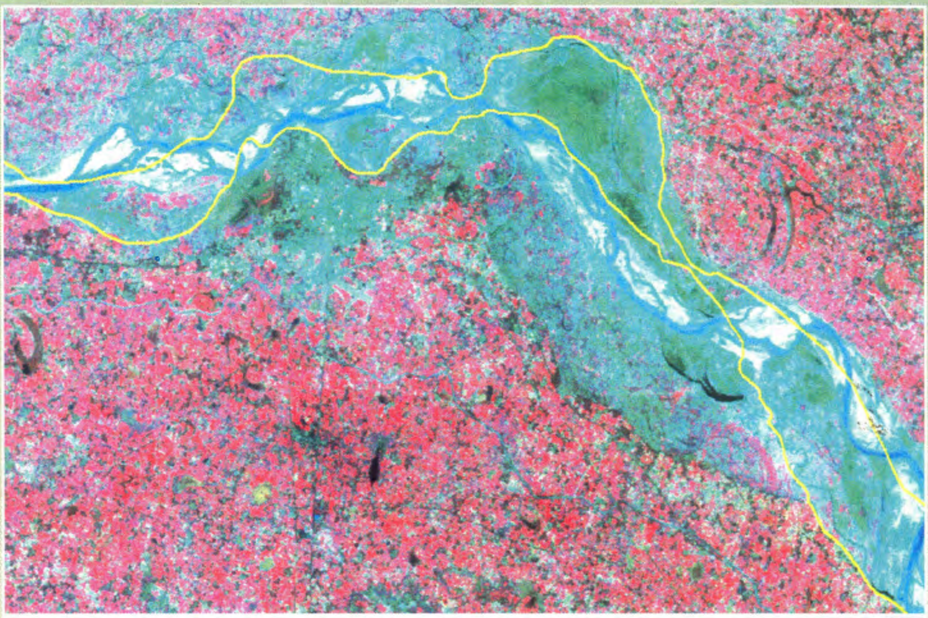
FINAL REPORT

MORPHOLOGICAL STUDY OF GHAGARA RIVER



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EXECUTIVE SUMMARY

Conventional techniques of monitoring both long term and short term changes in river morphology are time consuming and expensive too. Their main disadvantage however is that they provide information only at a particular point and instant of time. On other hand, remote sensing techniques are capable of providing information through time and space, which can never be appreciated from the ground. Remote sensing data obtained through satellites may be effectively used to evaluate the shifting characteristics of rivers in a quick and cost effective manner. Further, satellite remote sensing presents an expedient and reliable alternative method for demarcation of rivers at suitable time-space intervals to establish the stability or otherwise of their channels.

The present study evaluates shifting characteristics of the river Ghagara using satellite remote sensing data. The Ganga river is the most important rivers in the Indian subcontinent. Ganga has numerous large and small tributaries, of which the Ghagara is one. The Ghagara, located in north east portion of UP state of India, is one of the major river in middle Ganga basin which is prone to river migration. For this reason, a reach of the river Ghagra from Manuhan (distt. Barabanki, UP) to Distt. Chappra was selected for evaluation of its shifting course.

The shifting characteristics of the river was evaluated for the identified reaches both on the right as well as left banks of the river courses using offset computation method of shifting. The Survey of India toposheets have been taken as the base for computation of shifting. The satellite data considered include 1990 (IRS-1A LISS II Data), 1995 (IRS-1A LISS II Data), 1999 (IRS-1D LISS III Data) and 2003 (IRS-1D LISS III Data). Normalized Difference Water Index (NDWI) has been used for delineation of rivers. Based on this analysis, the critical locations along the Ghagra River were Aypdhya Tanda, Golabazar, Barhaj and Bansdih. Detailed study, of identified critical locations was carried out using IRS-1D PAN data, having a spatial resolution of 5.8 m, for years 1999 and 2003 along with SOI toposheet of the scale 1:50,000. It is observed that the maximum shift was 4.5 to 6.3 km in Ghagara River.

It is expected that evaluation of shifting characteristics of the rivers using remote sensing technique will help in understanding the changes in river migration in both space and time. Also, timely preventive measures taken at the identified critical locations will help in minimising erosion at these locations and reducing tangible and intangible losses resulting from the river migration.

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Conventional techniques of monitoring both long term and short term changes in river morphology are time consuming and expensive too. Their main disadvantage is however that they provide information only at a particular point and instant of time. On other hand remote sensing techniques are capable of providing information through time and space, which can never be collected from the ground. Remote sensing data obtained through satellites may be effectively used to evaluate the shifting characteristics of rivers in a quick and cost effective manner. Further, satellite remote sensing presents an expedient and reliable alternative method for examination of rivers at suitable time space intervals to establish the stability or otherwise of their channels.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

River morphology is concerned with the structure and form of rivers, including channel configuration (planform), channel geometry (cross-sectional shape), bed form, and profile characteristics. Channel morphology changes with time and is affected by water discharge, including velocities; sediment discharge, including quantity and sediment characteristics; the composition of bed and bank materials apart from varied geological controls.

The processes responsible for the formation and evolution of rivers and their features are erosion, sediment transport, and deposition. Rivers are able to do work on the landscape because the energy stored in the water, or potential energy, is translated as it flows downhill owing to gravity into the kinetic energy, which is used for erosion, transport, and deposition. The amount of potential energy available to a river is proportional to its elevation above sea level. In order to minimize the loss of potential energy to thermal energy (or heat) as a result of friction, and thus maximize available kinetic energy, the river follows the path of least resistance downhill. Even so, it is estimated that 95 per cent of a river's potential energy is used to overcome friction, which occurs mainly along the channel boundaries (the bed and banks), although the internal friction of the water and air resistance on the surface are also important.

A river is in a state of equilibrium if the discharge, sediment load, sediment size and slopes are delicately balanced such that there is no change in bed elevation in a given reach over a long period of time. A change in any of these controlling variables or the imposition of an artificial change by the construction of structures along or across the stream disturbs its equilibrium and the stream then aggrades or degrades. This process of aggradation or degradation may continue for a long time till a new equilibrium is established. In their natural condition, rivers seldom reach a state of equilibrium, even over short reaches. Each river is different and every reach of a stream is different from almost all other reaches of the same stream. Meandering is one of the means through which rivers tend towards the so-called dynamic or quasi-equilibrium state. River training and the construction of training works are also designed to achieve a proper equilibrium. The more the planned channel pattern, channel geometry, slope conditions, etc., correspond to the natural conditions of the river in question, the better will the river accept the new artificial state.

Prediction of when and where future erosion will occur and the extent of such erosion are very uncertain because of the many interacting factors involved. The proper understanding of meander development and channel pattern changes of alluvial rivers is very important. The practical reasons for studying river pattern change are wide and varying. These include, firstly, awareness that human activity in the vicinity of river channels has unfortunately proceeded in ignorance of the pattern changes that may be expected and that this ought to be corrected. Secondly, channel pattern change is one of the more rapid forms of geomorphological change, with developing forms and patterns of erosion and sedimentation that should be incorporated more fully into a general understanding of fluvial geomorphic systems. Thirdly, pattern changes involve the reworking of floodplain environments, and the soils, sedimentation, and morphological patterns that result, are of very broad concern.

1.2 MORPHOLOGY OF ALLUVIAL STREAMS

A thorough understanding of the hydro-morphology of alluvial streams requires actual knowledge of their plan-form. The plan-form of alluvial streams can be classified into the following three categories.

1.2.1 Straight Channels:

These are usually relatively short reaches and are transitory because even minor irregularities in channel shape or alignment or a temporary obstruction can create a local disturbance that sets up a transverse flow leading to meandering. Straight reaches (Figure 1.1) have negligible sinuosity at bankfull stage. At low stages there are sand bars along the banks on alternate sides of the stream and the thalweg the line of maximum depth meanders in a sinuous path around the bars. If the stream banks are not stable, more than one channel will develop, and the reach will become braided. It is extremely difficult to find straight reach of stream over large lengths. Straight reach implies neither constant depth across the channel nor a straight thawed. Even though the channel is straight, thalweg moves back and forth from one bank to another.

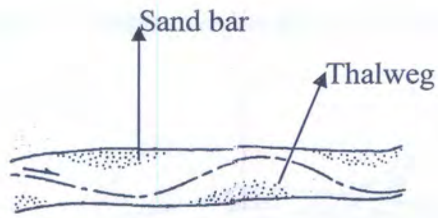


Fig.1.1 Straight Channel Reach

1.2.2 Meandering Stream:

These consist of a series of bends of alternate curvature connected by straight crossing reaches (Figure 1.2). Slopes are usually relatively flat. Meandering channels are unstable, with banks caving in the downstream reaches of concave bends. There are deep pools in the bends and high velocities along the outer concave bank. Depths in crossing are relatively shallow compared to depths in bends.

Meandering streams are of two types: those with "surface" bends and those with "entrenched" bends. Streams with free surface bends generally flow in alluvial valleys and change their course on the floodplain with time. Streams with entrenched bends, however, are cut into resistant parent material and generally maintain a stable course.

Fig.1.2 Meandering Pattern of a Stream

1.2.3 Braided Channels

There are numerous channels (Figure 1.3), which divide and rejoin in braided reaches. The stream is wide, and the banks are poorly defined and unstable. At low flows there are two or more main channels which cross each other, subsidiary channels, sand bars, and islands. At high flows, most bars are inundated. Such rivers often have relatively steep slopes and carry a large sediment load.

Fig.1.3 Braided Channel Reach

1.3 PHYSICAL CHARACTERISTICS OF RIVERS

Different rivers and different reaches of the same river have different alignments, channel cross-section shape, bed and bank material, slope, and valley characteristics.

Lane (1957) stated that, while a great many factors affect stream channel form directly, others affect it indirectly by their influence on the directly affecting variables. He identified the most important variables as:

- Stream discharge
- Longitudinal slope
- Sediment load
- Resistance of banks and bed to movement by flowing water
- Vegetation
- Temperature
- Geology
- Works of man

Lane stated that "these factors are not all independent ones, as many depend, to a greater or less extent, on the others. The interrelation between longitudinal slope, sediment load and resistance of the banks and bed to movement is particularly close and complex."

Anding (1970), in discussing the more important variables, stressed the following: "Stream discharge is the most obvious factor in determining stream form. The discharge of a natural stream influences its form not only because of the magnitude of the discharge, but also because of the integrated effect of its constant fluctuation."

The longitudinal slope is set largely by the geology and topography of the area through which the stream flows. It also follows that the slope is related to the sediment size of the material of the bed and banks, which were laid down by the stream.

The amount and character of the particles comprising the sediment load exercise an important effect on the shape of the channel. The configuration of the channel cross-sections and the alignment of the stream are affected by the sediment load and pattern of deposition.

Channel shape changes with changing discharge, and changes occur more rapidly during high flows than during low or moderate flows. Overbank flow, in general, has a negligible effect on channel shape.

Anding quotes Schumn (1963) as stating that classification of river channels might be based on the independent variables discharge and sediment load. Since discharge mainly determines the size of the channel, Schumn used sediment load as the basis of classification because of its influence in determining channel stability, shape, and sinuosity. He established three classes of channels—stable, eroding, and depositing—and then established three subclasses based on the predominant mode of sediment transport—bed load, mixed load, and suspended load. Schumn's classification of alluvial channel, based on data from rivers transporting materials finer than coarse gravel.

1.4 REMOTE SENSING APPROACH

Conventional measurements of planform characteristics of meandering rivers are a time consuming, laborious and expensive procedure. Their main disadvantage, however, is that they provide information only at a particular point and instant of time. On the other hand, remote sensing techniques are capable of providing information through time and space, which can never be appreciated from the ground. Further, the migratory rivers invariably leave their footprints behind. These include meander scars, abandoned channels, oxbow lakes and natural levees, thus giving clues as to where and how the river migrated. However, because of the large size of these features, they cannot always be recognized in the field. Aerial photographs and satellite sensor images can provide an extremely powerful means of detecting these clues for the delineation and reconstruction of the river courses (Baker, 1986).

Satellite remote sensing presents an expedient, reliable and cost effective alternative method for demarcation of rivers at suitable time-space intervals to establish the stability or otherwise of their channels. Advantages of the information acquired by satellite remote sensing are of synoptic coverage and repetivity. Because of the repetitive nature of satellite coverage, space borne observations are particularly suited for monitoring dynamic changes in surface parameters in remote areas or areas that are difficult to access. Various satellites having sensors which operate both in the optical as well as in microwave region of electro magnetic spectrum at different spatial resolutions can be used for obtaining valuable information on planform characteristics of river courses.

1.5 OBJECTIVES OF THIS STUDY

(i) To delineate the course of Satluj River along with the major roads, railways and important places from SOI toposheets and the digital data of IRS LISSII and LISSIII for the years 1990, 1995, 1999, and 2003.

(ii) To study the shifting course of Satluj river from SOI toposheet to 1990, 1995, 1999 and 2003, and identify the critical locations along the river where major shifting has taken place.

(iii) To identify all major morphological problems both natural and man made.

(iv) Evaluate performance of major flood control structures executed so far from morphological point of view as well as their effect on river morphology.

(v) Preparation of detailed morphological report as per 'Guide lines for preparation of river morphological reports of CWC (April 1991).

CHAPTER 2

REVIEW OF LITERATURE

The manner in which rivers change the form and pattern of their channels has been a recurring theme in river studies for many years. Many workers have carried out studies on channel changes (Dury, 1977; Knight, 1975; Hickin and Nanson, 1975; Lewin and Hughes, 1976) and the field has been reviewed by Gregory (1977, 1979, 1983). River migration or river changes are taken to include any change in river geometry within the context of the cross section, the pattern or network of a drainage basin (Gregory, 1977). Planform analysis helps us to understand one of these, the changes in channel pattern in both time and space. Planform properties of meandering rivers include not only the geometry and sinuosity of the meandering course, but other properties such as variability of width and development of bars (Brice, 1984). Planform and planform changes are not independent of other aspects of river geometry, and together with these other aspects they deserve to be considered in relation to the hydraulics of channels with loose boundaries.

Many investigators have studied river's channel changes of different rivers. Thomas et al. (1998) studied the shifting of Ravi. In this study, remote sensing data of IRS-1A and IRS- 1B of LISS- II of the period 1991-1993 were analysed. They found drastic changes in the course of Ravi due to human activities along its course. Another study was carried out by Jain (1993) on migration behaviour of Ganga River between Allahabad and Buxar. In this study Landsat MSS and TM data of winter season in the form of FCC of year 1982 and 1987 were used for the delineation of Ganga River. Visual Interpretation technique was used for assessment of channel migration and found maximum shift in mid channel. Vinod et al. (1994) carried out a study on Hooghly River. In this study time series analysis between 1971 to 1991 period was used. Thematic maps were generated from Landsat MSS and IRS- 1A LISS-I satellite data for 1986 and 1991 period. Critical zone with respect to cut off and future channel migration for river stabilization were identified. Safuddin et al. (1999) carried out a study on migration of Yamuna River from Mahabharat period to the present. They also used IRS-1 B LISS II data for their study. Netramani et al. (2003) also studied the shifting pattern of the Ganga River during different periods of time. This study shows that the shifting direction of the river varies through out the course of the river. Shifting was not in a uniform pattern at some place it was westward and at other places it was eastward. Westaway et. al. (2003) also done a remote survey of large-scale braided, gravel- bed rivers using digital photogrammetry and image analysis. For this study Ariel photographs were used.

River Kosi due to its inherent shifting chracteristics, has been the focus of attention in many studies. Ghosh (2002) studied the shifting pattern and braiding character of River Kosi with the help of satellite data. In this study the analysis was carried out on yearly basis and river position was identified and compared to previous years of data to calculate the shifts in the river position. Result shows that the river is moving westwards and it was predominantly braided in character.

Rannel (1979), Ferguson (1963) and Shillingfield (1893) studied the behavioural pattern of Kosi River. However, no published records of their observations are available. Mookerjea (1961), and Mookerjea & Aich (1963) studied the rapidly shifting nature, hydrological and sediment load characteristics of Kosi River. On the basis of this, a map showing positions of the Kosi River over its megafan in the last 200 years has been published. Singh and Singli (1971) published a detailed map showing sixteen paleocourses of the Kosi. Dhanju (1976) has described the changes in course of the River Kosi within embankments in recent years using Landsat imagery.

Other notable studies on Kosi region have been carried out by Gupta et. al. (1980), who described changes in the plan-form of the Kosi River bed. Gohain and Prakash (1990) correlated downstream and temporal changes in planform of the river with relative aggradation and degradation in different reaches of the river using Landsat images, air photos and topographic maps.

Prasad (1970) studied some aspects of meandering streams of the Barakar basin, Bihar, and their sinuosity indices. The Barakar basin ($23^0$41'30" N to $24^0$31'30" N Lat. and $85^0$10' E to $86^0$54' E Long.), is characterized by meandering and sinuous courses of streams. The basin is drained mainly by Karkara, Saghar, Harnaro, Keso, Pachkara, Baretu, Irga Khakho, Usri, Beri, Rajoya and Barki Jhar from the north, and Kewta, Kolhuwatari, Barsoti, Khero, Bakra, Chirki, Khudia and Pusai from the south including the main stream Barakar (a tributary of the Damodar) in the basin area of about 7026.1 km^2 in the Chota Nagpur Highlands of Bihar (India). Barsoti is its principal tributary from the south and the Usri from the north.

Philip et al. (1989) selected an area in the middle Ganga basin lying around Monghyr, Bihar, India, for channel migration investigations, using mainly remote sensing data. Changes in planform of the rivers over approximately 50 years are evaluated and the palaeocourses of the Ganga and Burhi Gandak rivers are reconstructed using the disposition and pattern of, among other things, oxbow lakes, meander scars and abandoned channels. It is inferred that the Ganga and the Burhi Gandak rivers moved from north to south by 20 km and 30 km respectively. The study demonstrates the utility of remote sensing data in such channel migration investigations. The study was based on a variety of data including aerial photographs (black-and-white, of 1:60 000 scale, 1966), Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data (black-and-white images, false-colour composites and digital data for 1975, 1982, 1983, 1984, 1985 and 1986), topographic maps (from surveys in 1935 and 1978 at 1:250 000 and 1:50 000 scales), lithologs of 45 wells and field observations.

Nagarajan et al. (1993) studied the migration behavior of River Rapti using temporal remotely-sensed data. The River Rapti is a tributary of River Ghagara which is a major tributary of Ganga. The study was taken up with an aim to (i) delineate the river course and its flood plain, (ii) identify surface indicators of channel migration, and (iii) predict the river stretches which are likely to shift. Landsat MSS images acquired in years 1975, 1982 and 1983 and Landsat TM image of 1990 were used to form a time series of flood related features of river Rapti. Aerial photographs of year 1982 and with a scale of 1:15,000 were used to study in greater details the palaeo channels and the process of channel migration. Topographical maps on a scale of 1:50,000 and prepared in 1972 and 1977 were used as base maps.

Bardhan (1993) studied the channel behavior of the Barak River from the Manipur-Assam border on the east to Assam-Bangladesh border on the west through IRS imagery to identify the river stretches, if any, which remained reasonably stable during the period 1910-1988. The study revealed that considerable channel pattern changes have taken place during the 78 years from 1910 to 1988 in the main river as is evident from the number of ox-bow takes, abandoned channels and buried channels etc., which are seen on both sides of the present course of the river. However, eleven stretches on the main river, ranging in lengths from less than 1km to more than 2 km and a few stretches on the tributaries could be delineated as the stable segment of the river/stream.

Bhagawati (1993) carried out performance evaluation of a system of spurs and tie bunds constructed in order to check bank erosion on the Brahmaputra at Gumi near Palasbari. Effects of a training measure on the river regime is reflected in changed river configuration, most of which may be studied through multi-dated satellite data. The relevant information was collected with the help of visual interpretation of multidated Landsat-5 data products. Landsat-5 data products including B&W and FCC of the post construction period, before and after the great flood of 1988 have been used to extract relevant information for evaluating the performance of the spur system. Temporal changes in the morphological features of the river were determined with reference to toposheets prepared by survey of India during 1967-68. The changes were quantified using the parameters 'Braiding Index' (ratio between the land area to the water area of the planform of the study area) and 'Arc-chord ratio' (ratio of length of embayed bank to the straight line between the tips of adjacent spurs). The adopted training measures seem to stabilize the bankline but indicate inadequacy in spacing certain spurs, which are adjacent to each other.

Nigam et al. (1986) gave in detail about the taming the Ghagara at Turtipar Srinagar. The details of this paper is given in Appendix I.

CHAPTER 3

THE STUDY AREA AND DATA USED

3.1 THE STUDY AREA

In the present study, evaluation of the shifting characteristics of reaches of the River Ghagara has been carried out. The description of the Ghagara River is given in the following sections.

The Ganga River is one of the most important rivers in the Indian subcontinent. It has numerous large and small tributaries, of which Ghaghara is one. The Ghagara River is one of the major rivers in Uttar Pradesh located in the north-east portions of the state. The River Ghagara originates under the name of the Karnali, the biggest river system of Nepal, near border of Nepal and China. The river and its tributaries drain Western Nepal. The river enters into India at Kotia Ghat near Royal Bardia National Park, Nepal Ganj, where it is known as the river Girwa for about 25 kms. A barrage called Girijapuri Barrage has been constructed at the end of the Girwa. Below the barrage the river attains the name of the Ghagara. The river receives many of the major tributaries like Saryu, Rapti etc originating in Nepal, and drains into the Ganga at Doriganj, Chappra in Bihar.

The Ghagara River is especially prone to river migration. For this reason, an alluvial reach of 310 Kms between Manuhan (Distt. Barabanki, U.P.) to Chappra (Bihar) of Ghagara River has been selected for present study. This area is bounded by Latitude $26^{0}55'$ N to $25^{0}45'$ N and Longitude $81^{0}35'$ E to $84^{0}45'$ E. The area is entirely an alluvial plain and the land is highly fertile. In this stretch, the 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 of toposheets for this area.

The river Ghagara has a wide flood plain increases towards its confluence with the Ganga.The confluence of the Ganga has tendency to shift downwards slowly because the former has a much higher velocity than the latter and bring down coarser sand, and as the combined stream flows with a slower current than the Ghagara, it is unable to carry the heavy silt which thus accumulates at the junction, forcing the two rivers apart.

There are a few sites on Ghagara and Rapti where chronic erosion problem exist for past few years. Some of the sites like Vikramjot- Dhuswa in Basti, Golabazar in Gorakhpur on Ghagara are worth mentioning, recurring expenditure is being made years after years to overcome erosion problem there is need for morphological study of these rivers over such critical reaches. The main soil types occur in the river system which can be broadly classified into two categories viz, (a) older alluvium (Bangar) and (b) Newer alluvium (Khader). The soil composition differing from one region to other is mainly alluvial (GFCC, 2001)

3.2 FIELD VISIT

To get a feel of the existing ground condition, we went for the field visit. A field visit to some of the critical locations on river Ghagara was made during May 13-18, 2005. As per the satellite data analysis, shifting is high at Tanda, Bansdih and Ayodhya. The visit was made to Tanda and Bansdih.

At Tanda, discussion was made with local people. They said that in the river mining activities might be reason for shifting. Photographs of the river reach was taken and shown in plates 1 to 4 for two sites. In these plates we can see that a large area is occupied by flood plains. The river course is mainly fluctuating within these flood plains. At some point the river course is changing beyond these flood plain due to heavy discharge. At Bansdih, the river course is having large curve and that may also lead to heavy erosion and thereby shifting of the river course.

3.3 DATA USED

For the present study, remote sensing data and Survey of India (SOI) toposheets were used. The details of the toposheets and satellite data used are given in Table 3.1 to Table 3.2. These data were procured from Survey of India, Dehradun and National Remote Sensing Centre (NRSC), Hyderabad. In the present study, satellite data of the year 1995 was used because non availability of cloud free satellite data of the year 1994.

Table 3.1: List of topographical maps (Ghagara River)

1:250,000 scale		1:50,000 scale	
No.	**Survey Year**	**No.**	**Survey Year**
63 F	1972-73, 1974-75	63 J/1	1972-73
63 J	1972-73, 1974-75	63 J/5	1972-73
63 N	1970-72	63 J/6	1972-73
72 B	1946	63 J/10	1972-73
72 C	1963-64, 1968-70, 1973-76	63 J/14	1974-75
		72 C/1	1963-64, 1968-70
		72 C/5	1963-64,1968-70

Table 3.2: Remote sensing data used for the 1990, 1995, 1999 and 2003 (Ghagara river)

LISSIII			**LISSII**		
Path/Row	**1999/2000**	**2003/2004**	**Path/Row**	**1990**	**1994/1995**
101-53	28/01/2000	14/12/2000	22-50 B1	2/11//1990	22/02/1995
102-53	16/12/1999	25/11/2003	22-50 A1	2/11/1990	22/02/1995
103-53	27/11/1999	30/11/2003	23-49 A2	25/11/1990	28/12/1995
104-53	2/12/1999		23-49 B2	25/11/1990	28/12/1995
PAN			24-49 A1	22/01/1990	23/05/1995
102-53 A	15/12/1999	4/12/2003	24-49 B1	22/01/1990	23/05/1995
103-53 D	17/11/1999	10/12/2004	25-49 B1	23/01/1990	23/04/1995
			25-48 A1	21/04/1990	19/03/1995
			25-48 A2	21/04/1990	19/03/1995
			25-49 A1	08/04/1990	23/04/1994

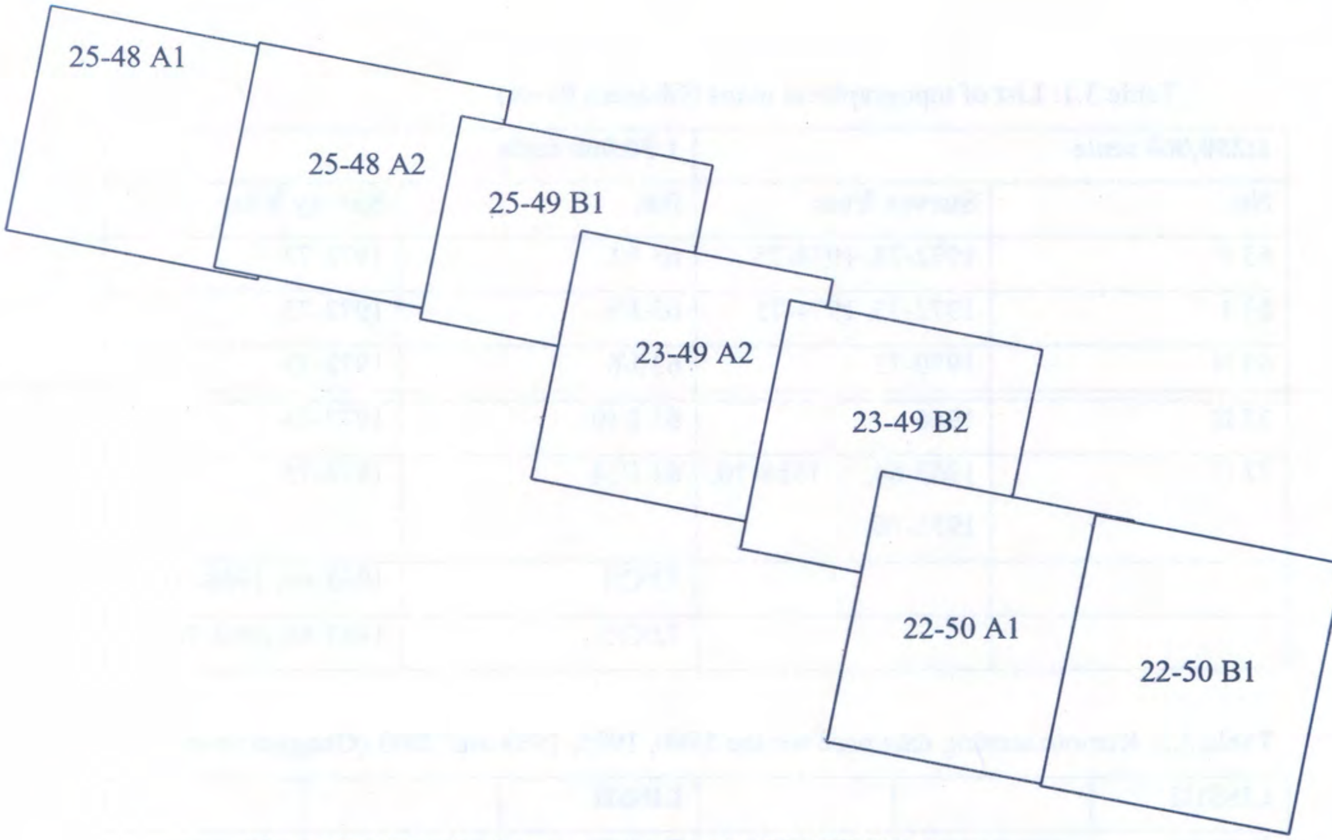


Figure 3.1 The Study area coverage in IRS LISSII Sensor

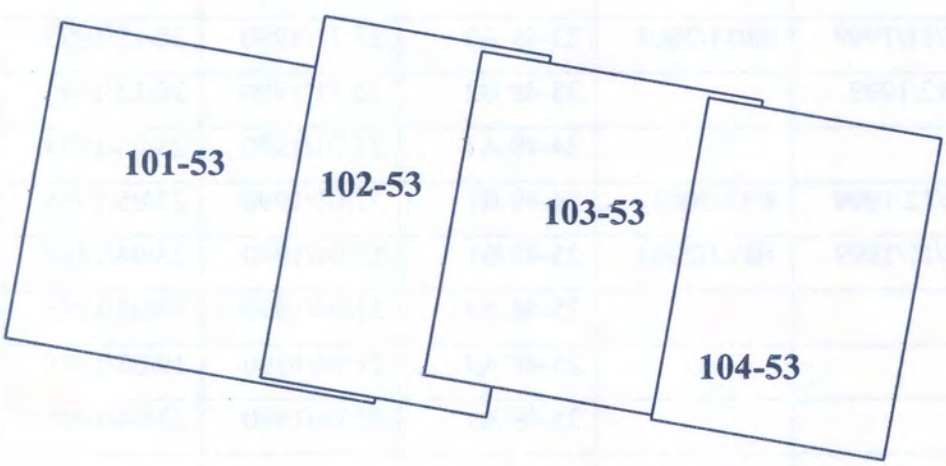


Figure 3.2 The Study area coverage in IRS LISSIII Sensor

Plate 1 : Ghagara river at Tanda

Plate 2 : Ghagara river at Tanda

Plate 3 : Ghagara river at Bansdih showing flood plain (Left bank)

Plate 4 : Ghagara river at Bansdih showing flood plain (Right bank)

CHAPTER 4

METHODOLOGY

In this study, Survey of India toposheets and satellite data have been used to delineate the course of River Ghagara. As mentioned earlier also, the study area is covered in five toposheets viz. 63 F, J, N & 72 B,C. The toposheet nos 63 J and N which covers most part of the river course was surveyed in the years 1970-72, 72-73 and 74-75 and the other toposheet nos 63F was surveyed in the years 1972-73 and 1974-75 while 72 B which was surveyed in the years 1946 and 72 C was surveyed in the year 1963-64, 1968-70 and 1973-76. All the digital maps were geo-referenced with the same projection and then the shifting course of the river was studied in a GIS environment by using the software ERDAS Imagine 8.5.

The remote sensing data were analysed to determine the water spread area, which represents the river course. In the present study, the river course from all the years were delineated using digital analysis of IRS-1C LISS-II and LISS-III and PAN digital data.

4.1 CREATION OF DATA BASE

The river course has been taken from Survey of India toposheets at a scale of 1:250,000. The analog maps were converted to digital form through scanning. These digital data was then edited and converted to vector form using R2V software. The drainage map and boundary maps were then imported to Integrated Land and Water Information System (ILWIS) GIS Software.

4.2 PROCESSING OF REMOTE SENSING DATA

4.2.1 Import and Visualization

The data of IRS satellite of LISS-II and LISSIII sensors for different dates pertaining to the years 1990, 1995, 1999 and 2003 were obtained from NRSC on the CD-ROM media. The data were processed and analysed using the ERDAS Imagine 8.5 software.

Initially, each band was checked individually for the pixel values. The spectral and spatial profile tools of ERDAS Imagine were used to check for the pixel values of water, soil and vegetation and verify whether the bands 1, 2, 3 and 4 correspond to the actual red, green, NIR and MIR bands. It was found that the bands specified by NRSA represent the true bands. Subsequently, False Colour Composite's (FCC's) of bands 3, 2 and 1 were prepared for all the scenes and used.

4.2.2 Geo-referencing

While using the temporal satellite data, it is required to geo-reference the imageries of different dates. These images were first registered by taking various control points from the Survey of India (SOI) toposheets. The projection type used was polyconic. Some clearly identifiable features like crossing of roads, railways, canals, bridges etc. located on toposheets and image was selected as control points. Some of the points, which generated big errors, were deleted and replaced by other points so as to obtain satisfactory geo-referencing. The error in geo-referencing was less than one pixel. Then using swipe function the matching of image with toposheet was checked.

4.2.3 Mosaicing

After geo referencing, the scenes were joined together to cover the full reach of the river course. For this purpose Mosaic function was used in ERDAS. For LISS II data, Ghagara River is covered in seven scenes and after stitching the total product is shown in Figure 4.1 and 4.2 for the year 1990 and 1995. For LISS III data, this river is covered in three scenes and shown in Figure 4.3 and 4.4 for the years 1999 and 2003. The PAN data for two locations Bansdih & Tanda was taken for detailed analysis and shown in Figures 4.5 for the years 1999. No cloud free data for Ayodhya site could be obtained from NRSC.

4.2.4 Separation of Area of Interest (AOI)

The sizes of the full scenes of the satellite remote sensing data were large in comparison to the study area. Hence, the study area was separated from the full image using a utility in the ERDAS Imagine software, namely, area of interest (AOI). A polygon was digitized which covered the entire study area and some portions surrounding it. The data corresponding to the AOI was saved in a new file. Separation of the area of interest from the full scene resulted in less consumption of computer space and appreciable reduction of analysis time.

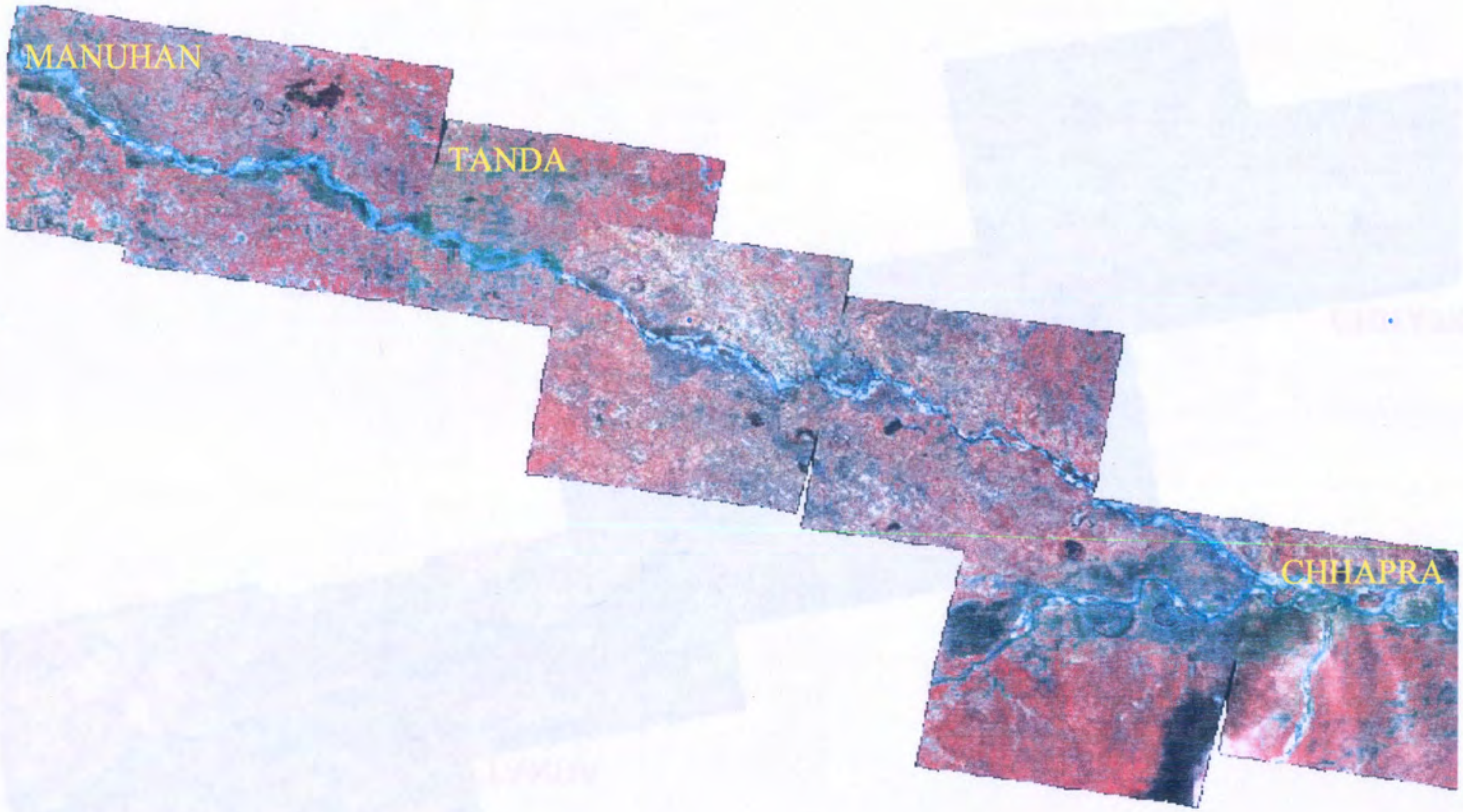


FIGURE 4.1 MOSAIC OF FCC OF GHAGARA RIVER OF 1990

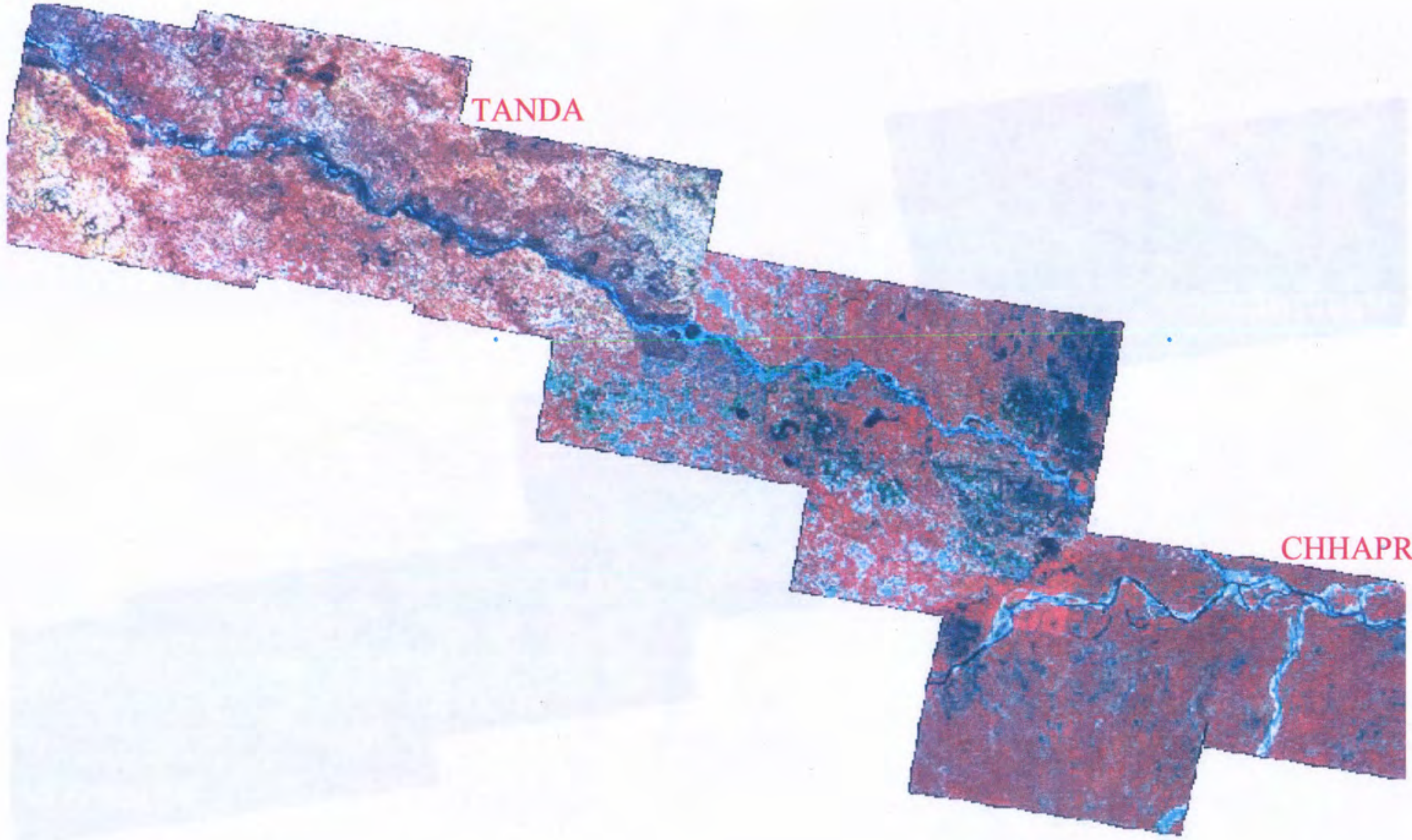


FIGURE 4.2 MOSAIC OF FCC OF GHAGARA RIVER OF 1995

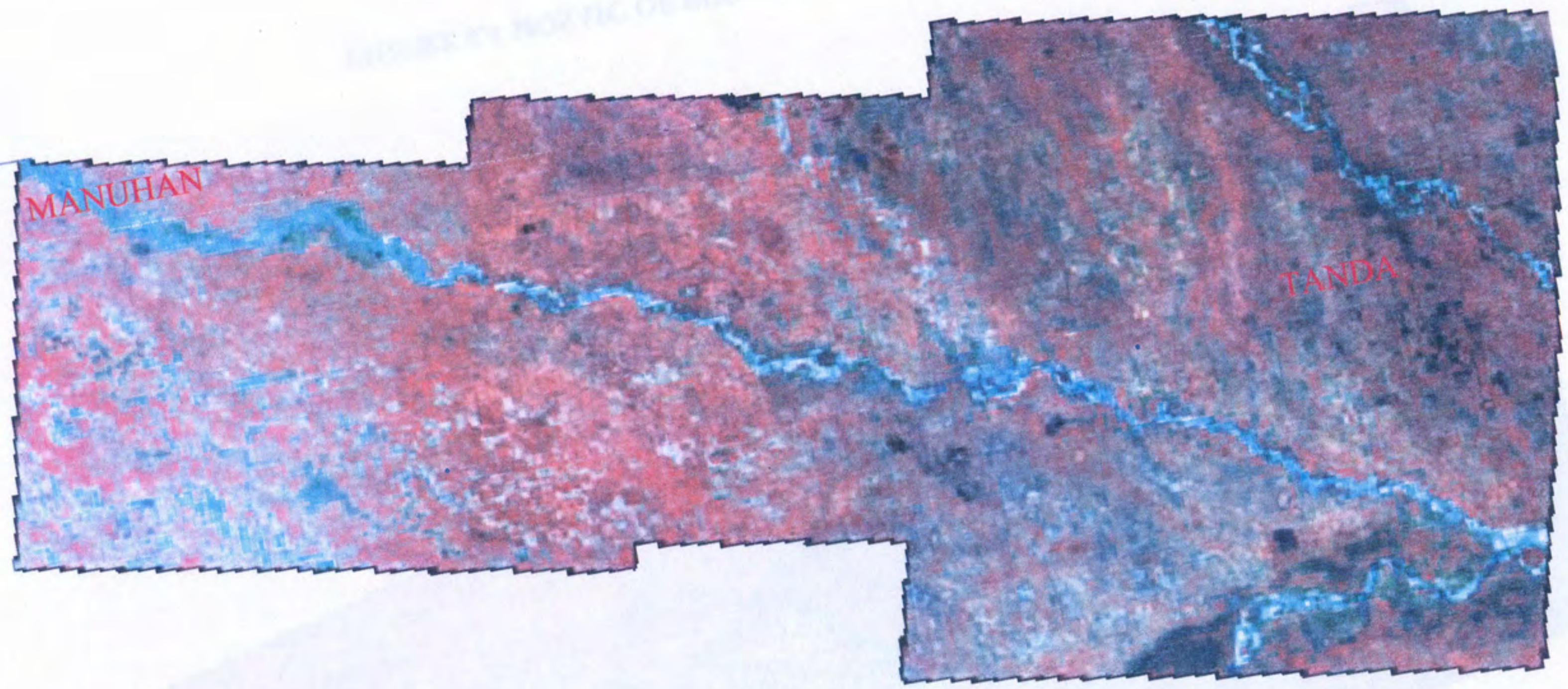


FIGURE 4.3 MOSAIC OF FCC OF GHAGARA RIVER OF 1999

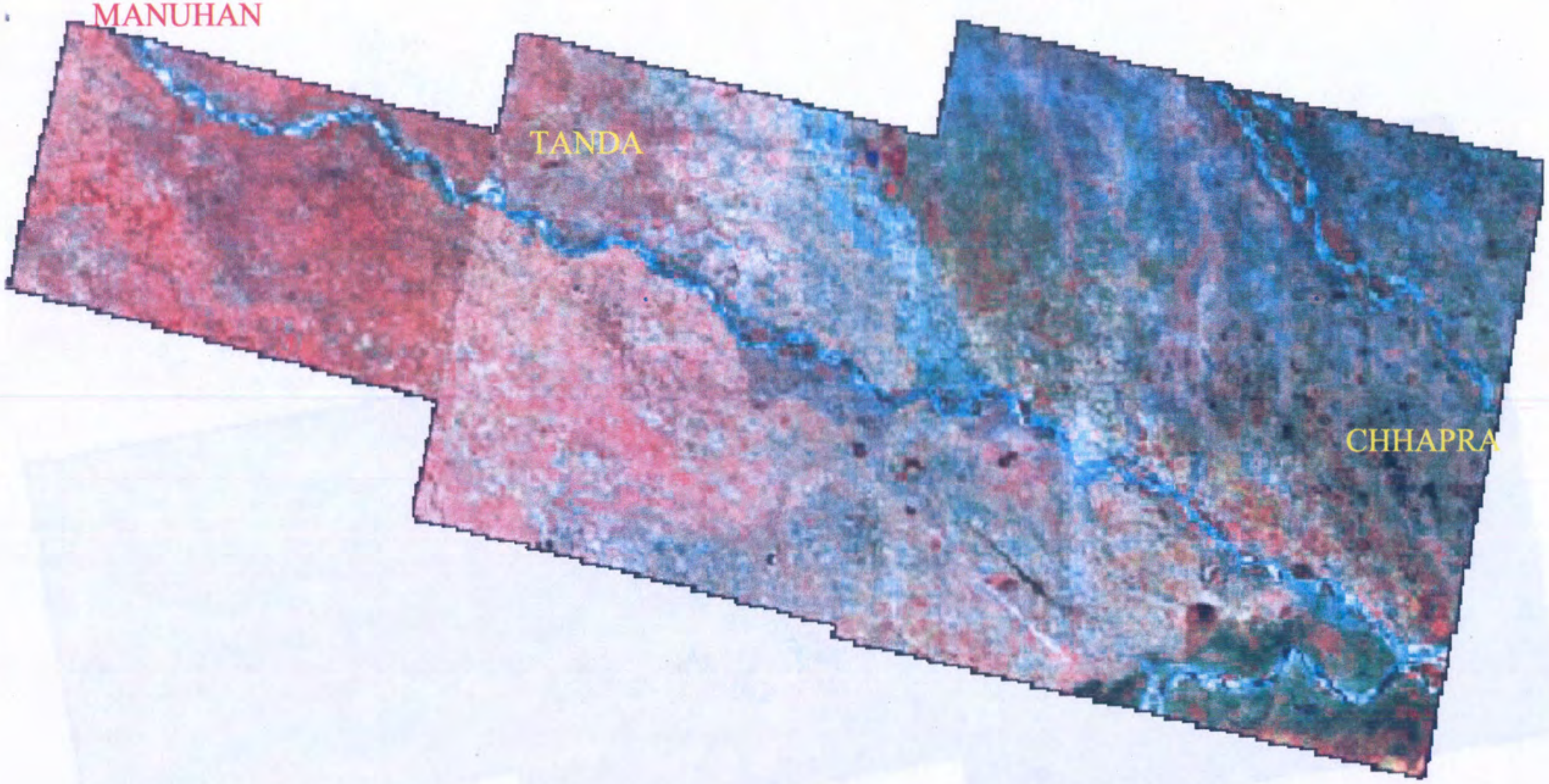


FIGURE 4.4 MOSAIC OF FCC OF GHAGARA RIVER OF 2003

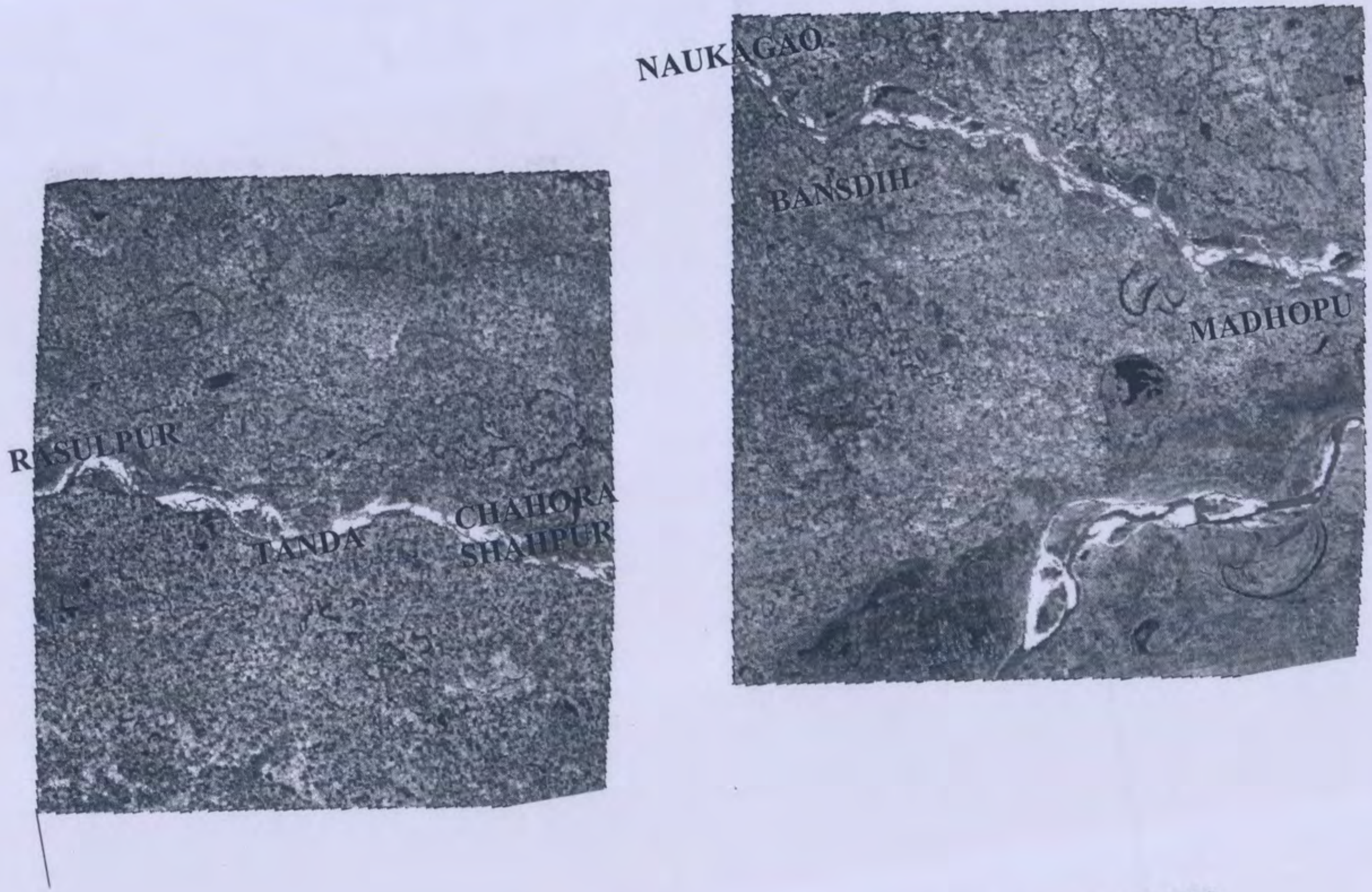


FIGURE 4.5: PAN IMAGE OF GHAGARA RIVER AT TANDA AND BANSDIH 1999

4.3 DELINEATION OF RIVER COURSE FROM REMOTE SENSING DATA

The remote sensing data were analysed to determine the water spread area, which represents the river course. There are two techniques of remote sensing data interpretation, i.e. visual and digital, for delineation of the water spread area. The visual techniques are purely based on the interpretative capability of the analyst and it is not possible to use the information of different bands, after the visual product is generated. Around the periphery of the water spread area, the wetland appears very similar to the water pixels and it becomes very difficult for the interpretator to decide whether a pixel near the periphery is to be classified as water or land. Using digital techniques, the information of different bands can be utilised to the maximum extent and consistent analysis can be carried out over the entire area. It is also easy to compute the water spread area. For these reasons, digital techniques are superior and are gaining recognition now-a-days.

In the present study the river course from all the years was delineated using digital analysis of IRS-1C LISS-II, LISS-III & PAN digital data in the Digital Image Processing (DIP) Software – ERDAS Imagine 8.5.

4.3.1 IDENTIFICATION OF WATER AREA

There are numerous vegetation indices developed to estimate vegetation cover/water area etc. with the remotely sensed imagery. A vegetation index is a number that is generated by some combination of remote sensing bands. The most common spectral index used to evaluate vegetation cover is the Normalized Difference Vegetation Index (NDVI). McFeeters (1996) developed an index similar to the NDVI, which is called the NDWI. This stands for the Normalized Difference Water Index. Any instrument having a green band and a near infrared band can apply this index. The NDWI was derived using principles similar to those that were used to derive the NDVI. The NDWI is calculated as follows:

$$NDWI = \frac{(GREEN - NIR)}{(GREEN + NIR)} \qquad (2)$$

where GREEN is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation. The selection of these wavelengths was done to: (1) maximize the typical reflectance of water features by using green light wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features. When equation (2) is used to process a multispectral satellite image that contains a reflected visible green band and an NIR band, water features have positive values; while soil and terrestrial vegetation features have zero or negative values, owing to their typically higher reflectance of NIR than green light. Image processing software can easily be configured to delete negative values. This effectively eliminates the terrestrial vegetation and soil information and retains the open water information for analysis. The range of NDWI is then from zero to one. Multiplying equation (2) by a scale factor (e.g. 255) enhances the resultant image for visual interpretation. Now in the output obtained water related features were identified.

After NDWI analysis, water spread area has been obtained and the river course has been delineated. The river course obtained in this way is having gaps in some parts, which have been improved manually using digitizing tools in ERDAS. The above methodology is depicted in the form of flow chart in Figure 4.6.

4.4 COMPUTATION OF SHIFTING

Shifting of River is calculated with the help of offsets drawn from a base line. The river course as obtained from ERDAS has been exported to ILWIS software. The base line has been drawn connecting first and last point of the river reach. Then at a regular interval of 5 kms, offsets have been drawn from base line. The length offsets have been measured with respect to both the banks. Offsets at fixed interval of the both riverbanks were measured on the topographical maps as well as on the maps prepared from satellite data. From these measurements, the respective shifts of the both the left and the right banks were computed.

The offsets from Manuhan to Pura are shown in Figure 4.7 for the river. Shifting is calculated by:

Shifting = offset distance for map – offset distance for image

The from Pura to Belghat are shown in Figure 4.8 for the river. Details for offsets and shifting are given in Table 4.1. There are some gaps in this table, they are because the cloud free satellite data of these data were not available.

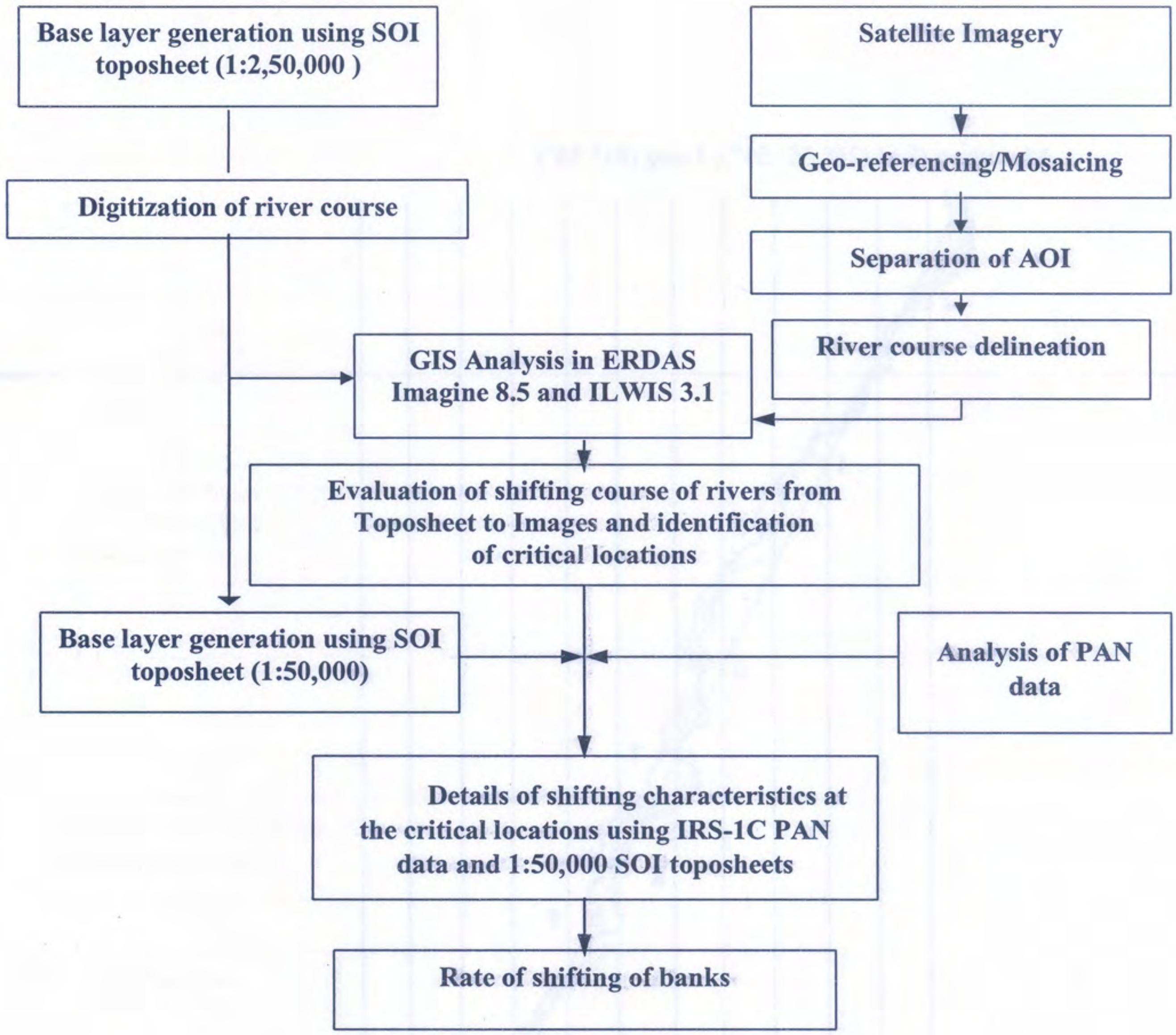


Figure 4.6 : Flow chart showing details of methodology for delineation of river course

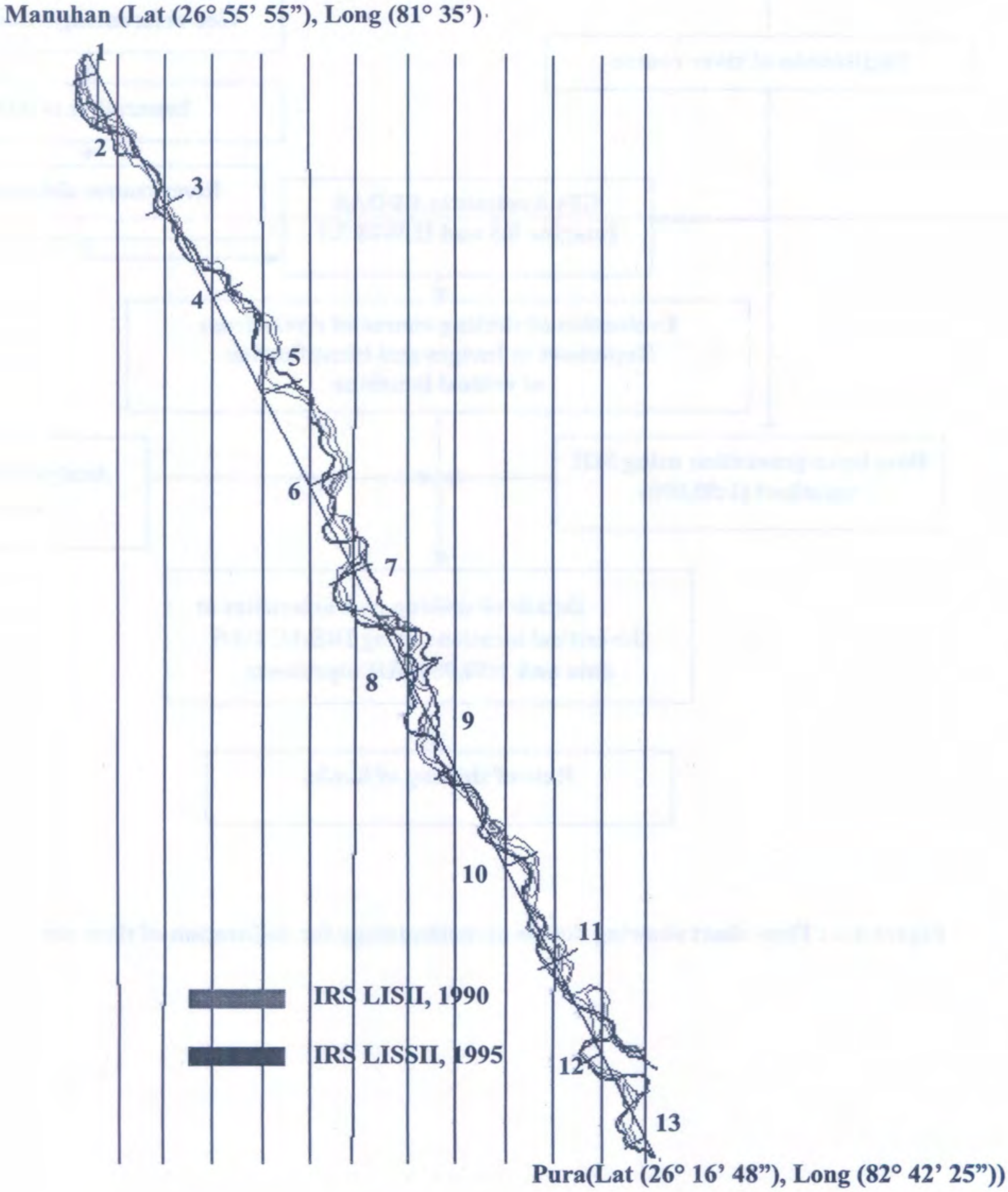


Figure 4.7 OFFSETS GHAGARA RIVER (Between Manuhan and Pura)

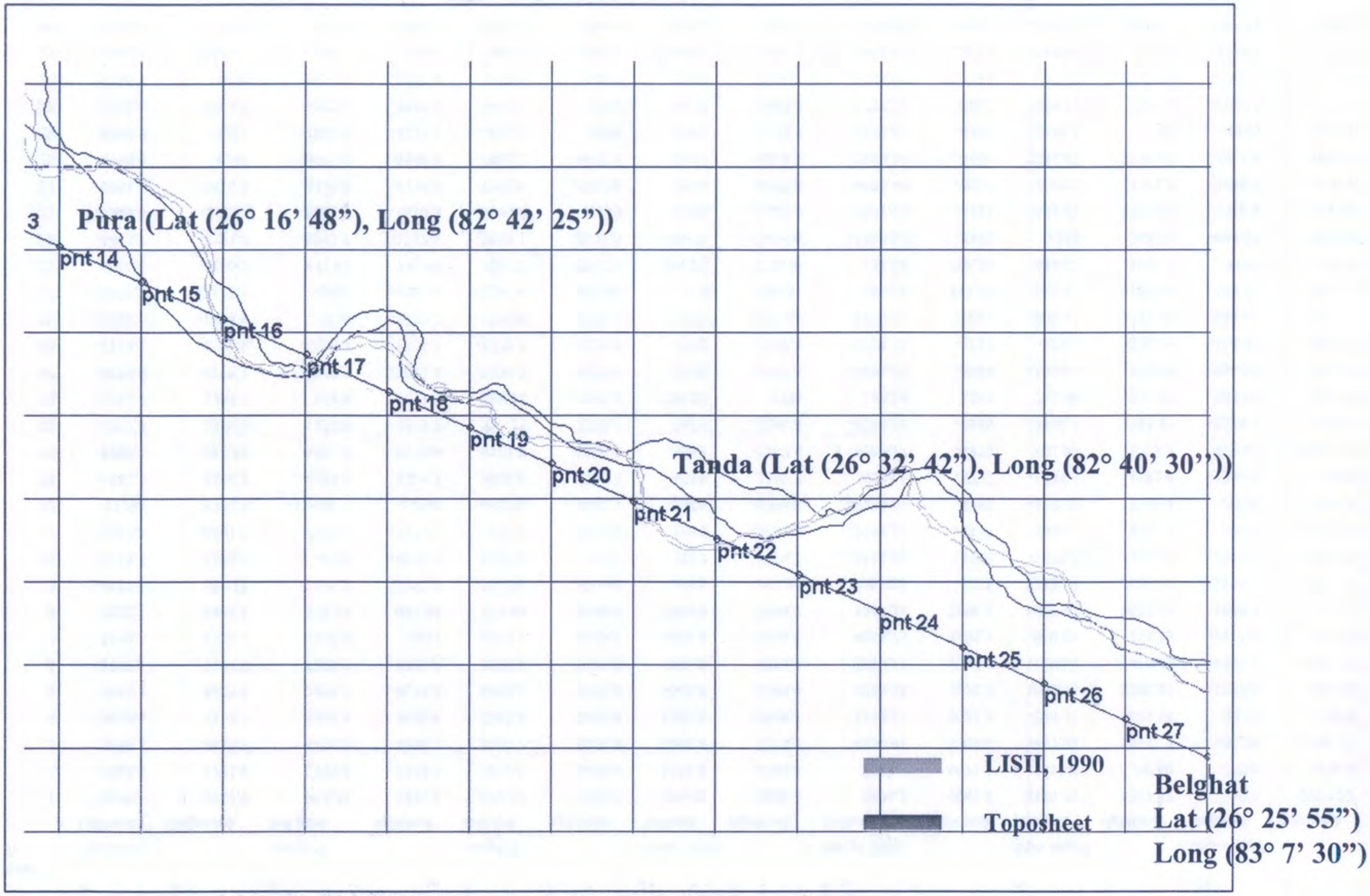


Figure 4.8 OFFSETS GHAGARA RIVER (Between Pura to Belaghat)

Table 4.1 : Length of offsets and shifting (meters) at an interval of 5 kms from the starting point for Ghagara river (LISSIII data)

Point No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Toposheet		image90		image95		Image 1999		Image 2003		topo-img90		topo-img95	
	Leftbank	Rightbank	left bank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank
1	2089.5	3212.9	903.35	1441.2	672.55	1133.7	404.43	2606.3	2606.3	4044.3	1186.19	1771.77	1417	2079.22
2	3864.5	5751.8	5380.4	5822.3	5572.5	6206.6	5639.5	6785.4	2538.9	6875.3	-1515.9	-70.49	-1708	-454.8
3	5954.1	6830.3	4496.5	4996.1	5053.7	5341.9	2965.8	7279.7	4650.91	7369.6	1457.61	1834.25	900.36	1488.37
4	5010.4	6358.5	5303.5	5668.6	7167.4	7436.4	5527.2	7998.7	5774.31	8021.1	-293.11	689.88	-2157	-1078
5	4628.4	6425.9	2824.7	4035.3	6168.2	6610.2	6043.9	6740.4	5796.78	6852.8	1803.75	2390.61	-1539.8	-184.28
6	3797.1	7144.9	5303.5	5726.3	5226.6	5687.8	4403.8	6875.3	3999.33	6987.6	-1506.4	1418.62	-1429.5	1457.05
7	3190.5	4785.7	4150.6	4631	4304.3	4650.2	4021.8	4785.7	4066.73	4898.1	-960.09	154.75	-1113.8	135.53
8	2022.1	3864.5	192.16	941.56	576.46	1498.8	359.49	1954.7	1213.28	2696.2	1829.97	2922.96	1445.7	2365.7
9	-1977.2	584.17	-3189.8	-2882.3	-807.06	-499.61	-1955	-381.96	-2269.28	-1056	1212.59	3466.51	-1170.1	1083.78
10	-6178.7	-3280.4	-4900	-4592.5	-5207.4	-4727	-5617	-4134.1	-5414.82	-3999	-1278.8	1312.18	-971.31	1446.69
11	-7639.2	-6201.2	-7225.1	-7071.3	-7840	-7436.4	-8560	-6201.2	-7751.51	-6314	-414.1	870.13	200.8	1235.23
12	-11796	-7908.8	-11318	-11068	-6667.8	-5822.3	-8246	-5796.8	-8200.87	-5842	-477.78	3159.4	-5128	-2086.5
13	-6583.2	-5886.7	-4688.6	-4304.3	-3631.8	-2286.7	-4786	-3392.7	-4583.5	-3797	-1894.6	-1582.4	-2951.5	-3600
14	-5909.1	-381.96	-6341.2	-6110.6	-6321.9	-5668.6	-6583	-5257.6	-6583.17	-4876	432.03	5728.6	412.81	5286.64
15	-1977.2	2359.2	1152.9	1575.7	557.25	2325.1	-3325	2246.8	-3280.35	-1820	-3130.1	783.47	-2534.5	34.06
16	876.26	1303.2	614.9	1037.6	288.23	1441.2	134.81	1393	112.34	1393	261.36	265.51	588.03	-138.02
17	-4875.6	-4179.1	-2959.2	-2613.3	-3939.2	-3420.4	-4965	-3707.2	-6493.29	-3078	-1916.4	-1565.8	-936.39	-758.69
18	-2134.5	-1595.2	-1806.3	-1364.3	-1979.2	-1229.8	-1842	-1348.1	-1752.52	-1213	-328.2	-230.93	-155.26	-365.44
19	-2426.6	-1864.9	-1518	-1133.7	-1594.9	-1076.1	-3303	-943.66	-4179.07	-1011	-908.53	-731.14	-831.66	-788.79
20	-3078.2	-2112.1	-2402	-1921.6	-3247.4	845.49	0	696.51	157.28	853.79	-676.27	-190.56	169.22	-2957.6
21	-4044.3	-1280.7	441.96	710.98	153.72	691.76	314.55	876.26	112.34	786.38	-4486.2	-1991.7	-4198	-1972.4
22	-4448.7	-2381.6	-3093.7	-2747.8	-3843.1	-2632.5	4403.8	-2426.6	-3302.82	-2472	-1355	366.21	-605.57	250.92
23	-7369.6	-6223.7	-8051.3	-7820.8	-6840.8	-6149	-6718	-6111.3	-7571.76	-6111	681.79	1597.07	-528.8	-74.66
24	-9481.6	-7414.5	-6840.8	-6110.6	-7032.9	-5937.6	-7864	-6043.9	-8470.49	-6044	-2640.8	-1303.9	-2448.7	-1476.9
25	-4740.8	-4269	-6975.3	-6648.6	-7052.1	-4477.2	-5437	-4516.1	-5369.89	-4494	2234.47	2379.65	2311.4	208.29
26	-6043.9	-4224	-4861.6	-4227.4	-4803.9	-4189	-4988	-4179.1	-5167.67	-4224	-1182.4	3.42	-1240	-35.01
27	-5751.8	-3864.5	-5092.1	-3939.2	-5476.5	-3920	-5617	-3909.5	-5774.31	-3887	-659.71	74.68	-275.39	55.46
28	-3280.4	-1438	-3535.7	-2709.4	-3458.9	-1133.7	-3595	-1280.7	-3505.03	-1168	255.32	1271.44	178.51	-304.24
29	-3662.3	2336.7	1787.1	2344.3	96.08	2863.1	1145.9	3415.2	1168.34	2201.9	-5449.4	-7.61	-3758.4	-526.43
30	-1190.8	67.4	-172.94	557.25	-653.33	1364.3	-516.8	1100.9	-674.04	1370.6	-1017.9	-489.85	-537.48	-1296.9

Point No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N
31	-4111.7	-1190.8	-2824.7	-1691	-1844.7	-1402.7	-3056	-966.13	-3482.56	-2764	-1287	500.16	-2267	211.93
32	-5684.4	-2156.9	-595.68	0	-5649.4	480.39	-5617	-5235.1	-5751.84	-4628	-5088.8	-2156.9	-35.05	-2637.3
33	-4875.6	-2201.9	-5015.3	-4458	-4631	-4400.4	-4921	-3055.7	-5010.4	-2382	139.68	2256.14	-244.63	2198.49
34	-5639.5	-988.6	-5783.9	-3497.2	-5745.5	-5418.8	-5707	-5032.9	-5684.44	-4831	144.4	2508.64	105.97	4430.2
35	-3033.2	494.3	-3151.4	-1863.9	-3132.1	-2959.2	-3056	-1707.6	-2988.26	-719	118.16	2358.21	98.94	3453.5
36	-2314.2	-337.02	710.98	1460.4	-787.84	1210.6	-1303	381.96	-1707.58	-808.9	-3025.2	-1797.4	-1526.4	-1547.6
37	-5010.4	-2831	-4150.6	-2786.3	-3920	-3074.5	-4224	3033.2	-4358.82	-3325	-859.83	-44.73	-1090.4	243.51
38	-8111	-5414.8	-7955.3	-5380.4	-7860	-5514.9	-8089	-4920.5	-6156.27	-4718	-155.74	-34.45	-251.02	100.06
39	-7818.9	-4583.5	-6610.2	-3900.8	-5418.8	-4169.8	-5280	-3931.9	-5167.67	-3954	-1208.7	-682.73	-2400.1	-413.71
40	-13885	-8313.2	-10991	-7167.4	-10050	-6975.3	-11481	-5864.2	-11301.5	-10111	-2894	-1145.8	-3835.6	-1338
41	-14380	-12492	-14373	-12567	-14373	-13412	-14155	-12447	-14154.9	-12807	-6.34	74.71	-6.34	920.2
42	-13121	-9077.1	-14450	-11145	-11991	-11030	-15054	-10066	-15233.4	-10380	1328.74	2067.92	-1130.9	1952.63
43	-12492	-8582.8	-11837	-10184	-10645	-10261	-11773	-10066	-11908.1	-10560	-655.68	1601.44	-1847.1	1678.3
44	-11594	-8987.3	-10261	-9915.3	-10761	-10069	-10740	-9481.6	-12357.5	-9392	-1332.4	927.99	-832.82	1081.72
45	-7234.7	-5167.7	-6033.7	-4996.1	-5649.4	-5034.5	-7100	-4987.9	-7055	-4741	-1201	-171.61	-1585.4	-133.18
46	-8582.8	-7279.7	-8839.2	-7225.1	-8032.1	-7340.4	-8718	-7189.8	-8740.11	-7212	256.35	-54.61	-550.71	60.68
47	-9930.9	-8313.2	-13220	-8493.3	-9530.9	-8301.1	-9639	-8088.5	-9301.81	-8089	3289.41	180.09	-399.98	-12.07
48	-10201	-7504.4	-13297	-10338	-9185.1	-8992.9	-10358	-8313.2	-10312.9	-8246	3096.66	2833.63	-1015.5	1488.54
49	-11684	-10920	-11453	-10688	-11395	-11030	-11549	-10066	-11593.6	-9953	-231.02	-231.14	-288.67	110.24
50	-10695	-8582.8	-10569	-7109.8	-6302.7	-6110.5	-9347	-6852.8	-9571.43	-6898	-126.26	-1473.1	-4392.1	-2472.3
51	-9122.1	-7841.4	-8070.6	-6341.2	-5476.5	-5188.2	-6875	-4987.9	-6515.76	-4921	-1051.5	-1500.2	-3645.6	-2653.2
52	-6515.8	-2471.5	-3843.1	-3305.1	-2728.6	-2709.4	-4134	-1078.5	-4830.65	-3033	-2672.7	833.58	-3787.2	237.9
53	-2920.9	0	-3343.5	-2805.5			-3775	-2718.7	-3842.05	-2696	422.65	2805.48		
54	-3662.3	-2134.5	-2536.5	-768.62			-4808	-2112	-5167.67	-1797	-1125.8	-1365.9		
55	-7324.6	-4606	-6302.7	-3074.5			-3954	-2741.1	-4044.27	-2179	-1021.9	-1531.5		
56	-6852.8	-3954.4	-6840.8	-5764.7			-7010	-5482.2	-5954.06	-4741	-12.03	1810.29		
57	-6403.4	-4740.8	-6379.6	-5495.7			-6606	-4066.7	-6695.51	-4673	-23.84	754.88		
58	-5841.7	-1258.2	-4765.5	-2805.5			-5123	-1438	-5639.5	-4112	-1076.3	1547.26		
59	-2898.4	-786.38	-3036.1	-1306.7	-2882.3	-1037.6	-3235	-1033.5	-3325.28	-1865	137.68	520.28	-16.05	251.26
60	-1325.6	1213.3	-13067	1037.6		1998.4		-1393		-1528	11741	175.64		

Table 4.1 : Length of offsets and shifting (meters) at an interval of 5 kms from the starting point for Ghagara river (LISSIII

	O	P	Q	R	S	T	U	V	W	X	Y	Z
	Topo-Image 1999			Topo-Image2003		img90-img95		img95-img99		Image1999-2003		Image90-2003
	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank
1	1685.1	606.64	-516.76	-831.33	230.8	307.45	268.12	-1472.6	-2201.9	-1438	-1702.95	-2603.1
2	-1775	-1033.5	1325.62	-1123.41	-192.15	-384.31	-66.98	-578.74	3100.6	-89.87	2841.47	-1052.92
3	2988.3	-449.37	1303.15	-539.24	-557.25	-345.88	2087.91	-1937.7	-1685.1	-89.87	-154.46	-2373.49
4	-516.76	-1640.2	-763.91	-1662.65	-1863.91	-1767.8	1640.26	-562.25	-247.15	-22.44	-470.8	-2352.53
5	-1415.5	-314.55	-1168.3	-426.89	-3343.52	-2574.9	124.28	-130.27	247.15	-112.34	-2972.09	-2817.5
6	-606.64	269.62	-202.21	157.28	76.87	38.43	822.88	-1187.4	404.43	-112.34	1304.18	-1261.34
7	-831.32	0	-876.25	-112.34	-153.73	-19.22	282.5	-135.53	-44.93	-112.34	83.84	-267.09
8	1662.6	1909.79	808.85	1168.34	-384.3	-557.26	216.97	-455.91	-853.79	-741.45	-1021.12	-1754.62
9	-22.47	966.13	292.08	1640.17	-2382.73	-2382.7	1147.67	-117.65	314.55	674.04	-920.51	-1826.34
10	-561.7	853.79	-763.92	718.98	307.45	134.51	409.61	-592.9	-202.22	-134.81	514.84	-593.2
11	921.19	0	112.34	112.34	614.9	365.1	720.39	-1235.2	-808.85	112.34	526.44	-757.79
12	-3550	-2112	-3594.9	-2067.07	-4650.18	-5245.9	1578	-25.55	-44.94	44.94	-3117.12	-5226.47
13	-1797.5	-2494	-1999.7	-2089.53	-1056.86	-2017.6	1153.96	1106	-202.21	404.43	-105.11	-507.18
14	674.05	4875.59	674.05	4493.63	-19.22	-441.96	261.24	-411.05	0	-381.96	242.02	-1234.97
15	1348.1	112.34	1303.15	4179.07	595.69	-749.41	3882.53	78.28	-44.93	4066.73	4433.29	3395.6
16	741.45	-89.87	763.92	-89.87	326.67	-403.53	153.42	48.15	22.47	0	502.56	-355.38
17	89.87	-471.83	1617.7	-1100.93	980	807.06	1026.26	286.86	1527.8	-629.1	3534.09	464.82
18	-292.08	-247.15	-381.95	-381.96	172.94	-134.51	-136.82	118.29	-89.87	-134.81	-53.75	-151.03
19	876.26	-921.2	1752.51	-853.79	76.87	-57.65	1707.92	-132.41	876.25	67.41	2661.04	-122.65
20	-3078.2	-2808.6	-3235.5	-2965.91	845.49	-2767.1	-3247.44	148.98	-157.28	-157.28	-2559.23	-2775.35
21	-4358.8	-2156.9	-4156.6	-2067.06	288.24	19.22	-160.83	-184.5	202.21	89.88	329.62	-75.4
22	-8852.5	44.94	-1145.9	89.88	749.41	-115.29	-8246.88	-205.98	7706.6	44.94	209.11	-276.33
23	-651.58	-112.35	202.21	-112.35	-1210.59	-1671.7	-122.78	-37.69	853.79	0	-479.58	-1709.42
24	-1617.7	-1370.6	-1011.1	-1370.56	192.16	-172.94	830.94	106.31	606.64	0	1629.74	-66.63
25	696.51	247.15	629.11	224.68	76.88	-2171.4	-1614.84	38.86	-67.4	-22.47	-1605.36	-2154.97
26	-1056	-44.94	-876.26	0	-57.65	-38.43	184.03	-9.93	179.74	44.94	306.12	-3.42
27	-134.8	44.94	22.47	22.47	384.32	-19.22	140.59	-10.52	157.27	-22.47	682.18	-52.21
28	314.55	-157.28	224.68	-269.62	-76.81	-1575.7	136.04	146.96	-89.87	-112.34	-30.64	-1541.06

	O	P	Q	R	S	T	U	V	W	X	Y	Z
29	-4808.2	-1078.5	-4830.7	134.81	1690.97	-518.82	-1049.8	-552.04	-22.46	1213.28	618.71	142.42
30	-674.04	-1033.5	-516.77	-1303.16	480.39	-807.06	-136.56	263.37	157.27	-269.62	501.1	-813.31
31	-1056	-224.68	-629.11	1572.77	-979.99	-288.23	1210.97	-436.61	426.89	1797.45	657.87	1072.61
32	-67.4	3078.14	67.4	2471.55	5053.71	-480.39	-32.35	5715.5	134.8	-606.59	5156.16	4628.49
33	44.93	853.79	134.81	179.74	-384.31	-57.65	289.56	-1344.7	89.88	-674.05	-4.87	-2076.4
34	67.41	4044.26	44.94	3842.05	-38.43	1921.56	-38.56	-385.94	-22.47	-202.21	-99.46	1333.41
35	22.47	2201.88	-44.94	1213.28	-19.22	1095.29	-76.47	-1251.6	-67.41	-988.6	-163.1	-1144.93
36	-1011.1	-718.98	-606.64	471.83	1498.82	249.81	515.31	828.62	404.43	1190.81	2418.56	2269.24
37	-786.39	-5864.2	-651.58	494.29	-230.59	288.24	304.03	-6107.7	134.81	6358.48	208.25	539.02
38	-22.47	-494.3	-1954.7	-696.51	-95.28	134.51	228.55	-594.36	-1932.3	-202.21	-1798.99	-662.06
39	-2538.9	-651.58	-2651.2	-629.11	-1191.37	269.02	-138.79	-237.87	-112.34	22.47	-1442.5	53.62
40	-2404.1	-2449	-2583.8	1797.45	-941.56	-192.16	1431.46	-1111.1	-179.74	4246.48	310.16	2943.24
41	-224.68	-44.86	-224.68	314.5	0	845.49	-218.34	-965.06	0	359.36	-218.34	239.79
42	1932.3	988.6	2112.01	1303.15	-2459.59	-115.29	3063.11	-964.03	179.75	314.55	783.27	-764.77
43	-719.18	1482.9	-584.38	1977.2	-1191.37	76.86	1127.87	-195.4	134.8	494.3	71.3	375.76
44	-853.79	494.3	763.92	404.42	499.61	153.73	-20.97	-587.42	1617.7	-89.88	2096.35	-523.57
45	-134.81	-179.74	-179.74	-426.89	-384.31	38.43	1450.54	-46.56	-44.93	-247.15	1021.3	-255.28
46	134.81	-89.87	157.28	-67.41	-807.06	115.29	685.52	-150.55	22.47	22.46	-99.07	-12.8
47	-292.09	-224.68	-629.11	-224.68	-3689.39	-192.16	107.89	-212.61	-337.02	0	-3918.52	-404.77
48	157.27	808.85	112.34	741.45	-4112.14	-1345.1	1172.75	-679.69	-44.93	-67.4	-2984.32	-2092.18
49	-134.9	-853.79	-89.96	-966.13	-57.65	341.38	153.77	-964.03	44.94	-112.34	141.06	-734.99
50	-1348.1	-1730.1	-1123.4	-1685.11	-4265.86	-999.25	3044.03	742.26	224.68	44.94	-997.15	-212.05
51	-2246.8	-2853.5	-2606.3	-2920.86	-2594.1	-1152.9	1398.8	-200.28	-359.49	-67.41	-1554.79	-1420.63
52	-2381.7	-1393	-1685.2	561.7	-1114.5	-595.68	1405.52	-1630.9	696.51	1954.73	987.53	-271.88
53	853.79	2718.65	921.19	2696.18					67.4	-22.47	498.54	-109.3
54	1145.9	-22.46	1505.36	-337.02					359.49	-314.56	2631.16	1028.83
55	-3370.2	-1864.9	-3280.3	-2426.56					89.88	-561.7	-2258.45	-895.09
56	157.28	1527.84	-898.72	786.39					-1056	-741.45	-886.69	-1023.9
57	202.21	-674.05	292.09	-67.41					89.88	606.64	315.93	-822.29
58	-719	179.74	-202.24	2853.45					516.76	2673.71	874.03	1306.19
59	337.02	247.15	426.89	1078.48	-153.73	-269.02	353.07	-4.11	89.87	831.33	289.21	558.2
60	-1325.6	2606.3	-1325.6	2741.11					0	134.81		

Table 4.2: **Length of offsets and shifting (meters) at an interval of 5 kms from the starting point for Ghagara river (PAN data)**

Point No.	Toposheet(1:50,000)		Pan1999		Pan2003		Topo-Pan1999		Topo-Pan2003		Pan1999-Pan2003	
	Leftbank	Rightbank	Leftbank	Rightbank	Leftbank	Rightbank	Leftbank	Rightbank	Leftbank	Rightbank	Leftbank	Rightbank
1	-391.76	0	-576.75	0	-1371.14	-783.51	184.99	0	979.38	783.51	794.39	783.51
2	-5506.34	-5038.41	-5571.63	-5147.23	-4603.13	-3961.08	65.29	108.82	-903.21	-1077.33	-968.5	-1186.15
3	-2013.19	-1099.09	-1795.55	-957.62	-1741.13	-990.27	-217.64	-141.47	-272.06	-108.82	-54.42	32.65
4	-1588.79	-228.52	-2524.65	-250.29	-3514.92	-3134.04	935.86	21.77	1926.13	2905.52	990.27	2883.75
5	-1501.73	-1001.15	1697.61	2317.89	1654.08	2350.53	-3199.34	-3319.04	-3155.81	-3351.68	43.53	-32.64
6	-1022.92	-282.93	2557.29	2927.28	2426.71	2949.05	-3580.21	-3210.21	-3449.63	-3231.98	130.58	-21.77
7	-1567.02	-217.64	-1490.85	348.23	-554.99	391.76	-76.17	-565.87	-1012.03	-609.4	-935.86	-43.53
8	-3514.92	-2742.29	-2959.93	-2459.35	-3982.85	-2600.82	-554.99	-282.94	467.93	-141.47	1022.92	141.47
9	-5147.23	-4603.13	-3547.56	-3264.63	-4233.13	-3689.03	-1599.67	-1338.5	-914.1	-914.1	685.57	424.4
10	500.58	794.39	-250.29	544.1	-217.64	620.28	750.87	250.29	718.22	174.11	-32.65	-76.18

CHAPTER 5

ANALYSIS AND RESULTS

5.1 DESCRIPTION OF REACHES OF THE RIVERS

As mentioned in the last chapter that offsets at 5 km. interval have been drawn. The total length of the river has been divided in a number of reaches and the details are as follows.

In the river, the total length of Ghagara River from Manuhan to Chappra has been subdivided at an interval of 5 Km. A base line joining these two stations has been drawn. The total length (310 km Manuhan to Chappra) of this base line is subdivided into 10 reaches of 30 Kms length,the last one being 40 Kms. Analysis reach is discussed in the following sections.

0 to 30 km	Reach 1	Manuhan to Mubarakganj
30 to 60 km	Reach 2	Mubarakganj to Ayodhya
60 to 90 km	Reach 3	Ayodhya to Mahuwari
90 to 120 km	Reach 4	Mahuwari to Phulpur (Near Tanda)
120 to 150 km	Reach 5	Phulpur to Ashrafpur (Near Belghat)
150 to 180 km	Reach 6	Ashrafpur to Karokand (Near Golabazar)
180 to 210 km	Reach 7	Karokand to Rasulpur (Near Barhaj)
210 to 240 km	Reach 8	Rasulpur to Ubhaon
240 to 270 km	Reach 9	Ubhaon to Chandpur (Near Bansdih)
270 to 310 km	Reach 10	Chandpur to Chappra

The False Colour Composites of the Year 1990 along with the river course obtained using the year 1995 (shown in red colour) are shown in figures 5.1 and Figure 5.2.

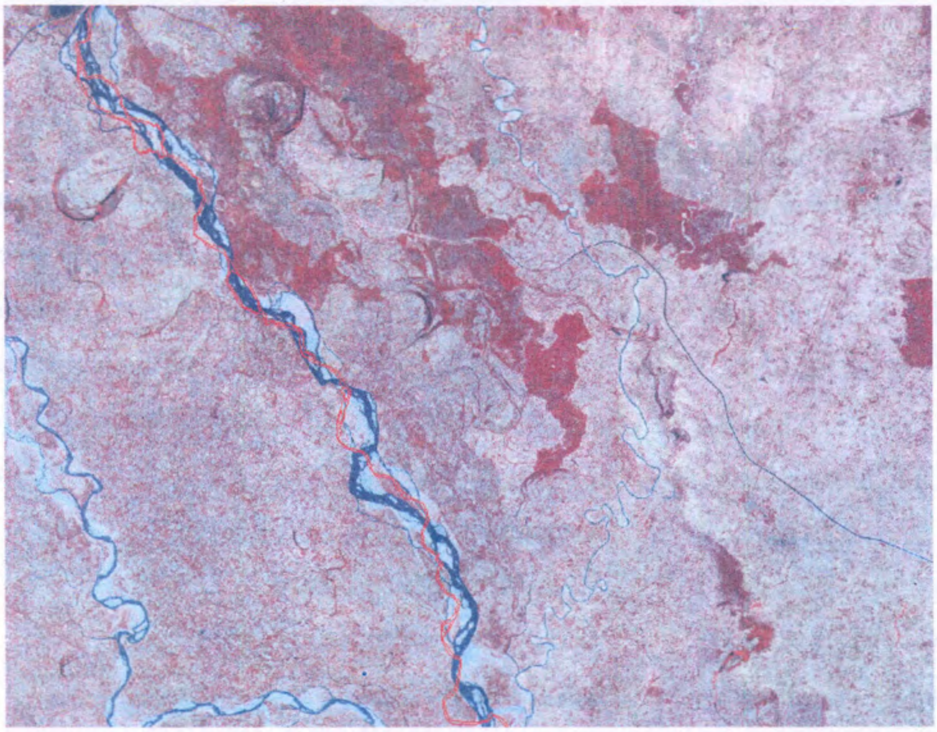


Figure 5.1 False Colour Composite (1990) overlaid by drainage from Satellite data of 1995 (shown in red colour)

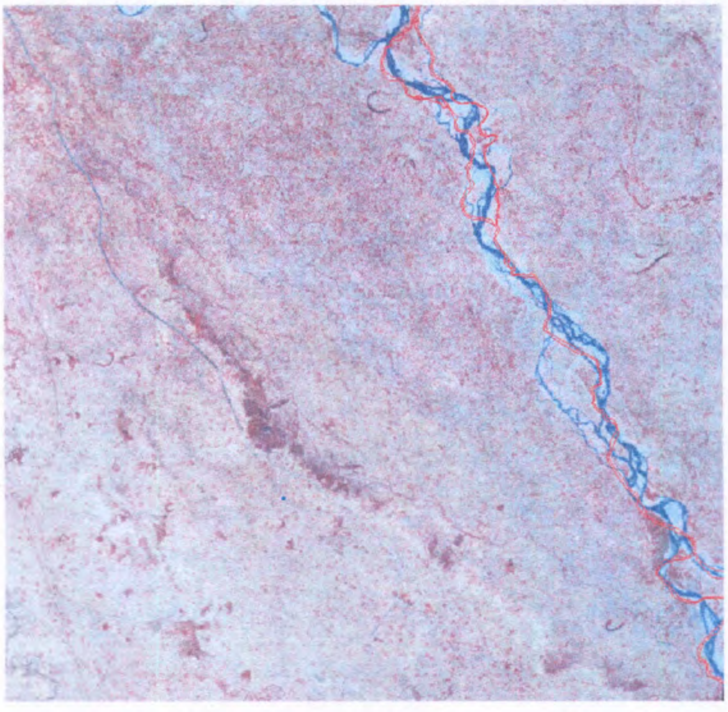


Figure 5.2 False Colour Composite (1990) overlaid by drainage from Satellite data of 1995 (shown in red colour)

5.2 REACH WISE ANALYSIS OF SHIFTING OF RIVER

The shift of both the banks at different chainage (5 kms) is given in the Table 4.1 for LISSIII and in Table 4.2 in for PAN data in the last chapter 4. As discussed earlier also, some of the reaches are having more shift and these are termed as the critical locations. In Ghagara River, shifting is high in almost all reaches; however it is higher in reaches nos 2 to 7 than other reaches. Some of the points or critical locations where shifting is high have been identified and they are at Ayodhya, Tanda, Golabazar, barhaj and Bansdih. The False Colour Composites alongwith the river course obtained using Survey of India toposheets are shown in Figures 5.3 to 5.6 for Ayodhya reach for the years 1990 to 2003. In Figures 5.7 to 5.10, the FCCs along with the drainage from toposheets are shown for the Tanda location for the four years. In Figures 5.11 and 5.12, the shift at Tanda in the years 1990/1995 and 1999/2003 have been illustrated.

The data given in Table 4.1 are also plotted and chainage of 5 kms interval has been taken on abscissa and shifting on ordinate. These shifts in different years for river Ghagara are illustrated through Figures 5.13 to 5.14 for toposheets versus image of different years. Similarly shift of image versus image of different years have been depicted in Figures 5.15 and 5.16. Some of the critical areas identified in the river were further studied using IRS PAN data and also the river course of these reaches was prepared using toposheets at a scale of 1:50,000. The analysis of the same has been presented later in this chapter.

In the following analysis, first the shifting with respect to toposheets has been presented and then shifting in different years with respect to satellite data has been covered. The results here are presented for each reach.

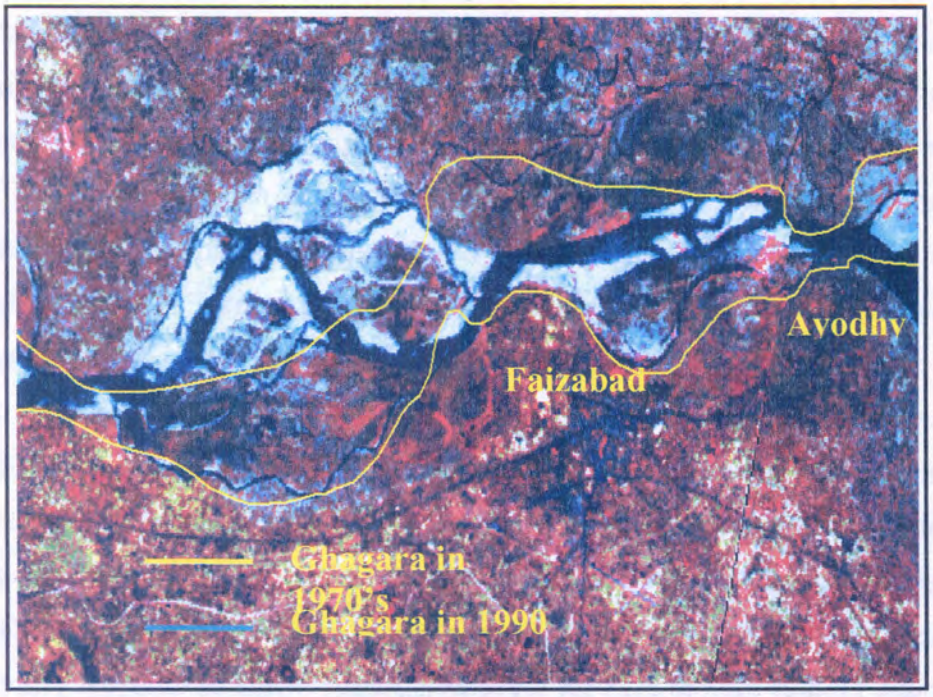


Figure 5.3 False Colour Composite (1990) overlaid by drainage from toposheet (Ayodhya)

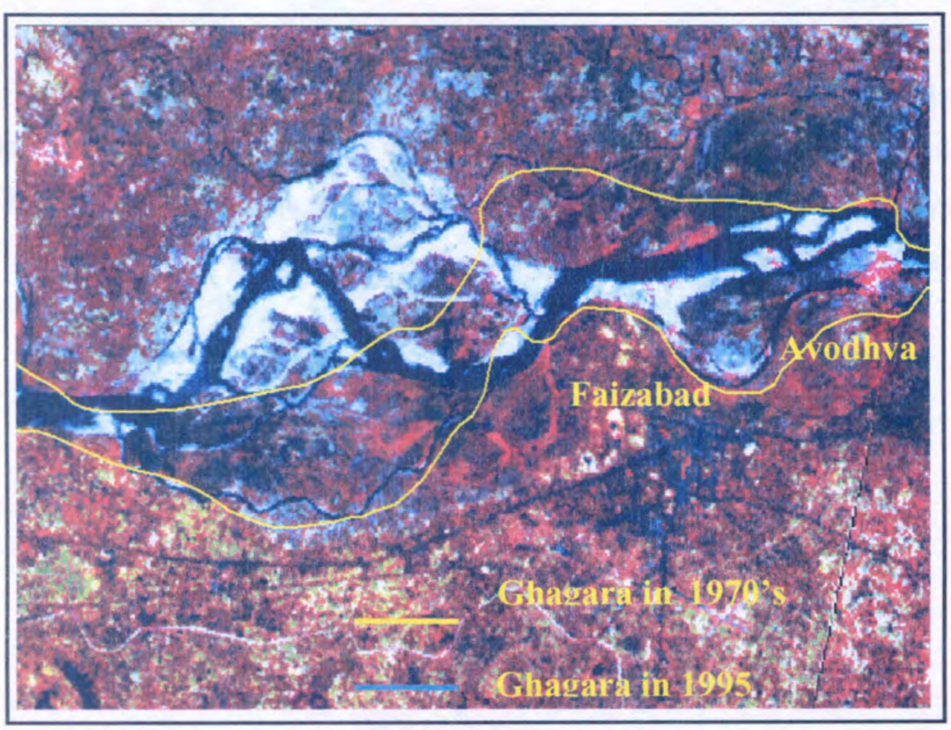


Figure 5.4 False Colour Composite (1995) overlaid by drainage from toposheet (Ayodhya)

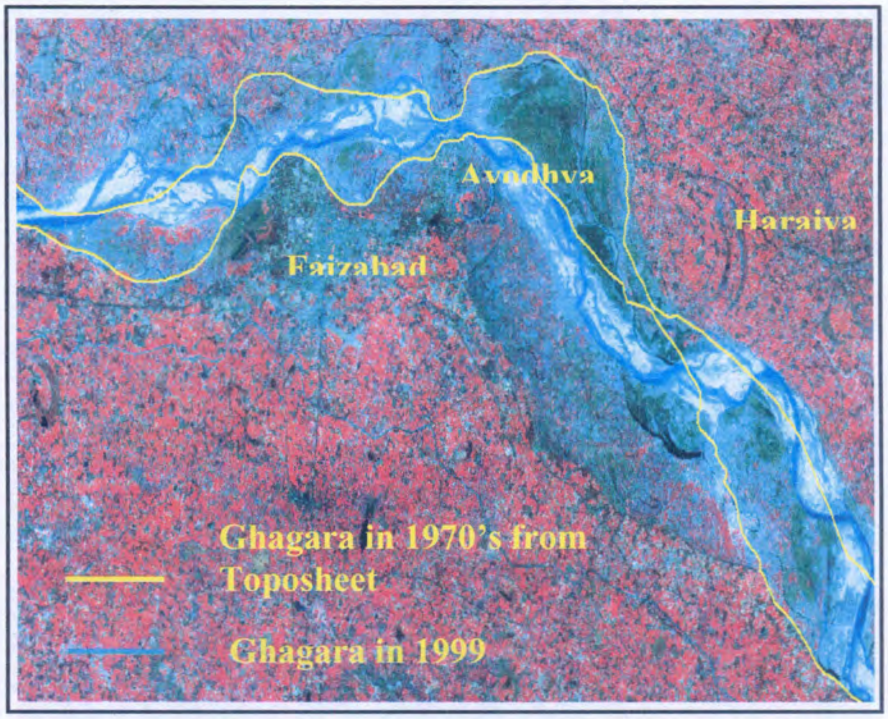


Figure 5.5 False Colour Composite (1999) overlaid by drainage from toposheet (Ayodhya)

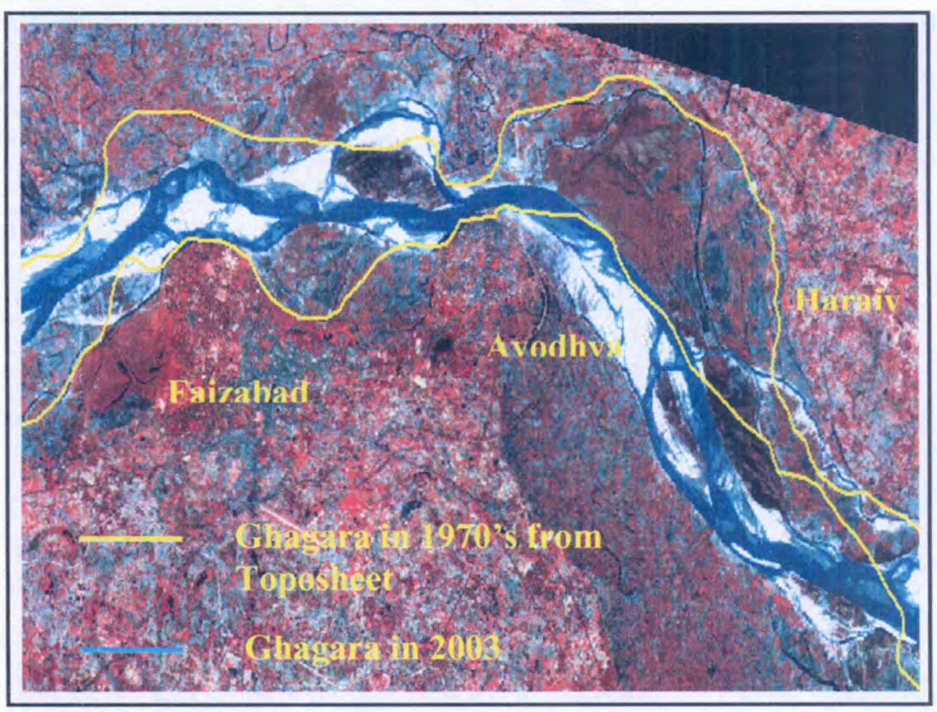


Figure 5.6 False Colour Composite (2003) overlaid by drainage from toposheet (Ayodhya)

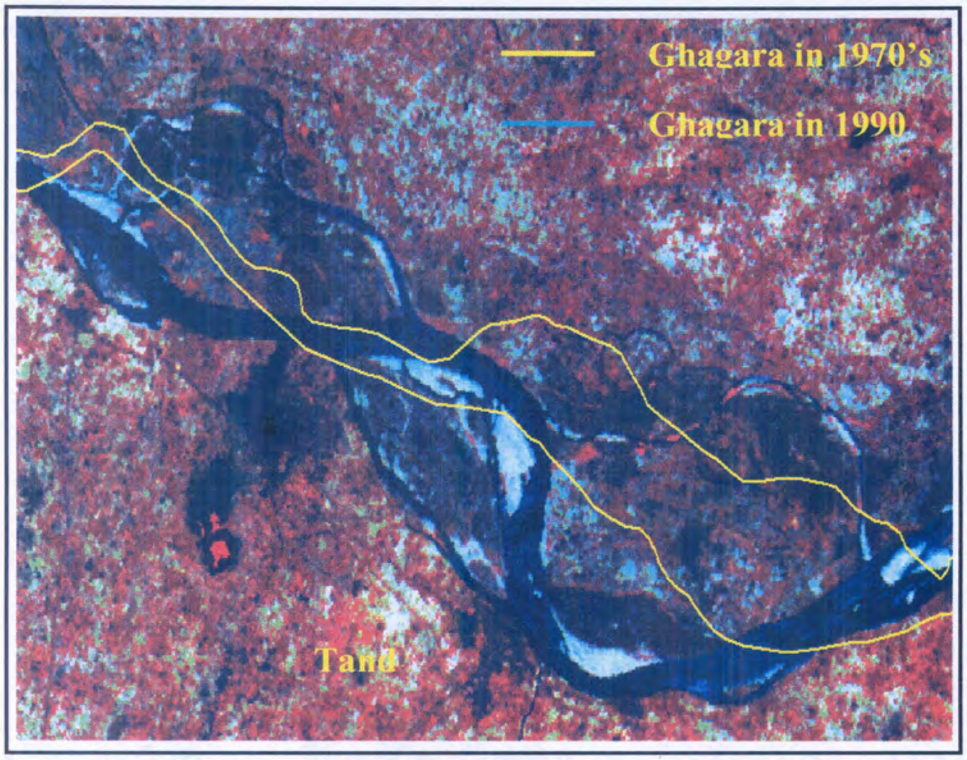


Figure 5.7 False Colour Composite (1990) overlaid by drainage from toposheet (Tanda)

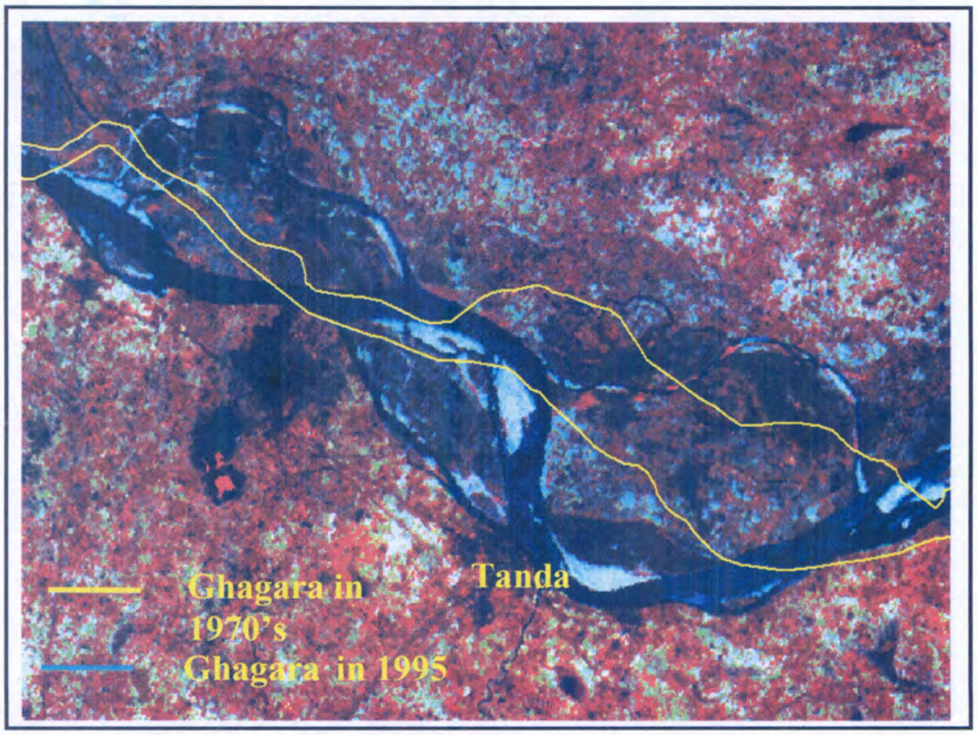


Figure 5.8 False Colour Composite (1995) overlaid by drainage from toposheet (Tanda)

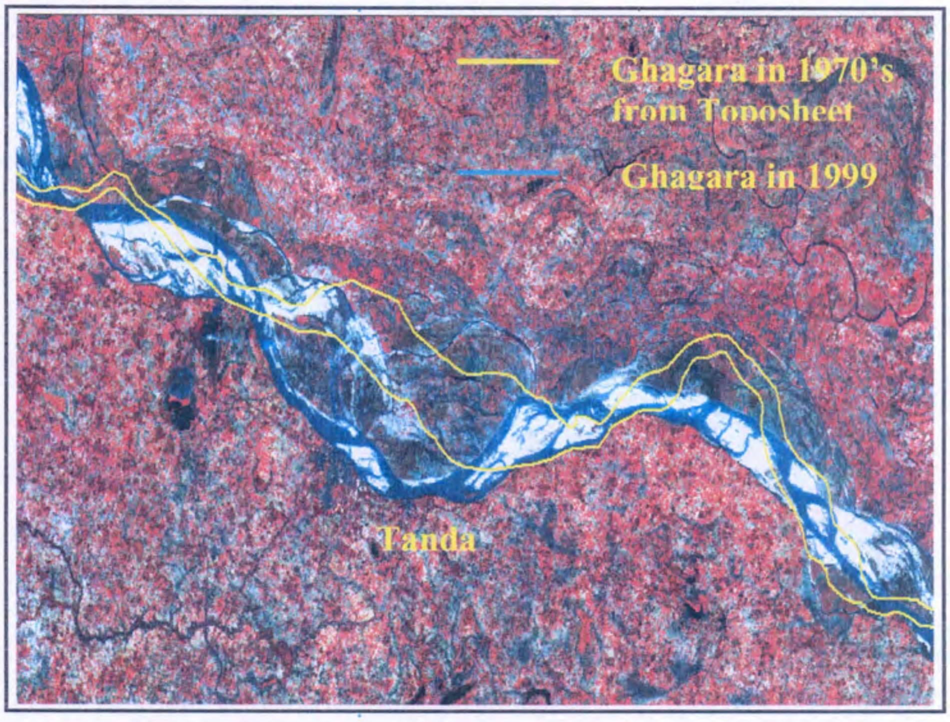


Figure 5.9 False Colour Composite (1999) overlaid by drainage from toposheet (Tanda)

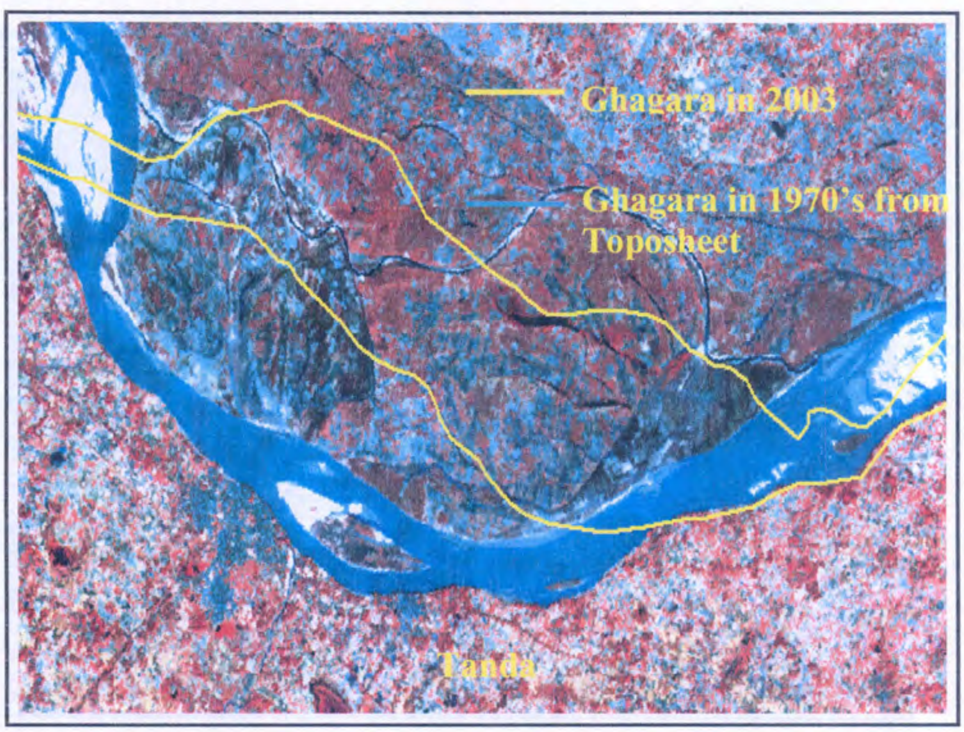


Figure 5.10 False Colour Composite (2003) overlaid by drainage from toposheet (Tanda)

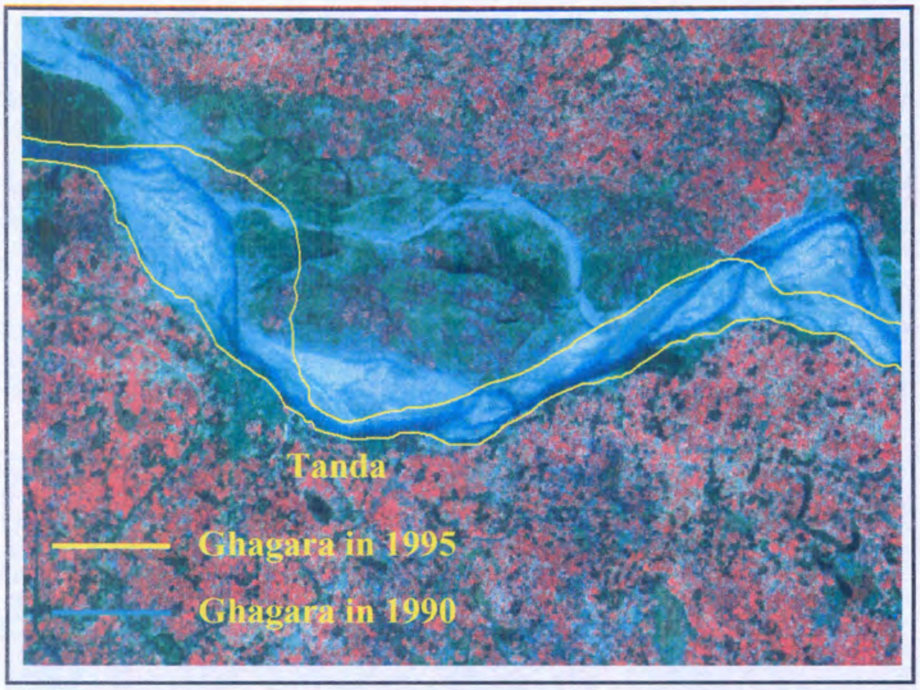


Figure 5.11 False Colour Composite (1990) overlaid by drainage from Image 1995

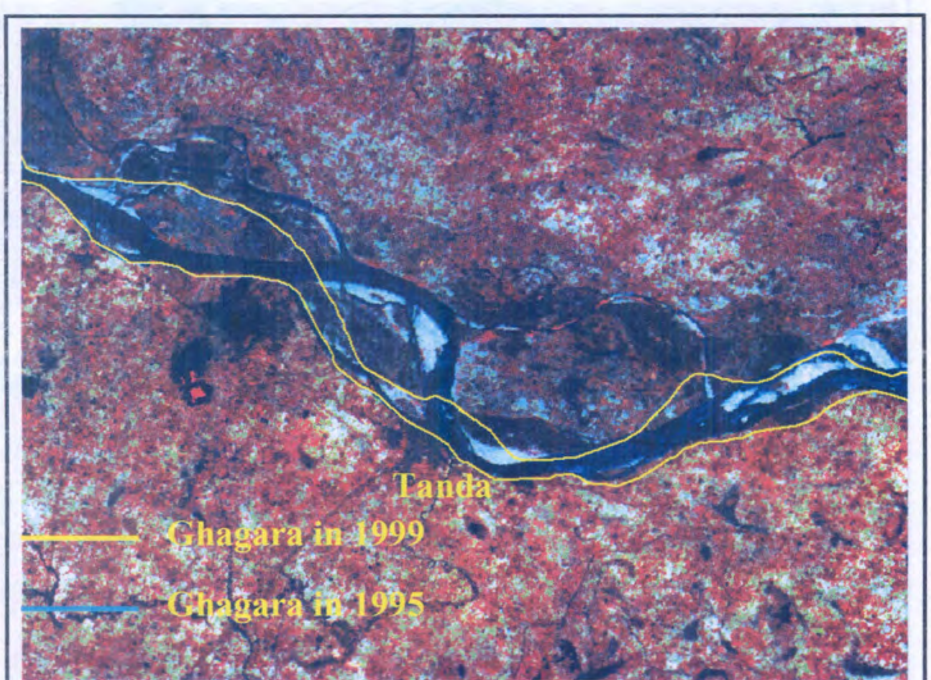
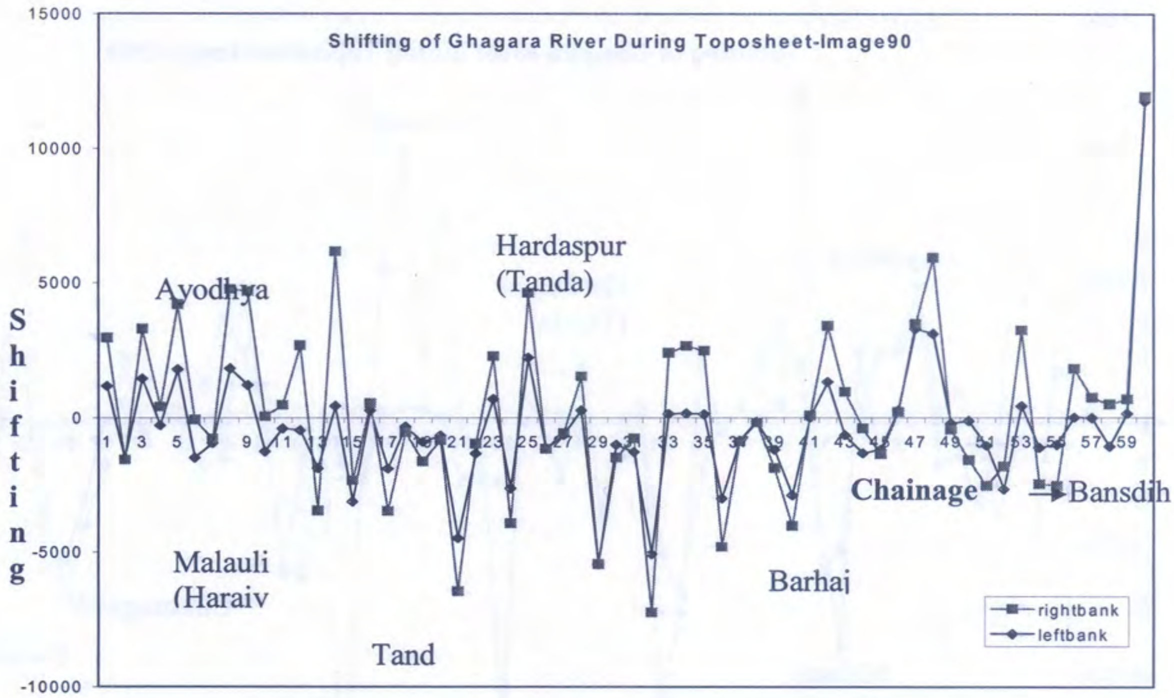


Figure 5.12 False Colour Composite (1999) overlaid by drainage from image of 1995



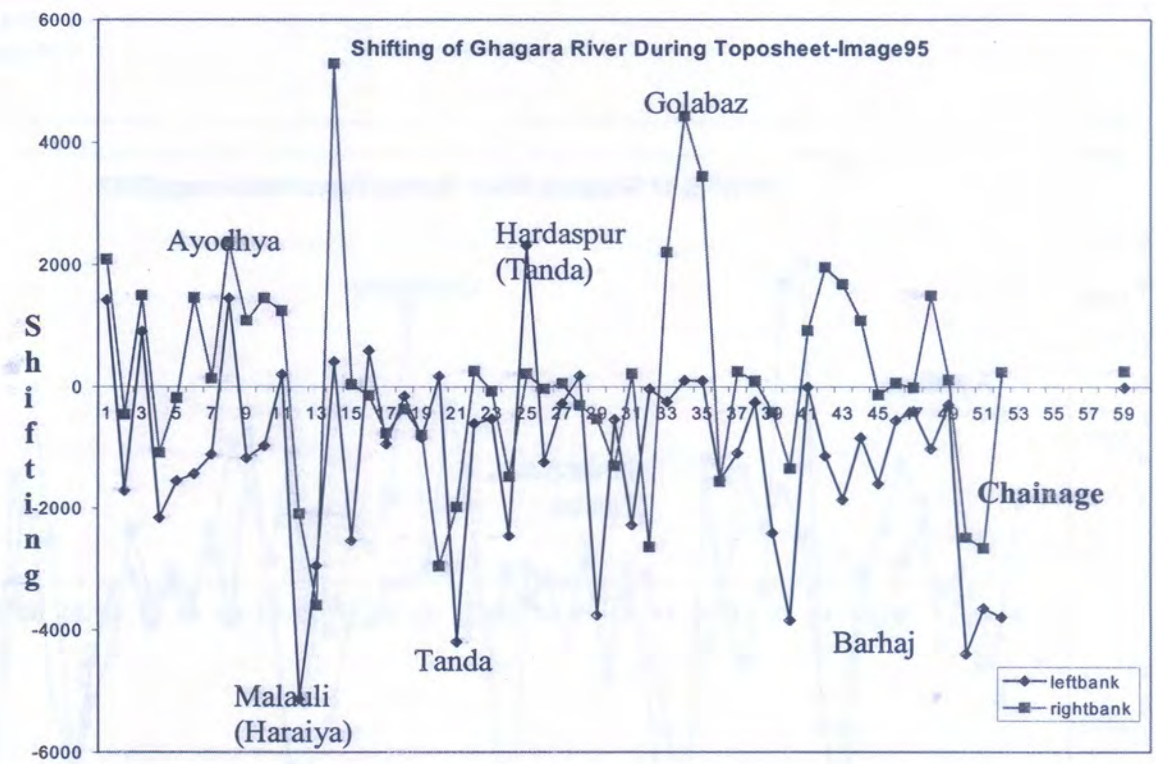


Figure 5.13 Shifting of Ghagara River from toposheet to LISSII data

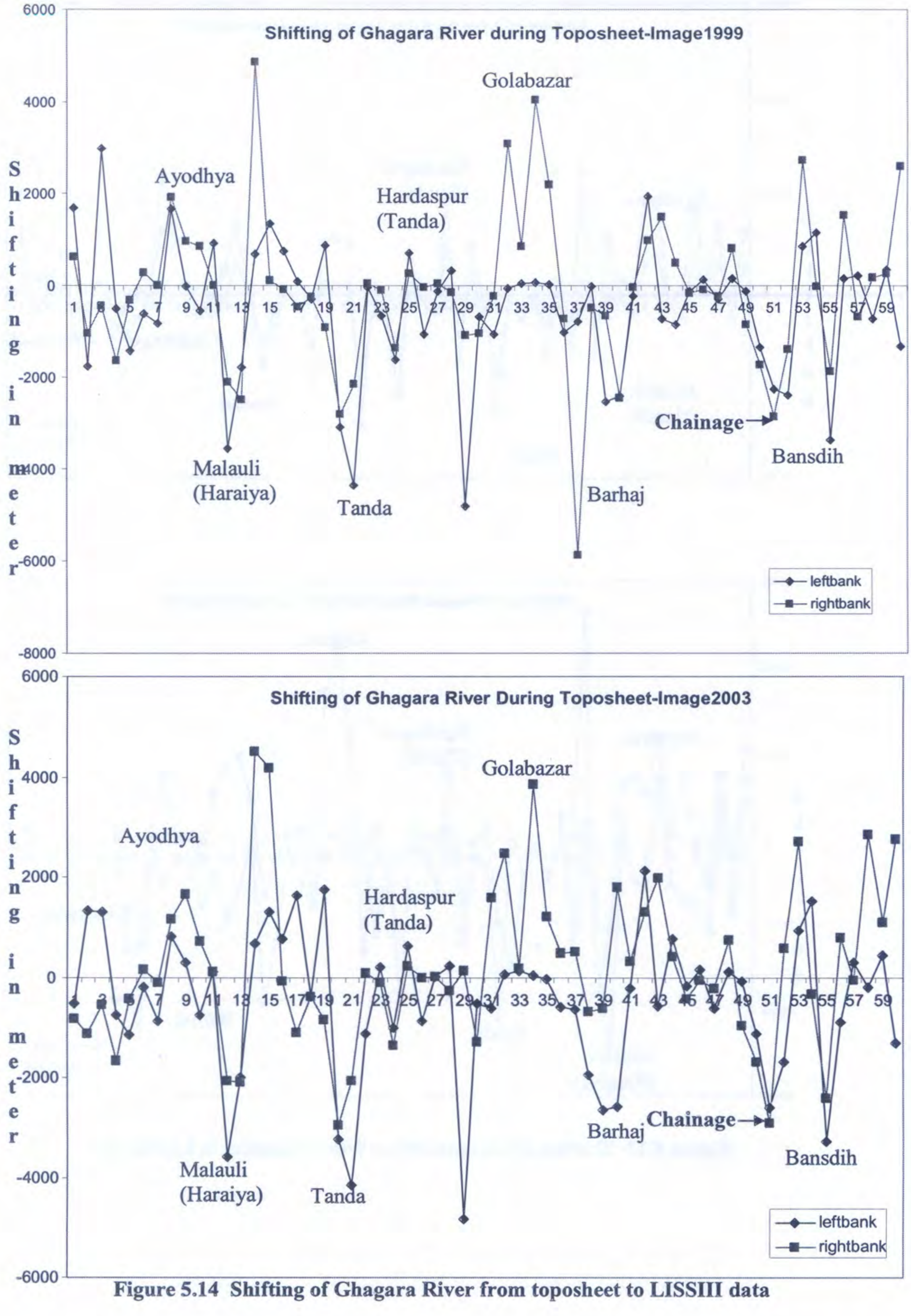
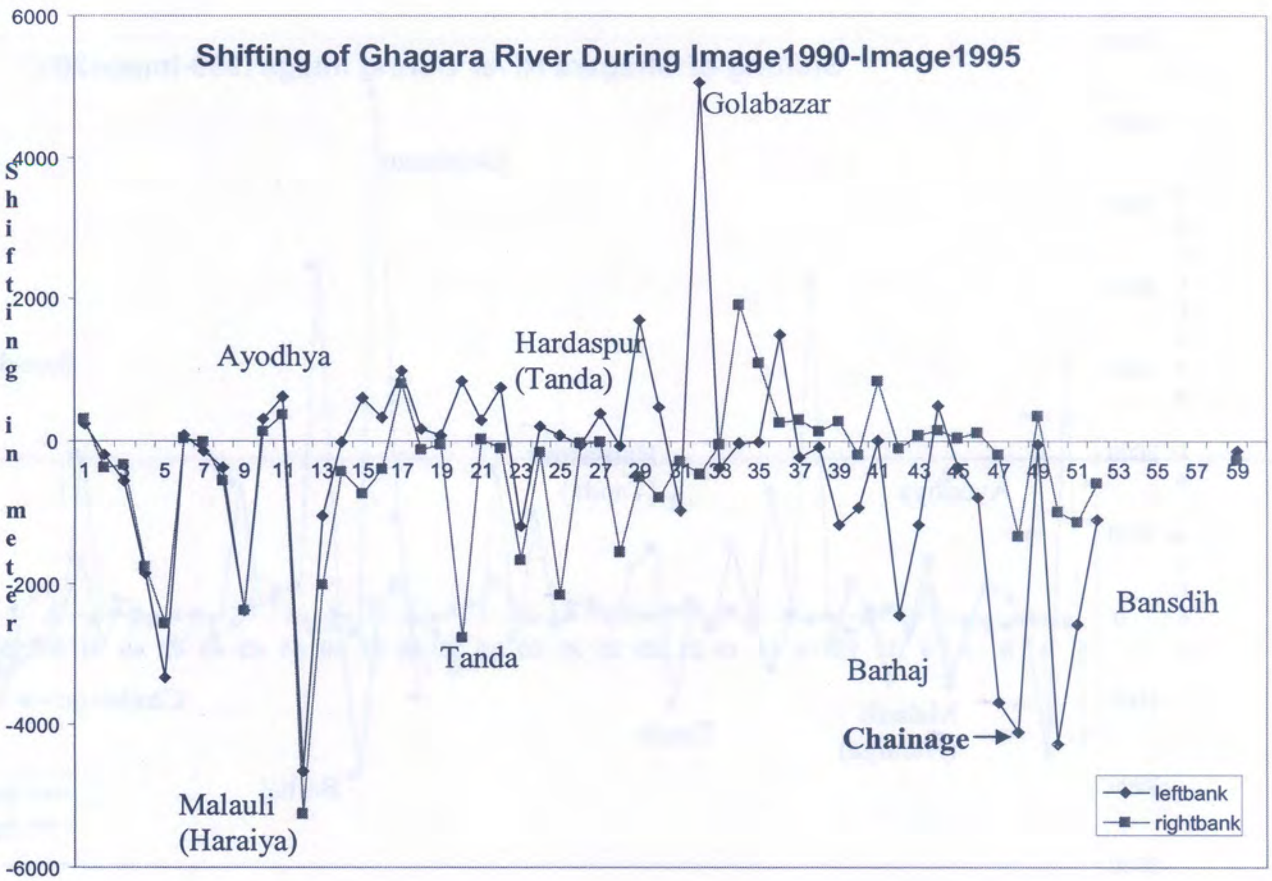


Figure 5.14 Shifting of Ghagara River from toposheet to LISSIII data



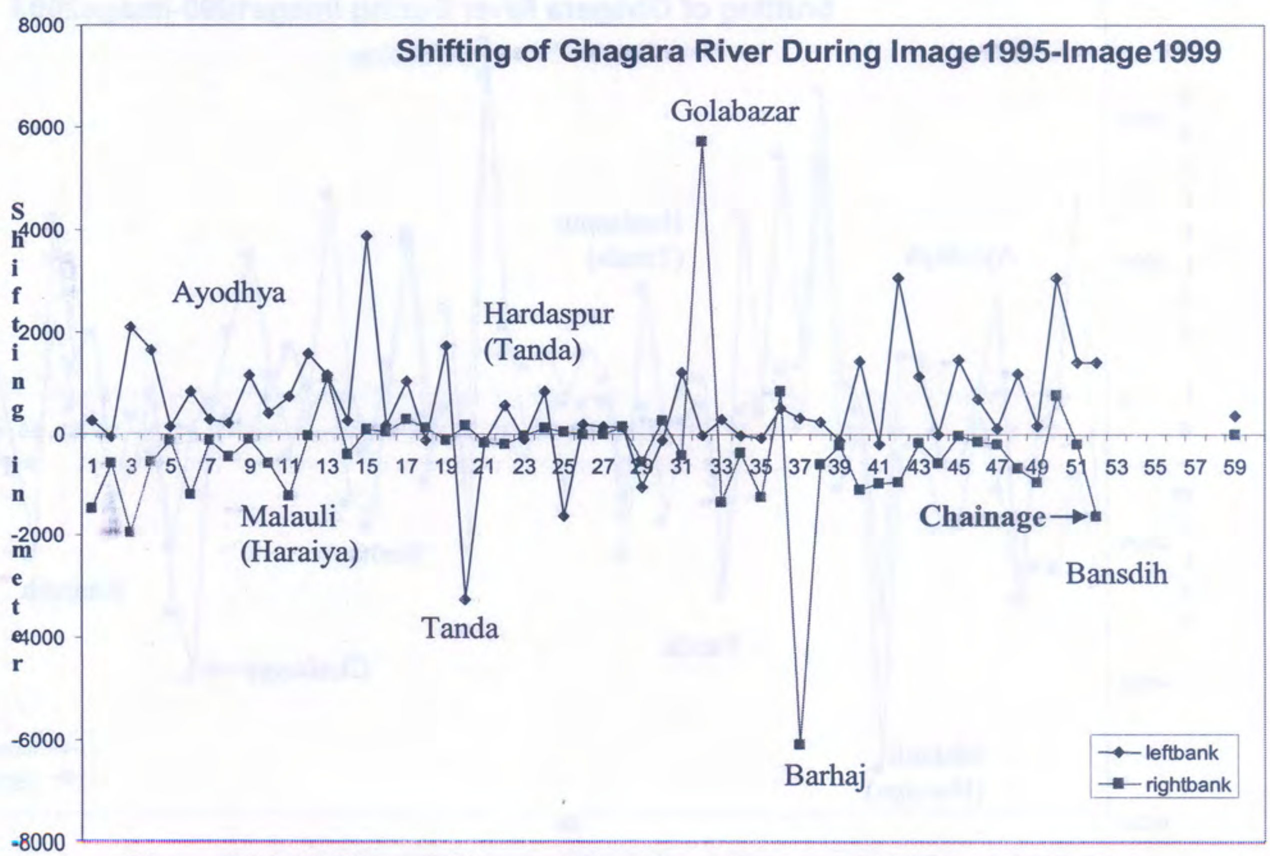
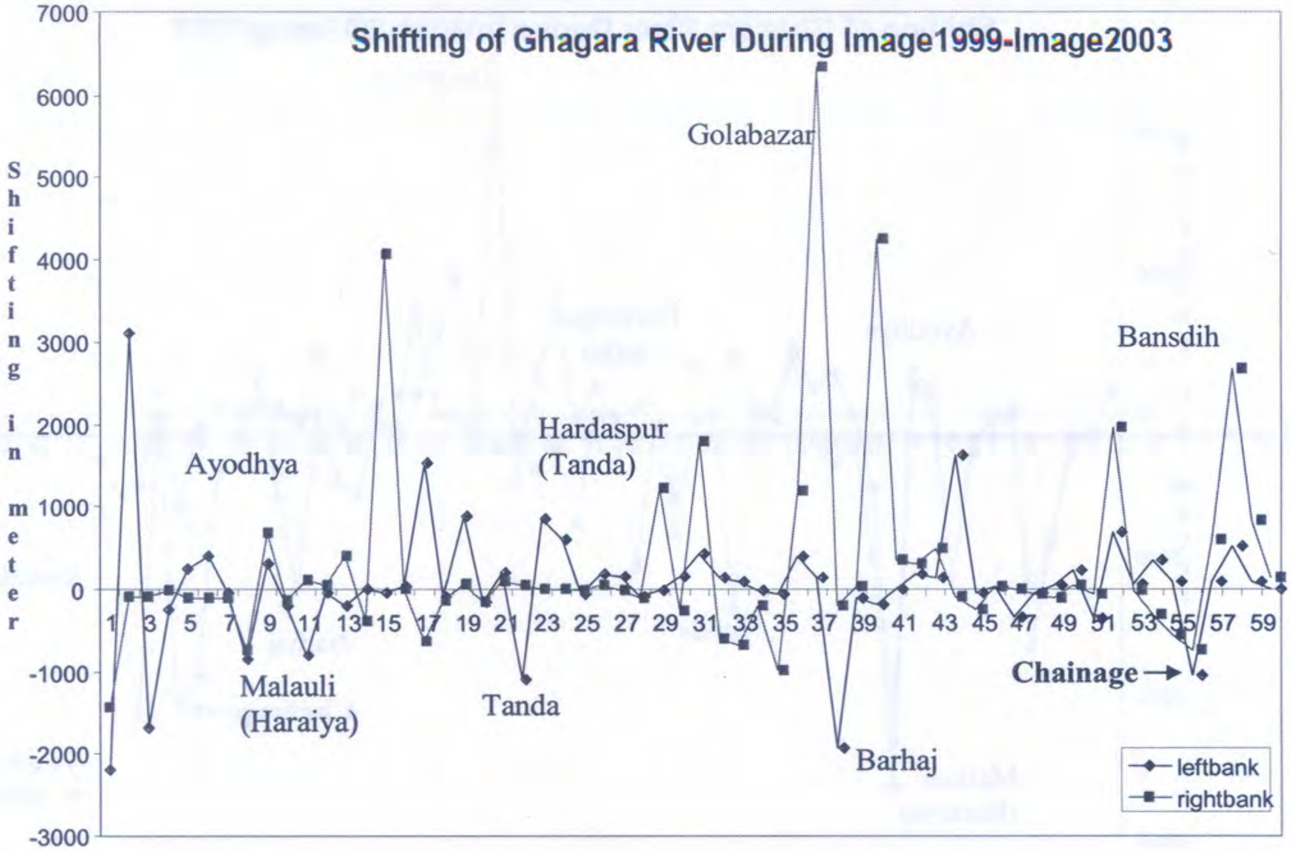


Figure 5.15 Shifting of Ghagara River from Image of LISSII and LISSIII data



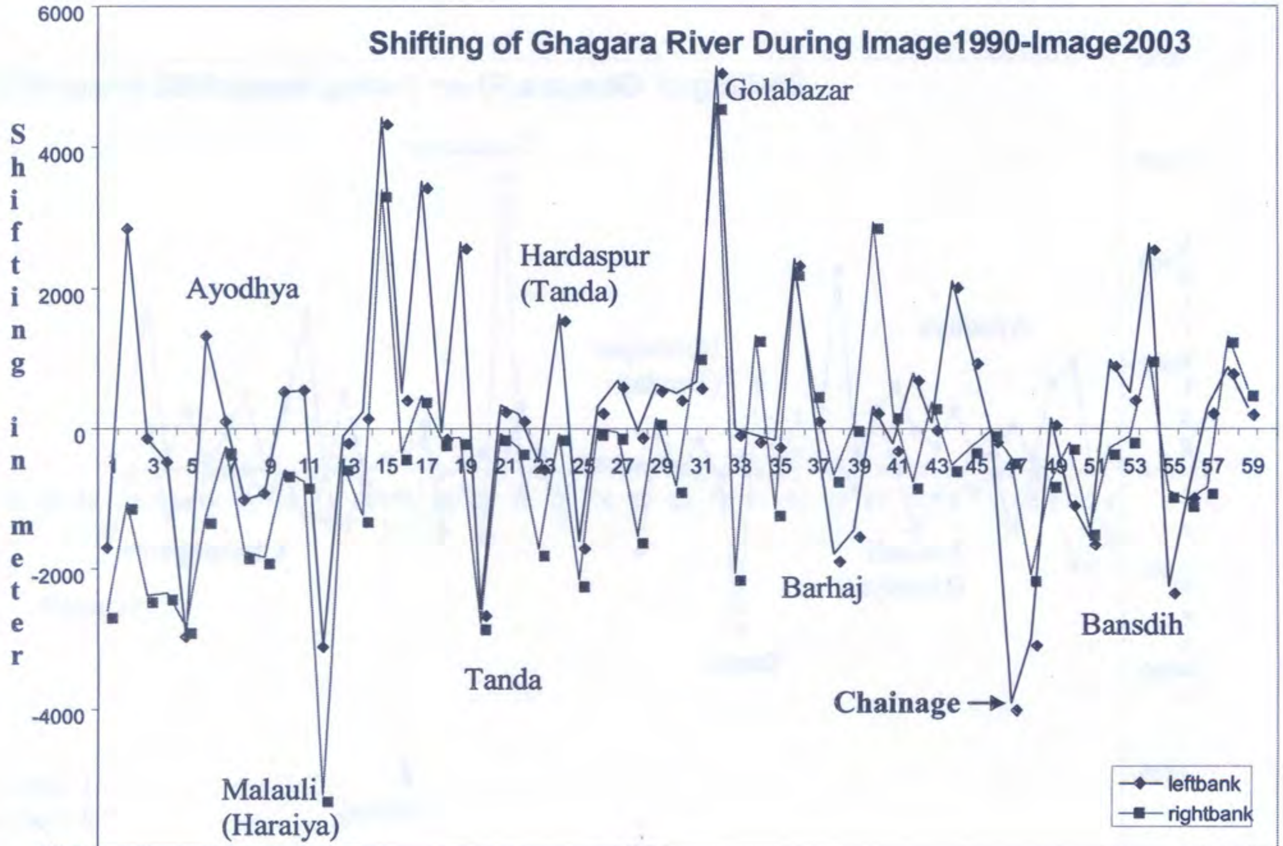


Figure 5.16 Shifting of Ghagara River from Image of LISSII to LISSIII data

5.2.1. Details of shifting (banks) of River Ghagara in different reaches

The shift have been computed for all the reaches i.e. total 10 reaches and the shift have been given for both the banks. As per the table 4.1 and 4.2, if the difference with respect to toposheet is negative then it is erosion and if the difference is positive then it is deposition.

Reach-I: Manuhan to Mubarakganj (0 to 30 km)

Period	Right Bank	Left Bank
Toposheet-Image90	Mostly deposition, order of maximum deposition is 3.5 km.	Both erosion and deposition is there, the order of maximum erosion is 2 km. where deposition of the order 1.8km.
Toposheet-Image95	Both erosion and deposition was observed. The order of maximum erosion is 1km and deposition is 1.5 km.	Both erosion and deposition is there, deposition is more, the order of maximum erosion 1km and deposition is 2km.
Toposheet-Image99	Mostly erosion, the order of maximum erosion is 1.8km.	Both erosion and deposition is there, the order of maximum erosion is 3 km and deposition is 1.8 km.
Toposheet - Image 03	Mostly erosion was observed of the order 1.75 km.	Both erosion and deposition is there, erosion of the order 1.25 km and deposition of the order 1 km.
Image90- Image 95	Mostly erosion was observed, of the order 2.75 km.	Mostly deposition is there, of the order 3.5 km
Image95- Image 99	Only erosion was observed, of the order of 2 km.	Only erosion is there, of the order 2 km.
Image99- Image 03	Slight erosion was observed.	Both erosion and deposition is there, erosion of the order 3 km. and deposition of the order 1.8 km.
Image90- Image 03	Only erosion was observed, of the order 3 km.	Both erosion and deposition, erosion of the order of 2.8 km and deposition of the order of 3 km.

Reach-II: Mubarakganj to Ayodhya (30 to 60 km)

Period	Right Bank	Left Bank
Toposheet - Image 90	Only deposition is there, of the order 5 km.	Both erosion and deposition is there, the order of maximum erosion is 2 km and the order of maximum deposition is 1 km.
Toposheet - Image 95	Mostly deposition is there, order of maximum deposition is 2.5 km whereas erosion is 3 km.	Both erosion and deposition is there. Order of maximum erosion is 1.5 km and deposition is 4 km.
Toposheet - Image 99	Mostly deposition is there, order of maximum deposition is 2 km and erosion is 2.25 km.	Both erosion and deposition is there, order of maximum deposition is 3 km. and erosion is 1.5 km.
Toposheet - Image 03	Mostly deposition, order of maximum deposition is 1.75 km and erosion is 2.25km.	Both erosion and deposition is there, order of maximum erosion is 3 km. and deposition is 0.75 km.
Image90- Image 95	Mostly erosion is there of the order 5km.	Mostly deposition is there, of the order 5 km.
Image95- Image 99	Only erosion is there, of the order 1.75 km.	Only erosion is there of the order 1.75 km.
Image99- Image 03	Slight erosion is there.	Slight deposition is there.
Image90- Image 03	Only erosion is there, order of maximum erosion is 5 km.	Mostly deposition is there, order of maximum deposition is 3 km.

Reach III: Ayodhya to Mahuwari (60-90km)

Period	Right Bank	Left Bank
Toposheet - Image 90	Both erosion and deposition is there, order of maximum erosion is 3.5 km. and deposition is 6 km.	Mostly deposition is there of the order 3 km.
Toposheet - Image 95	Both erosion and deposition is there, order of maximum erosion is 3.5 km and deposition is 5 km.	Mostly deposition is there of the order 2.5 km.
Toposheet - Image 99	Both erosion and deposition is there, order of maximum erosion is 2.75 km and deposition is 5 km.	Mostly erosion is there of the order 1.25 km.
Toposheet - Image 03	Mostly deposition of the order 4.5 km. and erosion of 1km.	Mostly deposition of 2 km. is there.
Image90- Image 95	Mostly erosion is there of the order 3km.	Mostly erosion is there, of the order 0.75 km.
Image95- Image 99	Slight deposition is there of the order 0.5 km.	Only erosion is there, of the order 3.75 km.
Image99- Image 03	Mostly deposition of the order 4km. and slight erosion is there of the order 0.5 km.	Mostly erosion is there of the order 1.25 km and slight deposition.
Image90- Image 03	Deposition of the order 3.5 km. and erosion of the order 1km. is there.	Highly deposition is there of the order 4.5 km.

Reach IV: Mahuwari to Phulpur (90-120km)

Period	Right Bank	Left Bank
Toposheet - Image 90	High erosion is there of the order 6 km. and slight deposition.	Highly deposited of the order 4.5 km and slight erosion is there.
Toposheet - Image 95	High erosion of the order 3 km is there.	Only deposition is there of the order 4 km.
Toposheet - Image 99	Only erosion is there of the order 3 km.	Highly deposited of the order 6km.
Toposheet - Image 03	Only erosion is there of the order 3.5 km.	Highly erosion of the order 4.25 km.
Image90- Image 95	Only Erosion of the order 2.75 km.	Erosion of the order 0.75 km and deposition of the order 1 km is there.
Image95- Image 99	There is no change.	Highly deposited of the order 6.5 km. and slight erosion of the order 1km.is there.
Image99- Image 03	No change	Only erosion is there of the order 6.5km.
Image90- Image 03	Erosion of the order of 3km	erosion of the order 2.0 km. and deposition of the order of the 3.0 km.

Reach V: Phulpur to Ashrafpur near Belghat (120-150 km)

Period	Right Bank	Left Bank
Toposheet - Image 90	Both erosion and deposition is there, erosion of the order 5 km. and deposition of the order 5 km.	Both erosion and deposition, erosion of the order 2.5 km. and deposition of the order 5 km.
Toposheet - Image 95	Mostly erosion is there of the order 1km.	Both erosion and deposition, erosion of the order 2.5 km and deposition 3.5 km.
Toposheet - Image 99	Mostly erosion of the order	Mostly deposition of the order 4.5 km.

	0.75 km.	
Toposheet - Image 03	Mostly erosion is there of the order 1km.	Mostly eerosion of the order 5km.
Image90- Image 95	Only erosion of the order 2 km.	Only erosion of the order 1.75 km.
Image95- Image 99	Slight erosion is there.	Only deposition is there of the order 1 km.
Image99- Image 03	No change	No change
Image90- Image 03	Only erosion is there of the order 2 km.	Both erosion and deposition is there, erosion of the order 0.5 km and deposition of the order 1.5 km.

Reach VI: Ashrafpur to Karokand near Golabazar (150-180km)

Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly erosion is there, of the order 6.75-km alongwith slight deposition of 2.5 km.	Only deposition is there of the order 4.5 km.
Toposheet - Image 95	Both erosion and deposition is there, erosion of the order 2.5 km and deposition of the order 4.5 km.	Mostly deposition is there of the order of 2 km.
Toposheet - Image 99	Mostly deposition of the order 4 km.	Slight deposition of the order 1 km.
Toposheet - Image 03	Only deposition of the order 4 km.	Slight deposition of the order 0.25 km.
Image90- Image 95	Both erosion and deposition is there, erosion of the order 0.5 km. and deposition of the order 1.75	Mostly erosion is there of the order 5km.

	km.	
Image95- Image 99	Both erosion and deposition is there, erosion of the order 5.5 km. and deposition of the order 2 km.	Only erosion is there of the order 1 km.
Image99- Image 03	Both erosion and deposition is there, erosion of the order 1 km. and deposition of the order 2.5 km.	Slight erosion is there.
Image90- Image 03	Both erosion and deposition, Erosion of the order 2km. and deposition of the order 4 km.	Mostly deposition is there, of the order 4 km.

Reach VII: Karokand to Rasulpur near Barhaj (180-210 km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly erosion of the order 4km and slight deposition of 3.5 km is there.	Mostly deposition of the order 2.5 km and slight erosion of 1 km is there.
Toposheet - Image 95	Both erosion and deposition is there, erosion of the order 1km and deposition of the order 2 km.	Only deposition is there of the order 3.75 km.
Toposheet - Image 99	Mostly erosion is there of the order 5km and slight deposition of 1km.	Mostly deposition is there of the order 2 km. and slight erosion of 1.75 km.
Toposheet - Image 03	Mostly deposition of the order 2km with slight erosion of 0.5 km.	Mostly erosion of the order 3 km. and slight deposition of 2 km.

Image90- Image 95	Slight deposition of 0.75 maximum order	Mostly deposition of the order 2.5 km
Image95- Image 99	Only erosion of the order 6km.	Only erosion of the order 3 km.
Image99- Image 03	Only deposition is there, of the order 6 km.	Slight deposition of the order 2 km.
Image90- Image 03	Mostly deposition of the order 2.75 km. and slight erosion of 0.75 km.	Mostly ereosion is there of the order 1.5 km. and slight deposition of 0.75 km.

Reach VIII: Rasulpur to Ubhaon (210-240km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly deposition of the order 5 km. and slight erosion of 1 km.	Mostly erosion of the order 3.5 km and slight deposition of 1 km.
Toposheet - Image 95	Only deposition is there of the order 1.75 km.	Only deposition is there of the order 1.75 km.
Toposheet - Image 99	Mostly deposition of the order 1.75 km.	Slight deposition of the order 0.5 km.
Toposheet - Image 03	Mostly deposition of the order of 1.75 km.	Slight erosion and deposition is there.
Image90- Image 95	Erosion of the order 1 km. is there.	Mostly deposition of the order 4.5 km.
Image95- Image 99	Slight erosion is there.	Only erosion is there of the order 1 km.
Image99- Image 03	Almost no change	Slight erosion is there.
Image90- Image 03	Mostly erosion of the order 2.0 km.	Both erosion and deposition is there, erosion of the order 4 km. and deposition of the order 2 km.

Reach IX: Ubhaon to Chandpur near Bansdih (240-270km)

Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly erosion of the order 1km and somewhere deposition of 3km. is there.	Mostly deposition is there of the order 1 km.
Toposheet - Image 95	Mostly erosion of the order of 2km.	Mostly deposition of the order 4 km.
Toposheet - Image 99	Both erosion and deposition is there, erosion of the order 3 km. maximum and deposition of the order 3 km. maximum.	Mostly deposition, the order of maximum deposition is 2.5 km. and erosion 1 km.
Toposheet - Image 03	Both erosion and deposition is there, the order of maximum deposition is 2.5-km. and erosion of 3 km.	Mostly deposition, the order of maximum deposition is 3 km and erosion 2.25 km. is there.
Image90- Image 95	Mostly erosion is there of the order 0.75 km.	Mostly deposition of the order 4 km.
Image95- Image 99	Slight deposition and erosion, but mostly erosion	Only erosion of the order 1.5 km.
Image99- Image 03	Slight deposition is there of the order 1.75 km.	Slight erosion of the order 0.5 km.
Image90- Image 03	Deposition and erosion both of the order 0.75 km. maximum.	Mostly deposition of the order of 2.75 km. and erosion of 1.25 km.

Reach X: Chandpur to Chappra (270-310 Km.)

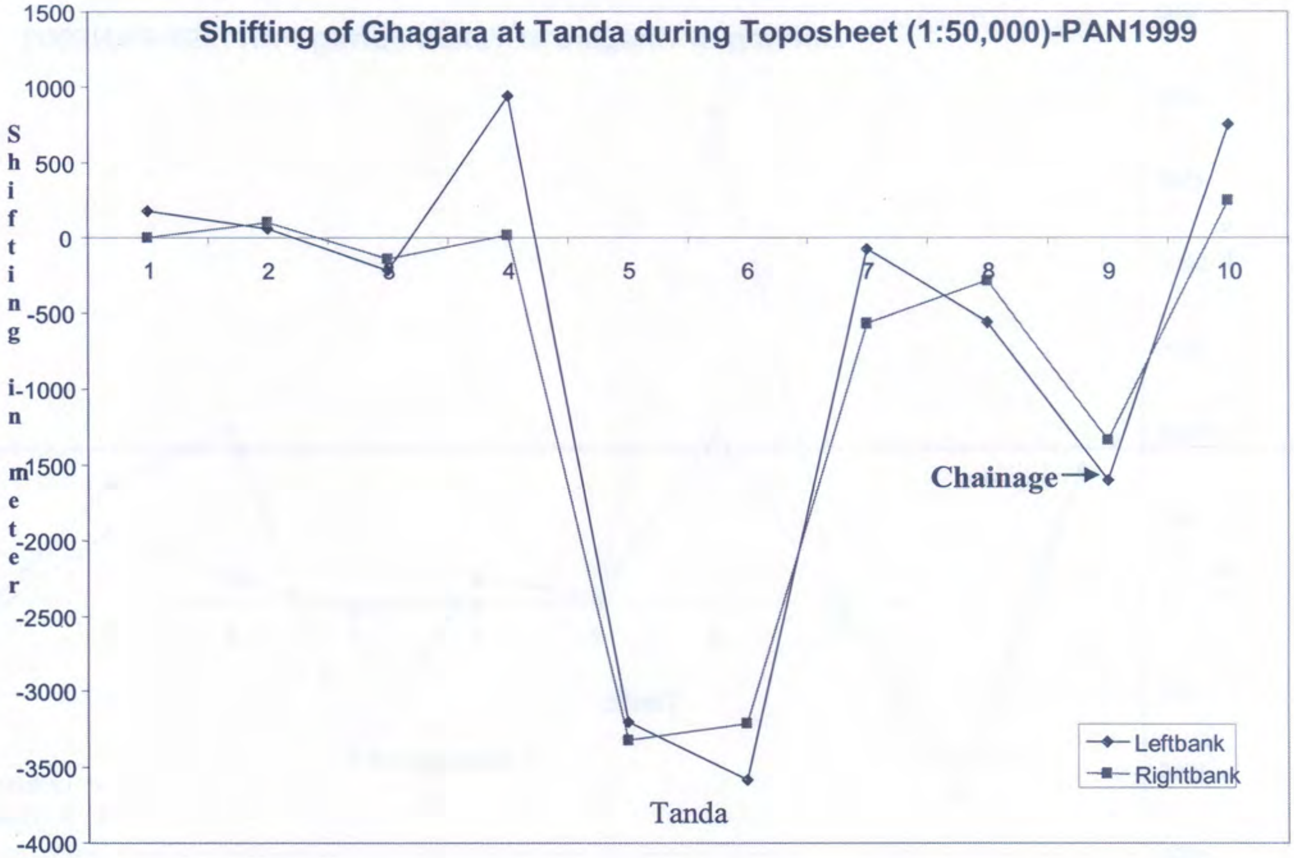
Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly deposition is there of the order 1 km. and erosion of 2.75 km.	Mostly deposition of the order 1 km.
Toposheet - Image 95		
Toposheet - Image 99	Both erosion and deposition is there, erosion of the order 2 km. and deposition of the order 2.5 km.	Mostly deposition is there of the order 3.5 km
Toposheet - Image 03	Mostly deposition is there of the order 3 km.	Mostly deposition of the order 3 km.
Image90- Image 95	Erosion of the order 2.25km	
Image95- Image 99		
Image99- Image 03	Very slight erosion is there and deposition of 2km maximum is there.	Slight erosion and deposition is there.
Image90- Image 03	Slight erosion and deposition of the order of 0.75 km.	Slight deposition is there and erosion of 2 km. maximum.

5.3 DETAILS OF SHIFTING CHARACTERISTICS AT THE CRITICAL LOCATIONS USING IRS-1C PAN DATA

As mentioned in the previous section, the critical locations along the river course were identified as Tanda, Ayodhya, Gola bazar and Bansdih on Ghagara River. Hence, for these locations detailed study was carried out using IRS-1C PAN data (having a spatial resolution of 5.8 m) for the years 1999 and 2003 along with SOI toposheet of the scale of 1:50,000. The river course using these toposheets has been delineated. Then the river course has been extracted from IRS PAN data. Initially, for the critical locations, the shifting of the river course from the SOI toposheet to IRS-1C PAN data was studied and subsequently, the shifting of the river course from the year 1999 (IRS-1C PAN data) to 2003 (IRS-1C PAN data) was studied so as to assess the recent trends in shifting. These shifts are given in Table 4.2.

The details of shifting course of river Ghagara near Tanda as delineated from 1:50,000 scale SOI toposheet and IRS-1C PAN data for the year 1999 and 2003 have been shown in Figures 5.17 to 5.18 It is observed that the river has shifted by 3.5 km in the year 1999 with respect to toposheets. It has shifted by 0.175 km between the year 1999 to 2003.

The details of shifting course of river Ghagara near Bansdih as delineated from SOI toposheet of scale 1:50,000 and IRS-1C PAN data for the year 1999 and 2003 are shown in figures 5.18 and 5.19. It is observed that the river has shifted by 2.5 km in the year 1999 with respect to toposheet, while it has shifted by 1 km from the year 1999 to 2003.



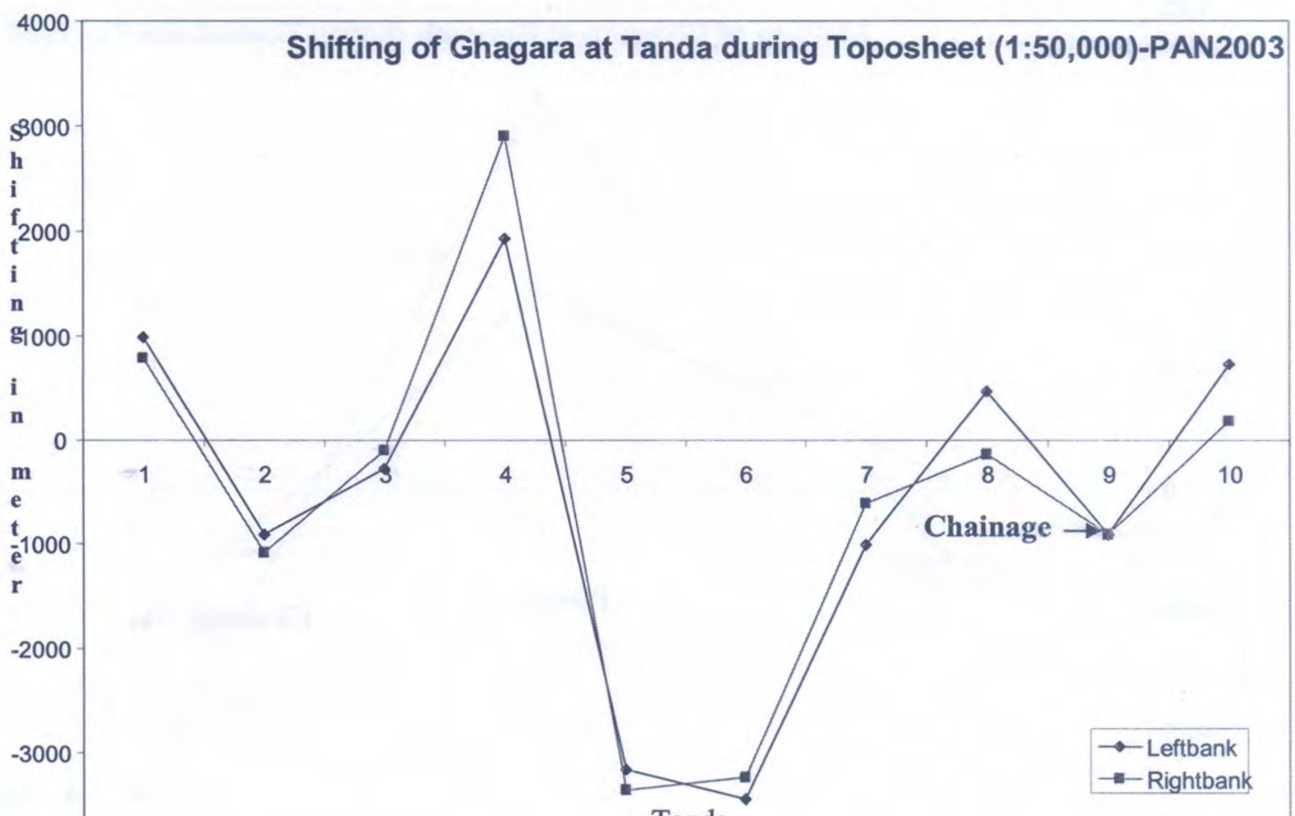
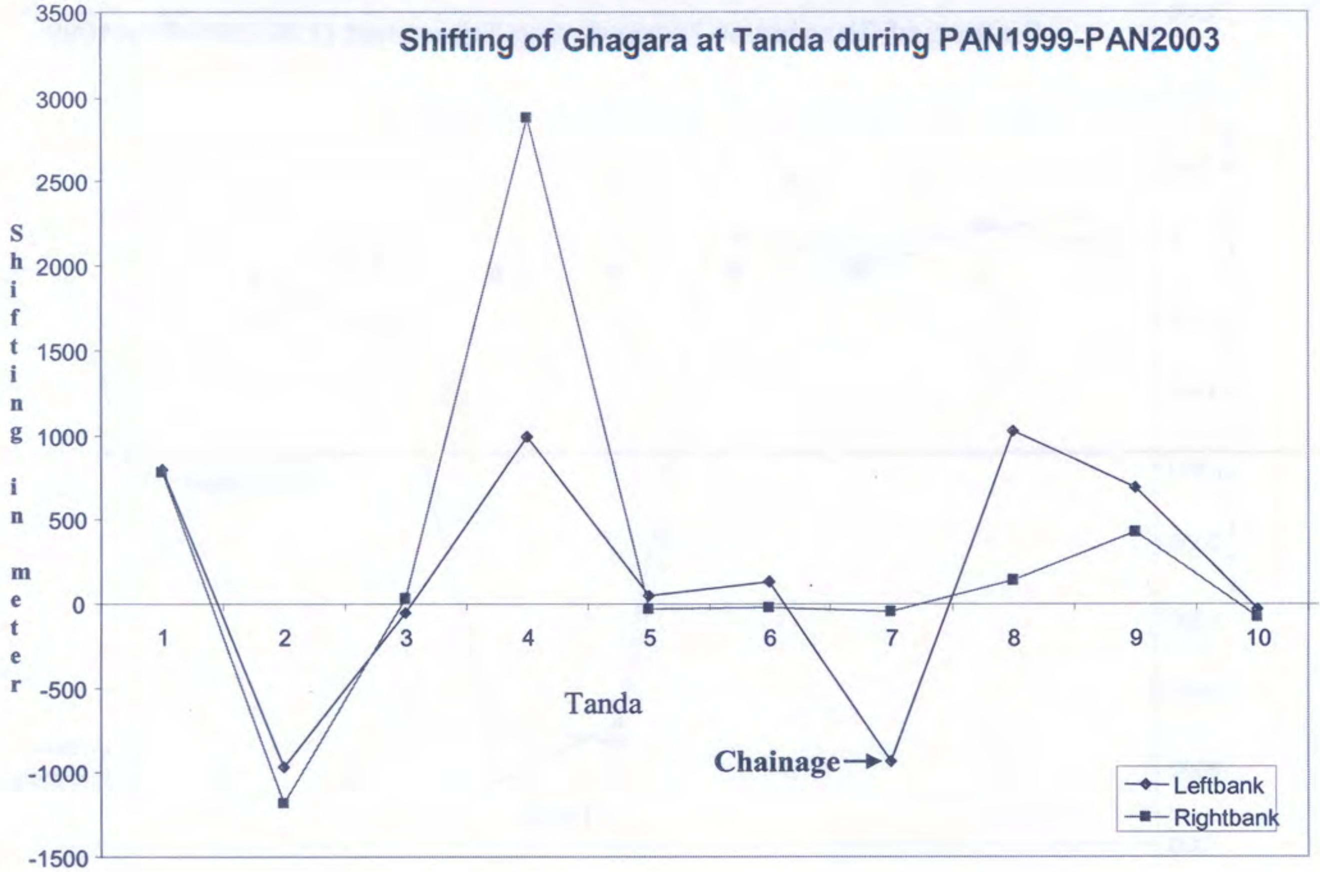


Figure 5.17 Shifting of Ghagara River from toposheet to PAN data



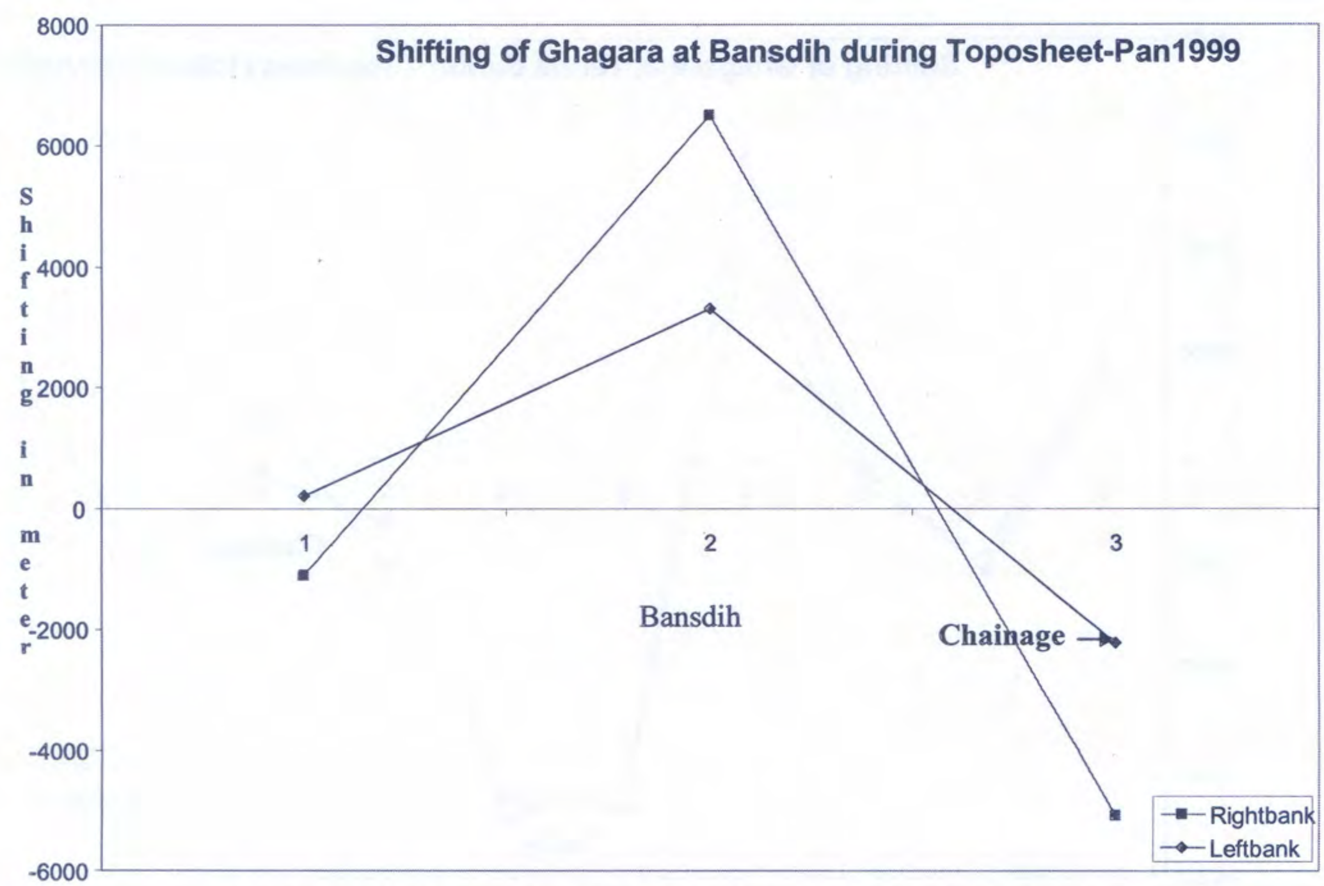
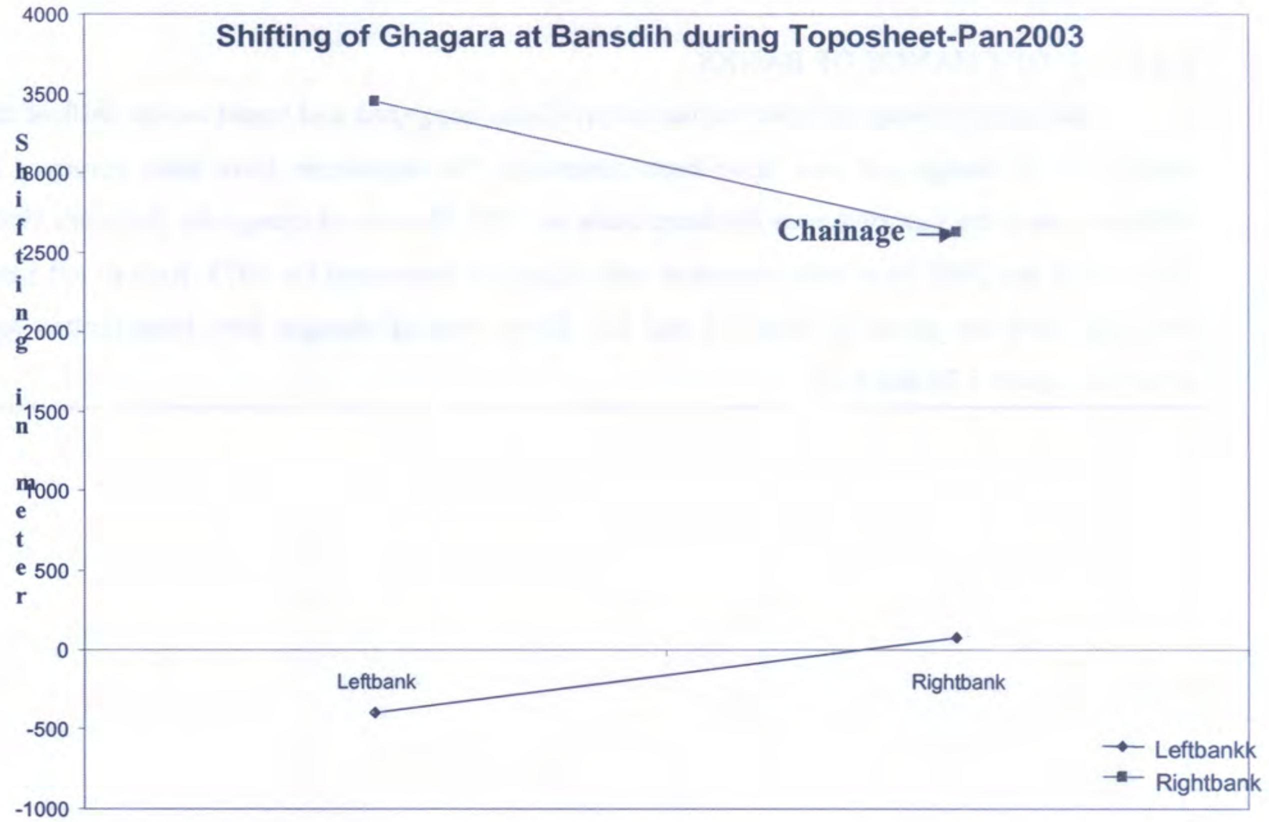


Figure 5.18 Shifting of Ghagara River from toposheet to PAN data



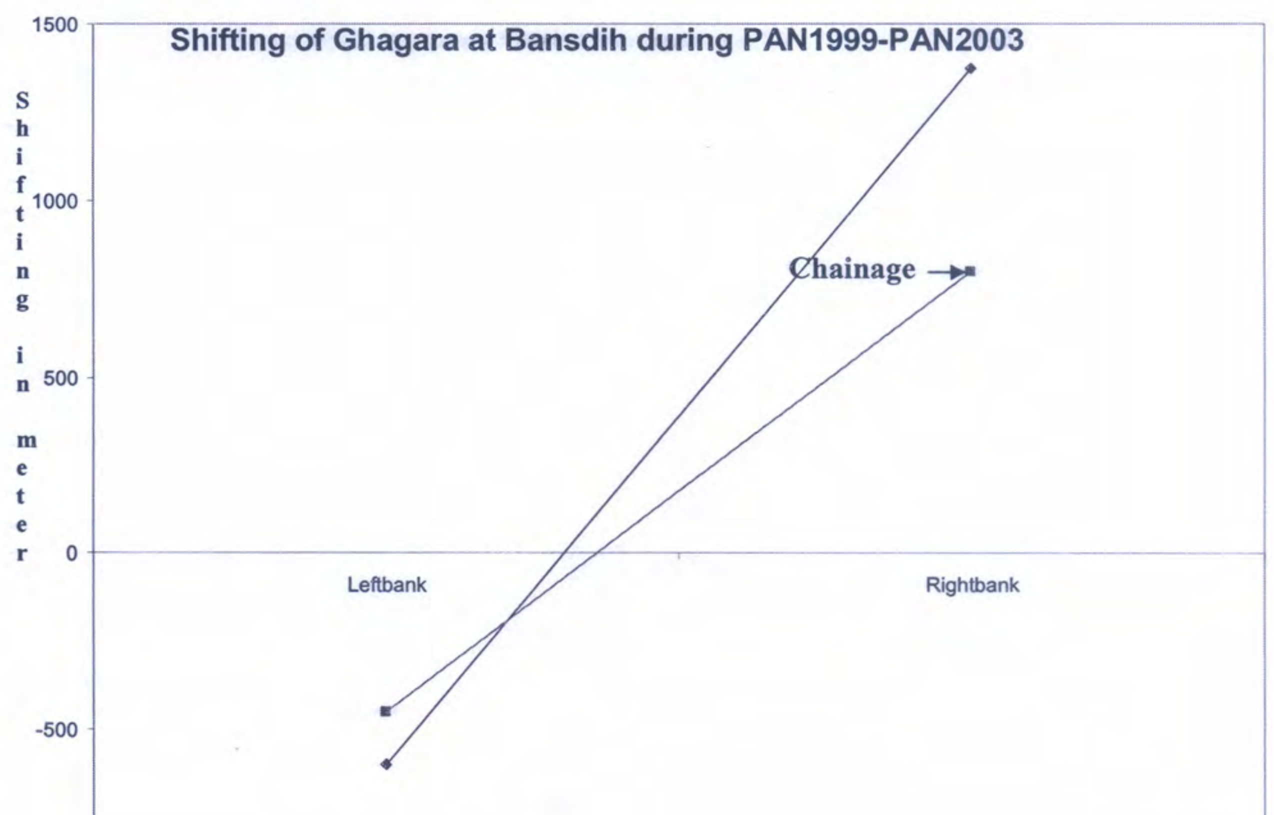


Figure 5.19 Shifting of Ghagara River from toposheet to PAN data

5.4 RATE OF CHANGE OF BANKS

The rate of change of both the banks have been computed and based on the shift of the banks rate of change per year have been computed. The toposheets have been surveyes in different years; the year of survey has been taken as 1975. The rate of change for the years 1990, 1994, 1999 and 2003 have been computed with respect to toposheets i.e. 1975. Rate of left bank and right bank are given in Table 5.1 and 5.2. These rates of changes have been plotted and given in Figures 5.20 and 5.21.

Table 5.1: Rate of change of left bank of Ghagara River per year (1975 – 2003)

	Status of Left bank of Ghagra river							
Location	topo-img90	ROC in 15 year(1975-1990)	topo-img95	ROC in 20 year(1975-1995)	topo-img99	ROC in 24 year(1975-1999)	topo-img2003	ROC in 28 year(1975-2003)
1	1186.19	79.08	1416.99	70.85	1685.11	70.21	-516.76	-18.46
2	-1515.85	-101.06	-1708.00	-85.40	-1774.98	-73.96	1325.62	47.34
3	1457.61	97.17	900.36	45.02	2988.27	124.51	1303.15	46.54
4	-293.11	-19.54	-2157.02	-107.85	-516.76	-21.53	-763.91	-27.28
5	1803.75	120.25	-1539.77	-76.99	-1415.49	-58.98	-1168.34	-41.73
6	-1506.39	-100.43	-1429.52	-71.48	-606.64	-25.28	-202.21	-7.22
7	-960.09	-64.01	-1113.82	-55.69	-831.32	-34.64	-876.25	-31.29
8	1829.97	122.00	1445.67	72.28	1662.64	69.28	808.85	28.89
9	1212.59	80.84	-1170.14	-58.51	-22.47	-0.94	292.08	10.43
10	-1278.76	-85.25	-971.31	-48.57	-561.70	-23.40	-763.92	-27.28
11	-414.10	-27.61	200.80	10.04	921.19	38.38	112.34	4.01
12	-477.78	-31.85	-5127.96	-256.40	-3549.96	-147.92	-3594.90	-128.39
13	-1894.59	-126.31	-2951.45	-147.57	-1797.49	-74.90	-1999.70	-71.42
14	432.03	28.80	412.81	20.64	674.05	28.09	674.05	24.07
15	-3130.14	-208.68	-2534.45	-126.72	1348.08	56.17	1303.15	46.54
16	261.36	17.42	588.03	29.40	741.45	30.89	763.92	27.28
17	-1916.39	-127.76	-936.39	-46.82	89.87	3.74	1617.70	57.78
18	-328.20	-21.88	-155.26	-7.76	-292.08	-12.17	-381.95	-13.64
19	-908.53	-60.57	-831.66	-41.58	876.26	36.51	1752.51	62.59
20	-676.27	-45.08	169.22	8.46	-3078.22	-128.26	-3235.50	-115.55
21	-4486.23	-299.08	-4197.99	-209.90	-4358.82	-181.62	-4156.61	-148.45
22	-1354.98	-90.33	-605.57	-30.28	-8852.45	-368.85	-1145.87	-40.92
23	681.79	45.45	-528.80	-26.44	-651.58	-27.15	202.21	7.22
24	-2640.81	-176.05	-2448.65	-122.43	-1617.71	-67.40	-1011.07	-36.11
25	2234.47	148.96	2311.35	115.57	696.51	29.02	629.11	22.47
26	-1182.38	-78.83	-1240.03	-62.00	-1056.00	-44.00	-876.26	-31.30
27	-659.71	-43.98	-275.39	-13.77	-134.80	-5.62	22.47	0.80
28	255.32	17.02	178.51	8.93	314.55	13.11	224.68	8.02
29	-5449.36	-363.29	-3758.39	-187.92	-4808.19	-200.34	-4830.65	-172.52
30	-1017.87	-67.86	-537.48	-26.87	-674.04	-28.09	-516.77	-18.46
31	-1286.98	-85.80	-2266.97	-113.35	-1056.00	-44.00	-629.11	-22.47
32	-5088.76	-339.25	-35.05	-1.75	-67.40	-2.81	67.40	2.41
33	139.68	9.31	-244.63	-12.23	44.93	1.87	134.81	4.81
34	144.40	9.63	105.97	5.30	67.41	2.81	44.94	1.60
35	118.16	7.88	98.94	4.95	22.47	0.94	-44.94	-1.60
36	-3025.20	-201.68	-1526.38	-76.32	-1011.07	-42.13	-606.64	-21.67
37	-859.83	-57.32	-1090.42	-54.52	-786.39	-32.77	-651.58	-23.27
38	-155.74	-10.38	-251.02	-12.55	-22.47	-0.94	-1954.73	-69.81
39	-1208.74	-80.58	-2400.11	-120.01	-2538.90	-105.79	-2651.24	-94.69
40	-2893.99	-192.93	-3835.55	-191.78	-2404.09	-100.17	-2583.83	-92.28
41	-6.34	-0.42	-6.34	-0.32	-224.68	-9.36	-224.68	-8.02

42	1328.74	88.58	-1130.85	-56.54	1932.26	80.51	2112.01	75.43
43	-655.68	-43.71	-1847.05	-92.35	-719.18	-29.97	-584.38	-20.87
44	-1332.43	-88.83	-832.82	-41.64	-853.79	-35.57	763.92	27.28
45	-1201.04	-80.07	-1585.35	-79.27	-134.81	-5.62	-179.74	-6.42
46	256.35	17.09	-550.71	-27.54	134.81	5.62	157.28	5.62
47	3289.41	219.29	-399.98	-20.00	-292.09	-12.17	-629.11	-22.47
48	3096.66	206.44	-1015.48	-50.77	157.27	6.55	112.34	4.01
49	-231.02	-15.40	-288.67	-14.43	-134.90	-5.62	-89.96	-3.21
50	-126.26	-8.42	-4392.12	-219.61	-1348.09	-56.17	-1123.41	-40.12
51	-1051.52	-70.10	-3645.62	-182.28	-2246.82	-93.62	-2606.31	-93.08
52	-2672.68	-178.18	-3787.18	-189.36	-2381.66	-99.24	-1685.15	-60.18
53	422.65	28.18			853.79	35.57	921.19	32.90
54	-1125.80	-75.05			1145.87	47.74	1505.36	53.76
55	-1021.89	-68.13			-3370.22	-140.43	-3280.34	-117.16
56	-12.03	-0.80			157.28	6.55	-898.72	-32.10
57	-23.84	-1.59			202.21	8.43	292.09	10.43
58	-1076.27	-71.75			-719.00	-29.96	-202.24	-7.22
59	137.68	9.18			337.02	14.04	426.89	15.25
60	11741.04	782.74			-1325.62	-55.23	-1325.62	-47.34

Table 5.2 Rate of change of right bank of Ghagara River per year (1975 – 2003)

Location	topo-img90	ROC in 15 year(1975-1990)	topo-img95	ROC in 20 year(1975-1995)	topo-img99	ROC in 24 year(1975-1999)	topo-img2003	ROC in 28 year(1975-2003)
1	1771.77	118.12	2079.22	103.96	606.64	25.28	-831.33	-29.69
2	-70.49	-4.70	-454.80	-22.74	-1033.54	-43.06	-1123.41	-40.12
3	1834.25	122.28	1488.37	74.42	-449.37	-18.72	-539.24	-19.26
4	689.88	45.99	-1077.96	-53.90	-1640.21	-68.34	-1662.65	-59.38
5	2390.61	159.37	-184.28	-9.21	-314.55	-13.11	-426.89	-15.25
6	1418.62	94.57	1457.05	72.85	269.62	11.23	157.28	5.62
7	154.75	10.32	135.53	6.78	0.00	0.00	-112.34	-4.01
8	2922.96	194.86	2365.70	118.29	1909.79	79.57	1168.34	41.73
9	3466.51	231.10	1083.78	54.19	966.13	40.26	1640.17	58.58
10	1312.18	87.48	1446.69	72.33	853.79	35.57	718.98	25.68
11	870.13	58.01	1235.23	61.76	0.00	0.00	112.34	4.01
12	3159.40	210.63	-2086.46	-104.32	-2112.01	-88.00	-2067.07	-73.82
13	-1582.35	-105.49	-3599.99	-180.00	-2493.96	-103.92	-2089.53	-74.63
14	5728.60	381.91	5286.64	264.33	4875.59	203.15	4493.63	160.49
15	783.47	52.23	34.06	1.70	112.34	4.68	4179.07	149.25
16	265.51	17.70	-138.02	-6.90	-89.87	-3.74	-89.87	-3.21
17	-1565.75	-104.38	-758.69	-37.93	-471.83	-19.66	-1100.93	-39.32
18	-230.93	-15.40	-365.44	-18.27	-247.15	-10.30	-381.96	-13.64
19	-731.14	-48.74	-788.79	-39.44	-921.20	-38.38	-853.79	-30.49
20	-190.56	-12.70	-2957.61	-147.88	-2808.63	-117.03	-2965.91	-105.93
21	-1991.66	-132.78	-1972.44	-98.62	-2156.94	-89.87	-2067.06	-73.82
22	366.21	24.41	250.92	12.55	44.94	1.87	89.88	3.21
23	1597.07	106.47	-74.66	-3.73	-112.35	-4.68	-112.35	-4.01

24	-1303.93	-86.93	-1476.87	-73.84	-1370.56	-57.11	-1370.56	-48.95
25	2379.65	158.64	208.29	10.41	247.15	10.30	224.68	8.02
26	3.42	0.23	-35.01	-1.75	-44.94	-1.87	0.00	0.00
27	74.68	4.98	55.46	2.77	44.94	1.87	22.47	0.80
28	1271.44	84.76	-304.24	-15.21	-157.28	-6.55	-269.62	-9.63
29	-7.61	-0.51	-526.43	-26.32	-1078.47	-44.94	134.81	4.81
30	-489.85	-32.66	-1296.91	-64.85	-1033.54	-43.06	-1303.16	-46.54
31	500.16	33.34	211.93	10.60	-224.68	-9.36	1572.77	56.17
32	-2156.94	-143.80	-2637.33	-131.87	3078.14	128.26	2471.55	88.27
33	2256.14	150.41	2198.49	109.92	853.79	35.57	179.74	6.42
34	2508.64	167.24	4430.20	221.51	4044.26	168.51	3842.05	137.22
35	2358.21	157.21	3453.50	172.68	2201.88	91.75	1213.28	43.33
36	-1797.41	-119.83	-1547.60	-77.38	-718.98	-29.96	471.83	16.85
37	-44.73	-2.98	243.51	12.18	-5864.19	-244.34	494.29	17.65
38	-34.45	-2.30	100.06	5.00	-494.30	-20.60	-696.51	-24.88
39	-682.73	-45.52	-413.71	-20.69	-651.58	-27.15	-629.11	-22.47
40	-1145.79	-76.39	-1337.95	-66.90	-2449.03	-102.04	1797.45	64.19
41	74.71	4.98	920.20	46.01	-44.86	-1.87	314.50	11.23
42	2067.92	137.86	1952.63	97.63	988.60	41.19	1303.15	46.54
43	1601.44	106.76	1678.30	83.92	1482.90	61.79	1977.20	70.61
44	927.99	61.87	1081.72	54.09	494.30	20.60	404.42	14.44
45	-171.61	-11.44	-133.18	-6.66	-179.74	-7.49	-426.89	-15.25
46	-54.61	-3.64	60.68	3.03	-89.87	-3.74	-67.41	-2.41
47	180.09	12.01	-12.07	-0.60	-224.68	-9.36	-224.68	-8.02
48	2833.63	188.91	1488.54	74.43	808.85	33.70	741.45	26.48
49	-231.14	-15.41	110.24	5.51	-853.79	-35.57	-966.13	-34.50
50	-1473.06	-98.20	-2472.31	-123.62	-1730.05	-72.09	-1685.11	-60.18
51	-1500.23	-100.02	-2653.17	-132.66	-2853.45	-118.89	-2920.86	-104.32
52	833.58	55.57	237.90	11.90	-1393.03	-58.04	561.70	20.06
53	2805.48	187.03			2718.65	113.28	2696.18	96.29
54	-1365.85	-91.06			-22.46	-0.94	-337.02	-12.04
55	-1531.47	-102.10			-1864.86	-77.70	-2426.56	-86.66
56	1810.29	120.69			1527.84	63.66	786.39	28.09
57	754.88	50.33			-674.05	-28.09	-67.41	-2.41
58	1547.26	103.15			179.74	7.49	2853.45	101.91
59	520.28	34.69			247.15	10.30	1078.48	38.52
60	175.64	11.71			2606.30	108.60	2741.11	97.90

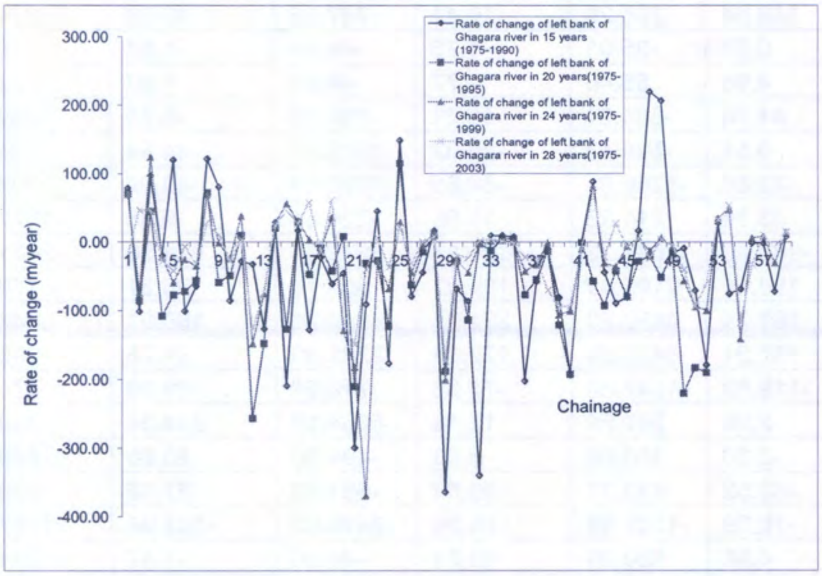


Figure 5.20 Rate of change of Left Bank

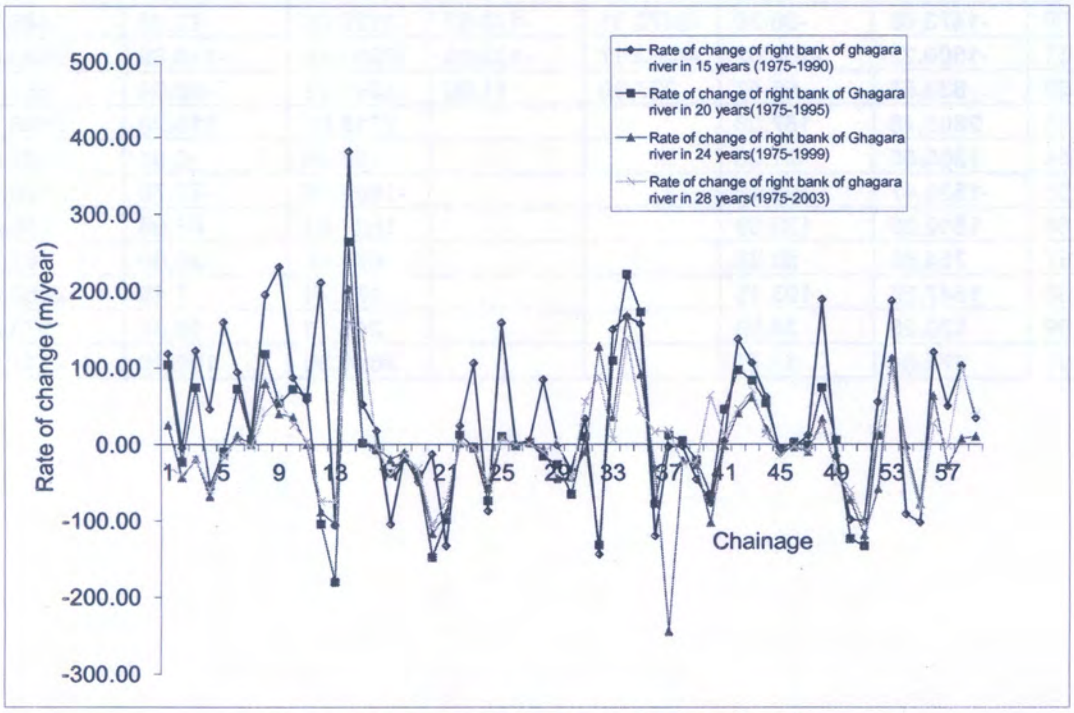


Figure 5.21 Rate of change of Right bank.

CHAPTER 6

CONCLUSIONS

The present study evaluates shifting characteristics of the river Ghagara using satellite remote sensing data. The shifting characteristics were evaluated for the different reaches both on the right as well as left banks of the river courses, using offset computation method of shifting. Conventional measurements of planform characteristics of meandering rivers are a time consuming, laborious and expensive procedure. On the other hand, remote sensing techniques are capable of providing information through time and space, which can never be appreciated from the ground. Further, satellite remote sensing presents an expedient, reliable and cost effective alternative method for demarcation of rivers at suitable time-space intervals to establish the stability or otherwise of their channels. Advantages of the information acquired by satellite remote sensing are of synoptic coverage and repetivity.

In the present study, evaluation of the shifting characteristics of reaches of the river between Manuhan (Ramsanehighat) to Chhapra, having length of 310 kms (approx.), was carried out. The Survey of India toposheets have been taken as the base for computation of shifting. The satellite data considered include 1990 (IRS-1A LISS II Data), 1995 (IRS-1A LISS II Data), 1999 (IRS-1D LISS III Data) and 2003 (IRS-1D LISS III Data).

The distance between first and last point of River Ghagara has been divided into ten reaches and reach wise analysis has been done. In reach nos. 1, 8 and 9 the shifting is less in comparison to other reaches. In these three reaches the shifting is of the order of approx. 3.5 kms. While in other reaches the maximum shifting is 6-6.75 kms. Based on this analysis, the critical locations along the river Ghagara, where major shifting has occurred are Ayodhya, Tanda, Golabazar, Barhaj and Bansdih.

Detailed study, of some of the identified critical locations, was carried out using IRS-1D PAN data, having a spatial resolution of 5.8 m, for years 1999 and 2003 along with SOI toposheet of the scale 1:50,000.

On the basis of analysis of toposheets and satellite data, the shift in different reaches has been computed. To ascertain the reasons of the shift, field visits of some of the points in both the rivers have been carried out. During the field visit discussion with Government officials and local people was made. On the basis of visit and literature survey, it was observed that heavy minning of sand from its course and variation in flow was the reasons for shifting in river Ghagara.

The causative factor of the historical rainstorm of 1988, which tops all storms in the region, was abnormal rainstorm.

As such no structure has been constructed on the river during the period of study, therefore effect of these structures on the river shifting could not be studied.

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ANNEXURE - I

EMBANKMENT

A 77 kilometer link Turtipar Srinagar marginal embankment was constructed in the year 1956 and 1957 at a cost of Rs.30.38 lacs along the right bank of the Ghagara river in Ballia district to protect an area of 36,500 hectare from inundation due to floods. This embankment has been provided with 44-gated regulators for draining off the surface drainage water from the area on the right of bund when the river gauge is low and to prevent floodwater from entering into the country side when the river stage is high. The Turtipar Srinagar bund behaved satisfactorily during initial year (up to 1963) and provided required flood protection. But in due course of time, the river started changing the course towards the right bank, which resulted in erosion of the right bank. Despite the execution of some anti-erosion works from time to time, the river continued its attacks on its right bank in the reach km 57 to 65 of Turtipar Srinagar bund and its severity increased progressively. The main bund breached in the year 1967 near km 57 when a retirement of bund had to be done. Due to progressive erosions of the bank and persistent river attack, the first retired bund breached and second retirement had to be done in 1979. The second retirement also breached in 1981 and a third retirement was done. Heavy river pressure continued on the bund. The affected reach of bund was provided with launching apron and pitching also the quantum of progressive damage as a result of river attack/pressure can assessed from the cost of localized protective measures undertaken from 1964 to 1984 which work out to Rs.382 lacs and the fact that the river which was at a distance of 2.5 kilometer away from bund started hugging the bund in span of about 16-17 years considering the severity of problem of bank erosion and ineffectiveness, of localised remedial measures it became essential to examine the whole problem in its broad perspective and above long term remedial measure for the safety of this vulnerable bund.

In order to work out an economical and effective solution to the seven problem of erosion and the safety of Turtipar Srinagar bund, the following aspect were considered which are described in the following paragraphs:

1. The river and its behaviour.
2. The remedial measures adopted in the past and their performance.

3. Analysis of the problem.
4. Approach for the solution of the problem.
5. Hydraulic model studies.
6. Evolving remedial measures.

The river and its behaviour

The River Ghagara is one the most important major tributaries of the Ganga with a maximum recorded discharge of 29,686 cubic meter per second at Turtipar in 1974. The frequency of flooding varies from 2 to 4 out of every nine years, which clearly indicates its flooding potential and its associated problems. The Ghagara causes heavy flood damages in Uttar Pradesh. The main current of the Ghagara has a changing tendency in a width varying from 6 to 8 km at a number of places.

During high floods, large areas are inundated affecting land in a width of 8 to 32 km. Heavy precipitation in general with synchronization of floods, prevents Ganga tributaries- Ghagara, Seti, Sarju, Sarda, Tirti, Kuwano, Daha etc., from flowing into the main channel and creates problems of inundation and bank erosion at places. The river carries considerable discharge as is evident from the fact that the river was navigable in the past by boats of large tonnage and streamers of considerable carrying capacity. The course of the river in the Balia district is stereotyped by Kanker reefs at Turtipar, Qutabganj and Aitasgarh near Maniar (km. 0.0, 18-19 and 38-40 of Turtlpar Srinagar bund). Between these points the variation in the channel are continuous and remarkable, but the greatest changes are those, which occur, downstream of Maniar where the whole country side on the south bank up to Bansdih and Reoti used to be inundated heavily. The changes effected by Ghagara are more sudden and sweeping and the extent of damages done by river is less but the Ghagara is much more unstables and its course cannot be predicted. Development of new spills, silting of existing spills, formation of diaras etc. are common features. The instability of the riverain increases more and more as its confluence with the Ganga is approached. The confluence of Ghagra and Ganga has a tendency to shift downstream slowly viz., 37 km in 55 years, as reported in 1907 Gazetteer of Ballia district, because of the appreciable difference in the grain size of sediment transported in the two rivers which results In continuous changes in the meandering pattern of the river Ghagara particularly downstream of Maniar.

There is sufficient evidence to indicate that the river course of Ghagara in Uttar Pradesh is very wide and has oscillations In some of the reaches. The past history of the river indicates that the course of the river is fairly well defined at km 0, 18-19 and 38-40 of Turtipar Srinagar bund and the river oscillates between these fixed nodal points. Also near km 53, the soil strata are hard on the right bank. The greatest changes occur downstream of km 38-40 of Turtipar Srinagar bund to its confluence with Ganga. Surveys of the problematic reach, from the year 1882 to 1976 indicate that the river course shown in 1882 survey confined towards the left bank up to 1935. In 1935 a spill of river opposite km 57 of Turtipar Srinagar bund got activated and river followed this course confined towards right bank during 1935 to 1957. During 1957 to 1964, the river again followed the old course of 1982. In 1964, the river started following the spill opposite km 57 of Turtipar Srinagar bund, i.e., spill towards the right bank. The spill gradually advanced towards the Turtipar Srinagar bund in the reach downstream of km 57. Comparison of different surveys from 1882 to 1984 indicate that the three meandering loops have a tendency of gradual shift towards downstream and at the same time the angle of Incidence of the second -loop opposite km 63 is getting acuter each year as a result of which the apex of this loop is getting shorter and shorter and its concavity is increasing. This behaviour of the river has a typical effect on the safety of Turtipar Srinagar bund at km 62 to 65, i.e., near Chandpur where heavy erosion and seourse has occurred along the bund.

Remedial measures adopted in the past and their performance

From 1957 to 1963, Turtipar Srinagar bund behaved very satisfactorily and provided the desired relief from floods. But in due course of time, the river as per its behaviour pattern described above, started changing its course towards the right bank in the reach from km.57 to 65 resulting into erosion of the right bank. To check the tendency of erosion, localised anti erosion works of different kind were exerted from time, which could not be effective; rather they were damaged and or washed away. The chronological details of measures adopted from time to time and their performance are described below.

In 1964, when river started erosion on right bank, localised protective measures were provided which could not be effective and the bund breached in 1967 near km 57. Therefore the first retirement of the bund had to be done from km 56 to 63 of Turtipar Srinagar bund. The eroding tendency of the right bank, of the river persisted and the first retired bund breached from km 58.5 to 59 in 1971. The bund was retired again in this reach. The eroding tendency continued and in 1972 one permeable balli spur of 380 meter was constructed for checking the erosion. It did not prove effective and its major length was washed away. In 1973, thirty-three submerged boulder bars were constructed to check the erosion which proved ineffective and were either completely washed away or damaged heavily during floods. In 1974, nine permeable balli spurs were provided which were out-flanked and damaged causing severe erosion. Eighteen dampners were constructed in 1975. As a result of progressive erosion of right bank, the river came as near as 180 meter away from bund near km.63.2 (originall 2.5 km. away). During 1979, fast erosion started when crated and uncrated boulder studs were provided which were damaged. Some floating tree (permeable) spur were also placed but in vain. The bund breached in 1979 and second retiremen was done. In 1980, five boulder spurs and five studs were provided. The erosion took place in between the spurs and caused heavy damage near km.63.2 damaging spurs. The river had a severe attack on the bund from km.58.5 to 63.2. Before 1981 floods the damaged spurs were repaired. New studs and dampners constructed but all of them were washed away and the main bund and its second retired bund breached in a length of 1 kilometer. In 1982 third retired bund was made from km 62 to 64 with launching apron and pitching, but heavy river action persists which damaged the launching apron, pitching and bund. Eroding tendency of river continued in 1983. The damages of 1982 were restored. The bund could however be saved by heavy flood fighting. Back rolling of flow was also observed down stream of km.64 of the bund. Similarly damages again occurred in 1983. 198 when 5 nos. studs introduced from km.62 to 63 and work on IVth retirement as second time of defense was done. Heavy flood fighting had to be done to save the bund from breaching. Restoring the damaged section of bund. Introduction of nineteen boulder studs and boulder filling between the studs and embankment were done. In the end of August 84, all the studs launched and earthen section of bund was damaged, flood fighting was continued and permeable bamboo spur filled with light locally available material were constructed to save the bund but due to heavy back roll in the river flow downstream of km.64, the bund was severely damaged. To summarise, the localised remedial measures executed at the site did not proved effective as the river continued to maintain its attack a the bund. Only launching apron & revetment proved partially effective.

Analysis of the problem

The study of river behaviour including its meandering pattern, the tendency of changes in the spills of rivers, development of new spills, deposition of excessive bed load at or near its confluence with Ganga, fixed model points on the bank of Ghagara in Ballia district, progressive trend of severity of river attack and damages thereof, the failure or ineffectiveness of various measures except for partial success of launching apron and pitching, and the survey or river in different years indicates that the problem of river attack damages etc., will keep on occurring so long the flow in the Ghagara-causes shifting of meandering loop in the reach from km 46 to 72, reduction of the angle of incidence of second meander loop near km.63 resulting in appreciable concentration of flow, scour and bar erosion, increase in velocity along bund continues. So the success of the remedial measures would be governed by the possibilify of change of river flow and reduction in concentration of flow along right bank and bund. It was, therefore considered that hydraulic model studies be also conducted for watching the behaviour of river and its effect on bund on the latest survey, covering a larger length of the river preferably between the two model po1nts on the banks of the river.

Approach for the solution to problem

The problem for protection of Turtipar Srinagar bund and success of any remedial measures essentially dictates the necessity of reducing pressure on the right bank of the river and making the right bank, Turtipar Srinagar bund and protective measures strong enough to hold the river along its present time. Considering various aspects of the problem including river behaviour, performance of Turtipar Srinagar bund protective measures taken from time to time, the socio- economic aspects, various model studies conducted, the approach for tackling the problem was kept as below:

I. To hold the existing Turtipar Srinagar bund its present location by suitable measures.

2. To complete the work of the retired bund under execution along with other necessary appurtenant works as second time of defense.

It is felt that the training and control of a mighty river like the Ghagra, is a long term affair and a continuous struggle with nature. There is nothing like permanent measures. The behaviour of the river has to be constantly watched and timely protection and remedial measures taken against the river attack. River training works for erosions control are very costly and strong or unnecessary armouring of the entire protective work would be prohibitive in cost. As along term measures, flood havoc can be minimised by moderation of floods by construction of reservoirs on rivers. Construction of reservoirs is not feasible in near future because all suitable sites are located outside Indian Territory.

Hydraulic model study

Model studies were conducted on river survey of different years and relevant hydrological data. The observation of running the model indicates as below:

1. The river attack increases on the upstream of km.64 up to km.62. This reach of the river was seen to come under direct river attack up to a discharge of 8500 cumec which is nearly the bank full discharge. There is a heavy back rolling between km.62 and 63 and downstream of km.64.

2. At a river discharge of about 11000 cumec the river has a tendency to straighten and the action on the bund is reduced. However the action at the nose of the bund at km.64 and the back rolling and bolling downstream of km.64 still persists.

3. It was observed that the back rolling downstream of km.64 can be reduced by permeable spurs and that no comb1nation of spurs of reasonable length could provide satisfactory protection. It was, therefore, inferred that extension of pitching & apron on the upstream is the only viable alternat1ve.

Remedial Measures

Considering all aspects and studies as above, the following measures were proposed to be accelerated before 1985 floods.

(A) Protective Measures Downstream of km 64

1. Restoration of Earthen section to its original design.
2. Provision of 0.45 m thick stone pitching over 0.225 m thick O.B.B. filter in the reach from km.64 to 64.30.

3. To break the back roll action downstream of km.64 three permeable short spurs made from boulder wire crates be provided at 100 m spacing at chainage of km.64.1, 64.2 & 64.3. The length of these spurs at top shall be about 25, 50 and 75 m length, with top width of 2.0 m keeping top laid 1.0 m above low water laid of 53.5 or a maximum of 1 m above existing level where they are above low water level with side slopes of 0.5 H:IV. The nose of these spurs shall be finished to have a slope of 1: 1 all around. Boulder wire crates. The quantity of stone shall correspond to the discharge of 3.0 lac cusecs, silt factor of 1 and scour depth of l R.
4. In between the three short spurs, the launching apron in width of 5 m shall be provided upto low level. The apron shall in lxlx0.6 m boulder wire crate with 1:1 side slope. The quantity of stone shall correspond to a discharge of 3 lac cusecs, silt factor 1 and scour factor of lR.

(B) Protective Measures U/S of km 64

1. Damaged pitching shall be restored.

2. 10 m long studs m in reach from km 63.9 to 63 shall be provided m boulder wire crates of at least 2x2x0.6 m with 0.5H:IV side slope and nose of 1:1 side slope at a spacing of 30 m centre to center at top and shall have atop width of 2 m with its top 1 m above the L.W.L.

3. Launching apron from chainage 63 to 62.3 should be provided for dominant flood discharge (persisting for long duration), which is considered as 3.0 lac cusecs, scour depth factcr of 1.25 R, silt factor of 1.0. The provision of 1.25 R has been made in the initial stage, which can be strengthened, if required, after watching its performance.

4. Revetment comprising of 0.45 m thick stone pitching over 0.225 m thick O.B.B. filter in the reach from km 63 to 62.5 to counteract the parallel flow.

5. The nose of existing spurs at km 63, 62.8 62.6, 64.4 and 62.025 shall be strengthened for a discharge of 3 lac cusecs silt factor of 1.0 and scour depth factor of 1.5. The noses shall be laid on the extreme end of river bank line at low water level. The top width of spur shall be 2.0 m and it shall be 1 m below HFL, i.e., RL 59.0.

6. Two more spurs at 61.6 and 61.2 shall be constructed with earthen shanks with 1.5: 1 side, slope and 4 m width at top and a free board of 1.22 m with 0.45 thick stone pitching over 0.225 m thick O.B.B. filter. Noses shall be safe for 30 lac cusecs discharge, silt factor 1.0 and scour depth factor of 1.5 R.

The measures as above were executed before 1985 floods, which were very satisfactorily except for very minor damages, which are being restored, subsequent model study indicates necessity of one more spur downstream of km.64 and strengthening of nose of spurs at km.61.8. The effectiveness of the measures is further proved by the fact that river has started eroding left, bank, induction of silting on right bank in some reaches reduction in velocities of flow along bund.

ANNEXURE – II

The replies of the comments raised on the report are given below:

(1) CONTENTS - 5.2 should be REACHWISE ANALYSIS OF SHIFTING OF RIVER - Page no. 35. For Content 5.3, page no. should be 45.

The corrections have been made in the report.

(2) LIST OF TABLES: In Table 4.1 (Upper Part) should not be mentioned.

It has corrected as suggested.

(3) The OBJECTIVES at page no. 6 are not the same as it was issued vide letter no. 4/64/2004/ Morpho/ 1322-25 dated 20th Aug, 2004 (copy enclosed).

The objectives have been modified.

(4) The study area (3.1) selected is an alluvial reach from Manuhan (distt. Barabanki, U.P.) to Chhappra (Bihar) .Please clarify why the stretch upstream of Manuhan upto Nepal border has not been studied.

The reasons for the same have been included.

(5) The digital data IRS LISS II for the year 1995 has been used instead of the year 1994 as indicated in the objectives. The reason for this is not indicated in the report.

The reason have been included in the revised report.

(6) In Table 3.2, in column for 1999 data-data for 28/1/2000 is indicated. Similarly in column for 2003- data for 14/12/2000 and 10/12/2004; in column for the 1995-data for 23/4/1994 is indicated. It may be clarified in the report.

It has been corrected.

(7) As per the objective, the river course is to be delineated along with major roads, embankments, railways and important places which is not done.

River course and other features are seen on satellite data.

(8) As per the objectives, the rate of shifting is to be worked out which is not done .In the Flow chart (Figure 4.6), 'Trend analysis at the identified critical locations is indicated but the same has not been carried out.

The rate of shifting have been carried out and included. The flow chart has been corrected.

(9) Figure 4.7 shows the offsets from Manuhan to Pura for the year 1990& 1995. Figure 4.8 shows the offsets from Pura to Balaghat for the year 1990 & toposheet. Why is there inconsistency of data? Instead offsets from Manuhan to Chhappra (ie for the whole length of the river) for the toposheet and the year 2003 should be shown which will exhibit the shifting of the course of the river from the toposheet (i.e. base year) to the year 2003.

The offsets have been drawn for the whole reach however for presentation only a part of the whole reach is covered.

(10) In Table 4.1, data is missing at many places.

The reason for the same has been included in the report.

(11) The sign convention in Fig. 5.14 indicates that positive value is deposition and negative value is erosion. but if for example , we consider point 1 and 10 :

Point No.	Toposheet		Image 2003		Topo-image 2003	
	L/B	R/B	L/B	R/B	L/B	R/B
1	2089.5	3212.9	2606.3	4044.3	-516.76(E)	-831.33(D)
10	-6178.7	-3280.4	-5414.82	-3999	-763.92(E)	718.98(E)

It is clear from above that even the negative values show deposition and positive value shows erosion. Therefore sign convention is not correct. In view of this,it appears that the graphs shown in Fig. 5.13 to 5.19 are erroneous.This aspect may be looked into and corrected.

Sign convention is now added in the report.

(12) Fig. 5.13 to Fig. 5.19 are indicated as shifting of the river .But, infact, they exhibit shifting of the left and right banks. How shifting of the river is derived is not clear in the report.

The shifting of left and right banks have been computed not shifting of river, this has been corrected.

(13) In article 5.2, it is mentioned that at Ayodhya, shifting is high. But Ayodhya is not shown in Fig. 5.13, 5.14, 5.15 & 5.16.

Ayodhya is now added in the figures.

(14) In Fig. 5.13, the shifting is not shown for the entire length of the river.

Some of the points are not available in this because of non availability of cloud free satellite data

(15) As per article 5.3,Ayodhya & Gola bazaar are critical locations. As per article 3.1,Vikramjot-Dhuswa is a critical location. But shifting at these places using IRS-1 C PAN data has not been carried out.

Cloud free IRS-1C PAN data was not available for some of the locations.

(16) The chainage shown in Fig. 5.17, 5.18 and 5.19 are not the same as shown in Fig. 5.13 to Fig. 5.16 for Tanda and Bansdih.

Corrected.

(17) In article 5.3, it is mentioned that the shifts using IRS- 1C PAN DATA from topo sheets as well as shift from 1999 to 2003 are included in Table 4.1. But it appears that Table 4.1 and Table 4.2 merely shows shifting for left and right bank using IRS-1C DATA and not the IRS- 1C PAN DATA.

Tables have been corrected now.

(18) Fig. 5.17 exhibits that both the banks have erosion of the order of 3.5 km from toposheet to PAN 1999 & PAN 2003. It is not clear how it is interpreted as shifting of the river as mentioned in 5.3. Similarly by 0.175 km from the year 1959 to2003 may be explained. Similarly, shifting at Bansdih as mentioned in 5.3 is not clear.

This paragraph is rewritten now and made more clear.

(19) Fig. 5.19 shows left bank & right bank on X-axis, it is not clear. It may be interpreted in the report.

Corrected in the report.

(20) The magnitude of erosion and deposition for left / right bank as given in 5.2.1(it should be 5.3.1) should be checked as it is wrong at many places.

Corrected.

(21) In Chapter 6 (CONCLUSION); As per the objective, the shifting from toposheet to images 1990, 1994, 1999 and 2003 should be discussed. The magnitude of shifting at critical locations along with rate of shifting should be elaborated in the report. It is said in the report that as there has been no structure constructed in last 20 years; therefore effect of

structures has not been studied. But the structures constructed after the base year i.e. of toposheet, should be considered for evaluation of their performance from morphological point of view as well as their effect on river morphology as per the objective. The report should be as per 'General guidelines for preparation of river morphological reports' of CWC as per the objective, which is not so.

Corrections have been made in the report.