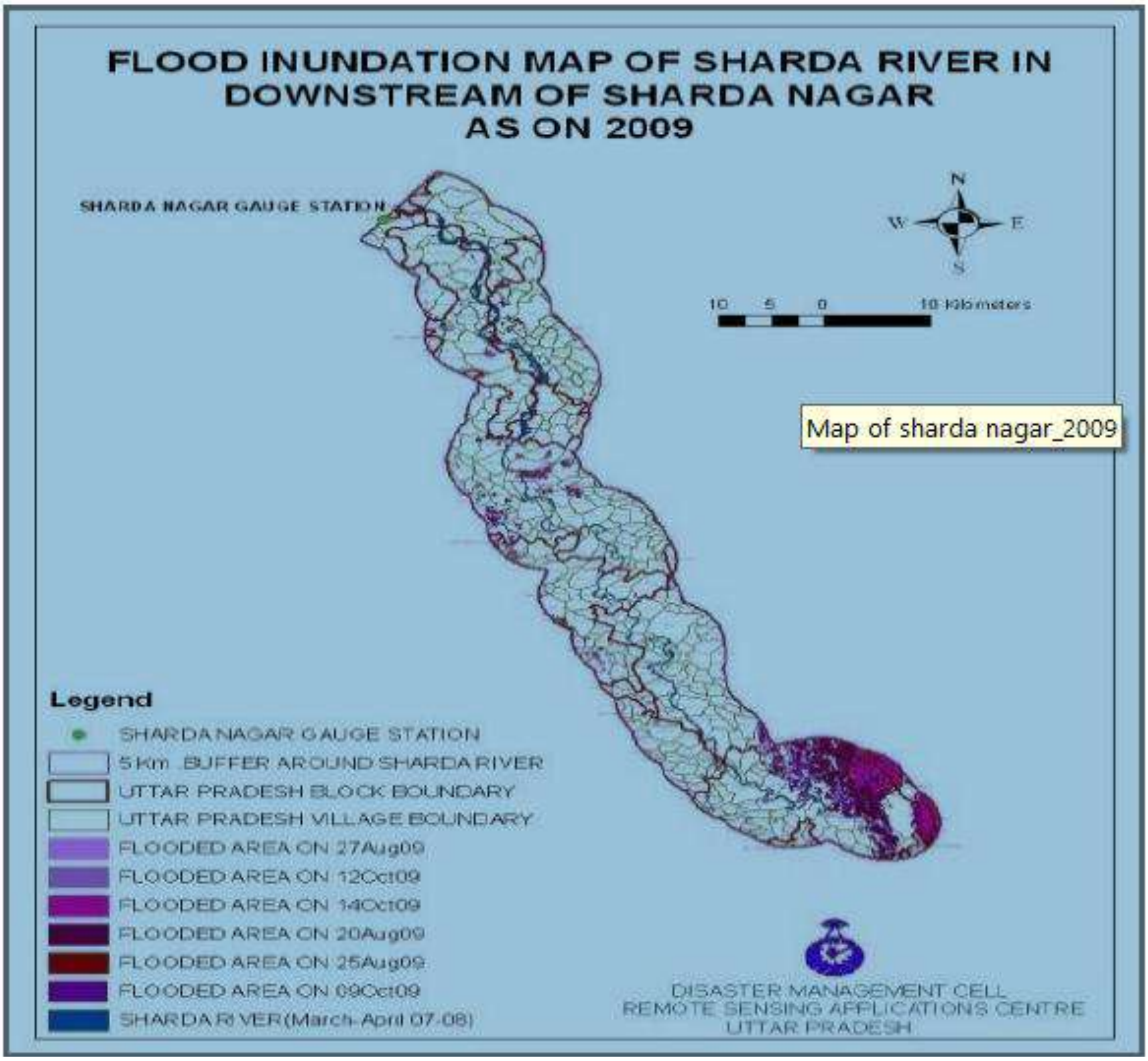


Figure 3.10 Flood inundation map for downstream of Sharda Nagar as on 2009 (Sunita and Dinkar 2015)

3.7 CONCLUDING REMARKS

Various aspects of the Sharda basin related to topography, soil, climate, geology, meteorological stations, land use land cover, flood map etc. are compiled in this chapter from the different sources like GSI, WRIS, NRSC. Following points may be noted in the respect of basin of the Sharda river:

a) Like most of northern India, Sharda Basin has an extreme Humid Subtropical with dry winter type of climate. Summers are hot with temperatures rising up to 40 °C.

b) A good number of Raingauge stations have been installed by IMD in the Sharda basin.

c) Geologically, the Sharda river basin may be divided into three zones: i) The northern mountain zone or Shiwalik Himalaya, (ii) The tarai zone, and (iii) The plain zone. The studied area is mainly in plain zone. Geological map of the Sharda river indicates that it is consisted of fluvial.

d) Land use and land cover map of the basin indicates that it is dominated by crop land followed by forest plantation. Scrub land can be seen along the Sharda river.

e) Flood Hazard Zone Map of Sharda indicates moderate flooding in the areas along the river flow.

Chapter 4 STUDY REACH

4.1 THE STUDY AREA

The reach of the river Sharda studied in this project work is from Tanakpur to confluence point of Sharda and Ghaghra which lies between longitudes 80°00' E to 81°20' E and latitudes 27°36' N to 29°10' N (Fig 4.1). The area is entirely an alluvial plain and the land is highly fertile. In this stretch, river course changes considerably in magnitude as well as direction. The area upstream of Manuhan up to Nepal border could not be taken because of non-availability of Survey of India (SOI) toposheets for this area. The Sharda river basin is diverse in its physiography. The lofty mountain, inner and outer Tarai and undulating plain regions constitute the topography of the entire basin. Due to difference in altitude, the Sharda river basin has two distinct climatic regions, the temperate climate prevails in the mountainous region while the plain region has subtropical climate. A photograph of Sharda river upstream of the Banbasa barrage is shown in Fig. 4.2.

Total drainage area : 18,140 km^2

Drainage area within study reach : 5132.81 km^2

Important Tributaries within Study Reach: Bamni, Ghaghi, Jagbura, Old Chauka

Important Habitat : Tanakpur, Banbasa, Palia Kalan, Nighasan

Water Resources Projects : Tanakpur Barrage, Banbasa Barrage, Lower Sharda Barrage, Sharda Canal (Fig. 4.3)

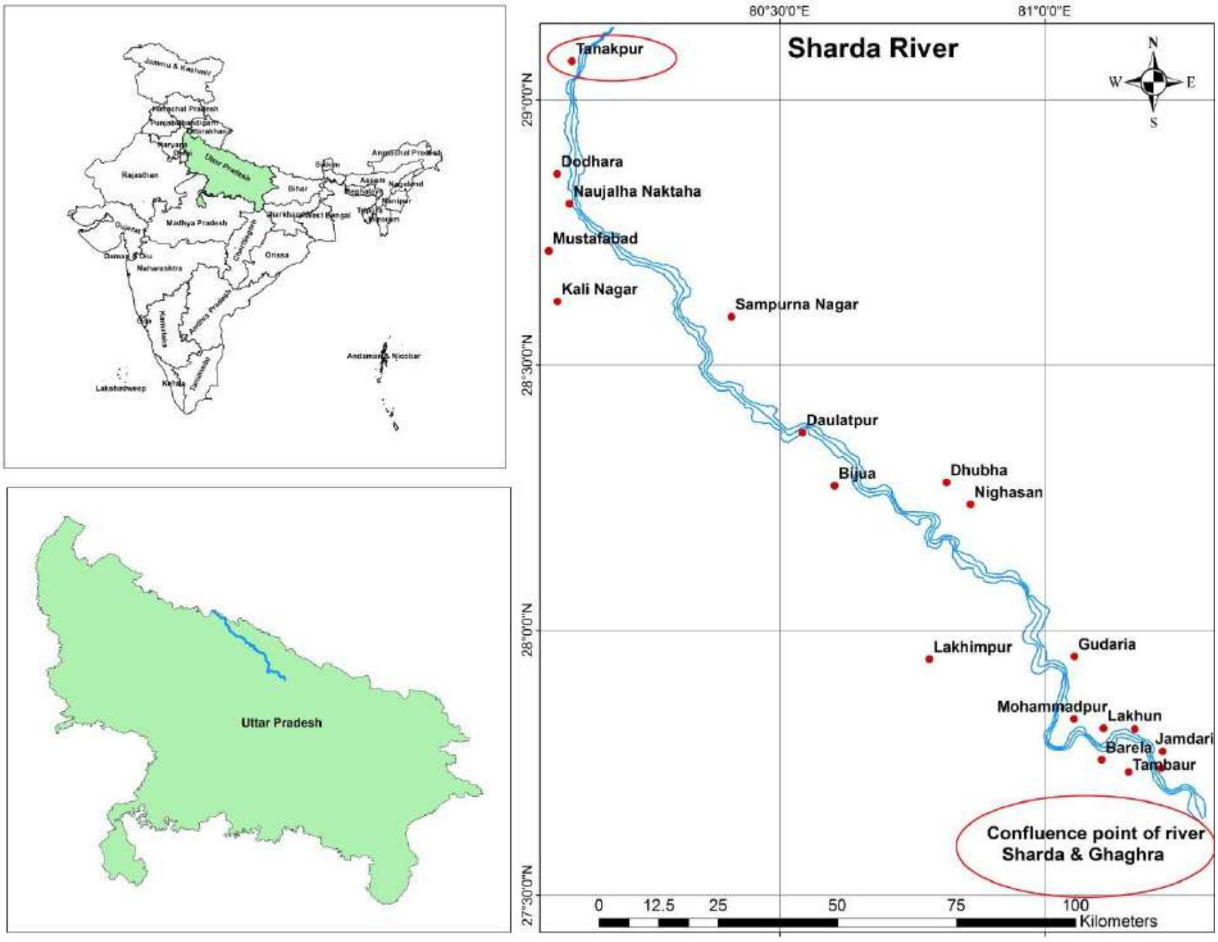


Figure 4.1 River Sharda from Tanakpur to confluence point of Sharda and Ghaghra river

Figure 4.2 Sharda river at Banbasa barrage

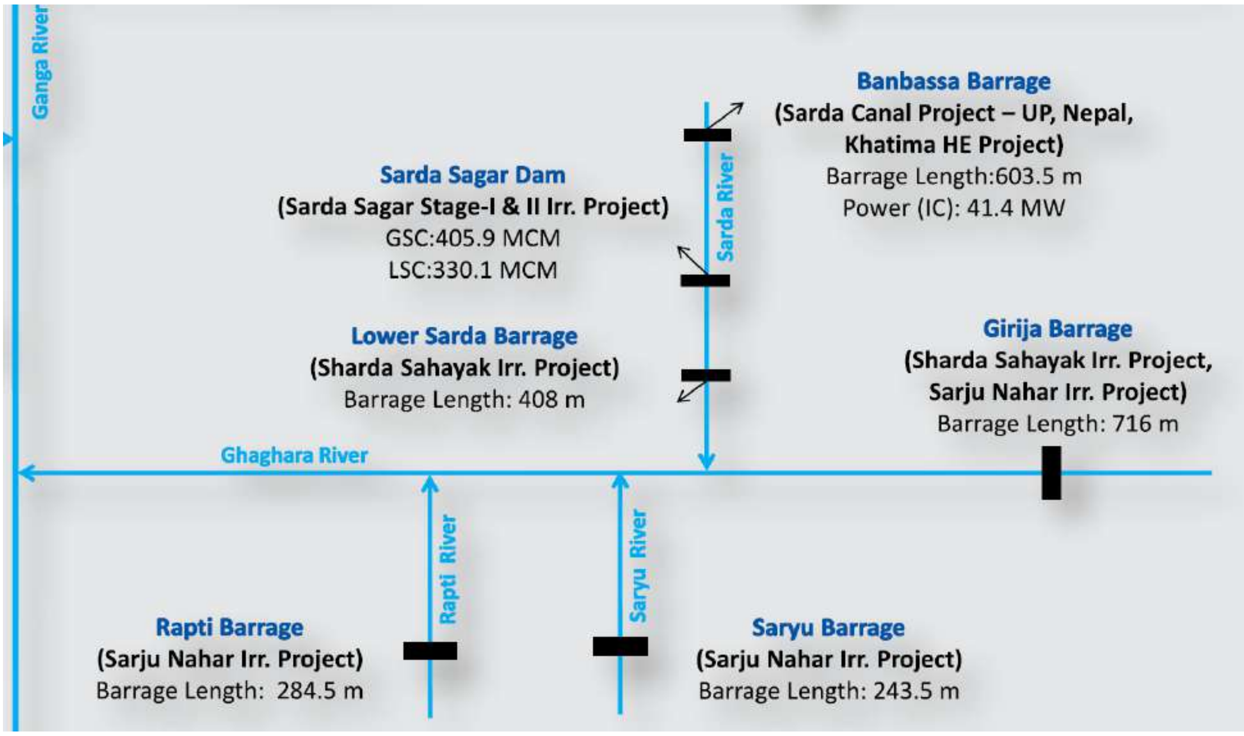


Figure 4.3 Major water resources projects (Source: INDIA-WRIS, 2012)

4.2 CONCLUDING REMARKS

Morphological changes of the rivers are more pronounced in the plain area. Therefore, in this study, considered reach of the Sharda river is relatively flat and varies from elevation 150 m to 115 m. It starts from Tanakpur and ends at the confluence point of Sharda river with Ghaghra river.

Chapter 5 INPUT DATA & METHODOLOGY

5. 1 HYDRO-METEOROLOGICAL DATA

The various gauging sites on Sharda River as given in Table 5.1 and shown in Fig. 5.1 were identified and requisition was sent to concerned Chief Engineers of CWC for the procurement of the data comprising of annual minimum and maximum discharge and water level data, 10-daily discharge, water level and silt data and also cross-section data.

Table 5.1 Hydro-meteorological data

S. No.	Name of River	Name of G&D Sites	District	Chainage (km)	Concerned Agency
1.	Sharda	Banbasa	Nainital, UK	275	CWC (MGD-I), Lucknow
2.	Sharda	Palia Kalan	Lakhimpur, UP	166	CWC (MGD-I), Lucknow
3.	Sharda	Sharda Nagar	Lakhimpur, UP	57	CWC (MGD-I), Lucknow

Following data have been received:

a) Gauging Site: Banbasa

Maximum water level from year 1974-2015

b) Gauging Site: Palia Kalan

Maximum water level from year 1961-2015

Maximum discharge from year 1961-2015

10-daily silt data year 1961-2015

Cross-sectional data: Pre-monsoon 2010, 2012, 2013 and 2014

Post-monsoon 2010, 2012 and 2013

c) Gauging Site: Sharda Nagar

Maximum water level from year 1971-2015

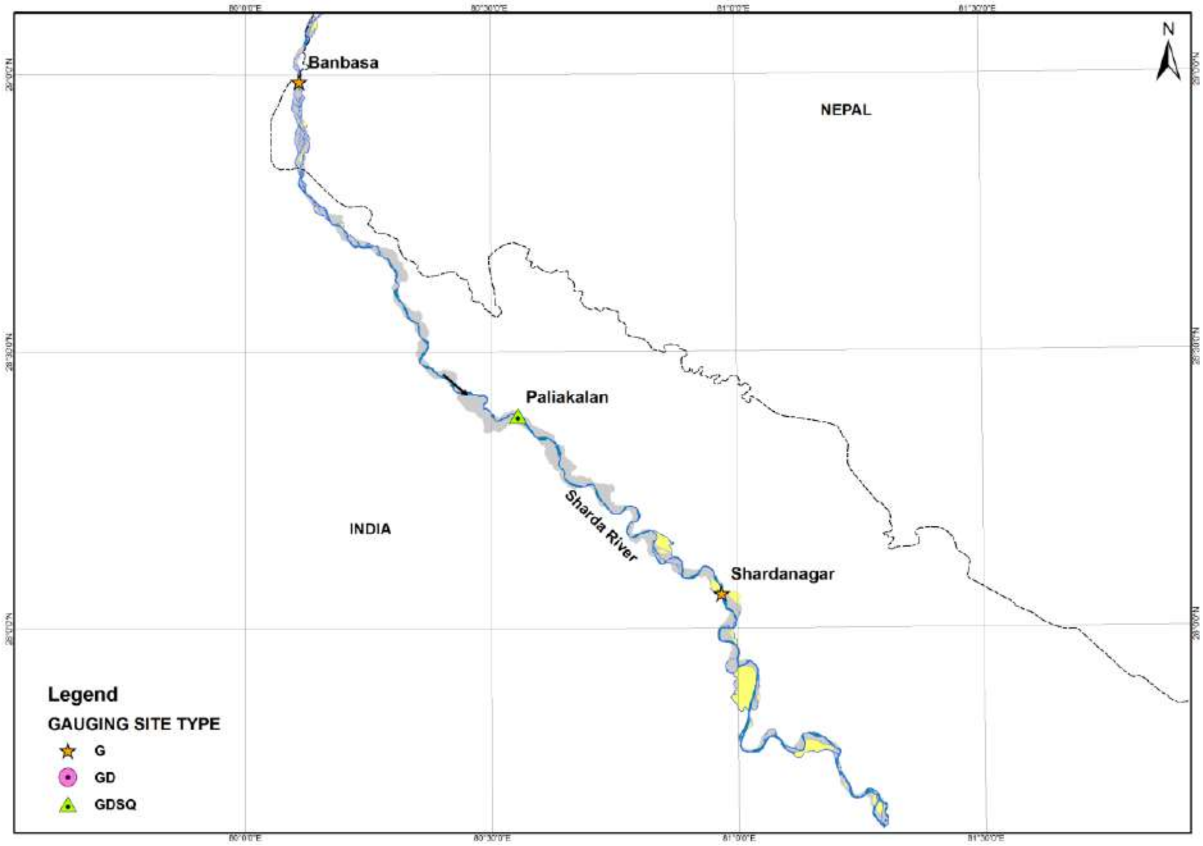


Figure 5.1 Location of Gauging Sites

5.2 TOPOSHEETS AND SATELLITE DATA

For the present study, data have been procured from government 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 5.2 and the specifications of sensors are given in Table 5.3.

Table 5.2 Data used and their sources

<table>
<tr><th colspan="7">Toposheets</th></tr>
<tr><th>S. No.</th><th colspan="3">Data</th><th>Data Source</th><th>Date/Year</th><th>Scale</th></tr>
<tr><td rowspan="5">1</td><td colspan="3">Toposheets</td><td rowspan="5">SOI, Dehradun</td><td rowspan="5">1968 onwards</td><td rowspan="5">1:50,000</td></tr>
<tr><td>62 D/1</td><td>62 D/2 (1968)</td><td>62 D/6</td></tr>
<tr><td>62 D/7 (1969)</td><td>62 D/11 (1969)</td><td>62 D/12 (1969)</td></tr>
<tr><td>62 D/16 (1969)</td><td>63 A/13 (1977)</td><td>63 E/1</td></tr>
<tr><td>63 E/2</td><td>63 E/6</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">Remote Sensing Digital Data</th></tr>
<tr><td rowspan="14">2</td><th>Sensor</th><th>Data Source</th><th>Date/Year</th><th>Path</th><th>Row</th></tr>
<tr><td rowspan="2">Landsat MSS</td><td rowspan="2">GLCF & USGS website</td><td>01/01/1979</td><td>155</td><td>40</td></tr>
<tr><td>01/10/1980</td><td>155</td><td>41</td></tr>
<tr><td rowspan="2">Landsat TM</td><td rowspan="2">GLCF & USGS website</td><td>23/10/1990</td><td>144</td><td>40</td></tr>
<tr><td>21/11/1989</td><td>144</td><td>41</td></tr>
<tr><td rowspan="2">IRS 1C LISS III</td><td rowspan="2">NRSC Hyderabad</td><td>08/10/2000</td><td>99</td><td>51</td></tr>
<tr><td>13/10/2000</td><td>100</td><td>52</td></tr>
<tr><td rowspan="2">IRS P6 LISS III</td><td rowspan="2">NRSC Hyderabad</td><td>28/10/2010</td><td>99</td><td>51</td></tr>
<tr><td>02/11/2010</td><td>100</td><td>52</td></tr>
<tr><td rowspan="4">Resourcesat 2 LISS IV</td><td rowspan="4">NRSC Hyderabad</td><td>04/11/2010
07/11/2015</td><td>99</td><td>51 A</td></tr>
<tr><td>04/11/2010
07/11/2015</td><td>99</td><td>51 C</td></tr>
<tr><td>04/11/2010
07/11/2015</td><td>99</td><td>51 D</td></tr>
<tr><td>03/12/2011
12/11/2015</td><td>100</td><td>52 A</td></tr>
</table>

Table 5.3 Sensor specifications

Specification	LANDSAT MSS	IRS 1C LISS III	IRS P6 LISS III
Spectral Bands	1-4	1-4	1-4
Spatial Resolution (m)	60	23.5	23.5
Swath Width (km)	185×185	141	141
Radiometric Resolution (bits)	8	7	7

5.3 SOFTWARE

The flowing softwares have been used in this study

- ArcGIS 10.2

- ERDAS Imagine 10.1
- Microsoft Office & Excel
- Sigma Plot
- Matlab

5.4 ACQUISITION OF DATA AND GEO-REFERENCING OF IMAGES

Firstly, the Survey of India toposheets (1:50000 scale) which cover the area of interest are procured. Then, these toposheets have been 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 NRSC (National Remote Sensing Centre), Hyderabad or 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.

5.5 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 Sharda 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.

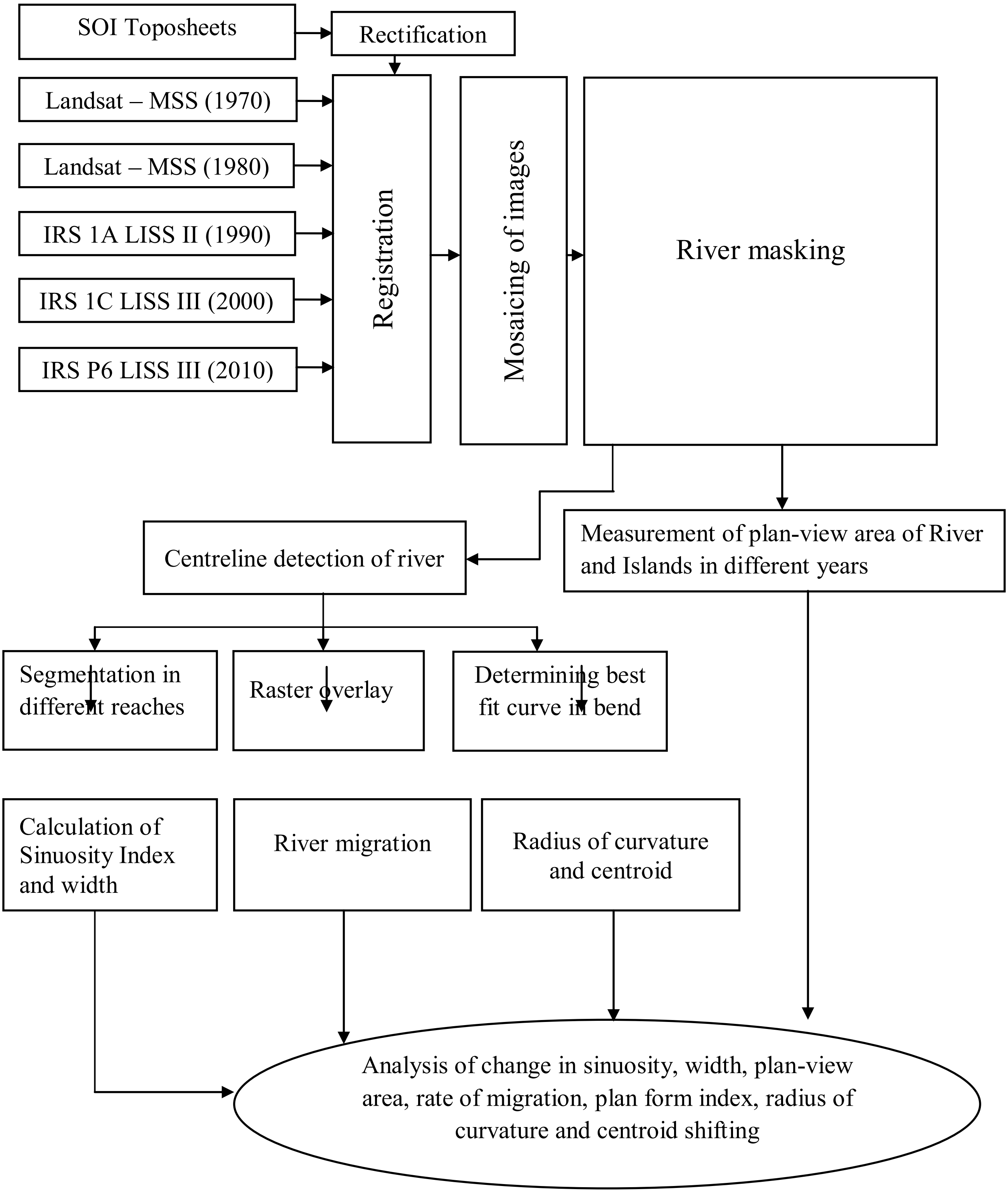


Figure 5.2 Flowchart of the methodology

5.6 FLOW PROBABILITY CURVES

Flood frequency analysis shall be 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 shall also be 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, second highest 2 and like-wise others. This arrangement of data gives an estimate of the exceedance 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

i. Gumbel's extreme value distribution method

ii. Log-Pearson Type-II distribution

iii. Log normal distribution

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.

5.7 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 6 HYDROLOGICAL DATA PROCESSING & ANALYSIS

6.1 INTRODUCTION

In this chapter, available discharge and water level data at the various gauging sites of the Sharda river have been analysed. Trend analysis of the maximum discharge and maximum water level has been carried to investigate the trend of variation of the these parameters with time. Further, peak discharge for different return periods have also been estimated using frequency analysis.

6.2 HYDROLOGICAL DATA

The various gauging sites on Sharda River as given in Table 6.1 were identified and requisition was sent to concern Chief Engineers of CWC for the procurement of the data of annual minimum and maximum discharge and water level data, 10-daily discharge, water level and sediment and cross-section of the river.

Table 6.1 Hydrological data of the Sharda river

S. No.	Name of River	Name of G&D Sites	District	Chainage (km)	Concerned Agency
1.	Sharda	Banbasa	Nainital, UK	275	CWC (MGD-I), Lucknow
2.	Sharda	Palia Kalan	Lakhimpur, UP	166	CWC (MGD-I), Lucknow
3.	Sharda	Sharda Nagar	Lakhimpur, UP	57	CWC (MGD-I), Lucknow

Following hydrological data were received:

a) Gauging Site: Banbasa

Maximum water level from year 1974-2015

b) Gauging Site: Palia Kalan

Maximum water level from year 1961-2015

Maximum discahrge from year 1961-2015

10-daily silt data year 1961-2015

Cross-sectional data: Pre-monsoon 2010, 2012, 2013 and 2014

Post-monsoon 2010, 2012 and 2013

c) Gauging Site: Sharda Nagar

Maximum water level from year 1971-2015

6.3 TEMPORAL VARIATION OF MAXIMUM DISCHARGE AND MAXIMUM WATER LEVEL

Temporal variation of maximum observed discharge and maximum observed water level at various gauging sites on Shrada river has been carried out using the available data. Temporal variation of the maximum observed discharge during period 1961-2015 at Palia Kalan gauging site station on Sharda river is shown in Fig 6.1. It may be concluded that maximum discharge at Palia Kalan has decreasing trend. Like-wise Fig 6.2a-c show temporal variation of maximum observed water level at Banbasa (period: 1974-2015), Palia Kalan (period: 1961-2015), and Sharda Nagar (near lower Sharda barrage, period: 1971-2015). It is imperative from the Figs. 6.2a-c that at these gauging stations, the maximum water level has increasing trend. Decreasing trend of maximum discharge and increasing trend of maximum water level at Palia Kalan may be attributed to silting on the river bed in the vicinity of this gauging site.

Frequency analysis of the observed maximum discharge data is an important tool for estimation of peak flood for different return periods. The objective of flood frequency analysis is to infer the probability of exceedance of all possible discharge values (the parent population) from the 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.

Annual maximum observed discharge data for period of 1961-2015 at Palia Kalan gauging site on Sharda river have been used to estimate the flood discharge for different return periods. Following distribution methods have been used herein.

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

The annual maximum discharge for T year returns 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== $\sqrt{\frac{(Z-\bar{Z})^2}{N-1}}$

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

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

$\bar{Z}$

6.6 CONCLUDING REMARKS

It may be concluded that there is a trend of decrease of maximum discharge at Palia Kalan gauging site on the Sharda river. However, at gauging stations Banbasa, Palia Kalan and Sharda Nagar (near lower Sharda barrage), the maximum water level has increasing trend. Decreasing trend of maximum discharge and increasing trend of maximum water level at Palia Kalan may be attributed to silting on the river bed in the vicinity of this gauging site.

Chapter 7 RIVER MORPHOLOGY

7.1 DELINEATION/DIGITIZATION OF RIVER BANK LINE

The Sharda river bank lines have been identified and delineated from mosaics for all the satellite images of year 1970, 1980, 1990, 2000 and 2010 as shown in Figs. 7.1 to 7.5. The identified river bank lines for the left, right and center (main channel) have been digitized using ArcMap software. The left bank, right bank and centerline have been prepared for the years 1970, 1980, 1990, 2000 and 2010. The length of arcs of the left bank, right bank and centerline for all the above years has been calculated using GIS software. Shifting of centerline, left bank, right bank of the river has been evaluated with respect to center line of year 2010.

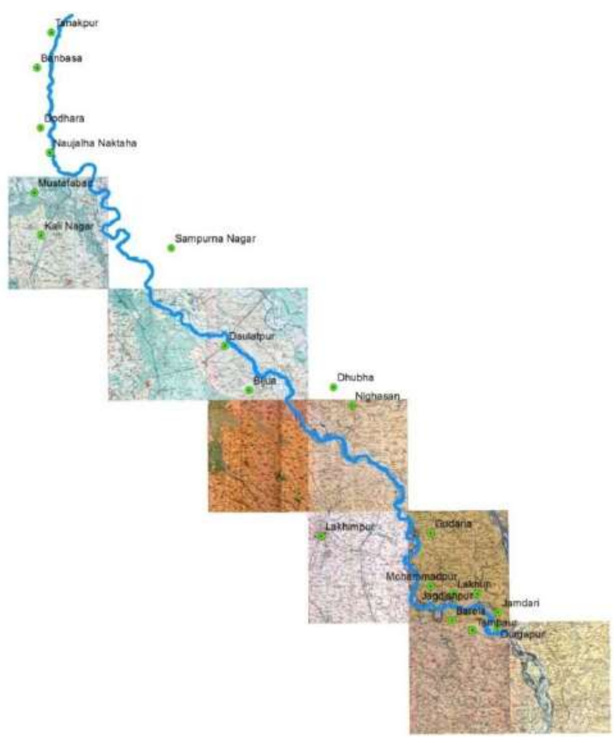


Figure 7.1 Mosaic of SOI toposheets of Sharda river of year 1970 (Scale 1:50,000)

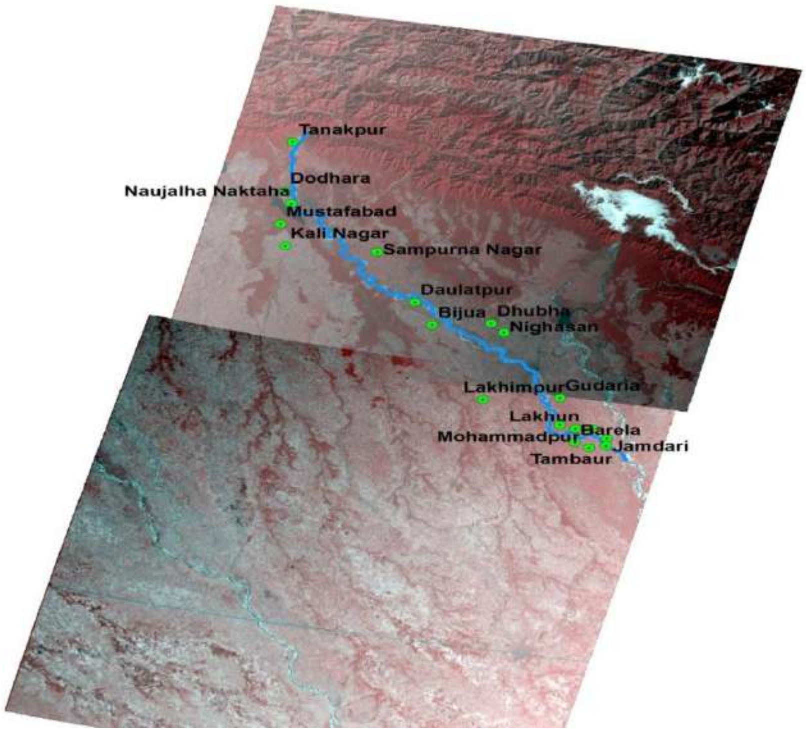


Figure 7.2 Mosaic of FCC of Sharda river of year 1980 (Landsat-MSS Images)

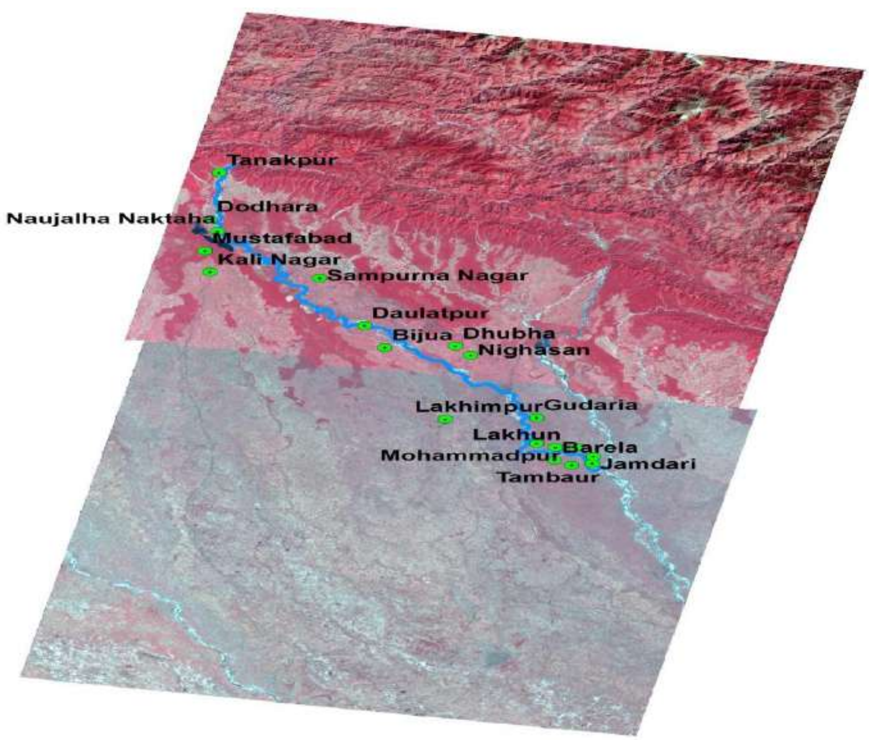


Figure 7.3 Mosaic of FCC of Sharda river of year 1990 (Landsat-TM Images)

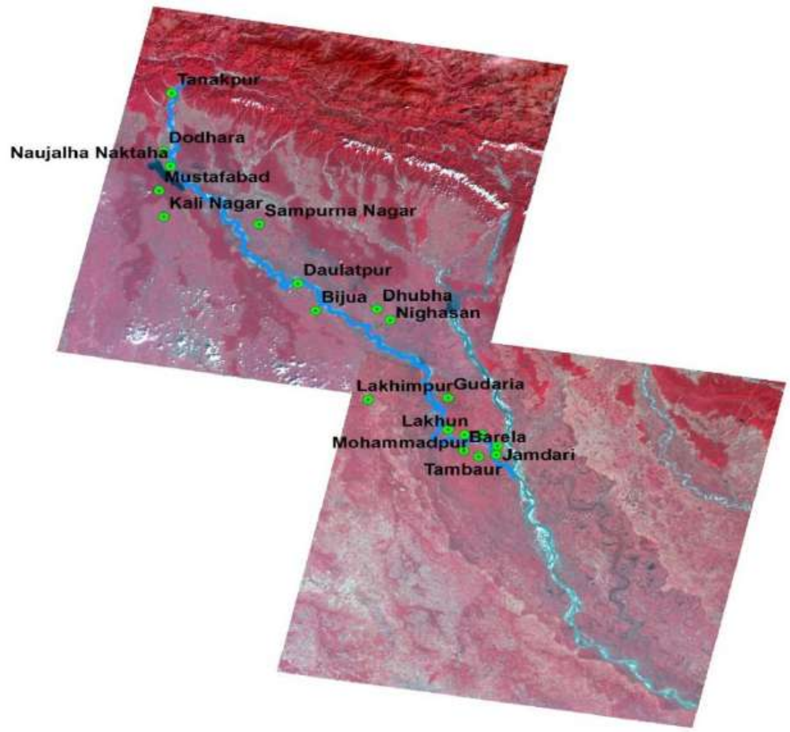


Figure 7.4 Mosaic of FCC of Sharda river of year 2000 (IRS 1C LISS III Images)

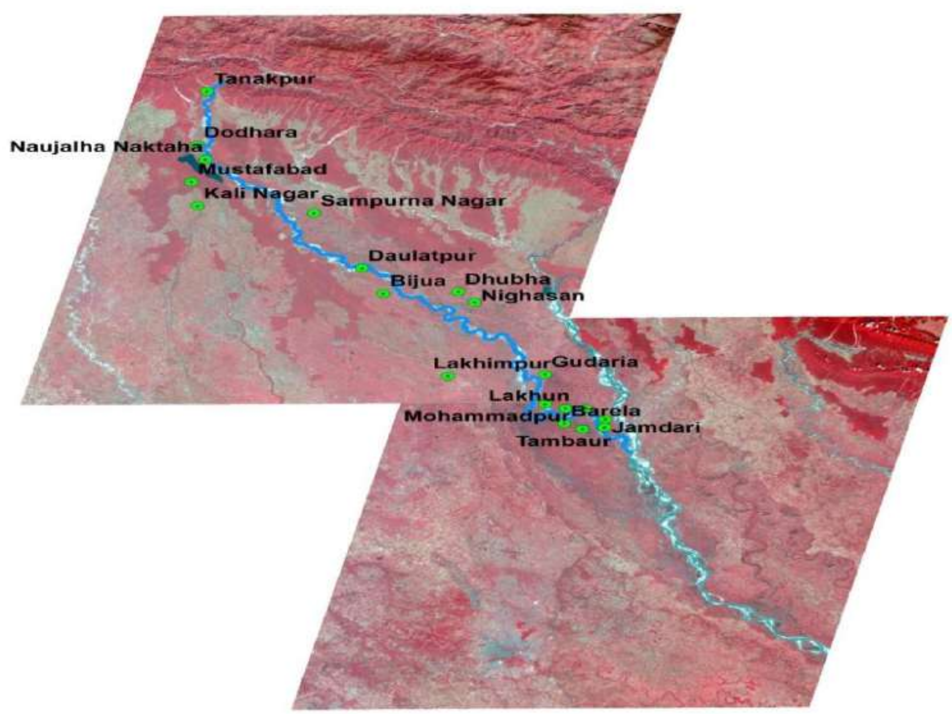


Figure 7.5 Mosaic of FCC of Sharda river of year 2010 (IRS P6 LISS III Images)

Total length of the Sharda river from Tanakpur to its confluence with Ghaghra is divided into six reaches, five reaches of 50 km length and one reach of 33 km length. Such reaches are described below:

Table 7.1 Reaches of the Sharda River

Chainage in km	Reaches	Start to end location
0 - 50	Reach A	Tambaur to Nai Ratauli
50 - 100	Reach B	Nai Ratauli to Nakahhiya
100 - 150	Reach C	Nakahhiya to Ballipur Kalan
150 - 200	Reach D	Ballipur Kalan to Nahrasa
200 - 250	Reach E	Nahrasa to Ramnagra
250 - 283	Reach F	Ramnagra to Tanakpur

7.2 PLAN FORM PATTERN OF THE RIVER

a) Sinuosity Ratio

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. 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 1.50 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 7.2, however, definition proposed by Leopold and Wolman (1957) is commonly used.

Table 7.2 Definition of sinuosity ratio

Sinuosity Ratio	Source
$\frac{\text{Thalweg length}}{\text{Valley length}}$	Leopold and Wolman, 1957
$\frac{\text{Channel length}}{\text{Length of Meander belt axis}}$	Brice, 1964
$\frac{\text{Stream length}}{\text{Valley length}}$	Schumm, 1963

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

$$P = L_{cmax}/L_R \tag{7.1}$$

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 7.6a. Figure 7.6b shows channel patterns for different Sinuosity ratio.

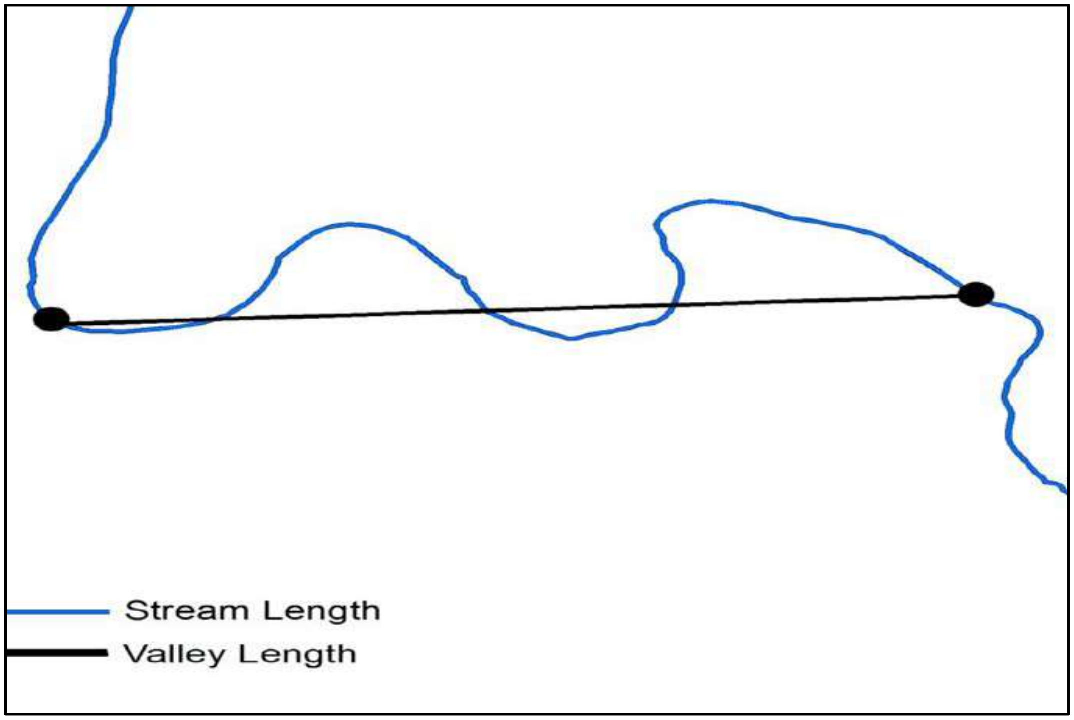


Figure 7.6a Diagram representing the calculation of the sinuosity

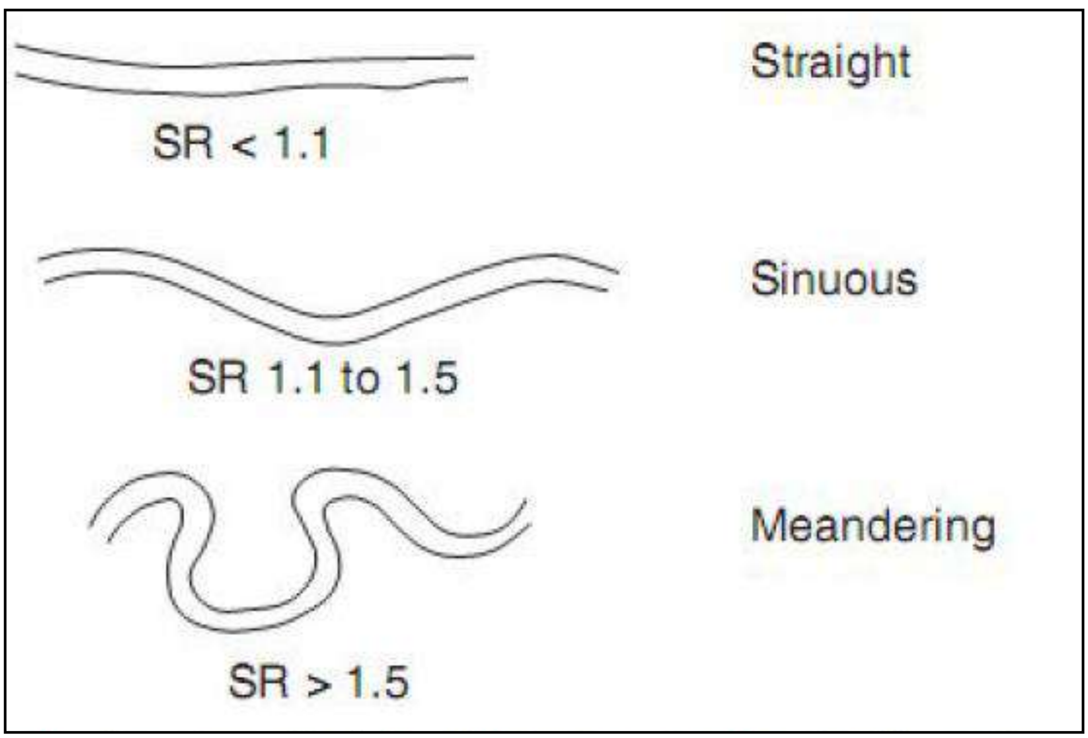


Figure 7.6b Channel patterns for different Sinuosity ratio

The studied reach of the Sharda river having length of 283 km has been divided into reaches of 50 km each. However, for calculating the sinuosity ratios, the river reach has been further divided into 25 km long reaches. Accordingly, the total length of the river has been sub-divided into 11 reaches of 25 km length; the last one being 9.97 km. Equation (7.1) has been used for the computation of sinuosity ratio. The calculated values of sinuosity ratio are given in Table 7.3 and graphically shown in Fig 7.7a.

The following data (Table 7.4a) have been extracted from the computed sinuosity ratio of the Sharda river:

Table 7.4a Sinuosity ratios of the Sharda river for different years

S.No.	Year	Maximum Sinuosity	Minimum Sinuosity	Average Sinuosity
1.	1970	1.83	1.12	1.35
2.	1980	1.51	1.10	1.31
3.	1990	1.77	1.11	1.35
4.	2000	1.50	1.13	1.27
5.	2010	1.57	1.15	1.31

It is apparent from the Tables 7.3 & 7.4a and Fig. 7.7a that Sharda is behaving as sinuos river from Tanakpur to its confluence with Ghaghra river except from Chainage 200-225 km near Sampurnnagar in which it had behaved as meander river before year 1990.

Table 7.3 Sinuosity ratios for Sharda river of year 1970, 1980, 1990, 2000 and 2010

Chainage (km)	Section	2010			2000			1990			1980			1970		
		L_{max}	L_R	Sinuosity	L_{max}	L_R	Sinuosity	L_{max}	L_R	Sinuosity	L_{max}	L_R	Sinuosity	L_{max}	L_R	Sinuosity
12.5	1	25	18.8	**1.33**	19.12	16.32	**1.17**	13.86	9.25	**1.50**	12.1	9.8	**1.23**	12.03	8.18	**1.47**
37.5	2	25	17.87	**1.40**	21.05	17.15	**1.23**	19.69	16.6	**1.19**	19.66	15.35	**1.28**	18.98	16.51	**1.15**
62.5	3	25	20.02	**1.25**	28.48	19.05	**1.50**	31.43	19.69	**1.60**	23.96	17.83	**1.34**	27.54	19.73	**1.40**
87.5	4	25	16.91	**1.48**	22.27	16.88	**1.32**	21.16	16.84	**1.26**	19.82	17.03	**1.16**	23.6	16.95	**1.39**
112.5	5	25	15.94	**1.57**	17.64	15.34	**1.15**	18.63	15.18	**1.23**	22.96	15.32	**1.50**	21.4	16.02	**1.34**
137.5	6	25	16.4	**1.52**	20.01	16.42	**1.22**	18.05	16.24	**1.11**	19.04	16.03	**1.19**	18.94	16.12	**1.17**
162.5	7	25	20.3	**1.23**	30.13	20.42	**1.48**	28.23	20.82	**1.36**	28.41	20.92	**1.36**	27.3	22	**1.24**
187.5	8	25	18.67	**1.34**	22.91	18.91	**1.21**	28.91	19.1	**1.51**	28.71	19.04	**1.51**	24.64	19.32	**1.28**
212.5	9	25	21.55	**1.16**	30.77	21.78	**1.41**	38.09	21.51	**1.77**	32.37	21.53	**1.50**	39.25	21.39	**1.83**
237.5	10	25	21.77	**1.15**	23.96	21.17	**1.13**	29.31	21.37	**1.37**	30.84	21.23	**1.45**	35.71	21.24	**1.68**
262.5	11	25	21.627	**1.16**	26.83	21.7	**1.24**	25.68	21.78	**1.18**	24.49	21.67	**1.13**	24.37	21.7	**1.12**
267.485	12	9.97	8.67	**1.15**	9.69	8.57	**1.13**	9.95	8.54	**1.17**	9.41	8.57	**1.10**	9.7	8.57	**1.13**
Maximum		**1.57**			**1.50**			**1.77**			**1.51**			**1.83**		
Minimum		**1.15**			**1.13**			**1.11**			**1.10**			**1.12**		
Average		**1.31**			**1.27**			**1.35**			**1.31**			**1.35**		

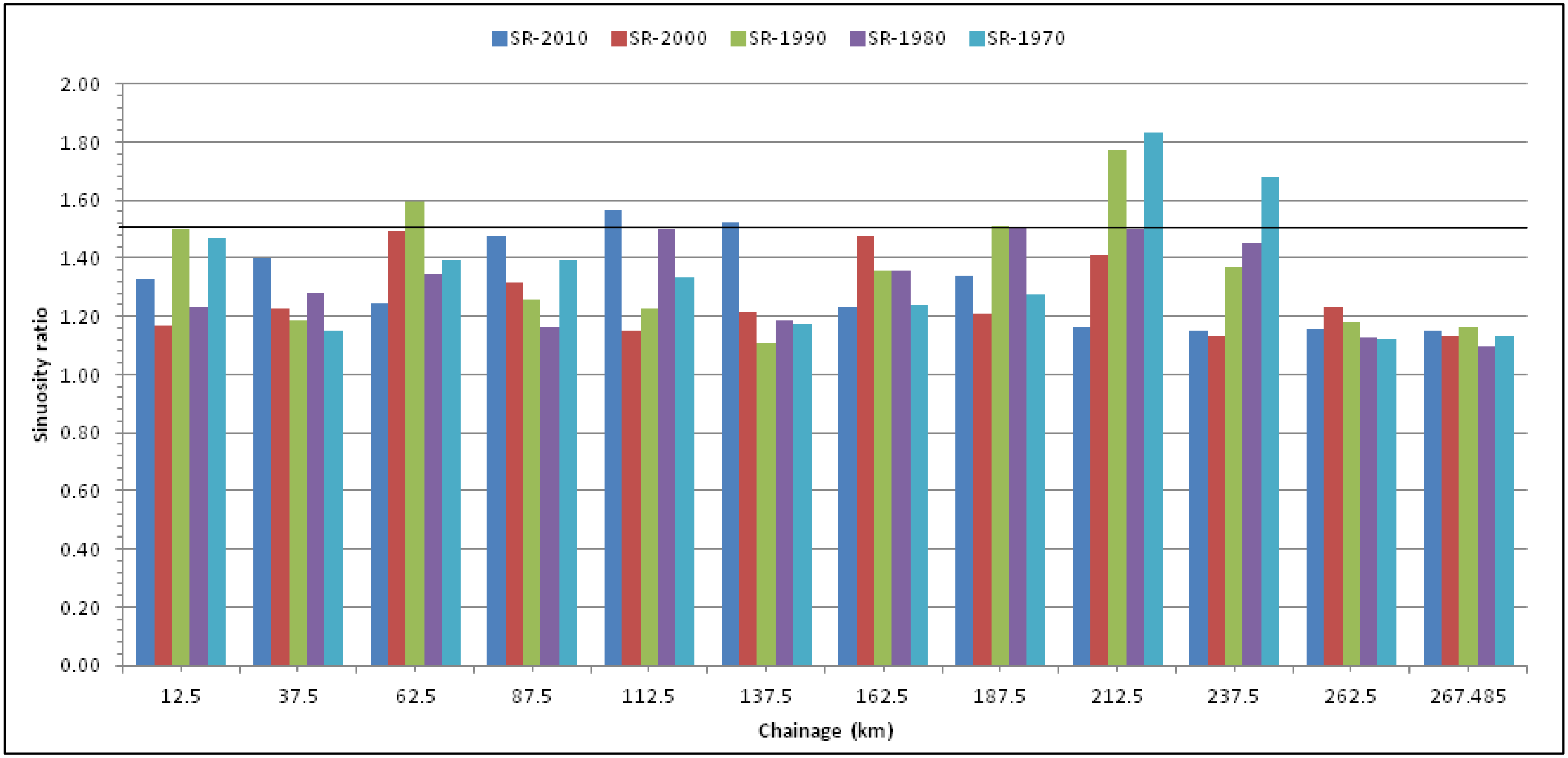


Figure 7.7a Sinuosity ratio of Sharda River of year 1970, 1980, 1990, 2000 and 2010

Geometrical parameters of the prominent meanders such as axial wavelength, amplitude and radius of curvature as shown in Fig. 7.7b have been calculated and listed in the Table 7.4b. Prominent meanders are numbered as M-1 to M-17 and shown in Figures 7.7c-f.

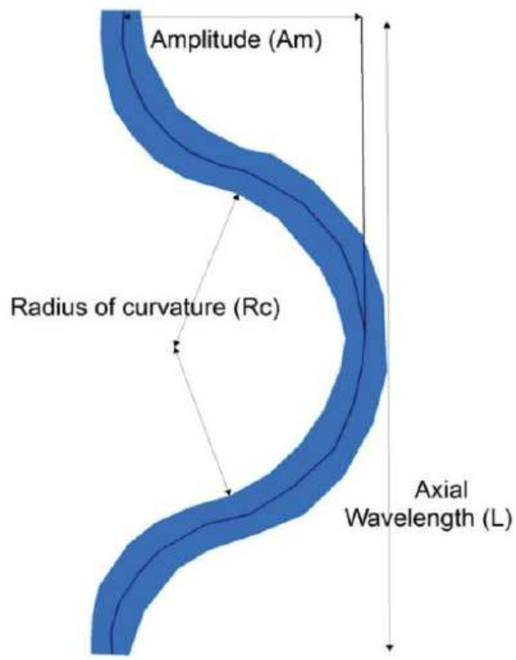


Figure 7.7b Geometrical parameters of a river meander (Sinha 2012)

Table 7.4b Geometrical parameters of the prominent meanders in the Sharda river

Meander No.	Chainage (km)	Location	Year	Axis wave length (km)	Amplitude (km)	Radius of Curvature (km)
M-1	10	Kamaraiya Sekhupur	1970	SR~1.0		
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	4.7	1.8	3.4
M-2	50	Nai Ratauli	1970	5.6	5.5	2.2
			1980	SR~1.0		
			1990	3.7	3.4	1.5
			2000	4.7	4.5	2.1
			2010	6.3	4	2.5
M-3	60	Mohammadpur	1970	SR~1.0		
			1980	SR~1.0		
			1990	2	2.2	1.2

			2000	SR~1.0		
			2010	SR~1.0		
M-4	63	Rajapur	1970	SR~1.0		
			1980	SR~1.0		
			1990	2.8	2.3	1.3
			2000	SR~1.0		
			2010	SR~1.0		
M-5	80	Banzaria	1970	SR~1.0		
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	3	2.8	1.3
M-6	115	Harisinghpur	1970			
			1980	2.7	2	1.4
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-7	120	Dirpura	1970	SR~1.0		
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	3	1.6	1.2
M-8.	125	Asarhi	1970	SR~1.0		
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	4	4.2	1.4
M-9	130	Jhau Paurwa	1970	SR~1.0		
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	4	3.8	1.6
M-10	175	Bhira	1970	SR~1.0		
			1980	SR~1.0		
			1990	3.3	2.4	1.2
			2000	2.8	3	1
			2010	SR~1.0		
M-11	190	Kanp	1970	SR~1.0		
			1980	3.5	2.8	1.1
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-12	195	Nahrasa	1970	SR~1.0		
			1980	3.5	2.8	1
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-13	210	Sampurna Nagar	1970	3.5	2	1.3

			1980	4	2.4	1.1
			1990	3	2.9	1.2
			2000	SR~1.0		
			2010	SR~1.0		
M-14	830	Simra	1970	3.1	4.6	1.3
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-15	215	Khajuria	1970	SR~1.0		
			1980	3.3	2.8	1.1
			1990	1.5	2.3	0.8
			2000	SR~1.0		
			2010	SR~1.0		
M-16	223	Palia	1970	3	2.9	1
			1980	SR~1.0		
			1990	SR~1.0		
			2000	SR~1.0		
			2010	SR~1.0		
M-17	235	Mataiya Lalpur	1970	4.8	4.7	1.9
			1980	4.2	3.7	1.5
			1990	1.9	2.3	0.9
			2000	SR~1.0		
			2010	SR~1.0		

From the Table 7.4b and Figures 7.7c-f, it may be concluded that in general the meanders are not stable and keep on changing. Close examination of these figures indicate that river has followed a relatively straight path over the years in the reaches 0-80 km and 210-240 km, while meandering has increased in the reaches 100-140 km and 170-200 km. Axial wave length, amplitude and radius of curvature of the meanders are of the order of 4 km, 3 km and 1.5 km, respectively.

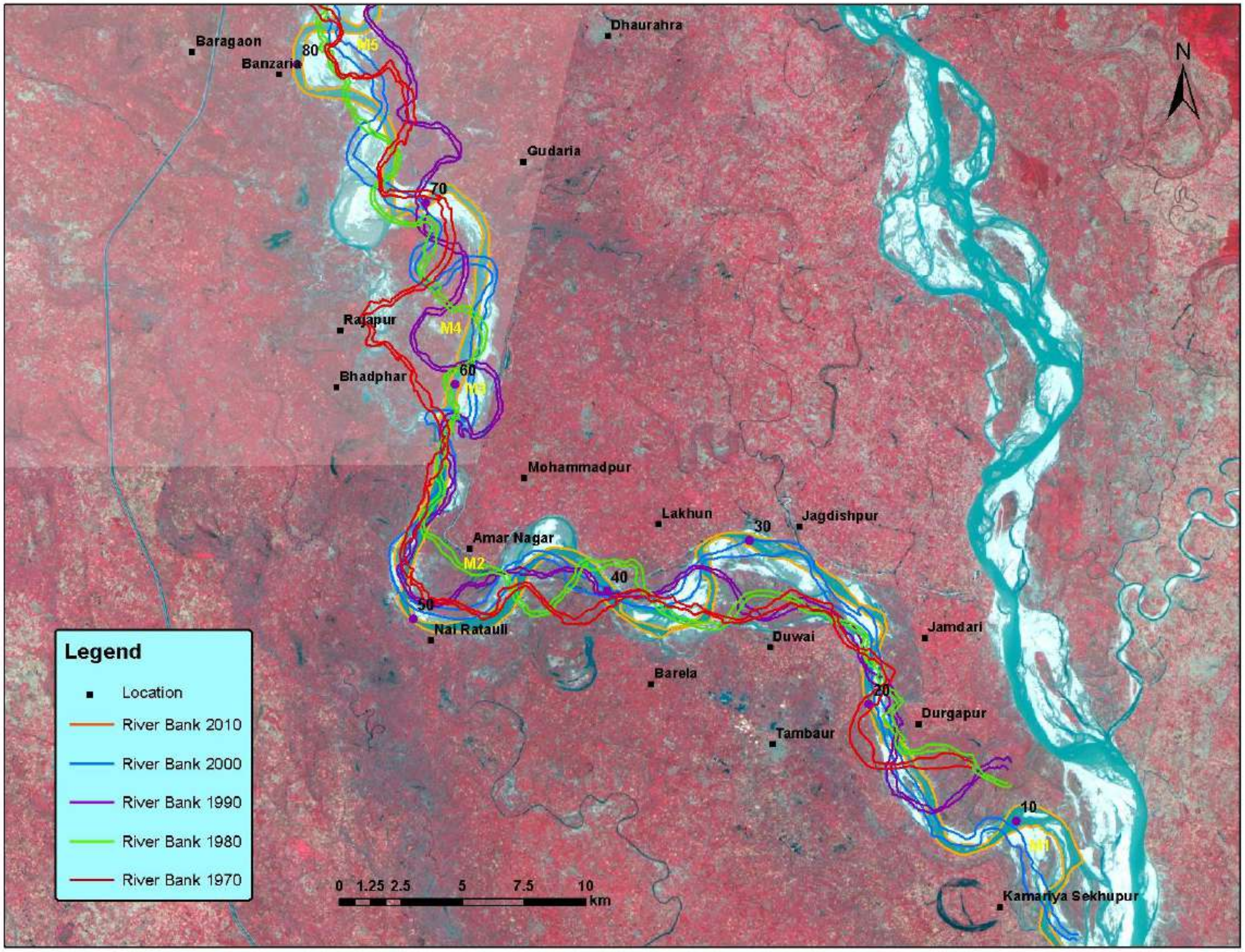


Figure 7.7c Meandering pattern of the Sharda river in the reach from chainage 0 km to 80 km u/s of confluence point

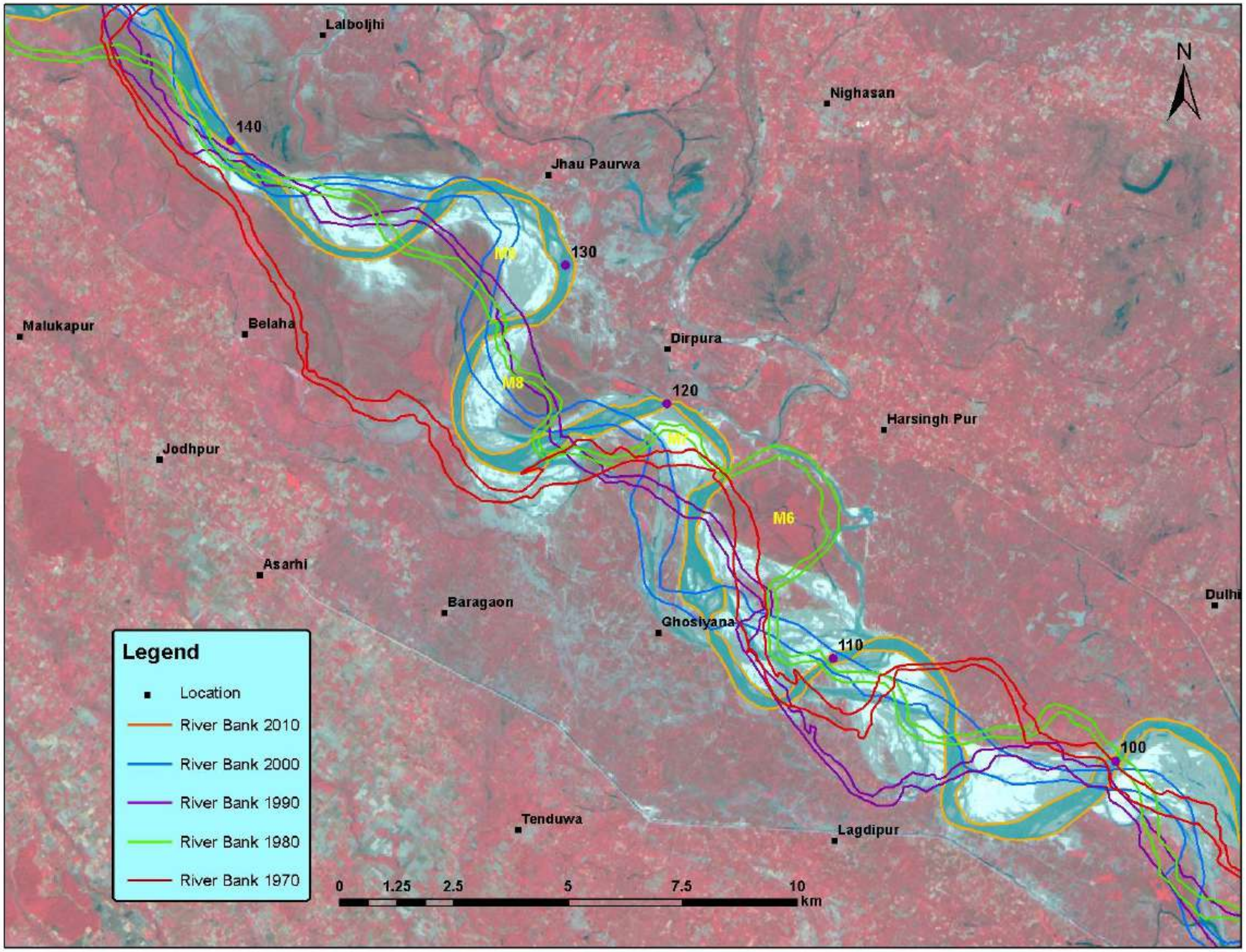


Figure 7.7d Meandering pattern of the Sharda river in the reach from chainage 100 km to 140 km near Ghosiyana

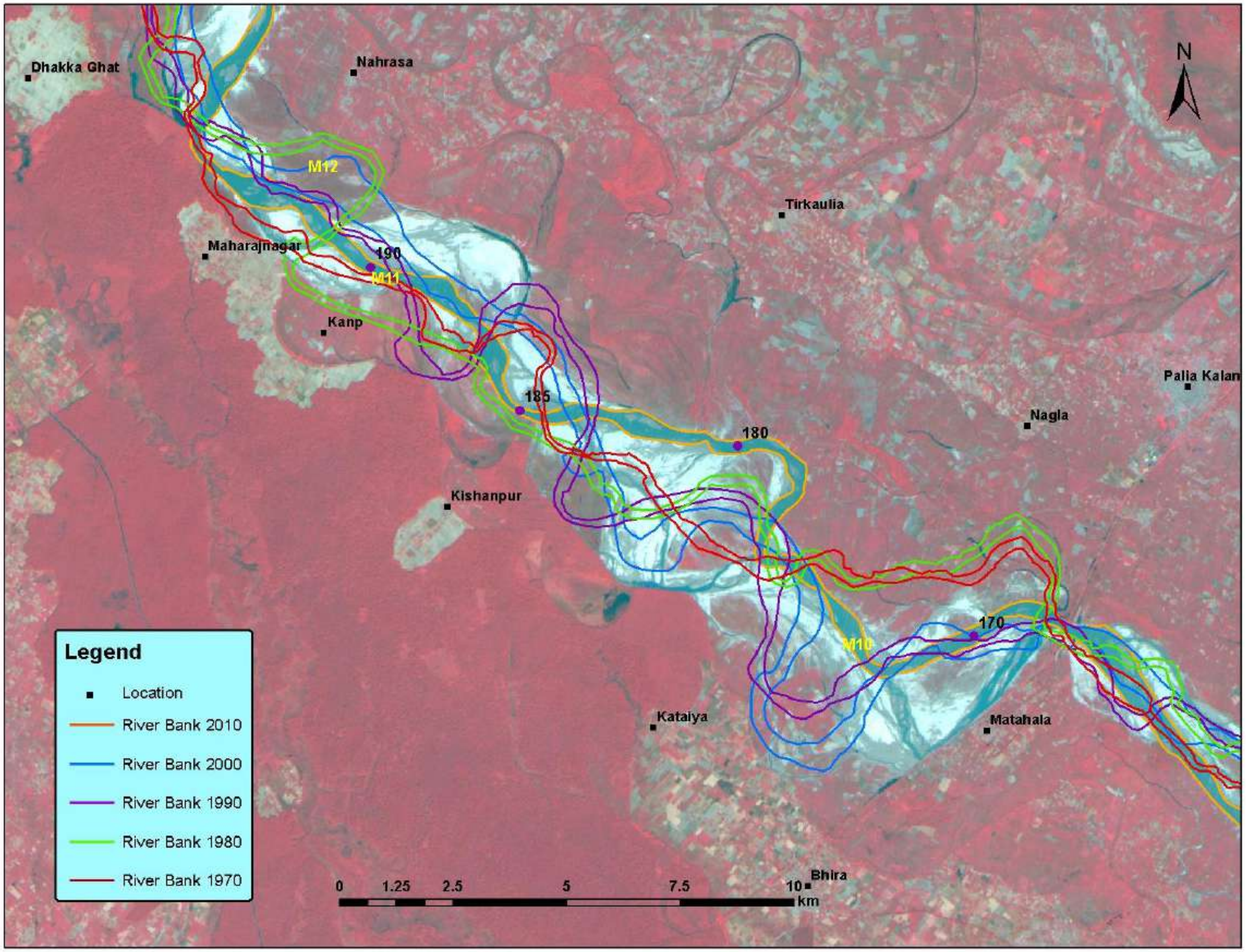


Figure 7.7e Meandering pattern of the Sharda river in the reach from chainage 170 km to 200 km u/s of Palian Kalan

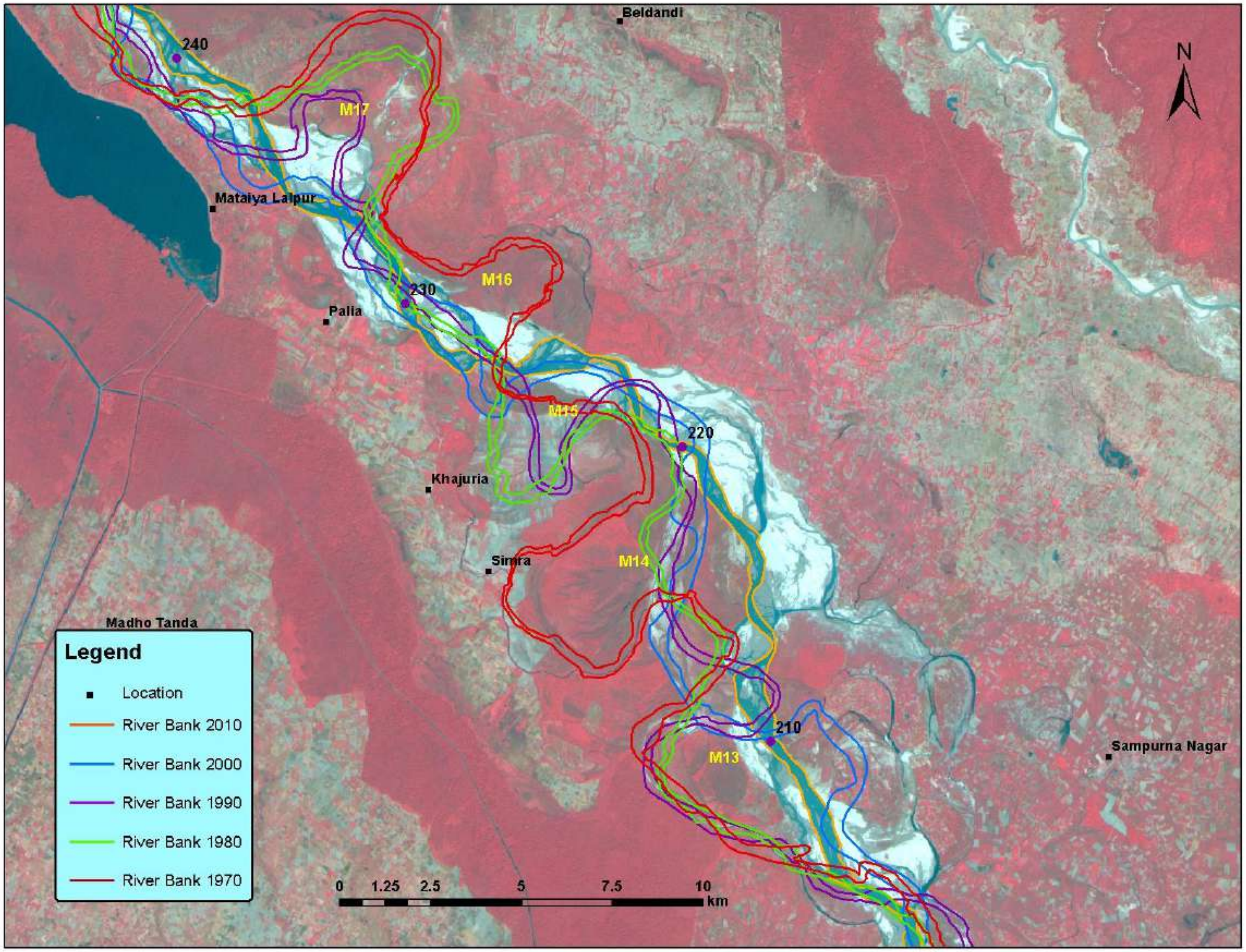


Figure 7.7f Meandering pattern of the Sharda river in the reach from chainage 210 km to 240 km near Madho Tanda

b) Planform Index

Braiding pattern of the rivers is characterized in different ways. Three parameters which are mentioned in the literature and commonly being used to characterize the braided pattern are proposed by Brice (1964), Rust (1978) and Friend and Sinha (1993) as shown in Fig. 7.8.

$$\text{Brice Index (BI)} = 2\ \Sigma Li/Lr \tag{7.2}$$

where ΣLi is the length of the islands or bars in a reach and Lr is the reach measured midway between the banks of the channel. The factor 2 in the Eq. (7.2) accounts for the total length of the bars.

Braiding parameter as given by Rust (1968)

$$RI = 2\ \Sigma Lb/Lm \tag{7.3}$$

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

$$BR = Lc_{tot}/Lc_{max} \tag{7.4}$$

where Lc_{tot} is the sum of mid-channel lengths of all the segments of primary channels in a reach, and Lc_{max} 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.

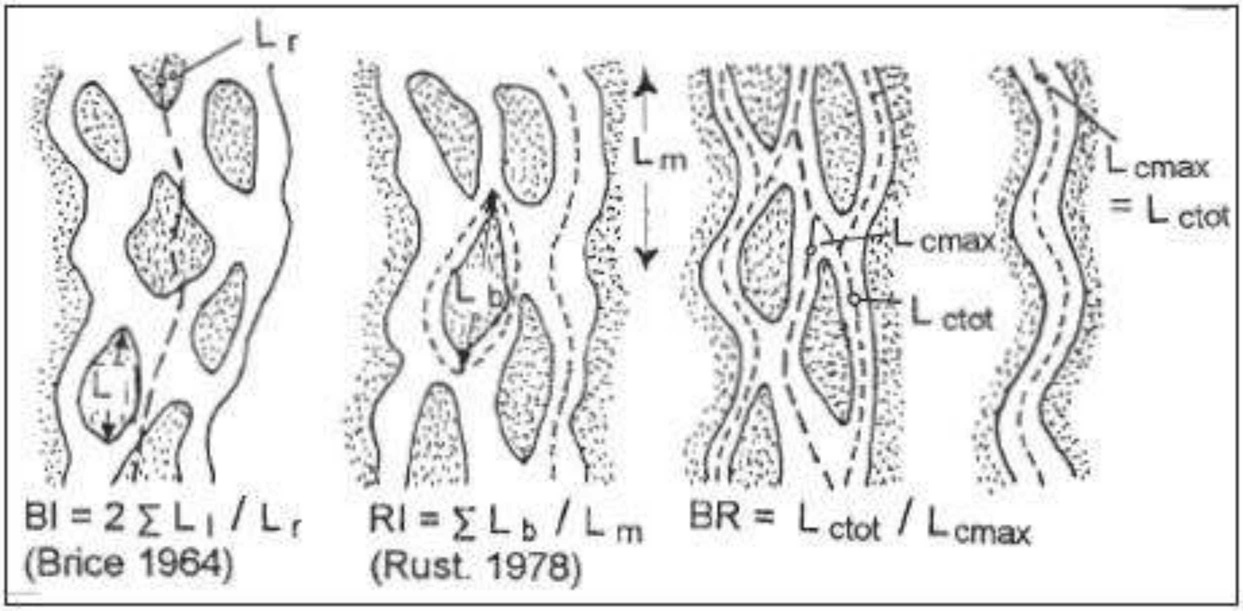


Figure 7.8 Braiding indices

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 Plan Form Index, Flow Geometric Index and Cross-Slope ratio can be expressed as (Fig 7.9)

$$\text{Plan Form Index} = \frac{\frac{T}{B}\times 100}{N} \tag{7.5}$$

$$\text{Flow Geometry Index} = \left[\frac{\sum d_i\, x_i}{RT}\right] \times N \tag{7.6}$$

$$\text{Cross} - \text{Slope ratio} = \frac{\frac{B_L}{2}}{(Bank\ level - Av.\ bed\ level)} \tag{7.7}$$

where, T = flow top width; B= overall width of the channel (refer to Fig. 7.9); N = number of braided channels; R = hydraulic mean depth; d_i and x_i are depth and width of submerged sub-channel. B_L = transect length across river width.

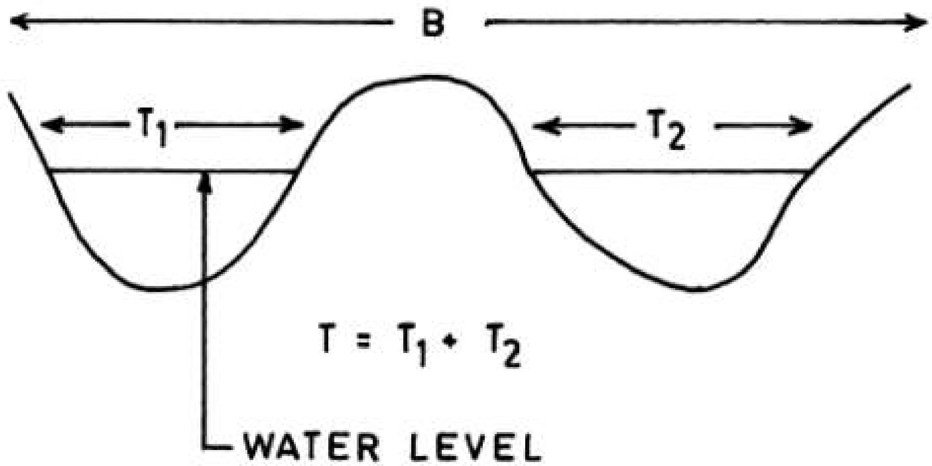


Figure 7.9 Definition sketch of PFI

PFI reflects the river landform disposition with respect to a given water level. Low value of PFI indicates higher degree of braiding. For the classification of the braiding intensity, the following threshold values for PFI as proposed by Sharma (2012), are adopted in this study.

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

In the present study of morphology of Sharda River, PFI of the Sharda river has been estimated at every km using the satellite images for the year 1970, 1980, 1990, 2000 and 2010. The computed PFI for different years and different reaches are given in Table 7.5 and graphically presented in the Figs. 7.10a-f.

Examination of the Table 7.5 and Figs. 7.10a-f reveals that Sharda may be considered moderately braided river in its major length from Tanakpur to its confluence with Ghaghra river. However, near Jagdispur, downstream of Banbasa barrage and Dodhara, braiding of the river is high. At other locations like Chandrika Gauri and Ghosiyana, it was highly braided in past.

Braiding pattern of the Sharda river at Dodhara, Banbasa barrage and Tanakpur barrage are shown in Figs. 7.11a-c, 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 slopes 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 sub-divisions 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 Sharda river in its upper reach i.e, Tanakpur, Banbasa, Dodhara is primarily due to aggradation which occurs as the river is incompetent to transport the sediment load that it is bringing from the relatively steep reach.

Table 7.5 Planform Index (in %) for Sharda River of Year 1970, 1980, 1990, 2000 and 2010

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

Chainage (km)	2010	2000	1990	1980	1970	Remarks
16	100.00	100.00	100.00	100.00	100.00	
17	100.00	25.48	100.00	100.00	100.00	
18	100.00	19.74	100.00	100.00	15.94	Durgapur
19	100.00	43.20	100.00	100.00	22.89	
20	100.00	10.47	100.00	100.00	100.00	
21	100.00	9.05	100.00	100.00	100.00	
22	22.98	12.14	100.00	100.00	100.00	
23	13.53	4.91	100.00	100.00	3.83	
24	19.13	10.92	100.00	100.00	6.75	Jamdari
25	10.49	6.49	100.00	100.00	6.22	
26	11.59	5.02	100.00	100.00	10.74	
27	5.59	5.05	100.00	100.00	100.00	Jagdishpur
28	5.90	5.20	100.00	100.00	100.00	Nandura
29	12.02	5.34	100.00	100.00	100.00	
30	7.76	5.84	100.00	100.00	100.00	
31	4.08	100.00	100.00	100.00	100.00	
32	100.00	100.00	100.00	100.00	100.00	
35	23.76	100.00	100.00	100.00	100.00	
36	8.38	100.00	100.00	100.00	100.00	
37	12.90	100.00	100.00	100.00	100.00	Barela
38	22.37	100.00	100.00	100.00	100.00	
39	18.31	100.00	100.00	100.00	100.00	

40	100.00	100.00	100.00	100.00	100.00	
41	100.00	100.00	100.00	100.00	100.00	
42	100.00	100.00	100.00	100.00	100.00	
43	11.05	100.00	100.00	100.00	100.00	
44	28.42	100.00	100.00	100.00	100.00	
45	100.00	100.00	100.00	100.00	100.00	
46	100.00	100.00	100.00	100.00	100.00	
47	100.00	100.00	100.00	100.00	100.00	
48	100.00	100.00	100.00	100.00	100.00	
49	100.00	100.00	100.00	100.00	100.00	Nai Ratauli
50	100.00	100.00	100.00	100.00	100.00	
51	100.00	100.00	100.00	100.00	100.00	
52	100.00	100.00	100.00	100.00	100.00	
53	100.00	100.00	100.00	100.00	100.00	
54	100.00	100.00	100.00	100.00	100.00	
55	100.00	16.20	100.00	100.00	100.00	
56	100.00	14.23	100.00	100.00	100.00	
57	100.00	100.00	100.00	100.00	100.00	
58	100.00	100.00	100.00	100.00	100.00	
59	100.00	4.21	100.00	100.00	100.00	Bhadphar
60	100.00	4.06	100.00	100.00	100.00	
61	100.00	4.93	100.00	100.00	100.00	Rajapur
62	100.00	8.23	100.00	100.00	100.00	
63	100.00	8.19	100.00	100.00	100.00	Dilkhuwa
64	100.00	100.00	100.00	100.00	100.00	Khurd
65	100.00	100.00	100.00	100.00	100.00	
66	100.00	12.43	100.00	100.00	100.00	
67	100.00	100.00	100.00	100.00	100.00	Samdaha
68	100.00	100.00	100.00	100.00	100.00	
69	100.00	100.00	100.00	100.00	100.00	
70	100.00	100.00	100.00	100.00	100.00	
71	100.00	100.00	100.00	100.00	100.00	

72	11.82	100.00	100.00	5.89	100.00	
73	100.00	100.00	11.27	6.67	100.00	
74	100.00	100.00	6.32	6.76	100.00	
75	100.00	100.00	6.81	5.17	100.00	
76	100.00	100.00	5.55	4.12	100.00	
77	100.00	100.00	6.46	4.75	100.00	
78	100.00	100.00	5.01	5.15	100.00	
79	100.00	100.00	4.85	11.05	100.00	
80	100.00	100.00	5.61	10.56	3.56	Banzaria
81	100.00	100.00	4.11	8.03	2.91	
83	100.00	100.00	3.17	4.51	100.00	Gundwa Gaon
84	100.00	100.00	100.00	4.00	100.00	
85	100.00	100.00	2.43	7.53	100.00	
86	100.00	100.00	4.26	6.32	100.00	
87	100.00	100.00	3.44	7.40	100.00	
88	100.00	100.00	100.00	9.31	8.47	
89	100.00	100.00	7.35	8.19	8.51	
90	100.00	100.00	3.70	4.44	8.05	Chandrika Gauri
91	100.00	100.00	2.92	10.59	100.00	
92	100.00	100.00	100.00	100.00	100.00	
93	100.00	100.00	100.00	100.00	25.57	
94	100.00	100.00	100.00	100.00	12.13	
95	100.00	100.00	100.00	100.00	23.39	
96	100.00	100.00	100.00	100.00	100.00	
97	100.00	100.00	15.01	100.00	100.00	Naikhayya
98	100.00	100.00	6.98	100.00	100.00	
99	100.00	100.00	7.00	100.00	100.00	
100	100.00	100.00	7.16	100.00	100.00	
101	100.00	100.00	14.35	100.00	100.00	
102	100.00	100.00	9.28	100.00	100.00	
103	100.00	100.00	17.72	100.00	100.00	
104	100.00	100.00	100.00	100.00	100.00	Narhar

105	100.00	100.00	100.00	100.00	11.35	
106	16.83	100.00	3.88	100.00	11.32	
107	10.41	100.00	13.30	100.00	100.00	
108	13.37	100.00	100.00	100.00	100.00	
109	13.88	100.00	100.00	100.00	9.39	
110	18.72	100.00	100.00	100.00	12.28	
111	100.00	100.00	100.00	100.00	15.55	
112	18.96	100.00	2.07	21.70	8.26	
113	21.95	100.00	100.00	12.51	7.92	
114	8.67	100.00	1.78	12.92	26.14	Ghosiyana
115	31.65	100.00	1.73	9.18	20.14	
116	15.57	100.00	1.64	9.67	12.92	
117	100.00	100.00	1.75	100.00	7.28	
118	100.00	100.00	100.00	100.00	100.00	
119	5.92	100.00	100.00	100.00	100.00	
120	100.00	100.00	100.00	100.00	100.00	
121	100.00	100.00	100.00	100.00	16.55	
122	21.75	100.00	100.00	100.00	100.00	
123	100.00	100.00	5.92	100.00	100.00	
124	100.00	100.00	8.38	100.00	14.67	
125	100.00	100.00	13.95	100.00	21.29	Jodhpur
126	100.00	100.00	11.18	100.00	8.84	
131	100.00	100.00	7.49	100.00	9.09	Nighasan
132	100.00	100.00	100.00	100.00	17.43	
133	100.00	100.00	100.00	100.00	13.74	
134	100.00	100.00	100.00	100.00	100.00	
135	100.00	100.00	100.00	100.00	100.00	
136	100.00	15.52	100.00	100.00	100.00	
137	100.00	5.16	100.00	100.00	100.00	
138	100.00	100.00	24.03	100.00	100.00	
139	100.00	100.00	31.04	100.00	100.00	
140	100.00	100.00	30.57	100.00	100.00	Lalbojhi

141	100.00	100.00	100.00	100.00	100.00	
142	100.00	31.17	100.00	100.00	100.00	
143	100.00	15.99	100.00	100.00	100.00	
144	100.00	7.01	100.00	100.00	100.00	
145	100.00	24.68	100.00	100.00	100.00	Padriyatala
146	100.00	25.08	100.00	100.00	100.00	
147	100.00	20.79	100.00	100.00	100.00	Gulariya
148	100.00	23.81	100.00	100.00	100.00	
149	36.76	16.71	100.00	100.00	100.00	
150	23.03	17.45	100.00	100.00	100.00	Rampur Kalan
151	24.59	10.02	100.00	100.00	100.00	
152	16.96	22.53	9.77	100.00	13.43	
153	6.02	22.56	8.88	100.00	16.74	
154	5.05	10.27	8.55	100.00	100.00	
155	8.07	6.49	25.35	100.00	100.00	Ballipur Kalan
156	100.00	8.09	22.21	100.00	100.00	
157	100.00	14.69	10.93	100.00	100.00	
158	100.00	100.00	100.00	100.00	100.00	
159	100.00	50.95	100.00	100.00	100.00	Bhanpur
160	100.00	33.61	100.00	100.00	100.00	
161	25.56	27.86	100.00	100.00	4.33	
162	13.40	100.00	100.00	100.00	5.97	
163	19.47	100.00	100.00	100.00	10.17	
164	22.33	100.00	100.00	100.00	8.05	Sarkhana Purab
165	21.35	100.00	100.00	100.00	100.00	
166	100.00	100.00	100.00	100.00	100.00	
167	100.00	100.00	100.00	100.00	100.00	
168	100.00	100.00	100.00	100.00	100.00	Daulatpur
169	23.41	100.00	100.00	100.00	100.00	Palia Kalan
170	23.05	100.00	100.00	100.00	100.00	
171	13.38	100.00	100.00	100.00	100.00	
173	100.00	100.00	100.00	100.00	20.25	

174	100.00	100.00	100.00	100.00	16.04	
175	100.00	100.00	100.00	100.00	8.09	Kataiya
176	100.00	100.00	100.00	100.00	100.00	
177	100.00	100.00	100.00	100.00	100.00	
178	100.00	100.00	100.00	100.00	100.00	
179	100.00	11.26	100.00	100.00	100.00	
180	6.14	10.91	100.00	100.00	5.37	Tirkaulia
181	4.82	100.00	100.00	100.00	4.41	
182	6.36	100.00	100.00	100.00	2.86	
183	4.25	100.00	100.00	100.00	5.72	
184	100.00	100.00	100.00	100.00	3.50	
185	100.00	9.24	100.00	100.00	2.74	Kishanpur
186	100.00	8.08	100.00	100.00	8.31	
187	100.00	100.00	100.00	100.00	100.00	
188	100.00	100.00	100.00	100.00	100.00	
189	100.00	100.00	100.00	100.00	100.00	
190	100.00	100.00	100.00	100.00	100.00	
191	100.00	100.00	100.00	100.00	100.00	
192	100.00	100.00	100.00	100.00	100.00	
193	100.00	100.00	100.00	100.00	100.00	Maharajanagar
194	100.00	100.00	100.00	100.00	100.00	
195	100.00	100.00	100.00	100.00	31.12	
196	100.00	100.00	14.89	100.00	17.91	Naharsa
197	100.00	100.00	100.00	100.00	11.57	
198	100.00	100.00	100.00	100.00	100.00	
199	100.00	100.00	100.00	100.00	100.00	
200	33.67	100.00	100.00	100.00	100.00	
201	7.36	100.00	12.84	100.00	100.00	
202	9.11	12.87	100.00	100.00	100.00	
203	8.05	13.09	100.00	100.00	100.00	
204	100.00	100.00	100.00	100.00	100.00	
205	100.00	8.88	18.95	100.00	100.00	

206	18.05	9.19	12.23	100.00	100.00	
207	10.73	16.44	100.00	100.00	100.00	Sampurna Nagar
208	10.97	4.64	100.00	100.00	100.00	
209	5.16	5.49	100.00	100.00	100.00	
210	5.70	3.67	100.00	100.00	100.00	
211	100.00	4.43	100.00	100.00	100.00	
212	100.00	5.55	100.00	100.00	100.00	
213	100.00	7.52	100.00	100.00	100.00	
214	9.96	6.73	100.00	100.00	100.00	
215	100.00	7.62	100.00	100.00	100.00	
216	100.00	10.93	100.00	100.00	100.00	
217	26.61	11.60	100.00	100.00	3.04	
218	18.24	29.95	100.00	100.00	1.99	Kali Nagar
219	12.91	23.52	100.00	100.00	1.93	
220	100.00	100.00	100.00	100.00	100.00	
221	100.00	100.00	100.00	100.00	100.00	
222	100.00	100.00	100.00	100.00	100.00	
223	100.00	100.00	100.00	100.00	100.00	
224	100.00	100.00	100.00	100.00	100.00	
225	100.00	100.00	100.00	100.00	100.00	
226	100.00	100.00	100.00	100.00	100.00	
227	100.00	100.00	100.00	100.00	100.00	
228	21.43	100.00	100.00	100.00	100.00	
229	13.78	100.00	100.00	100.00	100.00	
230	21.97	100.00	100.00	100.00	100.00	
231	25.23	100.00	100.00	100.00	100.00	
232	100.00	100.00	100.00	100.00	10.84	
233	20.38	100.00	100.00	100.00	3.57	Madho Tanda
234	100.00	100.00	100.00	100.00	11.66	
235	100.00	20.60	100.00	100.00	12.74	
236	100.00	12.58	100.00	100.00	14.32	
237	100.00	26.81	100.00	100.00	33.49	

238	8.19	100.00	100.00	100.00	100.00	
239	14.95	40.84	100.00	100.00	100.00	
240	100.00	13.52	100.00	100.00	100.00	
241	100.00	10.19	100.00	100.00	100.00	
242	100.00	100.00	100.00	100.00	100.00	
243	100.00	100.00	14.18	100.00	14.91	
244	17.21	18.56	24.90	100.00	8.13	
245	15.67	8.45	100.00	100.00	8.97	Naujalha
246	31.18	100.00	34.23	100.00	5.92	
247	33.93	100.00	11.91	12.16	5.50	
248	38.18	100.00	11.25	100.00	14.37	Naktaha
249	10.24	100.00	5.62	100.00	6.96	
250	3.65	13.12	5.65	7.05	8.38	
251	4.05	15.47	7.91	100.00	6.82	
252	19.55	36.02	9.39	7.11	10.40	
253	5.35	10.32	5.96	100.00	11.25	
254	2.93	4.01	2.08	5.47	17.52	Dodhara
255	3.37	4.16	3.28	5.22	10.30	
256	5.46	3.07	4.34	6.73	8.31	
257	4.62	3.62	3.99	6.58	9.43	
258	5.88	3.89	5.85	100.00	100.00	
259	8.38	5.25	7.21	15.75	100.00	
260	4.89	10.12	14.41	17.48	100.00	
261	13.09	8.47	6.37	14.32	100.00	
262	3.29	5.64	5.40	14.89	100.00	
263	3.90	3.86	5.35	8.08	100.00	
264	2.92	3.13	2.75	8.55	100.00	
265	5.64	3.22	3.90	11.87	100.00	
266	4.00	7.21	100.00	28.27	100.00	
267	9.40	100.00	100.00	100.00	100.00	
268	15.59	15.80	100.00	100.00	100.00	
269	100.00	100.00	100.00	100.00	100.00	

270	100.00	100.00	7.37	11.11	23.26	
271	100.00	9.03	6.66	13.38	7.80	
272	100.00	23.36	2.95	7.14	100.00	
273	100.00	100.00	3.09	2.58	6.20	Banbasa
274	11.90	25.91	2.81	3.90	3.93	
275	6.93	10.50	3.67	4.21	6.12	
276	6.42	7.42	6.01	5.63	8.02	
277	100.00	100.00	15.89	10.82	17.01	
278	40.33	27.69	28.26	13.22	100.00	
279	4.61	42.11	18.62	6.85	10.88	Tanakpur
280	4.23	16.33	100.00	5.43	6.94	
281	5.30	21.30	100.00	7.58	8.62	
282	100.00	19.90	100.00	5.85	6.03	
283	10.71	100.00	100.00	7.47	27.93	
284	100.00	100.00	100.00	100.00	100.00	

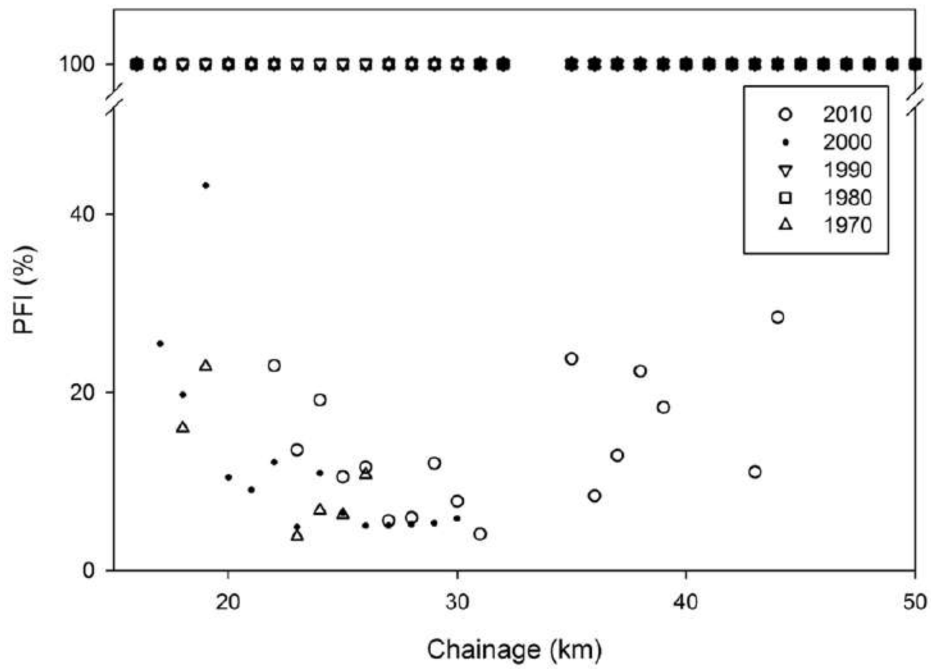


Figure 7.10a Planform Index of Sharda river for the year 1970, 1980, 1990, 2000 and 2010 from chainage 0- 50

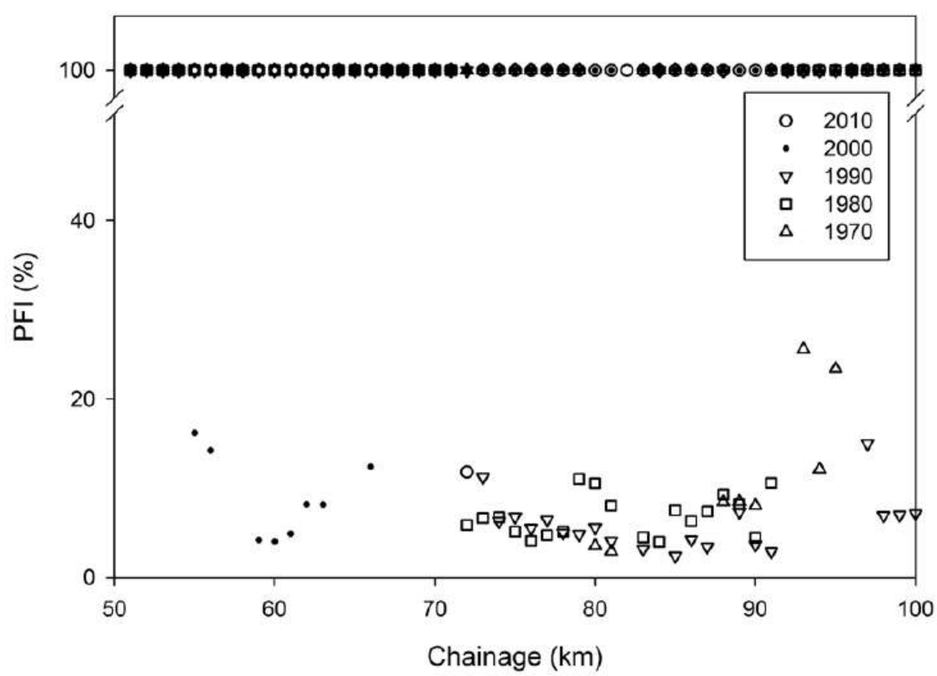


Figure 7.10b Planform Index of Sharda river for the year 1970, 1980, 1990, 2000 and 2010 from chainage 50- 100

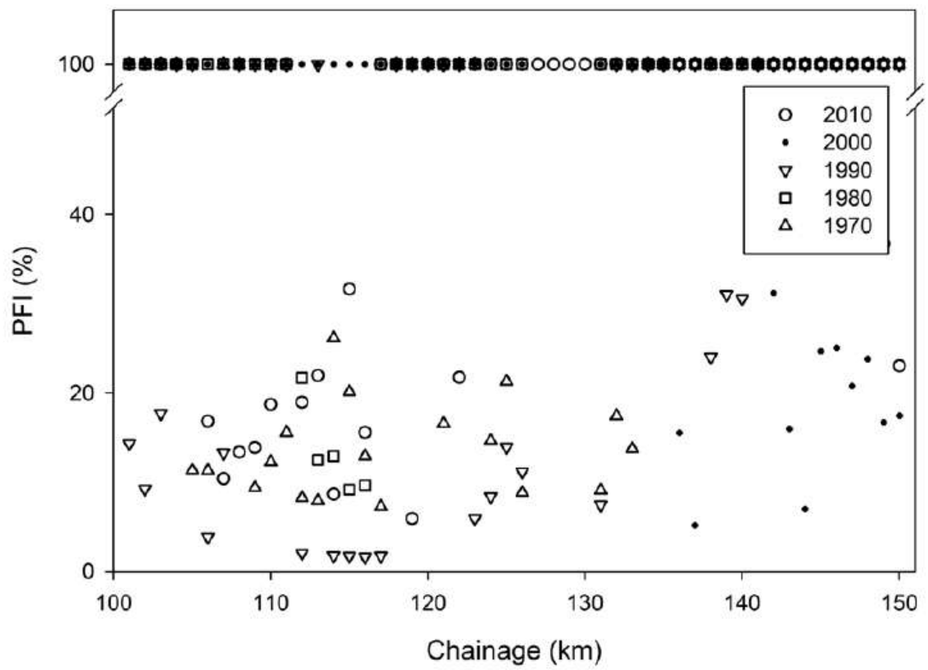


Figure 7.10c Planform Index of Sharda river for the year 1970, 1980, 1990, 2000 and 2010 from chainage 100- 150

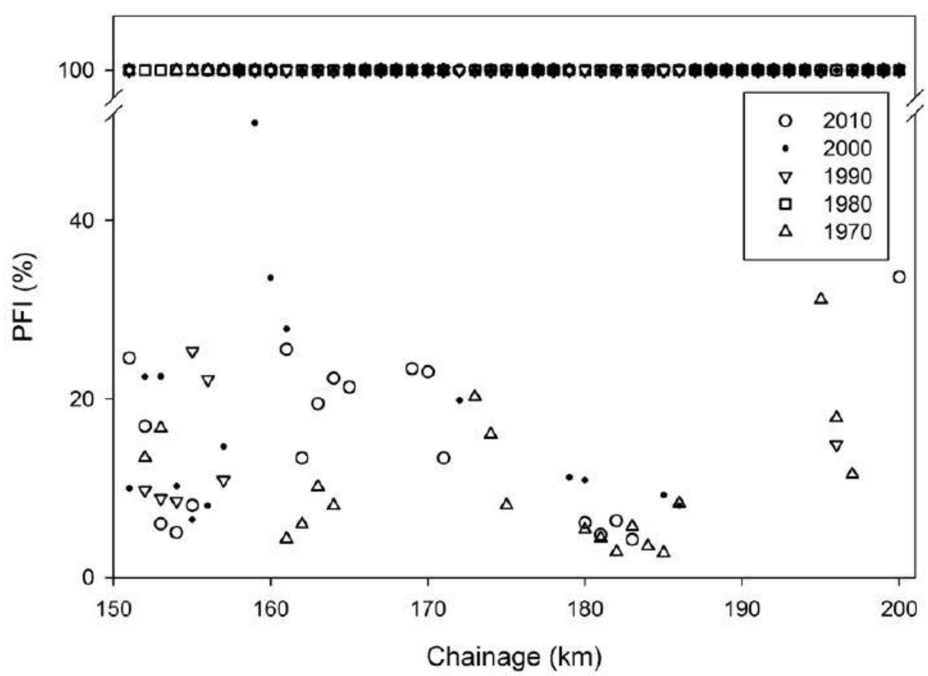


Figure 7.10d Planform Index of Sharda river for the year 1970, 1980, 1990, 2000 and 2010 from chainage 150- 200

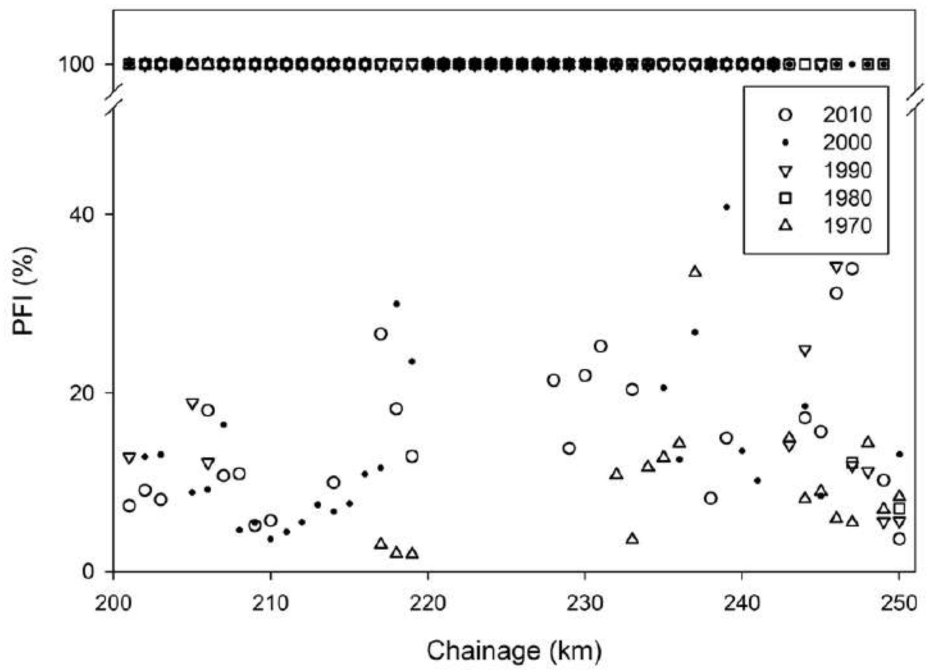


Figure 7.10e Planform Index of Sharda river for the year 1970, 1980, 1990, 2000 and 2010 from chainage 200- 250

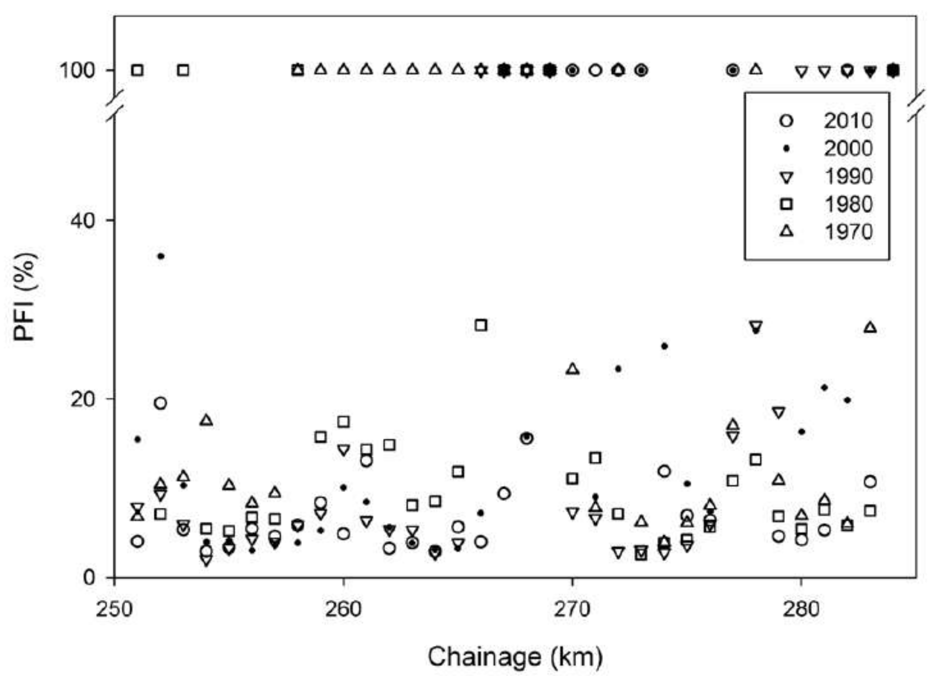


Figure 7.10f Planform Index of Sharda river for the year 1970, 1980, 1990, 2000 and 2010 from chainage 250- 283

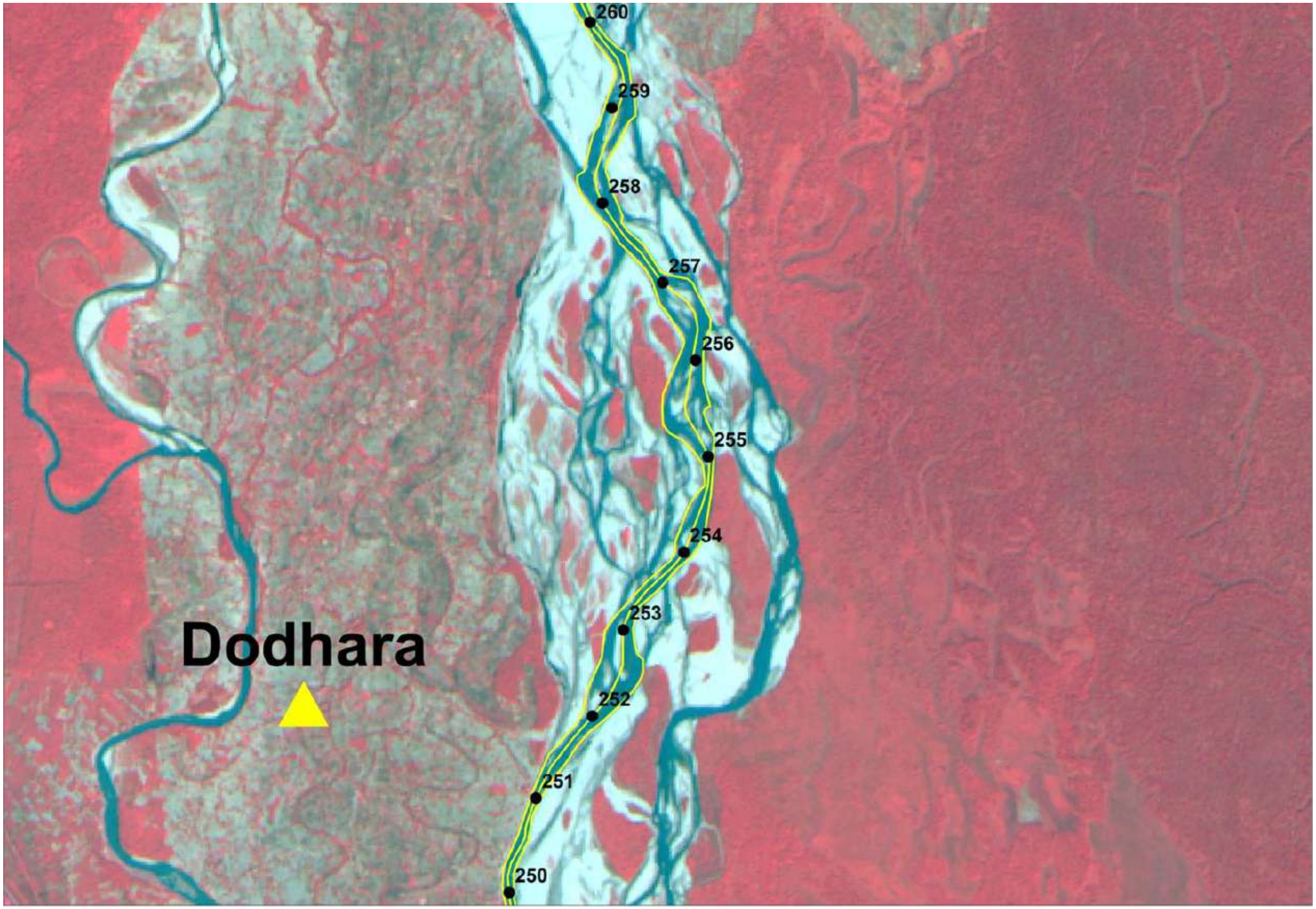


Figure 7.11a Braiding pattern of Sharda river from chainage 250- 260 in year 2010

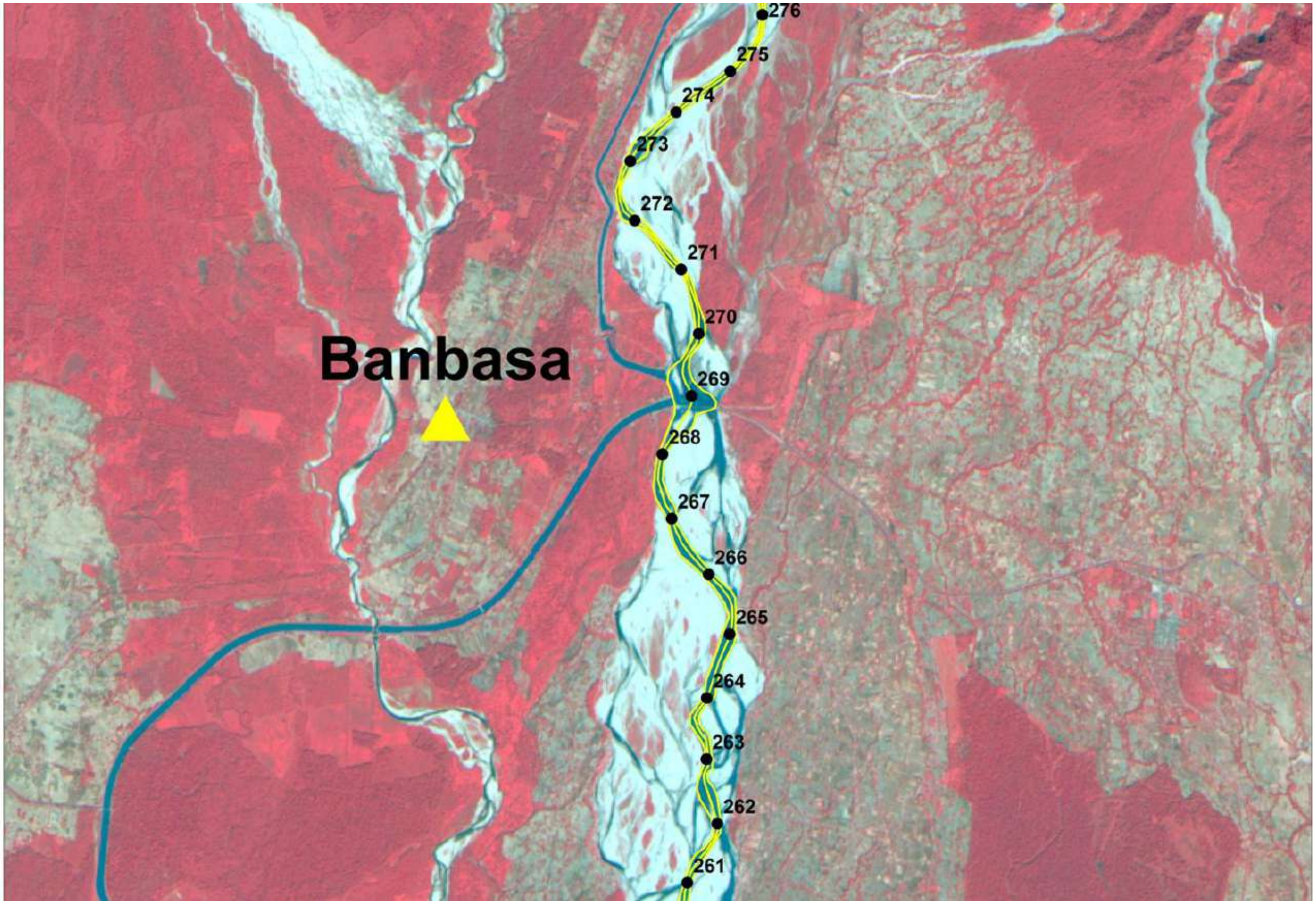


Figure 7.11b Braiding pattern of Sharda river from chainage 261- 275 in year 2010

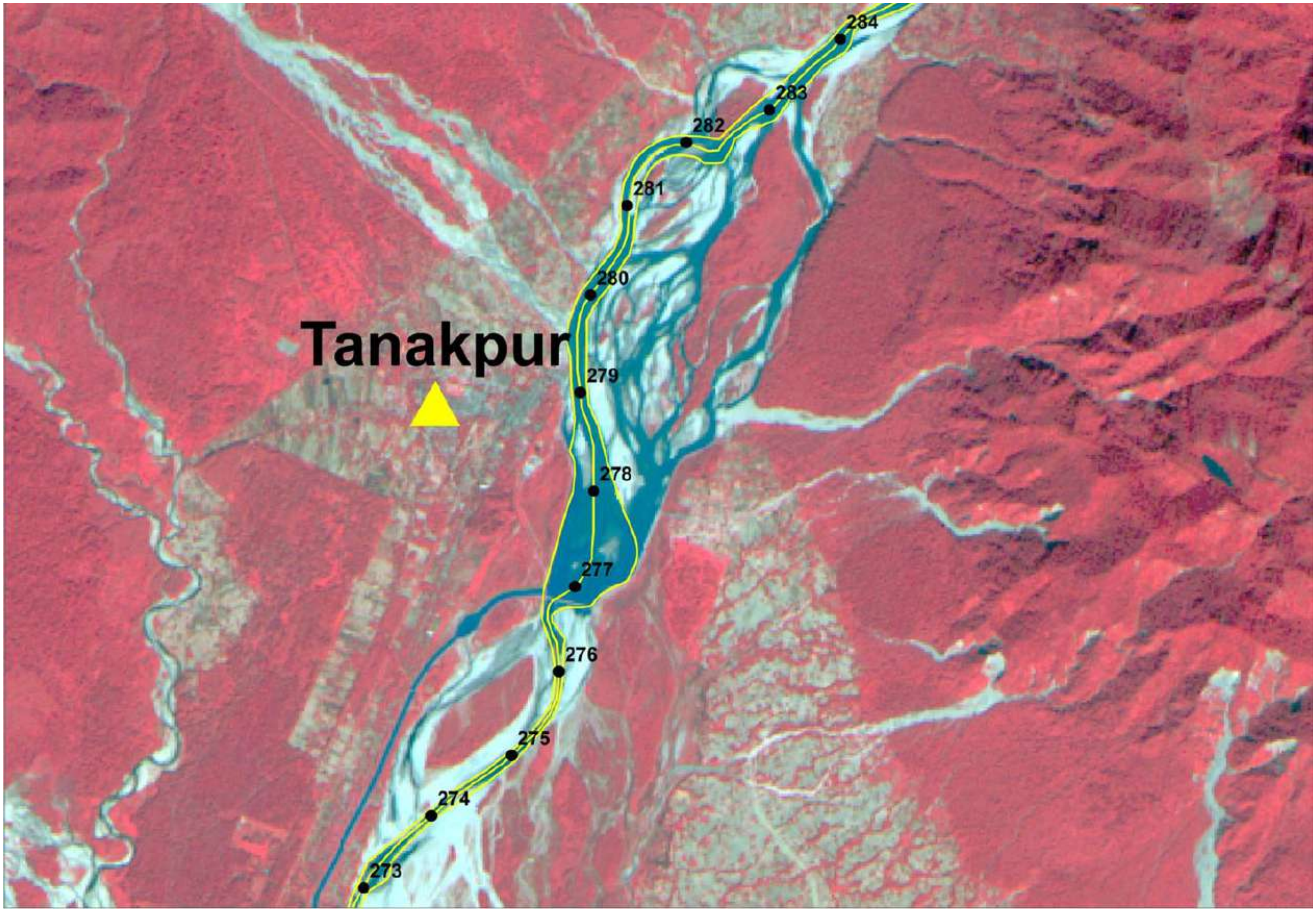


Figure 7.11c Braiding pattern of Sharda river from chainage 273- 284 in year 2010

7.3 COMPUTATION OF SHIFTING OF RIVER COURSE

Shifting of the river is calculated on the basis of center line of year 2010. Center line of year 2010 is bisected perpendicularly at a regular interval of 5 km, and it's further bisected at an interval of 1 km near the places where river taking sharp turn. The shift of left bank, right bank and center line in left and right directions has been computed for the year 1970, 1980, 1990 and 2000 with respect to base year 2010 in the GIS software. The sample map of computation of river shifting is shown in Fig 7.12 and results of the river shifting are given in Table 7.6.

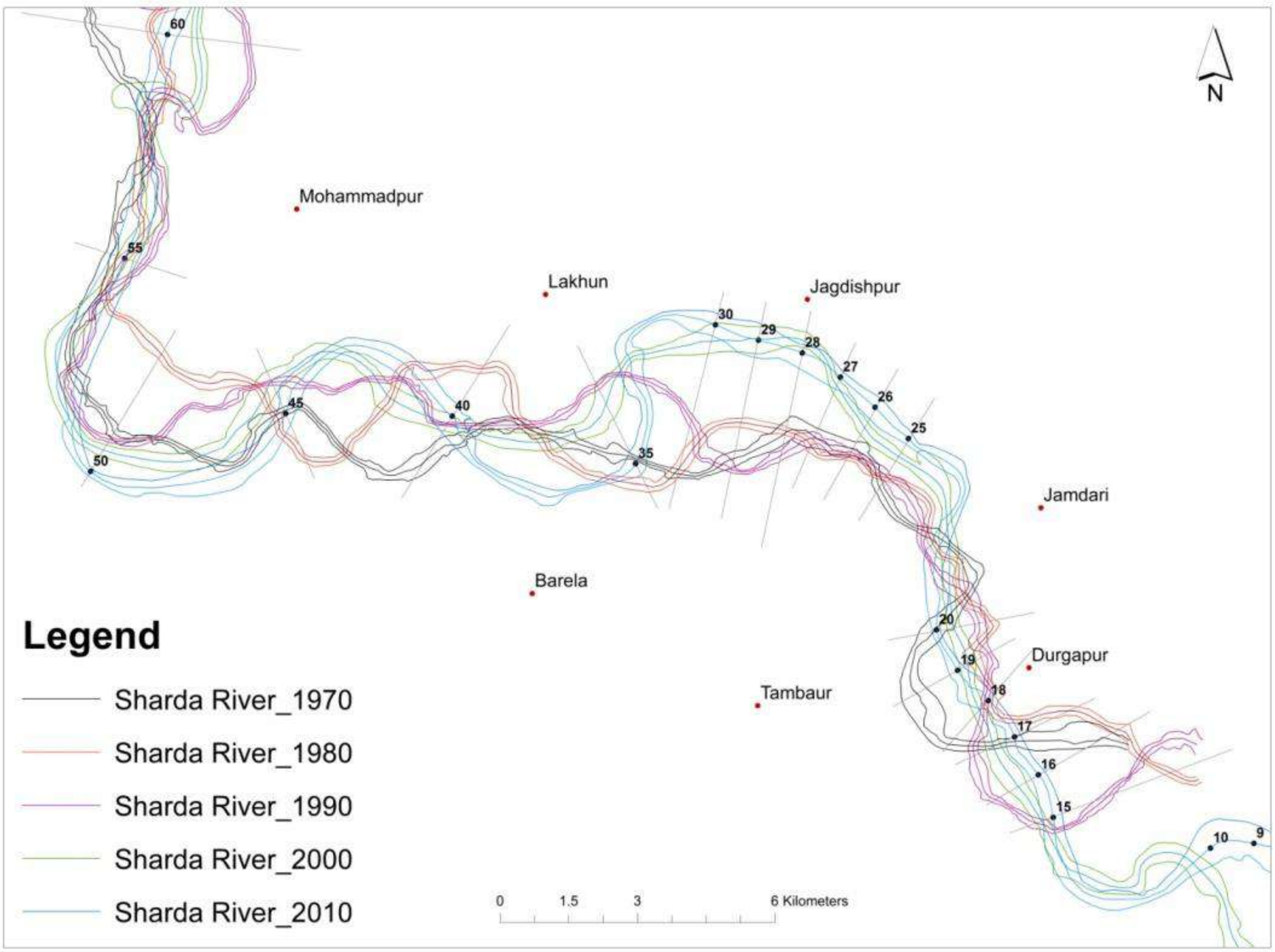


Figure 7.12 Sample map for the computation of shifting of the river

Table 7.6 Changes in the Course of Sharda river of Year 1970, 1980, 1990 and 2000 w.r.t. Center Line of Year 2010

Chainage	1970			1980			1990			2000		
	Left Bank	Centerline	Right Bank	Left Bank	Centerline	Right Bank	Left Bank	Centerline	Right Bank	Left Bank	Centerline	Right Bank
km	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
0												
15	-2169.70	-2284.00	-2389.80	-2640.18	-2729.00	-2830.90	381.33	397.57	355.77	371.14	267.66	167.60
16	-1715.88	-1648.70	-1384.30	-2083.45	-2002.95	-2033.50	1134.20	1080.50	1003.88	470.32	509.67	559.90
17	191.48	420.41	456.42	-1387.83	-1316.51	-1155.94	995.78	970.80	868.38	480.98	510.50	477.52
18	1316.96	1284.19	1186.08	-155.22	-172.17	-160.30	156.81	130.77	-8.80	330.22	283.72	205.50
19	947.73	1024.21	1191.36	-418.60	-413.50	-462.98	-676.33	-768.60	-883.60	-295.98	-263.18	-262.82
20	-305.23	68.40	316.64	-1233.19	-1188.60	-1180.84	-1003.35	-940.18	-936.21	-447.82	-380.56	-315.63
25	1234.03	1227.43	1242.35	1031.35	975.12	927.95	974.41	944.17	931.38	458.94	437.58	428.76
26	1072.00	1012.96	907.22	1385.55	1229.46	1032.80	1259.73	1100.92	958.00	582.62	495.95	396.68
27	1345.13	1412.27	1395.40	1617.16	1625.38	1484.40	1447.25	1447.60	1365.82	188.15	200.71	110.62
28	1646.47	1772.35	1702.90	1827.68	1737.15	1483.97	2333.22	2281.03	2081.08	-287.03	-259.77	-453.96
29	2818.87	2633.98	2459.77	2086.81	1838.89	1557.24	3043.01	2874.35	2560.92	57.03	-24.24	-78.98
30	3496.71	3348.18	3177.90	3027.98	3215.89	3207.50	2277.39	2143.71	2021.53	216.46	371.76	396.03
35	25.03	-161.09	-358.95	617.56	531.68	424.97	-1666.95	-1890.21	-2066.30	-1676.18	-1453.38	-1344.15
40	831.37	1166.81	1176.83	-1086.85	-1227.46	-1537.64	389.96	-201.05	-186.50	225.15	189.56	-62.11
45	150.65	-61.24	-227.37	1044.72	1085.34	942.87	-496.63	-743.41	-934.50	-707.00	-765.13	-749.50
50	-1068.80	-986.15	-953.70	-3037.30	-2985.06	-2965.56	-800.32	-814.41	-842.40	-595.65	-542.20	-504.03
55	458.50	314.44	138.54	191.62	20.61	-166.65	-218.84	-434.84	-644.00	83.71		-129.43
60	1837.06	1694.72	1605.70	530.83	373.18	237.09	-1594.42	-1766.34	-1915.90	-542.67	-653.23	-752.18
61	3006.83	2843.09	2693.46	-102.84	-274.18	-435.93	-401.71	1621.57	1575.11	-225.91	-380.36	-502.80
62	4397.00	4329.66	4253.03	-514.60	-607.16	-734.90	2374.00	2240.25	2108.21	-246.95	-276.93	-316.90
63	3509.82	3391.37	3683.85	115.62	63.93	110.68	1321.73	1235.47	1182.35	-262.55	-141.00	-117.16
64	2241.35	2215.71	2198.70	1784.63	1945.98	1978.00	824.67	763.30	669.76	-407.66	-374.53	-612.40
65	1681.60	1523.45	1433.37	2498.87	2301.37	2150.00	887.20	690.97	525.55	-236.08	-351.52	2657.17
67.5	1156.15	1166.08	1236.33	1951.06	2011.89	2187.46	2106.60	2034.92	1988.72	1730.50	1818.90	1862.73
70	-210.41	-431.34	-532.93	953.95	733.50	650.27	437.58	568.31	767.36	545.86	-383.34	384.44

72.5	440.82	307.85	132.50	680.40	602.76	484.43	-1655.12	-1681.61	-1724.42	86.11	237.34	257.00
75	-956.87	-908.89	-862.64	891.30	821.76	775.24	-834.72	-942.54	-1010.87	514.28	901.58	1147.86
76	-1431.04	-1451.64	-1579.00	970.51	866.73	689.35	-1477.00	-1475.20	-1638.00	-307.95	-413.31	-589.33
77	-1930.60	-2211.41	-2959.90	514.04	217.52	-540.98	-2308.48	-2536.16	-3260.20	-971.90	-1187.60	-1717.67
78	-2049.86	-2931.12	-3346.95	235.27	-689.98	-1161.46	-2577.50	-3453.21	-3906.40	-1330.84	-2143.52	-2383.42
79	-3738.00	-3746.04	-2424.31	-1734.76	-1766.92	-1810.70	-4274.25	-4286.46	-4330.80	-3028.82	-2965.80	-2906.20
80	-1389.19	-1494.87	-1610.40	-1232.54	-1328.75	-1418.90	-4174.78	-4246.32	-4345.09	-2683.85	-2535.65	-2347.00
81	-1245.03	-1368.42	-1502.90	-827.91	-959.23	-1083.18	-3936.30	-3972.92	-4026.60	-1901.05	-1555.38	-1423.10
82	72.02	-1960.73	-1333.26	906.25	-81.26	-380.60	-2050.32	-3010.97	-3262.34	342.04	-623.96	-891.74
83	1073.70	152.68	23.75	1838.99	996.49	281.40	-798.90	-1665.72	-2318.70	1159.55	333.26	-280.02
84	1511.90	1864.43	1934.91	1850.83	1738.07	1596.48	-514.40	-503.76	-519.90	1331.90	1371.56	1456.20
85	2905.51	2779.26	2598.50	2377.20	2267.15	2090.60	199.80	65.85	-56.00	1810.78	1758.60	1596.70
90	-1022.64	-1197.19	-1462.02	1018.57	864.76	669.28	-1746.52	-1952.55	-2263.60	-1305.22	-1356.75	-1467.40
95	935.41	737.58	495.60	1744.47	1698.74	1650.77	1826.45	1953.38	1872.60	2344.11	2250.68	2160.00
96	924.03	925.26	771.53	2282.30	2271.25	2167.30	2045.56	2267.87	2214.37	1645.72	2093.55	2240.57
97	1208.27	1235.40	1438.13	2398.13	2386.06	2413.51	2404.45	2491.89	2574.70	1409.52	1493.72	1554.30
98	1641.67	1647.37	1703.80	1572.23	1581.49	1642.80	2163.17	2081.96	2030.93	1251.70	1394.32	1477.40
99	1236.83	1158.39	-822.20	1045.60	937.60	-1151.42	1497.32	1438.79	-597.53	1325.21	1383.83	-549.55
100	1152.70	138.04	-1138.62	99.65	-52.33	-1379.71	1375.76	461.06	-771.74	1315.70	445.25	-732.35
101	883.70	-903.44	-1708.00	630.40	-1063.33	-1851.78	1097.57	-475.92	-1125.67	1177.36	-460.36	-1141.94
102	-1366.67	-1839.34	-2155.45	-1570.89	-2109.65	-2504.95	-843.04	-1284.82	-1625.58	-706.70	-1157.98	-1521.72
103	-2123.96	-2234.58	-2307.00	-2853.47	-2968.23	-3010.00	-2006.23	-1975.64	-1802.90	-1507.94	-1520.41	-1451.16
104	-2602.88	-2629.05	-2571.00	-2228.81	-2313.91	-2334.00	-1810.82	-1826.03	-1859.96	-1641.51	-1508.98	-1324.40
105	-1875.66	-2309.27	-2674.05	-742.78	-1160.43	-1523.29	103.30	-232.64	-481.52	-644.12	-828.51	-879.13
110	1050.26	1099.02	1177.22	414.64	222.49	43.55	1617.70	1483.34	1298.34	99.33	35.38	-27.25
115	-1334.26	-1227.53	-1376.56	-3309.55	-3396.83	-3838.82	-690.36	-774.38	-1218.57	402.23	520.56	168.73
120	1425.35	1416.43	1388.38	1154.47	1197.73	1278.70	1936.88	1949.89	1942.50	754.05	826.99	886.41
125	362.68	440.13	583.21	-2106.80	-2111.57	-2114.36	-2043.16	-2022.91	-2026.62	-1328.80	-1272.00	-1220.74
126	976.75	953.78	922.15	-1277.74	-1334.63	-1360.00	-1705.68	-1514.33	-1496.00	-734.37	-733.25	-661.42
127	2059.07	2513.96	2508.00	-567.06	-690.89	-795.44	-1055.23	-946.90	-978.85	-92.00	-91.54	-32.00
131	5598.97	5645.76	5572.50	2210.40	2095.28	1943.90	1894.04	1837.66	1712.74	1792.44	2019.64	2377.80

133	5459.37	5369.10	5267.00	1929.50	1820.03	1706.00	1349.90	1240.10	1140.15	52.93	75.42	101.78
135	4820.74	3615.71	3368.50	1346.58	148.71	-85.93	566.60	-581.96	-801.26	-82.06	-1178.97	-1327.30
140	865.86	878.59	1018.88	481.66	432.05	407.00	333.94	329.44	294.00	84.69	168.59	284.20
145	-1877.23	-1994.56	-2239.60	2104.20	1888.90	1648.00	-17.78	-220.00	-403.24	12.28	-76.80	-234.00
150	-5188.76	-5235.74	-5160.00	-2569.63	-2538.50	-2545.14	-1441.37	-1461.30	-1514.40	-439.85	-386.16	-320.90
155	1438.90	1328.20	1161.60	179.10	12.85	-175.50	868.35	909.30	809.23	2268.23	2244.85	2222.20
160	492.36	409.53	-106.80	895.73	1105.24	518.30	-766.00	-667.97	-1058.00	-47.00	-131.77	-712.00
165	213.68	62.54	-94.65	-660.10	-1901.44	-914.60	86.20	424.54	346.81	-385.96	-402.60	-333.50
170	-1195.51	-1223.42	-1372.11	-1721.48	-1794.73	-1944.40	291.12	250.39	64.37	254.65	268.88	255.80
171	-1596.10	-1736.80	-1814.00	-1772.90	-1887.80	-1919.18	-76.92	-176.15	151.70	-469.73	-405.21	302.60
172	-2077.95	-2084.93	-2062.40	-2074.20	-2063.12	-2044.82	-408.35	-433.58	-417.40	-80.45	-33.79	13.50
173	-977.74	-1463.97	-1614.90	-902.45	-1415.64	-1556.00	990.26	545.97	690.00	1589.38	1487.63	1636.00
174	-712.57	-703.13	-838.50	-575.48	-588.37	-749.80	2347.48	2430.57	2292.00	3214.48	3355.95	3213.00
175	-223.10	-344.73	-434.80	-357.70	-475.92	-552.20	2327.42	2427.20	2438.50	70.14	92.99	205.70
177.5	2362.40	1009.89	738.90	1406.32	70.02	-154.70	1232.92	32.91	139.70	1330.00	208.96	146.00
180	2182.75	2077.57	1946.60	1251.55	1799.51	1830.00	1580.27	1623.01	1686.37	2844.83	3165.38	3323.60
181	1469.63	1428.47	1358.09	2291.10	2232.56	2139.86	2434.00	2539.67	2523.20	2441.04	2433.02	2385.00
182	1048.66	931.99	747.70	1835.88	1702.78	1523.70	2852.71	2678.67	2454.00	1513.98	1374.72	1187.30
183	1192.98	1141.33	1055.70	1135.58	1115.31	1087.30	635.23	690.57	960.75	571.03	650.05	711.75
184	854.85	520.06	323.08	950.60	654.14	502.85	-679.78	-869.36	-919.34	-113.48	-300.37	-331.00
185	-617.28	-611.64	-551.60	310.82	287.55	314.30	-1842.22	-1796.22	-1696.40	-1353.91	-1264.88	-1160.80
187.5	713.93	800.68	882.75	970.47	991.48	1031.77	-175.52	1396.02	1658.40	-417.85	-380.53	-140.76
190	388.21	330.85	238.88	1291.00	1218.16	1143.28	-436.72	-448.64	-500.00	-849.26	-781.46	-804.88
192.5	933.30	816.08	769.55	-1453.84	-1616.22	-1840.00	-86.90	-228.69	-394.35	-510.68	-492.20	-533.28
195	63.75	30.98	-12.18	-732.95	-638.35	-556.90	-919.80	-854.86	-235.08	-909.90	-674.64	-298.47
196	455.13	346.53	237.88	1342.78	1177.03	1053.90	775.31	699.91	632.07	98.43	141.21	188.56
197	1097.17	874.53	544.00	2143.22	2002.73	1735.12	1602.20	1500.05	1385.20	896.74	984.44	901.26
198	2494.46	2450.89	2309.30	2094.18	2037.29	1861.30	2590.77	2510.00	2299.30	1726.95	1697.13	1625.43
199	2295.57	2304.39	2272.64	1773.50	1768.75	1675.35	1972.30	2274.17	2313.97	1320.33	1508.14	1509.85
200	1452.70	1108.84	929.30	1251.88	793.54	555.80	1003.43	640.15	473.00	752.30	454.24	724.60
205	-690.77	785.07	-793.78	33.58	-43.02	-40.60	296.57	262.33	235.48	-775.07	-787.94	-713.46

206	164.90	126.02	-1.84	407.75	336.61	172.65	758.57	689.28	536.60	-602.26	-629.27	-728.90
207	872.68	1224.93	1035.97	1291.15	1200.61	1146.36	1245.13	1120.73	926.70	-330.62	-212.58	-197.70
208	2152.44	2119.89	2403.30	1783.48	1657.79	1512.60	1775.61	1616.48	1458.96	-1664.67	-1660.52	-1679.60
209	2628.68	2625.57	2583.80	2424.93	2477.58	2509.40	2461.06	2644.21	2620.30	-1544.12	-1494.66	-1434.80
210	2784.27	2818.71	2826.00	2899.38	2858.25	2800.00	2948.78	2982.76	2960.90	-1572.45	-437.93	-378.72
212.5	1187.75	983.25	800.52	1499.28	1251.76	983.30	241.37	343.03	306.20	2387.57	2249.02	2047.00
215	1370.57	1356.64	1373.85	1484.16	1423.86	1416.30	2339.22	2309.24	2310.30	2936.43	2900.25	2906.90
216	2199.08	2083.23	1878.44	2538.38	2416.07	2206.41	2994.91	2883.09	2645.45	3015.68	3198.35	3334.90
217	5953.86	5908.31	5881.80	2767.11	2659.09	2567.80	2437.15	2401.15	2580.00	1510.68	1522.45	1984.80
218	6516.17	6352.12	6198.60	2550.02	2408.58	2283.30	1155.14	1098.61	1036.20	621.05	838.58	1018.94
219	6722.67	6611.84	6454.67	894.32	837.12	708.73	561.74	606.54	523.40	130.74	561.28	685.97
220	1197.41	1115.76	1132.14	263.37	192.02	194.60	337.28	255.01	231.86	-626.11	-635.74	-524.40
222.5	870.23	875.91	842.00	1079.95	1010.61	917.94	95.36	33.51	-96.96	113.44	134.19	123.30
225	2052.33	1495.22	1388.54	2342.60	1885.59	1388.54	1555.21	1178.01	549.74	881.98	2189.92	1638.46
226	2050.80	696.12	566.60	1926.41	652.44	591.63	1432.85	265.16	275.65	2574.46	1375.50	1375.26
227	-659.45	-725.66	-702.65	-337.82	-323.56	-276.70	-165.03	-154.49	-125.00	264.83	528.28	598.60
228	-3546.73	-3856.19	-3750.08	-534.21	-820.40	-759.00	-469.33	-451.59	-701.12	495.02	-358.65	-192.20
229	-3861.80	-3874.54	-3862.55	435.42	-482.43	-480.67	-732.18	-618.87	-442.70	-1035.23	-319.82	-206.12
230	-1333.28	-1392.28	-1572.87	150.03	17.90	-156.33	-265.23	-364.26	-472.40	-286.52	18.59	88.97
231	-523.56	-609.85	-729.30	63.89	125.32	158.90	354.48	305.71	240.80	168.89	565.11	722.16
232	-394.93	-459.37	-562.42	-251.58	-171.47	-178.00	817.42	893.18	900.26	278.35	407.31	538.57
233	-2163.31	-1998.08	-1899.17	-1269.59	-1287.37	-1232.66	-319.90	-385.83	-487.30	202.37	77.70	35.00
234	-3695.21	-3958.96	-4071.30	-4424.83	-4643.88	-4710.40	-603.91	-832.23	-869.90	-370.21	-597.47	-603.10
235	-5444.49	-5423.09	-5430.55	-5022.53	-5010.74	-5025.67	-2732.10	-2709.37	-2744.30	-376.79	144.30	531.69
236	-5420.55	-5570.64	-5726.53	-4453.36	-4556.85	-4461.26	13.41	-53.68	-159.80	1123.25	1072.48	1062.85
237	-4691.72	-4644.57	-800.00	-1590.18	-1502.85	-1266.87	1056.90	1046.61	948.85	939.58	1182.07	1269.15
238	500.58	489.27	479.60	311.98	607.59	655.60	1421.37	1498.92	1519.40	984.31	1199.84	1549.30
239	612.77	709.73	548.96	842.75	892.85	743.10	1241.31	1228.09	1007.62	908.30	1095.31	994.90
240	1281.87	1231.25	840.27	1410.28	1285.41	842.05	967.70	1231.88	794.77	1328.08	1215.58	807.38
245	-15.45	98.08	153.15	-352.48	-446.75	-490.27	-246.08	-302.35	-300.21	-679.81	-741.66	-759.00
250	-358.29	-171.82	-59.50	-306.68	-258.31	-204.53	-188.89	-100.43	-119.00	-123.43	-42.00	43.93

251	-117.95	-26.42	47.70	-225.87	-170.12	-88.20	37.08	63.23	65.14	-191.46	-81.82	15.70
252	-201.59	-104.06	0.15	34.57	-26.61	-76.50	-13.06	-65.01	-107.24	-77.02	-52.22	-9.32
253	-195.40	-176.33	-215.44	-345.77	326.70	-362.00	-29.47	-93.65	-208.25	-248.80	-237.10	-276.23
254	786.73	824.39	903.15	726.43	700.66	720.10	845.42	758.33	688.57	-934.94	-1283.39	-947.00
255	1354.87	1451.65	1510.90	1172.28	1229.37	1248.55	1258.23	1245.30	1184.80	-364.38	-381.86	-427.58
256	1646.17	1775.22	1860.22	1633.70	1645.78	1546.63	1619.06	1587.68	1440.66	-398.19	-395.05	-522.05
257	1542.78	1522.89	1586.61	1507.17	-1455.46	1456.93	1707.44	1614.92	1610.00	-208.83	-273.95	-276.48
258	345.83	290.07	271.80	160.08	144.20	157.55	418.08	369.56	311.30	-465.64	-538.86	-590.35
259	607.88	438.34	449.20	598.38	446.56	472.12	230.00	70.33	83.84	250.64	65.91	47.50
260	261.89	347.99	432.60	340.19	385.99	431.30	421.90	444.32	469.73	-204.83	-182.54	-166.36
262.5	537.88	575.67	602.10	600.37	612.29	577.90	1643.36	1605.36	1543.28	307.89	-249.60	185.43
265	453.34	494.99	525.14	52.89	1073.85	1094.09	1440.18	1405.27	1352.18	1309.57	1292.72	1255.15
270	47.89	111.51	263.00	132.88	156.86	197.40	225.84	215.45	267.45	223.45	200.99	209.40
271	380.00	501.94	648.74	253.51	373.50	549.38	395.97	451.68	502.28	453.99	469.49	480.76
272	-312.71	-373.32	-460.00	-485.91	-498.45	-475.50	-402.42	-534.59	-725.20	173.21	150.36	-7.85
273	-1047.80	-883.63	-692.78	-513.10	-497.24	-487.17	-317.07	-312.84	-341.56	-52.74	-14.01	21.30
274	-440.82	-394.71	-320.70	-180.05	-124.14	-60.10	-87.90	-86.82	-96.70	-58.70	-24.65	0.96
275	-35.29	32.26	118.11	-6.72	51.48	114.40	159.98	181.61	200.17	22.61	15.57	27.47
276	54.53	161.05	274.75	-73.47	-23.31	370.20	-15.47	132.29	219.05	-10.68	-5.19	-0.70
277	313.90	220.47	82.92	248.51	94.75	-118.18	359.21	245.57	67.48	-25.13	11.43	-41.70
278	105.49	-53.42	-28.91	84.08	-186.52	-320.74	145.21	-131.94	-289.30	399.03	159.71	37.07
279	-444.26	-412.41	-379.84	-1158.04	-1155.41	-1169.72	-698.03	-732.97	-769.50	-153.23	-55.64	36.16
280	-722.17	-680.55	-523.34	-1542.37	-1579.05	-1597.40	-202.06	64.88	54.08	-15.10	-7.82	7.45
281	-557.48	-550.80	-524.20	-1730.41	-1765.91	-1756.76	-180.59	-108.03	-125.00	-95.19	-134.12	-121.50
281.5	-679.57	-763.32	-718.32	-1798.76	-1877.82	-1839.20	-457.49	-379.47	-319.90	82.13	-24.39	-6.90
282	-104.87	-362.86	-375.30	-1307.25	-1585.10	-1628.20	-107.53	-394.26	-283.70	92.68	-106.61	-42.00
283	-44.89	5.33	35.38	-218.21	-237.16	-291.70	172.04	116.39	25.50	13.80	1.80	-10.86

*positive (+) value indicates that the river course was towards right side and negative (-) value indicates it was towards left side with respect to course of the river in year 2010

Figures 7.13 to 7.18 show the shifting of center line of river of year 1970, 1980, 1990 and 2000 with respect to year 2010, while Figs 7.19a to 7.24a show decadal changes in the course of river and Figs 7.19b to 7.24b show change in river course for year 1970 with respect to year 2010 in respect of shifting of centreline, right bank and left bank.

Figures 7.13 to 7.18 reveal major shifting of the river course in span of year 1970 to 2010 in the whole reach except in the upper reache i.e., Chainage 150 km to 284 km, which can be attributed to the presence of two barrages in this reach that control the lateral shifting of the river course. Major shifting of the river course from left to right has been noticed over the years near Duwa, Rajapur, Belaha, and Simra while from right to left near Amar nagar, Dhauraha, Chidaipatia, and Beldandi. Maximum wandering of the Sharda river has been found at Kataiya, where river has wandered randomly over a width of about 10 km during 1970 to 2010. No progressive shifting of the course of the river with respect to time has been noticed as evident from Figs. 7.13 to 7.24.

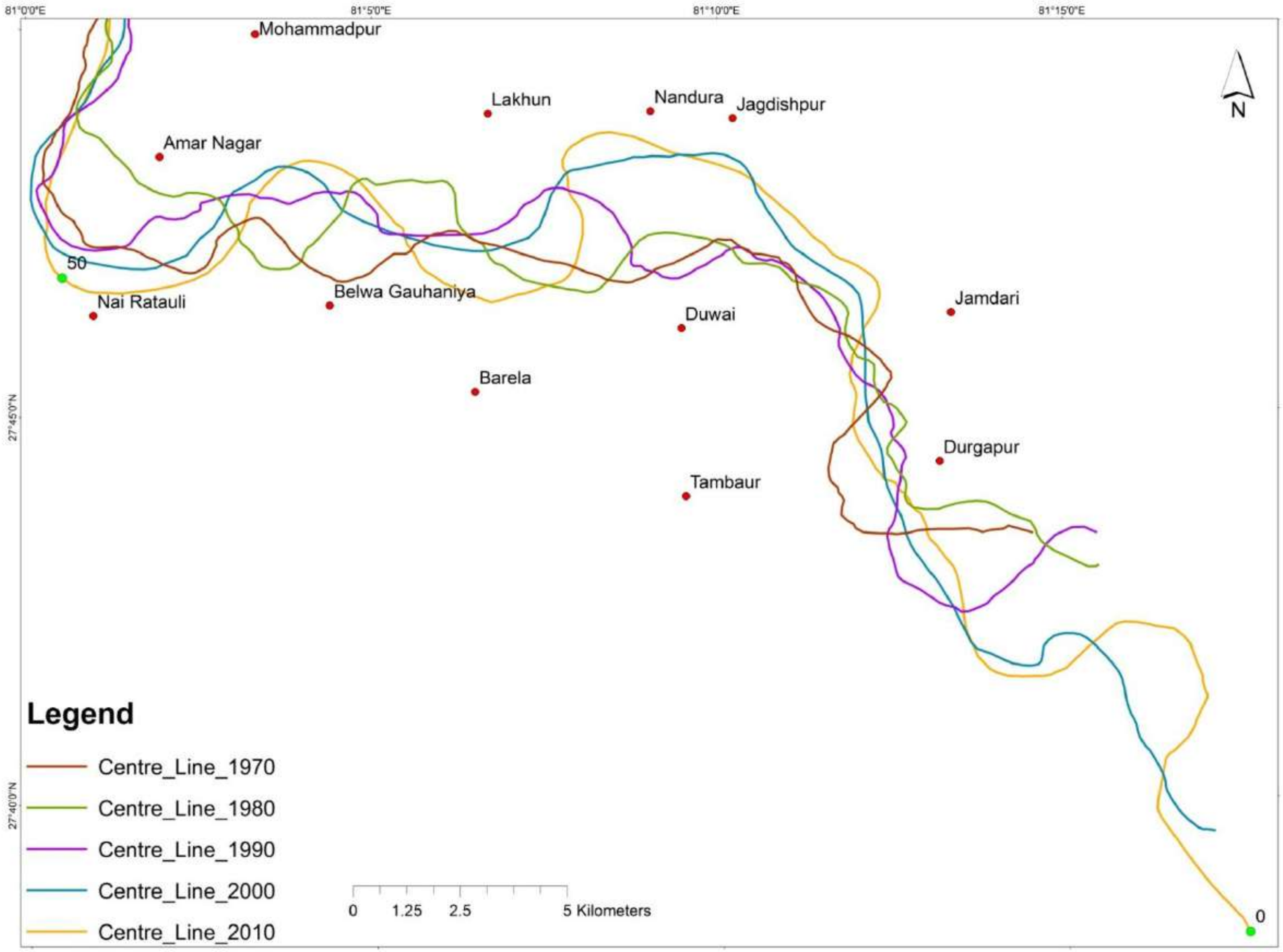


Figure 7.13a Shifting of center line of Sharda river from chainage 0-50 km

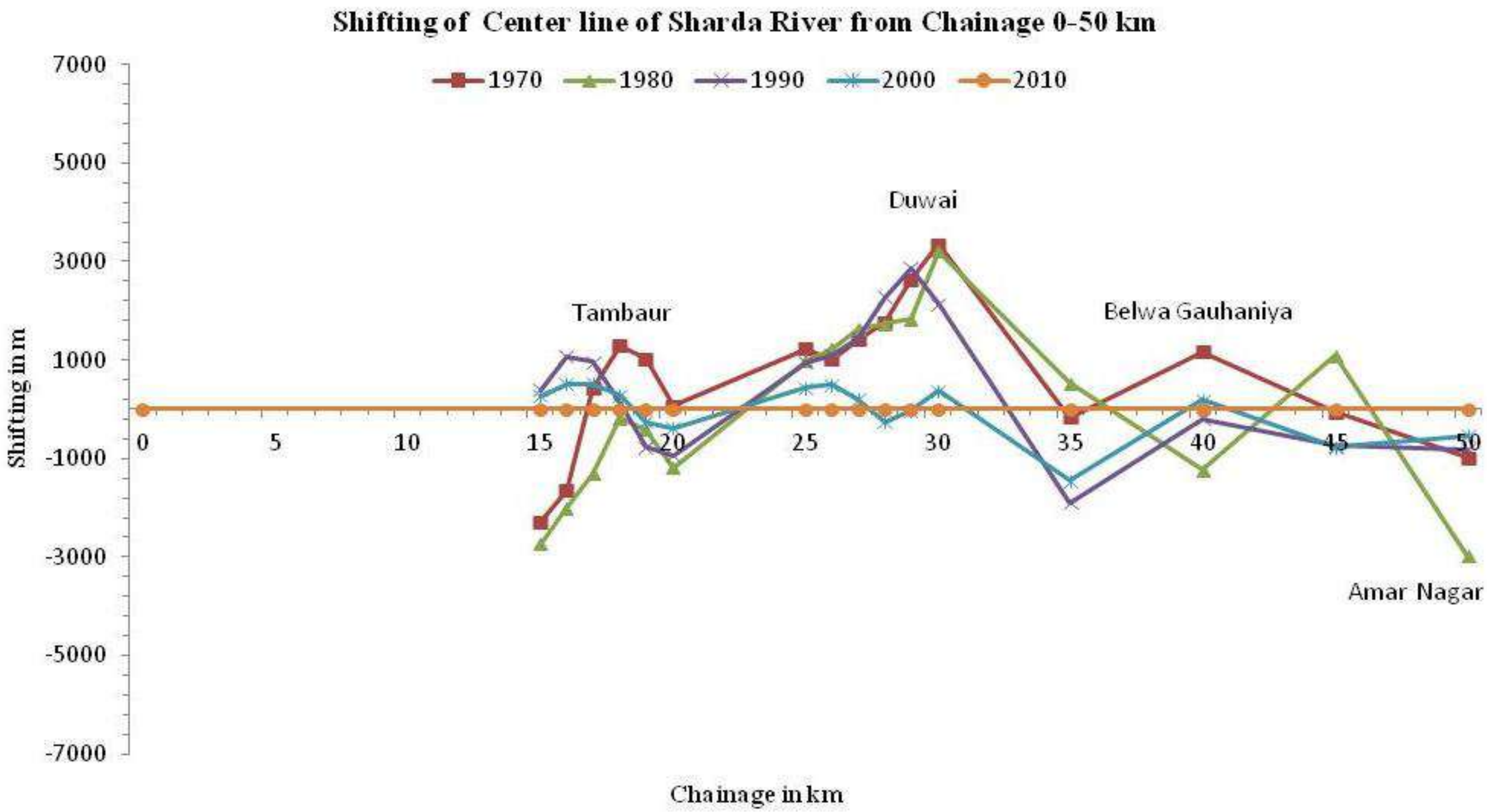


Figure 7.13b Shifting of center line of Sharda river from chainage 0-50 km

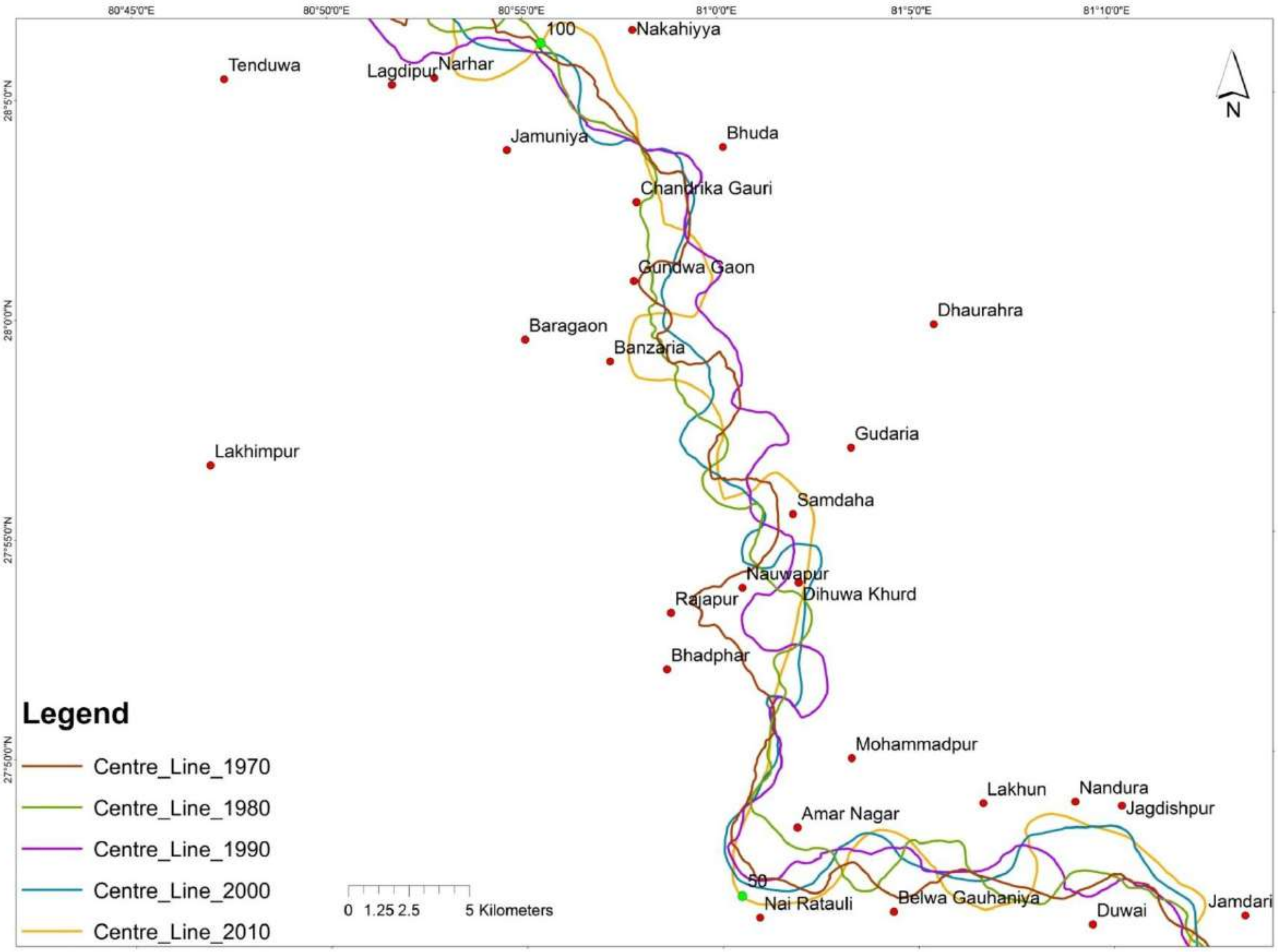


Figure 7.14a Shifting of center line of Sharda river from chainage 50-100 km

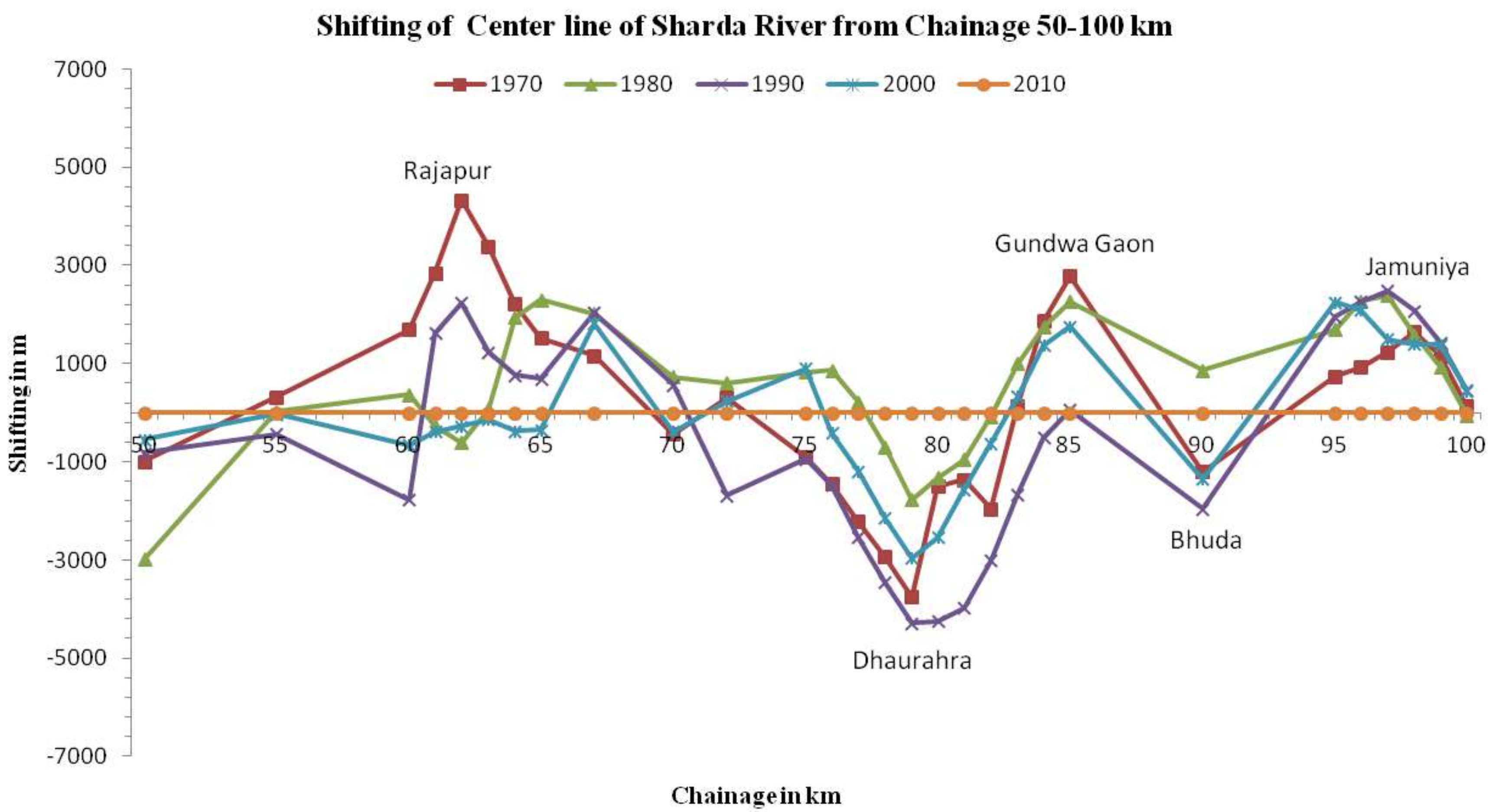


Figure 7.14b Shifting of center line of Sharda river from chainage 50-100 km

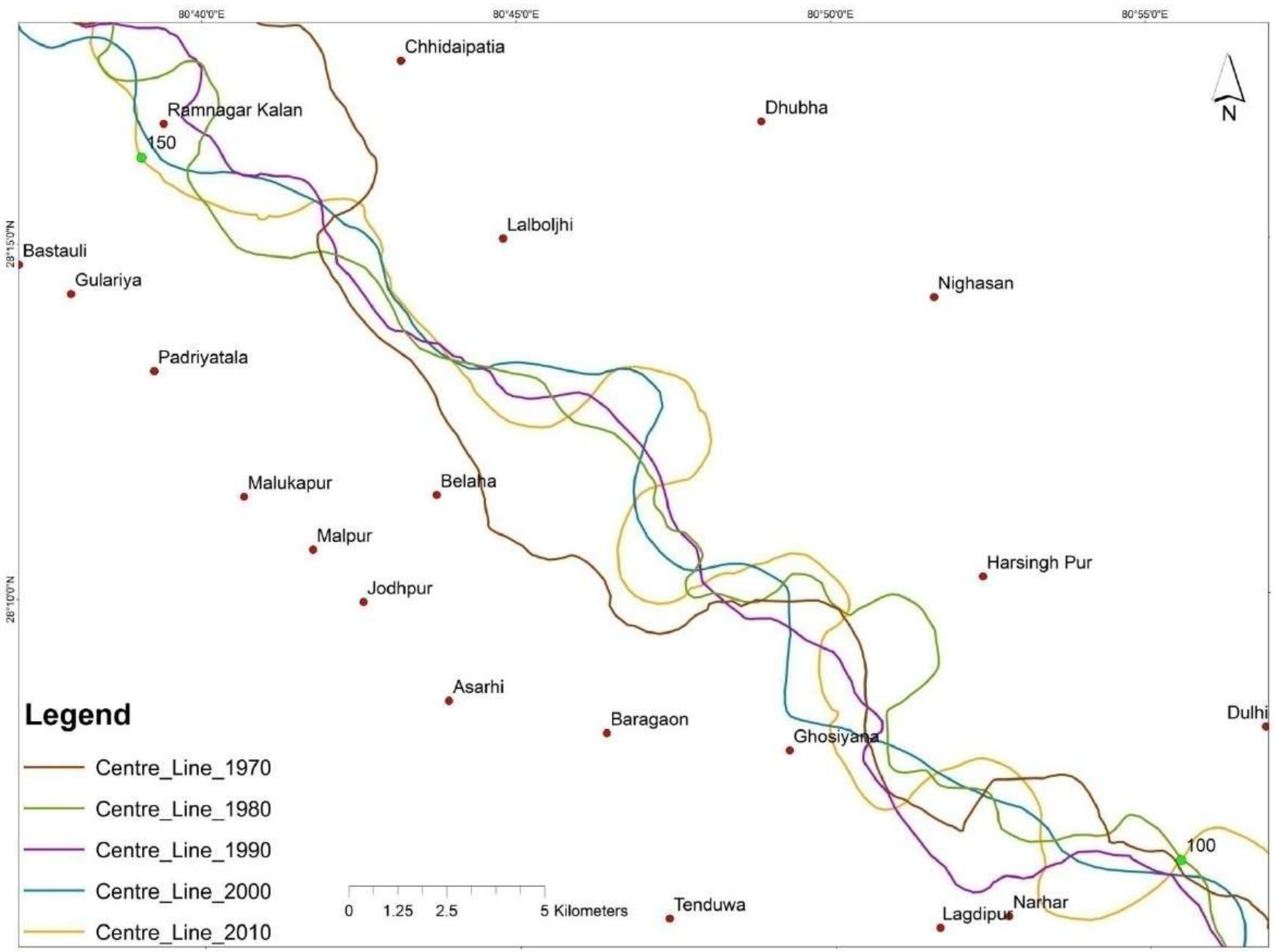


Figure 7.15a Shifting of center line of Sharda river from chainage 100-150 km

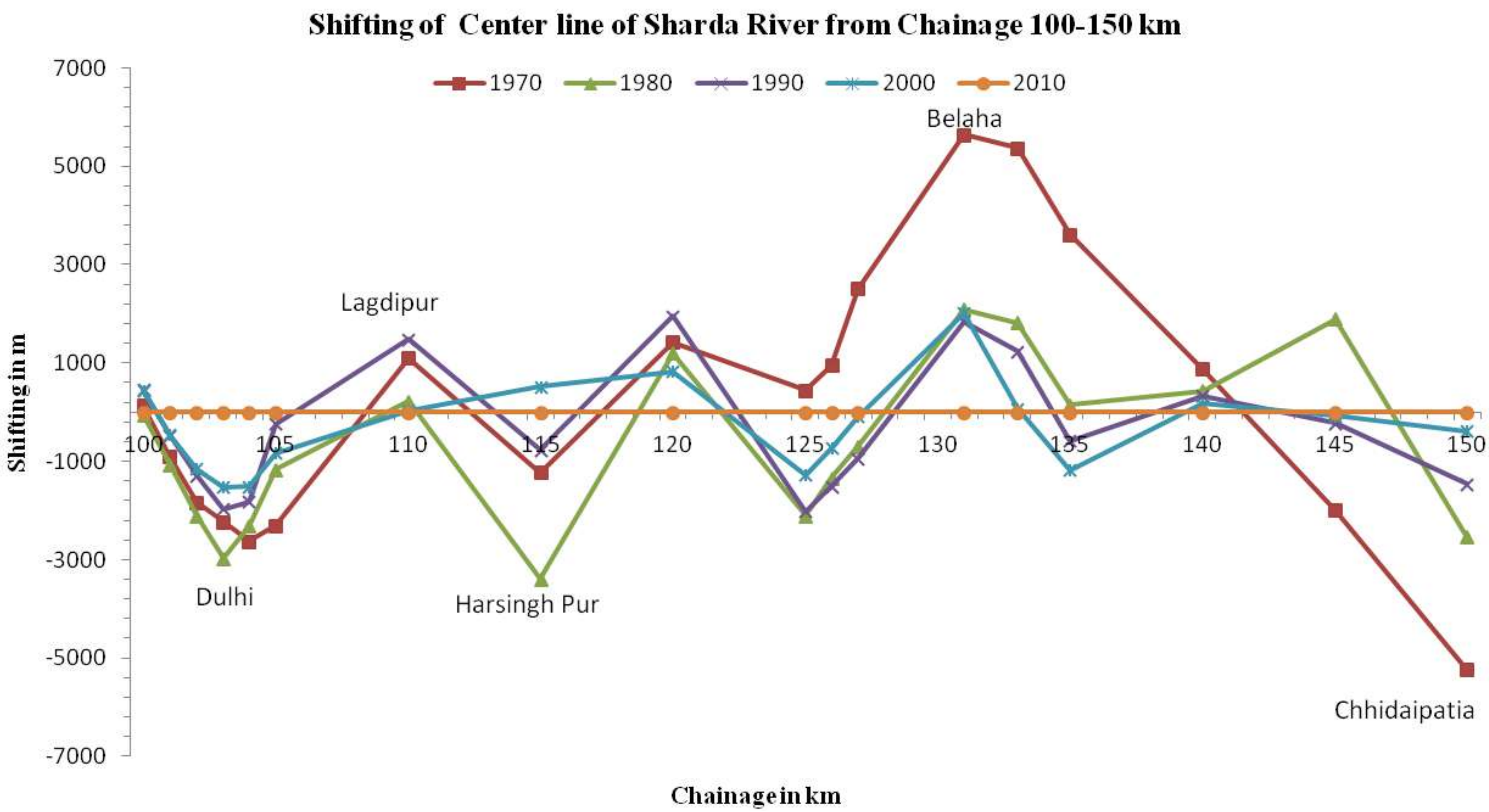


Figure 7.15b Shifting of center line of Sharda river from chainage 100-150 km

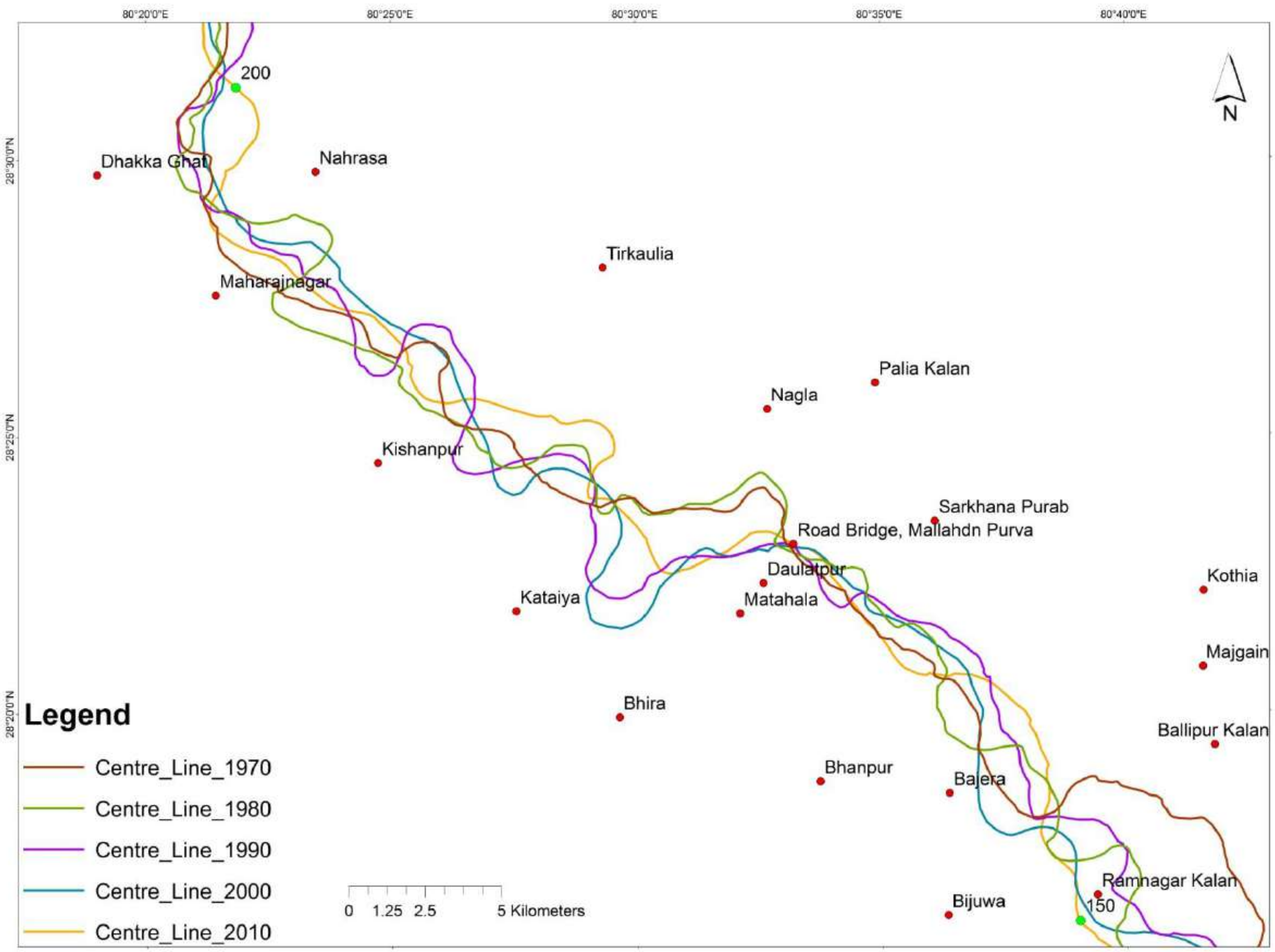


Figure 7.16a Shifting of center line of Sharda river from chainage 150-200 km

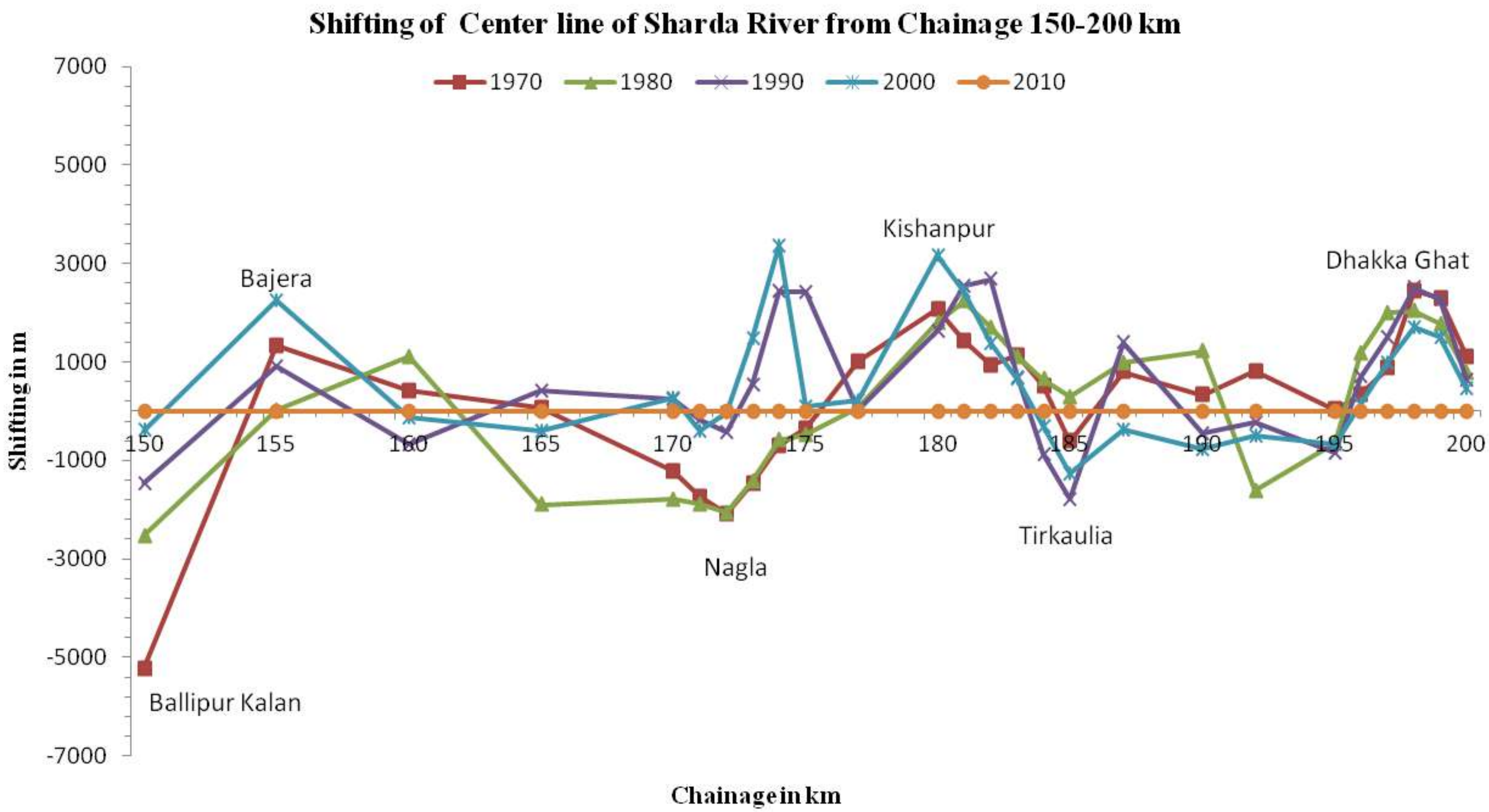


Figure 7.16b Shifting of center line of Sharda river from chainage 150-200 km

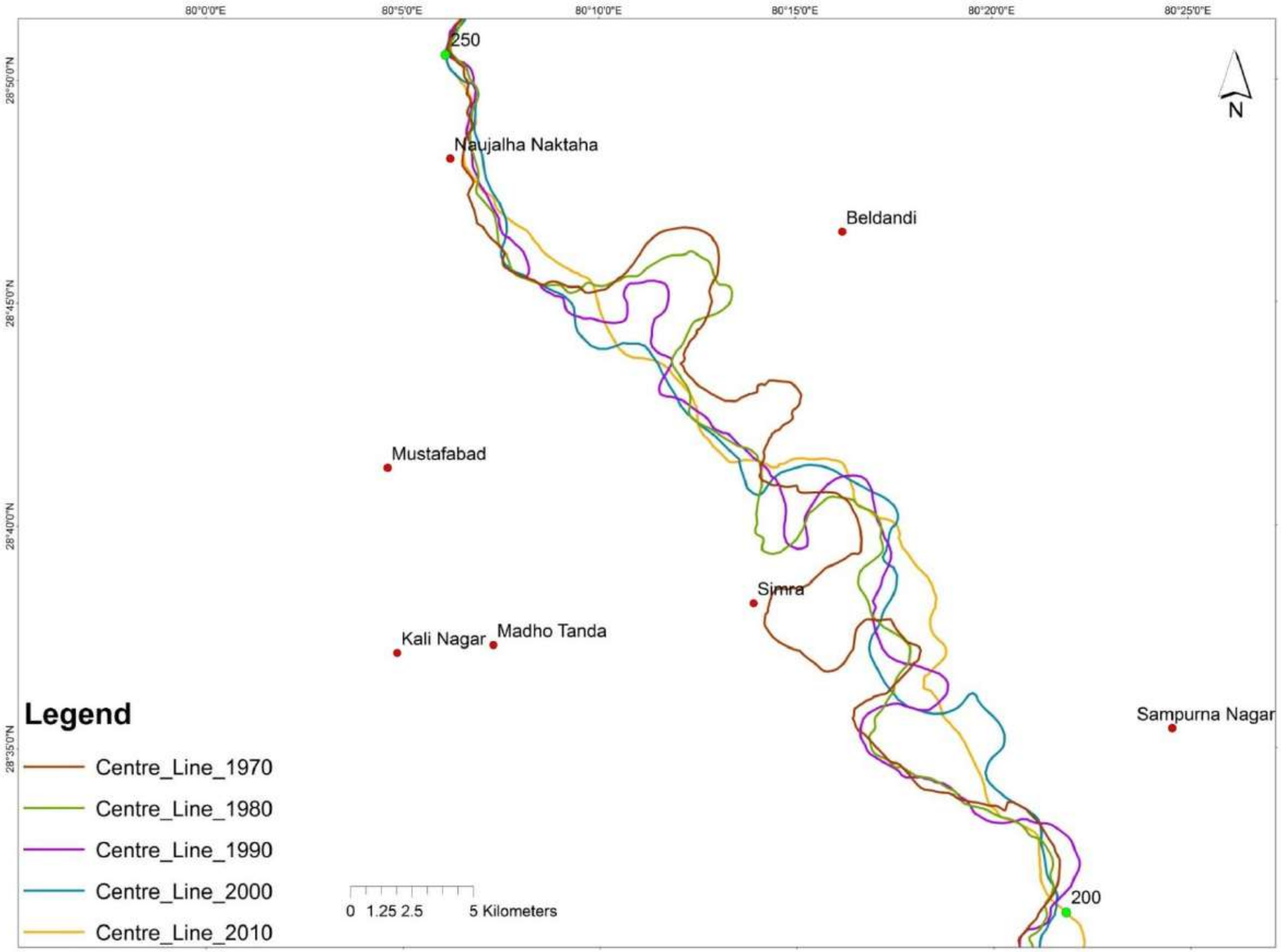


Figure 7.17a Shifting of center line of Sharda river from chainage 200-250 km

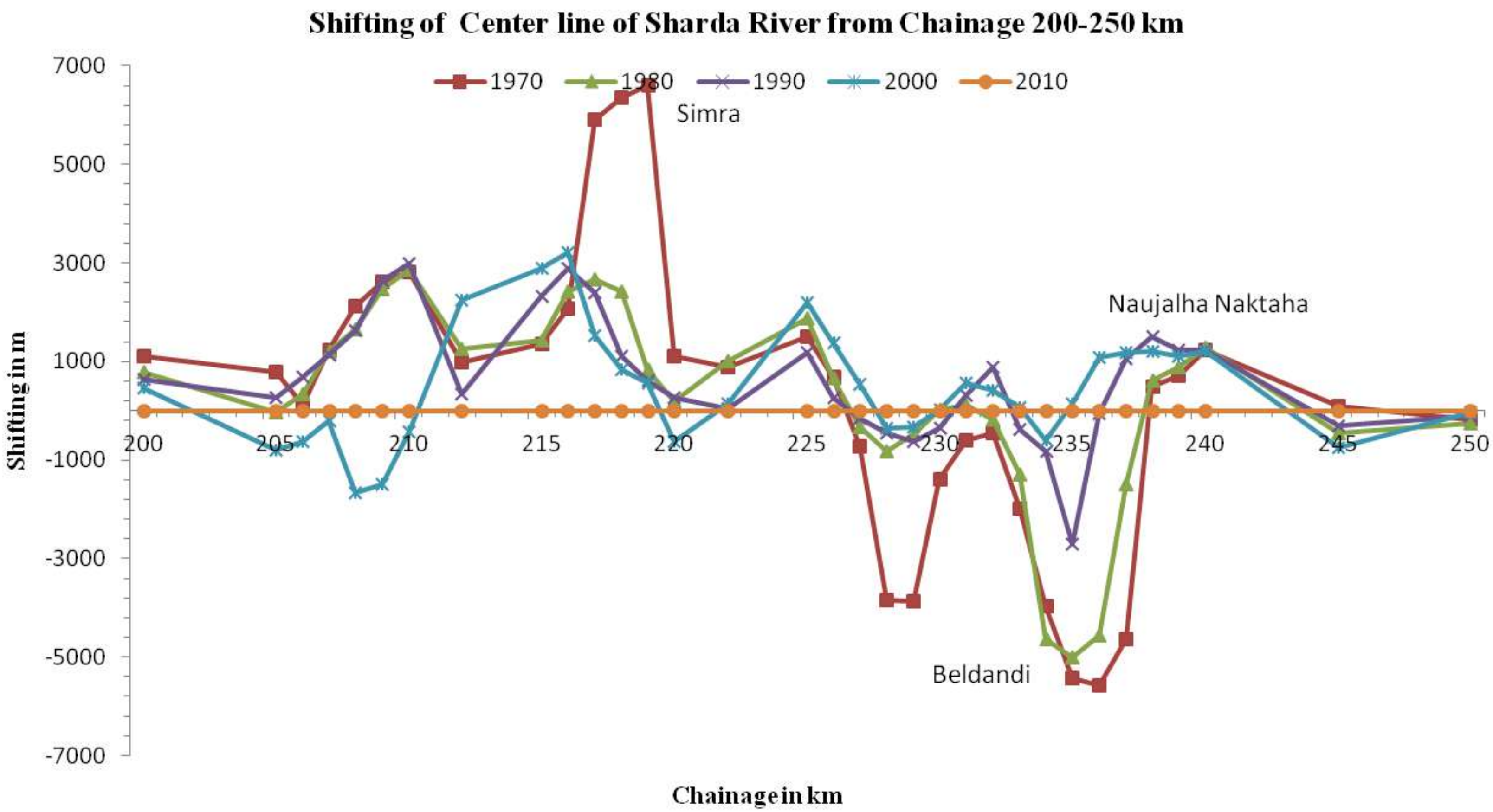


Figure 7.17b Shifting of center line of Sharda river from chainage 200-250 km

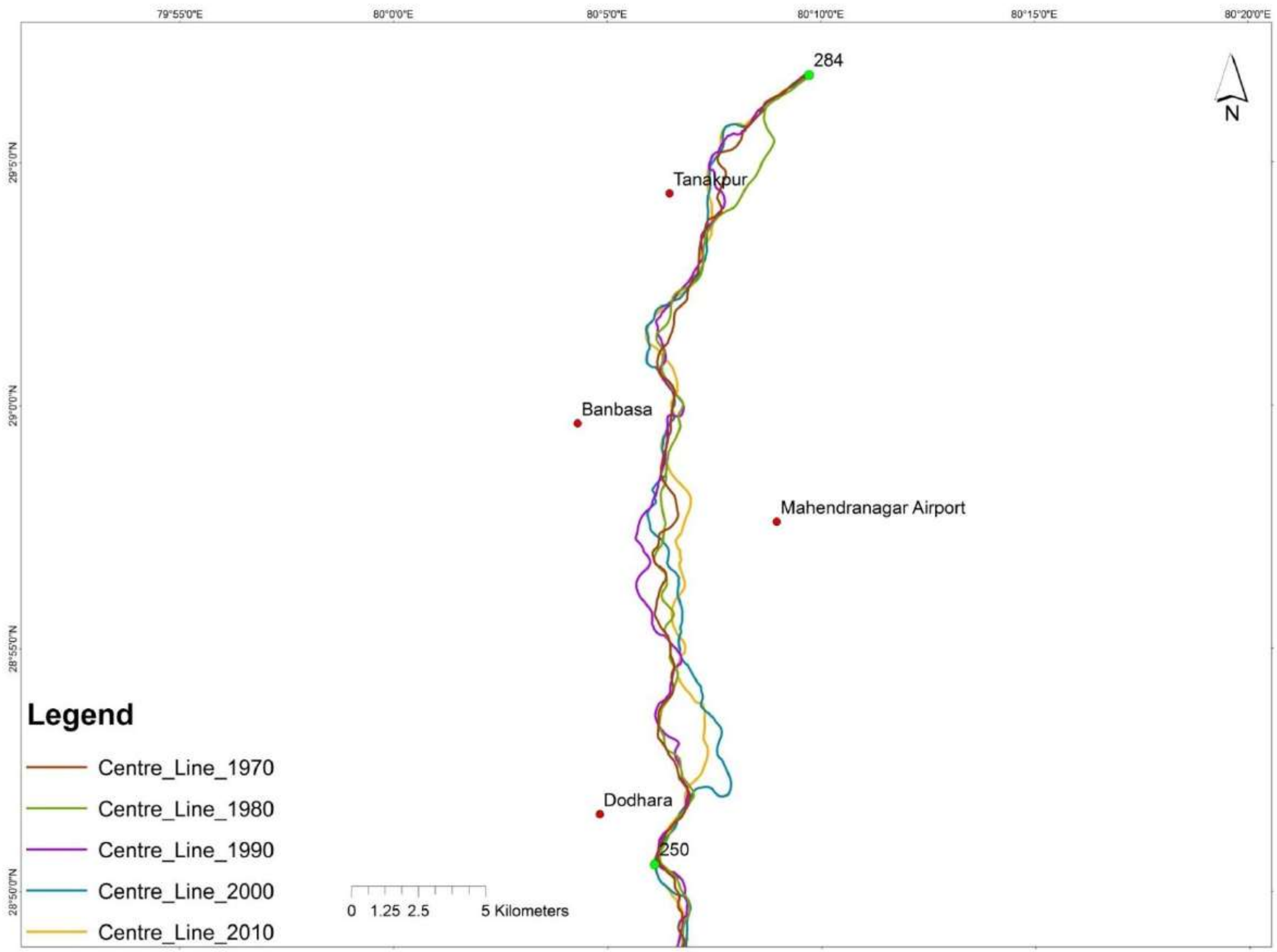


Figure 7.18a Shifting of center line of Sharda river from chainage 250-283 km

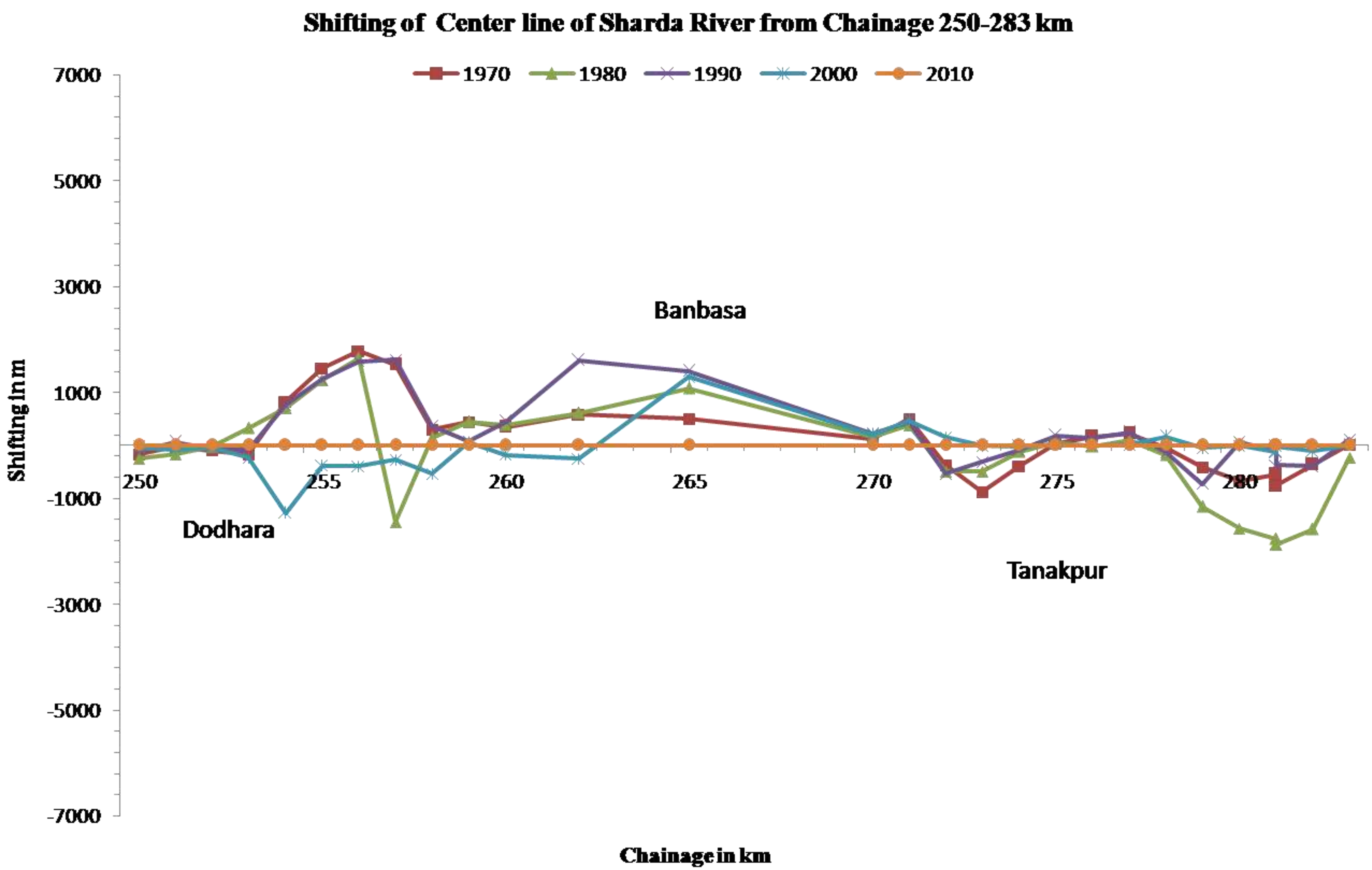


Figure 7.18b Shifting of center line of Sharda river from chainage 250-283 km

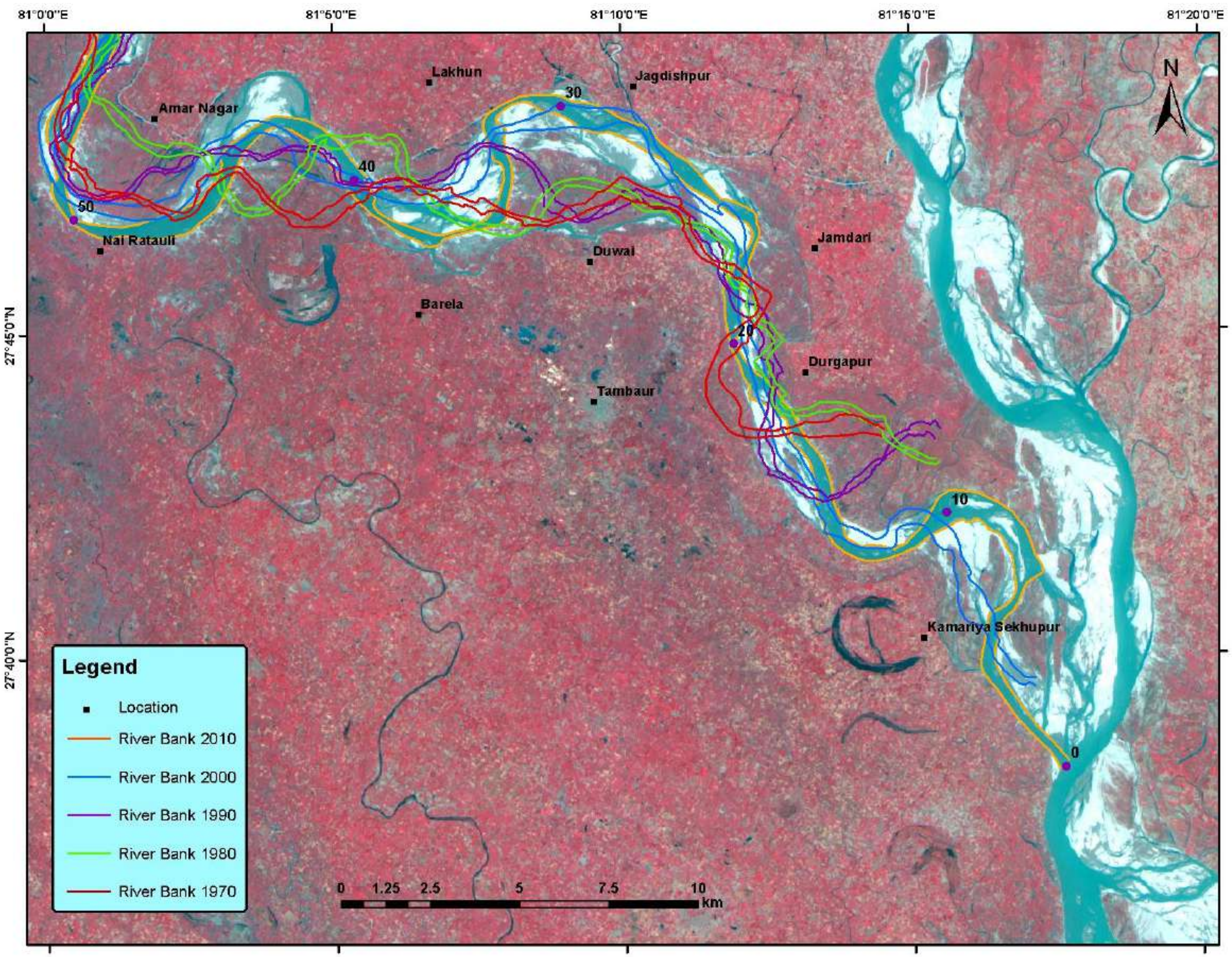


Figure 7.19a Decadal changes in the course of Sharda river from chainage 0-50 km

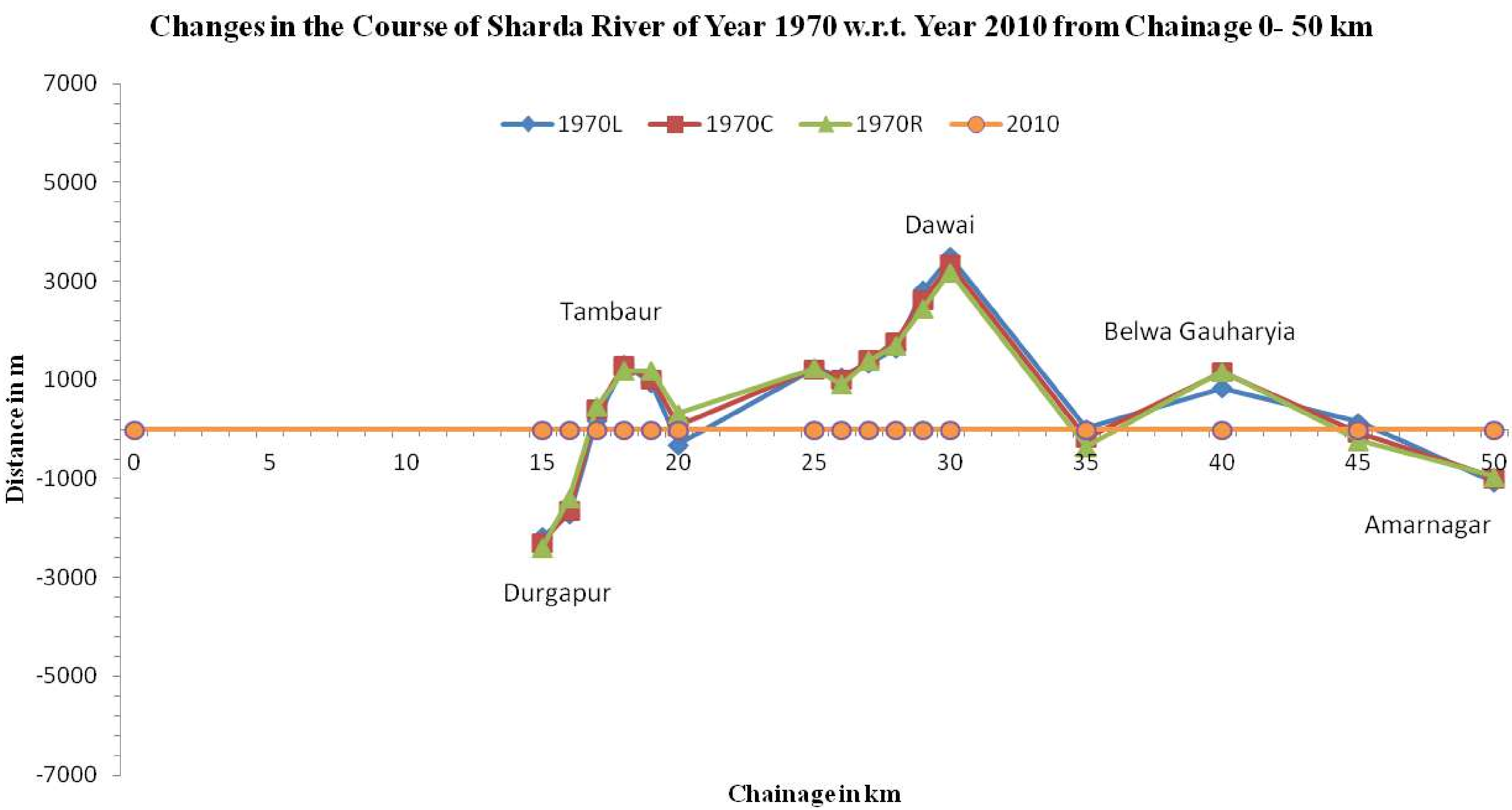


Figure 7.19b Changes in the course of Sharda river of year 1970 w.r.t. center line of year 2010 from chainage 0-50 km

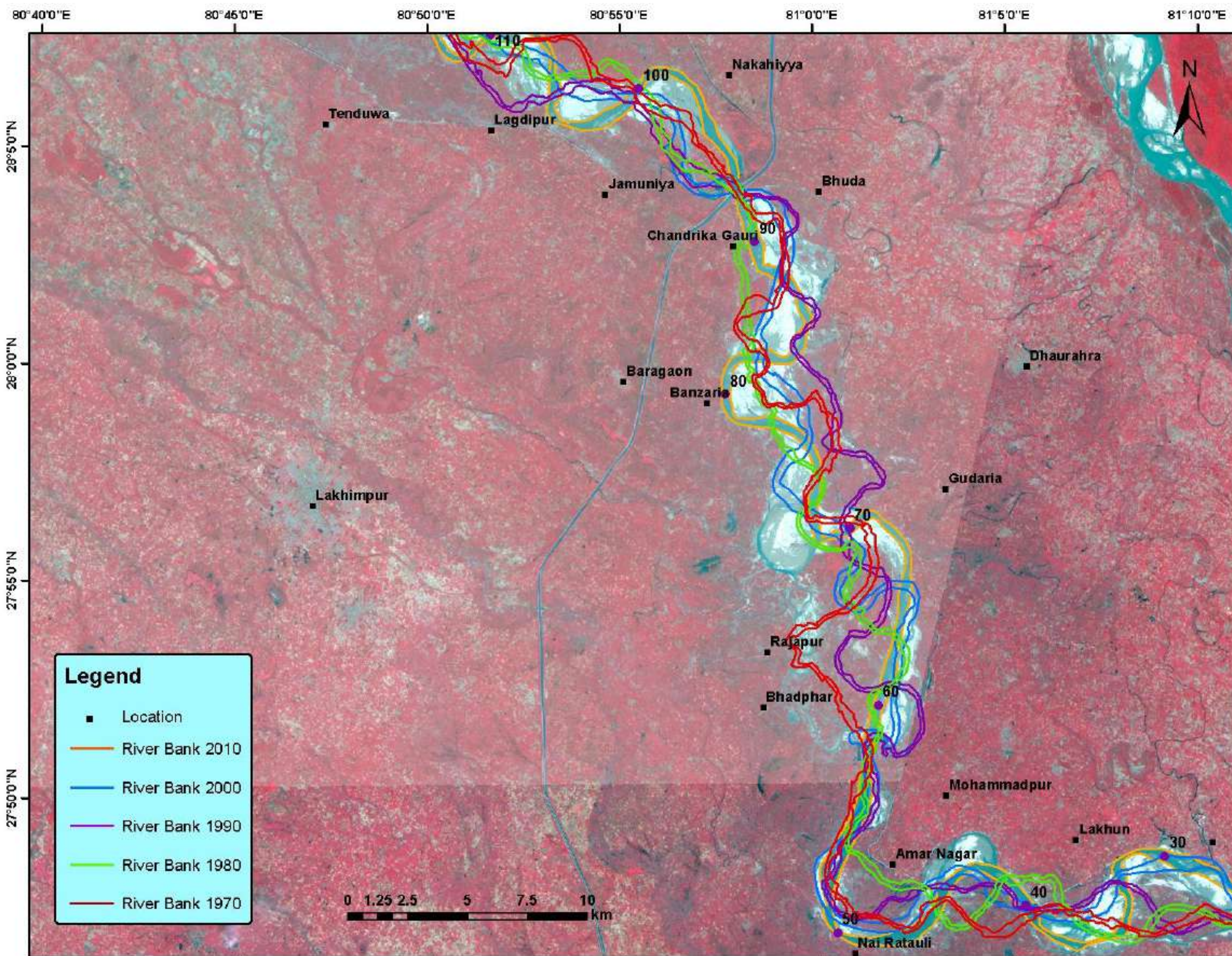


Figure 7.20a Decadal changes in the course of Sharda river from chainage 50-100 km

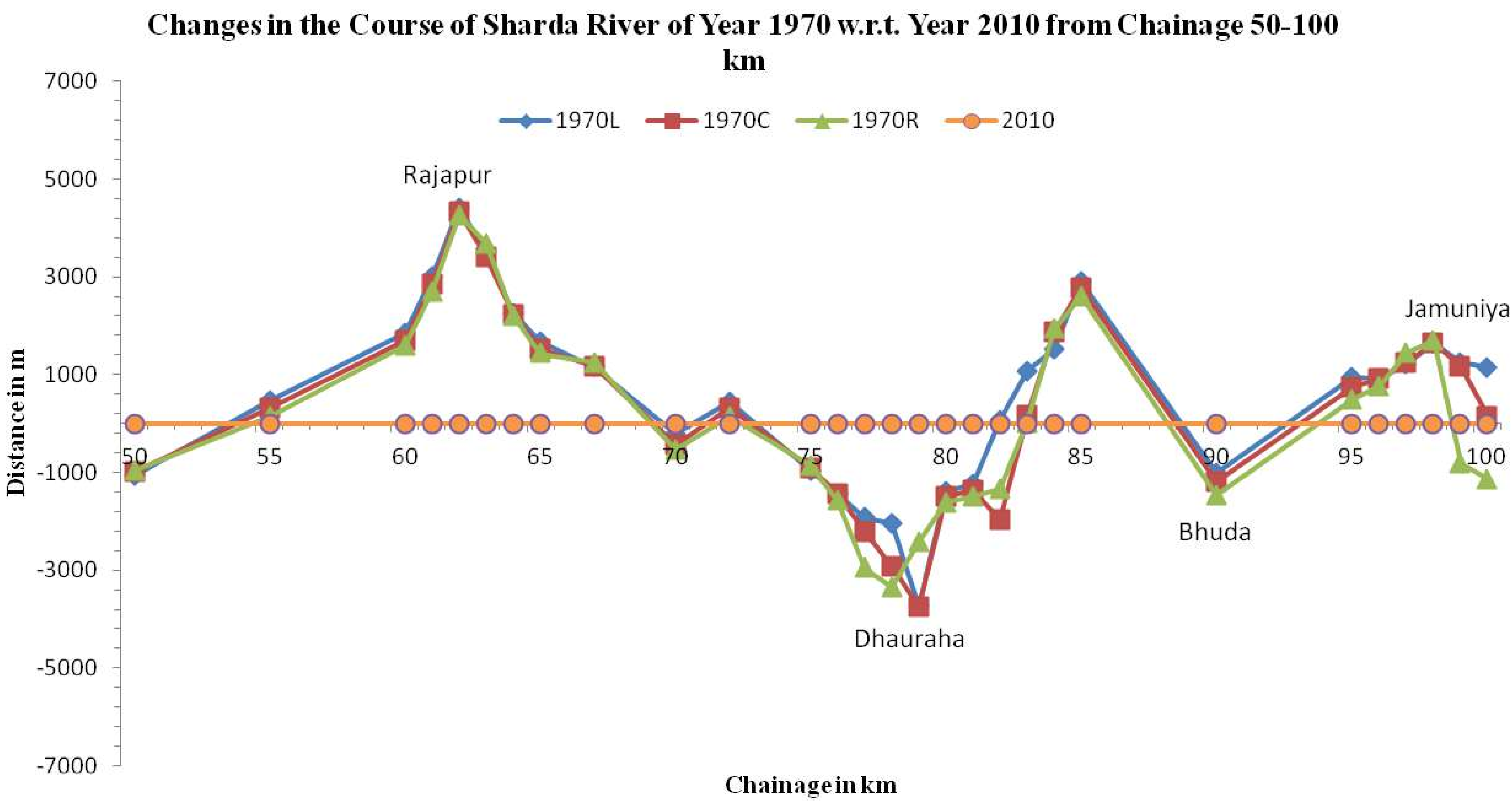


Figure 7.20b Changes in the course of Sharda river of year 1970 w.r.t. center line of year 2010 from chainage 50-100 km

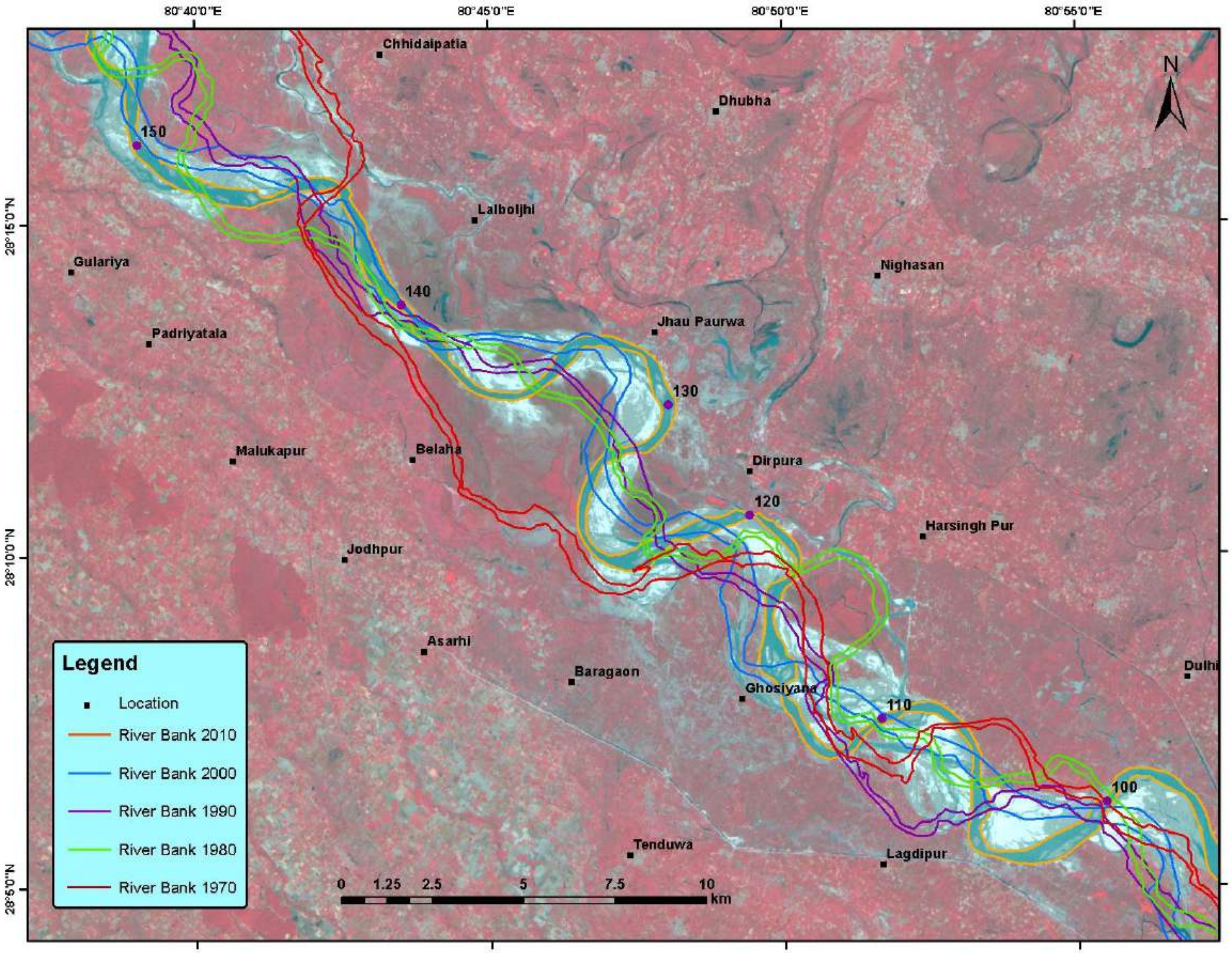


Figure 7.21a Decadal changes in the course of Sharda river from chainage 100-150 km

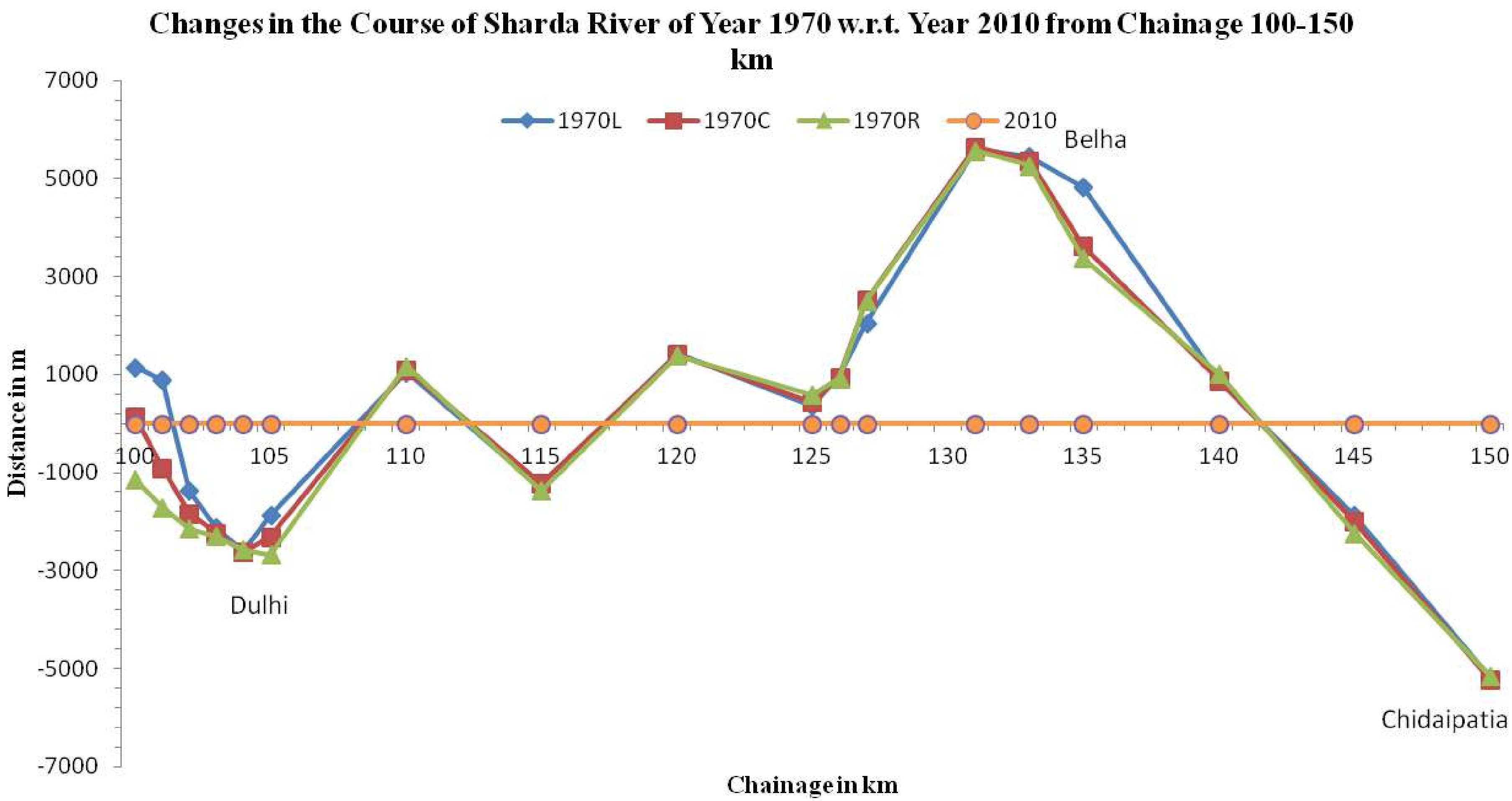


Figure 7.21b Changes in the course of Sharda river of Year 1970 w.r.t. center line of year 2010 from chainage 100-150 km

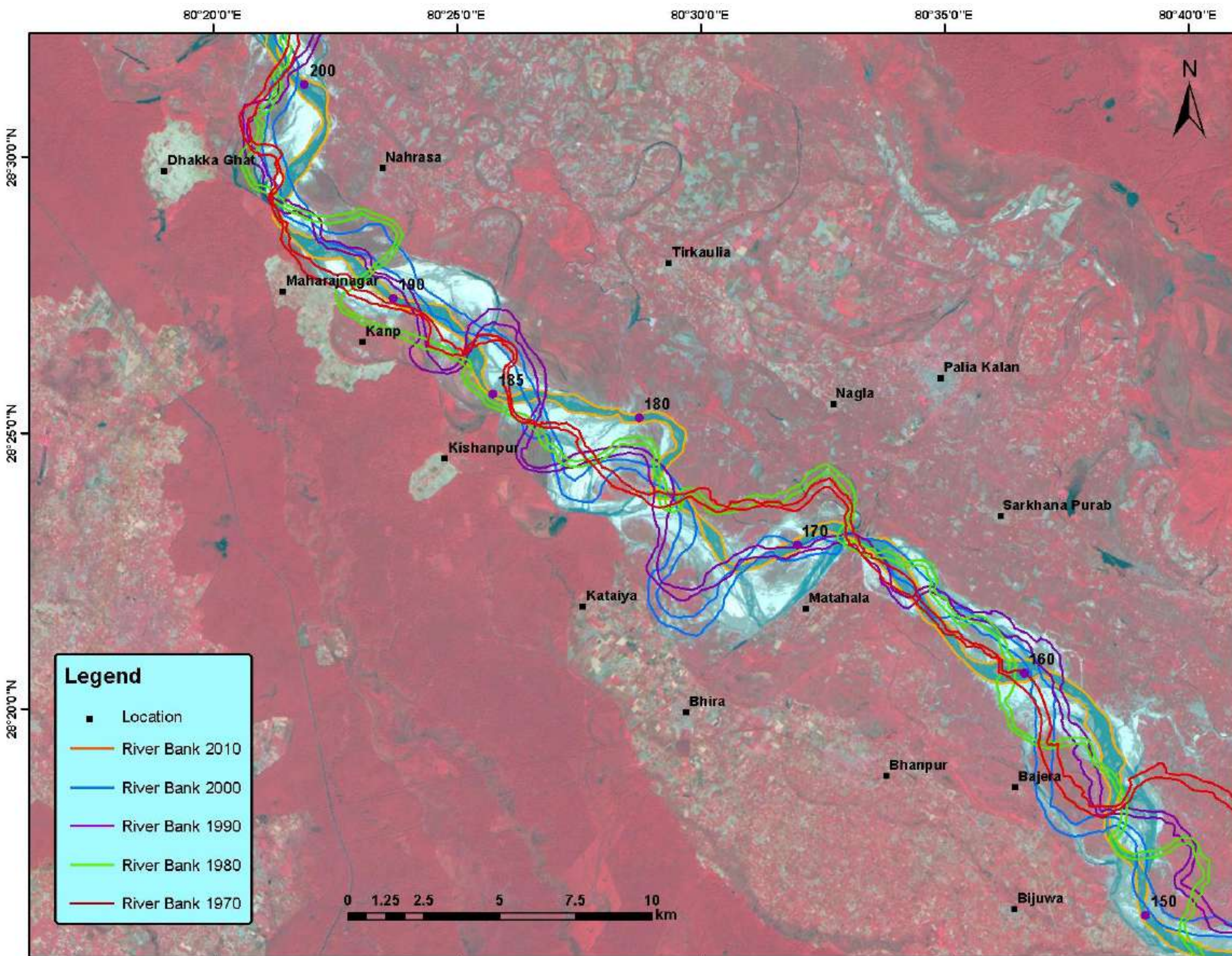


Figure 7.22a Decadal changes in the course of Sharda river from chainage 150-200 km

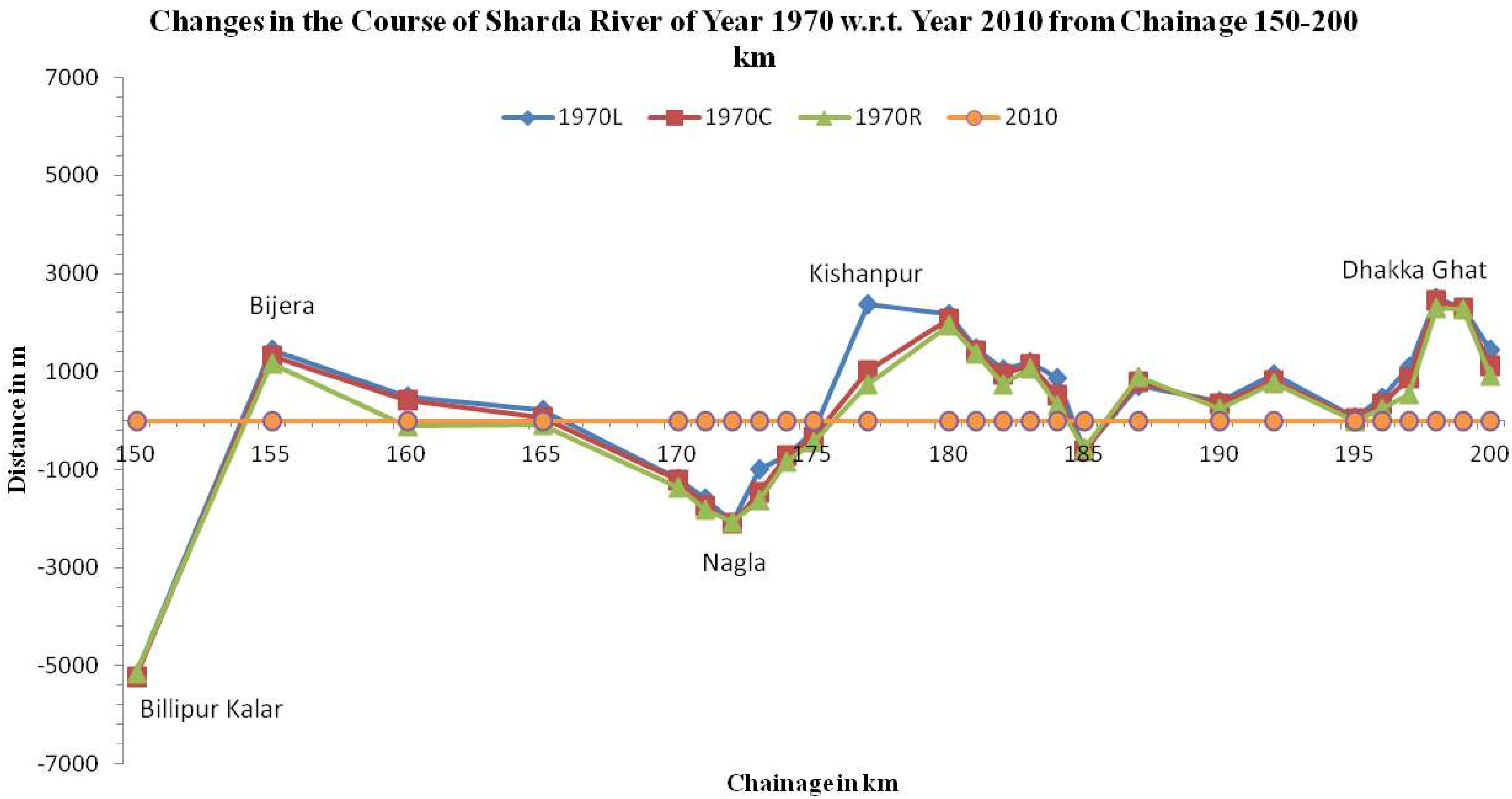


Figure 7.22b Changes in the course of Sharda river of year 1970 w.r.t. center line of year 2010 from chainage 150-200 km

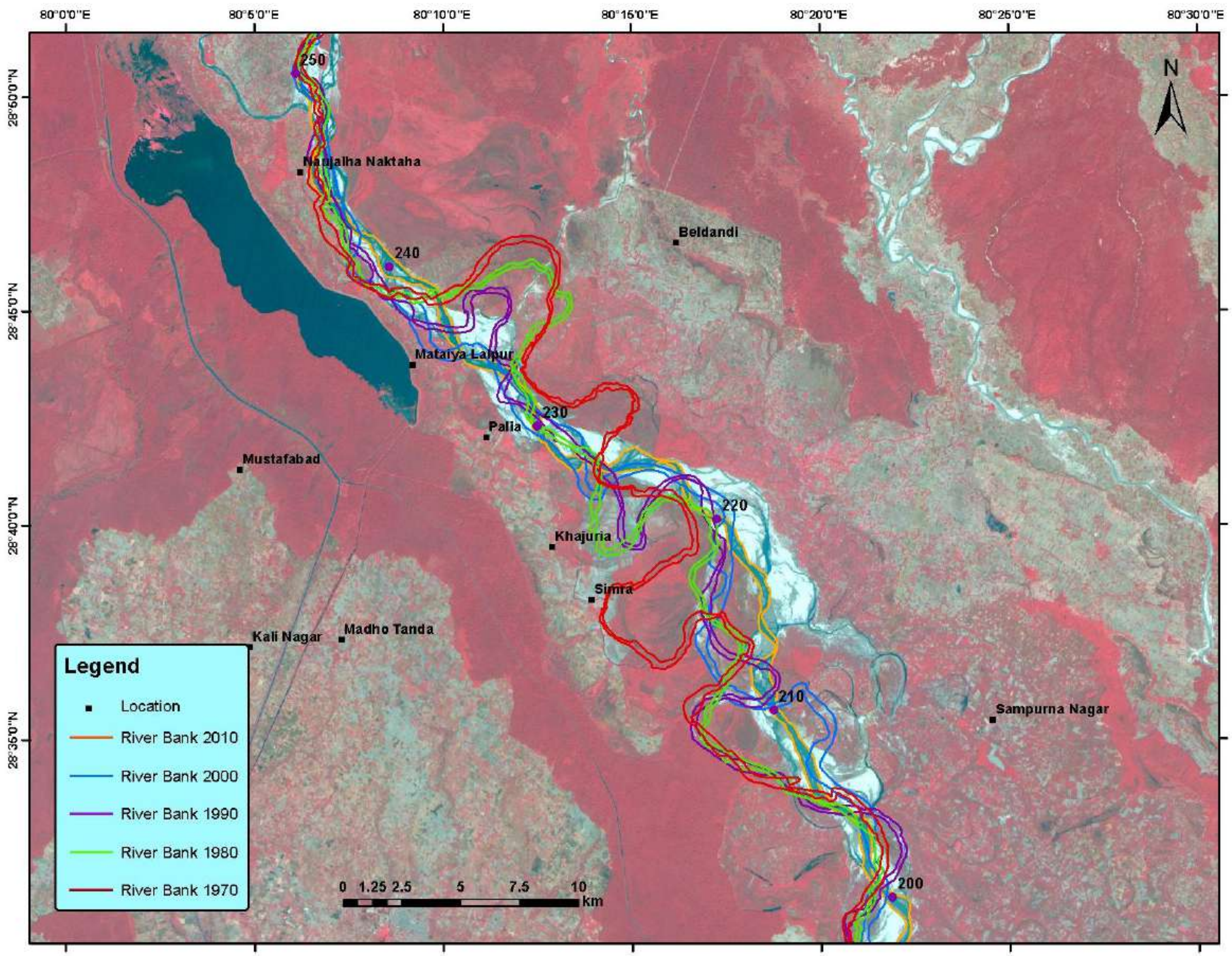


Figure 7.23a Decadal changes in the course of Sharda river from chainage 200-250 km

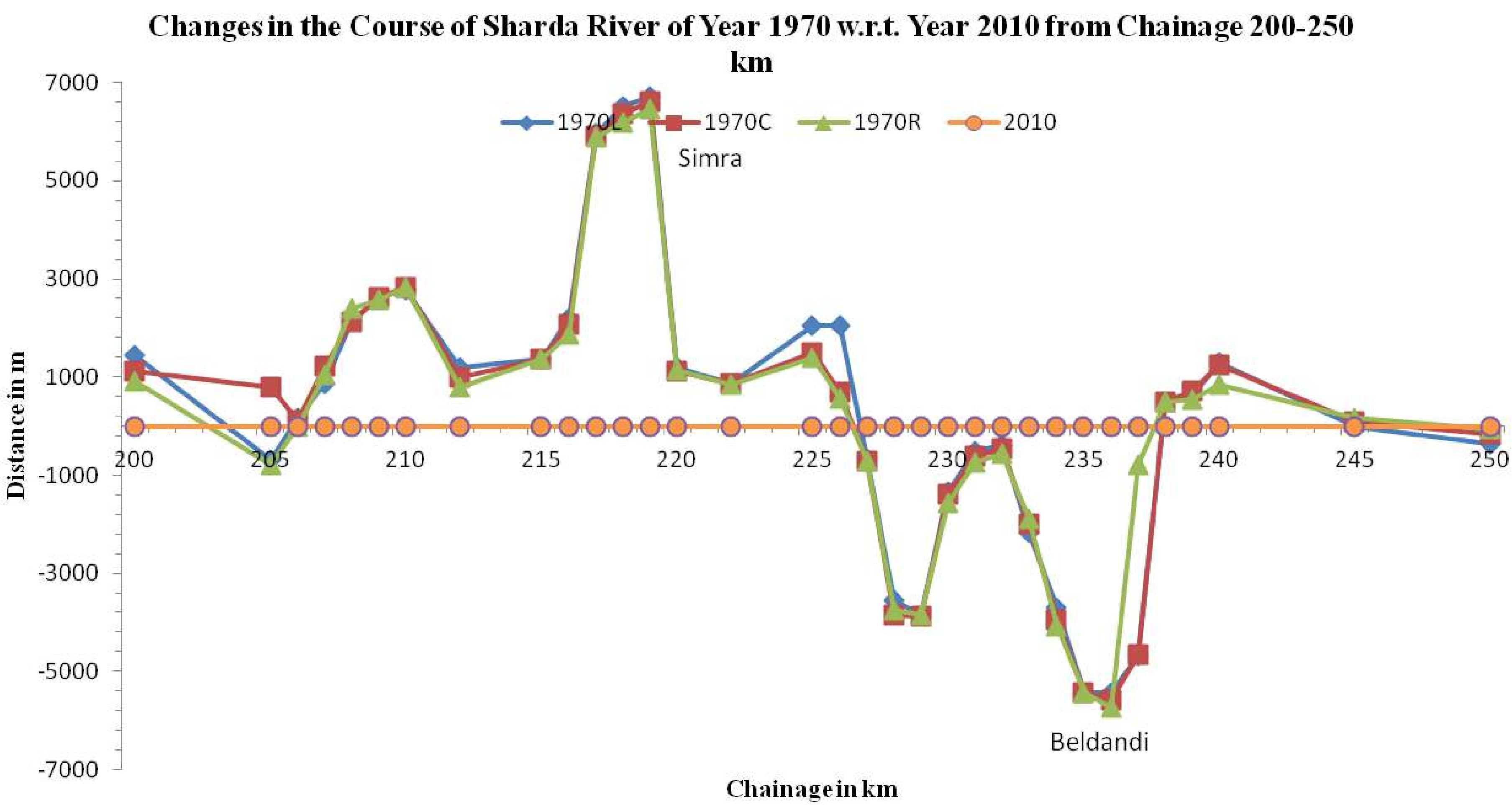


Figure 7.23b Changes in the course of Sharda river of year 1970 w.r.t. center line of year 2010 from chainage 200-250 km

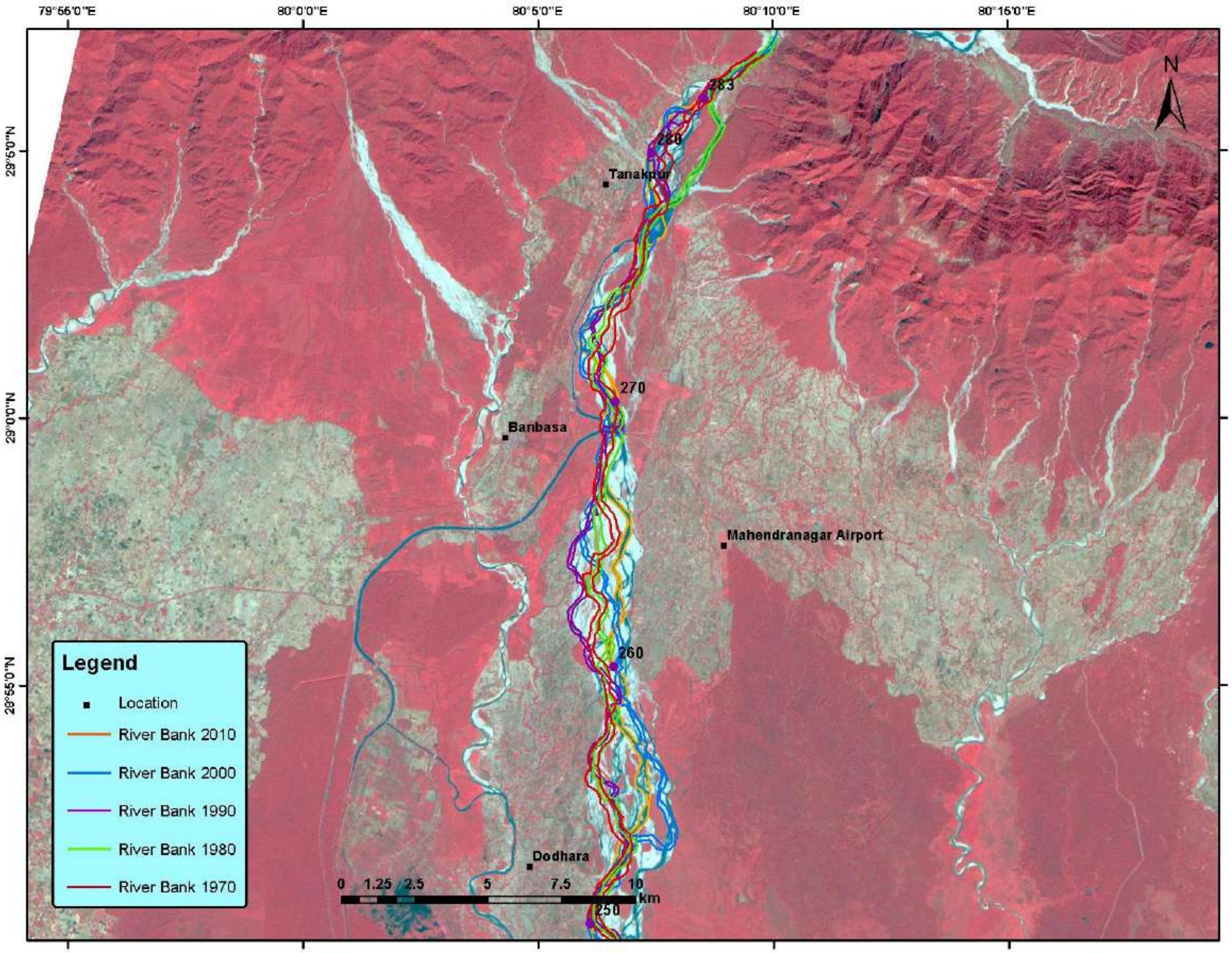


Figure 7.24a Decadal changes in the course of Sharda river from chainage 250-283 km

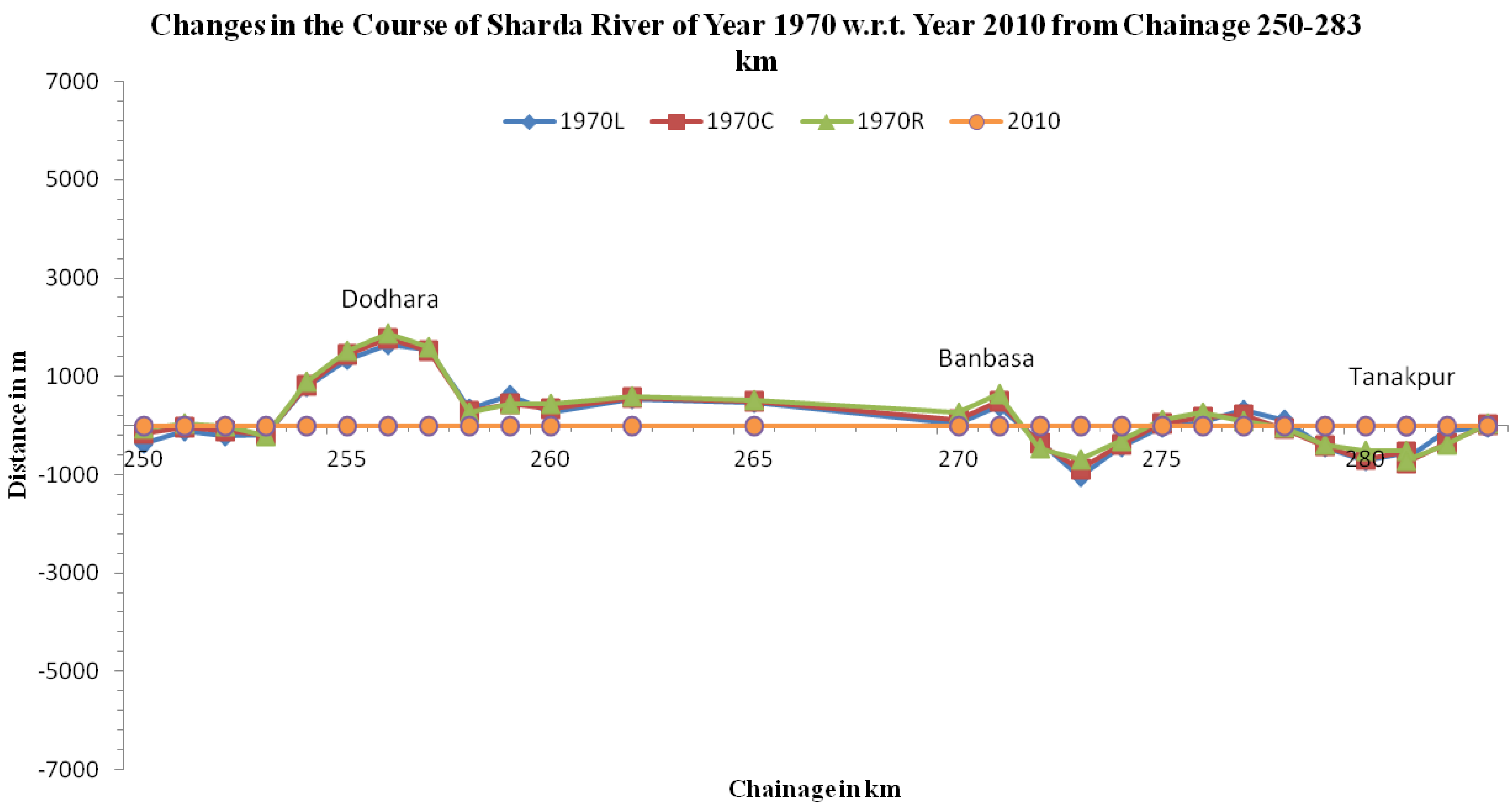


Figure 7.24b Changes in the Course of Sharda river of year 1970 w.r.t. center line of year 2010 from chainage 250-283 km

7.4 RIVER WIDTH

The width of the Sharda 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 Sharda 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 5 km and at an interval of 1.0 km near the places where river is taking sharp turn. The sample map that depicts the computation of river width is shown in Fig 7.25. Computed widths of the river for years 1970, 1980, 1990, 2000 and 2010 are given in Table 7.7, and graphically shown in Figs. 7.26 to 7.31. 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. 7.32. Figures 7.26 to 7.32 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 Sharda river.
- From chainage zero to 225 km, the average width of the river is almost constant and is equal to about 300 m, however, in the upper reach i.e., chainage 225 km to 248 km, the average width is about 240 m.

As the active channels are considered in regime condition, it should follow the regime equation and width be related to the discharge. Estimated peak discharge at Palia Kalan gauging site (Chainage =166 km) for 25, 50 and 100 years return periods are 7559.3 m^3/s, 8476.9 m^3/s, and 9386.0 m^3/s, respectively. Even though 1.5 to 2 year return period discharge is considered as disharge that govern the morphological changes. In the absence of that let consider discharge, Q of 25 years return period which is 7559.3 m^3/s. From this, the width equation for the Sharda river in its reach zero to 225 km may be expressed as

$$\text{River width} = 3.45 \times Q^{0.5}$$

which is comparable to Lacey equation. Here River width is in m and Q in m^3/s.

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. 7.33, 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 Sharda river.
- From chainage zero to 248 km, the average width of the river is almost constant and is equal to about 754 m, while the maximum width of 6.4 km was noticed in year 1980 at Chainage 115 km.

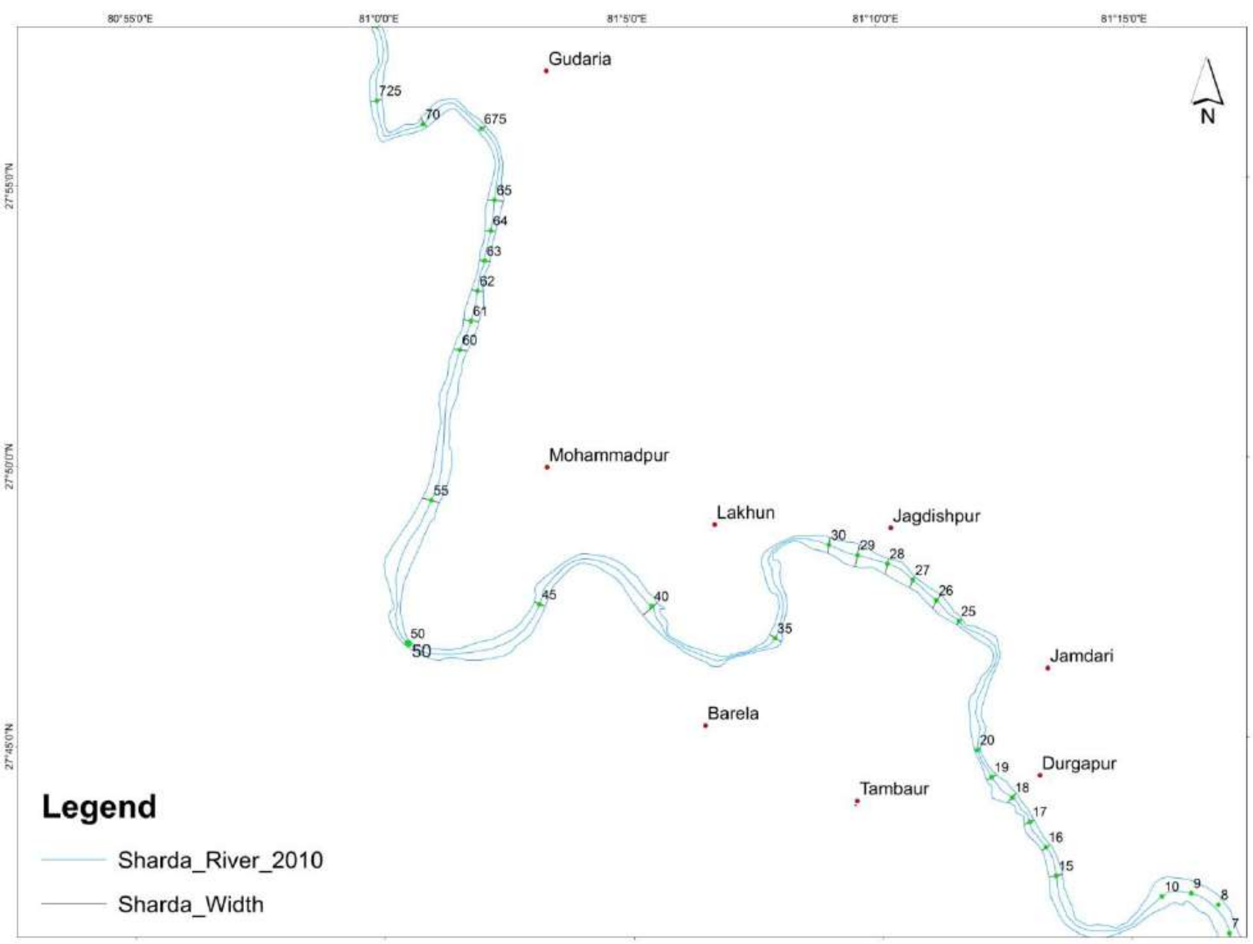


Figure 7.25 Sample map of width computation of Sharda river for year 2010

Table 7.7 River width of the active channel of Sharda river of year 1970, 1980, 1990, 2000 and 2010

Chainage (in km)	Width (m)				
	2010	2000	1990	1980	1970
15	431.86	230.38	236.17	247.33	NA
16	331.23	416.94	160.69	265.71	456.30
20	173.01	306.48	239.31	194.01	449.52
25	248.09	222.77	200.17	143.25	224.11
30	515.49	636.34	194.56	265.46	185.18
35	474.93	604.13	140.71	295.66	108.14
40	609.30	364.88	70.32	164.05	386.16
45	375.94	500.63	116.42	180.30	180.71
50	173.01	261.60	146.88	230.82	235.35
55	576.63	357.95	136.20	196.71	251.35
60	445.62	230.49	121.70	143.51	207.60
65	517.17	258.05	154.14	156.71	251.63
70	357.33	385.91	346.77	133.46	266.84
75	318.51	612.25	66.72	166.40	329.64
80	349.22	519.40	161.28	163.72	117.25
85	448.93	221.72	118.24	156.00	140.84
90	586.39	424.21	63.58	175.26	135.90
95	519.75	372.83	608.44	398.71	125.96
100	272.48	418.00	391.47	168.62	247.65
105	452.67	777.70	227.87	152.64	179.49
110	215.52	394.37	196.13	153.52	646.97
115	842.37	472.13	235.19	272.13	515.84
120	114.62	263.39	109.90	145.80	100.05
125	160.93	248.58	162.42	152.25	381.46
131	387.92	459.06	243.91	162.06	349.98
135	298.05	269.78	229.19	157.32	141.98
140	247.50	444.06	199.27	171.81	399.47
145	311.74	417.35	287.09	185.85	281.80
150	283.65	404.36	211.14	287.70	303.62
155	471.03	465.73	343.32	161.80	243.16
160	721.85	359.95	747.97	531.15	429.51
165	488.37	540.82	337.28	218.73	170.84

170	376.01	430.28	202.38	190.87	233.70
175	357.54	421.35	346.89	193.09	141.59
180	302.02	634.42	297.40	169.69	216.62
185	133.03	284.16	289.03	145.32	169.79
190	290.73	358.10	248.66	153.60	131.64
195	229.93	703.77	179.48	132.81	137.90
200	495.03	810.67	305.72	139.86	278.05
205	276.31	364.37	180.35	222.93	202.91
210	317.40	299.60	304.84	218.34	331.31
215	147.83	283.58	273.35	224.22	305.51
220	240.04	430.54	236.10	273.36	248.84
225	878.39	353.17	336.54	211.10	83.96
230	439.77	832.14	257.12	156.69	211.90
235	189.45	503.73	129.19	174.58	160.93
240	743.67	222.97	560.14	195.70	270.34
245	319.54	243.83	270.65	186.99	496.70
250	98.55	263.57	169.45	194.01	397.76
255	150.42	80.00	76.89	195.29	296.08
260	111.22	143.70	145.64	201.14	284.41
265	186.74	113.21	99.43	216.38	241.16
270	155.14	132.69	157.11	178.00	372.97
275	101.09	109.35	139.11	185.70	257.27
280	191.95	214.52	469.20	137.08	268.08
283	238.66	216.97	95.13	124.98	321.93

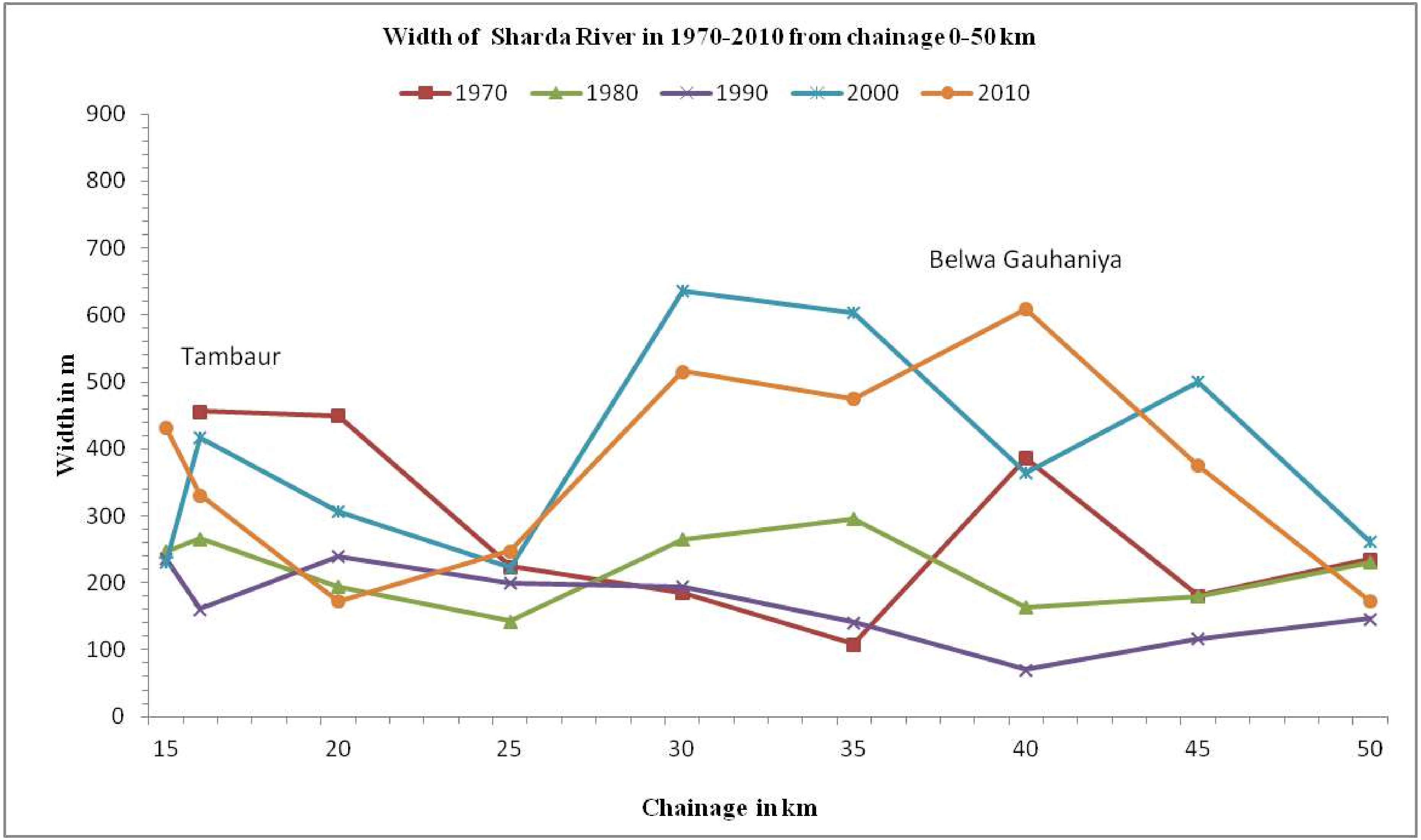


Figure 7.26 Width of Sharda river in years 1970, 1980, 1990, 2000, and 2010 from chainage 0-50 km

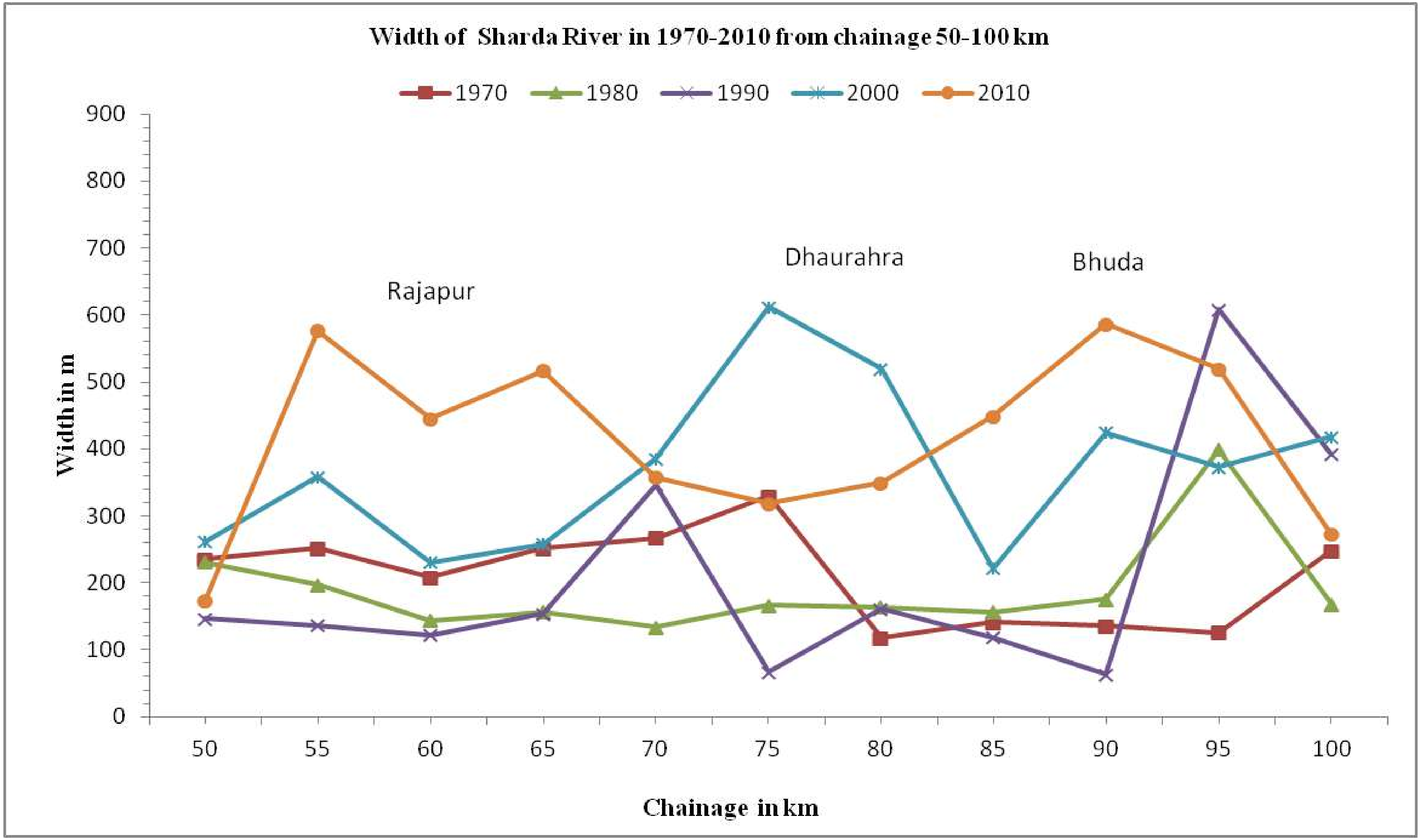


Figure 7.27 Width of Sharda river in years 1970, 1980, 1990, 2000, and 2010 from chainage 50-100 km

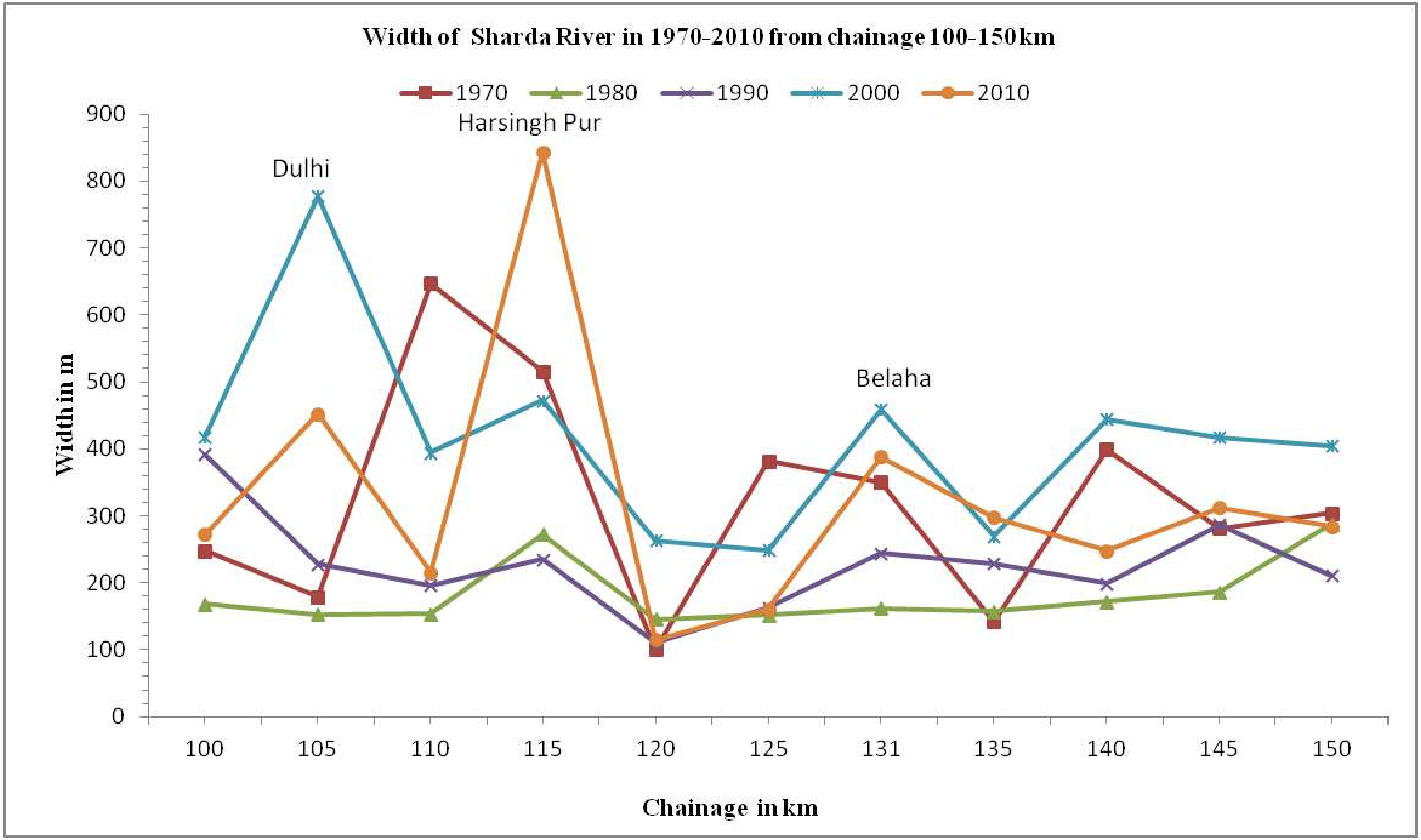


Figure 7.28 Width of Sharda river in years 1970, 1980, 1990, 2000, and 2010 from chainage 100-150 km

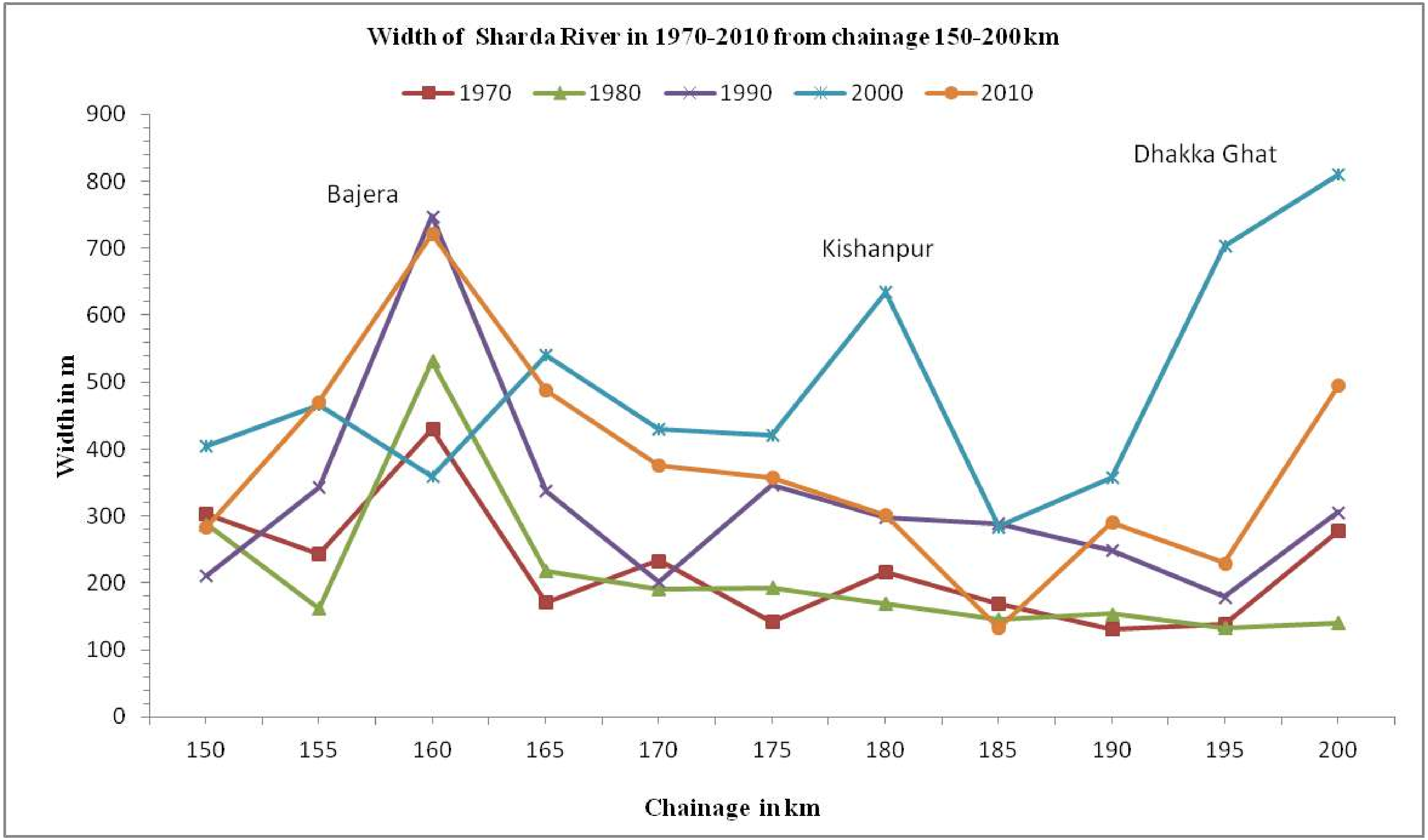


Figure 7.29 Width of Sharda river in years 1970, 1980, 1990, 2000, and 2010 from chainage 150-200 km

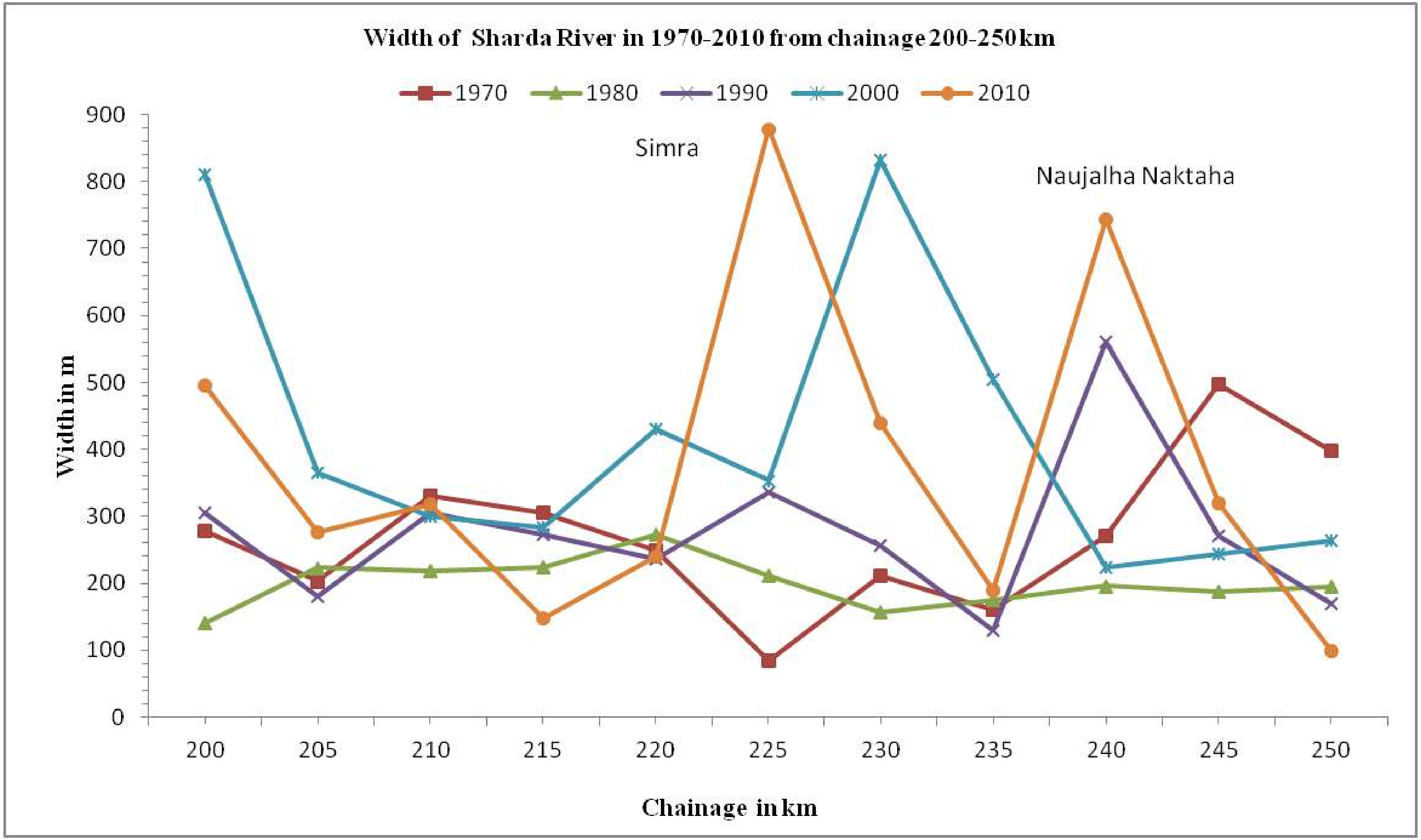


Figure 7.30 Width of Sharda river in years 1970, 1980, 1990, 2000, and 2010 from chainage 200-250 km

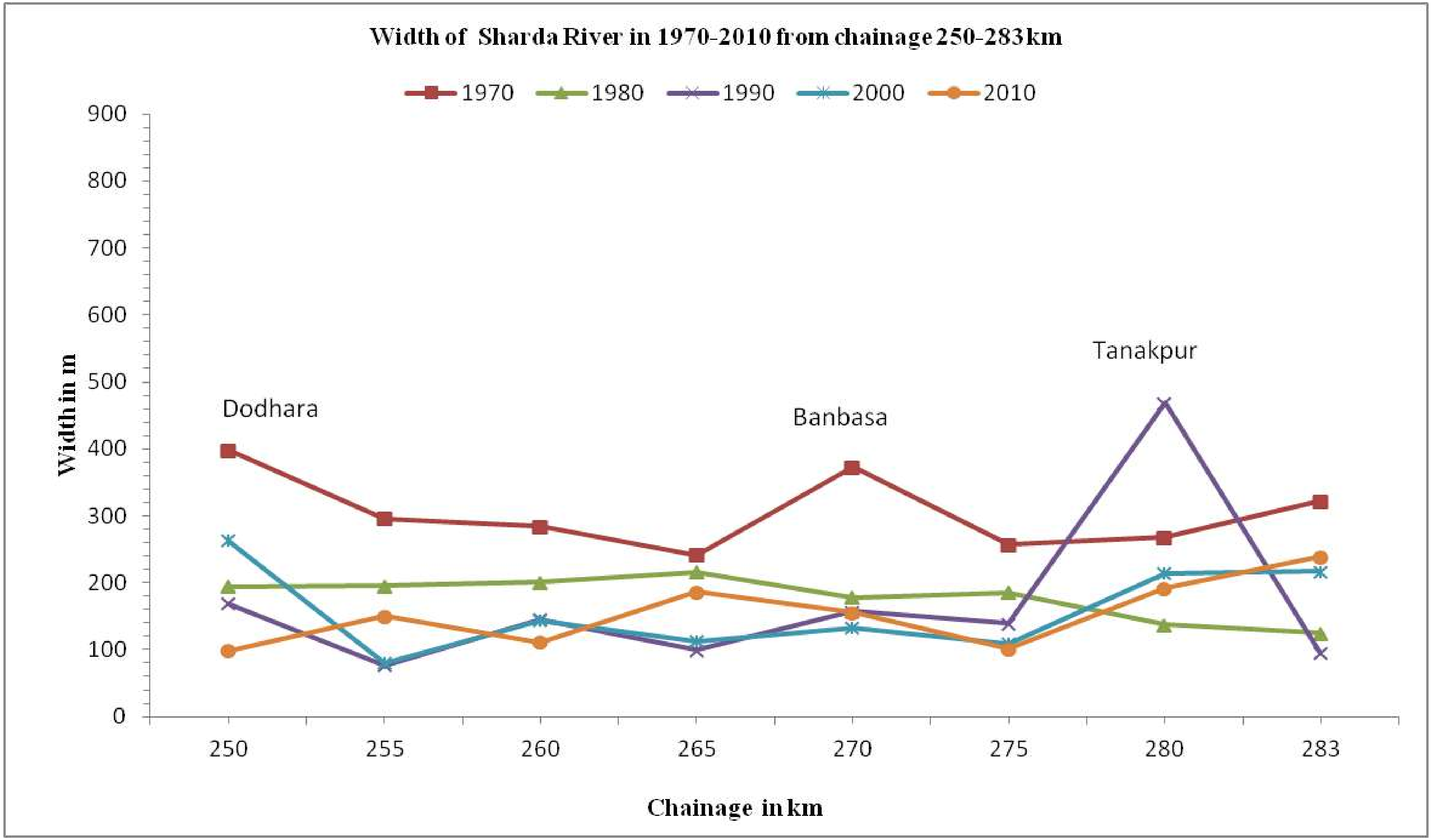


Figure 7.31 Width of Sharda river in years 1970, 1980, 1990, 2000, and 2010 from chainage 250-283 km

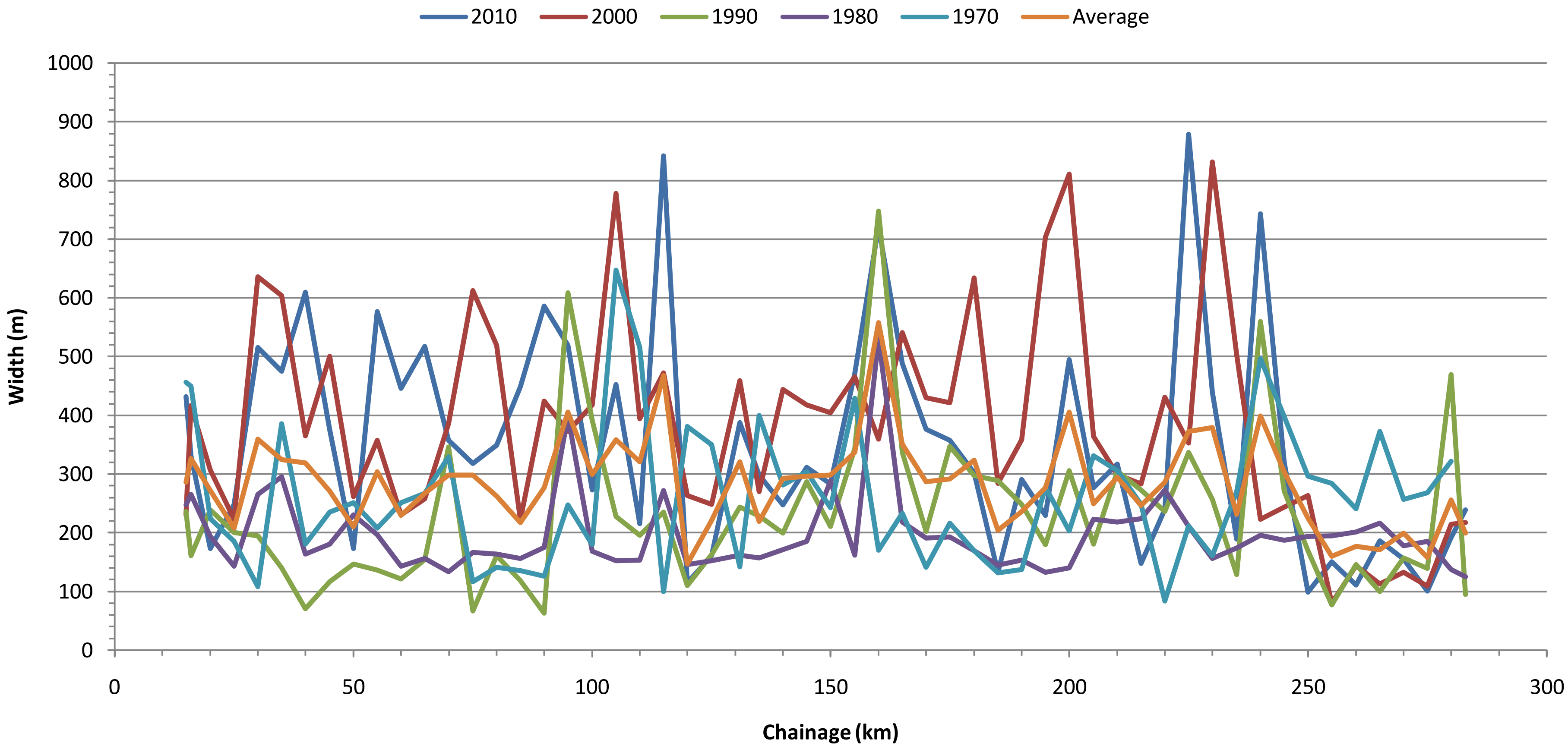


Figure 7.32 Width of the river based on active channel during post monsoon

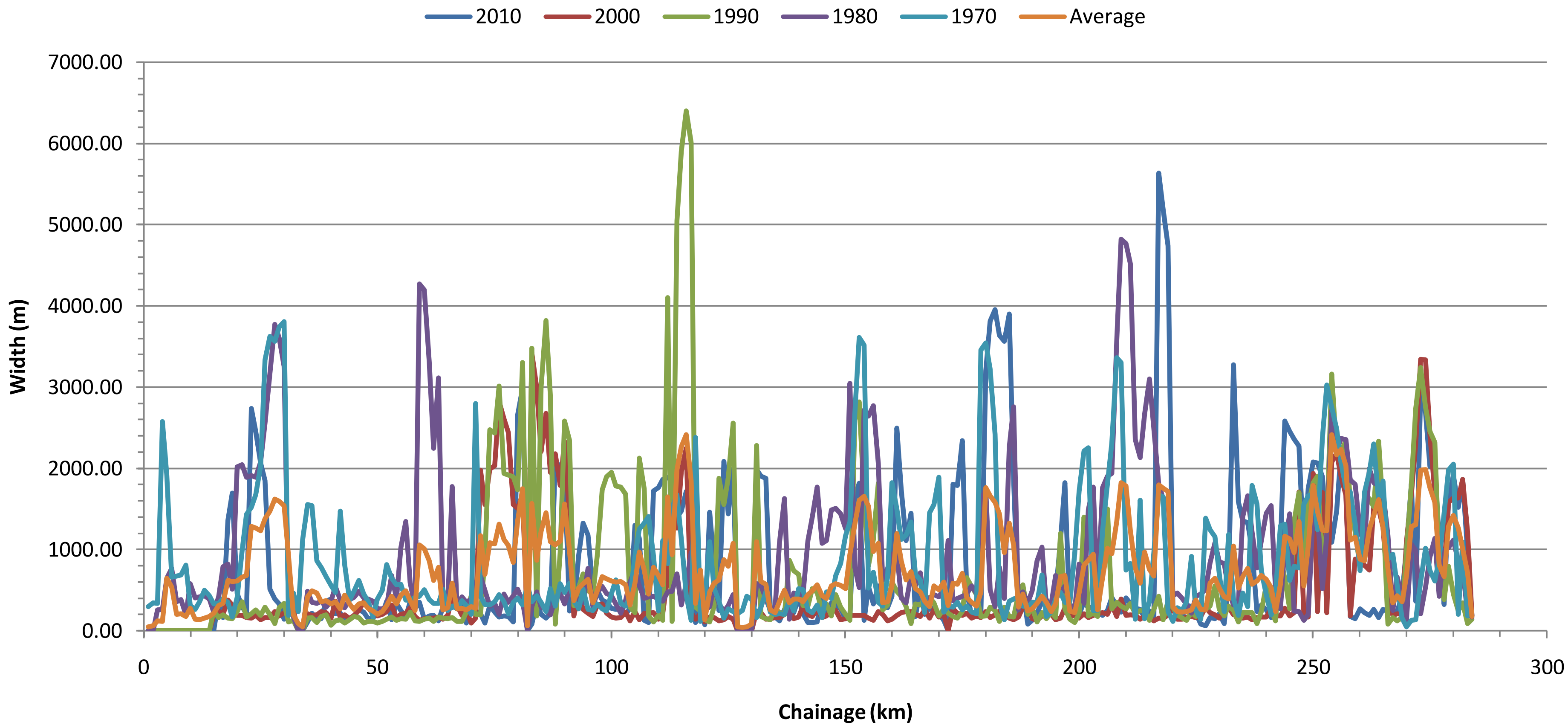


Figure 7.33 Width of the river based on extreme banks

7.5 DISCUSSIONS ON RIVER COURSE SHIFTING AND ITS WIDTH

Detailed reach-wise discussion on shifting of the river course and river width is given below:

1. **Reach (0-50 km):** The confluence point of Sharda river with Ghaghara river has shifted by 15 km towards downstream of Ghaghara river in a span of year 1970 to 2010, as evident from the Fig. 7.13a. There is no progressive shift of the river in this reach, however, in general river has shifted from right to left. From year 1970 to 2010, the maximum shifting of the order of 3.25 km from right to left has been found at Duwai, while maximum shifting of the order of 3 km from left to right is found at Amarnagar from year 1980 to 2010.

   There is no any progressive change in the width of active channel of the river in this reach. The average width in this reach is of the order of 300 m. The maximum width of the river is of the order of 650 m from chainage 30 - 45 km.

2. **Reach (50-100 km):** There is no any progressive change in the course of the river in this reach. However, major lateral shifting of the order of 4.5 km has been found at some locations in this reach. Maximum shifting from right to left has been found during the year 1970 to 2010 at Rajapur (4.5 km), Gundwa Gaon (3 km), and Jamunia (4 km). The maximum shift from left to right of the order of 5 km has been found near Dhauraha.

   Average width of the active channel in this reach is about 300 m, however, it varies from 100 m to 600 m. Even though there is no definite progressive change in the width in this reach, however, in general the width of river has increased from year 1970 to 2010.

3. **Reach (100-150 km):** There is no any progressive change in the course of the Sharda river in this reach, however, river has shifted right to left in the reach of chainage 110-140 km from year 1970 - 2010. The average shifting of the river course is in a band of about 4 km with maximum shift from right to left of the order of 5.5 km at Belaha. While the maximum shift from left to right is of the order of 6 km at Chidaipatia.

   The average width of active channel is about 300 m. There is no any progressive change in the width. The width varies from 100 m to 850 m in this reach with maximum width at Ghosiayana.

4. **Reach (150-200 km):** There is no any progressive change in the course of the river in this reach from year 1970 to 2010. The average lateral shifting of the river is order of 2.5 km with maximum shift from right to left at Kishanpur of the order of 3 km and maximum shift from left to right of the order of 5 km at Balipur Kalan.

   Average width of the active channel in this reach is about 300 m. The width varies from 100 m to 800 m in this reach with maximum at Bhanpur and Dhakka ghat. Even though there is no any progressive change in the width of the river in this reach, however, it has increased over the years.

5. **Reach (200 - 250 km):** The major lateral shifting of the course of river has been noticed in this reach. The maximum shift from right to left is of the order of 7 km at Simra from year 1970 to 2010, while the maximum shift from left to right is of the order of 5.5 km at Beldandi. There is no any progressive shift in the course of a river over the years in this reach.

   The average width of active channel of the river in this reach is of the order of 300 m. Over the years, the river width has increased. The maximum width of the order of 800 m can be seen at Madhuland and Mustafabad.

6. **Reach (250 - 283 km):** No major change in the course of the river has been found in this reach. Further, there is no progressive change in the course of river over the years. The maximum shift from right to left of the order of 1.5 km can be seen at Dadhara, while maximum shift from left to right is of the order of 1.5 km at Tanakpur. The limited shifting of the river course in this reach is attributed to the existence of Tanakpur and Banbasa Barrages that control the lateral shifting.

   Over the years the width of active channel has reduced from about 300 m to 150 m. Average width of active channel in this reach is about 240 km.

7.6 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 7.8 . This will be helpful in planning of structures like bridge in the future.

Table 7.8 Nodal points of minimum morphological changes

Sl. No.	Chainage (km)	Latitude & Longitude	Location
1.	21.5	81°11'59.309"E 27°45'31.84"N	Jamdari
2.	53.5-57.5	81°0'40.928"E 27°48'51.447"N - 81°1'16.363"E 27°50'54.544"N	Amar Nagar
3.	100	80°55'19.92"E 28°6'5.66"N	Dulhi
4.	138-141	80°43'59.383"E 28°13'18.924"N - 80°42'53.225"E 28°14'39.209"N	Lalboljhi
5.	162-167	80°35'4.722"E 28°21'14.446"N - 80°32'56.292"E 28°23'8.081"N	Matahala
6.	194	80°21'16.963"E 28°29'9.978"N	Maharajnagar
7.	199	80°21'30.035"E 28°31'33.248"N	Dhakka Ghat
8.	220	80°16'26.748"E 28°40'51.058"N	Simra
9.	226-228	80°13'17.826"E 28°41'29.208"N - 80°12'28.873"E 28°42'19.064"N	Palia

7.7 CONCLUDING REMARKS

1. Remarkable shifting of the course of the Sharda river from 1970 to 2010 has been noticed. The maximum shift is of the order of 7 km at some locations. The confluence point of Sharda and Gaghara rivers has shifted 15 km downwards in year 2010 w.r.t. year 1970.
2. Sharda behaves as sinuous river from Tanakpur to its confluence with Ghaghra river except from Chainage 200-225 km near Sampurnnagar in which it had behaved as meander river before year 1990. The meanders of the river are not stable and keep on changing. The river has followed a relatively straight path over the years in the reaches 0-80 km and 210-240 km while meandering has increased in the reaches 100-140 km and 170-200 km. Axial wave length, amplitude and radius of curvature of the meanders are of the order of 4 km, 3 km and 1.5 km, respectively.
3. Sharda may be considered moderately braided river in its major length from Tanakpur to its confluence with Ghaghra river. However, near Jagdispur, downstream of Banbasa barrage and Dodhara braiding of the river is high. At other locations, like Chandrika Gauri and Ghosiyana, it was highly braided in past. High braiding in the Sharda river in its upper reach i.e, Tanakpur, Banbasa, Dodhara is primarily due to aggradation which occurs as the river is incompetent to transport the sediment load that it is bringing from the relatively steep reach.

4. There is no definite progressive change in the width of the active channel of the river over the span of year 1970-2010 in the whole studied reach of the Sharda river. From chainage zero to 225 km, the average width of the river is almost constant and is equal to about 300 m, however, in the upper reach i.e., chainage 225 km to 248 km, the average width is about 240 m.

Chapter 8 EROSION & SILTATION

8.1 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 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. 1970 has been considered as base year and the changes have been plotted graphically

8.2 EROSION & DEPOSITION

Erosion and deposition studies have been carried out for the Sharda River from Tanakpur to the confluence point of Sharda and Ghaghara using the remote sensing techniques. The SOI toposheets and post-monsoon images of years 1970 & 2010 have been used and the study is carried out to quantify sediment erosion and deposition in the duration from year 1970 to year 2010. The erosion and deposition has been expressed in the terms of area having unit km^2.

For the estimation of erosion and deposition, the extreme left and right banks have been identified based on the sand deposit and vegetation. Based on the shifting of the extreme left and right banks, the erosion and deposition are calculated.

8.3 RESULTS AND ANALYSIS

Estimation of erosion and deposition has 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 8.1 and also shown in Fig. 8.1. Net erosion and deposition in every reach of 50 km are shown in Fig. 8.2.

Table 8.1 Erosion and deposition in Sharda River based on shifting of extreme right and left banks

Chainage (km)	Erosion (ha)	Deposition (ha)	Erosion & Deposition (ha)	Net Erosion/ Deposition (ha)
0-50	-2042.81	3396.87	586.51	1354.06
50-100	-1624.28	2870.65	3972.26	1246.37
100-150	-1361.25	3997.38	7973.81	2636.13
150-200	-933.71	3537.77	7471.95	2604.06
200-250	-1388.53	5970.85	5195.72	4582.32
250-283	-194.21	1652.5	313.54	1458.29
Total	**-7544.79**	**21426.02**	**25513.79**	**13881.23**

*-'indicates erosion and '+' indicates deposition

1 ha = 0.01 km^2

From the above table, it can be summarized that total eroded area = 7544.79 ha, total deposited area = 21426.02 ha and total eroded and deposited area = 25513.79 ha. Net deposited area is 13881.23 ha during the period 1970-2010.

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.8.3-8.8.

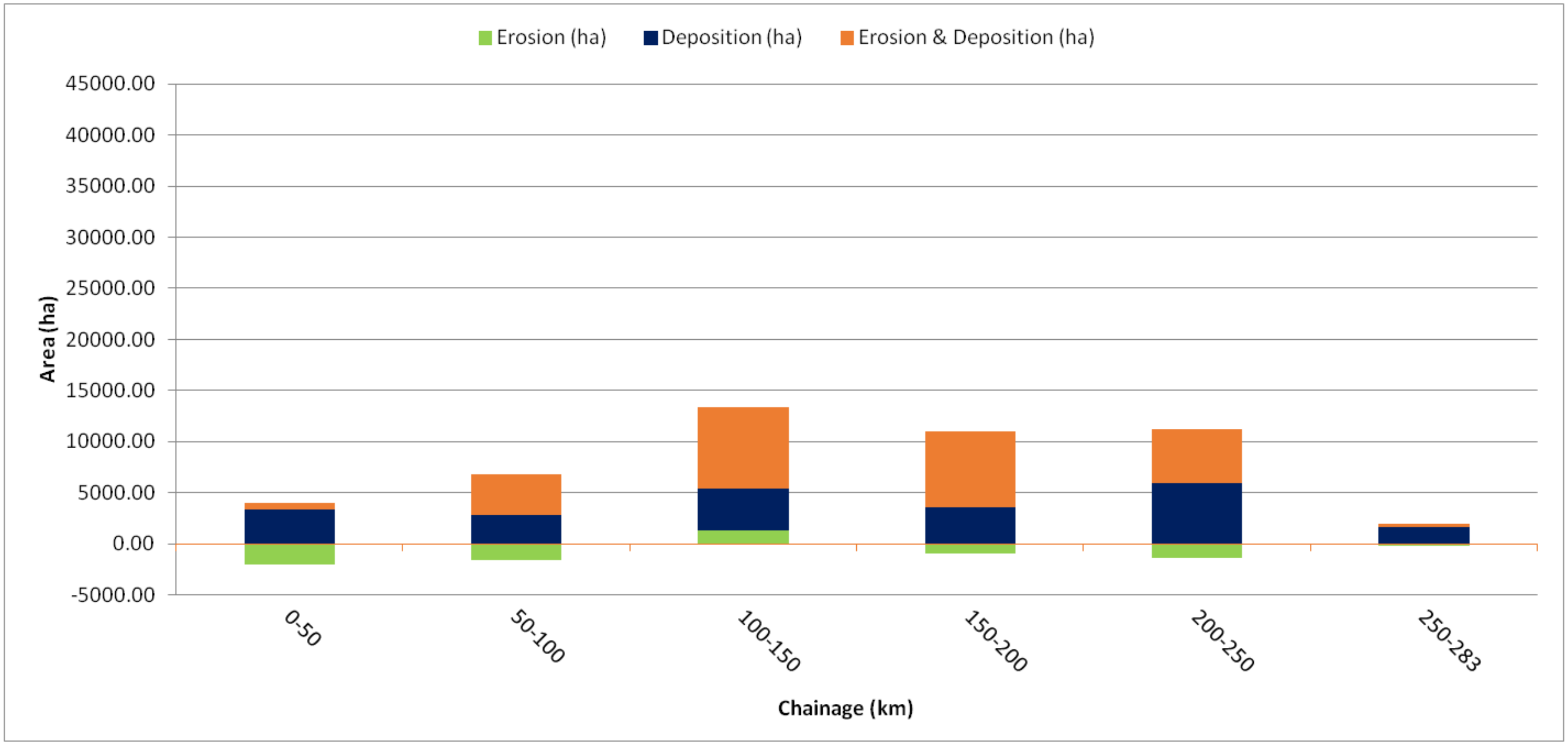


Figure 8.1 Erosion and deposition in Sharda river based on shifting of extreme right and left banks during the period 1970 to 2010

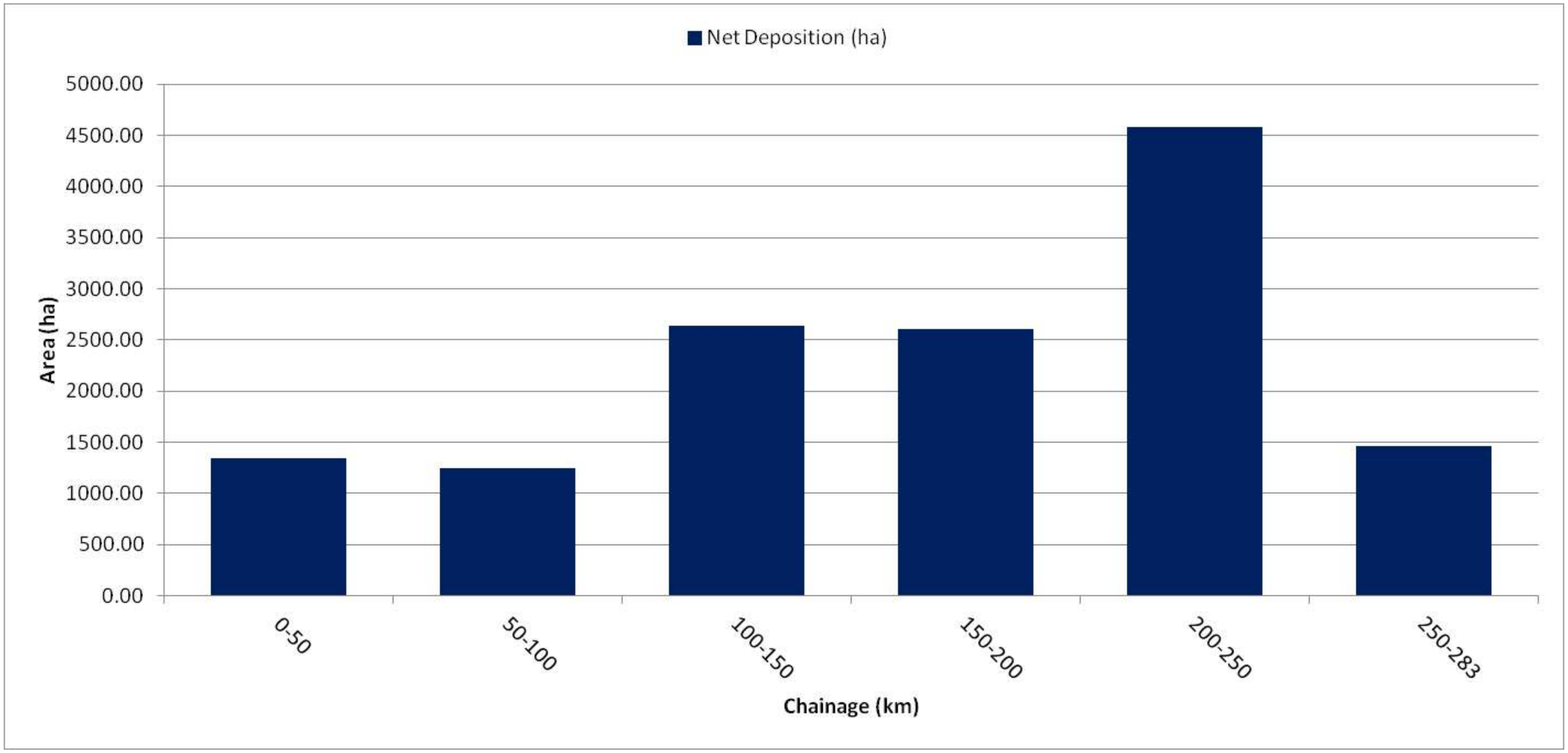


Figure 8.2 Net erosion and deposition in Sharda river during the period 1970 to 2010 based on shifting of extreme right and left banks

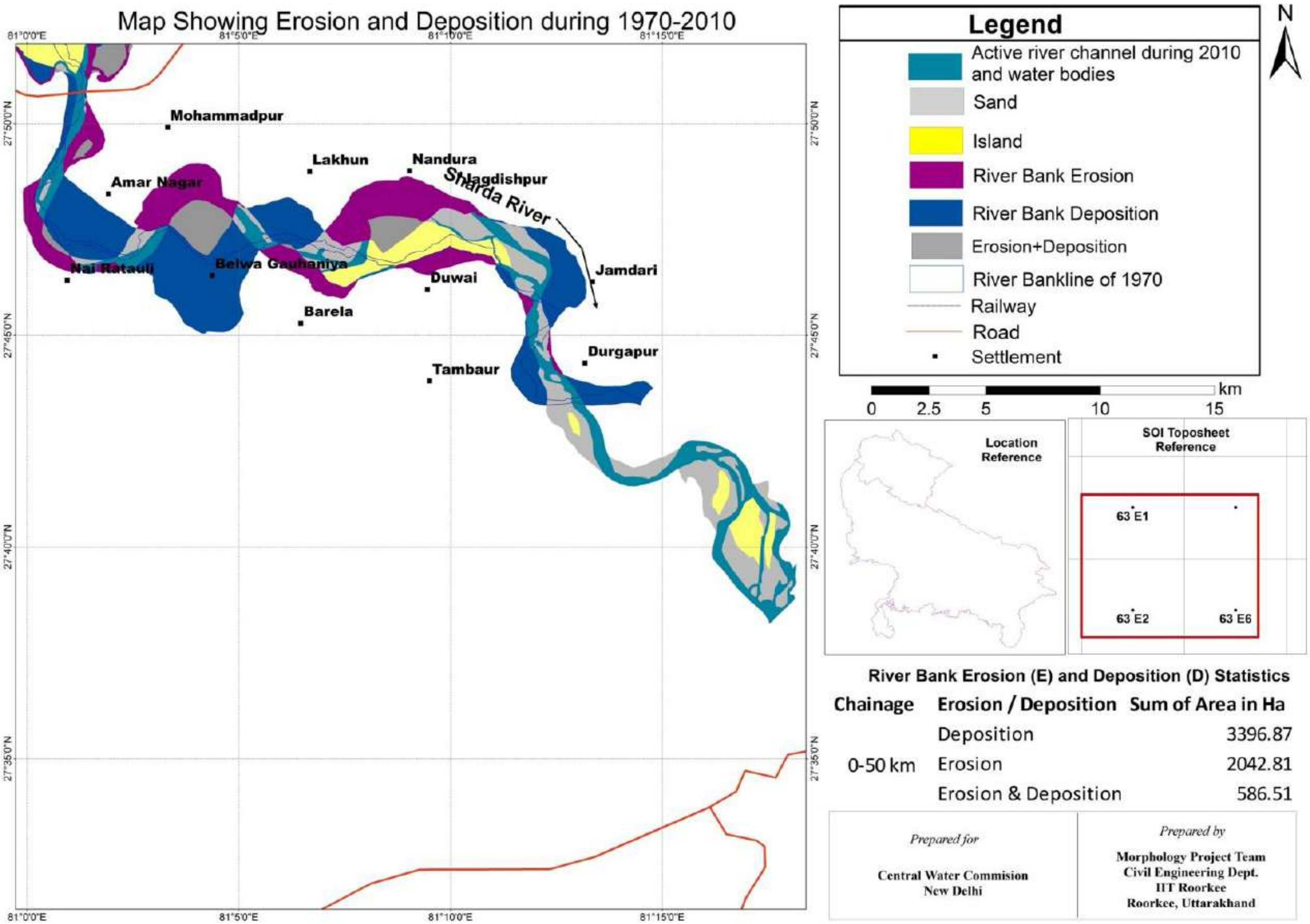
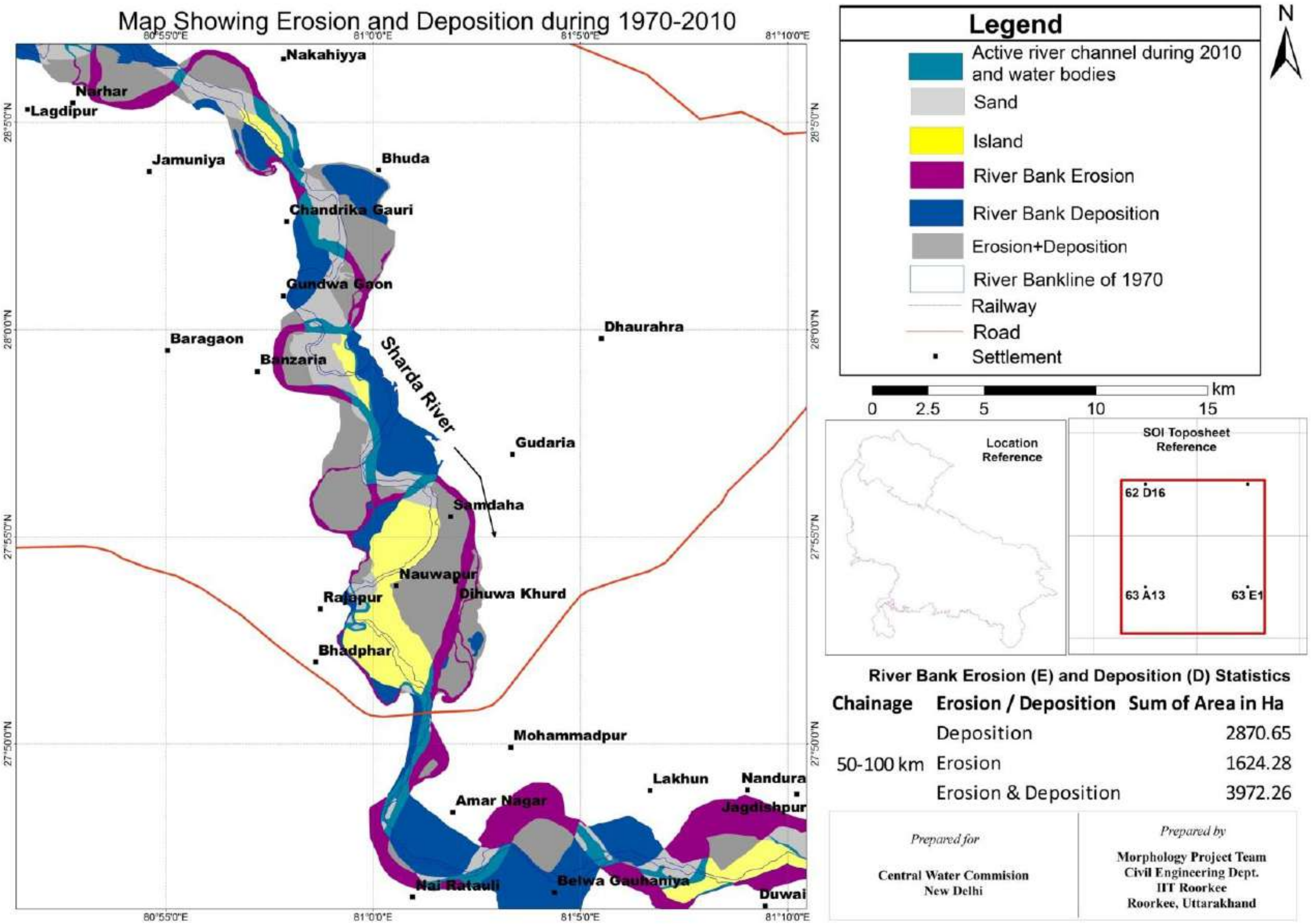


Figure 8.3 Erosion and deposition map of Sharda river of period 1970-2010 from chainage 0-50 km



River Bank Erosion (E) and Deposition (D) Statistics

Chainage	Erosion / Deposition	Sum of Area in Ha
50-100 km	Deposition	2870.65
	Erosion	1624.28
	Erosion & Deposition	3972.26

Figure 8.4 Erosion and deposition map of Sharda river of period 1970-2010 from chainage 50-100 km

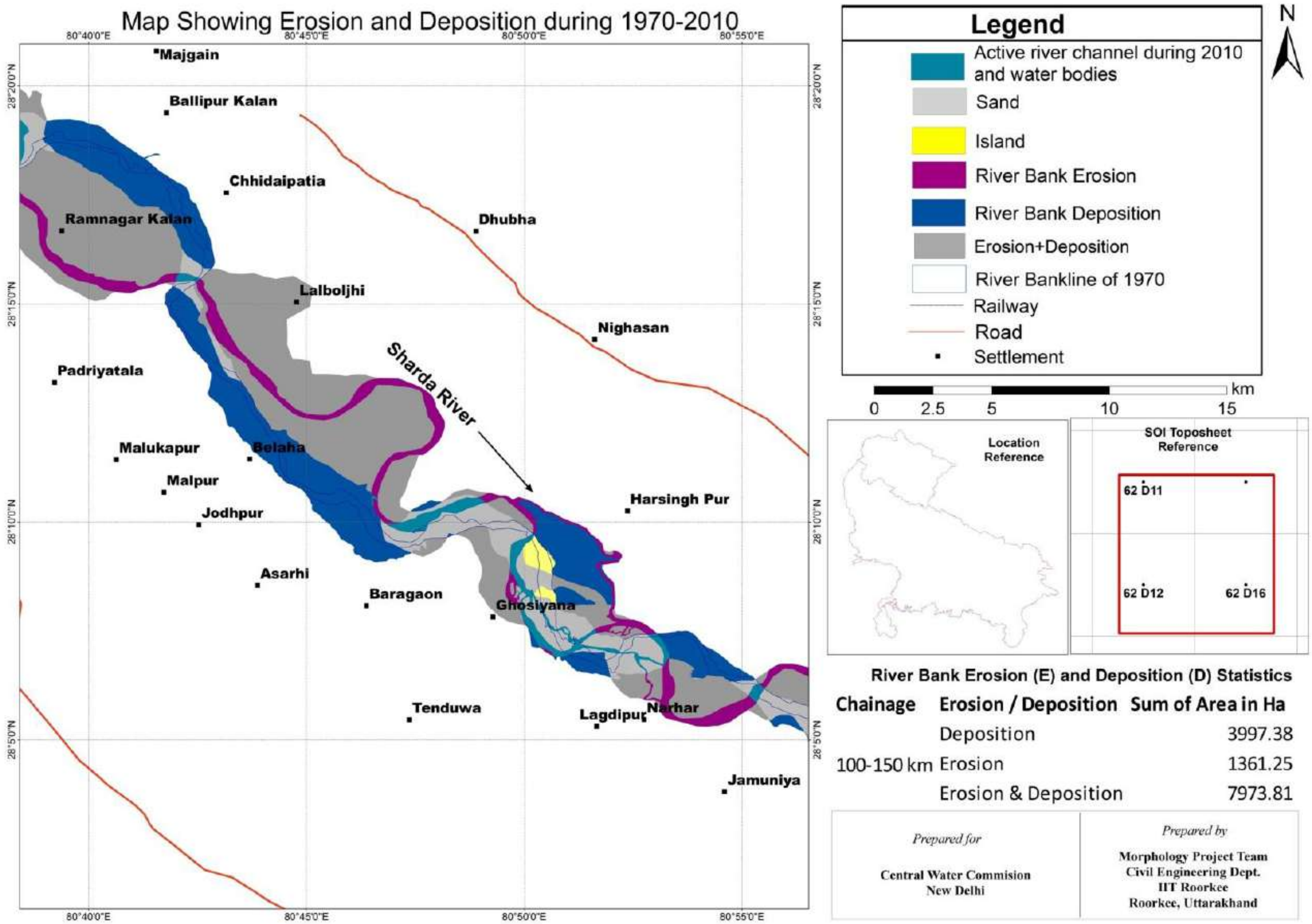


Figure 8.5 Erosion and deposition map of Sharda river of period 1970-2010 from chainage 100-150 km

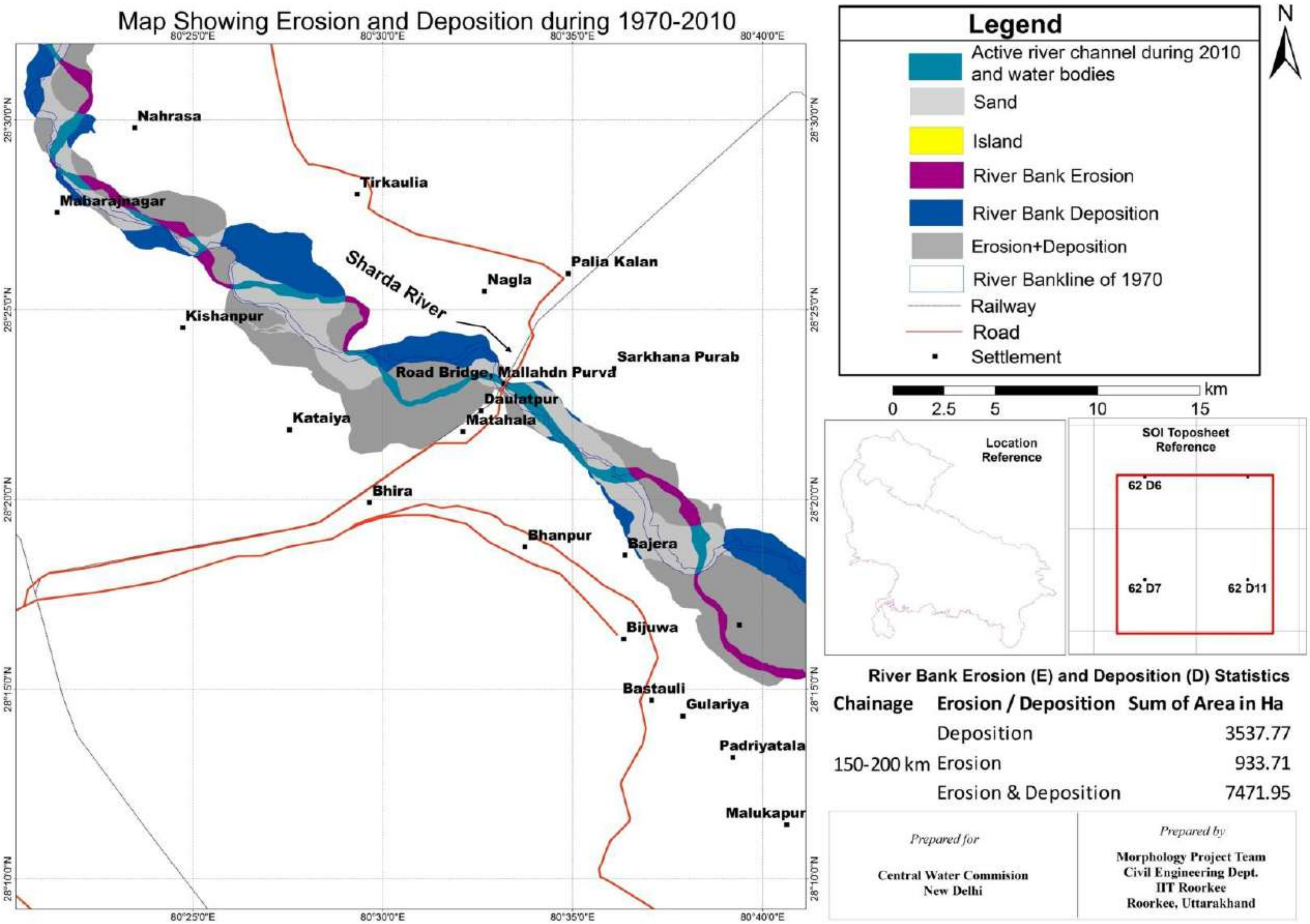


Figure 8.6 Erosion and deposition map of Sharda river of period 1970-2010 from chainage 150-200 km

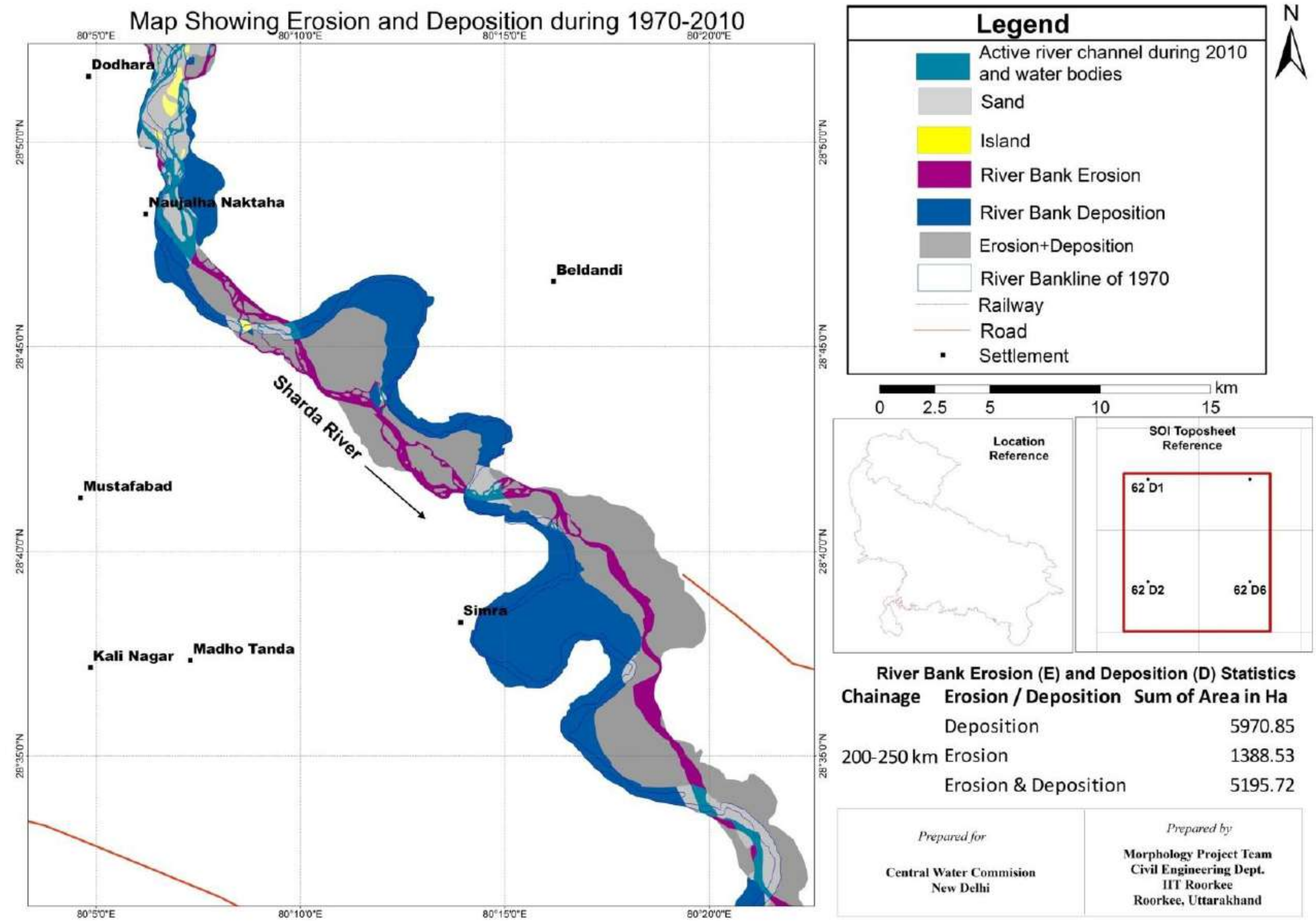


Figure 8.7 Erosion and deposition map of Sharda river of period 1970-2010 from chainage 200-250 km

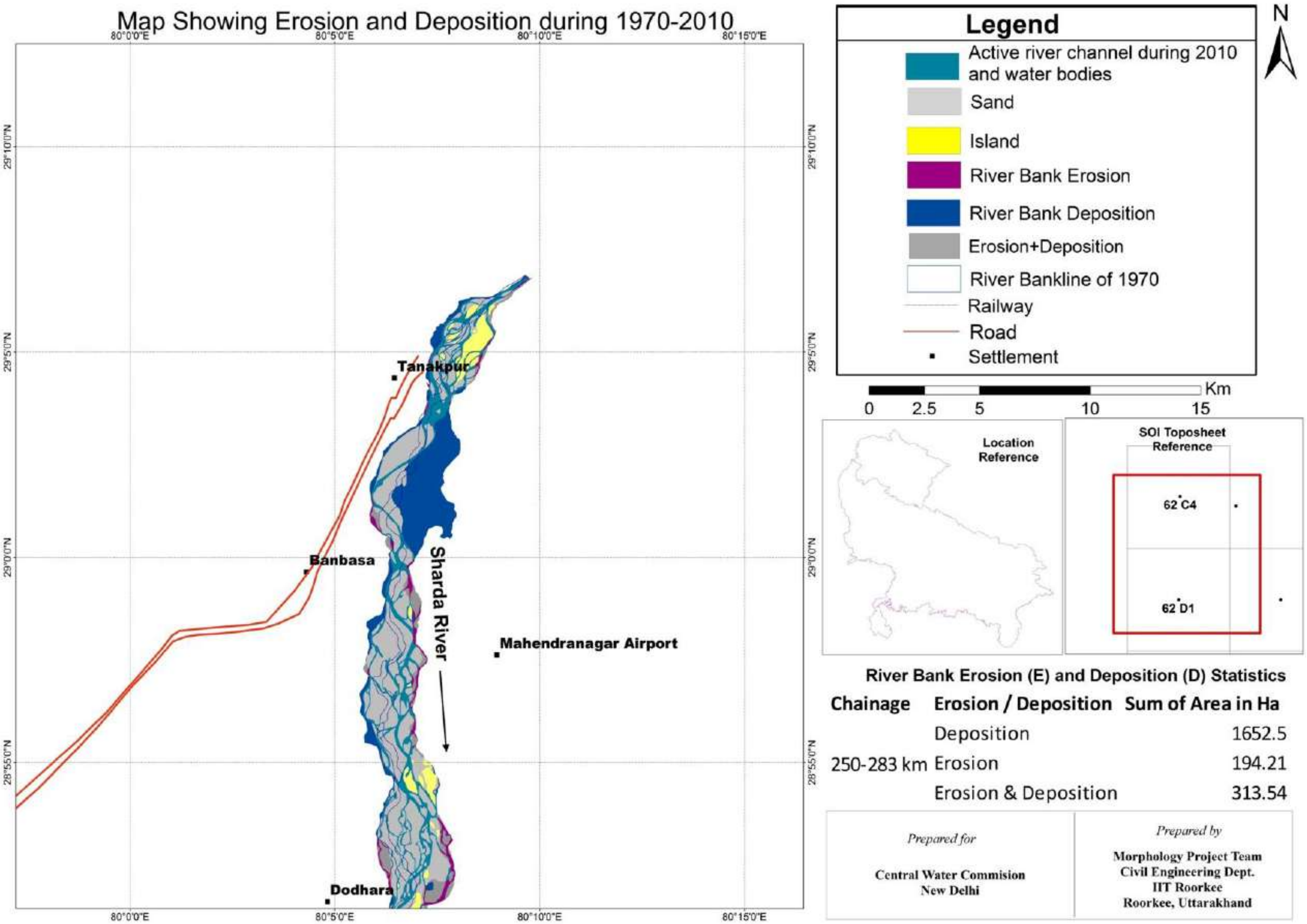


Figure 8.8 Erosion and deposition map of Sharda river of period 1970-2010 from chainage 250-283 km

8.4 AGGRADATION AND DEGRADATION

Available measured cross sections of the Sharda river at the gauging station of Palian Kalan have been used to study the aggradation and degradation in the river bed. As the cross sections 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 Sharda river. However, such cross sections shall indicate aggradation and degradation process in the vicinity of the gauging stations.

Figure 8.9 shows measured cross sections of the Sharda river for different years at gauging station of Palian Kalan, which indicates that there is no progressive aggradation or degradation at this location. However, adjustment in the cross-sections of different years may be seen.

The following points may be noted regarding erosion and siltation based on the shifting of extreme left and right banks.

1. In the reach 0-50 km, total eroded area, total deposited area and total eroded & deposited area are 2042.81 ha, 3396.87 ha and 586.51 ha, respectively. Deposition in an area of 1354.06 ha has occurred in the reach. The confluence of Sharda and Ghaghara River has also shifted almost 15 km downwards. Near Nandura and Mohammadpur, left bank is eroded in the period 1970-2010. Deposition has occurred on both the banks near Nai Ratauli and Jamdari. The possible reason behind this is frequent shifting of river course and its meandering behavior which causes deposition towards convex bank.
2. In the reach 50-100 km, total eroded area, total deposited area and total eroded & deposited area are 1624.28 ha, 2870.65 ha and 3972.26 ha, respectively. Deposition in an area of 1246.37 ha has occurred in the reach. Erosion and siltation are relatively low in this reach. The entire reach has suffered with erosion plus deposition in a span of 1970 to 2010. The major erosion plus deposition have occurred upstream of Lower Sharda barrage near Bhadphar and Nauwapur due to lateral shifting of the main course of the river. Deposition has been found near Gudaria.
3. In the reach 100-150 km, total eroded area, total deposited area and total eroded & deposited area are 1361.25 ha, 3997.38 ha and 7973.81 ha, respectively. Deposition in an area of 2636.13 ha has occurred in the reach. There is deposition on left bank near Ramnagar Kalan and Ghosiyana whereas on right bank deposition is found near Belaha. In this reach, deposited area is higher than eroded area. The entire reach has suffered with erosion plus deposition in a span of 1970 to 2010. Major erosion plus deposition has occurred in this reach near Belaha and Ramnagar Kalan. The possible reason for morphological changes is continuous shifting of river course and meandering behavior of the river.
4. In the reach 150-200 km, total eroded area, total deposited area and total eroded & deposited area are 933.71 ha, 3537.77 ha and 7471.95 ha, respectively. Net deposition in this reach is 2604.06 ha. Because of the Road and Railway Bridges between Bhira to Palia Kalan, there is a heavy deposition near Mallaha Purva and Tirkaulia. The entire reach has suffered with erosion plus deposition in a span of 1970 to 2010 in particular upstream of the bridges. The possible reason behind this is continuous shifting of river course.

5. In the reach 200-250 km, total eroded area, total deposited area and total eroded & deposited area are 1388.53 ha, 5970.85 ha and 5195.72 ha, respectively. Net deposition in this reach is 4582.32 ha. Heavy siltation is visible in this reach in particular towards Madhotanda. The entire reach has suffered with erosion plus deposition in a span of 1970 to 2010. The possible reason behind this is continuous shifting of river course and braiding & meandering nature of the river.
6. In the reach 250-283 km, total eroded area, total deposited area and total eroded & deposited area are 194.21 ha, 1652.50 ha and 313.54 ha, respectively. Net deposition in this reach is 1458.29 ha - mainly towards left side in the reach from Tanakpur barrage to Banbasa barrage. River is mostly braided in this reach.

8.6 CONCLUSIONS

Following conclusions may be drawn from the study of erosion and siltation in the Sharda river:

1. In the studied reach of the Sharda river, the total eroded area is 7544.79 ha, total deposited area is 21426.02 ha and total eroded and deposited area is 25513.79 ha in a span of year 1970 to 2010 while net deposited area is 13881.23 ha.
2. Erosion and siltation are noticeable throughout the entire reach of Sharda River from Tanakpur to the confluence point (Durgapur). This is due to shifting and meandering nature of the river course. Noticeable amount of siltation has occurred near Tanakpur and Durgapur - the starting and ending points of the river. Major deposition has taken place near Nai Ratauli, Jamdari, Gudaria, Baleha, Ghosiyana, Tirkaulia, Mallaha Purva, Madhotanda and Tanakpur while erosion has taken place at Nandura, Mohammadpur, and Ramnagar Kalan due to regular shifting of the river course in these areas. Major erosion plus deposition has occurred in the reach 50-250 km in a span of year 1970-2010 especially at Nauwapur, Bhadpur, Baleha and Ramnagar Kalan.
3. Measured cross sections of the Sharda river for different years at gauging station of Palian Kalan, indicate no progressive aggradation or degradation, however, adjustment in the cross-sections of different years may be seen.

Chapter 9 MAJOR STRUCTURES & THEIR IMPACT ON THE MORPHOLOGY

9.1 IDENTIFICATION OF MAJOR STRUCTURES

Major structures such as Barrages and Railway & Road Bridges located on Sharda River from Dodhara, Uttar Pradesh to Tambaur (Ghaghra confluence) have been identified using Google Earth and WRIS Website. Details of such structures are given in Table 9.1.

Table 9.1 Major Structures

ID	Name	Chainage (km)	Nearby Place	Length (m)	Type	Long.	Lat.
1	Road Bridge (SH 26)	57	Ludhoni (Lakhimpur)	585.29	Road	81.018738	27.846033
2	Lower Sharda Barrage (SH 21, Nighasan Road)	92	Mundi (Lakhimpur)	403.52	Barrage/ Road	80.966366	28.064610
3	Road Bridge (SH 90)	168	Daulatpur (Palia Kalan)	495.93	Road	80.552398	28.382956
4	Road (SH90) cum Railway Bridge	168	Daulatpur (Palia Kalan)	490.05	Railway	80.550887	28.383258
5	Banbasa Barrage	269	Banbasa	600.00	Barrage/ Road	80.109042	28.996243
6	Tanakpur Barrage	277	Tanakpur	480.00	Barrage/ Road	80.120233	29.055632

9.2 IMPACT OF MAJOR STRUCTURES/ BARRAGES ON THE RIVER MORPHOLOGY

There are three barrages, namely Tanakpur, Banbasa, and Lower Sharda at chainages 277 km, 269 km and 92 km, respectively. With the use of the historical toposheets and images, impact of construction of such barrage on the morphology of river has been studied herein.

9.2.1 Tanakpur Barrage

Tanakpur Barrage was constructed across the Sharda River for diverting river flow into a 6.2 km long power channel for the utilization of 24 m head available between Tanakpur Barrage and just upstream of Banbasa Barrage (Fig. 9.1a). The tail race channel joins to the Sharda River from right side upstream of the Banbasa barrage. The project was designed to produce 94.2 MW power with 90% dependable flow.

Figure 9.1a Location of the Tanakpur barrage

The construction of the Barrage was started in 1988 and completed in April 1992. In the spirit of furthering co-operation within the Sharda river (Mahakali river) area, Governments of India and Nepal entered into a Memorandum of Understanding (MOU), commonly referred to as the Tanakpur Agreement on 6th December 1991. The agreement provided for the construction of the left afflux bund (the retaining wall) on Nepalese territory for which the Nepalese provided 2.9 hectares of land to construct the left afflux bund of 577 m length. As a quid pro quo, the Agreement provided for the installation of a head regulator (main part of the reservoir regulating the water flow) at the Tanakpur Barrage with a capacity of 28 m^3/s, and required India to construct a canal so that 4.2 m^3/s of water could be delivered to Nepal. India was also required to provide 10 million kWh of power to Nepal free of charge. There is a provision for the supply of 9.9 m^3/s of water for irrigation of Dodhara Chandni area. India has also agreed to construct a road linking Tanakpur to Nepal's East-West highway.

Major salient features of the barrage are as follows:

Salient Features (India-WRIS)	
Name of the Structure	Tanakpur Barrage
Nearest city	Khatima
District	Champawat
State	Uttarakhand
Name of the River	Sharda
Basin	Ganga
Design flood (cumecs)	188.7
Length of Barrage and Anicut (m)	475.3
Height upto crest (m)	8.9
No. of bays (i.e. number of openings)	22
Type of spillway gate	Others
Pond level (m)	246.7
Status of BWA Construction	Completed

A photograph of the Barrage is shown in Fig. 9.1b.

Figure 9.1b A photogragh of the Tanakpur Barrage

Impact of the Tanakpur Barrage

To study the impact of barrage on river morphology, decadal satellite images and geospatial datasets are examined. Fig 9.2a shows major course of Sharda River for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs 9.2b-g show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

It is clear that even before the construction of barrage i.e., year 1992, the river was wide spread upstream and downstream of the barrage location. There was a spill channel on the left side which had taken a shape of main channel in year 1980. There were no remarkable changes in the course of river before commissioning of the barrage in year 1992. During the period 2000 to 2010, no noticeable changes in the planform of river near the barrage have been noticed. However, after year 2010, siltation in upstream of the river has occurred. In year 2015, it is clearly visible that the main river is flowing in two channels - both are in extreme left and right with heavy siltation in upstream of the barrage between these two channels. It may be noted that this conclusion has been drawn on the basis of images which gave the planform of river. Any aggradation or degradation of the river that has arisen due to construction of the barrage and its backwater effect in upstream could not be studied through the images.

A site visit was undertaken to Tanakpur Barrage on 15th August 2016. Number of silted islands were noticed both in upstream and downstream of the barrage. Such islands were matured and vegetations were grown up over them. River was flowing in two channels upstream of the barrage. At the outset, it may be concluded that no noticeable changes in the morphology of the Sharda River has occurred due to construction of the barrage.

As such, no river training works have been provided in the Sharda river near the Tanakpur barrage except for protection of both the banks upstream and downstream of the barrage in the form of boulder pitching and vortex breakers.

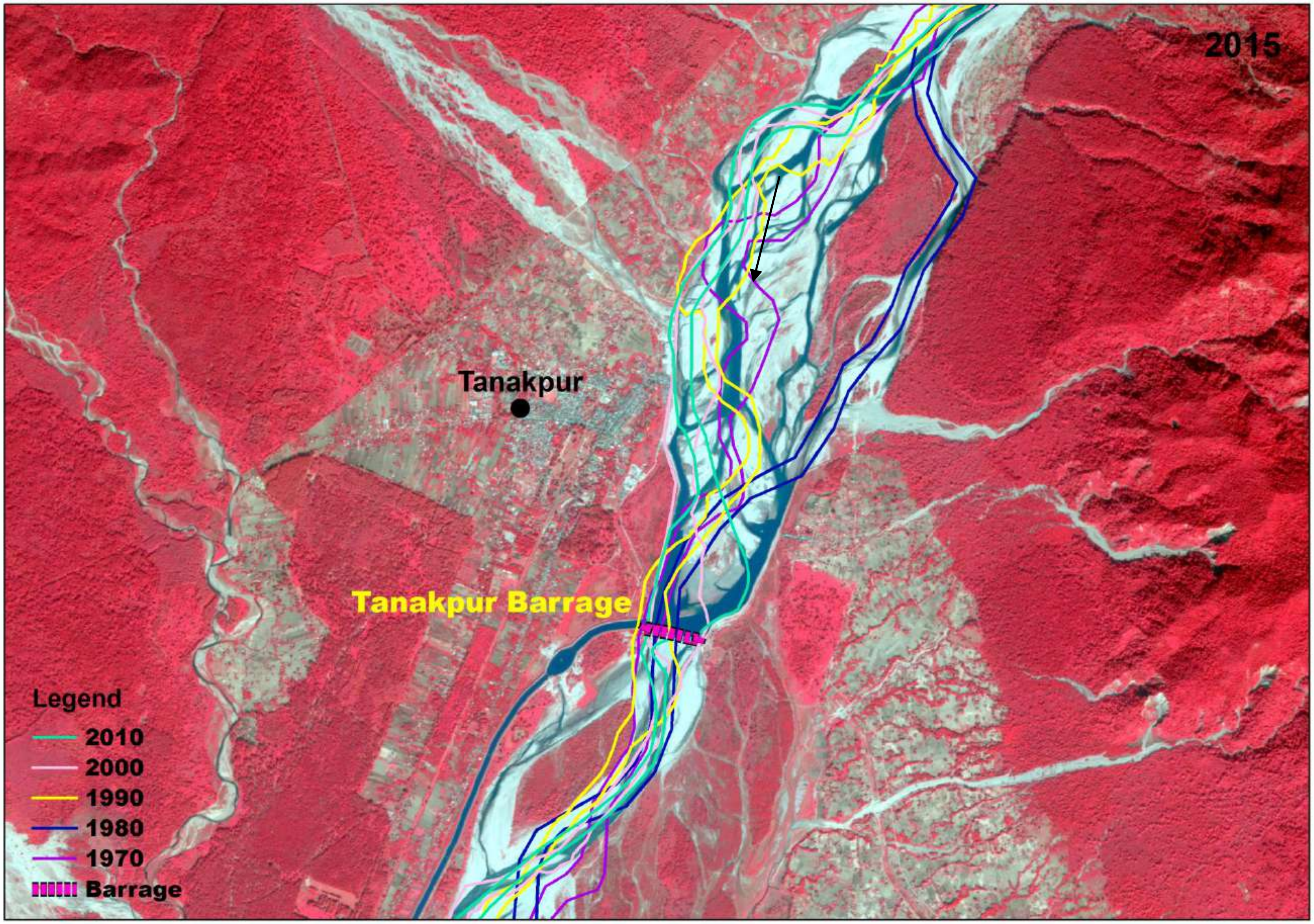
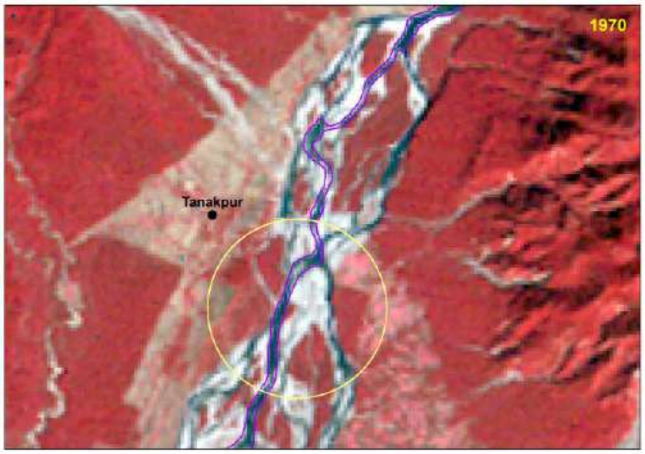


Figure 9.2a GIS layer of the Sharda river of the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of 2015



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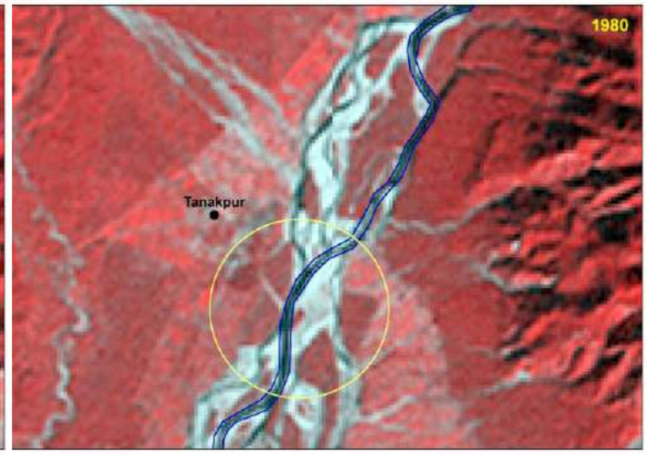

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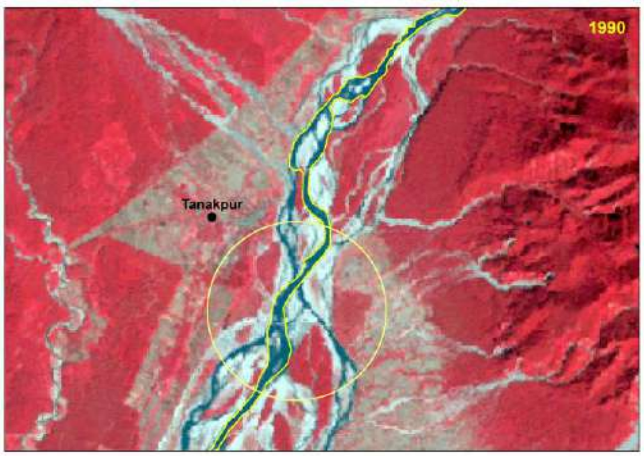

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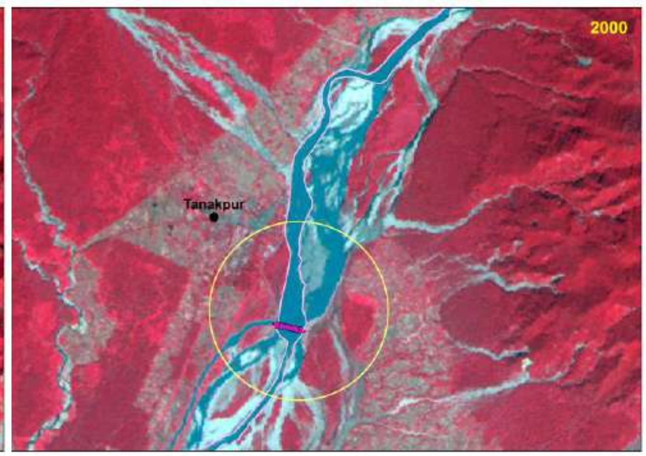

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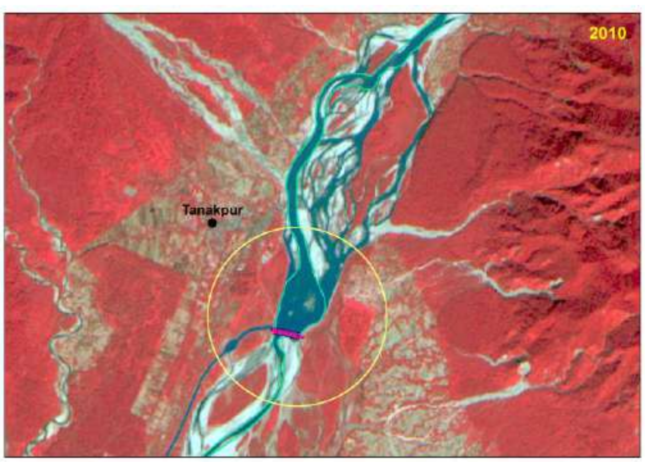

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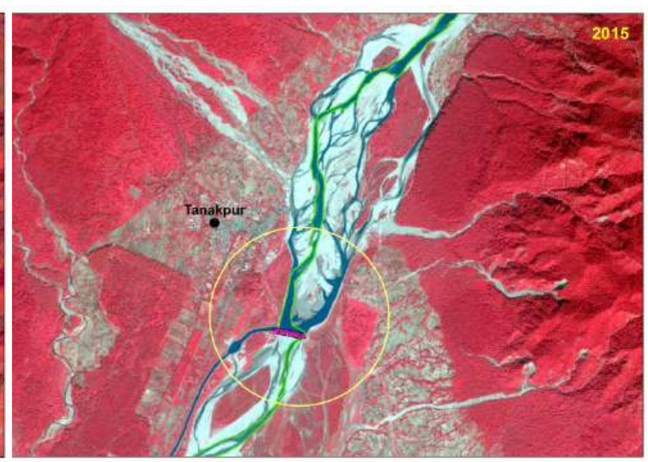


(g)

Figure 9.2b-g Images of Sharda river for the year 1970, 1980, 1990, 2000, 2010 and 2015

9.2.2 Banbasa Barrage (Upper Sharda Barrage)

It is located on Sharda river (also known as Mahakali River) at about 7 km downstream of the Tanakpur Barrage as shown in the Fig. 9.3a. Tail race channel of the power house joins the Sharda river from the right side just upstream of the Banbasa barrage. Sharda canal offtakes from the right bank of the Sharda river at the barrage. This barrage is also known as upper Sharda Barrage. It is the first irrigation project that was built in 1920s under an agreement signed between British India and Nepal to exchange 4000 acres (for a compensation of Rs 50,000 to Nepal) of the eastern flank of West Nepal.

The barrage still regulates the diversion of the Sharda River exclusively for the purpose of irrigation and power in Uttar Pradesh in India. Before 1920, the Sharda was a border river with left bank in Nepal and the right bank in India. The Sharda Agreement of 1920-transferred ownership of part of the left bank area (in the vicinity of the Barrage) from Nepal to India and the Sharda Barrage belongs to India.

Figure 9.3a Location of the Banbasa barrage

A photograph of the barrage is shown in Fig. 9.3b.

Figure 9.3b A photograph of the Banbasa Barrage (chainage 269 km)

This agreement was subsumed in the Mahakali Treaty signed in February 1996 and ratified on 27 November 1996, which entails the following supply from Sharda Barrage to Nepal.

a) Although the Sharda Agreement was made in 1920, Nepal could utilise its share of water only after the construction of Mahakali Irrigation Project in 1975. Water is diverted from the Barrage to the Sharda Right Bank Canal with a capacity of about 396 m^3/s for irrigation in India
b) In addition to the irrigation facilities, India also generates hydropower with an installed capacity of 41 MW from the canal head power station.

Major salient features of the barrage are as follows:

Salient Features (India-WRIS)	
Name of the Structure	Banbasa Barrage
Nearest city	Banbasa Khatima
District	Champawat
State	Uttarakhand
Name of River	Sharda
Basin	Ganga
Year of completion	1928
Design flood (Cumecs)	19821
Length of Barrage and Anicut (m)	603.5
Height upto crest (m)	9.146
Type of spillway gate	Others
Spillway gates - Number	16
Status of BWA Construction	Completed

Impact of the Banbasa Barrage

To study the impact of barrage on river morphology, decadal satellite images and geospatial datasets are examined. Fig 9.4a shows the major course of Sharda River for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs 9.4b-g show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

The barrage was commissioned in year 1920. From Figs 9.4a and 9.4b-g, one can conclude that no remarkable changes in the water course of Sharda River have occurred. There is no sign of siltation upstream of the barrage. As the image of the Sharda before its construction is not available, thus it is difficult to draw conclusion in respect of impact of Banbasa barrage on the morphology of river near the barrage. Further, any aggradation or degradation of the river that has arisen due to construction of the barrage and its backwater effect in the upstream could not be studied through the images.

A site visit was undertaken on 14th August 2016 to the Banbasa barrage to have comprehensive idea of the river morphology near the barrage. River was wide both in upstream and downstream of the barrage. Silted islands of temporary nature were noticed both in upstream and downstream of the barrage.

An elliptical guide bund towards left side of length 0.5 km is provided. About 1.5 km upstream of the barrage towards right side, a series of spurs have been provided. A series of short spurs were also provided towards right side downstream of the barrage.

It may be concluded that over the years no remarkable changes in the morphology of the Sharda River near the barrage have occurred.

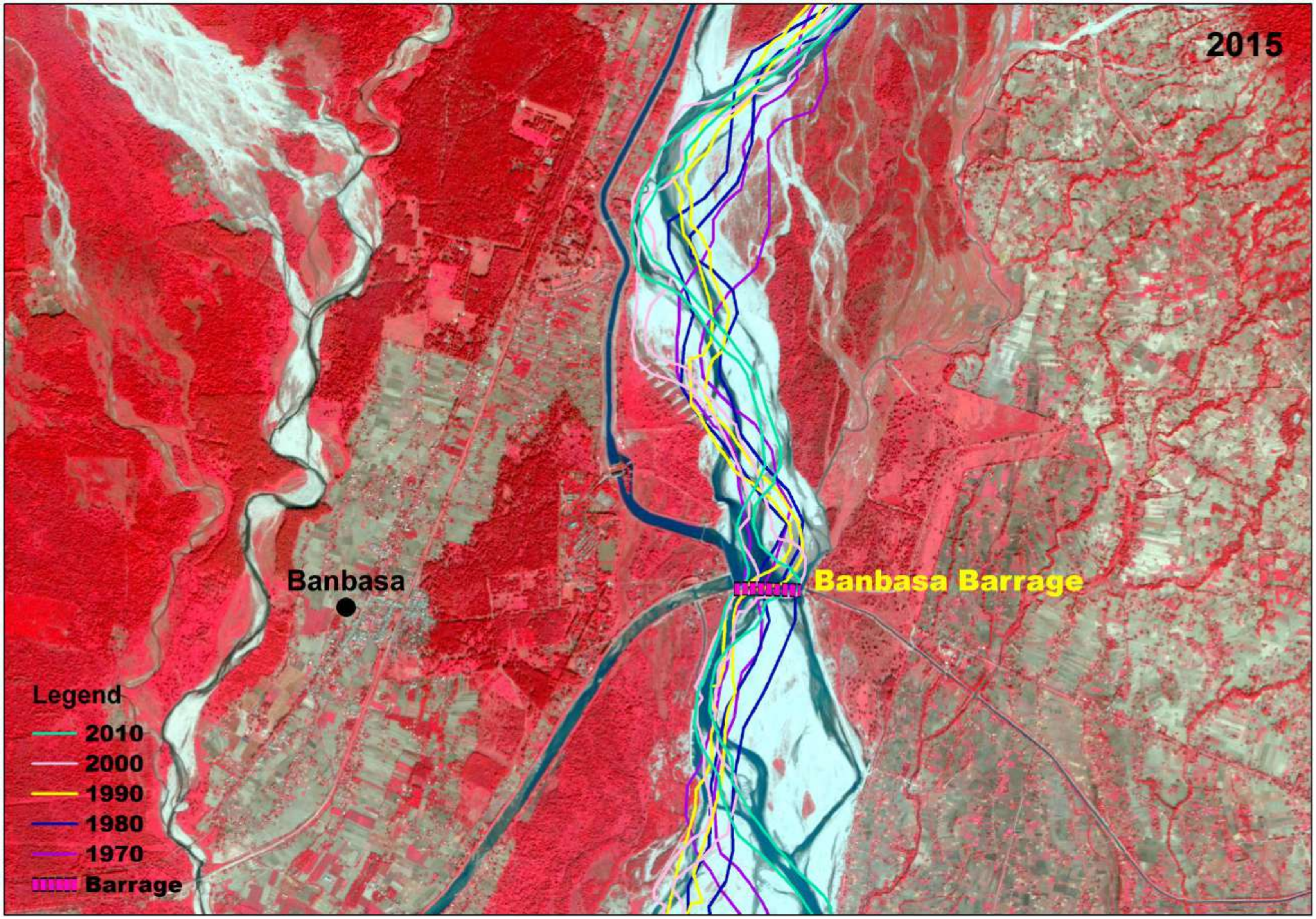
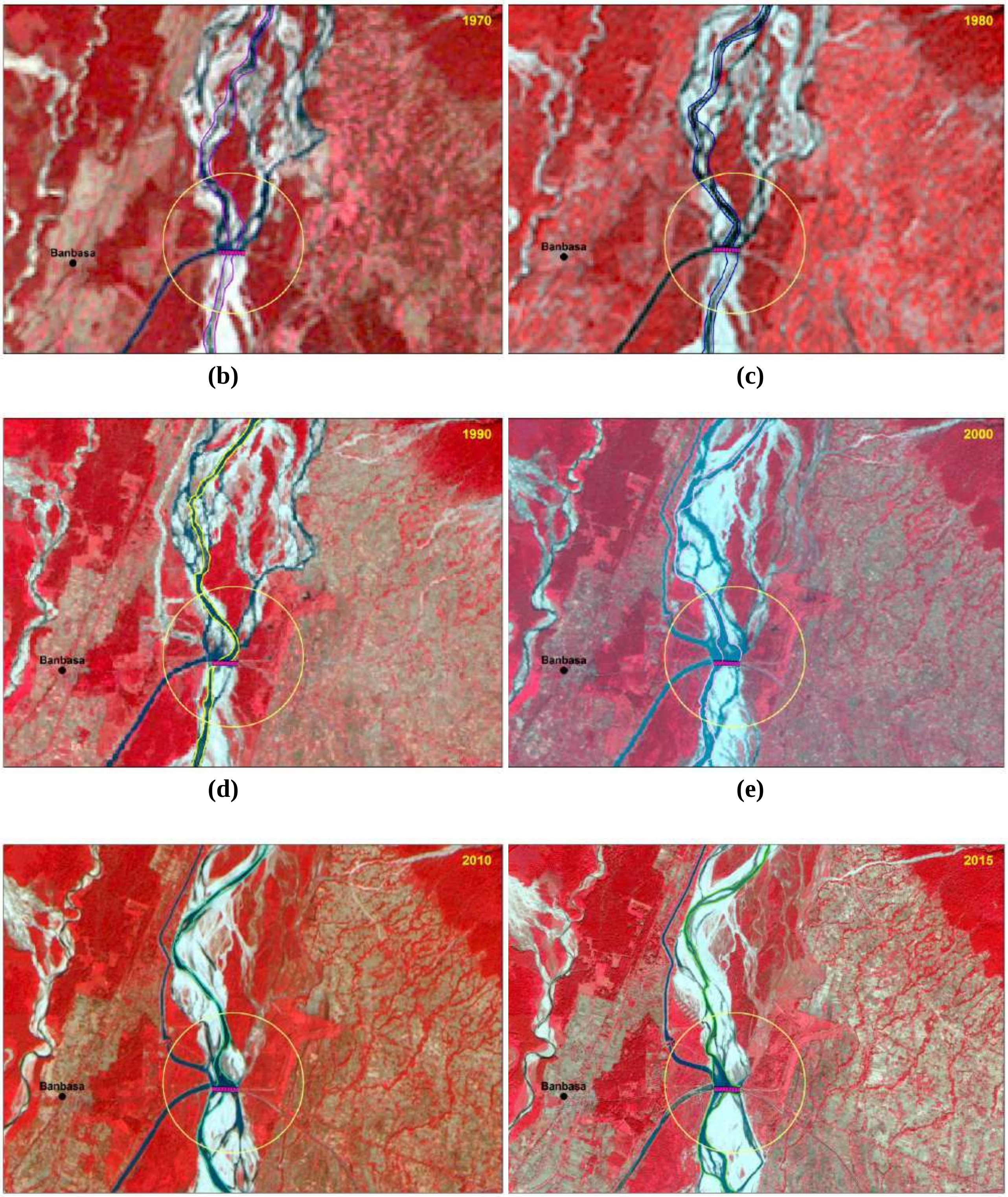


Figure 9.4a GIS layers of the Sharda river of the year 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015



(f) (g)

Figure 9.4b-g Images of Sharda river for the year 1970, 1980, 1990, 2000, 2010 and 2015

9.2.3 Lower Sharda Barrage

The Lower Sharda Barrage was constructed in year 1974, across the Sharda River, about 177 km downstream of the Upper Sharda (Banbasa) Barrage, and nearly 28 km from Lakhimpur city (Fig. 9.5a). This project is a part of the Sharda Sahayak Pariyojana (SSP), and primarily depends on water diverted from the Karnali (Ghaghra) at Girjapur through the Sharda Sahayak link canal of 28.4 km length for over eight months in a year during the lean season; but it indents on Sharda supplies during the monsoon between July and October when the Karnali (Ghaghra) carries a lot of silt. A photograph of the barrage is shown in Fig.9.5b.

Figure 9.5a Location of the Lower Sharda Barrage

Figure 9.5b A photograph of the Lower Sharda Barrage

The SSP aims at irrigating culturalable command area (CCA) of 1677,000 ha with 70% irrigation intensity. The 258.80 km long feeder channel of SSP takes off from the right bank of Sharda Barrage with discharge of 650 cumecs. Supplies are then fed into the different branches of the Sharda canal system, namely, the Daryabad branch, the Barabanki branch, the Haidergarh branch, the Rae Bareli branch and the Purva branch. SSP provides protective canal irrigation for cultivable area of 2 Mha to lakhs of farmers in 150 development blocks of 16 districts in eastern Uttar Pradesh. The project was commissioned in 1974, and completed in 2000 with an estimated cost of Rs. 13 billion.

Major salient features of the barrage are as follows:

Salient Features (India-WRIS)	
Name of the Structure	Lower Sharda Barrage
Nearest city	Nighasan
District	Kheri
State	Uttar Pradesh
Name of River	SHARDA
Basin	Ganga
Year of commencement	1972
Year of completion	1974
Design flood (Cumec)	11400
Length of Barrage and Anicut (m)	408
No. of bays (i.e. number of openings)	11
Width of Bay (m)	8
Type of spillway gate	Others
Spillway gates - Number	20
Pond level (m)	136
Under sluice bay - Number	9
Gates for under sluice - Number	20
Gates for under sluice -Size (m)	18×6
Means for dissipating energy (Hydraulic)	Chute Blocks and Baffle Blocks
Status of BWA Construction	Completed

Impact of the Lower Sharda Barrage

To study the impact of barrage on river morphology, decadal satellite images and geospatial datasets have been examined. Fig 9.6a shows the major course of Sharda River for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015, while Figs 9.6b-g show images for years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

The barrage was commissioned in year 1974. From Figs 9.6a and 9.6b-g, one can conclude that remarkable changes in the water course of Sharda river near the barrage has occured. The river has shifted right to left over the years upstream of the barrage and left to right downstream of the barrage. It is difficult to draw conclusion in the respect of silting in river upstream of the barrage due to its construction with use of historical images of the river.

A site visit was undertaken to the lower Sharda barrage on 22nd October 2016. Elliptical guide bunds of length of 550 m are provided towards both the sides. Three to four spurs were seen towards right side of the feeder channel near the barrage. Three spurs of varying length are also provided towards right side downstream of the barrage for the protection of the bank.

No noticeable silting in upstream and downstream of the barage was noticed. For the containment of flood water, embankments are provided on both the sides upstream of the barrage. The length of right embankment is about 8 km and length of left embankment is about 18 km.

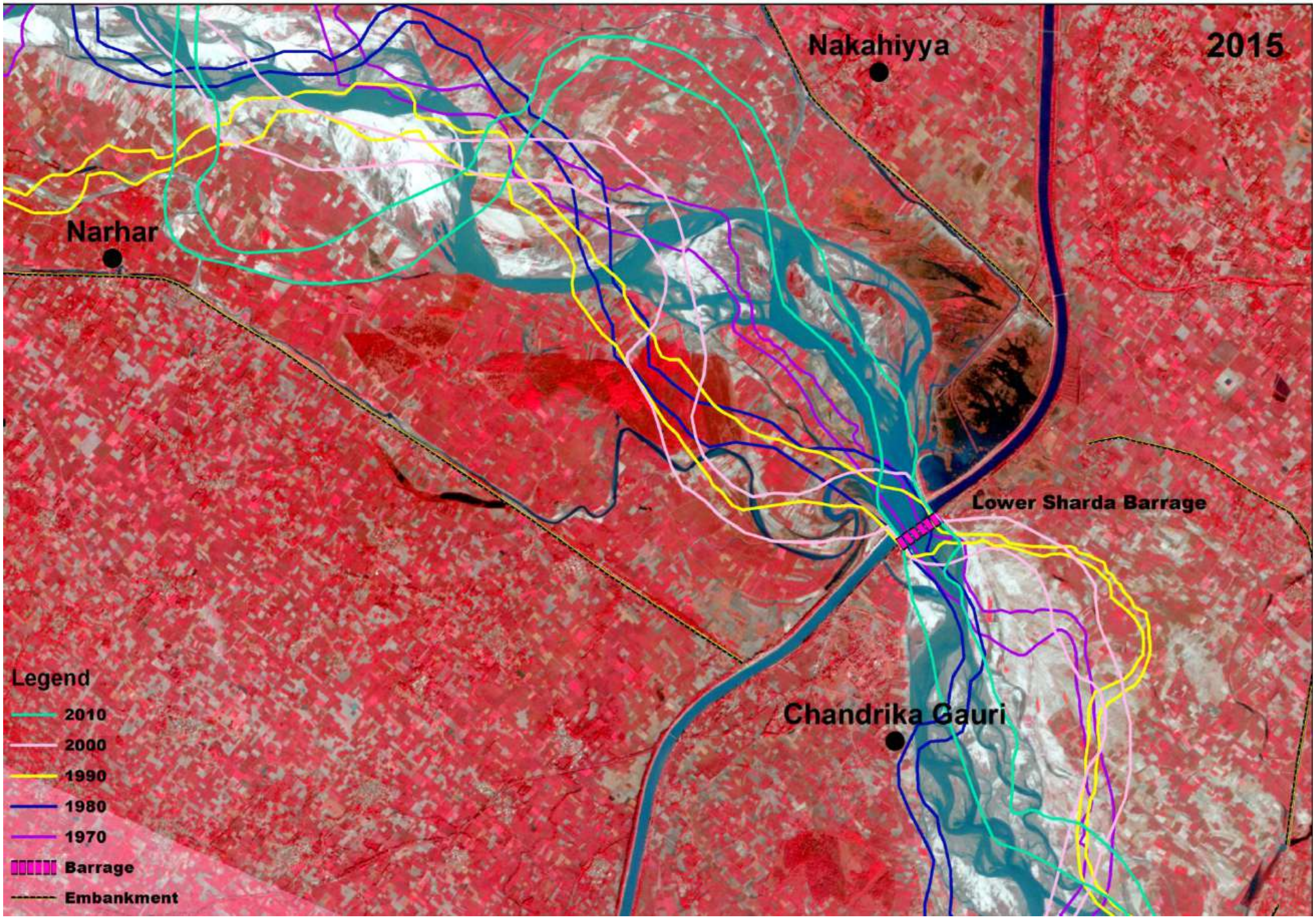


Figure 9.6a Water course of the Sharda river of the 1970, 1980, 1990, 2000 and 2010 on the satellite image of year 2015

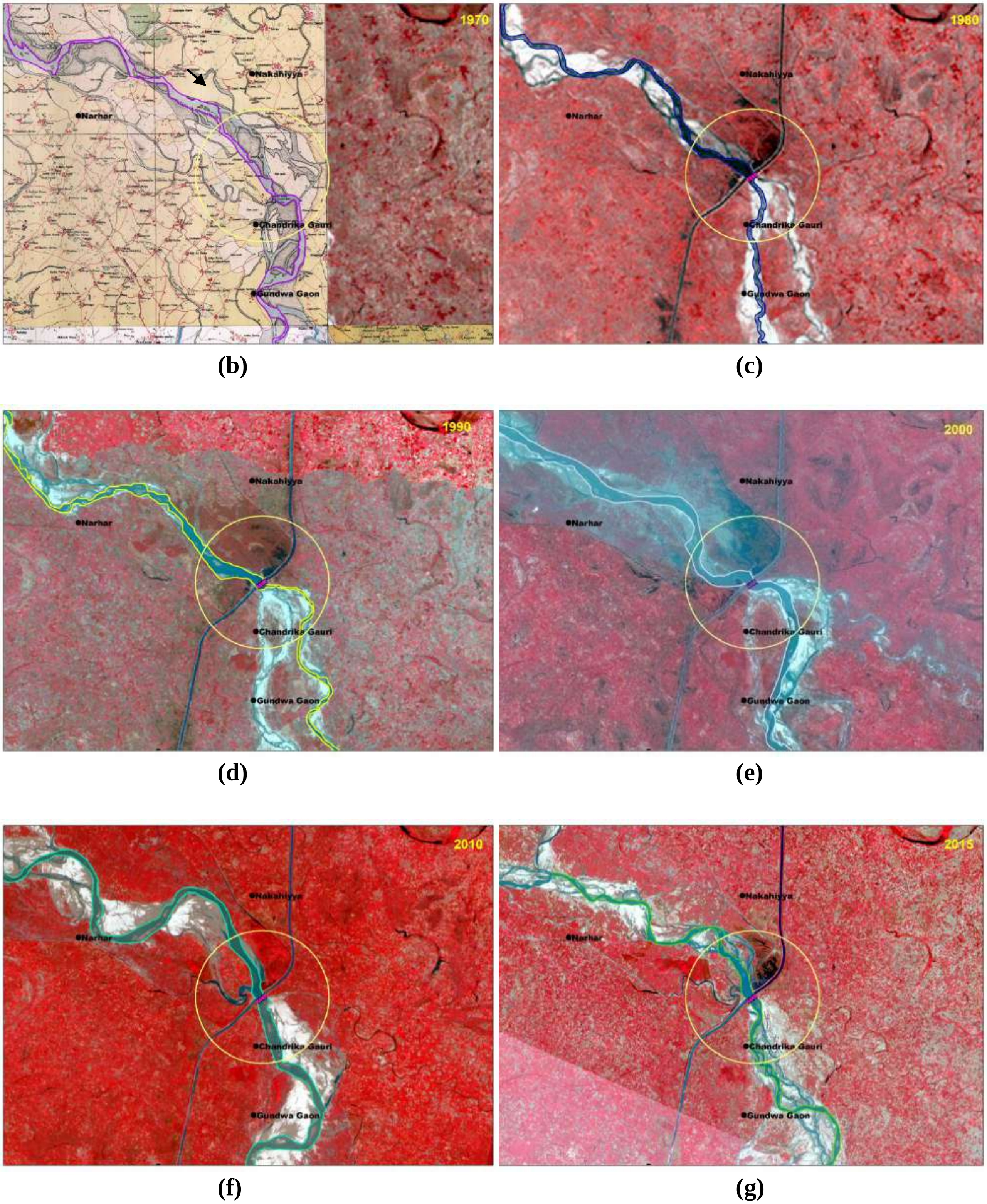


Figure 9.6b-g Images of Sharda river for the year 1970, 1980, 1990, 2000, 2010 and 2015

9.2.4 Road (SH 90) cum Railway Bridge at Palia Kalan

A road cum Rail Bridge which connects Bhira and Palia Kalan is constructed across Sharda River at chainage 168 km. Location of the bridge on the Sharda river is shown in the Fig. 9.7. The salient features of the bridge are given below.

Salient Features	
Type of Bridge	Rail cum Road Bridge (19 x 24.38 m)
Location	241/ 1-5
Rail Level	158.95 m
Maximum scour Level	14.85 m below Rail Level
Bottom of Girder	156.80 m
Danger Level	155.00 m
Top of Foundation	7.68 m below Rail Level
Bottom of Foundation	25.98 m below Rail Level
Highest Flood Level	155.32 m (1934)
Length of Guide Bund (left)	472 m
Length of Guide Bund (right)	500 m

The bridge was constructed before 1970, therefore, it is difficult to draw conclusion in respect of impact of construction of bridge on river morphology. However, the morphological changes of river near the bridge can be extracted from the historical images. Figure 9.8a shows the major course of Sharda River for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of the year 2015, while Figs. 9.8b-g show images of the years 1970, 1980, 1990, 2000, 2010 and 2015. It may be concluded from these figures that the river course wanders both upstream and downstream of the bridge. There is no specific progressive shifting of river near the bridge. It is difficult to draw conclusion in respect of silting in river near the bridge with the use of historical images of the river.

Figure 9.7 Location of Road (SH 90) cum Railway Bridge at Palia Kalan

A team of IIT Roorkee, visited the site of road bridge (SH90) and Railway Bridge (Bridge No. 97) located near Palia Kalan on 22nd Oct. 2016.

Guide bunds have been provided on both the sides of the river, however suitable upstream curved mole has not been provided in particular to the right guide bund. It seems that the upstream nose of the right guide bund is damaged due to past floods. River is wide in both upstream and downstream of the bridge. Local enquiry and available literatures indicate that heavy erosion towards right bank along the railway line had occurred in the flood of 2008. The river has come very close to the railway line and about to erode it. To protect such erosion, series of spurs orienting normally to the railway track were provided. Such spurs performed well and at outset the river which was abutting the railway track, shifted towards left side.

At present, river is stable near to the bridges, therefore as such no river training/protection works are required. However, it is recommended to repair the washed out upstream mole of the right guide bund.

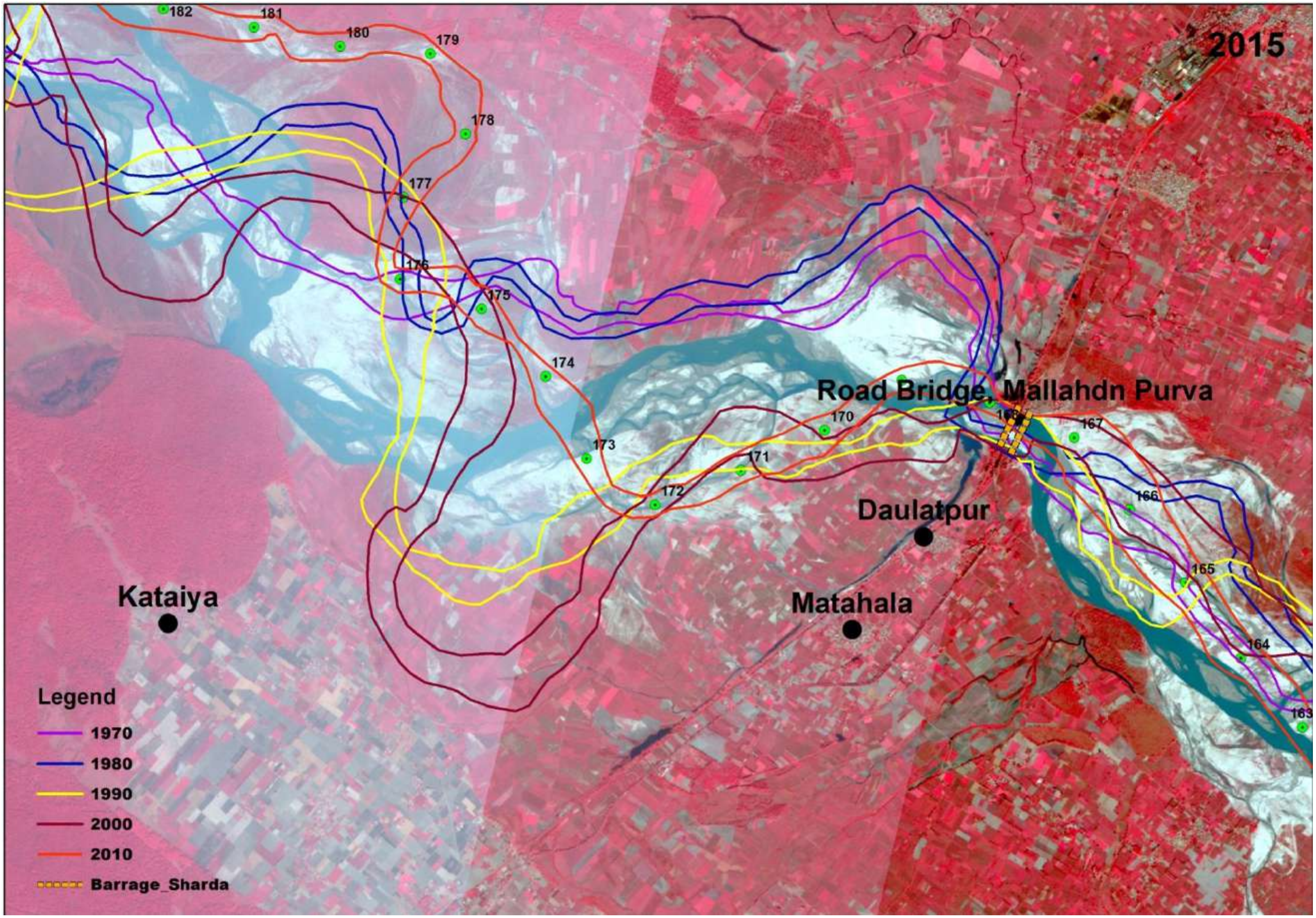
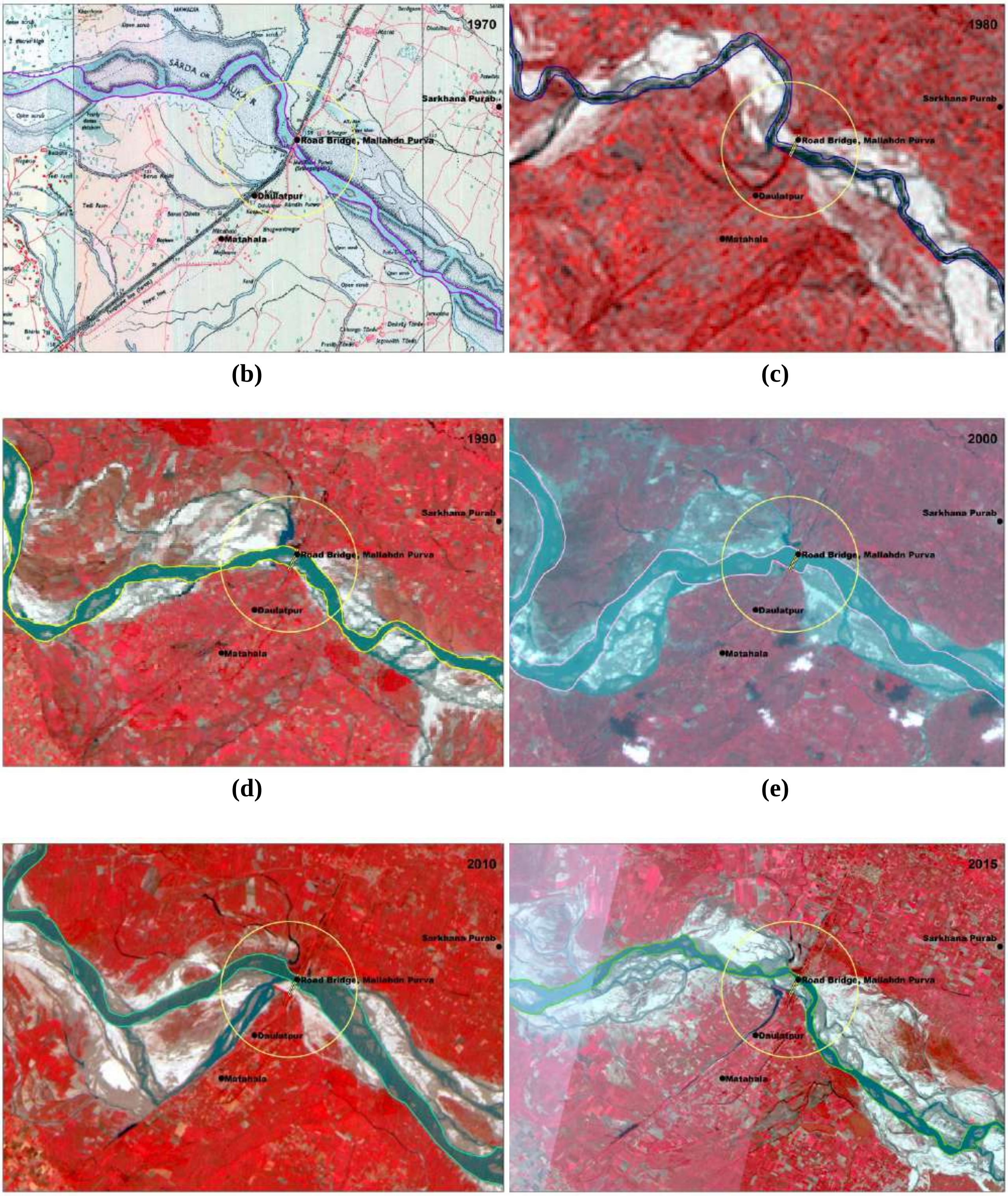


Figure 9.8a Water course of Sharda river of the year 1970, 1980, 1990, 2000 and 2010 on the satellite images of year 2015



(b) (c)

(d) (e)

(f) (g)

Figure 9.8b-g Images of the Sharda river for the year 1970, 1980, 1990, 2000, 2010 and 2015

9.2.5 Road Bridge (SH 26)

A road bridge (SH 26) of length 590 m is constructed across Sharda River at chainage 57 km (Fig. 9.9). Guide bunds of length 900 m are provided towards both sides with their proper curved moles.

River mainly flows in two channels upstream of the bridge. The river is widely spread both in the upstream and downstream of the bridge. No other river training/protection works have been provided.

The morphological changes of river near the bridge can be extracted from historical images. Figure 9.10a shows the major course of Sharda River for years 1970, 1980, 1990, 2000 and 2010 on the satellite image of the year 2015, while Figs. 9.10b-g show images of the years 1970, 1980, 1990, 2000, 2010 and 2015, respectively.

Historical images of the river near the bridge indicate that performance of both the guide bunds are satisfactory as no damage to the guide bunds and approach roads have been seen. However, river has come very close to right approach road. Therefore, it is recommended to protect the embankment of the road by boulder pitching and/or provision of series of spurs.

Figure 9.9 Location of the Road bridge (SH 26) on Sharda river

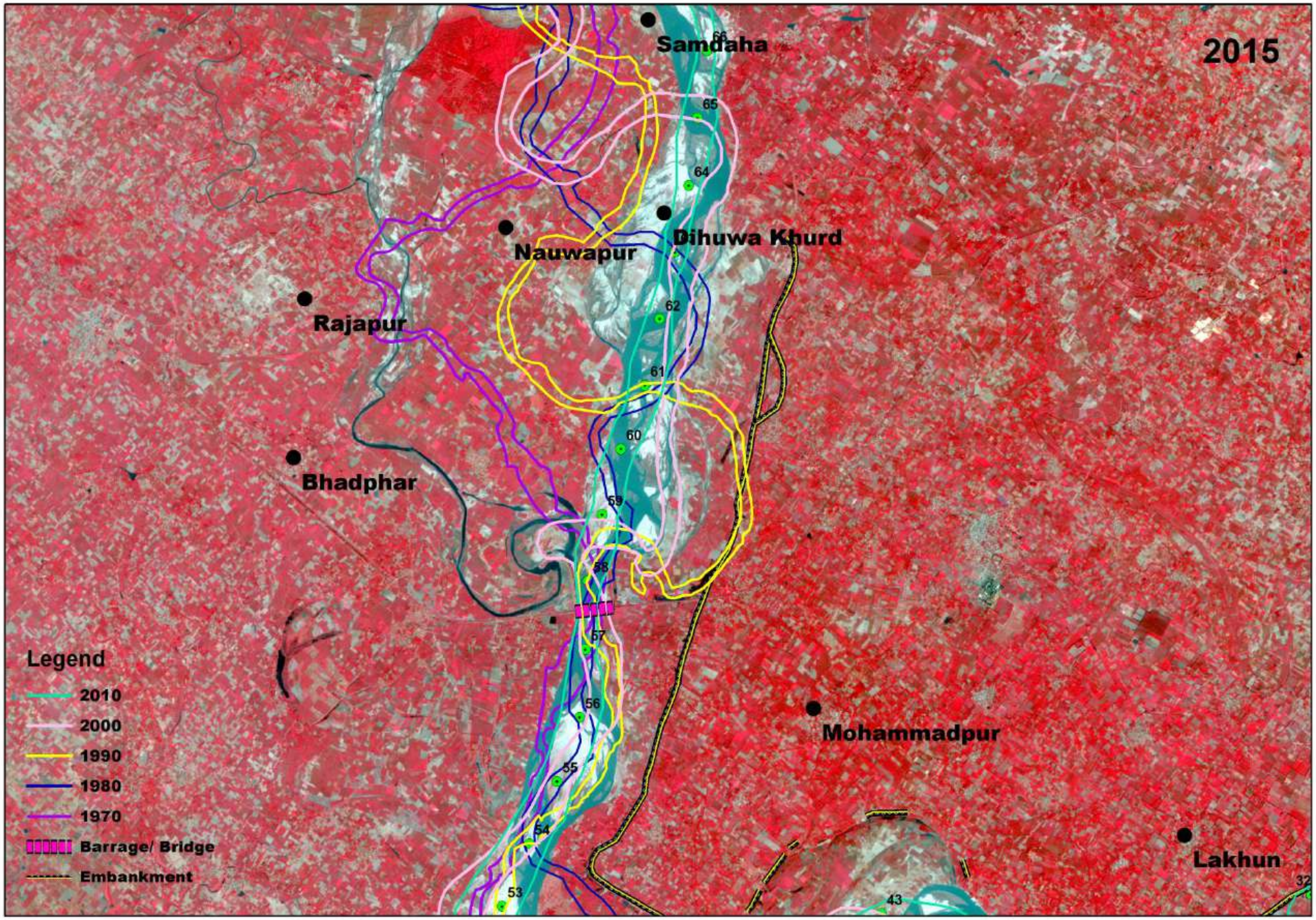
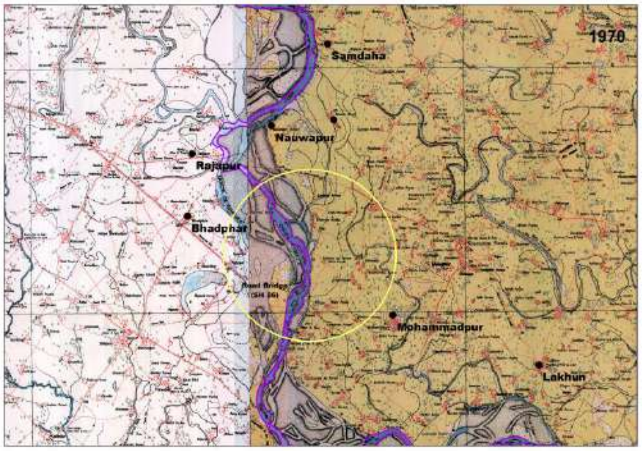


Figure 9.10a Water course of Sharda river of the year 1970, 1980, 1990, 2000 and 2010 on the satellite images of year 2015



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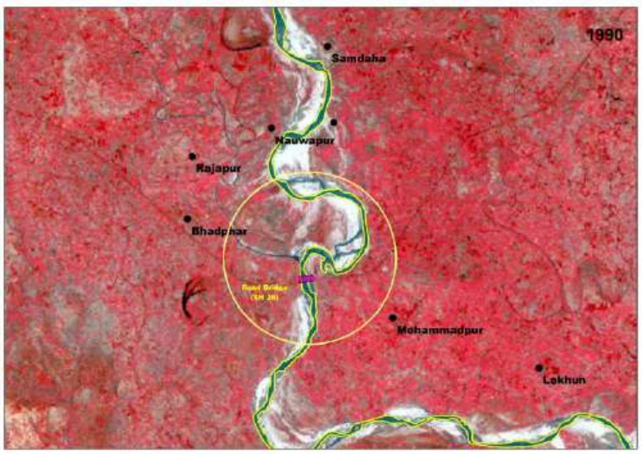

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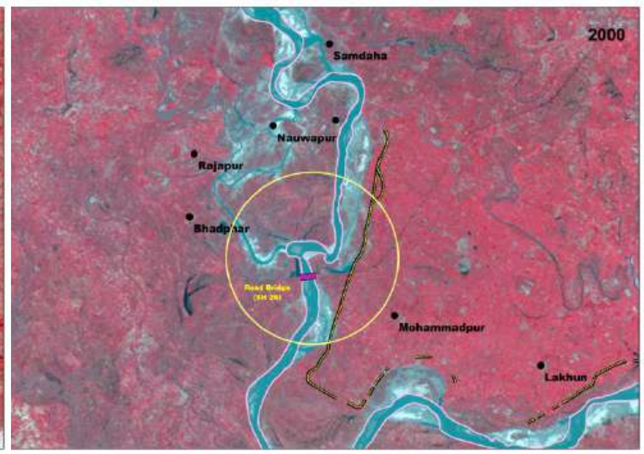
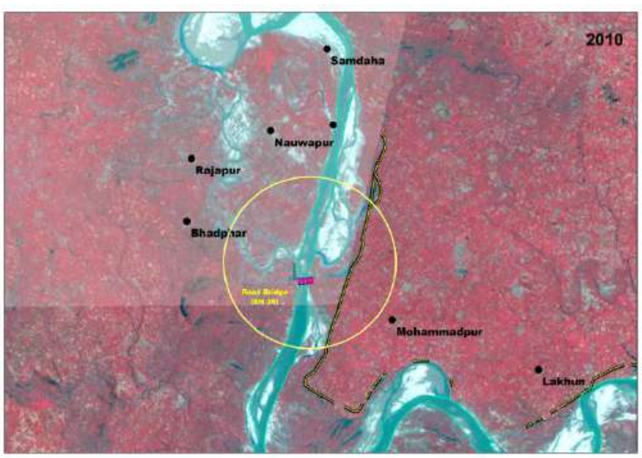
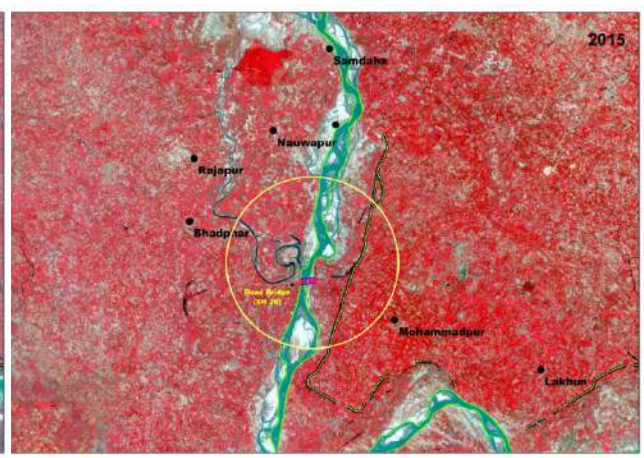


(e)



(f)



(g)

Figure 9.10b-g Images of the Sharda river for the year 1970, 1980, 1990, 2000, 2010 and 2015

9.3 CONCLUDING REMARKS

Following conclusions may drawn from this study:

a) It is concluded that even before the construction of the Tanakpur barrage in year 1992, river was wide spread upstream and downstream of the barrage location. During the years 2000 to 2010, no noticeable changes in the planform of the river near barrage have been noticed. However, after year 2010, siltation in upstream of the river has occured. In year 2015, it is clearly visible that the main river is flowing in two channels - both are in extreme left and right with heavy siltation in upstream of the barrage between these two channels.

b) Banbasa barrage was commissioned in year 1920. No remarkable changes in the water course of Sharda river have occured. There is no sign of siltation upstream of the barrage. As the satellite image of Sharda river before its construcion is not available, it is difficult to draw conclusion in the respect of impact of the Banbasa barrage on morphology of river near the barrage.

c) Lower Sharda barrage was commissioned in year 1974. It may be concluded that remarkable changes in the water course of Sharda river near the barrage have occured. The river has shifted right to left over the years upstream of barrage and right to left downstream of barrage. It is difficult to draw conclusion in respect of silting in river upstream of the barrage due to its construction with use of historical images of river.

d) As road cum rail bridge at chainage 168 km (Palia Kalan) was constructed before 1970, therefore, it is difficult to draw conclusion in the respect of impact of construction of the bridge on river morphology. However, it is found that the river course wanders both upstream and downstream of the bridge. There is no specific progressive shifting of the river near the bridge.

   At present, river is stable near to the bridges, therefore as such no river training/protection works are required. However, it is recommended to repair the washed out upstream mole of the right guide bund.

e) At road bridge (SH 26) (chainage 57 km), river flows mainly in two channels upstream of the bridge. The river is widely spread both in the upstream and downstream of the bridge. Performance of the guide bunds are satisfactory as no damage to the guide bunds and approach roads have been seen. However, river has come very close to right approach road. Therefore, it is recommended to protect the embankment of the road by boulder pitching and/or provision of series of spurs.

Chapter -10 GROUND VALIDATION

10.1 INTRODUCTION

This chapter deals with details of the site visit undertaken to various locations of the Sharda river by team of IIT Roorkee. 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.

10.2 SITE VISIT TO BANBASA BARRAGE, UTTARAKHAND ON 14.8.2016

At Banbasa Barrage, Sharda canal offtakes from the right bank of Sharda River upstream of barrage. On the day of visit, Sharda river was flowing with bankfull discharge. Tanakpur barage on the Sharda River is on the upstream of the Banbasa barrage. Before reaching to Tanakpur, the river flows along India-Nepal border for about 25 km. After the Banbasa barrage, it again enters the territory of Nepal for about 18 km and then again emerges at Indian border at Naujalha Naktaha.

On the day of visit, Sharda River was flowing at 219.60 m level, which is close to danger level o 221.70 m. The water was spread over both the banks of the river. The discharges on upstream and downstream sides of Banbasa barrage were 79,636 cusecs and 68,220 cusecs, respectively while 11,166 cusec water was flowing in the Sharda canal.

A numbers of islands were formed on upstream and downstream sides of the barrage. Prominent mature/ grown-up vegetation was not visible over these islands. There was a large island on downstream side, which does not get submerged even in high flow in the monsoon period. The flood water was spread towards both the banks downstream of the barrage. On the right bank (known as right bell bank) on downstream side, seven numbers of spurs were constructed for right bank protection. Spurs appear of varying length. However, after discussions with

Department officials, it was emerged that the spurs were constructed of same length, about 20 m long, but few spurs are damaged in the subsequent floods. The spurs closer to barrage have been repaired while others are yet to be repaired. The spacing between spurs is about 80 m. The spurs have been constructed by stones/ boulders with wire mesh crates. It has been told by Department officials that the river sometimes breaches the side bunds.

On the upstream side of the Banbasa barrage, there was a big island formed near the left bank. This island has also not submerged even in high flow level of river. The river channel was flowing near the right bank. There were three to four spurs on upstream side of the barrage towards right side. It was intimated that in the year 2013, maximum discharge of 5.44 lakh cusecs has passed through the barrage.

Some of the photographs taken during the site visit are shown in Figs. 10.1 to 10.3.

<table>
<tr><td></td><td>Figure 10.1 Series of spurs provided on right banks of Sharda river downstream of the Banbasa barrage</td></tr>
<tr><td></td><td>Figure 10.2 A spur on right banks downstream of the Banbasa barrage</td></tr>
</table>

Figure 10.3 A large island in the mid of the river downstream of the Banbasa barrage

10.3 SITE VISIT TO TANAKPUR BARRAGE, UTTARAKHAND ON 15.8.2016

Tanakpur barrage is constructed on Sharda River approximately 7 km upstream of the Banbasa barrage. Near the barrage, Sharda River flows along India-Nepal border from Himalayan foothills. On the upstream side of the Sharda river on right bank, vortex breakers are provided for the bank protection. The river was flowing about 1 m below the right bank level. On the left bank, water flow was relatively low. A number of islands have formed on upstream and downstream sides of the barrage which didn't submerge even in high flow condition. On upstream side, most of the islands are towards left bank, although river flows in two channels of almost equal width, touching the left and right banks just upstream of the barrage. Prominent mature/ grown-up vegetation was visible over these islands on the upstream and downstream of the barrage, which indicates the near permanent nature of the islands. On the downstream side of the barrage, water flows towards right bank. The boulder bed was exposed on left bank. On downstream side, river bifurcates into two parts due to presence of a large island almost in the center of the river.

Bunds with stone pitching are provided up to few hundred meters for bank protection, on the left and right banks. There is a canal that off takes from right bank of the Sharda River, which supplies water to the power house. Tanakpur Barrage is operated and controlled by National Hydro Power Corporation (NHPC), which has a power house on the canal that takes off from this barrage.

The main barrage has total 22 bays. On the day of visit, the discharge was approx. 78,000 cusecs. On the day of the visit, the water level on upstream was 246.78 m which is closer to the design pond level of the barrage. If the river water goes beyond this level, the barrage gates would be fully opened. The downstream water level was 236 m.

Few bank protection measures have been adopted. Due to siltation in the center of river, entire flow concentrates towards banks causing their breach. A 100 m long spur has been provided at Sharda Ghat about 2 km upstream of barrage. Near the barrage only bank protection has been provided in the form of boulder pitching and vortex breakers.

Few photographs taken during the site visit are shown in Figs. 10.4 to 10.7.

	**Figure 10.4** Right bank erosion upstream of the Tanakpur Barrage
	**Figure 10.5** Vortex breakers provided on the right bank of the Sharda river upstream of Tanakpur Barrage

	**Figure 10.6** Heavy deposition in the form of island near the left bank upstream of the Tanakpur Barrage
	**Figure 10.7** Upstream view of the Tanakpur barrage

10.4 SITE VISIT TO SHARDA BARRAGE ON 22.10. 2016

The IIT Roorkee team visited the site of Sharda Barrage also known as Lower Sharda Barrage, on 22nd October 2016. Sharda Sahayak link canal of length 28.4 km which offtakes from barrage of Ghaghara river on Girijapuri and joins the Sharda river to its left bank just upstream of the Sharda barrage. A feeder channel of Sharda Sahayak Pariyojana (SSP) off takes from right bank of the Sharda river which augment the supplies in the lower reaches of old Sharda canal system. The length of feeder channel is approximately 258.8 km.

The construction of the Sharda barrage was commenced in 1972 and completed in 1974. The design discharge of the barrage is 11,400 m^3/s while its length is 40 m. The looseness factor of the barrage is computed as 1.24.

Remarkable changes in the course of Sharda river have been noticed. Over the years the course of Sharda has shifted from right to left in upstream and left to right in downstream. During the year 2004, the river was flowing abutting the feeder channel - spurs were provided along the feeder channel for its protection.

Guide bunds are provided towards both the sides of the river both in upstream and downstream. No noticeable damage to such bunds was observed during the site visit.

No noticeable silting in upstream and downstream of the barrage was seen during the site visit. However, series of spurs have been provided along right bank of downstream of barrage to protect the left bank erosion.

Some of the photographs taken during the site visit are shown in Figs. 10.8 to 10.12.

Figure 10.8 Upstream view the river from the Sharda barrage

Figure 10.9 Head regulator of feeder channel of Sharda Sahayak Pariyojana (SSP)

	**Figure 10.10** Upstream view of the Sharda Barrage
	**Figure 10.11** Regulator of Sharda Sahayak link canal
	**Figure 10.12** Series of spurs along right bank downstream of the Sharda Barrage

10.5 SITE VISIT TO PALIA KALAN RAIL BRIDGE/ROAD BRIDGE ON SH 90 OF SHARDA RIVER ON 22 OCTOBER, 2016

The IIT Roorkee team visited the site of State Highway No. 90 road bridge and also railway bridge No. 97 across Sharda river on 22nd October 2016. The length of both the bridges is of the order of 463 m.

Guide bunds have been provided on both the sides of the river, however, suitable upstream curved mole has not been provided in particular to the right guide bund.

Remarkable changes in the course of the river have been observed during the year 2008 - the river was flowing towards right side abutting railway line. The water level during flood of 2008 was just about 1 to 1.5 feet below the deck of the railway bridge. Heavy erosion towards right bank along the railway line had occurred in the flood of 2008.

The main course of river was towards left side in 1970-1980 and then it shifted to right side. Presently the river is flowing relatively straight in upstream of the bridges. No remarkable changes in the course of river in downstream of the bridges have been noticed.

Some of the photographs taken during the site visit are shown in Figs. 10.13 to 10.15.

Locations of the sites that were visited by team of IIT Roorkee is shown in Fig. 10.16.

Figure 10.13 Upstream view of Sharda river from railway bridge No. 97 at Palia Kalan

	**Figure 10.14** Road bridge on State Highway No. 90 at Palia Kalan
	**Figure 10.15** Downstream view of the river from road bridge at Palia Kalan

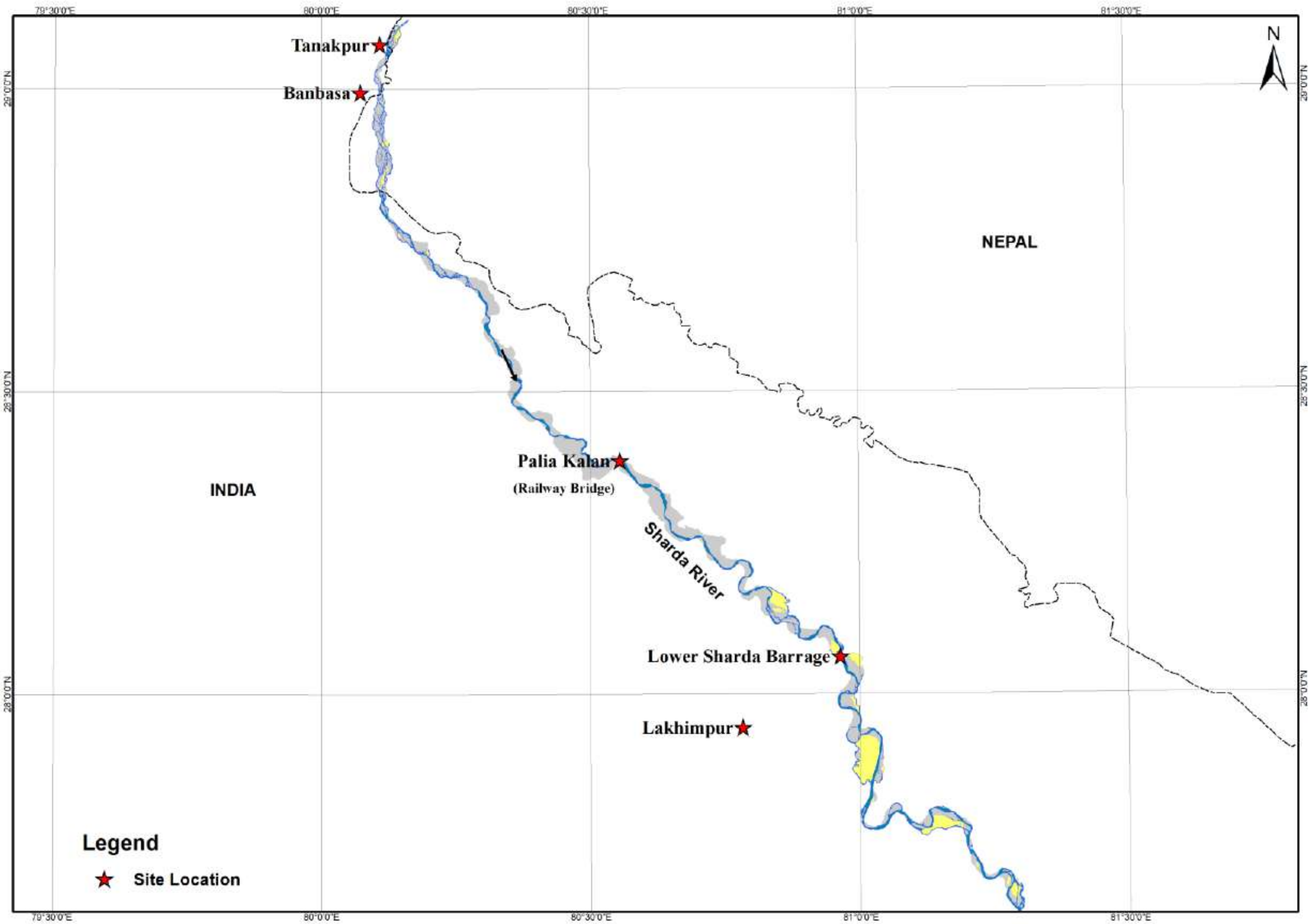


Figure 10.16 Location of the sites of the Sharda river visited by the IIT Roorkee team.

Chapter -11 IDENTIFICATION OF CRITICAL REACHES & RIVER TRAINING WORKS

11.1 IDENTIFICATION OF THE CRITICAL REACHES

The plan form changes of the river in the terms of bank line shifting, sinuosity, plan form index etc. has been mentioned in the previous Chapters. For fulfilling the objective of the study regarding identification of the critical reaches and provision of river training works thereof, suitable approach has been discussed here.

The proposed basis for the identification of the critical reaches is as follows:

a) The reach of the river that has been progressively shifting towards either side 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 revenue.

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 wandering 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 causes huge inundation can be controlled.

The above basis has been adopted in this study for the identification of critical reaches of the Sharda River.

As per the IS code 12094:2000, spacing between embankments/ levees for the containment of the river should not be less than 3 times the 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 a half times Lacey's wetted perimeter from the river bank.

In the present study for the relatively straight reach, width of the river is kept 3 times of the Lacey perimeter. However, at locations where sinuosity ratio of the river is higher, it is proposed to place the embankments apart at 4 times the Lacey perimeter.

Lacey's perimeter for the alluvial river may be obtained by

$$P = 4.75\sqrt{Q} \tag{11.1}$$

Where P is in m and Q in cumecs.

Invoking the methodology/ criteria discussed in the above section, the identified critical reaches of the Sharda river are given in Table 11.1 with justification. Four reaches of Sharda river have been identified as critical. Out of which, three reaches of the Sharda river i.e., 213-230 km, 167-202 km, and 53-87 km, have been wandering within wide width, even though there is no progressive shift in the either directions. Such reaches are located near Mustafabad, Dhakka Ghat, and Chandrika Gauri. The exreme left and right banks of the river have wandered in period 1970 to 2010, which are marked on the LISS IVimages of year 2015 as yellow color in Figs. 11.1a, 11.1b, and 11.1d for the above three reaches. It is to be noted that all the three reaches are comprised of agricultural land.

In the reach from 143-160 km, the historical images of river indicates its progreesive shift from left to right. This reach is located near Ramnagar Kalan and Bhanpur, UP. The left and right banks of the river for years 1970, 1980, 1990, 2000 and 2010 are marked on LISS IV image of year 2015, and shown in Fig. 11.1c. The land in this area is primarily agricultural.

Table 11.1 Critical Reaches of the Sharda River

Chainage (km)	Location	Justification	Figure No.
213-230	Mustafabad, UP	Agricultural land on either sides of the river. No progressive shifting of river course, however, river is too wide and spread of flood water needs to be contained.	11.1a
167-202	Dhakka Ghat, UP	Agricultural land on either sides of the river. No progressive shifting of river course, however, river is too wide and spread of flood water needs to be contained.	11.1b
143-160	Ramnagar Kalan, Bhanpur, UP	Progressive shifting of river course from year 1970 to 2015 towards right side	11.1c
53-87	Chandrika Gauri, UP	Agricultural land on either sides of the river. No progressive shifting of river course, however, river is too wide and spread of flood water needs to be contained.	11.1d

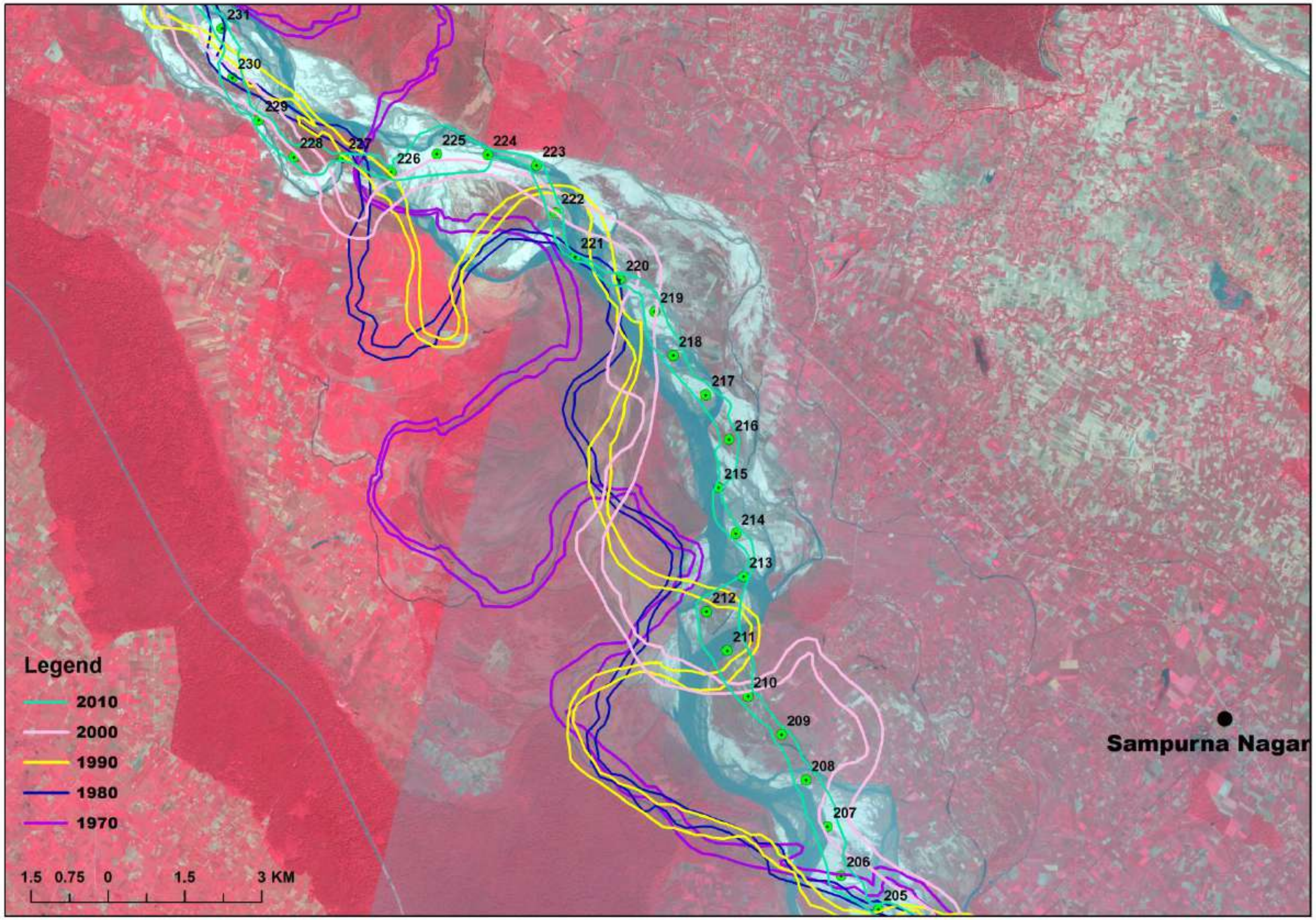


Figure 11.1a Critical reach of Sharda river from chainage 213- 230 km

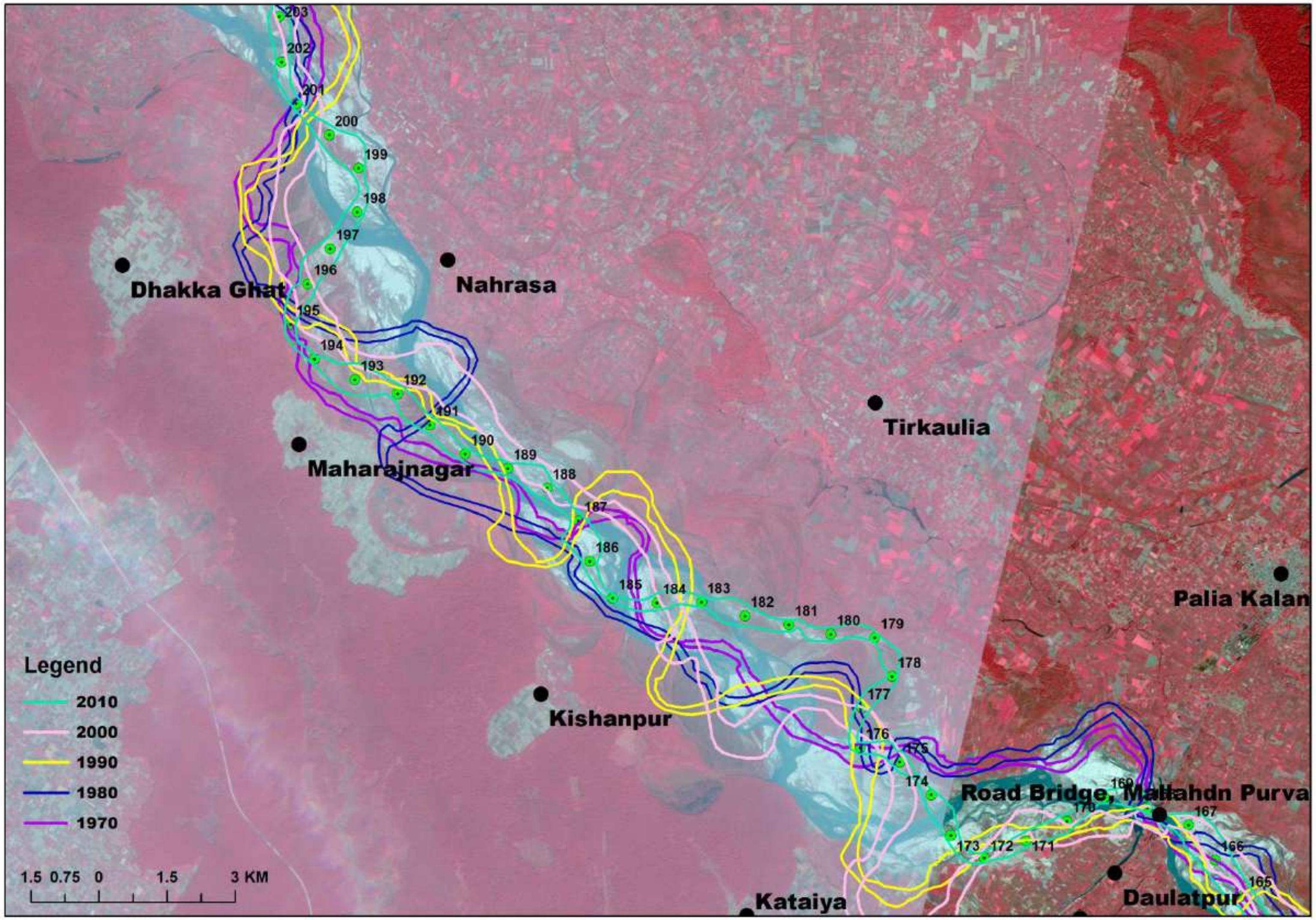


Figure 11.1b Critical reach of Sharda river from chainage 167- 202 km

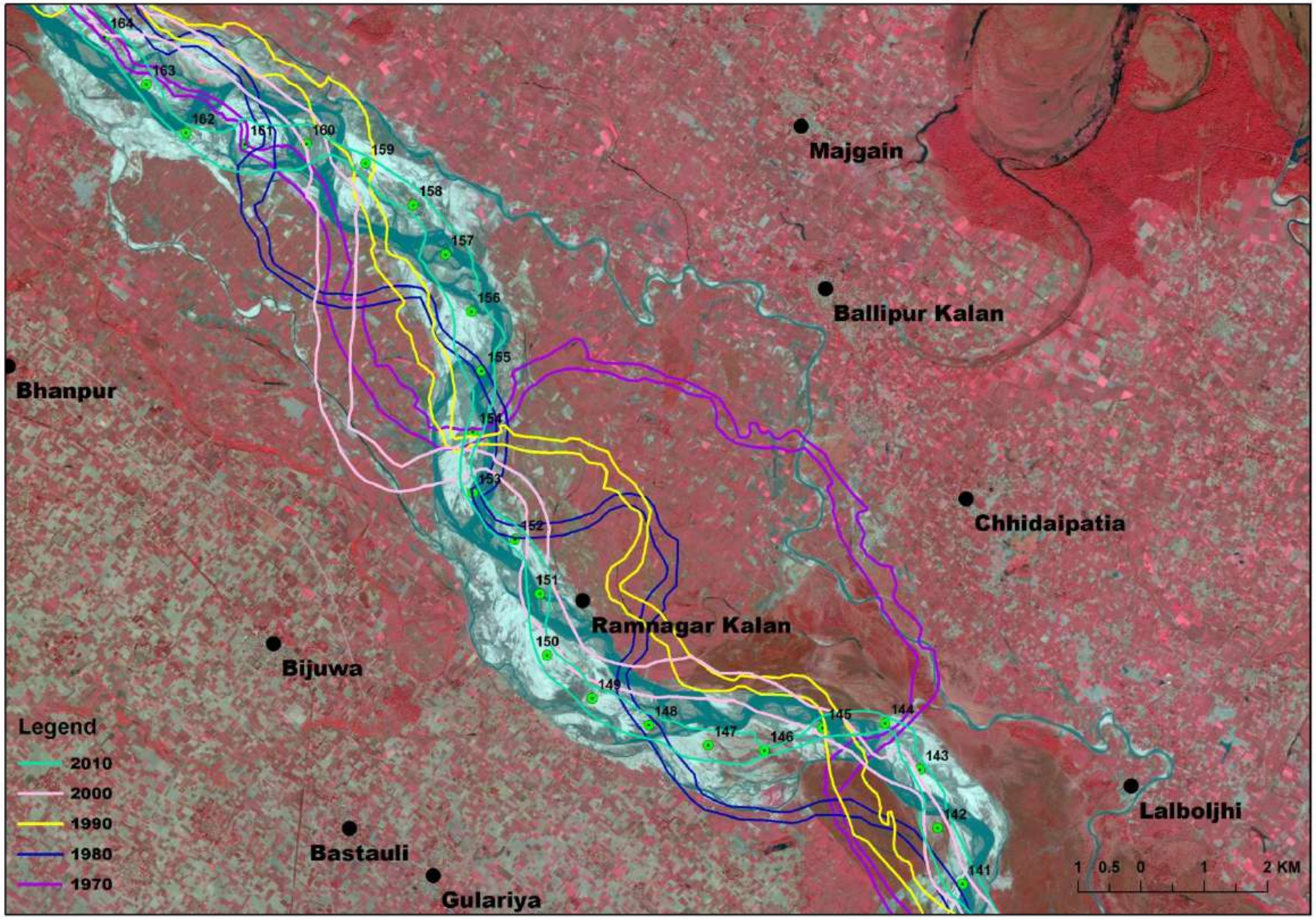


Figure 11.1c Critical reach of Sharda river from chainage 143- 160 km

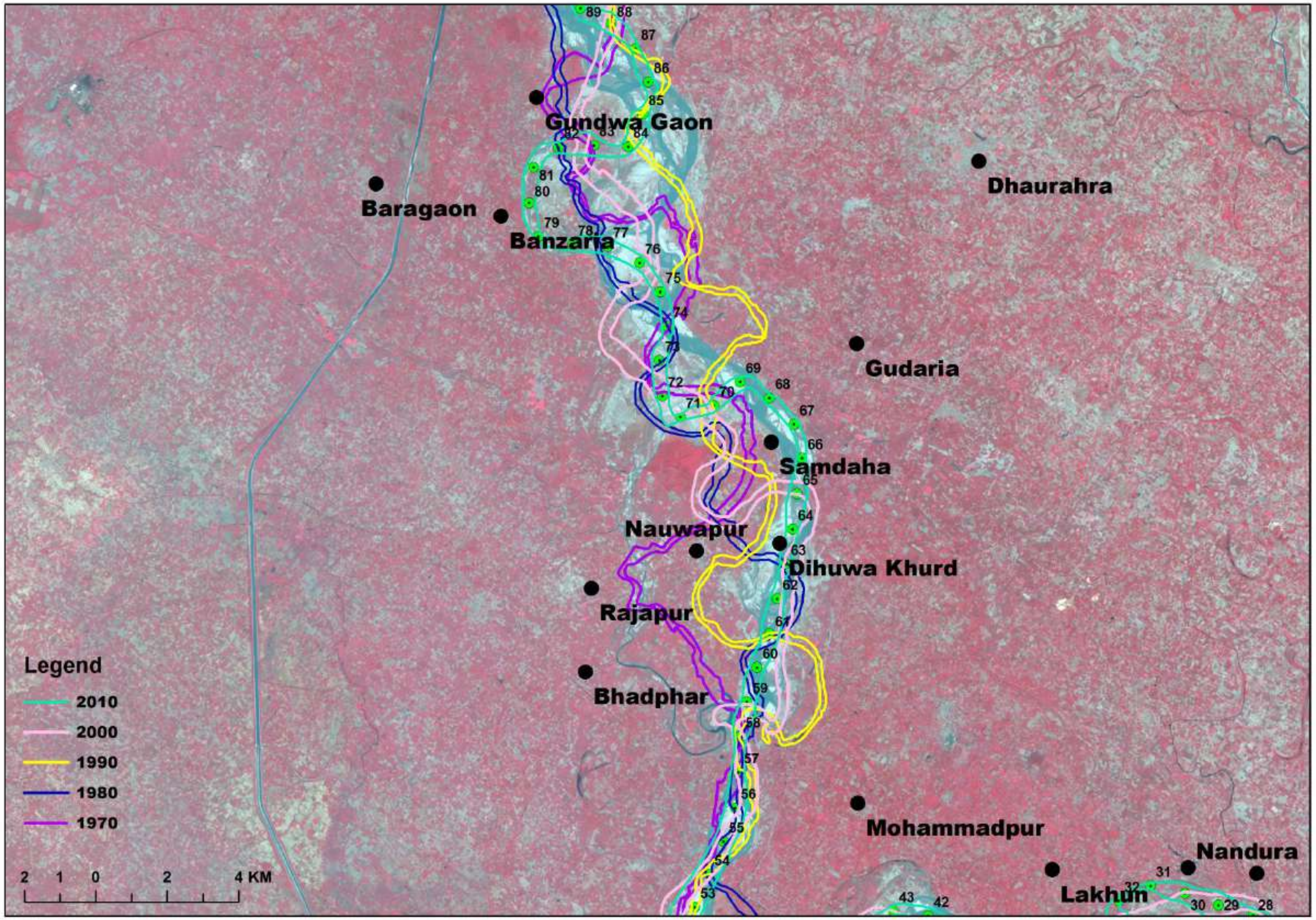


Figure 11.1d Critical location of Sharda river from chainage 53- 87 km

11.2 PROPOSED RIVER TRAINING WORKS FOR RESTORATION OF CRITICAL REACHES

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.

For the containment of flood water at critical reaches located near Mustafabad, Dhakka Ghat, and Chandrika Gauri, Lacey waterway has been estimated using Eq. (11.1), and lines of 4 times the Lacey perimeter are marked on LISS IV image of year 2015 and shown in Figs. 12.1a, 11.2b, and 11.2d. In the absence of the peak flood discharge at these locations, design discharges of barrages constructed across the Sharda river are being considered. The computed Lacey waterway corresponding to the design discharge of the three barrages on Sharda river are given in Table 11.2.

Table 11.2 Lacey waterway of the Sharda River at the Barrages

Barrage	**Chainage** (km)	**Discharge (m^3/s)**	**$P=4.75\sqrt{Q}$ (m)**
Tanakpur	277	566.0	113.01
Banbasa	269	19821.0	668.74
Lower Sharda	92	11400.0	507.16

Proposed river training works for various critical reaches are mentioned in Table 11.3 with justification. For positioning the levees/embankment, the extreme left and right banks of the Sharda river attained during the period 1970-2010 have been marked along with buffer of four times Lacey perimeter (P) on the satellite images of 2015 for different critical reaches.

Estimated peak discharge at Palia Kalan (Chainage = 168 km) gauging site for 25, 50 and 100 years return periods are 7559.3 m^3/s, 8476.9 m^3/s, and 9386.0 m^3/s, respectively. Even though one take discharge for 100 year return period, the Lacey perimeter $P = 4.75\sqrt{9386}$ = 460.18 m. An average Lacey Parameter P = 500 m is adopted from Chainage 53- 230 km.

The alignment of the levee has been marked such that it should be close to extreme banks and 4P lines. Figs. 11.2a-d show extreme banks, 4P lines and location/alignment of the suggested works for different critical reaches.

Table 11.3 River training works for the Critical Reaches of the Sharda River

Critical Reaches (Chainage Location)	Type of River Training Works	Justification
213-230 km (Mustafabad, UP)	Embankment/ Levees	River width is much higher than 4 times of the regime width of the channel. Thus for the containment of flood water, levees are to be provided towards both sides. Length of levees on left side = 16.8 km Length of levees on right side = 15.4 km
167-202 km (Dhakka Ghat, UP)	Guide bunds, Spurs, Levees	River width is much higher than 4 times of the regime width of the channel. Thus for the containment of flood water levees are to be provided towards both sides. Near the railway bridge right guide bund be repaired and spurs on the right side is required for diverting the flow towards the left side. Length of levees on left side = 29.3 km Length of levees on right side = 32.8 km
143-160 km (Ramnagar Kalan, Bhanpur, UP)	Levees	Reaches with progressive shifting from the year 1970 to 2015, so levees should be provided. Length of levees on left side = 16.5 km Length of levees on right side = 15.6 km
53-87 km (Chandrika Gauri, UP)	Embankment/ Levees	Reaches with 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 course of the river. The protection work in the form of levees is needed on both sides. Length of levees on left side = 11.6 km Length of levees on right side = 25.6 km

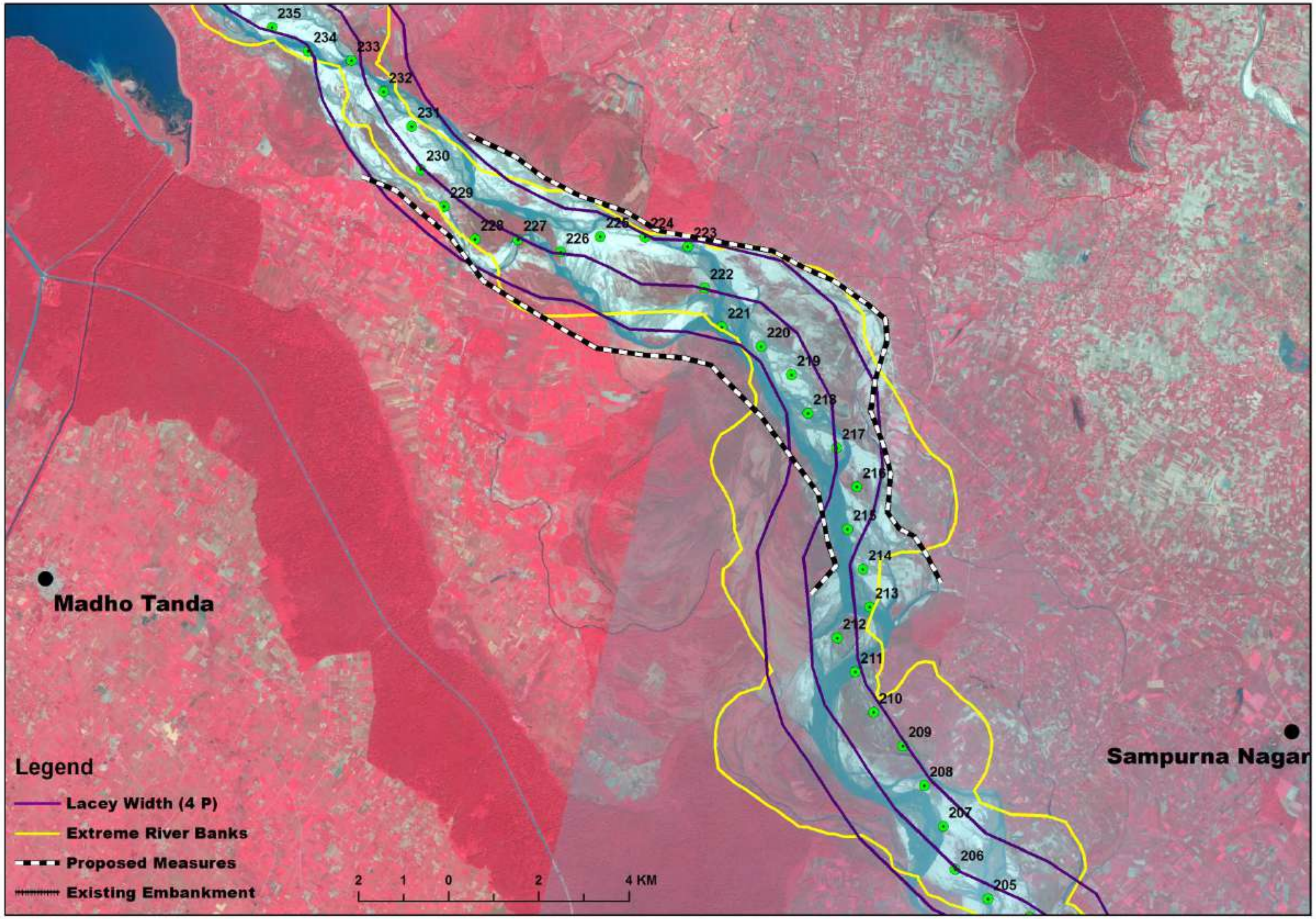


Figure 11.2a Extreme banks, 4P lines and location/alignment of the suggested works from chainage 213-230 km

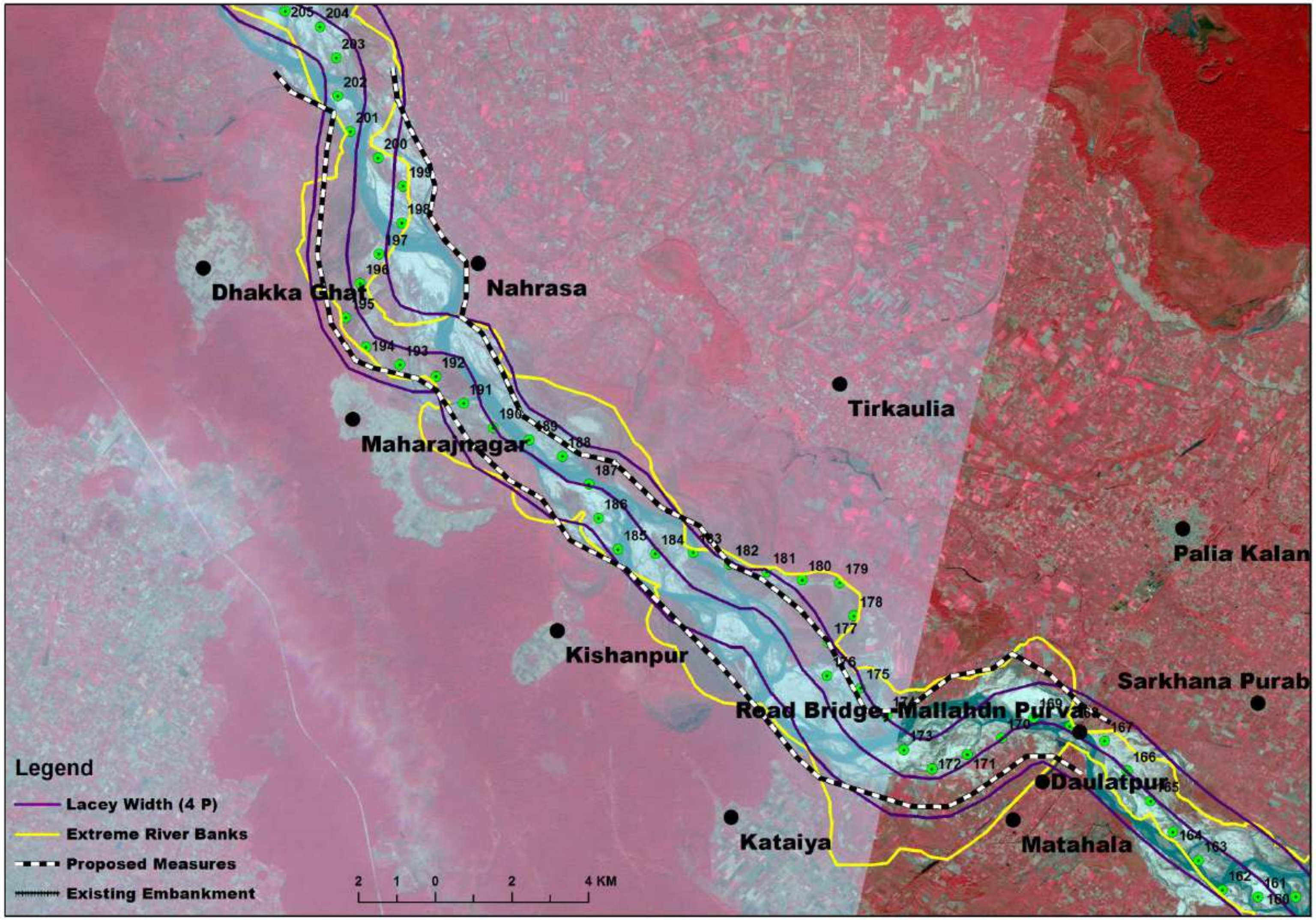


Figure 11.2b Extreme banks, 4P lines and location/alignment of the suggested works from chainage 167-202 km

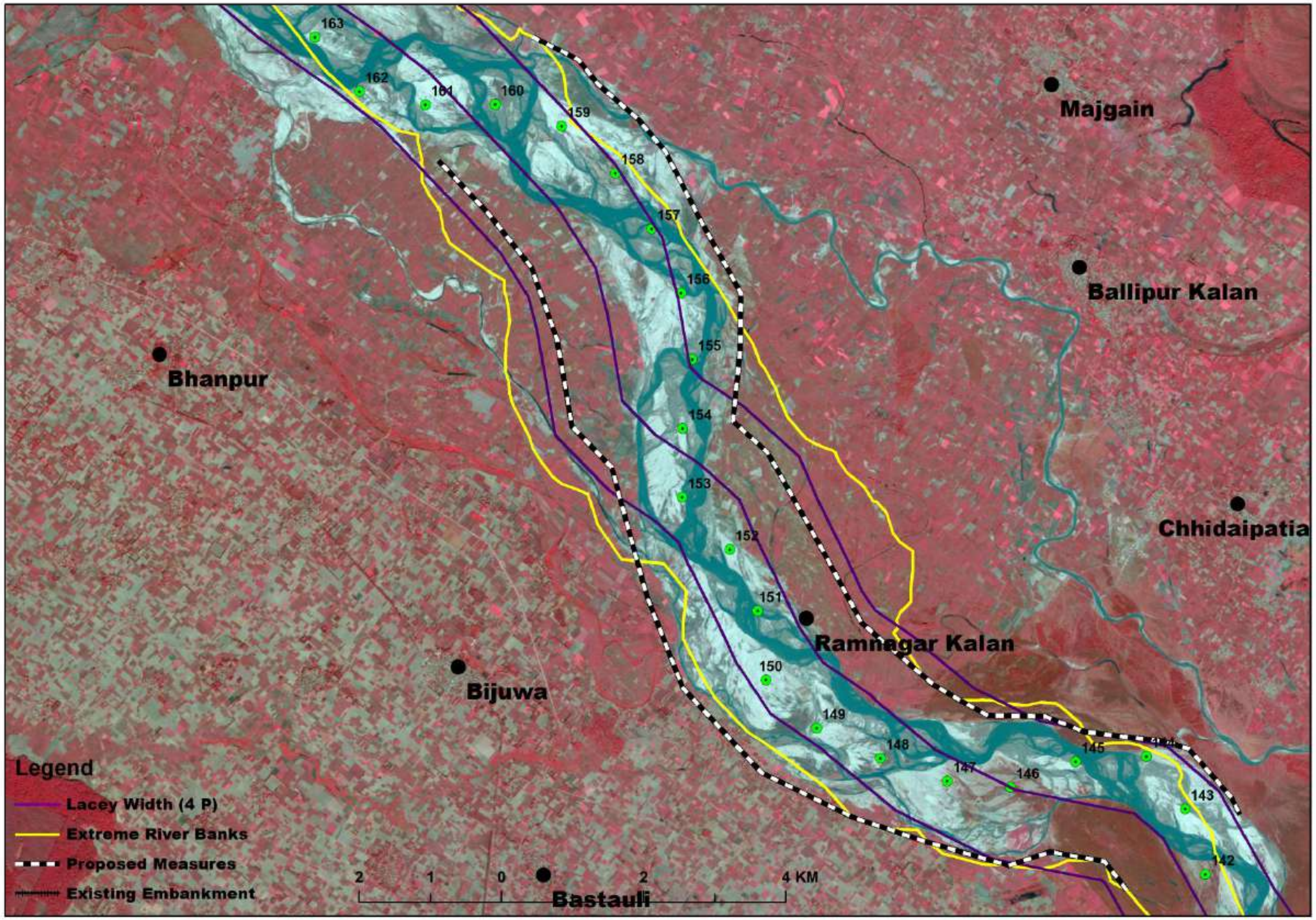


Figure 11.2c Extreme banks, 4P lines and location/alignment of the suggested works from chainage 143-160 km

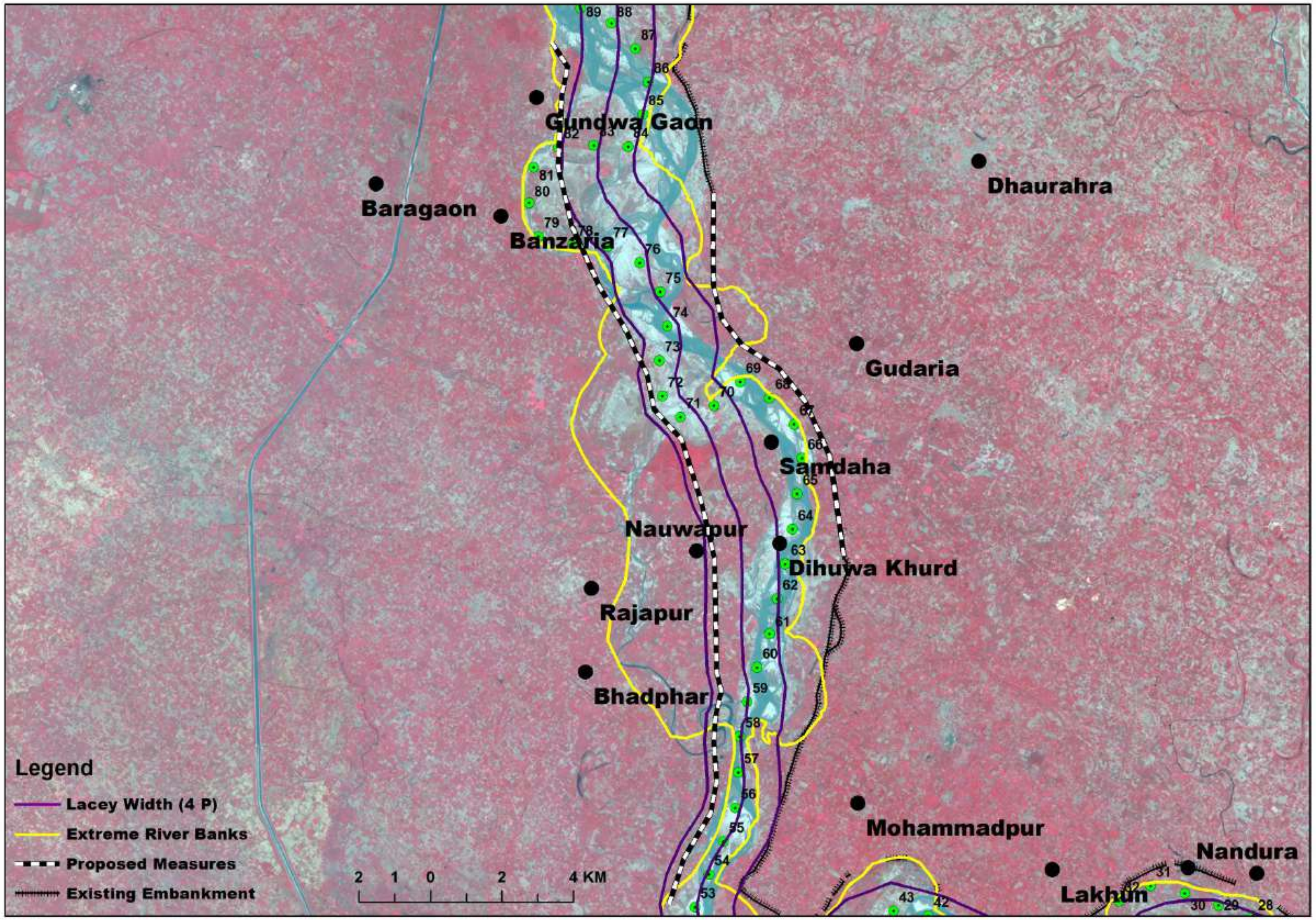


Figure 11.2d Extreme banks, 4P lines and location/alignment of the suggested works from chainage 53-87 km

11.3 EXISTING RIVER TRAINING WORKS

Earthen embankments are provided in the lower reach of the Sharda river i.e., from chainage 23 km to 138 km. Locations of such embankments are shown in the Figs. 11.3a-c. It may be noted that embankments are not continuous and also mostly provided on one side only except Nakahiyya and Narhar. Distances of the embankment at different chainages from the centreline of the river as in year 2015 are given in the Table 11.4 and also shown graphically in Fig. 11.4.

It may be noted that the proposed embankments, as mentioned in the section 11.2, are suggested to be provided in the upper reach of the Sharda river on its both sides.

Table 11.4 Distance of the embankment from centreline of the river as in year 2015

Chainage (km)	Distance from Centreline (in meter)		Nearby Location
	Right Embankment	Left Embankment	
23		3,153.50	Jamdari
24		1,857.38	
25		1,167.38	
26		1,989.28	
27		3,013.32	
29		3,105.01	Jagdishpur
30		3,379.46	Nandura
31		3,371.93	
32		2,944.42	
33		3,030.58	Lakhun
34			
35		2,762.90	
36		2,952.70	
37		2,629.58	
42		541.494	
43		2,377.59	
44		2,189.01	Mohammadpur
45		1,898.60	
48		3,116.35	Nai Ratauli
49		3,621.42	
50		3,459.65	
51		3,437.00	
54		693.433	
55		1,374.22	

56		1,451.30	
57		1,442.12	
58		1,678.62	
59		1,468.67	Bhadphar
60		1,842.58	
61		2,280.93	Rajapur
62		1,623.77	
63		1,939.34	
64		2,008.29	Dihuwa Khurd
80		1,253.31	
81		138.739	
84		411.454	Gundwa Gaon
85		244.534	
86		803.045	
87		2,430.73	
88		3,084.22	
89		3,573.52	
90		4,209.94	Chandrika Gauri
91		3,551.03	
92	2,353.68	2,000.18	
93	2,971.51	2,183.99	
94	3,207.10	1,895.76	
95	3,366.97	1,971.30	Nakahiyya
96	4,125.75	1,255.84	
97	2,337.54	2,903.14	
98	1,863.36	4,240.36	
101	2,493.26	3,883.86	
102	3,157.89	3,840.27	Narhar
103	2,696.43	4,152.37	
106	2,535.15	4,941.27	
107	2,712.31	4,749.76	
108	3,157.88	4,847.25	
109	2,851.88	5,634.44	
110	2,690.23	6,226.93	
111	2,633.95		
112	2,716.64		
113	3,504.23		
114	3,949.48		Ghosiyana
115	4,282.62		
116	5,025.54		
117	5,007.80		
119	4,990.15		
120	4,792.63		
122	6,436.27		

124	7,234.47		Baragaon
125	8,511.90		
130	8,645.44		
131	8,973.76		
132	9,269.00		Asarni
135	9,029.21		
136	8,823.58		
137	8,062.01		Jodhpur
138	6,062.61		Belaha

11.4 OTHER WORKS

1. At Road (SH 90) cum Railway Bridge at Palia Kalan, Guide bunds have been provided on both the sides of the river, however suitable upstream curved mole has not been provided in particular to the right guide bund. It seems that the upstream nose of the right guide bund is damaged due to past floods. At present, river is stable near the bridges, therefore as such no river training/ protection works are required. However, it is recommended to repair the washed out upstream mole of the right guide bund.
2. At road bridge (SH 26) (chainage 57 km), Sharda river has come very close to right approach road. Therefore, it is recommended to protect the embankment of the road by boulder pitching or provision of series of spurs.

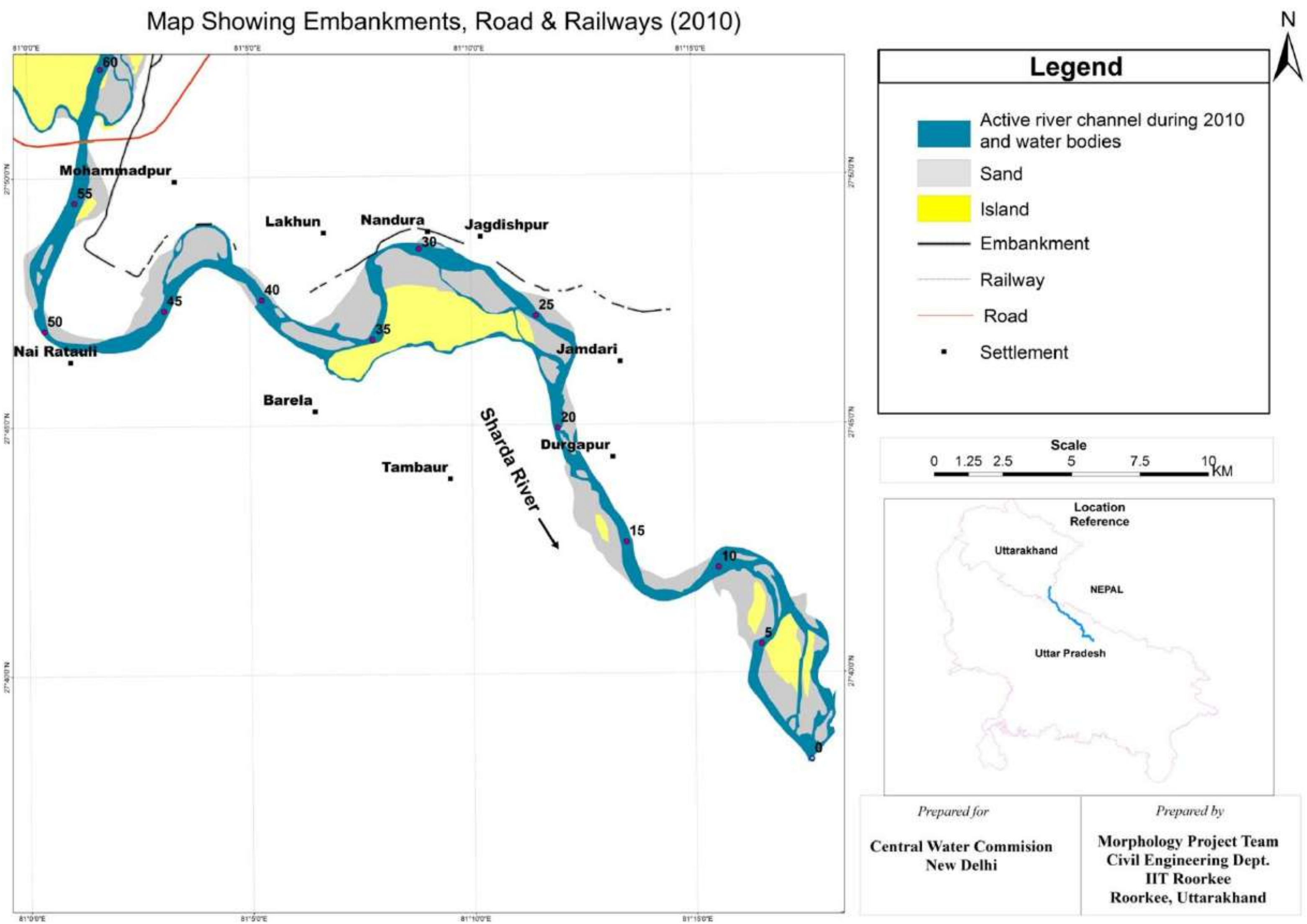


Figure 11.3a Existing embankments on Sharda river from chainage 0-50 km

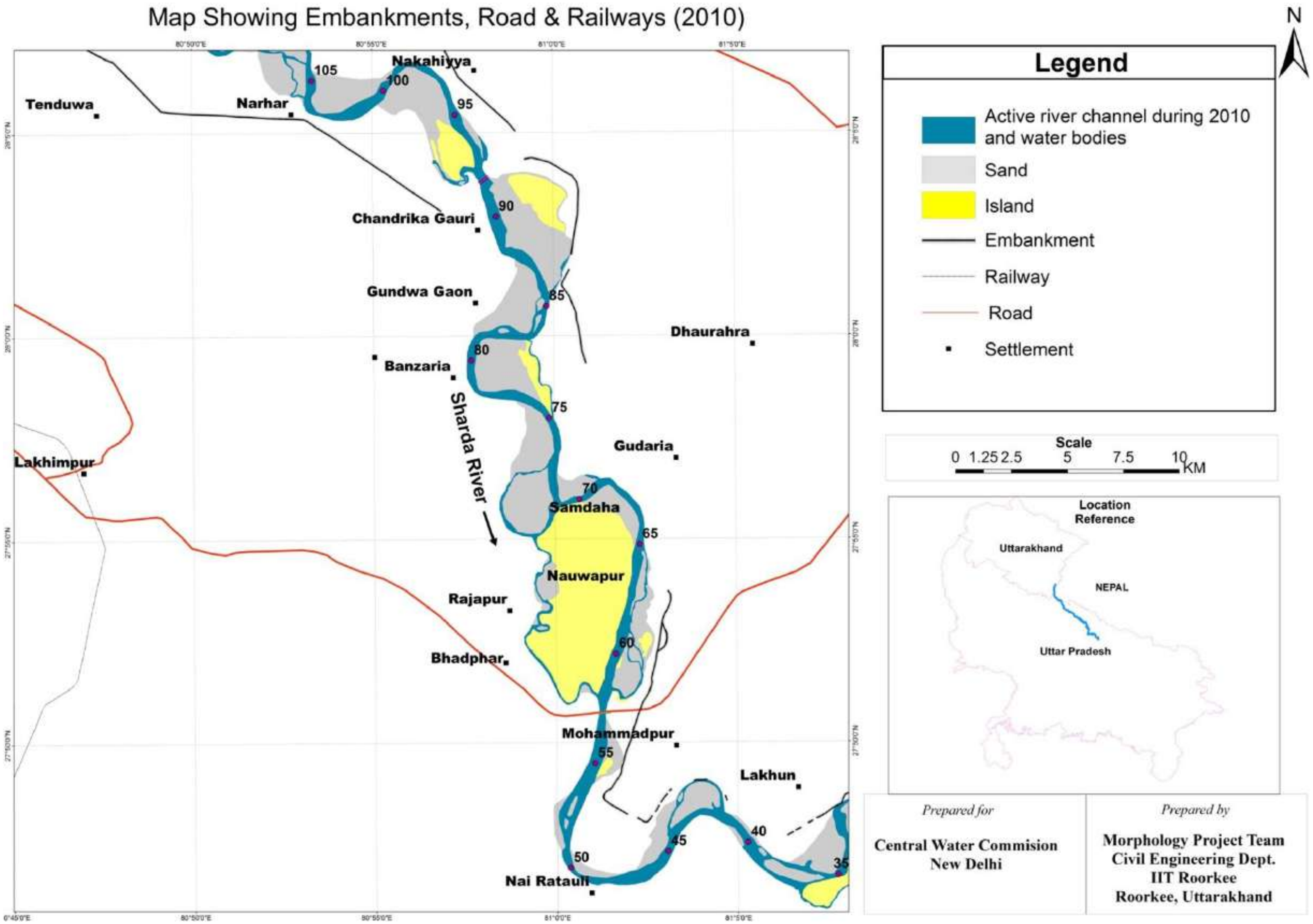


Figure 11.3b Existing embankments on Sharda river from chainage 50-100 km

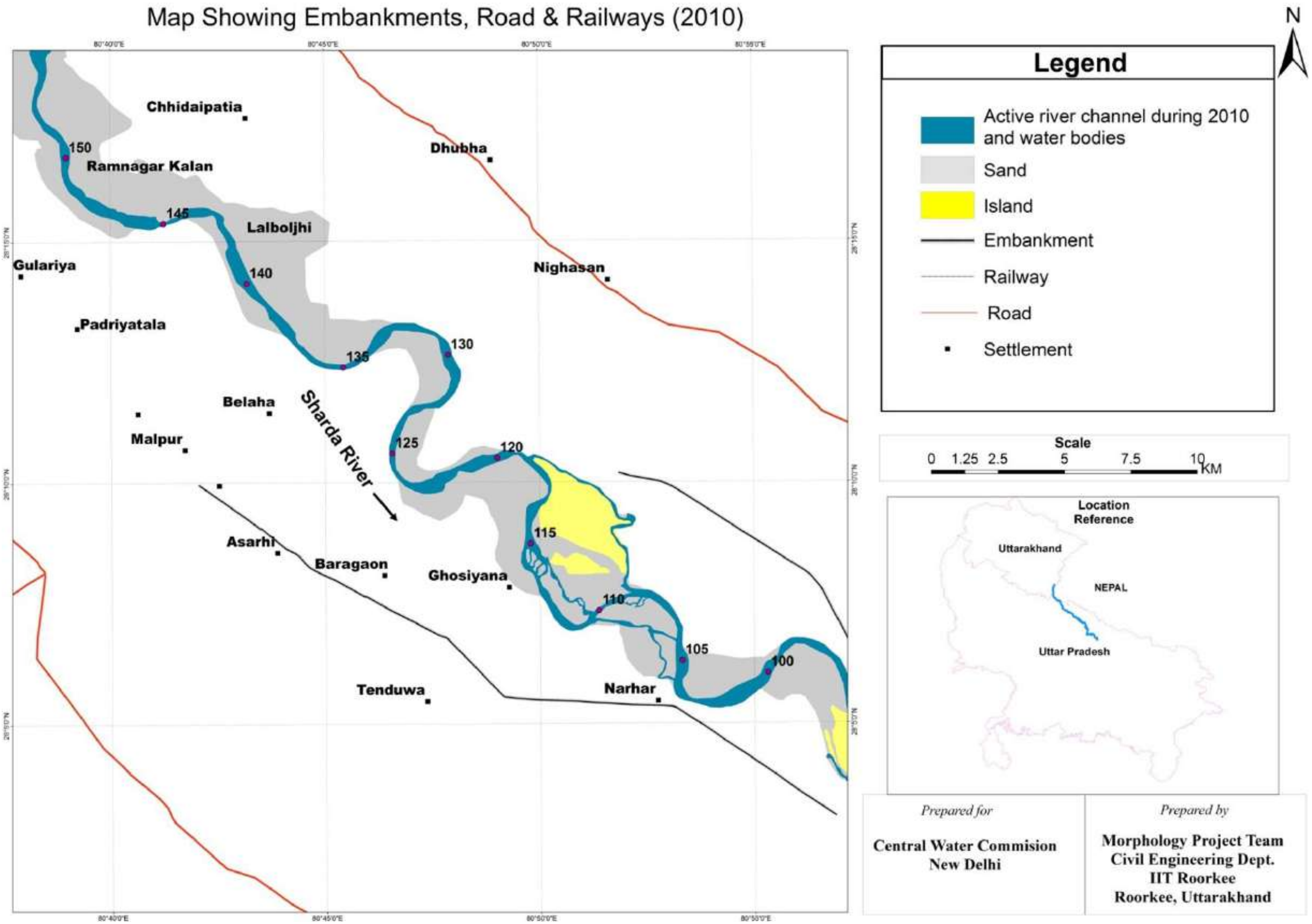


Figure 11.3c Existing embankments on Sharda river from chainage 100-150 km

Figure 11.4 Distance of the embankment from centreline of the river as in year 2015

11.5 TENTATIVE DESIGN OF RIVER TRAINING WORKS

Levees/Embankment

A sample design of Levees/embankment has 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 required data and invoking the methodology described in the Annexures-A and B.

A sample design of Levees/Embankment in the reach Chainage 167-202 km

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. 11.5). 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.

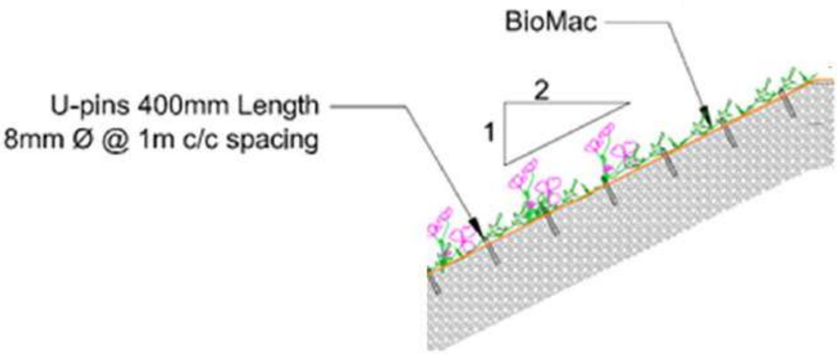


Figure 11.5 Details of BioMac

Nearest hydrological station to the reach 167-202 km is Palian Kalan (Chainage 168 km). Peak discharge for 25 years return period at Palian Kalan is estimated as 7560 m^3/s and ever maximum recorded water level at this station is 155.3 m. Let adopt these data for the design of the embankment in the reach 167-202 km.

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

$$W = \frac{0.0232\ 3\ S_s}{K\,(S_s - 1)^3} V^6 \qquad (1)$$

$$K = \left[1 - \frac{\sin^2\theta}{\sin^2\phi}\right]^{\frac{1}{2}} \qquad (2)$$

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

$$U = \left(\frac{Qf^2}{140}\right)^{1/6} \qquad (3)$$

For Q = 7560 m^3/s and f = 1, the above equation yields V = 1.94 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 = 13.62 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:

$$T = \frac{V^2}{2g(S_s - 1)} \qquad (4)$$

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. (4) yields T =0.27 m

Pitching may be provided in double layers of geo-bags (in loose).

Launching Apron

Figure 11.6 shows the general arrangement of a launching apron that is generally provided at the toe of the embankment. 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. 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.

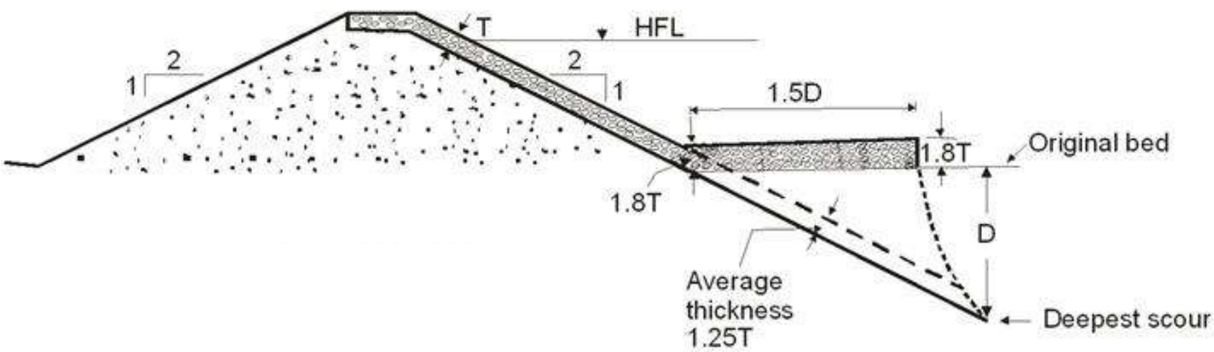


Figure 11.6 A typical sketch of embankment & launching apron (conventional)

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

$$R = 0.48(Q/f)^{1/3} \quad \text{in SI units} \qquad (5)$$

where f is Lacey's silt factor, let assume f = 1.

For Q = 7560 m^3/s i.e. discharge adopted for the scour computations as per IRC: 78-2000 and f = 1.0, Eq. (5) gives

$$R = 0.48(7560 /1.0)^{1/3}$$

$$= 9.42 \text{ m}$$

Maximum scour depths D_{se} at the toe of the embankment measured from HFL at different locations = 1.5R = 14.13 m

High flood level (HFL) =155.3 m (assumed value at Palian Kalan)

Deepest scour level = 155.3- 14.13 = 141.17 m

Bed level of the river = 155 m (assumed value at Palian Kalan)

Scour below bed level D = 155-141.17 = 13.83 m

Length of the launching apron = 1.5D = 20.745 m , provide 20 m

Thickness of launching apron = 1.8T = 1.8×0.27 = 0.486 m, let provide 0.50 m thick geo-bags in 3-4 layers.

Disclaimer: ***The above is a 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.***

11.6 CONCLUSIONS

Following conclusions have been drawn from the study carried out in this report:

a) Four reaches of the Sharda river have been identified as critical. These reaches are at chainages 213-230 km (Mustafabad), 167-202 km (Dhakka Ghat), 143-160 km (Ramnagar Kalan and Bhanpur) and 53-87 km (Chandrika Gauri). In the three reaches i.e., 213-230 km, 167-202 km and 53-87 km, river has been wandering within wide width even though there is no progressive shift in the either directions. However, in the reach 143-160 km, historical images of the river indicate its progreesive shift from left to right.

b) Methodology for the design of various river training works has been discussed and based on the morphological changes of the river in the critical reaches, the following training works are suggested

Chainages 213-230 km	Embankment/ Levees
Chainages 167-202 km	Guide banks, Spurs, Levees
Chainages 143-160 km	Levees
Chaianges 53-87 km	Embankment/ Levees

c) Earthen embankments are provided in the lower reach of the Sharda river i.e., from chainage 23 km to 138 km. It may be noted that embankments are not continuous and also mostly provided on one side only except Nakahiyya and Narhar.

d) At Road (SH 90) cum Railway Bridge at Palia Kalan, it is suggested to repair the washed out upstream mole of the right guide bund (see Fig. 9.7). At road bridge (SH 26) (chainage 57 km), it is suggested to protect the embankment of the road by boulder pitching or provision of series of spurs (see Fig. 9.9).

Chapter -12 CONCLUSIONS & RECOMMENDATIONS

12.1 CONCLUSIONS

Following conclusions have been drawn from the study carried out in this report:

a) General

Following points may be noted in the respect of basin of the Sharda river:

1. Like most of northern India, Sharda Basin has an extreme Humid Subtropical with dry winter type of climate. Summers are hot with temperatures rising up to 40 °C.
2. Geologically, the Sharda river basin may be divided into three zones: i) The northern mountain zone or Shiwalik Himalaya, (ii) The tarai zone, and (iii) The plain zone. The studied area is mainly in plain zone. Geological map of the Sharda river indicates that it is consisted of fluvial.
3. Land use and land cover map of the basin indicates that it is dominated by crop land followed by forest plantation. Scrub land can be seen along the Sharda river.
4. Flood Hazard Zone Map of Sharda indicates moderate flooding in the areas along the river flow.

b) Hydrological Analysis

1. Available discharge and water level data at the various gauging sites of the Sharda river have been analysed.

c) Morphological Changes

1. Reach (0-50): The confluence point of Sharda river with Ghaghara river has shifted by 15 km towards downstream of Ghaghara river in a span of year 1970 to 2010 as evident from the Fig. 7.13a. There is no progressive shift of the river in this reach, however, in general river has shifted from right to left. From year 1970 to 2010, the maximum shifting of the order of 3.25 km from right to left has been found at Duwai,

while maximum shifting of the order of 3 km from left to right has been found at Amarnagar from year 1980 to 2010.

There is no any progressive change in the width of active channel of the river in this reach. The average width in this reach is of the order of 300 m. The maximum width of the river is of the order of 650 m from chainage 30 - 45 km.

2. Reach (50-100 km): There is no any progressive change in the course of the river in this reach. However, major lateral shifting of the order of 4.5 km has been found at some locations in this reach. Maximum shifting from right to left has been found during the year 1970 to 2010 at Rajapur (4.5 km), Gundwa Gaon (3 km), and Jamunia (4 km). The maximum shift from left to right of the order of 5 km has been found near Dhauraha.

   Average width of the active channel in this reach is about 300 m, however, it varies from 100 m to 600 m. Even though there is no definite progressive change in the width in this reach, however, in general the width of river has increased from year 1970 to 2010.

3. Reach (100-150 km): There is no any progressive change in the course of the Sharda river in this reach, however, river has shifted right to left in the reach of chainage 110-140 km from year 1970 - 2010. The average shifting of the river course is in a band of about 4 km with maximum shift from right to left of the order of 5.5 km at Belaha. While the maximum shift from left to right is of the order of 6 km at Chidaipatia.

   The average width of active channel is about 300 m. There is no any progressive change in the width. The width varies from 100 m to 850 m in this reach with maximum width at Ghosiayana.

4. Reach (150-200 km): There is no any progressive change in the course of the river in this reach from year 1970 to 2010. The average lateral shifting of the river is order of 2.5 km with maximum shift from right to left at Kishanpur of the order of 3 km and maximum shift from left to right of the order of 5 km at Balipur Kalan.

   Average width of the active channel in this reach is about 300 m. The width varies from 100 m to 800 m in this reach with maximum at Bhanpur and Dhakka ghat. Even though there is no any progressive change in the width of the river in this reach, however, it has increased over the years.

5. Reach (200 - 250 km): The major lateral shifting of the course of river has been noticed in this reach. The maximum shift from right to left is of the order of 7 km at Simra from year 1970 to 2010. While the maximum shift from left to right is of the order of 5.5 km at Beldandi. There is no any progressive shift in the course of a river over the years in this reach.

   The average width of active channel of the river in this reach is of the order of 300 m. Over the years, the river width has increased. The maximum width of the order of 800 m can be seen at Madhuland and Mustafabad.

6. Reach (250 - 283 km): No major change in the course of the river has been found in this reach. Further, there is no progressive change in the course of river over the years. The maximum shift from right to left of the order of 1.5 km can be seen at Dadhara, while maximum shift from left to right is of the order of 1.5 km at Tanakpur. The limited shifting of the river course in this reach is attributed to the existence of Tanakpur and Banbasa Barrages that control the lateral shifting.

   Over the years the width of active channel has reduced from about 300 m to 150 m. Average width of active channel in this reach is about 240 km.

7. The sinuosity of Sharda River is calculated using the formulation given by Friend and Sinha (1993). From the sinuosity plot of Sharda river, the following data were extracted:

Year	Maximum Sinuosity	Minimum Sinuosity	Average Sinuosity
1970	1.83	1.12	1.35
1980	1.51	1.10	1.31
1990	1.77	1.11	1.35
2000	1.50	1.13	1.27
2010	1.57	1.15	1.31

8. Sharda behaves as sinuous river from Tanakpur to its confluence with Ghaghra river except from chainage 200-225 km near Sampurnnagar in which it had behaved as meander river before year 1990.

9. The meanders of the river are not stable and keep on changing. The river has followed a relatively straight path over the years in the reaches 0-80 km and 210-240 km while meandering has increased in the reaches 100-140 km and 170-200 km. Axial wave length, amplitude and radius of curvature of the meanders are of the order of 4 km, 3 km and 1.5 km respectively.

10. The plan form index (PFI) of Sharda River is calculated using the formulation given by Sharma (2004). Low value of PFI indicates higher degree of braiding. For the classification of the braiding intensity, the following threshold values for PFI are proposed by Sharma (2012).

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

11. Sharda may be considered moderately braided river in its major length from Tanakpur to its confluence with Ghaghra river. However, near Jagdispur, downstream of Banbasa barrage and Dodhara braiding of the river is high. At other locations like Chandrika Gauri and Ghosiyana, it was highly braided in past. High braiding in the Sharda river in its upper reach i.e, Tanakpur, Banbasa, Dodhara is primarily due to

aggradation which occurs as the river is incompetent to transport the sediment load that it is bringing from the relatively steep reach.

12. The nodal points along the reach of the river i.e. wherein minimum morphological changes are seen, have been identified. This will be helpful in planning of structures like barrage and bridge in the future.

d) Erosion and Siltation

1. In the studied reach of the Sharda river, the total eroded area is 7544.79 ha, total deposited area is 21426.02 ha and total eroded and deposited area is 25513.79 ha on span of year 1970 to 2010 while net deposited area is 13881.23 ha.
2. Erosion and siltation are noticeable throughout the entire reach of Sharda River from Tanakpur to the confluence point (Durgapur). This is due to shifting and meandering nature of the river course. Noticeable amount of siltation has occurred near Tanakpur and Durgapur - the starting and ending points of the river. Major deposition has taken place near Nai Ratauli, Jamdari, Gudaria, Baleha, Ghosiyana, Tirkaulia, Mallaha Purva, Madhotanda and Tanakpur while erosion has taken place at Nandura, Mohammadpur, and Ramnagar Kalan due to regular shifting of the river course in these areas. Major erosion plus deposition has occurred in the reach 50-250 km on the span of year 1970-2010 especially at Nauwapur, Bhadpur, Baleha and Ramnagar Kalan.
3. In the reach 0-50 km, total eroded area, total deposited area and total eroded & deposited area are 2042.81 ha, 3396.87 ha and 586.51 ha, respectively. Deposition in an area of 1354.06 ha has occurred in the reach. The confluence of Sharda and Ghaghara River has also shifted almost 15 km downwards. Near Nandura and Mohammadpur, left bank is eroded in the period 1970-2010. Deposition has occurred on both the banks near Nai Ratauli and Jamdari. The possible reason behind this is frequent shifting of river course and its meandering behavior which causes deposition towards convex bank.
4. In the reach 50-100 km, total eroded area, total deposited area and total eroded & deposited area are 1624.28 ha, 2870.65 ha and 3972.26 ha, respectively. Deposition in an area of 1246.37 ha has occurred in the reach. Erosion and siltation are relatively low in this reach. The entire reach has suffered with erosion plus deposition on the span of 1970 to 2010. The major erosion plus deposition have occurred upstream of Lower Sharda barrage near Bhadphar and Nauwapur due to lateral shifting of the main course of the river. Deposition has been found near Gudaria.
5. In the reach 100-150 km, total eroded area, total deposited area and total eroded & deposited area are 1361.25 ha, 3997.38 ha and 7973.81 ha, respectively. Deposition in an area of 2636.13 ha has occurred in the reach. There is deposition on left bank near Ramnagar Kalan and Ghosiyana whereas on right bank deposition is found near Belaha. In this reach, deposited area is higher than eroded area. The entire reach has suffered with erosion plus deposition on the span of 1970 to 2010. Major erosion plus

deposition has occurred in this reach near Belaha and Ramnagar Kalan. The possible reason for morphological changes is continuous shifting of river course and meandering behavior of the river.

6. In the reach 150-200 km, total eroded area, total deposited area and total eroded & deposited area are 933.71 ha, 3537.77 ha and 7471.95 ha, respectively. Net deposition in this reach is 2604.06 ha. Because of the Road and Railway Bridges between Bhira to Palia Kalan, there is heavy deposition near Mallaha Purva and Tirkaulia. The entire reach has suffered with erosion plus deposition on the span of 1970 to 2010 in particular upstream of the bridges. The possible reason behind this is continuous shifting of river course.
7. In the reach 200-250 km, total eroded area, total deposited area and total eroded & deposited area are 1388.53 ha, 5970.85 ha and 5195.72 ha, respectively. Net deposition in this reach is 4582.32 ha. Heavy siltation is visible in this reach in particular towards Madhotanda. The entire reach has suffered with erosion plus deposition on the span of 1970 to 2010. The possible reason behind this is continuous shifting of river course and braiding & meandering nature of the river.
8. In the reach 250-283 km, total eroded area, total deposited area and total eroded & deposited area are 194.21 ha, 1652.50 ha and 313.54 ha, respectively. Net deposition in this reach is 1458.29 ha - mainly towards left side in the reach from Tanakpur barrage to Banbasa barrage. River is mostly braided in this reach.
9. Measured cross sections of the Sharda river for different years at gauging station of Palian Kalan, indicate no progressive aggradation or degrdation, however, adjustment in the cross-sections of different years may be seen.

e) Major Structures & their Impact on the Morphology

Major structures which are located on the Sharda river are Road Bridge (SH 26), Sharda Barrage (SH 21, Nighasan Road), Road Bridge (SH 90), Road (SH90) cum Railway Bridge, Banbasa Barrage and Tanakpur Barrage.

1. It is concluded that even before the construction of the Tanakpur barrage in year 1992, river was wide spread upstream and downstream of the barrage location. During the years 2000 to 2010, no noticeable changes in the planform of the river near barrage have been noticed. However, after year 2010, siltation in upstream of the river has occured. In year 2015, it is clearly visible that the main river is flowing in two channels - both are in extreme left and right with heavy siltation in upstream of the barrage between these two channels.
2. Banbasa barrage was commissioned in year 1920. No remarkable changes in the water course of Sharda river have occured. There is no sign of siltation upstream of the barrage. As the satellite image of Sharda river before its construcion is not available, it is difficult to draw conclusion in the respect of impact of the Banbasa barrage on morphology of river near the barrage.

3. Lower Sharda barrage was commissioned in year 1974. It may be concluded that remarkable changes in the water course of Sharda river near the barrage have occured. The river has shifted right to left over the years upstream of barrage and right to left downstream of barrage. It is difficult to draw conclusion in respect of silting in river upstream of the barrage due to its construction with use of historical images of river.
4. As road cum rail bridge at chainage 168 km (Palia Kalan) was constructed before 1970, therefore, it is difficult to draw conclusion in the respect of impact of construction of the bridge on river morphology. However, it is found that the river course wanders both upstream and downstream of the bridge. There is no specific progressive shifting of the river near the bridge.
5. At road bridge (SH26) (chainage 57 km), river flows mainly in two channels upstream of the bridge. The river is widely spread both in the upstream and downstream of the bridge. Performance of the guide bunds are satisfactory as no damage to the guide bunds and approach roads have been seen. However, river has come very close to right approach road.

f) Critical Reaches and River Training Works

1. Four reaches of the Sharda river have been identified as critical. These reaches are at chainages 213-230 km (Mustafabad), 167-202 km (Dhakka Ghat), 143-160 km (Ramnagar Kalan and Bhanpur) and 53-87 km (Chandrika Gauri). In the three reaches i.e., 213-230 km, 167-202 km and 53-87 km, river has been wandering within wide width even though there is no progressive shift in the either directions. However, in the reach 143-160 km, historical images of the river indicate its progreesive shift from left to right.
2. Methodology for the design of various river training works has been discussed and based on the morphological changes of the river in the critical reaches, the following training works are suggested

Chainages 213-230 km	Embankment/ Levees
Chainages 167-202 km	Guide banks, Spurs, Levees
Chainages 143-160 km	Levees
Chaianges 53-87 km	Embankment/ Levees

3. Earthen embankments are provided in the lower reach of the Sharda river i.e., from chainage 23 km to 138 km. It may be noted that embankments are not continuous and also mostly provided on one side only except Nakahiyya and Narhar.
4. At Road (SH90) cum Railway Bridge at Palia Kalan, it is suggested to repair the washed out upstream mole of the right guide bund. At road bridge (SH 26) (chainage 57 km), it is suggested to protect the embankment of the road by boulder pitching or provision of series of spurs.

12.2 RECOMMENDATIONS

(i) It is recommended to repair the washed out upstream mole of the right guide bund at Road (SH90) cum Railway Bridge at Palia Kalan. At road bridge (SH 26) (chainage 57 km), it is suggested to protect the embankment of the road by boulder pitching or provision of series of spurs.

(ii) Recommended to implement the suggested measures in the identified four critical reaches of the Sharda river. It is further suggested that such reaches be studied in more details based on ground survey and analysis of high resolution satellite data.

(iii) Suggested measures are prioritized as follow:

a) Repair of washed out upstream mole of the right guide bund at Road (SH90) cum Railway Bridge at Palia Kalan.

b) Protection of the embankment of the road by boulder pitching and/or provision of series of spurs at road bridge (SH 26) (chainage 57 km).

c) Provision of Guide banks, Spurs, Levees in the reach Chainages 167-202 km

d) Provision of embankment/ Levees in the reach Chainages 213-230

e) Provision of embankment/ Levees in the reach Chainages 143-160 km

f) Provision of embankment/ Levees in the reach Chainages 53-87 km

(iv) 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 the Sharda river to avoid outflanking of the river and to minimize protection works.

(v) Large scale de-silting from the rivers are 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.

(vi) Detailed survey of the area and data collection/analysis is proposed before implementing the recommendations, so as to incorporate the current ground conditions and river behaviour.

(vii) 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.

(viii) 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 in such a way that incoming sediment can be passed downstream during the flood time, to maintain the sediment equilibrium.

12.3 SUGGESTED FURTHER STUDY

(i) 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 is suggested 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.

(ii) Erosion and siltation in the Sharda river has been studied herein on the basis of the shifting of the banks of the river. 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.

(iii) 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.

(iv) 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 of the river.

BIBLIOGRAPHY

1. Ahluwalia, A. S., Kaur, M., & Dua, S. (1989). Physico-chemical characteristics and effect of some industrial effluents on the growth of a green alga Scenedesmus sp. *Indian Journal of Environmental Health*, *31*(2), 112-119.
2. Aswathy, M.V., Vijith, H. andSatheesh, R. (2008), "Factors influencing the sinuosity of Pannagon River, Kottayam, Kerala, India: An assessment using remote sensing and GIS", *Environmental monitoring and Assessment,* Vol.138 Issue 1-3, pp. 173-180.
3. Avtar, R., Singh, C.K., Shashtri, S. and Mukherjee, S. (2011), "Identification of erosional and inundation hazard zones in Ken–Betwa river linking area, India, using remote sensing and GIS", *Environmental Monitoring and Assessment*, Vol. 182, Issue.1-4, pp. 341-360.
4. Bagnold, R. (1960), "Some aspects of the shapes of river meanders", *U.S. Geological Survey Professional Paper,* vol.282-E, pp. 135-144.
5. Bali, R., Agarwal, K. K., Nawaz Ali, S., Rastogi, S. K. and Krishnal, K. (2012), "Drainage morphometry of Himalayan Glacio-river basin, India: hydrologic and neotectonic implications", *Environmental Earth Sciences,* vol. 66Issue 4, pp. 1163-1174.
6. Bawa, N., Jaina, V., Shekhar, S., Kumar, N. and Jyani, V. (2014), "Controls on morphological variability and role of stream power distribution pattern, Yamuna River, western India". *Geomorphology* vol. 227, pp. 60–72.
7. Bhutiani, R., Khanna, D. R., Kulkarni, D. B., & Ruhela, M. (2014). Assessment of Ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices. *Applied Water Science*, 1-7.
8. Bjerklie, D.M. (2007), "Estimating the bankfull velocity and discharge for rivers using remotely sensed river morphology information", *Journal of Hydrology,* vol. 341, pp. 144-155.
9. Brice, J.C. (1974), "Evolution of meander loops", *Geological Society of America Bulletin,* vol.85, pp. 581-586.
10. Brice, J. E. (1964). Channel patterns and terraces of the Loup River in Nebraska. United States Geological Survey Professonal Papers, 422-D.
11. Brice, J.C. (1981), "Meander Pattern of the White River in Indiana: A Analysis," in *River Geomorphology,* edited by Morisawa, M., pp.178-200.
12. Chamyal L S, Maurya D M and Raj R (2003) Fluvial systems of the dry lands of western India: a synthesis of Late Quaternary environmental and tectonic changes *Quaternary International* 104 69-86.

13. Chandra, A.M. and Ghosh, S. (2006), "Remote Sensing and Geographical Information System", *Narosa publication.*

14. Chorley, R.J. (1969), "*Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-economic Geography*", pp. 588, Methuen & co. Ltd., London.

15. Chu, Z.X., Sun, X.G., Zhai, S.K., Xu, K.H. (2006). "Changing pattern of accretion/erosion of the modern Yellow River (Huanghe) subaerial delta, China: Based on remote sensing images". *Marine Geology* vol.227 pp.13– 30.

16. Clerici, A., Perego, S., Chelli, A. and Tellini, C. (2015). "Morphological changes of the floodplain reach of the Taro River (Northern Italy) in the last two centuries". *Journal of Hydrology,* vol. 527 pp. 1106–1122.

17. Das, K., Gupta, K., Swarnakar, S., & Talapatra, S. N. (2015). Biomonitoring tool: morphological anomalies in Zygnema sp. of Ganga River Bank. *International Letters of Natural Sciences*, *47*.

18. David, M. and Bjerklie (2007). "Estimating the bankfull velocity and discharge for rivers using remotely sensed river morphology information". *Journal of Hydrology,* vol.341, pp.144– 155.

19. Densmore, A. L., Sinha, R., Sinha, S., Tandon, S. K., & Jain, V. (2015). Sediment storage and release from Himalayan piggyback basins and implications for downstream river morphology and evolution. *Basin research.*

20. Devkota, R., Brant, S. V., & Loker, E. S. (2016). A genetically distinct Schistosoma from Radix luteola from Nepal related to Schistosoma turkestanicum: A phylogenetic study of schistosome and snail host. *Acta Tropica*, *164*, 45-53.

21. Dewan, A., Corner, R., Saleem, A., Rahman, M. M., Haider, M. R., Rahman, M. M., & Sarker, M. H. (2017). Assessing channel changes of the Ganges-Padma River system in Bangladesh using Landsat and hydrological data. *Geomorphology*, *276*, 257-279.

22. Dingle, E. H., Sinclair, H. D., Attal, M., Milodowski, D. T., & Singh, V. (2016). Subsidence control on river morphology and grain size in the Ganga Plain. *American Journal of Science*, *316*(8), 778-812.

23. Dubey, A.K., Gupta P.K., Dutta, S., Singh R.P. (2015). "An improved methodology to estimate river stage and discharge using Jason-2 satellite data". *Journal of Hydrology,* vol.529 pp.1776–1787.

24. Dutta, V., Srivastava, R. K., Yunus, M., Ahmed, S., Pathak, V. V., Rai, A., & Prasad, N. (2011). Restoration plan of Gomti River with designated best use classification of surface water quality based on river expedition, monitoring and quality assessment. *Earth Sci India*, *4*(III), 80-104.

25. Eaking, H.M. (1910), "The Influence of the Earth's Rotation upon the Lateral Erosion of Streams", *Jour. Geol.* Vol. 18, pp. 435-447.

26. Fan, H., Huang, H., Zeng, T. Q. and Wang, K.(2006), "River mouth bar formation, riverbed aggradation and channel migration in the modern Huanghe (Yellow) River delta, China", *Geomorphology,*vol.74, pp. 124– 136.

27. Florsheim, J. L., Jeffrey F. M. and Anne, C. (2008), “Bank erosion as a desirable attribute of rivers”, *Bioscience,* vol.58, Issue 6, pp. 519-529.

28. Friend, P.f. and Sinha, R. (1993) Braiding and meandering parameters. In braided rivers (Eds. Best, J.L. and Bristow, C.S.) Geographical society of Special Publication No. 75, pp. 105-111.

29. Garde, R. J. (2006) “River morphology”, *New age International Publishers.*

30. Gautam, D. K., and Phaiju, A. G. (2013). Community based approach to flood early warning in West Rapti River Basin of Nepal. *IDRiM Journal*, *3*(1), 155-169.

31. Ghosh, K. (2014) “Planform Pattern of Teesta River after the Gazaldoba Barrage”. *Indian Journal of Geography & Environment. Vol.13, pp.127-137.*

32. Gregory K J and Lewin J (2014) The Basics of Geomorhology: Key Concepts. Sage Publications.

33. Gregory, K.J. and Walling, D.E. (1973), *Drainage Basin Form and Processes: A Geomorphological Approach,* Edward Arnold, London, pp. 447.

34. Griggs, R.F. (1906), “The Buffalo River: An Interesting Meandering Stream”, *Bull. Geol. Soc. Am.,*Vol. 38, No. 3, pp. 168-177.

35. Gupta, L. P. and Subramanian, V. (1994). Environmental Geochemistry of the River Gomti: A Tributary of the Ganga River. Environmental Geology, v. 24, pp. 235-243.

36. Gupta, L. P. and Subramanian,V. (1998). Geochemical factors controlling the chemical nature of water and sediments in the Gomti River, India. Environmental Geology, v. 36(1/2), pp.102-108.

37. Harmar, O.P. and Clifford, N. J. (2006), “Planform dynamics of the Lower Mississippi River”, *Earth Surface Processes Landforms,* 31, pp. 825-843.

38. Hazarika, N., Das, A.K. and Borah, S.B. (2015), “Assessing land-use changes driven by river dynamics in chronically flood affected Upper Brahmaputra plains, India, using RS-GIS techniques”, *The Egyptian Journal of Remote Sensing and Space Sciences* 18, 107–118.

39. Heo, J., Due, T.A., Cho, H. and Choi, S. (2009) “Characterization and prediction of meandering channel migration in the GIS environment: A case study of the Sabine River in the USA”, *Environ Monit. Assess,* 152, pp. 155-165.

40. Hickin, E.J. (1974), “The development of meanders in natural river-channels”, *American Journal of Science*, vol.274, pp. 414-442.

41. Hjulstorm, F.A. (1957), “A Study of the Meander Problem”, *Institute of Hydraulics, Royal Institute of Technology, Stockholm,* and Bull. No. 51.

42. Hooke, J. M. (1987),“Changes in meander morphology”, In: International Geomorphology 1986 Part I (ed. by V. Gardiner), pp. 591–609. Wiley, Chichester, UK.

43. Hooke, J.M., (2006), "Spatial Variability Mechanism and Propagation of Change in An Active Meandering River". *Geomorphology,* Vol. 84, Issues 3-4, pp.277-296.

44. Hossain, M.A., Gan, T.Y., Basar, A. and Baki, M. (2013) “Assessing morphological changes of the Ganges River using satellite images”. *Quaternary International* 304, pp.142-155.

45. Idris, S., Abdu, Y. A., & Saini, G. (2016). Assessment of Surface Water Quality Using Qual2k Software: A Case Study of River Yamuna, India. *European Journal of Advances in Engineering and Technology*, *3*(7), 16-23.

46. Inglis, C. C. (1947), “Meanders and Their Bearing on River Training”, *ICE (London), Maritime Paper* No. 7, pp. 3-54.

47. Jain V, Tandon S K and Sinha R (2012) Application of modern geomorphic concepts for understanding the spatio-temporal complexity of the large Ganga river dispersal system *Curr Sci* 103 1300-1319

48. Jindal, R., & Sharma, C. (2011). Biomonitoring of pollution in river Sutlej. *International Journal of Environmental Sciences*, *2*(2), 863-872.

49. Juyal N, Chamyal L S, Bhandari S, Bhushan R and Singhvi A K (2006) Continental record of the southwest monsoon during the last 130 ka: evidence from the southern margin of the Thar Desert, India *Quat Sci Rev* 5 2632-2650

50. Kellerhals, R., Church, M., and Bray, D.I. (1976), “Classification and analysis of river processes”, *Journal of Hydraulic Engineering, American Society of Civil Engineers*, vol. 102, pp. 813-829.

51. Khadri, S. F. R. and Thakur, N. G. (2013), "Geomorphological investigations of Bore River Basin (Tributary of Pedi River) Amravati District, Maharashtra using Remote Sensing and GIS techniques", *International Journal of Scientific & Engineering Research,* vol.4, pp. 1089-1098.

52. Kinoshita, R. (1961), “Investigation of Channel Migration of the Ishikari River”, *(In Japanese) Science and Technology Agency, Bureau of Resources*, No. vol. 31, pp. 138.

53. Kumar, A., Narayana, A.C., Jayappa, K.S. (2010), “Shoreline changes and morphology of spits along southern Karnataka, west coast of India: A remote sensing and statistics-based approach”, Geomorphology 120, pp. 133–152.

54. Kumar, A., Sarkar, S. A., & Sharma, N. (2015). Snowmelt Runoff Modeling in an Indian Himalayan River Basin using WinSRM, RS & GIS. *Water and Energy International*, *58*(1), 65-72.

55. Kumar, R., Kamal, V., & Singh, R. K. (2013). Geomorphic Effects of 2011 Floods on Channel Belt Parameters of Rapti River: A Remote Sensing and GIS Approach. Corona. *Journal of Science and Technology*, Vol. 2, No. II (2013), pp. 4-12

56. Lahiri S K and Sinha R (2014) Morphotectonic evolution of the Majuli Island in the Brahmaputra valley of Assam, India inferred from geomorphic and geophysical analysis *Geomorphology* 227 101-111.

57. Lamadrid, A.J., and MacClume, K.L., (2010). Climate and hydrological modeling in the Hindu-Kush Himalaya region. Feasibility report for a Himalayan climate change impact and adaptation assessment. Centre for International Climate and Environment Research, Oslo and Institute for

58. Langbein, W.B. (1964), "Geometry of River Channels", *JHD, Proc. ASCE,* Vol. 90, No. HY2, March, pp. 301-347.

59. Latrubesse, E. (2008), "Patterns of anabranching channels: the ultimate end-member adjustments of mega-rivers", *Geomorphology*, 101 pp. 130–145.

60. Latrubesse, E. M., Stevaux, J. C., & Sinha, R. (2005). Tropical rivers. *Geomorphology*, *70*(3), 187-206.

61. Lauer, J. W. and Parker, G. (2008), "Net local removal of floodplain sediment by river meander migration", *Geomorphology, vol.96, pp. 123–149.*

62. Legleiter, C.J. and Roberts, D.A. (2005), "Effects of channel morphology and sensor spatial resolution on image-derived depth estimates", *Remote Sensing of Environment,* vol. 95, pp. 231–247.

63. Leliavsky, S. (1955), "An introduction to River Hydraulics", *Constable and Co. Ltd., London,* pp. 115-120.

64. Leopold, L. B. and Wolman, M. G. (1970), "River channel patterns, in Dury, G. H., ed., Rivers and river terrances", *New York, Praeger",* pp. 197-238.

65. Leopold, L.B. and Maddock, T., (1953), "The hydraulic geometry of stream channels and some physiographic implications", *United States Geological Survey Professional Paper,* vol. 252, pp. 57.

66. Leopold, L.B. and Wolman, M.G. (1957), "River Channel Patterns: Braided, Meandering and Straight", *USGS Prof. Paper* vol. 282-B, pp. 85.

67. Leopold, L.B., Wolman, M.G. and Miller, J.P. (1964),"River Processes in Geomorphology", *Freeman, San Francisco.pp. 522.*

68. Luchi, R., Hooke, J. M., Zolezzi, G. and Bertoldi, W. (2010), "Width variations and mid-channel bar inception in meanders: River Bollin (UK)", *Geomorphology,* vol. 119, pp.1-8.

69. Marchetti, M. (2002), "Environmental changes in the central Po Plain (northern Italy) due to river modifications and anthropogenic activities", *Geomorphology*, vol.44, pp.361-373.

70. Mehrotra, A., Mishra, A., Tripathi, R. M., & Shukla, N. (2016). Mapping of arsenic contamination severity in Bahraich district of Ghagra basin, Uttar Pradesh, India. *Geomatics, Natural Hazards and Risk*, *7*(1), 101-112.

71. Midha, N., & Mathur, P. K. (2013). Channel Characteristics and Planform Dynamics in the Indian Terai, Sharda River. *Environmental management*, *53*(1), 120-134.

72. Midha, N., and Mathur, P. K. (2010). Conservation implications of the channel changes in Sharda River on endangered swamp deer population and floodplain ecosystem in Kishanpur Wildlife Sanctuary, Uttar Pradesh, India. *Current Science*, *98*(5), 665-672.

73. Mishra, S. S. and Mishra, A. (2008) Assessment of physico-chemical properties and heavy metal concentration in Gomati river. Research in Environment and Life Sciences, v.1(2), pp. 55-58.

74. Neu, H.A. (1967), "Transverse Flow of a River Due to Earth's Rotation", *JHD, Proc. ASCE,* Vol. 93, No.HY5, Sept. pp. 149-165.

75. Nicoll, T. J. and Hickin, E. J. (2010), “Planform geometry and channel migration of confined meandering rivers on the Canadian prairies”, *Geomorphology,* 116, pp. 37–47.

76. Pal, R., and Pani, P. (2016). Seasonality, barrage (Farakka) regulated hydrology and flood scenarios of the Ganga River: a study based on MNDWI and simple Gumbel model. *Modeling Earth Systems and Environment*, *2*(2), 1-11.

77. Panda D K, Kumar A, Ghosh S and Mohanty R K (2013) Streamflow trends in the Mahanadi River basin (India): Linkages to tropical climate variability. *Journal of Hydrology* 495 135-149

78. Panda, D. K., Kumar, A., & Mohanty, S. (2011). Recent trends in sediment load of the tropical (Peninsular) river basins of India. *Global and Planetary Change*, *75*(3), 108-118

79. Panda, S. and Bandyopadhyay, J. (2011), “Morphodynamic Changes of Bhagirathi River at Murshidabad District Using Geoinformatics”, *Journal of Geographic Information System,* 3, pp. 85-97.

80. Prus-Chacinski, T.M. (1954), “Patterns of Motions in Open Channel Bends”, *Assoc. Intl. d’Hydrologie, Publ. 38,* Vol. 3, pp. 311-318.

81. Rajendran, C. P., John, B., Rajendran, K., & Sanwal, J. (2016). Liquefaction record of the great 1934 earthquake predecessors from the north Bihar alluvial plains of India. *Journal of Seismology*, 1-13.

82. Rosgen, D.L. (1994), “A classification of natural rivers”. Catena, 22, pp. 169-199.

83. Roy, P. K., Ray, D., Pal, S., Banerjee, G., Majumder, A., & Mazumdar, A. (2014). Qualitative and Quantitative Assessment of Pollutional Load in River Ganga in West Bengal Using Statistical Technique. *World Applied Sciences Journal*, *29*(5), 634-640.

84. Roy, S. and Sahu, A.S. (2015), “Quaternary tectonic control on channel morphology over sedimentary low land: A case study in the Ajay-Damodar interfluve of Eastern India”, *Geoscience Frontiers,* vol.30, pp.1-20.

85. Rozo, M. G., and Castro, C.S. (2012), "Multitemporal Analysis of the Amazon River BetweenCorea Island (Colombia) and Aramosa Island (Brazil),"*IngenieríaInvestigación y Desarrollo*, 9(2), pp. 13-17.

86. Rozo, M. G., Nogueira, A. C. R. and Castro, C. S. (2014), “Remote sensing-based analysis of the planform changes in the Upper Amazon River over the period 1986-2006”, *Journal of South American Earth Sciences,* vol.51, pp. 28-44.

87. Rudra K (2010a) Banglar Nadikatha (Bengali). Sahitya Sanshad, Kolkata

88. Rudra K (2010b) Dynamics of the Ganga in West Bengal, India (1764–2007): implications for science policy interaction. Quatern Int 227:161–169

89. Rust, B. R. 1978. A classification of alluvial channel systems. Canadian Socity of petrolium Geologists, Memoir, 5, 187-198.

90. Saeedrashed, Y. and Guven, A. (2013), "Estimation of Geomorphological Parameters of Lower Zab River-Basin by Using GIS-Based Remotely Sensed Image", *Water Resources Management,* 27(1), pp.209-219.

91. Sarkar A., Garg R.D. and Sharma N. (2012), "RS-GIS based assessment of river dynamics of Brahmaputra river in India," *Journal of Water Resource and Protection*, vol.4, pp. 63-72.

92. Sarma, J.N. and Phukan, M.K. (2004). "Origin and some geomorphological changes of Majuli Island of the Brahmaputra River in Assam, India".*Geomorphology,* vol.60 pp.1–19.

93. Schoklitsch, A. (1937), "Hydraulic Structures, Vol. 1*", Am. Soc. Mech. Engineers,* pp. 504.

94. Schumm, S. A. (1963), "Sinuosity of alluvial rivers on the great plains", *Geological Society of America Bulletin,* vol. 74, pp. 1089-1100.

95. Schumm, S. A., (1969), "River metamorphoses", *Journal of the Hydraulics Division, American Society of Civil Engineers,* vol. 95, pp. 255-273.

96. Schumm, S. A., (1977), The fluvial System. John Wiley and Sons. A Wiley Interscience Publication, New York, Chapter V, pp. 106-111.

97. Schwenk, J., Khandelwal, A., Fratkin, M., Kumar, V., & Foufoula-Georgiou, E. (2016). High spatio-temporal resolution of river planform dynamics from Landsat: the RivMAP toolbox and results from the Ucayali River. *Earth and Space Science*.

98. Sharma, N., Bakimchandra, O. and Parida, B. R. (2004) "Remote sensing based study on channel changes and wetland ecosystem dynamics of Brahmaputra River in India," *Technical Report*. IIT Roorkee, India.

99. Shilpakar, R. L., Bastiaanssen, W. G., & Molden, D. J. (2011). A remote sensing-based approach for water accounting in the East Rapti River Basin, Nepal. *Himalayan Journal of Sciences*, *7*(9), 15-30.

100. Shrestha, H. M. (2016). Naumore Storage Project Should be the Last Resort of Development on the Main Course of Rapti (West), Nepal. *Hydro Nepal: Journal of Water, Energy and Environment*, *18*, 1-5.

101. Shukla A. C., Asthana V., (2005) Anatomy of Interlinking Rivers in India: A Decision in Doubt ACDIS Publication Series: ACDIS Swords and Ploughshares, University of Illinois.

102. Shukla, U. K., Srivastava, P. and Singh, I. B. (2012), "Migration of the Ganga River and development of cliffs in the Varanasi region, India during the late Quaternary: Role of active tectonics." Geomorphology, vol. 171–172, pp. 101–113.

103. Singh IB (2007) The Ganga River: geomorphology and management. In: Gupta A (ed) Large rivers. Wiley, London, pp 347–371

104. Singh M, Singh IB, Muller G (2007) Sediment characteristics and transportation dynamics of the Ganga River. Geomorphology86:144–175

105. Singh R (1971) India: a regional geography. National Geographical Society of India, Varanasi

106. Singh, D. S., Prajapati, S. K., Singh, P., Singh, K., & Kumar, D. (2015). Climatically induced levee break and flood risk management of the Gorakhpur region, Rapti River Basin, Ganga Plain, India. *Journal of the Geological Society of India*, *85*(1), 79-86.

107. Singh, N., & Sharma, R. C. (2016). Assessment of Physico-chemical parameters of Mountain River Baldi, Garhwal Himalayas.

108. Singh, V.P. (1989), "Hydrologic Systems Watershed Modeling", Vol. II, Prentice Hall, Englewood Cliffs, New Jersey, pp. 107-135.

109. Sinha R (2009) The Great avulsion of Kosi on 18 August 2008 Current Science 97 429-433

110. Sinha R, Gaurav K, Chandra S and Tandon S K (2013) Exploring the channel connectivity structure of the August 2008 avulsion belt of the Kosi River, India: Application to flood risk assessment Geology 41 1099-1102

111. Sinha R, Kumar R, Sinha S, Tandon S K and Gibling M R (2007) Late Cenozoic fluvial successions in northern and western India: an overview and synthesis Quat Sci Rev 26 2801- 2822

112. Sinha R, Mohanta H, Basu L, Jain V, Chakraborty T, Ghosh P, Pandey A, Pati J K and Mukherjee S (2016) Geomorphology of the Ganga River. In Biodiversity of the Ganga River basin Springer (In Press) Social and Environment Transition.

113. Sunita; P. P., and Dinkar, G.K. (2015). Forecasting Model of Flood Inundated areas along Sharda River in U.P. J. Applied Geology and Geophysics,vol. 3, p 1-11.

114. Tiwari, P. C. (2000). Land-use changes in Himalaya and their impact on the plains ecosystem: need for sustainable land use. Land Use Policy, 17(2), 101-111.

115. Talchabhadel, R., & Sharma, R. (2014). Real Time Data Analysis of West Rapti River Basin of Nepal. Journal of Geoscience and Environment Protection, 2(05), 1.

116. Twidale, C. R. (2004), "River patterns and their meaning". Earth-Science Reviews vol. 67, pp. 159–218.

117. Wandre, S. S. and Rank, H. D. (2013), "Assessment of morphometric characteristics of Shetrunji River basin using remote sensing and geographical information system (GIS)", African Journal of Agricultural Research, vol. 6 (3), pp.503-514.

118. Yang, C. and Ouchi, K. (2012), "Analysis of bar morphology using multi-temporal and multi-sensor satellite images: Example from the Han Estuary, Korea", Marine Geology 311-314, 17–31.

119. Yao, Z., Wanquan T., Xiaopeng J. and Jianhua X. (2011). "Bank erosion and accretion along the Ningxia–Inner Mongolia reaches of the Yellow River from 1958 to 2008". Geomorphology vol.127 pp. 99–106.

120. Zhang, S. and Mao, X. (2015), "Hydrology, sediment circulation and long-term morphological changes in highly urbanized Shenzhen River estuary, China: A combined field experimental and modeling approach". Journal of Hydrology vol.529, pp. 1562–1577.

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.

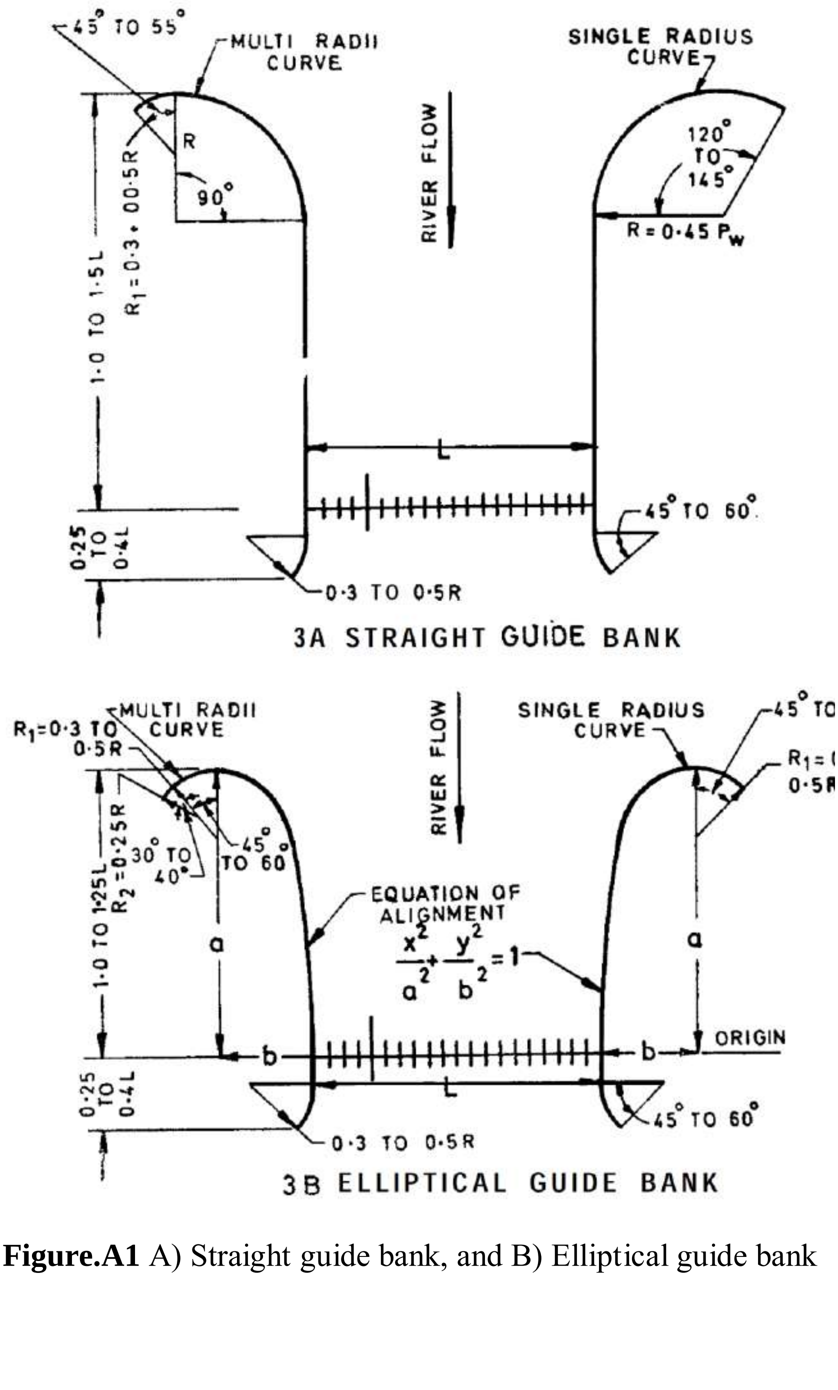


Figure.A1 A) Straight guide bank, and B) Elliptical guide bank

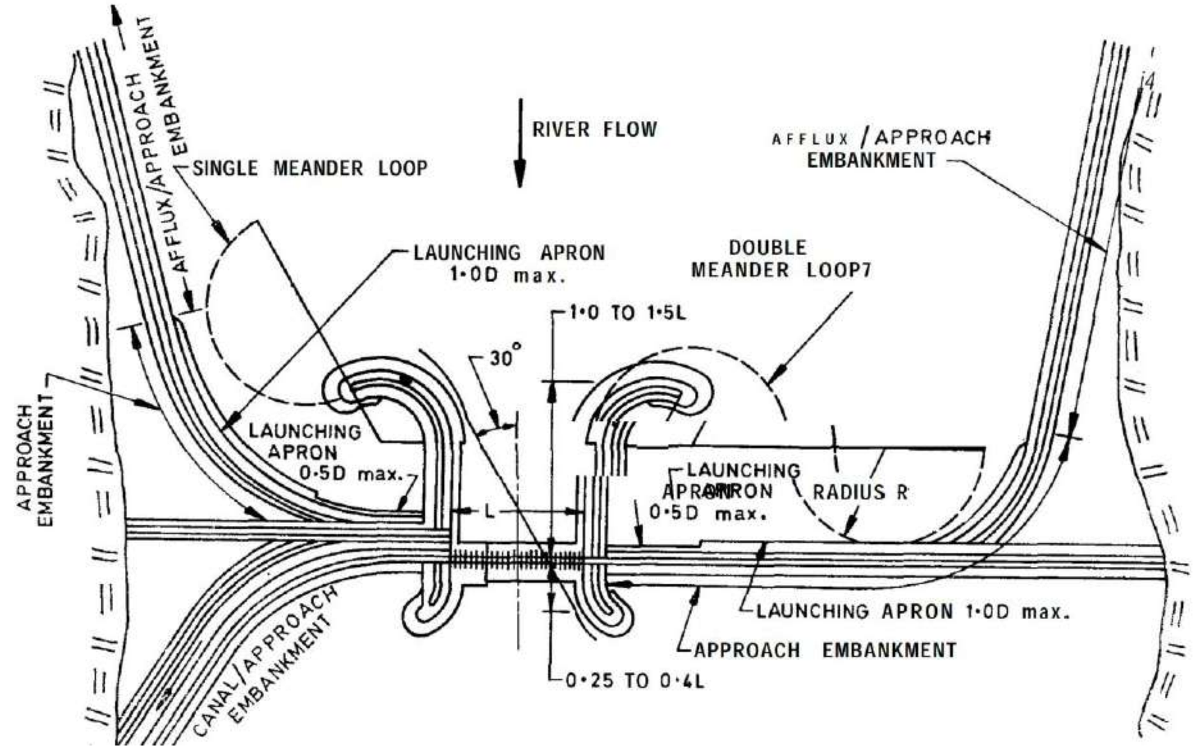


Figure. A2 Typical layout of the guide bank

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

$R_2 = 1.1\sqrt{Q}$ 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:

$$t = \frac{V^2}{2g(G_s - 1)} \tag{A4}$$

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):

$$d_{min} = 0.023 \text{ to } 0.046\ U_{max}^2 \tag{A5}$$

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:

$$V = 4.893\, d^{1/2} \tag{A6}$$

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:

$$R = 0.473\left(\frac{Q}{f}\right)^{1/3} \quad \text{(A7)}$$

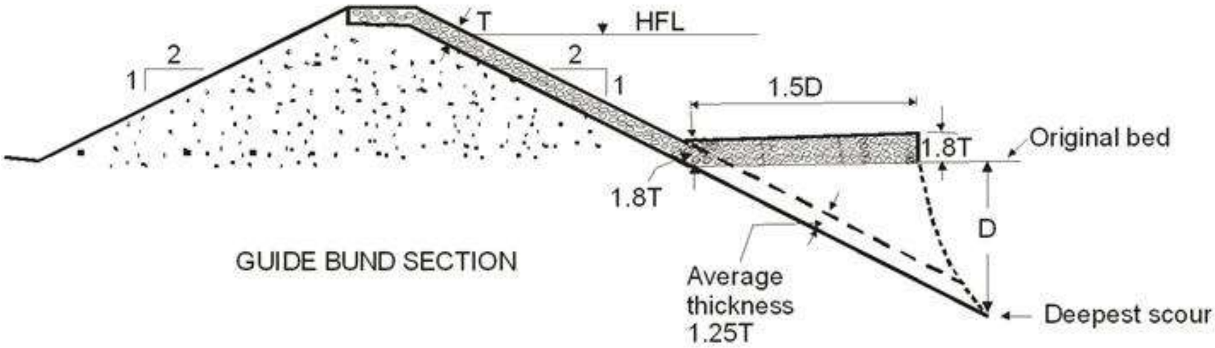


Figure. A3 A typical sketch of guide bund & launching apron

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.

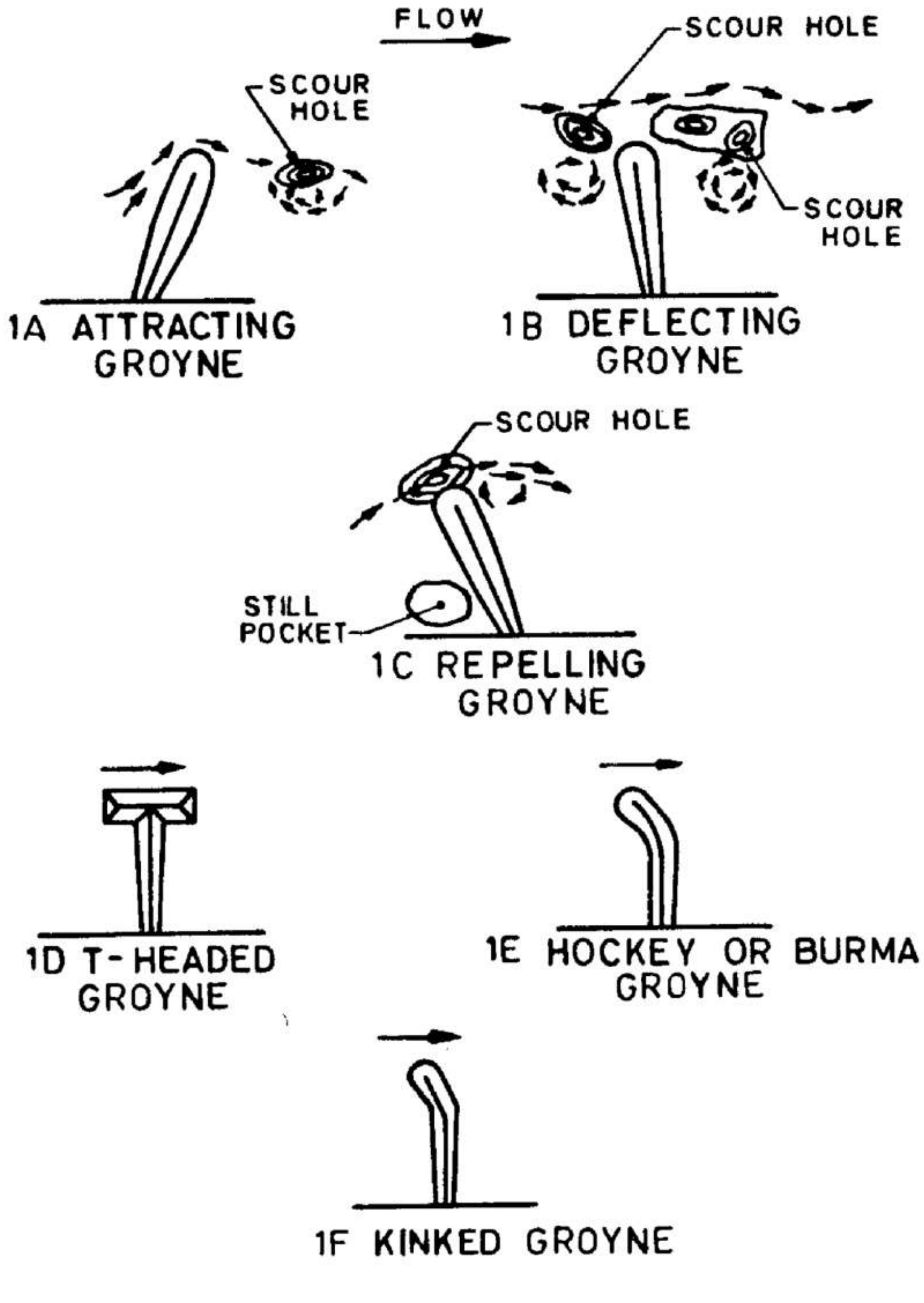


Figure. A4 Types of spurs

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.

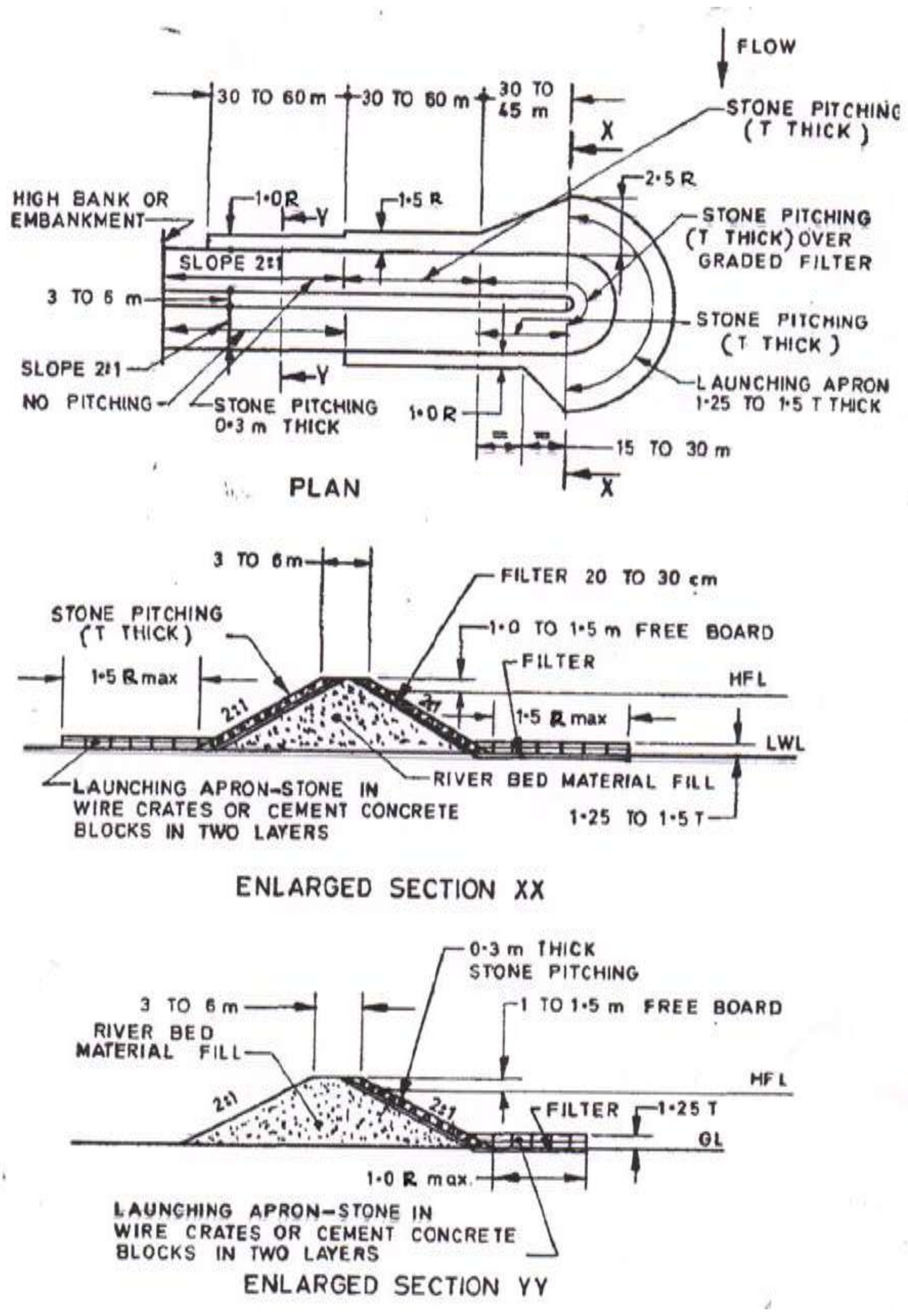


Figure. A5 Layout of a typical spur

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.

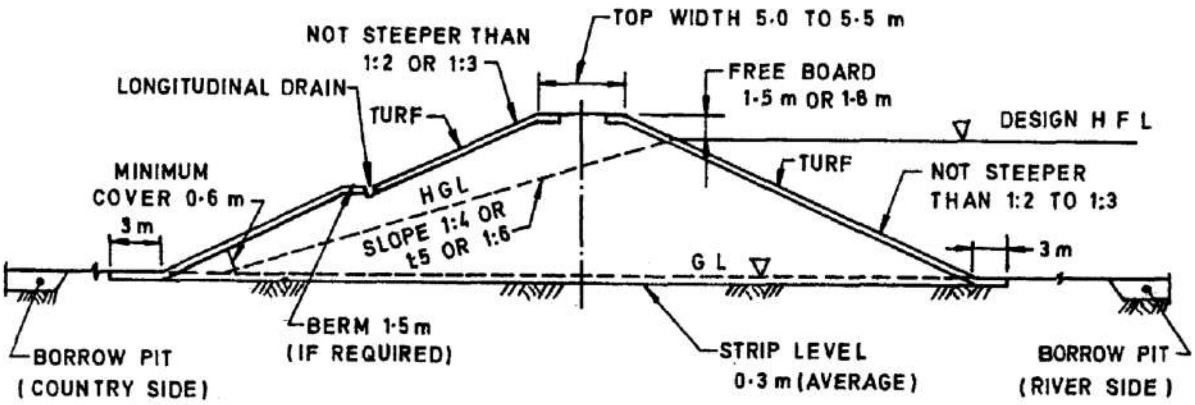


Figure. A6 Typical cross-section of Homogeneous embankment

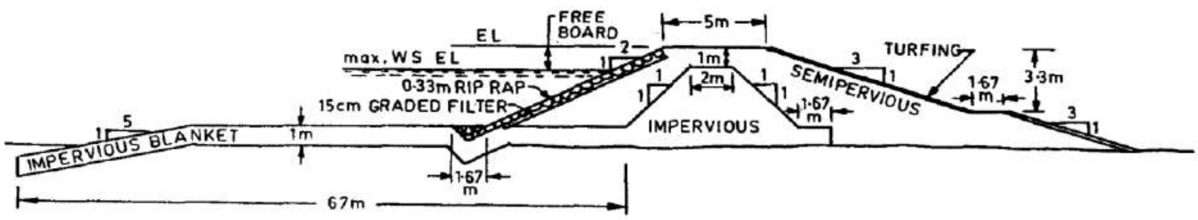


Figure. A7 Typical cross-section of Zoned embankment

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).

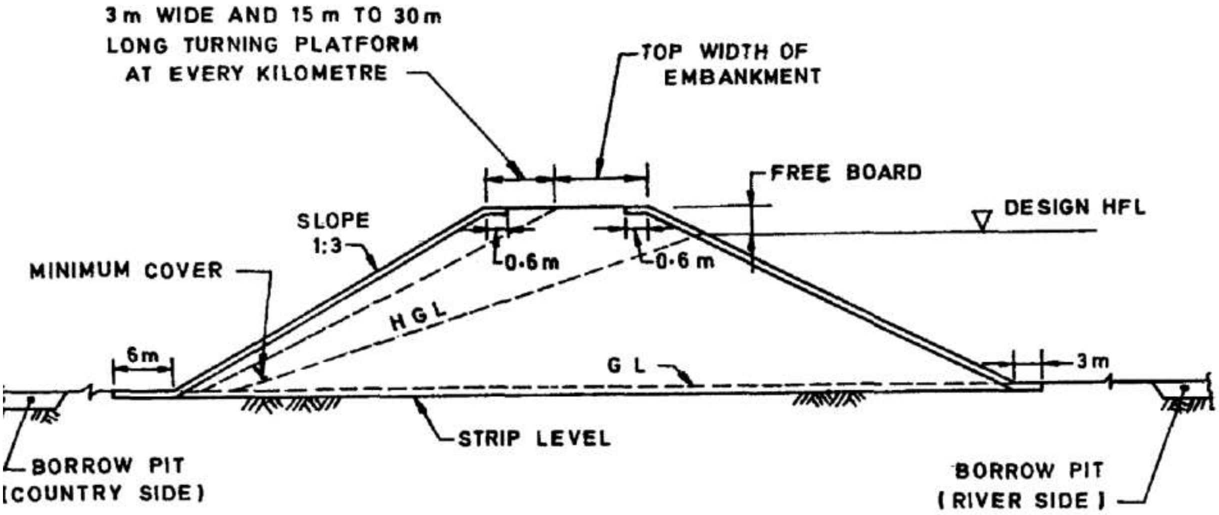


Figure. A8 Typical cross-section showing turning platform

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).

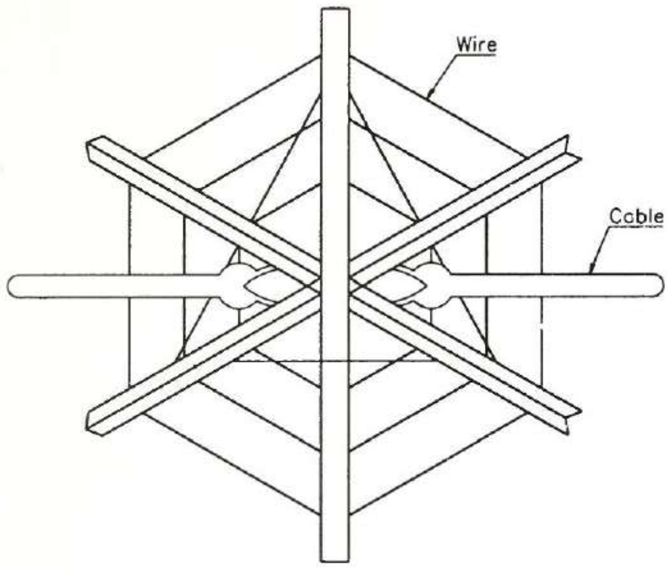


Figure. A9 Kellner Jack type porcupine

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.

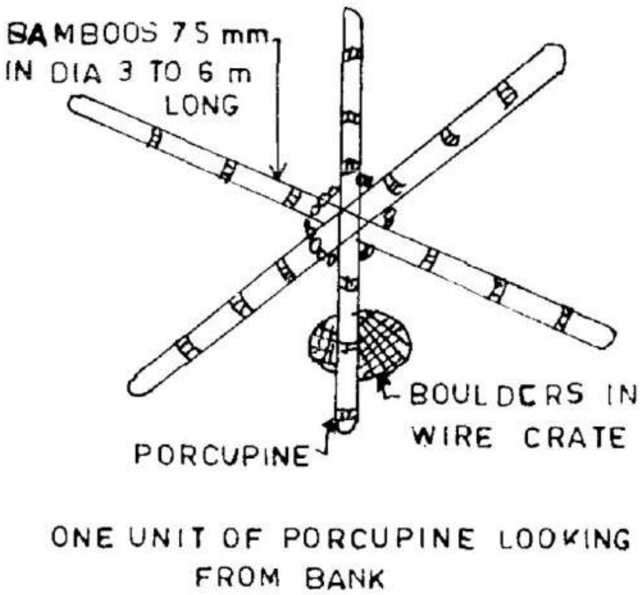


Figure. A10 Bamboo type porcupine

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.

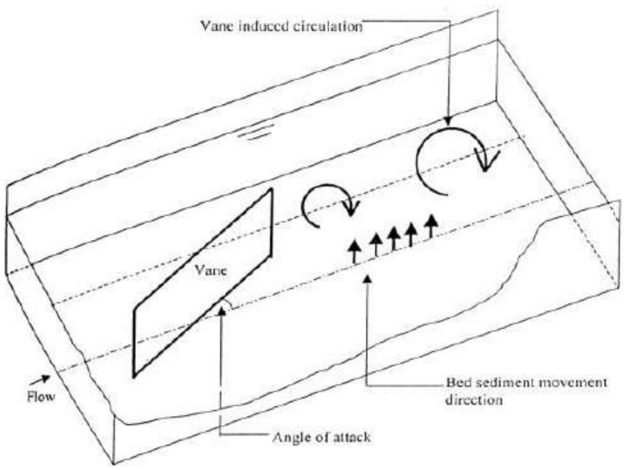


Figure. A11 Definition sketch of a submerged vane

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.

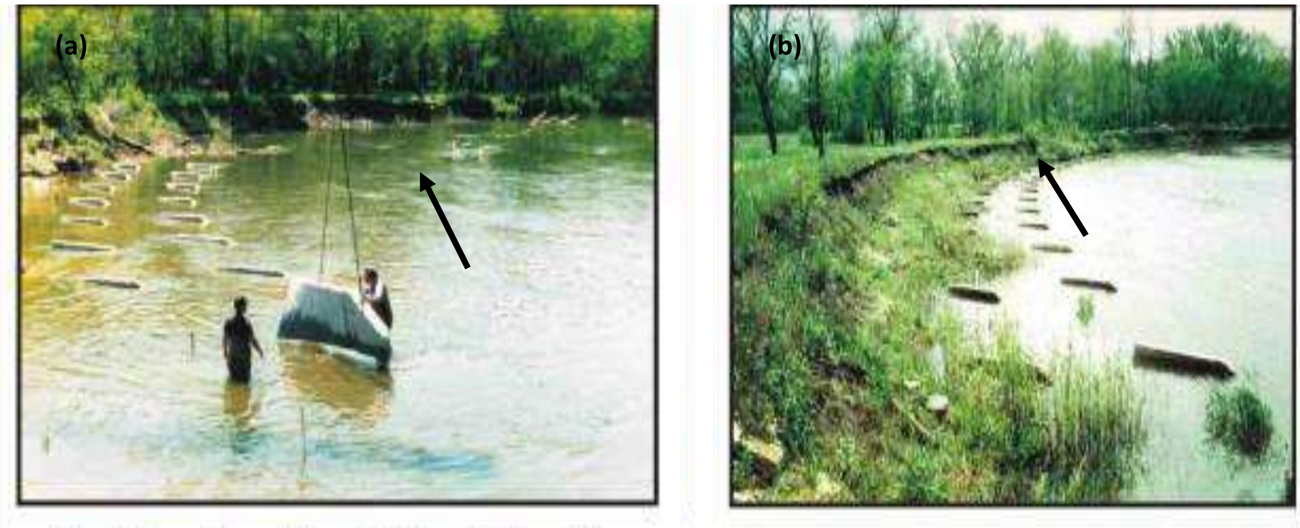


Figure. A12 Installation of Iowa Vanes in Wapsipinicon river bend
(a) During low flow in the Summer of 1988 (b) Low flow, May 10, 1990

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.

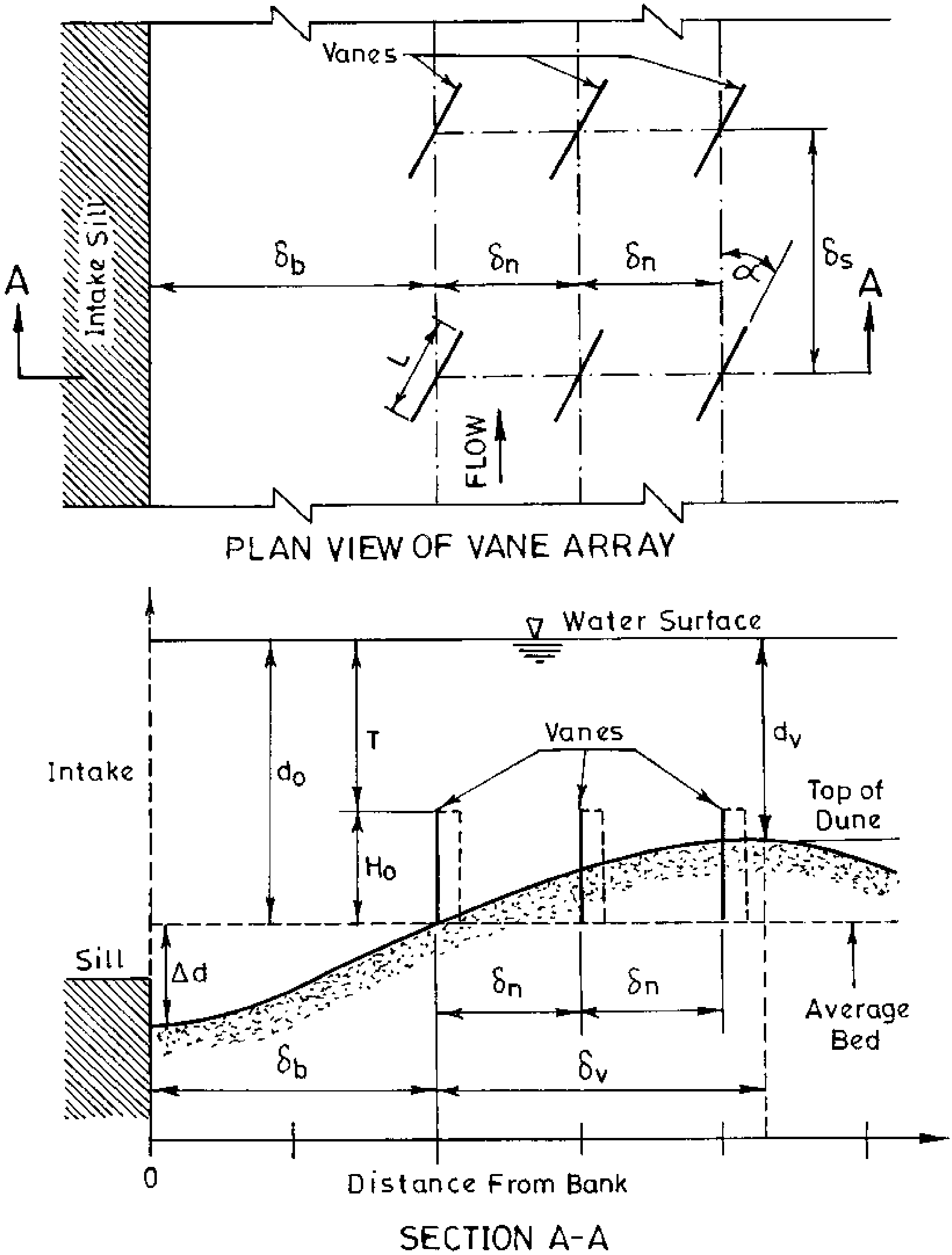


Figure. A14 Design variables of a submerged vane system

Table A2 Vane induced maximum increase in bed level along the bank of a stream.

F_D	m	$(d_0\text{-}d_v)/d_0$											
		Three vanes array				Two vanes array				One vane array			
		T/d_o=0.5	0.5	0.7	0.7	0.5	0.5	0.7	0.7	0.5	0.5	0.7	0.7
		$\delta s/H_o$= 15	30	15	30	15	30	15	30	15	30	15	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-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:

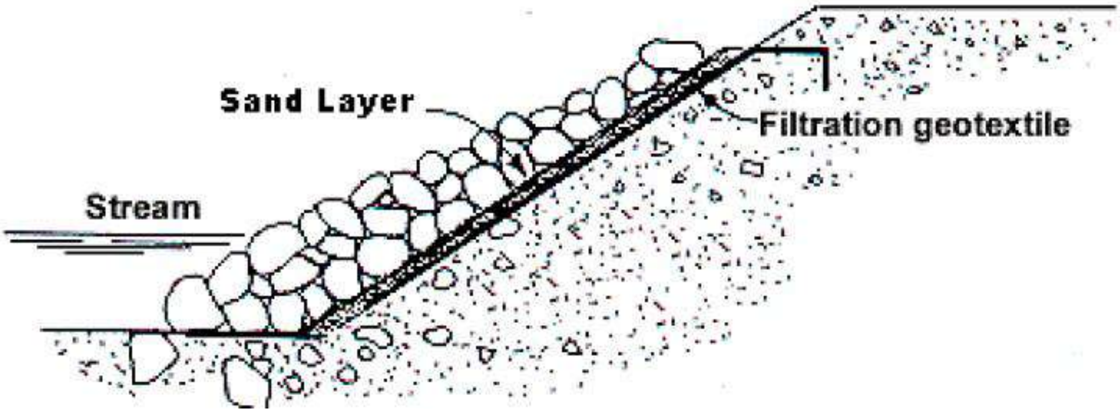
a) For granular material containing 50 percent or less fines by weight, the following ratio should be satisfied:

$$\frac{85\%\ passing\ size\ of\ bed\ material\ (mm)}{Equivalent\ opening\ size\ of\ bed\ of\ fabric\ (mm)} \geq 1$$

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:

$$W = \frac{0.0232\ 3\ S_s}{K\,(S_s - 1)^3} V^6$$

$$K = \left[1 - \frac{\sin^2\theta}{\sin^2\phi} \right]^{\frac{1}{2}}$$

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

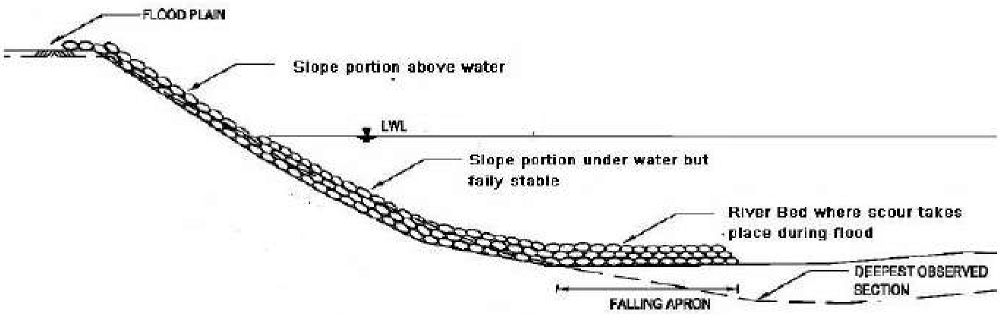
Ss - Specific Gravity of protection material (adopted between 1.5 to 1.8)

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).

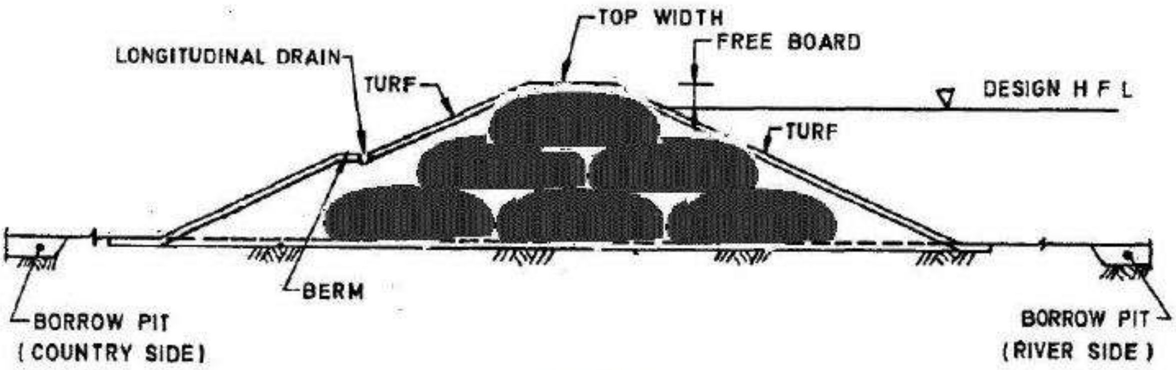
A. Check bearing capacity and rotational slope stability at the ends of the embankment (Steps 5 and 6)
B. Use strength and elongation determined from Steps 7 and 8 to control embankment spreading during construction and to control bending following construction.
C. As the strength of the seams transverse 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 Φsg = 2/3Φ; 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.

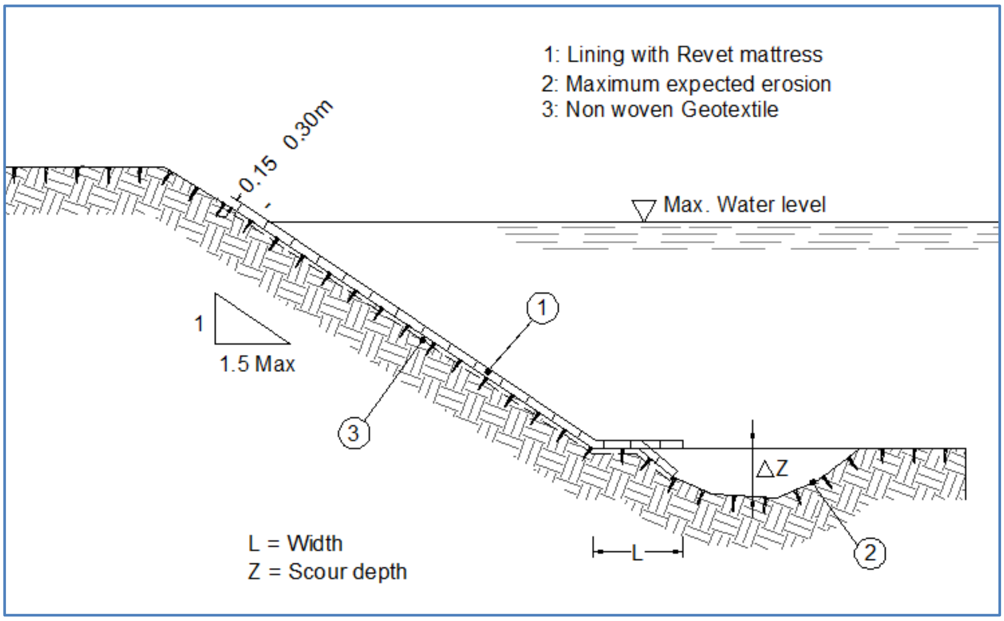
Rock and wire mattress revetments can be used to protect either the channel bank or the entire channel perimeter. When used for bank protection, rock and wire mattress revetments consist of two distinct sections: a toe section and upper bank and toe protection.

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

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:


MORPHOLOGICAL STUDY OF
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