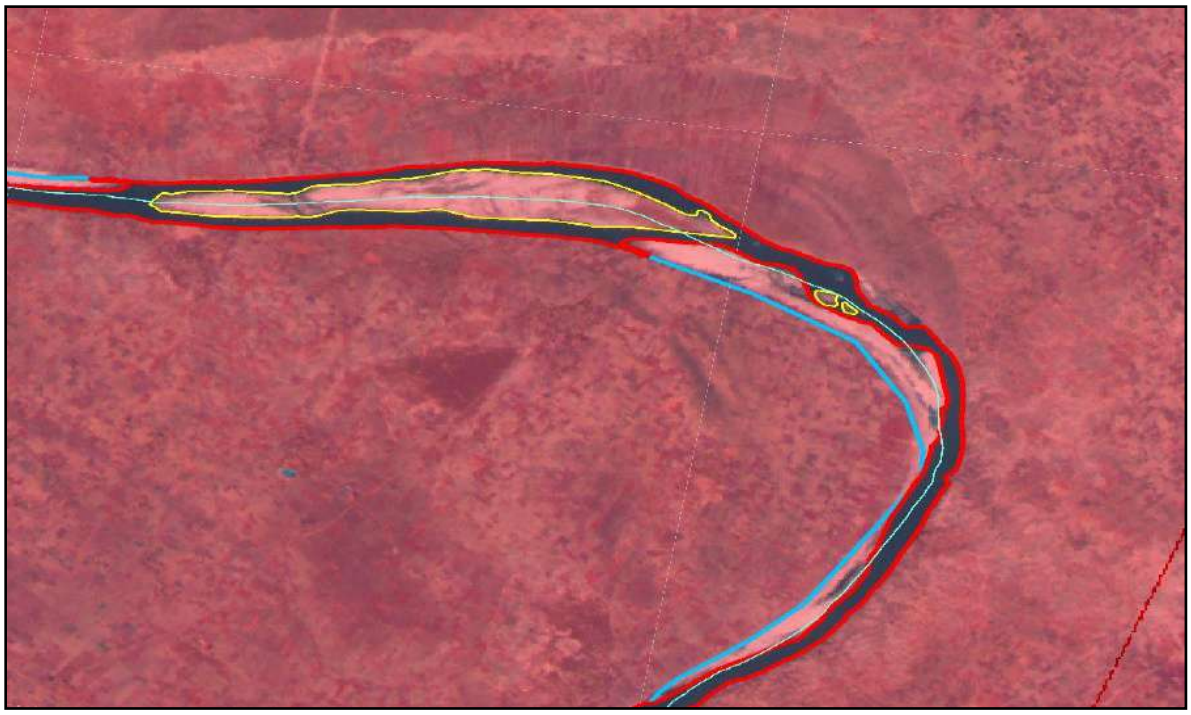
Final Report

MORPHOLOGICAL STUDY OF YAMUNA RIVER



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Executive Summary

Management, conservation, preservation, restoration and improvement of natural systems including river basins and other ecological assets is indeed an emerging concern. Towards this goal, amongst numerous other aspects, a scientific understanding of evolving plan forms & river channel morphology, river flow regimes and the overall dynamics of the river, as influenced by auto and allocyclic triggers, is imperative when planning the management and developmental protocol for the river basin and its water resources. Over the years, a diverse set of direct and indirect methods of observing and recording morphometric and other attributes of these rivers have been developed. Direct observation of river morphology includes physical recording of long- and short-term changes in channel cross sections and sediment transport mechanism. Though it is time consuming and expensive to record these morphological observations on ground, it helps in developing a sound physical understanding of the natural system. However, spatial and temporal scale of observation is limited for such observations. On the other hand, remote sensing technique provides observations on spatial and temporal scale depending on availability and recording of data through satellite. In both techniques, observations made are at a particular point and time but considering coverage, uniformity and high recurrence interval with advancement in remote sensing technology, indirect observations made about river morphology provide considerable amount of information about the areal extent of river functions, changes in river courses, seasonal variations in water line etc. This information can be used effectively to predict critical and stable reaches in particular system in a specified time frame, though ground survey-based observation is obligatory for detailed modelling exercises.

The present study evaluates channel bank retreat on account of erosion-deposition and river course dynamics of the Yamuna using satellite remote sensing data in GIS framework. For analyzing complete reach of Yamuna from its origin to its outfall into Ganga at Prayagraj, various river features like channel area, active water area, sandbars and water bodies are extracted from satellite data (NRSC and USGS images) at an interval of about 10 years depending on availability of cloud free data. Five years identified for the comparative analysis are 1975, 1990, 2000, 2010 and 2016.

Trasnsitions in channel area, bank lines, active water area, and sandbars have been measured for computation of channel bank retreat on account of erosion and deposition on grid scale of 25 km and results of each grid are analyzed. Analysis of river course dynamics in the form of movement of channel centreline on decadal time frame is carried out at 1 km interval and decision about critical

and stable reaches are made accordingly. Some of the major findings drawn from the study are as follows

- Land-use changes in Yamuna River Basin have been estimated using remote sensing imageries of different years. Based on satellite imagery of the year 2016, agriculture area in the basin accounts for 81.54% followed by forest (11%), Barren land (3.42%), Water bodies (1.9%), Built-Up area (1.8%), and Snow/Glaciers (0.08%). Land use change analysis indicate that built-up area and agriculture have increased by 1.06% and 11.42% from 1977 to 2016, whereas forest and barren land have shown the reduction of 7.06% and 4.22% respectively. As discussed in Chapter 17, direct assessment of impact of land-use change on morphology cannot be achieved. However, based on changes in land use type, one may indirectly predict the pattern of erosion and deposition. Accordingly, it can be said that over the years, a decrease in forest and increase in agriculture and urban area has been observed which might have resulted in increased erosion in the basin.
- Hydrologic analysis of the observed streamflow data has been carried out and presented in detail in Chapter 9. From the analysis of 1.5 and 2-year return period flood events, at few locations sudden rise or fall in streamflow values have been observed. Though the frequency analysis based on observed streamflow has been attempted, it may not represent the actual reality of the system as regulated flow regime in present condition has been used to perform the frequency analysis. Therefore, results of this frequency analysis may be used in the limited context of morphological study and might not be suitable for other applications such as design flood estimation.
- Indices to understand sinuosity, radius of curvature, braiding, planform of the river have been estimated. Average sinuosity for the entire stretch of Yamuna River is 1.38 whereas radius of curvature varied between 0.25 to 39.32 km. Based on Braiding Index and Planform index, it can be said that braiding is indeed evident though limited only over some identified reaches and are located mainly in the downstream of Hathnikund Barrage. Additionally, improvements over existing Plan Form Index and Braiding Index have also been suggested.
- Understanding of River Course Dynamics has been carried out at 1 km interval and it has been seen that river has experienced changes in its course at a few locations. Those locations are concentrated in the middle stretch of the river. River is found to be stable in Himalayan region as well as in the region after its confluence with Chambal River.

- From the analysis of confluence points, except Hindon-Yamuna confluence, other confluence zones are stable and have not gone through significant change in last 40 years. Hindon confluence has experienced change between 1990 and 2000, which is reflected in satellite image of the year 2000. Confluence has moved towards upstream and taken the shorter path.
- During 1975-1990, the areal extent of erosion and deposition is of similar order of magnitude (the difference between area eroded and deposited is only 21 sq.km). During 1990-2000 significant variation is noticed as the areal extent of erosion is found to be 171.5 sq.km more than deposition. In 2000-2010 and 2010-2016 time periods, not many variations are observed in areal extent of erosion and deposition. While 2000-2010 indicates overall deposition of 48 sq.km, the 2010-2016 period suggests an erosion of 32 sq.km of the area.
- Suspended Sediment Load (SSL) varies spatially across Yamuna River. Delhi recorded maximum value of SSL in 1995. The year 1999-2000 can be considered as a breaking point after which SSL for all available stations reduced drastically.
- Based on Meander-Migration modelling exercise, a few locations have been identified in the stretch of Kalanaur to Gokul Barrage that may experience neck cut off/ ox-bow formation/ abandonment of reach. However, some of these areas are already protected with flood protection structures which ultimately restrict the river movement. From the combined approach of remote sensing image analysis and simulation studies, chainages are identified as morphologically active stretches 163-164 (Jathlana), 178-179 (Gumthala Rao), 362-368 (Garhi Samstipur), 405-416 (Bilochpur), 453-468 (Muhul Sakraya).
- Based on the physiography, channel geomorphology, flow regime and outcomes of present study, the entire Yamuna is divided into five zones and results from the morphological study are juxtaposed to define the zones either stable or active. Based on this, zone 'C' (Hathnikund Barrage to Vrindavan) is found to be morphologically active whereas other zones are comparatively stable.

The study confirms that observed rates of channel bank retreat on account of erosion and deposition are conspicuously significant at a few locations along Yamuna and movement of channel centreline is also significant. Detailed results have been presented in subsequent parts of the report. Most importantly, attempt has been made to define various terms such as channel centerline, shifting, river course dynamics, morphologically stable, active, and critical reaches which are commonly used in field of river morphology and have not been defined in a scientific manner in previously carried out morphological studies in Indian context.

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Chapter 1 Introduction

1.1 General

Many natural sculptors shape the Earth's surface by working together; among which, rivers, contributing to processes like weathering, erosion, transportation and deposition and moulding the contours of the earth more than the other natural factors, are of prolific importance (Marsh and Kaufman, 2013; Twidale and Campbell, 2005). River's shape is determined by processes which are in turn functions of natural characteristics of river basin like topography, geology, soil properties, climate and also human-induced changes in land use and flow regimes of the river (Dominick and O'neill, 1998). Other factors such as tectonic activities, lithology, glacial lake outbursts, landslides, vegetative factors etc., are also responsible for the genesis of changes in river shape. River morphology; a special fluvial subsector of geomorphology (science of landforms), deals with the shapes and forms of river channels and adjoining areas and changes in them on account of erosion, transportation and deposition of sediments by flowing water along with origin and formational processes of the rivers (Garde, 2005).

River Morphology is the subject of great challenge as each river on the earth is unique (CWC, 2009) on account of unique combinations of the above mentioned factors that are responsible for shape of the river. Based on such combinations of contributing factors, different patterns and shapes of rivers (meandering, braided, straight, etc.), drainage basins (fern shaped, fan-shaped, etc.) and drainage networks (dendritic, parallel, rectangular, etc.) are commonly observed (Leopold and Wolman, 1957; Murthy, 2002; Matsuda, 2004). River channel behaviour often needs to be studied for its natural state and also in response to human-induced changes in such behaviour (Chang, 2008). While natural states are unique; human interactions with different rivers are also unique on account of their geographical extents, hydrological enormousness and various demographic, socio-economic factors. This makes morphological study of each individual river system more critical and a meticulous requirement.

Study of morphological behaviours of the rivers is also important for basin planning endeavours considering elevated risks from floods. Several researchers have linked floods with sediment transport process altered by hydraulic structures which on other hands also threatens, destabilizes

such hydraulic structures and disrupts their operations (Gharbi et al., 2016). In alluvial rivers, cross-sections may face severe morphological changes during flood events due to sediment transport, log jam, rock jam, etc., which ultimately alter the water levels significantly. This implies the necessity of incorporation of calculated or estimated morphological changes to the flood risk assessment (Neuhold et al., 2009). Morphological study can provide information on the major river processes and associated hazards, and river's response to past floods and control efforts (Field et al., 2014).

Challenges in a morphological study are conspicuous on account of the need for involvement of knowledge of related sciences such as physics and geology, hydraulic engineering and hydrology, climatology and landscape ecology, etc. (Mangelsdorf et al., 1990). Special impulses of hydraulic engineering experiments obligate the morphological studies. In recognition of the fact that every river engineering effort must be based on a proper understanding of the morphological features and their possible responses to the imposed changes (Chang, 2008); and that the morphological studies are prerequisite of flood management issues; morphological studies are important for sustainable river management and also for restoration and mitigation activities.

1.2 Remote Sensing and GIS applications in morphology studies

Changes in river morphology can be studied with the use of physical, analytical and numerical models (Cao et al., 2002; Chang, 2008), however, they are complex and time-consuming. Also the solutions obtained from these traditional techniques are time and space-specific (NIH, 2013). Thus when the changes take place over large lengths and are slow, it is advantageous to use remote sensing techniques that are capable of providing information through time and space.

Remote sensing technique derives information about the earth's surface without physically coming in contact with it. It involves (i) making observations using sensors mounted on platforms; (ii) recording the observations on a suitable medium; (iii) transmission of data to the ground station; (iv) corrections to data to remove geometric and radiometric distortions (pre-processing); and (v) generation of output in the form of satellite imageries, the photographic enlargements with appropriate rectification (Garde, 2005)

These satellite imageries may be effectively used to evaluate the shifting characteristics of rivers in a quick and cost-effective manner and they can also be used for an expedient and reliable

demarcation of rivers at suitable time-space intervals to establish the stability or otherwise of their channels. As a special advantage, areas that may be so inaccessible for data collection can also be studied using remote sensing methods (Garde, 2005; NIH, 2013). Knowledge and hands-on experience of using image processing software and platforms like ERDAS and Arc-GIS, etc., are core to use of remote sensing data in morphological studies.

General Guidelines for Preparing River Morphological Reports, prepared in April, 1991 have now been revised to incorporate remote sensing as an advanced technology in morphological computations (CWC, 2009). Several river morphological studies incorporating the use of satellite-based data are reported in global literature in recent times. Davinroy et al., (2003) studied morphology of the Kaskaskia River, a tributary of the Mississippi River, through use of aerial photography and USGS quadrangle maps. Mohammadi et al., (2008) determined the morphological changes of Gorganrud River in Iran using satellite images of Landsat, ETM+. Legleiter (2010) studied morphology of Snake River in Wyoming, USA. Other case studies of different morphological aspects like coastal effects, aquatic habitat conditions, anthropogenic effects on morphology of river etc., studied using remote sensing and GIS approach are also reported in the literature (Ghoshal et al., 2010; Legleiter et al., 2004; Seker et al., 2003; Tamminga et al., 2015). Morphological behaviour of River Brahmaputra in Bangladesh has been studied extensively (Alam et al., 2007; Bhuiyan et al., 2015; Islam et al., 2017; Uddin et al., 2011).

A few studies for morphological behaviour of Indian rivers are also seen to be based on remote sensing approach. Manjusree et al., (2013) used remote sensing for morphological study of various reaches of River Brahmaputra and Ganga. Pan (2013) studied morphology of various river courses in Bankura District of West Bengal. Sarkar et al., (2012) studied the morphology of Brahmaputra River in Assam State of India using remote sensing techniques.

1.3 Objectives of the study

The present study aims at studying morphological aspects of Yamuna River using remote sensing technique. Broad objectives of the study are:

1. To study morphological behaviour of the River Yamuna
2. To estimate erosion and deposition (areal retreat) on a decadal time scale
3. To analyze the dynamics of the river course
4. To identify stable and critical reaches in the river.

Chapter 2 Review of Literature

2.1 Overview

Several processes are responsible for complex and time-varying phenomena of river evolution which in turn drives the river morphology. Among these, the processes such as sediment transport and erosion-deposition are predominant and carry much weightage than others. Multiple methods are available to assess the impact and rate of these processes. They can broadly be categorized into; i) field observation based and ii) remote sensing based methods. Both methods have their advantages and disadvantages. The field observation based methods involve field measurements for estimating linear rates and volumes of erosion/deposition, and morphological cross-sections to track the changes in channel profile over a period (seasonal and annual scale). In contrast, remote sensing based methods engage with analysis of the archival information available at various scales. The archival sources can be conventional survey maps (Toposheets), aerial photographs and/ or satellite images.

In the present era, remote sensing and GIS play a key role in geomorphological studies for various reasons. Availability of multitemporal and high-resolution data allow the user to analyze the river channel settings, shifting of courses, formation and abandonment of oxbow lakes, pattern of erosion and deposition etc., which otherwise would require deployment of significant resources. More importantly, coupling of information drawn from remote sensing observations at wider spatial scale with ground-based observations captured at the local scale is found to be useful to arrive at more rational outcome.

The literature review presented in this chapter includes the morphological indices that are commonly used to present a quantitative characterization of the underlying morphometrics as well as to present a qualitative characterization of the system's morphological behaviour. The review also touches upon a few case studies which highlight the use of remote sensing and GIS in river morphology as well as morphological studies focusing specifically on the Yamuna River System.

2.2 Morphological Indices

2.2.1 Meandering Parameter

A meandering river is the one which flows over a broad plain rather than just being confined to a narrow valley. The river turns its course on both sides of the bank following

a looping and winding path along its way. Meandering starts when any river reaches its mature (old) stage, the lateral (sideways) erosion & deposition is greater than vertical erosion & deposition and thus a winding course develops due to the deposition of silt on one bank and erosion along the other bank. There are several indices which address the meandering behaviour of the river. Some of the notable contributions are discussed here.

1. Mueller's Sinuosity Index

   Mueller's sinuosity index quantifies the percentage of a stream channel's departure from a straight-line segment on account of hydraulic factor within the valley or topographic interference (Ezizshi, 1999). The index was redefined to incorporate the hydraulic sinuosity and topographic sinuosity.

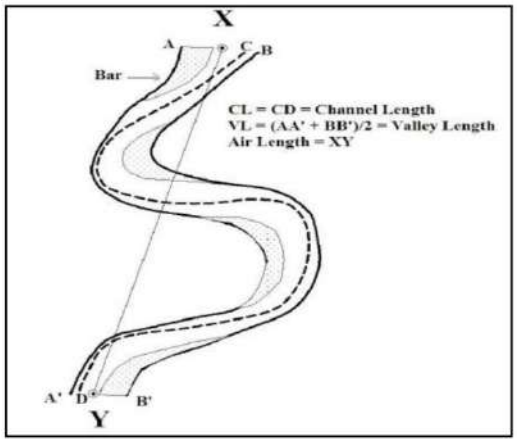


Figure 2-1 : Mueller's Sinuosity Index

   CL = the length of the channel (thalweg) in the stream under study

   VL = the valley length along a stream, the length of a line which is everywhere midway between the base of the valley walls.

   Air = the shortest air distance between the source and mouth of the stream.

   CI (Channel Index) = CL / Air

   VI (Valley Index) = VL / Air

   HSI (Hydraulic Sinuosity Index) = % equivalent of (CI – VI) / (CI – 1)

   TSI (Topographic Sinuosity Index) = % equivalent of (VI – 1) / (CI – 1)

   SSI (Standard Sinuosity Index) = CI / VI

2. Sinuosity Index (Friend and Sinha, 1993)

It is calculated as the length of the stream divided by the length of the valley. A perfectly straight river would have a meander ratio of 1 (it would be the same length as its valley), while the higher this ratio is above 1, the more the river meanders. According to Friend and Sinha (1993), the sinuosity parameter P is defined as,

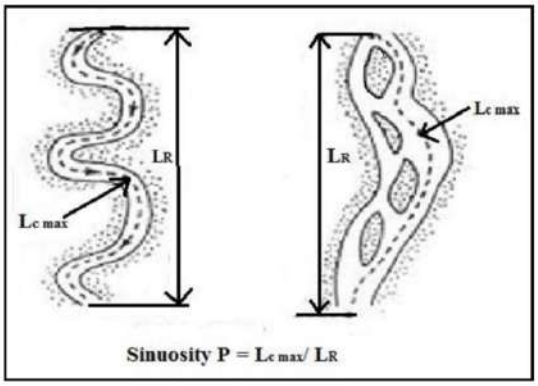


Figure 2-2 : Friend and Sinha (1993) Sinuosity Index

$P=L_{cmax}/L_r$

Where L_r = overall length of the channel belt and L_{cmax} = mid-channel length for same reach or mid-channel length of the widest channel. It is possible to estimate this Index using aerial photographs and satellite images.

2.2.2 Braiding and Planform Parameters

Rivers which have lots of channels that continually split and join are called braided rivers. These rivers are usually wide but shallow and characterized by steep slopes and riverbanks settings which accelerate the erosion processes. According to Leopold and Wolman (1957) braided river is the one which flows in two or more anastomosing channels around alluvial islands. Brice (1964) highlighted the significant impact arising on account of differences between mid-channel bars within braided rivers and regions of the floodplain exposed to channel diversions and avulsions. Schumm (1977) differentiated braided rivers at low stages with islands of sediment supporting temporary vegetation from the multiple-thread rivers that have branches with individual channel patterns. Bridge (1993) reviewed the existing definitions of the braided pattern and raised the concerns related to the difference between mid-channel bars and islands, the precise nature of the interaction between flow stage and bars or islands and the differences between the mechanisms of channel divergence that lead to two terms braiding and anastomosing.

There are several definitions and indices developed by researchers to characterize braiding phenomena in the past. A few of the important indices are discussed here

1. Braiding Index (Brice, 1964)

   Braiding Index defined by Brice (1964), is

$$Braiding\ Index = 2 * \frac{\sum L_i}{L_r}$$

   Where, $\sum L_i$ = length of all islands/bars in a reach

   L_r = length of reach measured midway between the banks

2. Braiding Index (Friend and Sinha, 1993)

   Braiding Index is defined as the ratio of L_{ctot} and L_{cmax} where L_{ctot} indicate the sum of mid-channel lengths of all the segments of the primary channel in a reach and L_{cmax} indicate the mid-channel length of the widest channel through the reach.

$$Braiding\ Index = \frac{L_{ctot}}{L_{cmax}}$$

3. Plan Form Index (Sharma, 1995)

   Plan Form Index (PFI) developed by Sharma (1995) focusses on the degree of braiding in a highly braided river. Index values reflect the fluvial landform disposition at a specified water level. Lower values of the Index indicate a higher degree of braiding.

   Planform Index (PFI) $= \frac{\frac{T}{B}}{N} \times 100$

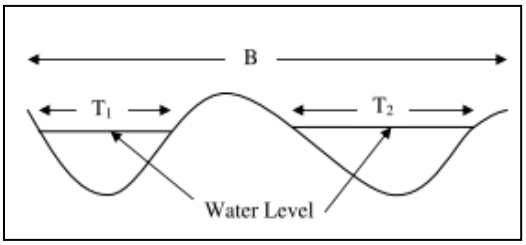


Figure 2-3: Planform Index (Sharma, 1995)

   Where,

   T= flow top width(T1+T2), and B = overall width of the channel,

   N = number of braided channels

2.3 Remote Sensing and GIS in morphological studies

There are several studies which signify the importance of remote sensing and GIS techniques in the field of water resources management which can further be classified into various sub-themes such as water resources assessment, planning and impact analysis, monitoring and evaluation. Use of remote sensing images for land-use land cover mapping has also evolved in the last two decades. This land-use land cover mapping exercise when focused on the river and surrounding environment, can also be used to draw inferences related to morphological changes/ evolution of river. Several studies have already been carried out in Indian and global context. Some of these studies are discussed here.

A study carried out on Subansiri River in Assam for investigating bankline migration by Goswami (1999) utilized topographic maps, aerial photographs, and satellite imageries of 50 years (1920-1970). It was reported that the high discharge of sediment load may have contributed to the formation of mid-channel bars which ultimately resulted in obstruction of the flow and associated bank erosion.

Karwan et al (2001) utilized aerial photographs and Landsat TM images for estimating land use changes and river channel morphology in the Venezuelan Andes, Jawra. It was observed that the rate of change in channel morphology was significantly high at the most deforested sites. Spatial variation in channel geometry expressed in the form of shape and channel were also important drivers of river morphology.

In Indian context, significant contribution has been made by a study from Kale et al (2002) which expresses the rich fluvial diversity of the Indian region. It also highlighted the gaps in the fluvial research focus on process dynamics. It argued for field-based studies for improving the understanding of the channel migration, avulsion and mechanisms of bank erosion, modes of meander development, and bedload transport. Another study by kale et al (2003) emphasized that the role of annual floods is more significant than occasional large floods in the Ganga-Brahmaputra Plains. Study also revealed that geomorphic effects of floods on peninsular rivers are modest.

Mani (2003) investigated the bank erosion and deposition pattern in Majuli island situated in the middle of the river Brahmaputra using satellite images from IRS satellites for the time frame of 1991-1998 and noticed that except for the 1997-1998 severe erosion was observed at the bank.

Chu et al (2006) used multi-temporal remote sensing data of Landsat MSS and TM for analyzing the patterns of erosion deposition of the modern Yellow River subaerial delta, China and juxtaposed with sediment discharge data. It was observed that cumulative increment in delta area is directly correlated with the cumulative Yellow River sediment discharge.

Evans et al (2007) analyzed the upstream channel changes after dam construction and its removal in Huron River, Ohio using remote sensing and GIS techniques. It was found out that dam construction resulted in reduction of the gradients and transport capacity upstream of the reservoir and ultimately resulting in no net downstream translation of the sediment wave.

Das (2007) analyzed morphological changes in the Barak River, India by utilizing the data of six different years from various sources such as toposheets, Landsat MSS, TM, and IRS LISS-II images. It was reported that overall trend indicates the intense shift of the river towards northward direction because of the uplift of the southern part of the river valley.

Surian et al (2009) examined the morphological effects of different channel-forming discharges in Tagliamento River, Italy by studying aerial photographs and ground truth information which include cross-section survey, grain-size analysis, and observation of painted sediments. It was found that bank erosion is a prominent process and accounts for tens of meters up to more than 100 m of erosion, associated with flood events with recurrence interval between 1 year and 12 years. Discharges equal to 20– 50% of the bankfull discharge are responsible for channel formation, whereas the bankfull discharge is a causal factor for the formation of low bars in Tagliamento River.

Ahmed & Fawzi (2011) assessed the meandering and bank erosion of the River Nile and its environmental impact on the area between Sohag and El-Minia using field observations, Landsat MSS (Multi-Spectral Scanner), Landsat Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) images. It was highlighted that presence of dam has resulted in significant change of sediment transport regime and system is moving towards new equilibrium which may result in deterioration of ecosystem on the downstream side of the dam.

Sarkar (2012) analyzed the bank erosion and deposition patterns along the Brahmaputra River for a period of 18 years (1990-2008) using remote sensing and GIS. It was noticed that both banks

have experienced significant erosion whereas deposition was limited to few locations. The study also marked the critical reaches that had undergone maximum erosion.

Yousefi et al (2016) studied the morphometric parameters of Karoon River, Iran using remote sensing images, topographical and geological settings, etc. Sand Mining activity has significant role in decreasing the flow length by increasing the probability of cutoff events. The study also brought out that dam building and land use change have an important role in decreasing channel width in the study reach of the Karoon River.

2.4 Morphological studies on Yamuna River

Bawa et al (2014) analyzed the controls on morphological variability and role of stream power distribution pattern in Yamuna River system. The study analyzes morphological variability through stream power distribution and sediment load data at selected locations. A non-linear pattern of stream power distribution was observed which is also in line with physiography of the basin and can be categorized into (a) high energy upstream reaches, (b) anthropogenically altered low energy middle stream reaches, and (c) rejuvenated downstream reaches again with higher stream power. The study also establishes the relationship between stream power and channel morphology (including sediment data) to define the maximum flow efficiency (MFE) as the threshold for geomorphic transition. The major drawback of the study is that polynomial fitting on discharge values at all stations with 10-year return period is performed on regulated flow values which in turn rules out the basic hypothesis behind the flood frequency analysis.

Khan et al (2018) used the remote sensing and GIS techniques for characterization of planform and sinuosity indices in a part of the River Yamuna. Study focused on Yamuna river segment in the vicinity of Agra, Firozabad, and Etawah districts and highlighted the paleochannels and meander cutoff at a few places based on satellite image analysis. Though the study utilizes the available morphological indices to certain extent, it is not able to address scale issues arising on account of temporal and spatial variation of the data used.

Ali et al (2019) analyzed the channel migration characteristics of the Yamuna River from 1954 to 2015 in the vicinity of Agra. Digital Shoreline Analysis System (DSAS) tool was used in a geographic information system (GIS) for quantifying the river migration in terms of: (i) net river migration; (ii) linear regression rate, and (iii) end point rate of stream reach. The bends in the

segment have been analyzed and it was noticed that bend 5 out of total 7 bends is found to be changing its location. The channel sinuosity index in this study indicates both narrowing and widening of channel. This study quantifies the migration rate, linear regression rate etc. However, selected river reaches which also carry impact of upstream flow regime and upstream channel morphology may not provide plausible justification for the changes observed.

Overall, it can be said that a very few studies focusing on morphology of River Yamuna have been carried out in recent past, however, hardly any of them address the basin scale approach. In addition, use of hydrological data in present form (highly altered flow regime) to lay down the foundation for such studies may not be appropriate.

2.5 Conclusion

The review of pertinent literature indicates that river morphology is studied and researched in both global and Indian context. Review of literature also highlights the role of remote sensing and GIS in morphological studies, outcomes, and its linkages with the ground observations. For Indian rivers, some of the studies emphasized on the usefulness of field-based observation data whereas studies based on remote sensing expressed the morphological attributes such as the bank erosion rate, eroded area, and deposition, if any, observed at spatial scale. The outcomes from remote sensing-based studies are generally expressed in areal form but miss out on volumetric analysis. Though few studies related to morphological understanding of Yamuna have been carried out, it is difficult to utilize them for the present study. However, overall review of literature both in global and Indian context can be used as a basis to come up with more rational approach for understanding the morphological behaviour of river at the basin scale.

Chapter 3 Study Area: Yamuna River Basin

3.1 Physiography

River Yamuna originates at Yamunotri, in the Yamunotri Glacier at an elevation of 6,387 m. It drains 366,223 sq. km. of area in its entire stretch of 1,376 km from its origin to Prayagraj (confluence with Ganga). The Yamuna is a mighty river in itself and has a number of tributaries. First 200 km stretch of Yamuna river features various tributaries like Rishi Ganga Kunta, Hanuman Ganga, Tons and Giri. In the middle section, Yamuna is joined by small tributaries like Sahibi and Hindon. Later, large rain-fed rivers, such as Chambal, Sind, Betwa, and Ken, join Yamuna system in Indo-Gangetic plains. The following figure depicts the Yamuna Basin and its major tributaries.

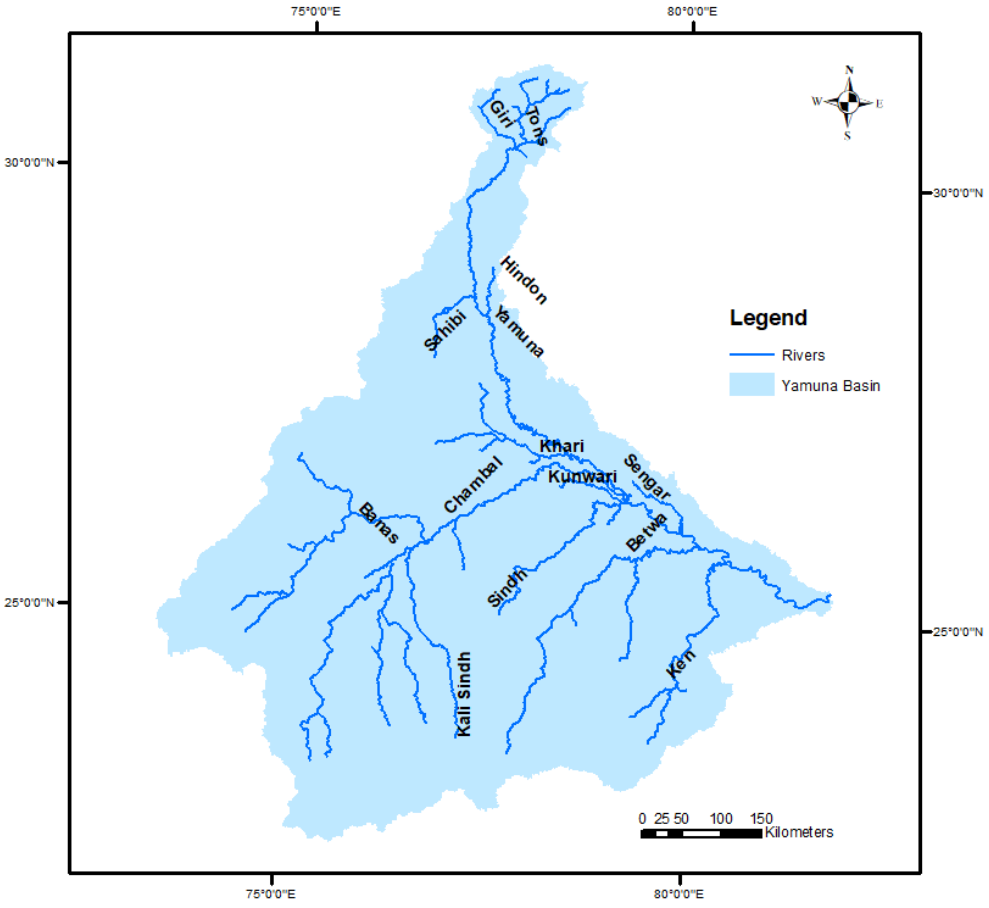


Figure 3-1 : River Yamuna and its Tributaries

3.2 Climate

Yamuna basin is a heterogeneous basin in terms of rainfall patterns with spatial variation of annual rainfall ranging from 200 to 2350 mm. However, the average annual rainfall varies between 400 to 1500 mm. Entire basin area receives rainfall from south-west monsoon, and a major part of the rainfall is received between June and September. In the basin, rainfall distribution increases from North-West to the South-East direction. Broadly, the climate of the basin can be classified as: (a) humid in the upstream Himalayan catchment; (b) semi-arid in north-west to western catchments; (c) sub-humid in south-west catchments and catchments located on the left bank of the river. The mean maximum temperature varies from 24–42.5◦C and the mean minimum temperature varies from –1.0 to 11.0◦C.

3.2.1 Rainfall

Though the rainfall is the only input to the hydrologic cycle in Yamuna Basin, upper Himalayan part of the basin, the river receives water from the glacier melt runoff. In the non-monsoon period, water availability in the river is either due to glacier melt runoff or base flow. Apart from upper Himalayan segment, the Yamuna River basin is rainfed and perennial nature of the river is due to upstream storages and base flow. Based on the 0.25-degree records of daily rainfall for the period of 1951–2019 from IMD, the average annual rainfall of the basin varies from 390 to 1800 mm with annual basin average of approximately 805 mm. The spatial variation of the annual rainfall pattern in the basin is shown in Figure 3-2.

3.2.2 Temperature

Temperature is one of the important drivers of the hydrological cycle. It has a significant impact on the snowmelt runoff, evapotranspiration rate, water use, and water quality in the river. The Yamuna Basin experiences wide Spatio-temporal variability in temperature. Mean maximum and mean minimum temperature in the basin spatially varies between 24.25 and 42.46 ºC and –1.05 to 10.81ºC, respectively.

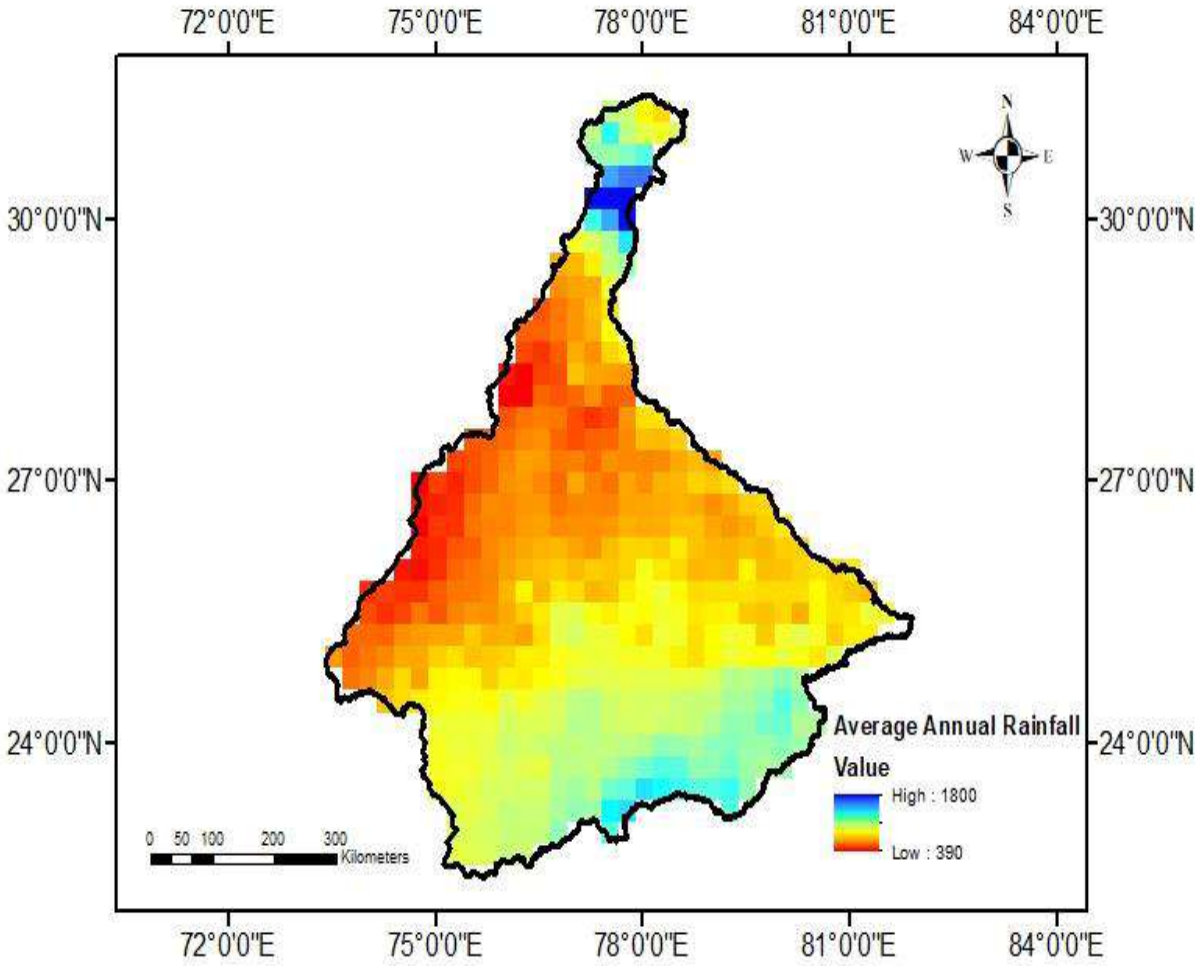


Figure 3-2 : Annual Rainfall in Yamuna

Based on soil types there are eight types of soils (Table 3-1) present in the entire Yamuna River basin. Majority of the soil type is alluvial, and it covers about 42% of the basin area, whereas calcareous sierozemic soils contribute towards the minimum, with about 0.5% of the basin area.

Table 3-1 : Dominant soil types in Yamuna Basin

Soil type	**% area covered in basin**	**Locations**
Red Sandy	2.5	Along Uttar Pradesh-Madhya Pradesh border in districts of Jhansi, Hamirpur, Chhattarpur

Soil type	% area covered in basin	Locations
Red and Yellow	5.0	Parts of Jaipur, Alwar, Sawai Madhopur, Banda, Panna districts and along western boundary of basin in Rajasthan
Calcareous sierozemic	0.5	Parts of Mohindergarh and Bhiwani districts in Haryana
Deep Black	5.5	On the southern boundary of the basin in Sehore, Bhopal, Raisen, Vidisha, Sagar and Damoh districts
Medium black	25.5	Most of the basin in MP and strips north of river Chambal in Rajasthan
Mixed red and black	15.0	Chittaurgarh, Bhilwara, Banda, Mandasaur, Shivpuri, Lalitpur, Tikamgarh, Panna and Chattarpur districts
Brown hill	4.0	Hills and foothills in the north
Alluvial	42.0	Plains and valley

3.3 Water resources development on Yamuna River

Available power potential in Yamuna River has been harnessed through storage and runoff the river schemes. Stage I was constructed in 1965 and included diversion headworks at Dakpathar and powerhouses at Dhakrani and Dhalipur for a total installed capacity of 84.75 MW whereas Stage II was executed in two parts in which the first part involved the construction of Ichari Dam and the 240 MW Chhibro powerhouse in 1975. The second part featured the 120 MW Khodri powerhouse which was constructed in 1984. Yamuna HEP stage IV was also taken up in two phases; in the first, Asan Barrage and Kulhal powerhouse were built in 1975 with a capacity to generate 30MW whereas the second phase comprised of Khara Hydroelectric Project with an overall capacity of 72 MW. Tejewala Barrage on Yamuna downstream of Paonta site was

operational from 1870s up to 1990s for supporting irrigation and it has been replaced by HathniKund Barrage in late 1990s. After this abstraction, flows are reduced significantly, and it is also important to note that part of the command area of this irrigation project irrigates agricultural land in the Indus basin in India.

Water abstraction and additions in River Yamuna is presented in the form of a line diagram. The river water is abstracted at different locations for varied uses. The annual abstraction at various locations is presented in the table below,

Sr no	Location	River water abstraction MLD	Abstraction Use
1	Hathnikund Barrage	20000	Irrigation, Drinking water supply and others
2	Wazirabad Barrage	1100	Drinking water supply
3	Wazirabad to Okhla Stretch	5000	Irrigation and others
4	Okhla to Etawah Stretch	400	Irrigation, Drinking water supply and others
5	Etawah to Prayagraj Stretch	475	Irrigation, Drinking water supply and others

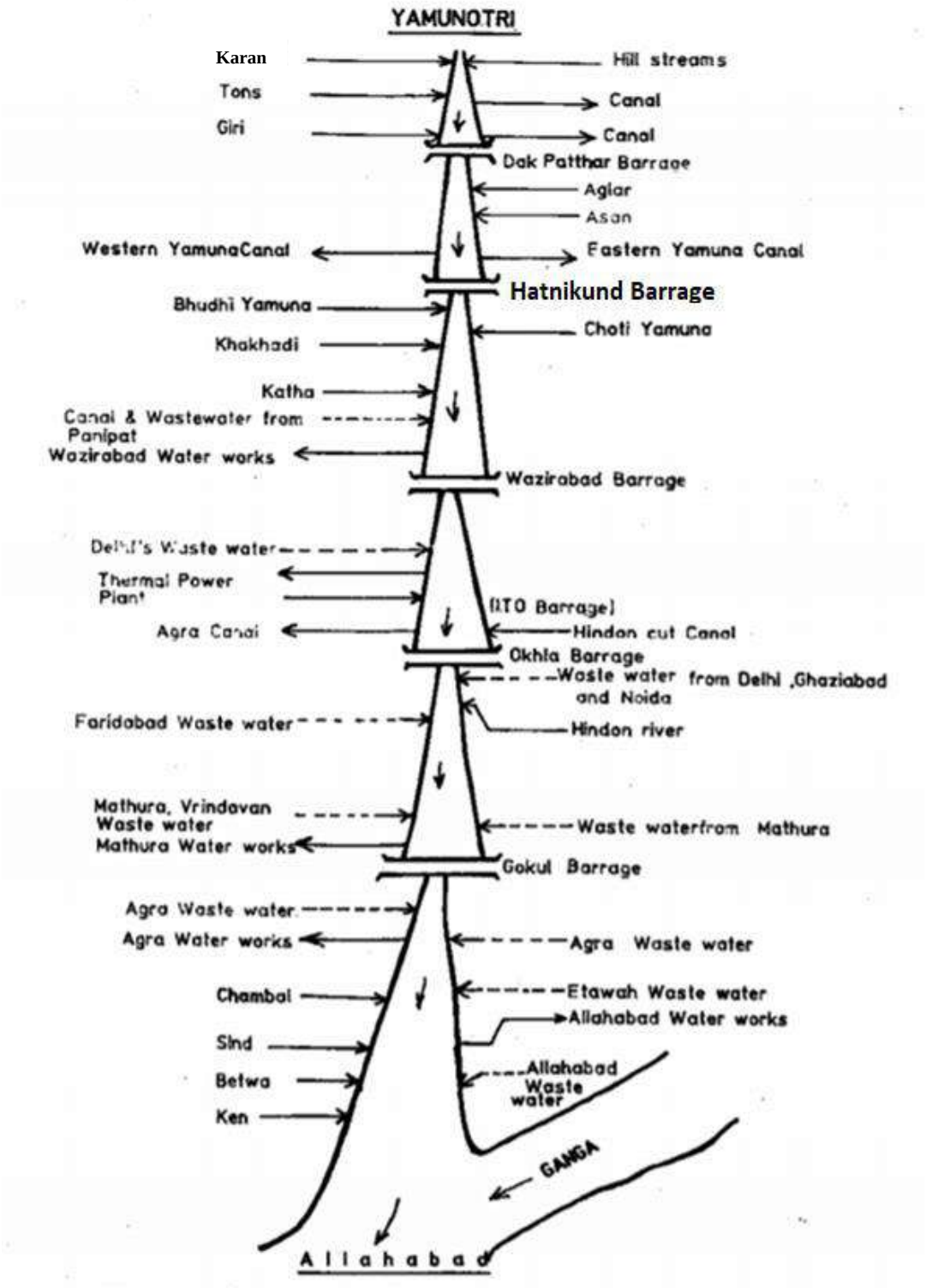


Figure 3-3 : Points of Water Abstraction & Additions in Yamuna River

WATER ABSTRACTION IS DISCUSSED AS BELOW:

Irrigation

Irrigation is an important use of Yamuna river water. It is estimated that about 92% of Yamuna river water is used for irrigation. In the entire Yamuna basin the irrigated land is about 12.3 million hectares and approximately half of it (about 49%) is irrigated exclusively from surface water. At present, there are four irrigation canals transporting the Yamuna river water to the command areas.

Western Yamuna Canal (WJC)

This canal originates from the right bank of Yamuna River at Hathnikund barrage. The capacity of the main canal is 163 m^3 /sec and irrigates an area of about 486,000 hectares annually in Haryana State. This irrigation system is more than 100 years.

Eastern Yamuna Canal (EJC)

This canal takes off from the left bank of the River Yamuna at the barrage. The canal is about 206 km long and has a capacity of 85m^3/sec. It irrigates an area of about 191,000 hectares annually in Uttar Pradesh.

Agra Canal

Agra canal originates from right bank of Yamuna River at Okhla barrage. The canal is 163 km long and carries discharge of about 63.5 m^3/sec. It irrigates about 138,000 hectares of land mainly in two districts of Mathura and Agra in Uttar Pradesh.

Gurgaon Canal

This canal is a interstate project between Rajasthan & Haryana and takes off from Agra canal at a distance of around 8 km from its off take at Okhla barrage. The water flow capacity of this canal is 14.15 m^3 /sec and land irrigated by this canal is about 40,000 hectares.

3.4 Socio-economic aspects

River Yamuna flows through seven Indian states. The state-wise catchment area is denoted in Table 3-2.

Table 3-3-2. Catchment Area of Yamuna Basin in different Indian states

Name of State	**Catchment area in the state (sq. km)**
Uttar Pradesh (including Uttarakhand)	74,208
Himachal Pradesh	5,799
Haryana	21,265
Rajasthan	102,883
Madhya Pradesh	14,028
Delhi	1,485

Among these states, Uttar Pradesh alone contributes 32.95% of the basin population followed by Madhya Pradesh, Rajasthan, Haryana, Delhi, Uttarakhand and Himachal Pradesh (Rai et al., 2012). The Yamuna River basin comprises 92 districts, and a few of them partly contribute to the area. Out of 92 districts, approximately 32 districts have industrial influence. Rural areas are dominantly agricultural communities. In the Yamuna basin, more than half of the population (i.e. 62.3%) is categorized as rural population, and the rest of the population (i.e., 37.6%) are urban population (Census, 2001). Major cities situated on bank of River Yamuna are Poanta, Karnal, Mawi, Sonipat, Delhi, Mathura, Agra, Etawah, Hamirpur and Prayagraj.

3.5 Reported issues

Important concerns with regards to Yamuna include (i) disproportionate level of abstractions for off stream uses including some deemed to be unsustainable, (ii) seriously compromised water quality regime arising from untreated waste returns from urban and industrial centres that dot much of the Yamuna basin, (iii) an archaic water sharing agreement amongst some of the co-basin states that disregards even reasonable e-flows suggestions for Yamuna, and (iv) unceasing crowding of the floodplain corridor of Yamuna that appears to seriously hinder the latter's riverine dynamics. For example, increasing population and abstractions of water to meet the demands results in reduced flows in the river. On the other hand, domestic sewage and industrial waste released into river without treatment deteriorate the water quality. Issue pertaining to attainment of

environmental flows in Yamuna has also been discussed in some of the reports. It is also discussed that on account of reduced flows and pollution, native faunal species like Gangetic Dolphin and Gharial that were observed in Yamuna in historical times are now only rarely sighted in the river.

Chapter 4 Geology of the Yamuna Basin

4.1 Introduction

This chapter analyses prominent features of Yamuna River basin in terms of topography, geomorphology, and geology and their variations across the spatial domain. Physiography, rainfall and temperature patterns, geomorphology and geology, are essential characteristics of the basin which are not only crucial for addressing water resources related issues but also the type of habitation. These parameters are vital for watershed management, flood and drought estimation/management, waterlogging, erosion estimation/mitigation, identification of recharge zone, installation of hydropower system, construction of rainwater harvesting structure, other structural development, etc. This chapter provides a discussion on topographic characteristics, followed by discussions on geological and hydrogeological formations. The tributaries contributing to the Yamuna River have also been discussed.

4.2 Topographic Characteristics

The topography of the Yamuna basin varies between the steep Himalayas to near flat in the middle and lower segments. The elevation in the Yamuna River basin ranges from about 6,320 m near Yamunotri Glacier to around 100 m near the confluence of Yamuna River with River Ganga at Prayagraj. The topography of the Yamuna basin can broadly be classified into three groups, i.e., hilly region (more than 600 m above msl); foothills and Plateau region (300–600 m); and plains and valleys (100–300 m above msl). Average slope of Yamuna is indicated in Table 4-1 and spatial variation of elevation in the form of DEM is provided in Figure 4-1.

Table 4-1 : Average Slope of River Yamuna

Sr no	Stretch	Length of river (km)	Rate of fall (m/km)	Slope (%)
1	Upper Himalaya	25	59	5.90
2	Himalaya Stretch	125	19.1	1.91
3	Total Plain Stretch	1224	0.20	0.02
4	Lower Plain Stretch	768	0.08	0.008

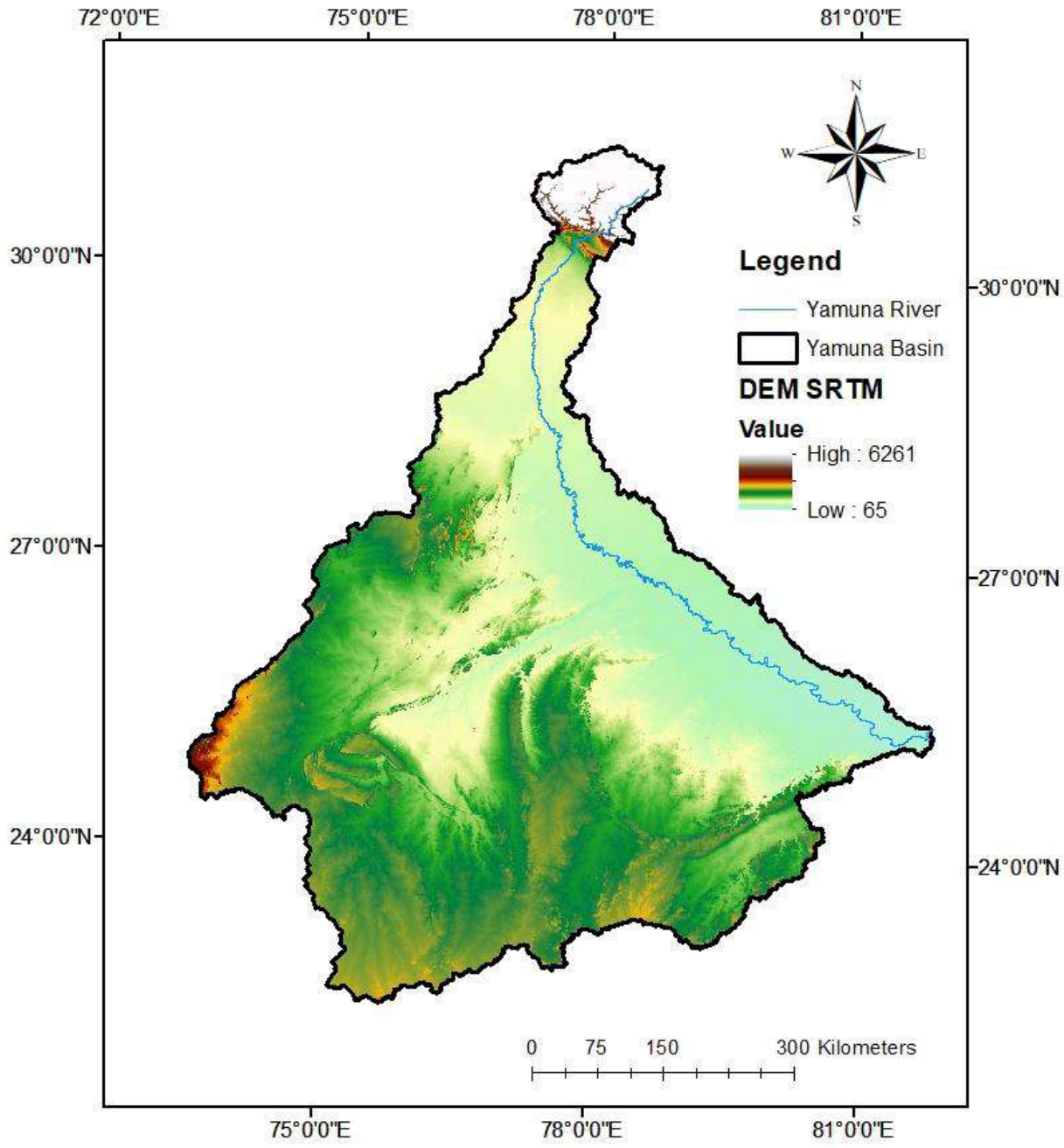


Figure 4-1 : DEM of Yamuna Basin

4.2.1 Tributaries of Yamuna River

The major tributaries of the Yamuna River are Tons, Chambal, Hindon, Sind, Betwa, Ken, Baghein, and Mandakini. Additionally, some notable minor tributaries of the Yamuna River include Rishiganga, Uma, Hanuman Ganga, Giri, Karan, Sagar and Rind (Rai et al., 2012). The main Yamuna and Tons are fed by glaciers, viz., the Bandar Punch Glacier and its branches and originate from the Great Himalayan range.

Tons River: Tons River is the longest tributary of the Yamuna in the upper Himalayan segment. It flows through Garhwal, the western part of the Himalayan state of Uttarakhand. The river originates at an elevation of 3,900 m and joins the Yamuna below Kalsi.

Kali River: It originates from the Doon Valley in Uttarakhand. The catchment covers a drainage area of approximately 750 km^2. From its origin up to the confluence with Hindon River, the river travels around 150 km through the districts of Saharanpur, Muzaffarnagar, Meerut and Ghaziabad. Despite a significant drainage area, mostly lying in plains, the river does not carry any significant flow. The city of Muzaffarnagar is situated on the left bank of the Kali River. Kali River is a highly polluted river which receives pollutants including heavy metals and industrial sludge from a dozen towns along the river from Saharanpur to Kalanauj.

Hindon River: It is an important tributary of the Yamuna River. Hindon, having a total run of nearly 400 km, originates from upper Shiwalik (Lower Himalayas) and its course is sandwiched between river Ganga on the left and river Yamuna on the right. Hindon is a rainfed river with its bank to bank width ranging from 20 to 160m and drains an area of about 7083 km^2.

Banganga River: The Banganga River originates in the Aravali hills, near Arnasar and Bairath in Jaipur District. It flows towards the south up to the village of Ghat, then east through partly hilly and partly plain terrain. The length of the river is approximately 240 km. The main tributaries of the Banganga River are Gumti Nala (latitude: 25°0.5'–25°53' N; longitude: 75°52'–76°01'E; length: 24 km; drainage area: 102 km^2), Suri River (latitude: 26°44'–26°53' N; longitude: 76°25'–76°30' E; length: 18 km; drainage area: 76 km^2), Sanwan (latitude: 26°59'–27°22' N; longitude: 76°16'–76°46' E; length: 29 km; drainage area: 660 km^2) and Palasan River (latitude: 27°02'–27°18' N; longitude: 76°25'–76°49'E; length: 24 km; drainage area: 539 km^2).

Chambal River: This tributary of Yamuna River is 960 km long with a drainage area of 134,689 km^2. The Chambal River joins the Yamuna River, at Sahon village in Etawah district at an elevation of about 122 m. Three dams, namely, Gandhi Sagar, Rana Pratap Sagar and Jawahar Sagar have been constructed in its basin.

Betwa River: The Betwa River originates at an elevation of 706 m in the Bhopal district in Madhya Pradesh. After traversing a distance of 590 km, the river joins the Yamuna River near Hamirpur of Uttar Pradesh at an elevation of 107m. The drainage area of Betwa River up to its confluence

with River Yamuna is catchment is 46580 km^2. The basin is bowl-shaped with sandstone hills around the perimeter.

Ken River: Ken is an inter-state river, flowing through the states of Madya Pradesh and Uttar Pradesh with the total basin area of 28,058 km^2. The river originates near the village Ahirgawan in north-west slopes of Kaimur hills of Jabalpur district of Madhya Pradesh at an altitude of 550m and joins the Yamuna near Chilla village in Uttar Pradesh at an elevation of about 95 m.

4.2.2 Geomorphic Parameters

Geomorphic characteristics of the basins often reflect on the basin hydrologic behaviour. Therefore, estimation, quantification and analysis of the geomorphic parameters is important in assessing the hydrologic response of the basins. These characteristics are mostly driven by physical characteristics of watershed and the properties of drainage channels. Physical characteristics include drainage area, basin shape, ground slope, and centroid (i.e. centre of gravity of the basin) whereas channel characteristics include channel order, channel length, channel slope, channel profile, and drainage density. Basin wide characteristics computed from SRTM DEM are listed in Table 4-2. For obtaining these characteristics, stream generation threshold of 1000 km^2 has been considered.

Table 4-2 : Geomorphologic characteristics of the Yamuna basin

Area (km2)	352188
Minimum elevation (m)	65
Perimeter (km)	6715
Relief (m)	6189
Length of basin (km)	1562
Mean slope (m/km)	3.96
Maximum elevation (m)	6261
Ratios	
Bifurcation ratio	3.375
Shape factor	6.93
Elongation ratio	0.428
Circulatory ratio	0.098

Compactness coefficient	3.214
Drainage density	0.033
Basin slope (m/m)	0.0036
Drainage frequency	0.004
Length of overland flow (km)	14.86
Form factor	0.144

4.3 Geological formations

The geological formation of the Yamuna basin can be categorized into Proterozoic, Cenozoic, Paleozoic, Mesozoic and Deccan Volcanics /Sediments.

Proterozoic: The Vindhyan range is a Proterozoic formation developed in the central part of the Indian shield. The dominant lithologies include conglomerate, sandstone, shale, limestone as well as volcaniclastics. The strata lie uncomfortably on the Achaean-early Proterozoic gneisses, high-grade rocks, granite-greenstones or metasedimentary of Proterozoic mobile belts. Most parts of the Vindhyas are composed of horizontally bedded sedimentary rocks of ancient age, the contemporaries of the Torridon sandstone of Scotland. Nearly half of the basin area belongs to this geological formation category. Significant portions of the Chambal, Sind, Betwa, and Ken catchments are constituted under the Proterozoic era.

Cenozoic: The Cenozoic is the most recent of the three classic geologic eras and covers the period from 65.5 million years to the present. Major Gangetic plain and trans-Yamuna catchments come under this category. A few parts of the other catchment before the confluence with higher-order streams also have this formation.

Mesozoic: The Mesozoic era is an interval of geological time from about 250 million - 65 million years ago. It is called the Age of Dinosaurs.

Deccan Volcanics/ Sediments: This is close to the Mesozoic era and characterised by the outcropping of enormous lava flows which spread over vast areas of the Western, Central and Southern India. They issue through long narrow fissures or cracks in the earth's crust, from a large magma basin and are, therefore, called fissure eruptions. The existence of Deccan volcanic rocks or sediments is evident in the upstream part of the Chambal, Betwa and Ken sub-catchments of Yamuna Basin.

Paleozoic: The Paleozoic era is the earliest of three geological eras of the Phanerozoic Eon and is subdivided into six geologic periods; from oldest to youngest these are: the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian. Fish population exploded in the Devonian. From the beginning of the Paleozoic, shallow seas began to encroach on the continents. As the era proceeded, the marginal seas periodically washed over the stable interior, leaving sedimentary deposits to mark their incursions. In this era, evidence of glaciers is also experienced.

4.4 Lithology

The Yamuna basin is confined by the Himalayas and Vindhyas on north and south respectively. In the east, it is separated by the ridge from the main Ganga catchment and on the west by the hill separating it from the Luni and the Ghaggar basins. Most parts of the watershed in Haryana and Uttar Pradesh lie in the Gangetic alluvial plains. The region-wise lithological and hydrogeological features of the Yamuna basin are discussed below,

Himalayan Region:

The Yamuna originates from the Yamunotri Glacier in the Higher Himalaya; and many tributaries, such as the Tons, the Giri, the Aglar, the Asan and the Bata join in the Himalayan segment. From the Higher Himalayas, the Yamuna flows in the southwest direction and enters the Lesser Himalayas where it drains a variety of lithologies. It flows through a vast stretch of quartzite of Berinag Formation. Downstream, it passes through the massive dolomitic limestone and marble of Mandhali and Deoban Formations. In the Lesser Himalaya, occurrences of shales are reported into the Infra Krol, the Lower Tal, the Deoband and the Mandhali Formations (Gansser, 1964; Valdiya, 1980). These are exposed at several locations in the Yamuna and the Tons catchments, the most significant being at Maldeota and Durmala, around Dehradun, where phosphorite is mined economically. Gypsum occurs in the Krol Formation in the form of pockets and bands (Anantharaman and Bahukhandi, 1984; Valdiya, 1980).

The soils in these regions have been grouped as Brownhill soils (Devi, 1992), which form from the weathering of granite, gneiss and schist. Soils on the slope (15–40%) are shallow due to erosion and mass wasting processes and usually have very thin surface horizons.

Delhi NCR Region:

The boundaries of these regions are defined by barren low hills of the Aravalli chain and its outcrops in the west, steep hills of the Aravalli range enclosing fertile valleys and high table lands in the south-west and the plains characterized by rainfed streams in the south.

The rock type exposed in this region belongs to Delhi Super-group of Lower Proterozoic age and consists of Quartzite of the Alwar Group, Phyllite and Slate of the Ajabgarh Group. The Quartzites are massive, thickly bedded, hard, and compact, and highly jointed and are intercalated with thin beds of Phyllite and Slates. These rocks are mostly covered by quaternary sediments and are exposed in isolated hills and pediments. These hills are exposed in south and south-west of Delhi at Delhi, Gurgaon, Rewari and Alwar. The quartzite and its associated rocks of the Delhi series are traversed by joints and are folded, faulted and fractured. The joints and fractures are open, often filled with debris and mutually interconnected; cavities created by the erosion of mica-schist add to the secondary porosity developed by these joints and fractures. Groundwater occurs in the consolidated rocks both in confined and semiconfined conditions. Mostly the topwater table zone and the deeper semi-confined aquifer have the same static water level surface because of their interconnections. The depth of the water table below ground level varies in general between 5 and 20 m. Several groundwater structures by way of open wells and shallow tube wells (60–70 m deep) exist in this formation in different parts of NCR with varying degrees of discharge rates.

Ken and Betwa Sub-basins:

The Ken basin covers the areas of Jabalpur, Sagar, Damoh, Panna, Satna, Chhatarpur and Raisen districts of Madhya Pradesh and Hamirpur and Banda districts of Uttar Pradesh. The upper reaches of Ken River are flanked by an undulating plateau with sandstone, shale and limestone. The stratigraphy of rock formations found in the region is mostly alluvial soil, Deccan traps, Lameta beds and Vindhyan system. The Betwa basin covers the areas of Bundelkhand uplands, the Malwa plateau and the Vindhyan scrap lands in Madhya Pradesh and Uttar Pradesh. The hydrogeological formations observed in the Ken and Betwa basins are The Older Metamorphies, The Purana Formations, and The Deccan Traps. The older metamorphies occur in Panna, and Tikamgarh districts of Madhya Pradesh. Groundwater occurs in them only in the fractured zone underlying them. The hydraulic conductivity is generally less than 1 m/d and the specific yield is generally less than 5%. The Purana formations of both Vindhyan and Cuddapah age comprise orthoquartzites, limestones and shale sequence are found in parts of Panna, Raisen and Bhopal

districts. The specific yield is generally in the range of 5 to 15%. The Deccan traps cover the Guna, Vidisha, Bhopal and Raisen districts. They are generally simple and a type of flow, where each flow is separable into vesicular and massive units. The wells of these areas can yield 250–750 m^3/d for a drawdown of 3 to 6 m.

Chambal Sub-basin:

It is the largest tributary of the Yamuna and originates in the Vindhyas just south of Mhow, at an elevation of 354 m. Soils in the alluvial plains of the Chambal sub-basin (where the annual rainfall is <100 cm) are saturated with alkaline and saline soils (Sarin et al., 1989). The river water is of variable quality, containing effluents from industries and urban conurbations and agrochemicals from the land surfaces (Rangarajan and Sarin, 2004).

Chapter 5 Input Data

5.1 Hydrometeorological Data

The various hydrological observation sites on the Yamuna River were identified and hydrological data in the form of daily/ Ten daily discharges are obtained from CWC. Details of observation sites have been mentioned in Table 5.1

Table 5-1: Details of CWC HO sites on the Yamuna River

No	HO Site	Catchment Area (sq. km)	Data period
1	Naugaon	794	1982-2011
2	Bausan	2075	1985-2011
3	Kalanuar	12639	1976-2011
4	Karnal	13578	1976-2011
5	Mawi	15622	1976-2011
6	Baghpat	17028	1975-2011
7	Delhi Railway Bridge	18522	1963-2011
8	Mohana	27670	1983-2011
9	Mathura	47360	1974-2006
10	Agra P G	49052	1977-2010
11	Etawah	98715	1960-2010

The following map shows locations of above mentioned hydrological observation sites. Though, the number of sites in the map are more than those mentioned in Table 5-1, analysis, in the present study, is restricted to these latter sites only for reasons of data availability.

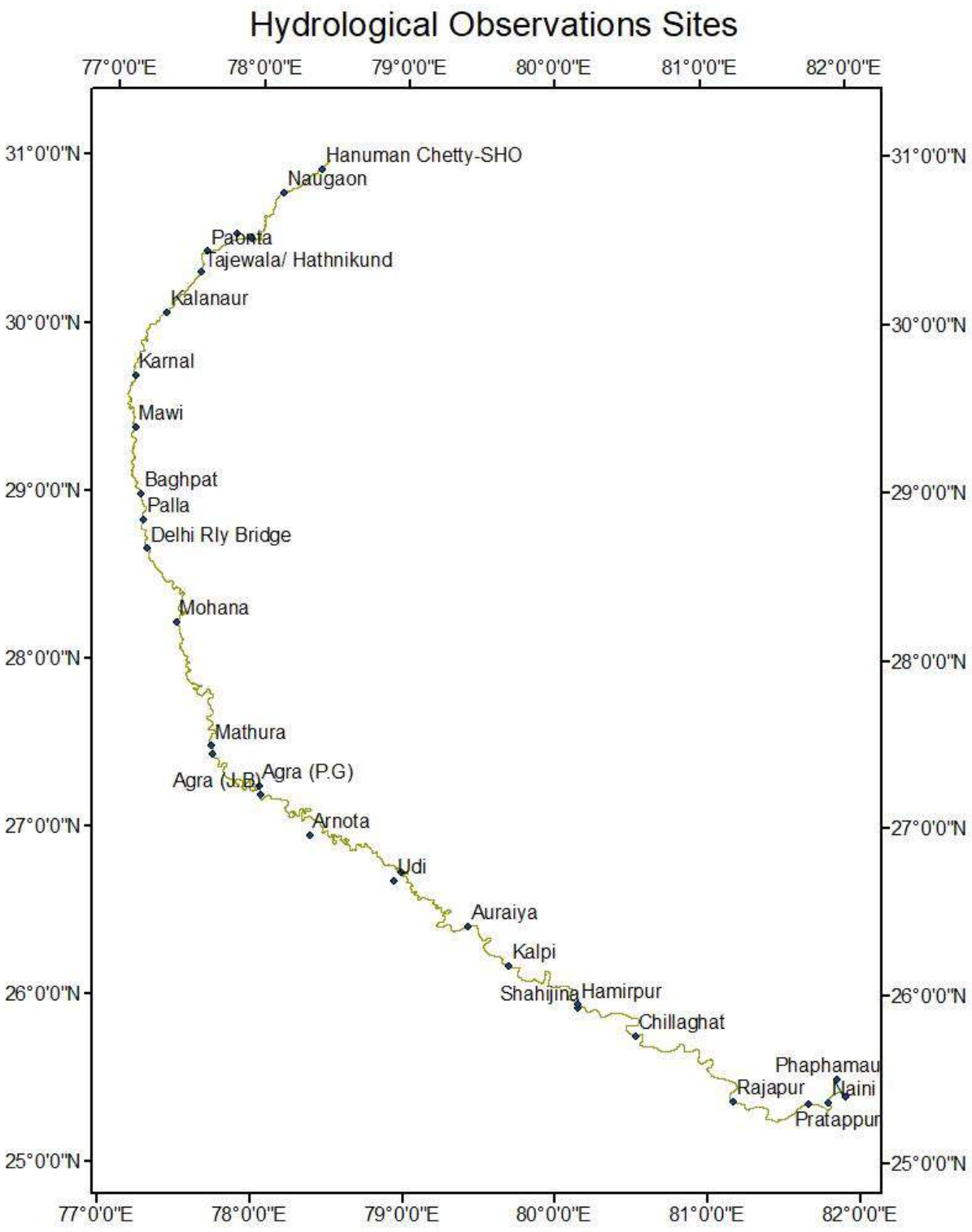


Figure 5-1 : HO sites on Yamuna River

Apart from the above mentioned Gauge-discharge data, cross-section data for some of these sites have been obtained from CWC. Out of these places, at a few locations temporal cross-sections pre and post-monsoon are available. Details about these cross-sections and their interpretation are discussed in Chapter 9.

5.1.1 Flow Probability Curves

Frequency analysis has been carried out using observed discharge data for estimation of discharge corresponding to 2-year return period. Higher return period flood peaks have also been estimated using frequency analysis to corelate with morphological parameters of the river. Details of frequency analysis are given below.

The two main methods of flood frequency analysis are analytical and graphical, with the IEA (Institution of Engineers Australia, 1987) recommending that both procedures be used in a complementary manner. The analytical method involves fitting a probability distribution function to model the observed peak flow data from which the probability of exceedance of discharge of a particular magnitude flood may then be estimated. Although this method is widely used, there is little theoretical basis in the choice of distribution (Cunnane, 1985; Kidson and Richards, 2005), and despite widespread research, no single distribution has appeared to be the best fitted across different sites (Adamowski et al., 1998). The parameters of the probability distribution are generally estimated through analysis of the selected data sample, which is assumed to be representative of its parent population. Methods such as L-moment diagrams and related goodness-of-fit measures have been encouraged for evaluating the suitability of various distributional alternatives for modelling flood flows on a regional scale (Vogel et al., 1993). However, the true distribution and its parameters may still differ significantly from the empirically fitted distribution, particularly when samples are small (Singh and Strupczewski, 2002). In the present study Gumbel extreme value, Log Pearson type III and Log-Normal distribution have been used and best-fitted distribution has been used to estimate discharge for higher return periods. In the case of the Graphical method, Weibull's plotting position has been used to determine discharge for 2-year return period. Results of flood frequency analysis are discussed in detail in Chapter 9.

5.2 Satellite Data

Satellite data for five different years (1975-80, 1990, 2000, 2010 and 2016) were obtained from NRSC (National Remote Sensing Centre) and additional data was also downloaded from USGS (the United States Geological Survey) website.

NRSC:

Satellite images for the study area were ordered and related details were reported in previous progress reports and also as a part of the interim report. These images are being used for the purpose of feature extraction. Features extracted from these images are active water area, bank lines, stream centerline, channel area and islands. For years 1990, 2000 and 2010 images from NRSC have been procured and details regarding their usage are shown in Table 5-2.

Table 5-2: Details of NRSC data used

Year	Product and resolution	Issues	Solution
2010	LISS 3, 23.5m	Translation errors (lateral shifts in x and y direction).	Corrected for further utilization.
2000	LISS 3, 23.5m	Lateral shifts (~20-25 km) with geo-referencing errors. Some of the scenes missing.	USGS images of 2000 (30m multispectral and 15 m panchromatic) are used
1990	LISS 1, 72.5m	A few scenes are missing. Without Geo-referencing	USGS images of 1990 (30 m) are used

United States Geological Survey (USGS):

In the absence of NRSC images, data from other satellites has been used to attain project objectives. Similar to NRSC image analysis, feature extraction is carried out on USGS satellite images (open sources data) and is discussed in Table 5-3.

Table 5-3: Details of USGS data

Year	Product and resolution	Issues	Solution
2016	LANDSAT 8, 30m multispectral	None	Not applicable
2000	LANDSAT 7 ETM+, 30m multispectral and 15m panchromatic	None	Not applicable
1990	LANDSAT 5 TM, 30m multispectral	None	Not applicable
1975	LANDSAT 1 and 2 MSS, 60m multispectral	Translation errors	Corrected for further utilization.

5.3 Toposheets

Survey of India (SoI) topographic sheets have been used to digitize features for preparation of baseline data. However, unavailability of topo-sheets of a complete stretch of the river surveyed in the same year lead us to use satellite data of the year 1975 as a baseline year. Though features extraction activity is performed on the toposheets, it has not been used in for the analysis purpose in the present study. Satellite imageries of the year 1975 and features extracted from those imageries are considered as a baseline in the present study.

5.4 Software Used

The following softwares are used for activities related to this project

a) Erdas Imagine/ ENVI: It has been used for satellite data processing
b) ArcGIS/ QGIS: Data digitization and GIS operations
c) MS-Office: MS-Word and MS-Excel have been used for report writing and tabular analysis receptively.
d) MATLAB: For data formatting, processing and rearrangement, frequency analysis

Chapter 6 Methodology

6.1 Defining terminologies

Terminologies related to river morphology that are used in the present study are explained in the subsequent section along with their adopted definitions.

6.1.1 Active water area

Active water area is that part of a river channel which represents actual flowing water at that time. Reasonably, active water area in monsoon season is different from active water area in the lean flow season. Moreover, in some cases, the active water area is also disconnected in lean season on account of different interactions between surface water and groundwater at different locations. Figure 6-1 shows some of the disconnected active water areas in the channel.

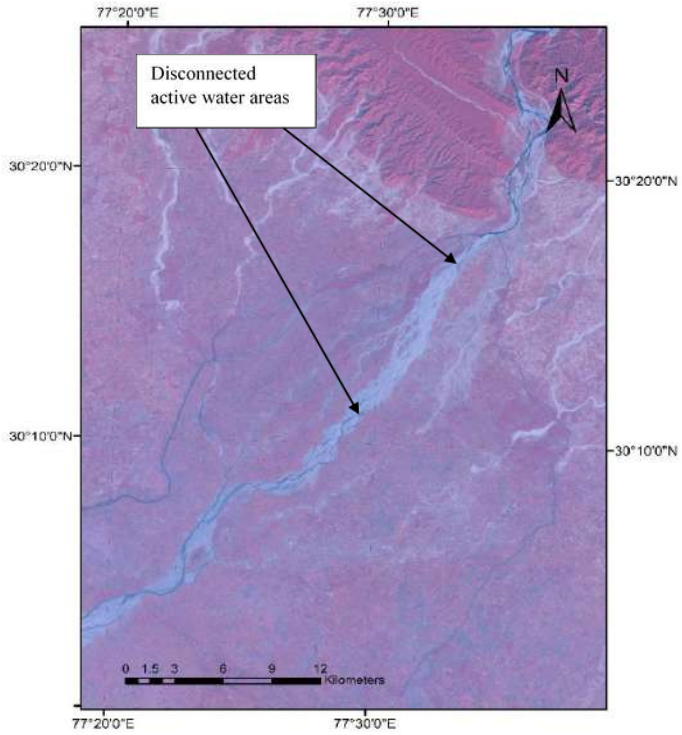


Figure 6-1: Disconnected active water areas

In the present study, active water area at varying time scales (1975, 1990, 2000, 2010 and 2016) have been marked using satellite images of the respective years. Considering seasonal

characteristics of flow, lean season (months of December to February), which has a significant impact on channel geometry is selected for marking active water area.

6.1.2 Channel Area

Channel area of the river is considered to be a combination of areas in which river flows in various seasons. While in monsoon season, the river is expected to flow with a larger top width of flow, in the lean season, however, the active water area is restricted to a smaller and deeper sub-section of river cross-section while the other sub-sections may remain largely bereft of flowing water. Channel area is inclusive of both active water area and those non-inundated sandy and gravel beds in the river. Though floods of different return periods will have a different extent of inundation in flood plains, it is not possible to mark those extents based on remote sensing images. In the present study based on tonal variation and reflectance characteristics of features, an attempt has been made to analyze the most probable river course on a decadal time scale.

6.1.3 Sand Bars

Floods often pack enough traction to displace river bed and bank material and conversely, when floods recede, these sediments (such as silt, sand or gravel) are likely to be deposited at different parts of the river channel, with some locations being more conducive than others. Over time, these preferred locations may experience an accumulation of these transported materials leading eventually to the formation of morphological entities known as sandbars which routinely appear as elevated regions of sediment deposits and which may not experience inundation for flow rates ranging appropriately from low to moderate.

Types of bars include mid-channel bars (also called braid bars, and common in braided rivers), point bars (common in meandering rivers), and mouth bars (common in river deltas). The locations of bars are determined by the geometry of the river and the flow through it. Bars reflect sediment supply conditions and can show where sediment supply rate is greater than the river's innate transport capacity.

Sandbars are a key element of riverine ecosystems as they offer a safe sanctuary to a variety of aquatic flora and fauna including birds and insects. They also provide refuge to benthic invertebrates against abrasive and fluctuating flows besides being the natural and protected spaces for their recolonization. Sandbars also serve as important habitats for reptilians in the riverine environment which use them for basking and nesting and, in their vicinity, hydrodynamic zones

of eddies and wakes become ideal spots where fish and other fauna feed (Hoeting, 1998; O'Neill and Thorp, 2011).

In the present study, only mid-channel bars (braid bars) that are altering active water area computations are considered (Figure 4-2). Point bars are considered as part of the channel area. Variations in the areal retreat of sand bars are assessed on decadal-scale for estimating erosion and deposition.

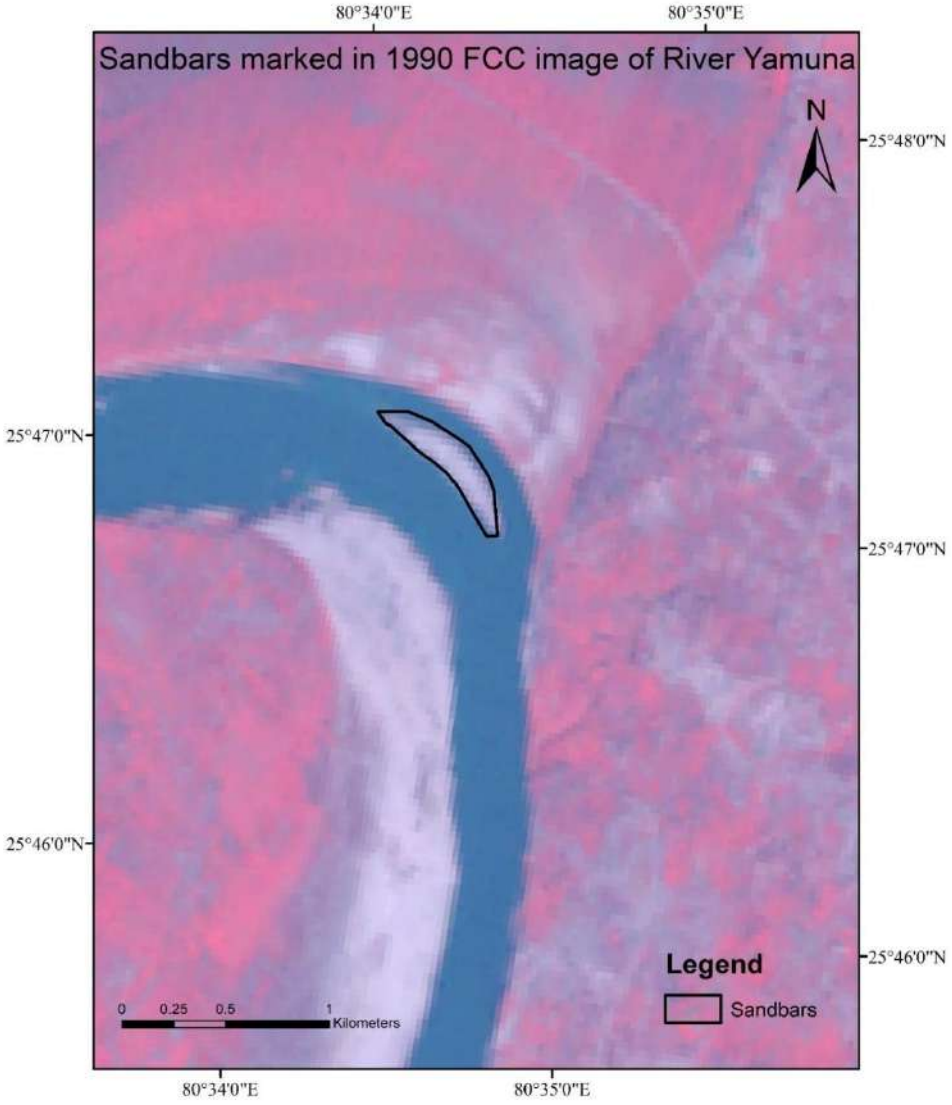


Figure 6-2 Sandbars in 1990 FCC image of Yamuna

6.1.4 Water Bodies

Water bodies are identified in the present study as independent water areas that are not part of the channel area. Generally, water bodies are ox-bow features, swamps and small wetlands around the river course. Figure 6–3 shows representative water bodies near the Yamuna River.

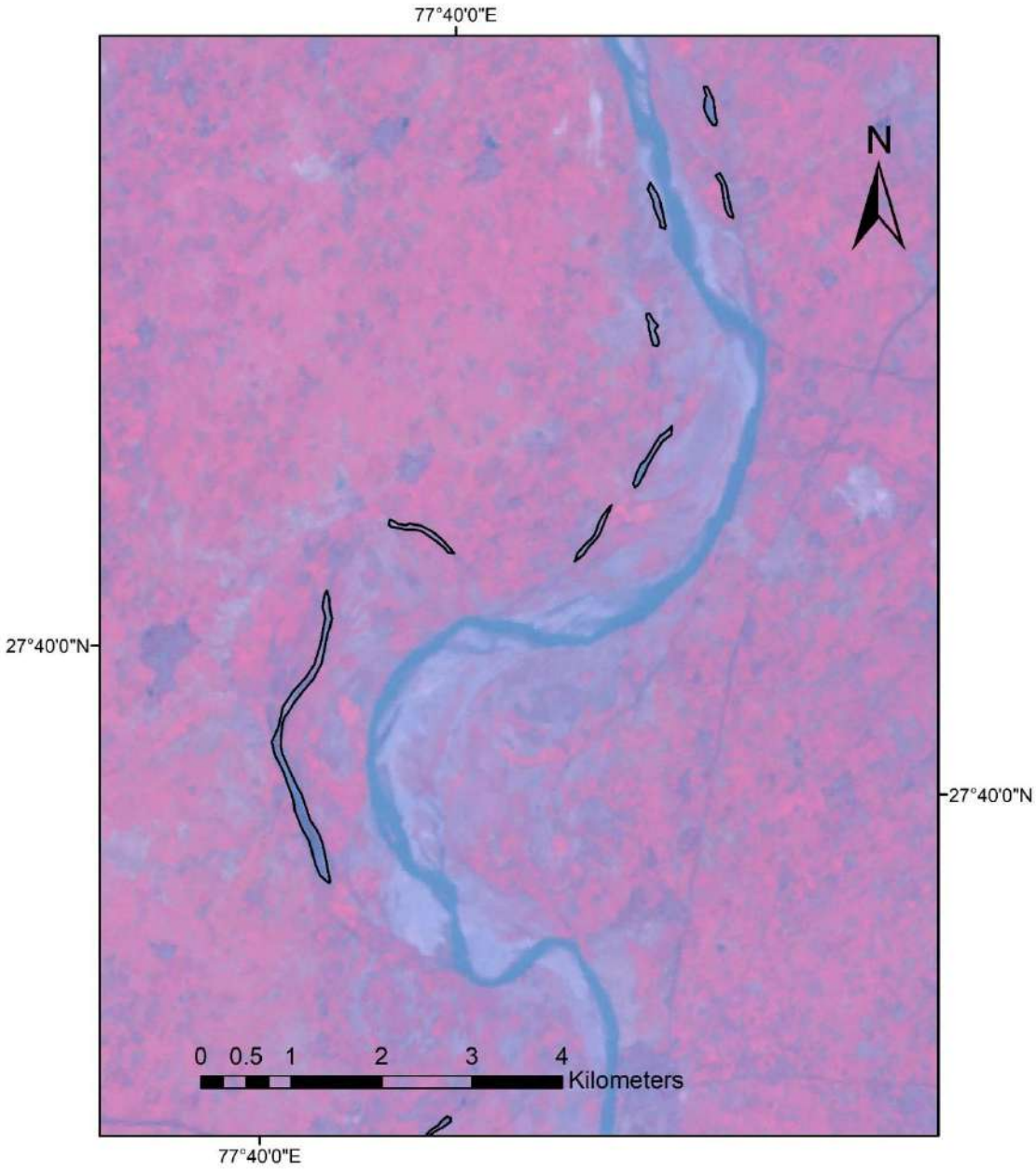


Figure 6-3 Representative water bodies near Yamuna River

6.1.5 Centre Line

There are diverse ways in which the wholly imaginary river centerline may be defined and as a result, the concept of the river centreline is not amenable to a consistent and objective specification. It can be defined as a line joining points of lowest bed elevations along the channel, also called as thalweg. It can also be defined as the centerline of the active water area. In some of the modelling approaches, the centerline is defined as channel centerline, irrespective of depth variation within the channel.

From remote sensing data, it is not possible to capture thalweg because most of the remote sensing products are often based on reflectance from the ground surface and only very few of them e.g. InSAR and Lidar datasets are able to capture the channel geometry. Though tonal variations in optical Remote Sensing data suggest about the qualitative depth of water on broad-scale like shallow and deep water, to generate exact information about the deepest point in the channel is not possible. Parmar and Khosa, 2017, as part of the ongoing Doctoral study of the first author, present a comprehensive discussion on the concept of river centreline and for an in-depth discussion on this important morphological concept, reference may be made to the latter report and the same is also annexed herewith as a separate memorandum.

Moreover, it is also important to note that centerline based on active water area may vary from season to season. Most importantly in dynamic rivers where releases from Hydel projects, dynamics in the opening of gates, and natural variability in flows within and across seasons have a significant impact on water depth. In some places, like downstream of barrages, the centerline is varying based on the opening of a number of gates and their locations; centerline may not exist at a few locations where the channel is not carrying any water. Figure 6-4 shows the channel centerline marked for a reach of Yamuna for different years.

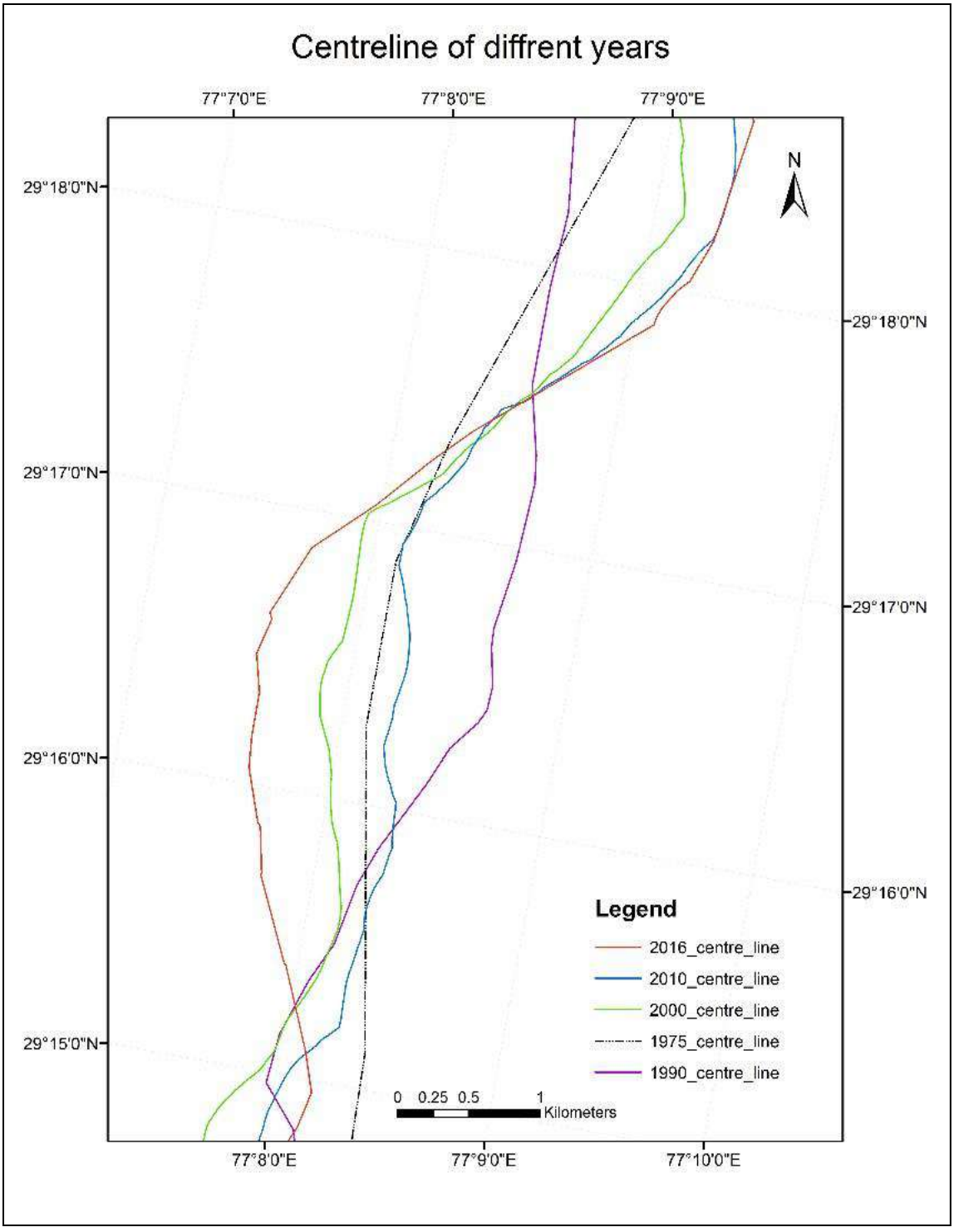


Figure 6-4 Channel centerlines marked for different years

6.1.6 Sinuosity Index (P)

Sinuosity index is a measure of the curvature of the channel. Leopold and Wolman, (1957) defined the sinuosity index as a ratio of thalweg length and valley length. They also claimed that streams for which this ratio is equal to or greater than 1.5, are the true meandering streams.

Friend and Sinha, (1993) modified the sinuosity index for Indian rivers with multi-channel situations. They defined sinuosity index as a ratio of L_{cmax} and L_R, where; L_{cmax} is the length of the primary channel in reach or length of widest channel in case of presence of more than one channel and L_R is the straight-line length of the channel for the same reach. Higher the value of sinuosity index (P); higher is the meandering in the reach. The radius of curvature is also computed on a grid basis and discussed in Chapter 11, Section 11-3.

6.1.7 Braiding

Climate and geologic processes combine to control water discharge, sediment supply, and channel slope, which dictate a river channel's pattern. Coarse sediments deposited during high flow become a barrier at low flow and thus river starts flowing in multiple channels separated by these barriers. Such rivers are called braided rivers. Leopold and Wolman (1957) defined them as such rivers which flow in two or more anastomosing channels around alluvial islands.

Braided channels are variable, dynamic systems with high fluvial activity rate and channel adjustment due to processes such as erosion and deposition. Braiding is typically referred to as the splitting of channels around bars or islands, which are contained within a dominant pair of floodplain banks.

Various types of braiding indices have been proposed in the literature. Notable among these are

- Leopold and Wolman (1957)
- Brice (1964)
- Rust (1978).
- Ashmore (1991)
- Cartoons and Ferguson (1993)
- Friend and Sinha (1993)
- Sharma (1995)

Parmar and Khosa, (2017), as a constituent part of the first author's ongoing Doctoral study, have examined the latter indices namely the indices by (i) Friend and Sinha (1993), and (ii) Sharma (1995 and 2004), for an objective perspective on them and have also suggested alternate forms which are summarized later in Chapter 11 and is a part of the annexed Memorandum enclosed herewith.

In the present study, braiding index, L_{ctot}/L_{cmax}, as suggested by Friend and Sinha (1993), has been adopted. Here, L_{ctot} is the sum of the mid-channel lengths of all the segments of primary channels in a reach, and L_{cmax} is the mid-channel length of the widest channel through the reach.

Apart from the braiding index, the plan form index is also computed and results are discussed in Chapter 11, Section 11-5.

6.2 Processing of Remote Sensing data

Data has been processed prior to feature extraction. Various operations have been performed on the data to make it usable for analysis.

6.2.1 Image processing and corrections

Image processing operation mainly involves geo-referencing and mosaicking of data. While using the temporal satellite data, it is required to geo-reference the imageries of different dates. Some clearly identifiable stable features like road crossings, railways, canals, bridges, barrages were selected as control points. Data prepared after image processing is checked for its consistency and error in geo-referencing was estimated to be less than one pixel. After georeferencing, the scenes were combined together to incorporate the entire reach of the river course. For this purpose, the Mosaic function in ArcGIS is used. Mosaic False Colour Composite (FCC) image of Yamuna River system after correction for the year 2010 is shown for representation purpose (Figure 6-5).

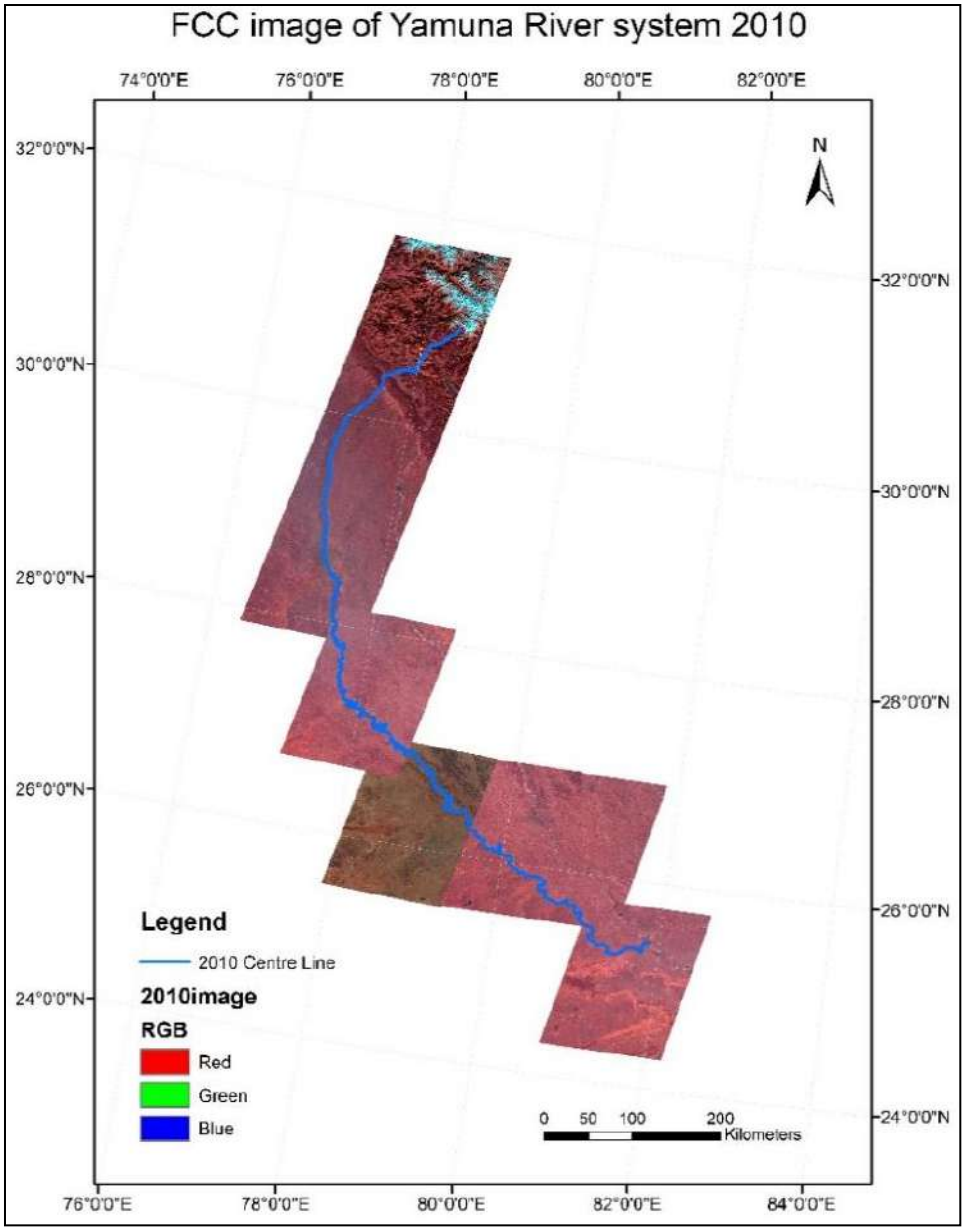


Figure 6-5 Mosaic False Colour Composite (FCC) image of Yamuna River

Features obtained from digitization of data from satellite imageries are Channel Area, Active Water Area, Sandbars, Water Bodies and Centre Line. All objects pertaining to these classes are obtained using the appropriate products for the desired years 1975-1979 (Landsat MSS data considered as baseline), 1990 (Landsat TM), 2000 (Landsat ETM+), 2010 (LISS III) and 2016 (Landsat 8). Shapefiles of these features are available in the soft copy of the report, which can be accessed in ARCGIS (Version 10.2 and above). A representative reach of Yamuna with these features is shown in Figure 6-6.

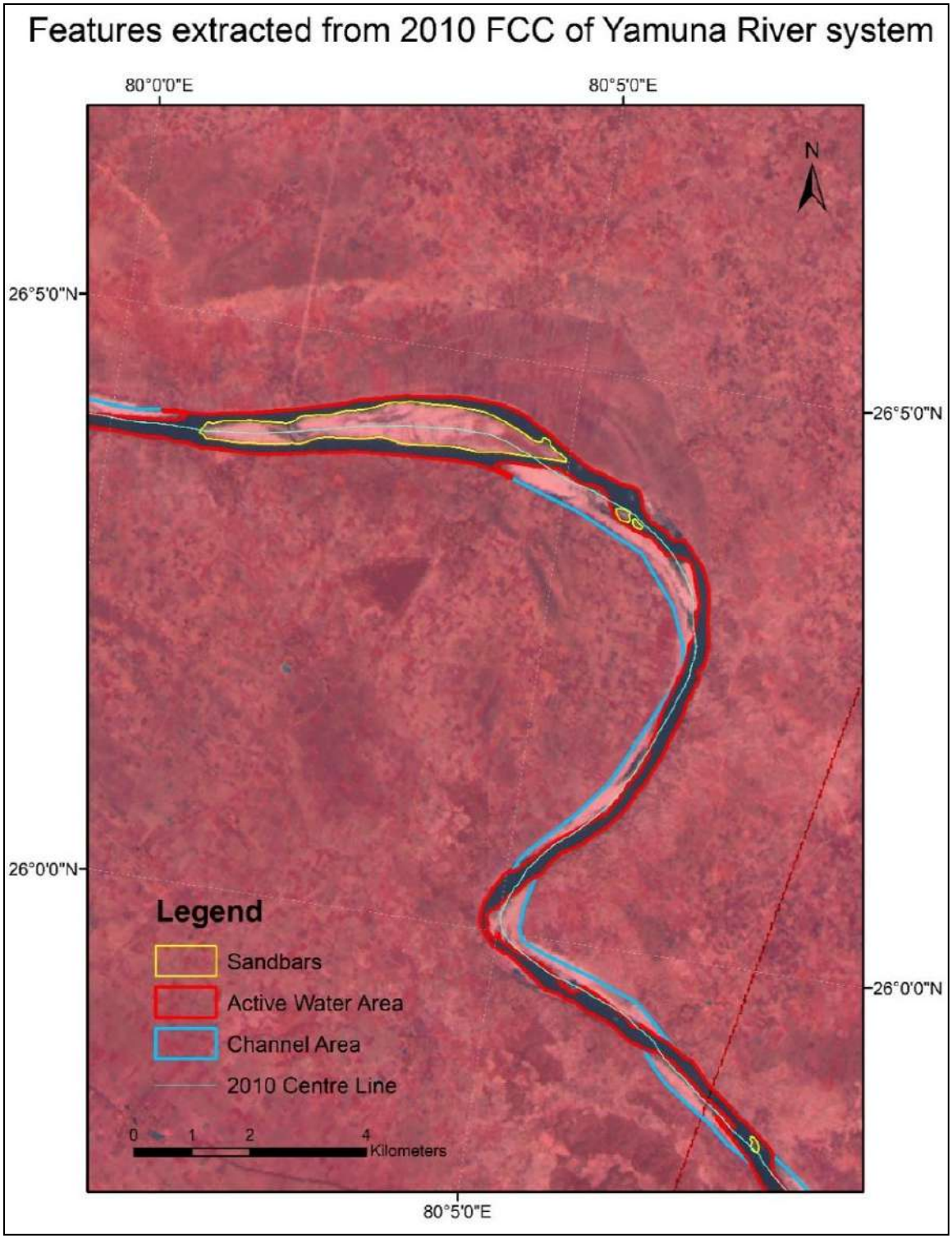


Figure 6-6 : Morphological features extracted from 2010 FCC

6.3 The scale of the study

As per MoU, river stretch has to be studied at an interval of at 50 km. However, an attempt has been made to analyze the river stretch at more detailed scale. Grid size of 25 km is adopted for capturing finer details and accordingly the grid has been prepared for the entire Yamuna stretch under the study. For this, total study area is divided into 1120 grids (25 km size). Numbering of these grids, as shown in explanatory Figure 6–7 starts from the origin at bottom left corner (grid number zero) and moves towards right end of the row and moving similarly for all rows above numbering ends at top right corner (at grid 1119). Each row of the template contains 32 grids and there are total 35 rows in the template.

Figure 6-8 shows the actual grid template used for analysis of the Yamuna river system. Grids in which the river course falls are considered as active grids and are used in the present analysis for computation of erosion and deposition.

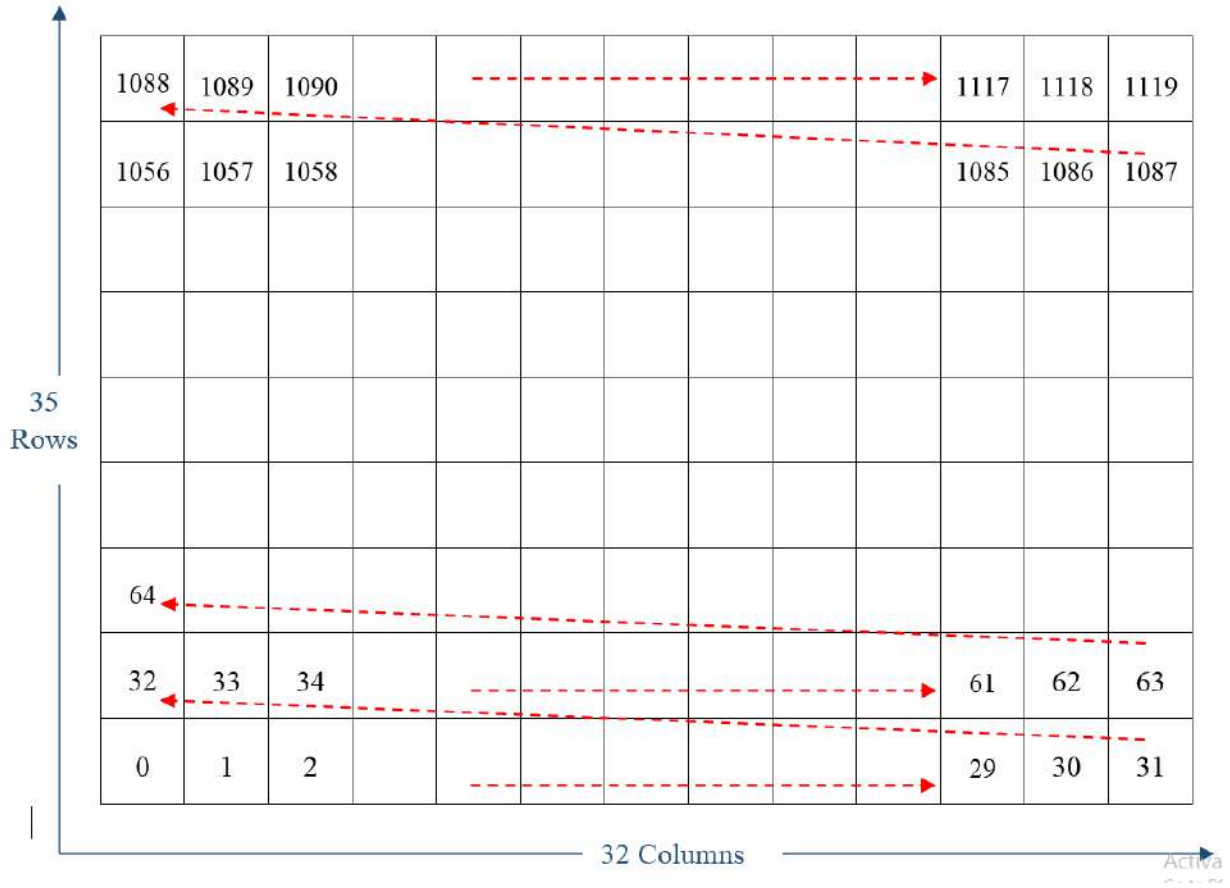


Figure 6-7 : Representation of numbering pattern of grids

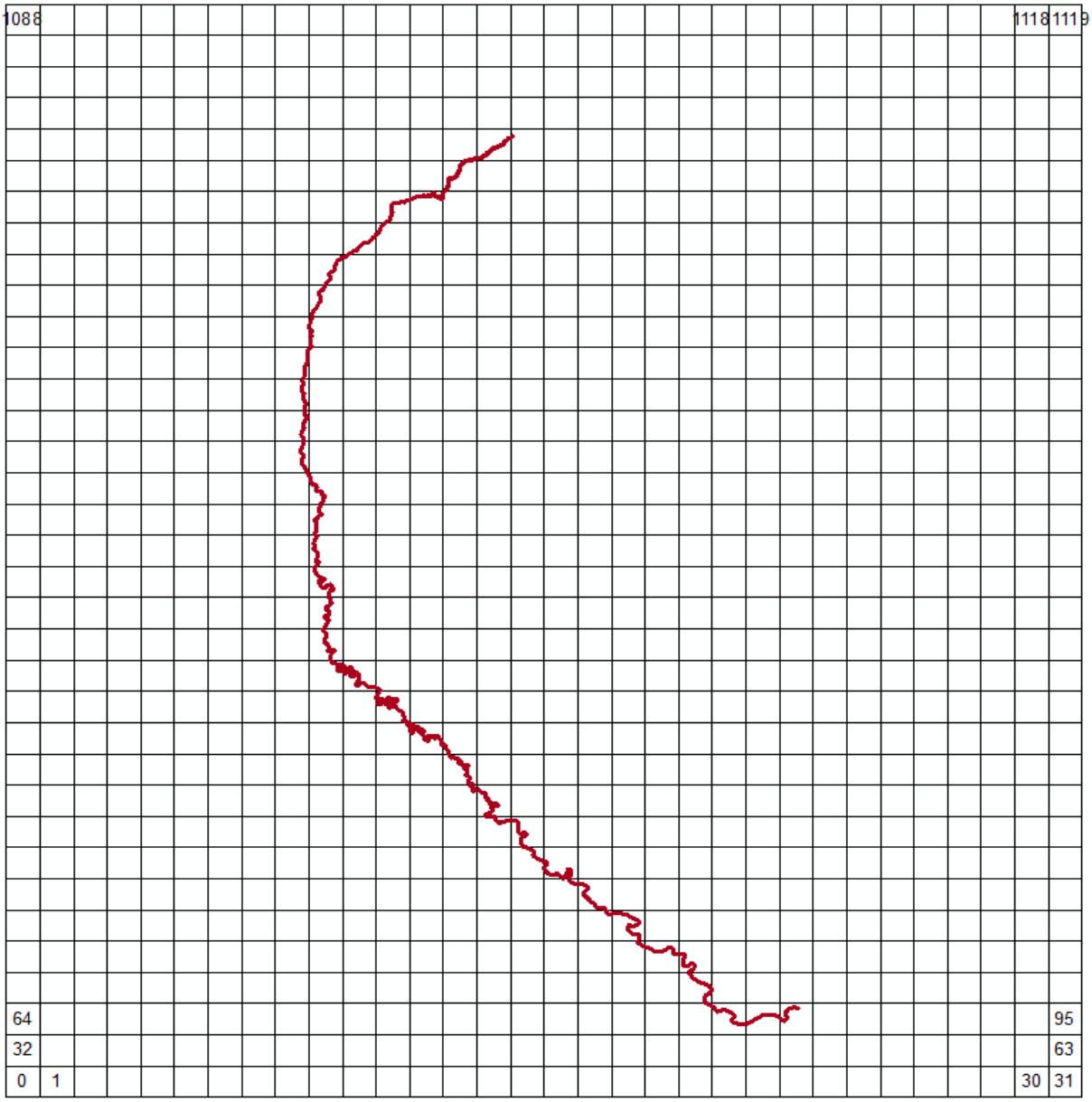


Figure 6-8 : Grid template used for analysis of the Yamuna River

6.4 Estimation of Channel Bank Retreat on Account of Erosion and Deposition

Channel bank retreat (area in km^2) on account of erosion and deposition is computed from digitized features. Difference in channel area, sandbars and water bodies based on their tonal variations as observed in satellite images are considered for estimation of channel bank retreat. Figure 6-9 shows grid wise erosion and deposition in a sample reach of the Yamuna River.

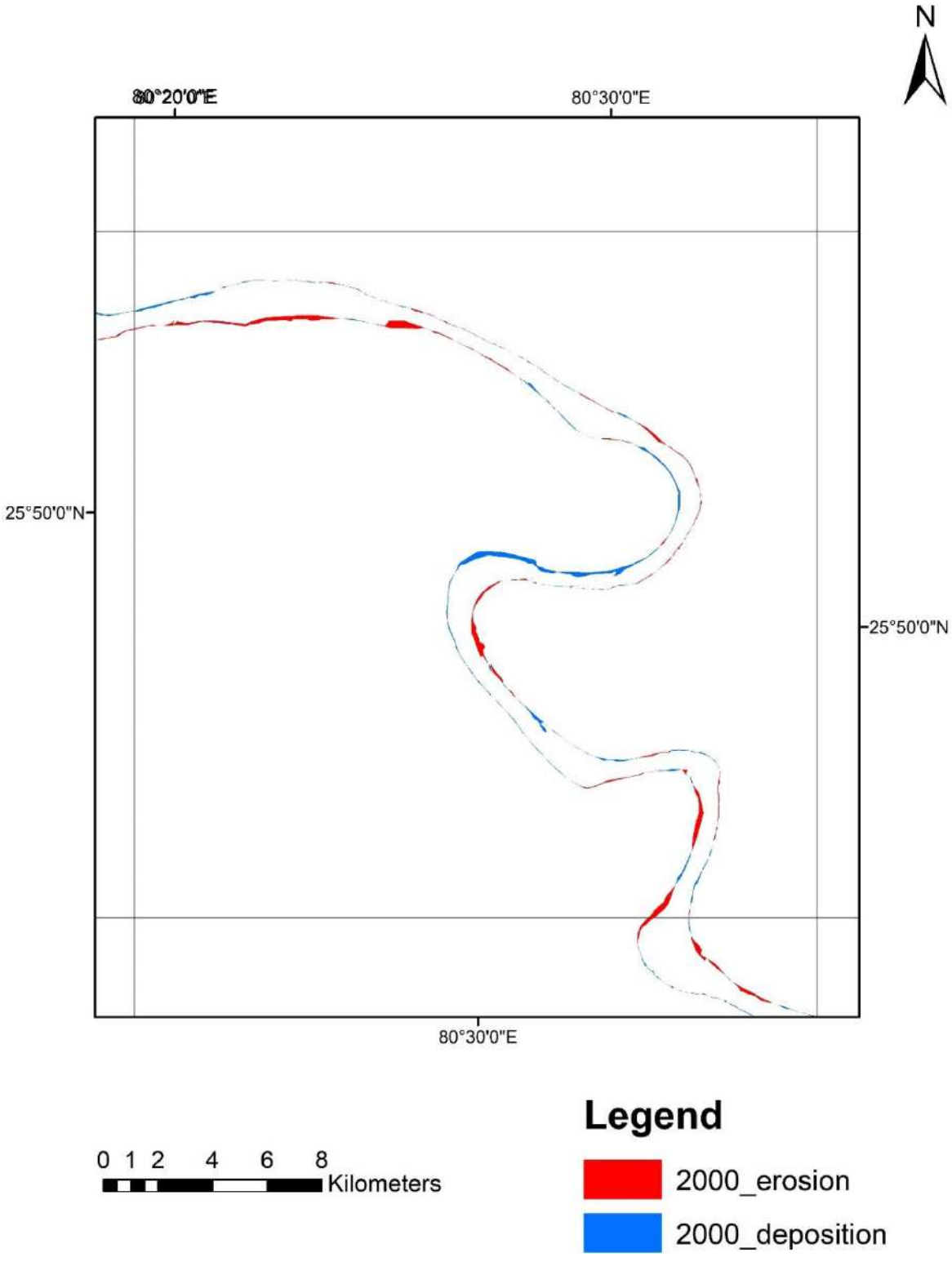


Figure 6-9 : Estimation of channel bank retreat on account of erosion-deposition on a grid basis

6.5 Understanding of River Course Dynamics

River course dynamics is a highly complex phenomenon considering river's inherent variability. Often, the term shifting is used to showcase river course dynamics, but it is important to note that river may follow its historical path and its movement may be limited to the paleo channels or to the extent of its 'swing zone' or, alternatively, its designated river corridor, a concept proposed and so designated by Parmar and Khosa (2017). Therefore, when the river course dynamics is limited to swing zone it should not be considered as shifting of river course.

Moreover, the term shifting has specific meaning in the context of morphology. It indicates the movement of river course which is irreversible and significant. If river swings and come back to its original position, then it does not represent an actual shifting of the river course rather it is indicative of possible flow paths within channel area or extensions of river course in the flood plain at a particular point of time.

In the present study, the river course dynamics is analyzed for all grids in a sequential manner. The centerline for all the years (1975, 1990, 2000, 2010, and 2016) are considered for shift analysis. The procedure followed for understanding of river course dynamics is explained below.

1. Based on the centerline of the year 1975, the reference line is created by converting centerline into a single straight line for each grid by removing vertices and retaining endpoints at the grid boundary. (Figure 6-10).
2. Next, perpendiculars are drawn to the reference line at an interval of 1 km. Intersection points of perpendiculars and reference line is referred as chainage in subsequent discussion. (Figure 6-11).
3. These perpendiculars are extended such that they intersect with the centerlines of other respective years and the distance between the centerline and the reference line is estimated for each time frame. The distance to the left of the reference line (in direction of flow) is being shown by a negative sign (-) and the distance to the right side of the reference line is being shown by a positive sign (+).(Figure 6-12).
4. Differences between these distances obtained for two consecutive years of study are considered as river course dynamics within that period. (Figure 6-13).

Zero chainage of reference line represents the origin of River Yamuna near Yamnotri. It may be noted that river course dynamics analysis of Yamuna has been started from Chainage 15 (which

represents perpendicular drawn at distance of 15 km on a reference line from its starting point). For first 15 km stretch of the river from Yamunotri, it is difficult to analyze and interpret the river course due to shadow effects, narrow river width and coarse resolution of images which make them incompatible for use in this analysis. For reference on ground, this chainage (Latitude $30^0$54’15” and Longitude $78^0$20’10”) is found to fall near the village Kupra on Google Earth Image. Similarly, major villages on the river and the chainages nearby are noted as shown in Table 6-1.

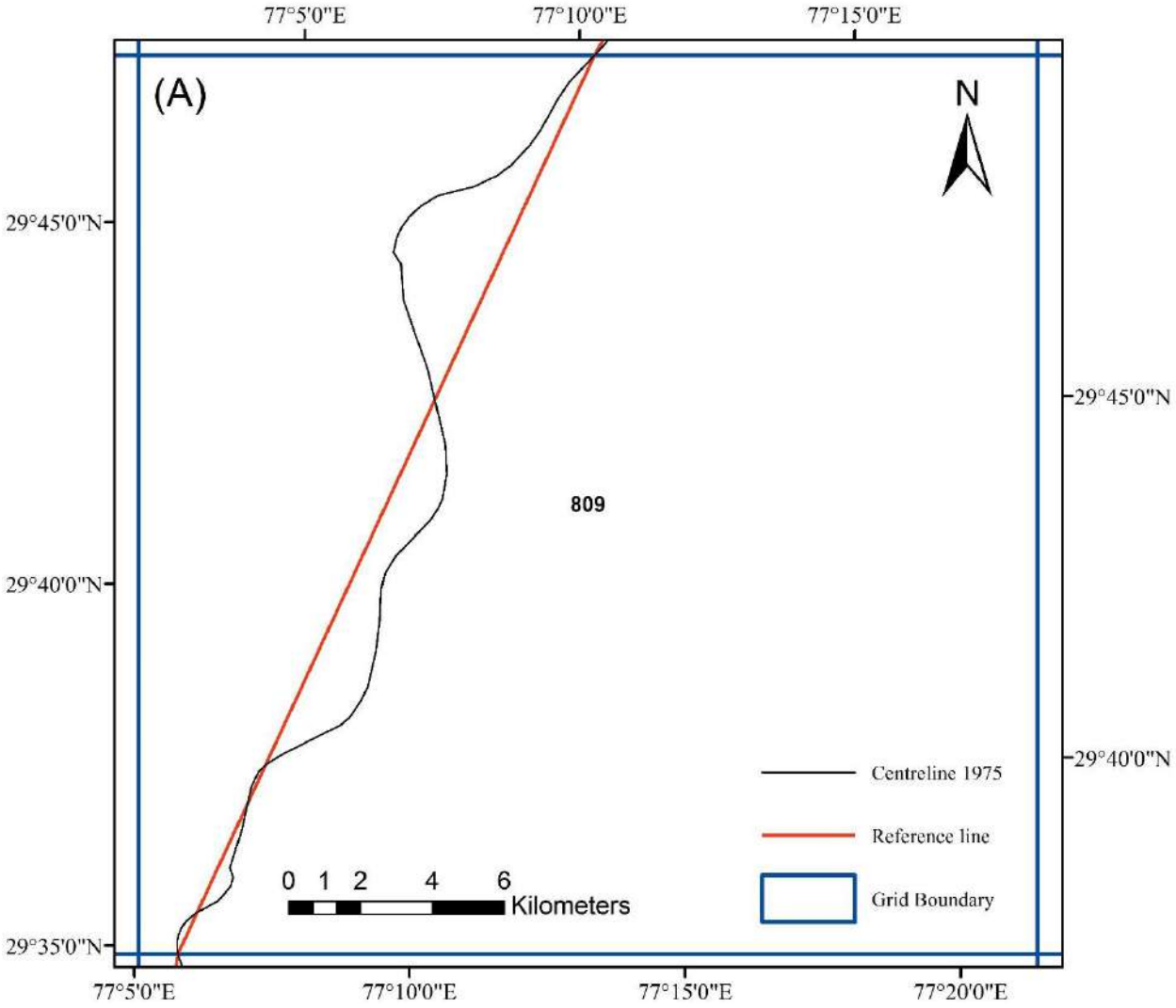


Figure 6-10: Creation of Reference Line based on 1975 Centreline

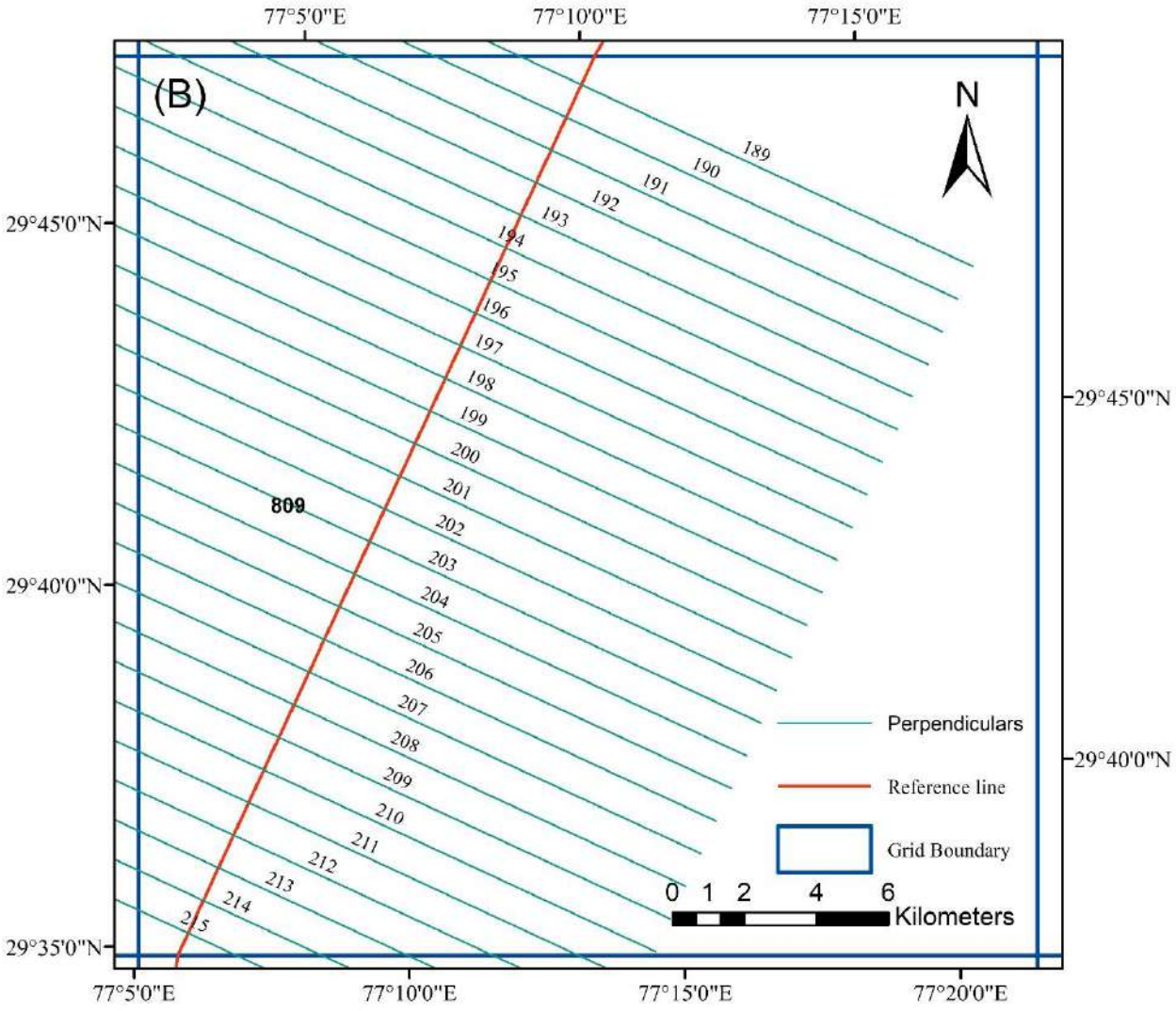


Figure 6-11 : Drawing Perpendiculars at 1 km interval on Reference Line

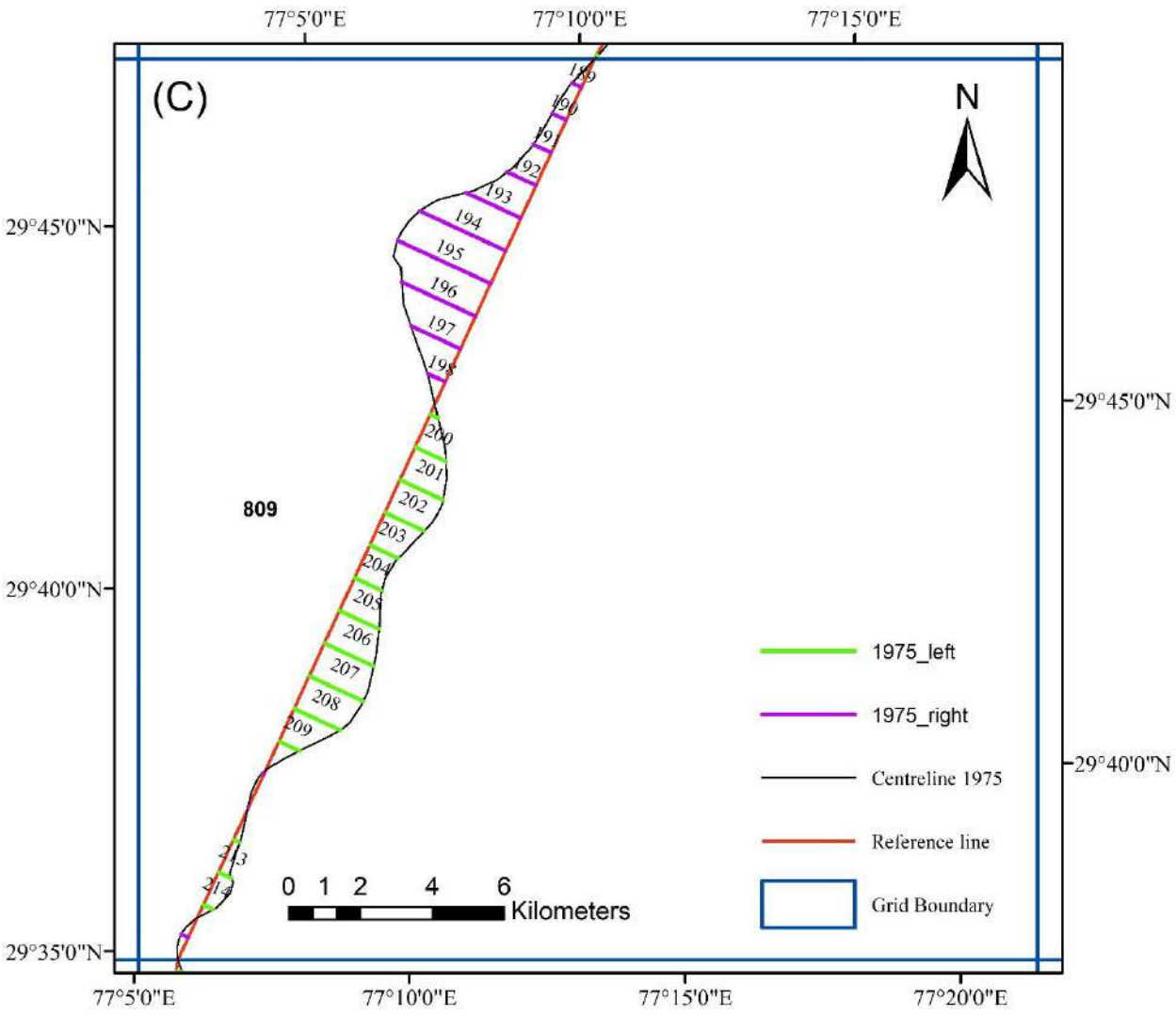


Figure 6-12 : Computation of distance between Reference Line and Centrelines

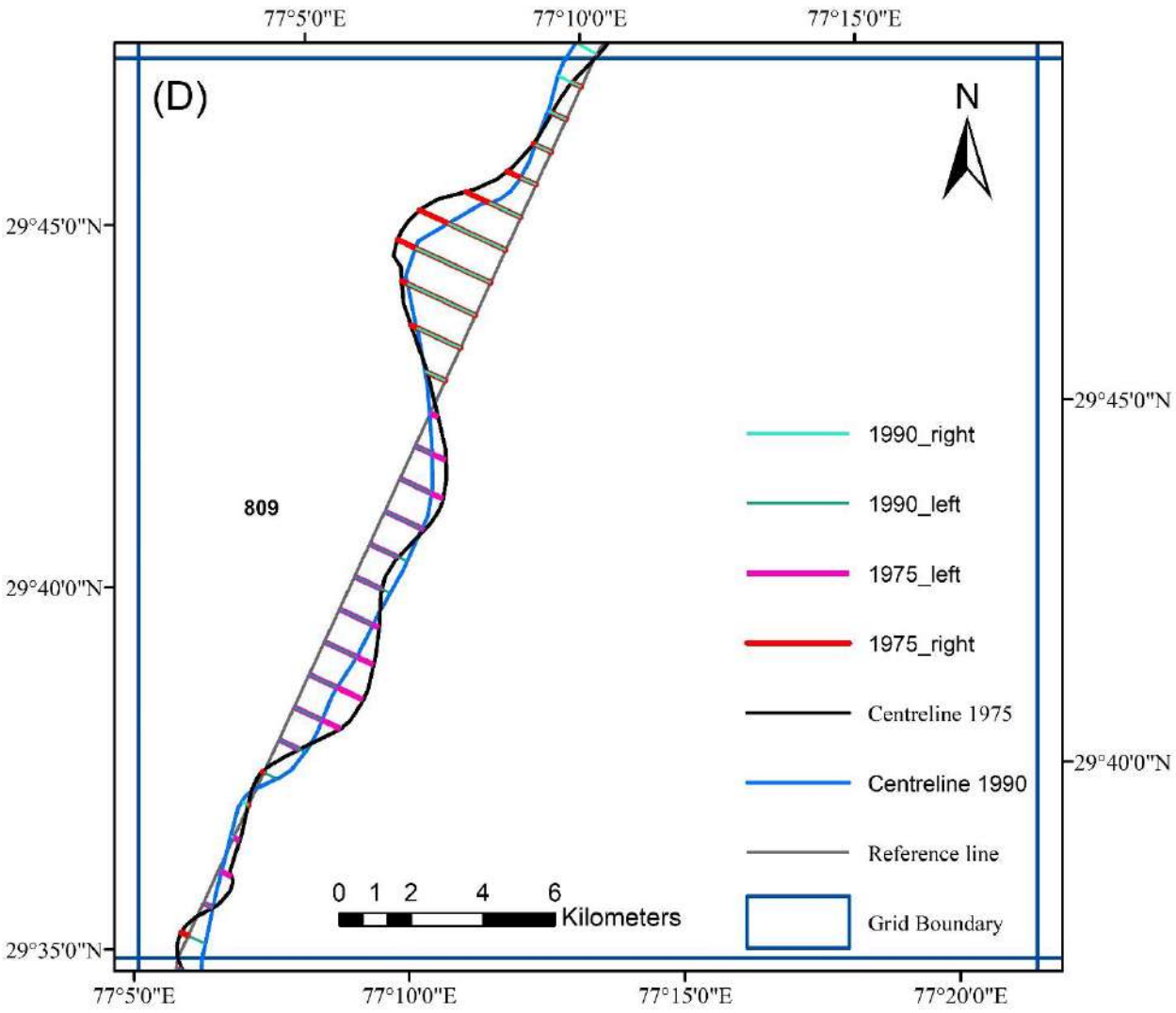


Figure 6-13 : Computation of swing displacement of channel centerlines

Table 6-1 : Names of Villages along river and nearby chainages

Village Name	Chainage (km)
Yamunotri	1
Kupra	15
Chakragaon	30
Naugaon	37
Barnigad Khatal	47
Kandi	58
Nainbagh	66
Busan	75
Kalsi	82
Dakpatthar Barrage	87
Dakhrani	96
Asan	100
Poanta Sahib	105
Kalesar	112
Tajewala	116
Bartha	128
Gayajudin Pur	141
Kalanaur	152
Jathlana	163
Gumthala Rao	170
Halwana	186
Karnal	202
Dhakwala	208
Mundi Garhi	222
Mandawar	231
Mawi	240
Khojkipur	254
Rakshera	263
Jagosh	270
Rajpur Khampur	279
Nethla	285
Baghpat	293
Katha	298
Palla (Sungarpur)	306
Burari	316
Wazirabad	320
Delhi Railway Bridge	326
ITO bridge delhi	330
Mayur Vihar	333

Village Name	Chainage (km)
Mant	458
Jahangirpur	462
Vrindavan	464
Mathura	474
Gokul Barrage	481
Farah	495
Akos Khadar	504
Akabara	510
Agra P G	520
Agra J B	524
Rudaunat mali	537
Bisarna	547
Bichola	555
Shankarpur	560
Begampur	573
Kalyanpur Mafi	584
Uganpura	595
Parana	604
Kachaura	612
Vijaipura	621
Bahuri	629
Etawah	632
Rampura	639
Kandhesi Dhar	648
Dibholi	655
Nogawan	661
Chakarpura	672
Ayana	683
Auraiya	693
Bhadaura	700
Raipur	707
Kondaki rihi dewara	715
Damanpur	721
Narhan Dewara	728
Kalpi	738
Abhirva	747
Manki Kalan	755
Bhauli	768

Village Name	Chainage (km)
Okhala	340
Kidawali	352
Mahawatpur	357
Garhi Samastpur	361
Chandpur	372
Chhainssa	380
Mohana	384
Thanthri	389
Pipli	394
Bilochpur	406
Ramgarhi-Untasani	416
Roopnagar Khadar	423
Lana Makhdoompur	430
Oba Bangar	437
Auhawa Khadar	445
Bhadavan Khadar	450
Muhal Sakraya	455

Village Name	Chainage (km)
Chandupur Daria	776
Hamirpur	781
Bhaura Daria	800
Gagaulli	815
Chilaghat	822
Dattauli	832
Gokan	847
Marka	857
Metehana	866
Kishanpur	872
Bilas Khadar	882
Saidpur	892
Rajapur	902
Silauta Ahmamali	917
Mau	928
Pali Gaon	942
Pratappur	960

6.6 Critical and Stable Reach

Understanding of the concept of critical and stable reach is important for the identification of a certain river reach for its critical or stable status. Usually, reference conditions are obligatory to identify such reaches and they can be based on expert judgement. No predefined methodology is available in the literature for identification of critical or stable reaches which is applicable for different river systems of the world. Moreover, a wide range of parameters is available to analyze the stability of the systems. Not only these parameters, but impacts observed due to fluctuations of these parameters from reference conditions on hydrology, river hydraulics, associated ecology, environmental needs and human demands can be used to define a particular reach as critical/stable reach. Hydrologist may suggest a particular reach of river as a critical reach where significant variations are observed in flow regime and its characteristics whereas ecologist may identify a particular fragment of the river as critical based on aquatic habitat conditions in that reach. For an administrator, river reach susceptible to flood risk is of highest priority and usually termed as critical reach with particular flag suggesting immediate actions to reduce damage and associated vulnerability. Mindset, an expert's background, and his/her judgement are the most important variables in declaring a reach as critical. It is important to note that, stability or criticality of a reach is also a function of temporal and spatial scales of study. The scale on which observations are made also plays an important role in defining the stability or criticality of the reach under study.

Our understanding of natural systems suggests that the river system in the unregulated flow scenario should be considered as a reference to discover changes occurred in the system over a temporal domain. In the present study, the system observed in 1975 is considered as a reference condition. Various features as explained above are marked on the 1975 image and used as a reference. Distance between bank lines (endpoints of channel area as observed in non-monsoon season) is used to obtain the location of centerline and channel width. If swing displacement of the centerline between various years is more than the width of the channel in that particular stretch, it is analyzed further to understand the dynamics of river functioning.

In the present study, the rate and scale of erosion-deposition and river course dynamics are used to identify a critical reach. If the movement of the river is limited to swing zone, it is considered as natural phenomena of river hydraulics and it may not be attributed as a critical reach. More details about identification of critical reaches and genesis behind it provided in Chapter 17.

Chapter 7 Land Use Changes

7.1 Introduction

Land-use changes change the water and sediment supply to rivers, which, in response, alter channel geometry and composition towards condition capable of passing the supplied sediment with the available water. Variations in water and sediment input can result from a wide variety of land uses, including mining operations, timber harvesting, agriculture, urbanization or mixtures of these changes. Although the general cause and effect of the relationship between water and sediment supply on channel change are apparent, the range of possible channel response is diverse. The rate and direction of changes in channel width, depth, or composition can vary with the relative magnitude of changes in water and sediment supply, as well as the quality of sediment supply. Adding to the complexity is the fact that land-use changes are spatiotemporal in nature. Channel response may lag behind the land-use change and will often integrate the effects of a complex sequence of spatially and temporally variable land-use patterns. The result is that the channel response to any particular land use is difficult to isolate and most modern channels in developed regions exhibit an incomplete and spatially varying response to the suite of previous land-use changes.

7.2 Land-use changes

In the present case, the land use classification has been performed on satellite images obtained from various sources. While most of the images (1990, 2000, 2010 and 2015) have a resolution of 30 m (in multispectral bands), the image of 1975-1980 has a resolution of 60 m.

The motive of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or "themes". The method used in the study is Supervised Classification of pixel-based classification.

7.3 Supervised classification

It is based on the notion that a user can select pixels in an image that are demonstrative of various classes and then direct the image processing software to use these training sites as references for the classification of all other pixels in the image. Training sites are nominated based on the

knowledge of the user. The user also sets the bounds for how likely other pixels must be to group them. These bounds are frequently set based on the spectral characteristics of the training area, plus or minus a specific increment. The user also labels the number of classes. Maximum Likelihood Classification (MLC) is used for the classification.

7.3.1 Maximum Likelihood Classification

The underline assumption behind this method is that the statistics for each class in each band are typically distributed. The algorithm estimates the probability that a given pixel belongs to a specific class. Each pixel is assigned to the category that has the highest probability (that is, the maximum likelihood). The algorithm utilized by the Maximum Likelihood Classification tool is based on two principles:

1. The cells in each class sample in the multidimensional space are typically distributed
2. Bayes' theorem of decision making.

The Maximum Likelihood Classification tool considers both the variances and covariance of the class signatures when allocating each pixel to one of the classes signified in the signature file. With the assumption that the distribution of a class sample is normal, a class can be categorized by the mean vector and the covariance matrix. Given these two properties for each cell value, the statistical probability is calculated for each class to define the membership of the cells to the class. Each cell is classified into the class to which it has the highest probability of being a member.

7.3.2 Signature File

Seven land use types, namely: a) water bodies b) Snow glaciers c) Forest d) Fallow land e) Built-up f) Barren Land and g) Agriculture are considered for land use classification. A signature file is first created consisting of all classes. For each category, we have considered 30 training areas and then merging into one common LULC class.

7.3.3 LULC Classes Identification Criterion

Vegetation: Appears in different shades of red since it has a high 25 reflectance in the NIR band. Shapes and total variations have been used to distinguish agriculture from other types of vegetation.

Built-Up Area: Appear in various shades of blue depending on their composition.

Open Area: Appear in different shades of grey and yellow.

Water Body: Appears dark-bluish (higher green band reflectance), while turbid water appears cyan (higher red reflectance due to sediments).

Accordingly, decadal land use maps have been prepared and presented in the following figures.

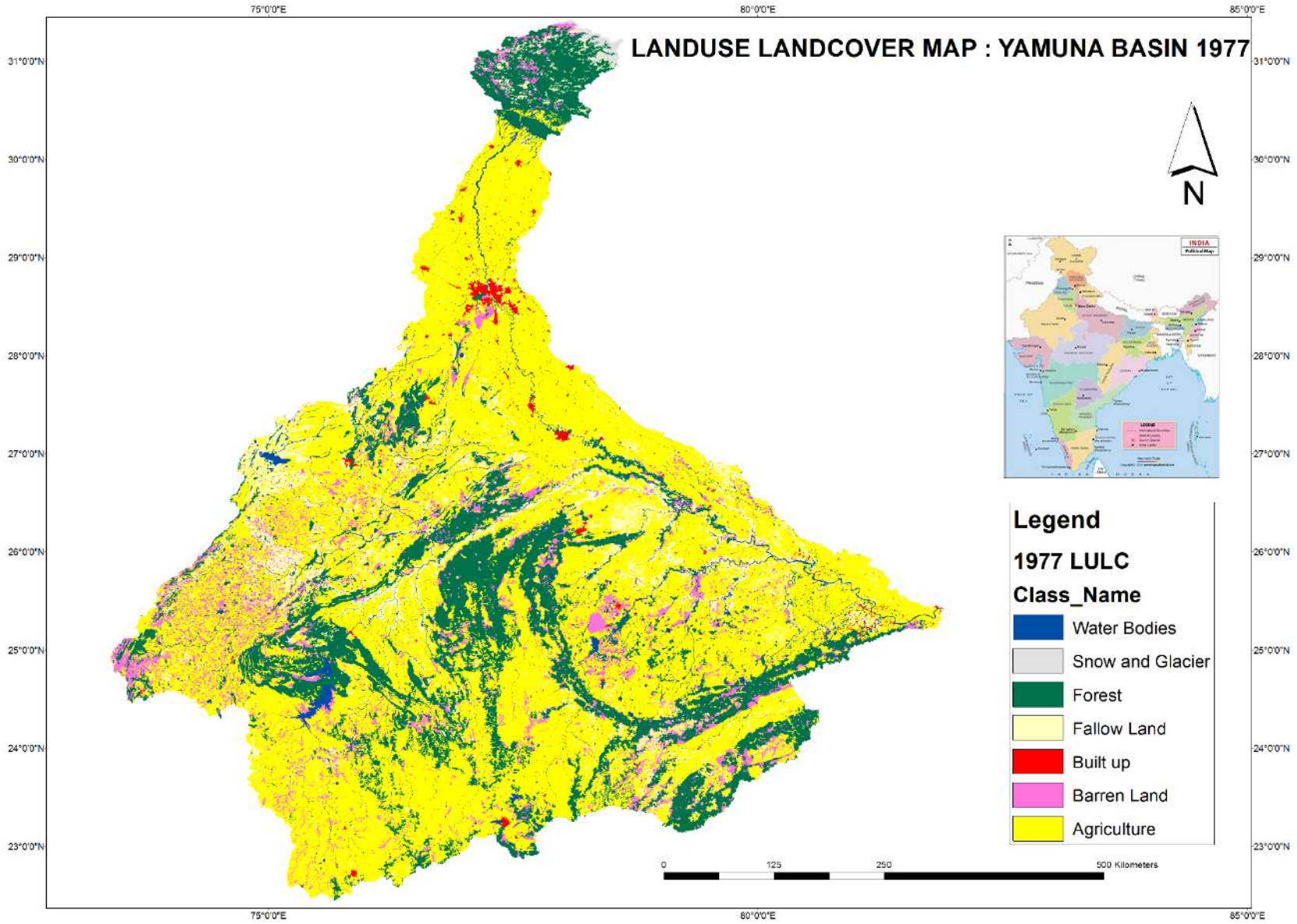


Figure 7-1 : Land Use Land Cover Map of Yamuna Basin (Year: 1977)

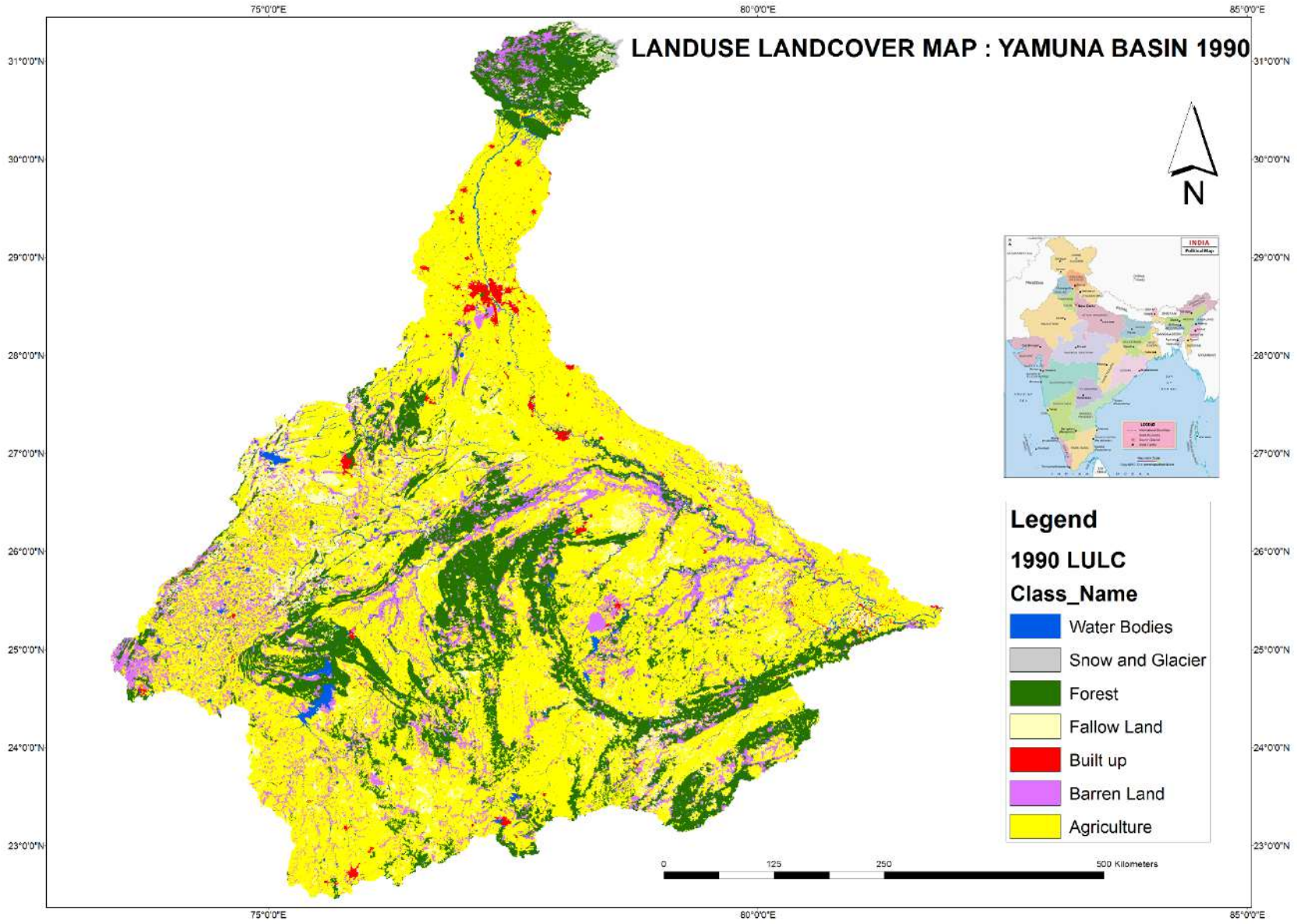


Figure 7-2 : Land Use Land Cover Map of Yamuna Basin (Year: 1990)

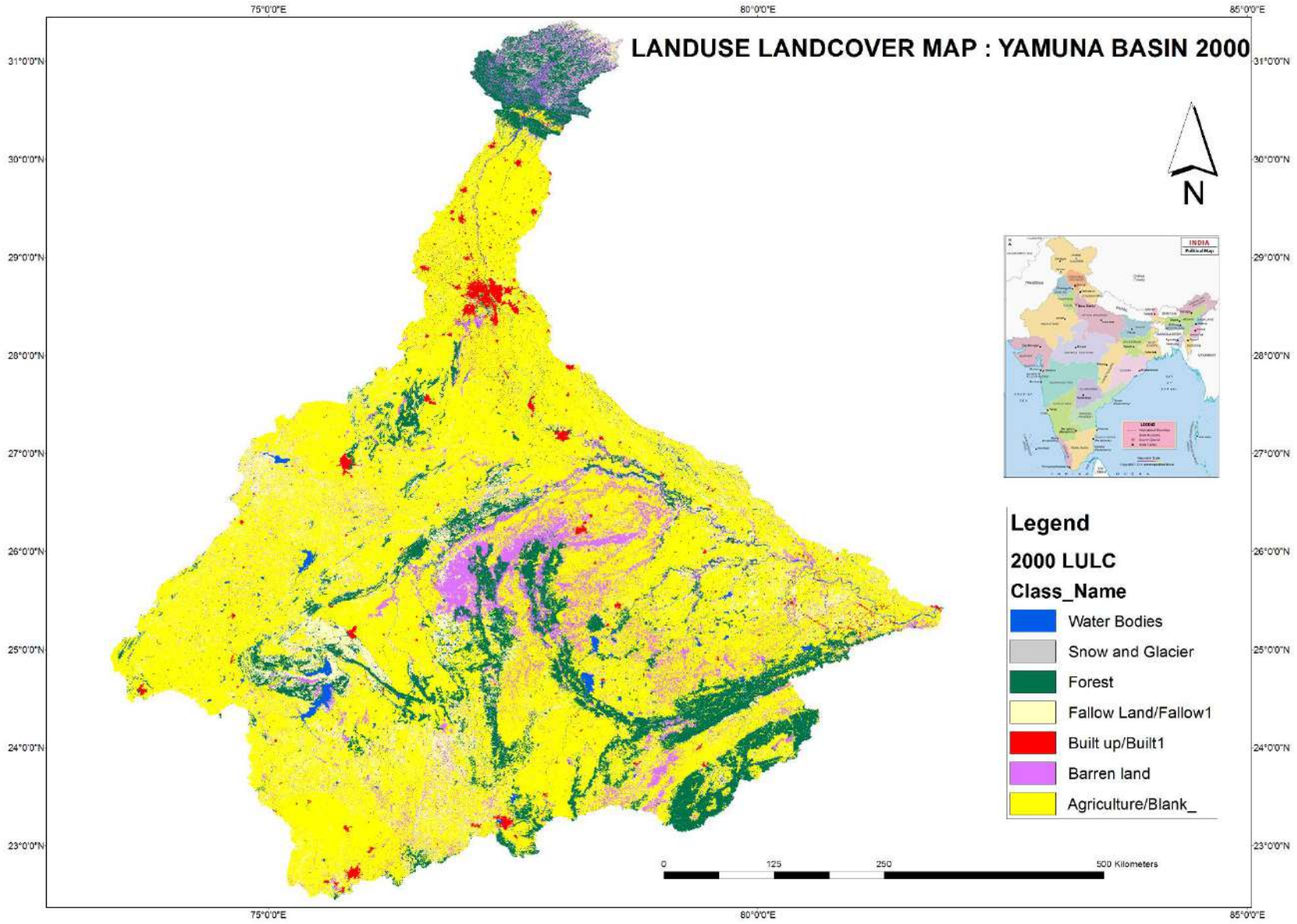


Figure 7-3 : Land Use Land Cover Map of Yamuna Basin (Year: 2000)

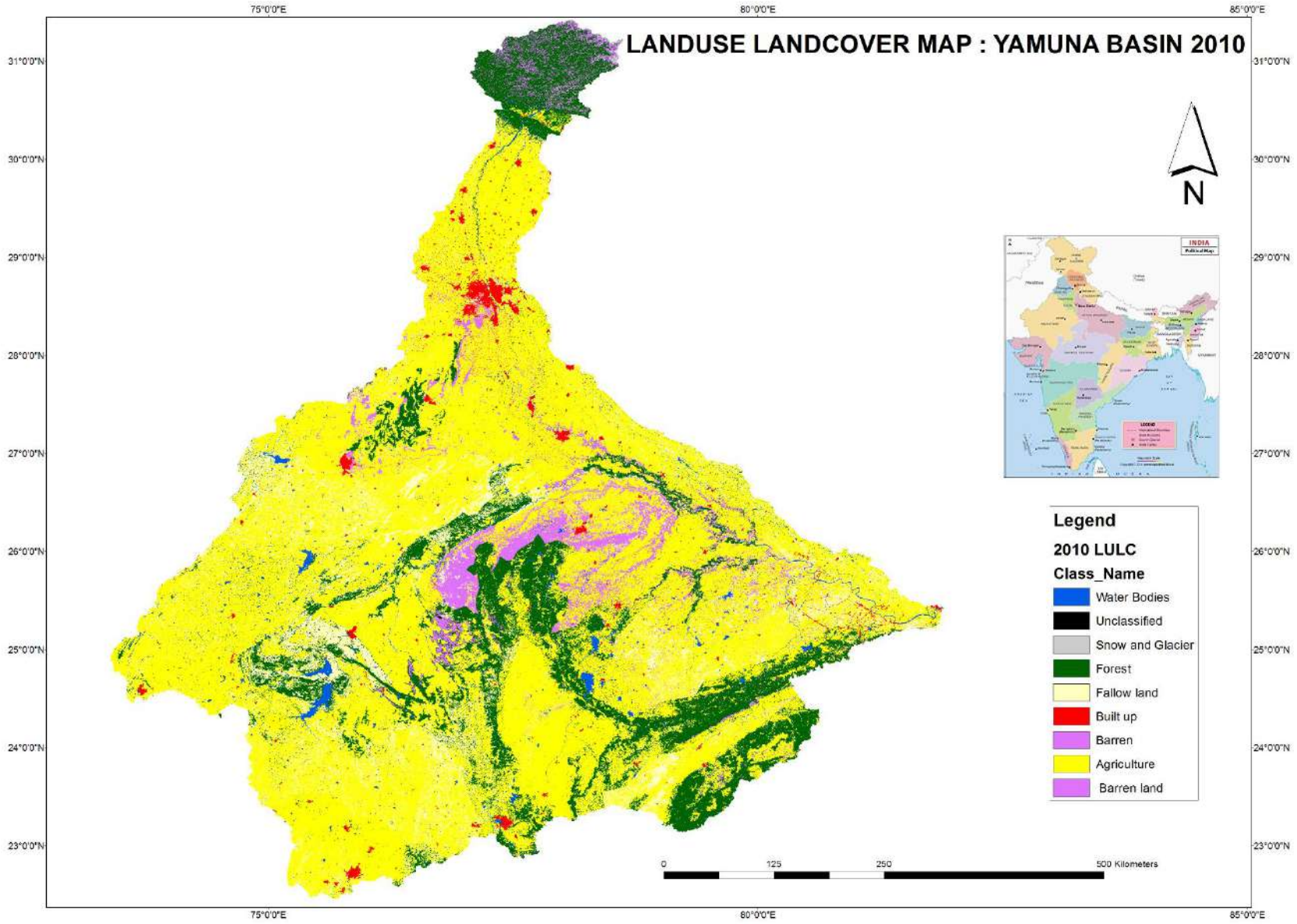


Figure 7-4 : Land Use Land Cover Map of Yamuna Basin (Year: 2010)

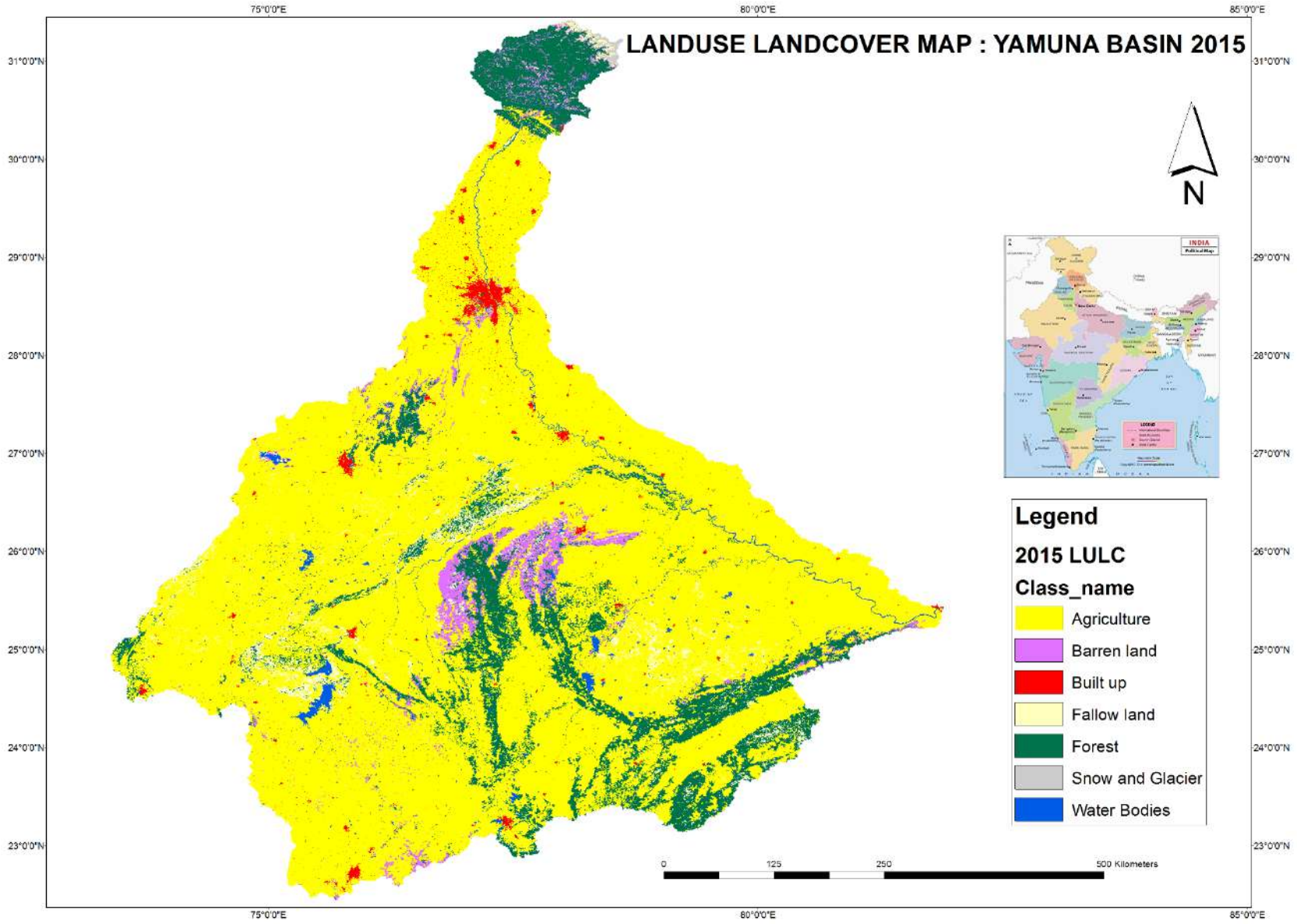


Figure 7-5 : Land Use Land Cover Map of Yamuna Basin (Year: 2015)

7.4 Land Use Area under different Land Cover classes

Based on land use classification, area for each class in respective year has been obtained and presented in the table below. Changes observed are discussed in subsequent paragraphs.

Table 7-1 : Land Use Area under different Land Cover Classes

Year/Class	1977	1990	2000	2010	2016
Built up	2551.85	3419.68	4566.59	5443.96	6217.7297
Agriculture	243212.55	238759.00	262899.37	274960.60	281873.65
Barren Land	26370.87	37897.32	30518.76	22920.216	11833.85
Water Bodies	9300.93	8777.32	5407.62	4497.81	6826.53
Snow and Glacier	745.95	609.7671	206.5	244.25	280.46
Forest	62973.94	55625.77	41586.67	37822.47	38672.62
sum	345156.09	345088.88	345185.51	345889.32	345704.85

It has been seen that some of the classes have shown either significant increase or decrease in these fifty years period. Specifically, land-use class agriculture, built up and forest have shown trends as depicted below in Figure 7-6.

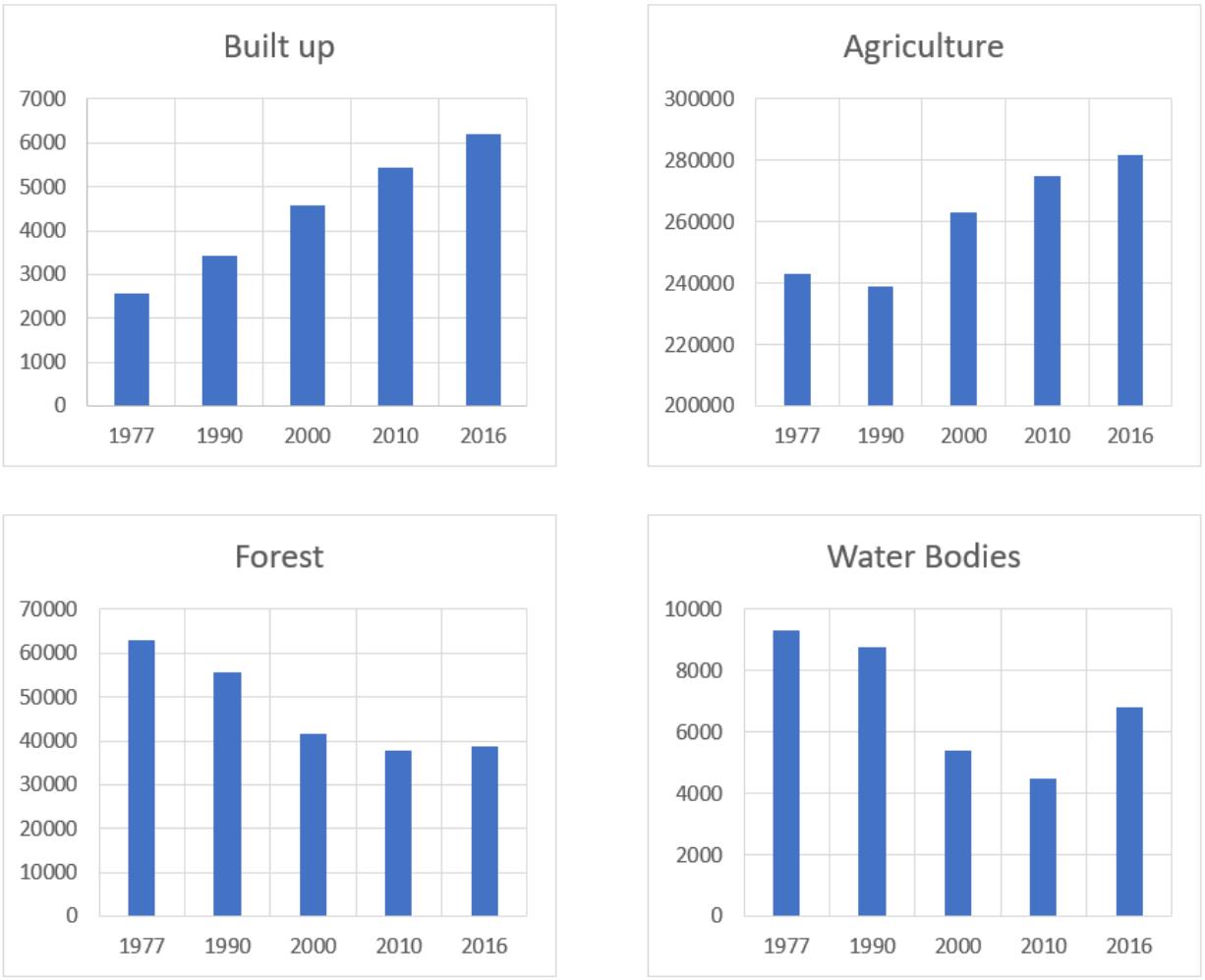


Figure 7-6 : Changes in Land Cover Classes over the years

Built-up and agriculture have shown an increasing trend whereas forest land use has shown a decreasing trend. Though water bodies have decreased from 1977 till 2010, it has shown some sign of recovery in the year 2016. Is important to note that land use prepared for the respective year does not represent land-use for that year, rather it's a land use based on an image of particular date and time of the year. Therefore, variations in land use are possible based on the images used for the preparation of land use. For example, Images of post-monsoon images represents substantial agriculture cultivation, whereas images of pre-monsoon after Rabi harvesting shows much of the land as barren. In the present study, based on classification it has been seen that much of the area belonging to forest and snow cover glacier lies in the upper part of the basin. Some of the forest areas also feature in rainfed tributaries of the basin. Most of the basin is dominated by agriculture area. Yamuna canal system and dams on the Chambal river system have brought the

significant area under agriculture cultivation. As these structures were built much before the availability of satellite images, it will be unreasonable to predict the impact of these structures on land-use change in the basin.

7.5 Effect of Land use change on Channel Morphology

For the purpose of examining land-use impacts on river channels, the land-use of different years i.e. 1977, 1990, 2000, 2010 and 2016 have been compared with hypothetical condition. This hypothetical condition is a condition where runoff contribution is considered from two land use types; one is forest and second is agriculture. Both the land use types are considered to be covering the area of 50% each in whole catchment. Though the unavailability of historical measurements prevents explicit estimates of water and sediment supply for hypothetical condition, it is possible to develop an index relating land-use change in water and sediment supply that provides a reference for assessing relative changes during the different time periods.

The land-use classification information (Table 7-1) is used to estimate the effect of land use on surface runoff and sediment yield relative to a hypothetical condition. Surface runoff for each land use class is determined by SCS curve number approach by considering a 1-hour rainfall of 68.9 mm (2-year recurrence interval). The average surface runoff ratio, weighted by percent cover for each land use in each time period, provides an index of the change in runoff relative to the hypothetical condition. The effect of land use on the relative rate of soil loss is estimated using the locally determined land-use cover factor from the Universal Soil Loss Equation. Since the same catchment area is considered for analysis over a period of time, other factors in the USLE remain constant. The soil loss for each land use is calculated as a ratio of land use cover factor of respective land use and that of hypothetical condition. Similar to the runoff estimate, the average soil loss ratio, weighted by the percent cover for each land use in each time period, gives an index of soil loss. The values of Curve number and C factor for different land use types used in the present study are displayed in Table 7-2.

Table 7-2 : curve number and c factor for different land use types

Year/Class	Curve Number	C factor
Built up	94	0.075
Agriculture	88	0.35
Barren Land	83	1
Water Bodies	100	0
Snow and Glacier	100	0
Forest	77	0.004

Respective ratios of Runoff and soil loss, to that of hypothetical conditions are presented in Table 7-3

Table 7-3: Land use, runoff, and soil loss for the different time periods

Year/Class	Percent in each land use*							
	Hypothetical condition	**1977**	**1990**	**2000**	**2010**	**2016**	**Runoff (ratio to surface runoff under hypothetical condition)**	**Soil loss (ratio to loss under hypothetical condition)**
Built up	0.00	0.74	0.99	1.32	1.57	1.80	1.688	0.424
Agriculture	50.00	70.46	69.19	76.16	79.49	81.54	1.279	1.977
Barren Land	0.00	7.64	10.98	8.84	6.63	3.42	0.999	5.650
Water Bodies	0.00	2.69	2.54	1.57	1.30	1.97	2.202	0.000
Snow and Glacier	0.00	0.22	0.18	0.06	0.07	0.08	2.202	0.000
Forest	50.00	18.25	16.12	12.05	10.93	11.19	0.721	0.023
Runoff, as ratio to hypothetical condition	1.000	1.186	1.187	1.207	1.218	1.233		
Soil loss, as ratio to hypothetical condition	1.000	1.832	1.996	2.014	1.955	1.816		

Various factors limit the accuracy of these estimates of runoff and soil loss, as well as uncertainty within the location and condition of agriculture, associated practices and scale issues related to application of runoff and soil loss parameters at range of scales (local, regional or global). However, similar methods of estimating soil loss and runoff have been used in the past and found useful (Knox, 1977; Jacobson and Coleman, 1986). Therefore, these estimates can only be used in a relative sense: changes in runoff and soil loss from one-time frame to the next on account of land use change. Following inferences that may be drawn from these estimates

1. Runoff and soil loss both increased sharply with increase in agriculture area
2. The changes in soil loss are of a larger magnitude than those in runoff

For evaluating the influence of soil loss on stream channel change, attention must be given to the ability of the eroded sediment and the spatial distribution of its source area. An estimate of the spatial distribution of coarse sediment supply can be made using topography and survey as a surrogate for actual observed records.

From the survey and slope computations using available data, it can be said that, coarse grained sediments are found in upper region of Yamuna Basin. After Yamuna enters Indo-Gangetic plains, slope reduces, and deposition of sediments coarse sediments occur. Most of locations upstream of

Hathnikund barrage, specifically upstream of the village Gumthala Rao feature coarse size sediments whereas downstream of Gumthala Rao, silt and fine sand are observed. This observation is also in line with topographic and flow characteristics of the Basin. More details related to aggradation, degradation and sediment analysis are represented in Chapter 12. In the limited context of Land use change and its impact on river morphology, it can be said that, land use change has bearing on Morphological behaviour of river, but to isolate and quantify the impact of land use change is very complex. Indirect assessment in terms of changes in runoff and soil loss (linked with land use change) can be done which in a way represent morphological behaviour of the river.

7.6 Conclusion

Following conclusions may be drawn

1. The major part of the basin is covered with agriculture (based on land use of year 2016) accounting for 81.54% followed by forest (11%), Barren land (3.42%), Water bodies (1.9%), Built-Up Land (1.8%), and Snow/Glaciers (0.08%).
2. The growing agriculture and deforestation in most areas of the Yamuna basin have led to soil erosion on the one hand and have accentuated flooding on the other. Most of the forest tracts within the Yamuna basin are degraded because of overexploitation. Though several forest areas in Yamuna basin have been declared as national parks, the overall ecosystem in Yamuna basin can be considered in a stressed situation if the forested area is used as a basis for comparison.
3. Though changes in land use have been observed, its direct impact on river morphology is difficult to predict because of several factors. Hydrological and meteorological factors, along with physiographic characteristics, have a significant bearing on morphological behaviour of the river. Anthropogenic activities and development around river corridor also affect morphological characteristics. As the combination of all these factors affects the river morphology, isolating the effect of land-use change from other factors is not possible. However, land-use changes reported in this study indicate that built-up area and agriculture have increased by 1.06% and 11.42% respectively, from 1977 to 2016, whereas forest and barren land have shown the reduction of 7.06% and 4.22% respectively.

Chapter 8 Reconnaissance

8.1 Introduction

This chapter deals with details of site visits undertaken to various locations of the Yamuna River by the team of IIT Delhi. The observations made during the site visits have been examined in the perspective of the outcomes of the morphological analysis carried out in this study. A line diagram showing tributaries, powerhouses, barrages, canal headworks etc in Upper Yamuna system is presented at the end of this chapter for better understanding of structures and their operation discussed in subsequent section.

8.2 Site Visit to Dakpatthar Barrage

A team of IIT Delhi visited Dakpatthar Barrage on 31st January 2019. This is the most upstream barrage on River Yamuna located at Dakpatthar. Barrage receives water from two sources: one from the River Yamuna and other from the release of Khodari powerhouse. A power canal offtake from the right side of the river feeds water to Dakrani powerhouse. Yamuna River near barrage is characterized by relatively steep slope with well-defined banks. On the downstream side of the barrage, historic flood occurrences have left their signature on the right side of the river. This has also resulted in a change in gate operation policy at Dakpatthar Barrage. Out of 25 gates, gate number 25, located on the extreme right of the barrage has been closed permanently. At present, as per present environmental flow policy, discharge of 400 cusecs is released in the river in non-monsoon tear. Limited operation of gates mainly sluices from number 1 to 6 during the non-monsoon season of the year results in the formation of a narrow but slightly deep channel within a very wide channel of the river in the downstream of barrage. All gates (except gate number 54) are active during flood seasons. Silt management during monsoon is done with the help of PPM measurement at 15 minutes interval. A threshold value of 3000 PPM has been utilized for the operation of silt gates. Following images show the upstream and downstream view as seen from the barrage.



Figure 8-1 : Dakpatthar Barrage Head Regulator



Figure 8-2 : Upstream view of Dakpatthar Barrage (focusing on the left bank)



Figure 8-3 : Upstream view of Dakpatthar Barrage



Figure 8-4 : Downstream View from Dakpatthar Barrage (left Bank)

In Figure 8-1, the left side indicates reservoir area and the right side shows the canal used for supplying water to the powerhouse. The head regulator is used for controlling flow through the canal. Figure 8-2 and 8-3 show area upstream of the reservoir as seen towards left and right bank respectively and Figure 8-4 shows a downstream view of Dakpatthar Barrage. During the visit, it was observed that in the non-monsoon season, release in the main channel was limited to leakage through gates only. Officials at the barrage site underscored that leakage through gates in of the magnitude of 400 cusecs which is equivalent to environmental flow as suggested by NGT. It has been seen that flow width downstream of a barrage in the main river was limited to 100 m with two small braids on the west and two on the east. These braids culminate in a single braid at approx. 2 km downstream of Dakpatthar Barrage.

8.3 Site Visit to Assan Barrage

Assan Barrage, in the Doon Valley, is situated in the border region of Uttarakhand and Himachal Pradesh. The barrage was constructed in 1967 on Asan river just before its confluence with the Yamuna. The reservoir creates a small lake named as Dillipur lake with an area of 4 sq. km. The reservoir is fed from the river Asan and the discharge from Yamuna (thorough canal from Dakpatthar head regulator). The lake is also known for ecological importance as some of the migratory birds visit this place. Barrage has 14 gates and a total width of 288 m.

A team of IIT Delhi visited Assan Barrage on 31st January 2019. Figure 8-5 and Figure 8-6 show an upstream and downstream view from the Assan Barrage. From the downstream view of the barrage, it shows that riverbed is almost entirely dry as most of the water from barrage is diverted to the powerhouse and released to the river at some downstream location. Barrage is operated is such a way that following requirements are fulfilled,

1) To absorb the discharge variations of a power station at stage I, in the pond of the barrage so as to pass constant discharge in power channel
2) To pass down the barrage surplus river discharge with adequate care of following factors
    a. Safety of structures
    b. Non-accumulation of shoal upstream of the barrage
    c. Ejection of the finer bedload through silt ejector channel



Figure 8-5 : Assan Barrage Upstream View



Figure 8-6 : Assan Barrage Downstream view

As the barrage is not located on the mainstream of River Yamuna, channel characteristics upstream and downstream of the structure have not been explored in detail. However, at the downstream of Assan Barrage, the confluence of Assan and Yamuna River is found to be stable confluence. Satellite images of Assan Barrage downstream area show a signature of sediment deposition

pattern. Downstream river reach of Assan barrage up to its confluence with the Yamuna is stable as it did not go through significant changes during the time scale of study.

8.4 Site Visit to Hathnikund Barrage

The Hathnikund is a concrete barrage located on the Yamuna River in Yamuna Nagar district of Haryana state, India. It was constructed between October 1996 and June 1999 for the purpose of diverting water for irrigation. It replaced the Tajewala Barrage 3 km downstream which was constructed in 1873 and is now out of service. The barrage diverts water into the Western and Eastern Yamuna Canals. The barrage is 360m long and its spillway is composed of ten main floodgates along with five under sluices on its right side and three on its left.

A team of IIT Delhi visited Hathikund Barrage on 1st February 2019. Figure 8-7 and Figure 8-8 show upstream and downstream view respectively from the barrage. During the visit, water-sharing arrangements between Haryana, Uttar Pradesh, Rajasthan and Delhi were also discussed. As per recent order, NGT order environmental flow of 352 cusecs is released to the Yamuna River continuously to meet the instream requirements. Priorities for release are as under

1. Release for environmental flow
2. Release for Delhi water supply
3. Division of remaining between three states i.e., Haryana, Uttar Pradesh and Rajasthan

Division of share between states is discussed for three periods i.e., March to June, July to October and November to February. The other operating conditions such as closing of canals based on discharge and silt disposal were discussed. It was revealed that for any discharge above 70,000 cusecs, canal operations are closed for proper disposal of silt by releasing all the water to the river. At the time of the visit, two braids of active water channels were seen at the downstream of barrage up to1km and the rest of the river was in dry condition. Width of the active water channel is around 80 to 100 m whereas the width of the river varies from 370m to 600m. Cobbles and boulders were observed in the riverbed with size ranging from 5cm to 50 cm in diameter. A few kilometres downstream, in surrounding areas, sand mining and stone crushing activities were also noticed. Following figures provide views for upstream and downstream areas from Hathinikund barrage. One may observe cobbles and boulders in the downstream area in the riverbed as well as stone lines in sand mining sites in surrounding areas.



Figure 8-7 : Hathnikund Barrage and upstream view



Figure 8-8 : Hathnikund Barrage Upstream- Inflow from Khara Powerhouse



Figure 8-9 : Hathnikund Barrage downstream view - Cobbles and Boulders



Figure 8-10 : Hathnikund Barrage Downstream view - section at the left bank



Figure 8-11 : Hathnikund Barrage downstream view - section at the right bank



Figure 8-12 : Stone line observed in the vicinity of downstream of Hathnikund Barrage



Figure 8-13 : Sand mining site seen at downstream of Hathnikund Barrage

Further downstream from Hathnikund Barrage, villages Bagwali and Gumthala Rao were also visited. Presence of fine sand characterizes the riverbed pattern in the surrounding areas. Following figures indicate the presence of fine sand in the area. It was also observed that the depth of the river in most of these locations was not much. Movement of people from one bank to another bank was also noticed due to this shallow depth.



Figure 8-14 : Fine sand on the right bank of Yamuna at Bagwali village



Figure 8-15 : Movement of people from one bank to another bank indicating the low depth of the river at Bagwali village



Figure 8-16 : Fine sand on the left bank and temporary sandbar in River Yamuna at Gumthalo Rao village

One of the important observations during the site visit to the above locations is variation in the presence of cobbles and boulders in river Yamuna. Moreover, sand mining and stone crushing activities downstream of Hathnikund Barrage indicate encroachment in flood plains. From the overall understanding of the flow regime and site visit to these places, it can be said that changes in channel characteristics and river bedforms are mostly the outcomes of high flow events and anthropogenic activities in the riverbed and adjacent flood plains. Changes on account of the natural evolution of channel in case of low flows are highly unlikely.

8.5 Site Visit to Wazirabad Barrage

The Wazirabad barrage was built across Yamuna River, north Delhi in 1959 to supply drinking water to the city of Delhi. Barrage receives water from upstream catchment and release from Hathinukund barrage. The barrage has 14ft tall 12 number of under sluice gates and 10ft tall 17 flood gates. A team from IIT Delhi visited the barrage on January 15, 2020. It was observed and indicated by the officials that the barrage operation policy at Wazirabad is highly driven water level with a target water level is 674.50 ft.

Increase in island/sandbar area in the upstream reservoir area towards the right bank as seen from satellite imagery is also seen on the ground. It was discussed that the formation of this sandbar/island started in 1995 and becomes stable and visible in the year 1999. With the

island/sandbar in place, the river has taken a slightly longer path than it was taking before.



Figure 8-17 : Google Earth imageries indicating the river Yamuna around Wazirabad Barrage

The following figures indicate a downstream view of Wazirabad barrage. It is evident that sand deposition is more prominent around the flood gates. Much of the riverbed is seen in dry condition during the visit. Release from barrage is mainly concentrated on the right side of the channel. After 1990, the area around the left bank immediate downstream of barrage has encroached, and path of the river is restricted in some way.



Figure 8-18 : Downstream view of River Yamuna from Wazirabad Barrage

In the case of upstream reach, expansion of sandbar/island on the right bank has been observed. The following figures indicate the upstream view of Wazirabad barrage. The following figures show the upstream area of Wazirabad barrage. Excess water from the treatment plant is released into a reservoir from under gravity tunnel on the right bank as shown in the figure,



Figure 8-19 : Upstream view from Wazirabad barrage and gravity canal inlet into the forebay

8.6 Site Visit to Okhla Barrage

New Okhla Barrage came into operation in the year 1987 while its construction started in 1979. This barrage was constructed to replace old Okhla barrage built during British Rule in 1874. The primary purpose of this barrage I to divert water for irrigation. Though the old barrage has been replaced with a new barrage, not many changes have been observed in river width both upstream and downstream section of the barrage. Some of the photographs captured during field visit (10 December 2013) are shown below,



Figure 8-20 : Visit to Okhla Barrage



Figure 8-21 : Water Hyacinth observed in the reservoir area of Okhla Barrage



Figure 8-22 : Water Hyacinth observed in the reservoir area of Okhla Barrage



Figure 8-23 : Canal outlet from Okhla Barrage



Figure 8-24 : Consutrction activities around Okhla Barrage



Figure 8-25 : Activities in the active floodplain around Okhla Barrage



Figure 8-26 : Activities in the active floodplain around Okhla Barrage

From the above figures, it can be said that significant water hyacinth is seen on the upstream side of the reservoir. Water in the irrigation canals is observed; this indicates the water availability around the December month. Few construction activities in the vicinity and movement of tractors in the riverbed have also been noticed. Though not much difference is seen in terms of width, sinuosity, and other morphological variables over a period, problems related to untenable water quality for aquatic fauna have been reported.

8.7 Site Visit to Gokul Barrage

The Gokul barrage, also known as Mathura barrage is barrage on river Yamuna at Gokul in Mathura district, top of which also serves as the road bridge. A team of IIT Delhi visited the barrage on 2nd February 2019. Following observations are made during the visit. In the downstream section, two braids of active water area have been noticed. The one on the left looks like the path that river follows for most of the year whereas one observed in the middle section of the channel seems temporary in nature. The release from left barrage gate is given priority considering the availability of water at the Ghats in the downstream area. Another observation is the prevalence of agricultural activities in the area adjacent to the right bank. Width of active water area after it results in two braids is around 100m. Moreover, agriculture within the river channel was also noticed on the right side of the river channel. On the upstream of the barrage, a small island is presently being used for agriculture activity, small boats are used by locals to connect with this island from the riverbank. It was informed that rehabilitation and settlement of land are still ongoing. Therefore, defined operation policy for the barrage is followed in a restricted manner to ensure that minimum/ no damage to agriculture and allied activities in the area until a settlement is reached. Following figures indicate upstream and downstream views from Gokul Barrage.



Figure 8-27: View Upstream from Gokul Barrage



Figure 8-28 : Water Intake Upstream of Gokul Barrage

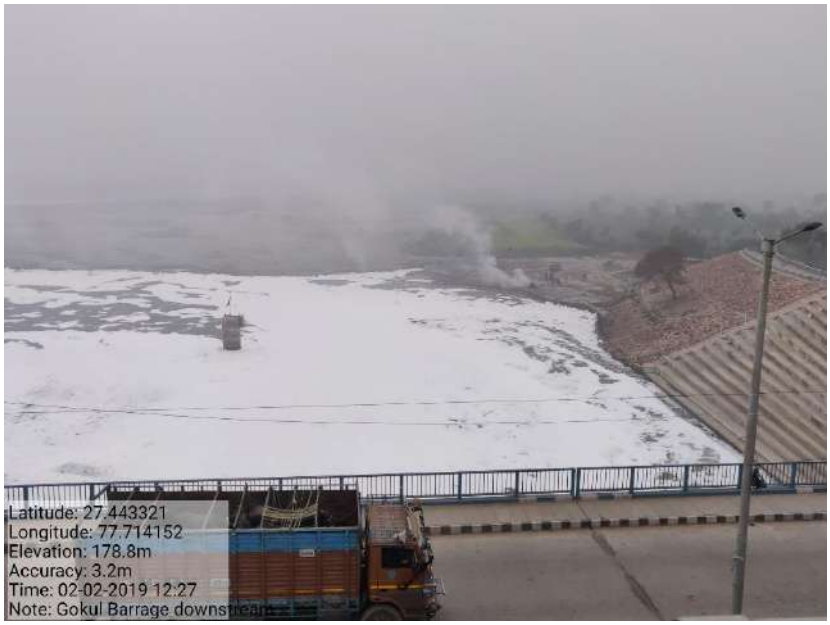


Figure 8-29 : View downstream of Gokul Barrage - Right bank

Overall analysis from satellite imagery and ground visit to Gokul barrage indicate that channel pattern on both upstream and downstream reach has not changed much in the time scale of the study and reach can be considered as stable at present. However, agricultural activities and encroachment in the right bank may change the channel pattern in the near future. The issue of water quality needs to be addressed as the odour and foam formations indicate the presence of chemicals which results in the poor quality of water released from the barrage.

8.8 Site visit to Confluence points

The confluence point is an important element in the morphological study; moreover, stability of confluence also drives upstream and downstream erosion deposition patterns. Therefore, to understand nature of the confluence, site visits to selected confluences was done to capture channel conditions around the confluence zone.

8.8.1 Tons-Yamuna Confluence

At confluence of River Tons with River Yamuna, it was observed that during the lean season, active water channel was limited to approximately 20-25% of the entire river channel. In the case of Tons River, much of part of channel indicate presence of sand and silt. Though cobbles and boulders were observed, at some locations, the concentration of such particles was limited, and a larger portion of channel constitutes sand and silt. Sand mining activity around the confluence zone was also noticed during the field visit. Considering the physiography of Tons river, abided by hills around, the movement of the water channel is restricted and erosion deposition zones upstream of confluence are almost the same.

In case of Yamuna channel before confluence, river flows through plain areas for almost a stretch of 2 km. From the site visit around the Kalsi bridge, it was observed that active water area consists of two braids separated by sandbar. At the bridge, scouring phenomena is observed, as shown in Figure 8-21. It was also observed that presence of boulders and cobbles was quite significant in Yamuna Channel, unlike Tons. Figure 8-22 indicates the area around the right bank of the river just downstream of Kalsi Bridge.



Figure 8-30 : Tons River around the confluence zone



Figure 8-31: Bridge Scour at Kalsi Bridge (before Tons Yamuna Confluence)



Figure 8-32 : Cobbles and Boulders in the Yamuna around Kalsi Bridge

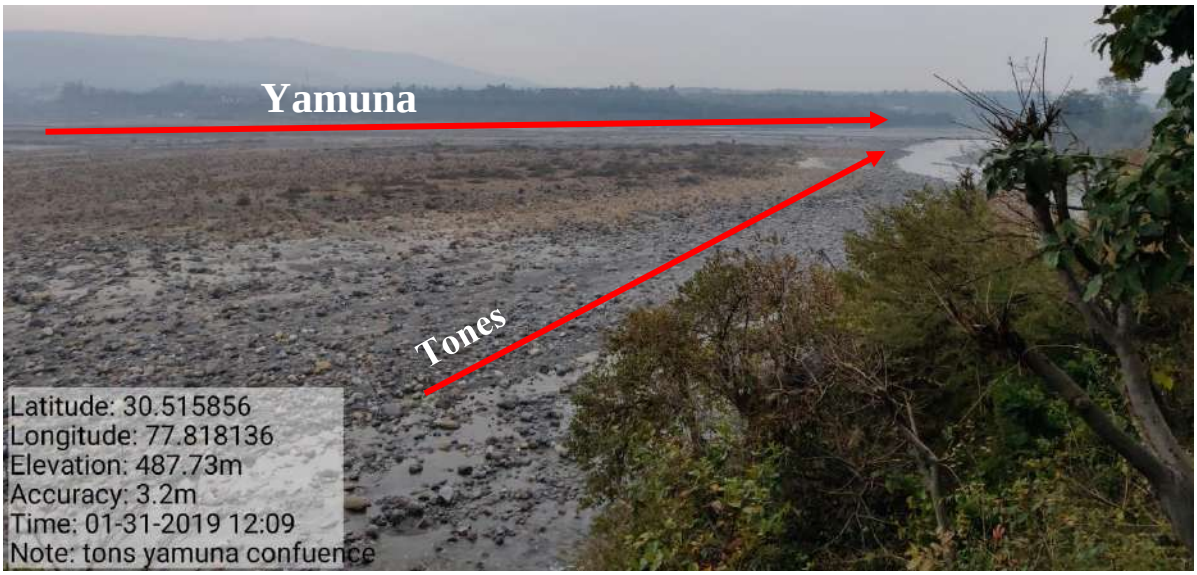


Figure 8-33 : Tons Yamuna Confluence

8.8.2 Giri Yamuna Confluence

Giri River outfalls into Yamuna River near Manpur Devar, just upstream of Asan Barrage from the right side. In comparison to other confluences of Yamuna, Giri-Yamuna confluence has significantly higher confluence zone area. Giri river branches into several small active water channels before it outfalls into river Yamuna.



Figure 8-34 : Google earth image of Yamuna Giri confluence indicating bifurcation of river Giri into small multiple active water channels before its outfall into River Yamuna

Site visit at the confluence indicated the presence of three active water channels before its outfall. River bedform in Giri River around the confluence had a mixed signature of cobbles, boulders and fine sand whereas, in case of River Yamuna particles present in the riverbed had high concentration of cobbles and pebbles with minimal fine sand.



Figure 8-35 : Giri River at the Giri-Yamuna confluence with mixed signature of sand, cobbles and pebbles

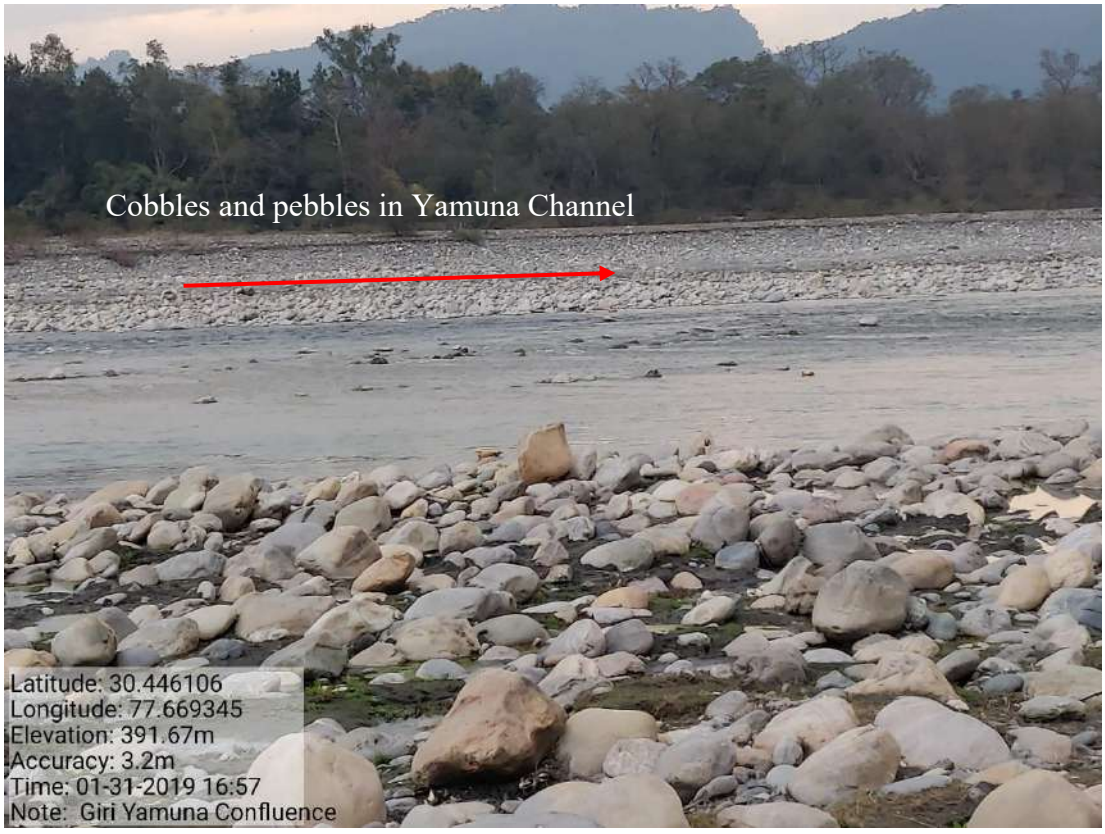


Figure 8-36: River Yamuna at the Giri-Yamuna confluence indicating the presence of cobbles and pebbles at the bank

8.9 Site visit for identification of sandbars

From the satellite image analysis, based on land use, shape size and centroid of sandbars have been classified into temporary and permanent sandbars. Temporary and permanent classification is detailed in Chapter 14. However, it is essential to note that based on satellite image analysis, it was not possible to distinguish sandbars from the island feature. A site visit to some of these features was done to find out if any conclusion can be drawn from the observation from the field. Following photographs were taken during the field visit to places around Delhi where the presence of sandbars existing for more than 20 years.



Figure 8-37: Field Visit for identification of sandbars/Islands around V-13 Krishna Kunj, Delhi NCR



Figure 8-38 : Field Visit for identification of sandbars/Islands around V-13 Krishna Kunj, Delhi NCR



Figure 8-39: Field Visit for identification of sandbars/Islands around V-13 Krishna Kunj, Delhi NCR



Figure 8-40 : Field Visit for identification of sandbars/Islands around V-13 Krishna Kunj, Delhi NCR



Figure 8-41 : Field Visit for identification of sandbars/Islands around V-13 Krishna Kunj, Delhi NCR

Based on the observations it was realized that, once the sandbar is formed in the riverbed and gets stabilized for years, it often attracts nearby farmers, villagers to grow crops during non-monsoon

season. From the satellite image, based on the land use pattern observed for 20 years, one may misinterpret it as an island since agriculture activities become dominant. From the ground-based observation, pattern of vegetation growth, conversation with local people in the area may give an ostensible idea about the presence of sandbar or island. However, proper analysis of vertical section and laboratory analysis of particles in the section is necessary to make a clear distinction between island and sandbar.

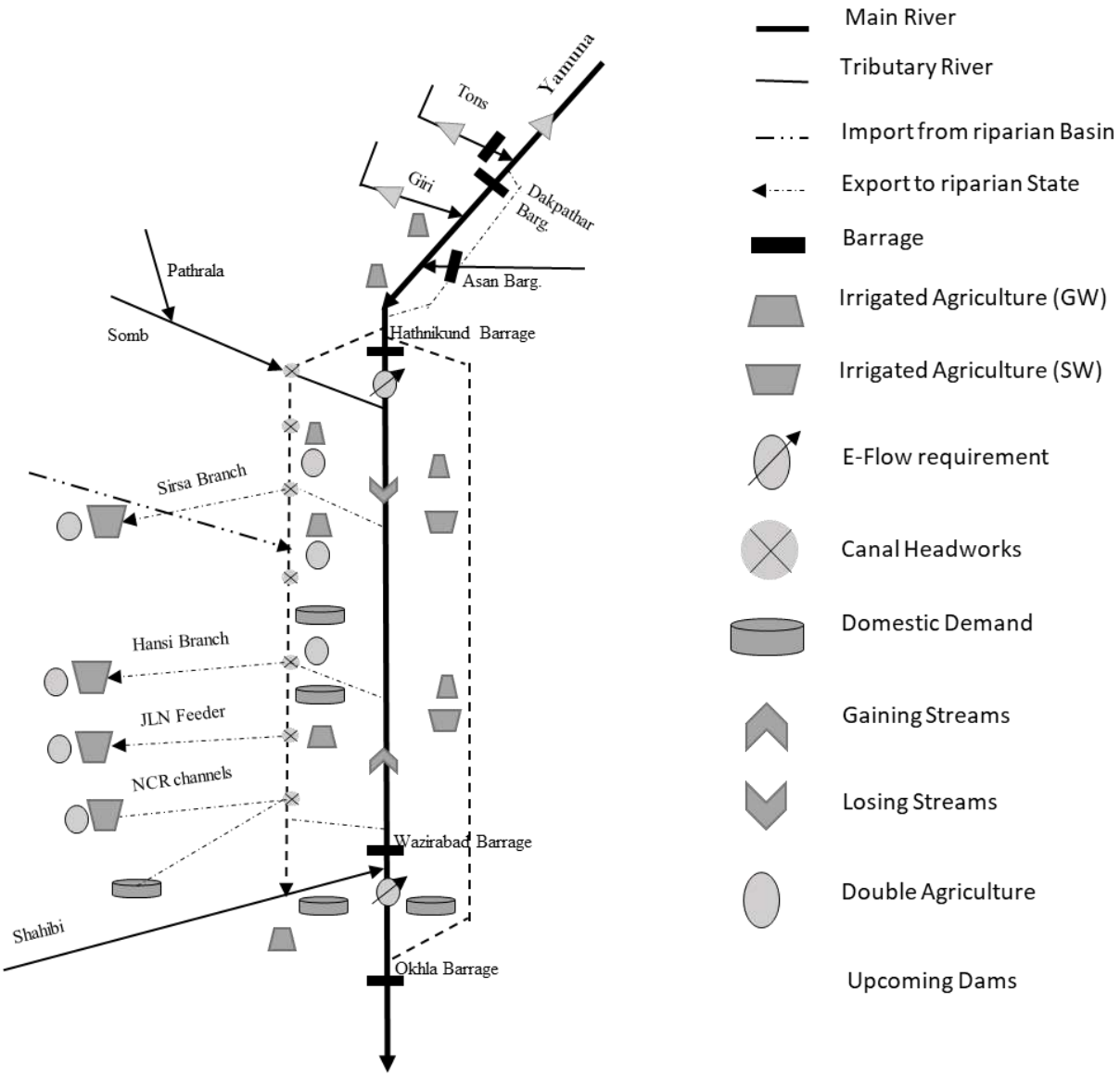


Figure 8-42 : Line diagram showing barrages, powerhouses, headworks and tributaries in Yamuna Basin up to Okhla Barrage

Chapter 11 River Morphology

11.1 Introduction

Various features like active water area, channel area, sandbars, channel centerlines have been digitized in ArcMap software. For this purpose, processed satellite data for 1975-1980, 1990, 2000, 2010 and 2016 has been used. Methodology as explained in Chapter 6 is used for deriving these features. These features are then further used to find out sinuosity, radius of curvature, plan form and braiding indices.

11.2 Sinuosity Index

Sinuosity ratio of 1.5 was considered by Leopold and Wolman to differentiate sinuous from meandering river (Leopold and Wolman, 1960). If the value is higher than 1.5, it is considered as meandering.

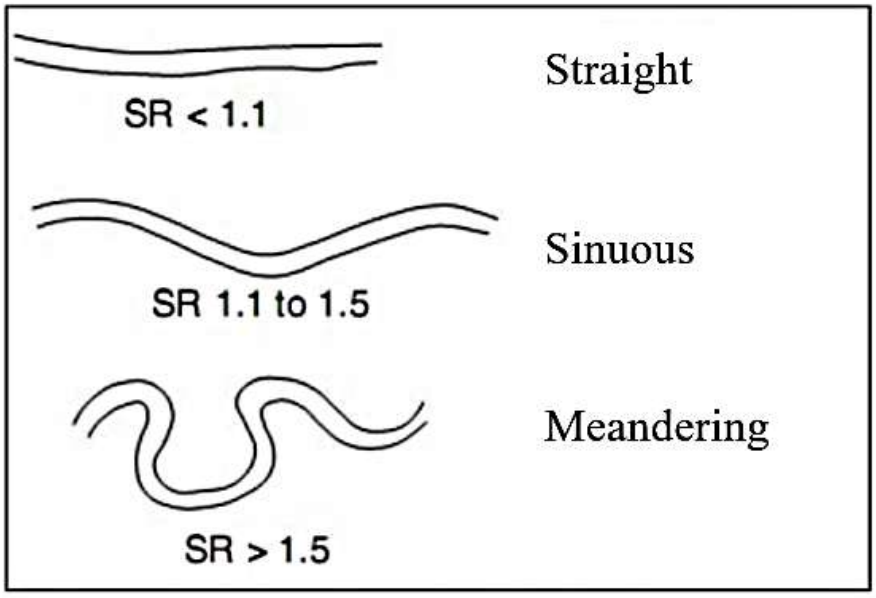


Figure 11-1: Channel Patterns for different Sinuosity Ratio

Sinuosity of Yamuna River is computed grid wise to understand the meandering behaviour of the system. Table 11-2 indicates sinuosity values of the Yamuna River on grid basis.

Table 11-1 : Sinuous and Straight length of reach in grid (km)

The Sinuous length and Straight length are in km										
Grid No.	1975		1990		2000		2010		2016	
	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length
84	4.09	4.08	3.99	3.99	4.00	3.98	4.19	4.16	4.00	3.98
85	36.75	28.71	36.71	28.75	37.34	28.74	37.60	28.76	37.48	28.79
86	27.35	25.52	27.28	25.51	27.50	25.52	27.57	25.52	27.37	25.51
116	36.99	28.55	37.07	28.57	37.08	28.63	37.39	28.51	37.26	28.54
146	7.49	7.03	7.37	6.75	7.64	6.66	7.62	6.52	7.41	6.60
147	31.13	25.81	31.04	25.81	31.25	25.80	31.34	25.82	31.15	25.82
148	29.19	16.33	29.26	16.35	29.59	16.33	29.60	16.30	29.13	16.28
177	5.96	5.26	5.97	5.23	5.99	5.21	5.92	5.05	5.93	5.17
178	51.42	29.11	51.44	29.33	51.82	29.45	51.80	29.50	51.92	29.47
208	8.82	7.38	8.80	7.38	8.98	7.47	8.96	7.40	8.73	7.42
209	37.85	29.64	37.66	29.65	38.09	29.65	38.39	29.83	38.04	29.69
239	22.27	17.81	22.18	22.17	22.55	20.96	22.78	17.90	21.84	17.83
240	42.77	23.45	42.47	20.34	42.71	20.93	43.02	23.42	42.90	23.41
270	21.72	12.51	21.26	12.42	21.66	19.25	21.91	19.27	22.26	19.12
271	35.27	24.00	35.37	24.12	35.46	24.01	35.82	24.16	35.26	24.11
301	10.15	5.57	9.88	5.60	10.15	5.59	10.17	5.66	10.29	5.57

The Sinuous length and Straight length are in km										
Grid No.	1975		1990		2000		2010		2016	
	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length
302	46.86	24.92	46.97	24.97	47.59	22.13	48.61	22.12	46.99	22.12
333	50.14	30.19	50.10	30.08	50.96	30.11	51.17	30.08	51.24	30.15
363	4.15	3.07	4.08	3.10	4.17	3.09	4.22	3.09	4.22	3.08
364	72.01	29.56	70.65	29.53	71.99	29.55	73.78	29.58	71.69	29.56
365	9.82	7.72	9.72	7.80	9.88	7.74	9.97	7.69	9.87	7.73
395	79.10	32.56	79.00	32.55	81.06	32.55	80.62	32.59	80.66	32.52
425	21.61	9.40	20.66	9.49	22.15	9.63	21.60	9.59	21.81	9.52
426	61.67	30.90	60.85	30.88	66.07	31.17	63.58	31.05	65.63	31.11
427	4.31	3.73	4.28	3.75	4.05	3.44	3.97	3.51	3.98	3.46
457	37.86	25.70	36.34	25.70	37.84	25.64	37.58	25.65	37.78	25.67
489	32.66	25.40	34.38	25.44	37.43	25.42	36.08	25.45	38.98	25.42
521	47.67	26.92	46.38	27.06	50.88	27.14	47.66	27.18	51.88	27.14
553	33.46	25.00	32.45	25.02	34.32	25.01	33.33	25.01	33.51	25.01
585	41.18	25.34	31.02	25.21	31.41	25.26	31.39	25.28	30.52	25.37
616	2.20	2.19	2.49	2.47	2.63	2.61	2.48	2.39	2.35	2.33
617	38.78	25.13	32.90	24.46	38.06	24.36	36.24	24.61	38.91	24.92
648	29.28	25.35	27.80	25.26	28.68	25.30	28.33	25.25	27.77	25.29

The Sinuous length and Straight length are in km										
Grid No.	1975		1990		2000		2010		2016	
	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length	Sinuous length	Straight length
680	33.36	25.09	28.56	25.03	29.91	25.08	28.96	25.05	28.50	25.08
712	27.12	25.01	27.52	25.02	29.56	25.05	27.97	25.04	27.33	25.03
744	23.47	25.32	26.04	24.24	26.16	16.93	25.22	15.10	25.13	16.43
745	0.00	0.00	1.71	1.71	3.76	8.82	4.34	10.65	4.66	9.24
777	28.12	25.03	24.50	25.01	26.26	25.22	27.32	25.23	28.27	25.00
809	31.00	27.55	28.94	26.97	29.50	27.17	29.04	27.25	29.22	26.88
841	26.91	25.02	28.93	25.77	31.39	24.55	29.28	24.57	30.27	25.02
842	6.44	6.42	6.15	5.90	6.74	6.12	6.05	5.78	6.46	5.67
874	27.01	26.42	26.26	25.02	28.52	25.39	28.72	25.73	28.50	25.95
875	10.16	10.09	12.17	12.06	12.38	12.03	12.53	12.02	12.14	12.03
907	32.02	25.55	31.36	25.51	32.30	25.58	32.00	25.32	31.85	25.21
908	42.06	25.56	42.39	25.64	43.67	25.65	43.54	25.71	44.48	25.69
909	2.87	2.31	2.61	2.11	2.85	2.08	2.75	2.09	2.85	2.14
941	37.22	30.07	38.13	30.11	39.43	30.10	38.86	30.10	39.08	30.09
973	7.72	6.68	8.08	6.65	8.29	6.66	8.30	6.69	8.56	6.64
974	33.43	30.02	34.58	29.99	0.00	0.00	0.00	0.00	34.74	29.39

As mentioned above, Sinuosity on grid scale in different years is indicated in the table below, where different colour indicates channel pattern in terms of sinuosity.

Straight	**Sinuous**	Meandering

Table 11-2: Sinuosity ratio for each grid

Grid No.	1975	1990	2000	2010	2016
84	1	1	1	1.01	1
85	1.28	1.28	1.3	1.31	1.3
86	1.07	1.07	1.08	1.08	1.07
116	1.3	1.3	1.3	1.31	1.31
146	1.06	1.09	1.15	1.17	1.12
147	1.21	1.2	1.21	1.21	1.21
148	1.79	1.79	1.81	1.82	1.79
177	1.13	1.14	1.15	1.17	1.15
178	1.77	1.75	1.76	1.76	1.76
208	1.19	1.19	1.2	1.21	1.18
209	1.28	1.27	1.28	1.29	1.28
239	1.25	1	1.08	1.27	1.22
240	1.82	2.09	2.04	1.84	1.83
270	1.74	1.71	1.13	1.14	1.16
271	1.47	1.47	1.48	1.48	1.46
301	1.82	1.76	1.81	1.8	1.85
302	1.88	1.88	2.15	2.2	2.12
333	1.66	1.67	1.69	1.7	1.7
363	1.35	1.32	1.35	1.37	1.37
364	2.44	2.39	2.44	2.49	2.43
365	1.27	1.25	1.28	1.3	1.28
395	2.43	2.43	2.49	2.47	2.48
425	2.3	2.18	2.3	2.25	2.29
426	2	1.97	2.12	2.05	2.11
427	1.15	1.14	1.18	1.13	1.15
457	1.47	1.41	1.48	1.47	1.47
489	1.29	1.35	1.47	1.42	1.53
521	1.77	1.71	1.87	1.75	1.91
553	1.34	1.3	1.37	1.33	1.34
585	1.62	1.23	1.24	1.24	1.2
616	1.01	1	1.01	1.04	1.01
617	1.54	1.35	1.56	1.47	1.56
648	1.15	1.1	1.13	1.12	1.1
680	1.33	1.14	1.19	1.16	1.14
712	1.08	1.1	1.18	1.12	1.09
744	0.93	1.07	1.55	1.67	1.53

Grid No.	1975	1990	2000	2010	2016
745	0	1	0.43	0.41	0.5
777	1.12	0.98	1.04	1.08	1.13
809	1.12	1.07	1.09	1.07	1.09
841	1.08	1.12	1.28	1.19	1.21
842	1	1.04	1.1	1.05	1.14
874	1.02	1.05	1.12	1.12	1.1
875	1.01	1.01	1.03	1.04	1.01
907	1.25	1.23	1.26	1.26	1.26
908	1.65	1.65	1.7	1.69	1.73
909	1.24	1.24	1.37	1.32	1.33
941	1.24	1.27	1.31	1.29	1.3
973	1.16	1.22	1.25	1.24	1.29
974	1.11	1.15	0	0	1.18

Following conclusions may be drawn from calculated values of sinuosity ratio of Yamuna River

1. In the whole reach of the river under considered grids, for the years 1975, 1990, 2000, 2010 and 2016, the maximum and average sinuosity ratio values are 2.49 and 1.38 respectively.
2. Sinuosity ratios for the grids 148, 178, 301, 302, 333, 364, 395, 425, 426 and 908 are relatively higher than other grids. As the average value is around 1.38, Yamuna may be considered as the sinuous river as per Leopold and Wolman (1957) except for the grids which can be considered as meander river.
3. No significant change is observed in Sinuosity ratio for the period from 1975 up to 2016.

11.3 Radius of Curvature

To determine geometrical parameters associated with Sinuosity, the radius of curvature for the different years has been worked out. The following table indicates the average radius of curvature calculated for each grid.

Table 11-3 : Grid Wise Average Radius of curvature for 1975, 1990, 2000, 2010 and 2016

Grid number	1975	1990	2000	2010	2016
974	1.22	0.32	0.77	1.49	1.49
973	0.50	0.48	1.29	1.46	1.46
941	0.73	0.42	0.48	0.25	0.25

Grid number	1975	1990	2000	2010	2016
909	1.87	0.63	0.42	0.72	0.72
908	1.29	0.63	0.36	0.39	0.39
907	6.85	4.74	1.24	1.47	1.47
875	10.49	7.97	3.75	1.53	1.53
874	28.00	5.27	1.38	0.76	0.76
842	9.07	9.66	2.42	0.77	0.77
841	3.86	2.63	1.80	0.86	0.86
809	2.82	5.58	2.74	0.56	0.56
777	3.51	5.96	7.30	1.56	1.56
776	3.92	0.90	1.20	0.42	0.42
745	2.91	7.22	4.28	1.88	1.88
744	12.02	7.97	5.72	0.86	0.86
712	2.82	1.41	9.05	1.35	1.35
680	2.32	4.59	1.91	0.98	0.98
648	1.64	3.60	1.00	2.58	2.58
617	1.25	2.40	0.34	0.35	0.35
616	2.51	2.97	1.48	0.29	0.29
585	1.24	2.05	1.05	0.55	0.55
553	1.38	2.38	3.81	0.31	0.31
521	1.46	2.04	2.30	1.58	1.58
489	1.43	2.95	0.80	0.44	0.44

Grid number	1975	1990	2000	2010	2016
457	1.99	2.26	2.23	1.08	1.08
427	2.65	5.16	1.46	0.54	0.54
426	2.54	4.17	0.76	1.26	1.26
425	1.20	3.01	1.95	1.80	1.80
395	1.77	2.08	1.95	3.00	3.00
365	2.74	5.46	5.45	0.99	0.99
364	1.59	1.45	0.80	1.11	1.11
363	1.59	1.42	0.61	5.15	5.15
333	1.60	2.23	0.91	1.05	1.05
302	2.24	2.71	4.53	1.20	1.20
301	4.24	0.54	1.27	0.81	0.81
271	4.65	6.03	8.89	3.41	3.41
270	3.69	3.51	4.81	2.75	2.75
240	3.23	6.05	4.06	2.96	2.96
239	10.10	9.83	4.21	5.16	5.16
209	4.64	7.20	3.10	11.39	11.39
208	3.90	1.10	33.37	1.85	1.85
178	8.03	6.72	4.09	3.12	3.12
177	11.14	3.28	2.04	1.52	1.52
148	1.23	1.05	3.83	4.36	4.36
147	8.21	10.88	11.03	3.37	3.37

Grid number	1975	1990	2000	2010	2016
146	1.21	1.25	12.09	2.04	2.04
116	11.56	23.53	3.89	9.28	9.28
87	3.90	4.45	11.16	1.20	1.20
86	13.01	4.99	4.61	2.12	2.12
85	3.66	5.93	39.32	2.57	2.57
84	15.98	15.50	4.79	1.20	1.20

The above table indicate that average radius of curvature (grid wise) varies from 0.25 to 39.32 km. It is important to note that higher value of radius of curvature estimated for few segments, is an indication of comparatively straight channel and the associated segment cannot be considered as meandering segment. Analysis of average radius of curvature suggests that, no significant trend is observed over past 50 years (1975 to 2016).

11.4 Braiding Index

In the present study, braiding index as suggested by Friend and Sinha (1993); L_{ctot} / L_{cmax}, has been adopted. Here, L_{ctot} is the sum of the mid-channel lengths of all the segments of primary channels in a reach, and L_{cmax} is the mid-channel length of the widest channel through the reach.

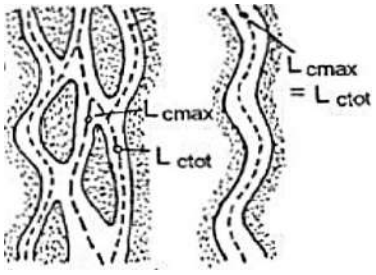


Figure 11-2: Braiding Index suggested by Friend and Sinha (1993)

Gird wise length of total channel and length of wider channel based on digitized data of different years is indicated in Table 11-4, and decadal variation of Braiding Index is shown in Table 11-5.

Table 11-4 : Gird Wise total length and length of wider channel (in km)

Grid No	1975		1990		2000		2010		2016	
	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}
84	4.52	4.52	7.24	4.15	4.31	4.31	4.12	4.12	4.21	4.21
85	40.37	40.37	41.44	39.8	43.22	40.51	42.47	40.45	41.41	41.41
86	33.77	28.66	36.99	28.12	37.38	27.57	41.04	28.23	28.02	28.02
87	27.67	25.35	26.15	26.15	26.21	26.21	29.18	24.37	28.25	24.5
116	39.12	39.12	38.65	38.65	41.27	38.44	39.62	39.62	39.53	39.53
146	8.38	8.38	8.64	8.64	9.08	9.08	9.37	9.37	7.86	7.86
147	33.1	33.1	32.75	32.75	32.92	32.92	33.07	33.07	34.57	34.57
148	32.17	32.17	32.22	32.22	31.67	31.67	32.45	32.45	36.11	32.32
177	6.42	6.42	6.39	6.39	6.38	6.38	6.3	6.3	6.43	6.43
178	55.77	55.77	60.46	56.12	54.58	54.58	64.92	54.85	56.56	56.56
208	9.56	9.56	11.55	9.49	9.62	9.3	13.73	9.26	13.59	9.65
209	40.38	40.38	45.97	41.24	45.96	40.85	45.63	40.52	46.9	41.62
239	24.96	24.96	24.48	23.75	25.38	25.38	25.7	22.7	27.49	25.17
240	47.83	45.12	45.69	45.69	44.22	44.22	53.84	45.44	48.77	44.73
270	23.35	23.35	23.23	23.23	23.46	23.46	27.02	23.15	22.91	22.91
271	42.65	37.5	49.42	38.17	42.58	37.22	44.18	37.29	42.72	37.59
301	11.24	11.24	10.95	10.95	11.12	11.12	12.22	10.38	11.68	11.19
302	51.88	49.55	50.6	50.6	50.97	48.73	53.1	48.73	51.68	49.98
333	57.78	54.1	57.12	55.8	56.72	54.54	55.34	52.73	58.2	54.12
363	4.41	4.41	4.35	4.35	4.41	4.41	4.34	4.34	4.36	4.36
364	78.44	77.26	78.81	76.75	76.88	75.78	76.97	73.63	76.39	76.39
365	11.22	10.35	10.67	10.67	10.35	10.35	10.05	10.05	11.7	10.31
395	83.67	83.67	89.15	84.13	92.16	83.53	88.13	81.66	91.54	83.45
425	25.74	22.71	22.71	22.71	22.62	22.62	23.18	22.64	22.79	22.79
426	70.32	66.13	76.85	68.52	73.4	68.35	77.72	67	71.08	68.53
427	5.12	5.12	5.94	4.23	6.14	4.1	3.96	3.96	4.39	4.39

Grid No	1975		1990		2000		2010		2016	
	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}	L_{ctot}	L_{cmax}
457	44.18	39.91	48.76	39.53	43.57	38.21	45.22	37.79	49.22	38.61
489	38.57	34.84	46.96	39.56	38.7	38.7	43.9	39.64	48.06	40.89
521	55.45	49.85	63.68	49.51	55.9	52.22	62.18	54.42	57.8	55.35
553	35.62	35.62	41.55	38.35	39.93	36.3	38.46	34.88	36.47	34.9
585	43.72	43.72	34.65	34.65	37	32.83	42.07	31.48	40.37	31.98
616	2.56	2.56	2.97	2.97	3.09	3.09	2.72	2.72	2.43	2.43
617	43.96	43.96	39.68	38.63	43.7	40.25	46.73	40.13	40.23	39.31
648	38	30.47	29.14	29.14	30.2	28.89	33.63	29	30.88	29.09
680	41.54	39.03	37	33.15	35.09	31.29	36	32.05	35.45	32.52
712	36.27	30.57	36.31	32.5	40.79	33.13	35.83	30.97	36.88	29.72
744	39.57	29.15	31.45	31.45	35.72	28.07	31.02	28.06	29.65	26.4
745	7.67	5	4.36	2.62	5.66	5.66	6.4	6.4	6.71	6.69
777	33.18	33.18	30.82	29.86	45.44	28.77	36.79	30.47	35.67	31.26
809	46.57	38.8	46.17	34.37	44.96	33.92	36.72	33.57	39.9	33.11
841	34.56	31.53	38.36	34.75	42.11	35.46	40.26	37.38	39.09	34.33
842	8.24	8.24	7.92	6.59	9.39	7.55	7.83	6.87	9.23	7.29
874	56.59	29.61	42.43	30.59	42.2	31.63	47.12	33.72	50.68	31.82
875	22.62	12.28	19.92	12.9	24.92	13.85	22.94	12.92	14.88	13.45
907	38.08	35.03	48.79	36	33.8	33.8	34.36	34.36	34.98	34.98
908	47.46	44.72	49.08	44.96	50.57	45.1	45.19	45.19	46.26	46.26
909	2.92	2.92	2.67	2.67	2.72	2.72	2.58	2.58	2.7	2.7
941	37.4	37.4	39.27	39.27	38.88	38.88	39.23	39.23	39.21	39.21
973	7.95	7.95	8.37	8.37	8.25	8.25	8.45	8.45	8.64	8.64
974	31.9	31.9	34.94	34.94	34.57	34.57	34.48	34.48	34.76	34.76

Table 11-5 : Braiding Index

Grid No	1975	1990	2000	2010	2016
84	1	1.74	1	1	1
85	1	1.04	1.07	1.05	1
86	1.18	1.32	1.36	1.45	1
87	1.09	1	1	1.2	1.15
116	1	1	1.07	1	1
146	1	1	1	1	1
147	1	1	1	1	1
148	1	1	1	1	1.12
177	1	1	1	1	1
178	1	1.08	1	1.18	1
208	1	1.22	1.03	1.48	1.41
209	1	1.11	1.13	1.13	1.13
239	1	1.03	1	1.13	1.09
240	1.06	1	1	1.18	1.09
270	1	1	1	1.17	1
271	1.14	1.29	1.14	1.18	1.14
301	1	1	1	1.18	1.04
302	1.05	1	1.05	1.09	1.03
333	1.07	1.02	1.04	1.05	1.08
363	1	1	1	1	1
364	1.02	1.03	1.01	1.05	1
365	1.08	1	1	1	1.13
395	1	1.06	1.1	1.08	1.1
425	1.13	1	1	1.02	1
426	1.06	1.12	1.07	1.16	1.04
427	1	1.4	1.5	1	1
457	1.11	1.23	1.14	1.2	1.27

Grid No	1975	1990	2000	2010	2016
489	1.11	1.19	1	1.11	1.18
521	1.11	1.29	1.07	1.14	1.04
553	1	1.08	1.1	1.1	1.04
585	1	1	1.13	1.34	1.26
616	1	1	1	1	1
617	1	1.03	1.09	1.16	1.02
648	1.25	1	1.05	1.16	1.06
680	1.06	1.12	1.12	1.12	1.09
712	1.19	1.12	1.23	1.16	1.24
744	1.36	1	1.27	1.11	1.12
745	1.53	1.66	1	1	1
777	1	1.03	1.58	1.21	1.14
809	1.2	1.34	1.33	1.09	1.21
841	1.1	1.1	1.19	1.08	1.14
842	1	1.2	1.24	1.14	1.27
874	1.91	1.39	1.33	1.4	1.59
875	1.84	1.54	1.8	1.78	1.11
907	1.09	1.36	1	1	1
908	1.06	1.09	1.12	1	1
909	1	1	1	1	1
941	1	1	1	1	1
973	1	1	1	1	1
974	1	1	1	1	1

Braiding index usually varies in the range of 1 to 1.7 for most of the years. However, it is important to note that, braiding is observed in only selected reaches of the Yamuna River. Downstream of Tajewala (Hatnikund) braiding is significantly high. Other locations that suggest high braiding index are near Mawi. In order to understand associated plan form in detailed manner, planform index is computed and discussed in the Section 11.5.

11.5 Plan Form Index (PFI)

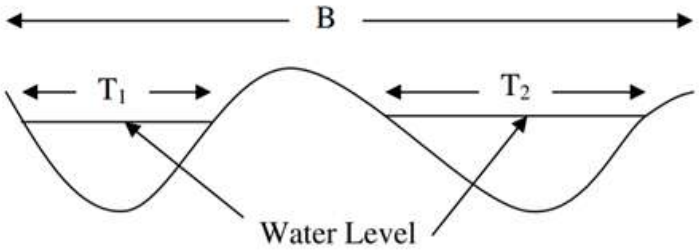
PFI of Yamuna River is calculated using approach given by Sharma (1995). The following equation has been used to find out plan form index.

$$Plan\ Form\ Index = \frac{\frac{T}{B} * 100}{N}$$

where, T = T1+T2 = Flow top width

B = Overall flow width

N = Number of braided channels



The total reach of the river is subdivided into 1 km long segments and the bed width, river width and the number of channels is computed. At each chainage, PFI (%) is calculated for the years 1975, 1990, 2000, 2010 and 2016. Calculated values are shown in the Table 11-6 and the graphical representations are shown in the Figure 11-3 to 11-31.

The Chainage is measured from the origin to the outfall where Yamuna forms a confluence with Ganga, i.e. from Yamunotri to Prayagraj. For better understanding of the geographical location of braiding patterns, along the flow path from origin point to the confluence point, various villages are depicted in the remarks section along with their corresponding chainages.

Table 11-6: Plan Form Index (in %)

Highly Braided	Moderately Braided	Less Braided
PFI < 4	4< PFI < 19	PFI > 19

Chainage	1975	1990	2000	2010	2016	Remarks
0	58.1006	88.3198	35.65432	100	100	Yamunotri
1	100	84.2485	58.03413	100	100	
2	44.5135	78.1829	63.55336	100	100	
3	75.2395	93.3781	82.30653	100	100	

Chainage	1975	1990	2000	2010	2016	Remarks
4	100	90.7595	75.34135	100	100	
5	100	86.4639	58.92875	100	100	
6	71.6557	100	79.20938	100	100	
7	41.9757	93.0126	100	100	100	
8	46.7748	83.8852	100	100	100	
9	71.2984	88.7263	85.36984	100	100	
10	71.2984	92.3937	100	100	100	
11	100	86.9723	100	100	100	
12	78.0762	84.9066	68.99742	100	100	
13	36.645	85.4873	67.12887	100	100	
14	89.1047	89.1249	100	100	100	
15	100	85.9037	100	100	100	
16	100	85.6873	81.77613	100	100	
17	53.823	83.8948	100	100	100	
18	35.1205	83.6375	100	100	100	
19	39.111	82.634	100	100	100	
20	38.69785	72.3749	56.77048	100	100	
21	50	44.05195	100	39.8286	100	Kupra
22	32.32105	79.1878	58.02722	100	100	
23	55.3545	82.2167	100	100	100	
24	82.3485	91.3418	48.49015	100	100	
25	100	70.7763	45.37443	100	100	
26	25	30.0919	58.35315	23.909	100	
27	100	39.3923	60.09037	22.7756	100	
28	100	79.5292	28.8791	39.9863	100	
29	75.567	80.2617	92.28354	100	43.6628	
30	72.234	28.4987	69.63732	50	58.2083	
31	68.459	29.1206	100	41.7429	100	

Chainage	1975	1990	2000	2010	2016	Remarks
32	63.5235	72.1542	60.96806	59.4622	25.7793	
33	52.2615	84.8006	100	17.6666	16.0237	
34	42.8196	87.6264	100	25.4478	100	
35	100	58.4311	100	13.1687	15.92465	
36	100	91.3622	100	20.97	26.9235	
37	50	82.8301	91.68216	37.4638	48.1348	Chakrgaon
38	19.0479	87.2897	100	100	62.1164	
39	13.55915	92.9196	61.98575	35.4507	38.7171	
40	17.4787	94.7931	20.219	32.5282	100	
41	14.1352	86.8692	94.80621	19.4558	16.6062	
42	7.9543	10.0921	100	26.0619	100	
43	5.084075	47.3091	81.79489	100	77.1195	
44	15.56795	39.7032	78.03075	100	100	
45	43.0451	89.9944	39.06553	45.8235	50	
46	48.2342	91.4671	100	100	100	
47	59.1322	86.5476	81.48938	100	100	
48	53.5633	74.1483	100	71.5525	100	Naugaon
49	74.4249	79.0545	100	100	100	
50	100	30.0332	66.6168	100	100	
51	97.6727	76.7408	80.30182	51.2963	100	
52	53.2902	78.6091	100	17.72755	100	
53	38.4436	91.1816	94.8474	100	15.5211	
54	39.9045	76.0154	100	26.211	100	
55	36.6158	81.8105	100	68.4684	100	
56	61.8168	86.0054	100	100	100	
57	17.8153	86.1154	63.11228	100	100	
58	41.035	85.0664	100	39.9535	73.5939	
59	16.8229	85.9904	100	100	100	

Chainage	1975	1990	2000	2010	2016	Remarks
60	16.6405	86.0053	100	34.7635	100	
61	30.505	89.1249	100	100	100	
62	34.7394	85.9037	100	100	100	
63	48.9082	85.6873	100	32.6463	100	
64	48.8394	83.8948	48.43786	100	100	
65	35.4304	83.6375	90.64387	100	100	Kaslana
66	46.1436	82.634	37.30174	100	100	
67	23.3344	72.3749	70.77756	60.0143	100	
68	68.2396	44.05195	100	100	100	
69	77.7096	79.1878	88.36612	33.3249	100	
70	55.8791	82.2167	27.52049	100	100	
71	62.4208	91.3418	100	60.2708	100	
72	43.8962	70.7763	33.59193	100	100	
73	54.3977	30.0919	89.81139	29.5376	100	
74	59.7493	39.3923	28.98428	41.2999	100	
75	65.5041	94.1858	100	24.09	100	
76	55.207	82.2977	20.82224	60.8005	100	Matla
77	39.2768	22.5554	100	100	100	
78	38.9076	87.6338	56.9754	60.0896	100	
79	65.3619	83.032	9.428987	100	100	
80	66.3803	71.6585	71.83216	42.121	100	
81	23.6126	85.3643	62.72489	100	100	
82	16.70285	84.0681	61.29258	69.2142	100	
83	71.7266	84.538	100	100	100	Marora
84	76.2471	88.3563	28.07335	100	40.3359	
85	41.1668	65.4416	39.57736	17.3236	100	
86	58.6764	81.8684	83.23872	100	100	
87	87.788	74.1165	73.80125	34.8496	29.8282	

Chainage	1975	1990	2000	2010	2016	Remarks
88	56.5182	89.2374	10.15341	41.0709	33.7334	
89	29.8967	50.8925	30.06812	100	44.7457	
90	10.4945	87.9746	100	17.7144	100	
91	20.2175	89.9791	30.24079	78.6913	20.4524	
92	43.84515	51.1444	100	37.7228	60.6978	
93	24.29725	85.4532	93.83113	35.8364	61.8529	
94	100	32.0739	35.58796	70.4966	61.7261	
95	77.1893	72.1149	60.28066	100	66.0949	
96	71.5538	43.4686	43.5471	57.9179	36.0765	
97	97.9261	41.8808	10.96739	34.9325	39.1455	
98	60.6907	37.1468	100	100	100	
99	47.3803	84.1069	21.80558	100	29.6707	
100	43.9542	22.3957	18.16018	20.5275	22.447	
101	32.4784	79.5704	6.223052	100	100	
102	28.219	97.2079	40.87427	100	100	
103	46.575	74.2021	4.883954	46.011	100	
104	44.4845	90.6636	8.966497	60.8106	100	
105	100	77.9701	40.5854	100	100	
106	96.1492	82.4777	6.260371	100	100	
107	64.3163	14.3018	7.57822	100	100	
108	40.5814	76.839	6.033444	100	100	
109	44.0781	90.0058	3.969549	100	100	
110	32.0894	17.9723	13.60628	100	100	
111	21.3611	90.784	7.51703	100	30.9746	
112	18.08395	74.4158	10.67813	9.07825	61.0421	
113	27.6503	82.9491	12.71713	100	12.97895	
114	17.99425	78.3948	66.57151	34.79155	30.7873	
115	13.7413	77.5063	43.00879	9.08975	38.5942	

Chainage	1975	1990	2000	2010	2016	Remarks
116	10.0813	35.3619	27.04714	14.3169	26.8179	
117	11.8395	45.1934	99.60031	5.27975	5.055367	
118	17.1534	63.8331	100	11.9161	16.6588	
119	12.8643	13.5261	6.596327	29.3056	50	
120	14.6912	26.2286	3.313004	100	71.932	Dakpathar
121	31.1236	29.3813	4.352184	50	41.9819	
122	56.0291	10.8538	18.73266	56.5604	31.3009	
123	42.4411	10.3745	12.19224	59.497	27.35935	
124	55.4085	6.47998	8.133594	30.1147	10.19595	
125	43.8428	33.30567	8.248188	11.0003	5.5776	
126	25.6776	21.6754	17.72522	74.5812	57.4604	
127	37.7039	26.2265	29.04405	9.01738	17.86853	
128	53.5108	42.48015	22.02373	14.5091	15.35815	
129	32.2599	29.66013	8.018946	20.5325	1.35031	
130	54.0435	30.73287	9.430871	3.60864	19.6652	
131	63.2186	36.67275	5.771467	8.38139	36.0817	
132	59.785	43.9007	9.084129	9.0436	10.3111	
133	53.6697	32.8733	9.053133	12.6526	3.451933	
134	54.1851	7.90765	2.853888	13.7795	11.5323	
135	33.2533	39.17045	10.86907	17.2582	14.0618	Barotiwala
136	52.2808	21.43015	20.6033	28.204	27.7034	
137	55.7929	9.06485	3.025277	16.4268	4.49394	
138	49.9773	17.8722	18.71631	6.22103	22.692	
139	61.4445	40.259	9.766847	9.37136	15.6568	
140	81.8158	8.88795	21.40241	23.249	9.3876	
141	34.5584	4.46211	10.06794	13.278	30.8749	
142	17.62445	4.34088	64.49399	6.4699	10.7199	
143	34.4581	8.32633	9.269483	14.622	7.11531	

Chainage	1975	1990	2000	2010	2016	Remarks
144	36.0255	27.5433	9.611395	3.175575	18.1122	Poanta Sahib
145	60.8509	33.7669	100	26.0656	18.5219	
146	76.028	8.23984	8.999578	15.3357	5.75175	
147	64.1385	19.5177	11.07728	20.9535	17.3451	
148	34.2673	8.41876	5.451316	23.6675	75.7671	
149	28.6327	28.483	3.792814	21.7453	19.74558	
150	31.8336	32.984	3.959047	24.08565	18.2026	
151	22.0345	28.8467	4.549815	85.6771	8.6972	
152	7.442967	46.4143	3.045502	100	12.792	
153	30.1002	22.9888	5.483382	21.8161	15.7554	
154	72.811	16.02725	9.057502	11.1129	21.7623	
155	74.3689	50	5.976391	17.442	100	
156	48.8263	26.48615	7.412608	22.5281	2.66303	
157	39.1651	15.07925	3.625804	76.0208	7.48122	
158	12.9875	23.41925	5.589	85.6708	8.41574	
159	17.38345	34.42975	4.340653	58.5844	5.34212	
160	49.8172	17.80723	5.968855	23.6533	7.04748	
161	29.1509	30.8879	4.911828	13.7814	36.9431	
162	31.5721	34.2888	8.006897	10.4862	14.7297	
163	50.1357	22.3276	14.8889	21.8336	4.518795	Hathnikud
164	58.4689	43.9845	5.916485	2.77522	9.44384	
165	45.6501	45.9139	17.59875	5.21036	3.77186	
166	44.4102	42.0966	12.80774	3.84263	3.86448	
167	56.6239	15.4564	21.56744	3.67133	5.11756	
168	54.0749	4.36357	24.01777	2.84168	5.90748	
169	80.8421	4.91016	100	2.1136	2.501385	
170	82.6494	4.14928	96.04029	2.1026	14.7173	
171	32.2929	3.83353	17.38192	2.24457	50.0417	

Chainage	1975	1990	2000	2010	2016	Remarks
172	26.5529	2.87155	20.32122	2.46191	24.0944	
173	71.0574	2.29727	6.681086	3.03455	19.8584	Balgarh
174	100	1.92174	5.113788	3.11378	11.12445	
175	100	2.10647	58.20563	3.41442	43.40095	
176	100	2.68105	12.63905	3.5613	30.0438	
177	100	1.69316	10.02743	24.05585	33.33333	
178	100	1.93244	8.447842	22.1317	22.10775	
179	48.7611	2.42128	18.60571	10.4554	9.81135	
180	28.486	3.33156	16.71986	4.43862	61.0645	
181	56.3962	3.9044	24.96372	1.52583	50	
182	100	10.7269	33.34308	5.59794	30.43815	
183	59.4611	19.1673	21.42128	8.3814	47.77685	
184	5.7783	8.03165	22.56562	7.10011	5.84305	Malimazra
185	53.7834	2.77617	8.693151	12.0516	20.4091	
186	12.5309	1.78344	7.137072	100	51.6568	
187	21.7881	8.11675	8.269011	50	5.60775	
188	24.8646	2.71599	18.32276	9.9234	9.3513	
189	36.0404	7.10766	15.87251	11.7727	10.8926	
190	17.4942	12.1327	16.42623	4.49654	22.9538	
191	16.4269	8.50238	10.01292	8.77437	16.4367	
192	16.573	10.96	28.11311	2.46482	39.0653	
193	22.0187	5.33902	60.5281	10.2602	71.6561	
194	29.0348	12.5681	22.15018	8.3133	16.4882	
195	72.7579	22.59995	11.27642	100	100	
196	64.2976	12.1157	14.82823	4.937167	29.43907	
197	71.8664	6.7105	17.38213	20.4323	15.51015	
198	33.5317	10.20515	21.75797	5.33871	9.052367	
199	21.4103	16.268	11.98509	5.10061	16.41697	

Chainage	1975	1990	2000	2010	2016	Remarks
200	13.4148	24.76815	13.65825	14.0025	10.5937	
201	23.459	49.7224	9.075131	9.38021	82.5206	
202	58.7762	39.7828	13.15246	7.20312	10.44535	
203	55.0499	29.05875	5.943944	7.86987	23.9342	
204	39.0561	33.15275	21.48936	9.73303	9.00619	
205	22.4805	5.2375	78.95874	41.0689	70.3826	
206	56.7828	6.73357	36.88356	3.50787	3.431933	
207	70.4411	12.7826	71.08263	18.8107	23.9624	
208	59.5847	6.00285	10.74216	8.93661	24.7054	
209	57.7334	7.9415	20.29585	18.3979	11.9214	
210	49.465	12.3338	14.33736	3.518	27.1216	
211	42.7689	17.1446	19.33046	31.8225	5.69773	
212	19.9154	15.0335	15.72785	37.7887	26.2834	Unheri
213	31.3817	6.43076	3.669147	17.1833	12.5508	
214	44.1405	11.2732	41.37832	2.68198	33.3998	
215	41.6564	7.22774	17.19413	3.91937	32.7592	
216	46.5955	4.69777	10.49744	13.6209	39.4307	
217	51.3858	9.34458	8.609071	18.9156	7.6537	
218	35.1303	11.1701	12.73728	21.5294	34.1549	
219	24.6243	14.4248	19.18853	30.5227	67.1214	
220	29.2838	37.012	17.46415	17.1693	27.4452	
221	30.7376	13.7638	11.05555	5.68596	17.8201	
222	65.9001	12.8272	21.89037	3.06032	34.177	Sandhala
223	51.1275	0.419198	9.376803	2.05219	23.3263	
224	74.9415	8.34129	9.57081	16.3605	16.4869	
225	50.3593	15.08335	8.623627	22.1156	21.485	
226	51.9483	19.02515	59.72915	7.90167	15.5736	
227	52.5588	20.581	52.7392	2.75999	54.7086	

Chainage	1975	1990	2000	2010	2016	Remarks
228	44.266	11.4267	62.19905	8.27308	35.15965	
229	17.8169	12.3298	11.60237	2.89311	11.20047	
230	28.6102	14.9531	40.88916	6.10609	42.2805	
231	63.5606	15.2403	42.48788	10.9023	30.4522	
232	53.2861	16.9945	14.778	4.10865	17.7625	Halwana
233	25.174	18.3681	8.580501	11.791	4.29477	
234	12.5191	33.26975	24.76767	19.0709	2.398725	
235	10.6438	42.94995	30.25529	10.6345	34.9906	
236	31.317	27.6902	11.33692	8.46545	18.21767	
237	19.22735	34.8147	8.136732	17.8807	100	
238	76.6424	28.4021	11.48152	10.0922	11.61365	
239	100	11.7705	22.85473	11.8136	20.31	
240	100	7.69541	83.66944	4.823395	100	
241	100	21.5887	28.64067	19.7388	7.013733	
242	100	16.7917	9.176923	18.4634	14.338	Nabiabad
243	7.10375	23.5469	23.89231	4.72536	30.8531	
244	13.93655	17.9901	72.24848	26.7181	18.3999	
245	20.6814	17.88225	7.180026	8.98181	12.7061	Nabiabad
246	9.0538	23.64327	8.636827	7.86335	12.3808	
247	13.9331	25.88257	12.01625	12.4843	39.0675	
248	17.6022	14.32103	26.04605	15.0062	10.0483	
249	17.079	22.83395	18.67544	21.0784	12.4753	
250	42.397	20.67383	5.171204	16.535	41.7928	
251	58.8147	11.0029	18.12609	4.02514	21.1043	
252	65.8682	5.45209	16.32198	6.21379	19.66925	
253	42.1153	4.28204	12.19658	27.9661	17.41905	
254	15.6134	4.758115	20.27141	5.76574	22.0704	
255	33.1272	6.93385	60.52267	10.8022	12.3284	

Chainage	1975	1990	2000	2010	2016	Remarks
256	52.1151	5.69916	1.616455	8.4957	10.734	
257	52.8186	7.14038	6.875325	3.582	9.32756	
258	37.3299	11.78775	46.86151	3.97371	11.2499	
259	28.2252	27.1273	98.0598	9.68662	6.66911	
260	28.1967	25.9493	50	20.22355	27.1587	
261	26.339	7.63015	100	6.163	10.8731	
262	78.9116	18.1265	100	16.9753	8.18689	
263	49.7404	6.36525	20.62339	12.5067	8.79939	
264	57.8492	5.49294	7.647572	52.5791	15.5908	
265	85.2777	3.30096	23.00557	21.8658	16.5144	
266	57.5643	13.4307	24.88725	7.02821	21.0283	
267	72.3904	17.1615	11.76275	5.23575	23.1494	
268	40.9656	21.3643	63.66902	6.1565	15.6212	
269	100	11.2691	8.478614	8.04506	18.1413	Mustafabd
270	45.463	8.75907	71.89426	4.69578	10.0584	
271	18.9499	20.6929	55.57883	9.2902	6.79879	
272	47.6809	7.9243	6.676484	63.6206	19.184	
273	59.534	5.19	7.649514	8.86261	22.6622	
274	11.0897	11.2801	7.2394	3.55047	7.30704	
275	55.8332	2.64902	25.10087	13.1181	9.05918	
276	15.04205	21.345	43.63189	3.87939	9.25886	
277	65.4438	25.789	4.668274	2.41234	25.1467	
278	55.53	20.4367	6.249914	18.4011	28.1788	
279	32.6626	19.4564	10.0102	7.1211	38.993	
280	45.6353	9.325	16.32584	21.1575	10.1662	
281	29.8431	9.345	10.98836	19.3891	12.0858	
282	55.8458	6.3456	20.82085	16.906	14.6796	
283	43.7129	5.5676	13.58754	16.102	53.2166	

Chainage	1975	1990	2000	2010	2016	Remarks
284	28.6944	6.3456	13.10127	23.475	50	
285	62.7503	6.5777	9.909075	30.7856	15.0936	
286	18.54665	7.46777	13.95958	50	7.94468	
287	31.2127	11.23466	36.7244	49.3962	47.9356	
288	22.884	14.45678	5.325128	14.6667	8.41217	
289	18.4201	23.3456	60.46785	9.60991	52.4074	
290	30.7638	9.3456	100	22.835	12.08375	
291	50	16.3456	65.68489	14.8765	31.7742	Devipur
292	50	8.57788	32.16137	3.38532	18.2344	
293	50	7.45677	32.01607	10.7323	16.2057	
294	50	5.67878	13.40174	6.36031	30.7016	
295	50	17.4567	24.69793	23.3794	5.95035	
296	50	21.5446	96.64088	9.44829	31.2367	
297	100	27.3456	100	26.4444	3.633667	
298	68.5046	15.345	40.84089	11.388	14.5969	
299	39.2536	7.8888	36.54984	5.51161	15.6585	
300	30.1911	27.3567	100	13.054	17.0128	
301	58.1216	4.85005	21.91011	23.7849	11.1451	
302	22.93675	11.9276	32.57435	13.2513	5.22688	
303	40.70665	14.58	46.74439	15.1961	4.30442	
304	23.20333	10.2619	29.99107	26.8427	4.70005	
305	44.9577	18.5433	42.51291	12.682	23.7999	
306	36.17835	18.4913	46.79452	6.6822	18.984	
307	31.0519	10.8045	50	40.2605	9.78357	
308	62.3929	22.8555	61.7319	38.949	10.5906	
309	37.4548	36.891	24.36775	50	16.2777	
310	67.7992	41.6067	30.32636	13.9028	17.1504	
311	60.6911	7.32329	27.94194	9.10809	34.4544	

Chainage	1975	1990	2000	2010	2016	Remarks
312	46.5565	27.846	31.44693	33.3941	15.0232	Nangal
313	36.82365	21.3758	92.79918	13.8776	25.089	
314	25.4837	9.28718	12.80752	16.2981	13.65645	
315	69.8347	14.3517	6.389242	15.4977	30.7379	
316	48.28679	15.47664	41.02521	7.964062	30.02835	
317	48.22736	15.512	41.42759	8.503694	29.98491	
318	48.16794	15.54736	41.82997	9.043326	29.94147	
319	48.10851	15.58272	42.23235	9.582958	29.89804	
320	40.303	6.03056	56.58943	19.9894	37.3521	
321	43.38715	15.8911	23.57931	22.954	9.0181	
322	33.1374	7.10086	9.983948	6.12714	18.7237	
323	16.0191	17.41945	38.73183	7.80638	66.8177	
324	23.1611	11.89868	31.13882	2.29124	50	
325	35.9017	35.1603	7.373341	3.625305	40.64175	
326	42.2381	4.85005	19.38116	13.9169	31.2729	
327	31.8258	15.9276	18.24539	31.9373	39.9964	
328	53.8771	14.58	52.38195	5.24939	37.2341	
329	70.9108	12.0619	100	4.13334	19.0045	
330	100	18.5433	100	7.23122	31.4495	
331	100	18.4913	18.56021	2.48853	22.7908	
332	100	10.8045	100	4.60205	19.3271	Bilaspur
333	55.4382	22.8555	100	8.54623	47.9185	
334	100	36.891	100	3.90294	11.9136	
335	100	45.6067	50	17.4132	11.3168	
336	46.708	5.62329	78.68169	7.7918	19.7665	
337	37.72185	27.846	100	7.24107	53.0508	
338	68.6369	25.3758	28.91701	8.06638	19.2323	
339	24.7748	9.28718	13.45631	66.3964	11.6678	

Chainage	1975	1990	2000	2010	2016	Remarks
340	50	16.4517	54.64968	29.3123	8.64519	
341	29.0402	4.36432	34.82184	33.5617	32.717	
342	21.8616	5.1899	45.32067	7.92623	27.7615	
343	41.2335	7.25813	68.58835	24.5407	9.58274	
344	73.8773	1.830775	100	22.44125	39.0032	
345	32.7479	4.03056	21.32955	35.556	61.9002	Bega
346	27.3347	15.8911	41.97549	47.9754	13.0607	
347	37.3788	9.10086	60.62622	100	19.6708	
348	32.8167	19.41945	34.93031	26.9764	27.2857	
349	23.969	9.89868	52.35129	21.4884	13.606	
350	25.5581	34.1603	53.93301	17.8086	23.8099	
351	20.7915	27.9419	34.53331	30.7502	12.4968	
352	33.8358	29.95965	16.01963	8.57738	23.1548	
353	19.3818	4.52455	21.5876	13.343	31.2222	Mimapur
354	16.8238	4.85005	40.90981	5.56852	21.13305	
355	15.661	15.9276	100	46.3536	18.4126	
356	42.0753	14.58	74.49263	9.64019	30.7355	
357	52.2374	12.0619	23.81884	13.266	37.1312	
358	46.0973	18.5433	61.23629	15.0165	31.7988	
359	40.9801	18.4913	77.23167	14.6205	75.2741	
360	90.3431	10.8045	28.0821	5.65321	77.4618	Baghpat
361	33.6212	29.64985	27.6324	93.3992	22.7869	
362	20.39805	39.1918	31.3931	37.6071	13.9522	
363	32.292	10.8226	26.02969	84.6006	7.18299	
364	25.5282	7.75895	14.73174	50	13.8698	
365	30.5555	22.4572	51.76718	74.1829	22.7841	
366	24.0361	6.80004	69.86213	9.75923	17.1027	
367	15.9735	16.1727	50.88349	20.5248	12.9929	

Chainage	1975	1990	2000	2010	2016	Remarks
368	16.07875	24.586	80.32033	22.0722	25.7828	
369	10.4943	15.4503	43.52237	13.3179	55.4117	
370	78.6149	6.99738	52.91069	53.1332	20.0604	
371	100	16.9106	19.67869	56.5738	35.0239	
372	100	40.88525	100	40.4919	30.1247	
373	80.1502	28.3967	100	24.202	34.29165	
374	59.9414	17.6037	82.8688	12.7211	30.5099	
375	66.3528	27.5796	100	50.2943	21.3685	
376	63.0228	8.46154	100	18.0832	48.4851	
377	52.4735	11.4253	100	12.3262	22.3683	
378	33.92	8.30049	100	35.7488	10.21733	
379	36.2224	12.6952	25.24063	71.3797	35.7178	
380	60.3782	12.6234	40.94521	27.8574	49.4204	
381	62.5615	22.7718	100	11.8243	20.2704	
382	73.1233	17.6766	53.73847	14.0912	10.9561	
383	76.3033	11.4319	100	26.5213	79.9009	
384	32.1952	11.056	100	30.2828	50	
385	57.2052	11.2584	100	30.7336	26.3521	Wazirabad
386	38.2383	48.6446	100	46.5622	20.8368	
387	74.3216	22.666	100	29.5602	100	
388	64.212	18.6175	78.60866	12.8338	31.7982	
389	12.4811	26.3839	100	28.6424	50	
390	6.712333	48.218	33.63001	35.9372	100	
391	38.6785	59.8606	48.75879	50.3716	50	
392	50	93.8751	100	58.0766	100	
393	50	12.3888	100	56.6637	100	
394	100	10.9232	56.88904	97.2399	100	
395	86.5632	36.95825	100	100	50	

Chainage	1975	1990	2000	2010	2016	Remarks
396	52.5598	25.921	100	100	100	
397	47.0356	48.715	100	100	100	
398	62.8118	29.4467	100	100	100	ITO Bridge
399	51.6527	97.8464	100	50	100	
400	13.24475	99.9697	100	100	45.62415	
401	36.0405	97.1762	31.78346	100	100	
402	37.3988	92.5092	44.60879	100	100	
403	42.2229	98.0398	56.27288	100	100	
404	54.6941	98.1381	79.95085	100	33.33333	
405	54.2826	24.7653	43.01401	30.90225	50	
406	26.4513	57.984	32.90176	50.1072	50	
407	30.1495	94.0668	14.50383	100	34.2452	
408	26.8571	98.6066	17.15024	50	100	Okhla
409	33.4527	49.94965	26.60423	100	100	
410	68.4288	99.1524	100	100	64.4302	
411	37.4261	99.4792	100	13.6921	46.0115	
412	45.0415	98.8607	64.60459	45.8775	49.5695	
413	23.73615	98.7641	37.30337	100	28.6244	
414	24.8632	49.83865	54.0967	43.294	33.5128	
415	33.2894	98.7172	23.20505	24.0699	77.9557	
416	29.309	23.0863	32.60913	9.13743	39.2148	
417	77.9282	38.5345	36.0469	13.85013	12.2703	
418	88.5299	23.6664	14.58014	21.305	26.1261	
419	24.87215	37.1871	23.94297	30.3844	63.5455	
420	24.5159	19.6523	32.85457	27.2521	50.8554	
421	64.8244	42.8207	15.09046	9.24863	47.7506	
422	36.7411	12.3926	26.27181	56.8308	11.4518	
423	60.5995	18.9393	10.59662	17.1919	6.58414	

Chainage	1975	1990	2000	2010	2016	Remarks
424	37.953	37.30275	26.99487	65.7166	10.422	
425	76.2977	45.0136	20.05027	28.5226	15.6967	
426	65.0901	13.0203	52.28452	10.3506	51.2814	
427	71.6523	3.98368	100	33.1166	100	
428	42.3009	11.75925	25.07613	19.9593	100	
429	55.9928	25.2228	47.69954	31.0783	39.2542	
430	64.7856	20.4105	17.85558	13.6911	5.74495	
431	85.484	7.01451	18.82946	6.86599	34.8556	
432	94.4101	19.1289	41.70048	81.9866	50	
433	61.1939	12.388	30.8199	30.307	9.87329	
434	87.6156	21.841	100	7.53194	27.3004	
435	86.0965	46.9345	40.7018	7.11914	45.8401	
436	83.1218	11.0596	14.285	8.97974	100	
437	16.89075	23.6808	37.93803	3.56096	100	
438	67.2855	10.4951	11.45258	12.1603	100	
439	86.7546	32.2073	24.87804	4.33898	50	
440	100	23.813	31.97479	12.5899	100	
441	100	12.4606	100	100	55.6103	
442	58.251	9.13043	100	100	85.0963	Lalpur
443	100	16.06205	100	72.426	33.6758	
444	50	11.1935	100	71.5636	18.0835	
445	100	19.99575	14.94033	36.4722	24.2624	
446	100	5.7743	16.86414	17.4492	50	
447	50	6.87801	28.04887	50	41.3867	
448	90.3622	30.8175	100	67.9168	28.9909	
449	32.92145	11.7122	67.48866	17.68	42.8742	
450	50	13.90885	55.80477	100	17.8203	
451	50	19.1974	14.31183	39.3245	50	

Chainage	1975	1990	2000	2010	2016	Remarks
452	39.774	13.2254	69.75073	7.6512	73.2197	
453	64.9156	11.1657	24.56618	12.9042	55.2017	
454	94.3488	5.33858	46.39075	100	34.3881	
455	55.51	11.9044	100	94.466	55.6767	
456	7.86566	46.6642	10.16471	100	58.281	
457	42.3629	36.5681	22.04279	100	33.1489	
458	50.655	21.5514	41.44895	100	14.09125	Mohana
459	29.4699	13.5902	28.64385	78.3766	14.5759	
460	70.2906	22.51325	62.31647	83.145	62.4239	
461	54.9585	24.01195	74.60595	24.7632	24.6181	
462	46.8034	9.0691	40.29043	17.2076	90.128	
463	96.7534	8.37792	45.61299	80.8259	33.33333	
464	36.3324	19.056	100	23.9384	50	
465	48.6461	11.3112	68.97163	58.2104	54.1902	
466	84.6301	19.8996	40.37168	66.037	39.2935	
467	91.1663	9.7116	100	31.97123	52.8431	
468	100	10.8392	58.5574	39.4241	42.36565	
469	95.3343	19.5755	100	37.1241	65.6904	
470	42.5973	28.1059	69.90793	51.6939	50	
471	28.6375	27.207	35.58102	100	50	
472	100	22.8141	15.00796	50	32.8894	
473	42.7979	15.8121	100	100	77.9826	
474	29.7393	17.8417	100	100	43.1399	
475	100	13.0004	100	64.8101	19.7586	
476	100	7.57787	35.2051	46.8223	16.5398	
477	46.6113	32.8837	28.36325	100	27.181	
478	43.6027	15.87365	24.53134	29.0262	100	
479	29.0778	13.35887	47.37733	69.2002	16.1344	

Chainage	1975	1990	2000	2010	2016	Remarks
480	51.0879	15.3925	15.54066	50	12.7704	
481	50	14.0944	100	100	17.9018	
482	15.0636	25.38265	73.11962	6.09273	14.6632	Thantri
483	66.7288	8.22132	100	4.83426	100	
484	28.1955	11.154	37.09559	18.3422	100	
485	27.2661	21.54355	62.00378	11.6419	8.78226	
486	17.8322	7.18349	79.34017	73.9003	26.23305	
487	35.6853	28.8418	74.26401	16.662	100	
488	85.223	85.9922	100	43.9447	47.4127	
489	48.0764	68.7131	50.49555	25.291	100	
490	63.0267	12.4426	72.26859	100	61.9251	
491	56.005	21.9663	76.01789	100	36.913	
492	31.4872	47.029	25.83837	100	88.2782	
493	33.3539	40.9624	69.7706	44.1096	100	
494	100	11.693	100	14.9919	51.4398	
495	100	13.0004	61.8049	46.222	100	
496	21.0096	7.57787	100	100	34.9814	
497	100	32.8837	82.45901	100	27.1958	
498	32.7154	45.7594	47.0354	100	100	
499	14.5652	62.4884	17.83552	100	63.9934	
500	76.6799	97.5969	23.72503	50	17.4755	
501	100	23.2501	35.95497	25.2515	98.5819	
502	33.7722	18.8595	100	40.8798	33.0871	Pipli
503	50	6.63431	100	35.3524	24.1974	
504	97.6368	9.94424	17.32219	12.6252	100	
505	31.0816	16.4244	45.35677	32.6098	50	
506	83.1388	13.54325	26.96228	38.3154	38.441	
507	71.372	24.5495	89.85505	24.5036	21.2678	

Chainage	1975	1990	2000	2010	2016	Remarks
508	51.1373	19.6609	64.64052	39.7786	67.4497	
509	72.975	34.0135	100	31.3764	100	
510	26.27885	25.70975	100	67.7252	21.0536	
511	91.7148	45.8795	100	50	45.9662	
512	74.1694	18.9597	38.04437	100	48.434	
513	100	24.4746	100	100	50	
514	56.5203	52.0407	56.03105	100	47.6704	
515	100	67.1138	34.41385	100	22.1905	
516	78.4416	42.5315	54.56588	100	26.52315	
517	15.18085	49.00625	20.58783	100	9.7485	
518	50.9546	27.6369	56.18453	49.2698	23.6113	
519	48.4734	41.3055	54.78441	17.5798	65.1561	
520	54.6456	94.0891	53.2929	14.3351	65.5877	
521	42.7536	49.4401	46.3029	100	49.0246	
522	33.5165	49.87185	38.9826	45.3012	16.1916	
523	61.4928	49.7781	56.90539	16.038	37.5196	
524	49.5331	23.3687	60.70384	100	45.3361	
525	65.2551	16.7982	59.5136	50.682	19.5336	
526	65.6038	12.2416	67.64331	21.3632	52.7186	
527	44.9294	76.0176	57.56921	31.0811	53.4806	
528	30.8751	49.116	73.9188	25.8141	34.6977	
529	26.69505	49.47435	53.72512	4.84675	100	
530	21.4165	46.85965	41.22414	9.68906	35.124	
531	14.8894	39.7731	55.12171	66.3523	51.2966	
532	29.759	49.2135	94.23187	100	100	Shahpur
533	82.2188	14.0921	100	100	57.6713	
534	100	96.4381	100	100	46.8982	
535	42.7141	35.87165	100	100	25.1978	

Chainage	1975	1990	2000	2010	2016	Remarks
536	41.4233	22.1084	82.29106	10.0328	25.6747	
537	53.064	37.1079	100	9.78412	37.4545	
538	100	94.9506	60.11851	20.2016	78.7658	
539	22.4783	43.4792	100	60.0016	66.0105	
540	33.6685	14.7693	100	100	39.61	
541	100	9.8628	100	31.1086	100	
542	34.3705	57.5495	30.03601	22.2139	75.5883	Majhoi
543	19.42495	22.28445	40.55137	42.6467	16.0085	
544	74.7922	23.6204	68.57436	100	100	
545	23.0015	15.8844	57.78624	27.5924	19.4859	
546	36.0509	40.8448	100	6.82477	40.11	
547	29.2293	38.3031	100	13.2442	45.6138	
548	100	49.22105	100	100	39.4532	
549	54.3594	36.4006	58.04129	30.4799	100	
550	30.4101	15.9792	100	17.9333	21.1912	
551	43.8107	18.5977	58.17305	38.1524	26.86075	
552	70.0384	9.61914	32.87868	34.8064	48.1911	
553	66.5915	36.1308	48.96111	38.2095	58.6108	
554	35.5427	84.4733	100	49.0687	58.7562	
555	52.4624	37.6074	28.09818	100	58.6271	
556	36.7591	96.5779	67.44593	72.3232	47.29805	
557	100	94.1196	11.4865	49.3353	100	
558	45.9634	46.3307	18.23315	18.92643	53.5832	
559	56.8376	38.1666	28.67784	34.658	18.3807	
560	51.8122	48.7237	26.82542	28.2051	20.1389	
561	50	13.7404	85.27981	22.14125	100	
562	25.9943	30.6431	36.96292	63.5554	30.82685	Oba
563	61.4385	49.07175	100	15.37045	50	

Chainage	1975	1990	2000	2010	2016	Remarks
564	17.68793	23.0194	100	21.2052	50	
565	50.1835	73.6498	100	12.134	76.9058	
566	32.5103	58.7692	32.2997	25.0165	50.1271	
567	21.2437	40.5911	100	6.32286	100	
568	67.7859	62.1769	31.27092	17.5501	23.4539	
569	39.045	10.0305	49.77765	7.20793	100	
570	69.6257	21.1539	38.00858	25.5509	50	
571	100	23.8778	24.1477	50	24.30375	
572	56.7432	13.6582	20.50391	28.4486	20.4436	Gulalpur
573	25.4052	19.9808	100	54.1911	45.7488	
574	60.2599	15.6871	17.40621	59.2267	34.9005	
575	64.2921	12.2847	100	19.5591	60.1412	
576	28.856	21.7221	74.53803	37.3604	55.3349	
577	100	18.1469	26.6482	21.6939	50	
578	23.4255	54.8634	35.81417	38.9129	30.728	
579	48.533	40.8146	38.34236	100	64.4972	
580	36.6351	95.0024	10.49347	100	50	
581	73.2566	48.58	21.63025	50	72.7911	
582	24.17925	27.7919	18.94632	100	27.3792	Bhogaon
583	42.1986	94.7032	85.07445	100	13.1416	
584	22.8545	48.84055	15.42037	42.5681	100	
585	38.563	15.05825	74.86399	11.6041	35.5327	
586	29.2757	17.4274	100	18.1612	23.3325	
587	28.6876	15.334	23.36113	41.3687	96.8764	
588	38.3134	39.476	100	32.4005	29.9701	
589	78.3075	51.8633	100	45.9691	33.40905	
590	43.5093	17.6603	100	10.7881	41.3235	
591	81.5783	11.58565	100	82.5714	47.6283	

Chainage	1975	1990	2000	2010	2016	Remarks
592	34.0291	11.8553	13.88107	37.4556	50	
593	36.2579	14.2655	58.86961	19.0039	31.5704	
594	41.9108	25.29175	57.37432	100	100	
595	100	22.8982	17.49243	100	100	
596	38.1887	44.2677	31.06111	100	100	
597	72.0451	47.5321	83.6106	100	50	
598	36.1925	36.4817	100	56.539	56.838	
599	59.7106	15.5851	15.76194	66.5824	62.3725	
600	61.9148	42.4021	14.99059	100	100	Vrindawan
601	72.4679	99.4117	26.24831	100	100	
602	42.5872	36.97185	39.83402	77.5306	50	
603	58.8911	33.2697	100	50	50	
604	75.4722	33.13857	93.35408	100	100	
605	61.984	39.3764	80.4132	50	50	
606	64.5222	21.8701	51.6388	100	50	
607	61.0159	48.9128	58.85323	100	33.33333	
608	100	36.1183	65.73215	50	33.33333	
609	27.9299	19.19245	100	100	50	
610	100	48.0383	100	97.0931	100	Mathura
611	98.7098	61.0778	100	86.6079	50	
612	54.3332	52.1917	100	100	50	
613	47.7472	49.0984	38.21535	100	35.3124	
614	84.1799	23.344	100	100	100	
615	52.0321	33.8019	65.27512	100	50	
616	100	48.92505	29.35844	100	61.2345	
617	32.6779	95.1333	100	100	45.9206	
618	14.62605	94.1647	100	100	100	
619	16.94845	30.945	100	51.4467	35.9064	

Chainage	1975	1990	2000	2010	2016	Remarks
620	47.9296	14.3071	100	15.7181	30.4383	
621	10.7659	61.4254	100	74.0463	100	
622	73.2879	93.0333	84.37205	100	41.2157	Masani
623	46.2239	61.7265	100	100	51.2859	
624	18.6772	17.1747	100	50	100	
625	38.1187	25.8019	100	100	100	
626	44.3624	52.336	100	100	100	
627	100	38.2215	100	100	50	
628	100	94.5499	46.03938	100	15.61	
629	100	61.1867	42.31958	100	100	
630	27.462	13.3204	95.06441	100	100	
631	100	20.575	39.28903	50	63.3695	
632	100	74.6586	28.30268	100	100	
633	30.2388	32.6661	54.62198	100	52.116	Gokul Barrage
634	31.6464	42.7057	100	100	50	
635	100	18.1107	61.9594	100	50	
636	100	54.315	28.8911	100	50	
637	100	49.97165	100	100	78.2612	
638	24.2795	28.0977	90.10105	50	21.2503	
639	65.3428	96.6134	25.46091	100	40.4143	
640	55.4497	49.2151	55.03088	74.7358	50	
641	68.2048	18.75985	100	69.8798	60.9754	
642	61.6329	15.3096	100	9.0215	53.2462	
643	100	17.4021	45.10099	18.1646	33.5777	
644	48.9193	95.5775	31.13084	21.5195	50	
645	74.3301	37.4854	100	29.97	36.0944	
646	99.4111	19.9025	100	50	13.8365	
647	25.8506	27.7309	100	87.174	22.9756	

Chainage	1975	1990	2000	2010	2016	Remarks
648	50	36.9274	67.34989	25.5602	100	
649	49.6403	24.2615	80.96502	28.4396	100	
650	88.9999	31.0232	31.75012	32.4608	40.03535	
651	56.1298	88.1024	76.68729	100	100	
652	49.1332	18.9562	100	72.294	100	
653	83.3346	48.9625	100	27.6952	59.6391	
654	56.9894	94.268	100	100	57.5629	
655	50.8575	97.8257	100	100	53.9944	
656	81.4982	98.4701	100	100	100	
657	31.4139	96.1698	37.11362	100	16.9514	
658	40.8362	46.6623	26.76285	100	100	
659	46.5106	35.78735	89.55104	50	100	
660	25.3012	51.8464	61.81381	33.7629	100	
661	37.4603	37.0045	23.20138	68.2931	35.2888	
662	67.1434	21.061	22.68692	64.5327	50.3972	
663	25.119	18.4726	100	13.92225	35.0649	
664	69.6523	11.6347	62.87978	46.6164	100	
665	91.7436	9.81263	100	52.6514	100	
666	58.8965	35.7092	100	17.088	50	
667	17.782	27.1654	100	13.9889	29.4014	
668	24.3444	14.2927	31.19375	19.5934	17.1196	
669	43.2239	41.2356	27.82081	100	18.8508	
670	43.1182	94.1324	100	79.2101	44.4716	
671	36.5842	91.9181	33.39813	100	100	
672	28.46495	20.279	100	100	57.8044	
673	100	96.1089	42.21096	100	100	
674	28.52615	96.9235	25.35629	90.3703	59.2572	
675	100	48.96215	100	25.48815	20.672	

Chainage	1975	1990	2000	2010	2016	Remarks
676	31.0254	34.94925	100	100	100	
677	47.1243	96.943	100	100	34.9755	
678	15.24265	22.9255	100	100	79.8828	
679	71.1068	15.1004	81.49702	33.33333	100	
680	58.1059	28.2209	60.94627	94.8721	32.6699	
681	84.0307	10.3613	49.38824	38.7402	100	
682	42.1089	32.4026	100	28.1875	50	
683	82.2791	33.796	100	24.9538	35.95845	
684	30.9625	99.7494	100	23.7208	25.905	
685	41.0233	49.5042	40.5192	26.8338	19.1477	
686	57.8417	31.1239	100	49.6232	18.0748	
687	27.6914	98.2239	100	100	100	
688	53.9417	98.9736	100	100	100	
689	57.9966	94.1923	50.35448	100	72.4335	
690	37.822	62.8558	100	100	50	
691	23.60355	49.25435	100	100	50	
692	29.80625	38.4612	76.34605	100	36.8348	
693	15.52035	49.6791	79.17839	100	100	
694	100	49.56685	32.12589	100	100	
695	42.9924	49.2335	27.05313	100	28.4929	
696	43.8082	55.3787	41.99007	100	69.5171	
697	77.8824	94.8858	100	100	100	
698	47.4907	48.6573	17.70272	100	50	
699	50	30.3238	38.43577	100	46.2598	
700	100	14.2861	45.00817	100	100	
701	19.2116	96.8482	100	100	33.7811	
702	57.3913	95.2952	100	100	46.8446	
703	42.9018	52.9977	81.92486	33.33333	50	

Chainage	1975	1990	2000	2010	2016	Remarks
704	17.7503	27.0138	34.0548	94.9729	16.91975	
705	30.5443	54.786	58.73578	100	21.72395	
706	100	49.4535	100	100	41.7676	
707	100	22.7484	31.73557	100	34.0027	
708	100	27.8198	88.05858	100	43.8393	
709	50	26.3698	100	100	15.4975	
710	50	36.6744	100	44.5161	21.9875	
711	100	98.0824	100	100	38.0132	Agra
712	28.112	35.7862	100	100	100	
713	50	17.2592	71.89697	100	77.5395	
714	17.4228	15.9244	31.07261	88.0236	23.7455	
715	19.5871	11.7502	100	92.5962	100	
716	44.2877	9.90521	36.46632	94.0034	38.133	
717	100	38.8378	100	48.49345	50	
718	50	21.46715	90.22752	93.5688	50	
719	82.0756	22.1559	19.87066	52.7019	100	
720	58.3514	54.525	100	30.0131	21.3094	
721	29.47137	49.9853	100	39.0536	86.743	
722	50	50.6126	100	46.0427	53.0549	
723	50	48.7426	33.48035	46.727	33.2103	
724	77.8932	49.15195	81.86751	62.7631	15.0016	
725	27.97215	32.7952	58.66726	35.5998	41.62575	
726	36.33975	19.7507	100	100	43.2262	
727	50	49.3306	100	50	90.5522	
728	100	14.5225	100	50	11.1439	
729	29.8037	39.3509	88.99378	100	49.8417	
730	32.4867	34.2147	100	50	45.2574	
731	18.68945	57.0785	60.00444	50.6355	45.8281	

Chainage	1975	1990	2000	2010	2016	Remarks
732	48.5307	49.6853	30.78983	47.849	100	
733	49.99995	96.728	38.60833	30.8698	50	
734	30.72345	96.6242	21.07193	40.4908	50	
735	50	94.4932	18.17411	100	42.4464	
736	46.4983	94.5262	97.57345	100	33.33333	
737	71.8745	97.2777	72.15463	100	29.3328	
738	20.6393	99.9507	57.41027	100	20.8418	
739	36.2734	68.8929	53.00008	100	11.5933	
740	36.69335	50.1909	78.40014	100	35.41475	
741	19.93203	98.7223	77.46256	100	43.3603	
742	68.4223	49.7095	100	100	50	
743	19.9988	94.9668	100	100	83.6895	
744	40.2703	49.2755	11.64502	23.12535	50.5282	
745	39.5063	18.0177	35.67077	83.1046	62.5339	
746	32.6126	95.8272	100	100	100	
747	89.5384	94.4603	100	100	100	
748	100	95.2499	100	100	100	
749	36.84205	30.8217	33.04396	100	19.1524	
750	100	18.6955	23.77361	44.4369	20.2201	
751	75.5986	24.225	100	52.044	100	
752	38.3926	20.3414	100	100	24.5722	
753	41.31945	97.9553	69.01095	100	49.7182	
754	8.277	97.471	21.46533	22.15813	62.3522	
755	21.3261	45.2471	43.35937	13.6503	26.2938	
756	24.4105	93.9167	49.78535	22.5249	32.3918	
757	14.08375	66.2134	100	24.8391	100	
758	16.9489	57.7441	52.86048	100	100	
759	44.7822	98.458	93.93104	66.0843	55.1022	

Chainage	1975	1990	2000	2010	2016	Remarks
760	28.5482	39.8815	42.81296	80.5033	15.2114	
761	41.1115	57.6832	65.09801	100	47.8977	
762	47.0267	94.0218	36.03754	32.8928	19.69845	
763	14.33635	96.6384	21.00121	79.9845	29.6167	
764	34.8449	46.1298	100	45.1494	100	
765	61.0157	92.9208	27.89277	56.808	38.8053	
766	79.0404	54.1137	25.48626	56.5362	29.6374	
767	17.7796	97.3225	46.90252	74.8253	100	
768	42.1216	32.2716	100	81.4615	25.134	
769	100	94.1486	100	31.6148	38.4596	
770	34.9847	96.6329	36.00431	100	47.5914	
771	27.7221	97.5963	100	100	100	
772	75.4896	51.5891	100	89.2147	36.5545	
773	31.1903	50.8819	30.2761	58.4884	100	
774	20.0356	28.0381	79.01487	100	100	
775	12.94825	78.045	100	100	19.3208	
776	12.52035	36.355	100	55.5537	100	
777	100	46.332	37.33035	100	41.5551	
778	37.657	34.0475	100	41.4931	96.6348	
779	16.82363	76.0772	37.93756	100	18.0358	
780	77.9424	63.9679	100	100	100	
781	49.392	100	100	33.82465	100	
782	8.228533	43.9167	100	69.3292	42.4214	
783	33.33333	100	100	74.3183	100	
784	50.2347	98.3694	52.52266	88.6861	22.2696	
785	67.0519	96.3203	53.89636	100	100	
786	33.014	24.0069	57.62199	100	86.5838	
787	100	42.8617	52.19525	100	50	

Chainage	1975	1990	2000	2010	2016	Remarks
788	100	58.5943	100	50	43.2754	
789	100	77.8408	100	100	72.5804	
790	100	25.2447	100	100	43.7649	
791	100	54.3694	100	100	25.1262	Shankarpr
792	100	49.36665	59.08339	44.1813	100	
793	100	49.1738	23.48627	100	30.7416	
794	50.212	31.0873	100	100	39.6338	
795	69.2535	30.1773	97.80486	50	100	
796	58.5438	7.26133	26.24267	100	100	
797	39.123	44.5589	100	100	91.1123	
798	100	38.5498	32.22913	95.3963	40.1211	
799	52.8052	23.4982	28.81378	45.8507	86.1579	
800	22.57355	67.5588	47.97383	72.4666	100	
801	82.6707	22.0594	38.66164	54.4133	53.6501	
802	54.4572	18.9834	18.83914	75.1119	81.0575	
803	56.028	35.2743	55.57267	100	60.4031	
804	18.8807	33.8761	100	48.6628	21.3049	
805	28.6149	34.2619	15.12346	87.7509	13.4868	
806	39.62575	49.2317	54.62912	100	34.6253	
807	29.32545	24.034	100	91.6221	24.9886	
808	20.13135	15.2435	14.01451	29.5843	70.8703	Rihauli
809	50	68.1181	26.48903	73.6537	100	
810	33.0744	22.3411	100	90.2001	50	
811	8.98315	34.2568	32.29838	71.8208	30.6364	
812	40.81425	56.5914	55.67945	100	100	
813	16.20955	36.6756	100	100	22.104	
814	9.754533	93.6141	27.88583	100	30.5257	
815	31.9398	28.6213	35.28813	100	45.1414	

Chainage	1975	1990	2000	2010	2016	Remarks
816	100	77.3606	100	100	36.284	
817	99.9999	28.8718	51.20264	100	28.981	
818	49.3076	98.6885	44.92048	100	100	
819	13.302	51.695	54.05587	100	28.3105	
820	6.89596	45.4203	40.07741	100	36.2934	
821	24.5991	46.6573	30.573	60.6877	100	Rampur
822	50	30.8486	37.85446	100	100	
823	100	15.8821	66.15518	100	61.845	
824	100	62.9012	26.58197	100	100	
825	50	38.3217	64.03911	100	100	
826	26.1998	30.4842	53.52838	100	100	
827	100	40.5958	100	100	27.7949	
828	99.9999	34.6767	36.5955	100	100	
829	50	52.132	30.61551	100	75.3148	
830	100	42.7261	55.70116	39.2097	50.5475	
831	50	9.87696	19.26729	100	21.926	
832	35.2337	16.8899	15.44446	66.6787	12.8458	
833	100	57.7369	46.2462	100	46.4012	
834	50	24.1567	77.74819	100	38.1449	
835	33.33333	28.8718	65.90915	100	49.6839	
836	100	98.6885	22.84496	100	81.6664	
837	49.0053	51.695	58.43541	100	38.04755	
838	22.05357	46.6573	13.10027	30.31755	41.6826	
839	15.5433	30.8486	28.79034	60.8167	100	
840	30.6274	60.9012	86.56634	100	100	
841	51.9345	62.9012	100	100	31.4774	
842	100	38.3217	41.97213	39.2415	96.46	
843	99.9999	64.5551	23.88884	33.174	34.4297	

Chainage	1975	1990	2000	2010	2016	Remarks
844	54.0179	18.183	100	100	38.2868	
845	70.4505	73.6558	32.32522	100	100	
846	44.4795	29.0412	55.50471	100	100	
847	41.9297	33.0406	39.04932	81.6046	54.3266	
848	30.0136	28.5449	25.43047	33.5734	25.1543	
849	100	10.8212	44.20313	100	100	
850	41.7962	45.6226	86.72637	100	45.4251	
851	62.1526	99.324	100	100	50	
852	23.3965	92.0775	100	100	100	
853	12.2837	95.2664	18.52768	100	49.9326	
854	18.006	20.2587	69.72493	100	82.1404	
855	27.6037	65.6277	75.59822	100	89.4912	
856	50	54.3034	30.58243	71.2499	60.4417	
857	33.33333	29.0897	38.35381	67.4612	100	
858	100	21.0033	58.36887	70.5835	42.9065	
859	100	39.3559	100	64.8119	34.6658	
860	28.0947	47.97565	29.61763	100	100	
861	49.9999	43.3563	36.53548	40.1521	32.0691	
862	41.7424	33.1321	84.76874	73.7743	74.4849	
863	23.2732	48.5177	100	100	100	
864	100	75.9399	34.14643	100	100	
865	47.3638	14.3492	100	100	33.1465	
866	50.7048	44.6855	16.36125	100	22.0862	
867	21.7896	64.307	88.69209	100	59.5912	
868	38.9222	22.5561	45.01709	100	63.2838	
869	8.7803	29.2175	23.84542	54.4058	99.1997	
870	100	59.558	60.0189	90.9407	37.2089	
871	34.8066	32.548	18.87221	100	18.5523	

Chainage	1975	1990	2000	2010	2016	Remarks
872	29.4633	12.7711	31.77578	50	65.334	
873	14.50455	43.0155	33.56476	100	20.2335	
874	63.3117	95.4448	100	100	69.1469	
875	12.59615	21.4179	25.09377	100	100	
876	29.1373	54.7124	100	100	66.6233	
877	100	35.42445	46.93113	100	12.7262	
878	100	76.5308	13.7337	75.4098	31.9256	
879	9.53	88.2429	72.3205	61.6333	100	
880	8.1589	46.2386	67.99111	77.9249	48.7368	
881	9.10355	21.8822	10.78037	46.8739	100	
882	39.5384	59.9928	100	50	76.3288	Purabirbal
883	15.032	26.2274	37.79773	100	100	
884	100	25.3102	18.66691	100	100	
885	100	97.8764	100	60.6578	83.0304	
886	50	38.814	41.16933	100	50.7303	
887	15.30925	22.3469	11.68181	100	68.9444	
888	50.9694	59.1486	100	100	34.4592	
889	50.6783	43.369	38.53274	100	54.3973	
890	100	48.5156	53.13607	66.061	100	
891	100	60.9737	100	28.533	100	
892	40.1562	49.30975	74.49252	100	29.9606	
893	15.11555	64.3264	62.61677	100	39.0111	
894	30.4183	28.2173	100	100	52.7944	
895	16.74713	27.77205	23.18747	59.5323	49.2191	
896	69.8444	15.3275	96.3429	50.1604	100	
897	50	28.9091	80.60917	29.7655	50	
898	49.8637	21.2251	32.63258	43.0499	35.1034	
899	17.90755	26.1015	28.73375	68.3359	100	

Chainage	1975	1990	2000	2010	2016	Remarks
900	8.8795	29.3735	100	63.3321	35.7421	
901	16.1829	35.9131	64.94839	100	12.0584	
902	38.4428	46.0598	28.1834	46.5475	19.2998	
903	50	27.6205	37.92664	67.2358	13.9699	
904	100	19.4303	26.69569	50.8957	100	
905	57.7271	31.0405	75.9775	72.5945	51.5778	
906	8.546533	31.3886	18.91256	51.5574	45.1572	
907	33.2717	41.2513	48.48443	68.9203	45.7113	
908	100	27.8176	35.66592	100	34.9428	Etawah
909	17.74017	21.1468	31.55353	100	46.711	
910	4.671267	25.9514	56.62049	62.5375	50.7648	
911	76.239	92.5264	100	100	31.5142	
912	46.9985	98.9579	100	90.0781	52.6705	
913	37.1907	59.8105	64.66002	100	95.5401	
914	54.9043	17.1609	25.73599	100	10.0718	
915	59.3307	60.5095	36.20584	94.7828	100	
916	87.0386	33.4135	66.95195	76.8769	42.1785	
917	10.9888	31.8708	21.36165	100	50	
918	14.134	40.1263	43.21587	45.4848	100	
919	33.8752	11.8064	33.76404	100	42.9661	
920	100	28.277	24.95471	79.6028	39.5906	
921	43.38	48.8901	26.41064	50	100	
922	100	8.4548	46.63499	69.038	50	
923	100	43.3266	100	58.7206	68.1503	
924	7.58714	54.1837	16.86976	61.1418	100	
925	100	33.7048	100	76.8166	21.7172	
926	99.9999	40.2977	35.69596	61.7992	100	
927	72.7437	25.2565	12.55738	100	32.7188	

Chainage	1975	1990	2000	2010	2016	Remarks
928	16.861	48.4237	100	100	100	
929	15.6335	63.6221	37.0408	100	50	
930	21.0727	27.0805	18.99103	60.1489	46.0042	
931	17.37185	18.566	19.84541	65.754	57.4351	
932	100	11.5708	45.43257	27.7246	66.4435	
933	9.7201	36.2935	37.16926	17.1229	33.6283	
934	12.20185	51.5103	49.41043	50	58.5567	
935	8.641333	49.8248	100	100	81.636	
936	40.1495	50.7188	24.52327	100	19.45925	
937	100	25.3434	37.68655	36.3956	100	
938	55.0149	64.7743	84.28109	100	100	
939	13.7318	34.6597	26.26728	100	23.7275	
940	25.8037	68.7151	70.43772	100	100	
941	27.2502	30.6052	26.38883	100	90.9013	
942	16.9572	42.5387	21.94136	100	44.6986	
943	69.4635	66.882	100	100	42.3382	
944	30.0805	11.4458	7.663666	62.8915	100	
945	55.7342	48.43815	43.94084	67.4351	28.2217	
946	23.3888	28.3845	20.56471	17.6881	100	
947	100	58.5629	35.90578	100	70.648	
948	96.5885	91.6534	91.13886	100	42.5416	
949	100	44.1576	37.25607	100	100	
950	13.7007	63.3717	100	100	9.49311	
951	9.52	47.2431	100	93.8056	17.3402	
952	50	33.9927	48.59148	87.845	100	
953	9.916133	50.0998	29.12927	100	40.7822	
954	100	68.6893	100	100	62.0339	
955	100	18.5793	80.90845	94.2669	80.445	

Chainage	1975	1990	2000	2010	2016	Remarks
956	42.396	16.4532	21.22411	100	52.8513	
957	83.4815	30.1031	35.01961	90.5668	100	
958	18.291	24.5618	100	95.541	38.9356	
959	13.3062	36.7393	21.41517	93.2386	38.7932	
960	100	24.3204	51.34269	35.3303	36.7639	
961	31.113	55.0491	46.84695	38.1237	85.9381	
962	21.00995	50.0998	31.89741	63.1499	35.7907	
963	10.9676	68.6893	100	100	100	
964	50.9112	18.5793	48.6844	50	50	
965	55.5405	16.4532	24.43223	100	55.0825	
966	49.4123	30.1031	34.6074	100	32.5341	
967	40.7428	24.5618	22.82303	100	33.62	
968	40.3833	41.083	17.14275	100	32.7223	
969	52.2494	100	42.08069	100	100	
970	14.48885	25.4269	100	100	100	
971	18.4444	30.8192	27.95999	100	47.5399	
972	76.5083	38.7099	29.57986	100	22.8968	
973	52.2012	26.9822	100	100	100	
974	100	31.5868	100	100	22.3217	
975	100	94.3276	53.57564	100	46.6479	
976	30.8722	46.0431	61.28294	100	97.6839	
977	26.0004	15.078	100	82.5962	48.6409	
978	15.4633	96.0181	33.172	67.4101	37.846	
979	43.3007	48.52165	55.10948	75.7742	100	
980	53.4149	48.8134	100	100	45.7677	
981	34.3913	60.2844	100	100	23.4452	
982	23.8904	45.3264	100	100	84.0582	
983	28.3722	29.1181	100	100	100	

Chainage	1975	1990	2000	2010	2016	Remarks
984	5.4037	33.5376	100	100	52.2794	
985	4.45057	92.6096	100	100	50	
986	14.6696	98.1545	100	100	100	
987	65.0284	92.1548	24.39249	100	100	
988	33.9878	94.435	16.16708	100	100	
989	2.385115	95.1649	29.62197	100	100	
990	3.6966	96.5357	31.53749	100	100	
991	27.4298	33.3241	40.36835	26.6035	100	
992	38.3077	94.5694	56.66958	60.78	100	
993	100	11.26375	32.37191	39.3894	100	
994	67.409	36.2562	32.11152	36.6683	100	
995	100	50.001	46.16335	61.4823	31.778	
996	17.3243	52.8956	29.43396	70.36	28.7163	
997	17.4725	56.4823	26.73737	44.0902	55.3329	
998	46.4889	66.2472	25.98236	64.4073	59.9269	
999	15.36443	65.701	46.69691	37.956	56.2587	
1000	100	83.2563	38.19067	71.8076	65.351	
1001	43.029	40.8899	48.59361	41.4105	77.537	
1002	24.9414	17.3465	55.61314	45.9387	93.2365	
1003	28.273	32.161	30.76105	51.9301	29.8938	
1004	17.3215	57.6194	61.08061	56.7742	33.8798	
1005	62.3678	38.8857	100	53.8908	40.4684	
1006	27.8709	55.9689	40.73283	37.2451	59.5556	
1007	32.4981	74.9276	48.21353	45.1302	52.3481	
1008	36.9104	36.977	100	100	81.6122	
1009	89.9918	56.0282	56.0727	43.2979	54.9792	
1010	60.6429	49.4353	44.43932	51.0676	57.764	
1011	24.9241	34.68305	45.53958	63.9843	44.4493	

Chainage	1975	1990	2000	2010	2016	Remarks
1012	99.9998	39.6317	31.00145	58.1013	44.1506	
1013	100	59.2569	40.73337	83.2457	34.4555	
1014	35.6633	98.9373	46.29996	44.4098	65.2014	
1015	100	51.7597	38.03158	27.7043	81.3845	
1016	100	20.9922	44.75215	82.3172	76.4813	
1017	100	21.52635	100	100	37.7572	
1018	50	35.1861	100	100	36.0439	
1019	100	51.4668	31.91923	100	45.7661	
1020	26.2163	56.9091	21.771	50	52.5194	
1021	37.2687	65.1428	28.06735	100	71.8015	
1022	100	98.6967	52.53081	43.88655	74.2234	
1023	50	41.3257	66.6587	51.9854	51.4098	
1024	19.795	30.4827	33.62472	39.5218	72.2475	
1025	38.3818	37.9068	28.27156	65.7789	23.6873	
1026	100	55.5107	24.65715	100	37.3515	
1027	100	68.6318	21.81553	100	36.7954	
1028	100	98.9758	51.469	100	55.4192	
1029	100	99.1283	45.45404	100	77.5665	
1030	100	49.57315	47.15442	52.3326	50	
1031	50	31.0151	57.92968	34.5983	100	
1032	100	42.8625	100	99.5332	74.7423	Mihauli
1033	100	59.8701	85.67061	100	35.6411	
1034	100	33.0127	100	100	53.9387	
1035	100	70.4387	100	100	45.07085	
1036	100	59.2439	74.12545	50	47.4542	
1037	100	44.1389	12.51992	100	56.9604	
1038	100	49.86695	35.38292	50	32.1837	
1039	50	49.82625	57.06221	100	31.3165	

Chainage	1975	1990	2000	2010	2016	Remarks
1040	39.8932	49.79935	73.63573	50	50	
1041	14.07435	29.9323	31.11047	72.8075	50	
1042	50	56.1714	16.51613	63.766	42.9649	
1043	52.901	22.5674	33.73415	58.9641	31.14405	
1044	40.2345	58.6027	60.03898	82.7224	41.495	
1045	17.0811	90.9343	45.68607	24.714	37.6633	
1046	9.66803	20.933	67.25285	28.5402	63.288	
1047	100	18.6276	28.69648	46.3817	100	
1048	50	43.1599	44.27173	60.0574	33.2811	
1049	49.9998	62.0913	21.0755	45.6647	29.5574	
1050	100	54.9517	47.12546	65.928	60.7005	
1051	100	52.6665	50.84379	45.4298	44.2877	
1052	38.82795	62.0761	51.99472	73.4492	52.2317	
1053	38.2987	35.7281	62.987	41.5536	54.8208	
1054	28.74505	37.9626	54.50933	55.1324	72.4987	
1055	10.26525	49.633	50.20046	76.1592	25.4822	
1056	25.5311	52.3829	24.11759	57.7826	41.2369	
1057	8.30065	67.1265	15.61533	100	64.6593	
1058	35.6476	56.1798	27.87318	86.249	70.1748	
1059	16.7675	81.5653	18.78465	55.2651	64.7633	
1060	23.9501	67.6083	38.28945	35.4738	67.0099	
1061	3.4651	48.3707	22.82001	23.2573	87.039	
1062	13.652	49.7234	26.80519	37.6152	50	
1063	11.07665	30.0368	40.18945	31.4152	22.6127	
1064	25.5132	35.5788	48.08539	40.0006	19.7839	
1065	3.866355	43.1338	12.04338	22.2367	28.4705	
1066	13.8784	36.8856	49.23916	37.7668	33.656	
1067	13.5868	29.8447	36.12786	59.4082	30.5455	

Chainage	1975	1990	2000	2010	2016	Remarks
1068	36.9546	36.2889	40.41612	21.4782	29.8345	
1069	12.7809	58.2521	40.07926	54.5146	60.9202	
1070	4.89974	20.1554	43.36398	40.4668	50	
1071	18.1678	58.6443	30.94876	100	23.2757	
1072	8.55915	45.7519	14.9005	23.9186	38.249	
1073	23.7339	42.813	16.84909	39.0971	39.12535	
1074	32.7493	57.9425	24.44714	47.4671	44.03685	
1075	28.788	38.3446	24.95624	28.3114	47.9228	
1076	11.5277	39.212	39.92695	17.508	59.3588	
1077	21.633	16.9684	25.20928	24.5942	37.0472	
1078	100	20.9947	36.63176	28.1651	19.2418	
1079	62.6055	32.2436	65.13164	28.3027	28.4617	
1080	60.0087	32.3966	54.69356	44.4682	21.4836	
1081	32.7121	27.6656	26.9038	58.9588	36.0404	
1082	7.2044	62.6536	44.54933	75.4262	15.2546	
1083	8.08089	75.5469	64.85801	17.7133	50.5187	
1084	25.0947	35.3615	100	20.569	62.6868	
1085	100	29.1331	82.37353	36.0975	35.00985	
1086	25.5668	37.4799	27.40652	60.1764	25.4799	
1087	35.438	61.3999	90.21305	61.3031	23.791	
1088	28.9611	60.7985	69.03492	49.39435	61.3499	
1089	40.8521	28.16853	30.60441	81.6682	73.8374	
1090	22.4193	36.4725	98.94684	30.40345	46.3358	
1091	27.2858	99.492	45.15494	63.5724	21.49257	
1092	20.1991	56.3004	46.09869	50.5443	37.6565	Daulatpur
1093	13.8312	15.5113	69.99639	35.5177	87.7852	
1094	6.80154	72.6353	100	100	41.1796	
1095	8.04876	42.5368	69.75765	49.3916	42.3284	

Chainage	1975	1990	2000	2010	2016	Remarks
1096	2.817387	56.0186	51.62883	77.9524	64.9243	
1097	4.714715	79.3678	95.92428	100	47.1902	
1098	27.83255	32.7838	93.11934	100	98.9468	
1099	31.4752	56.7541	42.01261	45.9682	99.2052	
1100	100	25.13	78.64539	30.7082	42.2729	
1101	63.1052	96.1238	42.4573	63.2844	56.5118	
1102	43.5287	62.7907	35.54887	42.5014	58.7341	
1103	11.91035	19.46365	27.0522	36.7264	100	
1104	24.978	70.9553	22.43217	73.0503	29.43385	
1105	100	51.7661	72.42888	51.7205	64.6265	
1106	22.5603	38.7858	37.99786	44.9092	58.6075	
1107	62.986	14.17725	60.0868	30.9182	56.7503	
1108	100	17.86605	37.4897	42.1334	48.3551	
1109	10.0895	18.32125	31.0833	38.9315	27.3513	
1110	16.3531	33.1938	28.33565	48.3644	30.9654	
1111	62.7405	54.4982	39.44477	62.4389	29.7425	
1112	71.1096	48.1303	100	52.0217	68.2231	
1113	50	38.0487	40.74081	40.8289	58.9902	
1114	72.9715	34.8074	31.08835	28.6248	37.8761	
1115	27.2617	35.59	54.24262	57.5089	20.3599	
1116	46.0344	50.5375	49.06167	77.3967	40.6814	
1117	67.7232	36.987	45.0317	54.2132	30.3307	
1118	75.2144	25.4644	62.03517	36.3312	38.4993	
1119	37.6906	57.1193	93.67667	91.4471	14.16315	
1120	57.3447	47.0001	50.19876	100	52.137	
1121	21.0234	66.4476	35.10878	100	60.2773	
1122	5.34195	87.3036	26.23487	100	65.5487	
1123	11.682	49.1455	29.65655	50	68.9973	

Chainage	1975	1990	2000	2010	2016	Remarks
1124	24.9822	49.29745	28.87201	100	67.0027	
1125	11.2864	32.90383	54.06329	50	49.50735	
1126	12.5722	49.53735	59.16302	100	50	
1127	3.975665	49.49765	58.74889	50	50	
1128	7.40509	46.14505	59.96742	88.3919	50	
1129	13.2104	37.3885	49.50594	31.8082	50	
1130	5.91223	54.1047	100	63.8019	28.07137	
1131	10.063	47.7202	100	60.0436	29.03605	
1132	15.8715	53.6624	33.33333	51.0702	64.4614	
1133	44.2209	63.1232	100	59.5115	49.3785	
1134	15.3015	49.39245	100	75.6579	64.385	
1135	13.4089	33.04863	100	100	56.9265	
1136	5.37415	49.4466	100	50	50	
1137	47.1358	49.63985	83.33042	100	50	
1138	13.8252	49.67215	45.43279	50	33.33333	
1139	8.34063	49.52855	20.15016	100	50	
1140	46.4758	49.28365	27.09149	40.86225	39.1825	
1141	55.2101	29.7296	48.47139	39.0665	36.21395	
1142	34.159	31.7778	61.84088	74.5748	22.72645	
1143	26.5648	41.7829	51.76174	36.5015	18.20535	
1144	6.01672	29.90775	66.48785	31.8871	54.7089	
1145	1.508055	53.4812	53.00876	79.6524	23.5144	
1146	3.93694	44.7537	76.42809	88.6733	18.9915	
1147	26.2622	44.4336	59.37741	39.5771	33.3741	
1148	13.7898	33.417	49.7222	38.6825	52.9666	Mau
1149	9.57413	48.82755	35.57976	58.9772	62.4126	
1150	8.439967	51.4904	52.14092	62.1068	72.5711	
1151	6.78654	40.2828	57.35857	14.2696	50	

Chainage	1975	1990	2000	2010	2016	Remarks
1152	6.47316	37.4872	33.38455	59.4331	54.7746	
1153	4.44958	49.3636	61.42997	61.3421	49.5148	
1154	13.0035	21.48505	33.274	65.8225	38.7944	
1155	7.80505	23.9615	36.68944	43.2576	48.1184	
1156	7.03415	27.8401	26.63383	37.0815	27.30425	
1157	34.98245	43.1407	55.18942	97.0405	38.1368	
1158	6.62735	41.805	47.78279	38.8953	55.4397	
1159	4.993805	31.6311	56.20864	43.4524	23.6135	
1160	7.43236	43.2411	32.22882	66.5717	37.0191	
1161	5.23585	56.863	54.37992	46.584	34.2061	
1162	5.40685	77.4387	41.88498	58.8554	57.1419	
1163	19.86215	41.725	52.36323	51.4191	45.4176	
1164	9.7768	59.1561	56.07888	44.3076	73.98	
1165	11.095	35.2937	39.54916	100	48.9305	
1166	19.1323	16.8267	84.47605	27.9817	53.8946	
1167	18.6468	61.517	31.56301	25.7729	61.1619	
1168	50	45.6019	26.48771	37.9018	34.0829	
1169	6.69275	77.2027	27.8432	28.3075	39.9101	
1170	7.3274	26.9413	40.22837	48.4209	42.8375	
1171	12.1315	30.5155	54.83435	27.0351	79.0441	
1172	7.22079	29.3223	41.84651	15.0251	17.9727	
1173	18.4502	41.1072	32.09704	34.1125	24.2548	
1174	16.394	57.9526	31.65989	100	33.0809	
1175	18.6085	50.2721	39.43658	100	49.129	
1176	21.6073	36.8317	62.21826	62.3683	83.3598	
1177	19.8147	20.1433	68.31398	37.3649	76.8445	
1178	6.88055	40.7311	34.97611	28.9325	46.4134	
1179	36.8081	61.2804	18.9712	33.8782	27.1799	

Chainage	1975	1990	2000	2010	2016	Remarks
1180	20.0216	65.3079	15.5109	60.0534	30.3159	
1181	8.61237	30.24655	25.57949	100	60.7289	
1182	8.5852	24.4842	20.26143	28.11005	63.1512	
1183	2.461035	13.5015	29.82003	18.9995	30.777	
1184	3.39327	2.875465	37.23696	17.0431	21.47445	
1185	23.2936	10.1911	27.30339	20.3438	15.9579	
1186	22.6857	13.68275	89.4961	21.328	17.2438	
1187	50.1773	18.21155	100	24.8078	10.17665	
1188	10.8104	47.4927	100	38.6005	19.405	
1189	11.1706	54.293	100	30.5556	32.6481	
1190	97.9895	99.1736	100	100	28.7794	
1191	100	99.2724	100	45.2727	38.5842	
1192	38.382	99.5391	100	100	18.33265	
1193	19.7517	28.879	16.91798	100	19.9326	
1194	38.6044	29.68935	20.3331	50	16.8102	
1195	6.36425	49.96235	23.58025	100	25.8591	
1196	7.64609	33.39325	53.74766	51.7544	24.8623	
1197	11.8752	14.818	68.80947	19.971	10.3878	
1198	51.739	32.303	14.23282	30.656	10.304	
1199	85.1146	57.5765	26.50745	21.9014	11.61565	
1200	45.84915	34.1339	42.88709	46.7957	26.6341	
1201	4.586005	39.3305	58.4325	63.3689	27.59395	
1202	4.338	30.3403	53.04014	16.3103	55.6234	
1203	6.0515	42.5775	47.33747	18.2101	30.8942	
1204	15.34833	52.0873	59.48593	32.2644	22.5962	
1205	21.1298	55.5678	77.33134	48.437	43.4488	
1206	6.749967	44.9982	100	40.8015	60.9174	
1207	33.33333	55.221	19.62669	19.8152	54.8238	

Chainage	1975	1990	2000	2010	2016	Remarks
1208	19.1684	98.8626	44.49999	46.4904	47.9131	
1209	13.5357	65.8202	37.27972	56.6622	87.0942	
1210	19.5894	20.927	30.25902	58.275	100	
1211	39.4506	27.0459	51.02268	30.3642	33.33333	
1212	11.8931	24.888	58.32952	34.3994	19.4655	
1213	11.4103	34.3271	50.98106	47.1343	20.0921	
1214	18.7743	42.7455	47.14483	23.3297	14.09715	
1215	30.0115	53.831	36.81133	38.4214	43.3825	
1216	15.8006	53.0333	26.19752	45.4013	56.8185	
1217	10.6227	49.82	22.0197	53.1881	51.9934	
1218	3.5035	49.865	20.79936	52.3851	44.0248	
1219	9.49308	46.7984	63.10877	38.0655	55.9785	
1220	10.51505	42.1387	73.01233	26.1768	38.9215	
1221	8.2495	21.742	99.31634	23.2681	28.6756	
1222	7.9354	22.2437	63.85628	13.3151	18.2947	
1223	14.4214	41.7202	46.30889	57.7439	22.2016	
1224	24.1117	70.9277	60.19392	60.8579	25.904	
1225	17.1228	76.429	54.53422	61.6726	57.8692	
1226	10.9516	88.0259	48.34212	32.98035	64.0487	
1227	9.35632	26.42905	70.44129	40.2798	36.9326	
1228	6.58111	44.8976	38.47188	54.4137	50.925	
1229	39.2628	37.223	8.940879	59.1467	62.3603	
1230	6.26673	50.8316	9.689738	100	59.3125	
1231	16.5683	62.4015	16.94326	100	60.9363	
1232	84.3618	31.932	46.66838	46.1842	67.8418	
1233	19.8519	13.3462	70.39508	7.33824	76.6756	
1234	29.6305	11.9609	62.40542	13.5239	19.45605	
1235	9.09243	11.5683	48.37109	18.8138	9.4352	

Chainage	1975	1990	2000	2010	2016	Remarks
1236	10.5697	36.8796	31.56128	52.5203	28.1699	
1237	10.6509	64.3264	29.32348	61.6011	66.342	
1238	10.3944	70.65	22.20365	94.5098	72.1224	
1239	16.1751	47.1754	28.51681	42.6716	46.1622	
1240	5.1419	33.6405	29.24368	36.3695	42.3665	
1241	11.6649	25.2693	22.82734	20.6963	29.9409	
1242	15.476	23.742	29.36237	29.4625	21.087	
1243	4.136025	34.6775	80.63105	29.1863	26.1132	
1244	27.04005	21.159	71.60842	30.9705	32.3514	
1245	16.1647	50.4287	17.12762	42.402	36.6329	
1246	8.29435	21.30465	60.24754	38.12	18.9417	
1247	20.1752	45.7049	75.93147	28.5228	22.71515	
1248	16.6834	32.35495	68.51433	37.777	27.9237	
1249	15.18625	47.5054	62.04638	49.3977	29.41875	
1250	11.726	53.4241	56.22607	61.3791	46.1019	
1251	3.8037	65.0125	58.43901	44.4899	68.5002	
1252	3.66376	61.8514	61.31339	57.3997	63.3334	
1253	9.8431	59.7441	49.14432	39.1403	21.59985	
1254	16.8038	53.3742	58.56116	48.3378	22.6123	
1255	10.6848	56.6919	86.14715	59.3981	47.8945	
1256	11.3045	63.9255	53.08683	66.0384	73.4391	
1257	17.3372	57.3502	45.52347	51.2633	100	
1258	8.31007	65.6256	33.03409	59.2297	100	
1259	18.3644	73.7154	61.50226	80.7163	100	
1260	1.90274	39.9992	55.08494	22.57045	50	
1261	1.53905	41.8088	53.19648	16.4891	17.9425	
1262	0.71919	38.151	63.34707	27.2266	21.5172	
1263	1.82509	62.6132	30.70737	63.1024	28.3847	

Chainage	1975	1990	2000	2010	2016	Remarks
1264	1.462065	62.8847	59.45039	61.4311	72.0407	
1265	1.041645	55.5406	65.87148	73.636	63.615	
1266	2.091543	42.2518	64.67931	50.3996	74.3034	
1267	2.55718	19.0726	39.09126	45.7532	63.3424	
1268	7.27395	50.9398	32.9528	55.3895	33.2853	
1269	3.81029	61.1774	80.16762	69.89	60.3049	
1270	7.7647	72.1047	49.71467	71.7305	78.2351	
1271	14.12375	32.8363	30.08334	52.43	72.3155	
1272	7.40395	43.8293	35.62614	33.8029	51.1842	
1273	13.2588	44.2988	46.17174	42.9993	49.2601	
1274	6.412825	27.793	65.24072	25.3015	43.3677	
1275	15.05135	28.9511	75.08386	25.431	26.2044	
1276	9.57805	41.8151	50.15306	36.4276	25.0011	
1277	60.8668	59.0385	48.6061	62.4543	37.3039	Bagha
1278	10.49045	68.5534	14.35777	100	56.293	
1279	5.958	68.9892	24.35885	100	84.243	
1280	13.5695	26.32713	24.9052	24.94445	85.6372	
1281	80.0667	22.1743	23.73606	35.5849	32.3235	
1282	100	23.1651	76.92304	26.9524	25.41855	
1283	37.8636	27.2865	58.46694	21.5519	15.6738	
1284	29.9509	30.2612	51.12869	23.7162	28.5748	
1285	100	29.5859	49.069	17.3438	24.5093	
1286	16.3797	77.9624	45.88143	41.4768	36.4392	
1287	18.2147	59.9757	27.03599	48.5623	69.6097	
1288	60.0489	62.0644	32.86868	61.5617	64.8231	
1289	14.4601	48.0913	40.28608	46.0212	63.1952	
1290	20.162	42.302	71.49353	63.838	60.4609	
1291	26.4853	26.6448	55.84957	38.8839	27.2203	

Chainage	1975	1990	2000	2010	2016	Remarks
1292	21.0774	42.5324	47.39762	19.2342	39.1346	
1293	11.50185	50.4582	38.77911	26.3849	47.9679	
1294	26.6126	71.2791	70.15199	67.2731	69.3193	
1295	8.73628	52.9806	90.39782	60.7546	70.1163	
1296	19.3076	43.7267	45.29225	55.744	58.2926	
1297	22.6941	60.2792	47.80696	44.8155	29.0544	
1298	23.6528	77.3328	64.54976	77.3382	58.9243	
1299	24.7892	92.8269	62.47415	100	100	
1300	16.3772	36.5875	57.73593	44.964	68.1731	
1301	8.97893	64.3314	43.78229	41.0732	41.9433	
1302	9.23036	71.7711	26.05685	100	100	
1303	29.1939	53.5036	33.32116	86.5963	66.837	
1304	15.2265	33.938	61.69671	78.6924	67.2415	
1305	63.1729	20.768	68.14028	49.3154	49.6892	
1306	60.4748	40.6525	49.40493	22.2212	34.0847	
1307	100	46.0893	64.81319	43.3709	31.3649	
1308	100	55.5032	46.09462	35.5747	55.6392	
1309	44.4247	75.1401	41.06494	37.7874	47.5361	
1310	42.295	63.292	30.57663	43.7647	55.1297	
1311	67.4968	60.6934	32.92476	67.4651	62.704	
1312	58.4109	45.1674	53.69374	22.9453	36.9447	
1313	100	49.87815	55.39095	28.2277	31.5338	
1314	54.0204	49.8801	50.41946	35.7901	34.8749	
1315	22.1346	49.8276	50.67534	44.0946	35.9739	
1316	100	49.8152	27.32458	34.1367	47.0352	
1317	51.5268	49.84385	52.34364	56.3735	25.6641	
1318	23.3175	49.8054	27.25362	45.8207	51.9123	
1319	15.2162	36.086	23.63077	23.2973	24.7296	

Chainage	1975	1990	2000	2010	2016	Remarks
1320	25.7539	38.18195	37.63315	27.5069	22.3369	
1321	100	68.6336	48.23318	36.2462	30.9494	
1322	100	57.7572	47.54131	32.8008	25	
1323	100	46.5378	65.87901	37.2173	27.5766	
1324	100	49.4125	73.74895	47.0829	25.10495	
1325	100	53.3205	89.36304	54.9613	50.8421	
1326	100	65.343	42.40036	46.3327	60.3412	
1327	100	97.9965	20.49867	55.9162	45.0348	
1328	100	98.4024	25.25927	63.2205	83.1678	
1329	99.999	93.9645	41.8325	38.1326	100	
1330	100	26.7073	36.59486	37.8006	38.18965	
1331	100	37.8793	45.5559	26.4902	32.235	
1332	100	37.9997	60.42477	29.3081	21.582	
1333	100	42.045	63.12607	27.5962	24.6876	
1334	100	55.1904	63.55243	32.5523	34.0016	
1335	99.9991	62.5975	78.46046	45.7281	46.7581	
1336	100	100	100	60.6709	54.8285	
1337	100	91.3646	72.79851	100	66.7665	
1338	100	93.5126	55.4299	90.9343	67.1254	
1339	100	49.96	37.90589	82.3533	72.2447	
1340	100	49.8568	39.37763	57.4625	84.536	
1341	100	49.2896	33.47571	38.8989	62.5189	
1342	100	33.31953	100	24.249	29.3769	
1343	100	14.4625	57.4271	37.8301	27.858	
1344	100	29.3169	45.14175	17.1177	23.7204	
1345	100	40.1772	71.8246	12.3552	24.6814	
1346	100	81.1506	89.32433	47.6163	49.5991	
1347	100	58.6882	65.50048	91.3029	65.5151	

Chainage	1975	1990	2000	2010	2016	Remarks
1348	49.99995	42.5261	18.88791	40.0356	50.174	
1349	50	80.7265	25.96317	26.0691	42.7019	
1350	100	40.8546	64.31224	100	37.9024	
1351	100	33.3341	54.73058	100	37.79795	
1352	100	24.4823	42.06466	38.0903	16.0677	
1353	100	65.6565	43.71567	15.3645	19.265	
1354	100	58.9574	53.14572	33.1895	44.9291	
1355	100	42.7222	62.709	56.5943	60.4213	
1356	100	46.4682	47.09446	51.471	35.3532	
1357	100	60.9305	46.94676	40.8053	39.2409	
1358	100	74.3869	50.32647	61.6093	42.6482	
1359	100	75.9281	68.7677	100	50.7482	
1360	100	52.0136	64.02115	78.8896	78.3972	
1361	100	45.8052	74.67987	53.0778	61.5504	
1362	100	70.4468	100	45.5578	42.2725	
1363	100	54.4494	51.04249	45.846	69.7365	
1364	100	66.2677	47.71936	59.8716	46.1845	
1365	100	98.3057	43.92964	62.6559	50.6573	
1366	100	83.1695	57.98745	100	58.7623	
1367	100	57.5462	39.19943	86.5983	54.678	
1368	99.9996	18.6676	31.08411	54.5661	40.5104	
1369	100	53.8955	23.04455	79.7653	26.01305	
1370	100	48.0247	17.83539	86.6093	70.7562	
1371	50	35.9473	19.91839	51.5201	32.41725	
1372	100	33.8157	31.89188	51.8658	25.972	
1373	100	16.0089	46.11492	12.3466	31.0056	
1374	100	17.8411	45.8413	13.9544	14.3402	
1375	100	48.2699	44.05809	15.146	15.3032	

Chainage	1975	1990	2000	2010	2016	Remarks
1376	100	61.6051	32.32768	28.411	26.7055	
1377	100	60.0249	39.63867	58.3177	31.1861	
1378	99.9994	50.8738	46.29668	34.8624	38.8888	
1379	100	42.881	57.06876	43.2416	26.3531	Paligaon
1380	100	42.1305	58.77542	41.2936	8.7541	
1381	100	48.7524	82.09141	41.9393	31.0451	
1382	100	65.1133	69.62689	42.926	28.2563	
1383	100	64.1702	61.41747	44.9021	32.4151	
1384	100	98.8824	77.29198	53.6844	49.1194	
1385	100	98.9801	100	65.4623	60.8055	
1386	100	98.8679	100	53.0091	61.6052	
1387	100	99.1346	100	57.2309	34.85025	
1388	100	49.56485	100	73.6903	66.4339	
1389	100	24.82465	100	100	20.5007	
1390	100	49.704	50	86.3972	22.7054	
1391	100	49.71525	100	47.07235	19.0081	
1392	100	49.70115	100	100	19.1864	
1393	99.9999	49.71745	100	50	19.6381	
1394	100	33.1045	100	100	18.4362	
1395	100	49.4634	100	50	24.4428	
1396	100	98.8101	85.51551	100	16.03335	
1397	100	98.6057	66.73563	50	84.4684	
1398	100	89.8619	64.85622	100	94.0218	
1399	99.9999	76.9227	67.67427	100	84.0964	
1400	100	55.3511	84.42332	100	81.3542	
1401	100	64.1596	71.51353	100	68.233	
1402	100	78.3233	100	82.4791	75.1506	
1403	100	99.7323	100	68.3147	77.2871	

Chainage	1975	1990	2000	2010	2016	Remarks
1404	100	24.8488	100	73.8076	89.8105	
1405	100	48.6842	100	63.6019	77.9031	
1406	100	74.5991	73.39474	100	33.33333	
1407	100	99.9514	55.98515	94.4553	89.6394	
1408	100	50	64.96468	94.6333	54.6554	
1409	100	49.9865	41.11461	76.1355	58.0559	
1410	100	49.57555	44.66735	96.3396	62.6116	
1411	100	56.8911	58.49875	97.2306	54.5957	
1412	100	43.7239	79.80353	46.642	79.2629	
1413	100	44.4761	100	100	59.3612	
1414	100	67.6586	100	49.864	38.8135	
1415	100	99.4088	35.63489	50.7492	41.5198	
1416	100	99.5102	79.29222	66.1635	67.9102	
1417	100	99.2888	100	100	100	
1418	100	42.7056	86.121	100	50	
1419	100	97.8673	77.57979	100	50	
1420	100	86.8982	42.4369	50	100	Prayagraj
1421	99.999	71.4661	68.93909	100	100	
1422	100	31.2297	87.95129	100	100	
1423	100	51.4128	63.9672	100	79.9356	
1424	100	98.3532	81.95422	100	70.5241	
1425	100	98.8284	72.02377	93.8501	62.2796	
1426	85.9153	99.1989	77.17842	88.4988	83.9504	
1427	44.9824	92.2049	40.21127	84.7926	85.0089	
1428	59.3032	62.3686	68.20769	78.259	73.8911	
1429	57.0882	78.3355	85.53784	82.778	73.8726	
1430	73.3062	78.2625	100	78.2801	58.6515	

Examination of the above table leads to the following conclusions:

- In the upper Himalayan segment of the river, significant braiding is observed downstream of Dak Pathar. In Yamunagar district of Haryana at Hathnikund, very low values of PFI have been observed. This is more likely the impact of barrage gate operations which diminishes as we move towards downstream. After 15 km in downstream direction, braiding phenomenon dilutes and river flows as single braid within its channel area.
- In the upper segment of the reach around Panipat and Baghpat, moderate to low braiding is observed. In the Delhi segment, very less braiding is observed, it is most likely due to the regulations of flows by Wazirabad, ITO and Okhla Barrage. Also, anthropogenic activities around the floodplains of Yamuna and river training works for flood control have restricted river activity to minimum level. Though, domestic and industrial wastewaters generated by Delhi NCR contributes to Yamuna at the downstream of Okhla barrage, no significant patterns have been noticed there.
- In the lowest segment of the river i.e., downstream of Etawah, moderate braiding is observed from chainage 1122 uptil 1280 for the year 1975. In the same year, a very high braiding i.e., low PFI values have been noticed for the chainage starting from 1260 upto 1270. The satellite images have revealed that formation of an ox-bow have started around the year 1975 leading to high braiding. Development of ox-bow lake and its cut off from the main channel in the next couple of years resulted in a straight river course with less to no braiding. After this point the river assumes an insignificant braiding pattern and flows as a single braid up to its confluence with Ganga at Prayagraj.

For more visual clarity, various PFI charts have been plotted (Figure 11-3 to Figure 11-13) for every 50 km chainage from upstream point of Yamunotri to downstream uptil Prayagraj for the years 1975, 1990, 2000, 2010 and 2016.

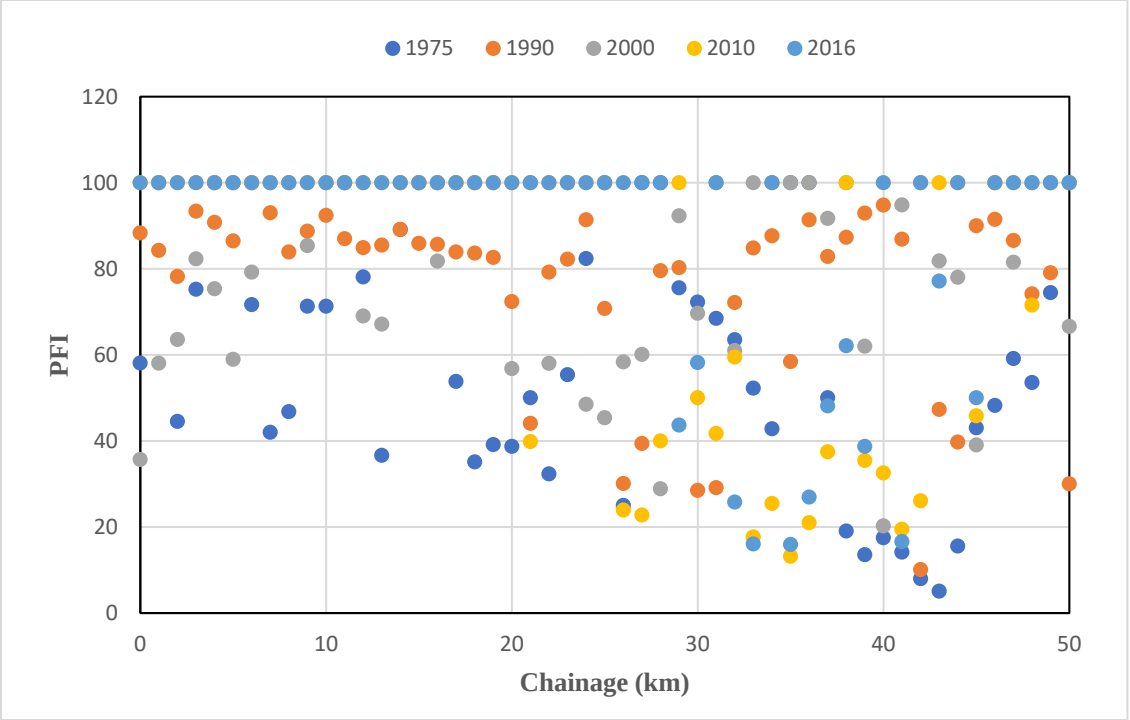


Figure 11-3: Plan Form Index of Yamuna river (chainage 0-50 km)

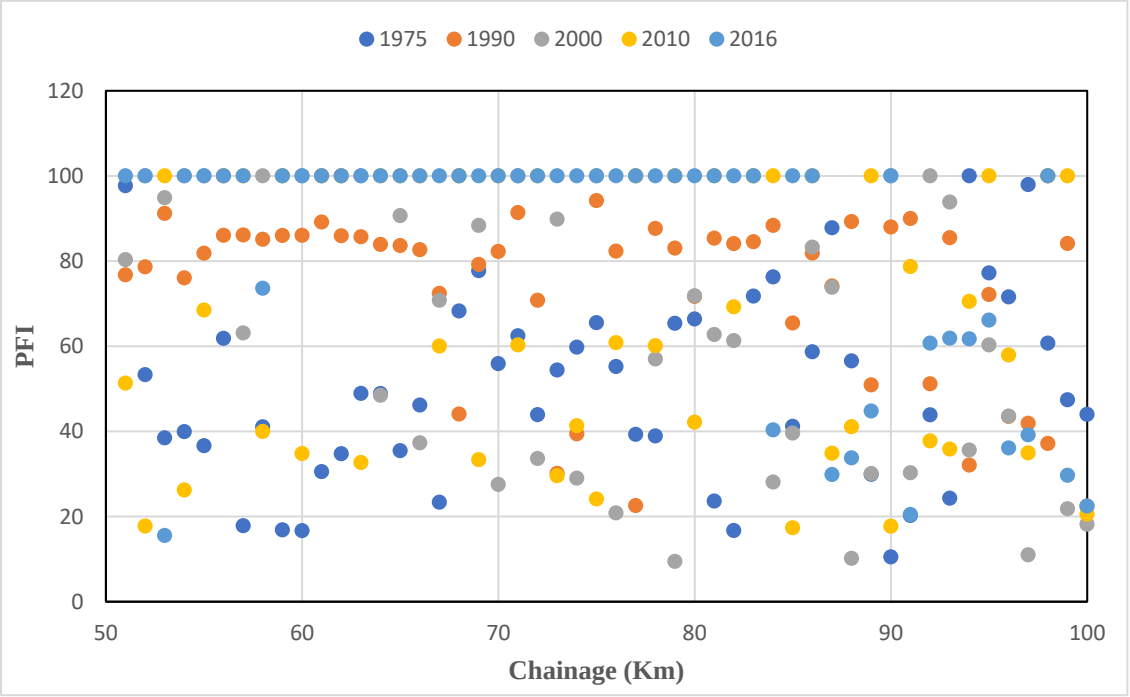


Figure 11-4: Plan Form Index of Yamuna river (chainage 50-100 km)

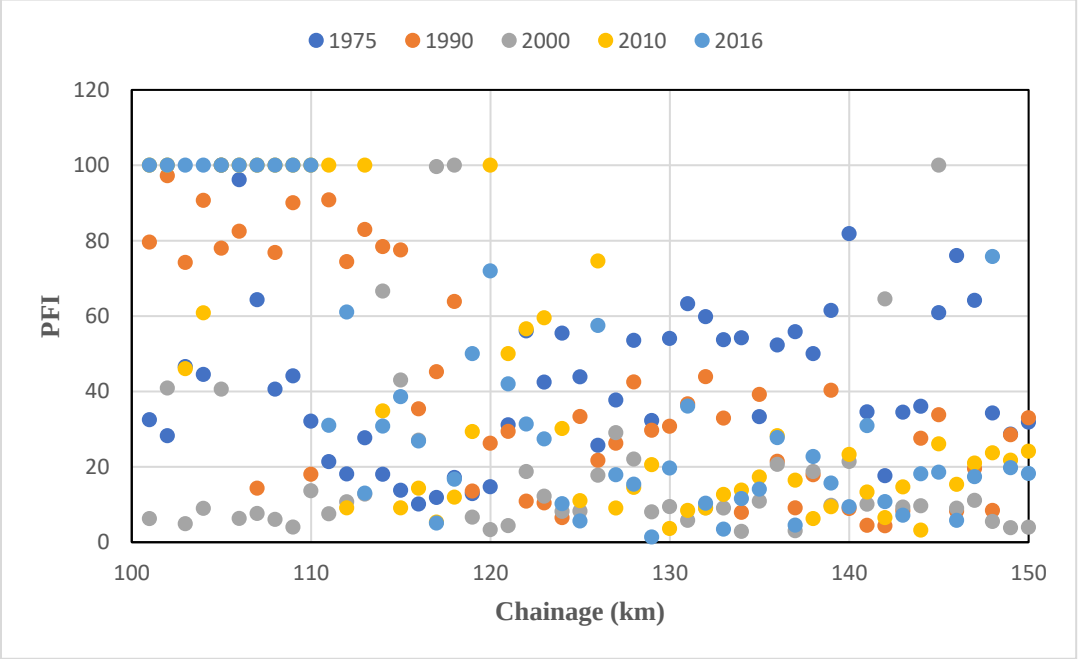


Figure 11-5: Plan Form Index of Yamuna river (chainage 100-150 km)

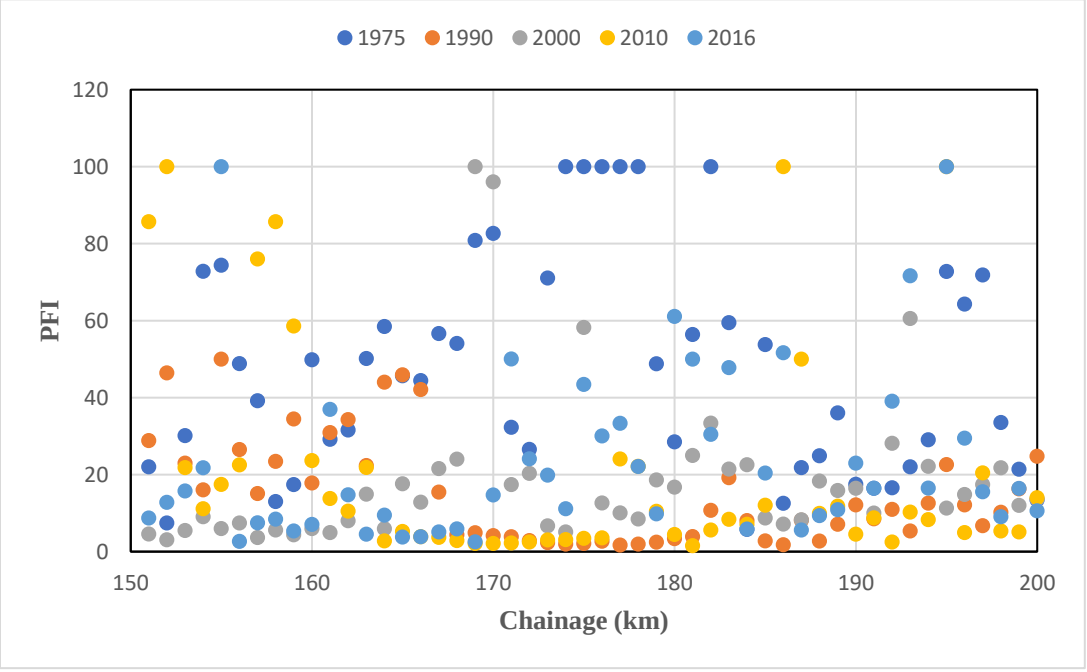


Figure 11-6: Plan Form Index of Yamuna river (chainage 150-200 km)

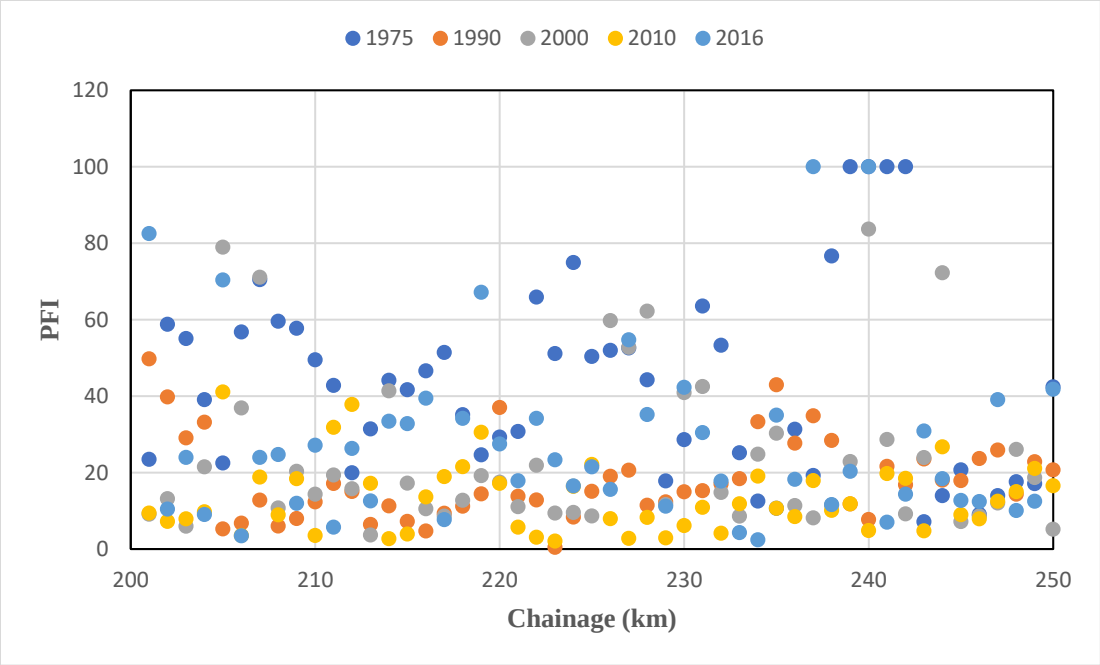


Figure 11-7: Plan Form Index of Yamuna river (chainage 200-250 km)

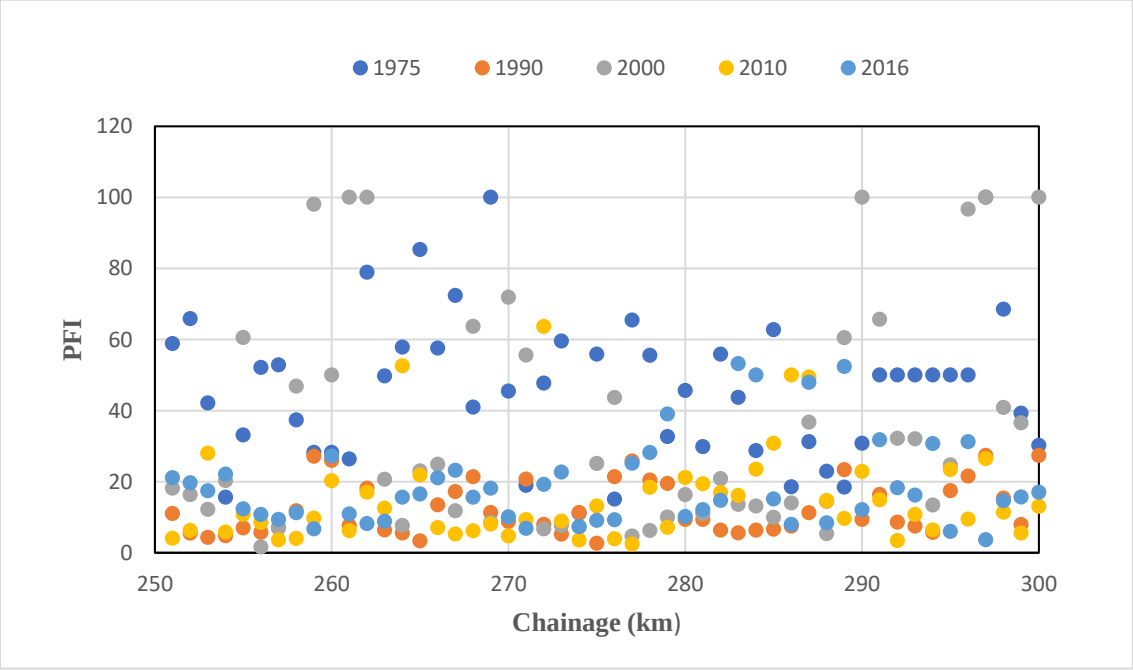


Figure 11-8: Plan Form Index of Yamuna river (chainage 250-300 km)

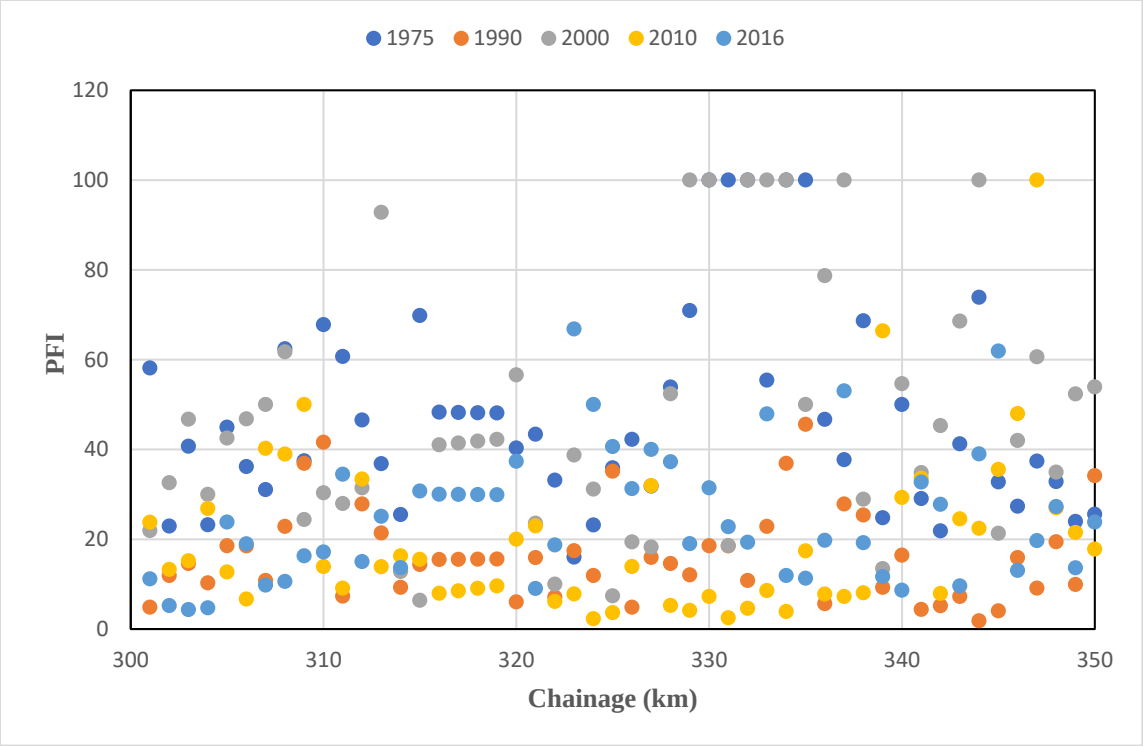


Figure 11-9: Plan Form Index of Yamuna river (chainage 300-350 km)

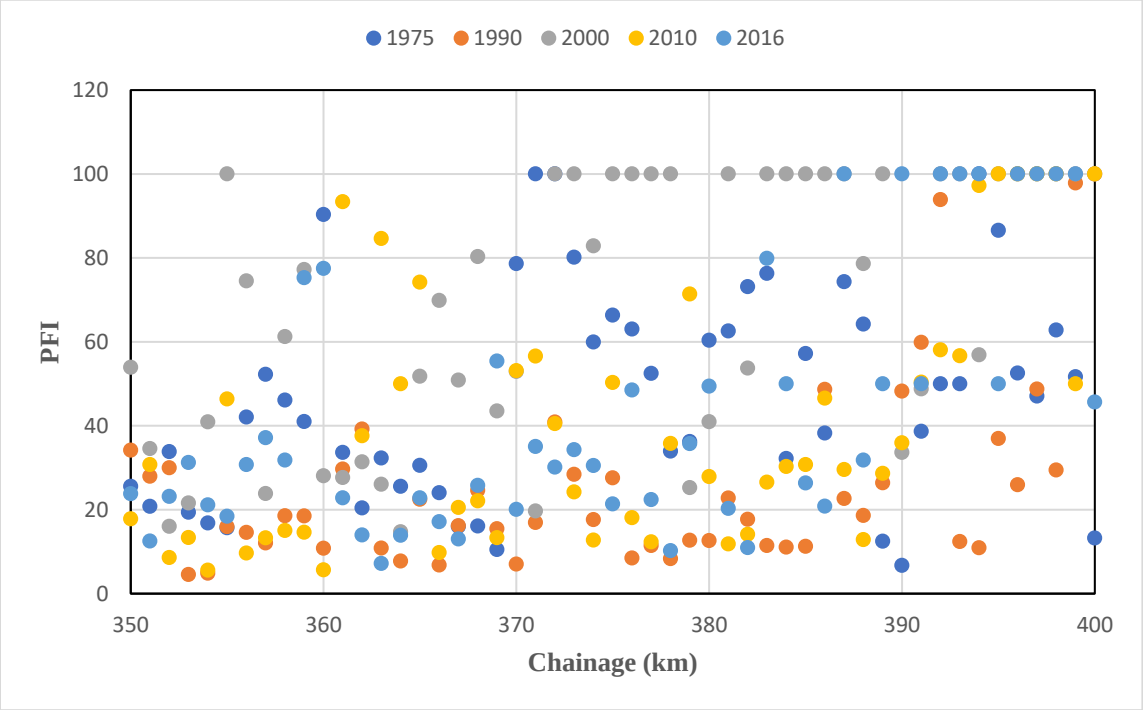


Figure 11-10: Plan Form Index of Yamuna river (chainage 350-400 km)

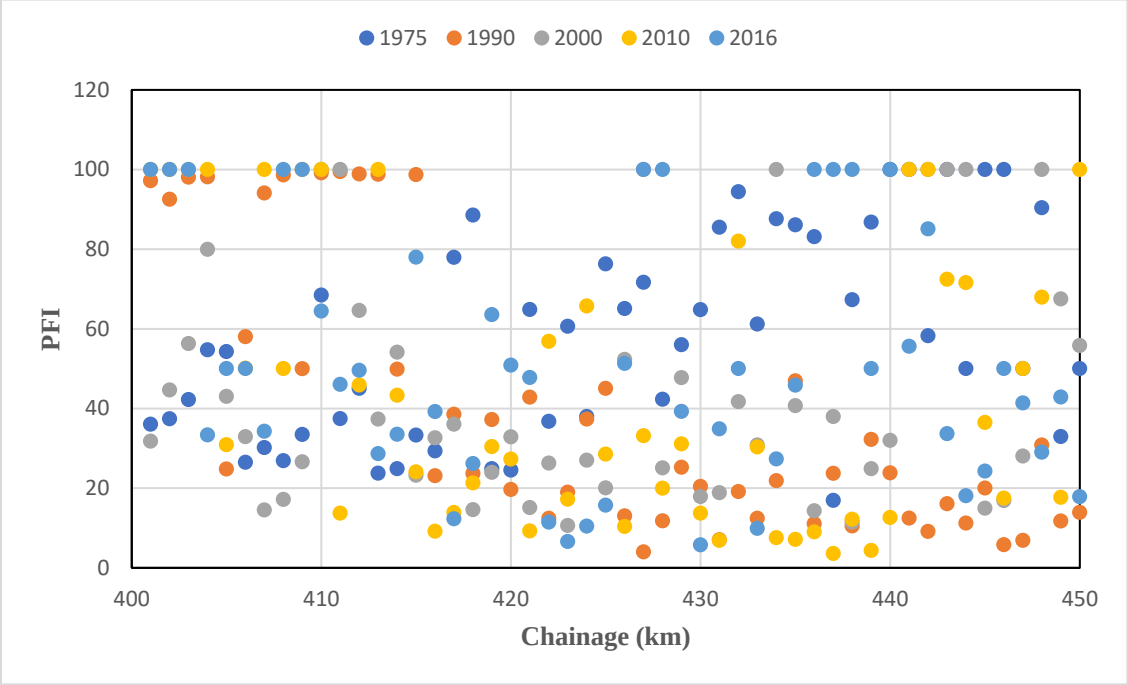


Figure 11-11: Plan Form Index of Yamuna river (chainage 400-450 km)

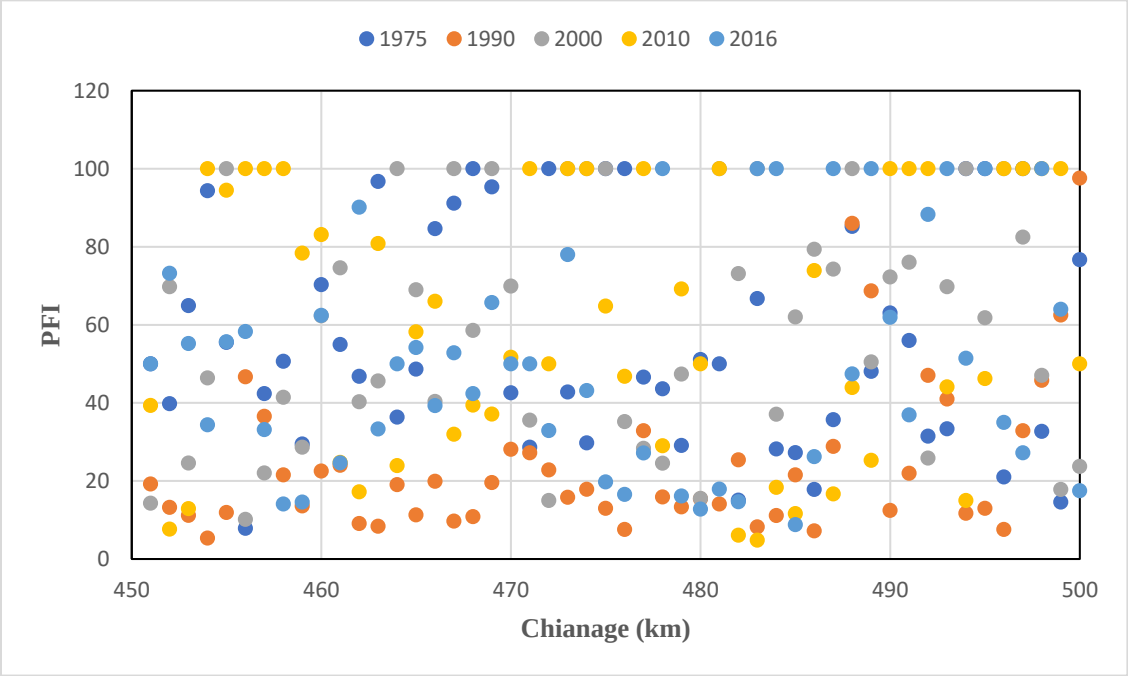


Figure 11-12: Plan Form Index of Yamuna river (chainage 450-500 km)

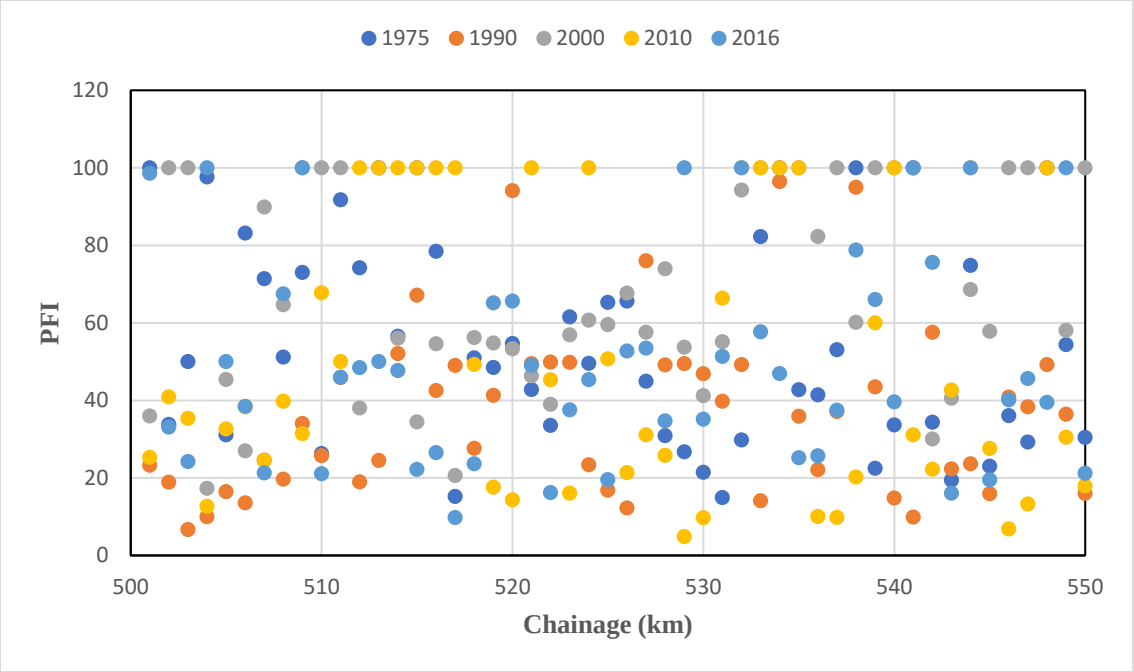


Figure 11-13: Plan Form Index of Yamuna river (chainage 500-550 km)

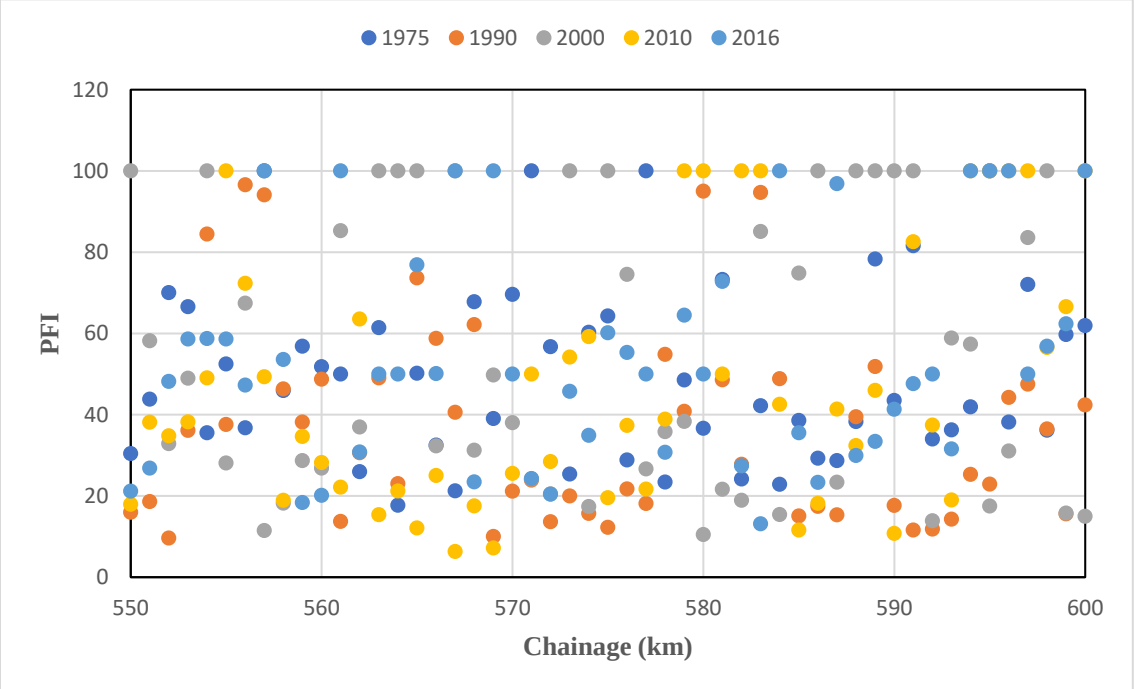


Figure 11-14: Plan Form Index of Yamuna river (chainage 550-600 km)

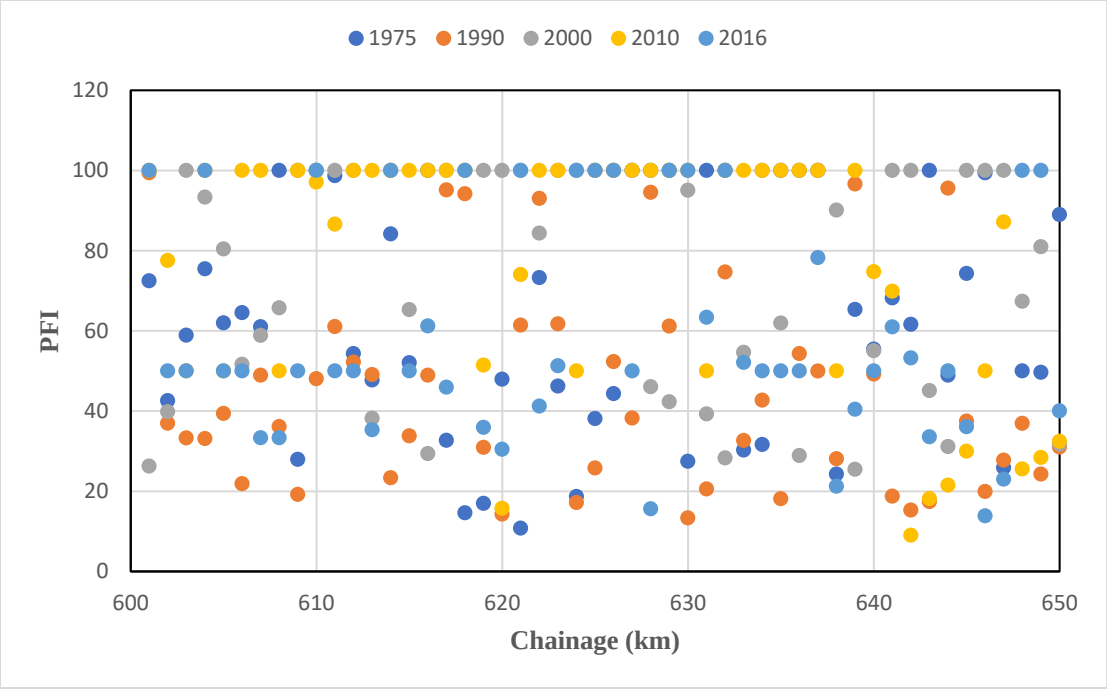


Figure 11-15: Plan Form Index of Yamuna river (chainage 600-650 km)

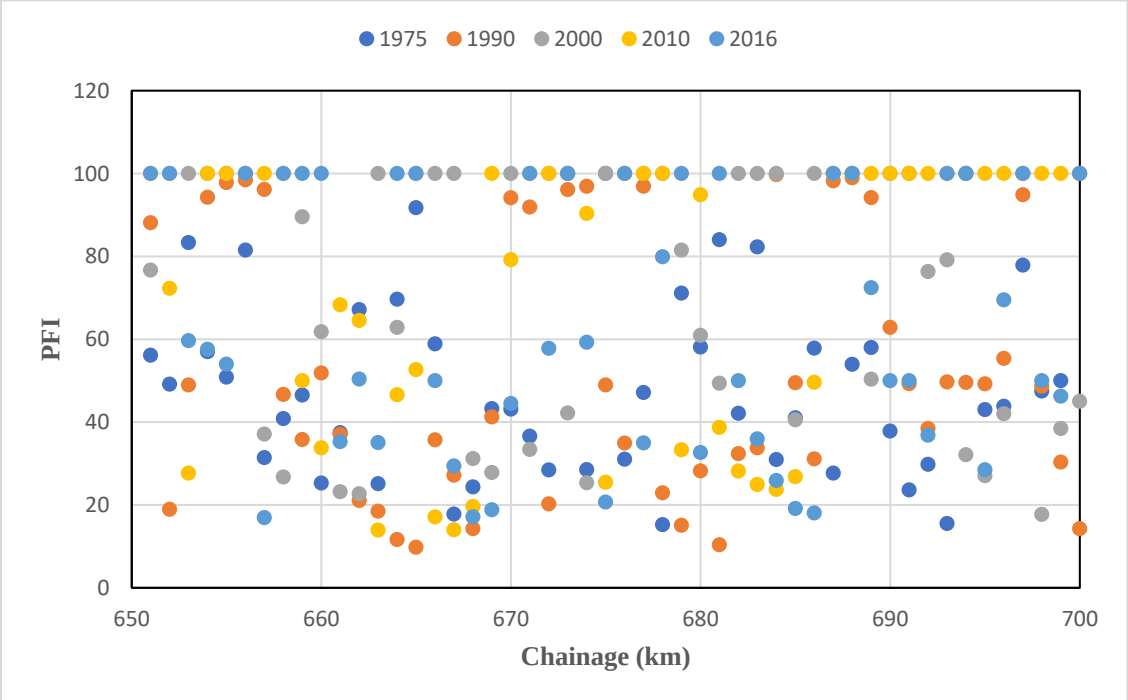


Figure 11-16: Plan Form Index of Yamuna river (chainage 650-700 km)

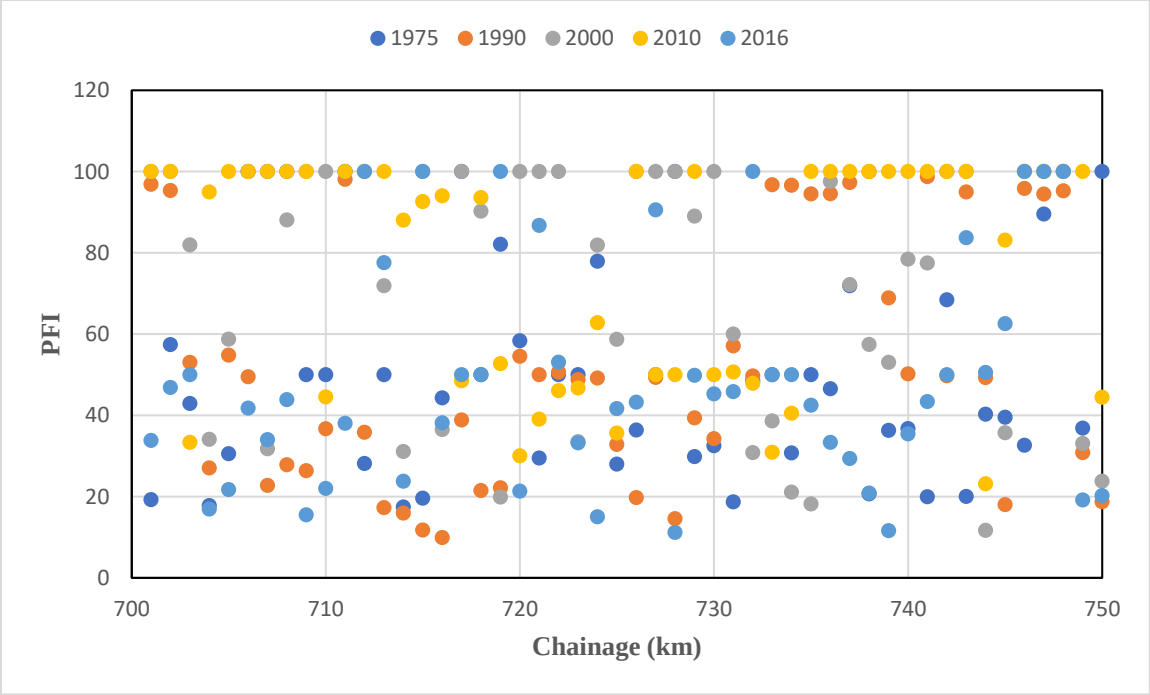


Figure 11-17: Plan Form Index of Yamuna river (chainage 700-750 km)

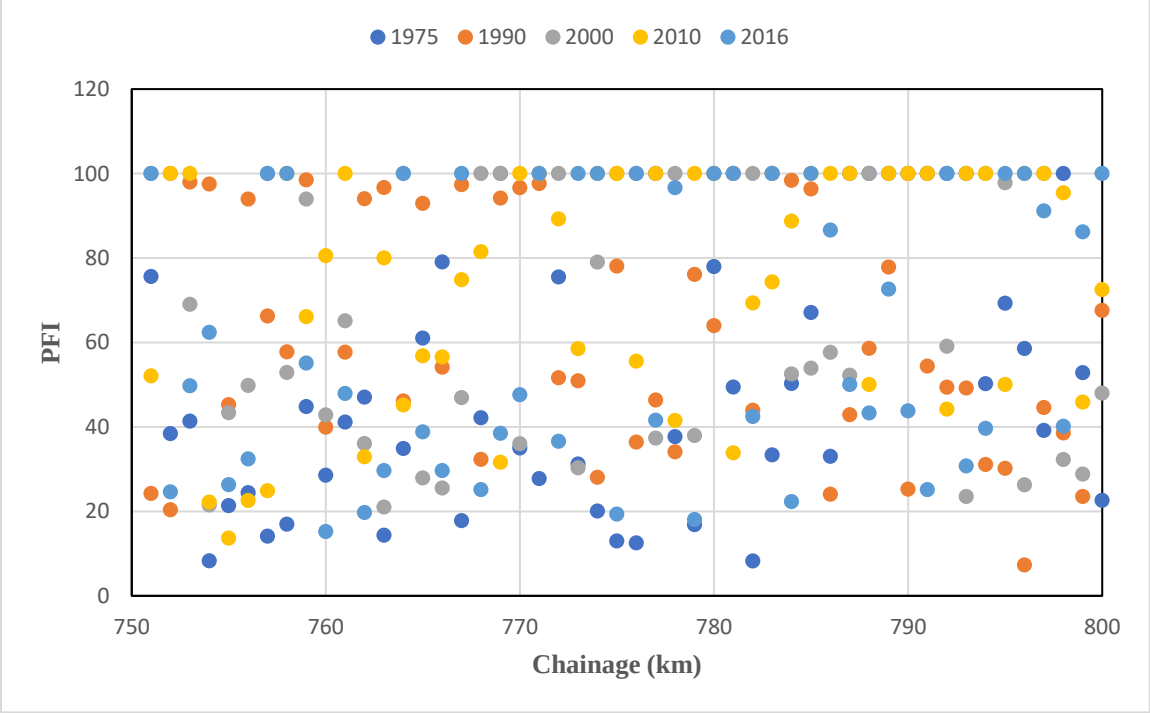


Figure 11-18: Plan Form Index of Yamuna river (chainage 750-800 km)

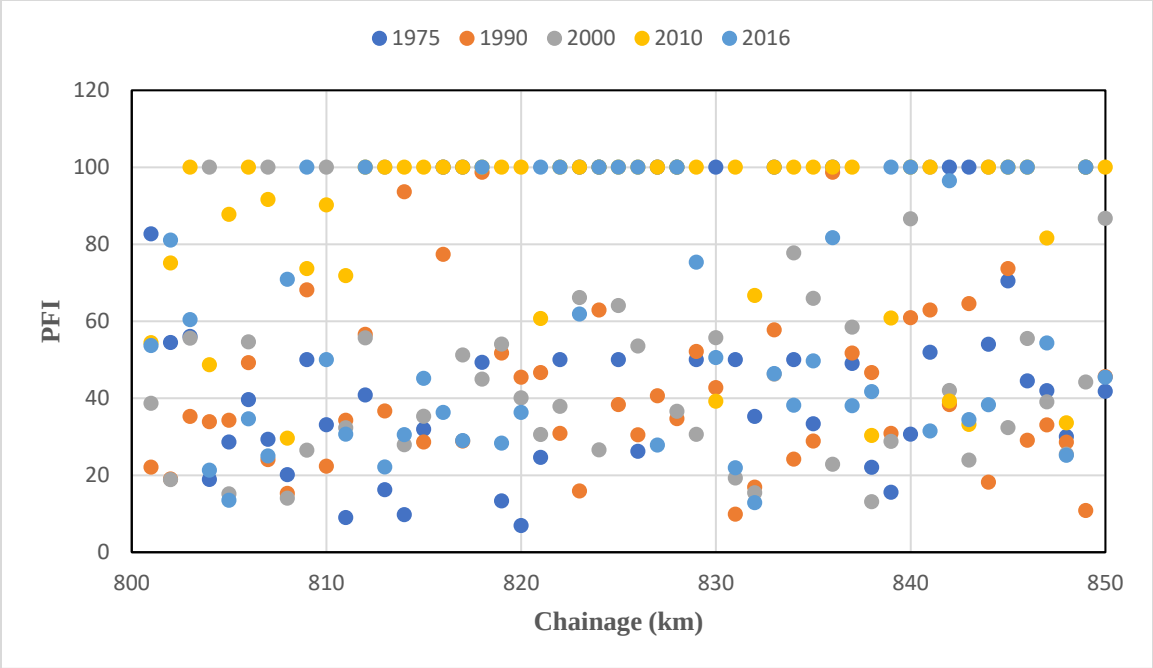


Figure 11-19: Plan Form Index of Yamuna river (chainage 800-850 km)

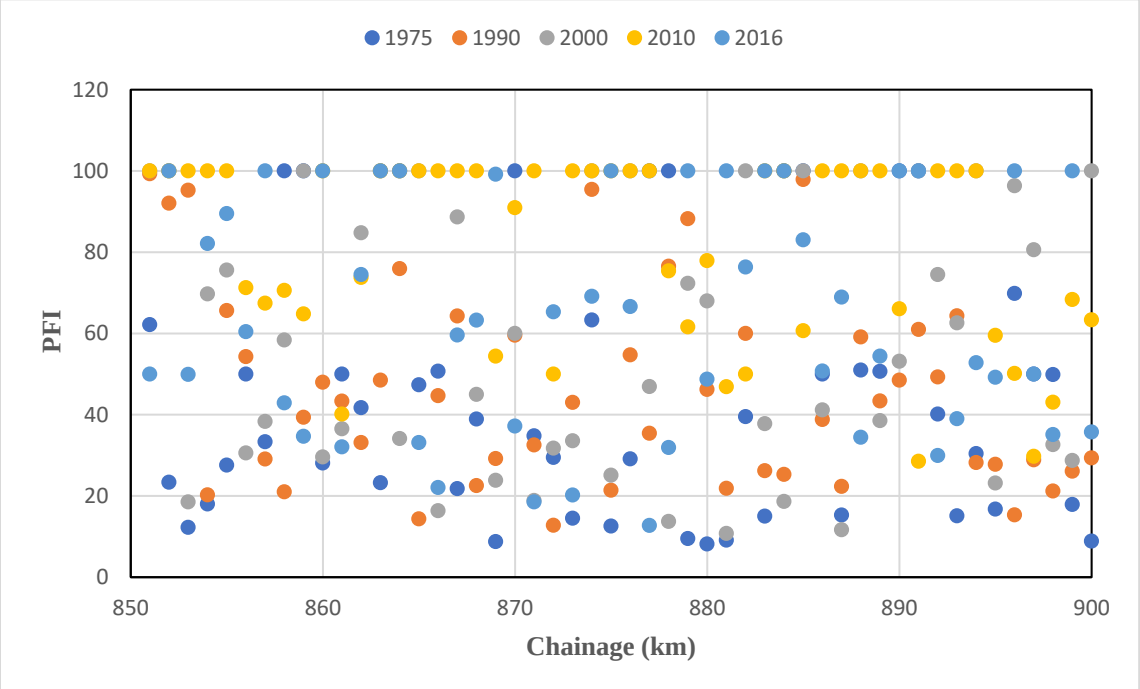


Figure 11-20: Plan Form Index of Yamuna river (chainage 850-900 km)

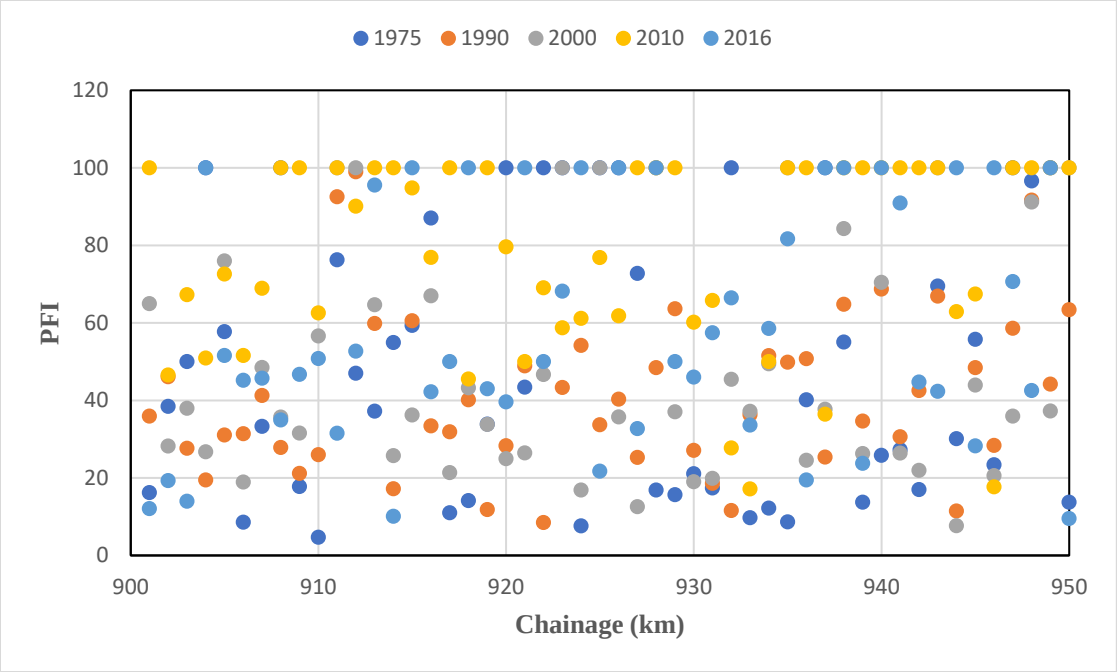


Figure 11-21: Plan Form Index of Yamuna river (chainage 900-950 km)

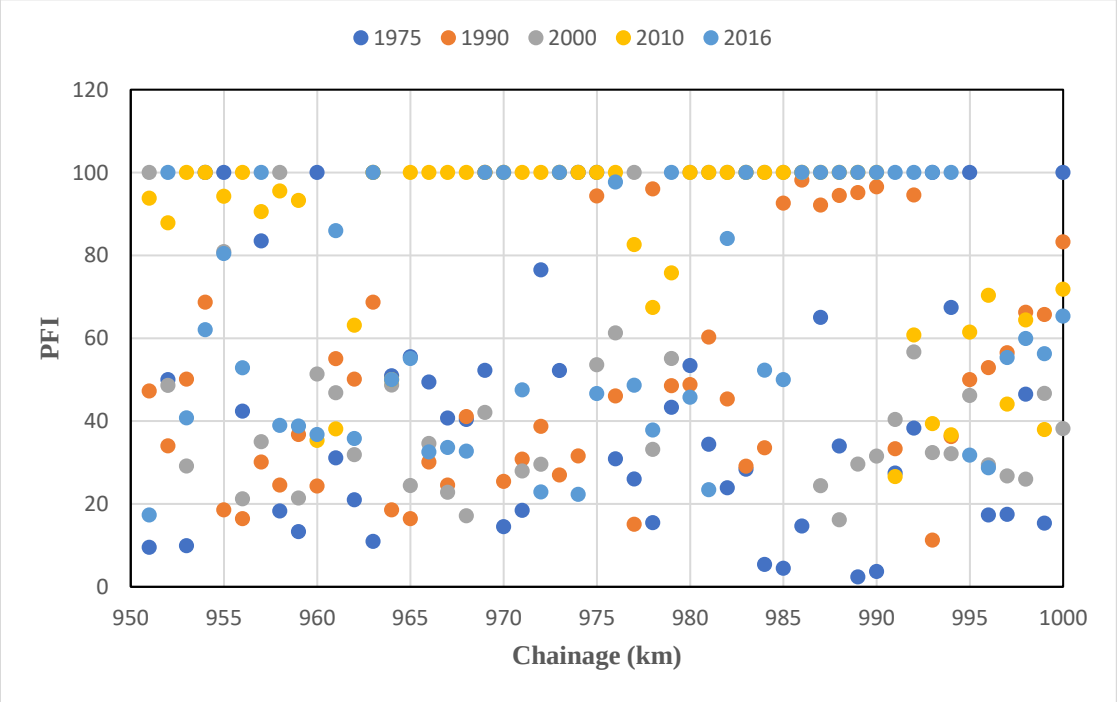


Figure 11-22: Plan Form Index of Yamuna river (chainage 950-1000 km)

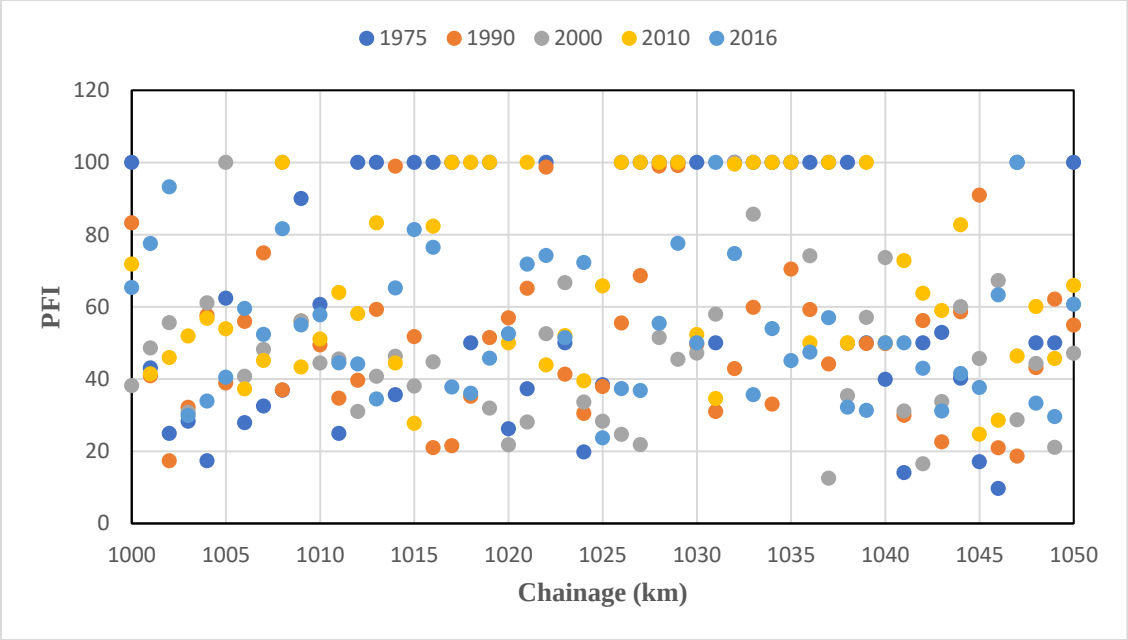


Figure 11-23: Plan Form Index of Yamuna river (chainage 1000-1050 km)

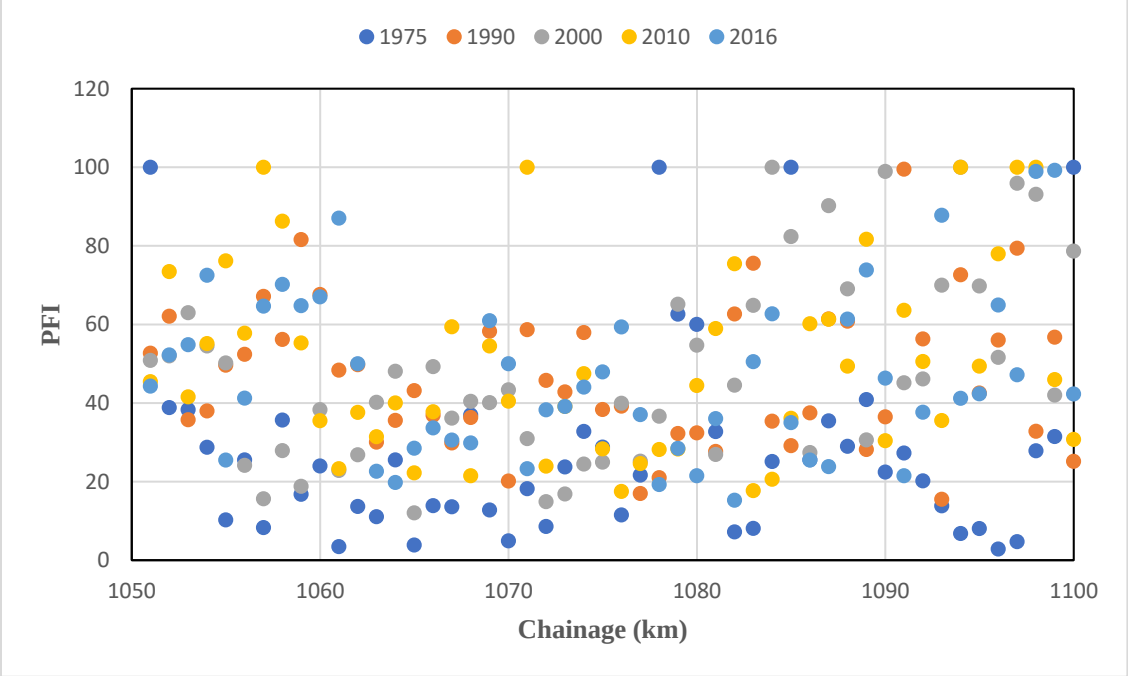


Figure 11-24: Plan Form Index of Yamuna river (chainage 1050-1100 km)

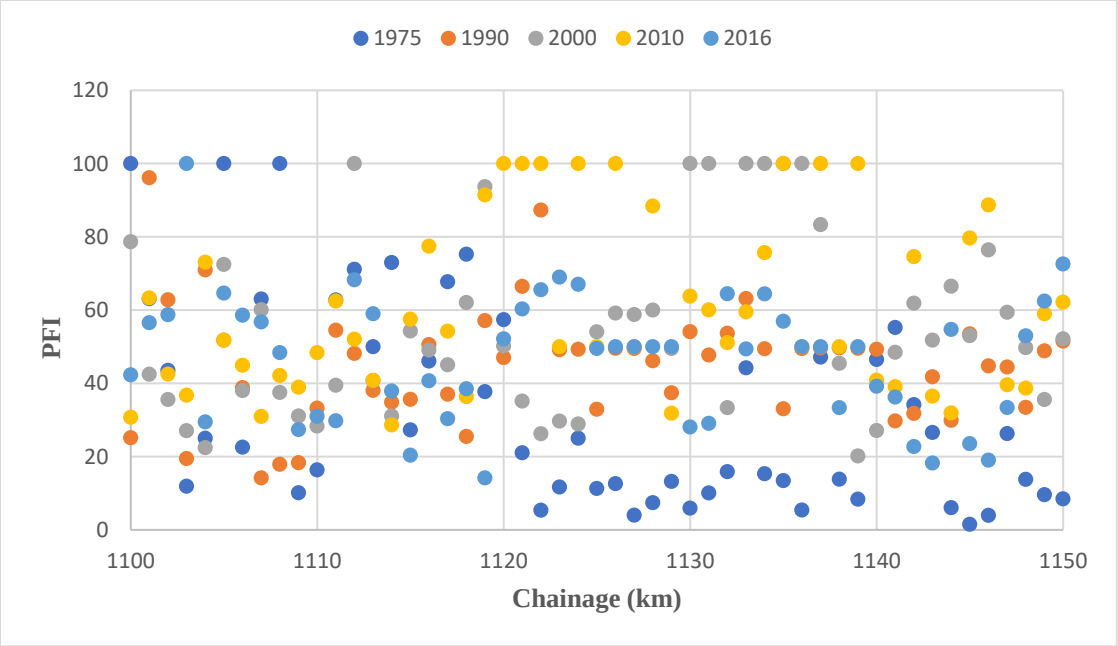


Figure 11-25: Plan Form Index of Yamuna river (chainage 1100-1150 km)

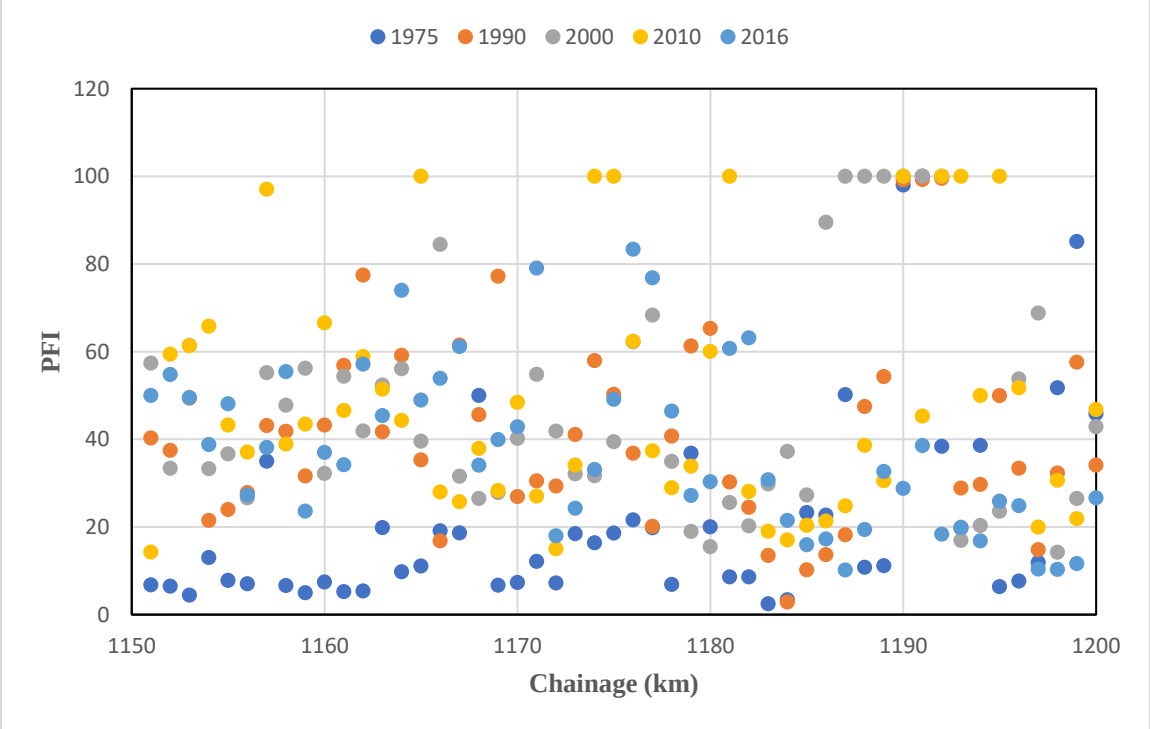


Figure 11-26: Plan Form Index of Yamuna river (chainage 1150-1200 km)

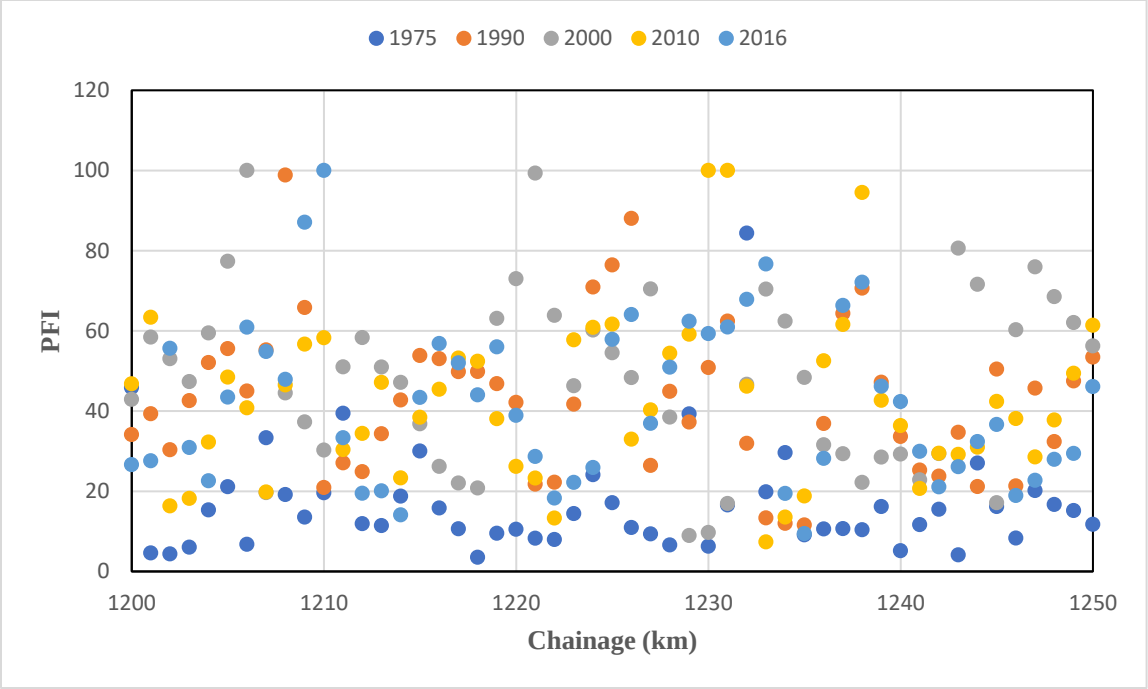


Figure 11-27: Plan Form Index of Yamuna river (chainage 1200-1250 km)

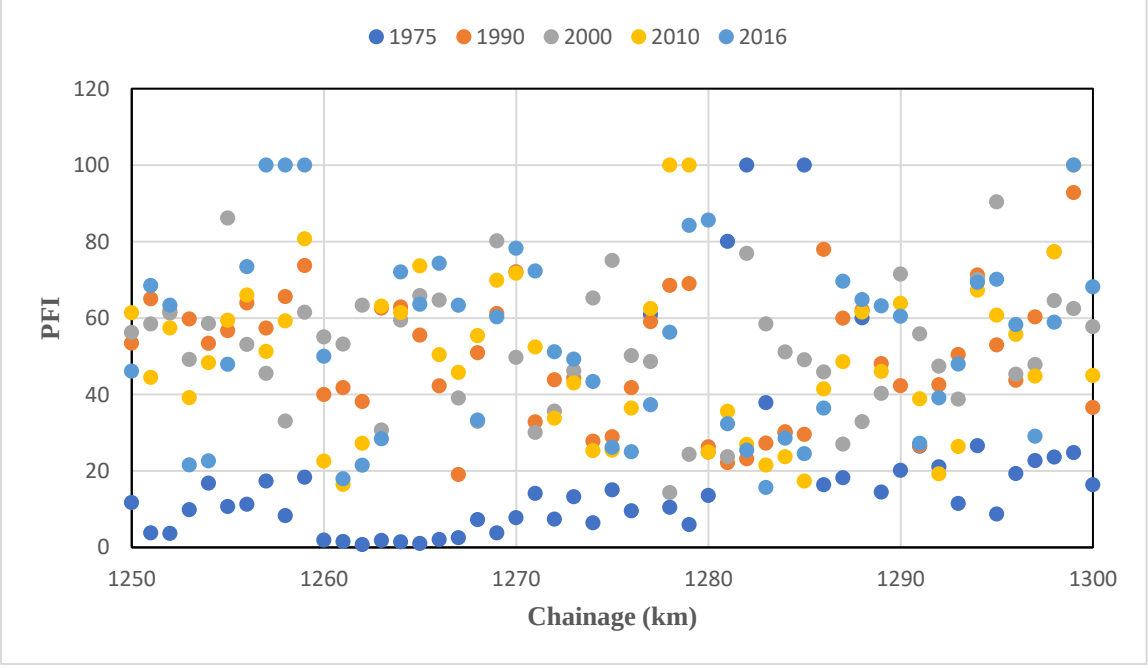


Figure 11-28: Plan Form Index of Yamuna river (chainage 1250-1300 km)

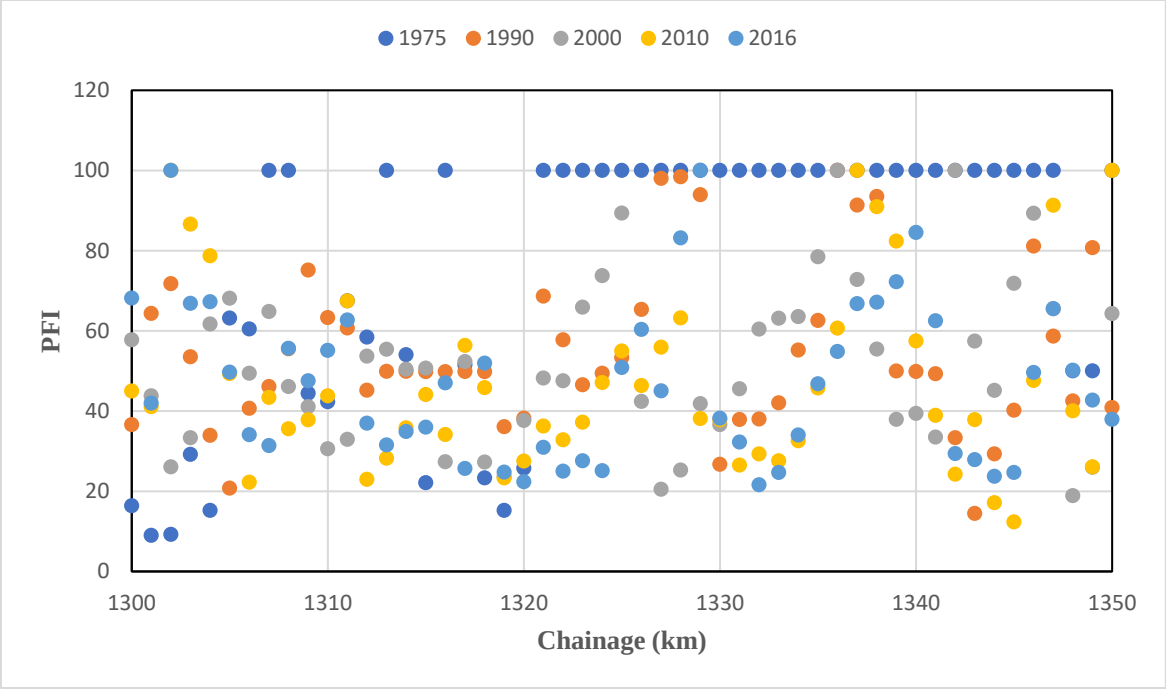


Figure 11-29: Plan Form Index of Yamuna river (chainage 1300-1350 km)

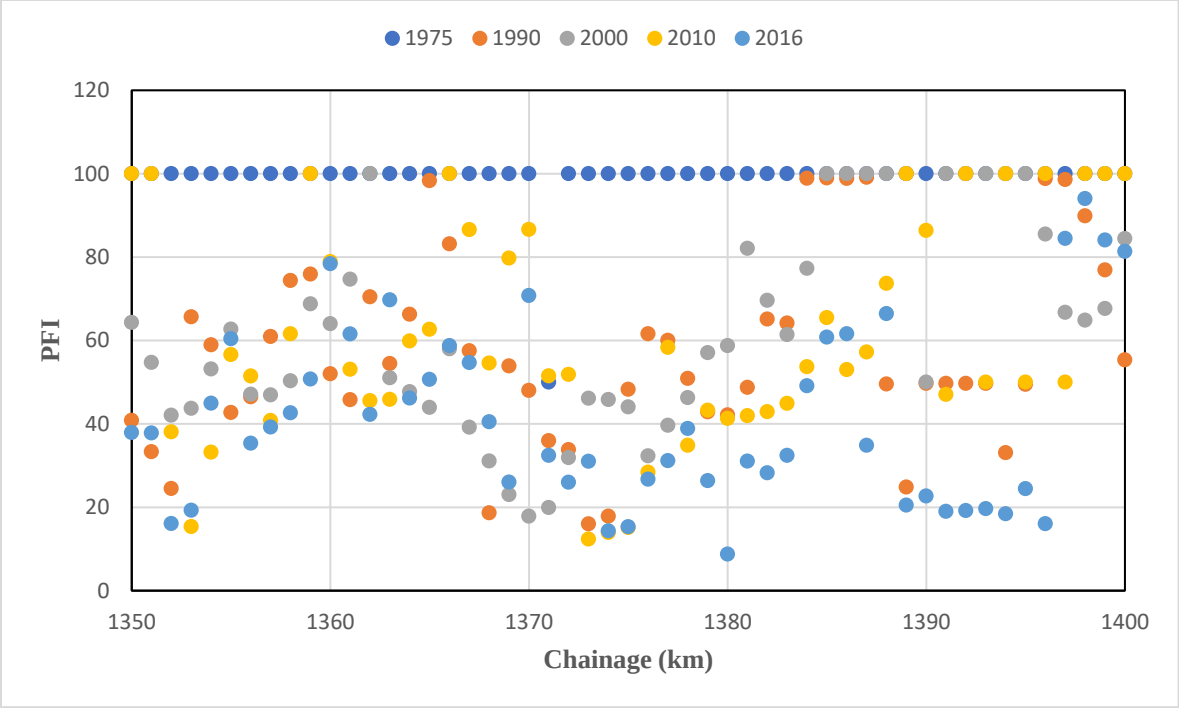


Figure 11-30: Plan Form Index of Yamuna river (chainage 1350-1400 km)

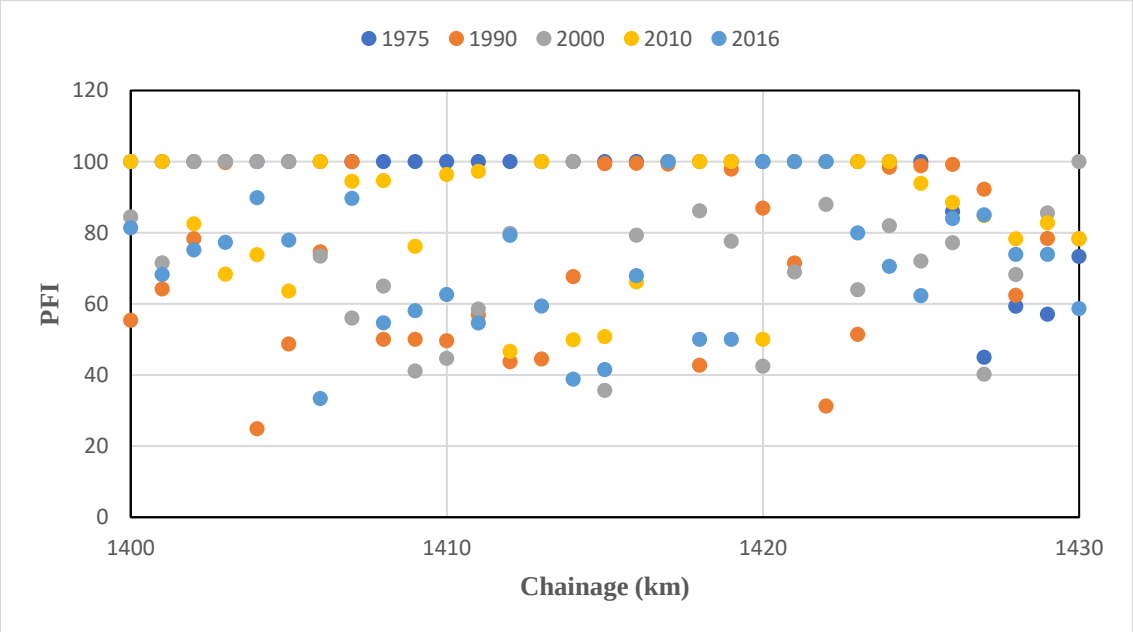


Figure 11-31: Plan Form Index of Yamuna river (chainage 1400-1430 km)

11.6 Understanding of River Course Dynamics

In the present study, river course dynamics has been analysed by recording the movement of channel centreline. The latter movement is recorded on a grid based template for an objective base reference as proposed by Parmar and Khosa (2017). Difference between distance of centrelines of two specific years (such as 1975-1990, 1990-2000, 2000-2010 and 2010-2016) from a predefined reference line and making the assessment of change at an interval of every 1 km. The reference line is drawn based on channel centreline of 1975. The difference in centreline is considered as the swing displacement in the river channel during the specified period. Figure 11-32 indicates river course dynamics in complete length of the River Yamuna from its origin to its confluence with the River Ganga. Detailed presentation of various segments are rearranged in separate graphs (Figure 11-33 to Figure 11-51) depicting only 50km reach of the river at a time.

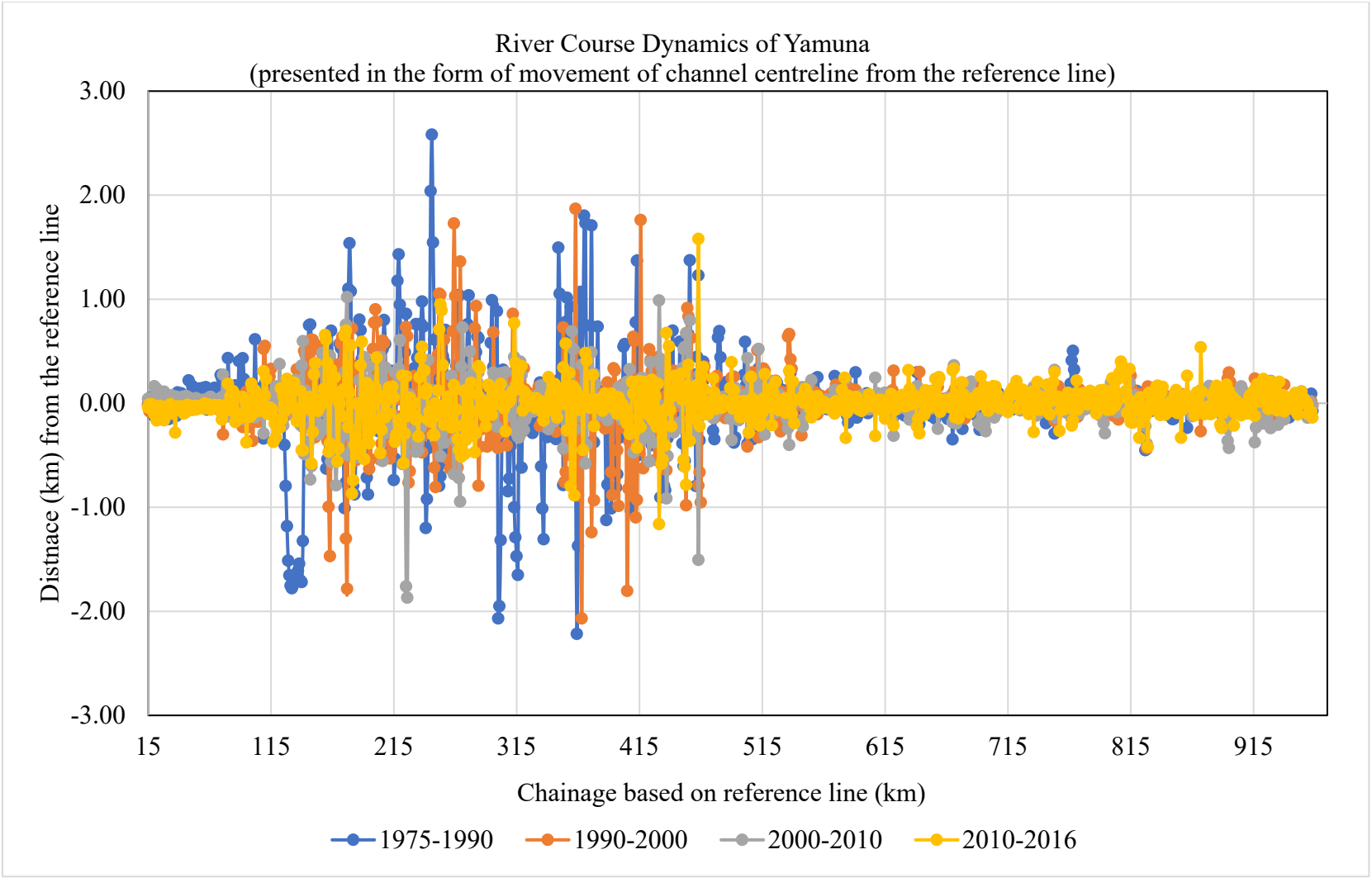


Figure 11-32 : River Course Dynamics for complete reach of Yamuna River (expressed in the of movement of channel centreline from reference line)

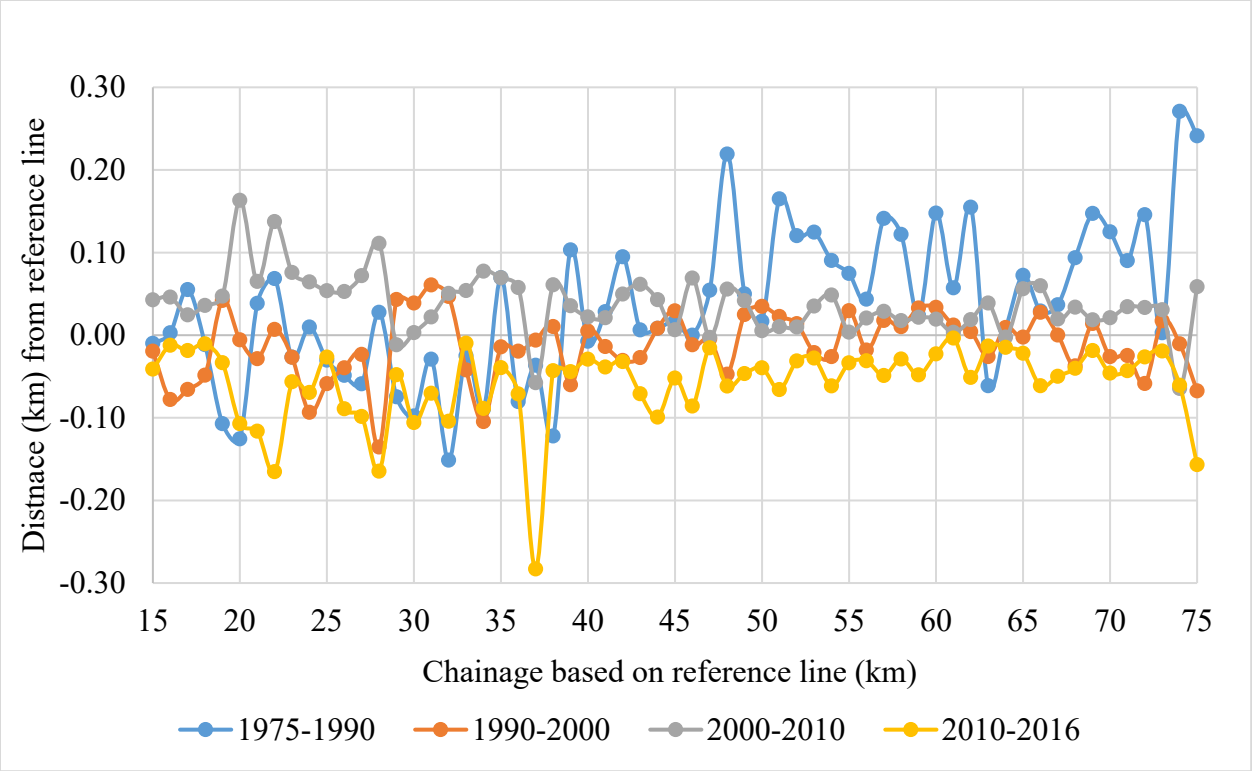


Figure 11-33 : River Course Dynamics (chainage 15- 75 km)

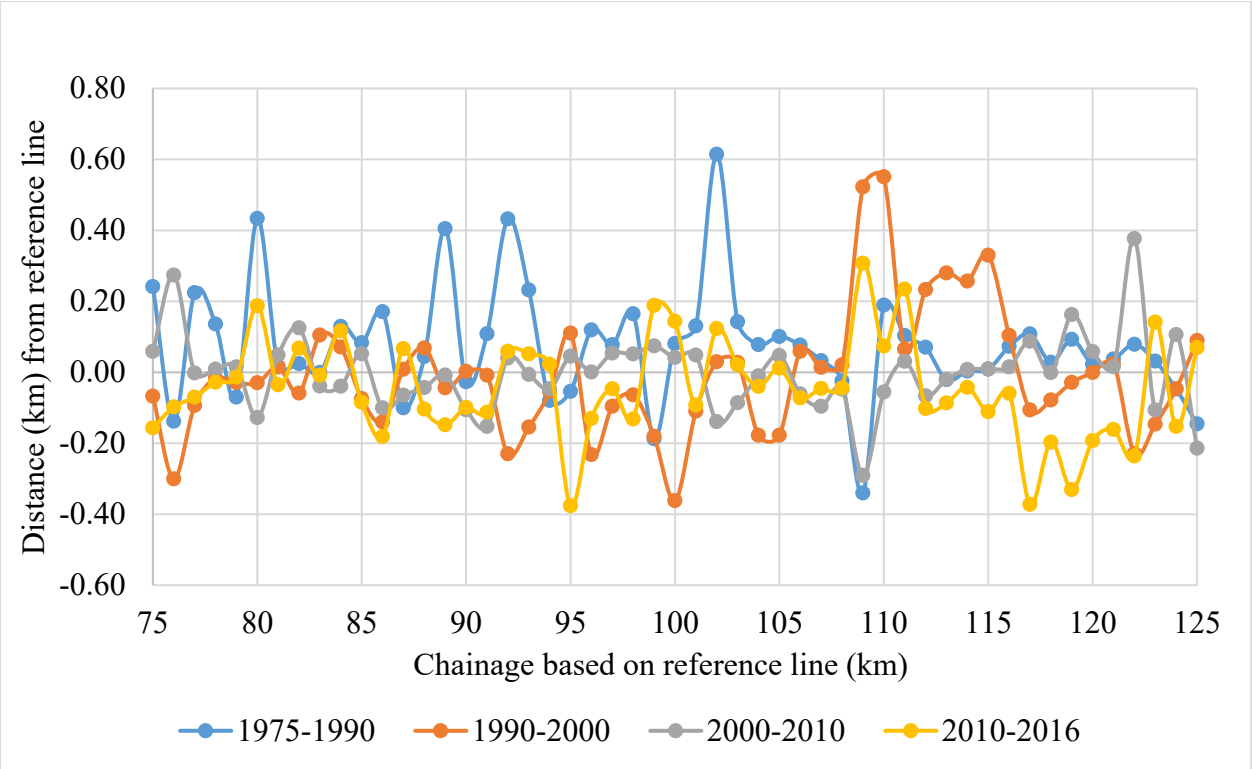


Figure 11-34 : River Course Dynamics (chainage 75- 125 km)

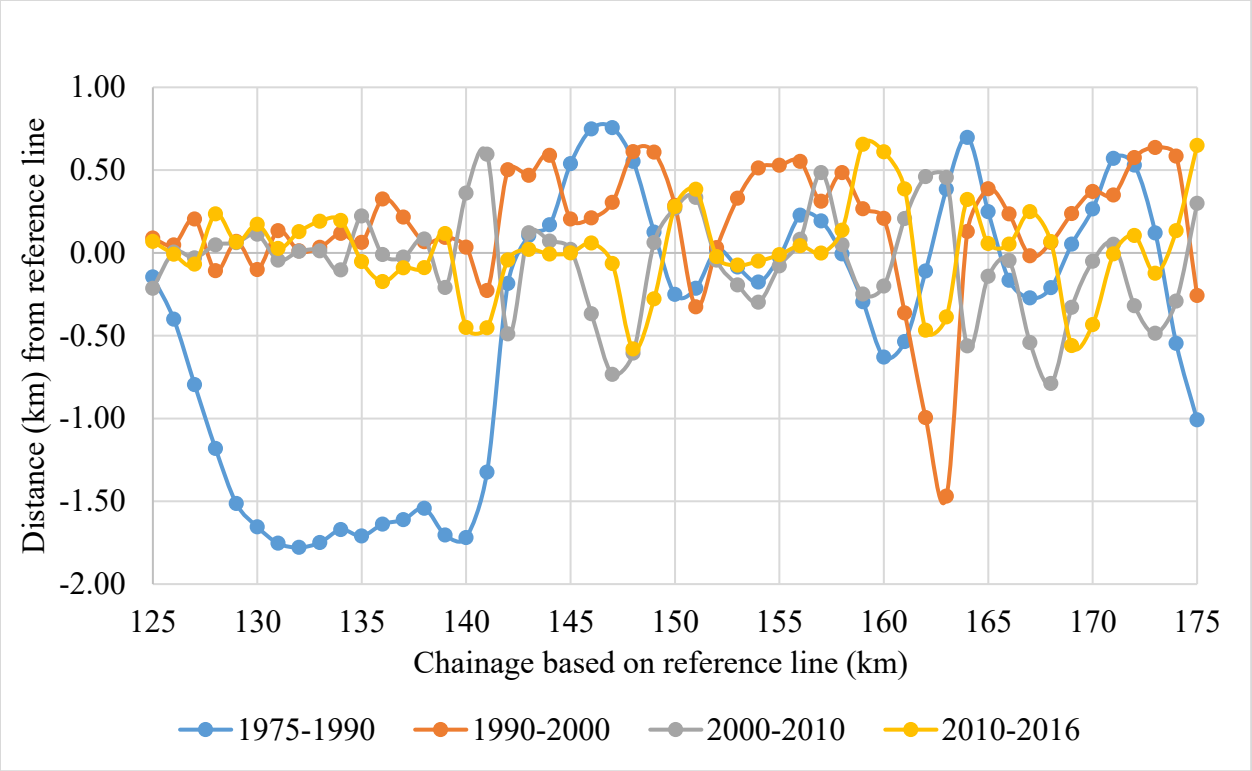


Figure 11-35 : River Course Dynamics (chainage 125- 175 km)

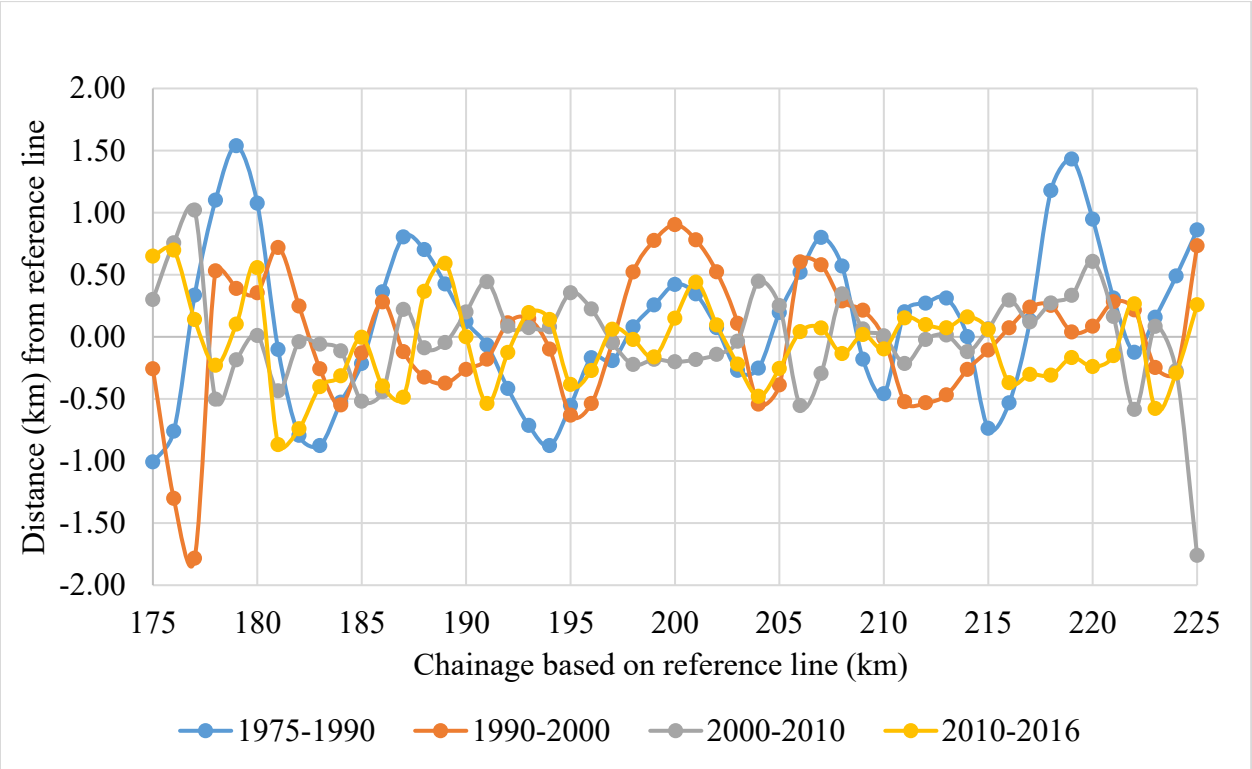


Figure 11-36 : River Course Dynamics (chainage 175- 225 km)

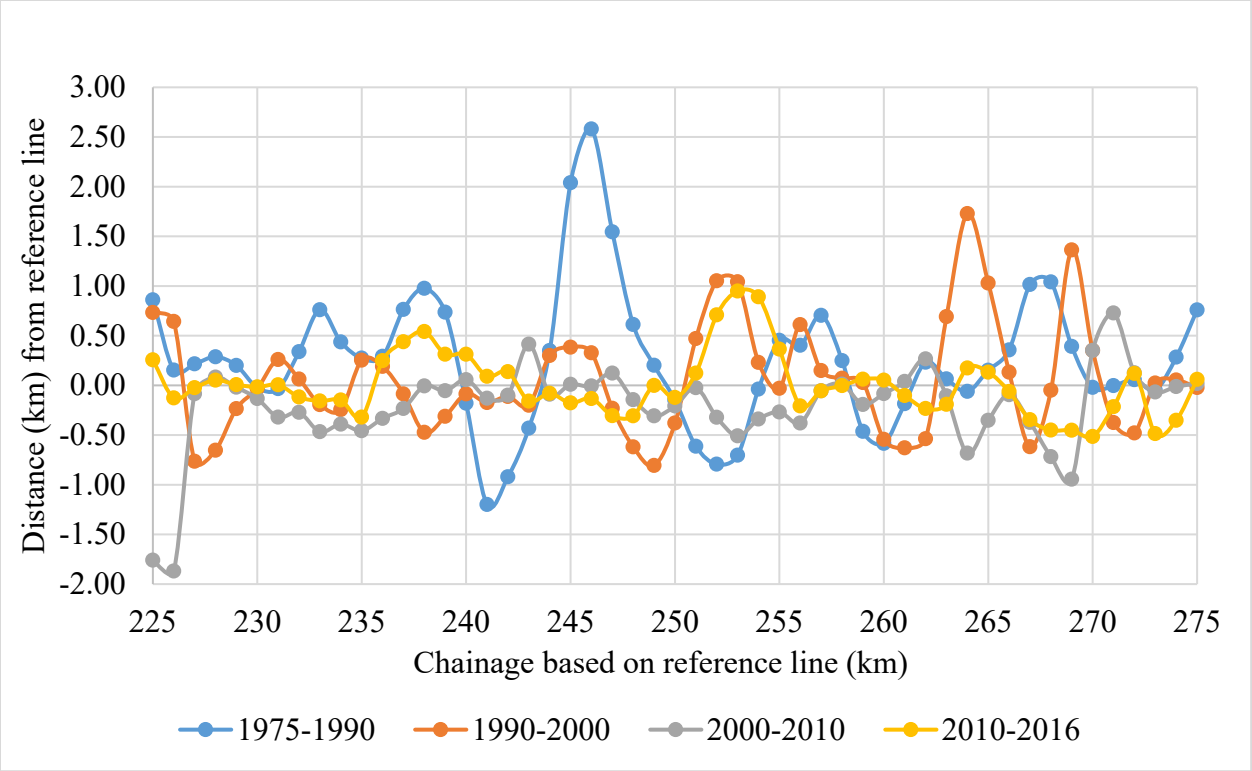


Figure 11-37 : River Course Dynamics (chainage 225- 275 km)

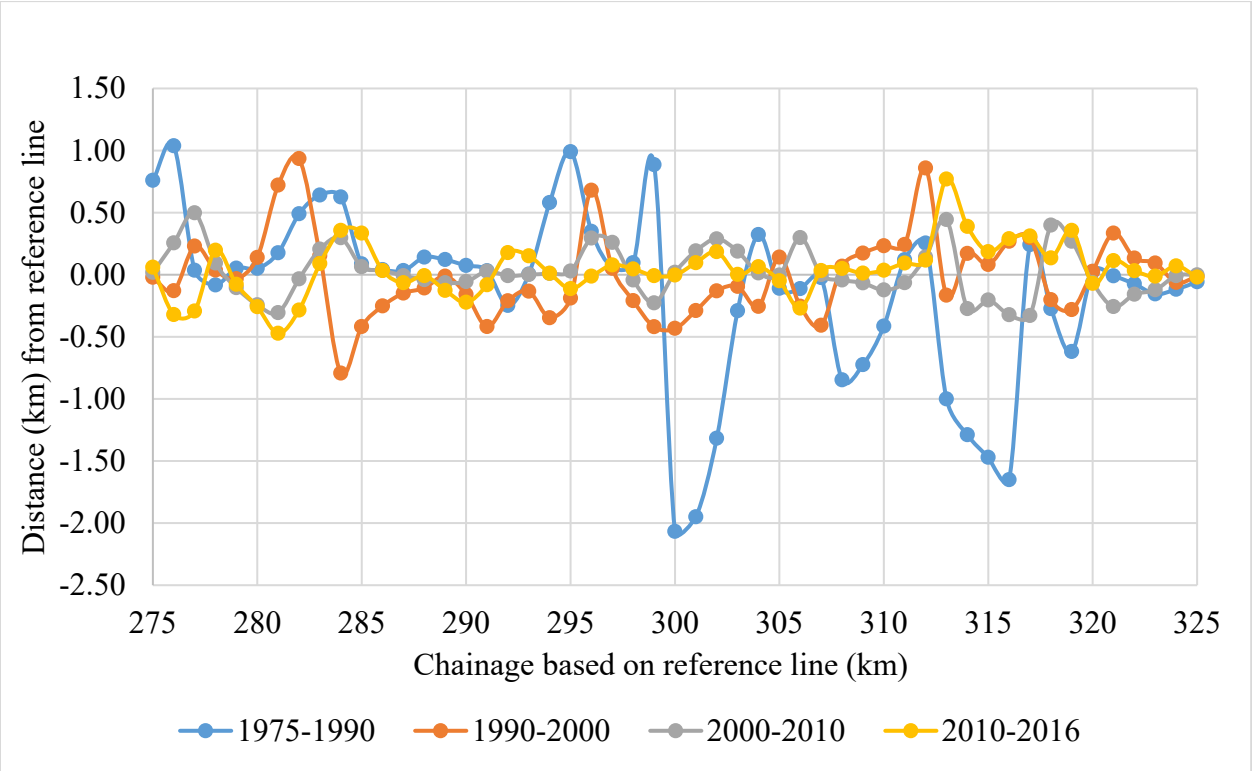


Figure 11-38 : River Course Dynamics (chainage 275- 325 km)

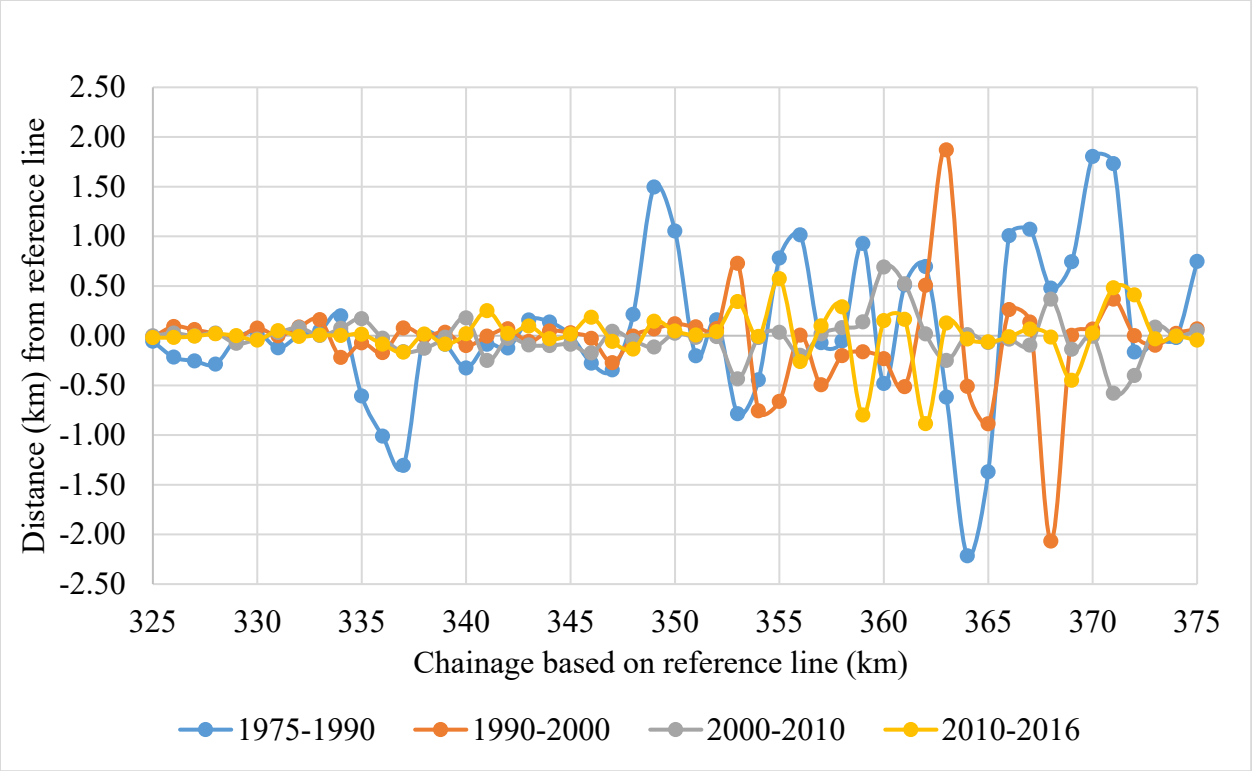


Figure 11-39 : River Course Dynamics (chainage 325- 375 km)

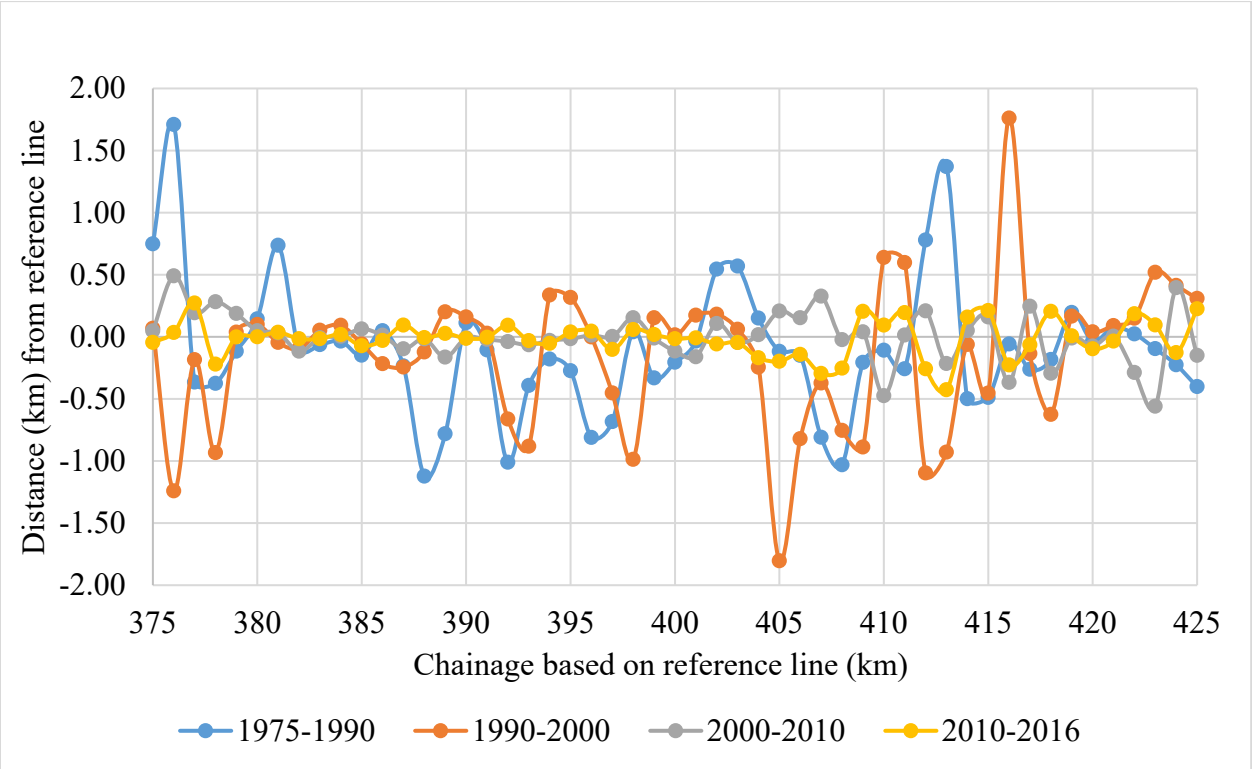


Figure 11-40 : River Course Dynamics (chainage 375- 425 km)

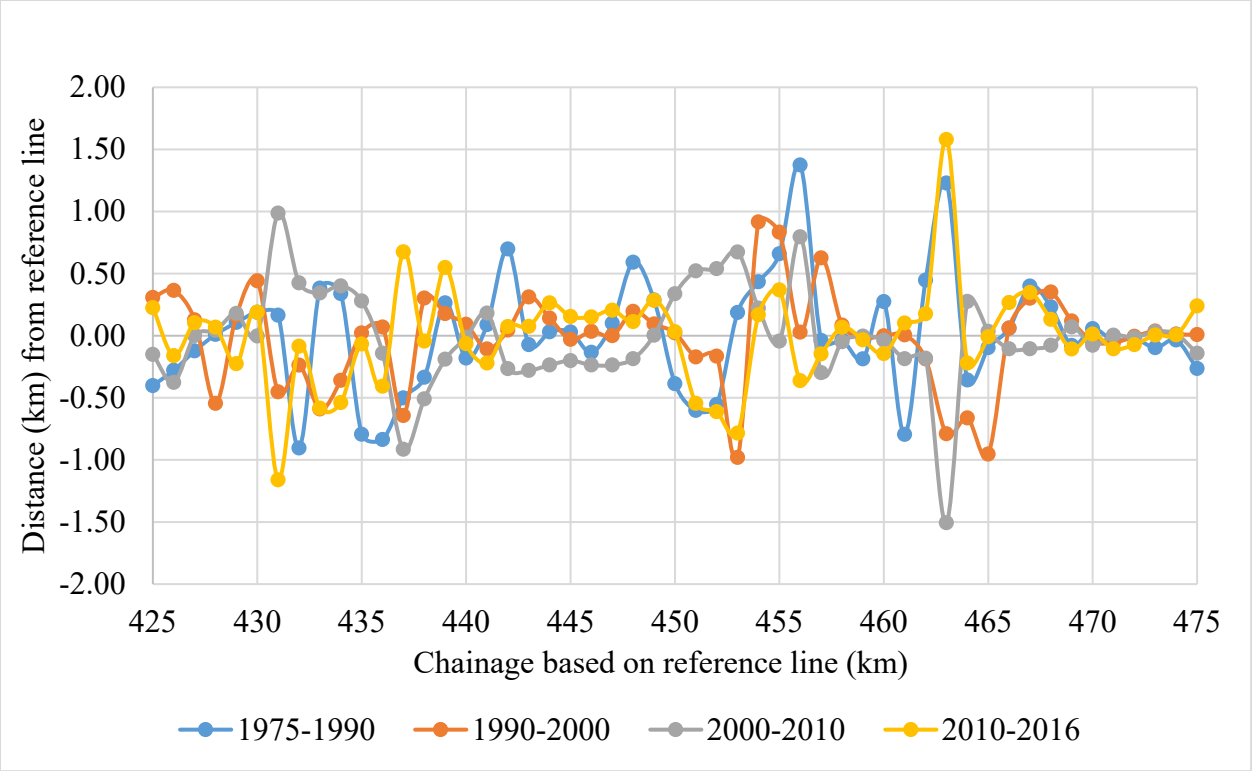


Figure 11-41 : River Course Dynamics (chainage 425- 475 km)

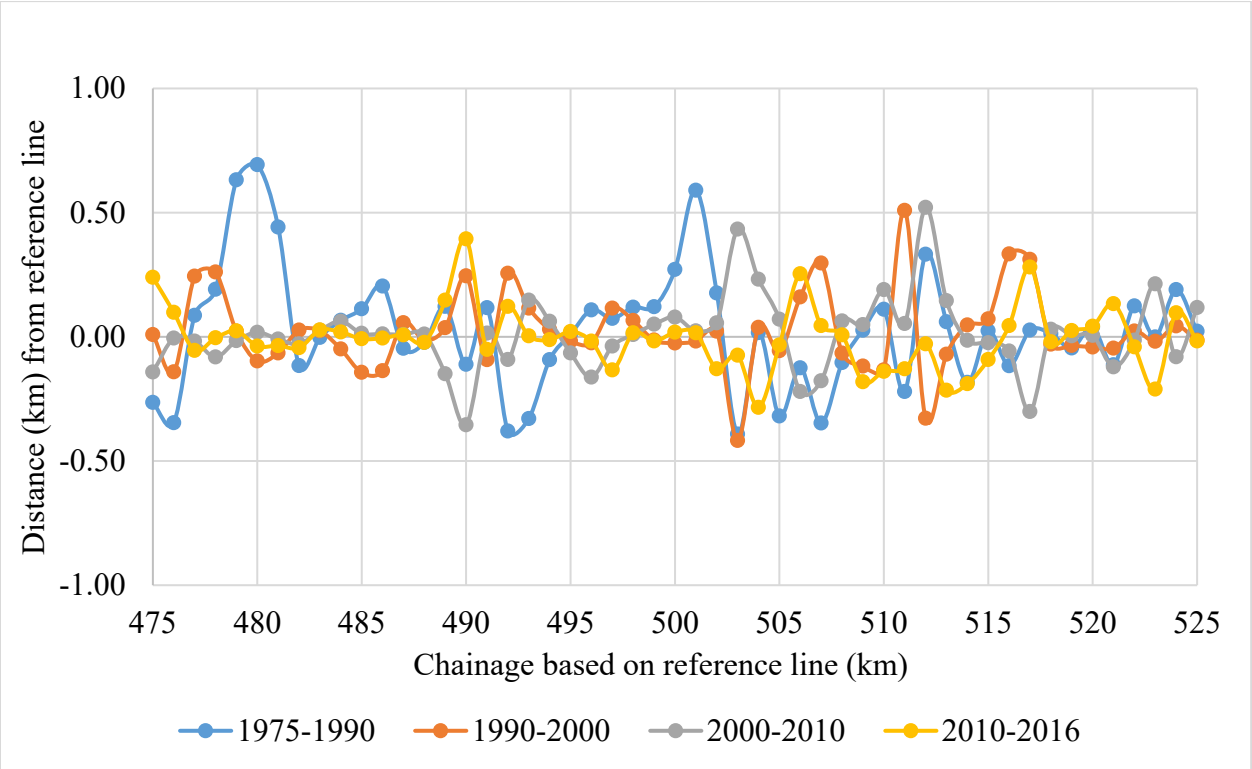


Figure 11-42 : River Course Dynamics (chainage 475- 525 km)

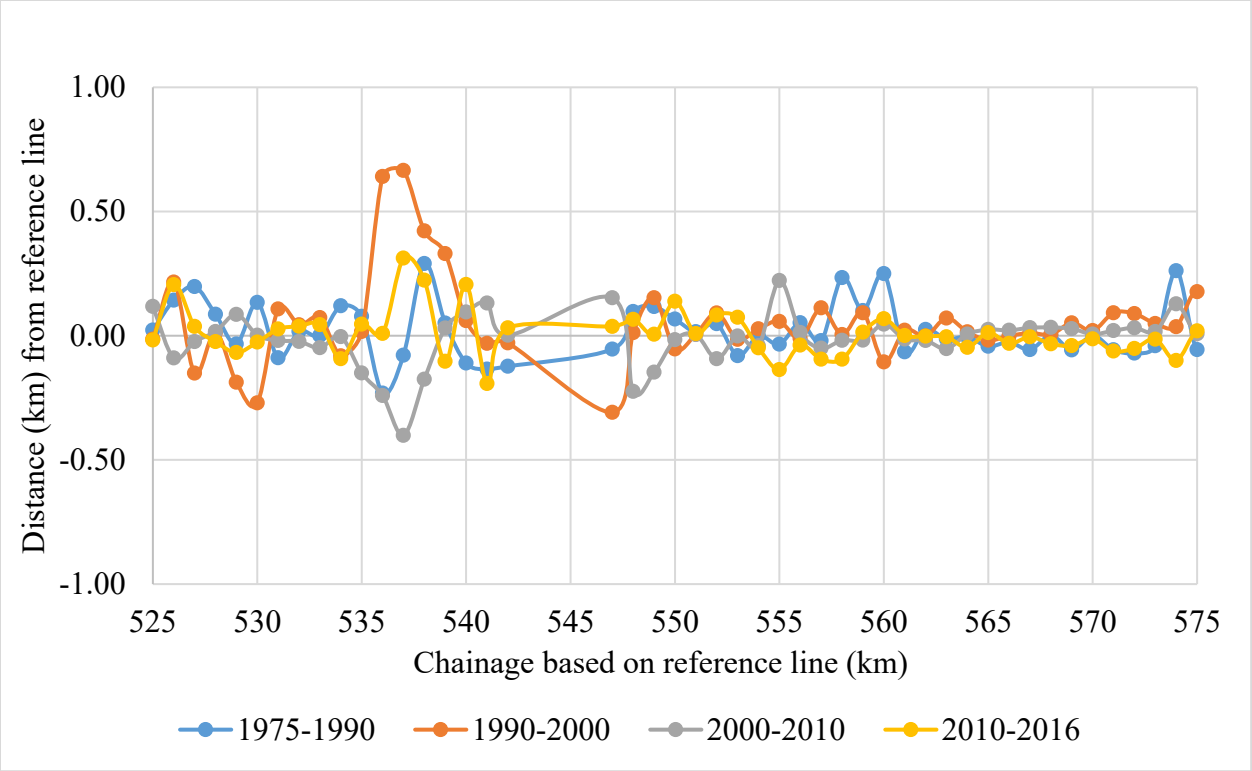


Figure 11-43 : River Course Dynamics (chainage 525- 575 km)

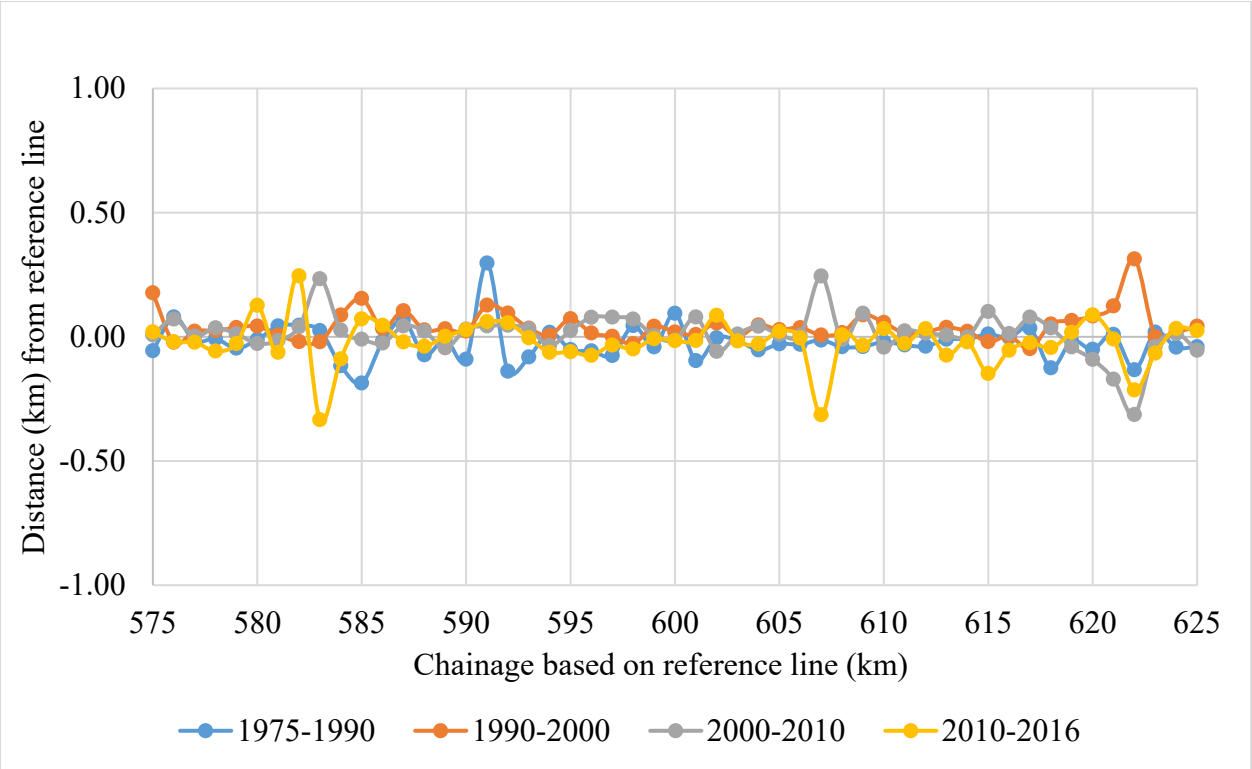


Figure 11-44 : River Course Dynamics (chainage 575- 625 km)

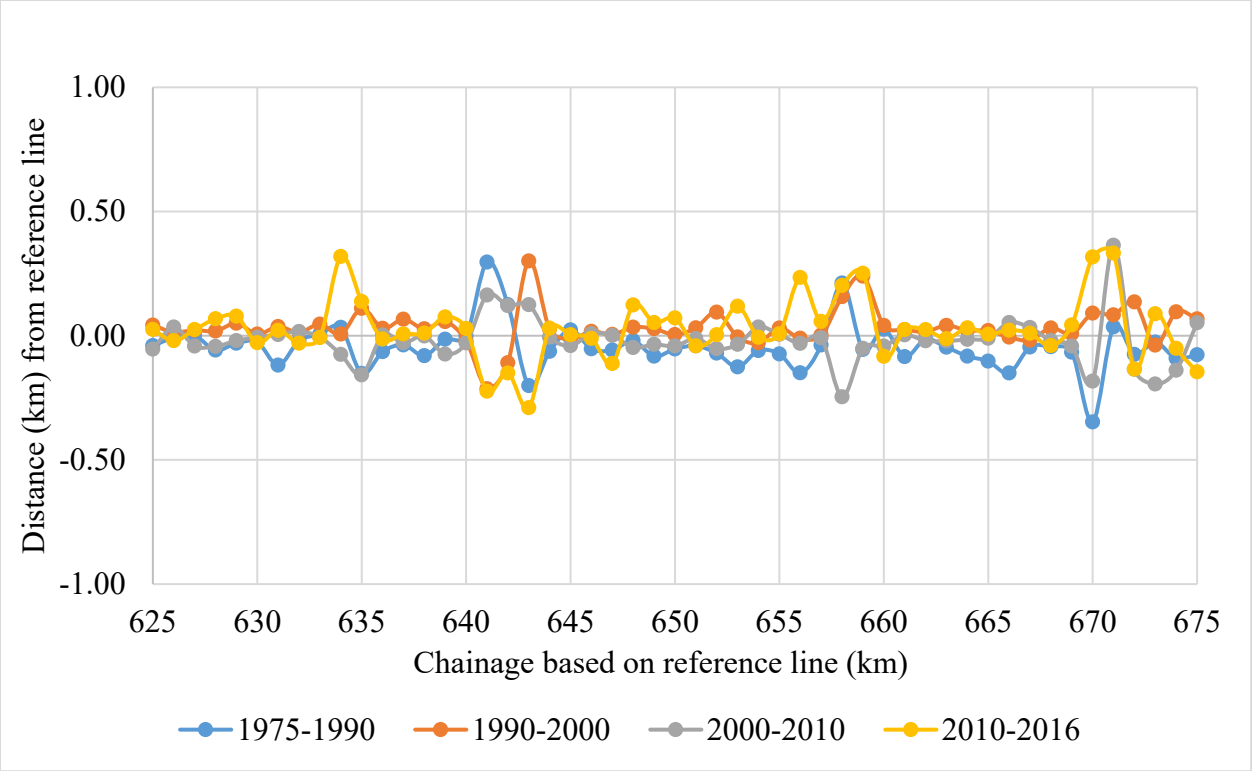


Figure 11-45 : River Course Dynamics (chainage 625- 675 km)

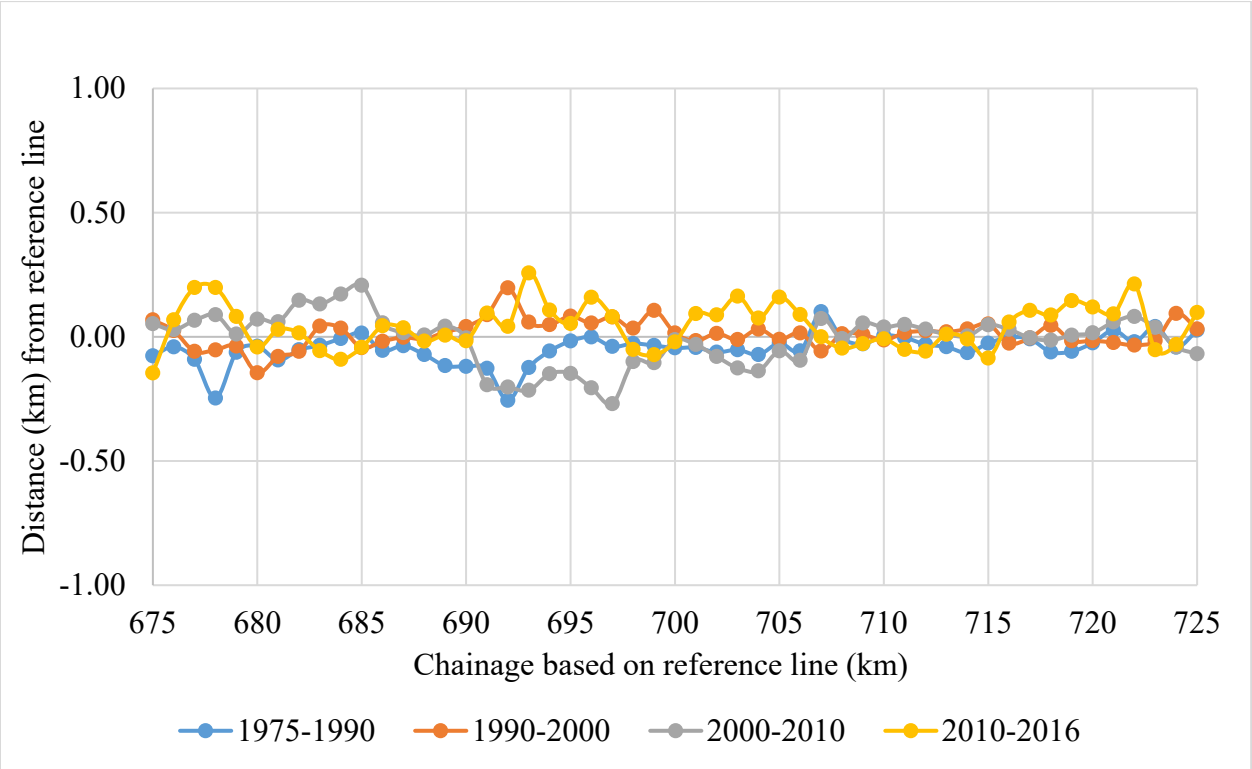


Figure 11-46 : River Course Dynamics (chainage 675- 725 km)

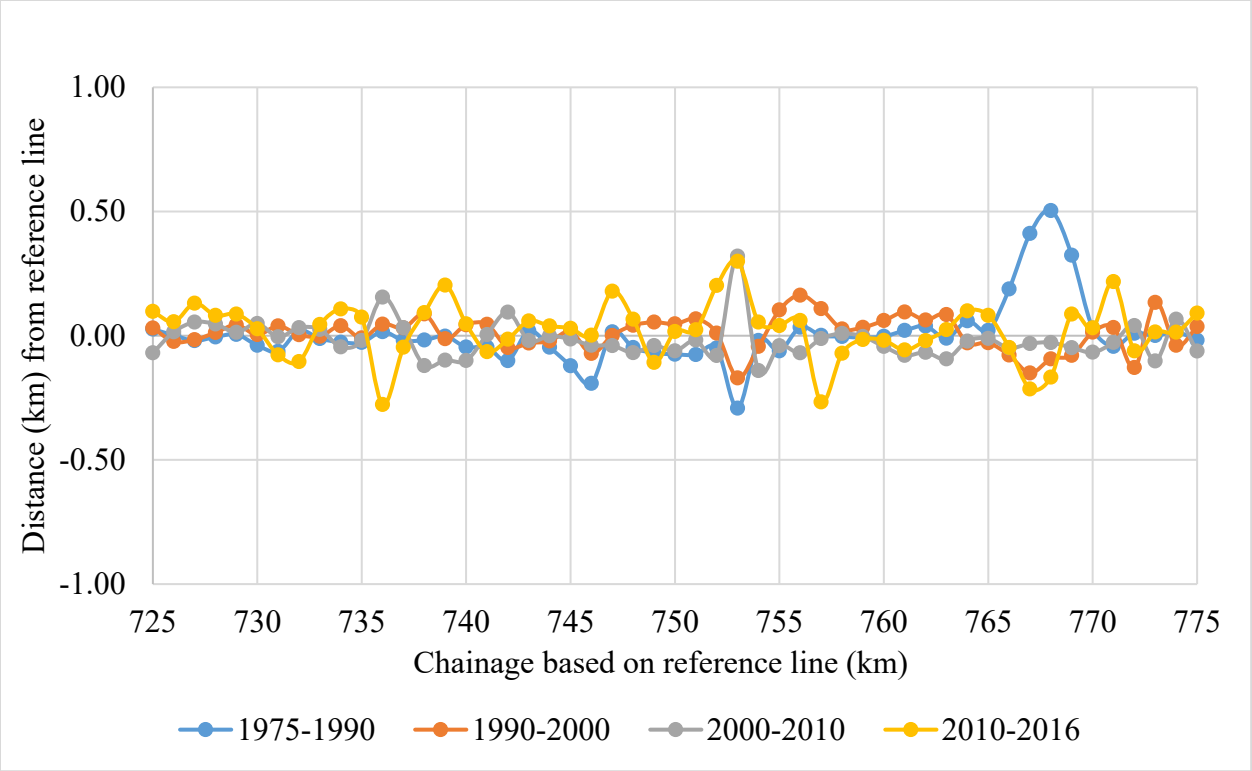


Figure 11-47 : River Course Dynamics (chainage 725- 775 km)

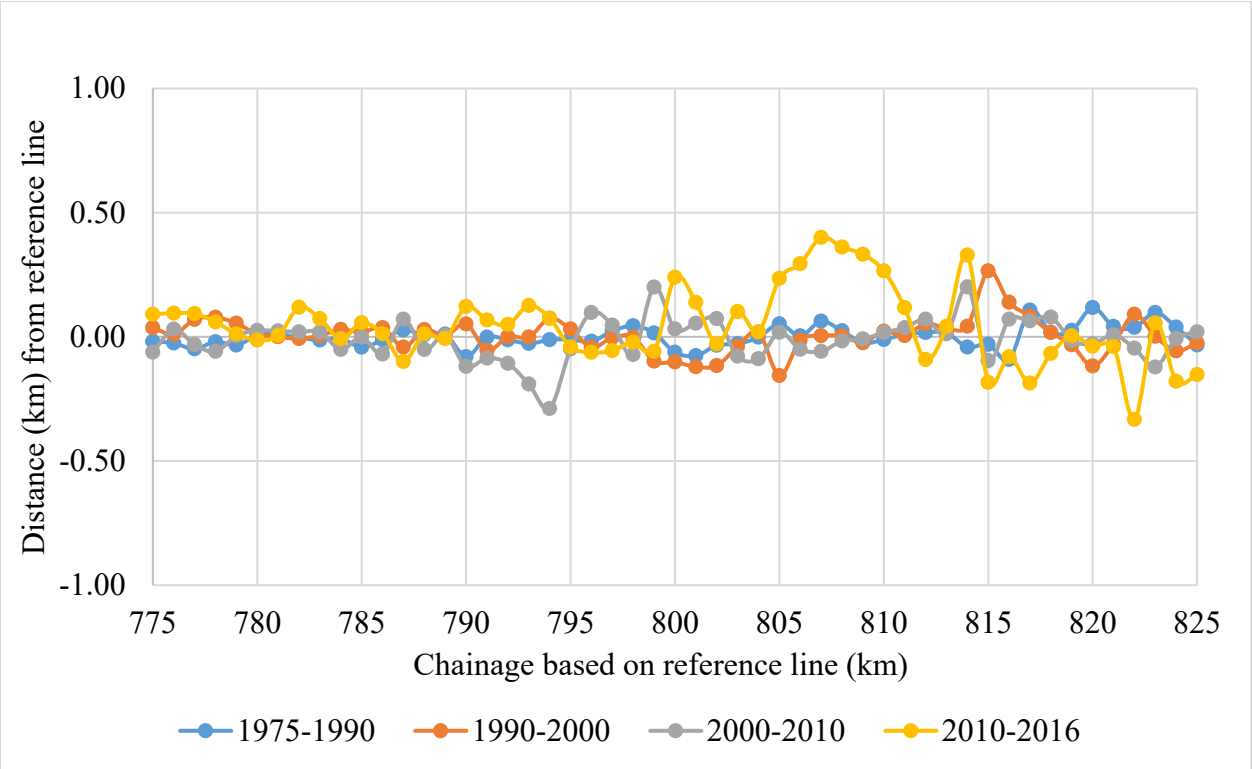


Figure 11-48 : River Course Dynamics (chainage 775- 825 km)

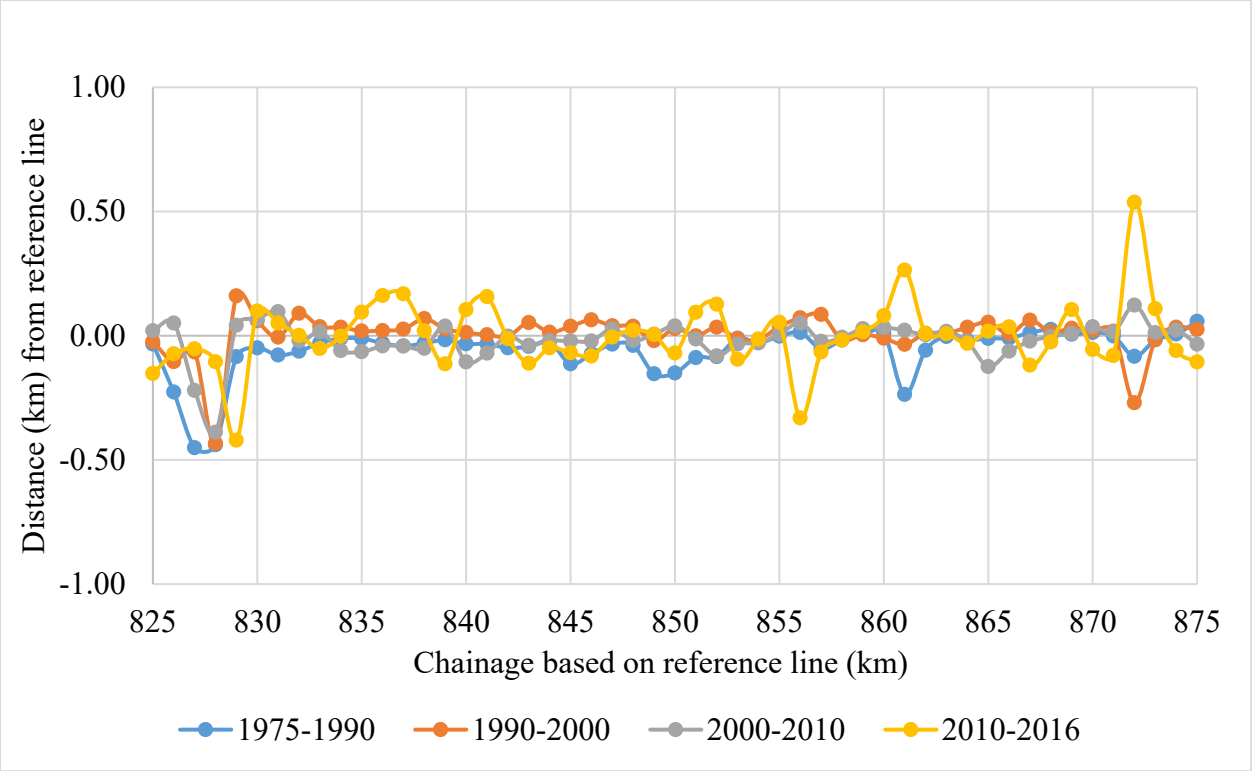


Figure 11-49 : River Course Dynamics (chainage 825- 875 km)

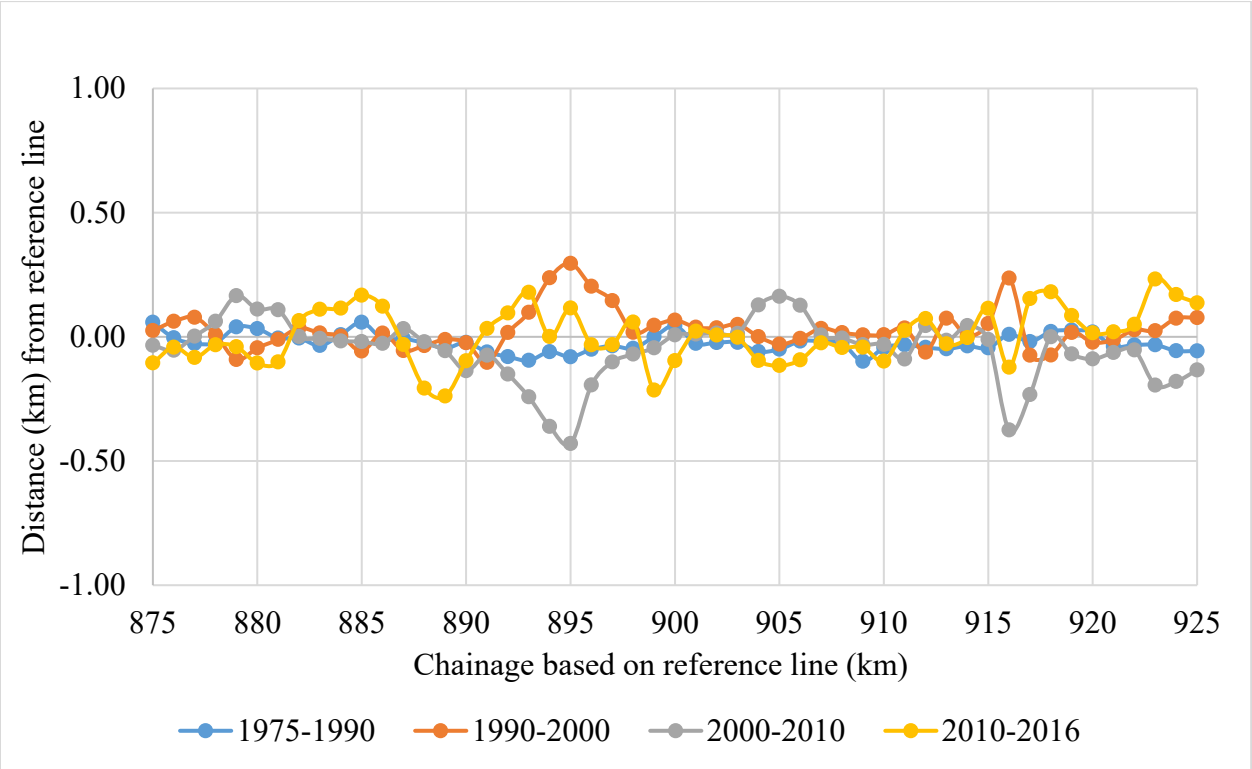


Figure 11-50 : River Course Dynamics (chainage 875- 925 km)

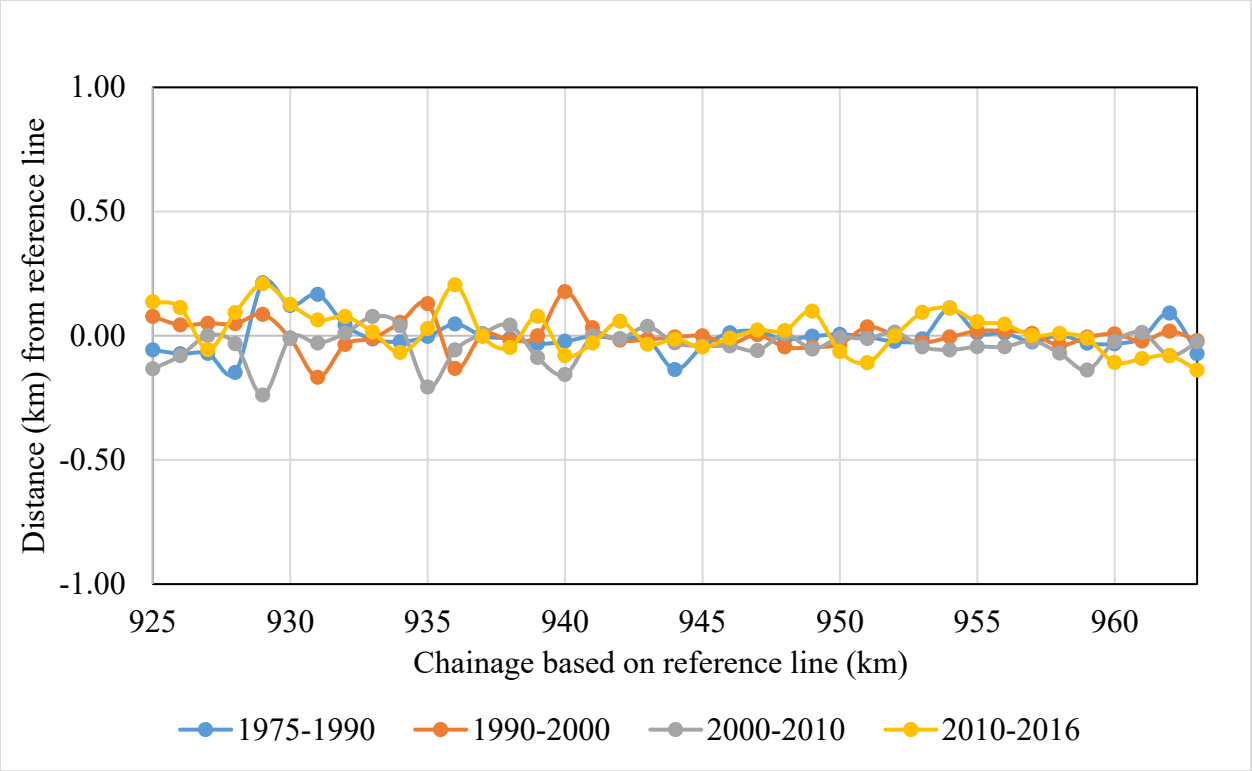


Figure 11-51 : River Course Dynamics (Chainage 925-975 km)

Table 11-7 : Grid-wise analysis of River Course Dynamics for main stream of Yamuna (in the form of movement of channel centreline)

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
974.00	78.33	30.92	234.89	30.02	15	0.02	0.01	-0.01	0.03	-0.01	-0.01	-0.02	0.04	-0.04
					16	-0.28	-0.27	-0.35	-0.30	-0.32	0.00	-0.08	0.05	-0.01
					17	-0.39	-0.34	-0.40	-0.38	-0.40	0.06	-0.07	0.02	-0.02
					18	-0.77	-0.78	-0.83	-0.80	-0.81	-0.01	-0.05	0.04	-0.01
					19	-0.83	-0.93	-0.89	-0.84	-0.88	-0.11	0.04	0.05	-0.03
					20	-1.00	-1.13	-1.14	-0.97	-1.08	-0.13	-0.01	0.16	-0.11
					21	-0.94	-0.90	-0.93	-0.86	-0.98	0.04	-0.03	0.06	-0.12
					22	-1.41	-1.34	-1.33	-1.20	-1.36	0.07	0.01	0.14	-0.17
					23	-1.62	-1.65	-1.67	-1.60	-1.65	-0.03	-0.03	0.08	-0.06
					24	-1.29	-1.28	-1.37	-1.31	-1.38	0.01	-0.09	0.06	-0.07
					25	-1.48	-1.51	-1.57	-1.51	-1.54	-0.03	-0.06	0.05	-0.03
					26	-1.30	-1.34	-1.38	-1.33	-1.42	-0.05	-0.04	0.05	-0.09
					27	-1.45	-1.51	-1.54	-1.46	-1.56	-0.06	-0.02	0.07	-0.10
					28	-1.10	-1.07	-1.21	-1.10	-1.26	0.03	-0.14	0.11	-0.16
					29	-0.39	-0.46	-0.42	-0.43	-0.48	-0.07	0.04	-0.01	-0.05
					30	0.00	-0.10	-0.06	-0.06	-0.17	-0.10	0.04	0.00	-0.11
973.00	78.05	30.89	250.81	6.68	31	-0.40	-0.43	-0.37	-0.35	-0.42	-0.03	0.06	0.02	-0.07
					32	-0.29	-0.44	-0.39	-0.34	-0.44	-0.15	0.05	0.05	-0.10
					33	-0.51	-0.53	-0.57	-0.52	-0.53	-0.03	-0.04	0.05	-0.01
					34	-0.47	-0.55	-0.66	-0.58	-0.67	-0.09	-0.10	0.08	-0.09
					35	0.29	0.36	0.34	0.41	0.37	0.07	-0.01	0.07	-0.04

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					36	0.07	-0.01	-0.03	0.02	-0.05	-0.08	-0.02	0.06	-0.07
941.00	78.10	30.68	210.62	30.07	37	0.39	0.35	0.35	0.29	0.01	-0.04	-0.01	-0.06	-0.28
					38	1.10	0.98	0.99	1.05	1.00	-0.12	0.01	0.06	-0.04
					39	1.45	1.55	1.49	1.53	1.48	0.10	-0.06	0.04	-0.04
					40	1.51	1.50	1.51	1.53	1.50	-0.01	0.00	0.02	-0.03
					41	1.66	1.69	1.68	1.70	1.66	0.03	-0.01	0.02	-0.04
					42	1.93	2.03	2.00	2.05	2.01	0.09	-0.03	0.05	-0.03
					43	2.43	2.44	2.41	2.47	2.40	0.01	-0.03	0.06	-0.07
					44	2.28	2.29	2.30	2.34	2.24	0.01	0.01	0.04	-0.10
					45	2.09	2.11	2.14	2.14	2.09	0.02	0.03	0.01	-0.05
					46	1.75	1.75	1.74	1.81	1.72	0.00	-0.01	0.07	-0.09
					47	0.90	0.95	0.95	0.94	0.93	0.05	0.00	0.00	-0.02
					48	0.73	0.95	0.90	0.96	0.90	0.22	-0.05	0.06	-0.06
					49	0.96	1.01	1.03	1.08	1.03	0.05	0.02	0.04	-0.05
					50	0.72	0.73	0.77	0.77	0.73	0.02	0.03	0.01	-0.04
					51	0.51	0.67	0.70	0.71	0.64	0.16	0.02	0.01	-0.07
					52	0.11	0.24	0.25	0.26	0.23	0.12	0.01	0.01	-0.03
					53	-0.02	0.11	0.08	0.12	0.09	0.12	-0.02	0.04	-0.03
					54	0.74	0.83	0.81	0.86	0.79	0.09	-0.03	0.05	-0.06
					55	1.14	1.22	1.24	1.25	1.21	0.07	0.03	0.00	-0.03
					56	1.32	1.37	1.35	1.37	1.34	0.04	-0.02	0.02	-0.03
					57	3.45	3.59	3.61	3.64	3.59	0.14	0.02	0.03	-0.05

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					58	2.98	3.10	3.11	3.13	3.10	0.12	0.01	0.02	-0.03
					59	2.30	2.33	2.36	2.38	2.33	0.02	0.03	0.02	-0.05
					60	2.23	2.38	2.41	2.43	2.41	0.15	0.03	0.02	-0.02
					61	1.45	1.51	1.52	1.52	1.52	0.06	0.01	0.00	0.00
					62	1.03	1.18	1.18	1.20	1.15	0.15	0.00	0.02	-0.05
					63	0.55	0.49	0.47	0.51	0.49	-0.06	-0.03	0.04	-0.01
					64	0.59	0.60	0.61	0.61	0.59	0.01	0.01	0.00	-0.01
					65	0.28	0.36	0.35	0.41	0.39	0.07	0.00	0.06	-0.02
					66	0.16	0.19	0.21	0.27	0.21	0.03	0.03	0.06	-0.06
909.00	78.14	30.47	231.21	2.31	67	-0.06	-0.02	-0.02	0.00	-0.05	0.04	0.00	0.02	-0.05
					68	0.33	0.43	0.39	0.42	0.38	0.09	-0.04	0.03	-0.04
					69	0.03	0.17	0.19	0.21	0.19	0.15	0.01	0.02	-0.02
908.00	77.87	30.44	253.08	25.56	70	-1.66	-1.54	-1.57	-1.54	-1.59	0.13	-0.03	0.02	-0.05
					71	-4.27	-4.18	-4.20	-4.17	-4.21	0.09	-0.02	0.03	-0.04
					72	-3.75	-3.60	-3.66	-3.63	-3.66	0.15	-0.06	0.03	-0.03
					73	-2.26	-2.26	-2.24	-2.21	-2.23	0.00	0.02	0.03	-0.02
					74	-2.84	-2.57	-2.58	-2.65	-2.71	0.27	-0.01	-0.06	-0.06
					75	-1.96	-1.72	-1.79	-1.73	-1.89	0.24	-0.07	0.06	-0.16
					76	-0.09	-0.23	-0.53	-0.25	-0.35	-0.14	-0.30	0.27	-0.10
					77	1.51	1.74	1.64	1.64	1.57	0.22	-0.09	0.00	-0.07
					78	0.96	1.10	1.08	1.09	1.06	0.14	-0.02	0.01	-0.03
					79	-0.08	-0.15	-0.18	-0.17	-0.18	-0.07	-0.03	0.01	-0.01

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					80	0.12	0.56	0.53	0.40	0.59	0.43	-0.03	-0.13	0.19
					81	0.50	0.52	0.53	0.58	0.55	0.02	0.01	0.05	-0.04
					82	0.50	0.53	0.47	0.59	0.66	0.02	-0.06	0.13	0.07
					83	0.90	0.90	1.00	0.96	0.96	0.00	0.10	-0.04	-0.01
					84	1.06	1.19	1.26	1.22	1.34	0.13	0.07	-0.04	0.12
					85	0.85	0.93	0.86	0.91	0.83	0.08	-0.07	0.05	-0.08
					86	1.09	1.26	1.12	1.02	0.84	0.17	-0.14	-0.10	-0.18
					87	1.73	1.63	1.64	1.57	1.64	-0.10	0.01	-0.06	0.07
					88	1.66	1.71	1.77	1.73	1.63	0.04	0.07	-0.04	-0.10
					89	1.16	1.57	1.52	1.52	1.37	0.40	-0.04	-0.01	-0.15
					90	1.21	1.19	1.19	1.08	0.98	-0.03	0.00	-0.11	-0.10
					91	0.78	0.88	0.88	0.72	0.61	0.11	-0.01	-0.15	-0.11
					92	0.28	0.72	0.49	0.53	0.58	0.43	-0.23	0.04	0.06
					93	0.34	0.57	0.41	0.41	0.46	0.23	-0.15	-0.01	0.05
					94	0.26	0.18	0.13	0.08	0.10	-0.08	-0.05	-0.05	0.02
					95	0.07	0.02	0.13	0.17	-0.20	-0.05	0.11	0.05	-0.38
					96	0.27	0.39	0.16	0.16	0.03	0.12	-0.23	0.00	-0.13
					97	0.53	0.61	0.51	0.57	0.52	0.08	-0.10	0.05	-0.05
907.00	77.59	30.4	222.12	25.55	98	0.74	0.90	0.84	0.89	0.76	0.16	-0.06	0.05	-0.13
					99	1.94	1.75	1.57	1.64	1.83	-0.19	-0.18	0.07	0.19
					100	2.81	2.89	2.53	2.57	2.72	0.08	-0.36	0.04	0.14
					101	3.10	3.23	3.13	3.17	3.08	0.13	-0.11	0.05	-0.09

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					102	3.14	3.75	3.78	3.64	3.77	0.61	0.03	-0.14	0.12
					103	5.00	5.14	5.17	5.09	5.11	0.14	0.03	-0.09	0.02
					104	5.89	5.96	5.79	5.78	5.74	0.08	-0.18	-0.01	-0.04
					105	6.48	6.58	6.40	6.45	6.46	0.10	-0.18	0.05	0.01
					106	6.94	7.02	7.08	7.02	6.95	0.08	0.06	-0.06	-0.07
					107	6.99	7.02	7.03	6.94	6.89	0.03	0.01	-0.10	-0.05
					108	6.60	6.57	6.59	6.55	6.50	-0.02	0.02	-0.05	-0.04
					109	5.50	5.16	5.68	5.39	5.70	-0.34	0.52	-0.29	0.31
					110	3.01	3.20	3.75	3.69	3.76	0.19	0.55	-0.06	0.07
					111	2.06	2.16	2.23	2.26	2.49	0.10	0.07	0.03	0.23
					112	1.58	1.65	1.89	1.82	1.72	0.07	0.23	-0.07	-0.10
					113	1.28	1.26	1.54	1.52	1.43	-0.02	0.28	-0.02	-0.09
					114	0.88	0.88	1.14	1.14	1.10	0.00	0.26	0.01	-0.04
					115	0.48	0.49	0.82	0.83	0.72	0.01	0.33	0.01	-0.11
					116	-0.10	-0.03	0.07	0.09	0.03	0.07	0.10	0.02	-0.06
					117	-0.73	-0.62	-0.72	-0.64	-1.01	0.11	-0.11	0.09	-0.37
					118	-0.59	-0.56	-0.64	-0.64	-0.83	0.03	-0.08	0.00	-0.20
					119	-0.28	-0.18	-0.21	-0.05	-0.38	0.09	-0.03	0.16	-0.33
					120	-0.03	-0.01	-0.01	0.05	-0.14	0.02	0.00	0.06	-0.19
875.00	77.64	30.19	222.73	10.09	121	0.08	0.11	0.14	0.15	-0.01	0.04	0.02	0.02	-0.16
					122	0.13	0.21	-0.02	0.36	0.12	0.08	-0.23	0.38	-0.24
					123	0.07	0.10	-0.05	-0.15	-0.01	0.03	-0.15	-0.11	0.14

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					124	-0.09	-0.14	-0.19	-0.08	-0.24	-0.05	-0.05	0.11	-0.15
					125	-0.26	-0.40	-0.31	-0.53	-0.46	-0.15	0.09	-0.21	0.07
					126	-0.32	-0.72	-0.68	-0.67	-0.68	-0.40	0.05	0.00	-0.01
					127	-0.20	-0.99	-0.79	-0.82	-0.89	-0.80	0.20	-0.03	-0.07
					128	-0.07	-1.25	-1.36	-1.31	-1.08	-1.18	-0.11	0.05	0.23
					129	0.05	-1.47	-1.40	-1.34	-1.27	-1.51	0.07	0.06	0.07
					130	0.01	-1.64	-1.74	-1.63	-1.46	-1.65	-0.10	0.11	0.17
					131	-0.06	-1.81	-1.68	-1.72	-1.70	-1.75	0.13	-0.04	0.03
					132	-0.14	-1.92	-1.90	-1.89	-1.77	-1.78	0.01	0.01	0.13
					133	-0.23	-1.98	-1.95	-1.93	-1.74	-1.75	0.03	0.01	0.19
					134	-0.34	-2.01	-1.89	-2.00	-1.80	-1.67	0.12	-0.10	0.20
					135	-0.45	-2.15	-2.09	-1.87	-1.92	-1.71	0.06	0.22	-0.05
					136	-0.55	-2.19	-1.87	-1.88	-2.05	-1.64	0.33	-0.01	-0.17
					137	-0.66	-2.27	-2.05	-2.08	-2.17	-1.61	0.22	-0.03	-0.09
874.00	77.37	30.16	225.11	26.42	138	-0.77	-2.31	-2.24	-2.16	-2.25	-1.54	0.07	0.08	-0.09
					139	-0.70	-2.41	-2.31	-2.52	-2.41	-1.70	0.09	-0.21	0.12
					140	-0.57	-2.29	-2.26	-1.90	-2.35	-1.72	0.03	0.36	-0.45
					141	-0.45	-1.77	-2.00	-1.40	-1.85	-1.32	-0.23	0.60	-0.45
					142	-0.32	-0.50	0.00	-0.49	-0.53	-0.18	0.50	-0.49	-0.04
					143	-0.19	-0.08	0.38	0.50	0.53	0.10	0.47	0.12	0.02
					144	-0.35	-0.18	0.41	0.48	0.47	0.17	0.59	0.07	-0.01
					145	-0.85	-0.31	-0.10	-0.08	-0.08	0.54	0.20	0.02	0.00

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					146	-1.31	-0.56	-0.35	-0.72	-0.66	0.75	0.21	-0.37	0.06
					147	-1.40	-0.65	-0.34	-1.08	-1.14	0.76	0.30	-0.73	-0.06
					148	-1.31	-0.75	-0.14	-0.75	-1.33	0.55	0.61	-0.61	-0.58
					149	-1.17	-1.05	-0.44	-0.38	-0.66	0.12	0.61	0.06	-0.28
					150	-1.06	-1.32	-1.03	-0.76	-0.48	-0.25	0.29	0.27	0.28
					151	-0.97	-1.18	-1.51	-1.17	-0.79	-0.21	-0.33	0.33	0.38
					152	-0.77	-0.75	-0.72	-0.76	-0.79	0.02	0.03	-0.04	-0.02
					153	-0.34	-0.42	-0.10	-0.29	-0.36	-0.09	0.33	-0.19	-0.07
					154	0.08	-0.10	0.41	0.11	0.06	-0.18	0.51	-0.30	-0.05
					155	0.06	0.04	0.57	0.49	0.48	-0.03	0.53	-0.08	-0.01
					156	-0.05	0.17	0.73	0.81	0.85	0.23	0.55	0.08	0.04
842.00	77.42	29.95	237.07	6.42	157	-0.01	0.19	0.50	0.98	0.98	0.19	0.31	0.48	0.00
					158	-0.02	-0.03	0.45	0.50	0.64	-0.01	0.48	0.05	0.14
					159	0.12	-0.18	0.09	-0.16	0.49	-0.30	0.27	-0.25	0.66
					160	0.20	-0.43	-0.23	-0.43	0.18	-0.63	0.21	-0.20	0.61
					161	0.18	-0.35	-0.72	-0.51	-0.12	-0.54	-0.36	0.21	0.39
					162	0.11	0.00	-1.00	-0.54	-1.00	-0.11	-1.00	0.46	-0.47
					163	0.01	0.40	-1.07	-0.61	-1.00	0.39	-1.47	0.46	-0.39
841.00	77.15	29.91	204.60	25.02	164	0.39	1.09	1.22	0.65	0.98	0.70	0.13	-0.56	0.32
					165	0.89	1.14	1.52	1.38	1.44	0.25	0.39	-0.14	0.06
					166	1.49	1.32	1.55	1.51	1.56	-0.17	0.23	-0.05	0.05
					167	2.11	1.83	1.82	1.27	1.52	-0.27	-0.02	-0.54	0.25

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					168	2.20	1.99	2.06	1.27	1.33	-0.21	0.06	-0.79	0.07
					169	1.89	1.95	2.18	1.86	1.29	0.05	0.24	-0.33	-0.56
					170	1.53	1.80	2.17	2.12	1.69	0.26	0.37	-0.05	-0.43
					171	0.95	1.52	1.87	1.92	1.91	0.57	0.35	0.05	-0.01
					172	0.70	1.23	1.81	1.49	1.59	0.53	0.58	-0.32	0.10
					173	0.80	0.92	1.56	1.07	0.95	0.12	0.64	-0.49	-0.12
					174	1.11	0.57	1.15	0.86	0.99	-0.55	0.58	-0.29	0.13
					175	1.51	0.50	0.25	0.54	1.19	-1.01	-0.26	0.30	0.65
					176	1.95	1.19	-0.11	0.64	1.34	-0.76	-1.30	0.76	0.70
					177	2.08	2.41	0.63	1.64	1.78	0.33	-1.78	1.02	0.14
					178	1.44	2.54	3.07	2.57	2.34	1.10	0.53	-0.50	-0.23
					179	0.76	2.30	2.68	2.50	2.60	1.54	0.39	-0.19	0.10
					180	0.38	1.45	1.80	1.81	2.37	1.07	0.35	0.01	0.56
					181	0.21	0.11	0.83	0.39	-0.48	-0.10	0.72	-0.44	-0.87
					182	0.26	-0.54	-0.29	-0.33	-1.07	-0.79	0.25	-0.04	-0.74
					183	0.47	-0.41	-0.66	-0.72	-1.12	-0.88	-0.26	-0.06	-0.40
					184	0.59	0.06	-0.49	-0.60	-0.92	-0.53	-0.55	-0.11	-0.31
					185	0.53	0.31	0.18	-0.34	-0.34	-0.22	-0.13	-0.52	0.00
					186	0.04	0.41	0.69	0.24	-0.15	0.36	0.28	-0.44	-0.40
					187	-0.18	0.62	0.50	0.72	0.23	0.80	-0.12	0.22	-0.49
					188	-0.03	0.67	0.34	0.26	0.62	0.70	-0.33	-0.09	0.37
809.00	77.2	29.71	198.70	27.55	189	0.29	0.71	0.34	0.29	0.88	0.42	-0.37	-0.05	0.59

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					190	0.43	0.56	0.29	0.49	0.49	0.12	-0.26	0.20	0.00
					191	0.55	0.48	0.30	0.75	0.21	-0.07	-0.18	0.44	-0.54
					192	0.88	0.47	0.58	0.66	0.54	-0.42	0.11	0.08	-0.13
					193	1.68	0.97	1.11	1.19	1.38	-0.71	0.14	0.07	0.19
					194	2.64	1.76	1.66	1.74	1.88	-0.88	-0.10	0.08	0.14
					195	2.85	2.30	1.66	2.02	1.63	-0.55	-0.63	0.35	-0.39
					196	2.26	2.09	1.55	1.77	1.50	-0.17	-0.54	0.22	-0.27
					197	1.52	1.32	1.28	1.23	1.29	-0.19	-0.05	-0.05	0.06
					198	0.54	0.62	1.15	0.92	0.90	0.08	0.52	-0.22	-0.02
					199	-0.24	0.02	0.79	0.61	0.44	0.26	0.77	-0.18	-0.16
					200	-0.95	-0.53	0.38	0.17	0.32	0.42	0.90	-0.20	0.15
					201	-1.32	-0.98	-0.20	-0.38	0.06	0.35	0.78	-0.18	0.44
					202	-1.21	-1.14	-0.62	-0.76	-0.67	0.07	0.52	-0.14	0.10
					203	-0.88	-1.15	-1.04	-1.08	-1.30	-0.27	0.11	-0.04	-0.22
					204	-0.84	-1.09	-1.64	-1.19	-1.67	-0.25	-0.54	0.45	-0.48
					205	-1.22	-1.03	-1.42	-1.16	-1.42	0.20	-0.39	0.25	-0.26
					206	-1.51	-1.00	-0.39	-0.95	-0.91	0.52	0.60	-0.56	0.04
					207	-1.66	-0.86	-0.28	-0.57	-0.50	0.80	0.58	-0.30	0.07
					208	-1.43	-0.86	-0.57	-0.23	-0.36	0.57	0.29	0.34	-0.14
					209	-0.63	-0.81	-0.60	-0.53	-0.51	-0.18	0.21	0.06	0.02
					210	0.05	-0.41	-0.42	-0.41	-0.51	-0.46	-0.01	0.01	-0.10
					211	0.02	0.22	-0.31	-0.52	-0.37	0.20	-0.52	-0.22	0.15

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					212	-0.18	0.09	-0.44	-0.47	-0.37	0.27	-0.53	-0.02	0.10
					213	-0.41	-0.09	-0.56	-0.55	-0.48	0.31	-0.47	0.01	0.07
					214	-0.30	-0.30	-0.56	-0.68	-0.52	0.00	-0.26	-0.12	0.16
					215	0.22	-0.52	-0.63	-0.56	-0.51	-0.74	-0.11	0.06	0.06
777.00	77.24	29.5	169.76	25.03	216	-0.17	-0.70	-0.63	-0.33	-0.70	-0.53	0.07	0.29	-0.37
					217	-0.92	-0.79	-0.56	-0.44	-0.74	0.13	0.24	0.12	-0.30
					218	-1.98	-0.81	-0.55	-0.28	-0.59	1.18	0.25	0.27	-0.31
					219	-2.19	-0.76	-0.72	-0.39	-0.56	1.43	0.04	0.33	-0.17
					220	-1.73	-0.79	-0.70	-0.10	-0.34	0.95	0.08	0.61	-0.24
					221	-0.91	-0.60	-0.32	-0.15	-0.31	0.31	0.28	0.16	-0.15
					222	0.12	-0.01	0.21	-0.37	-0.11	-0.13	0.22	-0.58	0.27
					223	0.30	0.46	0.21	0.29	-0.29	0.16	-0.25	0.08	-0.58
					224	-0.08	0.41	0.13	-0.15	-0.44	0.49	-0.28	-0.27	-0.29
					225	-0.60	0.26	1.00	-0.76	-0.51	0.86	0.73	-1.76	0.26
					226	-1.28	-1.13	-0.48	-2.35	-2.48	0.15	0.64	-1.87	-0.13
					227	-1.98	-1.77	-2.53	-2.61	-2.64	0.22	-0.76	-0.08	-0.02
					228	-2.06	-1.77	-2.43	-2.34	-2.29	0.29	-0.65	0.08	0.05
					229	-1.83	-1.63	-1.87	-1.89	-1.88	0.20	-0.23	-0.02	0.01
					230	-1.47	-1.50	-1.53	-1.66	-1.68	-0.02	-0.03	-0.13	-0.02
					231	-1.55	-1.59	-1.33	-1.65	-1.64	-0.03	0.26	-0.32	0.01
					232	-2.05	-1.71	-1.65	-1.92	-2.03	0.34	0.06	-0.27	-0.12
					233	-2.38	-1.62	-1.81	-2.28	-2.44	0.76	-0.19	-0.47	-0.16

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					234	-2.01	-1.57	-1.81	-2.20	-2.35	0.44	-0.24	-0.39	-0.15
					235	-1.59	-1.31	-1.06	-1.52	-1.84	0.27	0.25	-0.46	-0.32
					236	-1.21	-0.92	-0.73	-1.06	-0.81	0.29	0.19	-0.33	0.25
					237	-1.46	-0.70	-0.78	-1.01	-0.58	0.76	-0.09	-0.23	0.44
					238	-1.91	-0.93	-1.41	-1.41	-0.87	0.98	-0.47	-0.01	0.54
					239	-2.30	-1.56	-1.88	-1.93	-1.62	0.74	-0.31	-0.05	0.31
					240	-1.79	-1.97	-2.06	-2.00	-1.69	-0.18	-0.09	0.06	0.31
744.00	77.02	29.25	178.37	25.32	241	0.25	-0.95	-1.12	-1.25	-1.16	-1.20	-0.17	-0.13	0.09
					242	0.78	-0.14	-0.25	-0.35	-0.22	-0.92	-0.11	-0.10	0.14
					243	0.85	0.42	0.22	0.63	0.47	-0.43	-0.20	0.41	-0.16
					244	0.31	0.66	0.96	0.88	0.79	0.35	0.30	-0.09	-0.08
					245	-1.44	0.60	0.98	0.99	0.82	2.04	0.38	0.01	-0.18
					246	-2.18	0.40	0.73	0.72	0.59	2.58	0.33	-0.01	-0.13
					247	-1.90	-0.36	-0.59	-0.47	-0.77	1.55	-0.23	0.12	-0.31
					248	-1.25	-0.64	-1.25	-1.40	-1.71	0.61	-0.62	-0.14	-0.31
					249	-0.88	-0.67	-1.48	-1.79	-1.79	0.20	-0.81	-0.31	0.00
					250	-0.50	-0.65	-1.03	-1.24	-1.36	-0.15	-0.38	-0.21	-0.12
					251	-0.14	-0.75	-0.28	-0.30	-0.18	-0.61	0.47	-0.02	0.12
					252	0.11	-0.69	0.36	0.04	0.75	-0.79	1.05	-0.32	0.71
					253	0.13	-0.58	0.46	-0.05	0.90	-0.70	1.04	-0.51	0.95
					254	-0.02	-0.06	0.17	-0.17	0.72	-0.04	0.23	-0.34	0.89
					255	-0.18	0.27	0.24	-0.02	0.34	0.45	-0.03	-0.27	0.37

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					256	-0.24	0.16	0.77	0.39	0.19	0.40	0.61	-0.38	-0.21
					257	-0.20	0.50	0.65	0.60	0.54	0.70	0.15	-0.05	-0.06
					258	0.06	0.31	0.38	0.39	0.39	0.25	0.07	0.01	0.00
					259	0.37	-0.09	-0.07	-0.26	-0.20	-0.46	0.03	-0.19	0.06
					260	0.39	-0.19	-0.73	-0.82	-0.77	-0.58	-0.54	-0.08	0.05
					261	0.02	-0.16	-0.79	-0.75	-0.85	-0.18	-0.63	0.04	-0.10
					262	-0.39	-0.16	-0.70	-0.43	-0.67	0.23	-0.54	0.27	-0.23
					263	-0.81	-0.74	-0.05	-0.16	-0.35	0.06	0.69	-0.11	-0.19
					264	-0.71	-0.77	0.95	0.27	0.45	-0.06	1.73	-0.68	0.17
					265	-0.31	-0.16	0.87	0.52	0.65	0.15	1.03	-0.35	0.13
					266	-0.01	0.35	0.48	0.38	0.32	0.36	0.13	-0.09	-0.06
					267	0.11	1.12	0.51	0.13	-0.21	1.01	-0.62	-0.37	-0.35
					268	-0.12	0.92	0.87	0.16	-0.29	1.04	-0.05	-0.72	-0.45
					269	-0.25	0.14	1.50	0.56	0.11	0.39	1.36	-0.95	-0.45
					270	0.15	0.13	0.48	0.83	0.32	-0.02	0.35	0.35	-0.51
					271	0.41	0.41	0.04	0.76	0.55	0.00	-0.38	0.73	-0.22
712.00	77.07	29.04	164.64	25.01	272	1.04	1.09	0.61	0.74	0.86	0.06	-0.48	0.13	0.12
					273	1.70	1.66	1.68	1.61	1.13	-0.05	0.02	-0.07	-0.49
					274	1.54	1.82	1.88	1.86	1.51	0.28	0.05	-0.01	-0.35
					275	0.79	1.55	1.53	1.55	1.61	0.76	-0.02	0.02	0.06
					276	-0.06	0.98	0.85	1.10	0.78	1.04	-0.13	0.26	-0.32
					277	-0.13	-0.09	0.14	0.64	0.34	0.04	0.23	0.50	-0.29

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					278	0.03	-0.05	-0.01	0.08	0.27	-0.08	0.04	0.09	0.20
					279	0.25	0.31	0.27	0.17	0.09	0.05	-0.03	-0.11	-0.08
					280	0.59	0.64	0.78	0.54	0.28	0.05	0.14	-0.24	-0.26
					281	0.47	0.65	1.37	1.06	0.59	0.18	0.72	-0.31	-0.47
					282	-0.10	0.39	1.32	1.29	1.00	0.49	0.93	-0.03	-0.29
					283	-0.58	0.07	0.22	0.42	0.51	0.64	0.15	0.21	0.09
					284	-1.05	-0.43	-1.22	-0.92	-0.57	0.62	-0.79	0.30	0.36
					285	-1.08	-1.00	-1.42	-1.35	-1.02	0.09	-0.42	0.06	0.33
					286	-1.14	-1.10	-1.35	-1.32	-1.28	0.04	-0.25	0.03	0.03
					287	-1.01	-0.98	-1.13	-1.14	-1.20	0.03	-0.15	-0.01	-0.06
					288	-0.99	-0.85	-0.96	-1.00	-1.01	0.14	-0.11	-0.04	-0.01
					289	-0.74	-0.62	-0.63	-0.69	-0.82	0.12	-0.01	-0.07	-0.13
					290	-0.29	-0.22	-0.38	-0.43	-0.65	0.07	-0.16	-0.06	-0.22
					291	-0.01	0.02	-0.40	-0.37	-0.46	0.03	-0.42	0.03	-0.08
680.00	77.12	28.84	172.75	25.09	292	-0.06	-0.31	-0.52	-0.53	-0.35	-0.25	-0.21	-0.01	0.18
					293	-0.54	-0.54	-0.67	-0.67	-0.52	0.00	-0.13	0.00	0.15
					294	-1.33	-0.75	-1.10	-1.09	-1.08	0.58	-0.35	0.01	0.01
					295	-2.08	-1.09	-1.28	-1.25	-1.36	0.99	-0.19	0.03	-0.11
					296	-2.81	-2.46	-1.78	-1.49	-1.50	0.35	0.68	0.29	-0.01
					297	-2.77	-2.72	-2.66	-2.40	-2.33	0.06	0.05	0.26	0.08
					298	-2.47	-2.37	-2.58	-2.63	-2.58	0.10	-0.21	-0.04	0.05
					299	-2.39	-1.51	-1.93	-2.15	-2.16	0.89	-0.42	-0.23	-0.01

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					300	1.11	-0.96	-1.39	-1.38	-1.38	-2.07	-0.43	0.02	0.00
					301	1.33	-0.62	-0.91	-0.72	-0.62	-1.95	-0.29	0.19	0.10
					302	0.84	-0.48	-0.61	-0.32	-0.14	-1.32	-0.13	0.29	0.18
					303	-0.03	-0.32	-0.42	-0.23	-0.23	-0.29	-0.09	0.19	0.00
					304	-0.58	-0.26	-0.51	-0.50	-0.44	0.32	-0.26	0.01	0.06
					305	-0.78	-0.89	-0.75	-0.76	-0.81	-0.11	0.14	0.00	-0.05
					306	-0.75	-0.86	-1.11	-0.82	-1.09	-0.11	-0.25	0.30	-0.27
					307	-0.20	-0.22	-0.63	-0.63	-0.60	-0.02	-0.41	0.00	0.03
					308	1.06	0.21	0.28	0.24	0.29	-0.85	0.07	-0.04	0.05
					309	1.40	0.67	0.85	0.78	0.79	-0.72	0.17	-0.07	0.01
					310	1.28	0.86	1.10	0.97	1.01	-0.41	0.23	-0.12	0.04
					311	0.71	0.83	1.07	1.01	1.10	0.12	0.24	-0.07	0.09
					312	-0.56	-0.31	0.55	0.69	0.81	0.25	0.86	0.14	0.12
					313	-0.42	-1.42	-1.58	-1.14	-0.37	-1.00	-0.17	0.44	0.77
					314	-0.03	-1.32	-1.15	-1.42	-1.03	-1.29	0.17	-0.27	0.39
					315	0.53	-0.95	-0.86	-1.07	-0.88	-1.47	0.08	-0.20	0.19
					316	0.87	-0.78	-0.52	-0.84	-0.55	-1.65	0.27	-0.32	0.29
					317	-0.98	-0.74	-0.44	-0.77	-0.46	0.24	0.30	-0.33	0.31
					318	-0.34	-0.61	-0.81	-0.41	-0.28	-0.27	-0.20	0.40	0.13
648.00	77.17	28.63	154.98	25.35	319	0.13	-0.49	-0.77	-0.50	-0.14	-0.62	-0.28	0.27	0.36
					320	0.34	0.37	0.40	0.33	0.26	0.03	0.03	-0.06	-0.07
					321	0.71	0.70	1.04	0.78	0.89	-0.01	0.33	-0.26	0.11

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					322	1.37	1.30	1.43	1.27	1.30	-0.07	0.13	-0.16	0.03
					323	1.77	1.61	1.71	1.58	1.57	-0.16	0.09	-0.12	-0.01
					324	1.95	1.83	1.77	1.76	1.83	-0.12	-0.06	-0.01	0.07
					325	1.91	1.85	1.84	1.84	1.82	-0.06	-0.01	0.00	-0.02
					326	1.33	1.11	1.20	1.23	1.21	-0.22	0.09	0.02	-0.02
					327	0.60	0.34	0.40	0.40	0.40	-0.25	0.06	0.00	-0.01
					328	0.55	0.26	0.28	0.31	0.33	-0.29	0.02	0.02	0.02
					329	0.92	0.89	0.87	0.79	0.79	-0.03	-0.02	-0.08	0.00
					330	1.74	1.77	1.85	1.81	1.77	0.04	0.08	-0.04	-0.04
					331	2.26	2.14	2.14	2.17	2.22	-0.12	0.00	0.03	0.05
					332	2.31	2.31	2.40	2.48	2.47	0.00	0.09	0.08	-0.01
					333	2.32	2.37	2.53	2.53	2.54	0.05	0.16	0.00	0.01
					334	2.18	2.37	2.16	2.23	2.23	0.20	-0.22	0.07	0.00
					335	2.31	1.71	1.63	1.80	1.82	-0.61	-0.07	0.17	0.01
					336	2.35	1.34	1.17	1.14	1.06	-1.01	-0.17	-0.03	-0.09
					337	2.35	1.05	1.12	0.96	0.80	-1.31	0.08	-0.16	-0.17
					338	0.79	0.80	0.79	0.66	0.68	0.01	0.00	-0.13	0.02
					339	0.60	0.52	0.55	0.53	0.45	-0.09	0.03	-0.02	-0.09
					340	0.61	0.29	0.19	0.36	0.38	-0.33	-0.10	0.18	0.02
					341	0.32	0.23	0.22	-0.03	0.22	-0.09	-0.01	-0.25	0.25
616.00	77.22	28.42	126.76	2.19	342	-0.05	-0.18	-0.11	-0.14	-0.11	-0.13	0.07	-0.03	0.02
					343	-0.06	0.10	0.04	-0.06	0.04	0.16	-0.06	-0.09	0.10

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
617.00	77.49	28.46	140.42	25.13	344	0.05	0.19	0.23	0.13	0.10	0.14	0.05	-0.10	-0.03
					345	0.15	0.16	0.19	0.10	0.12	0.00	0.03	-0.09	0.02
					346	0.46	0.18	0.15	-0.02	0.17	-0.28	-0.03	-0.17	0.19
					347	0.91	0.56	0.29	0.33	0.28	-0.35	-0.27	0.04	-0.06
					348	0.52	0.73	0.73	0.68	0.54	0.21	-0.01	-0.05	-0.14
					349	-0.74	0.76	0.83	0.71	0.86	1.50	0.07	-0.11	0.14
					350	-0.34	0.71	0.83	0.85	0.90	1.05	0.12	0.02	0.05
					351	0.80	0.60	0.69	0.67	0.67	-0.20	0.09	-0.02	0.01
					352	0.15	0.31	0.38	0.37	0.41	0.16	0.07	-0.01	0.04
					353	-1.23	-2.02	-1.29	-1.72	-1.38	-0.79	0.73	-0.44	0.34
					354	-1.56	-2.00	-2.76	-2.78	-2.79	-0.45	-0.76	-0.02	-0.01
					355	-2.53	-1.75	-2.41	-2.38	-1.81	0.78	-0.66	0.03	0.57
					356	-2.18	-1.17	-1.16	-1.36	-1.62	1.01	0.01	-0.20	-0.26
					357	0.06	-0.01	-0.50	-0.49	-0.39	-0.07	-0.49	0.02	0.10
					358	-0.27	-0.33	-0.53	-0.45	-0.16	-0.05	-0.20	0.08	0.29
					359	-3.26	-2.34	-2.50	-2.36	-3.16	0.93	-0.16	0.14	-0.80
					360	-3.53	-4.01	-4.24	-3.55	-3.40	-0.48	-0.23	0.69	0.15
					361	-3.95	-3.44	-3.95	-3.43	-3.27	0.51	-0.51	0.52	0.16
					362	-3.95	-3.25	-2.75	-2.73	-3.62	0.70	0.51	0.02	-0.89
					363	-3.43	-4.05	-2.18	-2.43	-2.30	-0.62	1.87	-0.25	0.13
					364	-1.98	-4.20	-4.71	-4.70	-4.73	-2.22	-0.51	0.01	-0.03
					365	-1.94	-3.31	-4.20	-4.27	-4.33	-1.37	-0.89	-0.07	-0.06

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					366	-3.78	-2.78	-2.52	-2.55	-2.56	1.01	0.26	-0.04	-0.01
					367	-3.33	-2.26	-2.13	-2.22	-2.16	1.07	0.14	-0.10	0.07
					368	-0.14	0.34	-1.73	-1.36	-1.38	0.48	-2.07	0.37	-0.01
585.00	77.54	28.25	179.04	25.34	369	-0.11	0.63	0.63	0.49	0.04	0.74	0.00	-0.14	-0.45
					370	-1.39	0.42	0.48	0.48	0.50	1.80	0.07	-0.01	0.02
					371	-1.12	0.61	0.98	0.40	0.88	1.73	0.37	-0.58	0.48
					372	1.51	1.34	1.34	0.94	1.35	-0.17	0.00	-0.40	0.41
					373	1.65	1.61	1.51	1.60	1.56	-0.04	-0.10	0.08	-0.03
					374	1.65	1.63	1.65	1.65	1.65	-0.02	0.02	0.00	-0.01
					375	0.61	1.36	1.43	1.48	1.43	0.75	0.07	0.05	-0.05
					376	-1.87	-0.16	-1.40	-0.91	-0.87	1.71	-1.24	0.49	0.03
					377	-1.28	-1.65	-1.84	-1.64	-1.37	-0.37	-0.19	0.19	0.27
					378	0.11	-0.26	-1.20	-0.92	-1.14	-0.38	-0.93	0.28	-0.22
					379	0.92	0.81	0.84	1.03	1.03	-0.12	0.04	0.19	0.00
					380	1.07	1.21	1.31	1.36	1.36	0.14	0.10	0.05	0.00
					381	1.01	1.74	1.70	1.73	1.76	0.74	-0.05	0.03	0.04
					382	2.96	2.86	2.77	2.65	2.63	-0.10	-0.10	-0.12	-0.02
					383	2.85	2.78	2.84	2.83	2.81	-0.06	0.05	-0.01	-0.02
					384	2.33	2.30	2.39	2.39	2.41	-0.04	0.09	0.00	0.02
					385	2.18	2.03	1.98	2.04	1.96	-0.15	-0.06	0.06	-0.07
					386	1.59	1.64	1.42	1.43	1.40	0.05	-0.22	0.01	-0.03
					387	1.64	1.41	1.16	1.07	1.16	-0.24	-0.24	-0.10	0.09

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					388	2.37	1.24	1.12	1.10	1.10	-1.12	-0.12	-0.02	-0.01
					389	1.77	0.99	1.19	1.03	1.05	-0.78	0.20	-0.16	0.03
					390	0.74	0.85	1.01	1.00	0.99	0.11	0.16	-0.01	-0.01
					391	0.89	0.79	0.82	0.79	0.79	-0.11	0.03	-0.02	0.00
					392	2.16	1.14	0.48	0.44	0.54	-1.01	-0.66	-0.04	0.09
					393	1.74	1.35	0.47	0.40	0.37	-0.39	-0.88	-0.07	-0.03
					394	0.12	-0.06	0.28	0.25	0.19	-0.18	0.34	-0.03	-0.05
					395	-0.34	-0.62	-0.30	-0.32	-0.28	-0.27	0.32	-0.02	0.04
					396	0.38	-0.43	-0.43	-0.42	-0.37	-0.81	0.00	0.01	0.04
					397	0.83	0.15	-0.31	-0.31	-0.41	-0.68	-0.45	0.00	-0.10
					398	1.07	1.10	0.12	0.27	0.33	0.04	-0.99	0.15	0.06
					399	1.63	1.30	1.45	1.44	1.46	-0.33	0.15	-0.01	0.02
					400	1.83	1.62	1.64	1.52	1.51	-0.21	0.01	-0.12	-0.02
					401	1.63	1.59	1.77	1.60	1.59	-0.04	0.17	-0.16	-0.01
553.00	77.59	28.04	168.03	25.00	402	0.94	1.48	1.67	1.77	1.71	0.54	0.18	0.11	-0.06
					403	0.28	0.85	0.91	0.87	0.82	0.57	0.06	-0.05	-0.05
					404	0.42	0.57	0.32	0.34	0.17	0.15	-0.25	0.02	-0.17
					405	2.01	1.89	0.09	0.29	0.09	-0.12	-1.80	0.21	-0.20
					406	1.41	1.27	0.44	0.60	0.45	-0.15	-0.82	0.15	-0.14
					407	0.31	-0.50	-0.87	-0.54	-0.84	-0.81	-0.37	0.33	-0.30
					408	0.04	-0.99	-1.74	-1.77	-2.02	-1.03	-0.75	-0.02	-0.25
					409	-0.68	-0.88	-1.77	-1.73	-1.53	-0.21	-0.89	0.04	0.20

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					410	-0.94	-1.05	-0.41	-0.89	-0.80	-0.11	0.64	-0.48	0.09
					411	-1.28	-1.53	-0.94	-0.92	-0.73	-0.26	0.60	0.01	0.19
					412	-1.97	-1.19	-2.29	-2.08	-2.34	0.78	-1.10	0.21	-0.26
					413	-1.95	-0.58	-1.51	-1.73	-2.16	1.37	-0.93	-0.22	-0.43
					414	0.34	-0.16	-0.23	-0.18	-0.02	-0.50	-0.06	0.05	0.16
					415	0.49	0.00	-0.46	-0.30	-0.09	-0.49	-0.45	0.16	0.21
					416	-1.85	-1.91	-0.15	-0.52	-0.74	-0.06	1.76	-0.37	-0.23
					417	-1.37	-1.63	-1.76	-1.52	-1.58	-0.26	-0.14	0.25	-0.06
					418	-0.85	-1.04	-1.66	-1.96	-1.75	-0.18	-0.63	-0.29	0.20
					419	-0.16	0.04	0.21	0.19	0.20	0.19	0.17	-0.01	0.01
521.00	77.63	27.83	141.61	26.92	420	1.63	1.59	1.63	1.56	1.46	-0.04	0.04	-0.07	-0.10
					421	1.65	1.72	1.81	1.82	1.78	0.08	0.09	0.00	-0.04
					422	1.72	1.74	1.89	1.60	1.79	0.02	0.15	-0.29	0.19
					423	1.73	1.63	2.15	1.59	1.69	-0.10	0.52	-0.56	0.09
					424	1.70	1.47	1.89	2.28	2.15	-0.23	0.41	0.39	-0.13
					425	1.89	1.49	1.80	1.64	1.87	-0.40	0.31	-0.15	0.23
					426	1.96	1.69	2.05	1.67	1.51	-0.28	0.36	-0.38	-0.16
					427	1.50	1.38	1.51	1.51	1.61	-0.12	0.13	0.00	0.10
					428	0.63	0.64	0.09	0.13	0.20	0.01	-0.54	0.04	0.07
					429	-0.81	-0.70	-0.54	-0.36	-0.58	0.11	0.16	0.18	-0.23
					430	-1.58	-1.40	-0.96	-0.96	-0.77	0.19	0.44	0.00	0.19
					431	-1.01	-0.85	-1.30	-0.32	-1.48	0.16	-0.45	0.99	-1.16

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					432	2.05	1.14	0.90	1.33	1.24	-0.91	-0.24	0.43	-0.09
					433	1.98	2.37	1.78	2.12	1.54	0.38	-0.59	0.34	-0.58
					434	1.97	2.31	1.95	2.35	1.81	0.34	-0.36	0.40	-0.54
					435	2.75	1.96	1.98	2.26	2.19	-0.79	0.02	0.28	-0.07
					436	2.56	1.72	1.79	1.65	1.24	-0.84	0.07	-0.14	-0.41
					437	-1.42	-1.92	-2.56	-3.48	-2.80	-0.50	-0.64	-0.91	0.68
					438	-4.90	-5.23	-4.93	-5.44	-5.48	-0.34	0.30	-0.51	-0.04
					439	-5.56	-5.30	-5.12	-5.31	-4.76	0.26	0.18	-0.19	0.55
					440	-5.34	-5.52	-5.42	-5.44	-5.50	-0.18	0.09	-0.01	-0.07
					441	-5.46	-5.37	-5.48	-5.30	-5.52	0.09	-0.11	0.18	-0.22
					442	-1.98	-1.28	-1.23	-1.50	-1.43	0.70	0.04	-0.27	0.07
					443	-0.68	-0.75	-0.44	-0.72	-0.65	-0.07	0.31	-0.28	0.07
					444	-0.40	-0.37	-0.23	-0.47	-0.20	0.03	0.14	-0.24	0.26
					445	-0.11	-0.08	-0.11	-0.32	-0.16	0.03	-0.03	-0.20	0.15
					446	0.01	-0.13	-0.09	-0.33	-0.18	-0.13	0.03	-0.24	0.15
					447	-0.66	-0.56	-0.56	-0.80	-0.59	0.10	0.00	-0.24	0.20
					448	-1.78	-1.19	-0.99	-1.18	-1.07	0.59	0.19	-0.19	0.11
					449	-1.94	-1.65	-1.55	-1.55	-1.27	0.29	0.09	0.00	0.28
489.00	77.68	27.62	180.10	25.40	450	-1.88	-2.26	-2.24	-1.90	-1.87	-0.39	0.02	0.34	0.03
					451	-1.57	-2.17	-2.34	-1.82	-2.37	-0.60	-0.17	0.52	-0.55
					452	-1.26	-1.82	-1.98	-1.44	-2.05	-0.55	-0.17	0.54	-0.61
					453	-0.29	-0.11	-1.09	-0.41	-1.20	0.19	-0.98	0.67	-0.78

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					454	0.21	0.64	1.56	1.78	1.95	0.43	0.92	0.22	0.17
					455	0.02	0.68	1.51	1.47	1.84	0.66	0.83	-0.04	0.37
					456	-1.08	0.29	0.32	1.11	0.75	1.37	0.03	0.80	-0.36
					457	-1.81	-1.85	-1.22	-1.52	-1.67	-0.04	0.63	-0.30	-0.15
					458	-2.13	-2.16	-2.08	-2.13	-2.06	-0.04	0.08	-0.05	0.07
					459	-2.04	-2.23	-2.24	-2.25	-2.28	-0.19	-0.02	0.00	-0.03
					460	-2.17	-1.89	-1.90	-1.93	-2.08	0.27	0.00	-0.04	-0.14
					461	0.39	-0.41	-0.40	-0.59	-0.49	-0.80	0.01	-0.19	0.10
					462	0.15	0.60	0.41	0.23	0.40	0.45	-0.19	-0.18	0.18
					463	-0.92	0.31	-0.48	-1.99	-0.41	1.23	-0.79	-1.51	1.58
					464	-2.66	-3.02	-3.68	-3.41	-3.63	-0.36	-0.66	0.28	-0.22
					465	-2.80	-2.90	-3.85	-3.82	-3.83	-0.10	-0.95	0.03	-0.01
					466	-2.29	-2.23	-2.17	-2.27	-2.01	0.06	0.06	-0.11	0.27
					467	-2.15	-1.75	-1.45	-1.56	-1.21	0.40	0.30	-0.11	0.35
					468	-1.81	-1.58	-1.23	-1.31	-1.18	0.23	0.35	-0.08	0.13
					469	-1.35	-1.43	-1.31	-1.24	-1.35	-0.08	0.12	0.07	-0.11
					470	-0.88	-0.83	-0.87	-0.95	-0.94	0.06	-0.05	-0.08	0.01
					471	-0.10	-0.14	-0.20	-0.19	-0.30	-0.04	-0.06	0.00	-0.11
457.00	77.73	27.42	151.26	25.70	472	0.38	0.36	0.35	0.34	0.27	-0.02	-0.01	-0.01	-0.07
					473	0.28	0.18	0.22	0.25	0.26	-0.10	0.04	0.03	0.00
					474	-0.13	-0.17	-0.16	-0.14	-0.14	-0.04	0.01	0.01	0.01
					475	-0.56	-0.83	-0.82	-0.96	-0.72	-0.26	0.01	-0.14	0.24

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					476	-0.61	-0.96	-1.10	-1.11	-1.01	-0.35	-0.14	-0.01	0.10
					477	-0.83	-0.74	-0.50	-0.52	-0.57	0.09	0.24	-0.02	-0.05
					478	-0.63	-0.44	-0.18	-0.26	-0.26	0.19	0.26	-0.08	0.00
					479	-0.60	0.03	0.05	0.04	0.06	0.63	0.02	-0.02	0.02
					480	-0.31	0.38	0.28	0.30	0.26	0.69	-0.10	0.02	-0.04
					481	0.47	0.92	0.85	0.84	0.81	0.44	-0.07	-0.01	-0.04
					482	1.69	1.57	1.60	1.57	1.52	-0.12	0.03	-0.03	-0.04
					483	1.49	1.49	1.51	1.54	1.57	0.00	0.02	0.03	0.03
					484	-0.21	-0.14	-0.19	-0.13	-0.11	0.07	-0.05	0.06	0.02
					485	-0.42	-0.31	-0.45	-0.44	-0.45	0.11	-0.14	0.01	-0.01
					486	-0.64	-0.43	-0.57	-0.56	-0.56	0.20	-0.14	0.01	-0.01
					487	-0.54	-0.59	-0.53	-0.52	-0.52	-0.05	0.06	0.01	0.01
					488	0.03	0.00	-0.01	0.00	-0.02	-0.02	-0.01	0.01	-0.02
					489	0.86	0.98	1.01	0.86	1.01	0.12	0.04	-0.15	0.15
457.00	77.73	27.42	151.26	25.70	490	-1.94	-2.05	-1.81	-2.16	-1.77	-0.11	0.24	-0.35	0.39
					491	-4.07	-3.95	-4.04	-4.03	-4.08	0.12	-0.09	0.01	-0.05
					492	-1.33	-1.71	-1.46	-1.55	-1.43	-0.38	0.26	-0.09	0.12
					493	-0.63	-0.96	-0.84	-0.70	-0.69	-0.33	0.11	0.15	0.00
					494	-0.25	-0.34	-0.31	-0.25	-0.26	-0.09	0.03	0.06	-0.01
					495	0.11	0.12	0.10	0.03	0.05	0.01	-0.02	-0.07	0.02
					496	0.20	0.31	0.28	0.12	0.10	0.11	-0.02	-0.16	-0.02
					497	0.05	0.13	0.24	0.21	0.07	0.07	0.12	-0.04	-0.13

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
425.00	77.77	27.21	102.66	9.40	498	0.54	0.66	0.73	0.74	0.75	0.12	0.07	0.01	0.02
					499	0.99	1.11	1.10	1.15	1.13	0.12	-0.01	0.05	-0.02
					500	0.97	1.24	1.22	1.30	1.32	0.27	-0.03	0.08	0.02
					501	0.66	1.25	1.23	1.25	1.27	0.59	-0.02	0.02	0.02
					502	0.85	1.02	1.05	1.10	0.97	0.18	0.02	0.06	-0.13
					503	1.81	1.42	1.00	1.43	1.36	-0.39	-0.42	0.43	-0.07
					504	4.24	4.26	4.30	4.53	4.24	0.02	0.04	0.23	-0.28
					505	3.52	3.21	3.15	3.22	3.19	-0.32	-0.06	0.07	-0.03
					506	2.64	2.51	2.67	2.45	2.71	-0.13	0.16	-0.22	0.25
					507	2.61	2.27	2.56	2.38	2.43	-0.35	0.30	-0.18	0.05
426.00	78.04	27.24	111.24	30.90	508	0.06	-0.04	-0.11	-0.05	-0.04	-0.10	-0.07	0.06	0.01
					509	0.44	0.47	0.35	0.40	0.22	0.03	-0.12	0.05	-0.18
					510	2.58	2.69	2.56	2.75	2.61	0.11	-0.13	0.19	-0.14
					511	4.49	4.27	4.78	4.83	4.70	-0.22	0.51	0.05	-0.13
					512	2.04	2.38	2.05	2.57	2.54	0.33	-0.33	0.52	-0.03
					513	-2.08	-2.02	-2.09	-1.94	-2.16	0.06	-0.07	0.15	-0.22
					514	0.84	0.66	0.70	0.69	0.50	-0.18	0.05	-0.01	-0.19
					515	2.67	2.70	2.77	2.74	2.65	0.02	0.07	-0.02	-0.09
					516	2.30	2.18	2.51	2.46	2.50	-0.12	0.33	-0.06	0.04
					517	1.62	1.65	1.96	1.66	1.94	0.03	0.31	-0.30	0.28
					518	-1.30	-1.29	-1.32	-1.29	-1.31	0.01	-0.03	0.03	-0.02
					519	-1.22	-1.27	-1.30	-1.30	-1.27	-0.05	-0.04	0.00	0.03

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					520	-1.15	-1.11	-1.15	-1.14	-1.10	0.04	-0.04	0.01	0.04
					521	-0.14	-0.26	-0.30	-0.42	-0.29	-0.11	-0.05	-0.12	0.13
					522	1.15	1.28	1.30	1.29	1.25	0.12	0.02	-0.01	-0.04
					523	2.55	2.55	2.53	2.74	2.53	0.00	-0.02	0.21	-0.21
					524	6.22	6.41	6.45	6.37	6.47	0.19	0.04	-0.08	0.10
					525	6.52	6.54	6.53	6.65	6.63	0.02	-0.01	0.12	-0.02
					526	4.45	4.59	4.81	4.72	4.92	0.14	0.22	-0.09	0.21
					527	2.74	2.94	2.79	2.77	2.80	0.20	-0.15	-0.02	0.04
					528	1.84	1.93	1.94	1.96	1.93	0.09	0.01	0.02	-0.02
					529	2.03	2.00	1.81	1.90	1.83	-0.03	-0.19	0.09	-0.07
					530	2.42	2.56	2.29	2.29	2.26	0.13	-0.27	0.00	-0.03
					531	3.01	2.93	3.03	3.01	3.04	-0.09	0.11	-0.02	0.03
					532	2.63	2.65	2.69	2.67	2.71	0.02	0.04	-0.02	0.04
					533	2.08	2.09	2.16	2.11	2.15	0.00	0.07	-0.05	0.04
					534	1.42	1.54	1.46	1.46	1.36	0.12	-0.08	0.00	-0.09
					535	0.95	1.03	1.05	0.89	0.94	0.08	0.02	-0.15	0.05
					536	0.74	0.50	1.15	0.90	0.91	-0.23	0.64	-0.24	0.01
					537	0.41	0.33	1.00	0.60	0.91	-0.08	0.67	-0.40	0.31
427.00	78.3	27.28	121.44	3.73	538	-0.55	-0.26	0.16	-0.01	0.21	0.29	0.42	-0.18	0.22
					539	-0.88	-0.83	-0.50	-0.47	-0.57	0.05	0.33	0.03	-0.10
					540	-0.75	-0.86	-0.80	-0.70	-0.50	-0.11	0.06	0.10	0.21
					541	-0.17	-0.30	-0.33	-0.20	-0.40	-0.13	-0.03	0.13	-0.19

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
395.00	78.35	27.07	124.16	32.56	542	-0.17	-0.30	-0.33	-0.32	-0.29	-0.12	-0.03	0.00	0.03
					547	0.12	0.07	-0.24	-0.09	-0.05	-0.05	-0.31	0.15	0.04
					548	0.60	0.70	0.71	0.49	0.55	0.10	0.01	-0.22	0.07
					549	0.54	0.66	0.81	0.66	0.67	0.12	0.15	-0.15	0.01
					550	0.89	0.96	0.90	0.89	1.02	0.07	-0.05	-0.02	0.14
					551	1.46	1.48	1.49	1.49	1.50	0.02	0.01	0.00	0.01
					552	1.16	1.21	1.30	1.21	1.29	0.05	0.09	-0.09	0.08
					553	0.33	0.25	0.23	0.23	0.30	-0.08	-0.01	0.00	0.07
					554	-0.52	-0.52	-0.49	-0.54	-0.59	0.00	0.03	-0.04	-0.05
					555	-3.62	-3.65	-3.60	-3.38	-3.51	-0.03	0.06	0.22	-0.14
					556	-5.70	-5.65	-5.66	-5.65	-5.69	0.05	-0.01	0.01	-0.04
					557	-4.12	-4.14	-4.03	-4.08	-4.18	-0.02	0.11	-0.05	-0.09
					558	-5.28	-5.05	-5.05	-5.06	-5.16	0.23	0.00	-0.02	-0.09
					559	-1.45	-1.35	-1.26	-1.28	-1.26	0.10	0.09	-0.02	0.01
					560	-2.47	-2.22	-2.33	-2.28	-2.21	0.25	-0.11	0.05	0.07
					561	-2.64	-2.70	-2.68	-2.69	-2.69	-0.07	0.02	-0.01	0.00
					562	-4.32	-4.29	-4.29	-4.31	-4.31	0.02	0.00	-0.02	0.00
					563	-4.05	-4.06	-3.99	-4.04	-4.05	-0.01	0.07	-0.05	0.00
					564	-3.72	-3.73	-3.71	-3.71	-3.75	-0.01	0.02	0.01	-0.05
					565	-3.42	-3.46	-3.48	-3.45	-3.44	-0.04	-0.02	0.02	0.01
					566	-3.40	-3.43	-3.43	-3.41	-3.44	-0.03	0.00	0.02	-0.03
					567	-3.90	-3.96	-3.95	-3.91	-3.92	-0.06	0.01	0.03	0.00

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					568	-4.23	-4.23	-4.22	-4.19	-4.22	0.00	0.01	0.03	-0.03
					569	-4.13	-4.19	-4.14	-4.11	-4.15	-0.06	0.05	0.03	-0.04
					570	-3.59	-3.59	-3.57	-3.56	-3.57	0.00	0.02	0.01	-0.01
					571	-2.57	-2.63	-2.54	-2.52	-2.58	-0.06	0.09	0.02	-0.06
					572	-1.93	-2.00	-1.91	-1.88	-1.93	-0.07	0.09	0.03	-0.05
					573	-1.43	-1.47	-1.42	-1.40	-1.42	-0.04	0.05	0.02	-0.01
					574	0.16	0.42	0.46	0.59	0.49	0.26	0.04	0.13	-0.10
					575	1.28	1.22	1.40	1.40	1.42	-0.06	0.18	0.01	0.02
					576	-0.48	-0.40	-0.42	-0.35	-0.37	0.08	-0.02	0.07	-0.02
					577	-0.72	-0.74	-0.72	-0.71	-0.74	-0.02	0.02	0.00	-0.02
363.00	78.39	26.86	132.12	3.07	578	0.49	0.48	0.50	0.54	0.48	-0.01	0.02	0.04	-0.06
					579	1.27	1.22	1.26	1.27	1.25	-0.05	0.04	0.01	-0.03
					580	0.83	0.81	0.86	0.83	0.96	-0.01	0.04	-0.03	0.13
364.00	78.66	26.9	108.46	29.56	581	-0.07	-0.03	-0.02	-0.03	-0.10	0.04	0.01	-0.02	-0.06
					582	-0.73	-0.68	-0.70	-0.66	-0.42	0.05	-0.02	0.04	0.24
					583	0.53	0.55	0.53	0.77	0.43	0.03	-0.02	0.23	-0.33
					584	0.92	0.80	0.89	0.92	0.83	-0.12	0.09	0.03	-0.09
					585	0.49	0.30	0.45	0.44	0.52	-0.19	0.15	-0.01	0.07
					586	-2.38	-2.40	-2.36	-2.39	-2.34	-0.02	0.03	-0.03	0.05
					587	-0.82	-0.75	-0.65	-0.60	-0.63	0.07	0.10	0.04	-0.02
					588	-0.15	-0.22	-0.20	-0.17	-0.21	-0.07	0.03	0.02	-0.04
					589	0.35	0.34	0.37	0.33	0.33	-0.01	0.03	-0.04	0.00

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					590	-0.42	-0.51	-0.49	-0.45	-0.43	-0.09	0.02	0.03	0.03
					591	-1.70	-1.40	-1.27	-1.23	-1.17	0.30	0.13	0.04	0.06
					592	-0.01	-0.15	-0.06	-0.01	0.04	-0.14	0.09	0.05	0.06
					593	1.17	1.08	1.12	1.15	1.15	-0.08	0.03	0.03	0.00
					594	1.30	1.32	1.32	1.29	1.22	0.02	0.01	-0.04	-0.06
					595	2.92	2.87	2.94	2.97	2.91	-0.05	0.07	0.03	-0.06
					596	3.91	3.85	3.87	3.94	3.87	-0.06	0.02	0.08	-0.07
					597	3.41	3.34	3.34	3.42	3.38	-0.08	0.00	0.08	-0.03
					598	0.37	0.41	0.38	0.45	0.40	0.04	-0.03	0.07	-0.05
					599	-1.24	-1.28	-1.24	-1.23	-1.24	-0.04	0.04	0.00	-0.01
					600	-2.48	-2.39	-2.37	-2.38	-2.40	0.09	0.02	-0.01	-0.02
					601	-1.08	-1.18	-1.17	-1.09	-1.11	-0.10	0.01	0.08	-0.01
					602	-1.05	-1.05	-1.00	-1.06	-0.97	0.00	0.06	-0.06	0.09
					603	-4.04	-4.05	-4.05	-4.04	-4.05	-0.01	0.00	0.01	-0.02
					604	-3.35	-3.40	-3.36	-3.31	-3.34	-0.05	0.05	0.04	-0.03
					605	-2.78	-2.81	-2.78	-2.77	-2.75	-0.03	0.03	0.01	0.02
					606	-2.65	-2.68	-2.65	-2.64	-2.65	-0.03	0.04	0.01	0.00
					607	-1.87	-1.88	-1.87	-1.63	-1.94	-0.01	0.01	0.24	-0.31
					608	-1.40	-1.44	-1.42	-1.43	-1.42	-0.04	0.02	-0.01	0.01
					609	0.37	0.33	0.42	0.52	0.48	-0.04	0.09	0.09	-0.03
					610	0.22	0.20	0.25	0.21	0.25	-0.02	0.06	-0.04	0.03
365.00	78.92	26.93	133.18	7.72	611	-1.40	-1.43	-1.42	-1.40	-1.42	-0.03	0.01	0.02	-0.03

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
365.00	78.92	26.93	133.18	7.72	612	-0.82	-0.85	-0.83	-0.82	-0.79	-0.04	0.02	0.01	0.03
365.00	78.92	26.93	133.18	7.72	613	-0.32	-0.33	-0.30	-0.29	-0.36	-0.01	0.04	0.01	-0.07
					614	-0.56	-0.57	-0.55	-0.55	-0.57	-0.01	0.02	0.00	-0.02
					615	-0.74	-0.73	-0.75	-0.65	-0.80	0.01	-0.02	0.10	-0.15
					616	-0.57	-0.57	-0.57	-0.56	-0.61	0.00	0.00	0.01	-0.05
					617	-0.40	-0.37	-0.42	-0.34	-0.36	0.03	-0.05	0.08	-0.02
333.00	78.96	26.72	130.21	30.19	618	0.03	-0.10	-0.05	-0.01	-0.05	-0.13	0.05	0.04	-0.04
					619	0.28	0.27	0.33	0.29	0.31	-0.02	0.07	-0.04	0.02
					620	0.60	0.55	0.63	0.54	0.63	-0.05	0.08	-0.09	0.09
					621	0.57	0.58	0.71	0.53	0.53	0.01	0.12	-0.17	-0.01
					622	-0.49	-0.63	-0.31	-0.63	-0.84	-0.13	0.31	-0.31	-0.21
					623	-1.93	-1.91	-1.91	-1.95	-2.02	0.02	0.00	-0.04	-0.07
					624	-2.25	-2.29	-2.27	-2.26	-2.23	-0.04	0.02	0.01	0.03
					625	-3.14	-3.19	-3.14	-3.20	-3.17	-0.04	0.04	-0.05	0.02
					626	-3.59	-3.60	-3.58	-3.55	-3.57	-0.01	0.01	0.03	-0.02
					627	-2.96	-2.96	-2.94	-2.98	-2.95	0.00	0.02	-0.04	0.02
					628	-4.10	-4.16	-4.14	-4.18	-4.11	-0.06	0.02	-0.04	0.07
					629	-1.74	-1.77	-1.72	-1.74	-1.66	-0.03	0.05	-0.02	0.08
					630	-2.78	-2.80	-2.80	-2.80	-2.83	-0.03	0.01	-0.01	-0.03
					631	-3.65	-3.77	-3.73	-3.73	-3.71	-0.12	0.04	0.00	0.02
					632	-3.84	-3.86	-3.85	-3.83	-3.86	-0.02	0.01	0.02	-0.03
					633	-3.98	-3.98	-3.93	-3.94	-3.95	0.01	0.05	-0.01	-0.01

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					634	-4.96	-4.93	-4.92	-5.00	-4.68	0.03	0.01	-0.08	0.32
					635	-3.03	-3.18	-3.07	-3.23	-3.09	-0.15	0.11	-0.16	0.14
					636	-3.72	-3.79	-3.76	-3.76	-3.77	-0.06	0.03	0.00	-0.01
					637	-3.28	-3.31	-3.25	-3.28	-3.27	-0.04	0.07	-0.03	0.01
					638	-2.96	-3.04	-3.01	-3.02	-3.00	-0.08	0.03	0.00	0.01
					639	-1.14	-1.15	-1.10	-1.17	-1.10	-0.01	0.06	-0.07	0.08
					640	-1.59	-1.59	-1.61	-1.64	-1.61	0.00	-0.02	-0.03	0.03
					641	-2.43	-2.14	-2.35	-2.19	-2.41	0.30	-0.21	0.16	-0.22
					642	-2.63	-2.50	-2.61	-2.49	-2.64	0.13	-0.11	0.12	-0.15
					643	-2.04	-2.24	-1.94	-1.81	-2.10	-0.20	0.30	0.12	-0.29
					644	-0.13	-0.20	-0.17	-0.17	-0.14	-0.06	0.03	-0.01	0.03
					645	0.15	0.18	0.16	0.12	0.13	0.02	-0.01	-0.04	0.00
					646	0.95	0.90	0.92	0.93	0.91	-0.05	0.02	0.01	-0.01
					647	-0.08	-0.13	-0.13	-0.13	-0.24	-0.06	0.00	0.00	-0.11
					648	-0.66	-0.68	-0.65	-0.70	-0.57	-0.02	0.03	-0.05	0.12
301.00	79	26.51	117.71	5.57	649	1.33	1.25	1.27	1.24	1.29	-0.08	0.03	-0.04	0.05
					650	0.67	0.62	0.63	0.58	0.66	-0.05	0.00	-0.04	0.07
					651	0.86	0.82	0.85	0.84	0.80	-0.04	0.03	-0.01	-0.04
					652	2.60	2.53	2.63	2.58	2.58	-0.07	0.09	-0.05	0.00
					653	1.82	1.70	1.69	1.66	1.78	-0.13	-0.01	-0.03	0.12
302.00	79.27	26.54	132.98	24.92	654	-0.87	-0.93	-0.96	-0.92	-0.93	-0.06	-0.03	0.03	-0.01
					655	-1.15	-1.23	-1.20	-1.19	-1.18	-0.07	0.03	0.01	0.01

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					656	-1.27	-1.41	-1.43	-1.46	-1.22	-0.15	-0.01	-0.03	0.23
					657	-1.89	-1.93	-1.93	-1.94	-1.88	-0.04	0.00	-0.01	0.06
					658	-2.81	-2.60	-2.45	-2.69	-2.49	0.21	0.16	-0.25	0.20
					659	-3.59	-3.64	-3.40	-3.45	-3.20	-0.06	0.24	-0.05	0.25
					660	-3.47	-3.44	-3.40	-3.44	-3.53	0.03	0.04	-0.04	-0.08
					661	-2.34	-2.43	-2.40	-2.40	-2.38	-0.08	0.02	0.00	0.02
					662	-2.47	-2.48	-2.47	-2.49	-2.46	-0.01	0.02	-0.02	0.02
					663	-2.73	-2.78	-2.74	-2.76	-2.77	-0.05	0.04	-0.02	-0.01
					664	-3.25	-3.33	-3.31	-3.33	-3.30	-0.08	0.02	-0.01	0.03
					665	-1.35	-1.46	-1.44	-1.45	-1.44	-0.10	0.02	-0.01	0.01
					666	-3.36	-3.51	-3.52	-3.47	-3.44	-0.15	-0.01	0.05	0.02
					667	-3.51	-3.55	-3.57	-3.54	-3.53	-0.05	-0.02	0.03	0.01
					668	-2.91	-2.95	-2.92	-2.94	-2.98	-0.04	0.03	-0.02	-0.04
					669	-2.15	-2.21	-2.21	-2.25	-2.21	-0.07	0.01	-0.04	0.04
					670	-3.16	-3.51	-3.42	-3.61	-3.29	-0.35	0.09	-0.18	0.32
					671	-5.60	-5.57	-5.48	-5.12	-4.79	0.04	0.08	0.36	0.33
					672	-3.75	-3.82	-3.69	-3.82	-3.96	-0.08	0.14	-0.14	-0.13
					673	-1.31	-1.34	-1.38	-1.57	-1.48	-0.03	-0.04	-0.20	0.09
					674	-0.70	-0.79	-0.70	-0.84	-0.89	-0.09	0.10	-0.14	-0.05
					675	5.92	5.85	5.91	5.97	5.82	-0.08	0.07	0.05	-0.15
					676	5.34	5.30	5.32	5.35	5.42	-0.04	0.02	0.03	0.07
					677	4.06	3.97	3.91	3.98	4.18	-0.09	-0.06	0.07	0.20

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					678	1.17	0.92	0.87	0.95	1.15	-0.25	-0.05	0.09	0.20
270.00	79.31	26.33	96.29	12.51	679	0.19	0.13	0.09	0.10	0.18	-0.06	-0.04	0.01	0.08
					680	1.52	1.49	1.34	1.41	1.37	-0.04	-0.15	0.07	-0.04
					681	3.42	3.32	3.24	3.30	3.33	-0.09	-0.08	0.06	0.03
					682	4.02	3.97	3.91	4.05	4.07	-0.05	-0.06	0.15	0.02
					683	3.97	3.94	3.98	4.12	4.06	-0.03	0.04	0.13	-0.06
					684	3.67	3.66	3.69	3.86	3.77	-0.01	0.03	0.17	-0.09
					685	3.26	3.27	3.23	3.43	3.39	0.01	-0.04	0.21	-0.04
					686	2.77	2.71	2.69	2.75	2.79	-0.06	-0.02	0.06	0.04
					687	2.15	2.12	2.12	2.13	2.17	-0.04	0.00	0.02	0.04
					688	1.50	1.43	1.42	1.43	1.41	-0.07	-0.01	0.01	-0.02
					689	0.91	0.80	0.82	0.86	0.86	-0.12	0.02	0.04	0.01
					690	0.49	0.37	0.41	0.41	0.39	-0.12	0.04	-0.01	-0.02
					691	0.07	-0.06	0.03	-0.17	-0.07	-0.13	0.09	-0.19	0.09
271.00	79.57	26.37	137.79	24.00	692	-2.09	-2.35	-2.15	-2.35	-2.31	-0.26	0.20	-0.20	0.04
					693	-3.46	-3.59	-3.53	-3.74	-3.49	-0.12	0.06	-0.22	0.26
					694	-3.99	-4.04	-3.99	-4.14	-4.04	-0.06	0.05	-0.15	0.11
					695	-4.02	-4.04	-3.95	-4.10	-4.05	-0.02	0.08	-0.15	0.05
					696	-3.73	-3.73	-3.68	-3.88	-3.73	0.00	0.05	-0.21	0.16
					697	-3.09	-3.13	-3.05	-3.32	-3.24	-0.04	0.08	-0.27	0.08
					698	-2.40	-2.42	-2.39	-2.49	-2.54	-0.03	0.03	-0.10	-0.05
					699	-1.84	-1.88	-1.77	-1.88	-1.95	-0.04	0.11	-0.10	-0.07

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					700	-1.65	-1.70	-1.68	-1.70	-1.72	-0.04	0.01	-0.01	-0.02
					701	-1.62	-1.67	-1.68	-1.71	-1.62	-0.04	-0.02	-0.03	0.09
					702	-1.55	-1.61	-1.60	-1.68	-1.59	-0.06	0.01	-0.08	0.09
					703	-1.55	-1.60	-1.61	-1.74	-1.57	-0.05	-0.01	-0.13	0.16
					704	-1.90	-1.97	-1.94	-2.08	-2.00	-0.07	0.03	-0.14	0.07
					705	-5.67	-5.69	-5.70	-5.76	-5.60	-0.03	-0.01	-0.06	0.16
					706	-5.69	-5.75	-5.73	-5.83	-5.74	-0.06	0.02	-0.10	0.09
					707	-1.02	-0.92	-0.97	-0.90	-0.90	0.10	-0.06	0.07	0.00
					708	0.40	0.40	0.41	0.40	0.36	-0.01	0.01	-0.01	-0.05
					709	0.86	0.83	0.84	0.90	0.87	-0.03	0.01	0.06	-0.03
					710	1.07	1.07	1.06	1.10	1.09	0.00	-0.01	0.04	-0.01
					711	1.10	1.10	1.12	1.17	1.11	0.00	0.02	0.05	-0.05
					712	1.02	0.99	1.01	1.04	0.98	-0.03	0.02	0.03	-0.06
					713	0.88	0.84	0.86	0.87	0.88	-0.04	0.02	0.01	0.01
					714	0.62	0.56	0.59	0.59	0.59	-0.06	0.03	0.00	-0.01
					715	0.10	0.07	0.12	0.17	0.09	-0.03	0.05	0.05	-0.09
					716	-0.24	-0.25	-0.27	-0.24	-0.18	0.00	-0.03	0.03	0.06
					717	-0.52	-0.52	-0.53	-0.53	-0.43	-0.01	0.00	0.00	0.11
239.00	79.61	26.16	114.03	17.81	718	-0.76	-0.83	-0.78	-0.79	-0.71	-0.06	0.05	-0.01	0.09
					719	-1.10	-1.16	-1.18	-1.17	-1.03	-0.06	-0.02	0.01	0.15
					720	-1.44	-1.46	-1.48	-1.46	-1.34	-0.02	-0.02	0.02	0.12
					721	-1.68	-1.66	-1.68	-1.62	-1.53	0.03	-0.02	0.06	0.09

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					722	-1.56	-1.58	-1.62	-1.53	-1.32	-0.02	-0.03	0.08	0.21
					723	0.82	0.86	0.85	0.88	0.83	0.04	-0.02	0.04	-0.05
					724	1.61	1.57	1.66	1.62	1.59	-0.04	0.09	-0.04	-0.03
					725	1.31	1.33	1.36	1.30	1.39	0.03	0.03	-0.07	0.10
					726	1.14	1.14	1.12	1.13	1.19	0.00	-0.02	0.02	0.06
					727	1.10	1.08	1.06	1.12	1.25	-0.02	-0.02	0.05	0.13
					728	1.10	1.09	1.11	1.15	1.23	-0.01	0.01	0.05	0.08
					729	1.03	1.04	1.08	1.10	1.18	0.01	0.04	0.01	0.09
					730	1.04	1.00	1.01	1.06	1.08	-0.04	0.00	0.05	0.03
					731	0.97	0.91	0.95	0.94	0.86	-0.06	0.04	0.00	-0.08
					732	0.51	0.53	0.54	0.57	0.46	0.02	0.00	0.03	-0.10
240.00	79.87	26.19	113.28	23.45	733	-0.02	-0.03	-0.03	-0.01	0.04	-0.01	0.00	0.03	0.04
					734	-0.34	-0.37	-0.33	-0.37	-0.27	-0.03	0.04	-0.05	0.11
					735	-0.13	-0.16	-0.17	-0.19	-0.12	-0.03	-0.01	-0.02	0.07
					736	4.53	4.55	4.59	4.75	4.47	0.02	0.05	0.15	-0.28
					737	5.09	5.07	5.10	5.13	5.08	-0.02	0.03	0.03	-0.05
					738	5.10	5.09	5.17	5.05	5.15	-0.02	0.09	-0.12	0.09
					739	5.29	5.29	5.28	5.18	5.38	0.00	-0.01	-0.10	0.20
					740	5.86	5.81	5.86	5.76	5.80	-0.05	0.04	-0.10	0.05
					741	5.97	5.93	5.97	5.98	5.91	-0.05	0.05	0.00	-0.06
					742	5.80	5.70	5.65	5.74	5.73	-0.10	-0.05	0.09	-0.01
					743	5.50	5.52	5.49	5.47	5.53	0.02	-0.03	-0.02	0.06

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					744	5.29	5.24	5.22	5.22	5.26	-0.05	-0.02	0.00	0.04
					745	4.93	4.80	4.82	4.81	4.84	-0.12	0.02	-0.01	0.03
					746	4.17	3.98	3.90	3.87	3.87	-0.19	-0.07	-0.04	0.00
					747	2.14	2.15	2.15	2.11	2.29	0.02	0.00	-0.04	0.18
					748	2.03	1.98	2.02	1.95	2.02	-0.05	0.04	-0.07	0.07
					749	2.50	2.43	2.49	2.45	2.34	-0.07	0.05	-0.04	-0.11
					750	2.81	2.73	2.78	2.72	2.74	-0.08	0.05	-0.06	0.02
					751	2.90	2.82	2.89	2.87	2.90	-0.08	0.07	-0.02	0.02
					752	2.78	2.73	2.74	2.66	2.86	-0.05	0.01	-0.08	0.20
					753	2.03	1.74	1.57	1.89	2.19	-0.29	-0.17	0.32	0.30
					754	-5.65	-5.67	-5.71	-5.85	-5.80	-0.02	-0.04	-0.14	0.05
					755	-4.00	-4.06	-3.96	-4.00	-3.96	-0.06	0.10	-0.04	0.04
					756	-1.19	-1.16	-0.99	-1.06	-1.00	0.03	0.16	-0.07	0.06
208.00	79.91	25.98	109.38	7.38	757	1.40	1.40	1.51	1.50	1.23	0.00	0.11	-0.01	-0.27
					758	1.80	1.80	1.82	1.83	1.76	0.00	0.03	0.01	-0.07
					759	1.78	1.78	1.81	1.81	1.79	-0.01	0.03	0.00	-0.02
					760	1.66	1.66	1.72	1.68	1.66	0.00	0.06	-0.04	-0.02
					761	1.37	1.39	1.48	1.40	1.34	0.02	0.09	-0.08	-0.06
					762	0.92	0.96	1.03	0.96	0.94	0.04	0.06	-0.07	-0.02
					763	0.50	0.49	0.58	0.48	0.51	-0.01	0.09	-0.09	0.02
209.00	80.17	26.01	121.06	29.64	764	-0.25	-0.19	-0.22	-0.24	-0.14	0.06	-0.03	-0.02	0.10
					765	-1.36	-1.34	-1.36	-1.38	-1.29	0.02	-0.03	-0.01	0.08

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					766	-2.35	-2.17	-2.24	-2.29	-2.34	0.19	-0.08	-0.05	-0.05
					767	-3.00	-2.58	-2.73	-2.77	-2.98	0.41	-0.15	-0.03	-0.21
					768	-3.39	-2.88	-2.98	-3.00	-3.17	0.50	-0.09	-0.03	-0.17
					769	-3.53	-3.21	-3.29	-3.34	-3.25	0.32	-0.08	-0.05	0.09
					770	-3.33	-3.30	-3.29	-3.35	-3.32	0.03	0.01	-0.07	0.03
					771	-2.86	-2.90	-2.87	-2.90	-2.68	-0.04	0.03	-0.03	0.22
					772	-1.14	-1.13	-1.26	-1.22	-1.28	0.01	-0.13	0.04	-0.06
					773	3.29	3.29	3.42	3.32	3.33	0.00	0.13	-0.10	0.01
					774	3.05	3.07	3.03	3.09	3.11	0.01	-0.04	0.07	0.01
					775	2.86	2.84	2.88	2.82	2.91	-0.02	0.04	-0.06	0.09
					776	2.81	2.79	2.80	2.83	2.92	-0.03	0.01	0.03	0.10
					777	2.88	2.83	2.90	2.87	2.96	-0.05	0.07	-0.03	0.09
					778	2.86	2.84	2.92	2.86	2.92	-0.02	0.08	-0.06	0.06
					779	2.91	2.88	2.93	2.94	2.95	-0.03	0.05	0.00	0.01
					780	2.89	2.90	2.91	2.94	2.92	0.01	0.01	0.03	-0.01
					781	2.86	2.87	2.87	2.90	2.90	0.01	0.00	0.02	0.01
					782	2.71	2.71	2.70	2.72	2.84	0.00	-0.01	0.02	0.12
					783	2.52	2.50	2.51	2.53	2.60	-0.01	0.00	0.02	0.07
					784	2.39	2.39	2.42	2.37	2.36	-0.01	0.03	-0.05	-0.01
					785	2.56	2.52	2.54	2.54	2.60	-0.04	0.02	0.00	0.06
					786	2.97	2.96	2.99	2.92	2.94	-0.01	0.04	-0.07	0.01
					787	3.24	3.27	3.23	3.30	3.20	0.03	-0.04	0.07	-0.10

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					788	3.20	3.20	3.23	3.18	3.19	0.01	0.03	-0.05	0.01
					789	2.28	2.29	2.30	2.30	2.30	0.01	0.01	0.01	-0.01
					790	0.99	0.91	0.96	0.84	0.96	-0.08	0.05	-0.12	0.12
					791	0.01	0.01	-0.05	-0.13	-0.06	0.00	-0.06	-0.09	0.07
					792	-0.24	-0.26	-0.26	-0.36	-0.31	-0.01	0.00	-0.11	0.05
					793	-0.13	-0.16	-0.16	-0.35	-0.22	-0.03	0.00	-0.19	0.13
177.00	80.21	25.8	114.61	5.26	794	0.27	0.26	0.33	0.04	0.12	-0.01	0.07	-0.29	0.07
					795	0.69	0.68	0.71	0.66	0.62	-0.01	0.03	-0.05	-0.04
					796	1.12	1.10	1.06	1.15	1.09	-0.02	-0.04	0.10	-0.06
					797	1.20	1.23	1.22	1.27	1.22	0.02	0.00	0.05	-0.06
					798	0.75	0.79	0.79	0.72	0.70	0.04	0.00	-0.07	-0.02
178.00	80.47	25.83	124.19	29.11	799	-0.55	-0.53	-0.63	-0.43	-0.49	0.02	-0.10	0.20	-0.06
					800	-2.05	-2.11	-2.21	-2.18	-1.94	-0.06	-0.10	0.03	0.24
					801	-3.50	-3.58	-3.70	-3.65	-3.51	-0.08	-0.12	0.05	0.14
					802	-4.82	-4.86	-4.97	-4.90	-4.93	-0.03	-0.12	0.07	-0.03
					803	-5.88	-5.90	-5.94	-6.02	-5.92	-0.03	-0.04	-0.08	0.10
					804	-6.64	-6.65	-6.63	-6.72	-6.70	0.00	0.02	-0.09	0.02
					805	-7.38	-7.33	-7.49	-7.47	-7.23	0.05	-0.16	0.02	0.23
					806	-8.07	-8.06	-8.08	-8.13	-7.83	0.00	-0.01	-0.05	0.29
					807	-8.61	-8.55	-8.55	-8.61	-8.21	0.06	0.00	-0.06	0.40
					808	-8.97	-8.95	-8.94	-8.96	-8.60	0.02	0.00	-0.02	0.36
					809	-9.29	-9.31	-9.34	-9.35	-9.01	-0.02	-0.02	-0.01	0.33

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					810	-9.60	-9.61	-9.59	-9.57	-9.31	-0.01	0.02	0.02	0.27
					811	-9.81	-9.80	-9.79	-9.76	-9.64	0.01	0.01	0.04	0.12
					812	-10.04	-10.03	-9.97	-9.90	-10.00	0.02	0.05	0.07	-0.09
					813	-10.46	-10.44	-10.40	-10.39	-10.35	0.02	0.03	0.01	0.04
					814	-10.94	-10.98	-10.94	-10.74	-10.41	-0.04	0.04	0.20	0.33
					815	-8.19	-8.22	-7.95	-8.05	-8.23	-0.03	0.26	-0.10	-0.18
					816	-7.17	-7.26	-7.12	-7.05	-7.13	-0.09	0.14	0.07	-0.08
					817	-5.76	-5.65	-5.57	-5.51	-5.69	0.11	0.08	0.06	-0.19
					818	-1.04	-1.02	-1.00	-0.93	-0.99	0.02	0.02	0.08	-0.07
					819	-1.05	-1.02	-1.05	-1.07	-1.06	0.03	-0.03	-0.01	0.00
					820	-1.08	-0.97	-1.09	-1.11	-1.15	0.12	-0.12	-0.03	-0.04
					821	-1.22	-1.18	-1.21	-1.20	-1.24	0.04	-0.03	0.01	-0.04
					822	-1.65	-1.61	-1.52	-1.57	-1.90	0.04	0.09	-0.05	-0.33
					823	-2.99	-2.89	-2.89	-3.01	-2.95	0.10	0.00	-0.12	0.06
					824	-4.39	-4.35	-4.41	-4.42	-4.60	0.04	-0.06	-0.01	-0.18
					825	-4.51	-4.54	-4.57	-4.55	-4.70	-0.03	-0.02	0.02	-0.15
					826	-3.62	-3.85	-3.96	-3.91	-3.98	-0.23	-0.10	0.05	-0.07
					827	-2.04	-2.49	-2.55	-2.77	-2.83	-0.45	-0.07	-0.22	-0.05
146.00	80.51	25.62	113.35	7.03	828	0.03	-0.41	-0.84	-1.23	-1.34	-0.44	-0.43	-0.39	-0.11
					829	0.89	0.81	0.97	1.01	0.59	-0.08	0.16	0.04	-0.42
					830	0.97	0.92	0.98	1.05	1.15	-0.05	0.06	0.07	0.10
					831	0.85	0.77	0.77	0.86	0.91	-0.08	-0.01	0.10	0.05

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					832	0.67	0.61	0.70	0.68	0.68	-0.06	0.09	-0.02	0.00
					833	0.48	0.45	0.48	0.50	0.45	-0.03	0.04	0.02	-0.05
					834	0.25	0.24	0.28	0.22	0.21	-0.01	0.03	-0.06	0.00
					835	0.01	0.00	0.02	-0.04	0.05	-0.01	0.02	-0.06	0.09
					836	0.10	0.07	0.09	0.05	0.21	-0.03	0.02	-0.04	0.16
					837	0.25	0.21	0.24	0.19	0.36	-0.04	0.03	-0.04	0.17
					838	0.51	0.48	0.55	0.50	0.52	-0.03	0.07	-0.05	0.02
					839	0.74	0.72	0.75	0.79	0.67	-0.02	0.03	0.04	-0.11
					840	1.07	1.04	1.05	0.95	1.05	-0.03	0.01	-0.11	0.10
					841	1.41	1.38	1.38	1.31	1.47	-0.03	0.00	-0.07	0.16
					842	1.70	1.65	1.65	1.64	1.63	-0.05	0.00	0.00	-0.01
					843	1.81	1.77	1.82	1.79	1.67	-0.04	0.05	-0.04	-0.11
147.00	80.77	25.65	94.96	25.81	844	1.70	1.67	1.69	1.66	1.62	-0.03	0.01	-0.02	-0.05
					845	1.66	1.55	1.58	1.56	1.49	-0.11	0.04	-0.02	-0.07
					846	1.46	1.39	1.45	1.43	1.35	-0.07	0.06	-0.02	-0.08
					847	1.17	1.13	1.17	1.20	1.19	-0.03	0.04	0.03	-0.01
					848	0.81	0.77	0.81	0.79	0.81	-0.04	0.04	-0.02	0.02
					849	0.42	0.26	0.24	0.25	0.25	-0.15	-0.02	0.01	0.00
					850	-0.25	-0.40	-0.37	-0.34	-0.41	-0.15	0.03	0.04	-0.07
					851	-1.16	-1.25	-1.25	-1.26	-1.17	-0.09	0.00	-0.01	0.09
					852	-2.48	-2.56	-2.53	-2.61	-2.48	-0.08	0.03	-0.08	0.13
					853	-3.61	-3.62	-3.63	-3.66	-3.76	-0.01	-0.01	-0.03	-0.10

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					854	-4.01	-4.04	-4.05	-4.08	-4.10	-0.03	-0.02	-0.03	-0.01
					855	-3.60	-3.61	-3.57	-3.56	-3.51	0.00	0.04	0.01	0.05
					856	-0.85	-0.84	-0.77	-0.71	-1.05	0.01	0.07	0.05	-0.33
					857	0.63	0.58	0.66	0.64	0.57	-0.05	0.09	-0.02	-0.07
					858	0.72	0.70	0.69	0.68	0.66	-0.02	-0.02	-0.01	-0.02
					859	0.54	0.54	0.55	0.58	0.59	0.00	0.00	0.03	0.02
					860	0.23	0.24	0.23	0.27	0.35	0.01	-0.01	0.03	0.08
					861	-1.18	-1.41	-1.45	-1.43	-1.16	-0.24	-0.04	0.02	0.26
					862	-2.97	-3.03	-3.02	-3.02	-3.01	-0.06	0.01	0.00	0.01
					863	-3.41	-3.41	-3.40	-3.38	-3.37	0.00	0.01	0.02	0.01
					864	-3.10	-3.12	-3.09	-3.11	-3.14	-0.02	0.03	-0.02	-0.03
					865	-2.43	-2.44	-2.38	-2.51	-2.49	-0.01	0.05	-0.12	0.02
					866	-1.64	-1.65	-1.64	-1.71	-1.67	-0.01	0.01	-0.06	0.04
					867	-0.84	-0.83	-0.76	-0.79	-0.90	0.01	0.06	-0.02	-0.12
148.00	81.03	25.68	138.13	16.33	868	-0.15	-0.12	-0.11	-0.11	-0.13	0.03	0.01	0.00	-0.03
					869	0.34	0.34	0.37	0.38	0.49	0.01	0.03	0.01	0.10
					870	0.53	0.54	0.56	0.60	0.54	0.01	0.02	0.04	-0.06
					871	0.18	0.18	0.20	0.21	0.13	0.00	0.02	0.02	-0.08
					872	-4.96	-5.04	-5.31	-5.19	-4.65	-0.08	-0.27	0.12	0.54
					873	-6.22	-6.24	-6.26	-6.24	-6.13	-0.02	-0.02	0.01	0.11
					874	-6.15	-6.14	-6.11	-6.09	-6.15	0.01	0.03	0.02	-0.06
					875	-5.55	-5.49	-5.46	-5.50	-5.60	0.06	0.03	-0.03	-0.11

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					876	-4.31	-4.31	-4.25	-4.30	-4.35	0.00	0.06	-0.05	-0.04
116.00	81.07	25.47	137.33	28.55	877	0.04	0.01	0.09	0.09	0.01	-0.03	0.08	0.00	-0.08
					878	0.15	0.12	0.13	0.19	0.16	-0.02	0.01	0.06	-0.03
					879	0.06	0.10	0.01	0.17	0.13	0.04	-0.09	0.17	-0.04
					880	0.03	0.06	0.01	0.12	0.02	0.03	-0.04	0.11	-0.11
					881	-0.01	-0.01	-0.02	0.08	-0.02	-0.01	-0.01	0.11	-0.10
					882	-0.16	-0.16	-0.13	-0.12	-0.06	-0.01	0.04	0.00	0.06
					883	-0.49	-0.52	-0.51	-0.51	-0.40	-0.03	0.02	-0.01	0.11
					884	-1.05	-1.04	-1.04	-1.05	-0.94	0.01	0.00	-0.02	0.11
					885	-1.75	-1.69	-1.75	-1.76	-1.60	0.06	-0.06	-0.02	0.17
					886	-2.36	-2.37	-2.35	-2.38	-2.26	-0.01	0.01	-0.03	0.12
					887	-3.03	-3.04	-3.10	-3.06	-3.10	-0.01	-0.06	0.03	-0.03
					888	-3.66	-3.69	-3.72	-3.75	-3.95	-0.02	-0.04	-0.02	-0.21
					889	-4.30	-4.34	-4.35	-4.41	-4.65	-0.05	-0.01	-0.06	-0.24
					890	-5.06	-5.09	-5.11	-5.25	-5.34	-0.02	-0.02	-0.14	-0.10
					891	-5.84	-5.90	-6.00	-6.07	-6.04	-0.06	-0.10	-0.07	0.03
					892	-6.61	-6.69	-6.67	-6.82	-6.72	-0.08	0.02	-0.15	0.10
					893	-7.34	-7.44	-7.34	-7.58	-7.40	-0.10	0.10	-0.24	0.18
					894	-8.01	-8.07	-7.83	-8.20	-8.19	-0.06	0.24	-0.36	0.00
					895	-8.33	-8.41	-8.11	-8.54	-8.42	-0.08	0.30	-0.43	0.12
					896	-8.19	-8.24	-8.04	-8.24	-8.27	-0.05	0.20	-0.19	-0.03
					897	-7.68	-7.72	-7.57	-7.68	-7.71	-0.04	0.15	-0.10	-0.03

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					898	-7.06	-7.11	-7.09	-7.16	-7.10	-0.05	0.02	-0.07	0.06
					899	-5.50	-5.50	-5.45	-5.50	-5.71	0.00	0.05	-0.04	-0.21
					900	-0.55	-0.50	-0.44	-0.43	-0.53	0.04	0.07	0.01	-0.10
					901	0.31	0.28	0.32	0.33	0.35	-0.03	0.04	0.01	0.02
					902	0.63	0.61	0.65	0.66	0.67	-0.02	0.04	0.01	0.01
					903	0.69	0.67	0.72	0.73	0.73	-0.02	0.05	0.01	0.00
					904	0.61	0.55	0.55	0.68	0.58	-0.06	0.00	0.13	-0.10
					905	0.27	0.22	0.19	0.35	0.24	-0.05	-0.03	0.16	-0.12
84.00	81.11	25.26	107.90	4.08	906	0.03	0.01	0.00	0.13	0.03	-0.02	-0.01	0.13	-0.09
					907	0.07	0.05	0.09	0.09	0.07	-0.02	0.03	0.01	-0.02
					908	0.05	0.02	0.04	0.03	-0.01	-0.03	0.02	-0.01	-0.04
					909	0.06	-0.04	-0.03	-0.06	-0.11	-0.10	0.01	-0.03	-0.04
85.00	81.37	25.29	107.90	28.71	910	-0.08	-0.13	-0.12	-0.15	-0.25	-0.04	0.01	-0.03	-0.10
					911	-0.12	-0.15	-0.11	-0.20	-0.18	-0.03	0.04	-0.09	0.03
					912	0.21	0.17	0.11	0.15	0.22	-0.04	-0.06	0.04	0.07
					913	1.07	1.02	1.09	1.08	1.05	-0.05	0.07	-0.01	-0.03
					914	1.71	1.68	1.68	1.73	1.72	-0.04	0.00	0.04	0.00
					915	1.93	1.88	1.93	1.92	2.04	-0.05	0.05	-0.01	0.11
					916	1.08	1.09	1.33	0.95	0.83	0.01	0.24	-0.38	-0.12
					917	-0.09	-0.11	-0.19	-0.42	-0.27	-0.02	-0.07	-0.23	0.15
					918	-1.21	-1.19	-1.26	-1.26	-1.08	0.02	-0.07	0.00	0.18
					919	-1.79	-1.76	-1.74	-1.81	-1.73	0.03	0.02	-0.07	0.09

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					920	-2.16	-2.14	-2.17	-2.26	-2.24	0.02	-0.02	-0.09	0.02
					921	-2.36	-2.40	-2.41	-2.48	-2.46	-0.04	-0.01	-0.06	0.02
					922	-2.53	-2.56	-2.54	-2.59	-2.54	-0.03	0.03	-0.05	0.05
					923	-2.65	-2.68	-2.66	-2.85	-2.62	-0.03	0.02	-0.20	0.23
					924	-2.71	-2.77	-2.69	-2.87	-2.70	-0.06	0.07	-0.18	0.17
					925	-2.68	-2.74	-2.66	-2.79	-2.66	-0.06	0.08	-0.13	0.14
					926	-2.48	-2.55	-2.51	-2.59	-2.48	-0.07	0.04	-0.08	0.11
					927	-1.93	-2.00	-1.95	-1.95	-2.00	-0.07	0.05	0.00	-0.06
					928	3.37	3.22	3.27	3.23	3.33	-0.15	0.05	-0.03	0.09
					929	3.43	3.65	3.73	3.49	3.70	0.21	0.09	-0.24	0.21
					930	3.23	3.35	3.34	3.33	3.46	0.12	-0.01	-0.01	0.13
					931	2.82	2.99	2.82	2.79	2.85	0.17	-0.17	-0.03	0.06
					932	2.66	2.70	2.66	2.67	2.75	0.04	-0.04	0.01	0.08
					933	2.53	2.51	2.50	2.58	2.59	-0.01	-0.01	0.08	0.01
					934	2.36	2.34	2.39	2.43	2.36	-0.02	0.05	0.04	-0.07
					935	1.95	1.95	2.08	1.87	1.90	0.00	0.13	-0.21	0.03
					936	1.23	1.27	1.14	1.08	1.29	0.05	-0.13	-0.06	0.20
					937	0.75	0.74	0.75	0.76	0.76	0.00	0.01	0.01	0.00
					938	0.18	0.17	0.15	0.20	0.15	-0.01	-0.02	0.04	-0.05
					939	0.06	0.03	0.03	-0.06	0.02	-0.03	0.00	-0.09	0.08
					940	0.01	-0.01	0.17	0.01	-0.07	-0.02	0.18	-0.16	-0.08
86.00	81.62	25.32	73.88	25.52	941	-0.16	-0.16	-0.13	-0.13	-0.16	0.00	0.03	0.00	-0.03

Grid Number	Longitude	Latitude	Bearing of reference line	Length of river reach (reference line) in km	Chainage (based on reference line) in km	Distance from reference Line (km)					Swing Displacement (movement of channel centreline in km)			
						1975	1990	2000	2010	2016	1975-1990	1990-2000	2000-2010	2010-2016
					942	-0.40	-0.42	-0.44	-0.45	-0.39	-0.01	-0.02	-0.01	0.06
					943	-0.66	-0.68	-0.69	-0.66	-0.69	-0.02	-0.02	0.04	-0.04
					944	-0.83	-0.97	-0.98	-1.00	-1.02	-0.14	-0.01	-0.03	-0.01
					945	-1.25	-1.29	-1.29	-1.33	-1.38	-0.04	0.00	-0.04	-0.05
					946	-1.64	-1.63	-1.66	-1.71	-1.72	0.01	-0.03	-0.04	-0.01
					947	-2.01	-1.99	-1.99	-2.05	-2.02	0.02	0.00	-0.06	0.02
					948	-2.37	-2.39	-2.43	-2.43	-2.40	-0.01	-0.05	0.01	0.02
					949	-2.78	-2.78	-2.83	-2.89	-2.79	0.00	-0.05	-0.05	0.10
					950	-3.15	-3.15	-3.18	-3.19	-3.25	0.01	-0.03	-0.01	-0.06
					951	-3.45	-3.45	-3.42	-3.43	-3.54	0.00	0.04	-0.01	-0.11
					952	-3.73	-3.75	-3.75	-3.74	-3.74	-0.02	0.00	0.01	0.00
					953	-4.01	-4.03	-4.05	-4.10	-4.01	-0.01	-0.03	-0.05	0.09
					954	-4.27	-4.16	-4.16	-4.22	-4.11	0.11	-0.01	-0.06	0.11
					955	-4.14	-4.13	-4.11	-4.15	-4.10	0.01	0.02	-0.04	0.06
					956	-3.94	-3.93	-3.91	-3.95	-3.91	0.01	0.02	-0.04	0.05
					957	-3.70	-3.73	-3.72	-3.74	-3.74	-0.03	0.01	-0.02	0.00
					958	-3.43	-3.43	-3.47	-3.54	-3.53	0.00	-0.04	-0.07	0.01
					959	-3.03	-3.06	-3.07	-3.21	-3.22	-0.03	-0.01	-0.14	-0.01
					960	-2.58	-2.61	-2.61	-2.63	-2.74	-0.03	0.01	-0.02	-0.11
					961	-2.09	-2.10	-2.12	-2.11	-2.20	-0.01	-0.02	0.01	-0.09
					962	-1.63	-1.54	-1.52	-1.60	-1.68	0.09	0.02	-0.08	-0.08
					963	-0.75	-0.82	-0.84	-0.87	-1.01	-0.07	-0.02	-0.03	-0.14

11.7 Abandoned Channels and Oxbow formations

Abandoned channels are geomorphologic evidence of channel movement. They are most likely outcome of channel migration/repositioning processes, such as meander cut-off and channel-belt avulsion. Abandoned channels are considered as oxbow lakes when sediment plugs cause the flow to change course. The oxbow lakes are formed from natural and engineered processes. Three stages of abandonment are generally noticed in case of meander cut-off,

(1) Cut-off initiation – the triggering of the cut-off when most of the river discharge becomes diverted from the meander and starts to flow along the newly activated channel (Lewis and Lewin, 1983; Hooke, 1995);

(2) Plug bar formation – an in-channel sedimentary response to reduced discharge that results in blockage of the upper and lower entrances, leading to further diversion and increased trapping of bedload and suspended load in old channel (Fisk, 1947; Constantineet al., 2010);

(3) Disconnected stage – discharge is no longer carried regularly through the old channel. The channel is 'disconnected' from the network of active river channels, and old channel is transformed into a floodplain lake that only receives suspended load during floods.

Based on the satellite image analysis on decadal scale, following observations have been made about abandoned channels and ox-bow lake formations.

Table 11-8 : Abandoned channels and Ox-bow formations

Sr. No	Chainage	Nearby Village/ town	Position	1975-1990	1990-2000	2000-2010	2010-2016
1.	176-179	Kharak	77.18 E, 29.89 N	Reach has moved to the right side & formation of three small oxbows have been observed across the left side of the river reach. Tonal variations seen in the satellite image of year 1975 indicate vegetation growth in channel which is disconnected from the main channel. Therefore, oxbow lakes seen in satellite image of year 1990 and image analysis of 1975 combinedly conclude that these formations are result of past events and have not been captured in the present study.	Reach swung towards its left at chainage 178-179. Formation of oxbow becomes clear in the year 2000 image which is slightly larger than the oxbow in the year 1990.	River re-traces its path as in the year 1990. One big oxbow lake is visible in the year 2010.	River maintains its path with the elimination of oxbows that had been observed in the previous images.
2.	213-215	Kamalpur	77.10 E, 29.59 N	Abandonment of reach is observed during 1975-1990.	The reach along chainage 214-215 swings towards it's right	The reach has swung towards it's left.	No change
3.	217-222	Pir Badauli	77.11 E, 29.55 N	One oxbow at the left side of the river can be seen during 1975-1990.	Formation of a new oxbow on the left side of river has begun in the year 2000,	Very Small new oxbow formations are prominent on the left side of	River reach swing towards it's right. The size of oxbow lake present to the left

Sr. No	Chainage	Nearby Village/ town	Position	1975-1990	1990-2000	2000-2010	2010-2016
					maintaining the presence of oxbow lake of the year 1990.	the river is visible in the year 2010.	of the reach diminishes.
4.	224-229	Garhi Bhalal	77.13 E, 29.49 N	The year 1975 witness the presence of two oxbow lakes, one on the right side & other on the left side of the river whereas the year 1990 witness the abolition of the oxbow lakes, along with increased meandering patterns.	Increase in the meandering length & elimination of an oxbow (1990) on the lower right corner corresponding to the chainage 228.	Formation of two oxbow along 224-225 chainages, as the meander length reduces from 2000-2010	River reach swings towards it's left, and no oxbows are clearly visible in the year 2016.
5.	237-248	Jharkheri	77.15 E, 29.35 N	Three oxbow lakes are visible at chainage 237 & 241 & 243 at the left side of the river during 1975-1990. Abandonment of the river reach at chainage 237-240 is observed in the year 1990. Formation of new oxbow lake at 245 by the year 1990.	No change	No change	Only one box lake is visible at the chainage 241 which increases in size between the years 2010 and 2016. Other oxbow features do not have a clear visibility in the year 2016. The meandering pattern remains same as before.

Sr. No	Chainage	Nearby Village/ town	Position	1975-1990	1990-2000	2000-2010	2010-2016
6.	260-270	Begah	77.15 E, 29.14 N	At chainage 260 presence of an oxbow lake is visible clearly in 1990, which has not been present in 1975 indicating the formation of the oxbow in the time span of 1975-1990.	The reach at 266 swings to its left side by 2000 & presence of small oxbow can be seen to its right. At 263 the reach swing to its right	In the time period an ox bow has been formed at 268 on the right side of the river, which can be seen clearly in the 2010 image.	In 2016, none of the old oxbow lakes are visible. The pattern remains same as in 2010.
7.	296-302	Sankrod	77.22 E, 28.87 N	Presence of two oxbow lakes can be seen in 1990 image on abandonment of the reach from 1975 to 1990. One on the left side & other on the right side.	No change in channel and flow pattern. The presence of large oxbow along the chainage 298-205 enhances in the 2000 image.	No change	No change
8.	307-315	Shahdara	77.23 E, 28.77 N	Presence of oxbow lake at chainage 308 & 315 on the right side of the river in the year 1990.	Oxbow at chainage 308 is not visible in the year 2000, although there is no significant change in the river pattern.	No change	No change. Visibility of oxbow at the chainage 315 enhances by 2016

Sr. No	Chainage	Nearby Village/ town	Position	1975-1990	1990-2000	2000-2010	2010-2016
9.	347-350	Noida	77.38 E, 28.49 N	Formation of an oxbow at the chainage 348 on the left side of river as visible in the 1990 image.	Oxbow visibility is lost by the year 2000.	Oxbow signature is visible at chainage 348, however spectral signature highlights the presence of other features such as vegetation in and around oxbow lake.	No oxbow is seen in 2016 image.
10.	352-357	Dalelpur	77.42 E, 28.45 N	In 1975, three oxbow are visible, two on the left side (at chainage 352 & 356), and one on the right side of the river (at chainage 352). In 1990, at chainage 354 the river has moved towards it's right side leading to large sized oxbow seen in 1990 image.	None of the old ox bows are seen in 2000. A new oxbow can be seen at 356 on the right side of the river	No significant change except at chainage 357 the river moves towards its right & a light spectral signature of small oxbow is visible at this chainage on the left side of the river reach.	No Change. No oxbows can be seen by 2016.
11.	361-371	Tilwada	77.49 E, 28.40 N	By the year 1990, three oxbows can be seen. Two on the left side of the river (at	By the year 2000 the river swings slightly, from the	The presence of two new oxbow at 367 can be	The river assumes straight path as compared to

Sr. No	Chainage	Nearby Village/ town	Position	1975-1990	1990-2000	2000-2010	2010-2016
				chainage 366 & 370) and one on the right side of the river (at chainage 363). In 1975 no oxbow has been observed.	left bank to the right & vice versa. The presence of the three major oxbows still visible in 2000 image.	seen in 2010, one at the right & other at left of the river, formed due to change in meandering pattern of river.	previous years. Visibility of one oxbow can be observed at the chainage 366.
12.	374-384	Chhainsa	77.46 E, 28.24 N	At the chainage 374, oxbow lake is visible on the left of river in the year 1990 & at chainage 377 oxbow on the right side of the river due to decrease in meander length of the reach around these places.	By the year 2000 the oxbow at the chainage 377 is abandoned, river retraces its path of year 1975 at this chainage.	No change	At 376, an oxbow is visible on the left side of the river due to change in river path at this place. No other significant change.
13.	413-424	Shahpur Bangar	77.52 E, 27.92 N	Formation of an oxbow begins around the year 1990 at chainage 421-423 on the left of the river.	An oxbow at the chainage 414 has been observed in the year 2000. A bright signature of oxbow at 415 on the left of the river can also be seen in 2000 imagery. At 418, the beginning of the formation of an oxbow can be witnessed on the	No significant change	Only one oxbow can be seen at the chainage 414 by the year 2016.

Sr. No	Chainage	Nearby Village/ town	Position	1975-1990	1990-2000	2000-2010	2010-2016
					right of the river. At 422 an oxbow lake can be seen that began in its formation in 1990.		
14.	430-437	Badhari	77.61 E, 27.80 N	At the chainage 434-436, formation of an oxbow lake took place in between 1975-1990 which is clearly visible on the right of the river	No change	No change, except in the radius of curvature of the meanders at the chainage 430.	An oxbow at chainage 430 on the right of the river is visible in 2016, which has been formed after 2010.
15.	452-462	Bheem Khader	77.71 E, 27.62 N	Three major ox bow lakes observed on the right of the river in 1975. By the year 1990 the oxbow at chainage 460 gets abandoned & becomes a part of the river at that place.	2000 image witness the presence of a new oxbow at the chainage 456.	The oxbow at chainage 453-455 gets abandoned & becomes part of the reach.	No significant change observed in 2016
16.	535-538	Surehra	77.17 E, 27.17 N	At chainage 536, on the left side of the river an oxbow lake is visible.	No change	No change	Oxbow at chainage 536 gets abandoned & is not visible in 2016 imagery.

11.8 Confluence Points

Channel confluence is a vital element of the river systems as they influence the geomorphology and hydrology of both upstream and downstream reaches. The dynamics of the confluence points affects the availability of water in different reaches and the pattern of sediment distribution in the confluence zone. A major implication of such movements is in terms of scouring or aggradation, which affects the stability of system under consideration and raises issues related to its management.

Variations in channel position as well as confluence points were analysed at decadal scale for last forty years using satellite images from Landsat MSS (spatial resolution 60 m), Landsat 5 TM (spatial resolution 30 m), Landsat 7 ETM+ and Landsat 8 (spatial resolution 30m and 15m for multispectral and panchromatic respectively), and Indian Remote Sensing Satellite (spatial resolution 23.5 m). Visual interpretation as well as digital image processing techniques such as contrast stretching, edge enhancement, image filtering, false colour composites, principal component analysis, image ratio and image subtraction were applied on the digital data to map the channel and confluences.

Various parameters affect the dynamics of confluences. Those parameters can broadly be categorised into two categories, allocyclic and autocyclic. In the narrow context of remote sensing-based morphological study of Yamuna River system, the effect of autocyclic and allocyclic behaviour cannot be explored in detail. However, channel characteristics such as channel position, top width, slope and junction angle which have indirect consideration for some of the autocyclic processes, are obtained using satellite imageries for understanding the system behaviour at the confluence. Terminology used for confluence analysis is explained in the form of template as shown in Figure 11-52

1. Confluence Points

Parmar and Khosa, 2017, have argued that the confluence points can be captured more objectively and with a relatively higher level of assurance if the approach based on intersections between banklines is followed. However, in this study, confluence points are generated from the intersection of the centre line of channel area of the main channel and tributary channel. The point P represents the confluence point (Fig 11-52). Confluence points are represented by labels of numeric values 1, 2, …, …, n. where 1, represents confluence for the first year of analysis which in this study is 1975. For the next target year of analysis, if point of confluence changes from its

original position then it is denoted by next successive number i.e., 2. If its geographical position doesn't change, then it is represented by the same number as it was in the previous analysis year. Confluence point for the first year i.e. 1975, is considered as reference point for the measurement of upstream and downstream channel sections from the confluence.

2. Area of confluence/ confluence zone

Confluence area (yellow shaded area in Fig. 11-52) is the area of polygon which is made up of four points. Two points are the end points of the tributary channel when it joins the mainstream whereas other two points are deduced by drawing perpendicular lines from these points to the channel flow in the mainstream. The intersection of these lines at the other bank of the main channel give the other two points for the polygon. Polygon formed by joining all these points is termed as area of confluence/ confluence zone in the present study.

3. Channel top width analysis

Channel area is determined by segregating channel from adjacent land features using satellite image analysis. Channel area obtained for the erosion/ deposition analysis as explained in Chapter 6 (Section 6.1) is used to determine the channel top width at the confluence. As shown in Figure 11-52, cross-sections at upstream of confluence point in the main channel (AA' and BB'), upstream of confluence point in the tributary channel (XX' and YY') and downstream of confluence in the combined flow channel (ZZ' and CC') have been drawn for analysing top width. It is important to note that, based on catchment characteristics and physical settings of different tributaries, the interval between the cross sections ranges from a few meters to a few kms (300m to 3.3 km).

4. Junction Angle

It is measured as the angle between the tributary channel and the main channel at confluence point. Preferably, it should be the angle between the tangents on the curved thalweg from the confluence point of the two channels. However, with the use of multispectral satellite data in the study which only provides surface reflectance, it is not possible to identify thalweg (or the depth of channel). Therefore, channel centrelines are considered for determining the junction angle between tributary and main channel. In Figure 11-52, this angle is represented by the red lines meeting at point P.

5. Slope

The slope is considered in the tributary and main channel upstream of the confluence and downstream of confluence. The average slope for a channel section is measured between cross sections, both upstream and downstream of confluence.

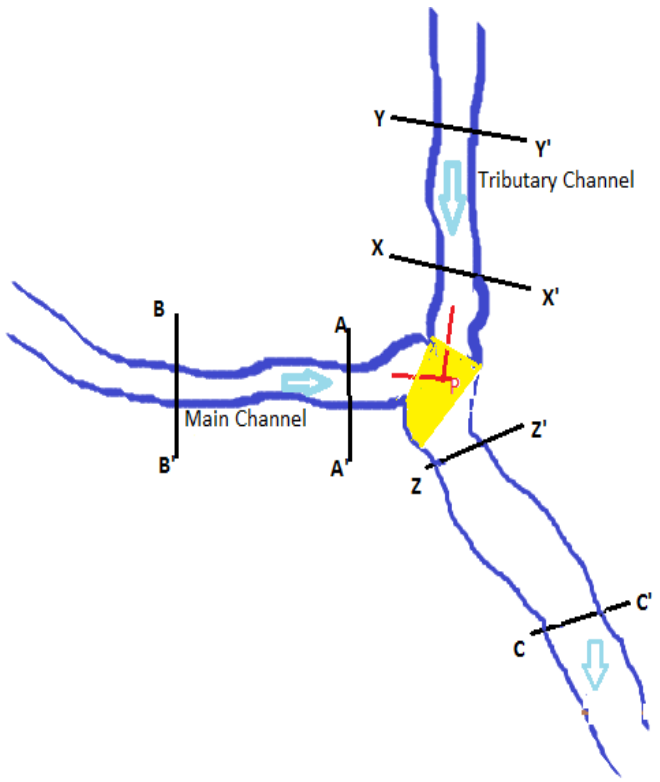


Figure 11-52 : Parameters used confluence analysis

1. **Tons-Yamuna (Upstream of Dak Pathar Barrage)**

The confluence points for the year 1975 and 1990 are labelled as point 1 (77.82 E, 30.507 N) & 2 respectively (77.823 E, 30.509 N). Point 2 is 155m north-west from point 1. The confluence point remains fixed at point 2 for the year 2000. After the year 2000, it moves 40m north-east of point 2 and respositionsed itself to point 3 by 2010 and this point again shifts to point4 (146 m, north-west of point3) by 2016. It is labelled as point 3 (77.82 E, 30.510 N). All the distances upstream and downstream discussed here are measured from point 1. At 900 km upstream of confluence, width of River Yamuna increases from 292m in 1975 to 542m in 1990. The width of Tons, at 830m upstream increases from 346m in 1975 to 527m in 1990 whereas the width of combined flow from Tons-Yamuna measures 376m in 1990 and 254m in 1975 at 690m downstream. Repositioning of river has been observed from 1975 to 1990 in tons channel, where the entire stretch of Tons shifts

westwards. At 1.12 km upstream of confluence the shift of 152m towards north-west has been observed. The changes from 1990-2000 are mainly visible in the upstream of confluence in the Yamuna channel. The downstream side shows relatively less change. At 570m downstream of confluence the width decreases from 393m to 234m during 1990-2000 whereas width of Tons remains constant. The variation in Yamuna width from 2000-2010 is as follows, at 807m upstream of confluence river width shows an increase from 360m to 577 m. The flow dynamics upstream of confluence uptil 2 km in Yamuna channel are almost same for 1990 and 2010. At 916m downstream the width of combined channel increases from 329m in the year 2000 to 434m in the year 2010. In the year 2016 width of Yamuna channel decreases in most of the section upstream of confluence. For instance, at 942m upstream of confluence, width decreases from 619m in 2010 to 312m in 2016. The width upstream in Tons channel remains constant but repositioning is observed from 2010 to 2016. The left bank swings eastwards across the whole length of Tons channel from 1 km uptil 3.2 km upstream. For example, 1.5 km upstream of confluence tons moves towards its east and 2 km upstream of confluence tons moves towards south-east.

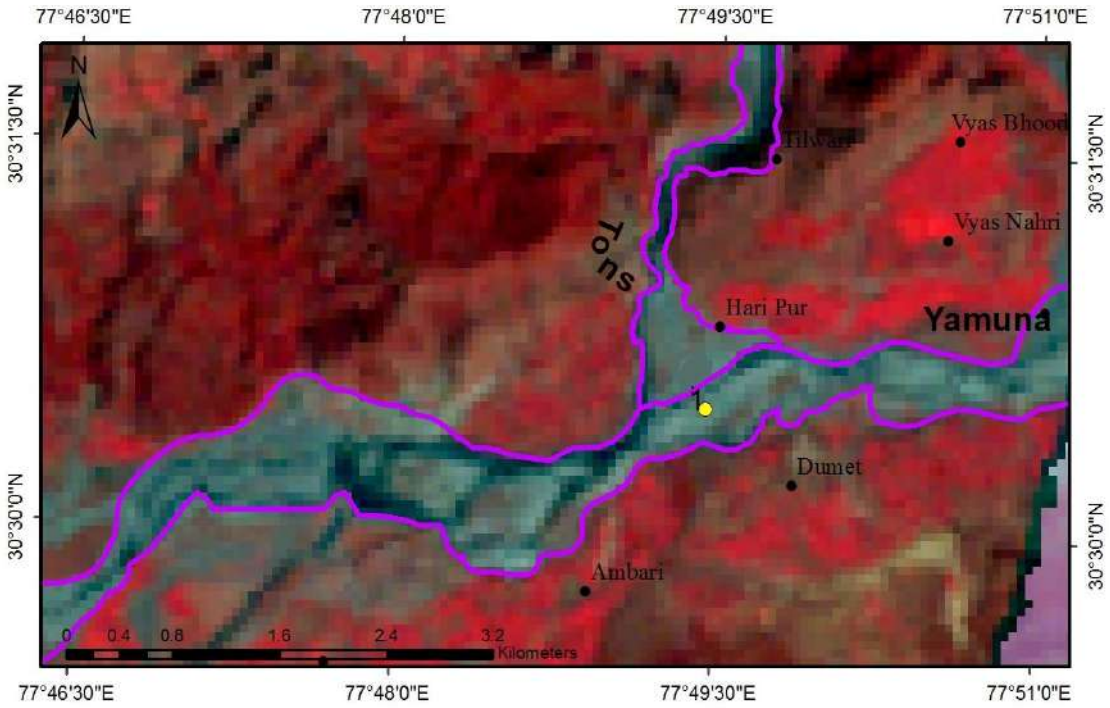


Figure 11-53: Confluence of Tons-Yamuna in 1975

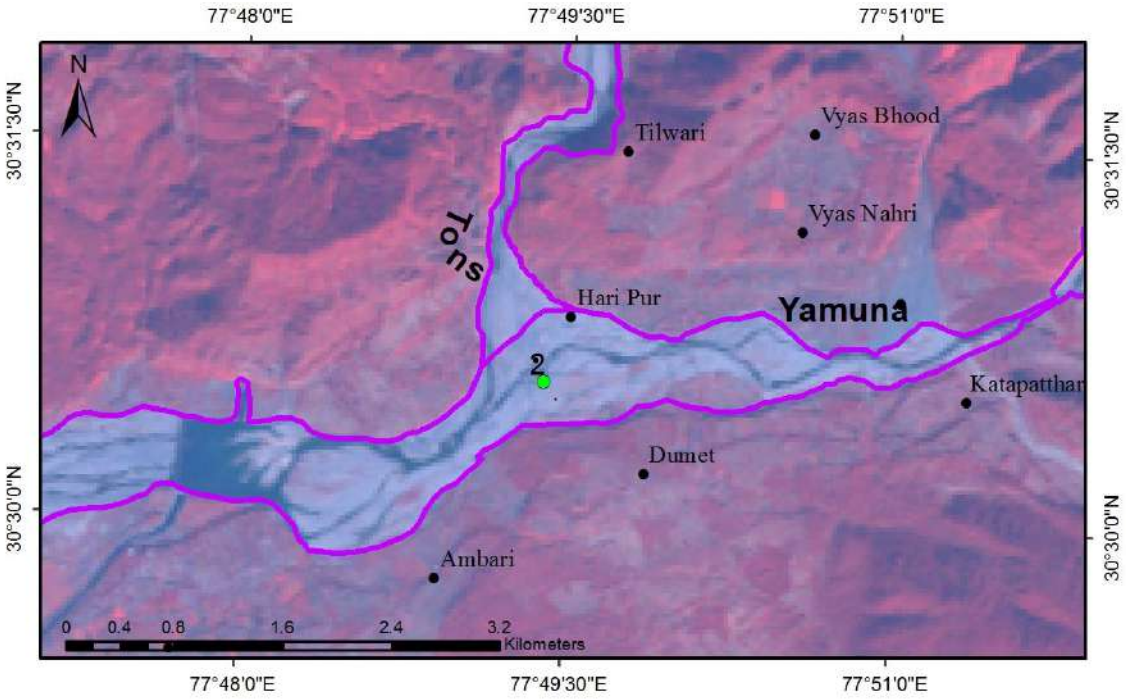


Figure 11-54: Confluence of Tons-Yamuna in 1990

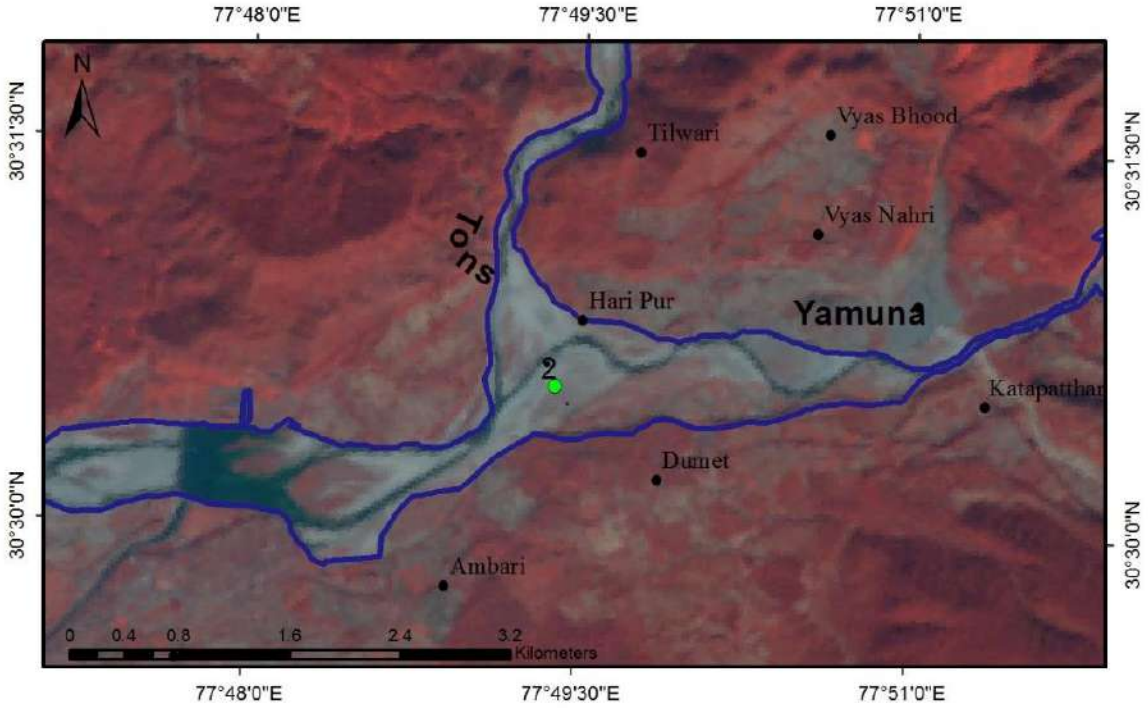


Figure 11-55: Confluence of Tons-Yamuna in 2000

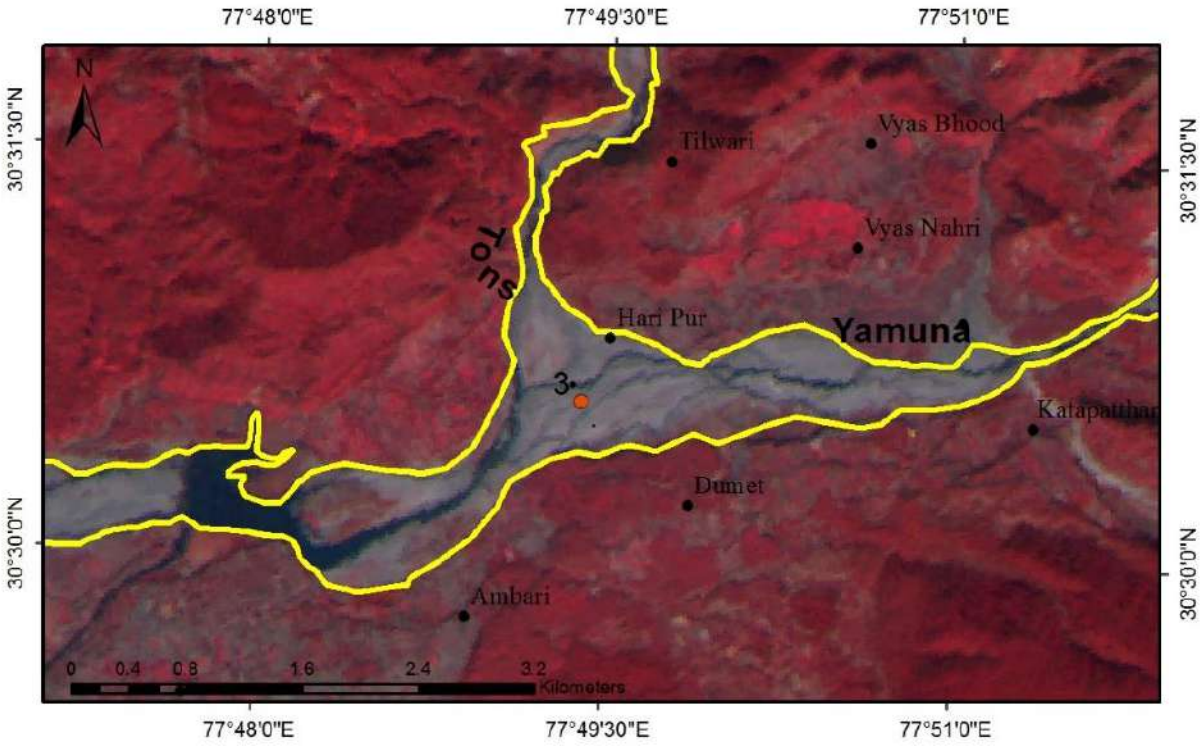


Figure 11-56: Confluence of Tons-Yamuna in 2010

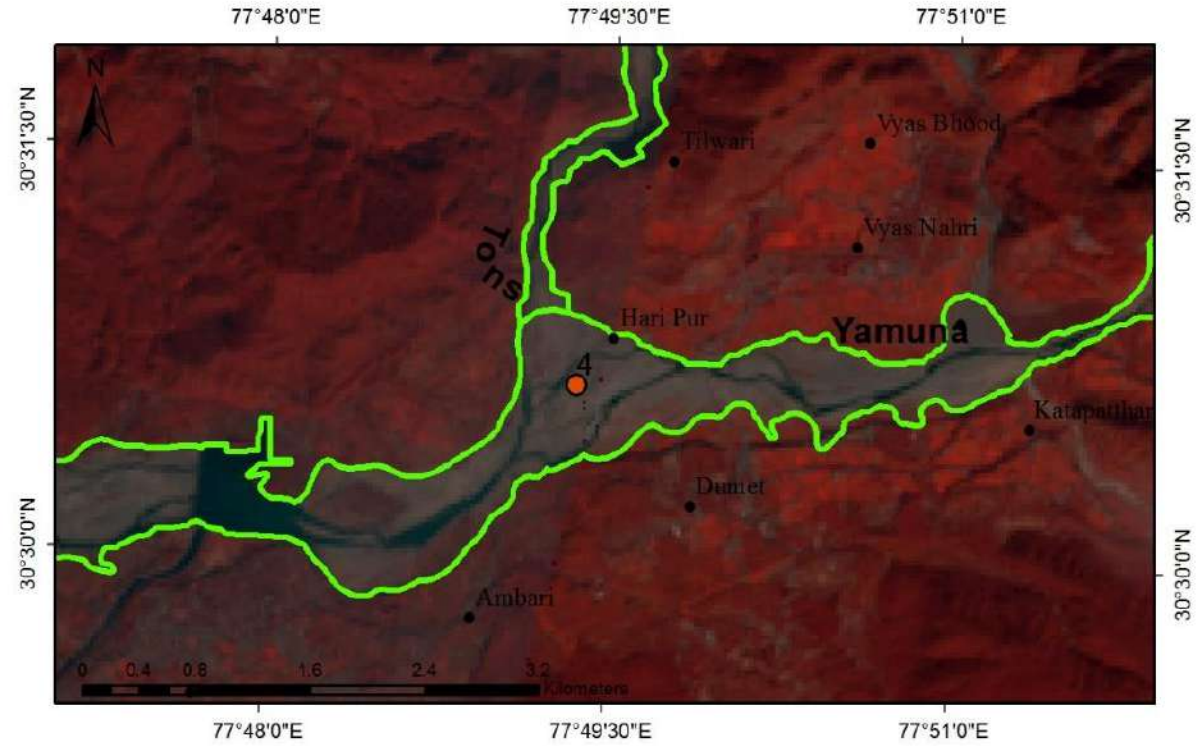


Figure 11-57: Confluence of Tons-Yamuna in 2016

The average bed slope of 1 km longitudinal section of Yamuna channel, upstream of confluence is 80 * 10^{-4}, the average bed slope of 1 km longitudinal section of Tons channel upstream of confluence is 190 * 10^{-4}. The bed slope at 1 km downstream of confluence is 20 *10^{-4}. The area of confluence zone is approximately 0.6 sq.km. in 2016. The Junction angle in 1975 & 1990 is 87˚ which becomes 68˚ by 2000, 112˚ in 2010 and remains constant at 108˚ by 2016. Due to mix spectral signature in the aerial images, no specific erosion and deposition patterns have been observed. From the analysis it can be observed that though there is shift in confluence point however, magnitude of the change is comparatively less and swing displacement of river is well within average channel width. Therefore, Tons-Yamuna confluence can be considered as stable confluence.

Giri Confluence

Giri flows through Himachal Pradesh and meets Yamuna on its right bank at Poanta. The path of Giri is very stable from 1975 -2016. The point of confluence for 1975 is at point 1 (77.68 E, 30.45 N) which shifts to point 2 (153m south-west of 1) by 1990. At 3 km upstream of confluence point 1, width of Yamuna channel increases from 871m to 1.6 km during 1975 to 1990 whereas at 1.2 km upstream of confluence the width increases from 1 km in 1975 to 1.5 km in 1990. The Giri channel width, 1.5 km upstream of point 1, increases from 295m in 1975 to 535m in 1990. As the combined flow from both rivers transcend through confluence downstream the width changes at 2.4 km downstream indicate decrease of channel width from 2 km to 1.4 during 1975 to 1990. Confluence point then shifts to point 3 (88m south-west of 2) by the year 2000. In the year 2000, width of River Yamuna at 3.3 km upstream of point1 decreases from 1.6 km in 1990 to 1 km in 2000 whereas at 1.6 km downstream of point1, the width decreases from 1.2 km in 1990 to 381m in 2000. In case of River Giri, no significant changes in channel width are observed. At 1.9 km upstream of point1, Giri channel width reduces from 344m in 2000 to 181m in 2010. Yamuna width, 1.4 km upstream changes from 1.1 km in 2000 to 1.25 km in 2010. On the other hand, at 2 km downstream of confluence the combined flow width is 1.2 km in 2000 and 1 km in 2010. The width of combined channel, up to 5 km downstream of confluence decreases from 2000 to 2010. The point of confluence in 2010 is point4 (39m north-east of point3) which migrates to point5 (310m north-east of point4) in 2016. The change in width from 2010 to 2016 indicates overall increase in channel width up to 5 km downstream of confluence. For one such section at 2.6 km downstream from confluence point1, width changes are, 1.17 km in 2010 and 1.52 km in 2016. In

the upstream channel of Yamuna, at 1.5 km from point1, width increases from 1.16 km in 2010 to 1.3 km in 2016.

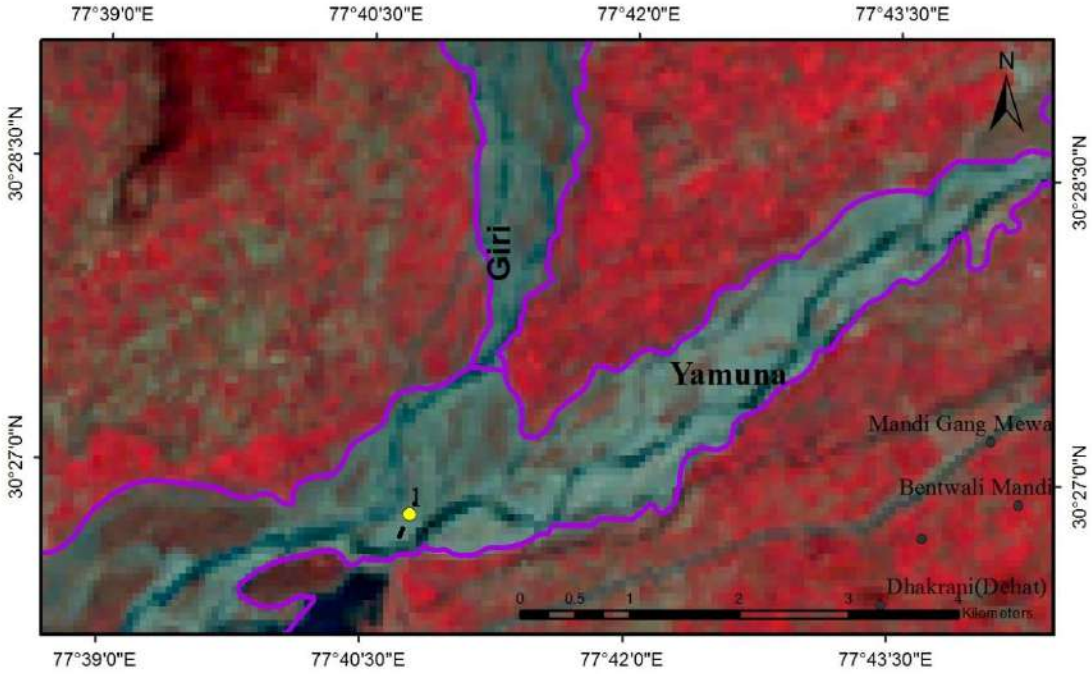


Figure 11-58: Confluence of Giri-Yamuna in 1975

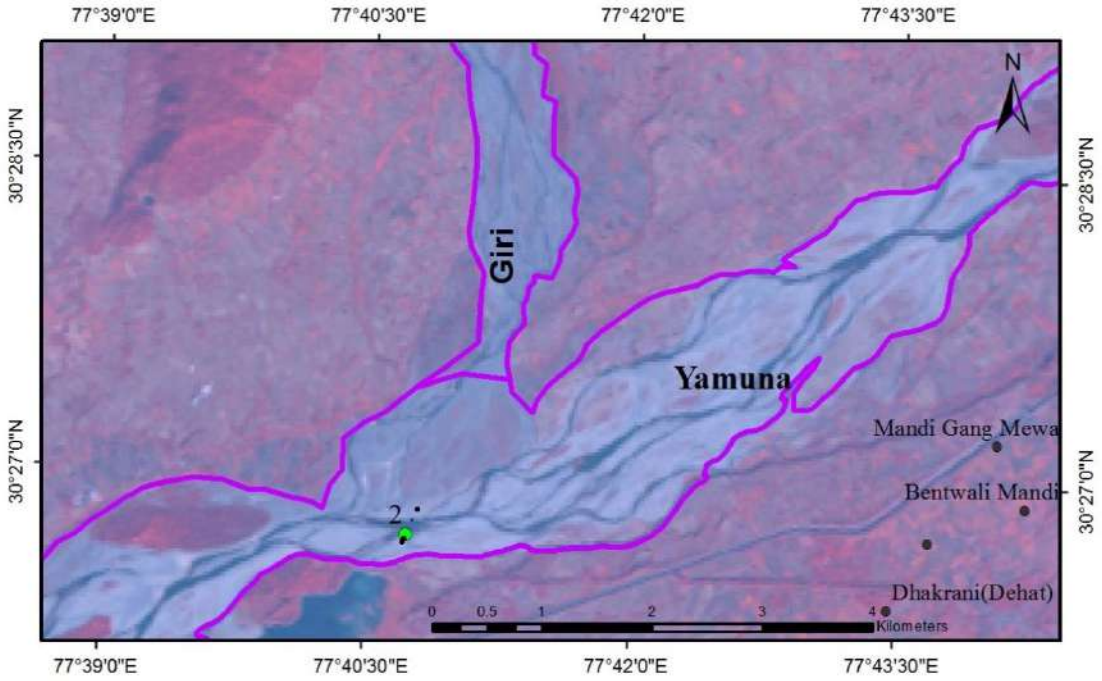


Figure 11-59: Confluence of Giri-Yamuna in 1990

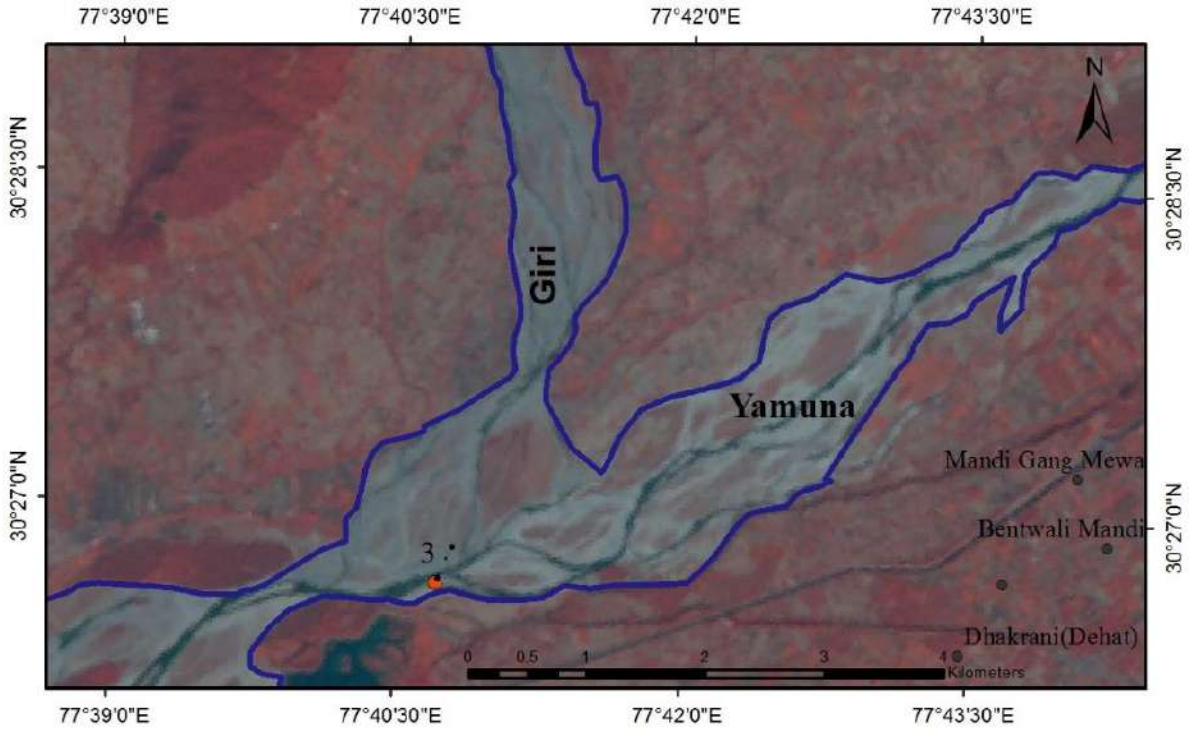


Figure 11-60: Confluence of Giri-Yamuna in 2000

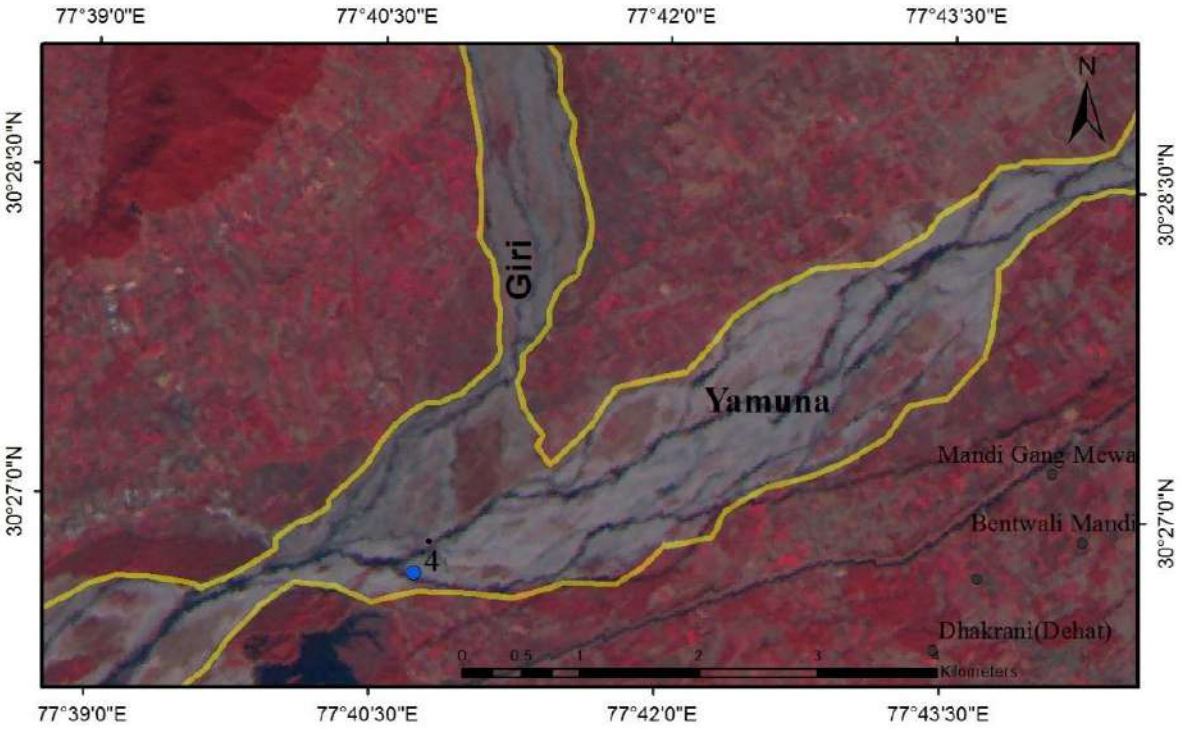


Figure 11-61: Confluence of Giri-Yamuna in 2010

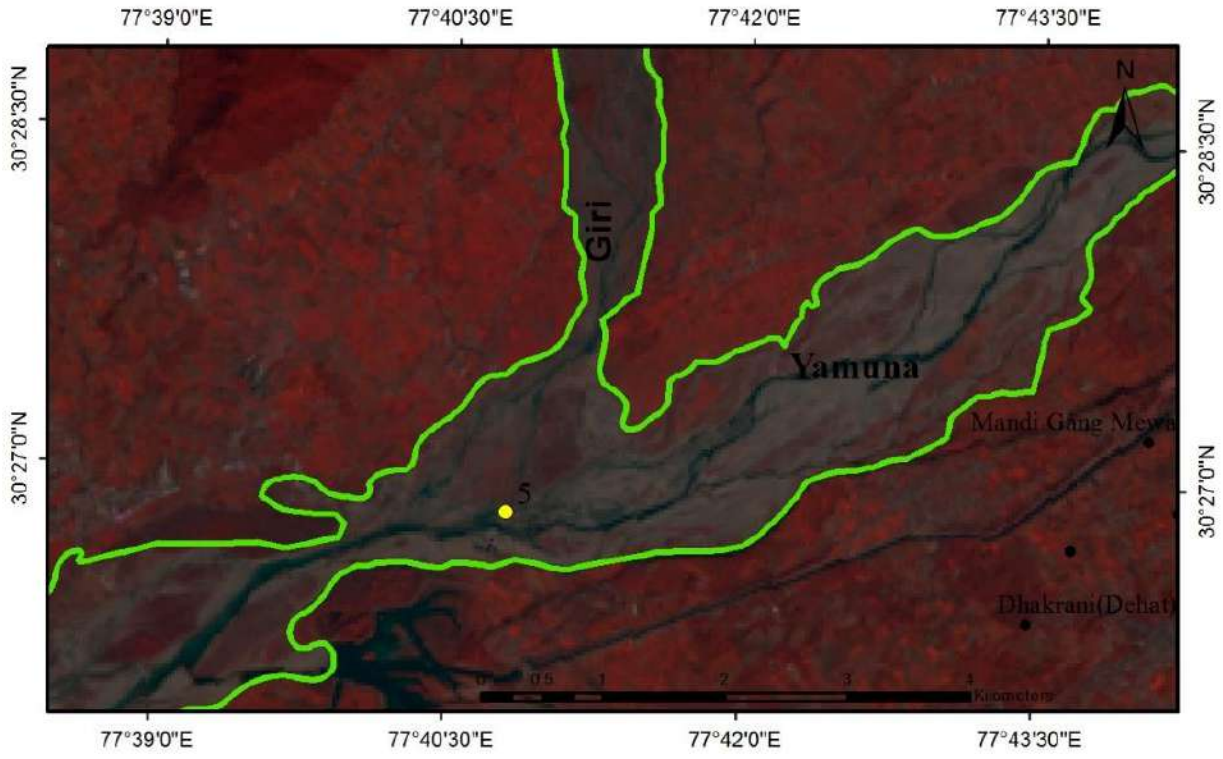


Figure 11-62: Confluence of Giri-Yamuna in 2016

The junction angle for the subsequent years are as follows, 63˚ for 1975 and 1990, 56˚ for 2000 and 2010, 45˚for 2016. The average bed slope of 2 km longitudinal section of Yamuna channel, upstream of confluence is 35 * 10^{-4}, the average bed slope of 2 km longitudinal section of Giri channel upstream of confluence is 500 * 10^{-4}. The bed slope at 1 km downstream of confluence is 60 * 10^{-4}. From the analysis it can be observed that though there is shift in confluence point however, magnitude of the change is comparatively less and swing displacement of river course is well within average channel width. Therefore, Giri-Yamuna confluence can be considered as stable confluence.

Hindon Confluence

River Hindon joins Yamuna on its left bank at Momnathal village near Gautambudhanagar. Significant movement of confluence point is visible from its trajectory across the years in Figures (11-63 to 11-67). There are 4 different confluence points used for different years representing the movement of confluence. In 1975, the point of confluence is shown by point 1 (77.495 E, 28.39 N), which shifts 1 km in the north direction to reach point 2 by the year 1990. At 3 km upstream of point 1, the width of Yamuna channel is 2.5 km, which reduces to 1.1 km during 1975 to 1990,

whereas at 1.2 km upstream of point 1, width of Yamuna is 1 km in the year 1975 which reduces to 552m in the year 1990 (taking point 2 as reference). The width of the mouth of Hindon channel witness a considerable decrease from 905m (upstream from point1) in 1975 to 366m (upstream from point2) in 1990. At 1 km downstream from confluence, the channel width increases from 240m to 555m during 1975 to 1990. Upward repositioning of river course and decrease in the width of the Yamuna are common observations in these years. In 2000, point 3 is taken as confluence point. Point 2 undergoes a north-east swing by 1.2 km during 1990 to 2000. Upstream of confluence in Yamuna channel formation of an ox bow (2000) from cut off (1990) is seen. The right bank of Yamuna, 2.6 km upstream of point 2 (1990) swings 1.7 km (south-west). Though, the river has been stable and no significant swing in river path has been observed during 2000 to 2010, confluence point moves to point 4 (203m north-east of point3). The changes in width of various channels from 2000 to 2010 are as follows: at 1.7 km upstream of confluence point 3, Yamuna channel width is 412m in 2000 and 1.1 km in 2010. At 291m upstream of point 3, the Yamuna width decreases from 519m in 2000 to 179m in 2010. Hindon also observes a decrease in width 566m upstream of point 3 from 68m in 2000 to 45m in 2010. The point of confluence remains stationary at point 4 in 2016. At 1.5 km upstream of point 4, the Yamuna channel is 984m wide in 2010 and 86m wide in 2016. The Hindon channel at the mouth of Hindon-Yamuna union witness a decrease in width from 158m in 2010 to 118m in 2016. Downstream of point 4, at a distance of 270m the combined channel width increases from 161m in 2010 to 304m in 2016.

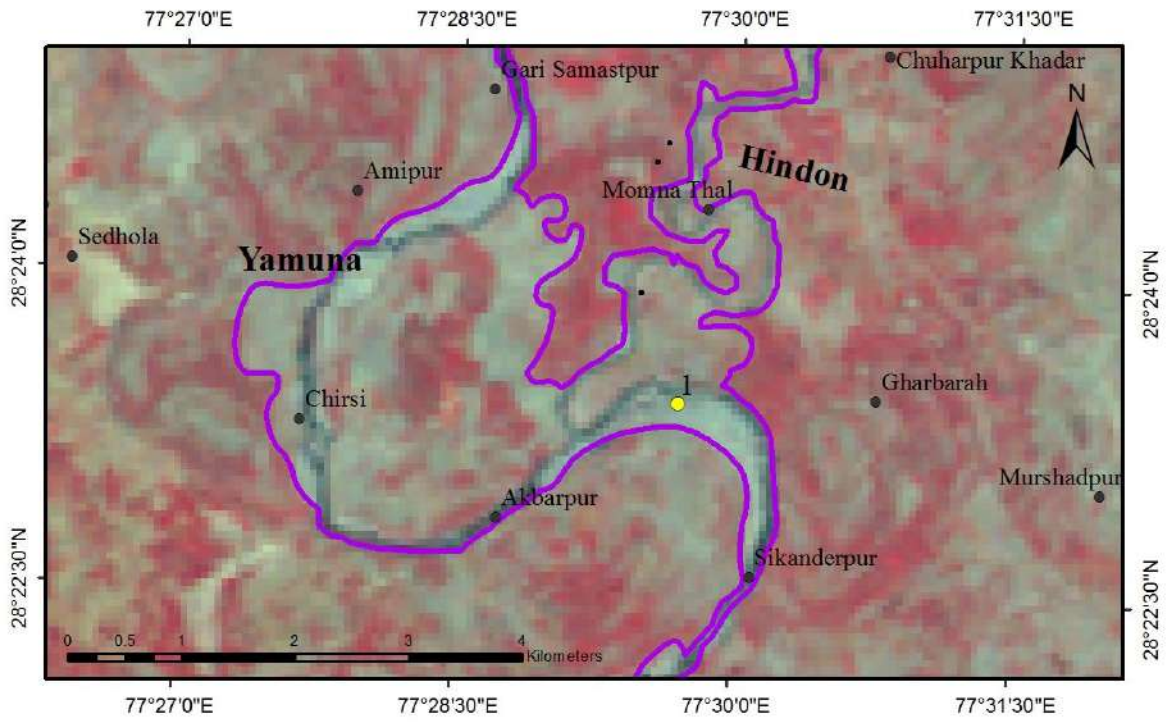


Figure 11-63: Confluence of Hindon-Yamuna in 1975

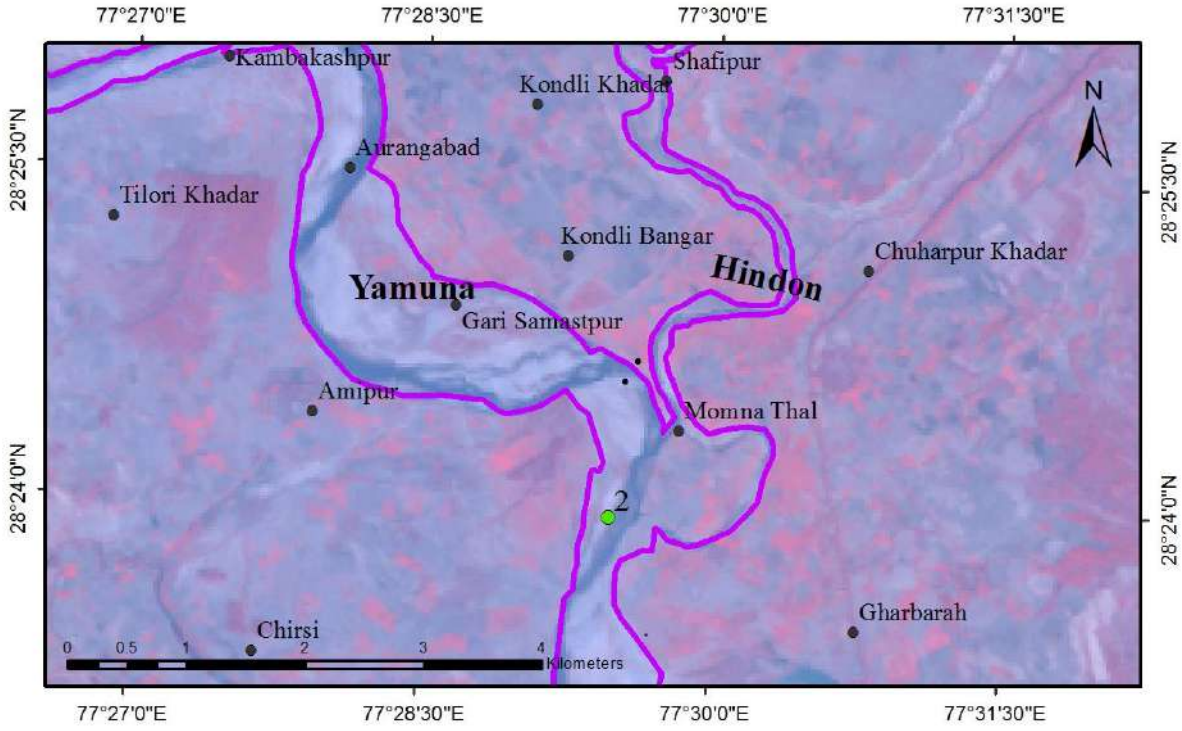


Figure 11-64: Confluence of Hindon-Yamuna in 1990

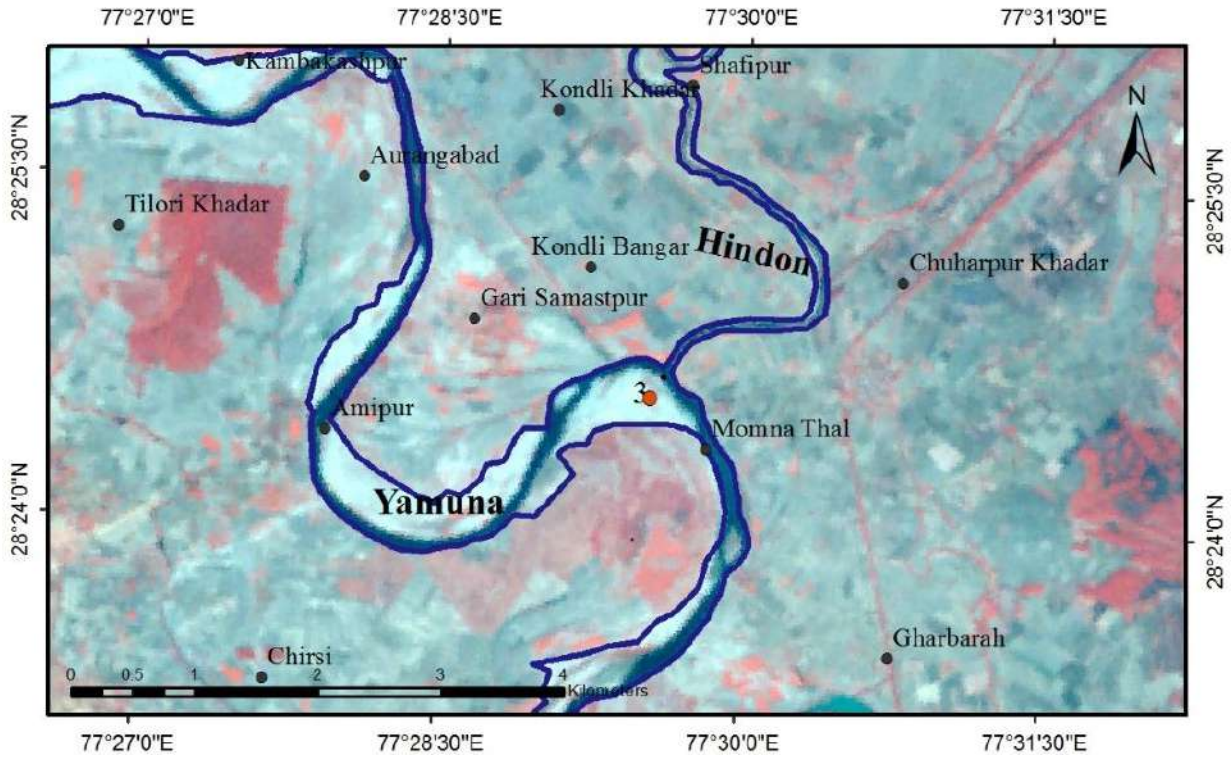


Figure 11-65: Confluence of Hindon-Yamuna in 2000

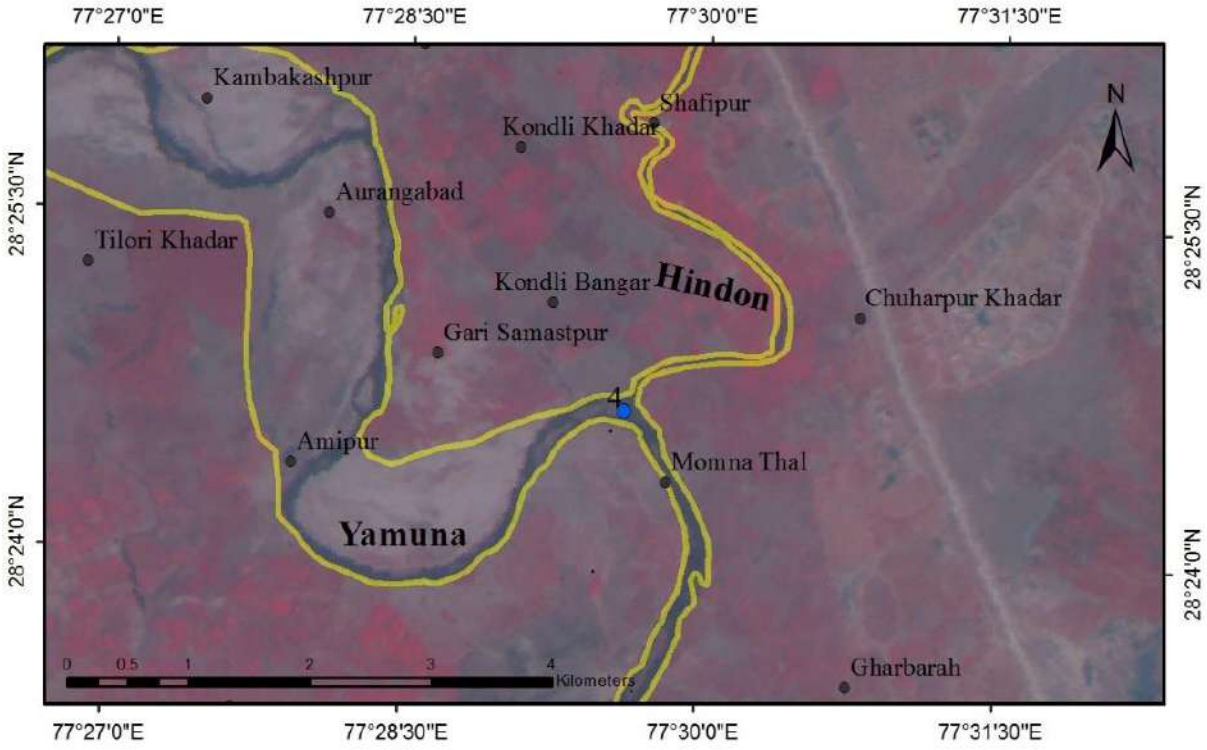


Figure 11-66: Confluence of Hindon-Yamuna in 2010

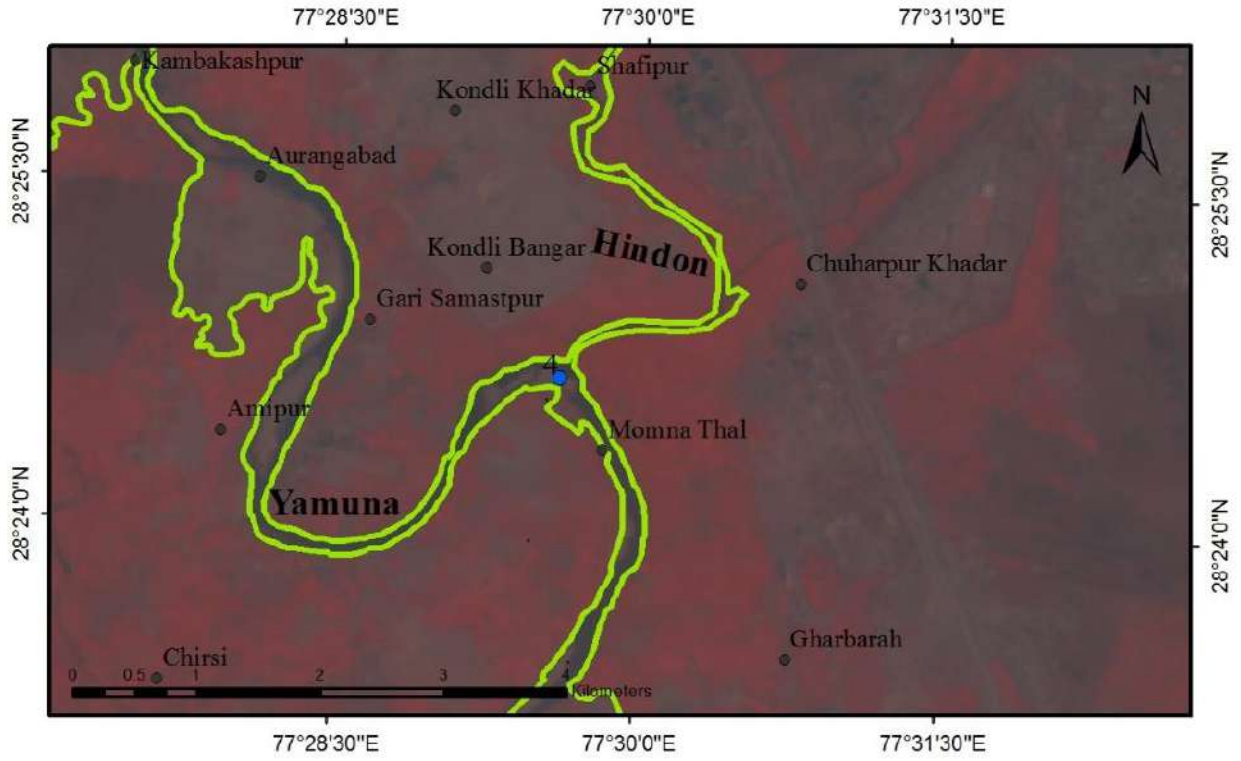


Figure 11-67: Confluence of Hindon-Yamuna in 2016

Though, the channel is stable between 2010 and 2016, a significant decrease in Yamuna channel width upstream of confluence is observed. This is most likely result of anthropogenic activities at the banks of Yamuna in city of Delhi and neighboring area. The average bed slope of 1.5 km longitudinal section of Yamuna channel, upstream of confluence is $33 * 10^{-4}$, the average bed slope of 1 km longitudinal section of Hindon channel upstream of confluence is $30 * 10^{-4}$. The bed slope at 1 km downstream of confluence is $20 * 10^{-4}$. The junction angle variation is as follows: 87˚ in 1975, 43˚ in 1990, 89˚ in 2000, 86˚ in 2010 and 2016. From the analysis it can be observed that there is significant change in confluence point, magnitude of the change is comparatively high and swing displacement of river is beyond average channel width. Therefore, Hindon-Yamuna confluence can be considered as unstable confluence and thus falls in the category of critical segment which needs attention.

Chambal Confluence

At the confluence, width of channels undergoes various changes as stated under. The reference point to measure distances has been considered as point 1 (79.253 E, 26.491 N), which is the confluence point for the year 1975, 2000 and 2010. It has moved towards point 2 (79.256 E, 26.492

N) for the year 1990 and 2016. From 1975 to 1990 at 2km upstream, width of Chambal River (610 m) remains constant whereas significant changes are observed in the width of Yamuna. At 1.4km upstream, the width of Yamuna increases from 100m in 1975 to 266m in 1990. The combined width of channel at 1 km downstream from the confluence is 784.8m in 1975 and 1.1km in 1990. Not much changes have been observed during 1990 to 2000. However, at 2.5km downstream of point 1, a west ward swing of 161m in channel is observed. By the year 2010 a decrease in channel width at 1.8 km downstream from confluence (774m in 2000 to 450m in 2010) has been noticed. Confluence area has also shown decreasing trend. The width of Yamuna River upstream of the confluence witnessed decrease in channel width from 537m in 2000 to 134m in 2010. This change is observed just before the confluence whereas image of year 2016 indicates increase in width at 2 km downstream of confluence from 314m in 2010 to 523m in 2016. Over the span of 40 years from 1975 to 2016, no significant change occurs in Chambal width upstream of confluence. River Yamuna from 1.7 km upstream of confluence up to confluence zone, has repositioned in north-west, however scale of change is within average channel width.

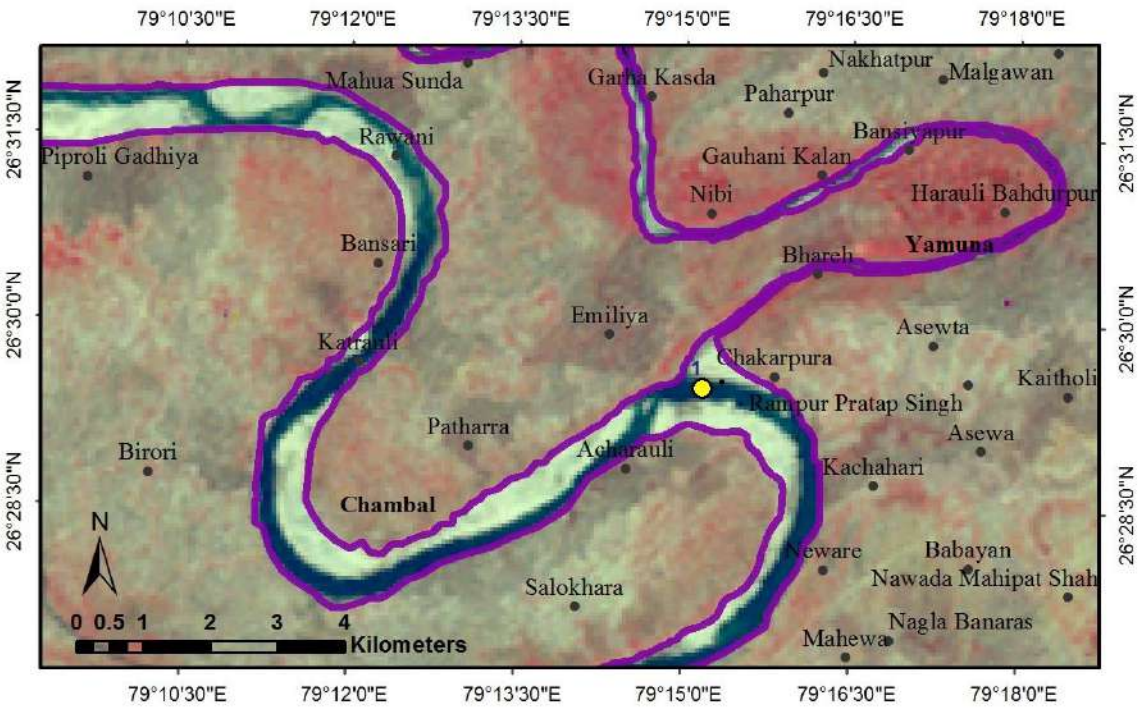


Figure 11-68: Confluence of Chambal-Yamuna in 1975

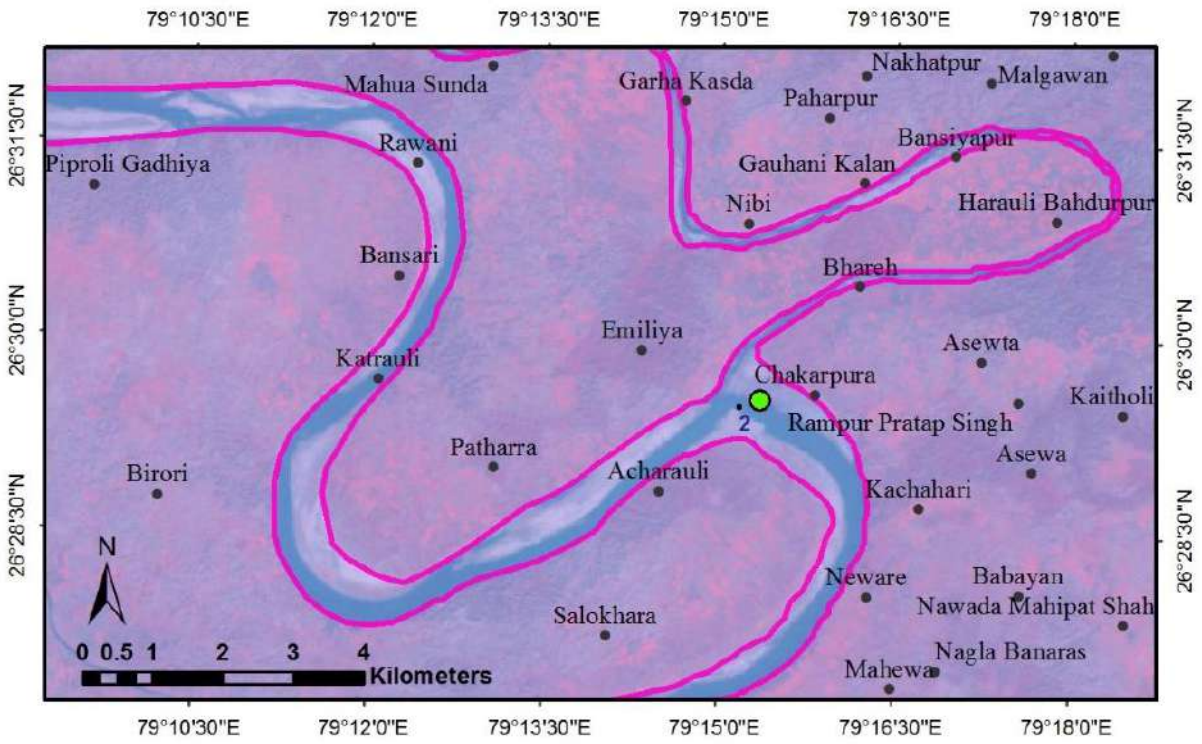


Figure 11-69: Confluence of Chambal-Yamuna in 1990

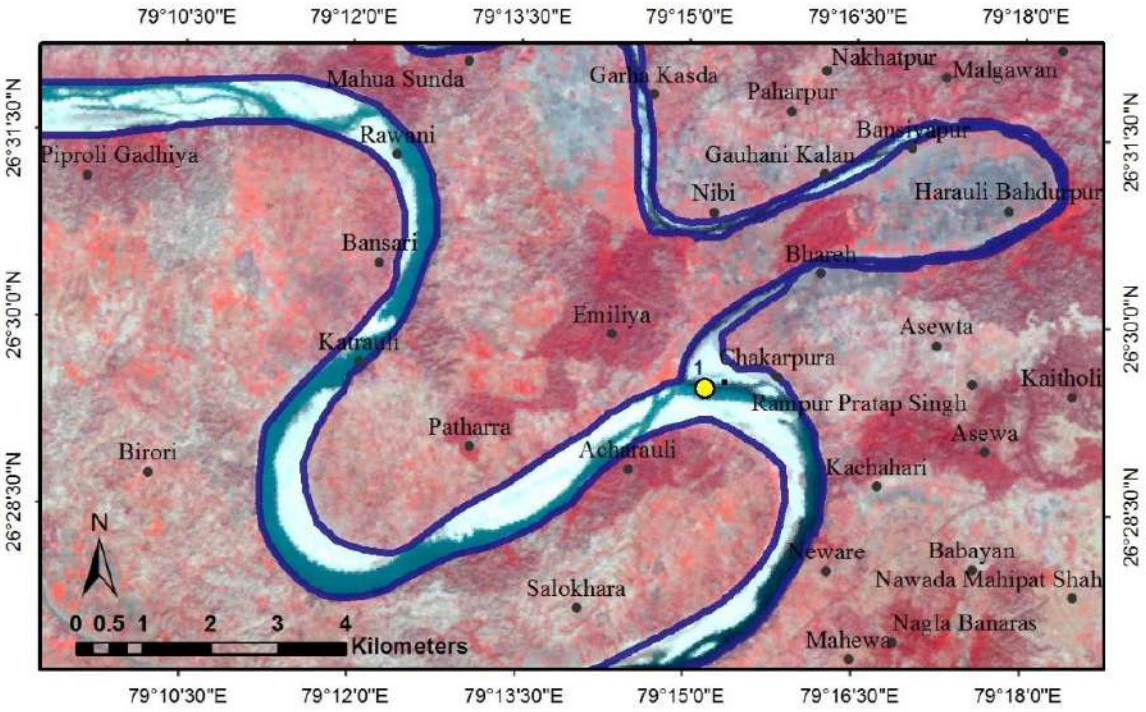


Figure 11-70: Confluence of Chambal-Yamuna in 2000

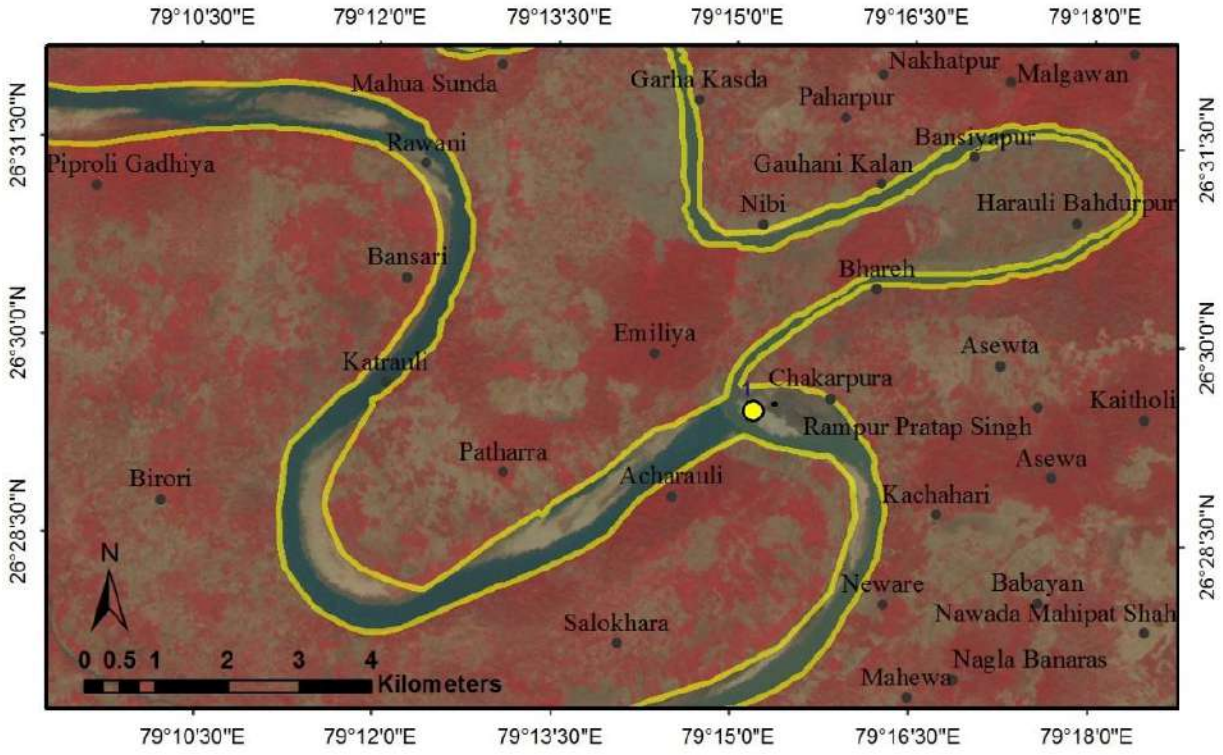


Figure 11-71: Confluence of Chambal-Yamuna in 2010

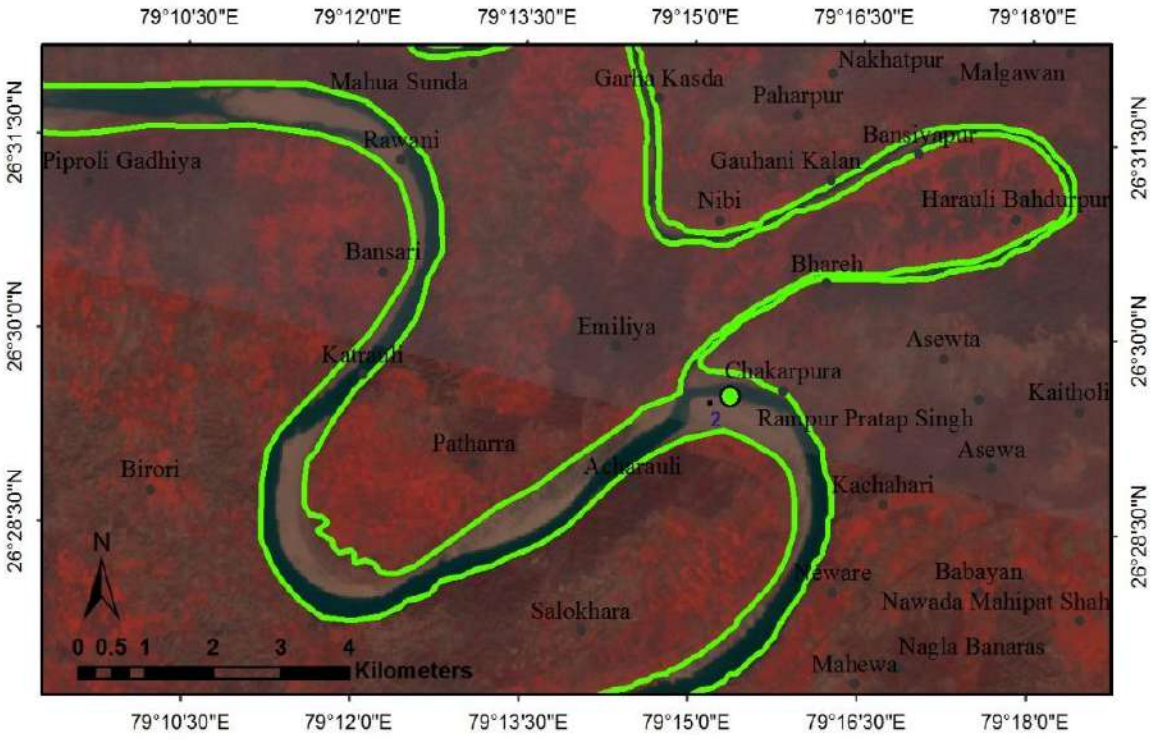


Figure 11-72: Confluence of Chambal-Yamuna in 2016

The junction angle for the year 1975 is 80˚, 70˚ in 1990, 75˚ in 2000 which changes to 65˚ by 2010 and it reaches to 45˚ by 2016. The average bed slope of 5.5 km longitudinal section of Yamuna channel, upstream of confluence is $5.45 * 10^{-4}$, the average bed slope of 3.2 km longitudinal section of Chambal channel upstream of confluence is $3.13 * 10^{-4}$. From the analysis it can be said that not much movement, and changes in confluence area have been observed for Chambal Yamuna confluence. Though, some changes in width in Yamuna channel upstream and downstream of confluence have been noticed, they are within average channel width and therefore this confluence can be considered as stable zone.

Sind Confluence

Sind River meets Yamuna near town Auraiya. The point of confluence for the year 1975 is denoted by label 1 in the Fig.11-73. This point is used as the reference point to measure distances upstream and downstream from confluence for all the years. At 1.5km upstream of point 1, the Yamuna width increases from 510m in 1975 to 848m in 1990. Significant changes in Sind width can be seen just upstream of confluence, where width increases from 184m in 1975 to 336m in 1990. At 2 km upstream, the left bank of Sind moves by 212m northwards. Immediate downstream of the confluence, the channel width decreases from 782m to 677m during 1975 to 1990. The confluence point moves to point 2 (79.216 E, 26.439 N) by the year 2000. During 1990 to 2000, at 2km upstream of the confluence the Sind channel undergoes decrease in width from 270m to 148m. Repositioning has been observed at various locations in both the river (upstream of the confluence) and downstream as well. At 880m upstream of confluence, Yamuna swings around 60m towards north-west whereas at 880m downstream of confluence, shift of 94m has been observed towards south-west. In 2010, the confluence point moves from point 2 to point 3 (79.216 E, 26.438 N). At 630m downstream of confluence width decreases from 657m in 2000 to 546m in 2010. Swing displacement is also observed at this location towards south-west. Before confluence, Yamuna width decreases from 794m in the year 2000 to 656m in the year 2010. In the year 2016, confluence point moves to new location i.e. Point 4 (79.218 E, 26.44 N). At the mouth of the confluence, the width changes in Yamuna are significant, channel with changes from 601m in the year 2010 to 843m in the year 2016. Width of Sind just before confluence is 85 m. In downstream section, at 556m from point 1, the width increases from 557m in the year 2010 to 763m in the year 2016. The area of confluence increases from 0.3 to 0.5 square kilometre during 2010 to 2016.

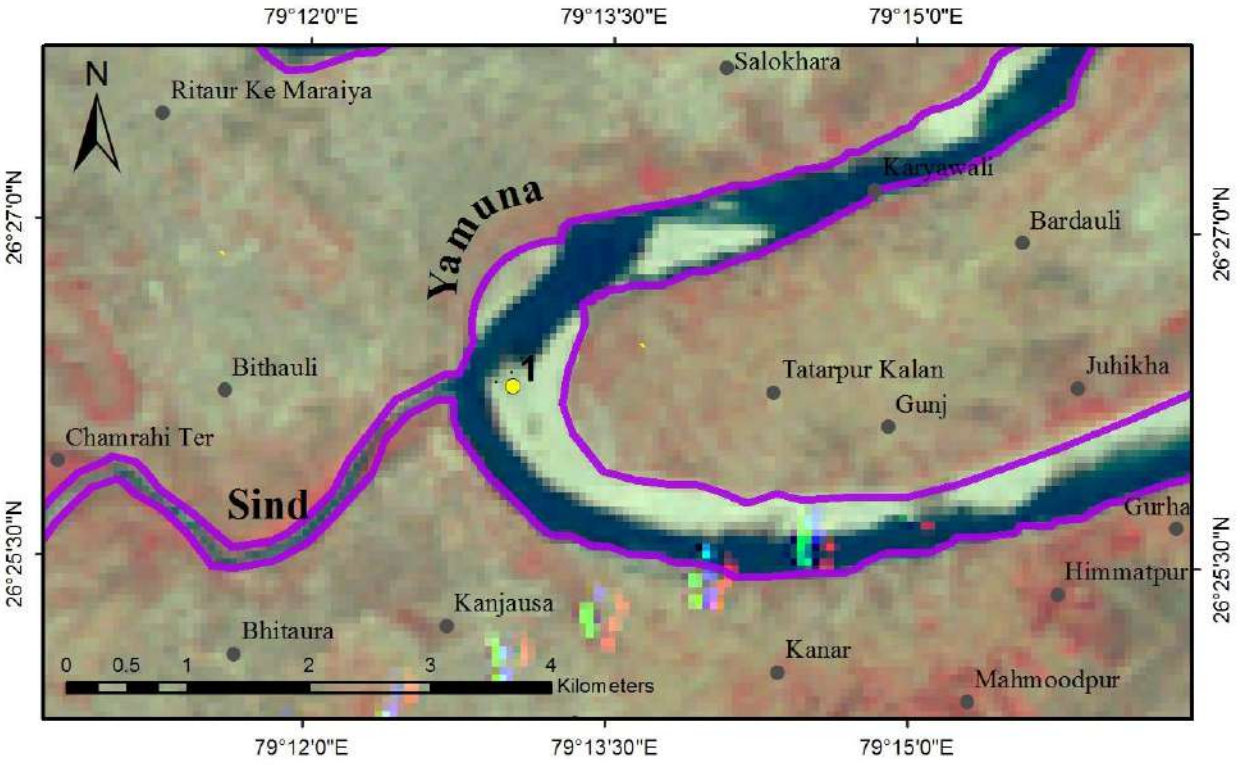


Figure 11-73: Confluence of Sind-Yamuna in 1975

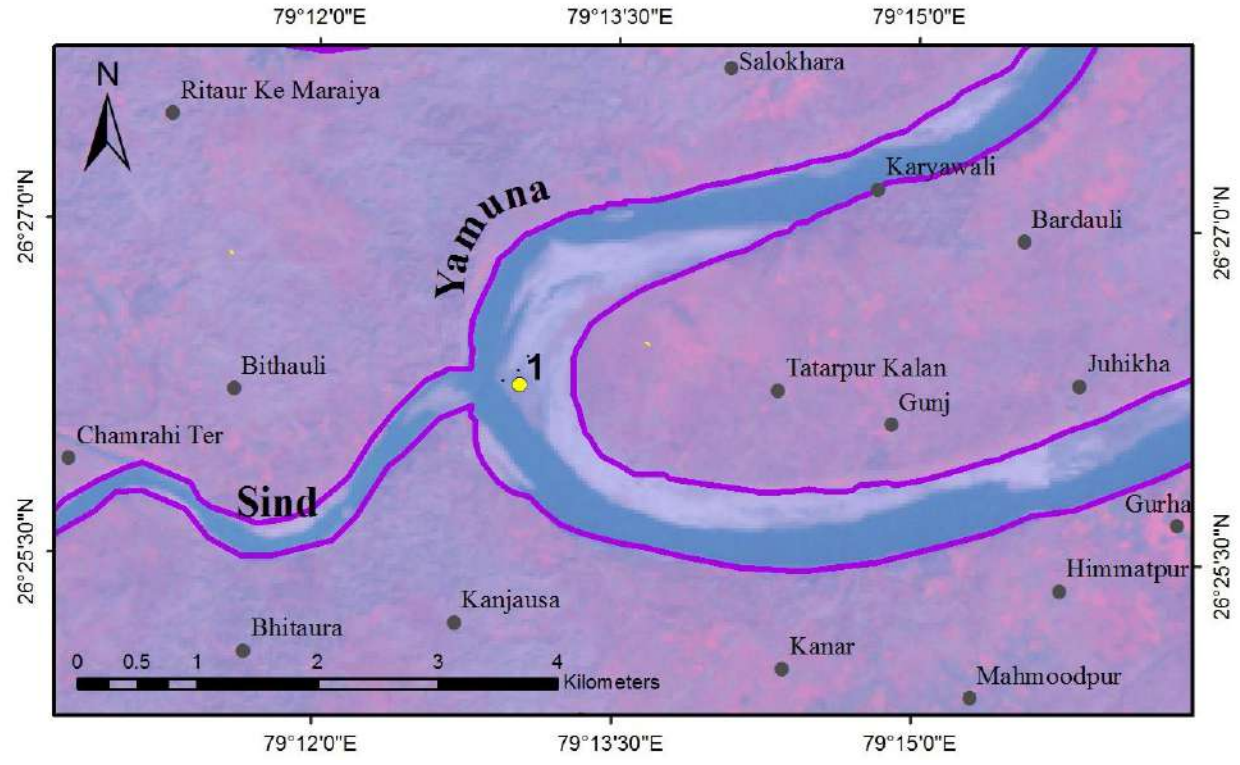


Figure 11-74: Confluence of Sind-Yamuna in 1990

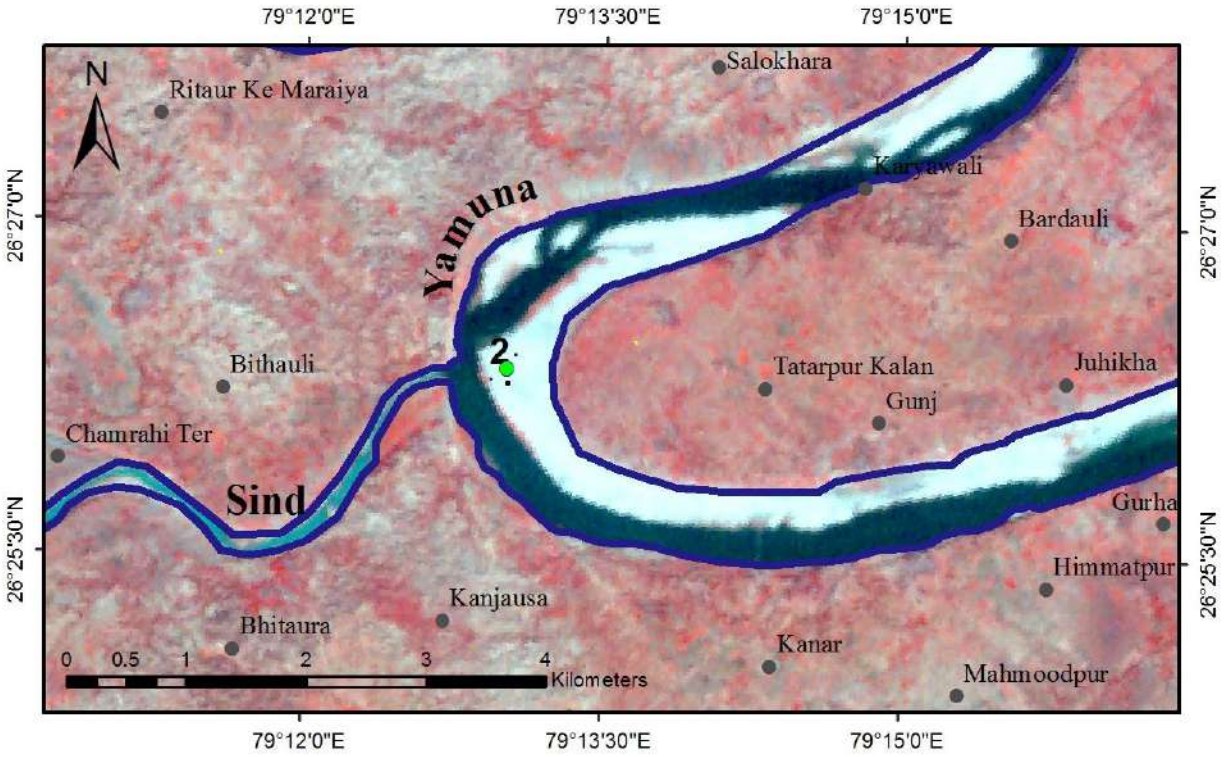


Figure 11-75: Confluence of Sind-Yamuna in 2000

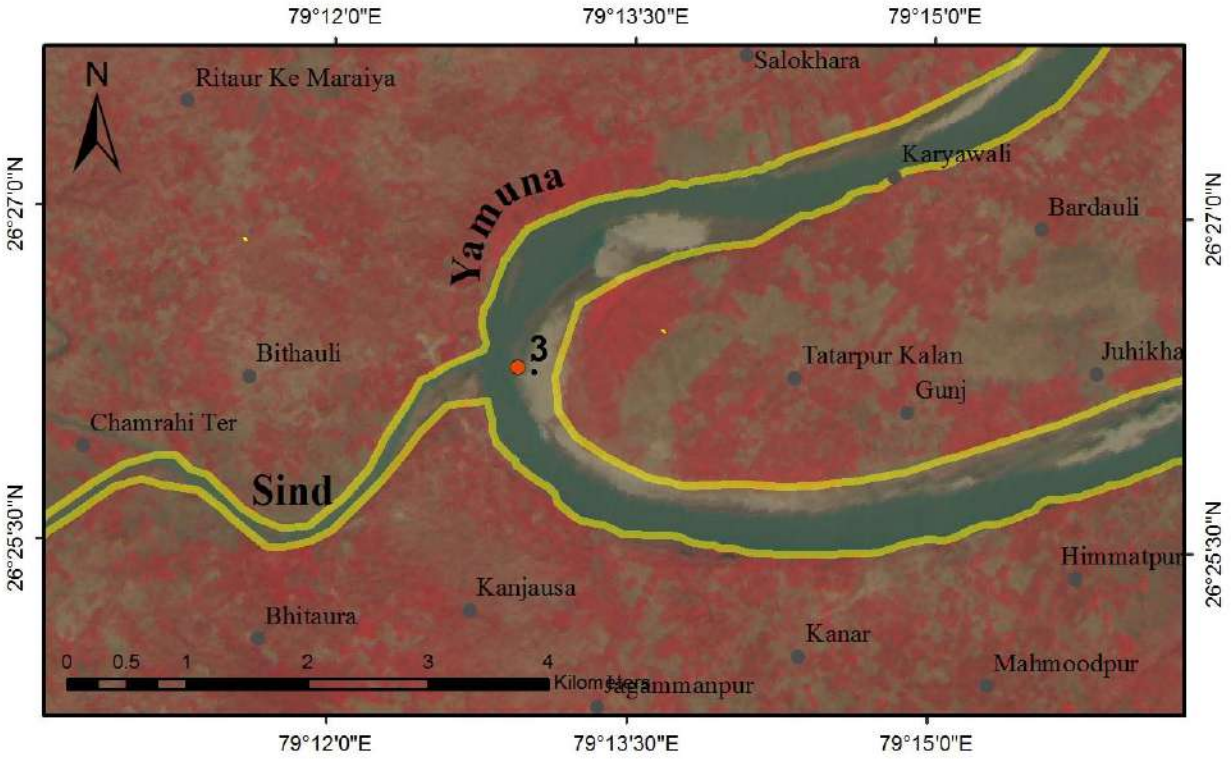


Figure 11-76: Confluence of Sind-Yamuna in 2010

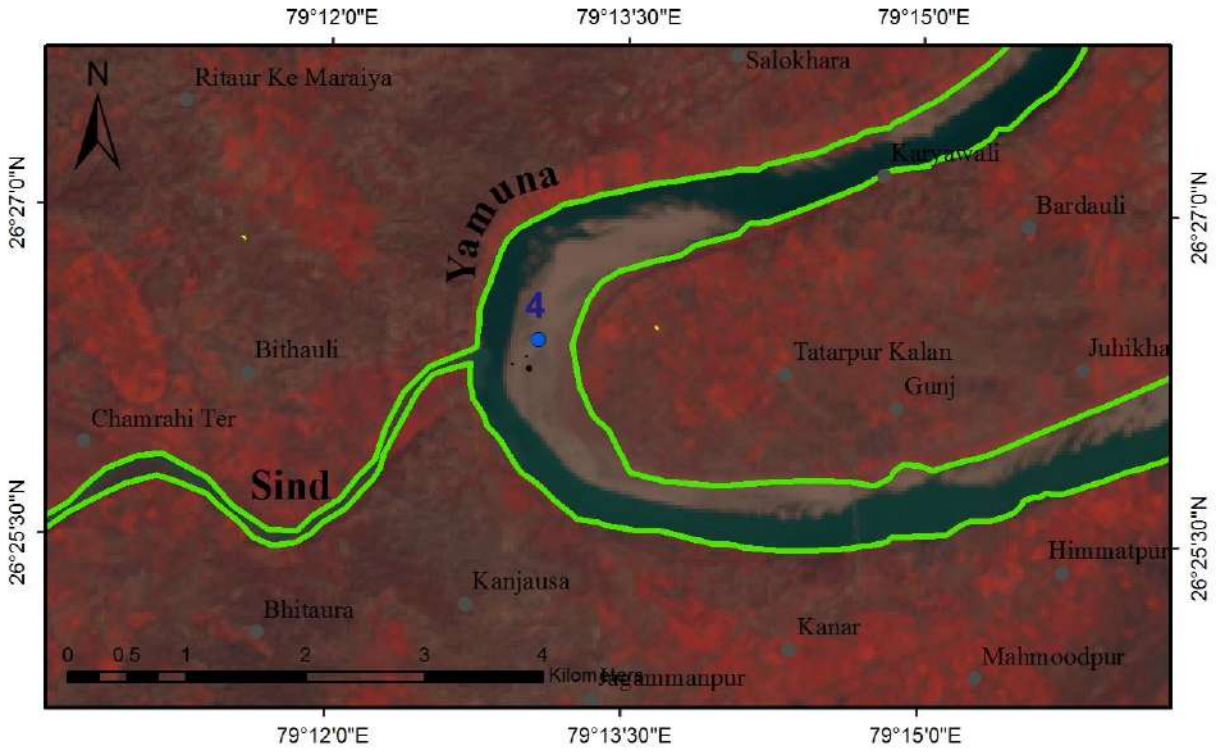


Figure 11-77: Confluence of Sind-Yamuna in 2016

The change in junction angle is as follows: 93˚ in 1975, 88˚ in 1990, 100˚ in 2000, 118˚ in 2010 and 104˚ in 2016. The average bed slope of 4 km longitudinal section of Yamuna channel, upstream of confluence is 2.5 * 10^{-4}, the average bed slope of 1.5 km longitudinal section of Sind channel upstream of confluence is 40 * 10^{-4}. The bed slope at the downstream of confluence is same as that of upstream Yamuna channel i.e. 2.5 * 10^{-4} for a stretch of 4 km from confluence. Thus, the Yamuna continues to flow in very relatively flat slope whereas River Sindh flows through comparatively steeper slope. Sandbar formation, demolition and erosion-deposition are prominent characteristics of this confluence. This are most likely on account on anthropogenic activities near the flood plains, however single factor suggesting the cause for these events may not be appropriate. Flood events, changes in physiographic characteristics, geologic settings also contribute to these changes. It is important to note that though changes in confluence point and a confluence area are noticeable, scale of change is well within the average channel width. Therefore Sind-Yamuna confluence may be considered as stable.

Betwa Confluence

River Betwa outfalls into River Yamuna at Hamirpur in Uttar Pradesh. The confluence is represented by point 1 for the year 1975 which then shifts to point 2, in the year 1990 (Fig.11-78). This further shift to point 3 by the year 2016. To measure distances upstream and downstream of the confluence, point 1 is used as reference point. In the year 1975, at 1.2km upstream of the confluence Betwa channel width increases from 219m to 343m during 1975 to 1990 whereas at 2.3km downstream of point 1, width increases from 600m in the year 1975 to 753m in the year 1990. At 1.1 km upstream, the Yamuna channel width has been observed to be 398m in the year 1975 and 577m in the year 1990. It can be said that Betwa and Yamuna Rivers both have experienced some changes in channel during 1975-1990 in both upstream and downstream sections. Point of confluence (year 1990) shifts to point 2 (80.217 E, 25.922 N). At 400m downstream of confluence channel width changes from 905m in 1990 to 1km in 2000 whereas at 3km upstream of confluence, Betwa width decreases from 684m in the year1990 to 495m in the year 2000. Significant difference is seen in the width of Betwa channel upstream at the confluence, reduction of 403m to 269m during 2000 to 2010. At 1.2 km upstream of confluence River Yamuna experienced reduction in channel width from 500m to 407m between 2000 and 2010. An increase in confluence area between 2000 and 2010 has been observed. The channel undergoes reduction in width at different sections between the year 2000 to 2010. In 2016, the width of Betwa at confluence is 87m, quite less than that of 2010. At 1 km upstream of confluence, width of River Betwa decreases from 314m in the year 2010 to 138m in the year 2016. Repositioning of left bank of River Betwa at this location by 237m northwards is also observed. The point of confluence reaches to point 3 (80.214 E, 25.922 N) by the year 2016. At 3.5 km upstream from point 1, left bank of River Betwa repositioned itself in south-west by 287m whereas width of River Yamuna at 1.5 km upstream from point 1 is observed to be increasing from 324m to 453m during 2010 to 2016.

The junction angle decreases from 95˚ in the year 1975 to 42˚ in the year 1990. For the years 2000 and 2010, the junction angle is found to be 41˚ which again increases to 83˚ in the year 2016. Overall the channel is stable from the year 1975 to 2016 in upstream and downstream section of River Yamuna, however, considerable changes have been observed in the upstream of Betwa channel where river width reduces to its half during 1975 to 2016.

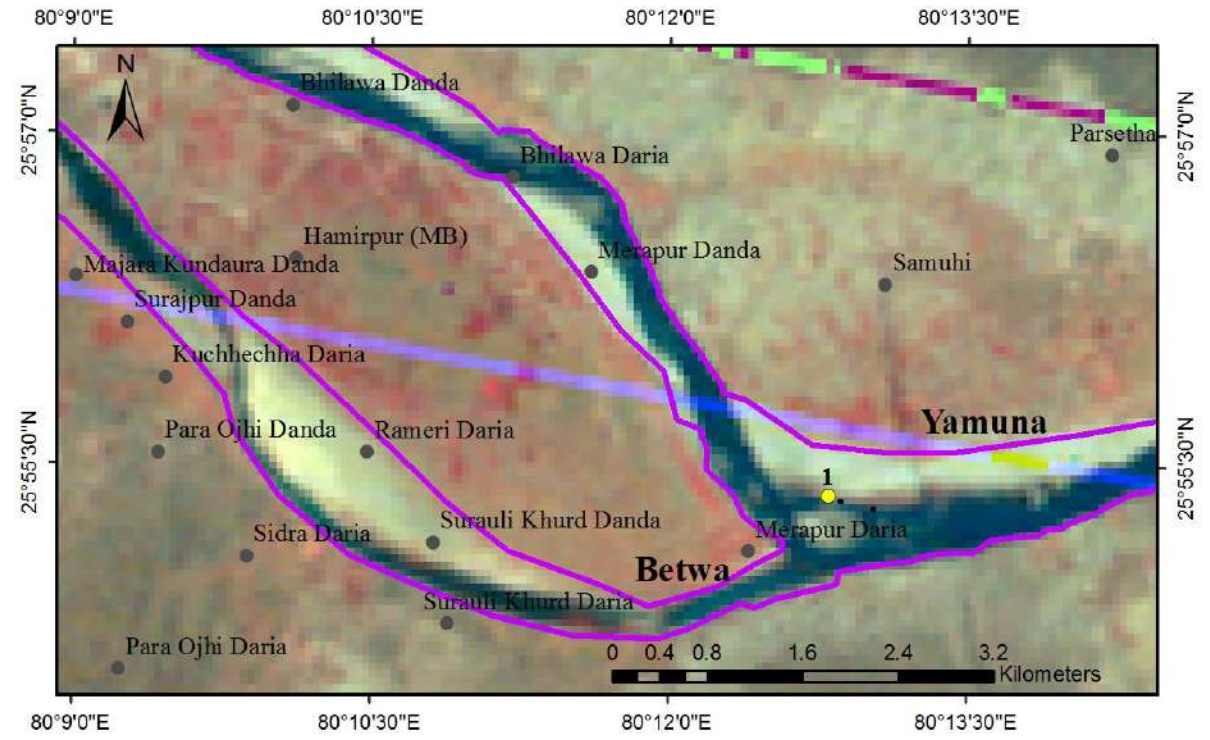


Figure 11-78: Confluence of Betwa-Yamuna in 1975

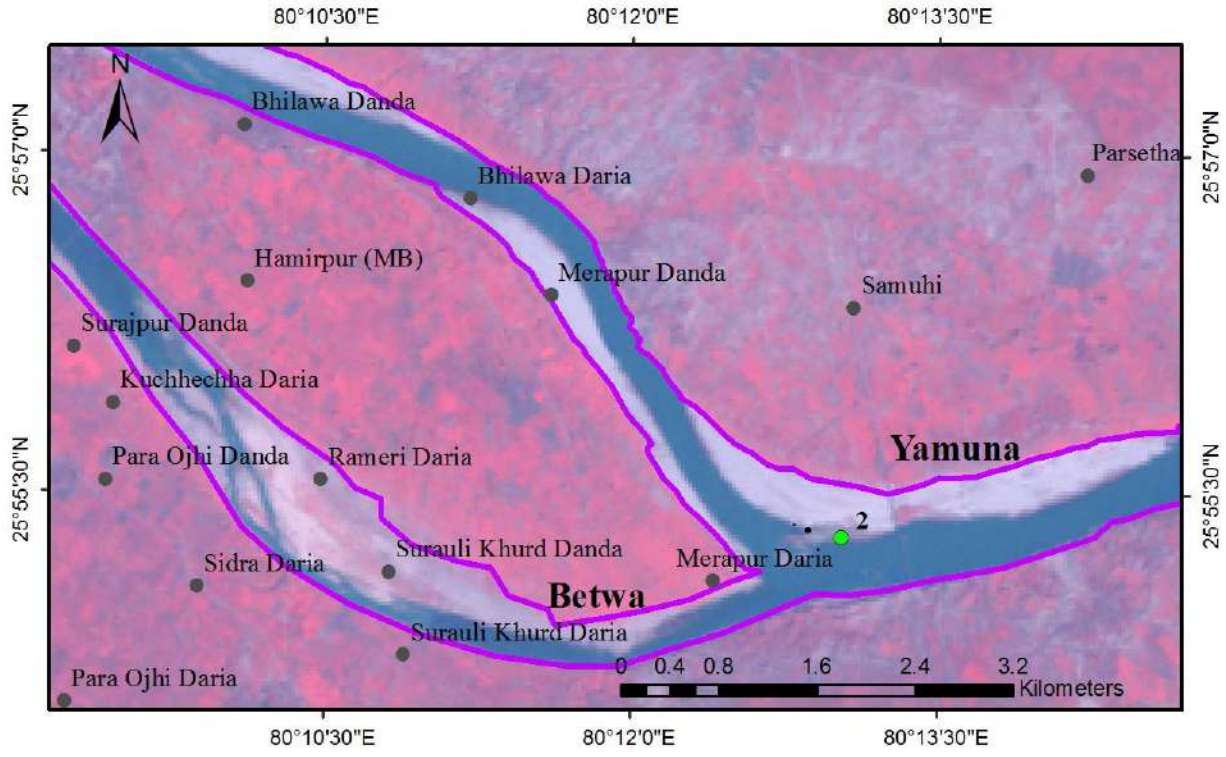


Figure 11-79: Confluence of Betwa-Yamuna in 1990

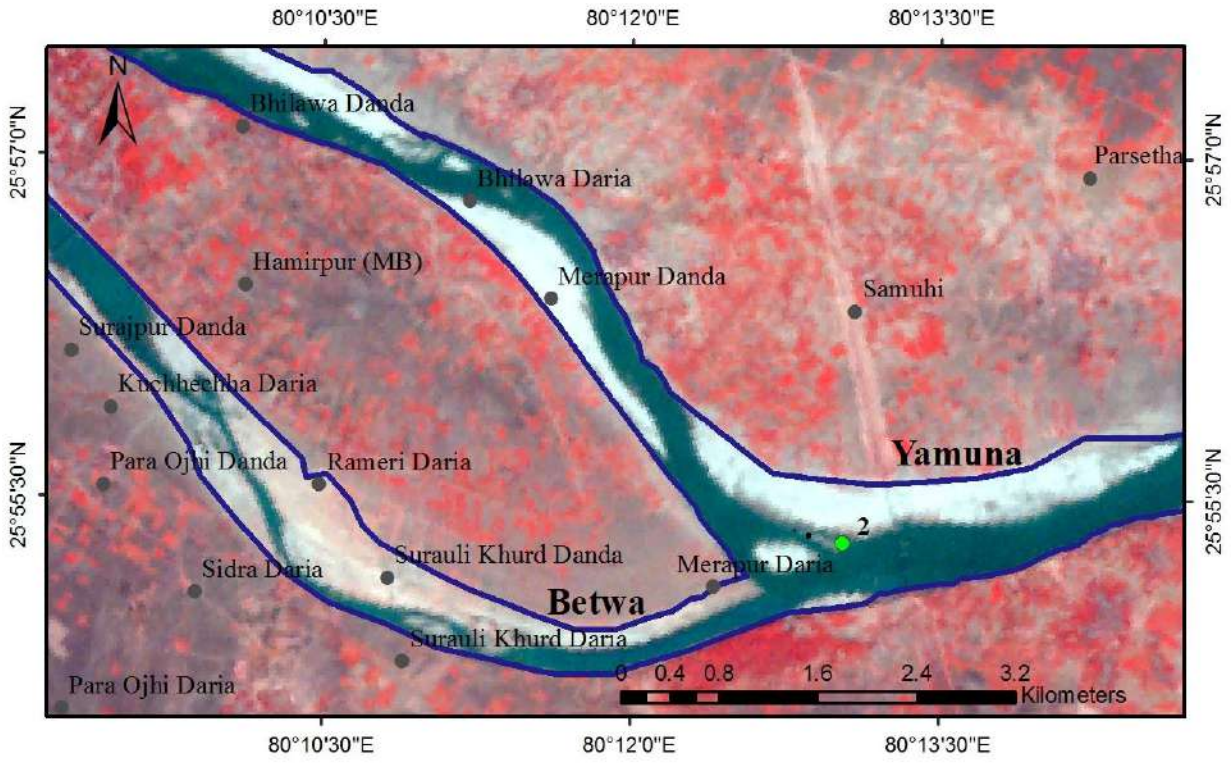


Figure 11-80: Confluence of Betwa-Yamuna in 2000

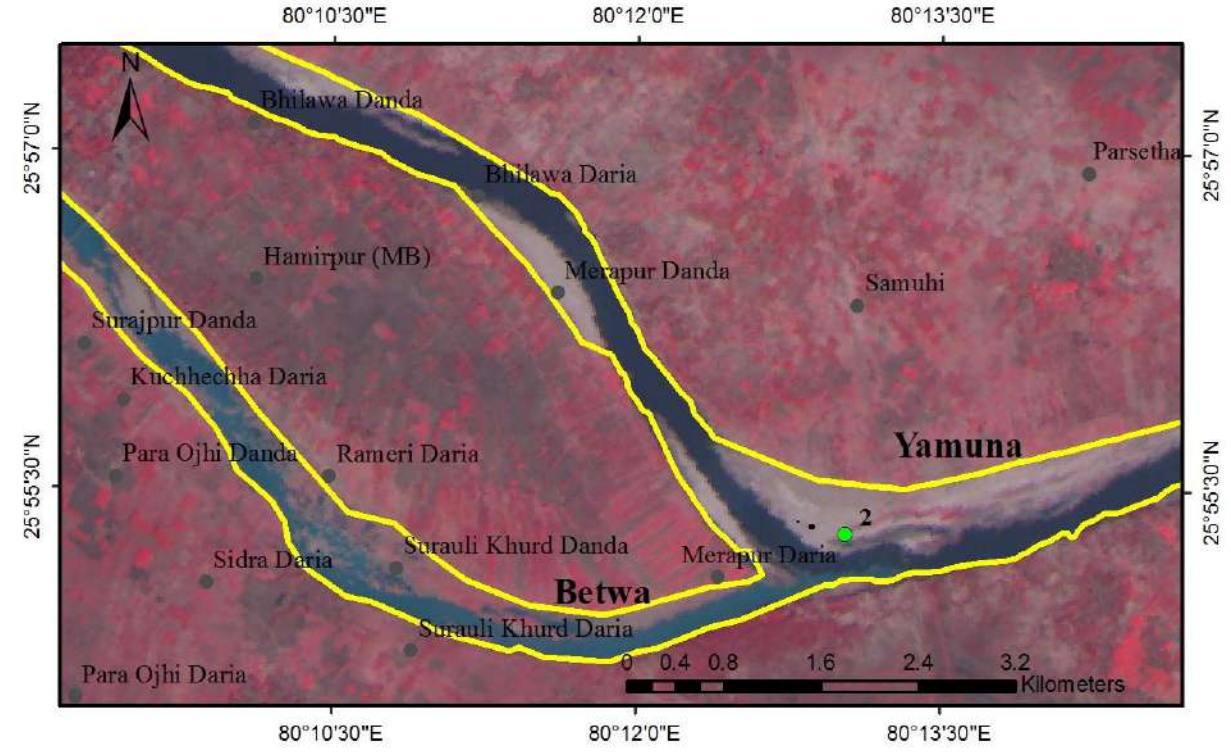


Figure 11-81: Confluence of Betwa-Yamuna in 2010

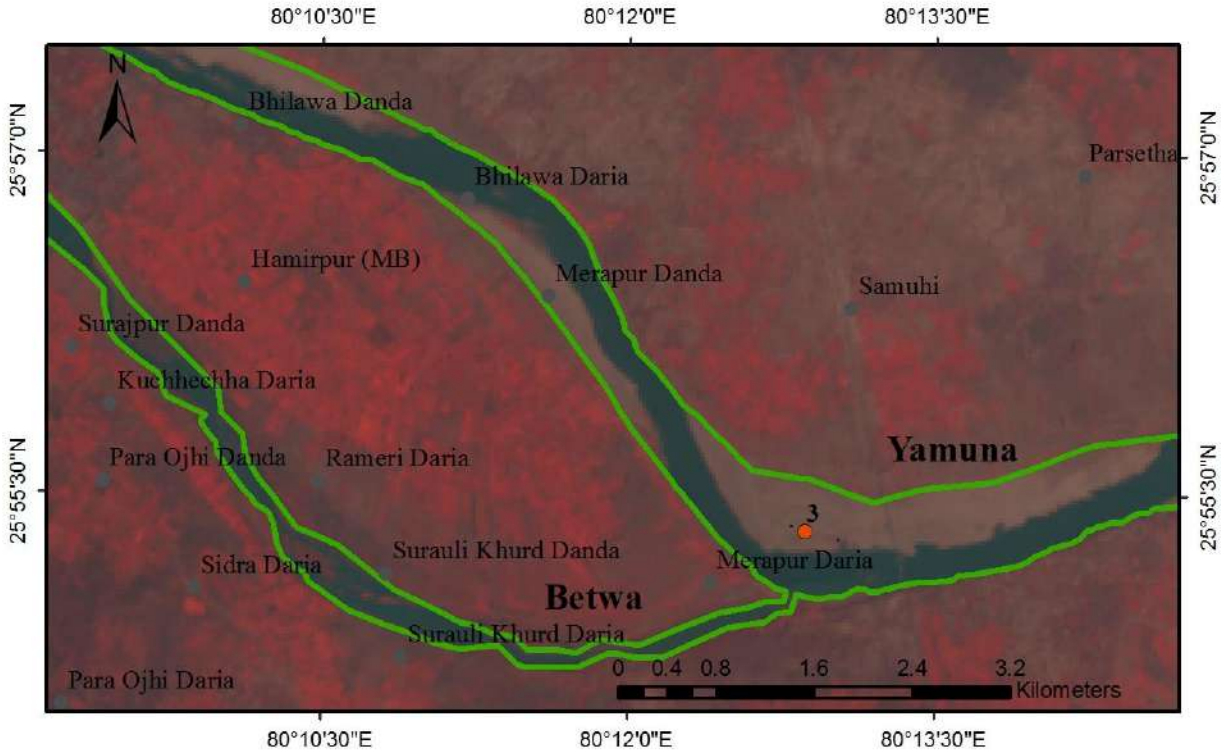


Figure 11-82: Confluence of Betwa-Yamuna in 2016

The average bed slope of 4.2 km longitudinal section of Yamuna channel, upstream of confluence is 14.29 * 10^{-4}, the average bed slope of 3 km longitudinal section of Betwa channel upstream of confluence is 6.67 * 10^{-4}. The bed slope at the downstream of confluence is 7.5 * 10^{-4} for a stretch of 4 km from confluence.

The sand bars at the confluence have migrated downwards over decadal timescale resulting in change in point of confluence. Though, the change in confluence point has been noticed, not much variations in the channel have been observed. It also indicates that change in confluence is limited and channel width changes are also within average channel width. The nature of evolution for this confluence will be considered as bar migration type.

Ken Confluence

River Ken joins River Yamuna at Chillaghat. The confluence observed in the year 1975 is represented by point 1 (80.529 E, 25.777 N). There is no significant change in confluence point over the span of 40 years. In the year 1975, 968m upstream of point 1, the Ken channel shows a change from 161m in the year 1975 to 236m in the year 1990. At 1.4 km downstream of point 1,

left bank of Yamuna has repositioned by 120m towards in south-east. Point of confluence shifts to point 2 (80.53 E, 25.777 N) by the year 2000. In the year 2000, at 1.2km upstream of confluence Ken channel sees a change in width from 231m in 1990 to 300m in 2000. The point of confluence shifts back to point 1 by the year 2010. In the year 2010, at 2 km downstream of confluence point 1, width increases from 547m to 642m between the year 2000 and 2010. A swing of the left bank of Ken by 91m towards its north-west during 2000 to 2010 is also noted. A major change in width is observed, at 1 km downstream of confluence where width increases from 733m in the year 2010 to 1.2km in the year 2016. Overall the channel and confluence is stable, not much changes have been observed. 2016 has its confluence point positioned at point3 (80.533 E, 25.779 N). The shift in confluence point from 2010 to 2016 is of 463m north-east of point1. The shift can be attributed to shift in Ken channel before the confluence in south-west direction from 2010 to 2016. The junction angle variation is 69˚ in 1975 &1990, 43˚ in 2000 & 2010, and 45˚ in 2016. From the observation of satellites images, only 1-2 sandbars were observed in the channels around the confluence which eroded by the year 2000.

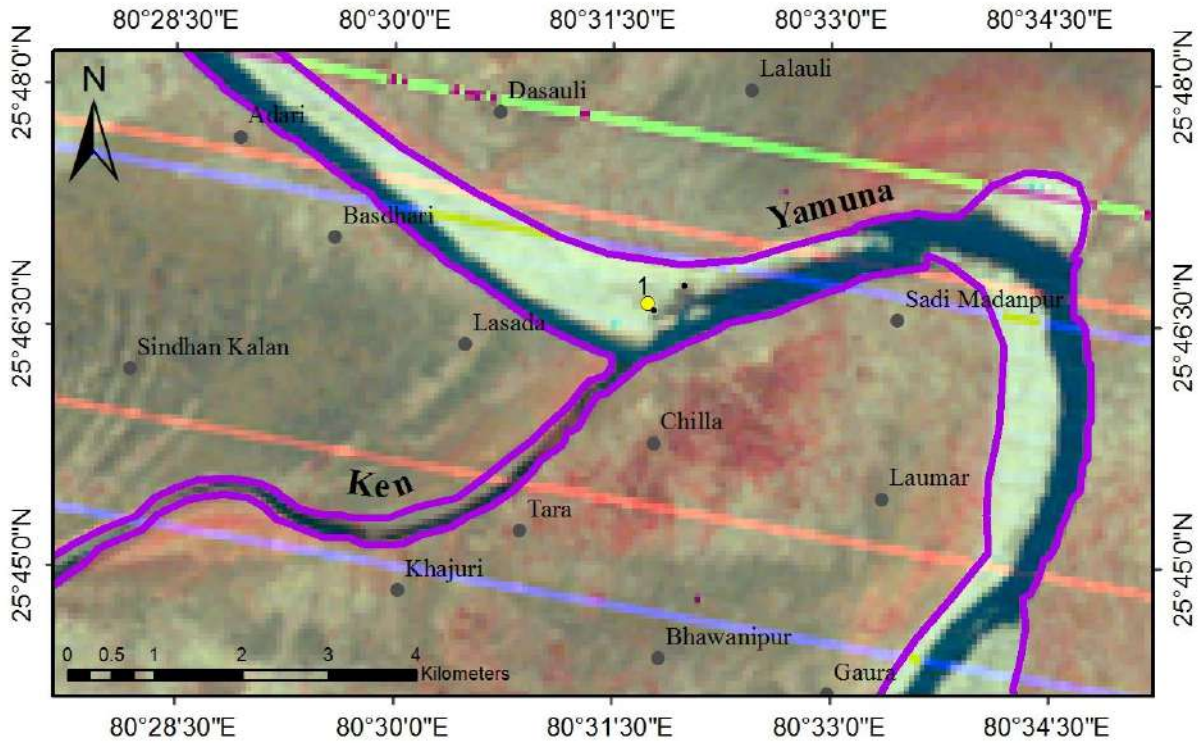


Figure 11-83: Confluence of Ken-Yamuna in 1975

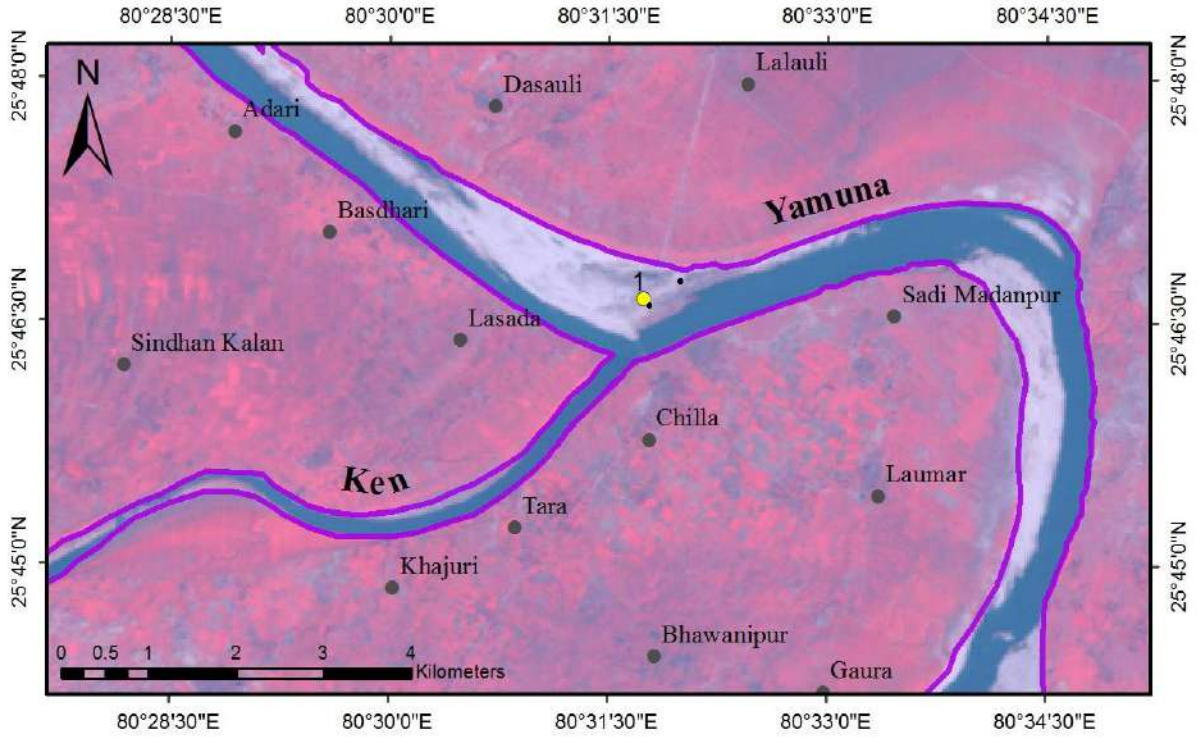


Figure 11-84: Confluence of Ken-Yamuna in 1990

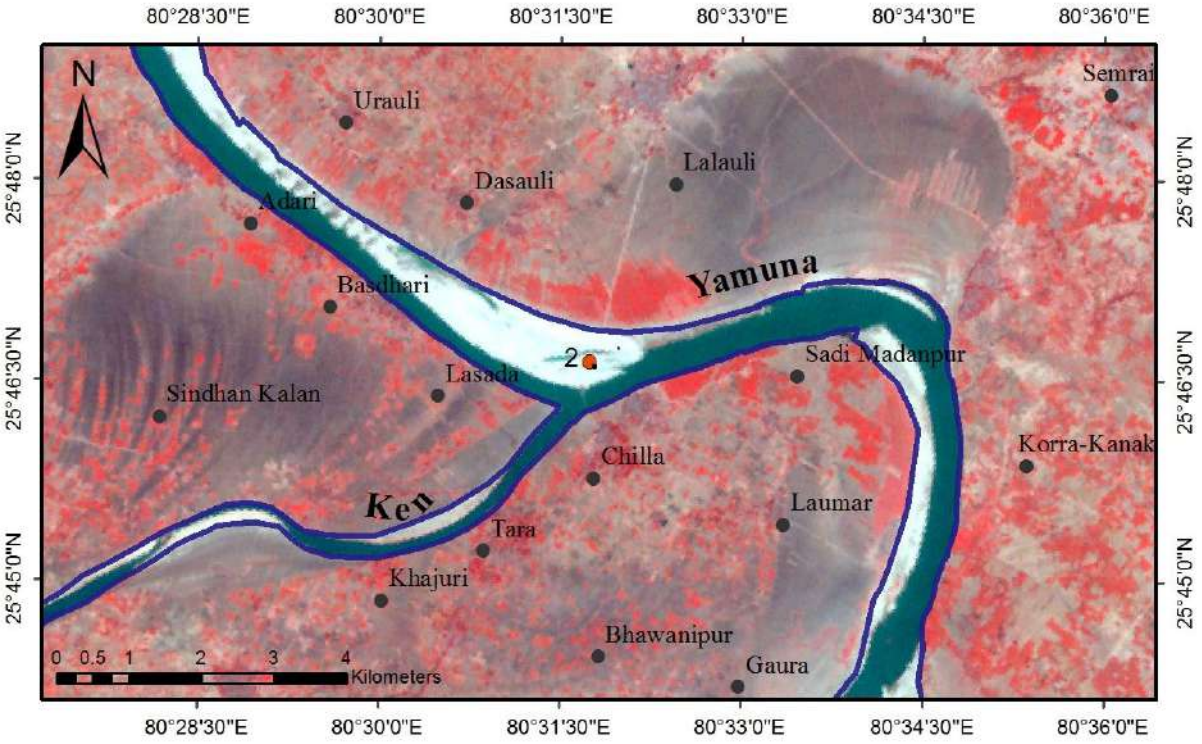


Figure 11-85: Confluence of Ken-Yamuna in 2000

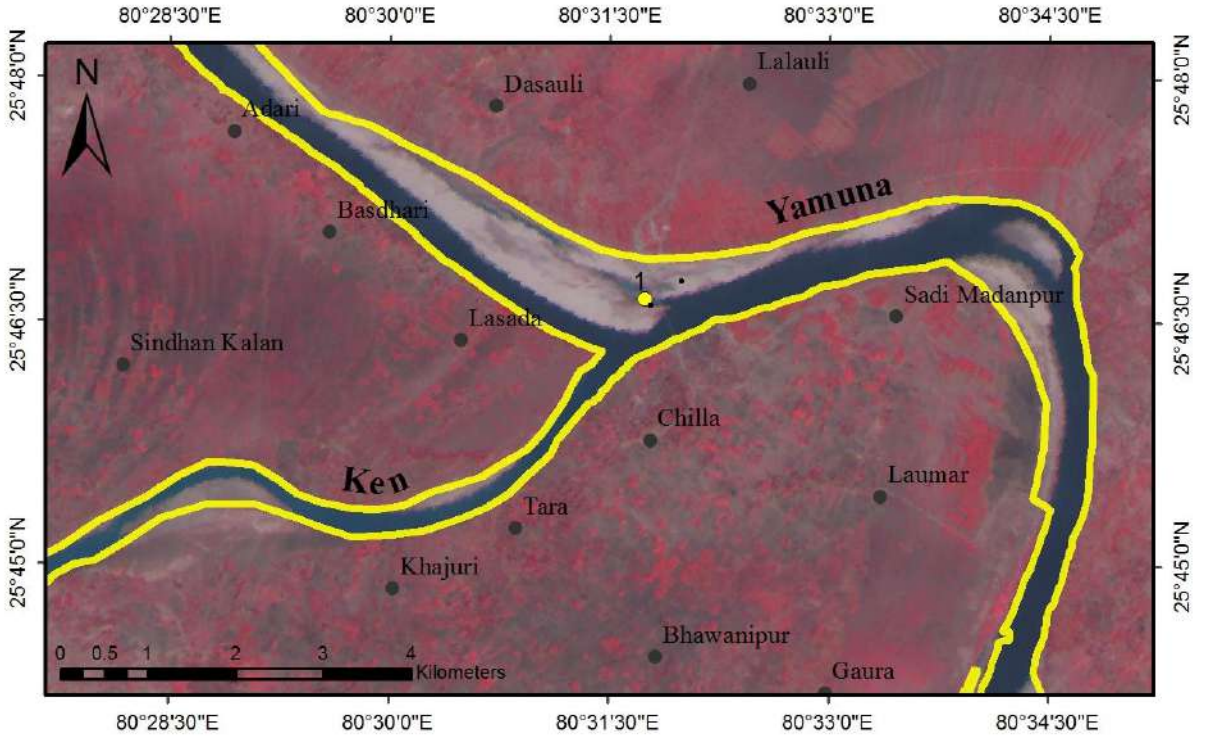


Figure 11-86: Confluence of Ken-Yamuna in 2010

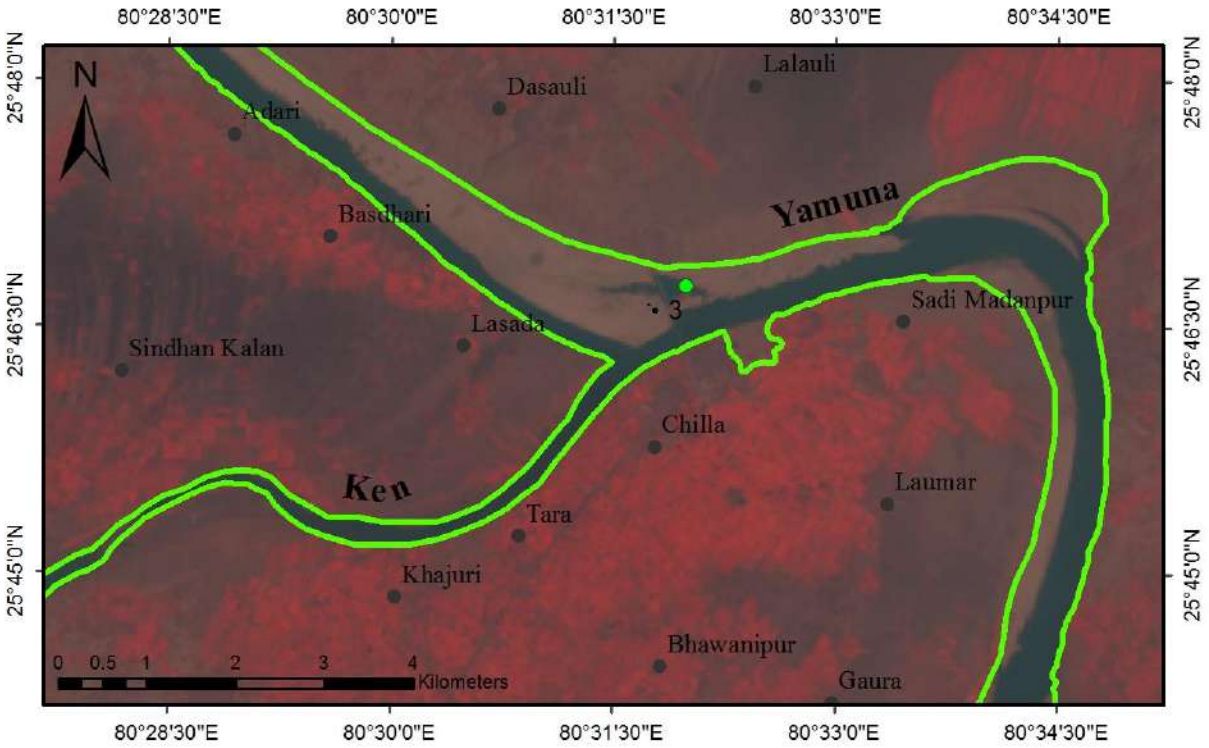


Figure 11-87: Confluence of Ken-Yamuna in 2016

The average bed slope of 3 km longitudinal section of Yamuna channel, upstream of confluence is 6.67 * 10^{-4}, the average bed slope of 3 km longitudinal section of Ken channel upstream of confluence is also 6.67 * 10^{-4}. This confluence constitutes of plain catchment area in both rivers upstream and downstream of confluence. From the analysis, it can be said that Ken-Yamuna confluence is stable and did not exhibit changes in channel characteristics. However, recent activities after the year 2010 around the banks, both upstream and downstream of confluence have triggered change in existing land use which may result in changes around confluence in near future.

Ganga-Yamuna Confluence

River Yamuna outfalls in River Ganga at Prayagraj. The point of confluence for the year 1975 is point 1 (81.892 E, 25.418 N) which shifts to point 2 (279m north-west of point 1) in the year 1990 & it further moves to point 3 (537m north-west of point 2) for the year 2000 and remain constant after that. Distances upstream and downstream of the confluence are measured from point 1 for all the years. At the mouth of confluence in Ganga channel the width of channel increases from 1.17km to 1.82km during 1975 to 1990. At 2.5 km upstream of confluence channel width in River Ganga is 925m for 1975 & 1.5 km in the year1990. The upstream of point1 in width of Yamuna for the year 1975 & 1990 was found to be 582m & 700m respectively whereas at 752m downstream of point1 the width increases slightly from 1.2km (1975) to 1.3km (1990). During 1990 to 2000, the significant changes in width of River Ganga are observed. At 1.5km upstream of confluence, the width of Ganga increases from 1.37km 1990 to 2.2 km during 1990 to 2000. In case of Yamuna, at 3km upstream of Yamuna the width changes from 730m to 827 m during 1990 to 2000. At 2.3km downstream of the confluence, width decreases from 1.3km in 1990 to 1.1km in 2000. Decade of 2000-2010 witness decrease in Ganga width upstream along with repositioning of the left bank of Ganga. The westwards movement begins 2.5km from point 1, at 3.8km upstream width of Ganga the at left bank shifts by 849m. At 3km upstream River Ganga width reduces from 2km in 2000 to 1.6km in the year 2010. At 3.6km upstream of Yamuna width changes from 799m in 2000 to 620m in the year 2010. At 1.56 km downstream of the confluence, width decreases from 1.36km in 2000 to 1.21km in 2010. Reduction in width & repositioning of Ganga channel are the important observations for 2010-2016 timespan. Swing displacement begins 2 km upstream of Ganga, where left bank moves westwards. The width also reduces significantly from 1.6km in

2010 to 784m in 2016 at 3.78 km upstream of point1. At 2.8km upstream of confluence, the width of Yamuna changes from 760.7m (2010) to 882.7m (2016).

The net westwards shift of Ganga channel from 1975 to 2016 is very significant. Based on the analysis of aerial imagery, it can be said that the migration of Ganga channel in 40 years is most likely result of land use changes in the neighbouring flood plains. It can be attributed to the excessive encroachment of the bank of River for anthropogenic activities. However, not much changes have been observed in Yamuna River system around the Yamuna-Ganga confluence. The junction angle is acute in all years 54˚ in 1975, 63˚ in 1990, 78˚ in 2000 & 2010, and 62˚ in 2016. From the overall analysis of Yamuna Ganga confluence, utilizing the data on channel characteristics, erosion and deposition patterns, rate and scale of swing displacement, it can be said that confluence is stable and changes in channel width in system under present study (Yamuna River) are within average channel width across the entire timespan.

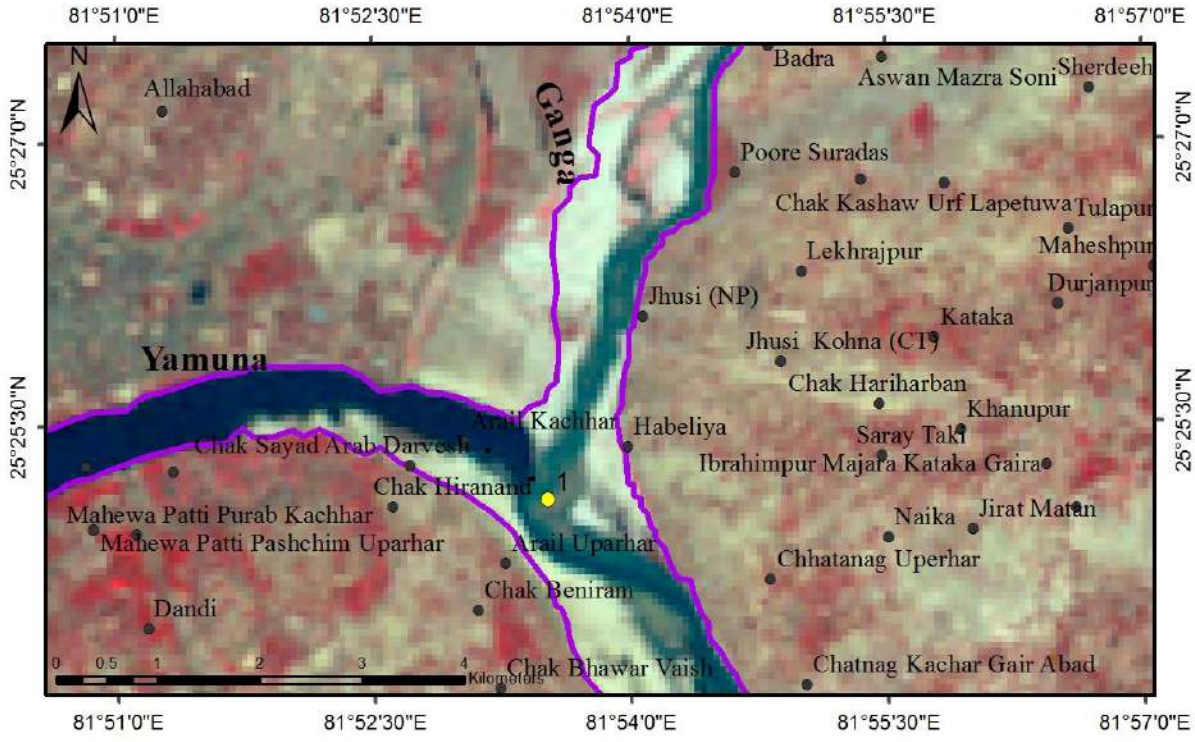


Figure 11-88: Confluence of Ganga-Yamuna in 1975

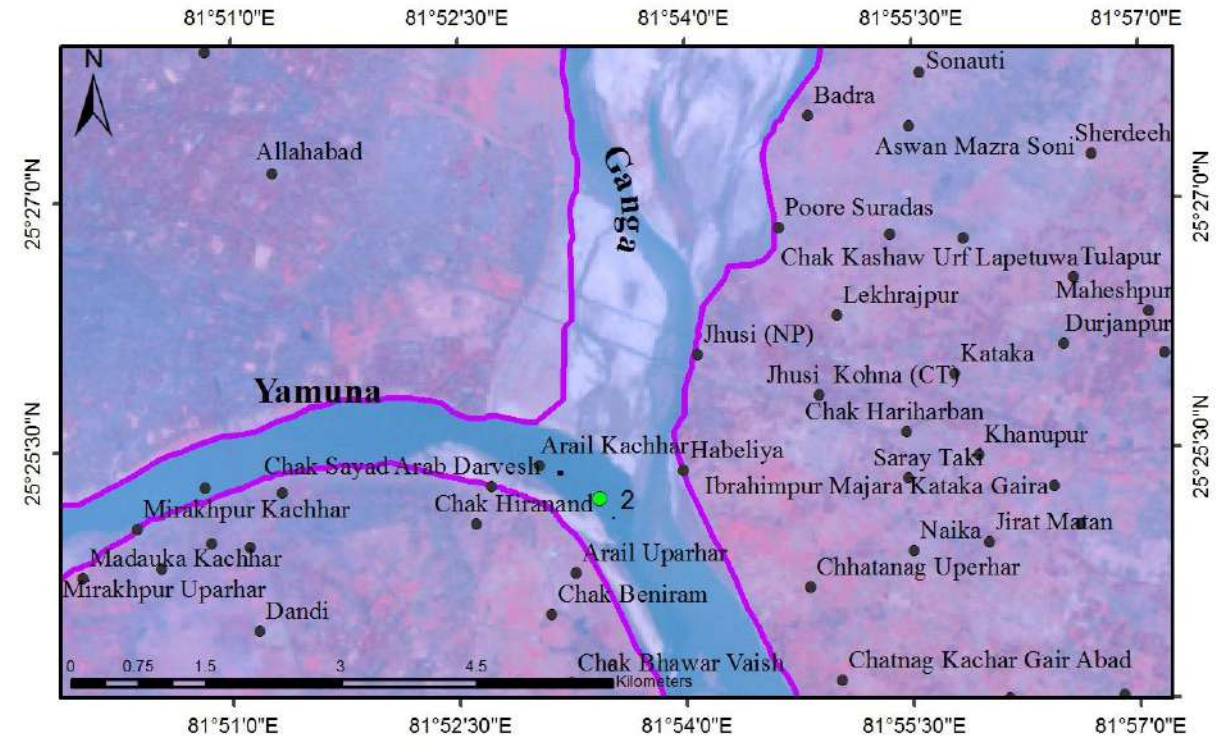


Figure 11-89: Confluence of Ganga-Yamuna in 1990

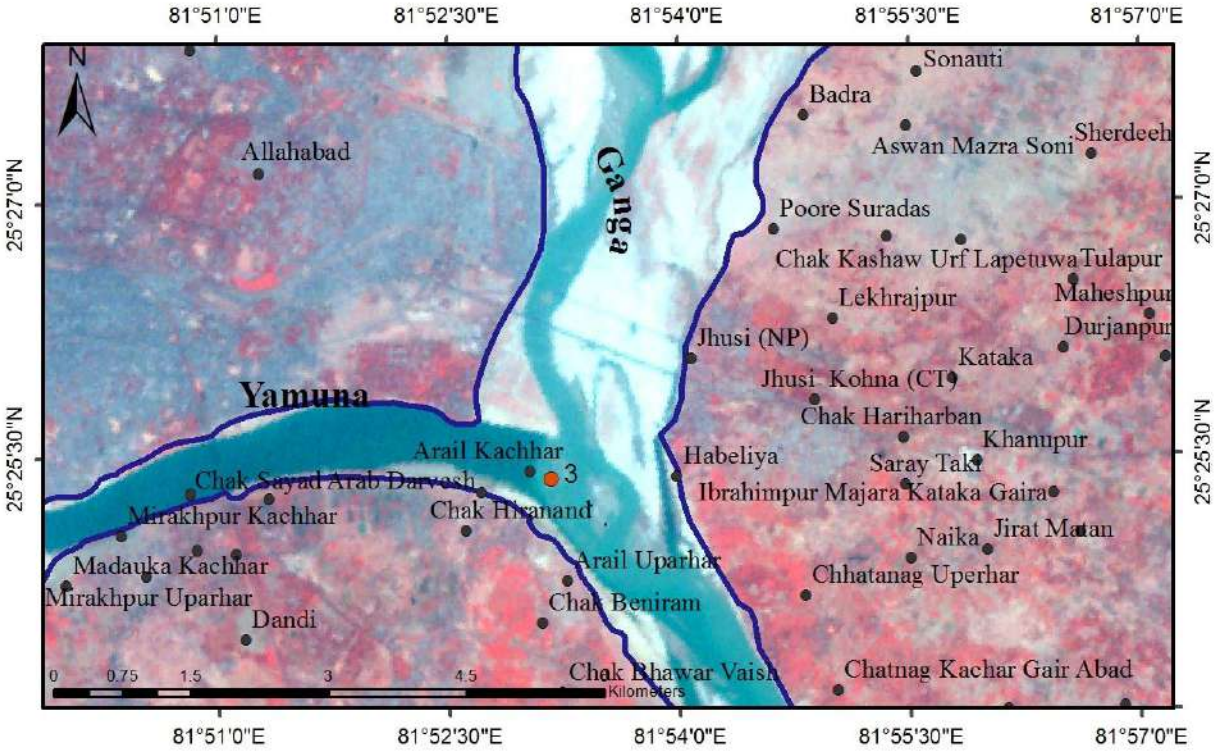


Figure 11-90: Confluence of Ganga-Yamuna in 2000

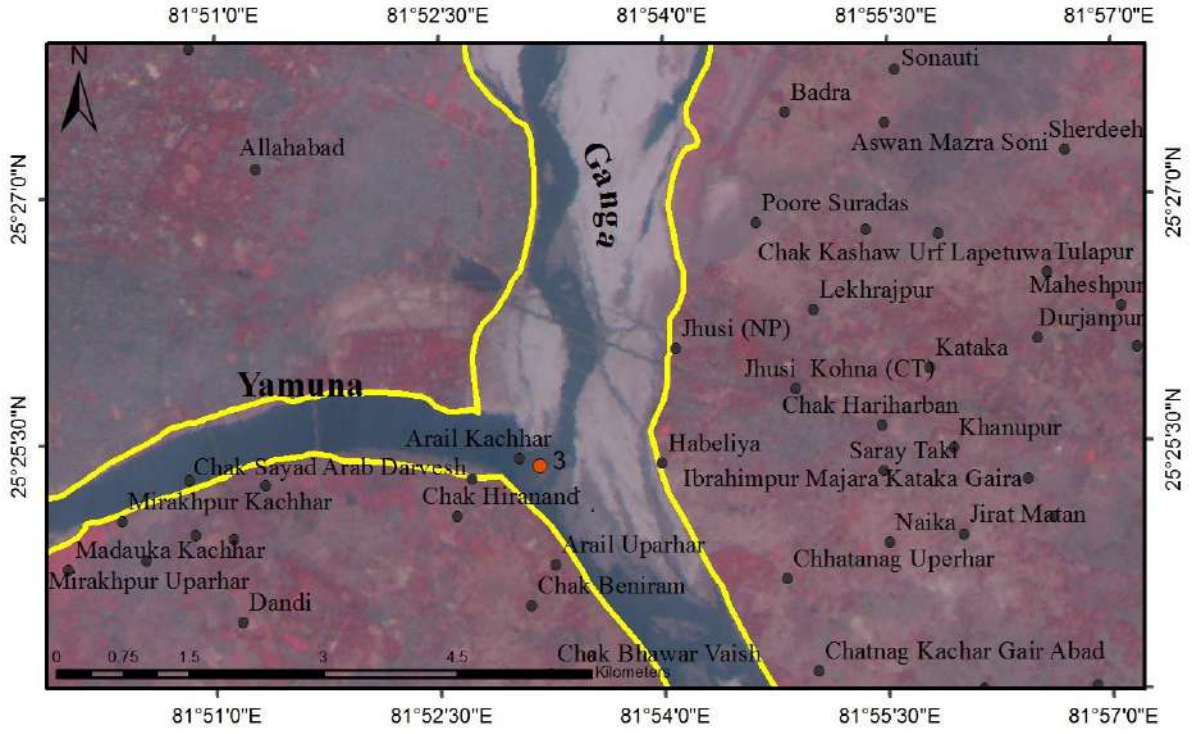


Figure 11-91: Confluence of Ganga-Yamuna in 2010

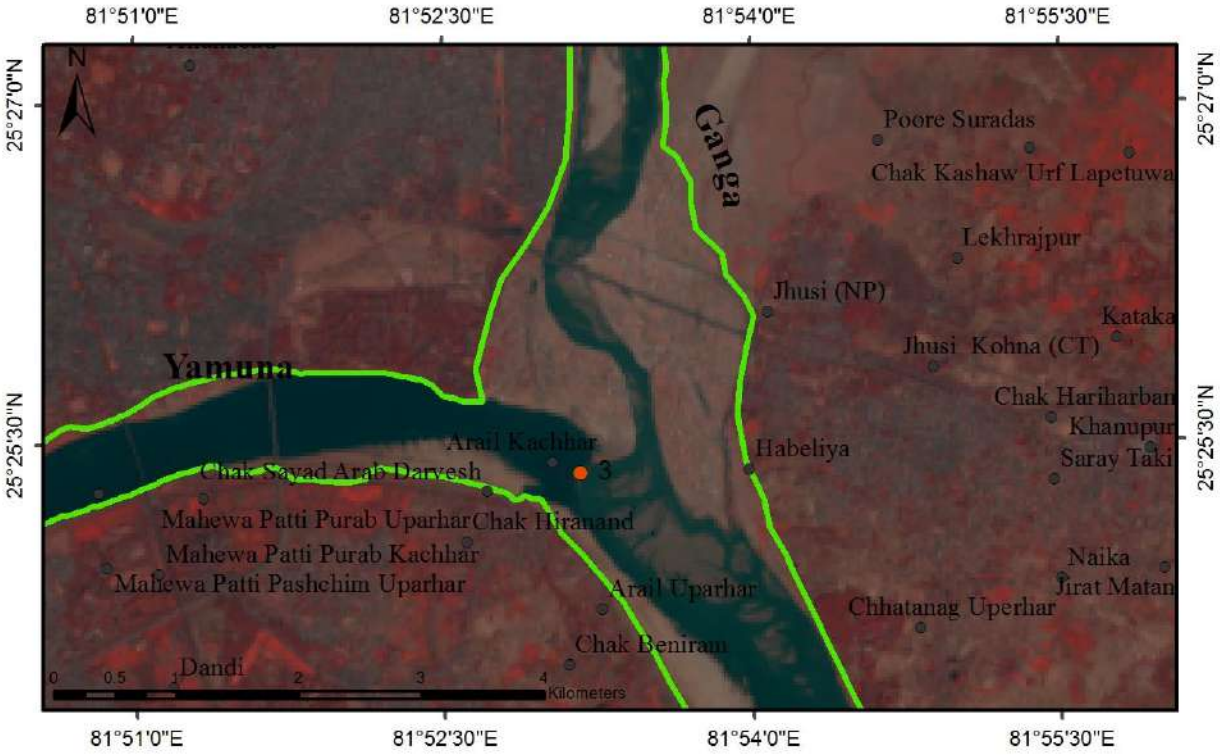


Figure 11-92: Confluence of Ganga-Yamuna in 2016

11.9 Improvements over existing Plan Form Index

Plan Form Index as defined earlier by Sharma (1995) has given consideration for number of braids in its formulation, however standalone value of index number is not good enough to capture the attributes of the same. In this regard, Parmar and Khosa, (2017), have discussed in detail some shortcomings in this approach and, further, the authors suggest the following alternatives as improvements to the existing PFI index.

1. T/B
2. (T/B)+N
3. {(T/B)/N}+N

The variables used in the proposed indices are the similar to PFI index defined by Sharma (1995) where T indicates total flow top width and B indicate entire channel width and N represents the number of braids. The first alternative presents the ratio flow top width (sum of top width from all active channels) to total channel width. Though it misses out on number of braids present in that cross section, it carries important information about proportion of channel which is active and carrying flows at that time. This information is useful in relating aquatic habitat preferences with the hydrodynamics and channel morphology, ecologic corridor planning, and environmental flow management.

Regarding the range of values of first index, if the ratio of T/B is equal to 1, it indicates fully wetted river width and braiding phenomenon is absent. If the value of T/B is less than 1 then further assessment is needed and computation of second index is necessary.

The second index (T/B)+N captures important attributes related to braiding. The index will generate the positive real number, integer part will define the number of braids while fractional part will indicate the ratio of flow top width to channel width. This index in much more comprehensive and should be utilized for finding out plan form index in the future.

The third index as proposed by Parmar and Khosa (2017) has the form {(T/B/N)+N} and is seen as an improved version of PFI index (Sharma, 1995) as it is capable of addressing equifinality present in existing version of PFI on account of multiple combinations of T/N for the same value of B. An example of the improved PFI indices is explained here,

Table 11-9 : Improved PFI indices (Parmar and Khosa, 2017, and comparison with PFI defined by Sharma (1995)

Cross section	T (meters)	B (meters)	N	T/B	Sharma PFI (T/B/N)	(T/B)+N	(T/B/N)+ N
section 1	57.15	2227.19	1	0.03	0.03	1.03	1.03
section 2	127.09	2242.82	2	0.06	0.03	2.06	2.03
section 3	171.01	2199.89	3	0.08	0.03	3.08	3.03
section 4	234.43	2036.80	4	0.12	0.03	4.12	4.03

Here, cross section at four different locations are considered. From the PFI estimation (T/B)/N as per Sharma (1995) for different number of braids, it is seen that the value of index is same and do not represent the ground reality whereas PFI indices proposed by Parmar and Khosa, 2017, indicate and capture the braiding pattern in much better way. For cross section 2, 3 and 4 number of braids are higher than 1 and does indicate the braiding phenomenon whereas cross section 1 has single braid carrying flows at that time. Improved version of PFI indices capture the number of braids whereas PFI index by Sharma categorizes all cross-sections in the same category. Though improvements in existing PFI index have been suggested, the caveat remains in all PFI indices on account of water level consideration. The flow top width and number of braids are the essence of PFI index and these attributes are extremely sensitive to water level which itself is highly dynamic attribute. Therefore, which water level should be selected is an important aspect while estimating the PFI value.

11.10 Alternative forms of Braiding Indices

The study has utilized the braiding index defined by Friend and Sinha (1993) for the present analysis. After a thorough analysis and understanding the significance of such index, Parmar and Khosa, 2017, have suggested the following indices which can be explored and utilize in the future studies as they capture the braiding phenomenon in much more detailed and also highlight other aspects such as junctions, nature of braiding etc. The variables used in defining the indices are as below,

Length of Reach: L_R (straight length of river along its course)

Number of Junctions over the given reach: N_J

Length of the Main (Principal Channel/Braid): L_{cmax}

Total length of all channels/braids over the given reach: L_{ctot}

Braiding Ratio: $R_B = L_{cmax} / L_{ctot}$ [Reciprocal of existing Braiding Index (Friend and Sinha, 1993)]

B_{AV}: Average bank to bank width of the river over the reach length, L_R.

The proposed indices have been categorised into four subcategories as tabulated below:

	INDICES						
FORMS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
INVERSE	**R_B / N_J**	**$(L_R/L_{ctot}) / N_J$**	**L_R / N_J**	**L_{cmax}/N_J**			
PROPORTIONATE	**N_J / R_B**	**$N_J /(L_R/L_{ctot})$**	**N_J / L_R**	**N_J / L_{cmax}**	**L_{ctot} / L_{cmax} (F-S Index)**	**L_{ctot} / L_R (Variant of F-S Index)**	**$N_J / (L_R*B_{AV})$**
NEUTRAL	**N_J / L_{ctot}**	**L_{ctot} / N_J**					
OTHERS	**$N_J*(L_{ctot}/ L_R)$**	**$N_J*(L_{ctot}/L_{cmax})$**					

For illustration purpose, indices computed for grid no. 239. 240 and 271 based on the satellite imagery of the year 1975 are shown in table below,

Table 11-10 : Modified Braiding Indices by Parmar and Khosa, 2017,

Sr No.	Grid Number	239	240	271
1	Lctot	24.96	47.83	42.65
2	Lcmax	24.96	45.12	37.50
3	LR	17.81	23.45	24.00
4	Braiding Ratio (RB)	1.00	0.94	0.88
5	Nj	3.00	13.00	11.00
6	R_B / N_J	0.33	0.07	0.08
7	(LR / Lctot) / NJ	0.24	0.04	0.05
8	L_R / N_J	5.94	1.80	2.18
9	L_{cmax} /N_J	8.32	3.47	3.41
10	N_J / R_B	3.00	13.78	12.51

Sr No.	Grid Number	239	240	271
11	N_J /(L_R / L_{ctot})	4.20	26.52	19.55
12	N_J / L_R	0.17	0.55	0.46
13	N_J / L_{cmax}	0.12	0.29	0.29
14	N_J / L_{ctot}	0.12	0.27	0.26
15	L_{ctot} / N_J	8.32	3.68	3.88
16	N_J *(L_{ctot} / L_R)	4.20	26.52	19.55
17	N_J *(L_{ctot} / L_{cmax})	3.00	13.78	12.51

It may be noted that these indices capture the presence of junctions, so innately typical to Braided reaches, which is one of the important attributes of braided river system. In general, high value of the number of junctions indicates a higher level of braiding severity and vice versa. When this information is used with other attributes it provides a significant range which can be used to define the overall braiding phenomenon over a defined reach length. As an illustrative example, values obtained by N_J /(L_R / L_{ctot}) for the grids, 239, 240 and 271 are 4.2. 26.52 and 19.55 respectively and these indicate the severity of braiding. It is a proportional measure, i.e. higher the value of ratio, high braiding and lower value indicate low braiding in the reach. Reference may be made to Parmar and Khosa, 2017, for more details regarding the analysis procedure to that is recommended to implement and explore use of the suggested indices.

11.11 Conclusions

From the analysis of various attributes of river morphology, following conclusions have been drawn,

1. Sinuosity index and radius of curvature do not show any significant trend. Average sinuosity for entire stretch of Yamuna River is 1.38 whereas radius of curvature varied from 0.25 to 39.32 km. However, scale of digitization, number of bends have significant role to play in the determination of radius of curvature. Therefore, sinuosity and radius of curvature presented in the present chapter are indicative of average values for the grid it belongs to. For the meandering grids, meander migration modelling study has been carried out separately and detailed in Chapter 14.
2. Braiding index and plan form index are computed on grid scale. It has been observed that braiding is significant in selected reaches, mainly on the downstream of Hathnikund Barrage. Formation and abandonment of ox-bow lakes have shown its bearing on braiding pattern. Changes associated with meander migration have been noticed at downstream of Etawah.
3. The braiding index (Friend and Sinha, 1993) and plan form index capture braiding pattern in two different forms. The first one captures it at reach scale whereas planform index captures it at cross section scale. Though, both represent braiding phenomenon, cross section-based index highly localised and also dependent on flow top width which is driven by flow depth and overall hydrodynamics of the channel which cannot be captured in proper manner using remote sensing data. On the other hand, braiding index suggested by friend and Sinha is driven by channel length and not directly linked with the parameters related to the depth of flow. Therefore, in the context of estimation of braiding phenomenon using remote sensing data, it is better to adopt braiding index by Friend and Sinha (1993) over PFI index suggested Sharma (1995).
4. River course dynamics of Yamuna River has been carried out using sections at 1 km interval and it has been seen that river has experienced changes in river course at few locations. Those locations are concentrated in the middle stretch of Yamuna River. River is found to be stable in Himalayan region and region after its confluence with Chambal (Figure 11-32).
5. From the analysis of confluence points, all confluence zones are stable and have not gone through significant change in last 40 years except Hindon-Yamuna confluence. Hindon-Yamuna confluence has experienced change between the year 1990 and the

year 2000, which is reflected in satellite image of the year 2000. Confluence has moved towards upstream and taken a shorter path.

6. Improved PFI indices and Braiding indices have been proposed by Parmar and Khosa (2017) and it is recommended that these latter alternative forms should be used in future assessments as it captures the number of braids and the ratio of flow top width to fully wetted river width and the overall braiding phenomenon.

Chapter 12 Erosion and Deposition

12.1 Channel Evolution analysis

Channel Evolution analysis delineate river channel geometry that includes channel dimensions, pattern and longitudinal profiles. Other aspects of channel evolution on a macro scale include identifying distinct river segments, i.e., channel in the upper reach, channel in flood plains, also aggradation and degradation zones, and bank erosion. Such a study needs to be carried out supported with field survey.

Some of the aspects derived from observed cross sections data have been discussed in Chapter 10, i.e., channel form and pattern. In the present chapter changes due to erosion and deposition estimated from satellite imageries on the decadal scale is presented.

12.2 Erosion and Deposition

Channel bank retreat [expressed in the form of area (km^2)] on account of erosion and deposition is computed from digitized features. The difference in channel area, sandbars and water bodies based on their tonal variations as observed in satellite images are considered for estimation of erosion and deposition. Accordingly, erosion deposition for the whole stretch of Yamuna has been carried out using a grid. The following map indicates the grid index. These grids represent the part covered by main channel of Yamuna, whereas other grids include different parts of Yamuna Basin but not the main Yamuna River.

12.3 Results and Analysis

Channel bank Retreat due to erosion and deposition for the time frames of 1975-1990, 1990-2000, 2000-2010 and 2010-2016 have been estimated on grid-scale and tabled in Table 12-1. Results represented in the table are displayed in the graphical format in the following maps. Each map indicates Grid wise channel bank retreat of erosion and deposition computed for the period mentioned on the map.

Table 12-1: Grid wise estimation of the channel bank retreat (km^2) expressed in terms of erosion and deposition

Grid Number	In Decimal Degree		River Length (km)	All units in square km																							
				1975-1990						1990-2000						2000-2010						2010-2016					
	Lat	Long		Erosion (-)	Deposition (+)	Sand bars 1975	Sand bars 1990	Change in sand bars	Net	Erosion (-)	Deposition (+)	Sand bars 1990	Sand bars 2000	Change in sand bars	Net	Erosion (-)	Deposition (+)	Sand bars 2000	Sand bars 2010	Change in sand bars	Net	Erosion (-)	Deposition (+)	Sand bars 2010	Sand bars 2016	Change in sand bars	Net
974	78.33	30.92	30.02	3.08	1.41	0	0.01	0.01	-1.66	0.99	1.03	0.01	0.01	0	0.05	1.42	1.69	0.01	0.08	0.06	0.34	1.13	2.34	0.08	0.06	-0.02	1.19
973	78.05	30.89	6.68	0.7	0.37	0	0	0	-0.33	0.19	0.36	0	0.03	0.03	0.19	0.27	0.54	0.03	0.12	0.1	0.37	0.36	0.29	0.12	0.06	-0.06	-0.14
941	78.1	30.68	30.07	4.31	0.59	0.2	0.05	-0.15	-3.86	0.88	0.68	0.05	0	-0.05	-0.24	0.77	1.5	0	0.14	0.14	0.88	1.21	0.89	0.14	0.02	-0.12	-0.44
909	78.14	30.47	2.31	0.25	0.09	0	0	0	-0.16	0.06	0.08	0	0	0	0.02	0.1	0.06	0	0	0	-0.04	0.05	0.06	0	0	0	0.01
908	77.87	30.44	25.56	5.08	5.18	1.98	4.89	2.91	3.01	3.97	1.14	4.89	0.72	-4.16	-6.99	1.9	3.2	0.72	2.39	1.67	2.97	1.3	2.22	2.39	3.04	0.65	1.57
907	77.59	30.4	25.55	4.64	4.11	2.57	7.19	4.63	4.1	7	2.66	7.19	0.75	-6.44	-10.79	2.97	2.26	0.75	3.3	2.55	1.83	0.85	8.5	3.3	3.15	-0.15	7.5
875	77.64	30.19	10.09	10.59	1.89	0	0.15	0.15	-8.55	1.86	1.22	0.15	0	-0.15	-0.79	0.76	2.39	0	0.03	0.03	1.67	0.41	4.43	0.03	0.9	0.86	4.88
874	77.37	30.16	26.42	51.46	6.52	2.48	6.91	4.43	40.51	10.74	4.69	6.91	0.29	-6.63	-12.68	5.24	5.76	0.29	1.64	1.35	1.87	3.23	5.63	1.64	8.45	6.81	9.21
842	77.42	29.95	6.42	0.89	2.42	0.32	0.56	0.24	1.77	6.11	1.68	0.56	0.07	-0.49	-4.92	0.83	2.58	0.07	0.38	0.31	2.07	3.61	1.2	0.38	0.61	0.22	-2.19
841	77.15	29.91	25.02	11.29	16.16	0.38	3.86	3.47	8.35	17.11	6.35	3.86	0.54	-3.31	-14.08	4.36	15.73	0.54	0.91	0.36	11.73	13.5	4.14	0.91	0.66	-0.24	-9.61
809	77.2	29.71	27.55	8.21	13.73	3.95	6.89	2.94	8.45	24.12	2.23	6.89	1.39	-5.5	-27.38	1.97	9.81	1.39	0.9	-0.49	7.35	8.52	3.46	0.9	1.49	0.59	-4.47
777	77.24	29.5	25.03	11.4	10.69	0.25	0.72	0.47	-0.24	9.21	5.97	0.72	4.66	3.94	0.7	7.94	6.02	4.66	1.85	-2.81	-4.74	5.69	3.86	1.85	0.64	-1.2	-3.03
744	77.02	29.25	25.32	16.94	8.07	4.7	0.94	-3.76	-12.64	12.34	9.07	0.94	6.47	5.53	2.26	5.61	6.91	6.47	0.45	-6.02	-4.72	6.08	5.16	0.45	0.22	-0.23	-1.15
712	77.07	29.04	25.01	9.44	6.41	2.49	1.22	-1.27	-4.31	11.61	4.37	1.22	2.4	1.18	-6.07	4.85	9.39	2.4	2.11	-0.29	4.26	8.72	4.99	2.11	1.84	-0.27	-3.99
680	77.12	28.84	25.09	18.08	11.67	0.5	2.13	1.63	-4.77	12.95	2.63	2.13	0.92	-1.21	-11.53	2.55	5.21	0.92	0.66	-0.26	2.39	2.22	4.84	0.66	0.36	-0.3	2.32
648	77.17	28.63	25.35	5.28	6.72	3.05	1.08	-1.97	-0.52	4.83	2.35	1.08	1.17	0.09	-2.39	1.64	4.51	1.17	1.15	-0.02	2.84	3.25	1.98	1.15	1.72	0.57	-0.7
617	77.49	28.46	25.13	10.91	15.08	0.02	0.91	0.89	5.06	12.12	6.04	0.91	0.75	-0.15	-6.24	3.04	8.04	0.75	0.66	-0.09	4.91	7.8	4.35	0.66	0.29	-0.37	-3.83
616	77.22	28.42	2.19	0.2	0.51	0	0	0	0.3	0.19	0.07	0	0.08	0.08	-0.04	0.33	0.05	0.08	0	-0.08	-0.36	0.25	0.08	0	0	0	-0.16
585	77.54	28.25	25.34	4.63	10.27	0.18	0.43	0.25	5.89	9.49	2.62	0.43	0.92	0.49	-6.38	2.64	4.17	0.92	2.3	1.38	2.91	2.98	2.13	2.3	1.68	-0.63	-1.48
553	77.59	28.04	25	6.04	12.52	0.05	0.86	0.81	7.29	12.2	5.91	0.86	1.55	0.69	-5.6	3.77	6.46	1.55	1.46	-0.08	2.61	6.67	2.31	1.46	0.17	-1.3	-5.65
521	77.63	27.83	26.92	4.36	13.66	0.29	3.92	3.63	12.92	14.48	4.65	3.92	1.42	-2.5	-12.33	3.13	18.78	1.42	1.25	-0.17	15.48	18.4	2.99	1.25	0.69	-0.56	-15.97
489	77.68	27.62	25.4	3.18	14.97	1.82	1.44	-0.38	11.42	14.41	4.16	1.44	0.56	-0.88	-11.13	2.36	13.68	0.56	0.68	0.12	11.44	14.81	1.82	0.68	1.04	0.36	-12.63
457	77.73	27.42	25.7	2.44	7.45	0.82	2.76	1.94	6.94	5.2	0.95	2.76	2.06	-0.7	-4.95	2.13	2.18	2.06	2.91	0.85	0.89	2.07	1.07	2.91	2.99	0.08	-0.92
427	78.3	27.28	3.73	0.74	1.08	0.05	0.58	0.54	0.88	1.56	0.17	0.58	0.68	0.09	-1.29	0.12	0.53	0.68	0.05	-0.63	-0.22	0.78	0.24	0.05	0	-0.05	-0.59
426	78.04	27.24	30.9	3.66	13.47	3.87	2.05	-1.82	7.99	16.94	1.34	2.05	2.3	0.25	-15.34	2.45	8.22	2.3	2.43	0.13	5.9	7.77	2.99	2.43	1.18	-1.25	-6.02
425	77.77	27.21	9.4	1.59	3.84	0.47	0.28	-0.19	2.06	4.25	0.31	0.28	0.3	0.02	-3.92	0.6	3.16	0.3	0.16	-0.14	2.42	2.48	0.58	0.16	0.1	-0.07	-1.97
395	78.35	27.07	32.56	3.99	5.96	1.79	1.37	-0.42	1.54	4.92	2.26	1.37	2.87	1.49	-1.16	1.92	4.19	2.87	2.32	-0.54	1.73	4.49	1.59	2.32	2.35	0.03	-2.87

Grid Number	In Decimal Degree		River Length (km)	All units in square km																							
				1975-1990						1990-2000						2000-2010						2010-2016					
	Lat	Long		Erosion (-)	Deposition (+)	Sand bars 1975	Sand bars 1990	Change in sand bars	Net	Erosion (-)	Deposition (+)	Sand bars 1990	Sand bars 2000	Change in sand bars	Net	Erosion (-)	Deposition (+)	Sand bars 2000	Sand bars 2010	Change in sand bars	Net	Erosion (-)	Deposition (+)	Sand bars 2010	Sand bars 2016	Change in sand bars	Net
365	78.92	26.93	7.72	0.38	0.29	0.08	0.11	0.02	-0.07	0.48	0.14	0.11	0.04	-0.07	-0.41	0.09	0.62	0.04	0.06	0.02	0.55	0.55	0.1	0.06	0.07	0.02	-0.43
364	78.66	26.9	29.56	3.32	3.85	0.1	0.43	0.33	0.86	2.83	1.37	0.43	0.32	-0.11	-1.57	2.35	2.65	0.32	0.42	0.09	0.39	3.03	2.85	0.42	0.18	-0.23	-0.42
363	78.39	26.86	3.07	0.13	0.19	0	0	0	0.06	0.16	0.06	0	0.06	0.06	-0.04	0.05	0.13	0.06	0	-0.06	0.02	0.22	0.05	0	0	0	-0.17
333	78.96	26.72	30.19	2.54	2.61	0.6	0.77	0.18	0.24	3.02	1.08	0.77	0.72	-0.06	-1.99	0.65	3.76	0.72	0.76	0.04	3.15	4.35	1.08	0.76	0.28	-0.48	-3.74
302	79.27	26.54	24.92	2.44	3.68	0.37	1.19	0.82	2.06	2.3	1.61	1.19	0.66	-0.53	-1.23	2.39	2.46	0.66	0.83	0.17	0.25	3.02	1.61	0.83	0.19	-0.64	-2.04
301	79	26.51	5.57	0.4	0.47	0	0.03	0.03	0.09	0.35	0.18	0.03	0	-0.03	-0.2	0.14	0.36	0	0.13	0.13	0.36	0.36	0.14	0.13	0.01	-0.12	-0.34
271	79.57	26.37	24	1.71	1.57	2.88	3.5	0.63	0.5	1.1	1.62	3.5	2.29	-1.22	-0.7	4.41	1.35	2.29	2.05	-0.24	-3.3	1.54	2.34	2.05	2.51	0.46	1.26
270	79.31	26.33	12.51	1.34	1.31	0.14	0.14	0	-0.03	1.32	0.53	0.14	0.54	0.4	-0.39	1.46	0.97	0.54	0.84	0.3	-0.19	0.79	1	0.84	0.08	-0.77	-0.56
240	79.87	26.19	23.45	2.78	1.46	2.17	2.1	-0.07	-1.39	1.66	2.26	2.1	0.83	-1.27	-0.67	3.82	1.13	0.83	1.99	1.16	-1.52	0.77	2.76	1.99	2.42	0.43	2.43
239	79.61	26.16	17.81	0.94	1.01	0.25	1.6	1.35	1.42	0.31	1.38	1.6	1.05	-0.55	0.52	1.86	0.27	1.05	1.02	-0.03	-1.62	1.25	0.73	1.02	1.37	0.35	-0.16
209	80.17	26.01	29.64	4.56	1.07	4.64	2.66	-1.98	-5.46	1.06	2.07	2.66	3.02	0.35	1.37	3.02	0.98	3.02	2.63	-0.38	-2.43	0.51	4.52	2.63	3.7	1.07	5.07
208	79.91	25.98	7.38	0.45	0.08	1.74	1.5	-0.24	-0.6	0.51	0.27	1.5	0.38	-1.12	-1.36	0.43	0.36	0.38	1.33	0.95	0.89	0.04	0.47	1.33	1.64	0.31	0.74
178	80.47	25.83	29.11	4.36	3.52	0.41	1.63	1.22	0.38	2.61	2.1	1.63	1.06	-0.57	-1.09	3.7	1.7	1.06	1.95	0.89	-1.1	2.62	10.61	1.95	0.73	-1.22	6.77
177	80.21	25.8	5.26	0.24	0.12	0	0	0	-0.12	0.08	0.67	0	0	0	0.59	1.41	0.06	0	0	0	-1.34	0.24	0.54	0	0.01	0.01	0.31
148	81.03	25.68	16.33	1.13	0.61	0.14	0.99	0.85	0.34	0.69	1.64	0.99	0.1	-0.89	0.05	2.96	0.56	0.1	0.17	0.07	-2.33	1.02	1.3	0.17	1.31	1.14	1.42
147	80.77	25.65	25.81	0.85	2.12	0.36	0.15	-0.2	1.06	0.95	0.8	0.15	0.3	0.15	-0.01	1.72	0.7	0.3	0.15	-0.16	-1.17	0.93	1.07	0.15	0.42	0.27	0.41
146	80.51	25.62	7.03	0.28	0.68	0.13	0	-0.13	0.27	0.4	0.19	0	0.02	0.02	-0.19	0.82	0.09	0.02	0.04	0.02	-0.71	0.5	0.13	0.04	0.22	0.18	-0.19
116	81.07	25.47	28.55	1.13	1.27	0.69	5.07	4.39	4.53	1.76	2.59	5.07	0.8	-4.27	-3.44	5.6	0.71	0.8	0.42	-0.38	-5.27	1.07	3.03	0.42	0.74	0.32	2.28
87	81.88	25.35	0	0.38	1.89	0.12	0.79	0.67	2.18	0.87	4.07	0.79	0.22	-0.57	2.63	6.02	0.29	0.22	0.77	0.55	-5.18	0.5	1.42	0.77	0.46	-0.31	0.61
86	81.62	25.32	25.52	0.28	2.22	1.04	4.99	3.95	5.88	1.14	0.53	4.99	5.79	0.8	0.19	1.78	0.9	5.79	5.8	0.02	-0.87	0.5	1.77	5.8	0.25	-5.55	-4.29
85	81.37	25.29	28.71	1.37	2.91	1.15	1.06	-0.09	1.44	1.45	1.56	1.06	0.77	-0.29	-0.17	6.35	0.57	0.77	0.05	-0.71	-6.49	0.73	7.53	0.05	1.31	1.26	8.07
84	81.11	25.26	4.08	0.03	0.21	0.52	0.85	0.33	0.51	0.1	0.06	0.85	0.16	-0.69	-0.73	0.3	0.09	0.16	0	-0.16	-0.37	0.05	0.27	0	0.03	0.03	0.25

12.4 Discussion on the results

The following points have been noted considering erosion and deposition based on changes in channel area estimated on a decadal scale. Grid wise analysis is presented here.

1. Grid no: 974, 973 and 941 which cover the chainage (based on reference line: created from 1975 river centreline) between 0 to 67 km, Yamunotri to Dehradun indicate an erosion in the 1975-1990 time period while for other periods, deposition has been noticed. Erosion of 5.85 sq.km and deposition of 2.2 sq.km have been estimated for the periods 1975-1990 and 1990-2016 respectively.
2. Grid no: 909, 908 and 907 which include chainage between 68 to 120 km, Dehradun to Poanta Sahib witnessed the cycle of erosion and deposition. In 1975-1990 there was a deposition of 6.95 sq.km followed by erosion of 17.75 sq.km from 1990 to 2000. After 2000 deposition 4.76 and 9.08 sq.km for the period of 2000-2010 and 2010-2016 respectively.
3. Grid no: 875,874, 842 and 841 which include chainage between 120 to 185 km, Poanta Sahib up to Gangoh Shows similar trend that of grid 909, 908 and 907. Channel deposition is dominant between 1975-1990 (deposition area 42.08 sq.km) followed by erosion from 1990 to 2000 (32.7 sq.km). For rest of the years' deposition at a slower rate is observed (1.2 sq.km per year).
4. Grid no: 809, 777 and 744, which cover chainage of 185 up to 265 km, Gangoh to Ganaur shows deposition across all time periods. Though the rate of erosion is not high (0.9 sq.km per year), the area has been exposed a lot to anthropogenic activities. As several town and villages are located on the bank of Yamuna River in this particular stretch, activities like agriculture temporary or permanent resulted in increased erosion over the years. Also, barrage and its operation have also influenced the downstream movement of water, and its sediment carrying capacity.
5. Grid no: 712, 680 and 648 which include chainage of 265to 340 km, from Ganaur to New Delhi, shows that channel has experienced erosion for the period 1975 up to 2000 at the rate of 1.17 sq.km per year whereas from 2000 to 2016 channel experienced deposition of 7.12 sq.km in total.
6. Grid no: 617,616 and 585 which include chainage from 340 to 390 km, Noida and surrounding Delhi NCR region, witnessed the cycle of erosion and deposition. During 1975-1990 channel has experienced deposition (11.25 sq.km) while for 1990-2000 its

erosion (12.66 sq.km). For other periods, 2000-2010 and 2010-2016, grids have experienced 7.46 sq.km deposition and 5.47 sq.km erosion respectively.

7. Grid no: 553,521 and 489 which include chainage from 390 km up to 470 km, from Hassanpur to Vrindavan, witnessed the cycle of erosion and deposition. During 1975-1990 channel has experienced deposition (31.63 sq.km) while for 1990-2000 its erosion (29.06 sq.km). For other time periods, 2000-2010 and 2010-2016, grids have experienced 29.53 sq.km depositions and 34.25 sq.km erosion respectively.
8. Grid no: 457, 425, 426 and 427 which include chainage from 470 km up to 540 km, from Mathura to Agra, also follow a similar trend. During 1975-1990 channel has experienced deposition (17.87 sq.km) while for 1990-2000 its erosion (25.05 sq.km). For other time periods, 2000-2010 and 2010-2016, grids have experienced 8.99 sq.km depositions and 9.5 sq.km erosion respectively.
9. Grid no: 395, 363, 364, and 365 which cover from 540 km up to 610 km, from Fatehabad to Jaswantnagar, experienced a little amount of erosion and deposition during different decades. While for 1975-1990 it experienced deposition (2.39 sq.km), for 1990-2000 its erosion (3.18 sq. km). Similar changes are observed for 2000-2010 and 2010-2016-time periods (2.69 and 3.89 respectively)
10. Grid no: 333,301 and 302 which include chainage from 610 km up to 675 km, from Etawah to Chakrapura, witnessed the cycle of erosion and deposition. Deposition and erosion for 1975-1990 and 1990-2000 are 2.39 and 3.42 sq.km respectively. For other decades, 2000-2010 and 2010-2016 channel experienced deposition and erosion of 3.76 and 6.12 sq.km respectively.
11. Grid no: channel in grid no: 270, 271, 239, and 240 which cover from 675 km up to 750 km, from Auraiya to kalpi did not exhibit many changes. During 1975-1990, deposition of 0.5 sq.km has been observed whereas for other years, i.e. for 1990-2000 and 2000-2010 erosion of 1.24 and 6.63 sq.km is noticed. In 2010-2016, again deposition of 2.97 sq.km had been observed.
12. Grid no: channel in grid no: 208, 209, 177, and 178 which cover from 750 km up to 825 km, from Hamirpur to Rithiya, shows that channel has experienced the erosion from 1975 till 2010 (10.27 sq.km), whereas for 2010 to 2016 deposition of 12.89 sq.km has been observed.
13. Channel in grid no: 146, 147, 148, and 116 which cover from 825 km up to 900 km, shows deposition of 6.2 sq.km during 1975-1990 followed by erosion of 3.59 and 9.48

hysteresis loop. In the present study, sediment rating curve at Mohna can be explained by presence of hysteresis, however, for other sites namely Mawi and Mathura exibits complex and unexplainable relationships, this might be on account of mixed population and there is also the other possibility of presence of noise in data on account of erred recordings.

12.7 Conclusions

Following conclusions have been drawn from erosion and deposition analysis

1. During 1975-1990, the amount of area exposed to channel bank retreat on account of erosion and deposition is almost equal (the difference between area eroded and deposited is 21 sq.km). During 1990-2000 significant variation is noticed as the areal extent of erosion is found to be 171.5 sq.km higher than deposition. In 2000-2010 and 2010-2016 time periods not many variations are observed in erosion and deposition. While 2000-2010 indicates overall deposition of 48 sq.km, the 2010-2016 period suggests an erosion of 32 sq.km of the area.
2. Erosion and deposition are not significant in the grids which are in the upper part of the Yamuna River in Himalayan valley. Middle reach of the Yamuna which flows in Gangetic plains has witnessed significant alterations in channel morphology on account of sediment transport processes. Effects of flow abstractions on alternations in river morphology are noticed in the form of disconnected active water areas and higher deposition in respective fragments.
3. No specific trend or pattern has been noticed in erosion and deposition processes in the Yamuna River.
4. Aggradation and degradation patterns analysed from observed cross-sections are in line with satellite-based captured erosion deposition maps.
5. Suspended sediment load (SSL) varies spatially across Yamuna River. Delhi recorded the maximum value of SSL in 1995. The year 1999-2000 can be considered as a breaking point after which SSL for all available stations reduced drastically.

Chapter 13 Major Structures and Their Impact on River Morphology

13.1 Identification of Structures

Various Structures built across the mainstream of Yamuna have been identified using satellite imageries and reported in subsequent sections. Some of the other pertinent details such as length of bridge and average width of river are obtained from secondary data (such as satellite images, high-resolution dataset on Google earth). They have been presented in tabular form in the following sections.

13.1.1 Road Bridges on Yamuna River

Road crossings on rivers, either permanent or temporary in nature, for national and state highways, expressways, district roads, trekking paths near mountain ranges have been captured using remote sensing observations. Associated river width and length of bridge are mentioned in the table below (from outfall to origin of the river).

Table 13-1 : Road Bridges across Yamuna River

S.No.	Name of Bridge	Length of Bridge (m)	Average Width of the River (m)
1	Naini Bridge	784	668
2	Lakhanpur to Baswar, Naini	1291	418
3	Road (SH 94) Near Mahewaghat	981	430.27
4	Bridge Near Augasi (under construction)	880	424.2
5	Road (SH 13) Near Bhendi ghat-Jauharpur	863	666
6	Road (NH 232) near Chilla ghat	1085	875.69
7	Bridge near Nanda Ka Pura	508	407.18
8	Galauli Road (Bandra Kanpur Bypass) near Kaptiha Khurda	163	162
9	Sagar road bridge near Manjhoopur Danda	696	320.86
10	Bridge near Musanagar Khachhar	757	334
11	Bridge near Daorahat Bangar	275	214
12	Kanpur Zansi Hiway (NH 27) near Kalpi	788	282.35
13	Gursahiganj Jalaun Road (SH 21) near Kasba Khanpur	888	340.75
14	Bridge near Dhakra	665	363.34
15	NH 92-SH 19 near Awari	598	353.69
16	Pinahat road bridge	210	201
17	Mumbai-Agra highway bridge near NH3	868	273.63

S.No.	Name of Bridge	Length of Bridge (m)	Average Width of the River (m)
18	Southern Bypass (Kanpur- Gwalior Bypass) (719)	455	94.37
19	Kauchora Bridge (SH 62)	425	69.34
20	Bridge near Bauth	429	144
21	Road (MDR 77W) narajgi ghat	423	76.1
22	Road (Rajaura- Sudar Pada)	431	105.94
23	Luheri Fatehabad (Agra Luckhnow expressway)	532	163.75
24	Fatehabad road	426	194.43
25	bridge connecting Indon-Chandvar	459	224
26	bridge connecting Indon-Chandvar	418	98.61
27	Taj Express Highway, Inner Ring Road, Agra	462	109.33
28	Ambedkar Bridge, Agra	465	137.48
29	Yamuna Bridge, (NH19) Agra Mathura Road	534	197.77
30	Road near Kailash Mandir, Bainpur Mustkil	222	97.05
31	bridge near Kanjaulighat Khadar road	366	105.09
32	Bridge near Nera Bangar	458	99.25
33	Tatrauta Khadar- Churmura road bridge	364	97.42
34	Gokul Barrage bridge, Gokul Dham	458	444.34
35	Yamuna Bridge (SH 33), Hathras Mathura Road, Sadar Bazar, Mathura	331	238.6
36	Yamuna Expressway Link Road, Vrindavan	522	298.6
37	Chatta Shergarh road bridge	581	238.6
38	Mohna Baghpur Road bridge	350	231.63
39	Amrapali marg, near Okhla Barrage	591	578
40	Delhi Noida Direct Flyway	561	209.91
41	Nizamuddhin road bridge	552	206.03
42	Eastern Peripheral Expressway, Faridabad	984	241.7
43	Palwal-Aligarh road SH22A	781	182.34
44	Vikas marg	612	446.6
45	Raja Ram Kohli Marg	564	148.8
46	old Yamuna bridge	825	176
47	Yudhishter Setu, GT Karnal Marg, North Delhi	623	113.72
48	signature bridge	2300	199
49	Wazirabad road bridge	497	160.11
50	Road (NH 334B), Mirakpur, Haryana	581	33.14
51	Yamuna Bridge Road, Mawi, (NH709AD)	213	67.37
52	Meerut Karnal Road bridge	606	98.17
53	bridge Naurangpur (SH6), near Kalanaur	461	120.69
54	Hathni Kund barrage	393	362.72
55	Kulhal bridgePaonta sahib	581	73.6
56	Dakpatthar Road at Dakpatthar Barrage	567	555
57	Kalsi bridge	403	40.76
58	Rajbala road	68.5	36.38

S.No.	Name of Bridge	Length of Bridge (m)	Average Width of the River (m)
59	Yamuna Bridge, Chakrata Road, Herbertput Poanta Saheb Road	282	26.88
60	Dhakimay Chak bridge	373	278
61	Yamua Bridge, Mussoorie, Bhendiyana	97.7	26.67
62	Naugaon Purola Marg, Naugaon	51	23.4
63	Yamuna Bridge, Barkot Yamunotri Road, Fooldhar	56.8	23.84
64	Yamuna Bridge, near Janaki Chatti, Yamnotri	90.8	16.14
65	Yamuna Bridge, Syana Chatti (NH94) Barkot Yamunotri Road	52.8	29.9
66	Barkot Yamunotri Road, Jamuna Chatti (NH94) Uttarkashi	59.7	10.5
67	Trecking Path to Yanotri, connecting bridge to Khasarali, Yamnotri Range	18.5	8.09

13.1.2 Railway Bridges on Yamuna River

Railway bridges constructed across the Yamuna River are as listed below,

Table 13-2 : Railway Bridges across Yamuna River

S.No.	Name of Bridge	Length of Bridge (m)	Average Width of the River (m)
1	Old Naini Railway Bridge, Prayagraj	1068	592.48
2	Yamuna south bank railway bridge at Hamirpur	1004	465.08
3	Railway Bridge Kalpi	811	373.51
4	Railway Bridge Kamet	649	108.33
5	Railway bridge near Banda junction	487	64.22
6	Railway Bridge Agra	495	140.6
7	Yamuna bridge near Agra fort railway station	697	80.54
8	Chambal bridge	875	247
9	Yamuna Railway bridge at Mathura Cant	349	221.41
10	Delhi Metro bridge near parallel to Amrapali Marg (nearest metro station Botanical Garden)	1377	561
11	Old Yamuna bridge Delhi	518	173
12	Delhi Metro Bridge (Kashmiri gate to Shastri Park)	2012	152
13	Delhi Metro Bridge near Gas Turbine Power station (Indraprastha to Yamuna Bank metro line)	1823	398
14	Kalanour railway bridge	457	146

13.2 Impact of Barrages

13.2.1.1 Dakpathar Barrage

To study the impact of the Dakpathar barrage on river morphology, the decadal satellite images and geospatial datasets have been examined. Figure 13-1 shows a major courses of Yamuna river for years 1975, 1990, 2000 and 2010 imposed on the satellite image of the year 2016.

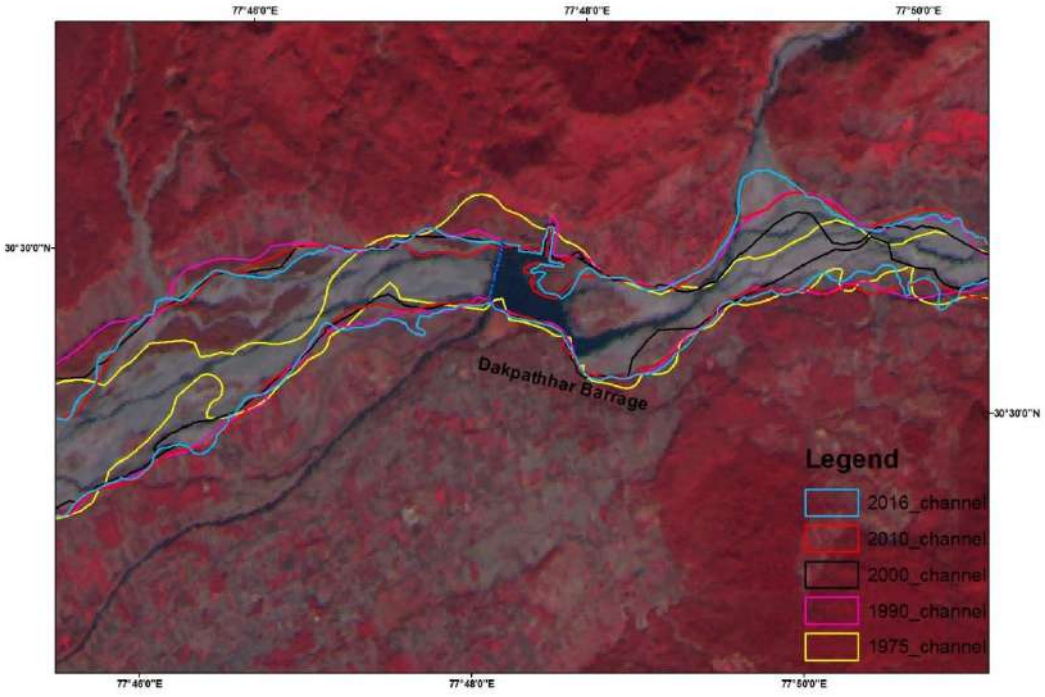


Figure 13-1: Courses of River Yamuna near Dakpathar Barrage

The Dakpathar Barrage is a concrete barrage across the Yamuna River adjacent to Dakpathar town in Uttarakhand, India. As part of run-of-the-river scheme, the barrage serves to divert water into the East Yamuna Canal for hydroelectric power production at the Dhakrani and Dhalipur Power Plants. The barrage is controlled by 25 floodgates and has a length of 516.5 m. The entrance to the canal is directly behind the barrage on its left bank. After travelling 10 km (6 mi), water reaches the Dhakrani Power Plant for power production. The 33.75 MW power plant contains three 11.25 MW Kaplan turbine-generators and has a design hydraulic head of 19.8 m. About 4 km after Dhakrani the canal reaches the 51 MW Dhalipur Power Plant. Both power plants were commissioned in 1965 and have a design discharge of 199 m^3/s. Water discharged from the Dhalipur Power Plant continues along the canal until it reaches the reservoir of the Asan Barrage. The satellite images of different years as shown below (Figures 13-2 to 13-6) are used to understand river course near barrage on a decadal scale.

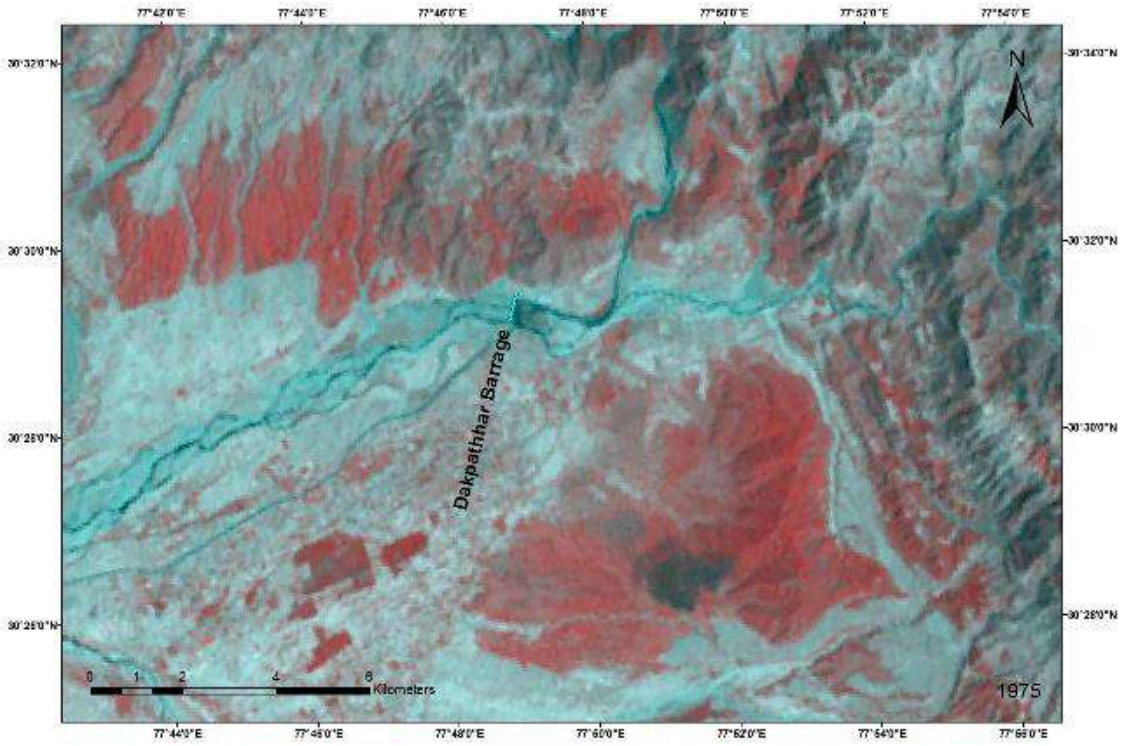


Figure 13-2: Course of River Yamuna near Dakpathar Barrage in 1975

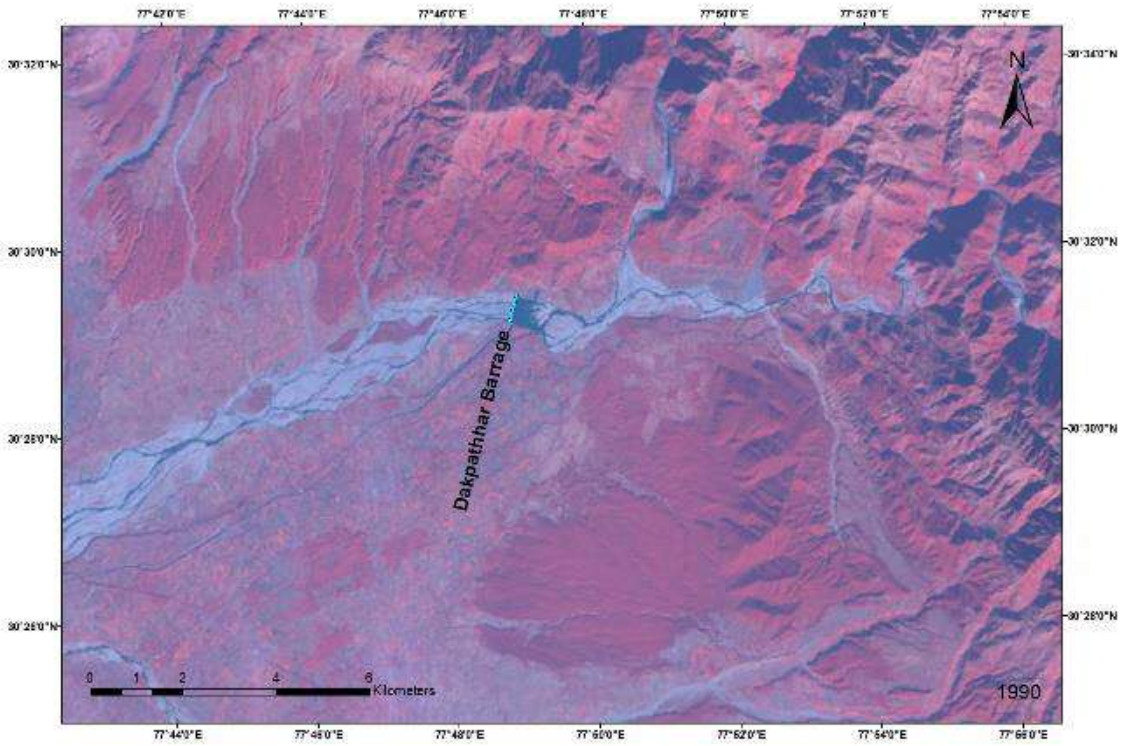


Figure 13-3 : Course of River Yamuna near Dakpathar Barrage in 1990

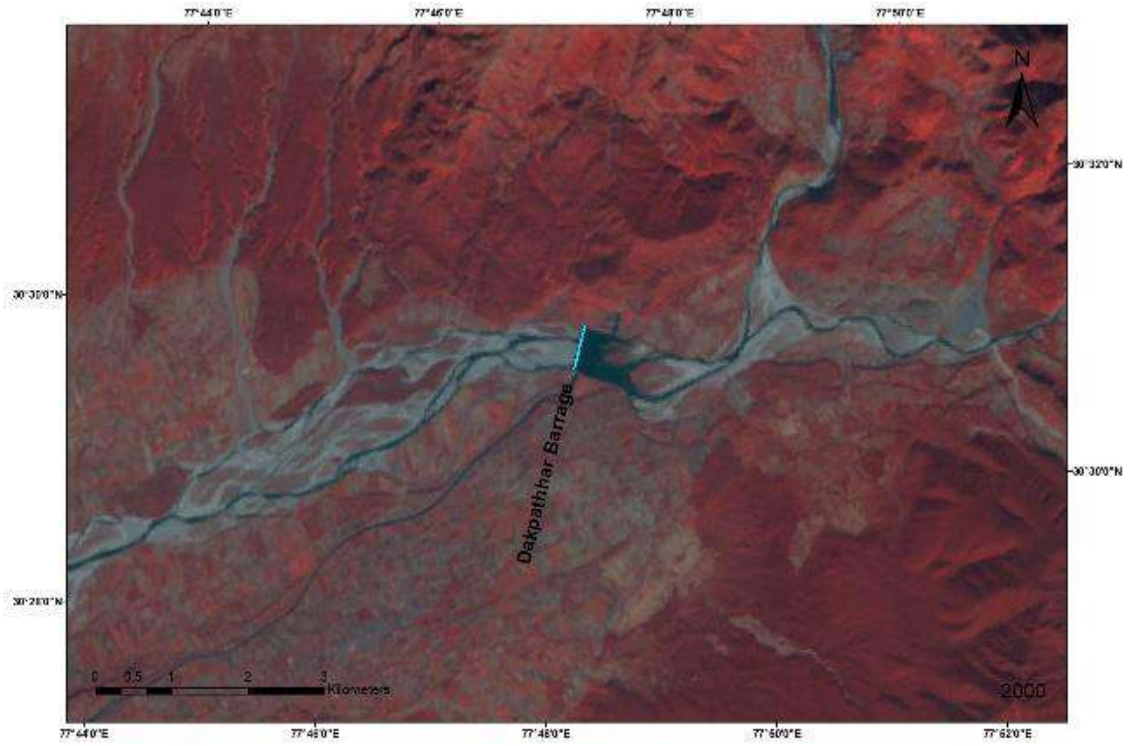


Figure 13-4 : Course of River Yamuna near Dakpathar Barrage in 2000

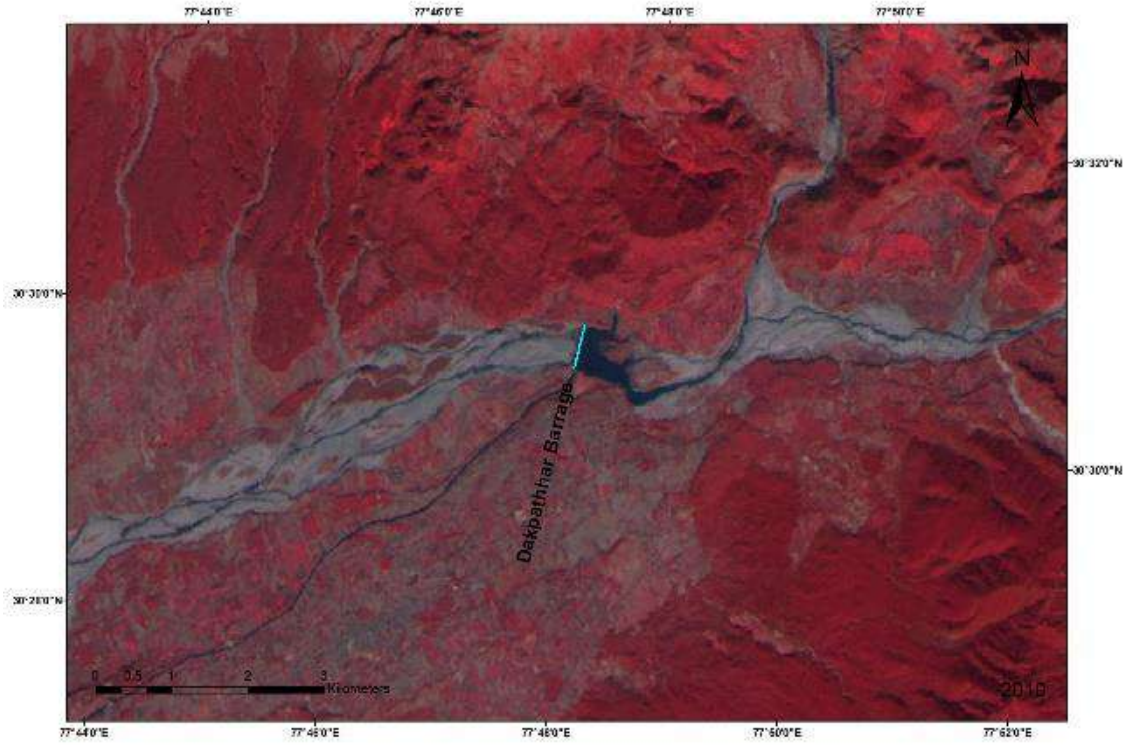


Figure 13-5 : Course of River Yamuna near Dakpathar Barrage in 2010

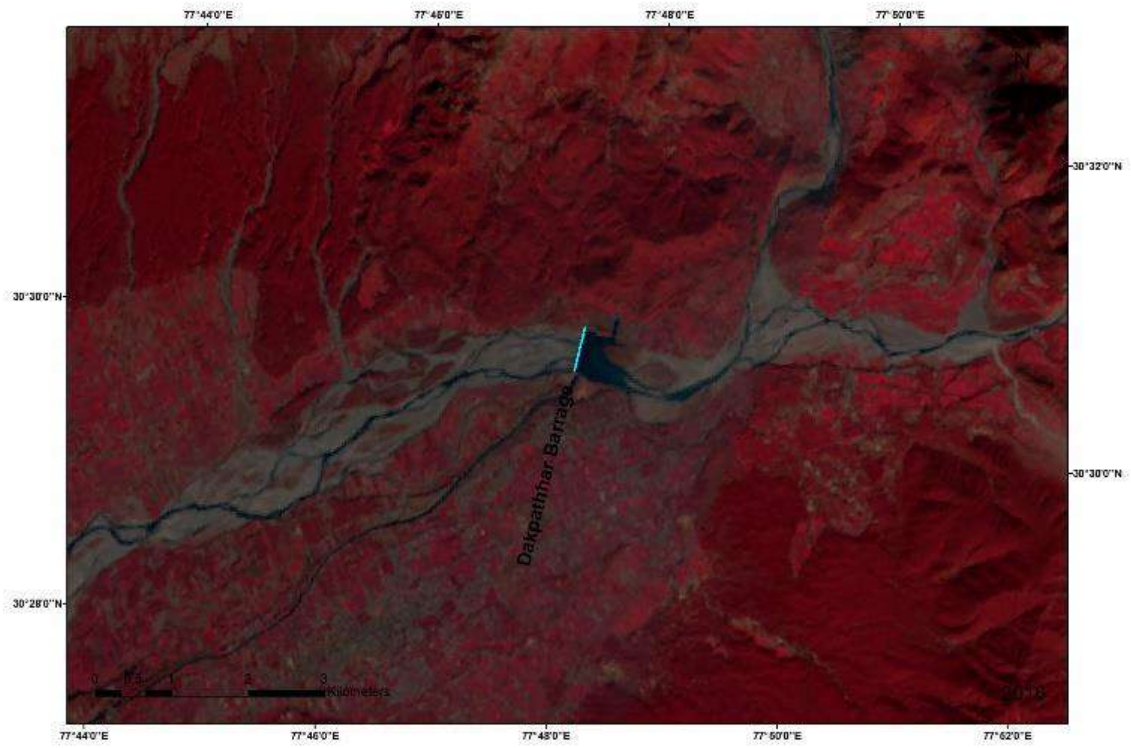


Figure 13-6 : Course of River Yamuna near Dakpathar Barrage in 2016

The width of the Yamuna river near the barrage is 600 m and changes in the width during the period 1975-2016 have been observed to be negligible. Near the barrage (2km upstream and downstream), the river is comparatively straight without many oscillations. No remarkable changes in the shape and size of the river upstream of the barrage have been noticed during the period 1970 – 2015 as the construction of barrage has been completed by 1965. About 4 km downstream of the barrage, braiding in the form of 2-3 channels have been observed. It can be concluded that there is negligible impact of Dakpathar barrage on the channel geometry of the Yamuna river in its vicinity during the temporal scale of the study. Upstream and downstream view of the barrage is shown in Figure 13-7 and Figure 13-8, respectively.



Figure 13-7 : Upstream of Dakpathar and Khodri powerhouse



Figure 13-8 : Downstream side of Dakpathar Barrage

13.2.1.2 Hathnikund Barrage

The Hathnikund barrage is a concrete barrage located on the Yamuna River in Yamuna Nagar district of Haryana. It was constructed during 1996-1999 for irrigation and it replaced existing Tajewala Barrage (3 km downstream) which was constructed in 1873. The barrage diverts water into the Western and Eastern Yamuna Canals. Although the barrage was completed in late 1999, it was not operational until March 2002 because of work delays. The barrage is 360 m long and its spillway has ten main floodgates along with five-under sluices on its right side and three on its left. The maximum discharge of the barrage is 28,200 m^3/s.

To study the impact of the Hatnikund barrage on river morphology, the decadal satellite images and geospatial datasets have been examined. Figure 13-9 shows the major courses of Yamuna river for years 1975, 1990, 2000 and 2010 imposed on the satellite image of the year 2016.

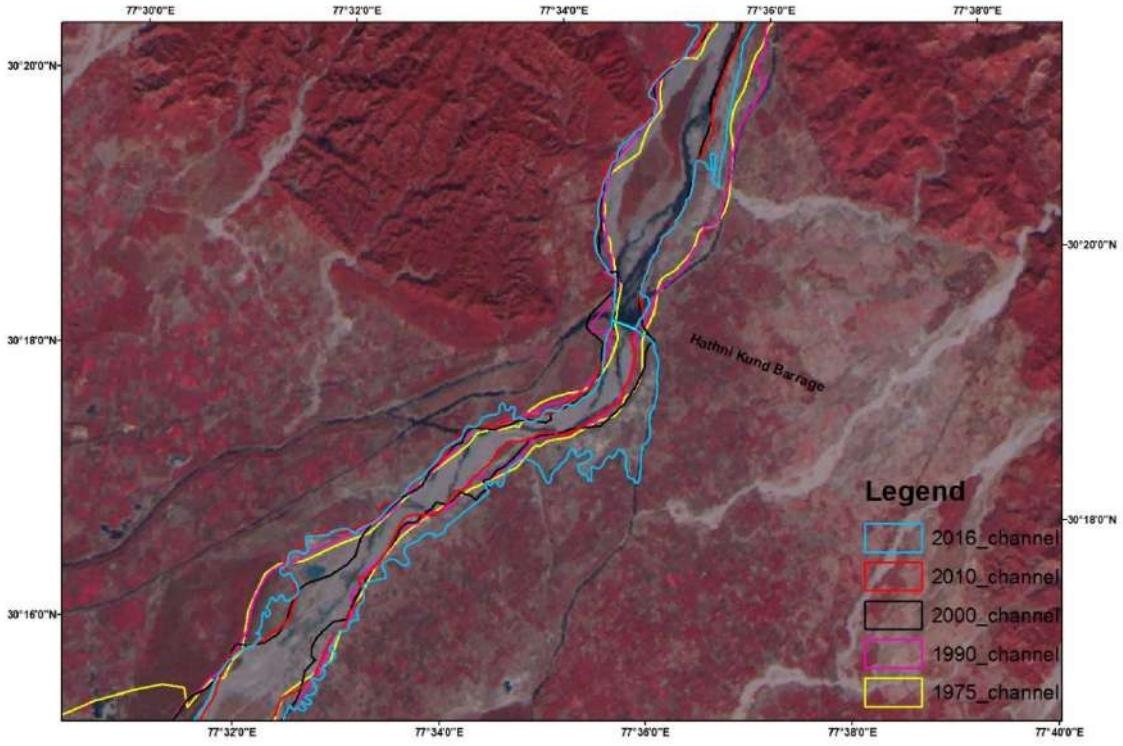


Figure 13-9: Courses of River Yamuna near Hathnikund Barrage

The satellite images of different years as shown below are used to understand river course near barrage on a decadal scale.

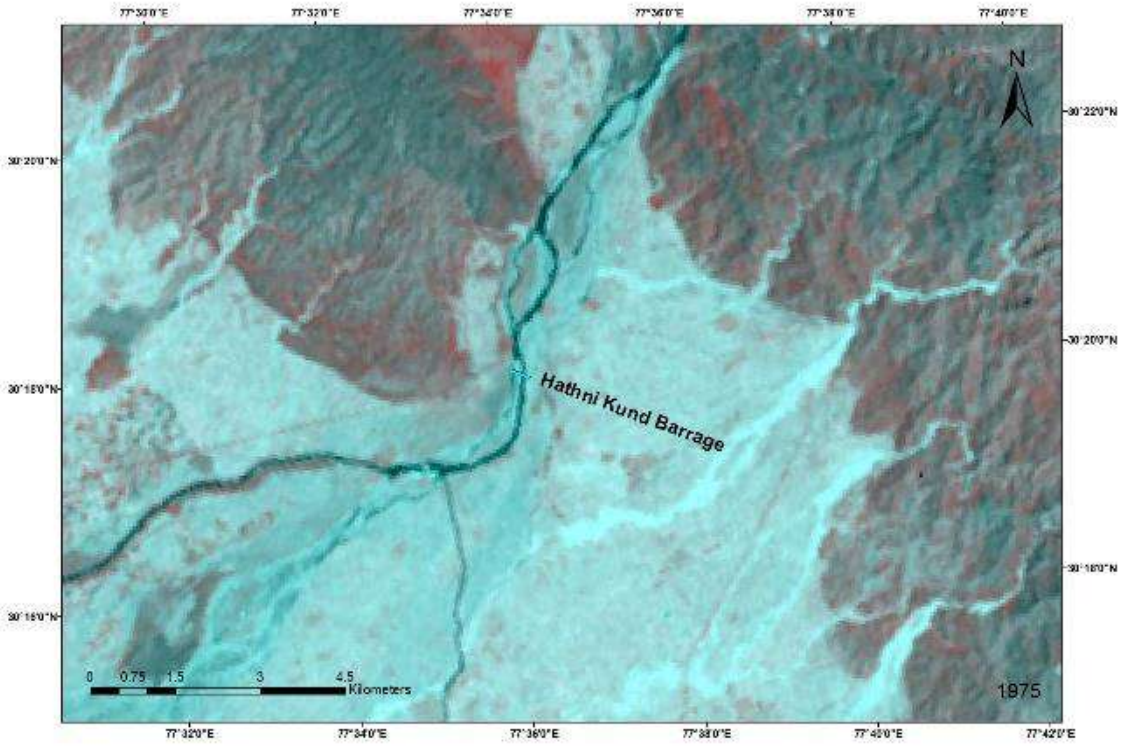


Figure 13-10 : Course of River Yamuna near Hathnikund Barrage in 1975

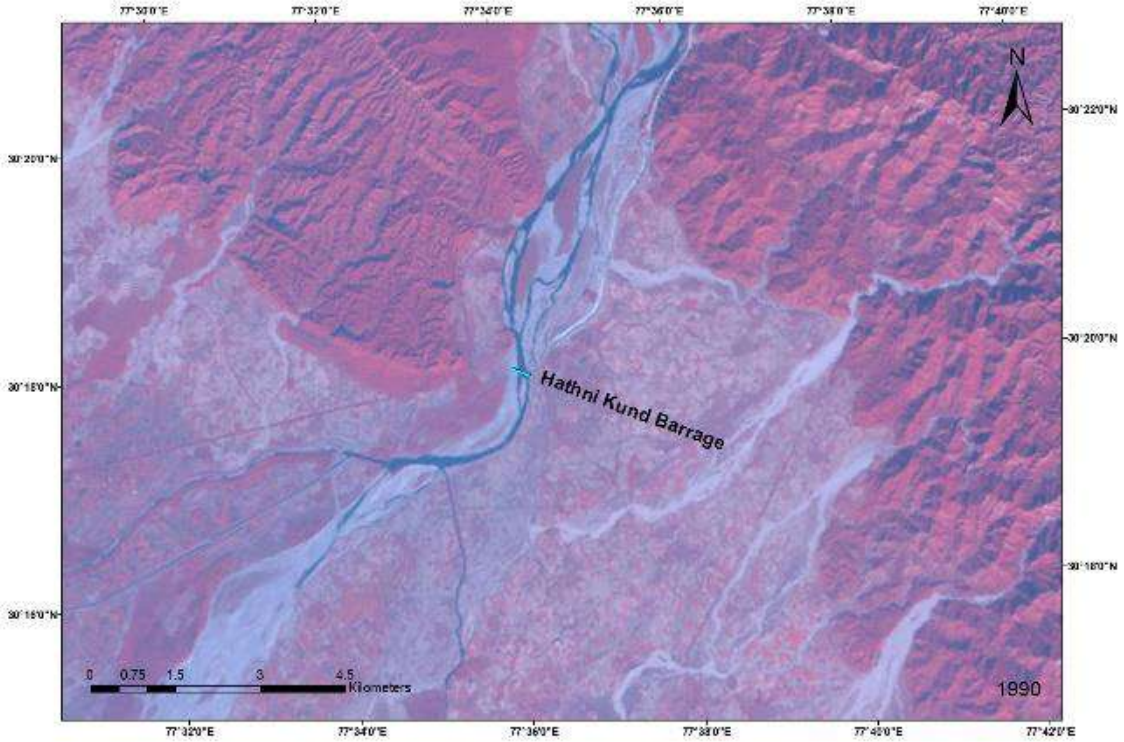


Figure 13-11 : Course of River Yamuna near Hathnikund Barrage in 1990

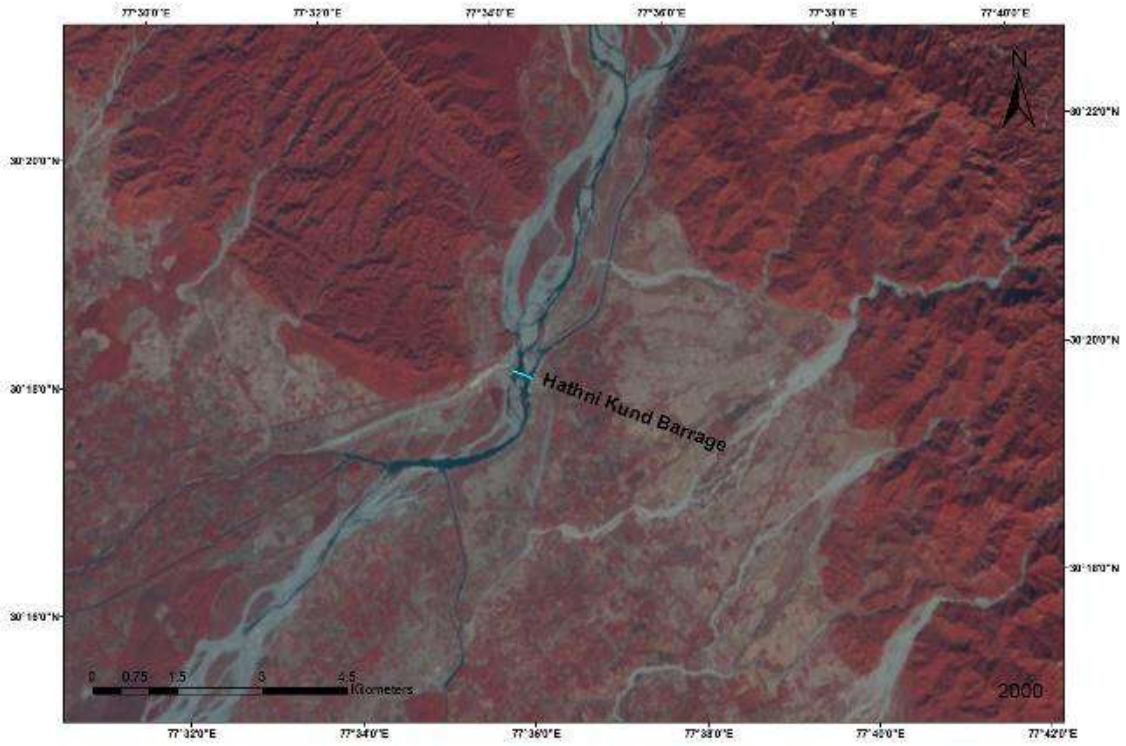


Figure 13-12 : Course of River Yamuna near Hathnikund Barrage in 2000

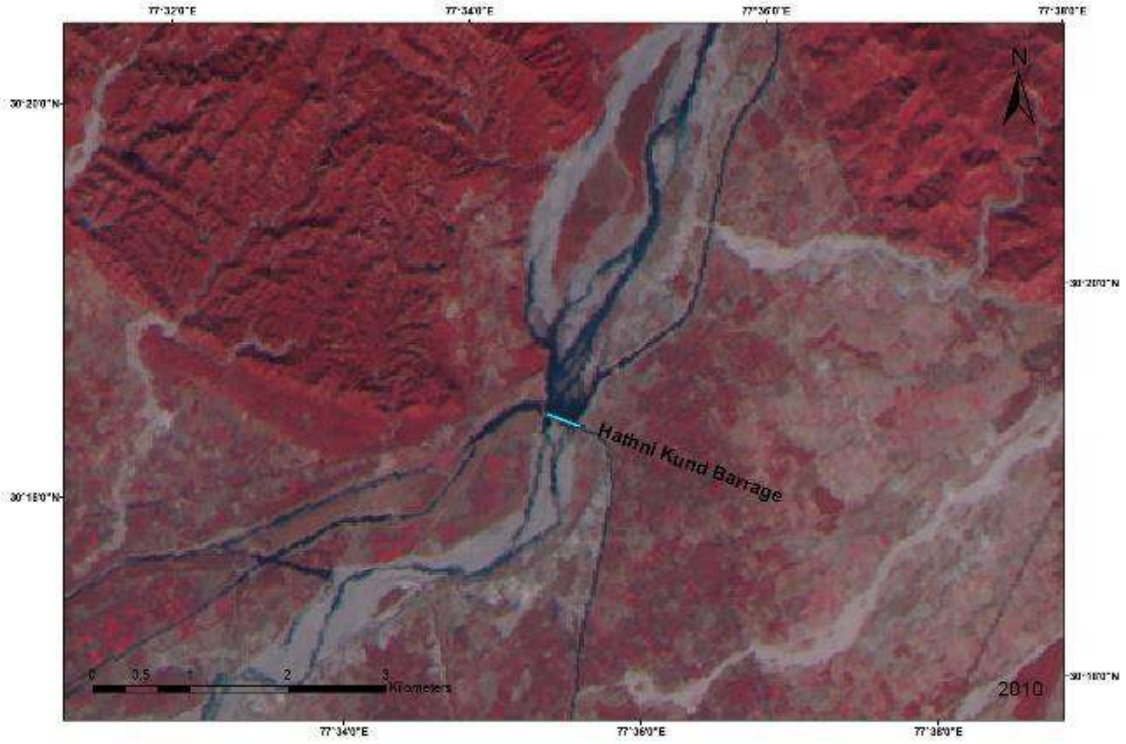


Figure 13-13 : Course of River Yamuna near Hathnikund Barrage in 2010

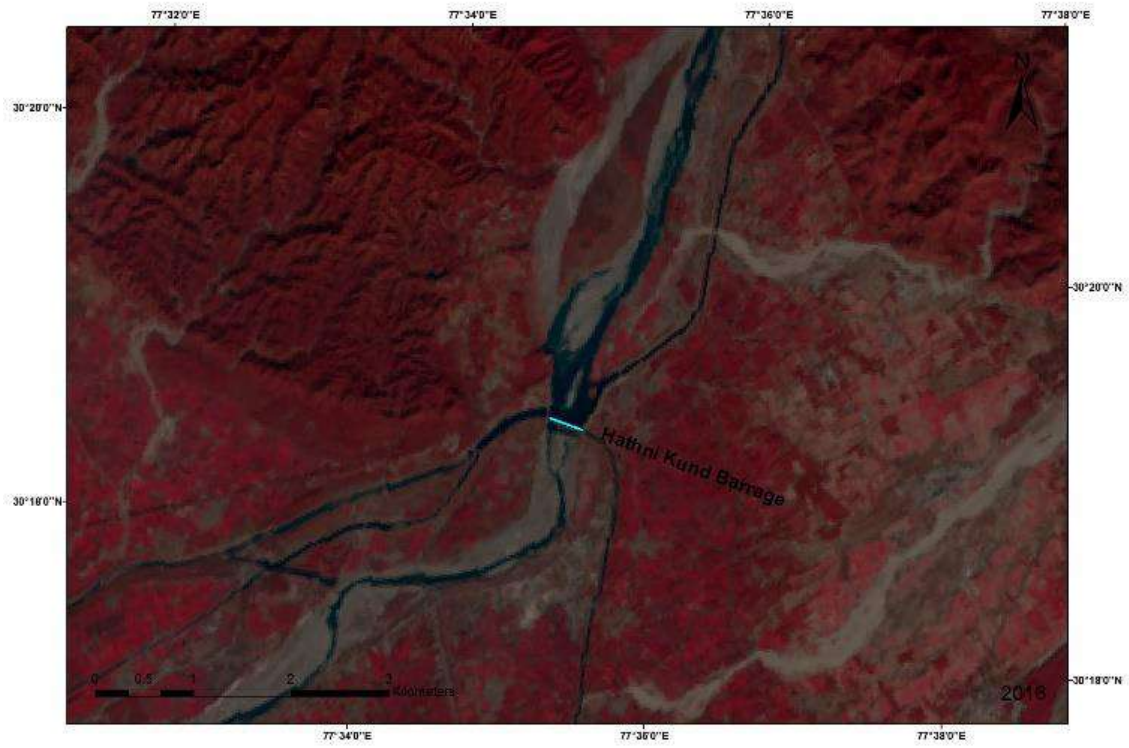


Figure 13-14 : Course of River Yamuna near Hathnikund Barrage in 2016

On the upstream side of the barrage, 2-3 braids have been observed from 1975-2016. The operation of Hathnikund barrage started in the year 2002, and it resulted in changes in active water area. The observation on the chronological scale suggests that braid around the right bank (on the upstream side of the barrage) is in the non-active state (images of 2010 and 2016). The river flows in the form of single braid during the lean season with an average width of 50m (active water area). Upstream and downstream view of the barrage is shown in Figure 13-15 and Figure 13-16, respectively.



Figure 13-15 : Upstream View and Eastern Yamuna Canal from Hathnikund Barrage



Figure 13-16 : Downstream view from Hathnikund Barrage

13.2.1.3 Wazirabad Barrage

The Wazirabad barrage, built in 1959 is a 1491 ft (454m) long barrage with 6 under-sluices of 60ft (18.28m) each on the right side and a 17 bays spillway of 58ft (17.68m) each. Top of spillway is 4 ft (1.2m) higher than the under-sluices. There is a concrete floor flexible apron, both upstream and down-stream. This barrage on Yamuna is part of National Waterway NW110, one of India's 111 National Waterways. The barrage lies on the Delhi-Faridabad Yamuna waterway. To study the impact of the Wazirababd barrage on river morphology, the decadal satellite images and geospatial datasets have been examined.

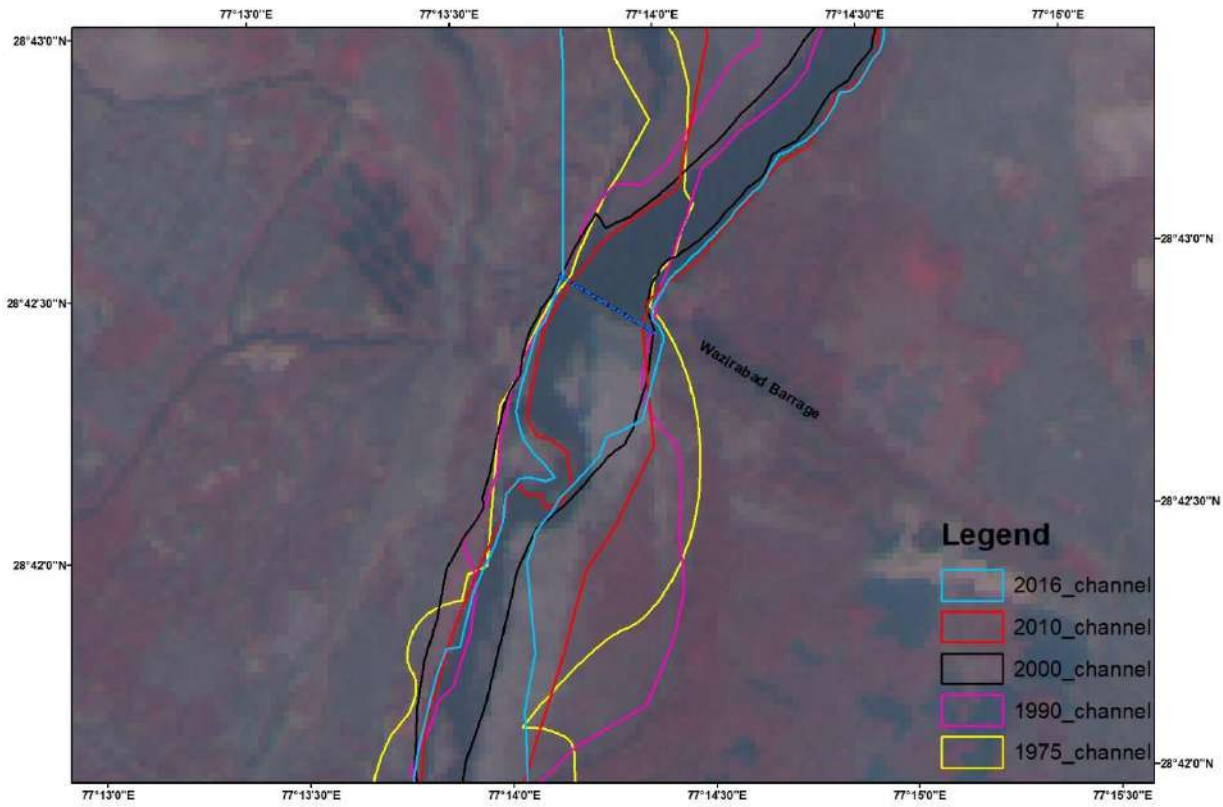


Figure 13-17 : Courses of River Yamuna near Wazirabad Barrage

Figure 13-17 shows major courses of Yamuna river for years 1975, 1990, 2000 and 2010 on the satellite image of the year 2016. The satellite images of different years as shown below are used to understand river course near barrage on decadal scale.

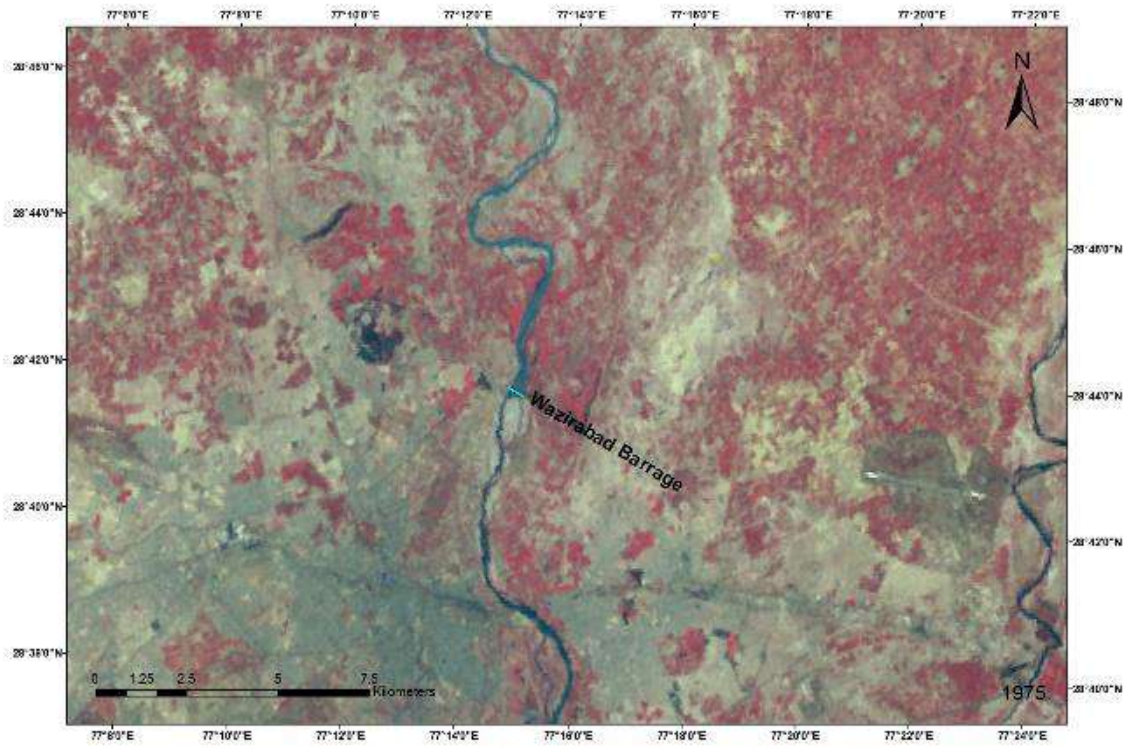


Figure 13-18 : Course of River Yamuna near Wazirabad Barrage in 1975

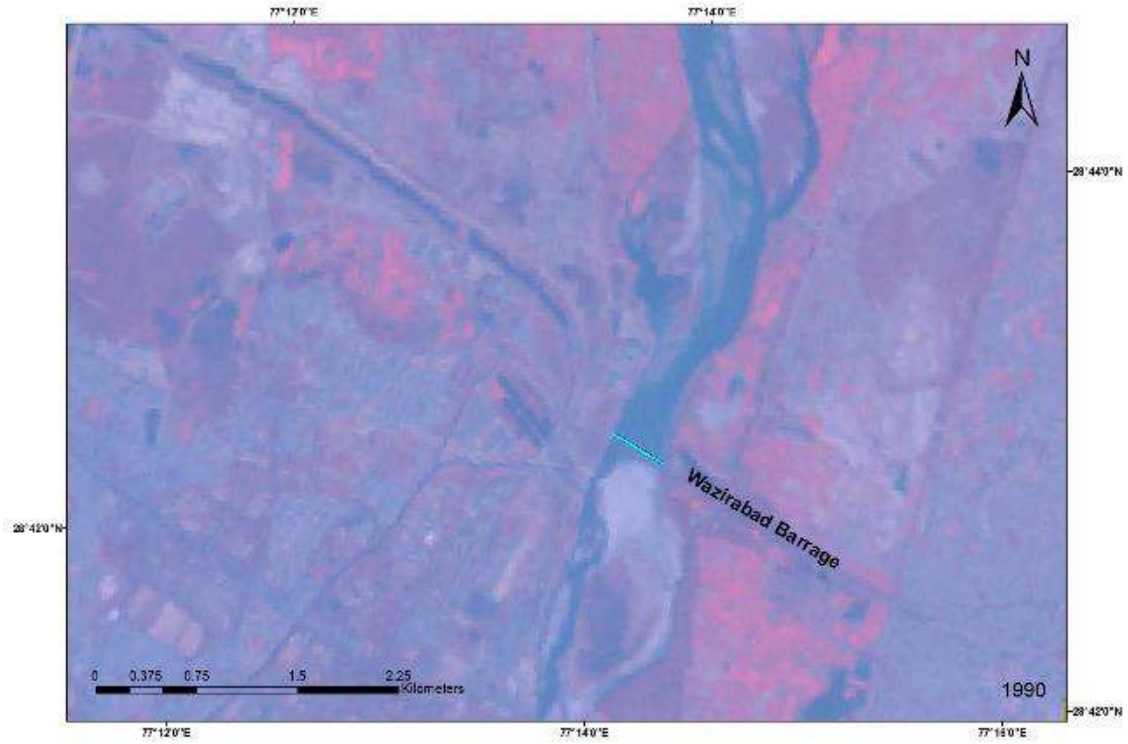


Figure 13-19 : Course of River Yamuna near Wazirabad Barrage in 1990

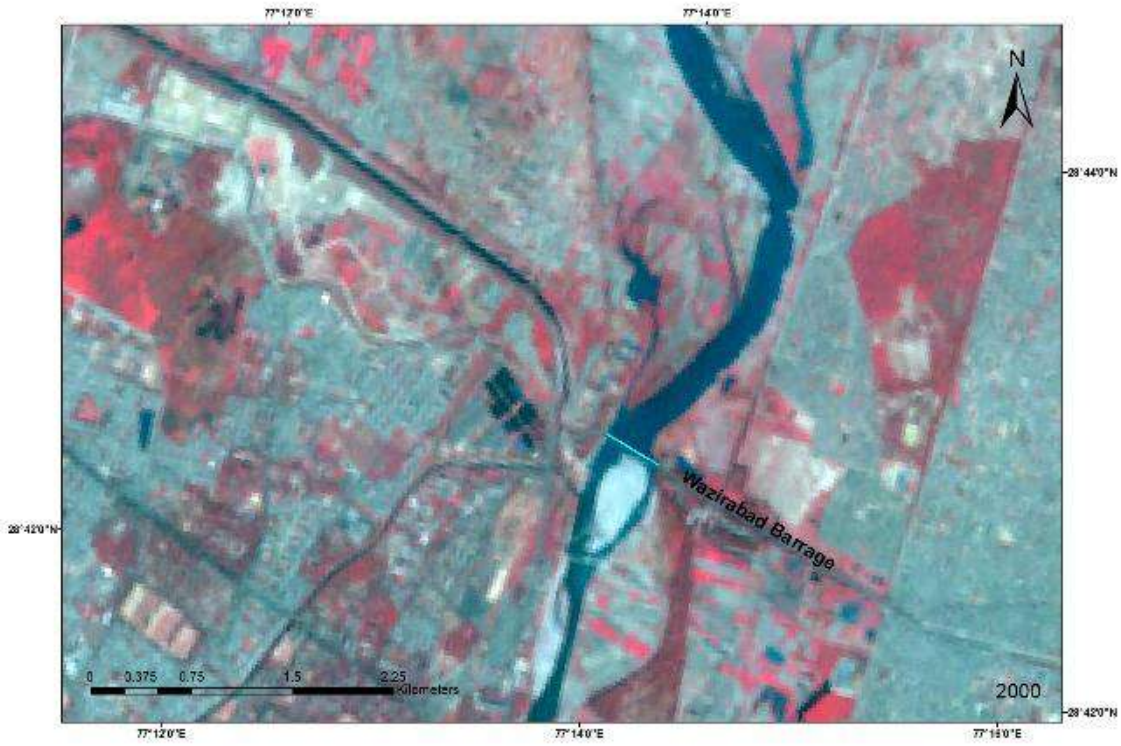


Figure 13-20 : Course of River Yamuna near Wazirabad Barrage in 2000

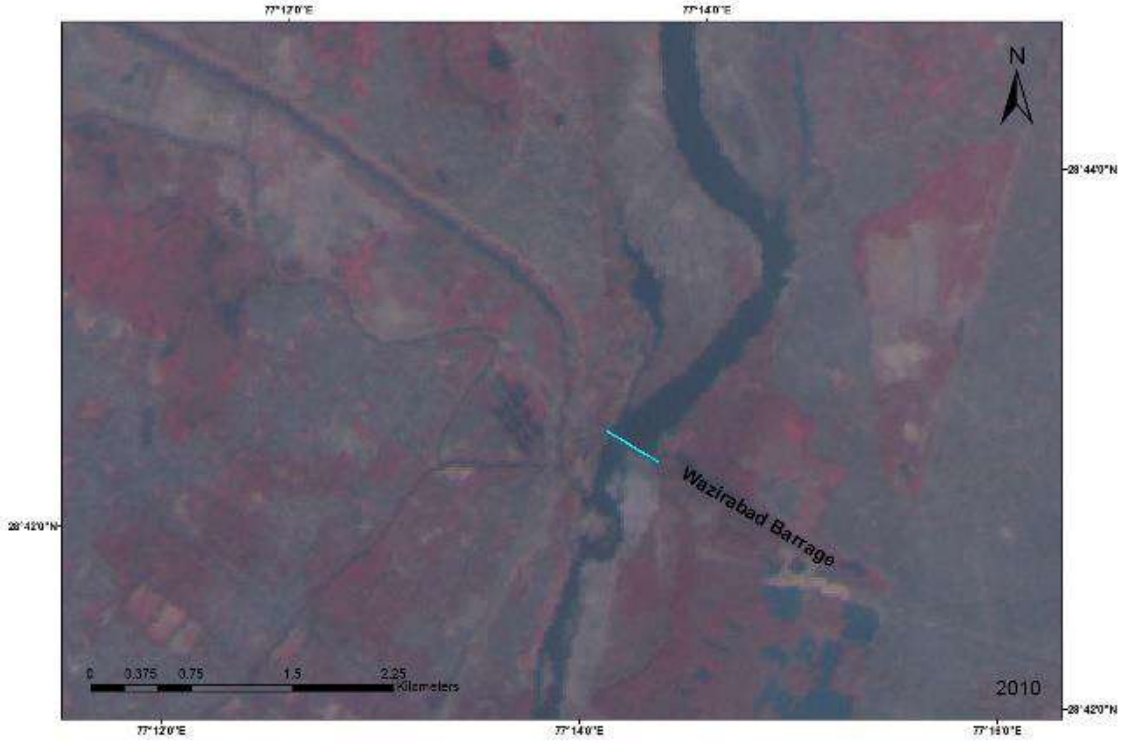


Figure 13-21 : Course of River Yamuna near Wazirabad Barrage in 2010



Figure 13-22 : Course of River Yamuna near Wazirabad Barrage in 2016

As the barrage has been constructed before the period for which the satellite imageries have become available, it is challenging to compare pre and post conditions. However, satellite images from the year 2000 onwards indicate increased agricultural activity in the riverbed, which might be temporary in nature. With increased agriculture, and reduced downstream flows, active water area has reduced. Width of active water area upstream is around 800 m whereas downstream width is approximate 300-400 m. It is also noticed that water of unknown quality (considering its colour) is released from Najafgarh drain into the river downstream of the barrage.

On the upstream side, a sandbar is formed between the years 1990 and 2000. It is observed that the river has taken slightly longer and sinuous path after this bar formation. Following figures (Figures 13-23 and 13-24) indicate the Wazirabad upstream and downstream areas captured during field visit.



Figure 13-23: Upstream view of Wazirabad Barrage



Figure 13-24: Downstream view of Wazirabad Barrage

13.2.1.4 ITO Barrage

The ITO barrage, also known as Indraprastha barrage is a 552 meter barrage on Yamuna River, which also serves as the bridge on the Paharganj-Gaziabad Vikas marg. Figure 13-25 shows major courses of Yamuna river for years 1975, 1990, 2000 and 2010 imposed on the satellite image of year 2016.

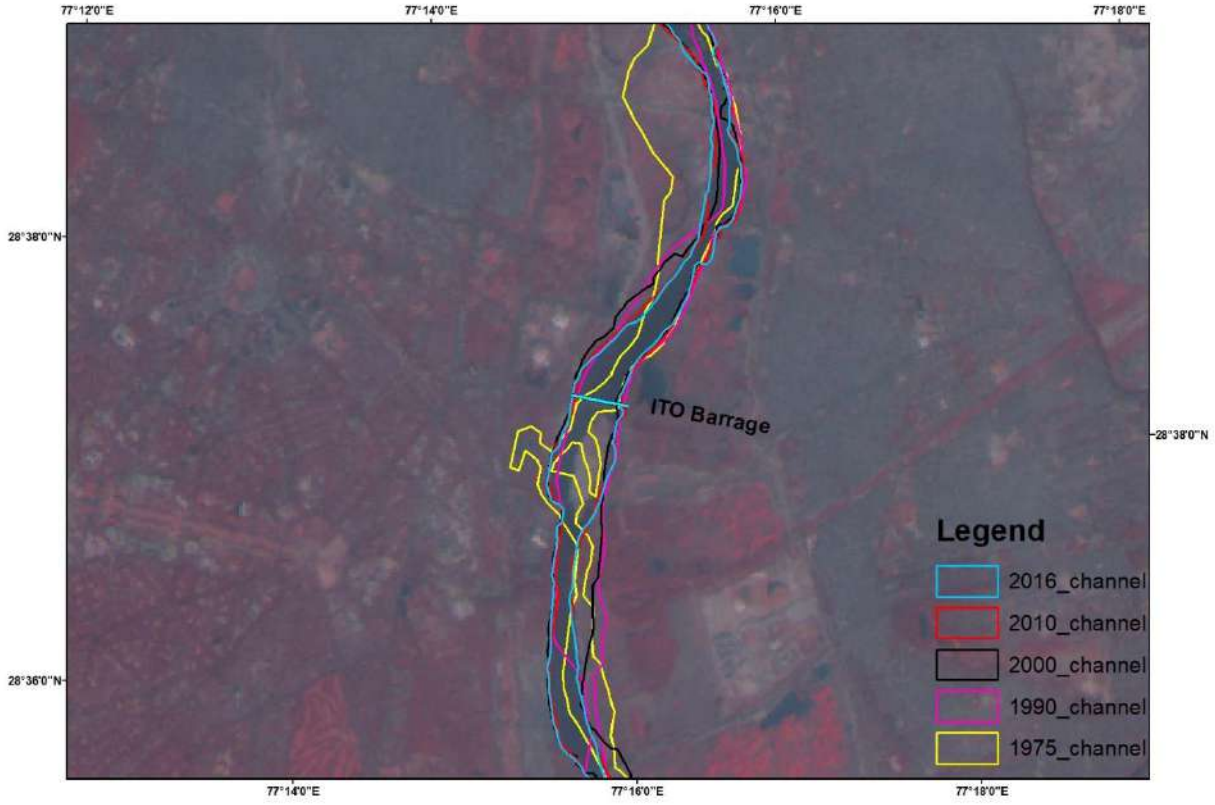


Figure 13-25 : Course of River Yamuna near ITO Barrage

The satellite images of different years as shown below are used to understand river course near barrage on decadal scale. Based on these images it can be said, not much changes have been observed around ITO barrage both on upstream and downstream side. On the downstream side, two braids, dominant on the right bank and smaller one on the left bank have been in 2000, 2010 and 2016 images. A small island/ sandbar on the downstream side of the barrage, is used for agricultural activities, this might be the reason for specific gates are operated for release during non-monsoon season.

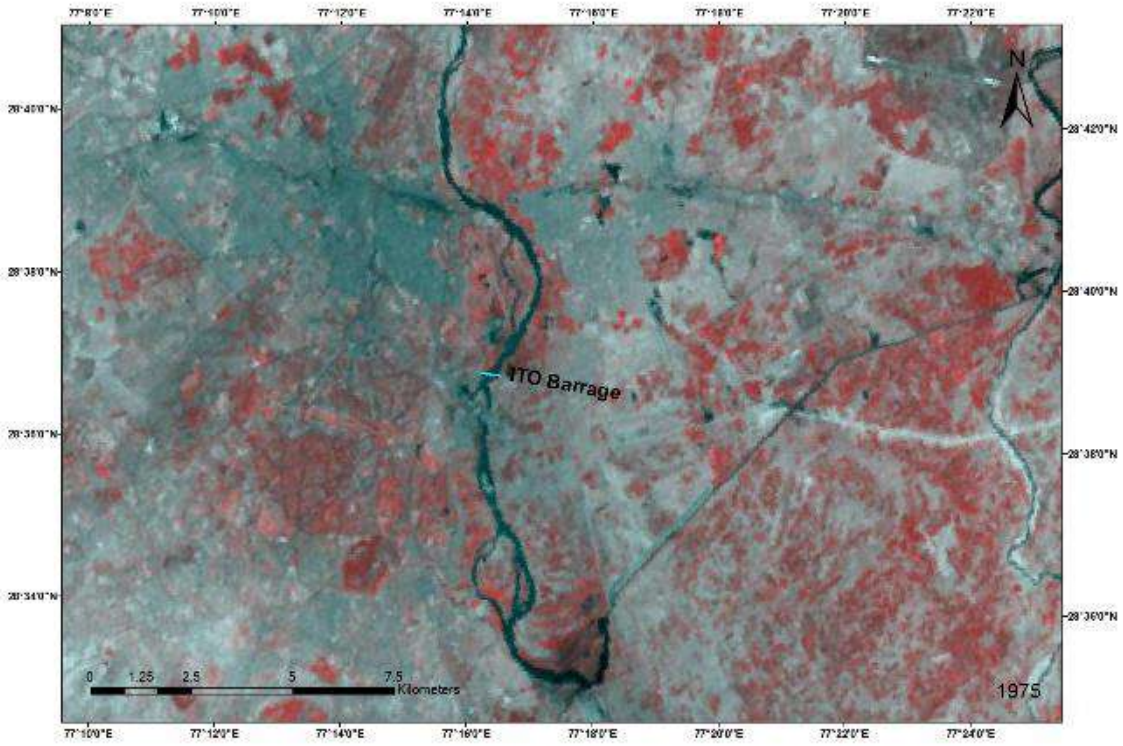


Figure 13-26 : Course of River Yamuna near ITO Barrage in 1975



Figure 13-27 : Course of River Yamuna near ITO Barrage in 2000



Figure 13-28 : Course of River Yamuna near ITO Barrage in 2010

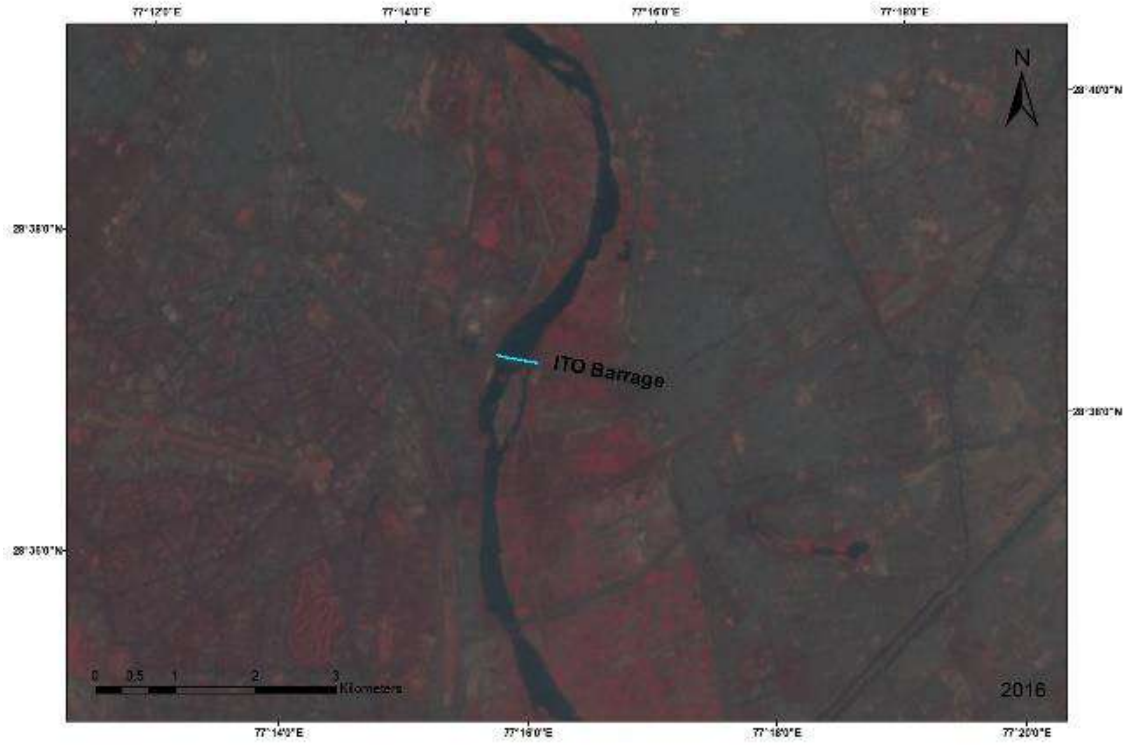


Figure 13-29 : Course of River Yamuna near ITO Barrage in 2016

13.2.1.5 Okhla Barrage

The Okhla barrage is 791 meters long weir across Yamuna River opened in 1874 by the British Raj for irrigation and water navigation. The top of barrage also serves as the Delhi-Noida carriageway of Mahamaya-Kalindi Kunj road. Nearby later-era New Okhla barrage is 554 meters completed in 1987. Okhla barrage now also serves as the location of Okhla Bird Sanctuary. Upstream of the barrage average river width up to ITO bridge is approximately 800 m whereas downstream average river width up to Kidawali is approximately 550 m. Though new barrage came in 1987, river width has not experienced any significant difference. Figure 13-30 shows major courses of Yamuna river for the years 1975, 1990, 2000 and 2010 imposed on the satellite image of the year 2016.

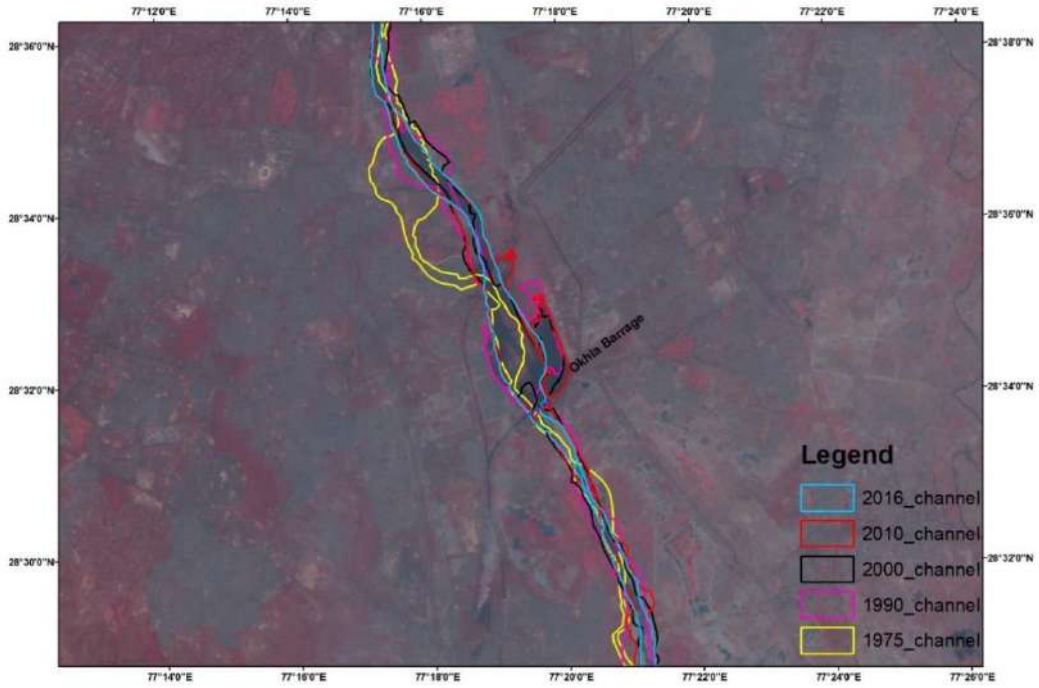


Figure 13-30 : Course of River Yamuna near Okhla Barrage

To study the impact of the Okhala barrage on river morphology, the decadal satellite images and geospatial datasets have been examined. Not much difference is observed. As barrage was constructed much before time frame of the present study (1975-2016), it is not possible to identify and detail on impact of barrage (prior construction). In terms of river width and erosion- deposition pattern, not much difference is observed in the period of 1975 to 2016. Following images indicate Okhla Barrage as seen in satellite images of different years

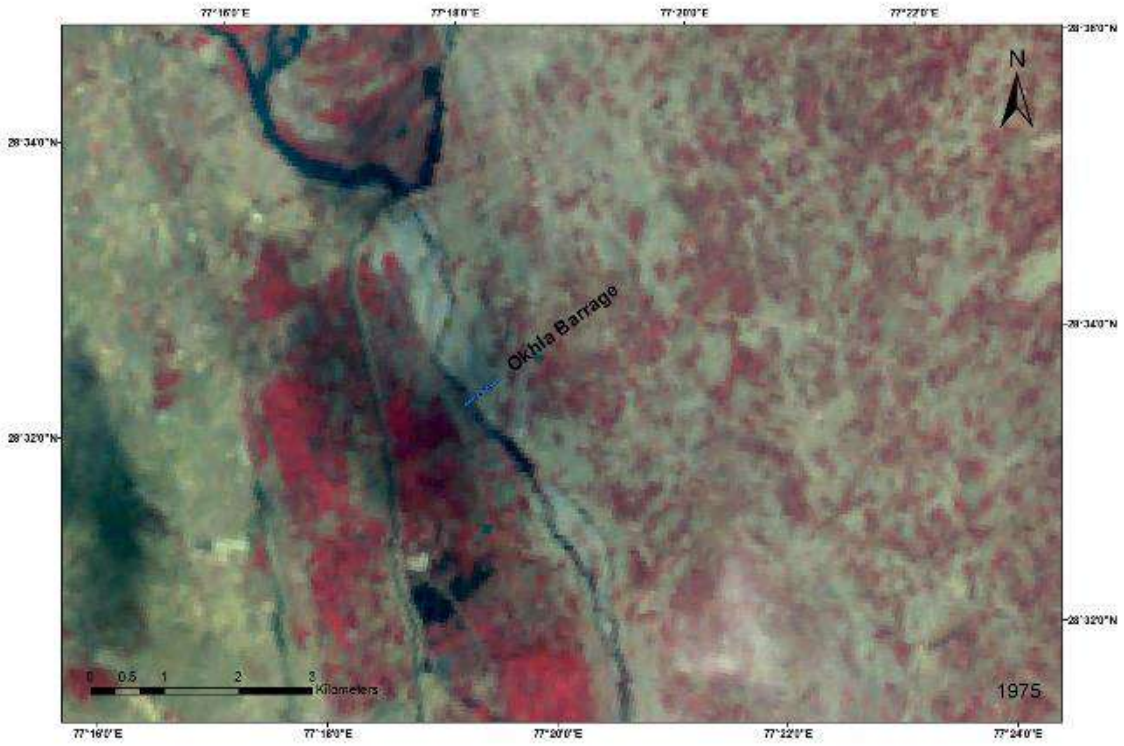


Figure 13-31: Course of River Yamuna near Okhla Barrage in 1975



Figure 13-32 : Course of River Yamuna near Okhla Barrage in 1990

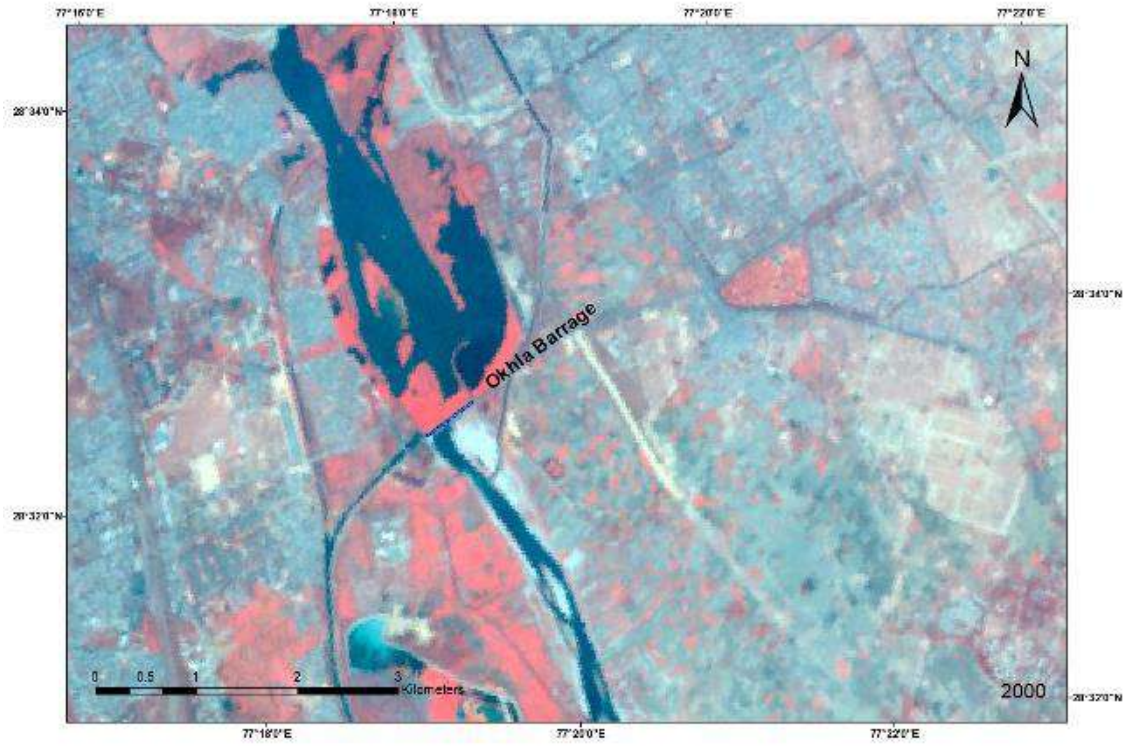


Figure 13-33 : Course of River Yamuna near Okhla Barrage in 2000

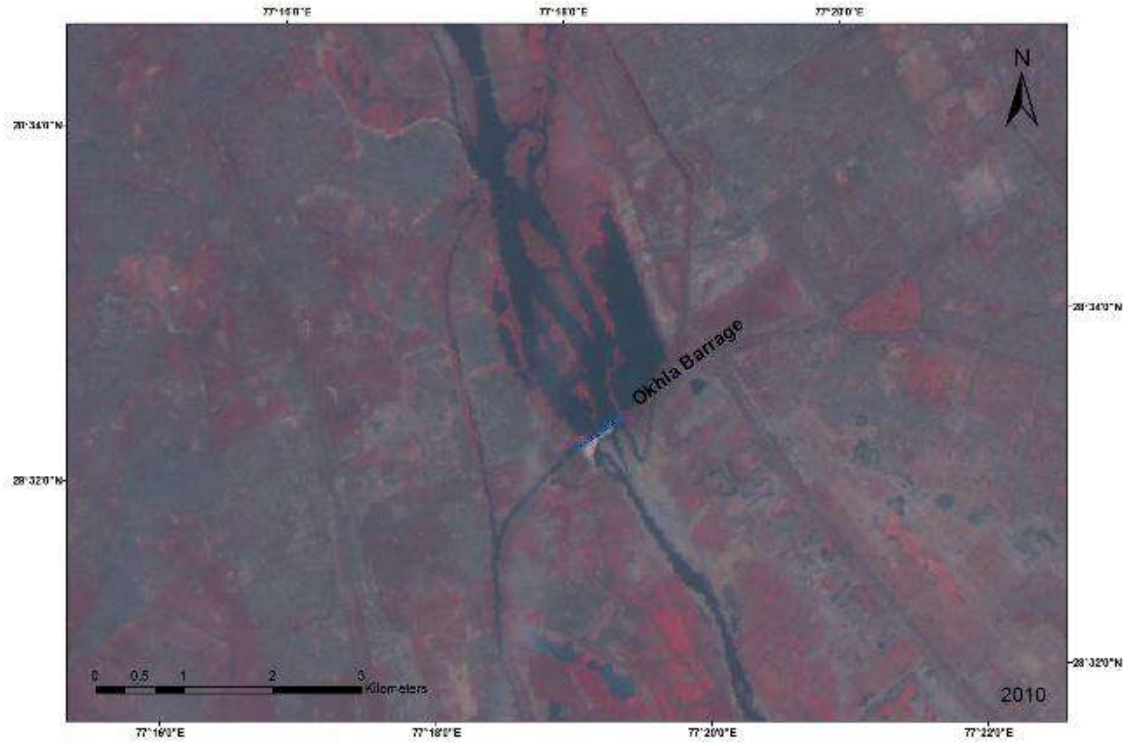


Figure 13-34 : Course of River Yamuna near Okhla Barrage in 2010

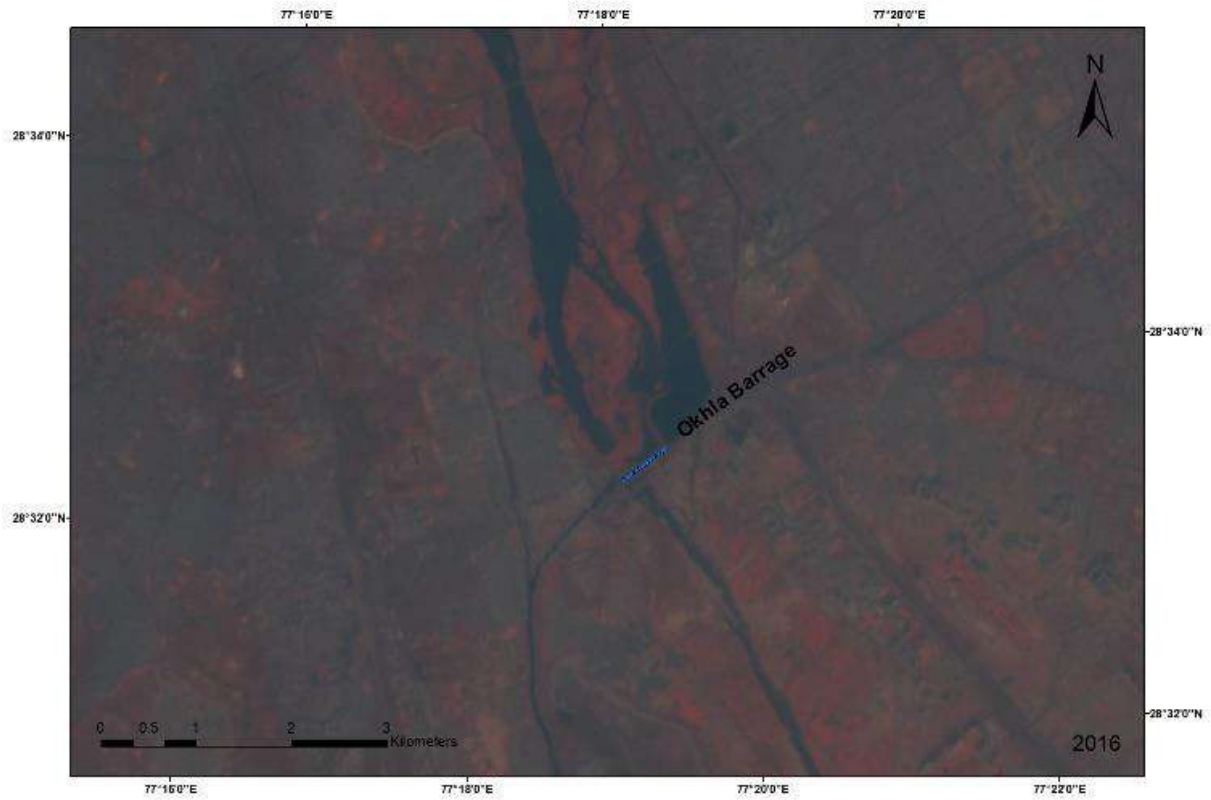


Figure 13-35 : Course of River Yamuna near Okhla Barrage in 2016

13.2.1.6 Gokul Barrage

The Gokul barrage (also known as Mathura barrage) is a barrage on Yamuna River at Gokul (7 km downstream from Mathura) in Mathura district, top of which also serves as road bridge. The project was commenced in 1990 and completed in year 2001. Near the barrage, the river is straight for around 6.8 km on upstream side whereas on downstream side, river starts meandering and its sinuosity increases as river reaches Agra. To study the impact of the Gokul barrage on river morphology, the decadal satellite images and geospatial datasets have been examined.

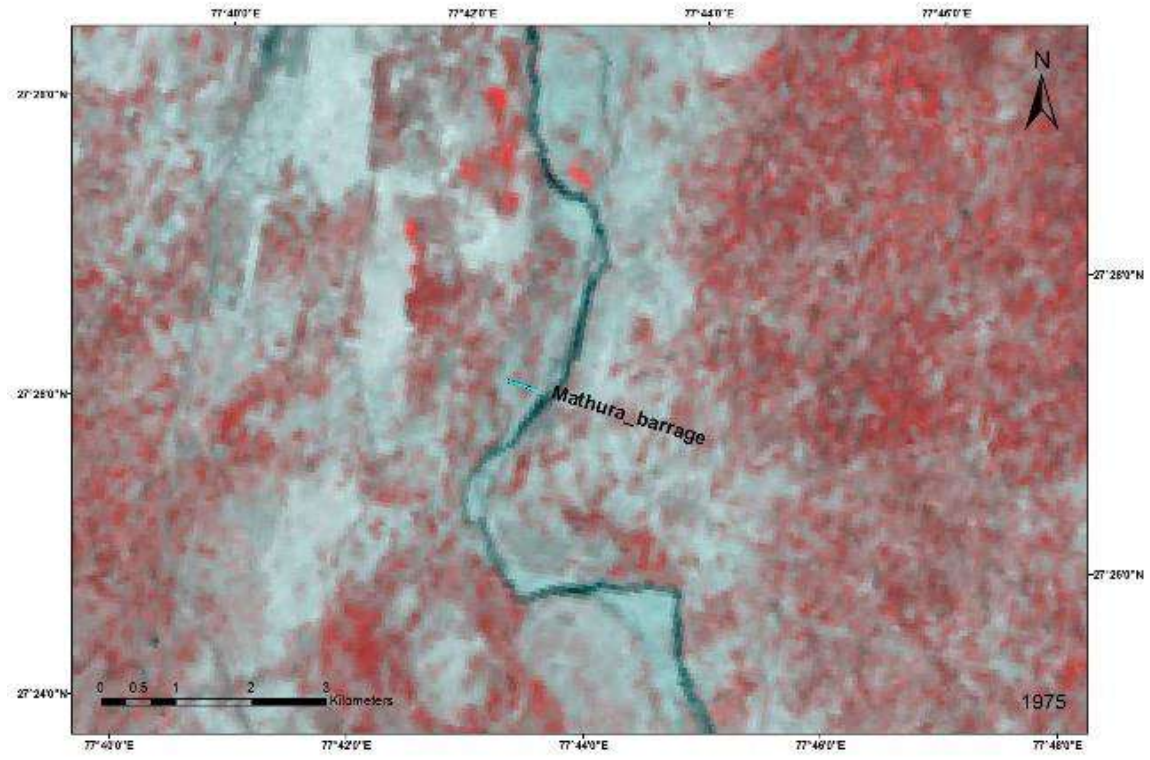


Figure 13-36 : Course of River Yamuna near Gokul Barrage in 1975

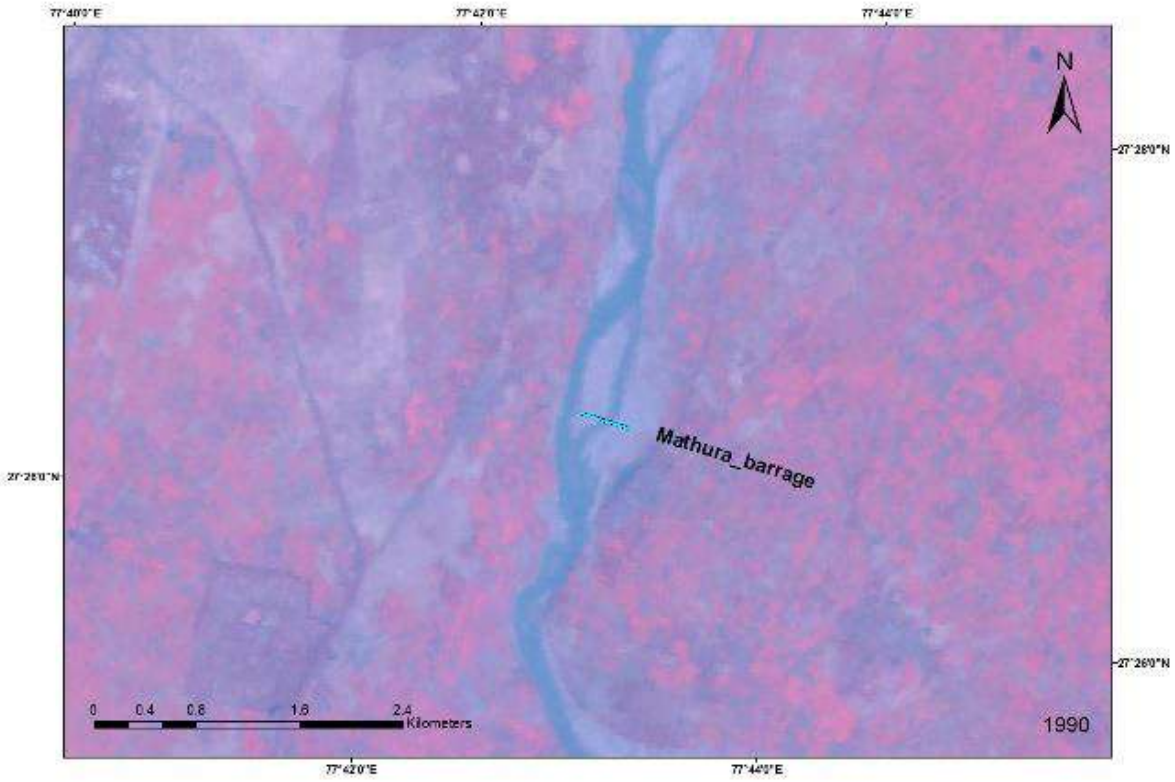


Figure 13-37 : Course of River Yamuna near Gokul Barrage in 1990

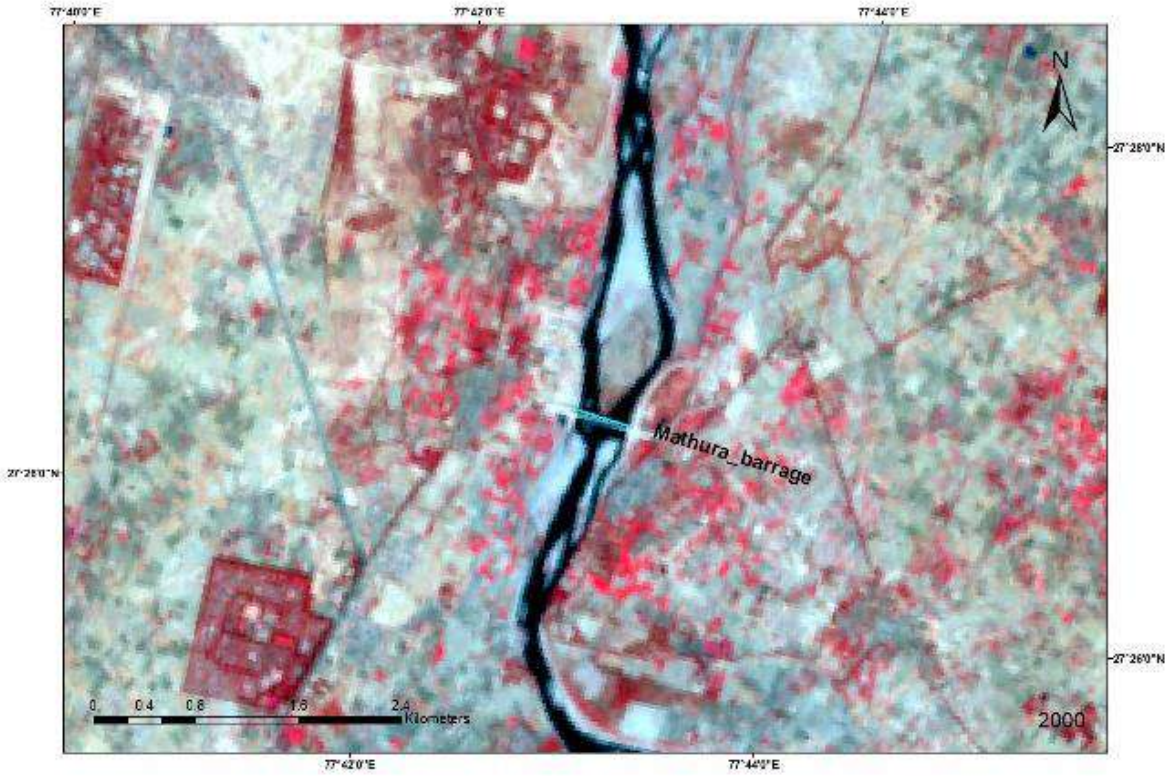


Figure 13-38 : Course of River Yamuna near Gokul Barrage in 2000

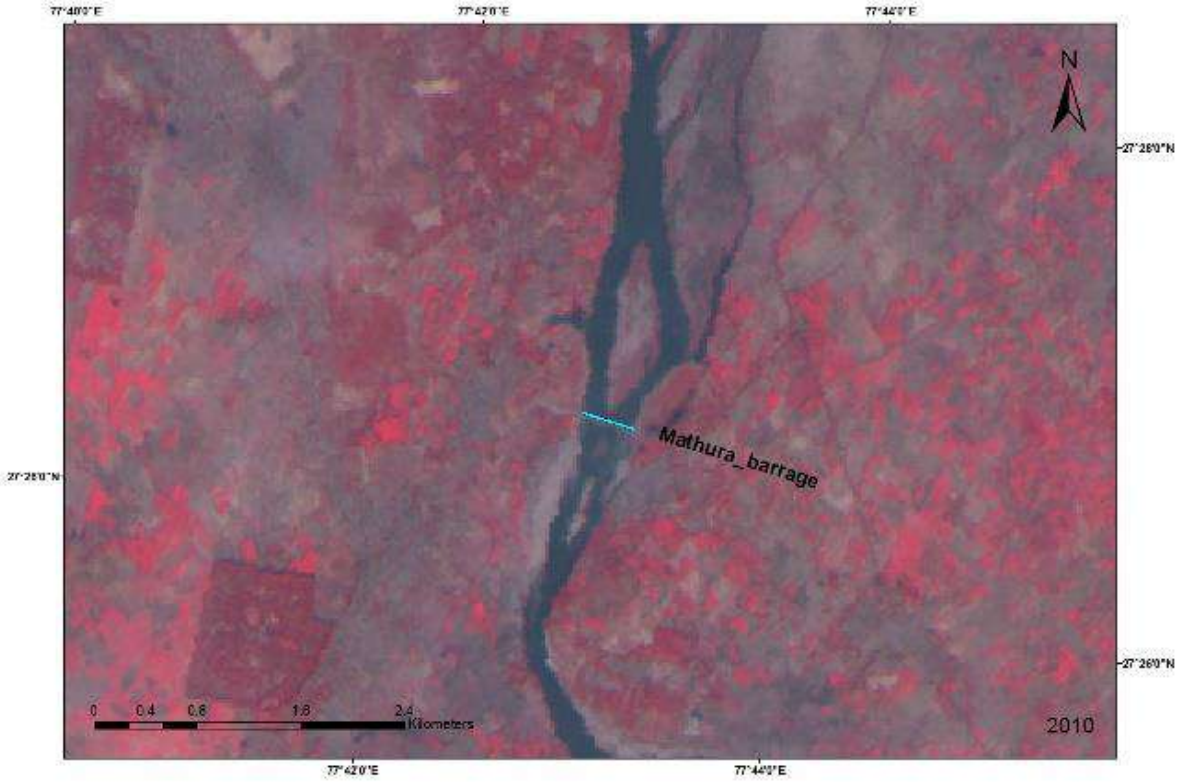


Figure 13-39 : Course of River Yamuna near Gokul Barrage in 2010



Figure 13-40 : Course of River Yamuna near Gokul Barrage in 2016

From observation of the imageries it can be said that changes in river course downstream of barrage are noticed. From the 2016 image, it is observed that river is mostly taking route near the left bank and channel area in the right bank remains dry. This is also verified during the field visit, much of the area in riverbed in and around the right bank is encroached for agricultural activities. In case of upstream side, reduction in area of island which falls under reservoir area has been noticed. Following figures indicate upstream and downstream view of the Gokul Barrage.



Figure 13-41 : Upstream view from Gokul Barrage also depicting the Island



Figure 13-42 : Downstream view of Gokul Barrage

13.3 Impact of Flood Control Structures

Several structural measures for flood control are in place along the banks of river Yamuna. These include groynes or spurs, guide bunds, marginal embankments. Some of these structures visible on google earth platform (higher resolution than the satellite images used in present study) have been marked and analyzed with respect to their impact on morphology.

Spurs are seen in the vicinity of Khari, Chajja Ahat (both locations downstream of Hathnikund Barrage on the left bank), Belgarh, Kaniawala, Yamuna Nagar Stone crusher zone (right bank of Yamuna), Dhaulara, Alamgirpur Guzzar (left bank of Yamuna), Mali Mazra(right bank), Jondha bBans (left bank), Sondhey Bans (right bank), Todarpur (left bank), Bhogpur, Bibipur (right bank), Sabapur, Lapra (right bank), Kamalpur Tapu, Manduali Tapu (right bank), Dikkha Tapri (right bank), Dikka Kalan (left bank), Dikka Khurd (left bank), Jathlana, Dhakwala (right bank), Majri Dayalgarhmajri, Nagla Rangharan (right bank), Gumthala Rao (right bank), Kalsoura, Ghar pur Tapoo (right bank), Dhundha Manjra Ahat, Rasulpur Gauzar (left bank), Haussainpur, Halwana Aht (left bank), Nagar, Tatarpur (right bank), Chapra Japti (left bank), Shrgah Tapu (right bank), Mawi TImli Hall (left bank), Adhmi, Jalmana, Mirzapur (right bank), Khojkipur, Bilaspur, Bhanuli, Chappruli Deht (right bank), Rakshera (right bank), Gaddi Mimarpur (right bank), Asadpur Nandnaur (right bank), Mahawatur (right bank), Amitngar, Kambakshur (left bank), Chhainssa (right bank), Gharvara (left bank), Bilochpur (right bank), Lalpur Raiyyatpur (left bank), Posh Colony, Vrindavan (right bank). Locations mentioned are the names of nearby places as seen in Google Earth platform. These location names are mostly the names of nearby settlements and are not aligned with the administrative boundaries.

The marginal embankments, also known as levees, which are constructed in the flood plains of a river and run parallel to the riverbank along its length. The aim of providing these embankments is to confine the river flood water within the cross section available between the embankments. The flood water of a river is thus not allowed to spill over to the flood plains. The region between Palla to Wazirabad barrage is protected by rural marginal embankment (RME). Some of these bunds have been constructed in active floodplain areas which resulted in restriction of the river course (for example, Jagat Pur bund and Shyam Ghat Mandir bund) and thus affect channel morphology. Other areas around Bagphat (left bank), Shahpur Jat, Kunda Kalan (left bank) have also been protected with levees along with spurs in a few locations.

In most cases embankments are found effective in controlling floods in adjacent settlements, however; in case of extreme events embankment breaches have also been observed. During 1978 flood event, embankment breach happened and caused inundation in Alipur block and urban colonies of Delhi like Adarsh Nagar, Model town, Mukerji Nagar.

Considering the exposure (settlement and agriculture activities) to the flood events, it is necessary to have flood control structures in place, however, it is important to acknowledge the impact of such embankments on river morphology. Such knowledge shall help in arriving at decision for construction of flood control embankments at respective locations after realizing their implications on morphology.

In case of Yamuna, following are some examples where embankments have affected the natural morphological behaviour.

1. This location is in the vicinity of Todarpur, Pankuan, and Maqsoodpur villages. Spurs constructed in the area are shown in red colour within yellow circle in the following images. Year of imagery is shown in right corner of the image. Though, it is not clear when spurs were constructed but it looks like they are constructed during 2014-2016. These spurs could not last too long. From the satellite image of year 2018 it is seen that river has migrated towards left bank and location of spurs is now part of river channel. This also indicate that these spurs were not planned and designed properly. A hydrodynamic impact study should be carried out before implementation of such structures Such studies can help in better understanding of river course dynamics before actual implementation.

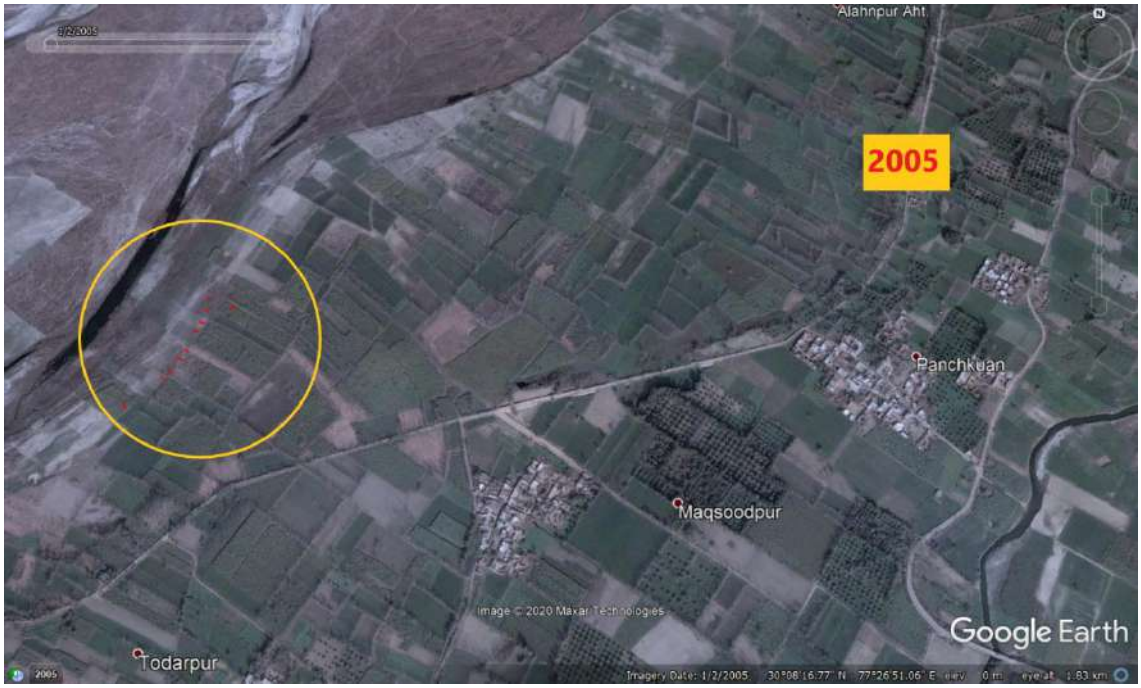


Figure 13-43 : Spurs location around Todarpur in year 2005



Figure 13-44 : Spurs location around Todarpur in year 2012



Figure 13-45 : Spurs location around Todarpur in year 2014



Figure 13-46 : Spurs location around Todarpur in year 2016



Figure 13-47 : Spurs location around Todarpur in year 2018

2. The second location is Yamuna stretch between Palla to Wazirabad barrage. This area is protected with rural marginal embankments (RME) which in turn have affected river

morphology. The presence of embankments has bearing on velocity vectors, and thus affect natural process of sediment transport in this region. This resulted in formation of sandbars on the upstream of Wazirabad Barrage, also the change in radius of curvature for bend is seen. The bend visible in the year 1990 is damped and resulted in another bend on the upstream side which can be seen in the imageries of subsequent years (Figures: 13-48 to 13-51). This also highlight that the river is becoming more sinuous and finding the path for energy dissipation and sediment deposition along its way. From the above information, it can be said that flood control structures have affected the river morphology to a certain extent. However, it is not possible to term this stretch as either critical or stable as swing zone of the river is modified and it has not been exposed to extreme events in the past.

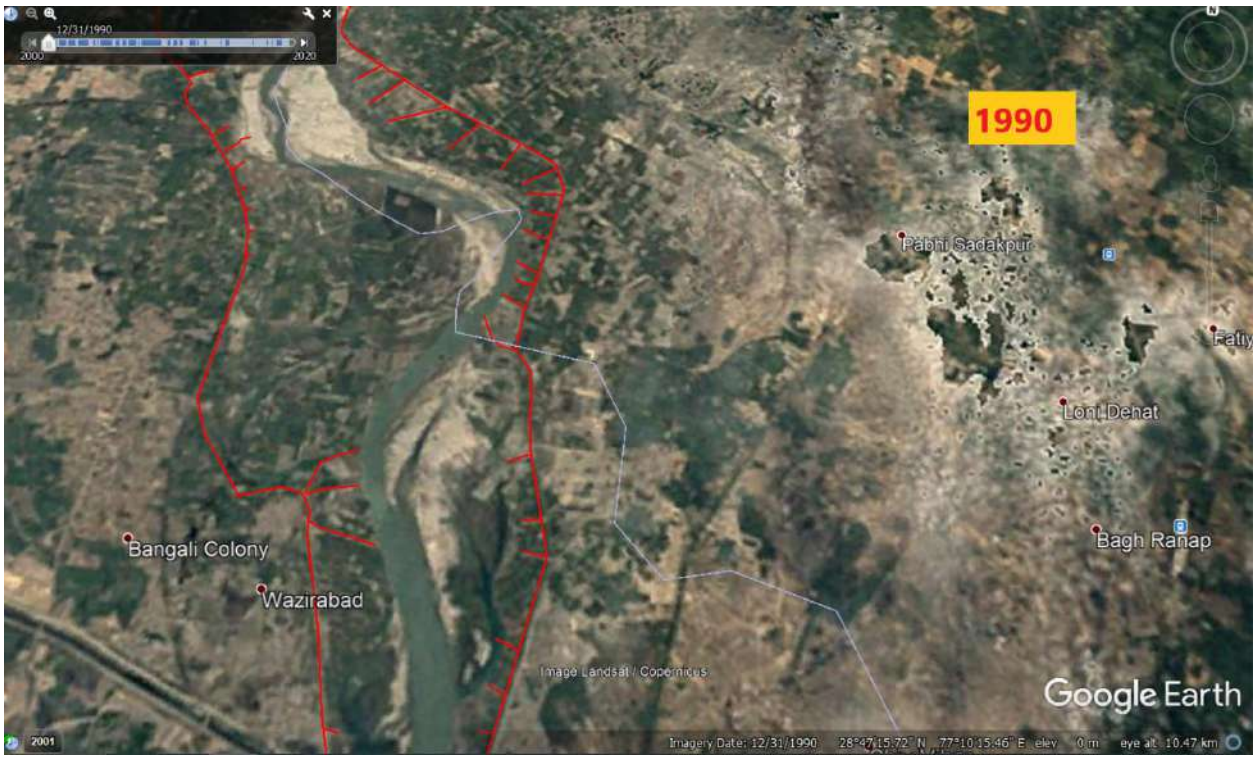


Figure 13-48: Palla to Wazirabad stretch of Yamuna River as seen in year 1990



Figure 13-49 : Palla to Wazirabad stretch of Yamuna River as seen in year 1999



Figure 13-50 : Palla to Wazirabad stretch of Yamuna River as seen in year 2012



Figure 13-51 : Palla to Wazirabad stretch of Yamuna River as seen in year 2019

On the other hand, presence of embankments results in flood control and associated exposure in the area. Though agriculture activities are seen in area within embankments, they are of temporary nature and thus allow river to utilize its floodplain up to the embankments during flood season. The other reality attached to embankments is that the area outside the embankment is allowed for construction activities. Moreover, by constructing the embankments, area belonging to paleo channels of the river have been filled up and settlements have come in those areas. For example, Batla House settlement as seen in following images in reverse chronologic order indicate the significant changes in channel morphology on account of anthropogenic activities. To capture the changes, a path (boundary line between settlement and adjacent floodplain) is drawn on 2018 image on Google earth which further overlaid on historical imageries (Figures: 13-52 to 13-56). From the figures, it is evident that channel area active during 1984 and 1990s has been transformed into settlement zone. From the image analysis, area of approx. 0.22 sq.km. is converted from channel to settlement zone during 1984 to 2020. Even the image of year 2000 indicate the active channel (of 0.1 sq.km.) is well within the boundary line. This also suggest that the more appropriate location of embankment should have given due weightage for active channel as seen in the years of 1984 and 1990s. Though, the flood protection measures are necessary to avoid loss of life and property, the possible impact of such structures on river morphology should be assessed. Moreover, hydrodynamic impact assessment studies should be carried out in preliminary phase of all future projects related to design and implementation of flood control structures.



Figure 13-52 : Embankment around Batla House settlement (based on 2018 google earth imagery) overlaid on google earth image of year 2018



Figure 13-53 : Embankment around Batla House settlement (based on 2018 google earth imagery) overlaid on google earth image of year 2008



Figure 13-54 : Embankment around Batla House settlement (based on 2018 google earth imagery) overlaid on google earth image of year 2000



Figure 13-55 : Embankment around Batla House settlement (based on 2018 google earth imagery) overlaid on google earth image of year 1990



Figure 13-56 : Embankment around Batla House settlement (based on 2018 google earth imagery) overlaid on google earth image of year 1984

13.4 Conclusion

Following are the major conclusions drawn with respect to the impacts of the structures on the river from the analyses of the imageries and the visit made to these sites.

1. Mostly changes in channel geometry are seen in downstream reaches of all barrages in comparison to their upstream reaches.
2. As much of the water is diverted from Hathnikund Barrage, lesser amount remained in the river channel which has resulted in reduction of active water area in downstream reaches.
3. In case of the Gokul barrage, gate operation policy may have impacted release pattern thereby affecting the riverbed downstream, which might have resulted in initiation of agricultural activities in the riverbed (riverbed adjacent to right bank of the river)
4. From the 2016 imageries, it can be said that flows are being released from all barrages in such a way that the river connectivity is maintained. As compared to initial years where disconnected water areas were seen downstream of Hathnikund barrage, present condition indicates continuously flowing river which is most likely related to environmental flow releases at Hathnikund.
5. From the analysis of impact of flood control structures, following conclusions can be drawn

- River morphology is affected due to embankments. The change in velocity vectors affect sediment transport phenomenon and ultimately affecting the erosion and deposition patterns in the river.
- Prior to design and construction of flood control structures (spurs, embankments etc), hydrodynamic impact assessment study should be carried out to understand the possible scenario post construction. This will ensure the optimized design and reduce the overall cost of work. It will also help in minimizing the adverse impact on river morphology on account of structural measures.

Chapter 14 Islands and Sandbars

14.1 Islands and Sandbars

The land feature which is formed in a water body (lake, river, ocean, etc.) and surrounded with water on all its sides is considered as an island. Typically, an island is above the water level at all times. This also suggests that even in high tide, an island will have at least part of its surface visible. Moreover, islands are more likely to be an outcrop with some form of geologic formation underneath. Therefore, island features are permanent and do not change very often. From geologic formation and foundation point of view, the island is significantly different from the bars.

A bar in a river is an elevated section of sediment that has been deposited by the flowing water. They can be categorised into mid-channel bars, point bars and mouth bars. The depositional pattern and settings of bars are driven by the geometry of the river and the quantum of flow through it. Presence of bars and their characteristics reflect upon sediment supply conditions and the transport capacity of the river.

A mid-channel bar is also known as a braid bar because they are mostly noticed in braided river channels. These kinds of river systems are characterised by a steep slope, high sediment supply, more stream power and bedload transport. The unpredictable channel patterns and varying sediment size of the braided system are responsible for the formation of mid-channel bars in the channel. Anastomosing river channels also produce mid-channel bars, but they are more likely to result in barrier island, which supports vegetation growth.

The other category of the bar is a point bar, and it is formed due to deposition typically observed in meandering rivers at the inside curve of meandering bend. The amount of sediment in excess of transport capacity settle down and over the period forms a point bar. These bars are mostly seen in the slow-moving and shallow parts of rivers and occupy the area farthest from the channel centerline on the outside curve of the river bend. Over an extended period, the combination of deposition along point bars and erosion along cut banks results in the formation of an oxbow lake.

A mouth bar is an elevated region of sediment mostly seen at the deltaic area near the mouth of a river into the ocean. It is mainly the result of widening of river width near the mouth, which

then translates in low flow velocities and finally results in sediment deposition at the mouth. As the sediment concentration increases across the mouth of the river, it builds up to eventually create a sand bar that has the potential to extend the entire length of the river mouth and block the flow.

14.2 Remote Sensing observations of Sandbars and Islands

From the satellite image observations, it is challenging to distinguish sandbars from islands. Though the indirect interpretation about sandbars and islands can be made from remote sensing data, confirmation from laboratory tests are essential. An indirect way of interpretation includes changes in shape, size and centroid of the sandbar/ island. The other characteristics include vegetation and land-use patterns.

In general, sandbars are temporary and vanish during flood seasons. However, with changes in flow characteristics (velocity, magnitude) and floods, some of the sandbars settle at specific locations and remains for several years and start supporting vegetation growth. For example, sandbars seen around the Chilka lake, Odisha feature dense vegetation which has a similar spectral signature as of forest. From remote sensing observation, one may interpret it as an island, though, from the ground observation, it is evident that it is a sandbar.



Figure 14-1: Sandbar around the Chilka Lake (Google earth image)

In reference to the study area, i.e., Yamuna Basin, a land feature located just upstream of Gokul Barrage, Mathura, is said to be an island as people have a historical claim on the land and settlement on the same is still going on. From the visit and discussion with local people and engineer posted at Gokul barrage, it was confirmed that the feature is an island. However, one

of the satellite images (the year 1987), as seen on Google earth platform, indicate the possibility of that feature to be sandbar, if not then just be part of the river channel. Therefore, conclusive evidence to suggest that the particular feature as a sandbar or island is not possible without going for geological investigation of the samples from the place.

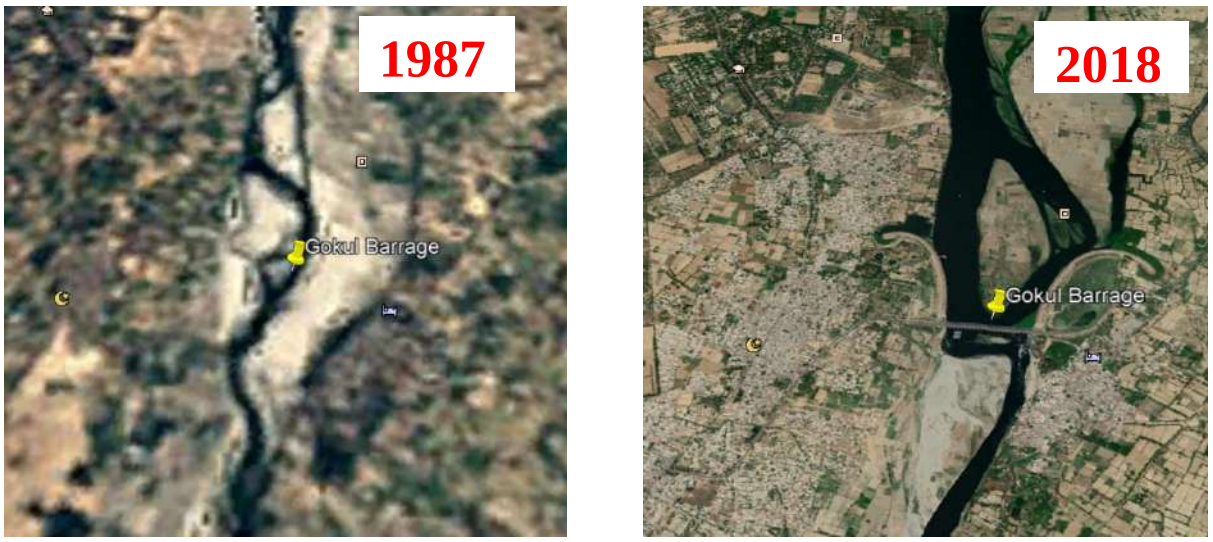


Figure 14-2: Land feature upstream of Gokul Barrage

14.3 The terminology used in the present study

Considering the limitations of remote sensing observations in distinguishing sandbars from islands, the present study attempts to define sandbars/islands based on their geometric characteristics and the period of their existence in the limited context of the scale of the present study. Sandbars and islands in the present study are categorised into two categories, i) permanent sandbars and ii) temporary sandbars.

i) Permanent Sandbars: These are islands or sandbars features observed in satellite imageries of River Yamuna for more than 30 years. Moreover, geometric properties, such as shape and centroid are constant. Though changes in size of these are observed, they are attributed to different flow conditions. Based on these characteristics and long period of existence, these are termed as permanent sandbars.

ii) Temporary Sandbars: These are sandbars or islands features which are visible in satellite imageries nut not in a consistent manner. Geometric properties of these features have changed over a period. Significant changes in centroid, shape and size of these features, shifting of these features over a period indicate their temporary nature. Thus, these features are termed as temporary sandbars.

Discussion on the some of the permanent sandbars analysed using remote sensing imageries is presented here. These features are listed here based on their location (from Prayagraj to Yamunotri).

1. Permanent sandbar near Piparhata village, Prayagraj

   This feature is located at 9 km from Sarai Aquil in Prayagraj. The shape of the feature remains same from the year 1975 up to the year 2016. However, a decrease in size of the landmass is observed which is most likely the result of variations in flow conditions and flood events. Area of this feature is 4.97 sq. km, with its length and maximum width being equal to 8 km and 0.9 km respectively. Cultivation and forest growth have been observed in parts on this feature. Satellite imagery of the year 2010 indicate presence of dense forest along the right length of the island and signatures of cultivation along the left length of the island.

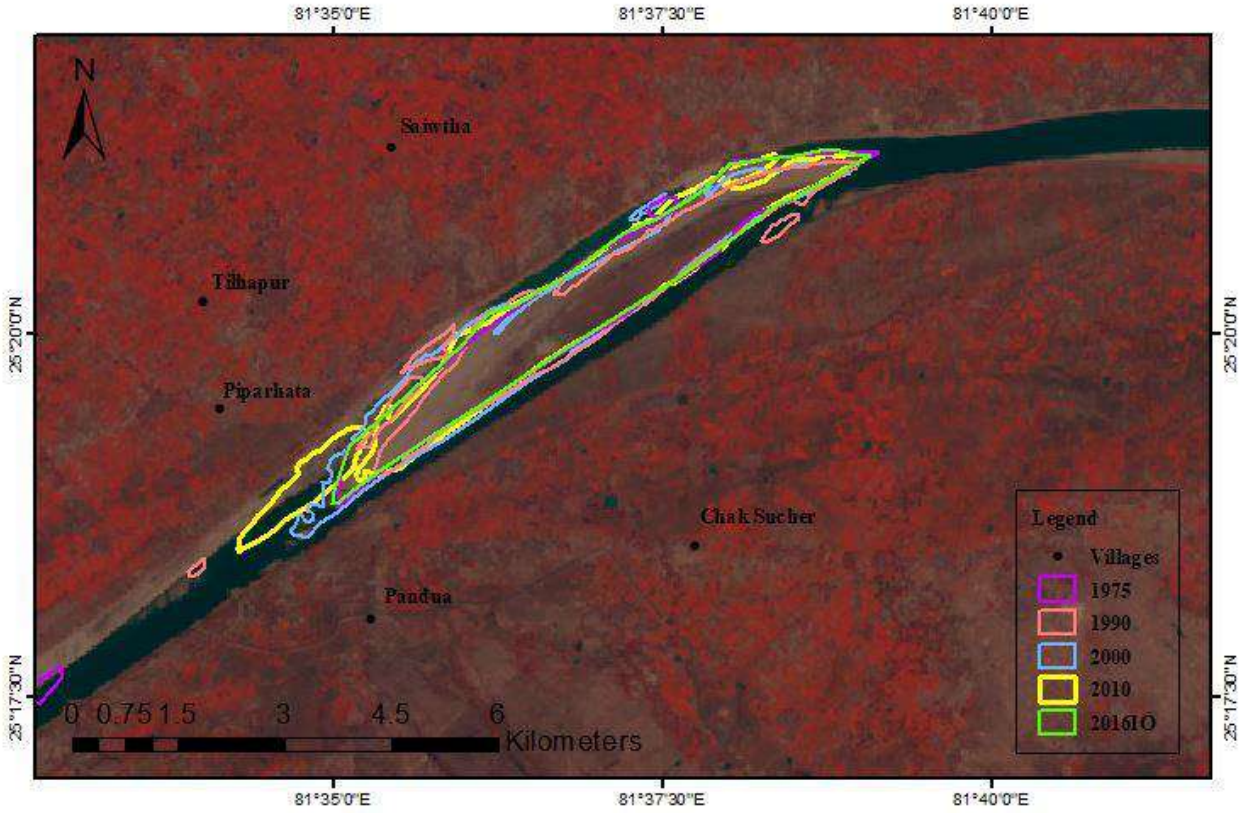


Figure 14-3: Permanent sandbar near Piparhata village, Prayagraj

2. Permanent sandbar near Siluata Ahmatali, Kaushambi

   It is located near Siluata Ahmatali, in Kaushambi & Manjhanpur districts in Uttar Pradesh. It exhibits similar geometric characteristics like shape and centroid for the entire period of study. Area of the feature is 0.70 sq. km with a length of 1.98 km and

a maximum width of 0.47 km. The land use analysed from satellite images indicates the fallow land up to the year 2000. From the images of 2003 and 2010, changes in land use pattern have been seen and an increase in agricultural activities has been noticed. Satellite image of the year 2016 imagery shows crops and trees grown evenly all over the island in well-defined rectangular patterns with trace of pathways which can be attributed to grazing by animals.

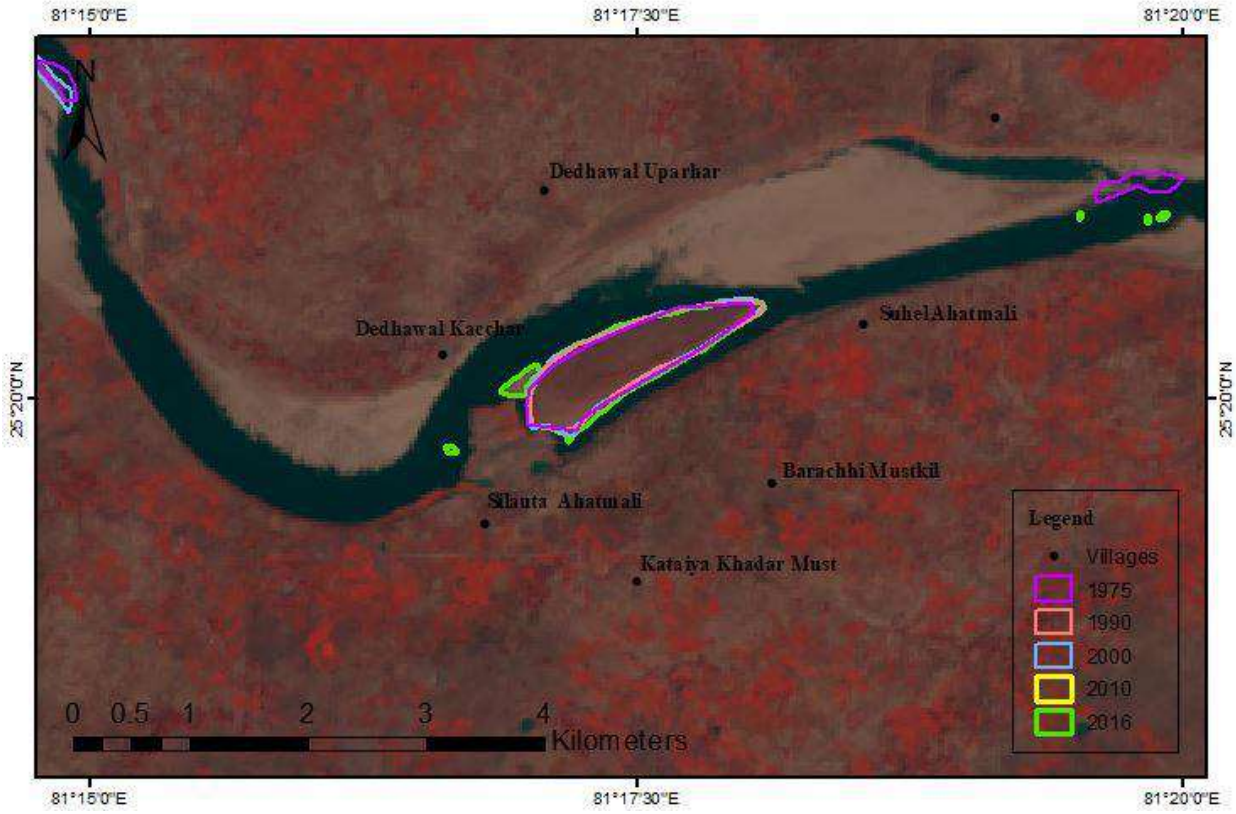


Figure 14-4: Permanent sandbar near Siluata Ahmatali, Kaushambi

3. Permanent sandbar near Patia, Hamirpur

This land feature is located 18km upstream of Hamirpur, in Uttar Pradesh. Area of the feature is 3.5 sq.km with a length and maximum width of 7km and 0.7km respectively. Vegetation signature has been observed at both the edges of the island, which reduces greatly from 2010-2016. From 1975-2000 it is divided in 3 fragments which consolidates to one big piece of an island after 2000 and remains like that up to 2016.

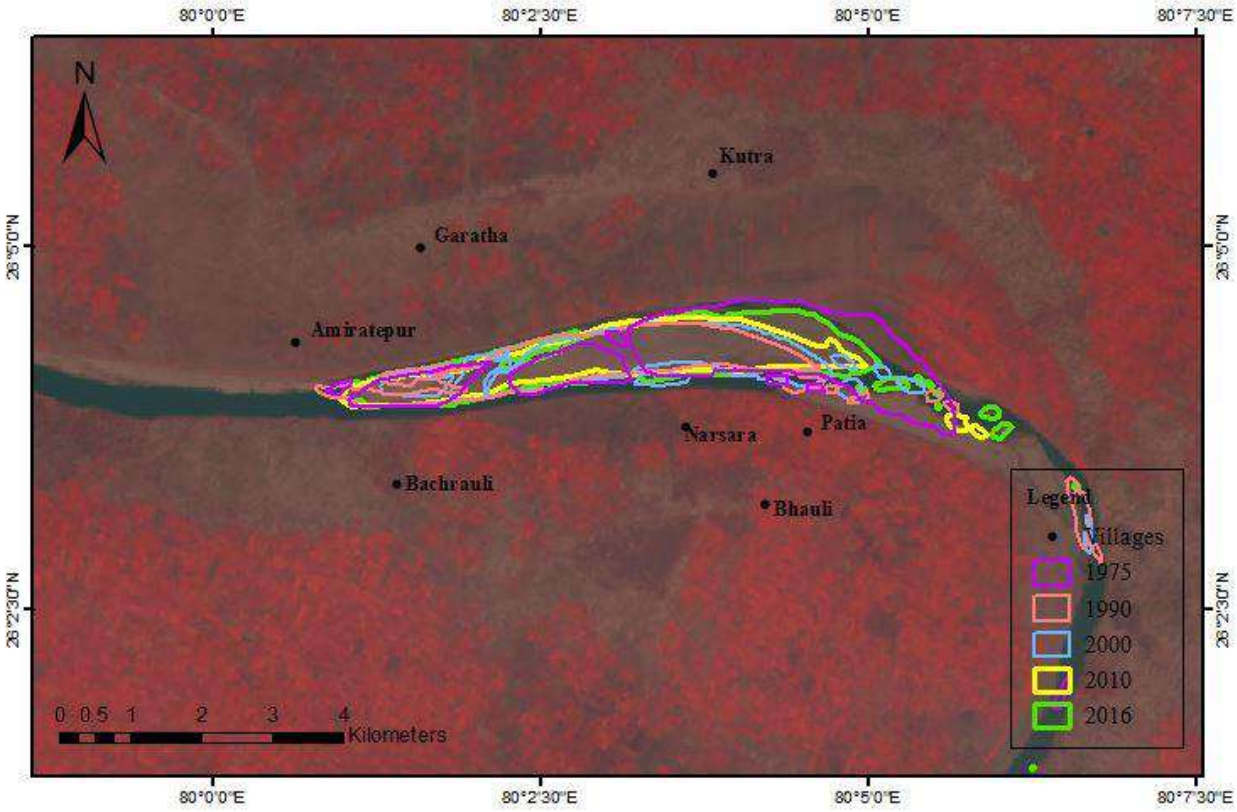


Figure 14-5 : Permanent sandbar near Patia, Hamirpur

It is located at 2km beside Katar in Uttar Pradesh. The area is observed to be 1.92 sq.km, with a length of 4.7 km and an average width of 0.53km. Unmanaged vegetation of shrubs has been observed since 2003, which reduces as time progresses and gets completely eliminated by 2016. Though not much vegetation growth and agriculture activities are observed on this feature, this piece of land in river Yamuna maintains the uniformity in shape and centroid from 1975 to 2016.

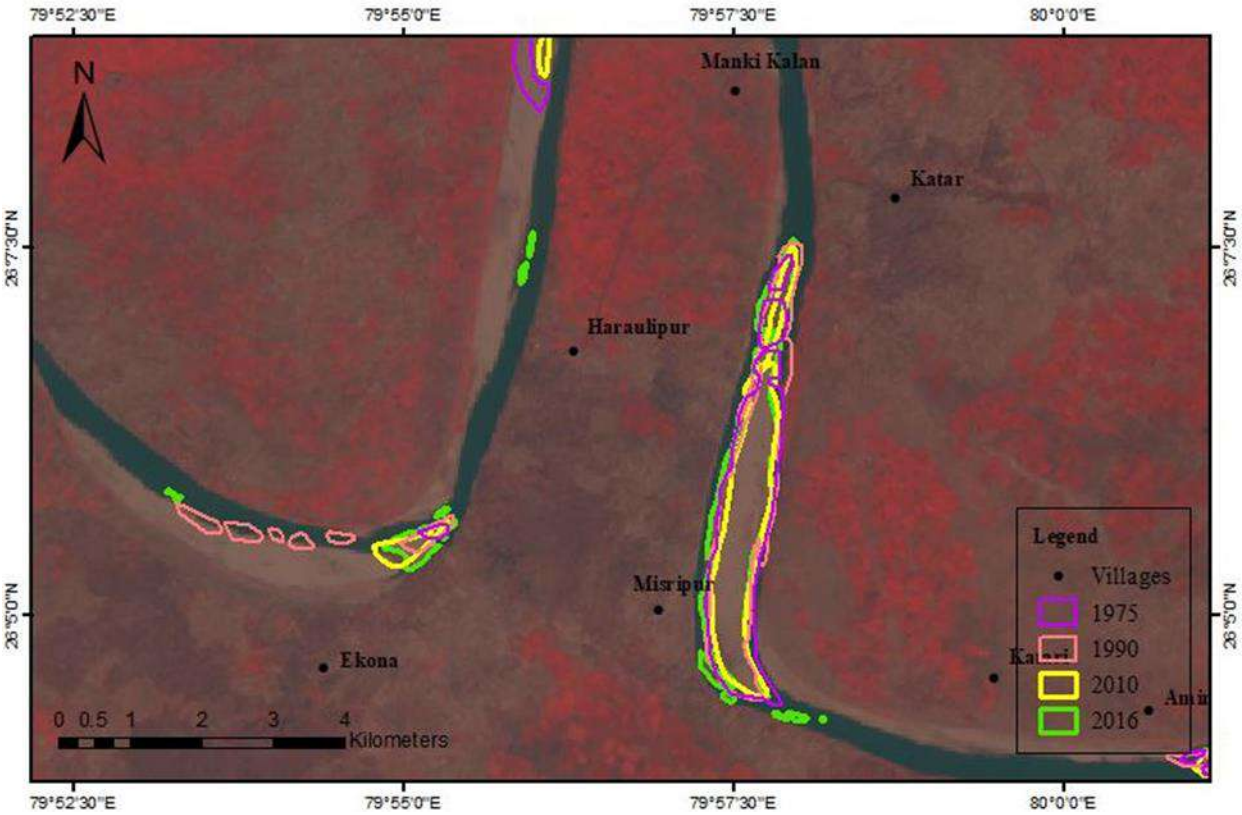


Figure 14-6: Permanent sandbar near Misripur, Katar

4. Permanent sandbar near Gauhani Kachhar, Auriya

   This feature is located at 10km downstream of Auraiya in Uttar Pradesh. The area of the feature is 2.08 sq. km, with a length of 4.48 km and a maximum width of 0.68 km. Between the year 1975 and 1990, the centroid of the island has shifted downstream; however, it becomes stable and does not go through change up to the year 2016. Changes in land use pattern such as vegetation growth and cultivation along both sides of the feature are observed; however, the rate of change (i.e. presence and absence of vegetation) is quite high.

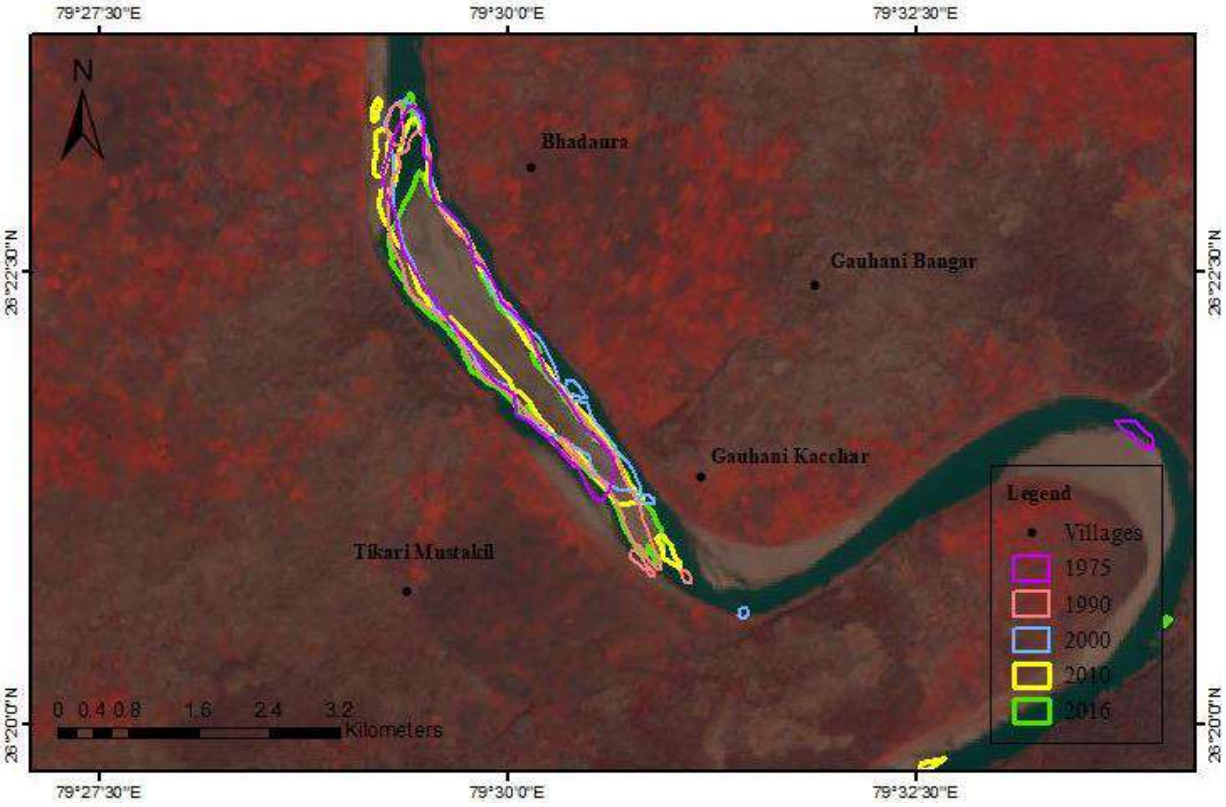


Figure 14-7: Permanent sandbar near Gauhani Kachhar, Auriya

5. Permanent sandbar near Bisrana, Agra

   It is located near Bamrauli Katara, at 12km downstream of Agra City. Geometric characteristics of the feature, like centroid and shape remain constant from the year 2000 to the year 2016; however, the changes in size are observed over a period. From the year 2000 up to the year 2016, spectral signature and patterns from satellite imageries indicate significant agricultural activities.

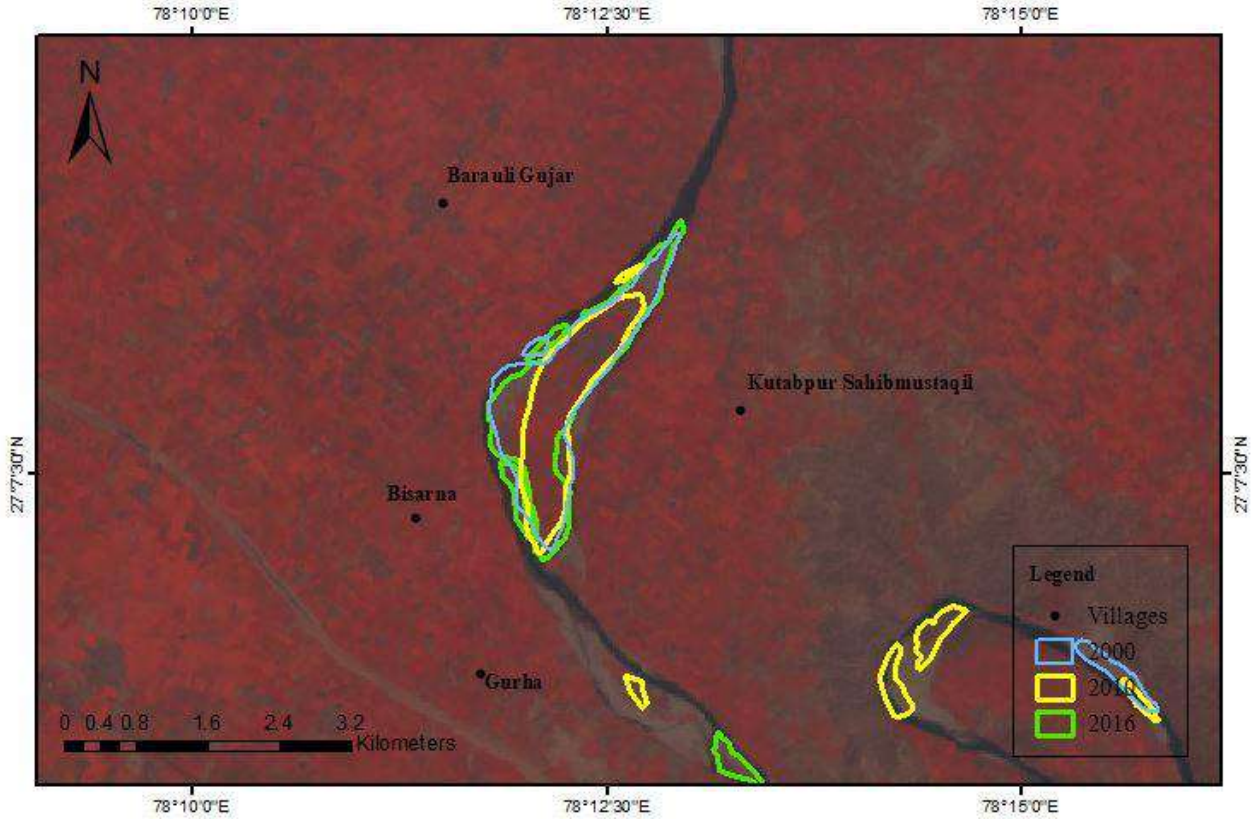


Figure 14-8: Permanent sandbar near Bisrana, Agra

6. Permanent sandbar near Gokul Barrage, Mathura

   This feature is in the pondage area of the Gokul Barrage. Area of the island by 2016 is about 0.35sq.km, with a length and maximum width of 1.2km and 0.4km respectively. The land-sat imagery represents variations in the area of Gokul island between the years 2000, 2010 and 2016. The change in the size of this feature is most likely result of barrage construction and its operation. From the satellite imageries, it is evident that this land is used primarily for agricultural activities.

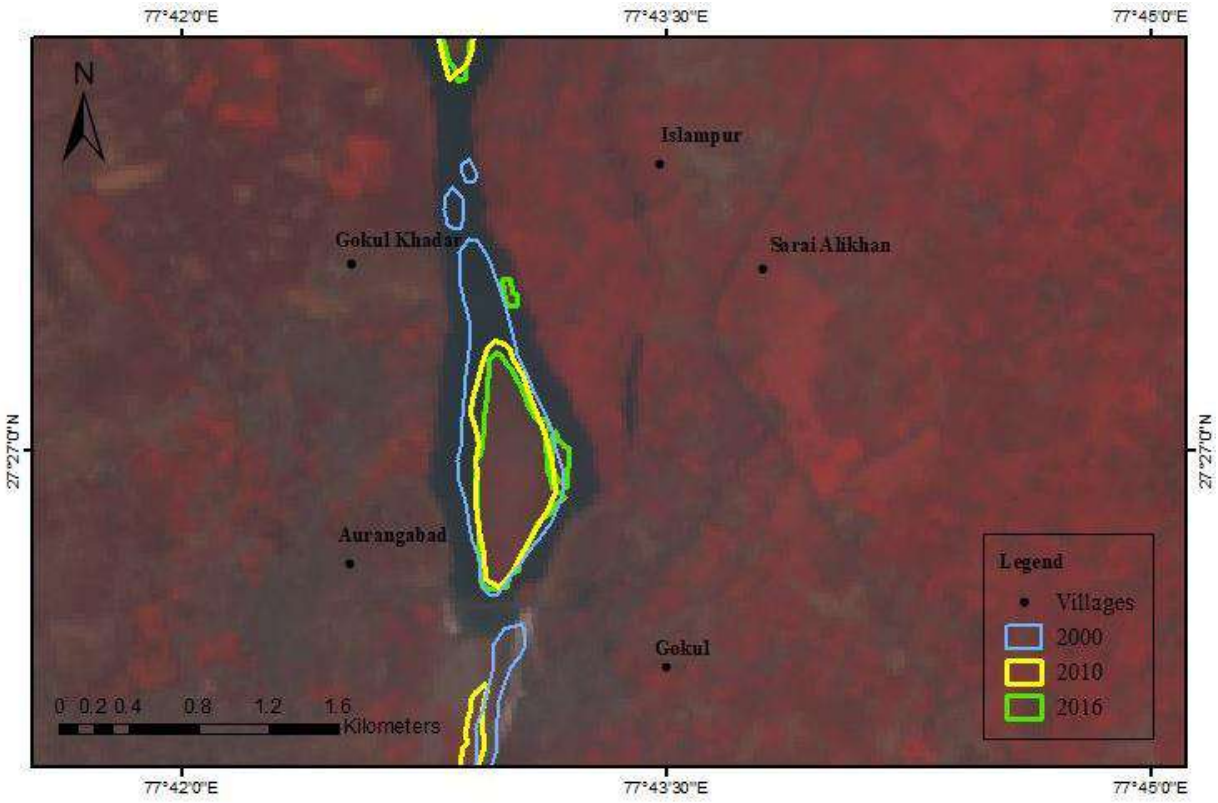


Figure 14-9: Permanent sandbar near Gokul Barrage, Mathura

7. Permanent sandbar near ITO, Delhi

   It is located downstream of ITO in Delhi. It has increased in size from 2000 to 2010 and remained constant up to 2016. Area of the feature is 0.2sq. km, with a length of 0.9 km & maximum width of 0.3 km. Area of the land is completely covered with agricultural activities. An important roadway, Subhash Chandra Bose Marg & Railway line passes over the island as can be seen from the figure below.

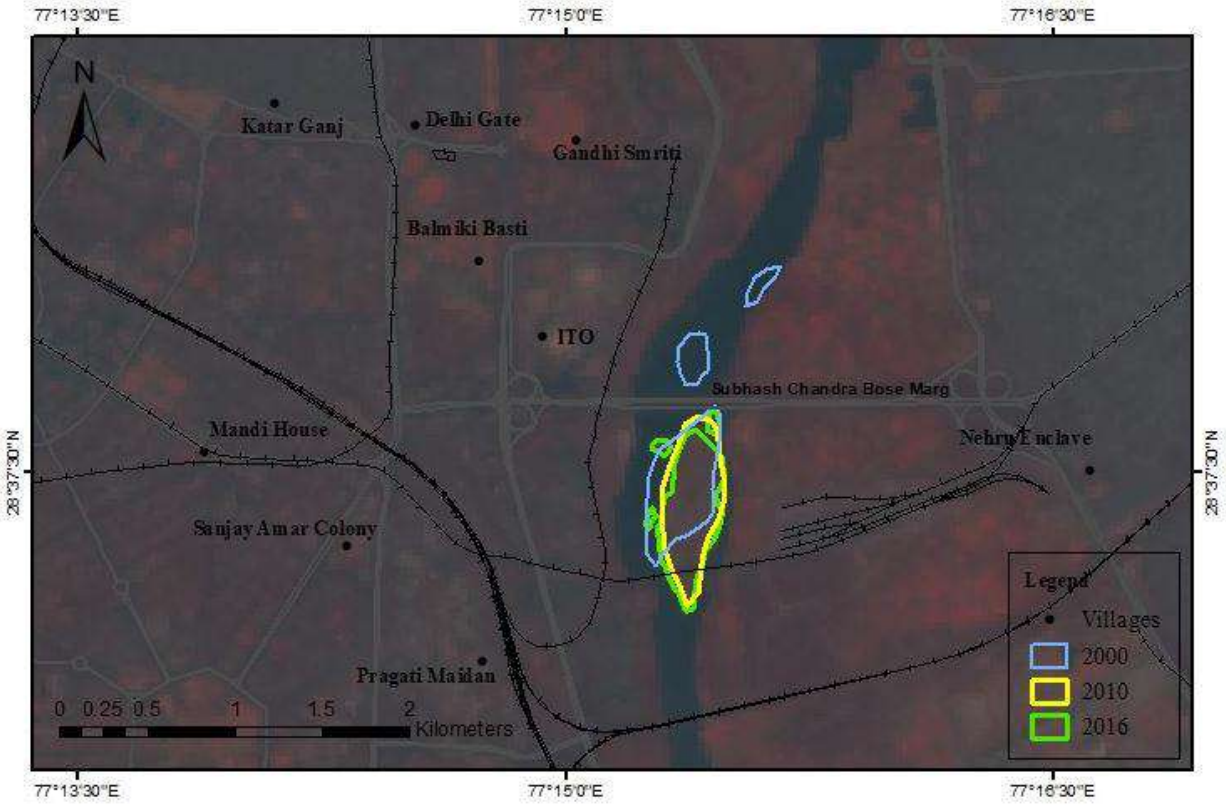


Figure 14-10: Permanent sandbar near ITO, Delhi

8. Permanent sandbar near Hathnikund Barrage (immediate upstream location)

   It is located at 2km downstream of Kalesar in Haryana. The feature is situated in the upstream reach of the Hathnikund barrage. It covers an area of 1.55 sq. km, with a length and maximum width of 3km and 0.75km, respectively. The land is covered with shrubs and trees; however, no particular cultivation patterns have been observed in any part of the land. The right side of the river water along the left side of the sandbar dries up in non-monsoon seasons.

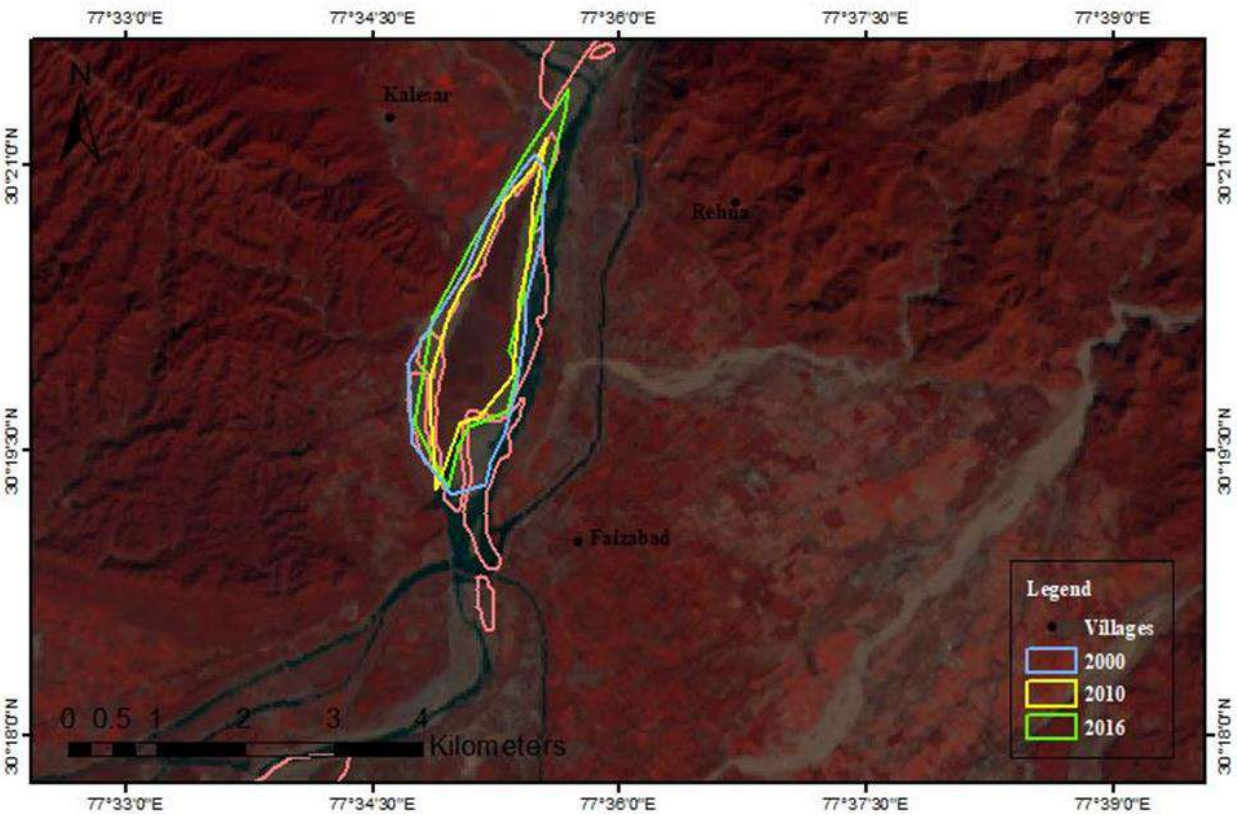


Figure 14-11: Permanent sandbar near Hathniund Barrage (upstream location)

9. Permanent sandbar near Kalesar (2km upstream)

   This land feature is located at 2 km upstream of Kalesar, Haryana. It occupies an area of 1.62sq. km, with a length of 2km and a maximum width of 0.85km in Yamuna River. This feature is visible across the entire time scale of the study, i.e., from the year 1975 to the year 2016. The centroid of the sandbar shifts towards the left during 1975-1990, after which it remains stationary. The deposition of sand/silt support vegetation growth and the same is visible from the satellite images of the year 2000, 2010 and 2016. The changes observed with respect to position, shape and size are indicated in Figure 14-12.

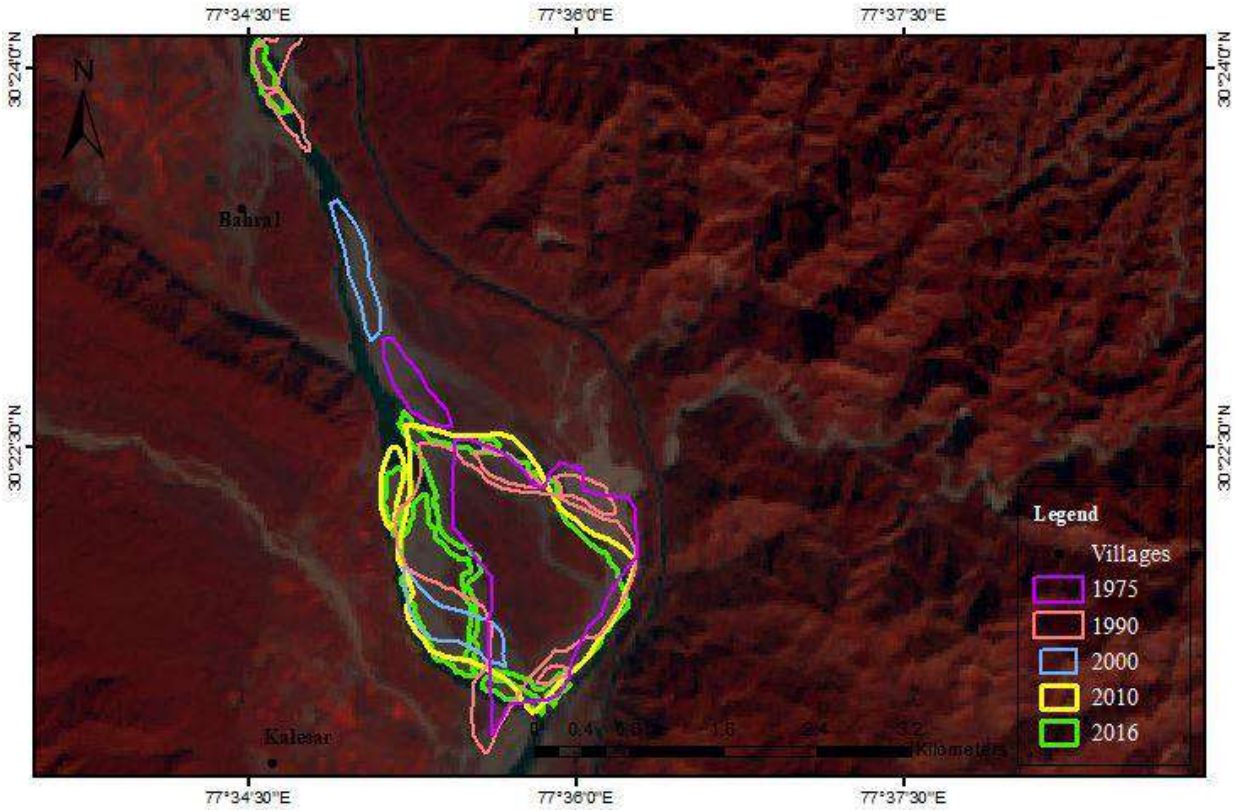


Figure 14-12: Permanent sandbar near Kalesar (2km upstream)

10. Permanent sandbar near Poanta Sahib (3km downstream)

    It is located at 3 km downstream of Poanta Sahib in Himachal Pradesh. This feature retains its geometric characteristics from the year 2000 up to the year 2016. It has an area of 0.93 sq. km, spread across a length of 1.6km with a maximum width of 0.67km. The central portion of the sandbar is covered with the growth of shrubs from the year 2000 up to the year 2016. The flow of the river is along the right side of the sandbar during the non-monsoon season.

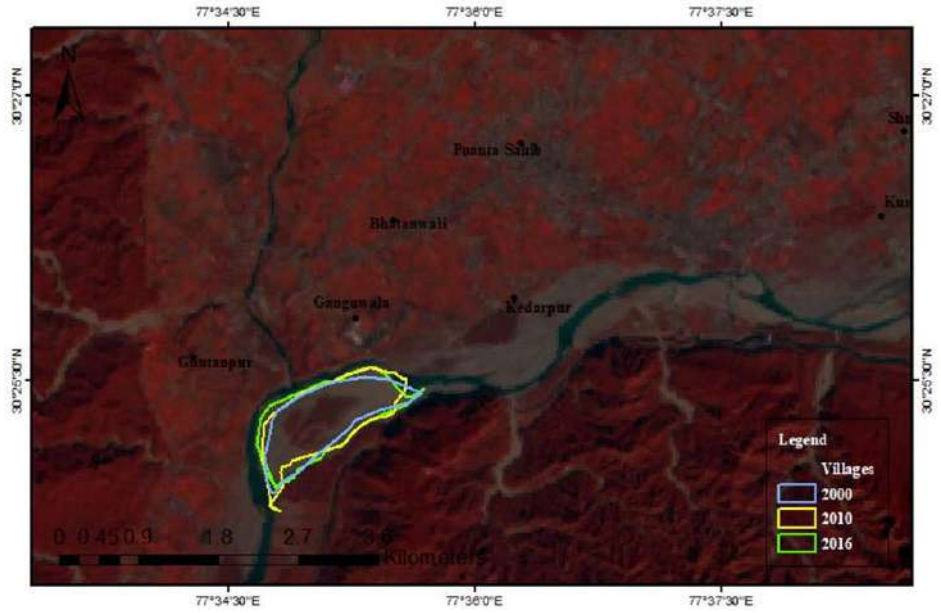


Figure 14-13: Permanent sandbar near Poanta Sahib (3km downstream)

A few sandbars/ islands features located upstream of Poanta Sahib are also seen. However, considering the resolution of data, not much information about land use pattern, vegetation growth and cultivation can be drawn. Therefore, changes in their area in respective years on decadal time scale have been considered in the estimation of channel bank retreat on account of erosion-deposition.

14.4 Conclusion

From the above analysis of sandbars/ islands, it can be concluded that

i) Differentiation of sandbars and islands is not possible based on remote sensing observations only, and laboratory-based analysis is required to identify appropriate geologic foundation to establish the conclusive evidence.

ii) From the high-resolution data, land use pattern of the feature can be established, which in turn may be used to define the risk, based on associated vulnerability. In the present study, Landsat MSS, TM, ETM+, and Landsat 8 along with IRS satellite images and data from Google earth have been used to identify land use pattern like fallow land, shrubs, forests, agriculture and cultivation practices, etc.

iii) In the limited context of morphological study using remote sensing technique, sandbars or islands which are used for agriculture activity are identified based on the signature and adjacent land use patterns. If the same piece of land is lawfully owned by farmers, then it may be considered as a critical segment for some of the return period flood events, more specifically higher return period floods.

Chapter 15 Modelling Study

15.1 Introduction

In this chapter, modelling studies undertaken in the context of the morphological study of Yamuna River have been discussed. Modelling activities include 1D hydrodynamic modelling to capture discharge vs river width relationships at hydrological observation sites of interest, followed by meander migration modelling for understanding future river channel movements on account of migration.

15.2 1D Hydrodynamic Modelling

One-dimensional hydraulic modelling has been performed using HEC-RAS model (version 5.0) to obtain top width for selected flows at various sites of interest. HEC-RAS is an open-source software developed at the Hydrologic Engineering Centre of the Institute for Water Resources, U.S. Army Corps of Engineers and this version facilitates 1D steady and unsteady state channel hydraulic estimations (Brunner, 2010). In the application of HEC-RAS, due to lack of boundary condition data (Stage hydrographs) to perform unsteady-state hydrodynamic modelling, a common approach of steady-state analysis with the boundary condition of normal depth has been applied.

15.2.1 Model Setup

With the help of available cross-sections at 10 km interval from Poanta Saheb up to Gokul Barrage, HEC-RAS 1D hydrodynamic model was set up to determine flow vs channel width relationship. Figure 15-1 demonstrates the total number of cross-sections used for HEC-RAS modelling of Yamuna main stretch for obtaining top width for HO sites of interest. Width corresponding to 2-year return period has been found out with the help of steady-state simulations at the HO sites.

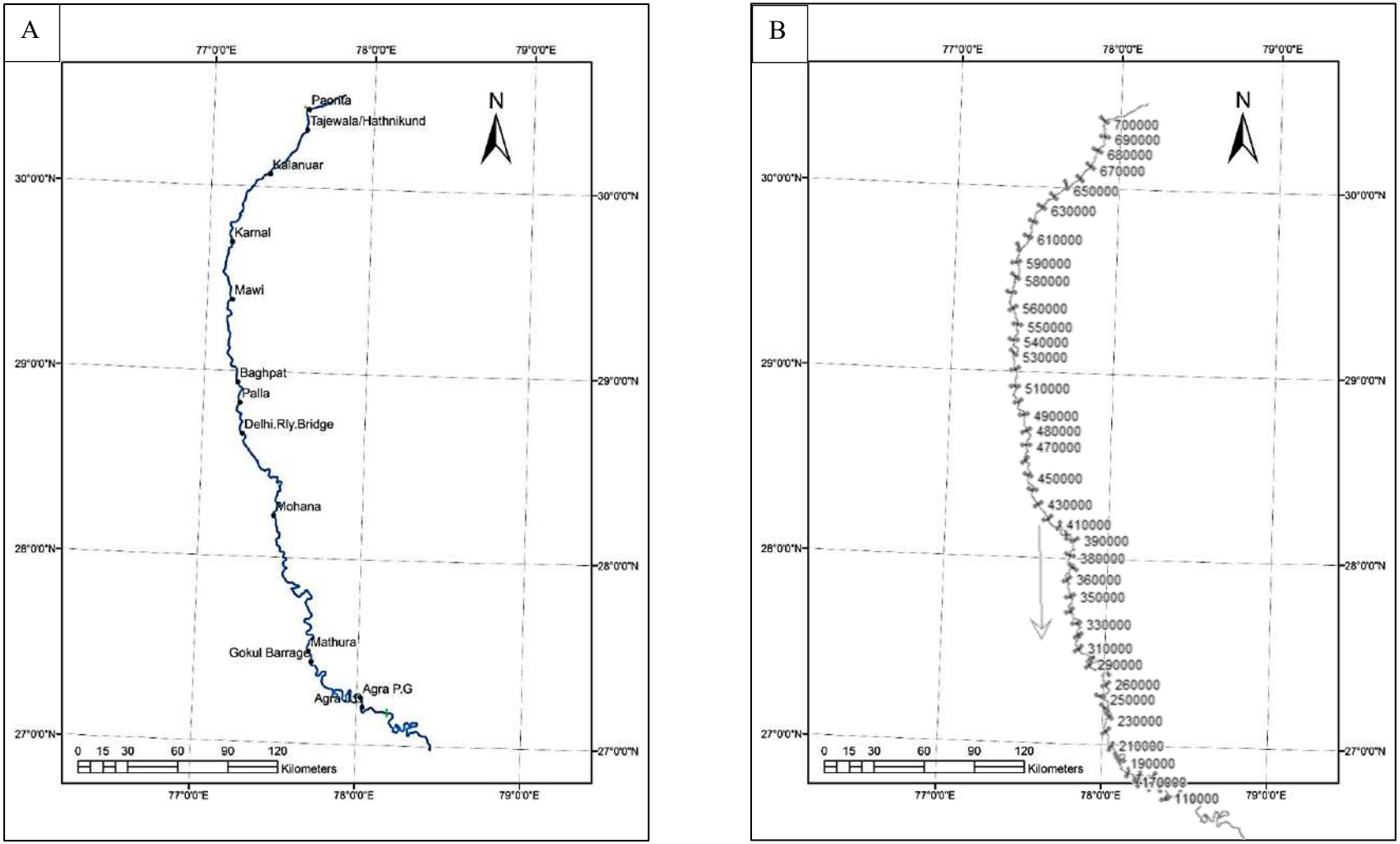


Figure 15-1: (A) Yamuna main stretch and HO sites; (B) HEC-RAS model set-up with cross-sections

15.2.2 Flow and River Width Relationship

The 2-year return period flood is considered as a discharge that governs the morphological changes. Accordingly, flow vs width relationships have been obtained for 2-year return period flood. Two approaches have been used:

1. HEC-RAS modelling using observed cross-sections
2. Remote Sensing images

For analysing flow width with the remote sensing technique, spectral signature and tonal variation of vegetation, sand and water have been used. The active water area and adjacent channel area are considered in combination as channel width in the present study.

Table 15-1: River Width corresponding to 2-year return period flood

HO Site	2-Year Return Period Flood Discharge (cumecs)	Flow Top width (HEC-RAS) model (meters)	Channel Width from Satellite Imagery of 2016 (meters)
Naugaon	292	35	42
Bausan	705	78	67
Kalanaur	2500	420	434
Karnal	2749	630	1070
Mawi	2710	369	271
Baghpat	2984	478	493
Delhi Railway Bridge	2593	453	320
Mohana	1405	228	226
Mathura	1708	279	268
Agra P.G.	1468	374	309
Etawah	1847	227	245

In the above table, width obtained from HEC-RAS modelling and that obtained from satellite imagery are juxtaposed for the HO sites. In a few cases, like Mawi and Delhi Railway Bridge significant differences between the widths from two approaches have been observed which can be attributed to location uncertainty, time of cross-section observation, impact of river training works if any, etc. However, considering overall results, it is possible to say that width obtained from HEC-RAS modelling for 2-year return period flood are of similar order of magnitude to that obtained from satellite imagery. Therefore, channel width considered in channel bank

retreat and understanding of river course dynamics using the remote sensing and GIS technique is analogous to the term bank-full width.

Flow Top width obtained from HEC-RAS modelling is then plotted against the square root of 2-year return period flood values to develop a relationship. Exponential Curve is fitted with R^2 value of 0.89. The plot and trendline along with equation in shown in the Figure 15-2.

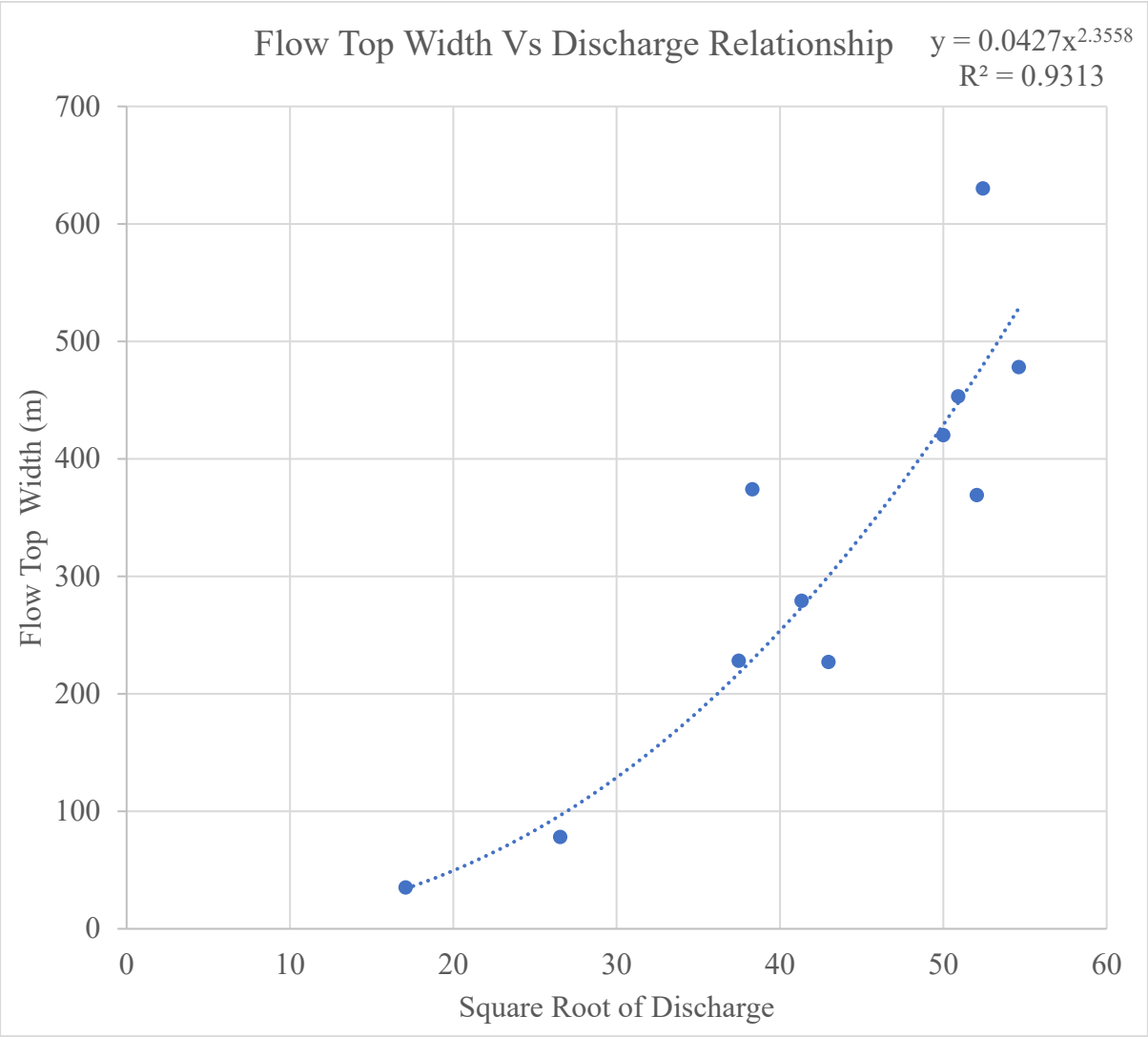


Figure 15-2 : Channel Width Vs Discharge Relationship

Meandering river bends are observed in natural river channels, at all scales, and in all parts of the world (Leopold et al., 1964; Thorne, 1992; and Leopold, 1994). This process becomes specifically important to people living in or near the floodplain or to organizations planning or maintaining infrastructure within or along the edge of the floodplain. Natural rates of channel migration can be accelerated by human or natural disturbance. For example, the clearing of floodplain vegetation can accelerate the rate of channel migration.

Under virgin state, meander bends tend to migrate naturally across the landscape (Brice 1977, Hooke 1984). Bend migration follows patterns that can be described by mechanical laws of fluid flow and by other methods (Brice 1974, Ikeda et al. 1981, Hooke 1984). When such migration occurs, an individual bend tends to move, unless constrained, both downstream and cross-stream. Considering this reality, it is essential to know the extent of channel migration for defining and prioritizing the particular stretch of river as stable or critical.

Therefore, modelling study in different stretches of the River Yamuna is proposed, and for the same, the Johannesson-Parker (JP) Meander Migration model is used.

The JP meander migration model (Johannesson and Parker, 1989; Larsen, 1995) is based on analytical expressions of sediment transport and fluid flow. It has been used to calculate how an alluvial river channel moves over time scales of years to decades. The model assumes that the local bank erosion rate is proportional to a local velocity factor such that

$$M = E_0 u_b \quad \text{.....1}$$

where M is the bank erosion rate (in meters per year), E_0 is a dimensionless bank erodibility coefficient of the order 10^{-8}, and u_b (meters per second) is a velocity factor equal to the difference between the velocity near the bank and the reach average velocity (Larsen and Greco, 2002). Higher E_0 values result in greater erosion potential. Based on land cover and geology data, erodibility potential was given values of $100*10^{-8}$ and $200*10^{-8}$ for natural vegetation and agricultural lands respectively. For geologically constrained areas it was given a value of zero.

The model requires six input values which represent the hydrology of the watershed and the hydraulic characteristics of the channel (initial channel planform location; bank-full discharge; reach average width, depth, and slope; and field measured median particle size of the bed material). The reach average width and depth are measured at a characteristic discharge (bank full), and the slope is the average water surface slope for the reach at the characteristic discharge. Using these input data, the model calculates other parameters required to predict the channel migration.

The model inputs relevant to this discussion are Depth (H), Slope (S), Width (B), Discharge (Q), and Grain Size (D). Friction (C_f) in the JP model is handled using a friction coefficient defined by:

$$C_f = \frac{\tau}{\rho U^2} = \frac{\rho g H S}{\rho U^2} \quad \text{.....2}$$

where:

$\tau =$ bed shear stress in the downstream direction

$\rho =$ denstiy of water

$g =$ gravitational acceleration

$H =$ average Depth

$S =$ average downstream slope

$U =$ vertically average velocity.

C_f is thus computed from the inputs $\rho, g, H, S,$ and U. The mean velocity U is computed by integrating a form of the logarithmic law of the wall. A generalisation of this is shown in Equation 2, for details refer Johannesson and Parker, (1989) for the specific formulation used:

$$U = \int_{bed}^{surface} \frac{\sqrt{gHS}}{\kappa} \ln\left(\frac{z}{k_s/_{30}}\right) dz \quad \ldots\ldots 3$$

Where,

$z =$ elevation from the bed

$\kappa =$ von Karmen′sconstant (0.4)

$k_s =$ rougness length (often we assume $k_s \sim D$ in the absence of dunes and bars)

and, Manning's n value as an initial check for internally consistent model inputs.

$$U = \frac{1}{n} H^{2/3} S^{1/2} \quad \ldots\ldots 4$$

where:

$n =$ Manning′s n

Solving for U and rearranging equations reveals how n and C_f are related.

$$n = H^{1/6} \sqrt{\frac{C_f}{g}} \quad \ldots\ldots 5$$

In the JP model version included in iRIC platform, the model inputs include $B, Q, H, S,$ and D. In iRIC platform there is a C_f scaling term, which further allows to alter the friction coefficient without substantially changing the hydraulics.

The output of the migration model depends on local hydraulic conditions through the hydraulic and geomorphic input variables and the heterogeneous erosion surface. The erosion coefficient is calibrated with a channel planform centerline from two points in time. The average annual rate of migration is calculated by mapping sequential channel centerlines and then quantifying the change in location of a channel centerline over time (Fremier, 2003).

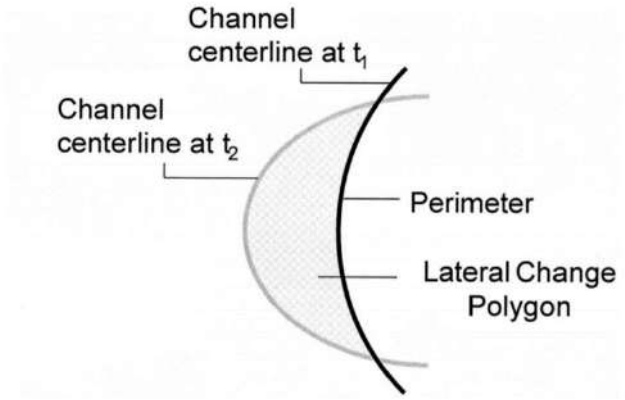


Figure 15-3: Change in location of a channel centerline over time

Using ArcGIS, an eroded area polygon is created by intersecting two channel centerlines mapped at two instances in time. The channel migration rate is then calculated as,

$$R = \frac{A_r}{t*L} \quad \ldots\ldots 6$$

Where R is channel migration rate, A_r is the area between two centerlines, L is average channel length of two centerlines for a given bend and t is the time in years that had elapsed between the two channel centerlines. The above equation calculates the migration rate as a linear distance per time. In the present study, channel centerlines of year 2000 and year 2010 have been used. The calibration process consists of adjusting the geomorphic and hydraulic parameters in the simulated migration until the simulated migration from 2000 to 2010 closely matches the observed migration in the same time-period. Then the model is used to predict future channel predictions for the constant discharge conditions.

15.2.3 JP Meander Migration Model Setup for Yamuna River

For modelling of Yamuna system, the entire stretch of Yamuna is divided into various segments based on the concept of breakpoint. The breakpoint is the location which indicates regime change. As the changes in flow regime are possible on account of natural and anthropogenic activities, many such breakpoints are possible. In the present study, breakpoints are determined based on hydraulic structures (dams, barrages, bridges) and confluence points. These breakpoints also reflect on changes in river width as observed from satellite imagery. In the present study, channel characteristics such as depth, width, slope, grain size and discharge are considered whereas flood control walls, embankments etc., are not used in the model set-up. However, presence and possible impacts of such structures are discussed while presenting the

simulation results to determine the stability of such reaches. Accordingly, following stretches of Yamuna have been modelled:

1. Yamunotri to Tons-Yamuna confluence
2. Tons-Yamuna confluence to Dakpatthar Barrage
3. Dakpatthar Barrage to Giri River confluence
4. Giri River confluence to Hathnikund Barrage
5. Hathnikund Barrage to Kalanaur Bridge
6. Kalanaur Bridge to Karnal Bridge
7. Karnal Bridge to Baghpat HO site
8. Baghpat HO site to Okhla Barrage
9. Okhla Barrage to Gokul Barrage
10. Gokul Barrage to Chambal Yamuna confluence
11. Chambal-Yamuna confluence to Sindh-Yamuna confluence
12. Sindh-Yamuna confluence to Betwa-Yamuna confluence
13. Betwa-Yamuna confluence to Ken-Yamuna confluence
14. Ken-Yamuna confluence to Yamuna-Ganga confluence

Section-wise modelling results have been discussed below,

1. Yamunotri to Tons-Yamuna confluence

This stretch covers the length of 110 km. For initiating simulation, centreline of the year 2000 has been used, whereas centreline of the year 2010 is used for the purpose of calibration. Based on the set of parameters, centrelines for future years on decadal scale, i.e., 2010, 2020, 2030, 2040 and 2050 has been simulated. Figure 15-4 indicates the channel centrelines obtained from modelling study. Figure 15-4 is further zoomed in (Figure 15-5 shows only part of the total stretch as sample) to show the channel centrelines for different years of simulations [Background map used in Figure 15-5 is used to create the spatial context in order to relate the area in terms of road, railways, villages etc. Source credits for the same are also displayed in the map]. Based on the given set of conditions, i.e., number of nodes to define the bend and straight channel threshold (sinuosity) of 8 and 0.0005 respectively, number of bends and their characteristics have been worked out and tabled in Table 15-2 for the year 2000.

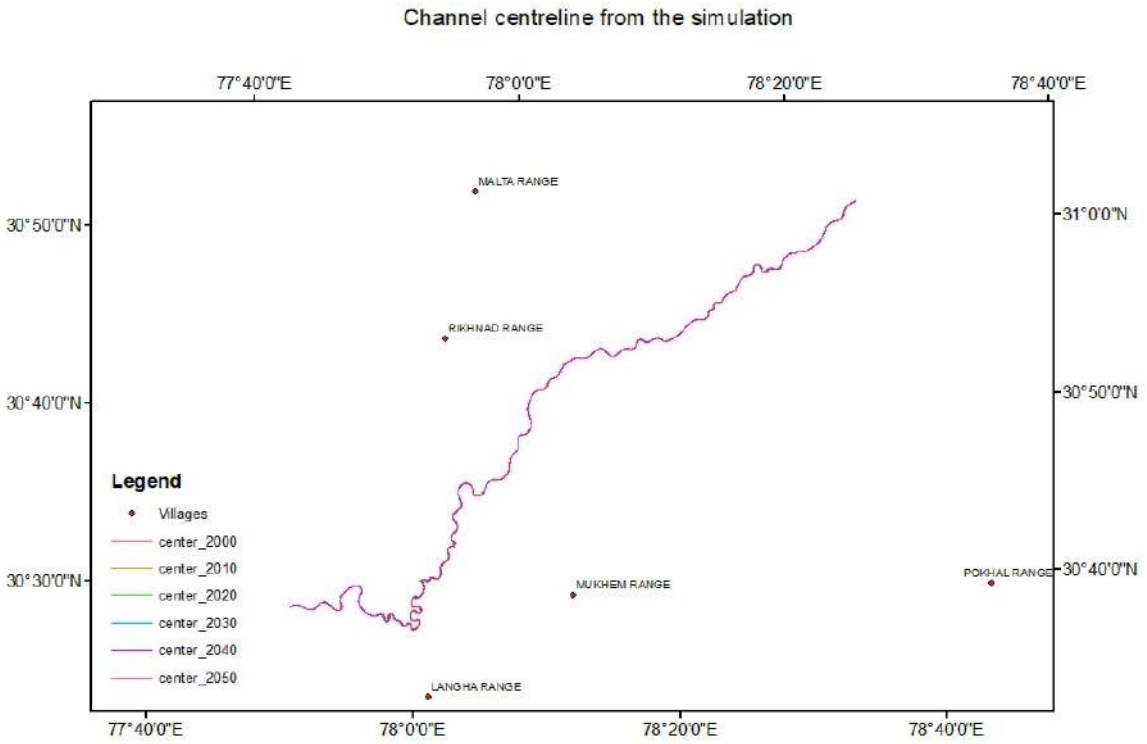


Figure 15-4: Channel Centerline for different years for the river reach between Yamunotri and Tons-Yamuna confluence

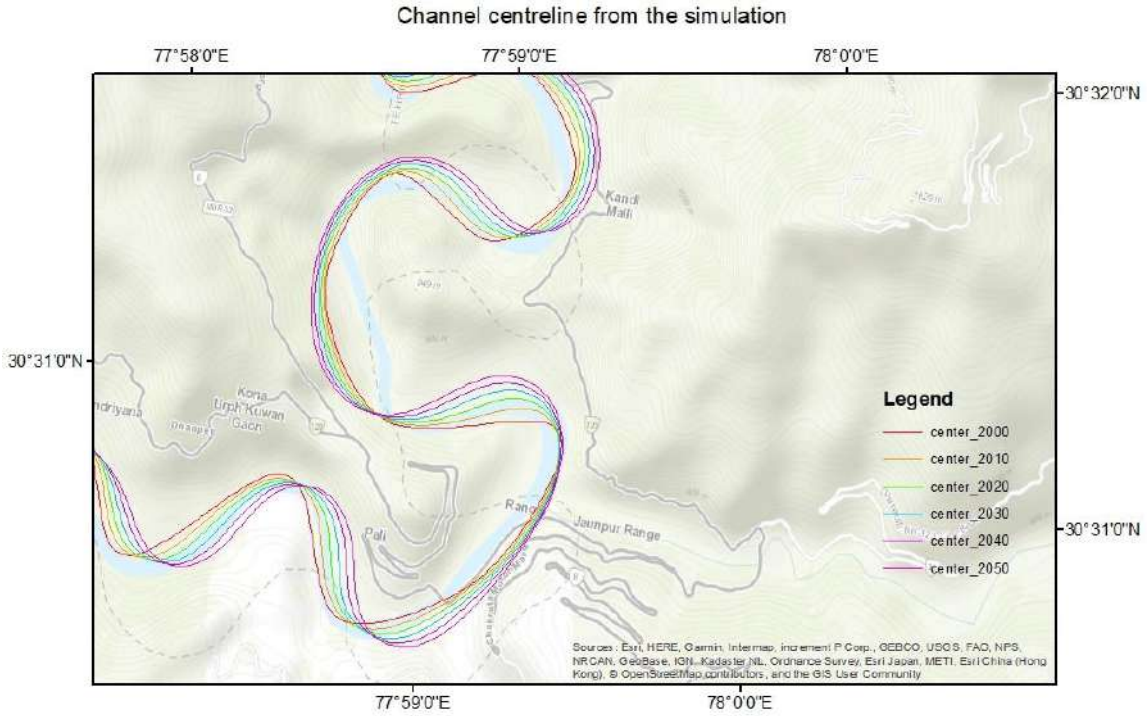


Figure 15-5: Channel Centerline from the modelling study

Table 15-2: Bend Characteristics for the river reach between Yamunotri and Tons-Yamuna confluence

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.0000000000	1706.7756111558	1636.3167384787	0.5069367265	0.3251632774	1.0430594340	2073.9464933920	0.0004821725	0.0009779165	600.1745508267
2	1706.7756111558	1875.5350649205	1742.8131420511	0.4278021199	0.5976634279	1.0761538456	-1829.3080755354	-0.0005466548	-0.0000104423	1725.5313537206
3	3582.3106760764	1875.5407593469	1670.1005839629	0.7221464430	0.6409164828	1.1230106602	1376.3343499554	0.0007265676	0.0019828032	4276.2530724731
4	5457.8514354230	37.4952964870	37.4952888382	0.0006382217	0.0006392537	1.0000002040	-29351.0991956689	-0.0000340703	-0.0000340703	5476.6142282295
5	5495.3467319103	150.1056747111	150.0298221399	0.0344927896	0.0580286255	1.0005055833	1624.0372512252	0.0006157494	0.0009704848	5588.9656869737
6	5645.4524066214	261.5183461564	257.3552524557	0.2343573794	0.2284810695	1.0161764474	-562.4616764226	-0.0017778989	-0.0001154664	5664.3306905004
7	5906.9707527776	75.1378700223	75.1348806704	0.0137259301	0.0112216173	1.0000397865	3013.7032662522	0.0003318177	0.0003994510	5925.8692448615
8	5982.1086227999	1237.5385911523	827.5829459122	0.8897977064	1.3930149997	1.4953650232	-543.4858245044	-0.0018399744	-0.0001646179	7200.9106806227
9	7219.6472139523	37.3707317934	37.3706753667	0.0017330157	0.0017425330	1.0000015099	10752.4912780243	0.0000930017	0.0000930017	7238.3837472820
10	7257.0179457454	150.5037277073	150.2995275093	0.0633055475	0.0848037667	1.0013586217	-1018.3519893597	-0.0009819787	-0.0003039904	7275.6521442088
11	7407.5216734529	220.7933435848	210.6749359319	0.3954349480	0.4375042928	1.0480285308	262.7552774785	0.0038058227	0.0063979327	7535.6323189654
12	7628.3150170375	113.4233665281	113.4083874947	0.0168922366	0.0240801158	1.0001320805	-2759.9446119135	-0.0003623261	-0.0000531154	7647.5357857511
13	7741.7383835658	4012.9761810702	2451.2793913163	1.0632902023	2.3490081537	1.6370945700	1176.8135956677	0.0008497522	0.0038494974	11210.9869651828
14	11754.7145646360	3825.9611135399	3108.1860932019	1.3661426990	1.1178768584	1.2309305166	-1540.5840456938	-0.0006491045	-0.0000053749	15561.9375699827
15	15580.6756781760	899.7523155295	718.7275320078	0.8671881868	0.7662623269	1.2518684417	552.1859046207	0.0018109843	0.0053709063	16011.9783128953
16	16480.4279937054	1160.1508325593	576.3687793054	1.4602176880	1.6716926950	2.0128620325	-370.7318797976	-0.0026973672	-0.0001225705	16499.1579682912
17	17640.5788262646	1011.5874681449	694.9510677256	1.9601827948	0.9329944311	1.4556240218	348.2966482494	0.0028711158	0.0106791139	17809.2533451911
18	18652.1662944096	637.5896046441	600.0300675583	0.4742630949	0.4513128690	1.0625960916	-689.4672441951	-0.0014503952	-0.0001795406	19270.9411754585
19	19289.7558990538	675.1701427390	594.0382802539	0.6173764735	0.6440597878	1.1365768254	536.1103223735	0.0018652877	0.0045784256	19645.9688672615
20	19964.9260417928	711.6911227019	515.4451680216	1.2034986588	0.7272143887	1.3807310008	-369.7546786845	-0.0027044959	-0.0000102623	19983.5598795273
21	20676.6171644949	824.2730865979	579.4071618779	0.8142821343	1.1215177275	1.4226145979	427.0580051288	0.0023416023	0.0083179764	21145.2201327133
22	21500.8902510924	2209.9325213421	984.9509373737	1.9385328908	2.6656277946	2.2436980742	-479.3021929664	-0.0020863664	-0.0000859820	23542.8074585237
23	23710.8227724348	2061.5649671675	1001.9024946662	1.3831818853	2.5421342204	2.0576502984	525.8181658664	0.0019017981	0.0073501740	25528.7695730308
24	25772.3877396023	1724.0772477284	528.1464521095	2.1039089971	2.0112517535	3.2643923685	-419.5334832680	-0.0023836000	-0.0000104628	25791.0508898019
25	27496.4649873308	1686.1378166571	955.7665058196	1.7786118013	1.8484684587	1.7644254181	465.9661865577	0.0021460785	0.0072339466	27815.3520241265
26	29182.8437039878	2137.7393492358	1696.3620602273	1.3254566889	1.2701608775	1.2601904979	-824.0534653968	-0.0012135135	-0.0000162968	29201.5645839114
27	31320.5830532237	76.4186748324	76.4167405557	0.0097610324	0.0104423631	1.0000253122	3780.3691884142	0.0002645244	0.0002796094	31378.4284870381
28	31397.0017280559	108.8802145545	108.8596890835	0.0234262478	0.0293429252	1.0001885498	-2054.2814678965	-0.0004867882	-0.0002073624	31415.5749690738
29	31505.8819426104	366.8868430618	176.6916213771	1.4331358179	1.2105179952	2.0764246782	129.2116162446	0.0077392423	0.0228737165	31673.2387781714
30	31872.7687856723	71.6955431318	71.6891437366	0.0215564004	0.0145720124	1.0000892659	-1985.6838866647	-0.0005036048	-0.0003051459	31926.3199653150
31	31944.4643288041	114.2435742679	114.2272091567	0.0259938841	0.0232655208	1.0001432681	2320.0125858959	0.0004310321	0.0005951406	32000.5995735570
32	32058.7079030721	861.1198251663	715.2273985333	0.5831864152	0.9396249159	1.2039804780	-567.1820135650	-0.0017631025	-0.0000580441	32901.2278576005
33	32919.8277282381	562.4519270382	442.3942258382	1.1288169629	0.6311438623	1.2713817093	320.2626106841	0.0031224375	0.0082308329	33126.0575588584
34	33482.2796552766	1500.0600894148	1177.0522242277	1.1553178479	0.9495949494	1.2744210142	-713.2862814477	-0.0014019616	-0.0000999168	34963.5752744660
35	34982.3397446913	1087.7559694957	996.4331550301	0.5327377999	0.5422204097	1.0916497148	1012.5110407798	0.0009876436	0.0023750842	35526.2436795544
36	36070.0957141870	1125.2209752163	1019.2346895117	0.6073523922	0.5375427995	1.1039861445	-983.4819029734	-0.0010167955	-0.0000268692	37176.5619134600
37	37195.3166894031	974.8508144944	809.9512828709	0.6303907734	0.9598436986	1.2035919136	614.1451807998	0.0016282795	0.0040027170	37851.6934988784
38	38170.1675038977	786.5339215223	486.9663074614	1.0978394647	1.0493915753	1.6151711309	-366.3396969945	-0.0027297069	-0.0000625256	38189.0923760257
39	38956.7014254199	1124.8284469803	966.0204710180	0.7862099809	0.6209857302	1.1643940069	800.3106619182	0.0012495148	0.0033484263	39387.6290833409
40	40081.5298724004	1387.7816325956	1229.3096444706	0.6576900305	0.5900919351	1.1289113681	-1112.8695332701	-0.0008985779	-0.0000071147	41450.5606717268
41	41469.3115049960	1312.7316706770	1103.3590420007	0.6890528945	0.7918902283	1.1897592902	887.2414805112	0.0011270889	0.0029799822	42200.7021049228
42	42782.0431756731	1612.8749297297	1433.4478204296	0.7287085390	0.5401022211	1.1251717061	-1271.6942926702	-0.0007863525	-0.0000059022	42800.7996917283

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
43	44394.9181054024	3338.0393806448	1749.9074878659	1.3950864527	1.9308057593	1.9075519156	1004.0583396266	0.0009959581	0.0026063016	47451.6067495278
44	47732.9574860475	2100.2346064855	1503.5560770503	1.6075767844	0.9465907394	1.3968448790	-823.0823311809	-0.0012149453	-0.0000271636	49814.4397098768
45	49833.1920925327	1575.4212046522	1443.6881184306	0.5089951912	0.5756052446	1.0912476071	1452.9708553094	0.0006882451	0.0016726068	50714.6818300481
46	51408.6132971851	2550.7039572647	2248.3271804717	0.7172827417	0.7614595414	1.1344896683	-1725.1977898110	-0.0005796437	-0.0000212004	53940.5624038786
47	53959.3172544497	1500.4469191364	1442.1686176801	0.3551858382	0.3966419275	1.0404101856	1996.0189485293	0.0005009972	0.0010798407	54803.3272490076
48	55459.7641735859	1237.8237572616	1151.0029514324	0.4280419392	0.5974377127	1.0754305675	-1207.5170511869	-0.0008281457	-0.0000308623	55478.5207526542
49	56697.5879308479	1125.1229556509	925.2699167193	0.7969915926	0.7339697121	1.2159943118	736.0148369269	0.0013586683	0.0037608968	57241.3926270641
50	57822.7108864986	2400.6119818036	2053.9300835335	0.9560421298	0.7475355957	1.1687895323	-1409.4732512686	-0.0007094849	-0.0000253761	60204.5670297144
51	60223.3228683023	3601.0587485174	3132.9100037525	0.7884255315	1.0543053017	1.1494293625	1954.4410631036	0.0005116552	0.0014921997	63393.0381519218
52	63824.3816168195	1012.7395371369	921.2952165738	0.4791824997	0.6614861731	1.0992562633	-888.5345289977	-0.0011254487	-0.0000117492	63843.1383984576
53	64837.1211539564	1012.7599464031	958.9431497614	0.5185335451	0.3744094065	1.0561209459	1134.6609913853	0.0008813205	0.0020306232	65193.4324569203
54	65849.8811003596	1200.3486592758	1154.8985224017	0.3729147299	0.3746173278	1.0393542255	-1606.0654135815	-0.0006226396	-0.0000341055	65868.6361625757
55	67050.2297596354	2925.9020327501	2756.2889292330	0.5985522005	0.5673517481	1.0615367648	2509.7325301503	0.0003984488	0.0010219813	67594.1429790119
56	69976.1317923855	1613.0019840104	1556.2151092029	0.3876016265	0.3304598056	1.0364903762	-2246.5814806160	-0.0004451207	-0.0000165968	71570.3787765559
57	71589.1337763959	1837.9639156580	1609.0519677856	0.5995057263	0.7306529969	1.1422651055	1382.2345605587	0.0007234662	0.0017616537	72695.6802234525
58	73427.0976920540	1725.4354891637	1535.8801190128	0.6400186423	0.5930070880	1.1234180766	-1399.8307440912	-0.0007143721	-0.0000034077	75133.7784505799
59	75152.5331812179	1312.8649524660	1277.0019164843	0.2933940403	0.3387555228	1.0280837762	2077.1317297495	0.0004814331	0.0010637847	75959.0325251241
60	76465.3981336838	1125.2398027438	990.1015311653	0.5811123029	0.7171035899	1.1364893067	-867.4973271170	-0.0011527413	-0.0000590473	76484.1535561264
61	77590.6379364276	1050.0936457980	870.9758080856	0.7829794419	0.7251391960	1.2056519091	697.3953861434	0.0014339068	0.0039210287	78096.9140956745
62	78640.7315822256	1087.8191476435	1056.5015182849	0.3605051014	0.2970281060	1.0296427680	-1654.6459261088	-0.0006043589	-0.0000354352	79709.7965580941
63	79728.5507298691	1200.3495280958	1153.2396915110	0.3499076985	0.4103542328	1.0408499958	1579.2002689142	0.0006332319	0.0013191594	80460.0210327605
64	80928.9002579649	1575.4847052826	1517.3991521980	0.4772486520	0.3009026114	1.0382796794	-2024.9330910763	-0.0004938435	-0.0000289931	82485.6287259063
65	82504.3849632474	150.0468567686	150.0455170978	0.0054744386	0.0064696566	1.0000089284	12562.3882726649	0.0000796027	0.0001236070	82598.1632168688
66	82654.4318200160	1462.9774377803	1450.5544367068	0.2658708957	0.1440750024	1.0085643122	-3568.8318303872	-0.0002802037	-0.0000049394	84098.6531113674
67	84117.4092577963	2175.6498611877	2087.7841237054	0.3298638179	0.4699823703	1.0420856431	2720.3143619475	0.0003676046	0.0010191351	85674.1533134496
68	86293.0591189841	1162.7227529023	1003.4554027456	0.5109215799	0.9530677007	1.1587189124	-795.1561694091	-0.0012576146	-0.0000417989	86311.8164227721
69	87455.7818718861	600.0782667154	536.0349455574	0.5882670847	0.6529478090	1.1194760187	484.3267804636	0.0020647217	0.0043921393	87774.6104057330
70	88055.8601386017	637.1567092773	520.6709715643	0.7289827850	0.8015255934	1.2237223584	-417.5809941357	-0.0023947450	-0.0000380515	88074.6699684570
71	88693.0168478792	749.8235787281	583.7127366466	1.0006690240	0.7223684987	1.2845763535	436.5094967458	0.0022909009	0.0065258163	89011.2062461233
72	89442.8404266071	975.1303733486	904.1811223326	0.5090784756	0.5040209735	1.0784679632	-963.1451235834	-0.0010382651	-0.0000557894	89461.5369404068
73	90417.9707999557	1050.3175703386	1015.1636987931	0.3917368882	0.3095414727	1.0346287713	1498.0373196692	0.0006675401	0.0014874837	90849.3446288380
74	91468.2883702945	1387.9131660482	1331.4620843746	0.4129364667	0.3679883599	1.0423978139	-1777.5617906575	-0.0005625683	-0.0000414654	92837.4467610686
75	92856.2015363426	1425.3757987554	1341.7251063471	0.4057834654	0.5413418934	1.0623456265	1505.3088256180	0.0006643155	0.0014395785	93812.7451707018
76	94281.5773350981	1012.6154777939	894.5336861272	0.5347349012	0.7541113243	1.1320037395	-786.5358967983	-0.0012713978	-0.0000113174	94300.3369884180
77	95294.1928128922	1537.3068754054	1033.3147966425	1.3467760246	1.3080203252	1.4877430193	579.8386125492	0.0017246178	0.0046643073	95725.4113222152
78	96831.4996882974	787.3490457231	570.7380337965	0.9123942470	0.9484927616	1.3795279079	-424.4678285149	-0.0023558911	-0.0000153826	97600.0298955688
79	97618.8487340205	900.0500738933	859.1276844103	0.5074754996	0.3302139174	1.0476324884	1075.0171125799	0.0009302178	0.0022460792	97900.0760636265
80	98518.8988079138	1537.8737961552	1371.2568222060	0.7319171248	0.5394591596	1.1215067603	-1210.0926095161	-0.0008263830	-0.0000079346	100038.0174287210
81	100056.7726040692	2250.6751554022	2099.6664535706	0.5957653244	0.4103864757	1.0719203289	2237.2099866361	0.0004469853	0.0012300753	100825.7516663435
82	102307.4477594711	3826.2013668011	3641.3230899230	0.4676035568	0.5616122373	1.0507722804	-3717.6206342260	-0.0002689893	-0.0000003230	102326.2038867824
83	106133.6491262722	74.9872872928	74.9867518114	0.0028981719	0.0064854407	1.0000071410	8000.7014797897	0.0001249890	0.0002208933	106189.8250118919
84	106208.6364135650	150.1496914548	150.0634081263	0.0358004773	0.0594133455	1.0005749791	-1575.4999849833	-0.0006347191	-0.0000543004	106227.4478152381

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
85	106358.7861050198	112.6873303676	112.6398945856	0.0338152617	0.0460584859	1.0004211277	1412.7592685083	0.0007078347	0.0011088589	106414.8307359353
86	106471.4734353876	190.2599229509	185.9868171297	0.2880367781	0.2822961717	1.0229753156	-333.4572071256	-0.0029988856	-0.0008406032	106642.3058707729
87	106661.7333583383	184.0972485317	174.5354440707	0.5033556660	0.4007647202	1.0547843134	202.1487448552	0.0049468524	0.0079585111	106752.5032594791
88	106845.8306068700	113.2348566014	113.2011017984	0.0369474727	0.0278453036	1.0002981844	-1755.2170212965	-0.0005697301	-0.0001686876	106940.6743673361
89	106959.0654634715	150.0738032089	149.9525292311	0.0699550079	0.0471789366	1.0008087491	1277.6052344815	0.0007827144	0.0012127749	107014.5210964537
90	107109.1392666804	37.6676902529	37.6676747768	0.0009016132	0.0009113897	1.0000004109	-20776.4204753295	-0.0000481315	-0.0000481315	107128.0746716198
91	107146.8069569333	1124.9558372637	1102.1029554861	0.2994356734	0.3052755730	1.0207357050	1860.6939986583	0.0005374339	0.0012406017	107840.4042653693
92	108271.7627941970	1162.7680268890	1046.8808475388	0.5521137219	0.6323290368	1.1106975828	-982.3326639837	-0.0010179851	-0.0000171921	108290.5166004354
93	109434.5308210861	2344.4689335595	2240.9823493443	0.6071776227	1.#QNAN00000	1.0461791162	-1.#IND000000	-1.#IND000000	0.0014599837	109828.4145180799

From the above analysis of modelling results, lower reach of this section, chainage from 59km up to the chainage 93km (measured from Yamunotri) witnesses comparatively higher movement of channel centreline. This is also in line with the physiography of the area. The movement of centreline from its original location (i.e. centreline of the year 2000) in this reach within span of 50 years i.e., up to the year 2050 is estimated to be 170m. Maximum shift of centreline and channel migration rate based on the simulation (between chainage 59km to 93km) is found out to be 170 m and 1.009m/year respectively. However, movement in both directions i.e. towards left and right bank in alternate years suggests that stretch is more of stable type. From the modelling study, it can be deduced that chances of neck cut off and ox-bow formation are minimal in this reach.

2. Tons-Yamuna confluence to Dakpatthar Barrage

This river stretch is 2.85 km long. Though, the stretch is comparatively smaller in length, significant changes in flows and sediment deposition are witnessed in this segment. The data used as an input for simulation include discharge (1500 cumecs), width (330m), depth (2.5m), slope (0.00045) and grain size (10 mm). The bend parameters used for simulation include number of nodes to define the bend and straight sinuosity threshold for which values of 8 and 0.0005 are used respectively.

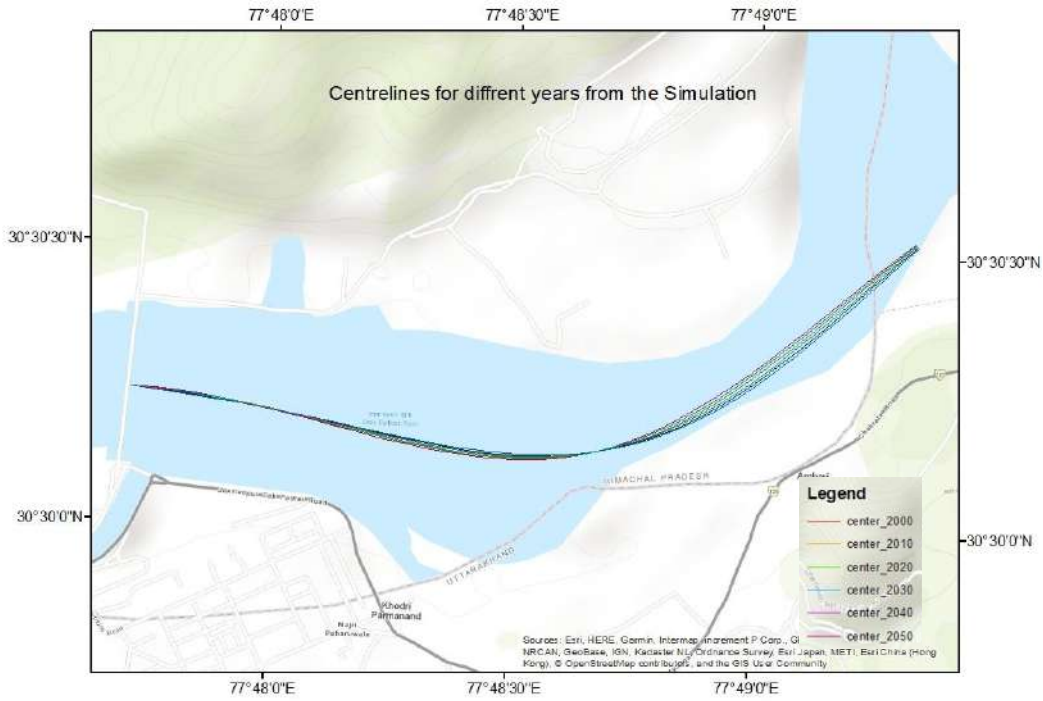


Figure 15-6: Centerlines for different years of simulation for the river reach between Tons-Yamuna confluence and Dakpatthar

From the meander migration modelling, average width of swing over span of 50 years is around 40m. Rate of channel migration as per Equation 6, is found out to be 0.13m/year. Three bends are observed in this section with average radius of curvature of 1.28km with maximum and minimum arclength of 1846m and 423m respectively. Figure 15-6 shows the swing of channel centreline for different years of simulation. Maximum variation in repositioning of channel centreline is noticed in upper reach, however, rate of change and rate of channel migration is minimal and well within the average channel width of the river. Therefore, this section of the river does not fall under the category of meandering/migrating channel and can be considered as stable section.

3. Dakpatthar Barrage to Giri-Yamuna confluence

The average width of the section used for simulation is 510m whereas length of this stretch is 12.96km. This section of the river Yamuna features highly controlled flow conditions as much of the water is diverted at upstream location i.e., Dakpatthar Barrage through headworks to power houses for generating power. Therefore, most of the morphological activities in this section are outcome of flood events. Bend characteristics obtained in this river stretch are listed in table below,

Table 15-3: Bend Parameters in the reach between Dakpatthar and Giri-Yamuna confluence

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.0000000000	3714.6828627914	3570.6588132015	0.4890317796	0.4455570929	1.0403354275	-4056.6843631703	-0.0002465067	-0.0000000001	0.0000000000
2	3714.6828627913	3032.7557626206	2966.4868702834	0.3686015347	0.3757084706	1.0223391828	4074.9322344105	0.0002454029	0.0003669237	6368.2994795883
3	6747.4386254119	2881.0878484633	2827.3715581069	0.3357410740	0.2602642949	1.0189986669	-4834.2019506247	-0.0002068594	-0.0000471441	6823.3708156494

From the analysis of simulation results, it can be said that rate of channel migration is minimal (0.07m/year). The presence of comparatively straight channels in this segment restricts formation of neck cut off and ox-bow lakes. In the view of above observations, this segment can be considered as stable stretch.

4. Giri-Yamuna confluence to Hathnikund Barrage

This stretch of River Yamuna is 22.8km in length, however, much of stretch is straight with minimal sinuosity. The flow data used as an input for simulation include discharge, width, depth, slope and grain size for which values of 2000cumecs, 700m, 2.5m, 0.0003 and 10mm are used respectively. The following figure indicates the channel centrelines for different years of simulation. This figure is further zoomed in following figures to highlight the extent of difference between centrelines on decadal scale.

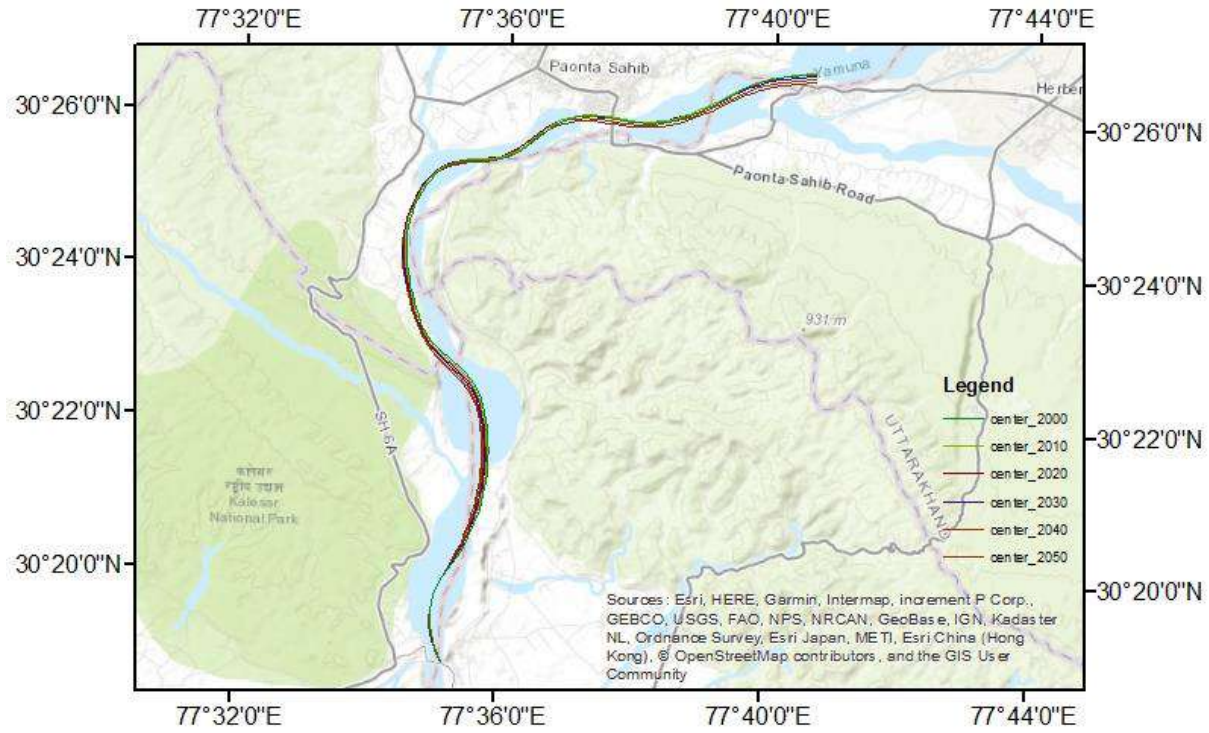


Figure 15-7: Centerlines for different years of simulation for the river reach between Giri-Yamuna confluence and Hathnikund

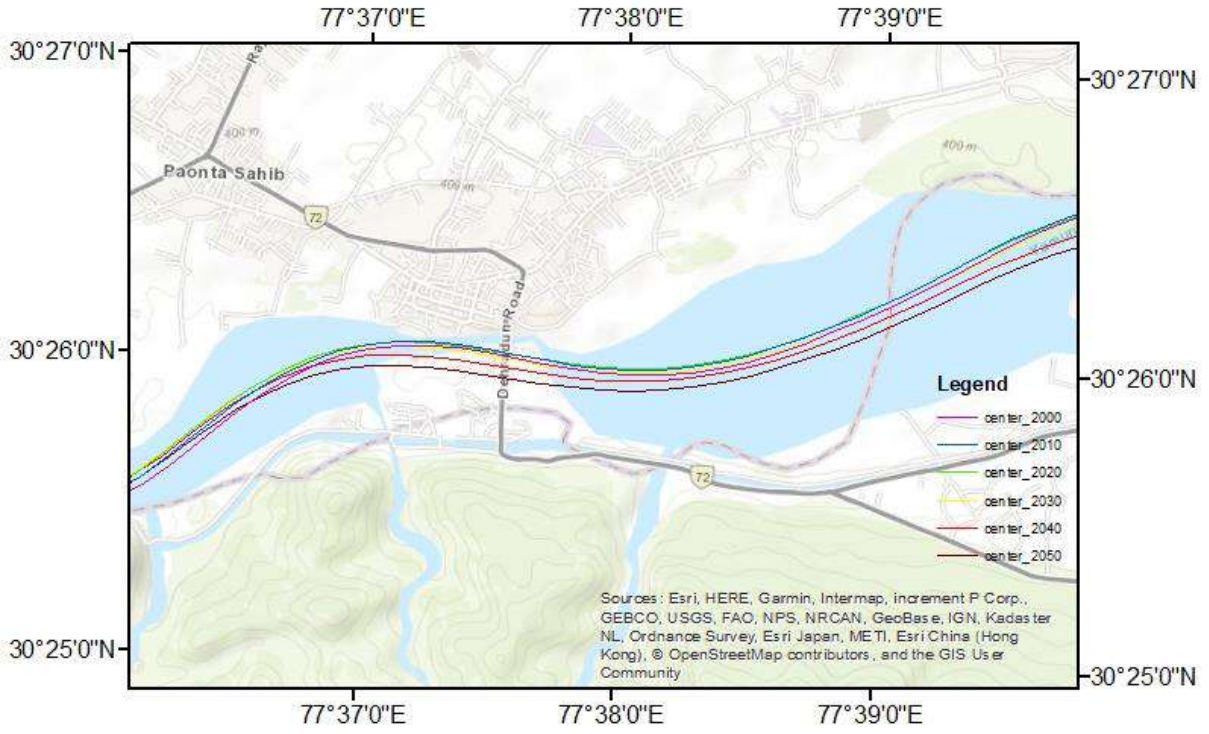


Figure 15-8: Zoomed in component (upper reach) of Figure 15-7

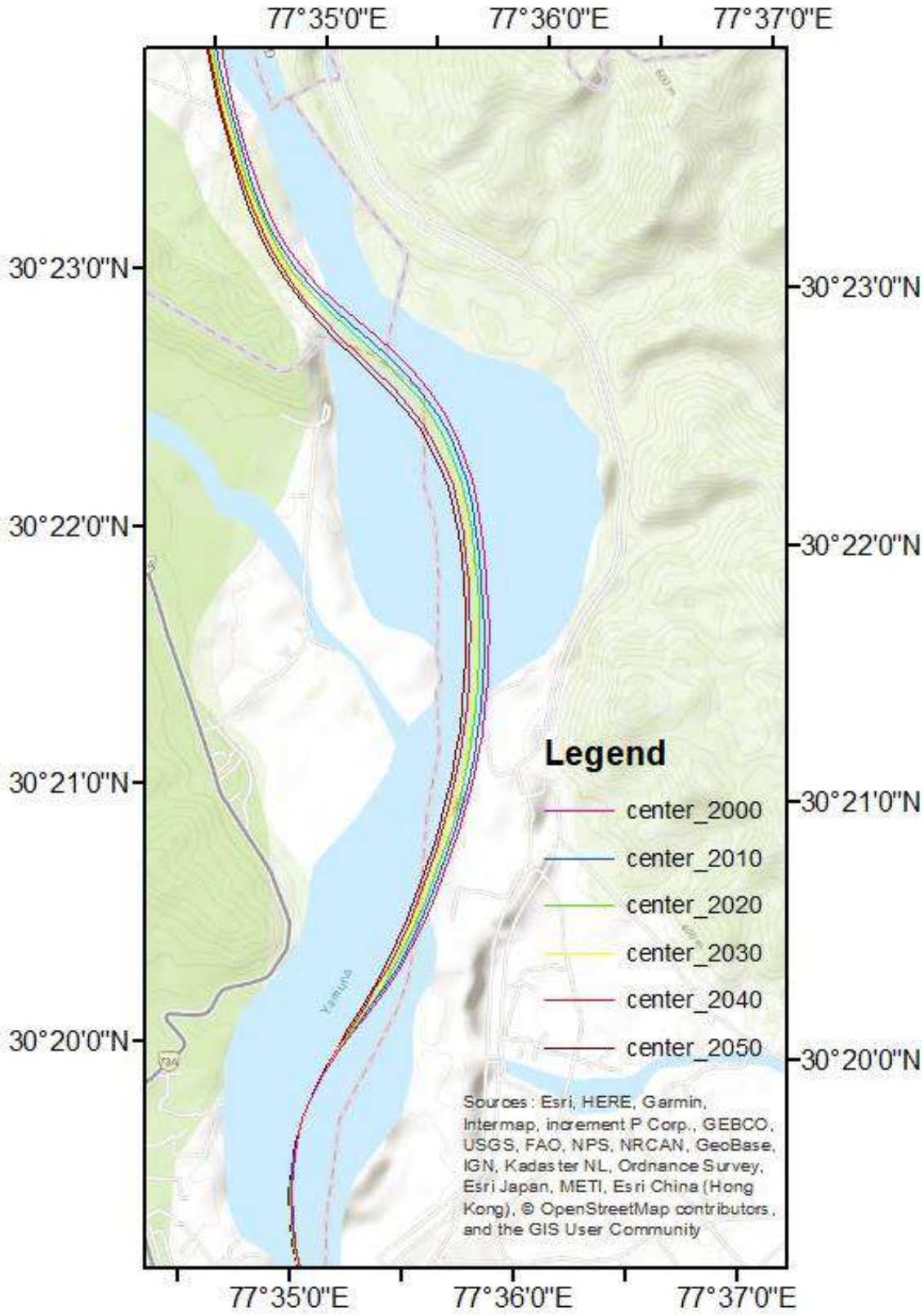

77°35'0"E
77°36'0"E
77°37'0"E
30°23'0"N
30°22'0"N
30°21'0"N
30°20'0"N
Legend
center_2000
center_2010
center_2020
center_2030
center_2040
center_2050
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), © OpenStreetMap contributors, and the GIS User Community

Figure 15-9: Zoomed in component (lower reach) of Figure 15-7

From the analysis of this simulation, rate of channel migration computed as per equation 6 is found out to be 1.01m/year. Though the changes in channel centerline over the span of 50 years is observed, maximum shift of centerline in 50 years is around 210m which is well within average width of channel considered for the analysis. Moreover, bend characteristics such as large radius of curvature and low sinuosity value indicate minimum possibility of neck cutoff. In view of the above observations, this section of River Yamuna can be considered as morphologically stable section.

5. Hathnikund Barrage to Kalanaur Bridge

This stretch of River Yamuna covers 38.6km length. Considering the significant differences in channel centrelines of the year 2000 and 2010, polygon-based modelling approach is used. This approach is slightly different from previous modelling exercise wherein fixed erosion potential for the entire reach was considered. For this stretch of river, different erosion potential was used for selected polygons in order to simulate the stretch. Location of polygons and significant changes in original centrelines are shown in figure below.

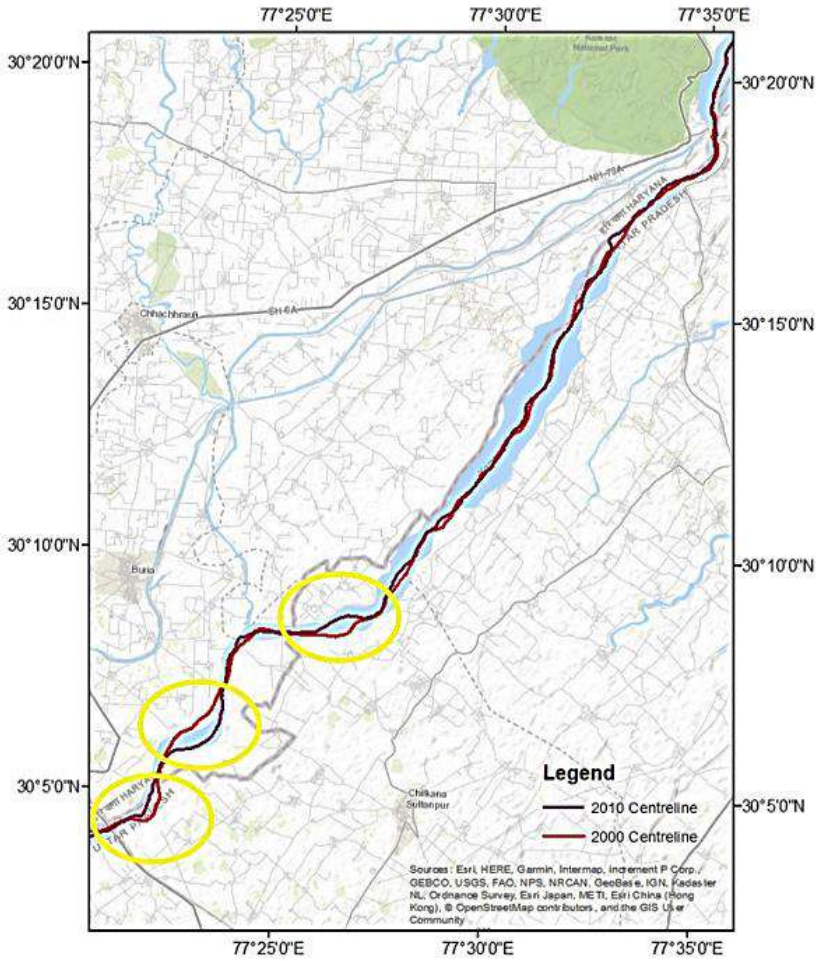


Figure 15-10: Centerlines of the year 2000 and 2010 (obtained from satellite imageries) and locations of polygons

For simulation, value of erosion potential and neck cutoff parameters are defined separately for selected polygons. For example, neck cutoff width based on above analysis is modified to 2000m from its original value of 700m (which was equivalent to average channel width). Similarly, values of sinuosity threshold, upstream cut factor, downstream cut factor and cut off recurrence interval were calibrated based on the changes during the year 2000 to the year 2010. Simulation results in the form the centrelines are presented in figure below.

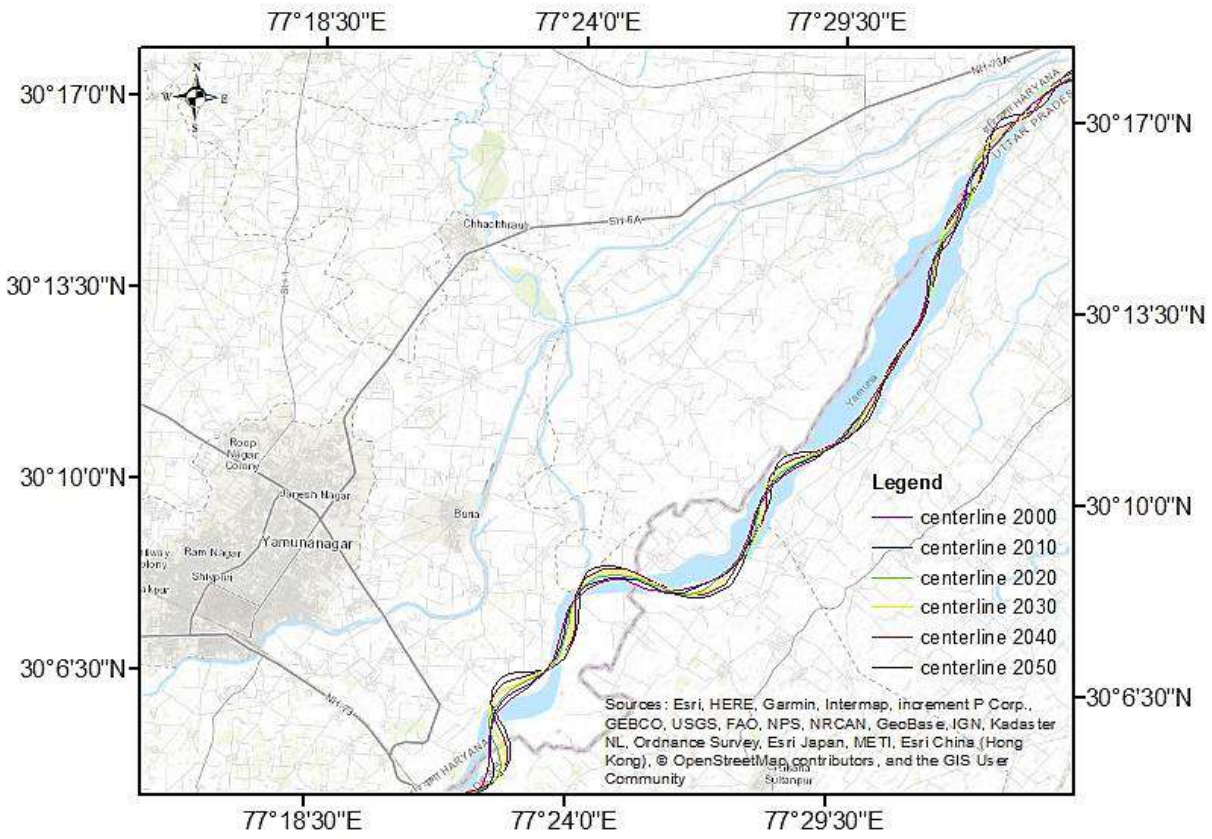


Figure 15-11: Centerlines for different years of simulation for the river reach between Hathnikund Barrage and Kalanaur Bridge

From the analysis of the modelling results, it is clear that the model captured the pattern of neck cut off for two out of three polygons. For the remaining stretch, not much movement/ channel migration is visible. The rate of channel migration for the entire stretch is found out to be 1.045m/year. For the lower part of the reach (11km, measured from Kalanaur towards Hathnikund), the rate of channel migration is around 2.7m/year and maximum movement of channel centreline from its original position is about 500m towards the left side of the bank. Considering the possibility of combined movement of approximately 1km (500m on towards left bank and 500m towards right bank), the movement in this lower part of the reach is beyond the average channel width. In the view of above observations, it can be said that lower reach of around 11km is not stable. However, some of the locations in this vicinity are already equipped with structures for flood protection and ultimately restricting the river course. The following screenshot from google earth shows flood protection structures on the right bank of the River Yamuna near the villages Bakpur and Sabpur located at 4.5km upstream of Kalanaur bridge.



Figure 15-12 : Flood protection structures around Bakpir and Subpur villages

6. Kalanaur Bridge to Karnal Bridge

This segment of River Yamuna is 69km long. The flow data used as an input for simulation include discharge, width, depth, slope and grain size for which values of 2625cumecs, 600m, 1.5m, 0.0003 and 10mm are used respectively. Simulation results in the form of channel centreline are shown in Figure 15-13. Number of bends and their geometric properties as based on the centreline of the year 2000 are listed in Table 15-4.

Table 15-4: Bends properties for the river reach between Kalanaur Bridge and Karnal Bridge

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.0000000000	4734.0628949626	4691.2441122730	0.1849543501	0.3321292806	1.0091273832	9303.7372384400	0.0001074837	0.0003314203	4360.1407767759
2	4734.0628949626	1352.2668893483	1237.8041657289	0.4758043774	0.6274571763	1.0924724014	-1228.1220599175	-0.0008142513	-0.0000023284	4808.4614353952
3	6086.3297843112	2100.4900777750	1743.5008087909	0.9281991592	0.9066995988	1.2047542893	1148.5362975866	0.0008706734	0.0012416452	7209.9094943600
4	8186.8198620860	5110.2398806935	4287.5181296171	1.1228904900	0.7668771699	1.1918876437	-2706.1526762928	-0.0003695283	-0.0000214416	13221.9790266476
5	13297.0597427794	9168.0948367291	8362.4411670673	0.6231528982	0.9636065547	1.0963419238	5777.9689581489	0.0001730712	0.0006453934	21188.4466805679
6	22465.1545795084	4810.0259214498	4587.7072163249	0.6591782061	0.5798812203	1.0484596542	-3882.8458897208	-0.0002575431	-0.0000692194	23893.4237399796
7	27275.1805009584	3005.5219123759	2741.2016318964	0.7009577427	0.6012482118	1.0964249683	2308.2017898319	0.0004332377	0.0007768438	28852.8308168233
8	30280.7024133342	4658.4139221598	3812.4030087399	0.9752483410	0.8985448351	1.2219101473	-2487.8593634745	-0.0004019520	-0.0000055632	34863.8156490525
9	34939.1163354940	5408.0073323270	3547.0228032260	0.8176037681	1.9648176369	1.5246609995	1948.5595138526	0.0005131996	0.0013364258	38321.1287841672
10	40347.1236678210	4505.6787444635	3053.5277100574	1.1979693442	1.6418636924	1.4755650422	-1589.0195917250	-0.0006293189	-0.0001601272	44776.8325458143
11	44852.8024122847	7364.1966805290	6843.5637941919	0.9783446704	0.6100260357	1.0760762816	4635.4514892278	0.0002157287	0.0007619267	45228.0823881741
12	52216.9990928135	1804.0736348715	1770.7007529538	0.2325362923	0.2959455542	1.0188472738	-3415.4522181687	-0.0002927870	-0.0000011744	53945.9509231310
13	54021.0727276850	3002.8870688653	2497.3213765055	0.8243936904	0.9651033227	1.2024431846	1680.8541030576	0.0005949356	0.0011507846	55146.6691118650
14	57023.9597965502	1652.4112761336	1522.1249987449	0.5775873156	0.5170937728	1.0855949922	-1511.9674286863	-0.0006613899	-0.0000244295	58601.2825968483
15	58676.3710726838	150.0257165742	150.0257140612	0.0001828479	0.0001832170	1.0000000168	409833.6666793543	0.0000024400	0.0000024400	58751.4595485194
16	58826.3967892581	2404.6937651153	2358.4872522383	0.3507534326	0.2571429059	1.0195915890	-3957.9801839565	-0.0002526541	-0.0000367913	61155.9109136447
17	61231.0905543734	2704.8689881807	2649.9573088145	0.2620415736	0.3793524854	1.0207217223	4217.4699420029	0.0002371090	0.0004024013	62809.0116177732
18	63935.9595425541	1353.0920488647	1325.1399939320	0.2687429803	0.2831608273	1.0210936618	-2452.6663478140	-0.0004077195	-0.0000066302	64011.1561148031

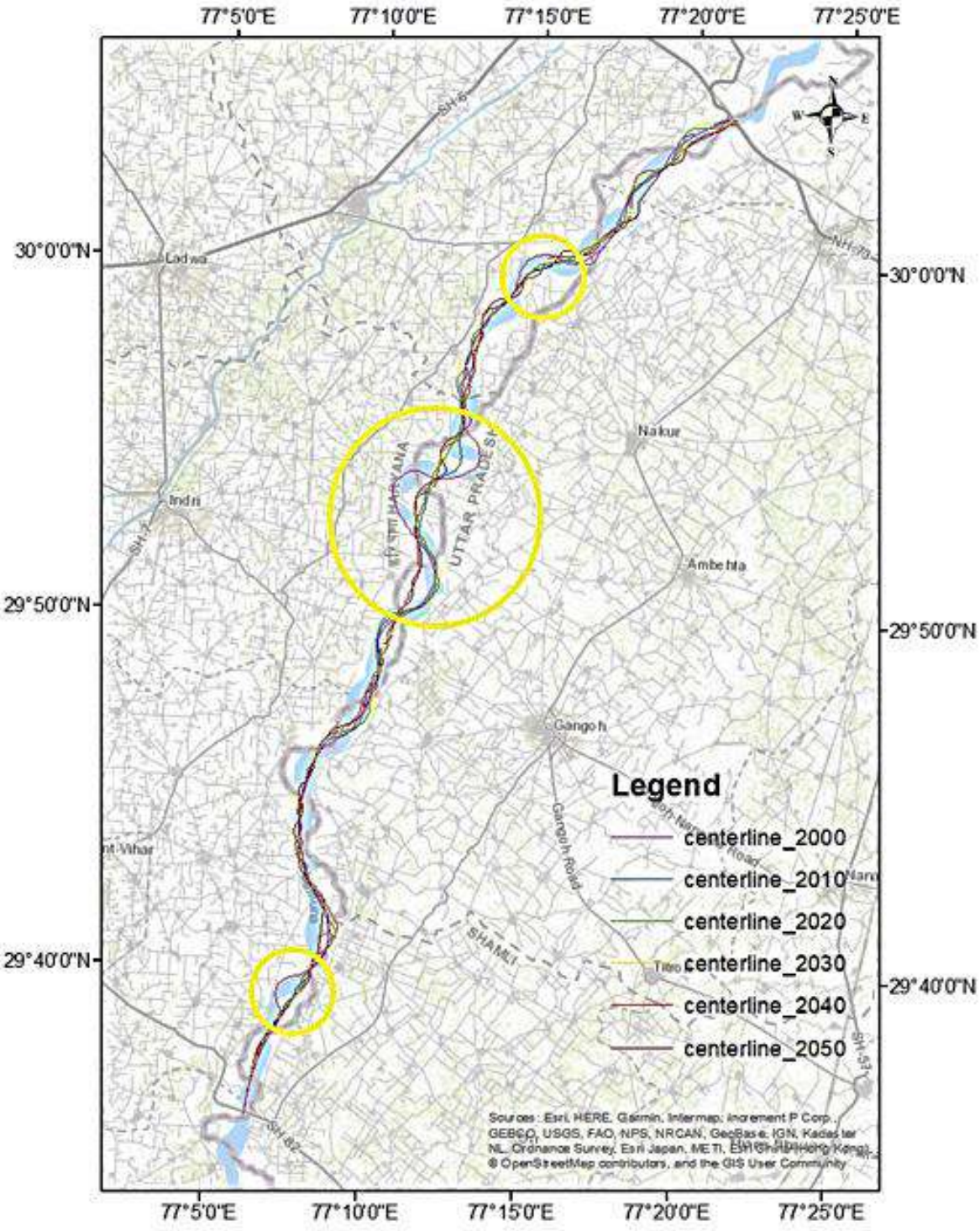


Figure 15-13: Centerlines for different years of simulation for the river reach between Kalanaur Bridge and Karnal Bridge

This figure is further zoomed in to enhance the representation of centreline changes in following figures.

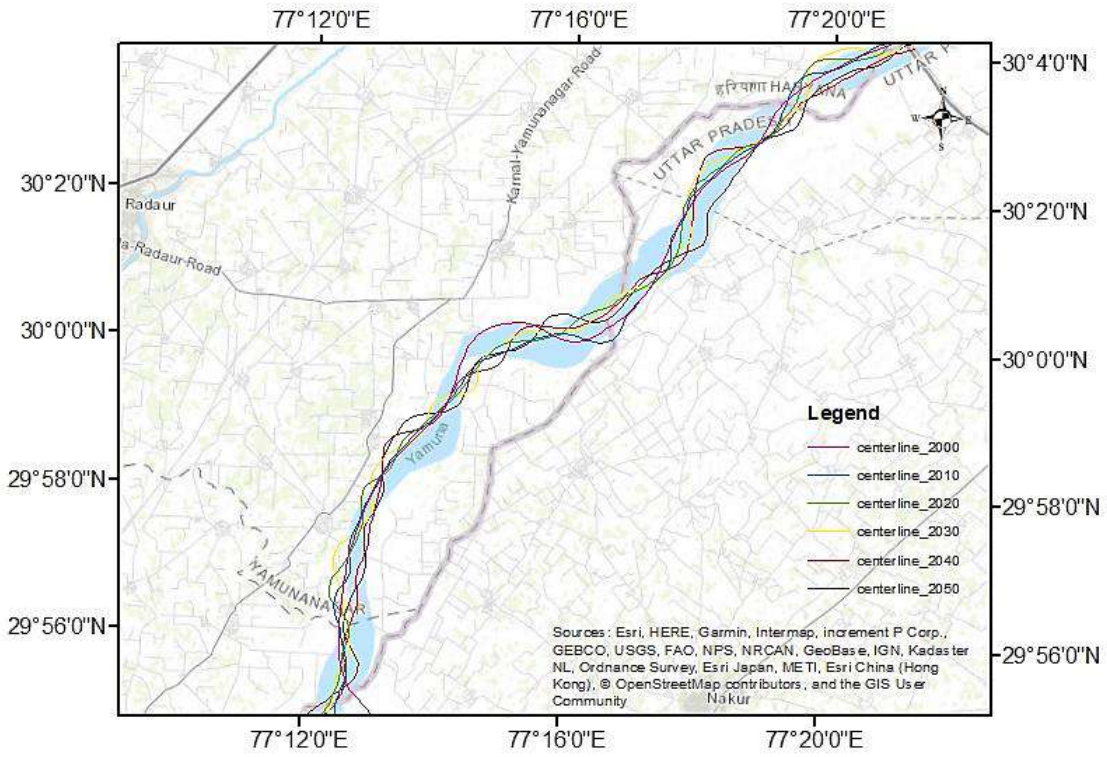


Figure 15-14: Zoomed in component of Figure 15-13 (upper reach)

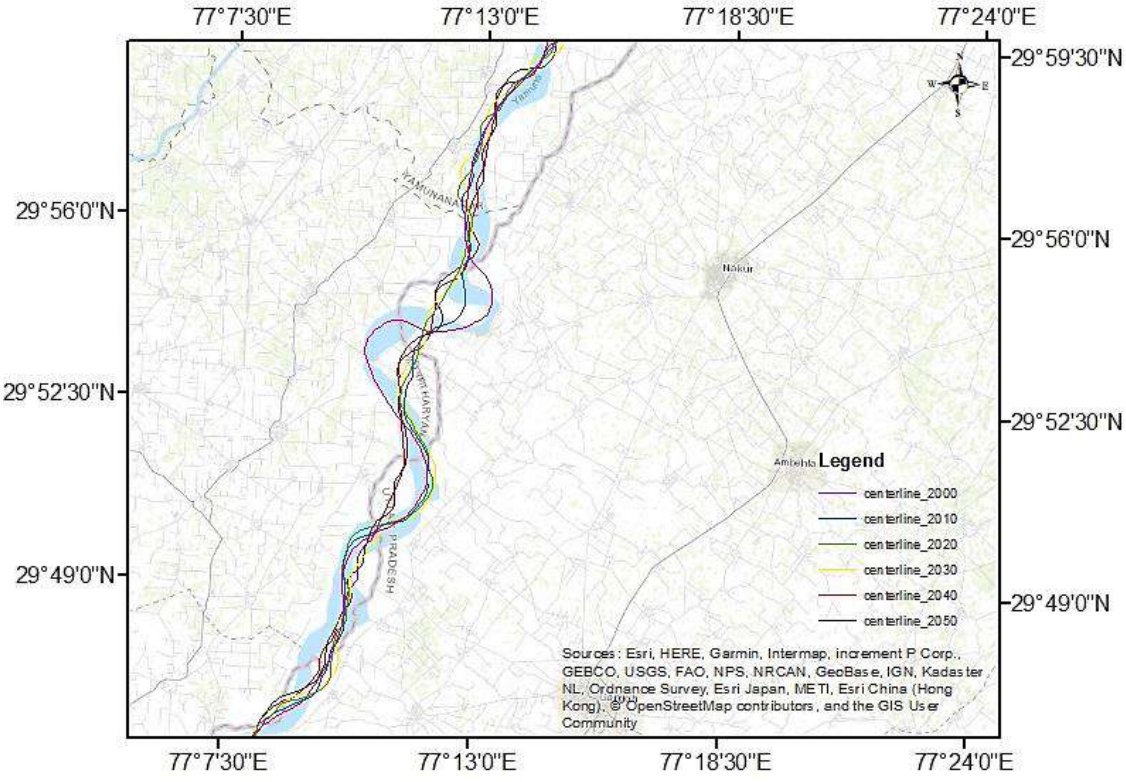


Figure 15-15: Zoomed in component of Figure 15-13 (middle reach)

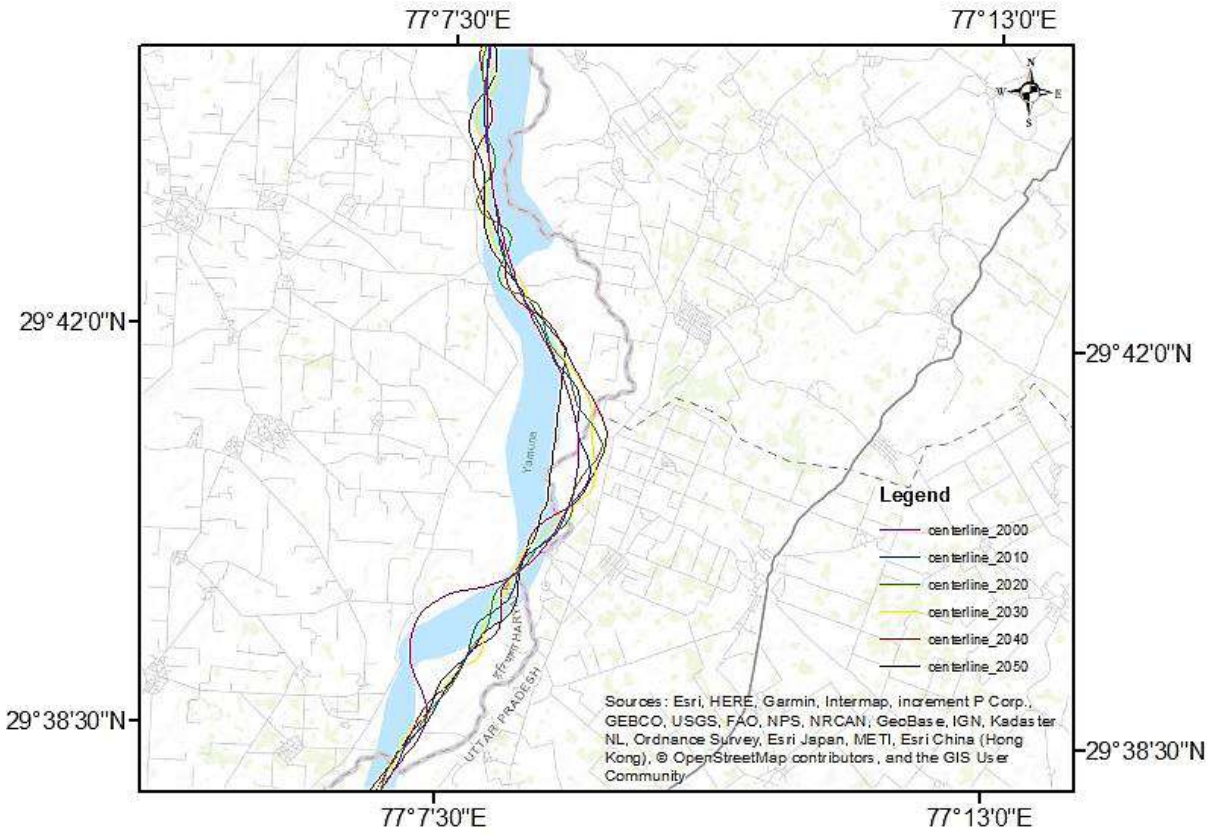


Figure 15-16: Zoomed in component of Figure 15-13 (lower reach)

Based on the simulation outcomes, rate of channel migration is found out to be 3.5m/year. This can be attributed to neck cut-offs in this segment. From the analysis of the modelling outcomes, three locations are identified where possible neck cut off may occur for the given set of boundary conditions in the modelling framework. The locations identified are in the vicinity of Modipur, Manimanzra, Shahpur Zat, Zapti Chapra and Jathlana villages. Google earth image shows presence of flood control leaves near Zapti Chaptra village.



Figure 15-17 : Flood control structures around Zapti Chapra village

In view of the above observations, this segment of river Yamuna can be considered as morphologically active since the rate of channel migration is comparatively higher than the upstream reaches. Also, the activities like the neck cut off, movement of channel centreline and change in river course are noticed while analysing the modelling outcomes.

7. Karnal Bridge to Baghpat HO site

This reach covers about 85km length. Reach is characterised by low slope, restricted channel width and intensive agricultural activities in adjacent floodplains. In terms of demography, several villages and towns are located on the bank of River Yamuna in this stretch. For the simulation, channel characteristics such as channel width, depth and slope are provided which are determined from the remote sensing observation the year 2000. To determine number of bends, similar boundary conditions (previous reaches) i.e. number of nodes to define bend and straight sinuosity threshold of 8 and 0.0005 have been used. Number of bends observed in this stretch are 30 with minimum and maximum length of 300m and 5km, whereas radius of curvature of the bends are found in the range 1.03km to 25.6 km. Simulation results in the form of channel centrelines for different years are displayed in Figure 15-18.

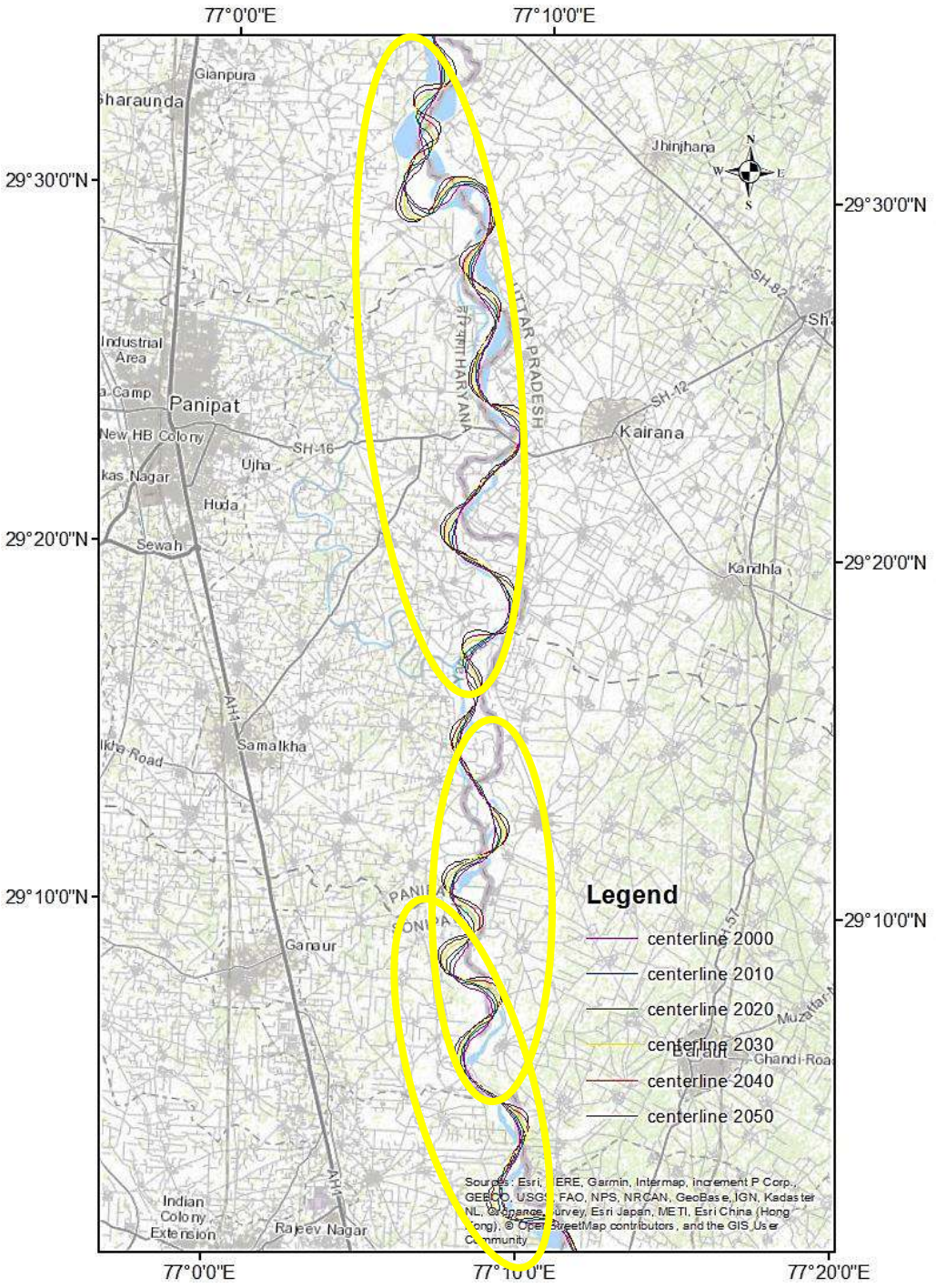


Figure 15-18: Centerlines for different years of simulation for the river reach between Karnal Bridge and Baghpat HO site

The figure is further zoomed in other Figures 15-19, 15-20 and 15-21 for better representation. To highlight the importance of modelling and possible outcomes, results at one location are imposed on google earth imagery (year 2019) to show the possible future channel migration patterns (Figure 15-22).

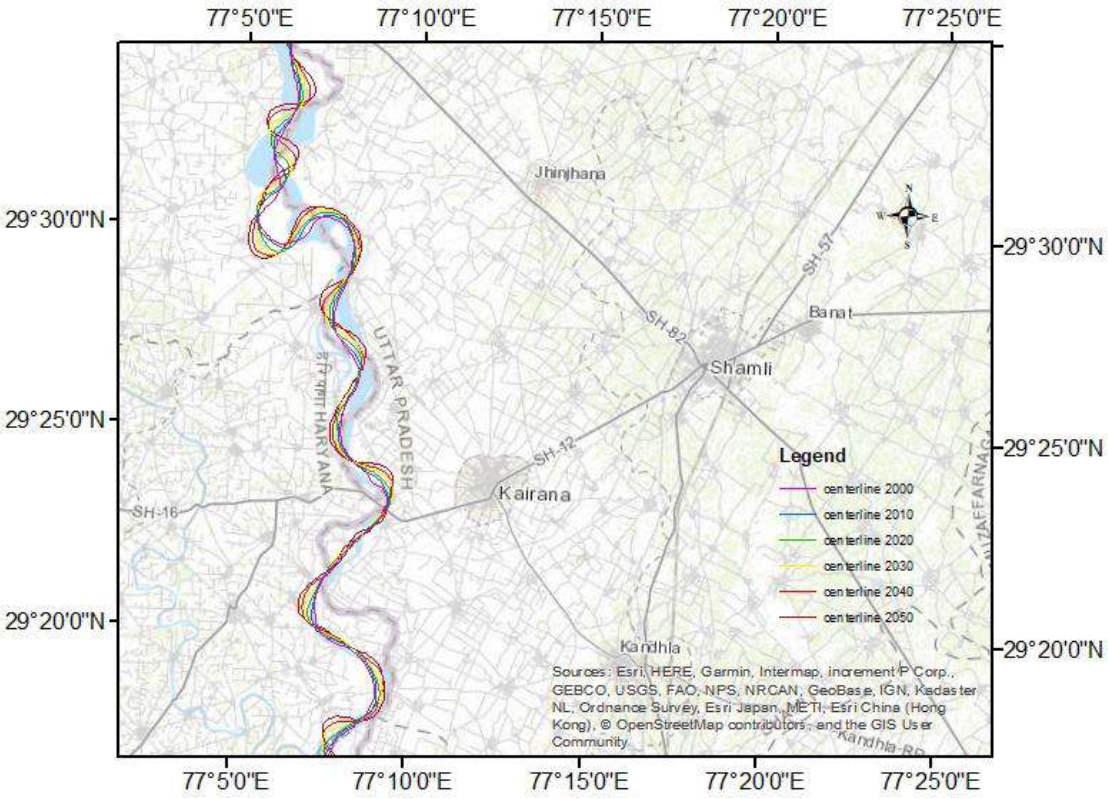


Figure 15-19: Zoomed in component of Figure 15-18 (upper reach)

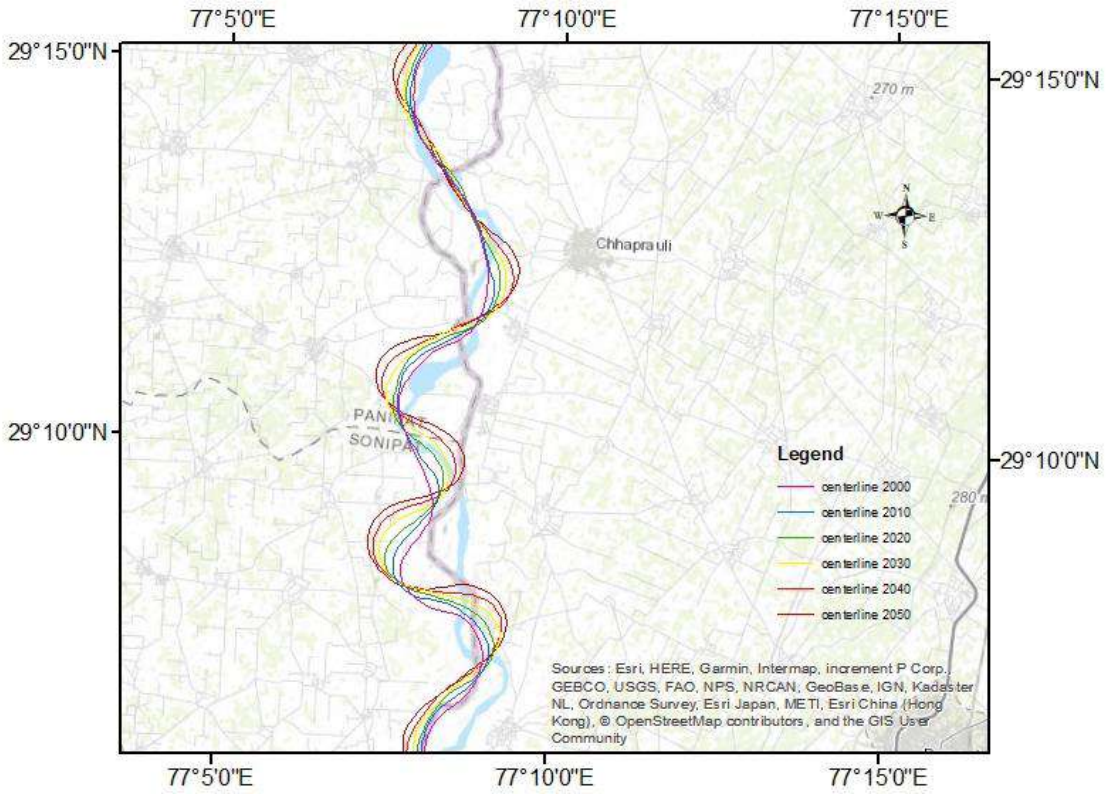


Figure 15-20: Zoomed in component of Figure 15-18 (middle reach)

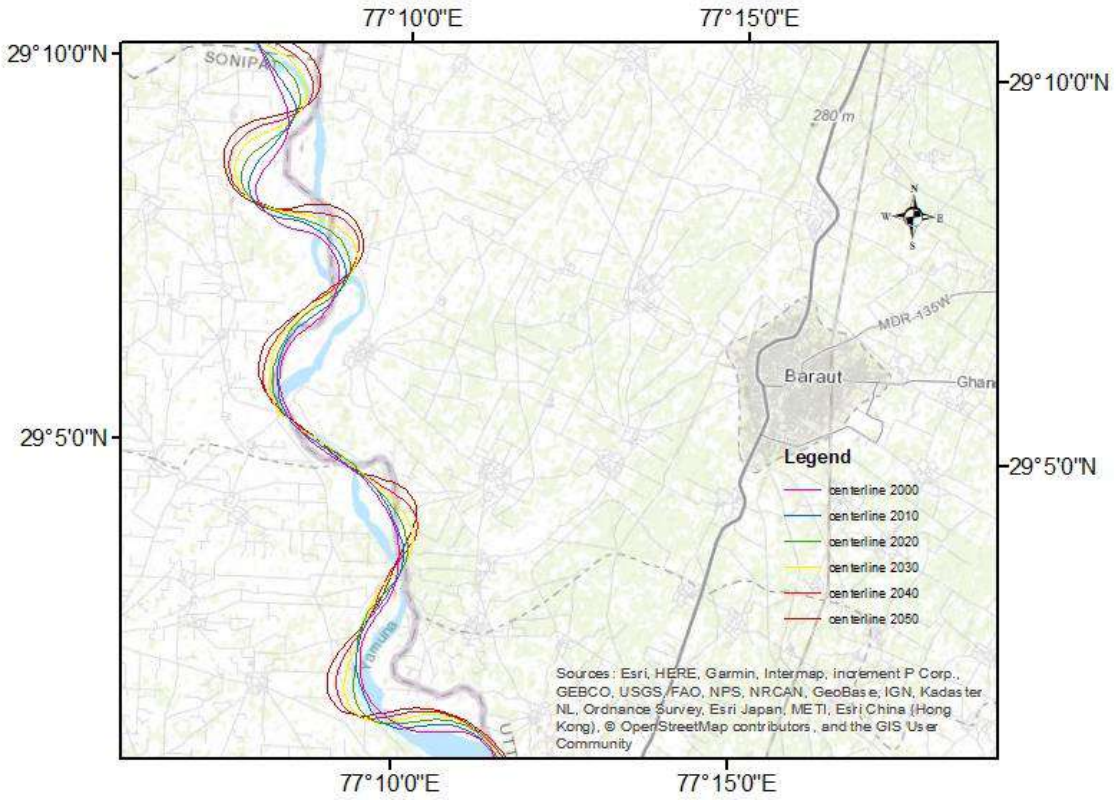


Figure 15-21: Zoomed in component of Figure 15-18 (lower reach)

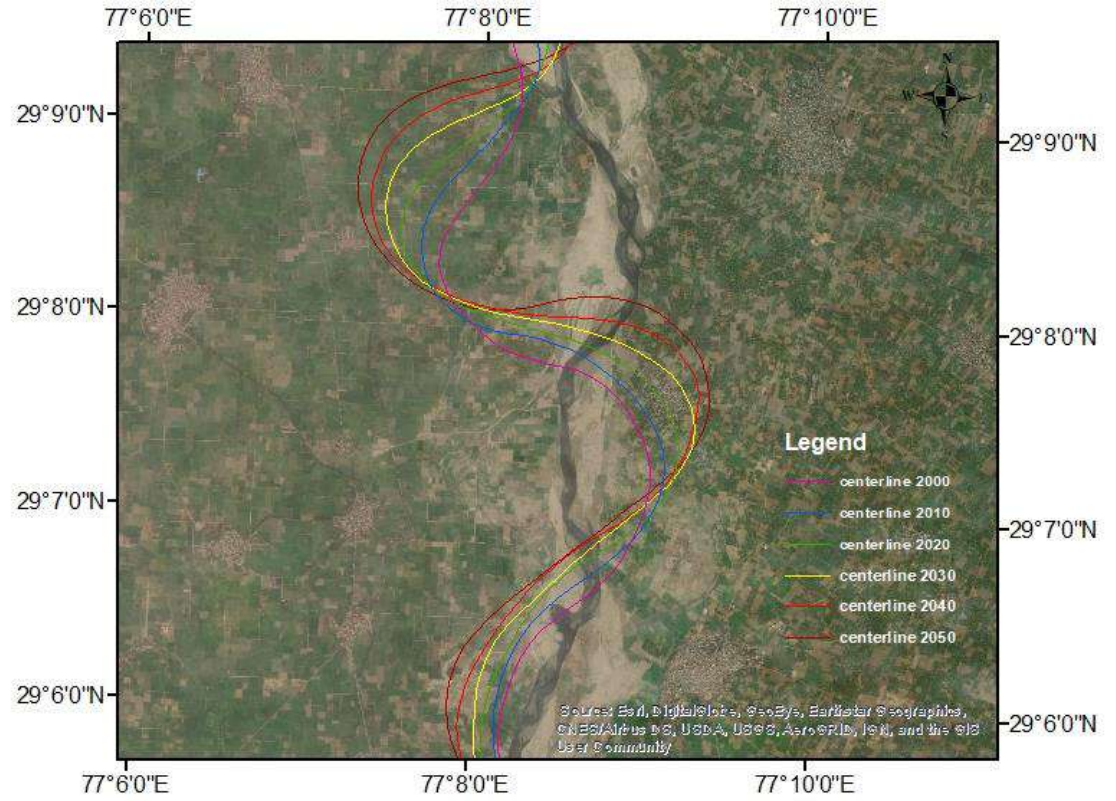


Figure 15-22: Possible future channel migration patterns based on simulation conditions

From the above analysis, it can be said that river is morphological active in this stretch. The rate of channel migration for this reach is found out to be 3.20m/year. The maximum width of meandering based on simulation in the span of 50 years is about 1.06km. Figure 15-22 shows possible migration overlaid on Google earth imagery. The area is in the vicinity of Panipat. Form the figure, it can be said that if the free movement of river in adjacent floodplains is allowed, the meandering may result in loss of agriculture land and community in the area may get exposed to flood inundation. So, from the community and agricultural activities point of view this section can be termed as critical section. More discussion on the critical reach is provided in Chapter 17.

8. Baghpat HO site to Okhla Barrage

This stretch of Yamuna covers the length of 59km. The stretch covers several important towns including Delhi NCR region. Simulation results in the form of centreline are shown in Figure 15-23. The number of bends and geometric properties are tabled in Table 15-5.

Table 15-5: Bends properties for the river reach between Baghpat and Okhla

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.0000000000	2594.3562061355	2477.2381168385	0.5380760057	0.3017826938	1.0472776874	-3226.1683986676	-0.0003099652	-0.0000000001	0.0000000000
2	2594.3562061356	2032.8805728363	2003.4872767462	0.2324718744	0.2392132873	1.0146710670	4310.2166095434	0.0002320069	0.0003854643	3611.2929894187
3	4627.2367789717	2257.4203456918	2209.2654650719	0.3355525009	0.2395661108	1.0217967833	-3929.1632714261	-0.0002545071	-0.0000157153	6772.0810040661
4	6884.6571246636	5649.2355909267	5001.5022442517	0.8063031500	0.7713908295	1.1295077589	3582.2188078892	0.0002791566	0.0005282158	8127.0594417662
5	12533.8927155903	3143.5326238802	2664.8776963748	0.9820434637	0.7821792582	1.1796160958	-1775.2521450737	-0.0005633003	-0.0000787511	15565.4616256358
6	15677.4253394704	6993.9654204582	6110.9947378237	0.9433538412	0.8861628239	1.1444888632	3828.1291461652	0.0002612242	0.0006406925	16917.6571590070
7	22671.3907599284	2705.6901218856	2318.2926838285	0.6820320914	0.9745106978	1.1671046287	-1634.3345069437	-0.0006118698	-0.0000137035	22784.7554002920
8	25377.0808818141	2934.8405536409	2511.0976102276	0.9110160267	0.8058726611	1.1687480971	1705.2672197368	0.0005864184	0.0010895139	26162.7439268158
9	28311.9214354550	444.8897746075	444.8890430109	0.0010554414	0.0031469480	1.0000016444	-105367.64422782	-0.0000094906	-0.0000000700	28424.9450245096
10	28756.8112100625	225.3933064690	225.3912925312	0.0042947977	0.0041609544	1.0000089353	26655.9366754064	0.0000375151	0.0000375151	28867.7240369815
11	28982.2045165316	2454.3144896621	1382.7861665358	1.2151558057	1.6390031305	1.7749052956	-866.2616577724	-0.0011543856	-0.0000165563	29096.6849960817
12	31436.5190061935	6986.3692031315	5081.8936416054	1.8689449324	1.0857935044	1.3747570681	2357.7891412699	0.0004241261	0.0013935763	31763.5525075478
13	38422.8882093251	2706.9826696128	2332.8055841670	0.6534261250	0.7435105170	1.1603978866	-1943.8444627408	-0.0005144445	-0.0000348399	38534.9117565159
14	41129.8708789377	5643.3263930193	5255.8464806814	0.6454692926	0.5880652291	1.0737235979	4578.1533419820	0.0002184287	0.0003986088	42145.5600730113
15	46773.1972719571	3385.0865660317	2868.9909626384	0.5954214786	1.0598214643	1.1798874971	-2041.3069949200	-0.0004898822	-0.0000787854	48012.0901410936
16	50158.2838379889	2028.4413834481	1921.3472662906	0.3950743050	0.4912305679	1.0557390738	2293.5045800427	0.0004360140	0.0008290164	51396.6949658157
17	52186.7252214372	2031.5689569550	2004.8391444367	0.3065390667	0.1785103763	1.0133326470	-4189.8307944566	-0.0002386731	-0.0000189304	54105.4913869220
18	54218.2941783920	4516.8665822693	4384.7236730296	0.4283955513	0.3427218149	1.0301371122	5859.4255484623	0.0001706652	0.0003250156	55235.0849900809

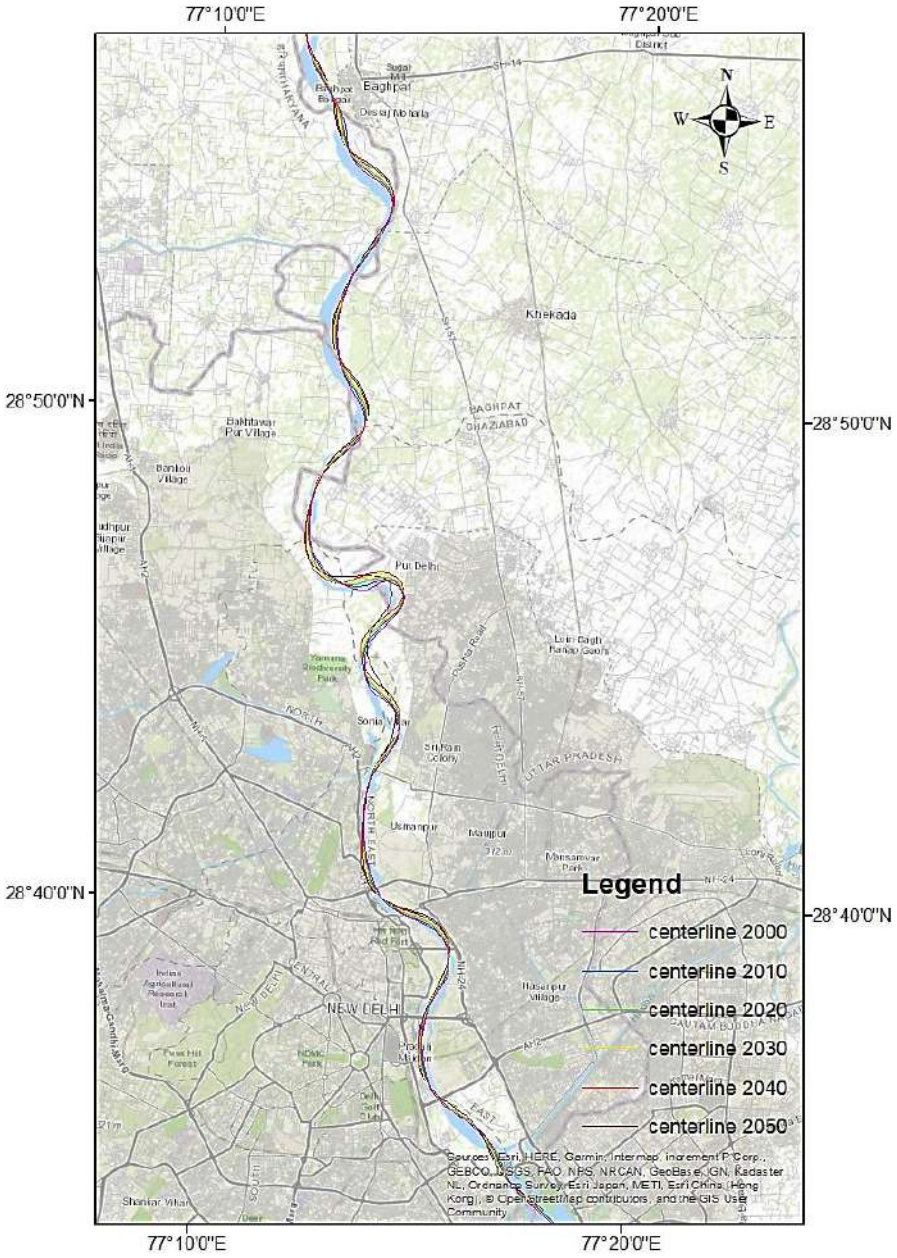


Figure 15-23: Centerlines for different years of simulation for the river reach between Baghpat and Okhla Barrage

Based on the simulation outcome, the rate of channel migration for this reach in found out to be 4.05m/year. Overlay analysis of these simulated channel centrelines over the span of 50 years indicates possible river movement in several areas where adjacent floodplain in one time period is replaced by river channel in the subsequent time period. For example, channel centreline variation as seen in Figure 15-24 (a) around the area of Ghaziabad and Pur Delhi showed movement of channel centreline by 272m in 50 years period whereas present river width is limited 300m.

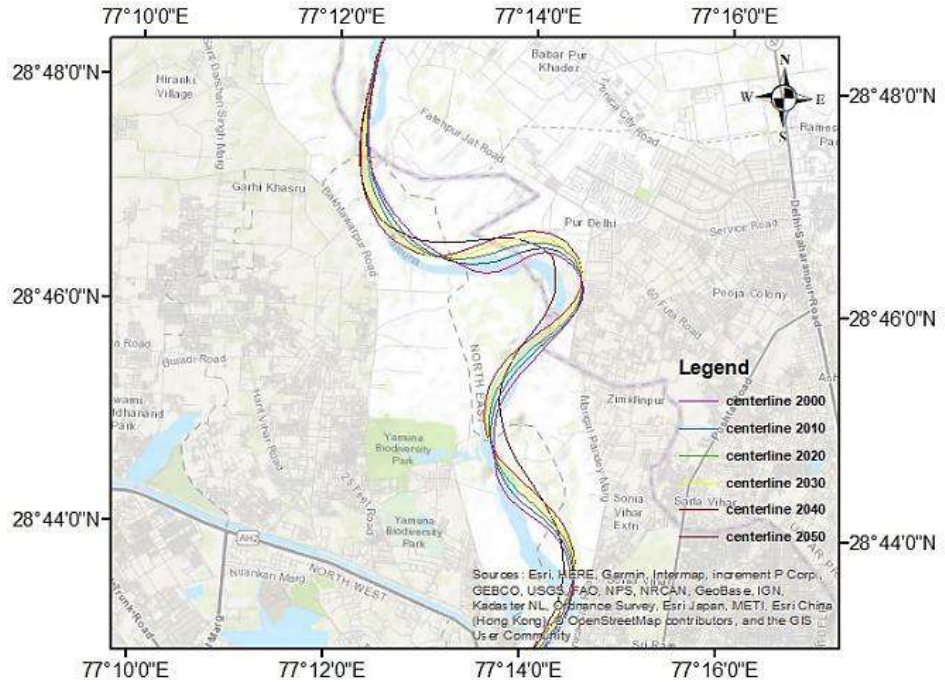


Figure 15-24: Zoomed in component of Figure 15-23 (Middle reach)

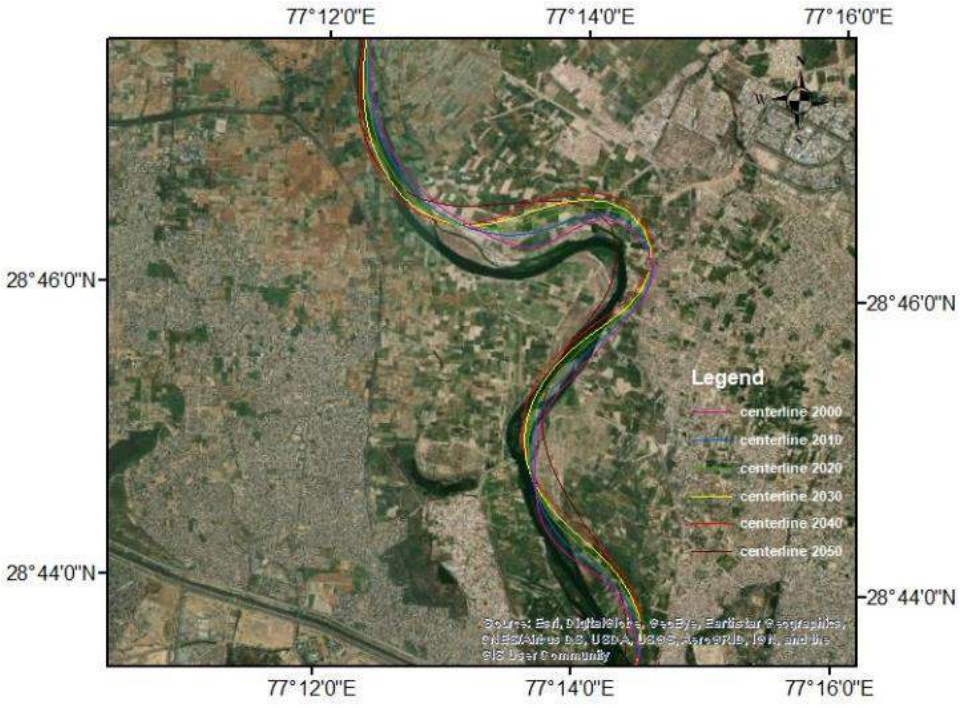


Figure 15-25: Google earth screenshot for the area shown in Figure 15-24

If river is allowed to flow without any hindrance such as flood protection structures, or regulated flows, chances of river occupying the significant part of adjacent floodplains in subsequent years

is quite high. Figure 15-25 shows google earth imagery of the year 2019 along with simulated channel centrelines of the year 2000, 2010, 2020, 2030, 2040 and the year 2050. Simulation outcome suggests the loss of agricultural or cultivable land to actual river channel. Therefore, this segment of the River Yamuna can be considered as morphologically active and can be considered as critical.

9. Okhla Barrage to Gokul Barrage

This stretch of River Yamuna is approximately 200 km in length. Based on hydrological data observed at Delhi Railway bridge, 2-year return period flood value i.e.2595 cumecs has been considered for the purpose of the simulation. Figure 15-26 indicates the simulated channel centrelines for the entire reach whereas subsequent figures indicate zoomed in part of the Figure 15-26 for better representation. Bend geometric parameters are tabled in Table 15-6.

Table 15-6 : Bend Geometric parameters for River reach between Okhla and Gokul Barrage

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.0000000000	2176.2380737406	2093.3187232700	0.3621470586	0.3680961827	1.0396114311	-3085.5678463018	-0.0003240895	-0.0000000001	0.0000000000
2	2176.2380737406	1801.3116284194	1763.0648709251	0.2490267357	0.3181193297	1.0216933354	3178.0368824294	0.0003146597	0.0005958187	3301.7988641634
3	3977.5497021602	3000.7406071632	2650.6449135522	0.7968750777	0.5028609445	1.1320794392	-2313.4452964744	-0.0004322557	-0.0000091422	6903.4647320306
4	6978.2903093231	4351.6787155944	3369.6983823519	0.8901786257	1.0607150983	1.2914742573	2233.6454154573	0.0004476986	0.0011607550	8854.4254482332
5	11330.1690249178	1800.1677800146	1650.3845571205	0.5223050308	0.5580452985	1.0907565587	-1669.7610890631	-0.0005988881	-0.0000092052	13055.4295573174
6	13130.3368049322	3450.7831158670	3070.6826890693	0.7474952559	0.9409812556	1.1237836876	2045.2919184964	0.0004889278	0.0009804427	16056.2358337649
7	16581.1199207992	4622.8692334592	2554.7610610008	1.7380626086	1.9470020694	1.8095113880	-1245.0592742879	-0.0008031746	-0.0001789168	20101.2046467533
8	21203.9891542584	5553.4459456801	2699.0437628817	1.6771247348	1.8559157591	2.0575605413	1574.8709501960	0.0006349727	0.0015665705	25485.4958062927
9	26757.4350999386	7205.0037989225	5008.8272892366	1.6500272473	0.9836083698	1.4384612171	-2736.7767535182	-0.0003653933	-0.0000192601	26832.3321252366
10	33962.4388988610	3894.0156401910	2401.1997874345	1.6184506394	1.1786965307	1.6216958125	1391.7246261356	0.0007185329	0.0014425151	36429.5273477053
11	37856.4545390529	5852.1880296495	4432.0754647623	1.0652948602	1.2092231531	1.3204170543	-2575.0376575726	-0.0003883438	-0.0000317160	43633.6219227655
12	43708.6425687013	5253.0642135182	5208.1696822533	0.2428196234	0.2519583510	1.0086200209	10617.8904315971	0.0000941807	0.0002086421	44083.5554938061
13	48961.7067822199	300.1389905953	300.1372594995	0.0048508659	0.0047540690	1.0000057677	-31248.2833951574	-0.0000320018	-0.0000313697	49186.7401349660
14	49261.8457728152	4352.7905216920	3624.6456852208	0.7767367856	1.0622149408	1.2008871762	2368.1542487070	0.0004222698	0.0009519427	52788.3207713345
15	53614.6362945071	4499.7890566338	2836.4830370993	1.4176983734	1.2130188328	1.5863973088	-1713.5492905508	-0.0005835840	-0.0000116587	53689.6874311283
16	58114.4253511408	2096.6630178974	1936.6735131544	0.4836363315	0.5200658179	1.0826104677	2095.4959517084	0.0004772140	0.0012141627	58238.1940577270
17	60211.0883690385	2545.4774899887	1581.7406519898	1.4099243955	1.6139820906	1.6092887837	-841.1425709086	-0.0011888591	-0.0000552438	60285.1343568525
18	62756.5658590270	1496.7466830654	1379.9834443036	0.7289053340	0.4561105887	1.0846120577	1262.9698680306	0.0007917845	0.0015826293	63129.9141730792
19	64253.3125420925	2100.8921634318	1994.3678465307	0.4193555407	0.5096390752	1.0534125724	-2262.7963626911	-0.0004419311	-0.0000292579	66278.9612252437
20	66354.2047055243	5852.4651223336	4580.5786147462	1.6018718146	0.9159197624	1.2776693982	2326.0923846995	0.0004299055	0.0013163545	67028.7465422361
21	72206.6698278578	1950.6822092653	1834.7021489885	0.4247355008	0.5124701015	1.0632146533	-2083.1906226151	-0.0004800329	-0.0000713050	74081.0161132615
22	74157.3520371231	3138.2640604524	1350.7976773874	1.7252951666	1.3478575599	2.3232672909	1019.5282531822	0.0009808458	0.0026042927	75573.0754521448
23	77295.6160975755	1949.1212528171	1818.7556210701	0.4263661485	0.5631373717	1.0716784763	-1973.7943051633	-0.0005066384	-0.0000185815	77370.0836723969
24	79244.7373503924	1351.0258462637	1273.7151557122	0.3684288255	0.6387038976	1.0606970014	1344.2343839935	0.0007439179	0.0014712963	80217.2184972971
25	80595.7631966564	3134.7139335576	1628.2019602343	2.5872881549	0.8491843787	1.9252611225	-913.5181506755	-0.0010946690	-0.0000050372	83656.1296753842
26	83730.4771302139	1950.3525921119	1867.0069360602	0.3858008460	0.3860514662	1.0446413211	2530.4057370429	0.0003951935	0.0007919985	84705.7971184942
27	85680.8297223257	1950.5790748962	1851.5126228786	0.4647004101	0.3976530314	1.0535056855	-2265.4505519030	-0.0004414133	-0.0000431124	87556.4421861940
28	87631.4087972221	3151.6256589248	2821.6026628566	0.6350254735	0.8829503122	1.1169629588	2077.7578867642	0.0004812880	0.0009922333	90108.6704420230
29	90783.0344561469	1650.4313606221	1591.5676239822	0.4309161623	0.3086375838	1.0369847537	-2233.5797028731	-0.0004477118	-0.0000305335	92358.4460048131
30	92433.4658167690	6454.6623834450	5256.1196200466	0.8938188664	1.2164509985	1.2280280606	3059.0096316729	0.0003269032	0.0007566604	93061.8847225133
31	98888.1282002138	2996.6497992055	1837.4176510815	0.9706750371	1.8727570921	1.6309029128	-1055.7410694201	-0.0009472020	-0.0000154387	99261.1490903899
32	101884.7779994194	1938.3304096163	1486.7217000677	0.7983056586	1.3163277285	1.3037614299	914.1503561109	0.0010939120	0.0024669678	103300.0359220194
33	103823.1084090355	1046.4510926540	975.6602105791	0.5954081811	0.4946660209	1.0725569018	-959.5851234373	-0.0010421170	-0.0004413447	104794.1563732852
34	104869.5595016896	1943.7110812905	1531.4307972736	1.0133006489	0.9277199867	1.2692124807	1002.5261759517	0.0009974802	0.0019316401	105543.3991393302
35	106813.2705829802	3295.6007843965	1860.5852064074	1.1964130265	1.9768846989	1.7712710888	-1038.4218647634	-0.0009629998	-0.0000277339	106888.8961894471
36	110108.8713673769	2690.9730061992	1644.0815328702	1.3116161400	1.7906852502	1.6367637203	866.3573927200	0.0011542581	0.0022444746	112276.9387026342
37	112799.8443735760	4511.3314952210	3165.2292203361	1.7901486728	0.9304880138	1.4252779755	-1657.0530513407	-0.0006034810	-0.0000228508	116626.9804322126
38	117311.1758687970	786.3086751714	579.4822059191	0.9511407165	0.8465816560	1.3569159970	394.4483167520	0.0025351864	0.0059254755	117650.6510075723
39	118097.4845439684	3009.9481352301	2729.7430976285	0.7304773879	0.5772371156	1.1026488675	-2306.8923384966	-0.0004334836	-0.0000203806	121032.4980769026

Bend	start_s	arclength	line_dist	entranceAngle	exitAngle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
40	121107.4326791986	5852.3877212258	4824.5680989120	0.9240993801	1.3097574516	1.2130386806	2620.9316487398	0.0003815437	0.0009679511	126285.6653434196
41	126959.8204004242	4351.0037848621	3715.7558196918	1.3015014437	0.7426721642	1.1709606325	-2130.8789743250	-0.0004692899	-0.0000631344	131235.9400025536
42	131310.8241852864	1500.7886152328	1404.2894628962	0.4723906696	0.5320028736	1.0687174225	1496.3929481560	0.0006682737	0.0011585864	132135.7378313394
43	132811.6128005190	1950.4800148728	1904.3241917399	0.3499654823	0.2535660119	1.0242373769	-3234.3886605081	-0.0003091774	-0.0000383574	132886.7502619899
44	134762.0928153918	2551.8019840775	2519.3371969659	0.2470717558	0.1926913725	1.0128862413	5803.6635798029	0.0001723050	0.0003296156	135737.7944536406
45	137313.8947994698	3302.1605143211	3185.0600665486	0.3478496685	0.3699573159	1.0367655383	-4601.9399850682	-0.0002172997	-0.0000200786	137388.9330636297
46	140616.0553137906	4051.7041118749	3428.0813654044	0.7028176187	0.9673124295	1.1819159699	2428.9247263197	0.0004117048	0.0008013392	142492.2418802242
47	144667.7594256653	1650.6769622217	1575.7807648614	0.4102513513	0.3917357171	1.0475295796	-2061.1034279705	-0.0004851770	-0.0000260974	146243.7932068684
48	146318.4363878871	2099.8030141234	1893.2676801066	0.7066679101	0.4807677668	1.1090893465	1773.2464900625	0.0005639374	0.0012644376	147143.4212596568
49	148418.2394020104	4650.3916392859	2570.7455420688	1.2417794521	2.0176588449	1.8089661397	-1428.3224205358	-0.0007001220	-0.0000699342	148493.4306611057
50	153068.6310412964	6300.8210484099	4557.0234184865	1.5377975936	1.0646117220	1.3826615468	2423.9269777382	0.0004125537	0.0010267595	155091.9433126059
51	159369.4520897060	1649.3431211030	1530.2485899545	0.4581160311	0.5588952901	1.0778269178	-1623.5898547550	-0.0006159191	-0.0000159387	159444.3418040380
52	161018.7952108092	1349.1656521353	1153.7712137336	0.8266147351	0.6790222730	1.1693528458	895.4019813864	0.0011168168	0.0019661650	161689.9835232132
53	162367.9608629445	4052.4627881678	3321.9872034569	1.0178189559	1.1311465888	1.2198911495	-1879.7761322411	-0.0005319782	-0.0000092485	166339.1452787214
54	166420.4236511123	1179.6036495141	844.2032405463	1.2521648146	0.8441409054	1.3972981776	549.8790004986	0.0018185819	0.0038166436	166925.5116505855
55	167600.0273006266	3738.1571079159	1893.2102912374	1.3650240936	2.2971805057	1.9745070715	-1019.9312467870	-0.0009804582	-0.0001963901	167674.9241325519
56	171338.1844085423	3893.6719433086	1930.0925392988	1.6443158479	1.5785818589	2.0173498752	1208.4843902027	0.0008274828	0.0018512819	173504.4528146732
57	175231.8563518511	2695.4705394846	1879.0376372210	1.1390641574	1.5244616693	1.4344952363	-1014.0082313267	-0.0009861853	-0.0002419427	177851.8998259965
58	177927.3268913356	1347.5618029406	1306.8396615454	0.3184006108	0.3838541451	1.0311606208	1922.0112588845	0.0005202883	0.0008705264	178750.9363588983
59	179274.8806942760	1198.7532686163	1118.2905291456	0.5191952977	0.5451428528	1.0719515523	-1126.8643057739	-0.0008874183	-0.0003122031	179350.5772715221
60	180473.6419628924	4199.7171210362	2948.0003657964	1.6804722849	1.1419896785	1.4245965753	1489.6836462495	0.0006712835	0.0015902501	180999.4331170986
61	184673.3590839286	4199.5863210736	2709.7213699290	1.1851008787	1.5361144304	1.5498221949	-1546.6733209991	-0.0006465489	-0.0000069929	184748.0102510098
62	188872.9454050020	7652.5391538271	6589.8731913335	1.3307344004	0.7373604116	1.1612574221	3698.9619816509	0.0002703461	0.0008343268	189547.9954635190
63	196525.4845588293	5101.0472842911	4939.0628983748	0.4941772869	0.5073128834	1.0327965829	-5089.1116608859	-0.0001964979	-0.0000430647	197650.0616171557

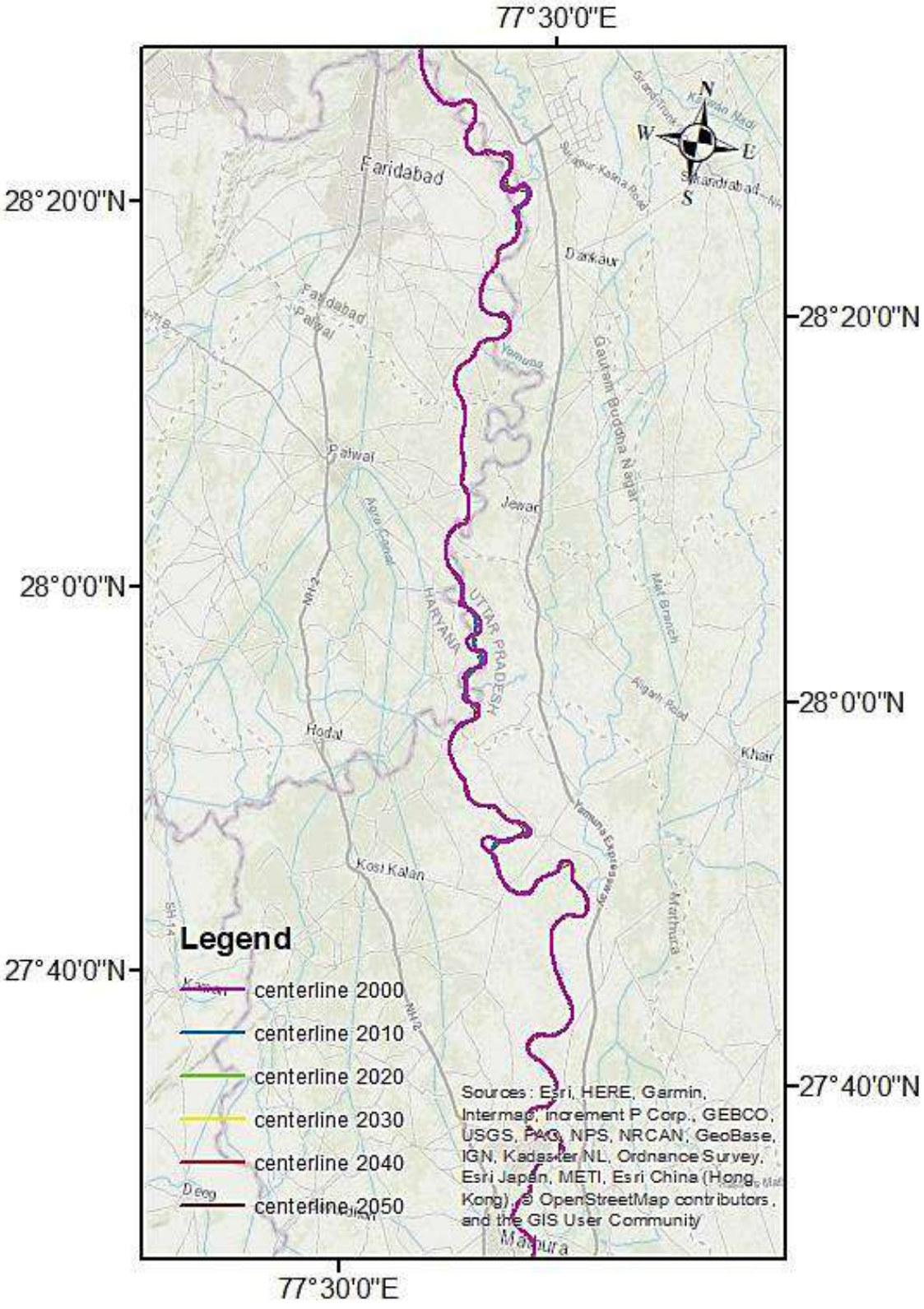


Figure 15-26: Centerlines for different years of simulation for the river reach between Okhla Barrage and Gokul Barrage

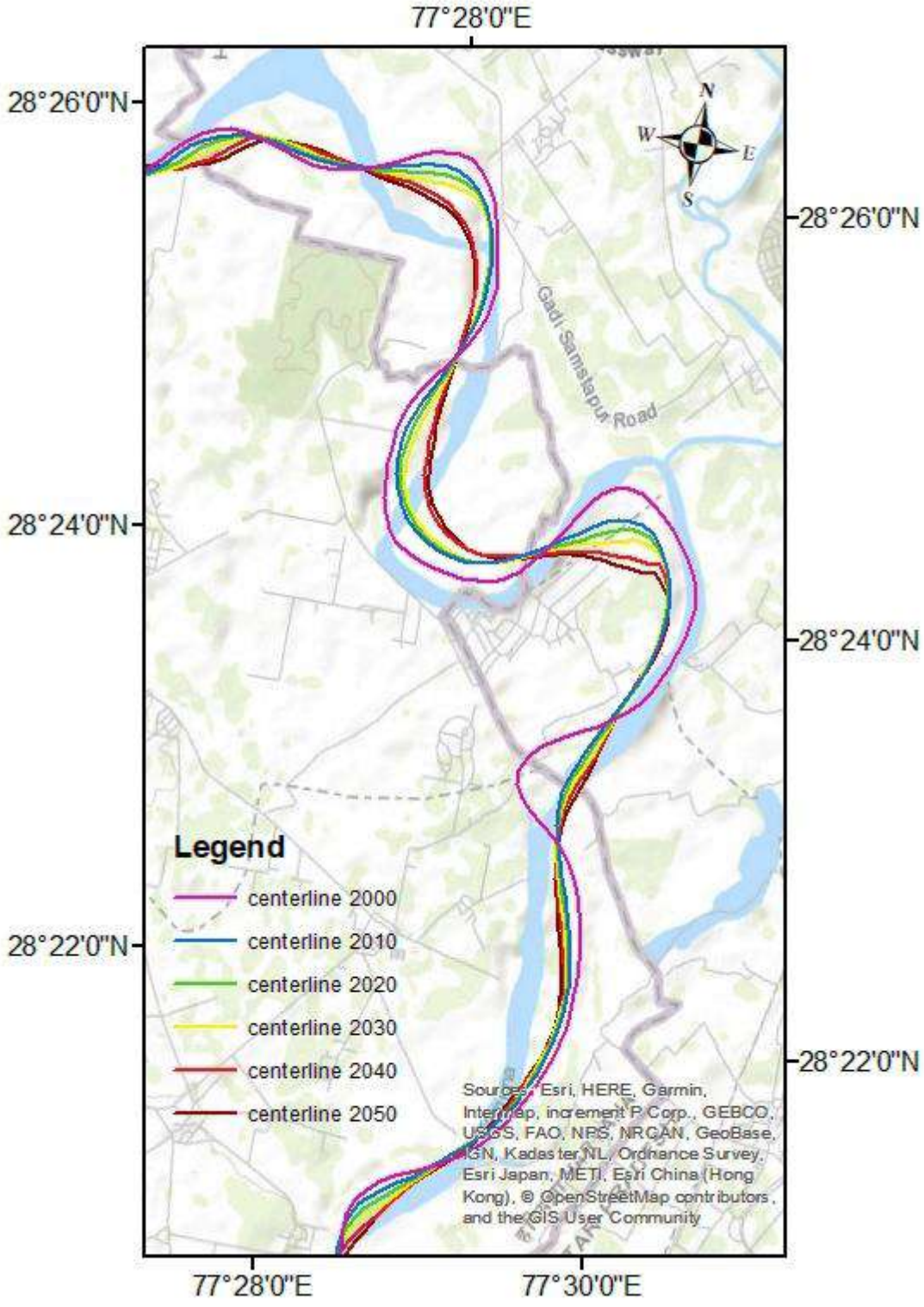


Figure 15-27: Zoomed in component of Figure 15-26 (Upper middle reach)

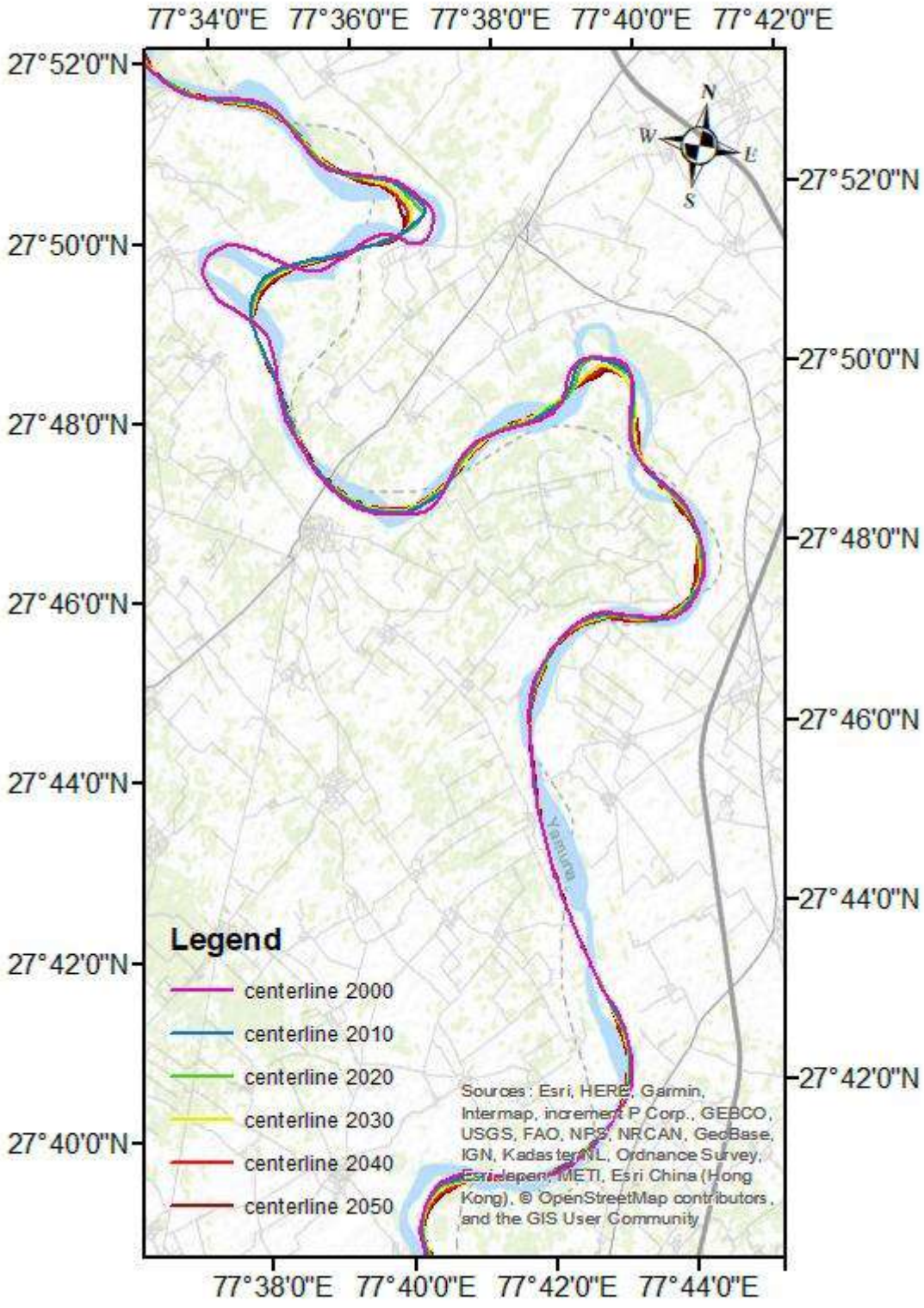


Figure 15-28: Zoomed in component of Figure 15-26 (Lower reach)

From the analysis of simulation results, the rate of channel migration is found out to be 2.59m/year. Maximum swing of channel centreline over the span of 50 years is around 500m whereas average shift of channel centreline is about 190m. At few locations, if allowed, river meandering may result in loss of agriculture and settlement in the vicinity. These locations are in the vicinity of Luksar (near Gadi-Samstipur Road), Hassanpur (near Hodal) and Ova (Shergad, Mathura). Moreover, probability of neck cut off and formation of ox-bow lakes is also high. This is also in accord with observations from satellite images on decadal scale. In the view of above observations at few locations (as mentioned earlier) river is morphologically active with significant meandering pattern.

10. Gokul Barrage to Chambal Yamuna confluence

This stretch of River Yamuna covers 385 km length. The flow data used as an input for simulation include discharge, width, depth, slope and grain size for which values of 1700cumecs, 600m, 2m, 0.0003 and 10mm are used respectively. Boundary conditions used to define the bend i.e. number of nodes and straight sinuosity threshold are given values of 8 and 0.0005 respectively. Based on the input and calibration data in the form of channel centrelines of the years 2000 and 2010, simulation results indicate that channel centrelines for given flow and channel conditions do not show significant change over span of the 50 years. The rate of channel migration in this stretch is found out be 1.63m/year. Though the sinuosity and number of bends are high in this region, flow patterns and channel characteristics ensure limited movement of channel centrelines. At few locations, simulation outcome has predicted reduction in radius of curvature of bends. Those locations are in the vicinity of the Purbia Tola (near Etawah), Bateshwar (Agra district), and Dangroli Must (near Runukta Railway station). However, overall analysis of this reach indicates that activities like channel migration, movement of channel centreline etc., are rare. In view of the above observations this section can be considered as stable reach.

11. After Chambal river outfalls into Yamuna, not much morphological changes have been observed in River Yamuna on the temporal scale of study. So, modelling study was not attempted for this section. However, if such study is attempted in near future, the results and inferences drawn from such study will be shared with CWC separately.

15.3 Conclusions

From the modelling study following conclusions can be drawn:

1. HEC-RAS modelling using channel cross-sections at selected intervals is useful to determine the relation between channel top width and discharge
2. JP meander migration modelling carried out for River Yamuna from Yamuntori to Chambal Yamuna confluence based on channel centreline of the year 2000 as a baseline can be used to predict future river channel centrelines and the rate of channel migration
3. The outcome of meander migration modelling suggests that upstream stretch of River Yamuna i.e., from Yamunotri up to Kalnaur Bridge is comparatively stable and does not feature meandering characteristics
4. After Kalanaur bridge, the rate of channel migration increases up to Okhla Barrage (from 3.5m/year to 4.05m/year) and then decreases (up to 2.59m/year) for the Okhla-Gokul barrage reach
5. A few locations identified in the stretch from Kalanur to Gokul Barrage may experience neck cut off/ ox-bow formation/ abandonment of reach based on the model simulations However, some of these areas are already protected with flood protection structures which ultimately restrict the river movement
6. Modelling outcomes along with other observations and indices captured from remote sensing observations on decadal scale are certainly useful in suggesting the stable or active segments in the entire river course.

Chapter 16 River Flood Affected Areas

16.1 General

The data from the secondary sources are collected to gather information about past flood events. The flood monitoring in River Yamuna started in the year 1963. Apart from hydrological observation sites flood monitoring is done at several other sites in River Yamuna, and the list is given in Table 16-1.

Table 16-1 List of Flood Forecasting Sites in River Yamuna

SN	Site	District/ State	Danger Level
1	Paonta	Sirmaur, HP	384.5 M
2	Karnal	Karnal, Haryana	249.5 M
3	Mawi	Muzzafar Nagar, UP	230.85 M
4	Dhansa	South West, Delhi	212.44 M
5	Delhi Railway Bridge	North, Delhi	204.83 M
6	Mathura (Prayag Ghat)	Mathura	166.0 M
7	Agra (J.B.)	Agra, UP	152.4 M
8	Mohana	Jalaun, UP	122.66 M
9	Etawah	Etawah, UP	121.92 M
10	Auraiya	Auraiya, UP	113.0 M
11	Kalpi	Jalaun, UP	108.0 M
12	Shahijina	Hamirpur, UP	104.54 M
13	Banda	Banda, UP	104.0 M
14	Hamirpur	Hamirpur, UP	103.63 M
15	Chillaghat	Banda, UP	100.0 M
16	Naini	Prayagraj, UP	84.73 M

Several flood events would have occurred in River Yamuna but the monitoring of events has been done along with flood warning only after the year 1958. Accordingly, appropriate action has been taken by authorities to minimise the loss of life and property. The river has seen high floods in 1978, 1988, 1995, 2010, 2013, 2018 and 2019. The 2010 and 2013 floods also crossed 207 meters mark but fell short of 1978 level at Old Delhi Railway Bridge. Figure 16-1 indicates the highest flood levels in different years at Old Delhi Railway Bridge.

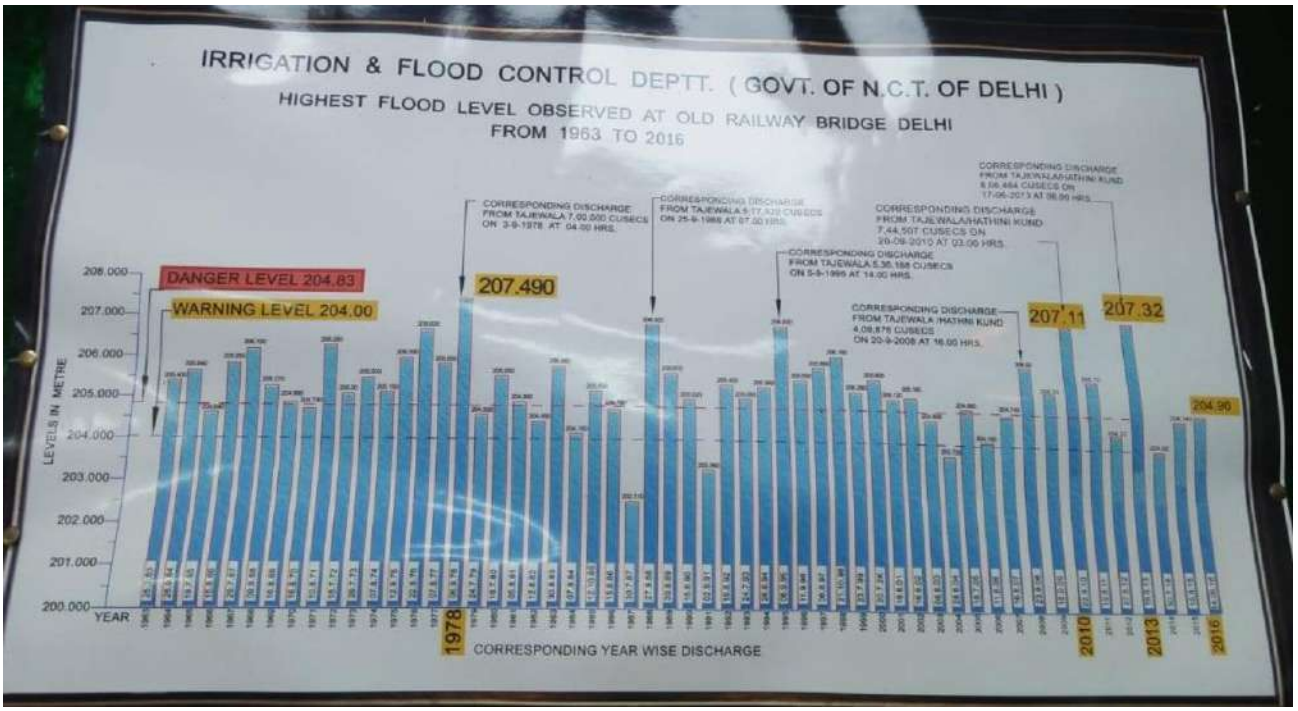


Figure 16-1: Highest flood levels at Old Delhi Railway Bridge

The river affected flood areas in River Yamuna include villages in the districts of Yamunanagar, Karnal, Panipat, Sonipat in Haryana, Delhi NCR region, and districts of Agra and Mathura in Uttar Pradesh. From the analysis of past flood events, in most cases flooding resulted due to high rainfall in upstream catchments and poor conveyance of the channel to carry the load. Information on some of the specific flood events is discussed in the following Section.

16.2 Historic Flood events

A devastating flood occurred in River Yamuna in 1978. Many rural embankments were breached due to heavy discharge coming from upstream of Tajewala Headworks in Haryana. The rise in water levels also caused reverse flows in the connecting drains and had an effect on the city drainage network, causing overflow resulting in damage to property, public utilities as well as agriculture. HFL at Delhi Railway Bridge was recorded as 207.49 m, 2.66 m above the danger level of 204.83 m. Colonies such as Model Town, Mukharjee Nagar and Nirankari Colony were inundated.

In 1988 flood in Delhi recorded the second-highest peak flow of 1,547cumecs. Continuous torrential rains in the Northwest part of the country caused heavy discharge in the Yamuna. The flow in the river Yamuna at Delhi Railway Bridge was recorded above warning level, i.e., 204 m.

It was a high magnitude flood causing misery and loss of life and property to the residents of the city and damage to the transport network. Several villages and localities in low lying areas like Shastri Park, Yamuna Bazar, Red fort, Geeta Colony were underwater for several days.

In September 1995, heavy rain in upstream Yamuna catchment resulted in huge discharge from Tajewala headworks. The flood-affected villages in the district of Yamuna Nagar and unplanned settlements situated within river bed caused the displacement of over 15000 families.

In September 2010, with flood level of 207.11 at Old Delhi Bridge, River Yamuna got flooded in several locations in Delhi NCR. Several low lying areas like Garhi Mandu, Usmanpur Pusta, Sonia Vihar, Yamuna Bazar and Kashmiri Gate were inundated for days. A few areas also faced the problem of waterlogging.

Another flood event occurred in June 2013 where discharge from Hathnikund Barrage resulted in inundation of several villages in Yamuna Nagar district and inundation along Yamuna Bank, Kashmiri Gate, ISBT in the Delhi NCR region. The highest water level recorded during this event at Old Delhi Bridge was 207.32 meters. Other flood events in the year 2018 and 2019 have also been noticed.

16.3 Morphological Changes

Flood events usually result in alternation between the two processes of erosion and deposition. In case of Yamuna, given the flow rates at the Old Delhi Railway Bridge and release from Hathnikund Barrage indicate that the erosion process is dominant. In fact, by reducing the magnitude of frequent, moderate floods, dams may lead to channel narrowing through lateral accretion. A similar observation is noticed in downstream reach of Hathnikund and Gokul Barrage, where the width of the active water area is limited to approximately 15% of the entire channel width. Flood events also trigger morphological evolution of cross-sections. In view of this, pre-monsoon and post-monsoon cross-sections at selected locations are analyzed to understand aggregation and degradation patterns. Detailed analysis of such sections and linking those results with satellite image observations is presented in Chapter 12. However, to assess the effect of a flood event on channel morphology detailed hydrodynamic modelling with focused attention on sediment transport is needed, which is beyond the scope of the present study. Therefore, in the present study, the information obtained from secondary sources about inundated areas in the past is used while discussing stable/ critical reaches in Chapter 17.

Chapter 17 Identification of Critical Reaches

17.1 General

Erosion and deposition often occur and result in the changes in channel morphology. This change in channel morphology then leads to change in inundation patterns in adjacent floodplains. Flood occurrence also modifies the landforms each year, and this leads to instability at the riverbank. The cyclic process ultimately results in the collapse of riverbank along with the river network and loss of the land in the vicinity. However, the movement of the river in its corridor is a natural process and an essential aspect of river landscape evolution. Therefore, to term or to define a river reach as stable/ unstable/ critical/ evolving is the topic for discussion and needs detailed discussion on various aspects which have a significant bearing on such identification/labelling. These aspects may broadly range from scale issues, modelling exercises, understanding and recreating historical events, perspective to priorities of the individuals and the organizations. Following on the above discussion, the approach adopted in the present study to define stable/critical reaches is presented as follows.

17.2 Scale Issues

Morphological processes occur at wide range of scales. For example, channel geometry and fluvial dynamics are not just determined by local geomorphological settings rather they are the results of influxes from the upstream watershed. Over a period, (different temporal scales ranging from seconds to million years: geologic time scales), combined effects of discharge and sediment transport within the local environment (e.g., geology, topography, microclimatic conditions) results in the formation of certain channel patterns. However, the typical sequence of morphological settings along a river's course from constrained upstream gorges to braided and meandering rivers to, finally, anastomosing lowland rivers is not observed in most of the river systems. Tectonic activities may foster channel patterns that would normally not be expected at a respective site in a given period of time. Changes in upstream sediment carrying capacities and altered hydrological regimes due to anthropogenic activities also trigger local channel alterations. Even downstream hydro-morphological changes may result in upstream channel geometry

fluctuations due to retrograde soil erosion. Therefore, morphological behavioural characteristics observed at selected river reach do not only affect the physical configuration and dynamic fluvial processes at the respective river reach but rather influence much longer river sections or even the whole river system, including the tributaries. Lane and Richards, (1997) discussed that the traditional view regarding interlinking of scales (that different scales of form and process are causally independent of each other) cannot be sustained, as short timescale and small space-scale processes influence processes over longer timescales and larger space-scales. Considering the importance of scale issue, the terms associated with scale issues, i.e. process scale, observation scale and modelling scales, scaling and linkages across scales in modelling framework are defined below. More details about these terms are available in Bloschl and Sivapalan (1995).

1. Process Scale:

   The process scale is the scale that natural phenomena exhibit and is beyond our control. They are further classified into 'characteristic time scales' and 'characteristic space scales'. As the morphological changes in the river are highly driven/influenced by hydrologic changes, characteristics time and space scales of hydrological processes also affect channel morphology. Characteristic time scales of a hydrological process can be defined as (a) duration of the event (for intermittent processes such as a flood, drought, rainfall event); (b) the cycle: recurrent phenomenon (for a periodic process such as snowmelt, monsoon rainfall); and (c) the correlation length (for a stochastic process exhibiting some sort of correlation). Similarly, characteristic space scales can be defined either as spatial extent, period or integral scale, depending on the nature of the process.

2. Observation Scale:

   The definition of the observation scale is related to the necessity of a finite number of samples. Consequently, observation scale in space and time can be defined as: (a) the spatial/ temporal extent; (b) resolution; or (c) the integration volume/ time of a sample. Ideally, processes should be observed at the scale they occur. However, this is not always feasible. Often the interest lies in large-scale processes while only (small-scale) point samples are available. Also, hydrological and morphological processes are often simultaneously operative at a range of scales.

3. Modelling Scale:

In space, typical modelling scales (Dooge, 1982; 1986) are: the local scale (1 m); the hillslope (reach) scale (100 m); the catchment scale (10 km); and the regional scale (1000 km). In time, typical modelling scales are the event scale (1 day); the seasonal scale (1 yr); and the long-term scale (100yrs). Unfortunately, often, the modelling scale is much larger or much smaller than the observation scale. To bridge that gap, 'scaling' is needed.

4. Scaling and linkages across scales in modelling:

   Upscaling refers to transferring information from a given scale to a smaller scale, whereas downscaling refers to transferring information to a larger scale (Gupta et al., 1986a). For example, measuring evapotranspiration in a Lysimeter and assuming it applies to the surrounding area involves upscaling. Also, flood frequency analysis for higher return period based on limited data involves upscaling. Conversely, using runoff coefficients derived from a large catchment for culvert design on a small catchment involves downscaling (Mein, 1993). Regionalization, on the other hand, involves the transfer of information from one catchment (location) to another (Kleeberg, 1992).

To bring in the component of scale is essential in the context of morphology study as the autocyclic and allocyclic processes which are core to channel evolution occur at different scales. The terms autocyclic and allocyclic processes are discussed below.

1. Autocyclic Processes

   According to Beerbower (1964), autocycles are produced by processes within sedimentary systems. Autocyclic processes tend to be instantaneous geologic events that are random in both time and space, and they contain few interregional feedback mechanisms. As a result, autocyclic processes are aperiodic. Autocyclic processes include phenomena such as stream avulsion and meandering, and fluvial point-bar migration or lateral migration of beach-barrier bars. Responses to autocyclic processes tend to be local and may range from millimetre-scale ripple migration to regional-scale events such as delta switching.

2. Allocyclic Processes

   Allocycles result from processes external to sedimentary systems and include tectonic activity, climatic change, and eustasy. Importantly, allocyclic changes commonly induce changes in autocyclic processes. For example, an allocyclic rise or fall in sea level may cause changes in the nature and degree of delta switching. Sedimentary responses to

allocyclic processes may occur on geographic scales that range from basin to global. For example, tectonic subsidence or uplift may affect only a single basin, but plate collision and/or rates of sea-floor spreading may have global implications.

Both autocyclic and allocyclic processes are responsible for changes in channel morphology, and they occur at different spatial and temporal scales. Moreover, one process also influences the characteristics of other processes. So, there is a significant overlapping of scales. For example, changes in channel morphology can be driven by changes in land use whereas evolution in channel morphology may lead to a change in land use type. Example of two systems, River Yamuna and River Kosi may be considered to elaborate little further. In case of River Yamuna, catchment land-use change might have triggered changes in channel morphology whereas, in case of Kosi, changes in channel morphology, the evolution of river system might have caused the change in land use type. In view of the above, to define a river reach either stable or critical without giving due attention to autocyclic and allocyclic processes may not be appropriate. In the case of River Yamuna, considering the geologic stability of the system, one may tend to consider the sole effect of autocyclic processes in defining the stability of the reach.

17.3 Perspective

To identify or to define a stretch either critical or stable has a lot to do with the perspective. Role of observer and object at multiple scales is important. Consider an example of an ant on a paper. For an ant if her position on the paper remains constant and if outside environment is not significantly different, there will not be an issue regarding criticality or stability even if the paper has moved from one place to another with above conditions. However, if an ant moves from one location to another on the given paper by a narrow distance which is beyond the observation scale of the observer, for him there may not be any change but for an ant, it may result in an unpleasant situation. So, the perspective, in this case, matters a lot as both ant and observer see the same things differently. For one it is stable whereas for the other it is critical. There are different viewpoints about defining the river reach as either stable or critical. Some of these are presented below.

17.3.1 Hydrologist

For a hydrologist, various aspects such as water audit, basin planning, design value for different hydraulic structures and other allied studies, require a thorough understanding of flow regime.

Pattern, changes and variations in flow regimes often result in modification of overall basin hydrology. Hydrologist may find a river reach critical if there is a significant change in flow regime or the pattern of changes, within or across defined time periods.

17.3.2 Ecologist

Ecological, hydrological and biogeochemical functions of river ecosystems provide a set of well-known ecosystem services. When ecosystems are maintained in a healthy state, their ability to provide these services is more significant, whereas deterioration of ecosystems may reduce the viability of the provided services. Intact river ecosystems are more effective at processing nutrients, breaking down waste, filtering water and providing habitat, food and shelter for the biota. The concept of environmental flow is based on this phenomenon. It has been discussed/ defined in several ways by outlining the required characteristics of flows regime by hydrological, hydraulic, eco-hydraulic and holistic means either alone or in combination. For an ecologist, a stretch of a river may be critical if water quantity and/ or quality is not up to the desired level for the species that are indigenous to that system. The other way of saying it is, if the environmental flow is not fulfilled the reach may be called critical.

17.3.3 Water User

For different water users like farmers, industries of different scales, hydropower generators and fishing community etc., definition of stability/criticality of a river reach may vary from that of above.

- For farmers cultivating in and around the floodplain- the quantity of water (water levels in a river during various seasons) and the quality of water is important. While sometimes lack of surface water from the river may be a manageable issue (groundwater resources may be used in such case), increase in water levels leading to inundation of crops is a difficult situation for them. Poor water quality may harm the quality of farm produce. River streams leading to such risks may be described as critical for farmers.
- For industries and hydropower generators, non-availability of standard water quality and quantity may lead to critical situations resulting in operational losses.
- For a fishing community which directly depends on certain river reaches, water quantity and quality are both important. For them river reaches prone to incidences/impacts such as extreme events, manmade changes (dried river reach on account of diversion/

abstraction), etc., can be critical. For them, the river reaches that have minimal effects due to anthropogenic activities etc., will be most stable - if they depend on indigenous aquatic species which thrive under such conditions.

17.3.4 Administrator/ Decision maker

Administrators and decision-makers ranging from the local body (panchayat) to district, state and federal government authorities are responsible for managing the water resources at the respective levels. Several issues such as management in case of extreme events, demand and supply analysis, prioritization of demands, trade-off among the different users and interstate dispute issues may trigger in demarcating river reach accordingly. For example, based on flood plain zoning, some of the areas are considered as prohibitive and restrictive zones. Existing settlements in such zones based on their vulnerability to flood events make that river reach critical.

17.4 Present study and approach

As discussed above, defining a reach as either critical or stable is an open-ended question. Based on the scale, perspective and interaction of variables driving the overall system one may choose one stretch as critical while others may term the same as stable. In the limited context of the morphological study of Yamuna River system, the results from remote sensing image analysis and modelling study can be used in combination to term the reach as either stable or critical. So, changes occurred over a period (between the years 1975 and 2016) have been used to understand the dynamics of the river course, the channel bank retreat on account of erosion and deposition and rate of meander migration. Our understanding of natural systems suggests that the river system in the unregulated flow scenario should be considered as a reference to discover changes occurred in the system over a temporal domain. In the present study, the system observed in the year 1975 is considered as a reference condition. Various features as explained in Chapter 6 (Section 6.1) are marked on 1975 image and used as a reference. Distance between bank lines (endpoints of channel area as observed in non-monsoon season) is used to obtain the location of centerline and channel width. From the remote sensing analysis rate of channel bank retreat and river course dynamics in the form of movement of channel centreline have been determined. The proposed basis for identification of the critical reaches are as follows,

17.4.1 Pendulum analogy and the grid template

In the case of a simple pendulum, three types of states are possible, i) at rest ii) undamped oscillations and iii) damped oscillations (Figure 17-1). A similar analogy can be drawn to a river system. Let us consider the river centerlines for different years obtained from remote sensing images. The movement of centrelines for different years also reflect the similar pattern of swing and shown in Figure 17-2 and the extent of swing can be considered swing zone of the river channel which is bound by river corridor. The annexed memorandum (Parmar and Khosa, 2017) may be referred to for a comprehensive discussion on the concept.

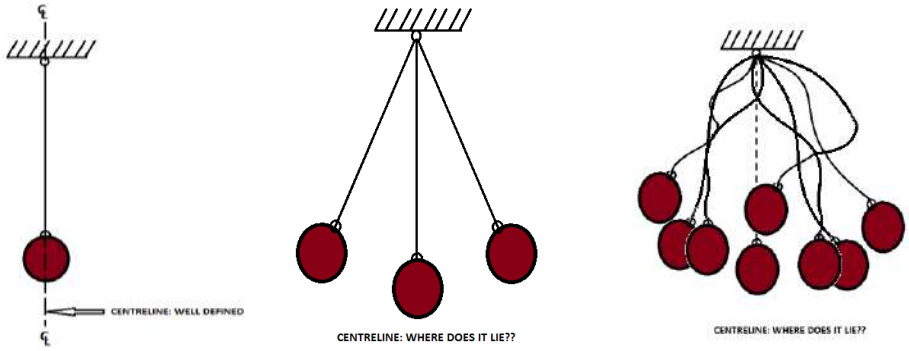


Figure 17-1 : Movement of Simple Pendulum

17.4.1.1 River Corridor

In general, for majority of major river systems across the globe, geological foundations such as fault lines provide a dedicated corridor for drainage paths to develop and which over time, acquire the configuration of river channels and the processes such as erosion and deposition occurring over a range of spatiotemporal scales results in evolution of channel geometry. Significantly, the aforementioned dedicated river corridor demarcates the swing width within which the riverflow can rightfully assume any pathway depending upon the topology of the available potential energy field and its lateral connectivity and exchange with subsurface flow pathways – a reality that has hitherto been disregarded or, at best, given a casual treatment in theoretical abstraction. The annexed memorandum (Parmar and Khosa, 2017) may be referred to for a comprehensive discussion on the concept.

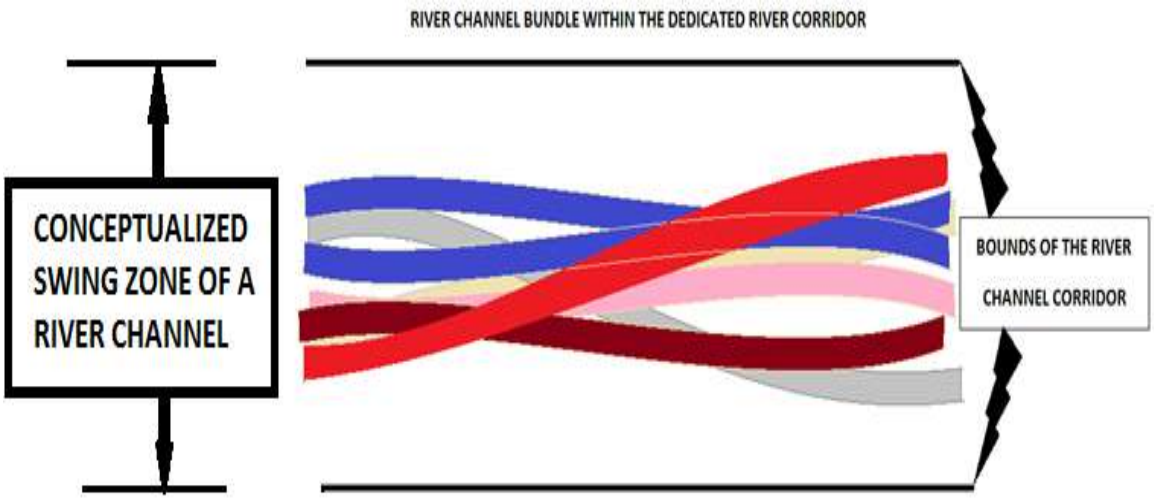


Figure 17-2 : Swing Zone of River Channel and River Corridor

However, to demarcate the boundaries of the river corridor may not be unidirectional. In case of upstream reaches of river which are generally bound by mountains, the river is restricted by adjacent valley and thus have well-defined swing zone for mean flow passing through that channel but when the river enters the plains, river moves to adjacent floodplain quite often and thus defining the corridor boundaries in such case becomes difficult. Though some attempts to define the river corridor in the form of meander belt and floodplain zones are made in the past it remains an open question. Several issues such as selection of return period for defining floodplain, spatial and temporal scale of study to define meander belt, nature of change (systematic or random and reversible or irreversible), unique characteristics of each river systems, both allocyclic and autocyclic drivers and most importantly interlinking and overlapping of scales in parameters which drives channel morphology influence the criteria of selection process and often ends with expert or administrative judgement which may lack scientific credence.

For example, river system such as Kosi which shifted its course for more than 133 km from east to west during the last 200 years, it is impossible to define the boundaries of the river corridor. These are most likely influenced by change/ pattern in the geologic foundation, movement of tectonic plates, the overall change in physiography or combination of these factors. Though attempts to construct embankments and river training works are made in the past to restrict river course and reduce the impact of flooding, these attempts could not

solve the issue at large. Therefore, understanding of the system behaviour becomes critically important prior to decision making.

In comparison with Kosi, River Yamuna has not changed much in the last century even though changes of smaller magnitude have occurred in a few stretches of River Yamuna. From a broad perspective, it can be said that River Yamuna has maintained its course from 1975 to 2015 (scale of this study) and swing is limited to its swing zone. For detailed analysis, grid template as shown in Figure 17-3 is used.

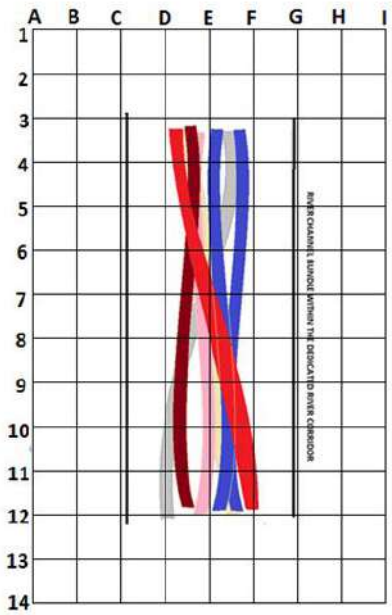


Figure 17-3 Grid Template for Swing analysis

A grid size of 25 km is chosen, and channel centerlines are captured on a decadal scale. Based on the analysis, if channel centerline has moved from one grid to another grid and/ or if angle θ between centerlines of two different time periods is more than 180º which represents unstable/equilibrium stage of a pendulum, these are analyzed further. Such river reaches can be considered as unstable/ critical.

The outcome from this analysis indicate that none of the rivers reaches has moved from one grid to another grid and angle between centrelines is well within the equilibrium limits. Therefore, none of the reaches is considered as unstable/ critical based on the above criteria. However, it is difficult to isolate the reason for the same. Though the physiography of basin seems to be the fundamental reason, the role of altered flow regime should not be neglected.

Both natural and anthropogenic activities have a significant bearing on channel morphology. Topography, well-defined valley, the geology of the basin did not change much and thus helped in maintaining the channel morphology. On the other side, anthropogenic activities such as encroachment, channelization of river courses, river training works and altered flow regime (reduction in flood events, and low flows on account of diversion) mostly result in stabilization of river courses. In the view of the above discussion, the entire course of River Yamuna can be considered as stable.

17.4.2 Swing of channel centerline from the reference and its comparison with the channel width

If the swing of the channel centerline between various years is more than the width of the channel in that stretch, it is analyzed further to understand the dynamics of river functioning. If the swing is limited to channel width, it is considered as natural phenomena of river hydraulics and it may not be attributed as a critical reach.

This concept is also analogous to pendulum analogy with the swing zone limited to twice of the channel width. If the centerline fluctuation between two years is less than the width equivalent to twice of channel width, then section can be considered as stable. However, the inverse of the above may not be always true. For example, section with centerline movement of 2km and channel width of 600m may be considered as unstable based on above criteria, however, if section is meandering and ox-bow formation, neck cutoff in the section may be the primary cause for centreline fluctuation and thus reflect the characteristic behaviour of particular river reach and may be considered as stable. Also, the scale at which these analyses are performed plays important role in defining a reach as either stable or unstable. If reach is studied at 1 km interval, there might be several stretches which will come under unstable criteria but if the same reach is studied at 10 km interval, it may fall under the category of stable reach.

17.4.3 Rate of channel bank retreat and changes in channel width

In case rate of channel bank retreat is high without any significant swing of channel centerline, it indicates uniform expansion/ contraction of the channel area. This might be on account of encroachment, building of flood control walls, spurs etc. This type of reaches

may become critical as reach with loss of channel capacity results in restricted channel pathway which might be insufficient to dissipate the energy associated with flood event.

17.4.4 Meander Migration modelling

The details regarding meander migration model have been presented in Chapter 15. From the modelling exercise, movement of centerline from its original condition for the characteristic flow (2-year recurrence interval discharge: approximate bankfull flow) and the rate of channel migration have been estimated. These results can be used to classify the river reaches based on meander migration rate.

The outcomes of the analysis based on the discussion made in Sections 17.4.2, 17.4.3 and 17.4.4, are used in combination to identify the stability of the reach. For example, river reach might have experienced changes in centerline more than the width of the channel over a period with insignificant changes in erosion/deposition and meander migration rate and vice versa. In such cases, the extent of change, time period, length of reach and adjacent structures, if any, are used in combination to demarcate the reach as either stable or unstable. Unstable/critical reaches based on the above approach are discussed below,

17.4.5 Unstable and stable reaches

Based on the above approach following reaches have been identified as unstable. However, to call them as critical or not is something related to perspective as mentioned earlier.

1. Chainage 163-164 (around village Jathlana)

   From the remote sensing observations, variations in channel geometry are observed from year 1975 to 2016. Though channel variations have reduced in the last two decades, the overall width of the river in which channel and active water areas are fluctuating is close to 3 km. It is significantly more than its observed width in any of the year.

   Meander migration modelling also suggests the neck cutoff at the given location based on the channel centerline and channel characteristics of the year 2000. Figure 17-4 indicate channel area as seen in the year 1975 and the year 2016. In all, based on the past actions in the reach and activities in channel section based on simulation, this river reach can be considered as active reach.

2. Chainage 178- 179 (around village Gumthala Rao)

   A satellite image of 1975 shows some signs of the formation of oxbow feature in the vicinity, whereas the image of 1990 indicates scouring of the channel and increased erosion. The meandering of the river is quite significant in this segment and braiding is also observed in 2000 which matches with the location of the historical oxbow. Figure 17-5 (lower section of the image, the area is located around the village Gumthala Rao) shows 2016 imagery overlaid with channel area in the year 1990, 2000 and 2016.

   From the figure, it is evident that the channel has moved significantly over the period of 1975 to 2016 with a maximum movement of centreline of around 1.6km towards the left. Figure 15-15 of modelling study also confirms the movement of channel centreline around this area. Moreover, chances of neck cut-off and the formation of oxbow during the period of 2030-2040 are also precited. From the overall analysis, it can be said that this reach is morphologically active and can be termed as critical as the movement of a river course over the span of 50 years is around 1.5 km.

   From the reconnaissance survey, it can be said that sand mining activities in the area are significant and thus altered an overall channel morphology a lot. Google earth imageries also highlight the recent activities in the area (Figure 17-6 and Figure 17-7).

3. Chainage 362-368 (Hindon Yamuna Confluence)

   Significant shifting of the confluence point (Hindon-Yamuna) is observed (Figure 17-8). In 1975, the confluence point is located between chainage 365 and 366. The upward movement is observed in 1990 imagery, confluence point has moved by 1.5 km (location of chainage: 364). Further movement is observed during 1990-2000 with a shifting of the confluence point to a new location of chainage: 363. After 2000, the confluence point has not moved. Overall upward movement around 2.4 km is observed at Yamuna-Hindon confluence during 1975-2000. During 1975-1990, two oxbow features one on each side have been formed on the Yamuna whereas one oxbow feature is observed on the downstream of Hindon-Yamuna confluence (originally part of Hindon stream).

   Simulation results from both HEC-RAS modelling and JP meander migration modelling indicated the variation in channel width and higher rate of channel migration (4.05m/year). From both approaches, i.e. remote sensing image analysis and modelling, significant

activities in this section have been noticed. Therefore, this stretch can be considered as morphologically active/ critical.

4. Chainage 405-416 and chainage 453-468 (around Bilochpur and Jahanginpur Khader)

   Remote sensing image analysis indicates the repositioning of the river course up to 1.7 km in these segments (Figure 17-9, Figure 17-10). These stretches have also witnessed the formation of oxbow features. Significant variations in centerline have also been observed. Chainage 405-416 is in the vicinity of the villages Bilochpur and Ramgarhi-Untasani, whereas chainage 453-468 is in the vicinity of villages Muhal Sakraya, Mant and Jahanginpur Khader respectively.

   Modelling results also suggest river reach in few locations in this chainage [located in the vicinity of Luksar (near Gadi-Samstipur Road), Hassanpur (near Hodal) and Ova (Shergad, Mathura)] as critical based on the fact that if allowed, river meandering may result in loss of agriculture and settlement in the vicinity. The simulation also highlights the movement of channel centerline more than 500m over 50 years.

5. Apart from above locations, the river reaches in areas such as the Bakpur, Sabpur Modipur, Manimanzra, Shahpur Zat, Zapti Chapra, Jathlana, Ghaziabad, Pur Delhi, Purbia Tola (near Etawah), Bateshwar (Agra district), and Dangroli Must (near Runukta Railway station) are found to be morphologically active as rate of meander migration and changes in channel patterns such as neck cutoff and ox-bow formations are predicted by the JP meander migration model. However, to consider these reaches as either critical or stable is not straight forward as some of the locations are equipped with flood protection structures and restrict the movement of rivers in adjacent floodplain ultimately preventing the likely damage on account of flood events.

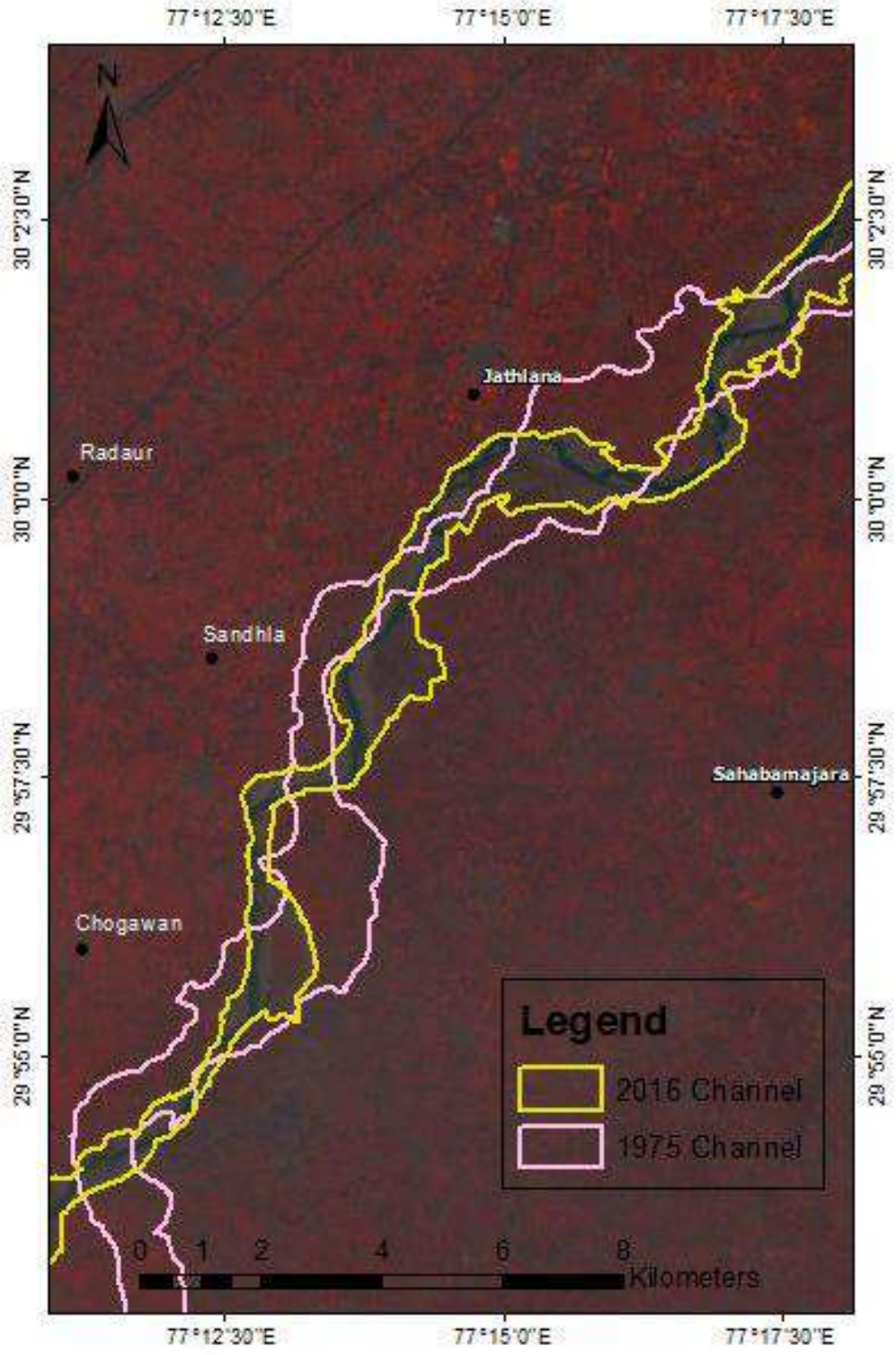


Figure 17-4 : Channel Area for the year 1975 and 2016 around village Jathlana

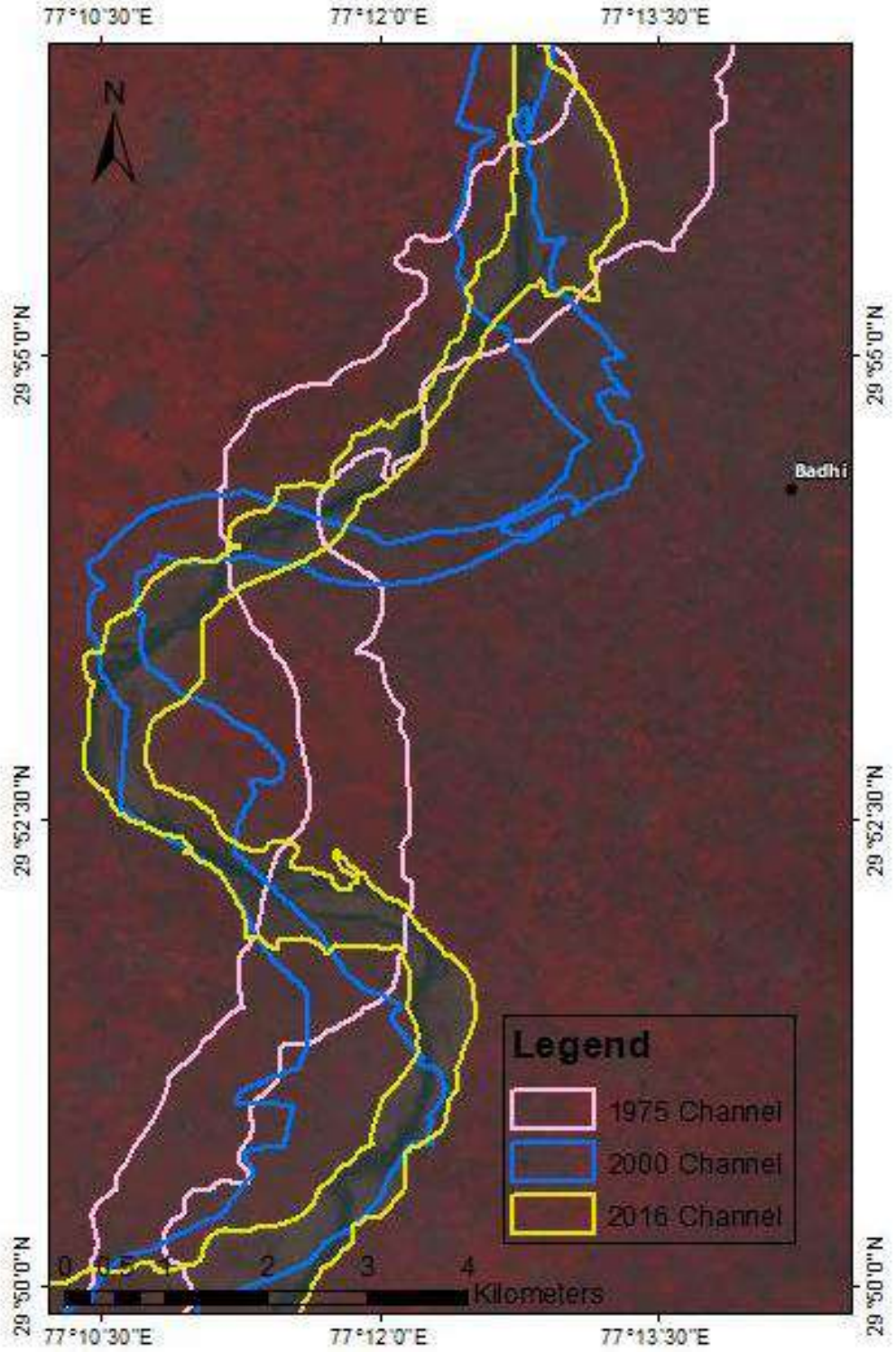


Figure 17-5 : Channel area for the year 1975, 2000 and 2016 around the village Gumthala Rao



Figure 17-6 : Sand Mining activities around Gumthala Rao



Figure 17-7 : Sand Mining activities around Gumthala Rao (zoomed in)

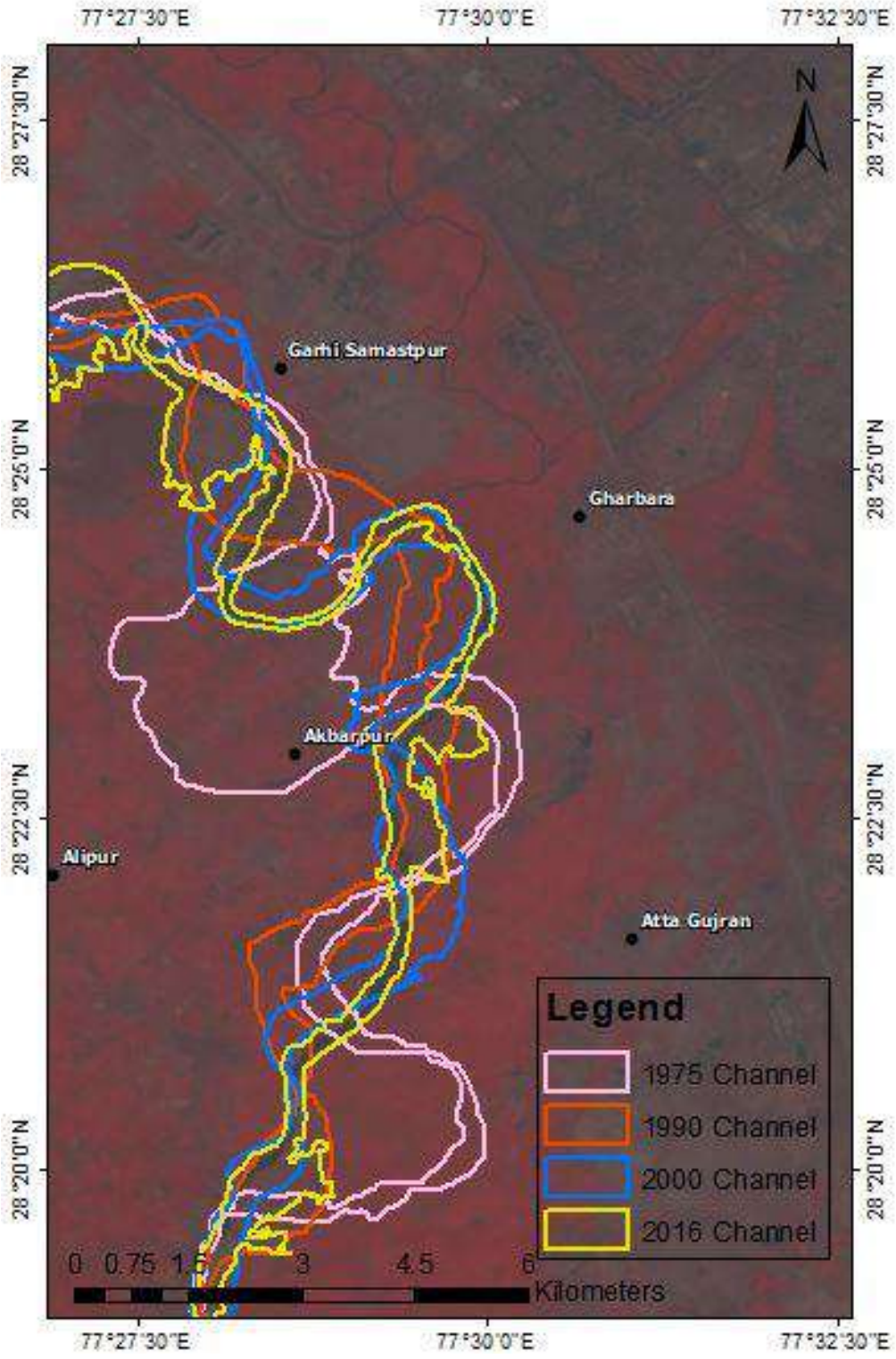


Figure 17-8 : Channel area around the Hindon-Yamuna confluence

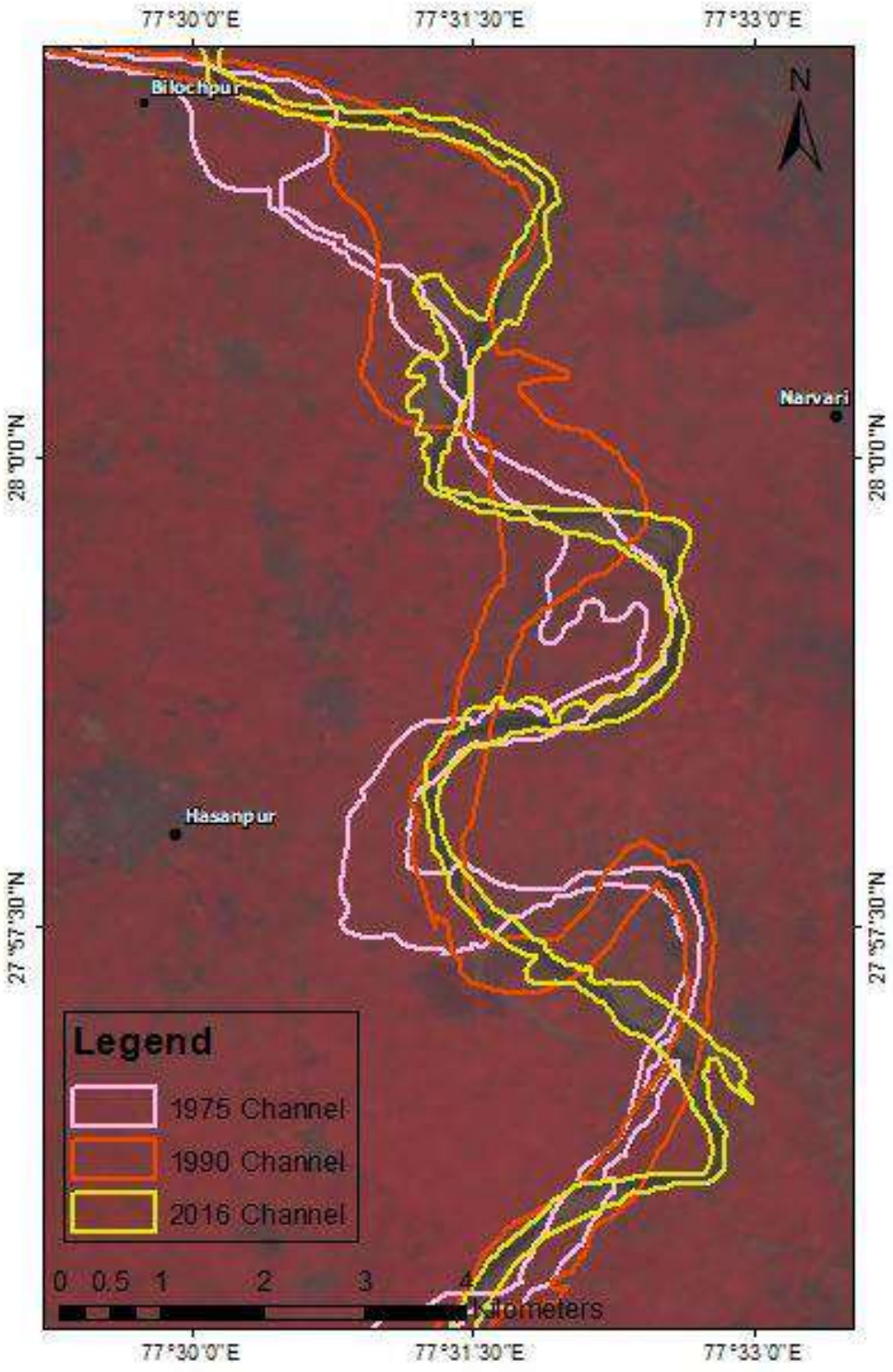


Figure 17-9 : Channel area around village Bilochpur in the year 1975, 1990 and 2016

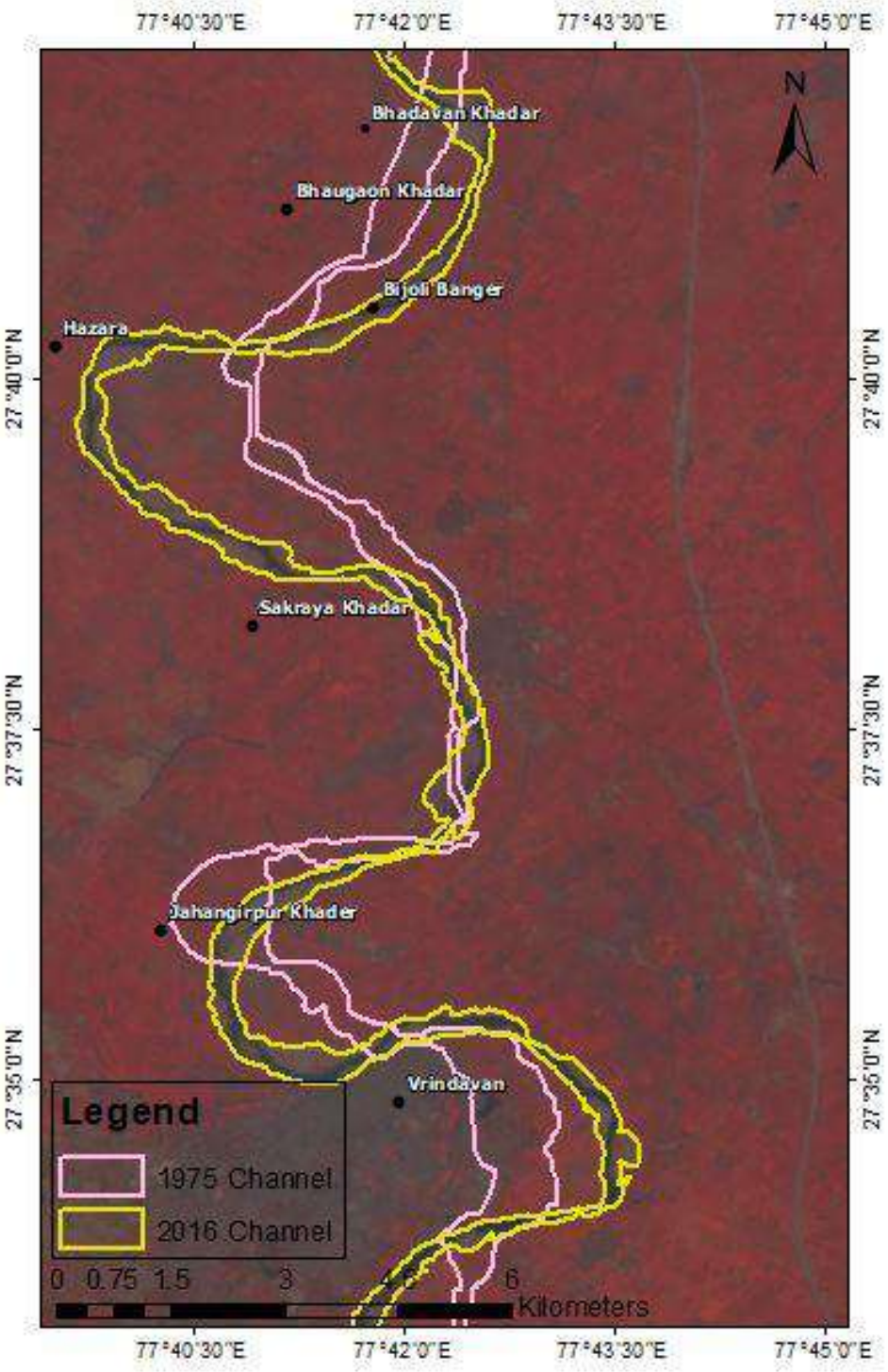


Figure 17-10 : Channel area around villages Sakraya and Jahanginpur Khader

17.5 Discussion and Conclusion

A grid-wise analysis is carried out to understand channel bank retreat on account of erosion and deposition and dynamics of river course on a decadal scale. The River Yamuna shows distinct patterns of channel bank retreat and river course dynamics. These patterns are in accordance with physiographical changes in the river from its origin to outfall, the abstraction of flows to fulfil off-stream requirements, land use, channel slope and nature of tributaries (rain-fed/snow-fed) and their confluences. According to these distinct patterns, River Yamuna has been divided into different zones as below:

i. Zone A: Yamunotri to Bausan (up to chainage 73)
ii. Zone B: Bausan to Hathni Kund Barrage (from chainage 73 to 116)
iii. Zone C: Hathni Kund Barrage to Vrindavan (from chainage 116 to 468)
iv. Zone D: Vrindavan to Chakarpura (Yamuna-Chambal Confluence)
    i. (From chainage 468 to 670)
v. Zone E: Chakarpura village to Prayagraj (from chainage 670 to 963)

These zones are discussed with respect to the results of analyses along with differences in their physiography.

Zone A:

This zone mainly covers the reach of Yamuna in Himalayan valley portion. The first 75 km of the reach of this zone represents river flowing through deep and narrow Himalayan gorges with comparatively higher flow velocities which conjunctively offer limited space for river's fluvial processes like channel bank retreat and swing of channel centerline. The channel width of this section varies between less than 100 m to 400 m. In this zone, only trivial course movement has been observed. In view of the above observations, this zone is among the most stable zones of the River Yamuna.

Zone B:

A major increase in river width is observed below the confluence of the Yamuna with River Tons where the river enters into relatively flat landscapes near Kalsi village. Several hydroelectric projects (Dakpatthar, Dakhrani, Dhalipur, Asan, Kulhaal, etc.) are located in this zone. As an effect of wider channel widths, reduced flow velocities and flow volumes reduced due to these projects, river reach in this zone are predominantly braided (except for flood season) with small

channels converging and diverging based on deposition patterns. Though braiding behaviour is observed, different active waterareas are well within the channel area and swing of the channel centreline is not significant in this zone. Also, the channel bank retreat and modelling exercise indicate that this zone is morphologically stable.

Zone C:

Upper Boundary of this zone is demarcated by the Hathni Kund Barrage where Western Yamuna Canal originates. Like Zone B, significant braiding is observed below the barrage and based on the opening pattern of barrage gates and prevailing deposition in the channel, width of the active water area is seen to have covered only a small portion of the channel width.

After an outfall of a small stream in Yamuna near Gayajudinpur, comparatively less braiding is observed. However, swing of channel centreline has been observed downstream of this location. Significant movement of channel centreline has been observed near villages Jathlana (Chainage-163), Badhi (Chainage-177), Mundi Gahri (Chainage-222), and in reach between Mawi (Chainage-240) and Jagosh (Chainage-270). Similar observations are made near Delhi city at villages Palla (near Chainage-300), Burari (Chainage-316), Okhla (Chainage-337), Kidawali (near Chainage-350). Sporadically, oxbow features are also formed near some of these locations.

In the vicinity of the confluence of Yamuna and Hindon Rivers, major movement of river course and formation of oxbow features have been noted over time. It is also noticed that the confluence point of these rivers has moved upstream by around 2.4 km.

River reach between Bilochpur to Ramgarhi (Untasani) has witnessed significant swing of channel centreline and the resultant formation of oxbows at places. A similar pattern has been observed between Sakraya and Vrindavan. Both these reaches are found to be important morphological sections of Yamuna River, which need detailed hydrodynamic studies to further understand the behaviour of this river stretch.

Zone D:

This zone represents the Yamuna River before its confluence with all its major right-side rain-fed tributaries. In this zone, though meandering of the river is prevalent, swing of channel centreline is well within average channel width and thus is not as significant as earlier zone (Zone C). Also, the sporadic formation of large sandbars at certain locations and the braiding of the river around

these sandbars has also been observed. In view of these observations, this zone of River Yamuna is found to be comparatively stable.

Zone E

In this zone, all major tributaries; Chambal, Sind, Betwa and Ken merge with Yamuna River. Flow volume in Yamuna in this zone is majorly brought by these tributaries (especially in monsoon season). Like Zone D, large sandbars are predominant in this zone and river is braided at certain locations due to such formations. However, meandering behaviour has significantly and evidently reduced in this zone in comparison to zone D and only limited repositioning of the river course has been noted. As a result, this zone is also considered as a stable zone of the river.

To summarize, all zones in River Yamuna are morphologically stable; however, Zone 'C' can be considered as morphologically active. Rate and scale of channel centreline movement observed in zone 'C' are comparatively higher than other zones. Processes like formation and abandoning of oxbows and variations in channel area in temporal scale of 10-15 years used in the present study indicate that zone 'C' is the active zone. While river course dynamics, meandering, channel bank retreat on account of erosion and deposition in Yamuna can be considered as natural and consistent phenomena which may occur in any river system over the time due to regular channel processes, a detailed study of zone 'C' is needed for better planning and management of the river.

Chapter 18 Conclusion

The conclusions drawn from the present study are discussed in this chapter.

1. Land-use changes in Yamuna River Basin have been estimated using remote sensing imageries of different years. Based on satellite imagery of the year 2016, agriculture area in the basin accounts for 81.54% followed by forest (11%), Barren land (3.42%), Water bodies (1.9%), Built-Up area (1.8%), and Snow/Glaciers (0.08%). Land-use change analysis indicates that built-up area and agriculture have increased by 1.06% and 11.42% from 1977 to 2016, whereas forest and barren land have shown the reduction of 7.06% and 4.22% respectively.
2. Considering the overlapping of scales, as discussed in Section 17.2 in Chapter 17, assessment of the impact of land-use change on morphology cannot be achieved. However, based on changes in land use type, one may indirectly predict the pattern of erosion and deposition. Accordingly, it can be said that over the years, a decrease in forest and increase in agriculture and the urban area has been observed which might have resulted in increased erosion in the basin.
3. Hydrologic analysis of the observed streamflow data has been carried out and presented in detail in Chapter 9. From the analysis of 1.5 and 2-year return period flood events, at few locations sudden rise or fall in streamflow values have been observed. This can be attributed to joining of tributaries or the abstraction of water through canals.
4. Though the frequency analysis based on observed streamflow has been attempted, it may not represent the actual reality of the system as a regulated flow regime in present condition has been used to perform the frequency analysis. Therefore, the results of this frequency analysis may be used in the limited context of the morphological study and might not be suitable for other applications such as design flood estimation.
5. Indices to understand sinuosity, the radius of curvature, braiding, planform of the river have been estimated. Average sinuosity for the entire stretch of Yamuna River is 1.38, whereas radius of curvature varied between 0.25 to 39.32 km. Based on Braiding Index and Plan form index, it can be said that braiding is higher in selected reaches, mainly in the downstream of Hathnikund Barrage.
6. River course dynamics has been analyzed in the form movement of channel centreline at 1 km interval, and it has been seen that river has experienced changes in its course at a few locations.

Those locations are concentrated in the middle stretch of the river. The river is found to be stable in the Himalayan region as well as in the region after its confluence with Chambal River.

7. From the analysis of confluence points, except Hindon-Yamuna confluence, other confluence zones are stable and have not gone through significant change in the last 40 years. Hindon confluence has experienced change between 1990 and 2000, which is reflected in a satellite image of the year 2000. Confluence has moved towards upstream and taken the shorter path.
8. During 1975-1990, the areal retreat of erosion and deposition is more or less similar (the difference between area eroded and deposited is 21 sq.km). During 1990-2000 significant variation is noticed as the areal extent of erosion is found to be 171.5 sq.km more than a deposition. In 2000-2010 and 2010-2016 time periods, not many variations are observed in erosion and deposition. While 2000-2010 indicates overall deposition of 48 sq.km, the 2010-2016 period suggests an erosion of 32 sq.km of the area.
9. Aggradation and degradation patterns analyzed from observed cross-sections are in-line with satellite-based erosion deposition maps.
10. Suspended Sediment Load (SSL) varies spatially across Yamuna River. Delhi recorded maximum value of SSL in 1995. The year 1999-2000 can be considered as a breaking point after which SSL for all available stations reduced drastically.
11. Based on Meander-Migration modelling exercise, a few locations have been identified in the stretch of Kalanur to Gokul Barrage that may experience neck cut off/ ox-bow formation/ abandonment of reach. However, some of these areas are already protected with flood protection structures which ultimately restrict the river movement.
12. From the combined approach of remote sensing image analysis and simulation studies, chainages are identified as morphologically active/ critical for stretches 163-164 (Jathlana), 178-179 (Gumthala Rao), 362-368 (Garhi Samstipur), 405-416 (Bilochpur), 453-468 (Muhul Sakraya).
13. Based on the physiography of River Yamuna, the entire stretch is divided into five zones and results from the morphological study are juxtaposed to define the zones either stable or active. Based on this, zone ‘C’ (Hathnikund Barrage to Vrindavan) is found to be morphologically active whereas other zones are comparatively stable.

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Annexure I

MEMORANDUM

MORPHOLOGICAL STUDY OF RIVERS KOSI, BAGMATI AND YAMUNA

A REVISED CONCEPTUAL FRAMEWORK

FOR

CENTRELINE, SHIFTING AND SOME BRAIDING PLANFORM INDICES

For:

Morphology Group

Water Resources Section

By:

Ms. Vilakshna Parmar

Prof. Rakesh Khosa



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INDIAN INSTITUTE OF TECHNOLOGY DELHI

HAUZ KHAS, NEW DELHI 110016, INDIA

November, 2017

MEMORANDUM

To: Morphology Group, Water Resources Section

From: Vilakshna Parmar and Rakesh Khosa

Topic: Centerline

INTRODUCTION: GENESIS OF A RIVER COURSE, THE RIVER CENTRELINE AND ITS INNATE DYNAMISM

No river in the world exhibits a consistent morphological behaviour across all spatial and temporal scales. Typically, a particular reach of a given river represents a complex mix of various geomorphological patterns and, importantly, may lend itself to distinct descriptive characterization that depends squarely on the scale over which the reach is abstracted. In the present discussion an effort has been made to present a more rational perspective on the widely used, albeit imaginary, concept of a river '**centreline**', and which is routinely estimated from satellite imageries.

It merits mention to note that an important but often missed morphological reality of a river course is that, by and large, development/evolution of river courses is essentially **intertwined with the presence and alignment of local/regional geological fault lineaments**. Of course, there are exceptions to this rule such as when an avulsion results in a river changing its course, temporarily or permanently, or indeed when surface incision occurs as illustrated in the following Figures 1 and 2 (Ref: web resources):



Figure 1: Channel formation by incision

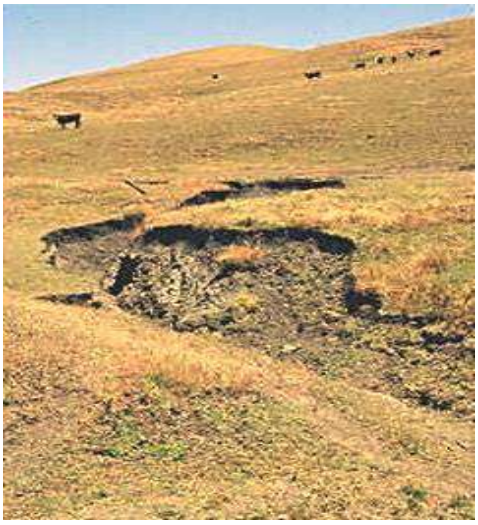


Figure 2: Channel formation by incision

It therefore becomes imperative to acknowledge that in general for a vast majority of major river systems across the globe, these geological fault lines act as delicately balanced cradles that provide a **dedicated corridor** for drainage paths to develop and which over time, acquire the configuration of river channels. Understandably, concomitant erosional and depositional processes, amongst others, would be expected to have shaped changes in the latter channels. The reality of these autocyclic as well as other allocyclic processes has indeed been recorded to be incessant and observed to occur over time scales ranging from geological to the relatively more rapid. Further, it must be understood that these river channels do respond to various natural triggers of a diverse nature in an autonomous and spontaneous manner.

Importantly, the aforementioned dedicated river corridor demarcates the **swing-width**, to so put it, within which the riverflow can rightfully assume any pathway depending upon a diverse set of factors that include:

(i) Signature of the underlying geological crucible.
(ii) Topology of the Hydro-Morpho-Dynamic Potential field,
(iii) Lateral connectivity,
(iv) Exchange with subsurface flow pathways, and
(v) Hydrodynamic compulsions

These and others, together, constitute a reality that has hitherto been disregarded or, at best, given only a casual treatment in theoretical abstraction.

It is reasonable to hypothesize that these aforementioned factors would trigger appropriate and, by no means arbitrary - albeit seemingly recalcitrant - responses which would manifest in various ways and manners including, for example, the river channel swinging courses between alternate flow paths, albeit restricted to within the overall corridor of the aforementioned dedicated passage ways as dictated by its underlying subsurface tectonic reality. The aforementioned concept of

channel course swings as experienced by the channel flow paths is illustrated in the following Figure 3.

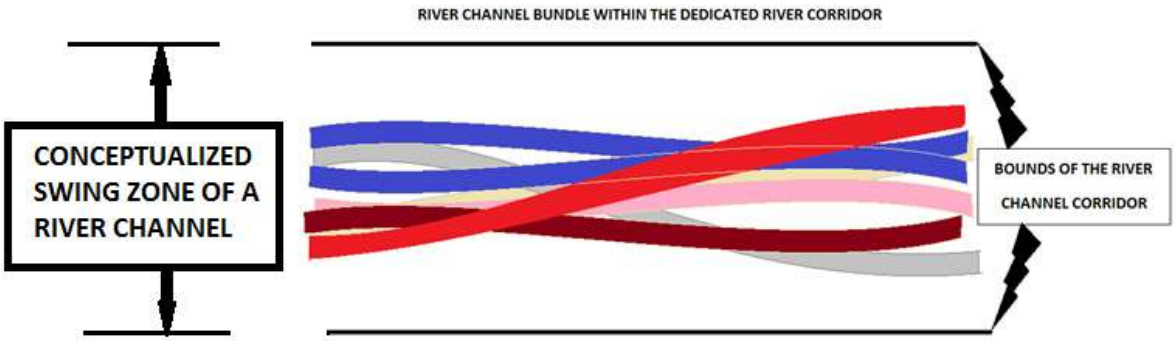


Figure 3: Schematic explaining the concept of alternate flow paths within the dedicated river corridor

CONCEPT OF RIVER CENTRELINE

A related, and no less profound, missing link in our understanding of the overall concept of the 'River Centreline' has made it imperative for morphologists to ponder over whether it is at all possible to develop a consistent association between the concept of 'centreline' and a specific set of hydrological, hydrodynamic and morphological attributes of the river. In other words, the question that arises is whether the notion of a river's imaginary centreline is just a representation of the current position of the river or it holds a deeper philosophical and hydro-morphological relevance and, therefore, the challenge that begs resolution may be stated as follows:

Does a 'River Centreline' have any one or more definable and distinctive aspects that could lead to its consistent and objective identification?

Consider the following contending considerations that may provide clues as well as the bases for the enigmatic and obdurate concept of 'centreline':

(i) Does the centerline coincide with the thalweg line?
(ii) Or does the centerline bifurcate the volumetric flow rate into two equal halves?
(iii) Or does it suffice to mark the river 'centerline' from the ad interim widest water bearing channel within the overall swingway of the dedicated river corridor?
(iv) Or does the centerline divide the bankfull width of the river into two equal halves between the connected bank lines?
(v) Or does the centerline bisect the wetted top width between the two water lines along the river banks?

(vi) Or where does the centreline lie in a braided reach with a highly skewed channelization form?

A difficulty presented by the aforementioned posers is that river cross sections are rarely, if ever, symmetric between banks as illustrated in Figure 4.

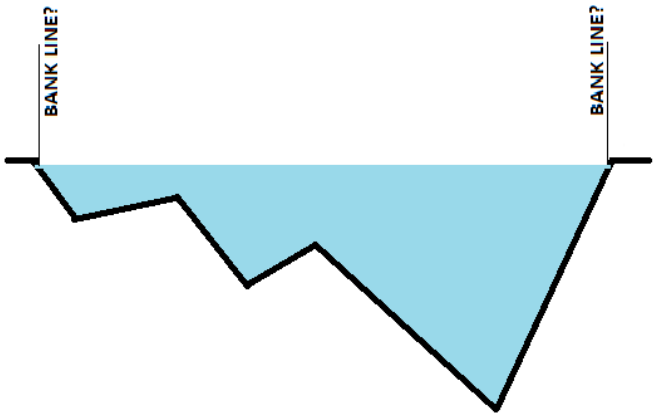
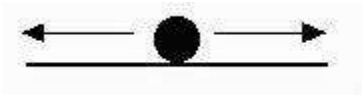


Figure 4: Asymmetry in river cross section profiles

Looking at it from a different perspective, it is now possible to theorize that for a river channel course, in the absence of allocyclic and other avulsive triggers, three broad categories of states, all stable within their respectively restricted context, may be defined. These may be depicted as shown below as Figure 4a, 4b, 4c, 4d and 4e:

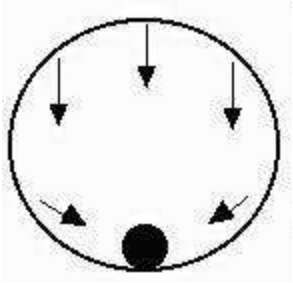
(i) Neutrally stable state (Figure 4a):



(ii) Locally stable state (Figure 4b):



(iii) Globally stable state (Figure 4c):



And, of course in the context of the hypothesized dedicated river corridor, globally stable state may be depicted as Figure 4d:



Figure 4d: Globally stable state for a river corridor

Alternatively and more realistically, a globally stable state for a river course may be depicted shown in Figure 4e although, within the overall available swing zone within its dedicated corridor, alternative channel courses are not just possible but indeed, is natural and more realistic.

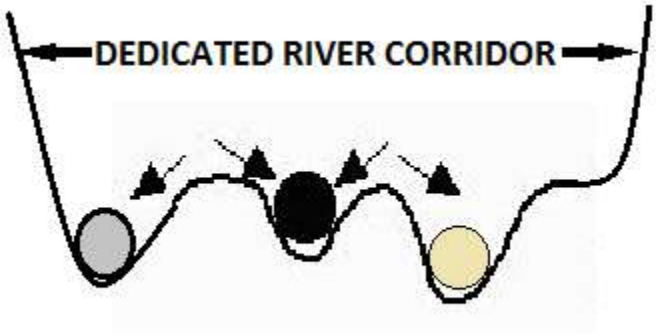


Figure 4e: Alternative representation of globally stable state for a river corridor

Figures 4 (a, b, c, d, e): Contexts of stability of river channel courses

Acknowledging the realism, as presented in the aforementioned depiction, is indeed essential in order to develop an objective capacity to better understand and appreciate the underlying

significance of otherwise esoteric concepts related to '**river centreline**', '**river course shifting**', '**critical river reach**' and '**river planforms**'.

Also, the waterline is not a static attribute but may show a wide range of variation in the water level between the wet and lean season flows and, as a result, the wet channel may lie quite skewed and off to one side of the river reach as is depicted for clarity in Figures 6 and 7, with the latter showing a reach of river Yamuna upstream of Hathnikund barrage. Further, and to complicate the issues further, water may occupy different channels within the overall **dedicated river corridor**, essentially prescribed by the underlying geological fault lineament, in different years and as illustrated above in Figure 3.

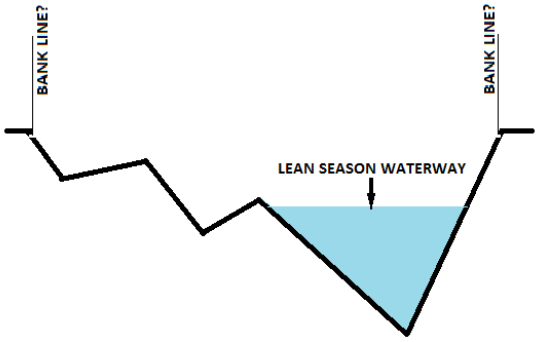


Figure 6: Skewed wet channel of a river during season of low flows



Figure 7: Skewed wet channel of Yamuna upstream of Hathnikund barrage

Realistically, it merits further mention that a river may have multiple wet channels or in extreme situations, none at all. In some cases the channels may even be disconnected as the river intercepts subsurface seepage. The three cases highlighted above are also captured for clarity in Figures 8, 9 and 10 respectively for river Yamuna.



Figure 8: Multiple wet channels of river Yamuna



Figure 9: No wet channel seen in river Yamuna downstream of Tajewala



Figure 10: Disjointed network resulting perhaps from disjointed interception and contribution by subsurface flows

River centreline

For the purpose of illustration, let us examine a parallel analogy with reference to a simple pendulum having definite attributes and placed in the following circumstances:

Attributes:

(i) The pendulum string is flexible.
(ii) The inertia of the two components is negligibly small and uniformly distributed over the bob and the string to which it is tethered.
(iii) The anchor of the pendulum is fixed.

Circumstances:

(i) Pendulum is at rest and in a tranquil/quiescent environment
(ii) Pendulum is swinging in a frictionless and tranquil/quiescent environment (undamped oscillations)
(iii) Pendulum is placed in a zone with strong and randomly turbulent air movements

It is indeed instructive to examine the concept of 'centreline' of the pendulum system corresponding to each of the aforementioned situations. These are shown below as Figures 11, 12 and 13 and with each depiction is an accompanying poser about the concept of the 'centreline' without any further attempts to elaborate and explain these posers.

Circumstance (i):

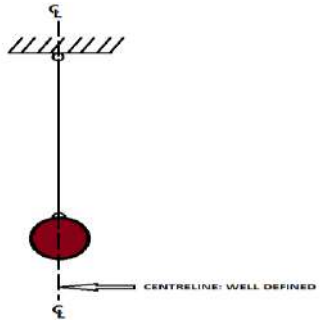


Figure 11: Centreline when Pendulum is at rest and in a tranquil/quiescent environment

Circmstance (ii)

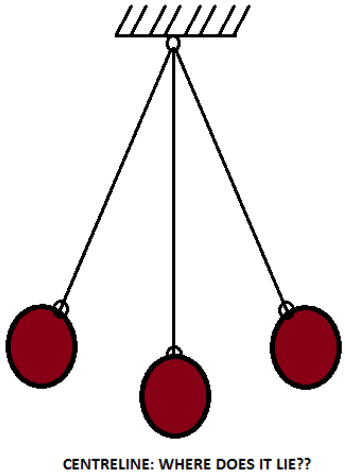


Figure 12: Pendulum is swinging in a frictionless and tranquil/quiescent environment (undamped oscillations)

Circumstance (iii):

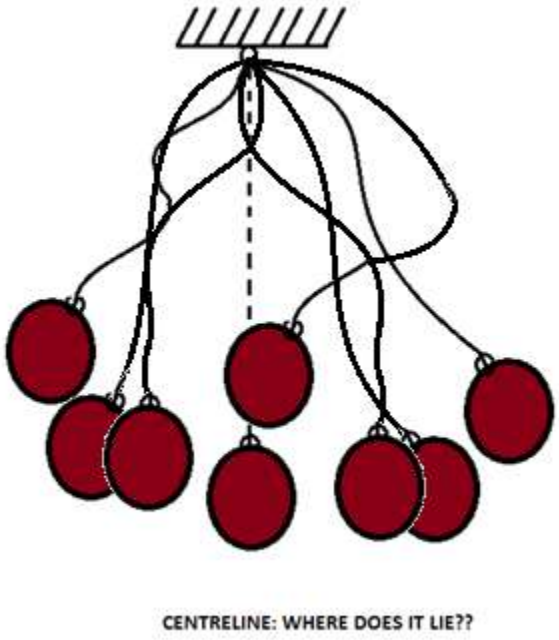


Figure 13: Pendulum is placed in a zone with strong and randomly turbulent air movements

Closely linked with the above illustration is the immutable and undisputed reality that the concept of 'centreline' is deeply rooted in the multi-scale dynamics that underscores the integrated domain of hydro-morphology of rivers together with the issues pertaining to **temporal and spatial scales** at which the natural system is observed and described. The same is illustrated in Figure 3 wherein the essence of the innately transitory nature of the river channel is captured and demonstrated. Accordingly, an attempt to demarcate the centreline of such hydro-morphological entities will not be anything but perilous – an attempt that cannot stand scrutiny of the entire spectrum of plausible contexts.

Figure 14 below shows a schematic of an observable river reach, marked in blue, together with its associated floodplain valley that extends beyond to the watershed divide. Clearly, the centreline will be dictated by the course of the river reach and will match its serpentine planform. Interestingly, it is possible to imagine scales of interest where finer detail features become relatively opaque to observation and, with reference to the following Figure 15, where the river details have been masked for effect, and the planform of the centreline is dictated essentially by the orientation of the floodplain valley.

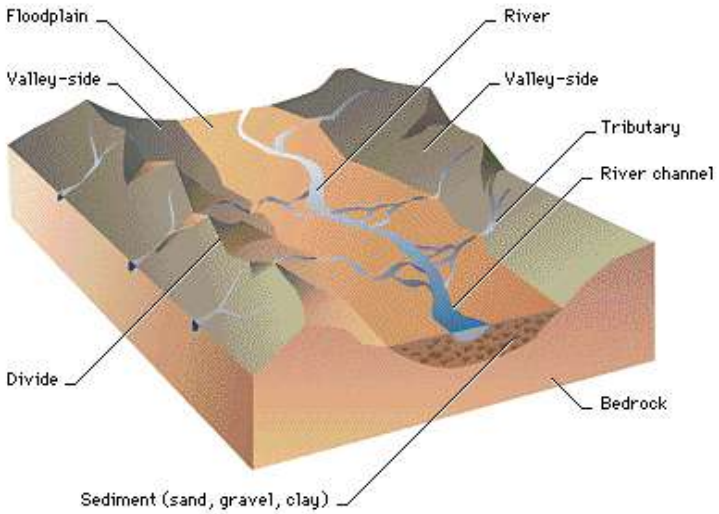


Figure 14: Schematic of a long & narrow floodplain valley along with its principal drainage feature (in blue)

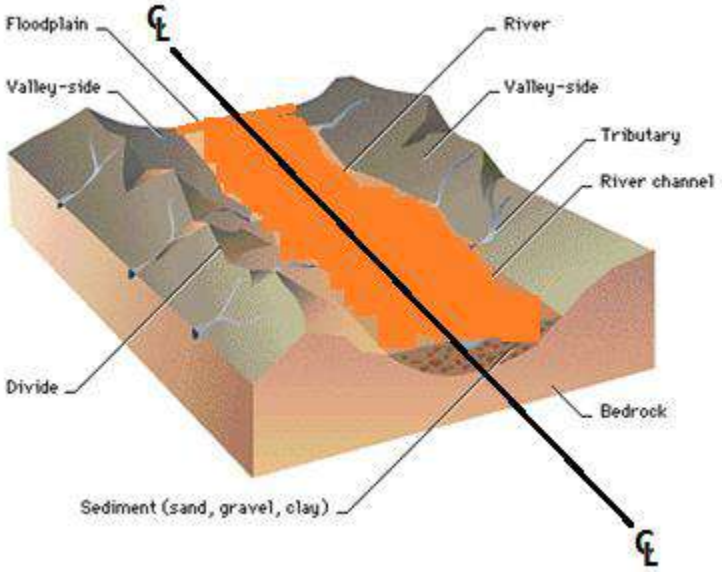


Figure 15: Schematic of a long & narrow floodplain valley with its principal drainage feature masked

Such a scenario is indeed not unrealistic and the underlying lack of integrity in the way centrelines may routinely be marked becomes evident when different perspectives emerge as river valleys are observed during seasons of lean flows and then compared with inferences based on observations recorded during the wet flood seasons.

As a further attempt to explain the proposed hypothesis, consider, for example the schematics shown in Figures 16 that depicts a hypothetical river reach along with some accompanying illustrative details. Figure 17 also depicts the same hypothetical river but in its natural setting complete with its associated floodplain valley and whose given lateral extent on either side stretches to the very edge of its water divide, thus capturing entirely its narrow and elongated floodplain.

During seasons when the flow rate is less than the bankfull rate as in Figure 16, the river channel is clearly visible and its centreline accordingly will follow the river's serpentine course. However, as shown in the accompanying sketch of Figure 17, the flood flows may occupy the entire floodplain valley as well during the ensuing wet season and the dominant flow paths are seen to be oriented along a direction that is essentially parallel to its flood plain valley.

In addition to the energy gradient along the shorter flood plain flow paths, the prevailing flood plain flow velocities also are sharper as compared to the corresponding hydraulic attributes of the segment of the total flood flows, albeit relatively minor, that is confined to the relatively limited waterway of the river channel. Further, the schematic sketch of Figure 17 also suggests the plausible and realistic scenario that the higher wet season flood flows may completely mask the latter river channel from view. Understandably, the centreline, if captured based solely on the wet season flood flow condition, will now be straighter and along the general orientation of the encompassing flood plain valley. Clearly, the sensitivity of the centreline configuration in plan to currently prevailing flood conditions is indeed indicated and, therefore, its suggested underlying hydro-morphological dynamics renders the judgement leading to the latter feature's delineation as inconsistent, subjective and without shelf life!!

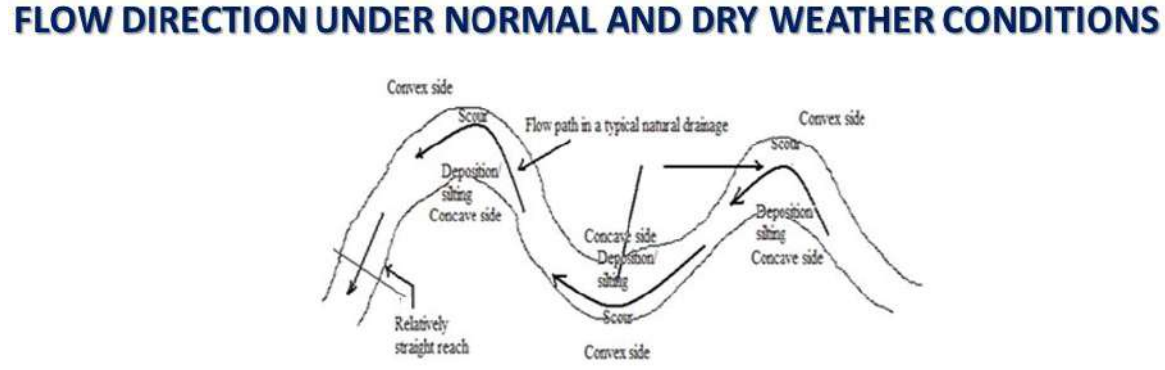


Figure 16

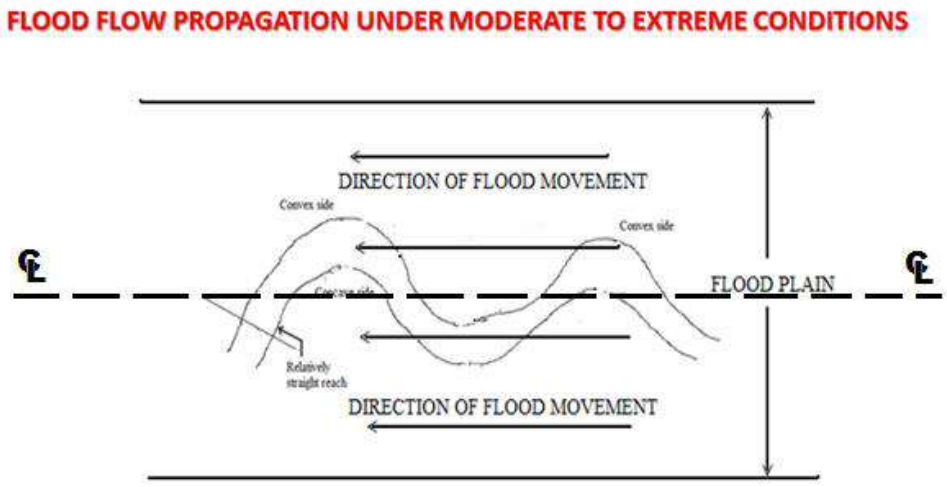


Figure 17

Figures 18 and 19 show a reach of river Gangless in Leh highlighting the constraining influence of the surrounding valley within which the river swings to adopt a transitory course as dictated by ensuing auto-cyclic and hydro-morphological reality.



Figure 18: Dedicated river corridor for Gangless river in Leh Valley (oriented upstream)



Figure 19: Dedicated river corridor for Gangless river in Leh (oriented downstream)
As an illustration of the aforementioned conjecture (ref: Figure 16 and 17), Figures 20 and 21 below show snapshot images of river Jhelum for a comparison between the post September, 2014 flood event wetted area and the wetted area when the flow is within banks.



Figure 20: Wetted area of Jhelum near Srinagar (September 10, 2014 Flood Event)



Figure 21: River course of Jhelum near Srinagar under less than bankfull conditions

While it has been reported in informal studies that the September, 2014 floods was a once in 50 year event, it is indeed understood that nature provides for flow possibilities that could span the entire range in magnitude from the bankfull discharge to the high value magnitude of flow rates observed during the aforementioned 50 year event and indeed beyond on either side of this spectrum. Attempts, therefore, to identify the river centreline from the wetted area would obviously have a severely restricted appeal, constrained as it would be by the specificity of the event captured by the available image which would come tagged by temporal attributes of day, month, season and year of capture. To further illustrate this point, consider Figure 22 which depicts river Jhelum during the Sptember, 2014 event. (*A satellite based rapid assessment on floods in Jammu & Kashmir-September 2014. Collaboration between NRSC Hyderabad and Deptt. Of Ecology, Environment and Remote Sensing, Govt. of J&K*)

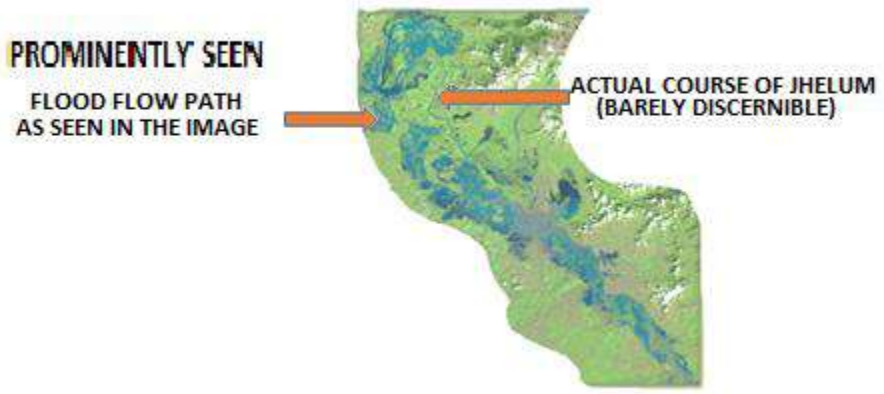


Figure 22: Flood mapping of September, 2014 event

The perils of centreline delineation based on the concept of wet channel, as has been captured by the satellite is clearly evident as the course of the river is likely to be misjudged to be following the wide expanse of water in the NW part of Figure 22 and ostensibly joining with lake Wular further North in the figure. It is indeed noteworthy to mention that this location is actually the site of River Jhelum's exit out of the lake whereas the rightfully designated course of Jhelum is as indicated by the orange arrow in the latter figure. Figure 23 depicts capture of similar details and the course of Jhelum is clearly discernible but has only a scattering of connected flooding pockets along it. To the contrary, the adjoining Flood Channel is seen to indicate extensive flooding along its course but it is noteworthy to recall that the Flood Channel has no formal outfall into any receiving water body, be it a lake or any other river. Clearly, in the task of centreline delineation based on the wetted area concept would result in an absurdity!!!

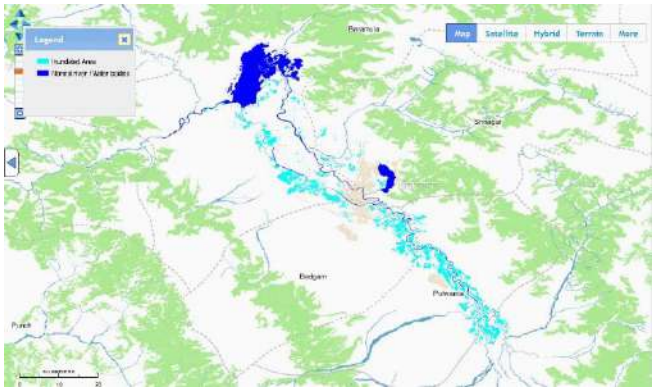


Figure 23: Flood mapping of September, 2014 event

Similar discordance between wet channel and course of Jhelum on its approach to Wular lake can be seen in Figure 24.

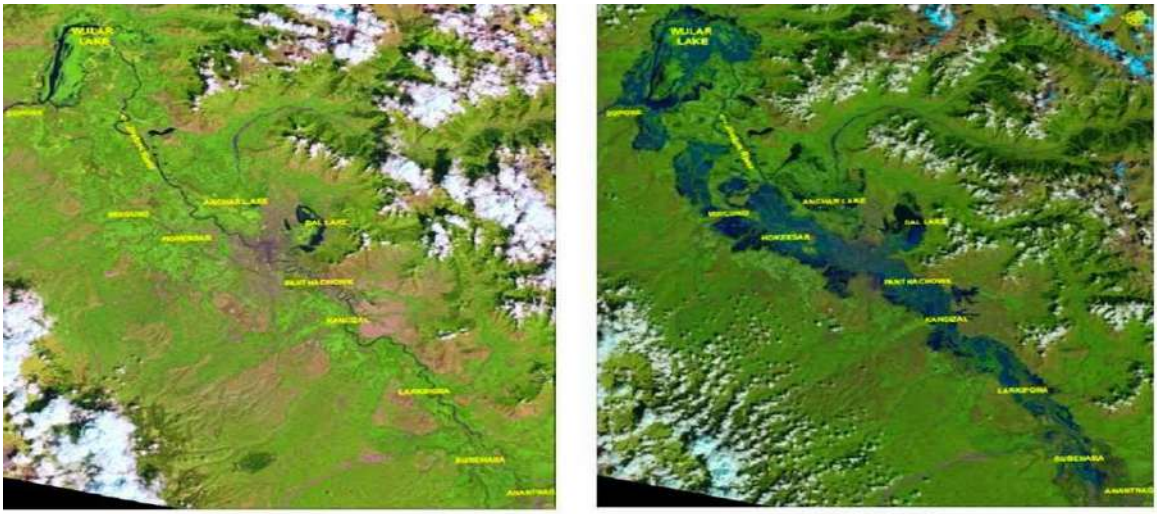


Figure 24: Comparison of river corridor between pre and post September floods

Obduracy innate to the concept of the river centreline is further evident from an examination of river Jhelum as it approaches its intermediate outfall into Wular lake (Figure 25) where the obscurity of a discernible and dominant channel feature is as conspicuous as it is anomalous.



Figure 25: River course of Jhelum as it approaches its intermediate outfall into Wular Lake

From the above discussion, it is evident that there is a need to be able to delineate river channel limits in a manner that is not only consistent but is also amenable to comparison between sites and over time as the river flow levels are indeed expected to be highly dynamic in nature. Clearly, the river cannot be defined as the wetted area at the time of assessment and understandably, therefore, the results yielded by any specific channel delineation method must not ideally be constrained by the time and day for which the channel image is available.

Concept of wetted area under 'Bankfull' conditions: A hydrodynamic attribute

The question of delineation based on the concept of wetted area has also been discussed in various studies (see, for example, Vermont Report) and it has been argued that instead of using wetted area at a given time **to define the river**, it may be more appropriate to define the size of the river based **upon the channel** as defined by the bankfull stage or the point at which the flow just begins to enter the active floodplain (Leopold, 1994). It has been averred in literature that hydro-morphologic significance of the bankfull width/bankfull stage with an average recurrence interval ranging from 1.5 years to 2.2 years, renders the latter concept to be a consistent and identifiable benchmark for spatial and temporal comparison. Remarkably, the latter index does indeed offer the potential to be a benchmark index from which to measure channel sizes for a consistent comparison between sites

The concept of 'bankfull' also has a morphological significance as studies have shown that it is the bankfull flow that transports the greatest amount of material over time (Leopold, 1994). While larger flow events transport greater quantities per event and smaller flow events occur more frequently, it is the bankfull flow that is the most effective determinant of a river's channel morphology and, appropriately, is also referred to as the "effective channel forming flow." An interesting but related concept alludes to a channel being defined as the waterway at bankfull stage

beyond which flooding of the active floodplain is an inevitability implying, therefore, that the active floodplain defines the limits of the bankfull channel and may, appropriately, be defined as the flat portion of the valley adjacent to the channel that is constructed by the present river in the present climate (Leopold, 1994).

As has also been illustrated above (see Figure 3), the phrase "by the present river in the present climate" is especially important because as and when the river degrades or incises, a former floodplain may become a terrace or an abandoned floodplain but within the overall confine of the dedicated corridor. An interesting and equally profound emerging corollary of the aforementioned discussion is that in addition to the attribute of an average recurrence interval, bankfull channel/bankfull wetted width also has a **hydrodynamic attribute** which merits much attention in channel delineation exercises.

Difficulty that arises, however, with the hydrodynamic approach relates to the question whether the bank full discharge occupies the entire channel corridor of an otherwise wide and highly braided river reach. For these circumstances, understandably, it is necessary to capture the role of evolving river bed morphology effectively as the latter feature is indeed a significant determinant of hydrodynamic attributes of flood flow propagation down the reach.

This is obviously an important consideration when remote sensing products are the only source of information and river channel is identified on the basis of reflectance characteristics that are typical of sand deposits. Clearly, old sand deposits of currently abandoned river beds are liable to be misconstrued as being part of current river course. Obviously, in case where high resolution bed morphometric details are not available, delineation of the 'bankfull' condition for rivers with these complex features is something of an impossibility.

Regardless of these imponderables and in furtherance to the above discussion, it is in order to identify various important suggested indicators of the 'bankfull' condition as gleaned from available literature.

Indicators of 'Bankfull'

In addition to the hydrodynamic basis to simulate wetted stage corresponding to flood events corresponding to average recurrence intervals ranging from 1.5 to 2.2 years, the following autocyclic manifestations and bank vegetation characteristics have been suggested as possible indicators of the bankfull stage (Vermont Agency of Natural Resources Report, May 2009).

(i) Nearly flat top of developing point bars as an evidence of developing active floodplain left in the wake of migrating channels.

(ii) Location of break in bank slope from steep to a relatively gentle slope and is seen on reaches of river that are not prone to active floodplain building.

(iii) Lower extent of persistent woody vegetation because only the most water tolerant species of vegetation will typically grow within the bankfull channel.

(iv) Erosion or scour features offer a satisfactory basis for defining bankfull condition on naturally entrenched rivers over steeper gradients wherein the active floodplain is either intermittent or may be absent altogether. It therefore becomes necessary to rely on erosional features along the banks as indicators of the flow stage that performs the most work. It must, however, be understood that erosion can be caused by many diverse nature of processes and may not be related at all to the stage of the bankfull flow. Accordingly, therefore, these features should be relied upon only when absolutely necessary. Two cases are presented as Figures 26 and 27 which respectively show the region around the confluence point of river Zanskar with Indus and a reach along Indus just upstream of this confluence point in Leh. The erosional features on the left and right banks of river Zanskar are indeed clearly evident.

(v) Flat depositional benches or lateral bars are often seen along relatively straighter sections of river and may also represent the active floodplain with its edges corresponding to the bankfull condition.



Figure 26: Erosional features on river Zanskar



Figure 27: Erosional features on Indus upstream of its confluence with Zanskar

IMPORTANT CONSIDERATIONS FOR RIVER CENTRELINE

Centreline for dry beds

As an opening remark, the discussion may best be initiated with a question: What constitutes a consistent centreline, arguably an imaginary concept, for a river reach having a dry bed at the time its image was captured by a satellite? Figures 9 and 10, together with Figure 28 represent a generic set of interesting but challenging case studies for centreline demarcation.



Figure 28: A dry and braided river bed and sensed on the basis of reflectance as deposits of white sand

Whether the river reach runs dry for reasons of upstream abstraction or the river is rainfed, ephemeral (non-perennial) and periodically does not receive enough contributions from its headwater reaches, these rivers do face many challenges that directly affect its morphometric prognosis. **Unauthorized sand mining and unregulated, also unauthorized, dumping of municipal and construction related solid wastes** have emerged as a bane for these rivers. A direct consequence of these two but competing practices is seen in the distinctively unnatural morphometric responses of the affected river's bed and banks, which translates into altered fluvial responses as is seen in terms of altered hydrodynamic and sediment transport characteristics. For example, newer braids may be carved and some old ones may experience their abandonment.

Centrelines with Hydrological Basis:

The water will occupy the steepest Hydro-Morpho-Dynamic Potential gradient and tracing this can give us the probable flow direction and, accordingly, the centerline may be represented by the **Thalweg, wherever it is possible to identify these and in some cases, indeed at multiple locations across a cross section**. The possibility of obtaining multiple 'deepest channel' points are in recognition of (i) limited precision in data as captured by remote sensing equipment, (ii)

ability of the sensing equipment to penetrate water in order to capture bed details with precision that is required, (iii) homogeneity of bed deposits, in terms of their reflectance, across the cross section, and (iv) just an 'Act of God' occurrence!

Thalweg also constitutes the basis for delineation of river networks on Digital Elevation Models in hydrological studies but, as is evident, this network is scale/resolution specific (Fractal structure of the river network) and, in relatively plain surface topography, may be influenced by floodplain ponding when the system is imaged during flood season. This definition of centerline may indeed be valid for a river in its upstream headwater reaches where the river is constrained by well defined, and often deep, valleys. It is understood that these river channels in rolling and highly undulating terrain, are generally expected to be rather well defined and the channel floodplain valley and dominant stream flow directions are oriented in a mutually congruous manner. Therefore, thalweg is likely to be a consistent approach as an aid to mark centerline of rivers/streams in the headwater valley reaches.

Centrelines with Hydrodynamical Basis:

The centerline may also possibly be defined on the basis of hydrodynamic modelling of flood flows leading also to simulated wetted width. Often, application is restricted to simulation of 1-D, vertically averaged flow velocities and flow depths but, as may be inferred from the schematics of Figures 14, 15, 16 and 17, the flow directions are sensitive to the severity of prevailing flood condition. Clearly, at different flood levels, orientation of flow paths are expected to be different and, as a result, also lending an aspect of dynamism to the orientation of the desired centerline and, as a further consequence, divesting the feature of its integrity as well. This phenomenon is commonly observed in river reaches that are in relatively mildly sloping flood plains and also in distributary (branching) systems.

Appropriately, therefore, simulated wetted area corresponding to bankfull discharge may also present itself as the elusive 'consistent' basis for the centerline delineation. Indeed, in fluvial morphology, bankfull discharge together with its connected attribute of bankfull width are important hydro-morpho-dynamic features of river systems as it has been theorized that river channel (cross-section) morphology evolves under the persistent action of this latter flow condition. It is understood, therefore, that centerlines that are mapped based on the simulated 'bankfull' is a valid and consistent approach that can be used for a river along its entire course while, at the same time also presenting important insights about its hydro-geo-morphogenesis.

Centrelines with Remote Sensing Basis:

Remotely sensed images of terrestrial features come with the specificity of time and date of image capture. With regards to the task of centreline demarcation, the current practice is to digitize the centreline based on the stream (observed water area) as captured by the satellite and obviously is just a snapshot of an otherwise dynamic wetted stream channel. Since these images are acquired at different times of the year, the centreline can be assumed to be representation of the flow

direction in the river at flows as on the date of image capture. Consistency in inferences is clearly compromised as the wet channel may correspond to a specific flow event that was captured in the image and could reflect a hydrological reality across a very broad spectrum of plausible flow conditions.

As an example, an image acquired during the monsoon season may be a precise capture of bankfull conditions or alternatively, may correspond to a relatively more extreme flood event with its water spread extending across a wider expanse. As highlighted in the aforementioned discussion, **bankfull conditions** are indeed of particular interest and, within a very restricted context, may also give a sense of general flow direction in the river during this near median event and may provide a **contextually relevant as well as a consistent** basis for centreline demarcation. However, demarcation of centreline based on the 'bankfull' concept does present issues that may bedevil river morphologists. The challenges that are likely to be encountered with this approach arise as a consequence of the following factors:

(i) Bankfull condition alludes to an integrated outcome of interplay between hydrologic exceedance, hydrodynamic transport attributes of flow and eroded material, contrasts between bank and floodplain vegetation morphology, morphometric attributes of river channel cross section etc.

(ii) Inferences based on examination of remotely sensed images remain conjectural in the absence of a comprehensive field campaign dedicated to site visits and supported by a detailed evaluation of the aforementioned attributes. In most cases capture of ground truths is not possible without a dedicated and patient field based observation study.

(iii) Non-availability of hydro-meteorological data has often been a bane of studies of this nature. These data are required to establish occurrence of bankfull discharge in terms of the average event recurrence interval as well as the specific dates of occurrence, if possible, from the available record.

(iv) Corroboration of these results with corresponding ground features captured in actual images for that day, month and year is often difficult as occurrence of such events is understandably restricted to the monsoon period. Presence of cloud cover, that masks the ground features of interest, is indeed a normal occurrence for this period of the year and this reality poses a challenge when attempting to extract morphometric features from these images.

(v) River cross section details and changes in them over time are either not available or, at best, scarce. Often, river cross section surveys are carried out without due diligence and, as a result, these important river morphometric details are rendered largely unusable.

(vi) The alternative presented by images captured in non-monsoon periods when the sky is expected to be essentially cloud free, presents different kinds of challenges. An important feature often seen in these images in the case of many rivers is the presumed channel area as sensed in the form of extensive sand beds that are characterized by relatively high reflectance. In hope that the region of visible sand area and inferred as the designated

stream channel under bankfull conditions presents a convenient paradigm for centreline delineation. However, it is indeed open to debate whether the entire extent of these sand deposits also matches precisely with the water channel that will develop in response to the near median flow event!! In this regard, it is indeed possible, especially under various conditions of channel course stability as have been discussed in the aforementioned sections, the actual stream channel may indeed occupy only a part of the identified field of sand deposits under bankfull conditions. Alternatively, it is also possible that part of the sand field, as captured by the available images may indeed include **abandoned** or **recently vacated, but often temporarily**, channel course.

(vii) Often it has been known in India that migrating populations, in the absence of a formally designated resettlement zones, begin to occupy easily available channel areas. Interestingly, the observed pattern of these settlements see and the occupation is not just limited to occupation of vast tracks of river flood plains but also the ephemeral sand bars that are commonly found within river corridors. Understandably, with expanding habitation clusters, Agriculture often becomes the principal occupation of the migrant settlers. With time, the occupied channel areas acquire a distinct vegetative cover which alters the reflectance characteristics of the tracts from the previously high values that are normally associated with a bare sand cover. As a result, the (mis)inferred course of the river channel shows a divergence, and may often be large, from the actual channel which in turn leads to an orientation of the centreline feature that is likely to be gross and unrepresentative.

(viii) It is acknowledged that remote sensing products are a source of abundant geophysical data of pertaining to various surface and near-surface aspects of hydro-geomorphological features of the imaged region. However, it is also important to understand that satellites capture just the static snapshot of the otherwise dynamic geomorphic system. Expectedly, therefore, these remotely sensed images cannot explain the dynamics of the system. Accordingly, researchers and other interested investigators need to use patience, cautious judgement and prudence when seeking to attribute any physical meaning to the features extracted from these imageries.

Multiple Thread (stream) Systems:

The following discussion features aspects pertaining to two special configurations namely:

a. Braided rivers
b. Anastomosing (anabranching) rivers

Braided rivers are highly dynamic and during a given length of duration, the streams may alternately occupy, abandon and reoccupy different single or multiple segments of the available channel corridor. While the commonly followed practice for centreline delineation is to select only the widest stream (water area), there is however a need for sufficient caution. Centreline delineation based on the widest stream (stream 1 in Figure 29) might lead to a later misjudgement

that on the date the image was captured, flow was taking place only in that (single) thread and, in the foreseeable future, if the other stream (stream 2 in Figure 17) gets wider, this could lead to a potentially damaging inference that the river has shifted course and comes with potentially grave ramifications with regards to any future water management proposal for this system.

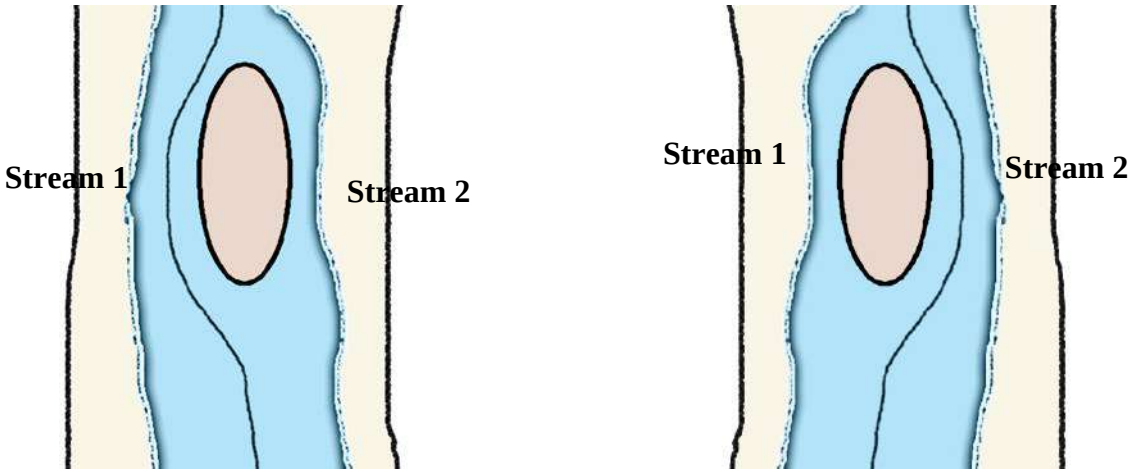


Figure 29: Braided rivers

In braided rivers, the position of the river system, defined in terms of its multiple active as well as currently unoccupied, streams must therefore be identified by marking out, at the very least, **all the occupied threads with corresponding multiple centerlines that pass through each occupied thread**. This obviously will also capture the hydrodynamic reality of flood flow movement in this river system. With regards to images available for the dry (low flow seasons), it therefore is logical to mark all the evident channel threads, including the unoccupied, dry sandy threads. Multiple channels can indeed be marked in a low flow image based on the presence of old sandbars, showing up with their characteristic vegetated or low reflectance signature, and/or river islands, if any. In the absence of these features, the river must be treated as a single stream system which, importantly, is also in accordance with the definition of braided rivers. Similar concept is also expected to work for **anastomosing or anabranching** systems.

Bankline vs Centreline: Applications in the study of junctions and confluence points

In the context of both the Centreline delineation as well as the delineation of banklines, establishment of the latter morphological feature of the river bankline finds useful applications in the important study and investigation of dynamics of confluence points/zones between a river and its tributaries. While the intersection point between centrelines of the dominant river and its tributary stream has an intuitive appeal, however, the latter concept is largely imaginary and intangible for reasons discussed in detail in the aforementioned sections and therefore may not be provide an objective basis for inferences when the study of confluence points is imperative in morphological and other related investigations. Clearly, confluences defined on the basis of

intersection of centrelines are liable to be poorly specified on account of the level of subjectivity that abounds in this approach.

Another challenge in approach based on the concept of centrelines arises on account of the vaguely definable orientation of the two approaching centrelines as these depend on the planforms of the main river and the approaching tributary. In addition to scale dominating the accuracy with which these approaching centrelines can be captured, it is also expected that the two courses would each carry a measure of tortuosity in planforms along their respective courses.

On the other hand, however, banklines are indeed amenable to a tangible and consistent identification, albeit subject to unambiguously specified adopted benchmark references. It is strongly averred that in the study of confluence points and their intrinsic dynamic nature, intersection of banklines presents a more credible and consistent basis. Such confluences can be easily captured - being intersection points of tangible morphological entities – as coordinates where the first bankline of the tributary (oriented with respect to the main river as the upstream intersection among the two intersecting points) meets the bankline of the main river course. As a better illustration, it may be noted that there are two alternative approaches namely:

(1) Tributary may approach the main river along the left bank:

In this case, the confluence point would be defined by the intersection point between the left bankline of the main river and the right bankline of the tributary.

(2) Tributary may approach the main river along the right bank:

In this case, the confluence point would be defined by the intersection point between the right bankline of the main river and the left bankline of the tributary.

CASE STUDIES:

CASE 1: Yamuna River

Yamuna is amongst the larger river systems in India and is under current scrutiny on account of the scale of abstraction of its waters for off-stream use and also its impaired water quality. It is observed that downstream of the now defunct Tajewala diversion facility, Yamuna remains dry or is in a near dry state (Figure 9) for some distance before getting replenished by seasonal tributary streams as well as on account of groundwater accruals (Figure 10).

Generally, the river rarely carries very little of its bankfull discharge and the braid like features that are observable (see also Figure 30) might be due to channel occupation by the river with that little flow (Figure 30). In the latter figure 30, the channel area occupation for agricultural landholdings is also clearly visible. The approximate channel and river centerline.



Figure 30: Yamuna River d/s of Hathinikund barrage.

Obviously, with changes in flows, as is inevitable, corresponding changes in the wet channel area are indeed natural. For example, increase in the water area is clearly evident from a comparison between Figures 31 (segment shown as reach 1 is also shown in Figure 7) and 32. Clearly, it follows, that if it is required to use the delineated centerline feature as a basis to calculate the shift in the course of the river channel, use of its wet stream channel is likely to lead to inconsistent and misleading inferences.

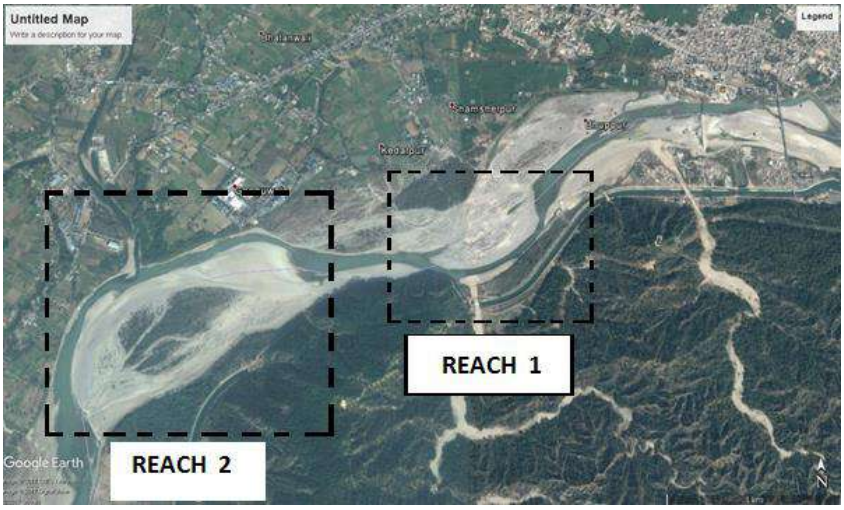


Figure 31: Yamuna River u/s of Paonta Sahib.

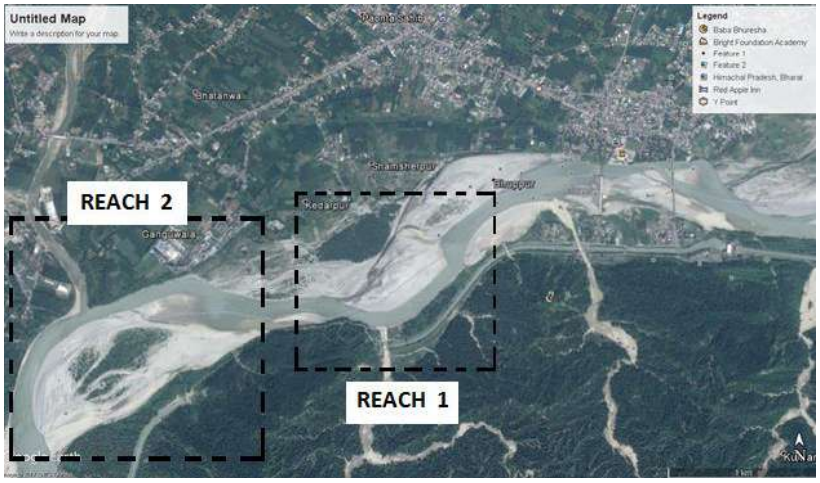


Figure 32: Yamuna u/s of Paonta Sahib (Imagery of different date).

IS THERE A WAY FORWARD?

In view of the aforementioned discussion, it is clear that in deference to the underlying hydro-morphological multi-scale non-stationarity that is abundantly evident in typical river systems, specification of the **river centreline must only be contextual** and whatever methodology is adopted and whichever context is specified, the same procedure must find a consistent application in order to avoid confusing and possibly conflicting inferences. In order to further illustrate the issues discussed, and as a possible way forward, the centreline may be estimated (or marked) on the basis of any one or more of the various, but context specific, considerations.

REFERENCE TEMPLATE

From the foregoing discussion, the spatio-temporal non-stationarity of any given river system is an immutable reality and for ease of capture as well as an unambiguous and consistent numerical comparison of the state of its various dynamic attributes is indeed important. For this purpose, a reference frame comprising of a system of meridional and latitudinal lines that enclose a square grid of pre-specified scale and relationship with the geographical coordinate system is proposed to be used as shown below in alternate forms as Figures 33 and 34. The addition of the river channel along with accompanying details are shown for illustration purposes in Figures 35 and 36. It is expected that this grid based reference template will be better able to capture river plan forms and changes in these forms as observed from one timeline to the next available capture. The use of this grid based system will be separately prescribed and communicated.

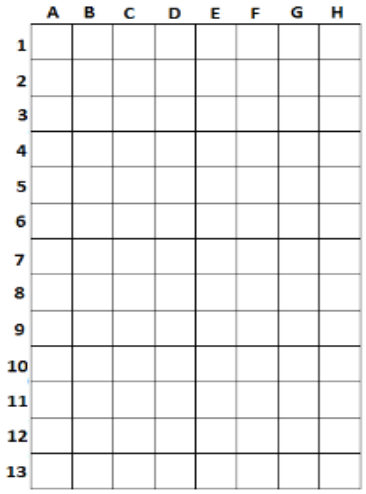


Figure 33: Reference Template (1)

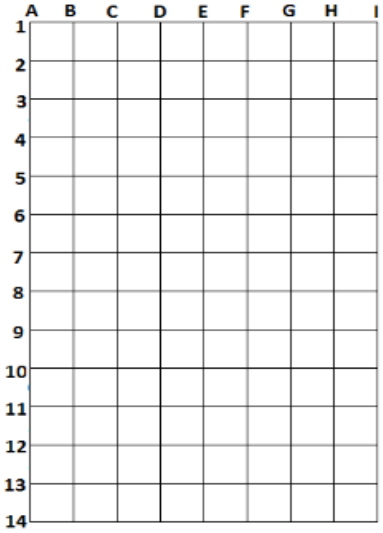


Figure 34: Reference Template (2)

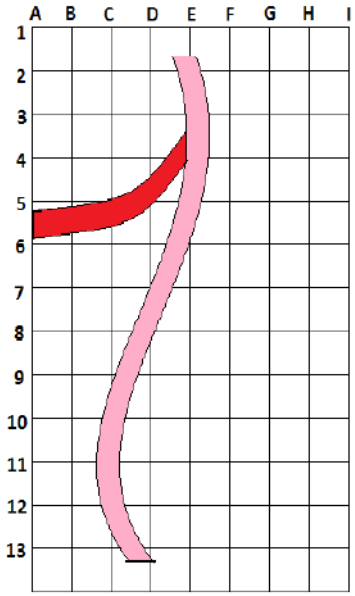


Figure 35: Reference Template

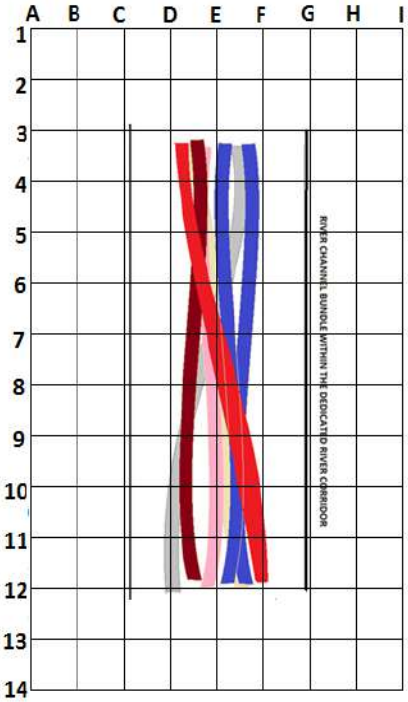


Figure 36: Reference Template

THE BIG QUESTION: HOW CAN A CENTRELINE BE DEMARCATED FOR AN ESSENTIALLY MULTIPLEX MORPHOLOGICAL ENTITY?

The discussion so far seems to lend weight to the hypothesis that, in general, any given river system is anything but intransigent and the position of its observed course over a given, but within a limited span, observational window is just a fleeting reality. As for the current practice, the centreline is digitized based on the active stream (or active water area), as just an anecdotal capture of the river details and, therefore, represents just a snapshot position of the stream. Since these images are acquired at different times of the year, the centreline can be assumed to be representation of the flow direction in the river at flows as on the date of image acquisition.

The relentlessness of underlying autocyclic as well as, to some extent allocyclic, triggers is a common and acknowledged reality facing all river systems. However, there indeed are differences in the scale of time, or morphometric epochs, over which these individual systems are observed to occupy a given state (for example, a river channel's course) between successive concomitant paired events of channel abandonment and a spontaneous and perhaps a simultaneous occupation of a newer one. Thus, rivers may differ in terms of (i) scale of changes that are observed, (ii) pace at which such transitions are seen to occur in them, (iii) length of the reach seen to be most vulnerable, and also (iv) time span over which transit in (or over) a given state is observed prior to its abandonment. It therefore merits mention that in addition to the strength of the underlying allocyclic and autocyclic, the duration of these latter transits are also controlled by the dynamics and scale & statism of river basin's morphological restraints as dictated by factors that include:

(i) Anthropogenic interventions in all its diversity
(ii) Deep valleys & gorges
(iii) Scale of undulations in surface topography
(iv) Movement of glaciers and ice caps
(v) Relatively rapid scale of changes in landforms as a result of avalanches and landslides

The way forward

A. A consistent and appropriately calibrated reference system shown as Figure 33 or 34 should serve as the basic template on which geo-referenced morphological entities can be mapped to scale together with a priori specified important attributes and corresponding chronology.

B. With regards to the task of delineation of the specific attribute of the river centreline, the latter feature should be captured in terms of its **entire range** of possible morphological facets. For example:

(i) Centreline corresponding to bankfull width.

(ii) Centreline of all continuous (uninterrupted) wet channels in the case of braided and ephemeral reaches.

(iii) In the case of dry reaches, centerline should be obtained for all discernible but 'plausible' channel trails as captured in terms of a sharp contrast in observed reflectance values between sand deposits, as an evidence of possibly consistent but intermittent stream pathways, and off piste regions that lie beyond.

(iv) Centreline between the edges of active floodplain on either side of the observed river course regardless of the extent of the observed wetted channel width.

C. Features captured on the reference template should also include numbered address (preferably a numerical bearing) of crossings of the mapped morphological entities with grid lines corresponding to each snapshot in time.

D. This will facilitate:

(i) Easy referencing

(ii) Mapping of timeline of changes from one image to the next in chronology

(iii) Some basic operations on the reference templates to model the captured transient nature of the underlying physical system and their rates along the entire timeline of interest.

SHIFTING, AVULSION AND AUTOCYCLIC EVOLUTION OF RIVERS.

River systems are highly dynamic natural systems. Processes responsible for the formation and subsequent evolution of rivers are indeed a complex interplay of multi-scale processes such as weather and long term climatic variability, feedback loop connecting them with basin physiography, hydrologic & morpho-hydrodynamic aspects, basin pedosphere & deeper regolith, upland and channel erosion, sediment transport &deposition and seismo-tectonic setting of the basin.

Shifting of River:

Rivers generally flow along the fault lines or lineaments and the channel morphology understandably bears their characteristic influence. Changes in these latter subsurface features may manifest on the surface as uplifting, subsidence, development of rifts and altered evolutionary trajectories of the water bodies among others.

Depending upon the magnitude of these subsurface and surface readjustments, transitions in the geo-coordinates of surficial features such as rivers may be observed at a range of time scales ranging from very slow and gradual to very rapid as when river avulsions are observed. There is need for a distinction to be made between the aforementioned transitions when observed in the river course within its designated and rightful river corridor against transitions that may be evident in the swing zone itself as defined by its river corridor or alternatively the Channel Evolution Band of the river.

The need for a clear distinction between the latter transitions is also necessitated by the range of underlying geo-morphodynamic reality. It must, therefore, be acknowledged that the reality of these latter influences is due on account of processes that occur at scales ranging respectively from mainly autocyclic (for the former case) to mainly allocyclic for the latter case.

Accordingly, therefore, the definition of the '**Shifting' feature in rivers may need to be recalibrated to mean, and be defined, as a gradual and unidirectional preferential movement of the river course on account of displacement of the river corridor itself - usually in response to allocyclic seismotectonic readjustments within the basin.** As an example, Kosi River in Bihar is known to have **shuffle shifted**, in incremental steps, by over 115 km in a consistently westerly direction over the past 200 years.

On the other hand, **avulsion is a sudden change - reversible and, in some cases, irreversible - of a river's course. A**vulsions can be triggered as much by the proverbial tectonic upheavals as also by landslides, engineering failures and also by sluggish autocyclic processes leading to an accumulation of strain energy over time till the morphological entity tips towards another dissipated state of hydro-morphodynamic potential. One can infer from the meaning itself the level of destruction that may accompany an avulsion. River Kosi – a tributary of Ramganga in Uttarakhand and the ancient Saraswati are often cited as classic examples.

Autocyclic Evolution of the Rivers:

It is widely acknowledged that rivers are non-stationary dynamic hydro-morphological features and bear a strong signature of both (i) hydrodynamic variability in flow, as well as (ii) history of erosion, deposition and transport of sediment down its course. The formation of oxbows by meandering rivers, movement of a river within its swing zone or corridor bands, abandonment and reoccupation of braids by water streams in braided rivers and observed alternate paths of the wet channels cannot therefore be attributed to or even characterized as shifting or avulsions.

Figures 37 and 38 below are two scenes that capture a reach segment of river Brahamputra in the years 2014 and 1990 respectively. It is observed that in the former, more recent scene, the principal wet stream skirts along the right bank while in the year of 1990, the wet stream is seen to be confined to the left side of the river. These stream movements have also been labelled as local avulsion by some researchers/investigators and is indeed an untenable characterization. To further drive the point, it is observed that while the wet streams appear to be having a distinctly wandering character and are also seen to be evolve rather rapidly in this markedly braided river reach, they, however, also seem to be confined within the latter river's swing zone or indeed its river corridor. It is argued that in the absence of any catastrophic geodynamic event, the river will remain within this Channel Planform Evolution Band or Channel Planform Evolution Width over the relevant morphological time scales.



Figure37: Brahmaputra in 2014



Figure 38: Brahmaputra in 1990

Importantly, delineation of the dedicated swing zone/channel corridor/channel evolution band is a connected challenge and in this regard, an approximate delineation of active floodplain may indeed be based on a return period of around 10 years and further, in case river terraces are of interest, these may be delineated based on hydrodynamic water spread corresponding to a flood even return period ranging from 25 to 50 years.

BRAIDING PLANFORM – SHARMA (1995) AND FRIEND & SINHA (1993) INDICES REVISITED

Introduction

River braiding, as a morphological feature, is an attribute of a river reach more than a cross sectional signature. The intertwining of wetted pathways within the confining bounds of the river banks is indeed the single most recognisable feature of a braided river reach. Obviously, this alludes to the presence of multiple wetted channels along the reach and additionally, an equal number of discernible intersections across the cross sectional transect.

In the context of braiding, it is therefore indicated that a morphometric basis for an otherwise purely qualitative and descriptive detail of river-braid planform may be obtained from a combination of, among others, the following:

(i) Cumulative length of all wetted braids along the reach,
(ii) Reach length,
(iii) Total wetted width as a fraction of the overall width of the cross section,
(iv) Overall interconnectedness amongst the multiple wetted channels

The aforementioned, therefore, lends itself to the understanding that description of river braids planform is essentially a loosely perceived, judgment based articulation of the river's planform presentation. Clearly, such a fuzzy characterization embraces the possibility of a diverse set of plausible and similarly credible descriptions of river channel section morphology.

From the above, it now emerges that a rigorous analytical formulation for an 'Index' based measure of a river's planform topology is indeed a far-fetched aspiration. The formulation is also likely to face challenges on account of the overlapping of scales of an innately diverse range of process and

observation scales within which the operational spatio-temporal dynamism lends its diverse set of signature characteristics to such a natural system. A further complexity arises from the now widely acknowledged fractal nature of the braided river's topological geometry.

An alternative way forward to achieve an 'objective' river braid planform characterization, having shunned the idea of a rigorous analytical formulation based approach, seems to point towards an intuitively arrived at construct for a 'planform index' and is therefore suggestive of a multiplicity of possible forms that such an index may have.

The benchmarks, as a guide towards the goal of arriving at those 'elusive' forms of planform indices, should include the following:

(i) Indices should be amenable to quantification without the need for complex arithmetic; and
(ii) Indices should be based on those river planform attributes that also lend themselves to routine measurements, albeit inevitably influenced by scale issues.

Accordingly, it is hypothesized that the braiding severity observed along a river reach may be captured in terms of the following:

(i) Ratio of cumulative length of all wetted braids to the reach length,
(ii) Number of wet braids across a cross section
(iii) Total wetted width as a fraction of the overall width of the cross section,
(iv) Junction density over the river reach

In the following discussion, modifications are suggested in the cross section based Braiding Index proposed by Sharma (). It is followed by alternate/substitute forms of the reach based indices proposed by Friend and Sinha (1993).

Sharma's Index {SI}:

Sharma's Braiding Index is a cross section based numeric and has the form given by the expression

SI = {(W/B)/N}

where N is the number of wet channels intersecting the indicated cross section profile, B denotes the maximum bank to bank width of the cross section and W is the cumulative total of widths of all wetted braids as seen across the latter cross section. The following points are worthy of note:

(1) The ratio {W/B} has a value less than unity for a braided cross section and, when divided by the number of wet channels N, SI is rendered still smaller. Thus, it is seen that the severity of braiding is proportional to the **reciprocal** of the numerical value of SI in the expression mentioned above.
(2) N (i.e. the number of wet channels) acts as a scaling factor to remove any ambiguity that might result without it in case W approaches B for a highly braided system in which the overall bank to bank width, B is interspersed by a hypothetically large number of narrow width wet braids.

Mathematically, the latter case presents an anomalous situation and leads to inconsistent inferences as indicated below:

$$\lim_{N\to\infty}\left(\frac{W}{B}\right) \rightarrow\Rightarrow 1$$

(3) As indicated, SI is a planform index that is based on cross section features rather than being a reach-based index which is intuitively more appealing.

(4) As mentioned in (1) above, a higher level of braiding severity is accompanied by a lower numerical value for SI although a larger value for N (number of wet channels) intuitively implies a higher braiding severity.

The consequent inconsistent inferences that are likely are illustrated by the following figure:

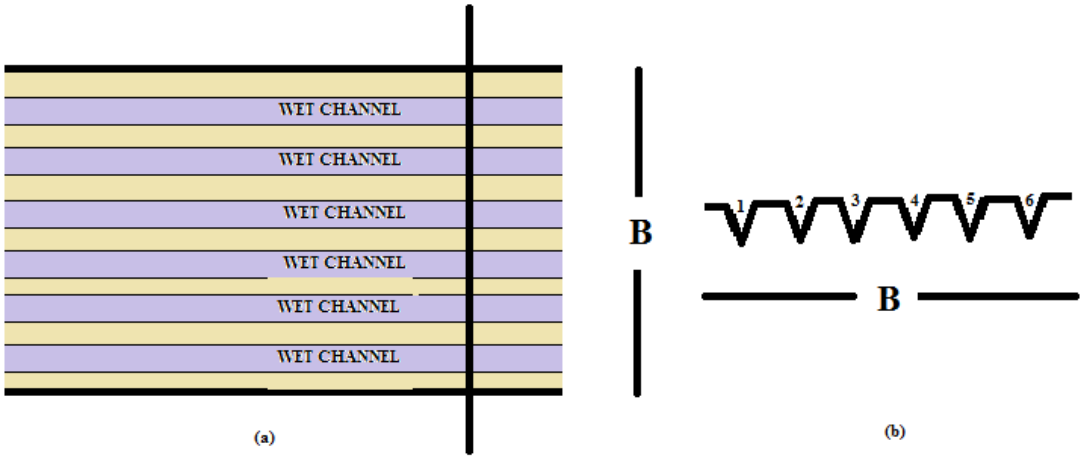


Figure 39 (a) and (b): Case of six parallel wet channels within the river width = B

For the configuration of Figure 39 (a) and (b), a value of SI << 1 is clearly indicated thus alluding to a highly braided planform. This inconsistency arises primarily on account of the earlier observation that SI is merely a capture of cross sectional features and not planform features namely braid junctions, which typically would require a two dimensional, (X,Y) based spatial context.

Misleading inferences are also likely as illustrated by the following example of two alternate channel cross section geometries in which one channel cross section is seen to have two wet braids while the other is seen with three wet braids.

With regards to the ratio (W/B), there are innumerable combinations possible in nature and it is realistically possible to obtain (W/B) ratio values of 0.5 and 0.9 respectively for the two cases as described above. Thus, we have the following interesting results for SI:

(1) Case of two wet channels: SI = 0.5/2 = 0.25
(2) Case of three wet channels: SI = 0.9/3 = 0.3

The interesting dilemma that now begs resolution depends on which channel cross section bears the signature of more braided planform? Is braiding implied to be more severe in the river whose cross section has two wet channels (SI=0.25) or is it the cross section with three wet channels (SI=0.3)?

Difficulties of specification also arise as these indices are severely dependent on the hydrodynamic attribute of the depth of the flow (wetted channels) as the two measures namely W as well as B are both dependent on the flow condition at the time of recording observations. For example, a braided reach may see a complete submergence of these features during even moderately high flows and thereby, leading to a comprehensively altered observer's perspective of the actual reality!! **As a cautionary note, it is strongly recommended that the reported value of SI should invariably be accompanied by a detailed note on date of channel planform observation and the prevailing hydrodynamic conditions**. This additionally accompanying information is expected to yield more informed inferences on channel planform characterization. Further clarity is also likely if the reported value of SI is accompanied by statistical details such as range of braid widths and standard deviation & coefficient of variation of braid widths.

Notwithstanding the foregoing difficulties, it would be highly desirable if the numerical value of SI, based as it is only on cross sectional features, could somehow reflect the important, but hitherto missing, information regarding the number of wet braids/channels that are actually present along the cross sectional transect and which, together, has returned the particular numerical value for SI (value is less than unity) as has actually been obtained.

Towards this end, alternate variations of Sharma's braiding index are proposed as given below:

(1) [{(W/B)/N} + N]
(2) [(W/B) +N]
(3) (W/B)*100 %

An obvious advantage of index (1) being that the numerical value of the index will be as a number having both (i) a non-zero integer component, and (ii) a real part after the decimal point. While the real part will reflect the braiding severity and would be the same value as returned by SI, the integer part, interestingly, will capture the actual number of wet channels that were observed to cut across the cross sectional transect and whose attributes would have been used to obtain a numerical value for {W}.

Friend and Sinha (1993) Index:

Friend and Sinha's Braiding Index (henceforth referred to as FSI) is a **Reach based Index** and has the form given by the expression:

FSI = $\{L_T/L_M\}$

This Braiding planform Index, being a reach based capture of channel morphometrics, therefore has a greater appeal as compared to the former index proposed by Sharma (). In the expression for FSI, the terms $\mathbf{L_T}$ and $\mathbf{L_M}$ are as described below:

(1) Length of the Main (Principal Channel/Braid): L_M
(2) Total length of all channels/braids over the given reach: L_T

The following points are noteworthy with regard to FSI:

(1) FSI is a reach based index of river planform.
(2) In contrast with SI, the hydrodynamic status of the river does not have a serious impact on the estimation of FSI as the latter factor is opaque to the wetted channel widths.
(3) The hydrodynamic status may, however, influence the number of channels within the bank to bank width of the river that are observed to be actively transporting water down the river reach.
(4) The hydrodynamic status may, however, influence the length of the observed wetted channels.

Notwithstanding the fact that FSI is a reach-based measure of braiding severity, in this case also, the channelization as depicted in Figure 37 above is liable to be adjudged as a case of a relatively high braiding severity. Clearly, these indices fail to capture the depicted morphological realities of Figure 39 rendering them as ineffective measures, albeit to varying degrees! As in the aforementioned discussion, the most important element that these latter indices fail to recognize is the significance of the number of braid junctions that are observed over the river reach.

It merits acknowledgement that other indices with alternate forms could be designed in the belief that these may be as successful, if not more, at capturing the braided planform signatures of river reaches.

ADDITIONAL BRAIDING INDICES AS MODIFICATIONS ON FSI (FRIEND AND SINHA, 1993)

In addition to (1) and (2) as above, define the following channel morphometric attributes

(3) Length of Reach: L_R
(4) Number of Junctions over the given reach: N_J
(5) Braiding Ratio: $R_B = L_M / L_T$; (Reciprocal of FSI Braiding Index)
(6) B_{AV}: Average bank to bank width of the river over the reach length, L_R.

Some intuitive choices for Braiding Indices

	INDICES						
FORMS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
INVERSE	R_B / N_J	$(L_R/L_T) / N_J$	L_R / N_J	L_M/N_J			
PROPORTIONATE	N_J / R_B	$N_J /(L_R/L_T)$	N_J / L_R	N_J / L_M	L_T / L_M (F-S Index)	L_T / L_R (Variant of F-S Index)	$N_J / (L_R*B_{AV})$
NEUTRAL	N_J/ L_T	L_T / N_J					
OTHERS	$N_J*(L_T/ L_R)$	$N_J*(L_T/L_M)$					

Procedure

The procedure recommended is based on a Delphi based approach in which experts will rank a collection of braided scenes based on an individual judgement. The formal procedure to be adopted is as explained below.

Step 1: Extract scenes of braided reaches (not necessarily of the same river; any number of rivers nationally/globally; assume 10 such scenes)

Step 2: Obtain numerical measures of the various braining indices for each scene and put together in the form of the following table (Table 1)

Table 1:

	Values for Braiding Indices (i), (ii), …, (x)									
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
Scene 1										
Scene 2										
Scene 3										
Scene 4										
Scene 5										
Scene 6										
Scene 7										
Scene 8										
Scene 9										
Scene 10										

Step 3: Obtain ranks of braiding severity from each individual member of the cohort group without sharing information in Table 1. These ranks are obtained individually, in confidence, and based on visual judgement only. These ranks can similarly be tabulated as in Table 2 below and provides the information for Table 3 as well.

Table 2

	Number ranks (1 to 10) based on judgement of each individual (expert) cohort member (a), (b), … (h)							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Scene 1								
Scene 2								
Scene 3								
Scene 4								
Scene 5								
Scene 6								
Scene 7								
Scene 8								
Scene 9								
Scene 10								

Table 3

	Ranking Statistics					
	Min	Max	Median	Mean	Std Dev	CV
Scene 1						
Scene 2						
Scene 3						
Scene 4						
Scene 5						
Scene 6						
Scene 7						
Scene 8						
Scene 9						
Scene 10						

Note: Rank =1 implies most braided and rank =10 implies least braiding

Step 4: Shuffle and redistribute individual assessments among the researchers without revealing identities. Each has his/her own original table and another table by someone not known. Comparison is made and each has the option to revise his/her original table. It is now possible to reconstruct Tables 2 and 3 again with refined ranks to obtain Table 4 and a table of important statistics as in Table 3 above.

Table 4

	Refined number ranks (1 to 10) based on judgement of individual researchers (a), (b), … (h)							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Scene 1								
Scene 2								
Scene 3								
Scene 4								
Scene 5								
Scene 6								
Scene 7								
Scene 8								
Scene 9								
Scene 10								

It is reasonable to expect that after this iteration, the column of std. dev. and CV in the table of statistics will have smaller numbers when compared with corresponding columns in Table 3

Step 5: Step 4 is repeated as many times as may be deemed necessary till no further changes are recorded. Two cases arise.

Case 1: **Special case**

All members of the cohort group converge to a common judgement and assign similar ranks from 1 to 10 to all the ten scenes. It is to be noted that for this latter special case, all Std. Dev. and CV values as per Table 3, will have reduced to zero for all scenes. Table 5 captures the scenario for this special case.

Table 5: Final (converged number ranks (1 to 10)

	Converged ranks
Scene 1	
Scene 2	
Scene 3	
Scene 4	
Scene 5	
Scene 6	
Scene 7	
Scene 8	
Scene 9	
Scene 10	

Finally, the information may be compiled and presented in the form of a final scores table as given below (Table 6).

Table 7

	Conv ranks	Score of each index based on absolute difference between ranks									
		(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
Scene 1											
Scene 2											
Scene 3											
Scene 4											
Scene 5											
Scene 6											
Scene 7											
Scene 8											
Scene 9											
Scene 10											
Sum total of differences											

<u>Case 2</u>: **General case**

No convergence of ranks is observed after many iterations and there are divergent judgments on some or all of the various scenes presented to the cohort group for examination and ranking. The final compilation of ranks awarded by each member of the cohort group may be arranged in a 'table of discord' as shown below as Table 7.

Table 7

	Final (discordant) number ranks (1 to 10)							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Scene 1								
Scene 2								
Scene 3								
Scene 4								
Scene 5								
Scene 6								
Scene 7								
Scene 8								
Scene 9								
Scene 10								

Further, information on some common statistics may be put together along the lines of Table 3 above and presented as a summary of rank statistics as shown in Table 8.

Table 8

	Statistics of final ranking					
	Min	Max	Median	Mean	CV	(X) percentile value
Scene 1						
Scene 2						
Scene 3						
Scene 4						
Scene 5						
Scene 6						
Scene 7						
Scene 8						
Scene 9						
Scene 10						

Now all that remains to be done is to compare assigned ranking with the numerical values for each of the braiding indices to establish the relative strengths and weaknesses in each of the proposed braiding indices. How to do that??

Procedure:

A basic element of the process is to resolve the conflict amongst the various braiding indices that have been proposed. Towards this goal, a tangible measure of synergy with the 'average' perception of the cohort group constitutes a key benchmarking element. Accordingly, data in Table 1 (reproduced below together with Table 7 for a quick and easy reference) needs to be organized and readjusted in a manner that presents the proposed indices on a scale of desirability in an unambiguous manner.

Table 1:

	Values for Braiding Indices (i), (ii), …, (x)									
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
Scene 1										
Scene 2										
Scene 3										
Scene 4										
Scene 5										
Scene 6										
Scene 7										
Scene 8										
Scene 9										
Scene 10										

Table 7

	Final (discordant) number ranks (1 to 10)							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Scene 1								
Scene 2								
Scene 3								
Scene 4								
Scene 5								
Scene 6								
Scene 7								
Scene 8								
Scene 9								
Scene 10								

Reconciliation of information in Tables 1 and 7 proceeds iteratively towards a resolved ranking of the suggested Braiding Indices.

To be continued…..

Annexure II

Bend characteristics obtained from JP meander migration modeling reaches of Yamuna

Yamunotri to Tons Yamuna Confluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	1706.78	1636.32	0.51	0.33	1.04	2073.95	0.0005	0.0010	600.17
2	1706.78	1875.54	1742.81	0.43	0.60	1.08	-1829.31	-0.0005	0.0000	1725.53
3	3582.31	1875.54	1670.10	0.72	0.64	1.12	1376.33	0.00	0.00	4276.25
4	5457.85	37.50	37.50	0.00	0.00	1.00	-29351.10	NaN	NaN	NaN
5	5495.35	150.11	150.03	0.03	0.06	1.00	1624.04	0.0006	0.0010	5588.97
6	5645.45	261.52	257.36	0.23	0.23	1.02	-562.46	0.00	0.00	5664.33
7	5906.97	75.14	75.13	0.01	0.01	1.00	3013.70	0.0003	0.0004	5925.87
8	5982.11	1237.54	827.58	0.89	1.39	1.50	-543.49	-0.0018	-0.0002	7200.91
9	7219.65	37.37	37.37	0.00	0.00	1.00	10752.49	0.00	0.00	7238.38
10	7257.02	150.50	150.30	0.06	0.08	1.00	-1018.35	-0.0010	-0.0003	7275.65
11	7407.52	220.79	210.67	0.40	0.44	1.05	262.76	0.0038	0.0064	7535.63
12	7628.32	113.42	113.41	0.02	0.02	1.00	-2759.94	0.00	0.00	7647.54
13	7741.74	4012.98	2451.28	1.06	2.35	1.64	1176.81	0.0008	0.0038	11210.99
14	11754.71	3825.96	3108.19	1.37	1.12	1.23	-1540.58	-0.0006	0.0000	15561.94
15	15580.68	899.75	718.73	0.87	0.77	1.25	552.19	0.00	0.01	16011.98
16	16480.43	1160.15	576.37	1.46	1.67	2.01	-370.73	-0.0027	-0.0001	16499.16
17	17640.58	1011.59	694.95	1.96	0.93	1.46	348.30	0.0029	0.0107	17809.25
18	18652.17	637.59	600.03	0.47	0.45	1.06	-689.47	0.00	0.00	19270.94
19	19289.76	675.17	594.04	0.62	0.64	1.14	536.11	0.0019	0.0046	19645.97
20	19964.93	711.69	515.45	1.20	0.73	1.38	-369.75	-0.0027	0.0000	19983.56
21	20676.62	824.27	579.41	0.81	1.12	1.42	427.06	0.00	0.01	21145.22
22	21500.89	2209.93	984.95	1.94	2.67	2.24	-479.30	-0.0021	-0.0001	23542.81
23	23710.82	2061.56	1001.90	1.38	2.54	2.06	525.82	0.0019	0.0074	25528.77

Yamunotri to Tons Yamuna Confluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
24	25772.39	1724.08	528.15	2.10	2.01	3.26	-419.53	0.00	0.00	25791.05
25	27496.46	1686.38	955.77	1.78	1.85	1.76	465.97	0.0021	0.0072	27815.35
26	29182.84	2137.74	1696.36	1.33	1.27	1.26	-824.05	-0.0012	0.0000	29201.56
27	31320.58	76.42	76.42	0.01	0.01	1.00	3780.37	0.00	0.00	31378.43
28	31397.00	108.88	108.86	0.02	0.03	1.00	-2054.28	-0.0005	-0.0002	31415.57
29	31505.88	366.89	176.69	1.43	1.21	2.08	129.21	0.0077	0.0229	31673.24
30	31872.77	71.70	71.69	0.02	0.01	1.00	-1985.68	0.00	0.00	31926.32
31	31944.46	114.24	114.23	0.03	0.02	1.00	2320.01	0.0004	0.0006	32000.60
32	32058.71	861.12	715.23	0.58	0.94	1.20	-567.18	-0.0018	-0.0001	32901.23
33	32919.83	562.45	442.39	1.13	0.63	1.27	320.26	0.00	0.01	33126.06
34	33482.28	1500.06	1177.05	1.16	0.95	1.27	-713.29	-0.0014	-0.0001	34963.58
35	34982.34	1087.76	996.43	0.53	0.54	1.09	1012.51	0.0010	0.0024	35526.24
36	36070.10	1125.22	1019.23	0.61	0.54	1.10	-983.48	0.00	0.00	37176.56
37	37195.32	974.85	809.95	0.63	0.96	1.20	614.15	0.0016	0.0040	37851.69
38	38170.17	786.53	486.97	1.10	1.05	1.62	-366.34	-0.0027	-0.0001	38189.09
39	38956.70	1124.83	966.02	0.79	0.62	1.16	800.31	0.00	0.00	39387.63
40	40081.53	1387.78	1229.31	0.66	0.59	1.13	-1112.87	-0.0009	0.0000	41450.56
41	41469.31	1312.73	1103.36	0.69	0.79	1.19	887.24	0.0011	0.0030	42200.70
42	42782.04	1612.87	1433.45	0.73	0.54	1.13	-1271.69	0.00	0.00	42800.80
43	44394.92	3338.04	1749.91	1.40	1.93	1.91	1004.06	0.0010	0.0026	47451.61
44	47732.96	2100.23	1503.56	1.61	0.95	1.40	-823.08	-0.0012	0.0000	49814.44
45	49833.19	1575.42	1443.69	0.51	0.58	1.09	1452.97	0.00	0.00	50714.68
46	51408.61	2550.70	2248.33	0.72	0.76	1.13	-1725.20	-0.0006	0.0000	53940.56
47	53959.32	1500.45	1442.17	0.36	0.40	1.04	1996.02	0.0005	0.0011	54803.33
48	55459.76	1237.82	1151.00	0.43	0.60	1.08	-1207.52	0.00	0.00	55478.52
49	56697.59	1125.12	925.27	0.80	0.73	1.22	736.01	0.0014	0.0038	57241.39
50	57822.71	2400.61	2053.93	0.96	0.75	1.17	-1409.47	-0.0007	0.0000	60204.57

Yamunotri to Tons Yamuna Confluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
51	60223.32	3601.06	3132.91	0.79	1.05	1.15	1954.44	0.00	0.00	63393.04
52	63824.38	1012.74	921.30	0.48	0.66	1.10	-888.53	-0.0011	0.0000	63843.14
53	64837.12	1012.76	958.94	0.52	0.37	1.06	1134.66	0.0009	0.0020	65193.43
54	65849.88	1200.35	1154.90	0.37	0.37	1.04	-1606.07	0.00	0.00	65868.64
55	67050.23	2925.90	2756.29	0.60	0.57	1.06	2509.73	0.0004	0.0010	67594.14
56	69976.13	1613.00	1556.22	0.39	0.33	1.04	-2246.58	-0.0004	0.0000	71570.38
57	71589.13	1837.96	1609.05	0.60	0.73	1.14	1382.23	0.00	0.00	72695.68
58	73427.10	1725.44	1535.88	0.64	0.59	1.12	-1399.83	-0.0007	0.0000	75133.78
59	75152.53	1312.86	1277.00	0.29	0.34	1.03	2077.13	0.0005	0.0011	75959.03
60	76465.40	1125.24	990.10	0.58	0.72	1.14	-867.50	0.00	0.00	76484.15
61	77590.64	1050.09	870.98	0.78	0.73	1.21	697.40	0.0014	0.0039	78096.91
62	78640.73	1087.82	1056.50	0.36	0.30	1.03	-1654.65	-0.0006	0.0000	79709.80
63	79728.55	1200.35	1153.24	0.35	0.41	1.04	1579.20	0.00	0.00	80460.02
64	80928.90	1575.48	1517.40	0.48	0.30	1.04	-2024.93	-0.0005	0.0000	82485.63
65	82504.38	150.05	150.05	0.01	0.01	1.00	12562.39	0.0001	0.0001	82598.16
66	82654.43	1462.98	1450.55	0.27	0.14	1.01	-3568.83	0.00	0.00	84098.65
67	84117.41	2175.65	2087.78	0.33	0.47	1.04	2720.31	0.0004	0.0010	85674.15
68	86293.06	1162.72	1003.46	0.51	0.95	1.16	-795.16	-0.0013	0.0000	86311.82
69	87455.78	600.08	536.03	0.59	0.65	1.12	484.33	0.00	0.00	87774.61
70	88055.86	637.16	520.67	0.73	0.80	1.22	-417.58	-0.0024	0.0000	88074.67
71	88693.02	749.82	583.71	1.00	0.72	1.28	436.51	0.0023	0.0065	89011.21
72	89442.84	975.13	904.18	0.51	0.50	1.08	-963.15	0.00	0.00	89461.54
73	90417.97	1050.32	1015.16	0.39	0.31	1.03	1498.04	0.0007	0.0015	90849.34
74	91468.29	1387.91	1331.46	0.41	0.37	1.04	-1777.56	-0.0006	0.0000	92837.45
75	92856.20	1425.38	1341.73	0.41	0.54	1.06	1505.31	0.00	0.00	93812.75
76	94281.58	1012.62	894.53	0.53	0.75	1.13	-786.54	-0.0013	0.0000	94300.34
77	95294.19	1537.31	1033.31	1.35	1.31	1.49	579.84	0.0017	0.0047	95725.41

Yamunotri to Tons Yamuna Confluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
78	96831.50	787.35	570.74	0.91	0.95	1.38	-424.47	0.00	0.00	97600.03
79	97618.85	900.05	859.13	0.51	0.33	1.05	1075.02	0.0009	0.0022	97900.08
80	98518.90	1537.87	1371.26	0.73	0.54	1.12	-1210.09	-0.0008	0.0000	100038.02

Tons Yamuna Confluence to Dakpatthar : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	654.19	653.10	0.09	0.07	1.00	4274.94	0.0002	0.0004	230.80
2	654.19	1846.33	1734.56	0.48	0.46	1.06	-1961.19	-0.0005	0.0000	692.69
3	2500.52	423.43	423.38	0.02	NaN	1.00	NaN	NaN	0.00	2769.98

Dakpatthar to Yamuna Giri Confluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	3714.68	3570.66	0.49	0.45	1.04	-4056.68	-0.0002	0.0000	0.00
2	3714.68	3032.76	2966.49	0.37	0.38	1.02	4074.93	0.0002	0.0004	6368.30
3	6747.44	2881.09	2827.37	0.34	0.26	1.02	-4834.20	-0.0002	0.0000	6823.37
4	9628.53	3715.02	3589.91	0.37	NaN	1.03	NaN	NaN	0.0004	11372.15

Giri Yamuna Confluence to Hathnikund : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	2464.10	2309.84	0.50	0.56	1.07	2395.17	0.0004	0.0007	1824.92
2	2464.10	5654.39	5117.66	0.70	0.86	1.10	-3640.39	-0.0003	0.0000	8027.32
3	8118.49	6013.22	4802.87	1.06	1.40	1.25	2452.91	0.0004	0.0008	13313.53
4	14131.71	1458.84	1412.89	0.36	0.33	1.03	-2113.42	-0.0005	-0.0001	15499.17
5	15590.55	2190.10	2082.45	0.45	0.43	1.05	2480.33	0.0004	0.0007	16775.97
6	17780.65	2920.89	2843.24	0.42	0.28	1.03	-4216.73	-0.0002	0.0000	20610.02

7	20701.54	2283.10	2254.88	0.28	NaN	1.01	NaN	NaN	0.0003	21341.06

Hatnikund to Kalanaur : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	848.53	837.59	0.20	0.24	1.01	2105.11	0.0005	0.0008	381.11
2	848.53	2437.89	2037.88	1.08	0.70	1.20	-1363.56	-0.0007	-0.0001	3191.64
3	3286.42	2447.20	2305.67	0.52	0.45	1.06	2511.71	0.0004	0.0006	4510.10
4	5733.62	2635.86	2546.79	0.36	0.37	1.03	-3599.02	0.00	0.00	5827.19
5	8369.47	3389.81	2909.21	0.82	0.96	1.17	1909.33	0.0005	0.0009	11099.03
6	11759.29	4895.96	4291.51	0.87	0.84	1.14	-2871.08	-0.0003	-0.0001	16561.18
7	16655.25	3013.43	2899.66	0.40	0.46	1.04	3501.65	0.0003	0.0005	19010.55
8	19668.68	4710.22	4646.80	0.42	0.18	1.01	-7964.48	-0.0001	0.0000	24284.75
9	24378.90	188.33	188.33	0.00	0.00	1.00	256861.54	NaN	NaN	NaN
10	24567.23	2637.16	2599.48	0.18	0.30	1.01	-5540.46	-0.0002	0.0000	27109.89
11	27204.39	1318.67	1288.70	0.31	0.30	1.02	2130.81	0.00	0.00	27864.26
12	28523.06	1318.86	1298.08	0.25	0.25	1.02	-2601.93	-0.0004	-0.0001	28617.67
13	29841.92	3578.95	3530.17	0.34	0.19	1.01	6768.19	0.0001	0.0004	30500.41
14	33420.86	188.33	188.33	0.00	0.00	1.00	-71736.28	NaN	NaN	NaN
15	33609.20	2449.23	2418.82	0.22	0.26	1.01	5081.80	0.0002	0.0003	35588.08
16	36058.42	2729.65	2473.01	0.53	NaN	1.10	NaN	NaN	0.0000	36152.22

Kalanaur to Karnal : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	4734.06	4691.24	0.18	0.33	1.01	9303.74	0.00	0.00	4360.14
2	4734.06	1352.27	1237.80	0.48	0.63	1.09	-1228.12	-0.0008	0.0000	4808.46
3	6086.33	2100.49	1743.50	0.93	0.91	1.20	1148.54	0.0009	0.0012	7209.91
4	8186.82	5110.24	4287.52	1.12	0.77	1.19	-2706.15	-0.0004	0.0000	13221.98
5	13297.06	9168.09	8362.44	0.62	0.96	1.10	5777.97	0.00	0.00	21188.45

Kalanaur to Karnal : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
6	22465.15	4810.03	4587.71	0.66	0.58	1.05	-3882.85	-0.0003	-0.0001	23893.42
7	27275.18	3005.52	2741.20	0.70	0.60	1.10	2308.20	0.0004	0.0008	28852.83
8	30280.70	4658.41	3812.40	0.98	0.90	1.22	-2487.86	-0.0004	0.0000	34863.82
9	34939.12	5408.01	3547.02	0.82	1.96	1.52	1948.56	0.00	0.00	38321.13
10	40347.12	4505.68	3053.53	1.20	1.64	1.48	-1589.02	-0.0006	-0.0002	44776.83
11	44852.80	7364.20	6843.56	0.98	0.61	1.08	4635.45	0.0002	0.0008	45228.08
12	52217.00	1804.07	1770.70	0.23	0.30	1.02	-3415.45	-0.0003	0.0000	53945.95
13	54021.07	3002.89	2497.32	0.82	0.97	1.20	1680.85	0.00	0.00	55146.67
14	57023.96	1652.41	1522.12	0.58	0.52	1.09	-1511.97	-0.0007	0.0000	58601.28
15	58676.37	150.03	150.03	0.00	0.00	1.00	409833.67	NaN	NaN	NaN
16	58826.40	2404.69	2358.49	0.35	0.26	1.02	-3957.98	-0.0003	0.0000	61155.91
17	61231.09	2704.87	2649.96	0.26	0.38	1.02	4217.47	0.00	0.00	62809.01
18	63935.96	1353.09	1325.14	0.27	0.28	1.02	-2452.67	-0.0004	0.0000	64011.16
19	65289.05	4133.52	4031.13	0.54	NaN	1.03	NaN	NaN	0.0006	65815.05

Karnal to Bagpat : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	5032.16	4368.39	0.61	1.17	1.15	-2875.00	0.00	0.00	0.00
2	5032.16	4205.60	3216.73	1.13	1.11	1.31	1876.72	0.0005	0.0009	5857.27
3	9237.76	4356.25	3823.46	0.88	0.74	1.14	-2681.72	0.00	0.00	13518.92
4	13594.01	4054.96	3312.64	0.77	1.18	1.22	2080.89	0.0005	0.0009	15922.84
5	17648.96	3154.15	2355.25	1.08	1.23	1.34	-1366.60	0.00	0.00	20726.18
6	20803.12	2249.39	1762.81	0.98	1.03	1.28	1117.11	0.0009	0.0019	22226.56
7	23052.51	2402.30	2195.72	0.66	0.47	1.09	-2143.88	0.00	0.00	25379.38
8	25454.81	3153.91	2700.12	0.75	0.87	1.17	1954.95	0.0005	0.0011	26881.93
9	28608.72	4806.99	4120.87	1.14	0.67	1.17	-2657.96	0.00	0.00	28684.04

Karnal to Bagpat : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
10	33415.71	3605.51	3282.46	0.54	0.75	1.10	2780.59	0.0004	0.0007	36345.49
11	37021.22	1802.10	1685.80	0.60	0.40	1.07	-1813.43	0.00	0.00	38748.45
12	38823.32	2854.46	2581.10	0.68	0.67	1.11	2110.28	0.0005	0.0008	39650.31
13	41677.77	4957.34	3880.29	1.10	1.09	1.28	-2269.22	0.00	0.00	41752.70
14	46635.12	4956.60	4012.76	1.17	0.73	1.24	2611.98	0.0004	0.0010	47610.65
15	51591.72	450.87	450.86	0.01	0.01	1.00	-25331.49	NaN	NaN	NaN
16	52042.58	1051.93	1048.59	0.11	0.10	1.00	4870.98	0.0002	0.0004	52567.96
17	53094.51	2855.67	2362.62	0.60	1.34	1.21	-1474.93	0.00	0.00	53169.61
18	55950.18	604.70	592.05	0.30	0.28	1.02	1039.69	0.0010	0.0014	56173.55
19	56554.88	749.95	727.94	0.33	0.31	1.03	-1154.99	0.00	0.00	57229.34
20	57304.83	3458.40	3098.55	0.97	0.68	1.12	2100.89	0.0005	0.0009	57531.90
21	60763.23	2553.06	2295.28	0.59	0.59	1.11	-2174.53	0.00	0.00	60838.55
22	63316.29	2854.41	2627.70	0.54	0.52	1.09	2702.46	0.0004	0.0008	64593.48
23	66170.70	1502.07	1494.07	0.12	0.16	1.01	-5473.24	0.00	0.00	67598.06
24	67672.77	299.54	299.54	0.01	0.00	1.00	23111.11	0.0000	0.0001	67747.48
25	67972.31	3302.18	2293.73	1.14	1.60	1.44	-1203.41	0.00	0.00	68047.60
26	71274.50	4050.74	2275.44	1.43	1.95	1.78	1198.98	0.0008	0.0020	74649.42
27	75325.24	1949.21	1768.44	0.55	0.55	1.10	-1773.68	0.00	0.00	77199.76
28	77274.44	2103.77	2002.67	0.52	0.35	1.05	2426.46	0.0004	0.0008	77951.30
29	79378.21	2553.99	2435.34	0.43	0.39	1.05	-3130.77	0.00	0.00	81857.03
30	81932.20	3831.71	3800.74	0.29	NaN	1.01	NaN	NaN	0.0003	82608.47

Bagpath to Okhla: Year 2000										
Bend	**start_s**	**arclength**	**line_dist**	**entranceangle**	**exitangle**	**sinuosity**	**avg_radius**	**avg_curve**	**max_curve**	**max_curve_s**
1	0.00	2594.36	2477.24	0.54	0.30	1.05	-3226.17	-0.0003	0.0000	0.00
2	2594.36	2032.88	2003.49	0.23	0.24	1.01	4310.22	0.0002	0.0004	3611.29

Bagpath to Okhla: Year 2000										
Bend	**start_s**	**arclength**	**line_dist**	**entranceangle**	**exitangle**	**sinuosity**	**avg_radius**	**avg_curve**	**max_curve**	**max_curve_s**
3	4627.24	2257.42	2209.27	0.34	0.24	1.02	-3929.16	-0.0003	0.0000	6772.08
4	6884.66	5649.24	5001.50	0.81	0.77	1.13	3582.22	0.0003	0.0005	8127.06
5	12533.89	3143.53	2664.88	0.98	0.78	1.18	-1775.25	-0.0006	-0.0001	15565.46
6	15677.43	6993.97	6110.99	0.94	0.89	1.14	3828.13	0.0003	0.0006	16917.66
7	22671.39	2705.69	2318.29	0.68	0.97	1.17	-1634.33	-0.0006	0.0000	22784.76
8	25377.08	2934.84	2511.10	0.91	0.81	1.17	1705.27	0.0006	0.0011	26162.74
9	28311.92	444.89	444.89	0.00	0.00	1.00	-105367.64	NaN	NaN	NaN
10	28756.81	225.39	225.39	0.00	0.00	1.00	26655.94	0.0000	0.0000	28867.72
11	28982.20	2454.31	1382.79	1.22	1.64	1.77	-866.26	-0.0012	0.0000	29096.68
12	31436.52	6986.37	5081.89	1.87	1.09	1.37	2357.79	0.0004	0.0014	31763.55
13	38422.89	2706.98	2332.81	0.65	0.74	1.16	-1943.84	-0.0005	0.0000	38534.91
14	41129.87	5643.33	5255.85	0.65	0.59	1.07	4578.15	0.0002	0.0004	42145.56
15	46773.20	3385.09	2868.99	0.60	1.06	1.18	-2041.31	-0.0005	-0.0001	48012.09
16	50158.28	2028.44	1921.35	0.40	0.49	1.06	2293.50	0.0004	0.0008	51396.69
17	52186.73	2031.57	2004.84	0.31	0.18	1.01	-4189.83	-0.0002	0.0000	54105.49
18	54218.29	4516.87	4384.72	0.43	0.34	1.03	5859.43	0.0002	0.0003	55235.08
19	58735.16	564.65	564.65	0.00	NaN	1.00	NaN	NaN	0.0000	58848.08

Okhla to Gokul : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	2176.24	2093.32	0.36	0.37	1.04	-3085.57	-0.0003	0.0000	0.00
2	2176.24	1801.31	1763.06	0.25	0.32	1.02	3178.04	0.00	0.00	3301.80
3	3977.55	3000.74	2650.64	0.80	0.50	1.13	-2313.45	-0.0004	0.0000	6903.46
4	6978.29	4351.88	3369.70	0.89	1.06	1.29	2233.65	0.00	0.00	8854.43
5	11330.17	1800.17	1650.38	0.52	0.56	1.09	-1669.76	-0.0006	0.0000	13055.43
6	13130.34	3450.78	3070.68	0.75	0.94	1.12	2045.29	0.00	0.00	16056.24

Okhla to Gokul : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
7	16581.12	4622.87	2554.76	1.74	1.95	1.81	-1245.06	-0.0008	-0.0002	20101.20
8	21203.99	5553.45	2699.04	1.68	1.86	2.06	1574.87	0.00	0.00	25485.50
9	26757.44	7205.00	5008.83	1.65	0.98	1.44	-2736.78	-0.0004	0.0000	26832.33
10	33962.44	3894.02	2401.20	1.62	1.18	1.62	1391.72	0.00	0.00	36429.53
11	37856.45	5852.19	4432.08	1.07	1.21	1.32	-2575.04	-0.0004	0.0000	43633.62
12	43708.64	5253.06	5208.17	0.24	0.25	1.01	10617.89	0.00	0.00	44083.56
13	48961.71	300.14	300.14	0.00	0.00	1.00	-31248.28	0.0000	0.0000	49186.74
14	49261.85	4352.79	3624.65	0.78	1.06	1.20	2368.15	0.00	0.00	52788.32
15	53614.64	4499.79	2836.48	1.42	1.21	1.59	-1713.55	-0.0006	0.0000	53689.69
16	58114.43	2096.66	1936.67	0.48	0.52	1.08	2095.50	0.00	0.00	59238.19
17	60211.09	2545.48	1581.74	1.41	1.61	1.61	-841.14	-0.0012	-0.0001	60285.13
18	62756.57	1496.75	1379.98	0.73	0.46	1.08	1262.97	0.00	0.00	63129.91
19	64253.31	2100.89	1994.37	0.42	0.51	1.05	-2262.80	-0.0004	0.0000	66278.96
20	66354.20	5852.47	4580.58	1.60	0.92	1.28	2326.09	0.00	0.00	67028.75
21	72206.67	1950.68	1834.70	0.42	0.51	1.06	-2083.19	-0.0005	-0.0001	74081.02
22	74157.35	3138.26	1350.80	1.73	1.35	2.32	1019.53	0.00	0.00	75573.08
23	77295.62	1949.12	1818.76	0.43	0.56	1.07	-1973.79	-0.0005	0.0000	77370.08
24	79244.74	1351.03	1273.72	0.37	0.64	1.06	1344.23	0.00	0.00	80217.22
25	80595.76	3134.71	1628.20	2.59	0.85	1.93	-913.52	-0.0011	0.0000	83656.13
26	83730.48	1950.35	1867.01	0.39	0.39	1.04	2530.41	0.00	0.00	84705.80
27	85680.83	1950.58	1851.51	0.46	0.40	1.05	-2265.45	-0.0004	0.0000	87556.44
28	87631.41	3151.63	2821.60	0.64	0.88	1.12	2077.76	0.00	0.00	90108.67
29	90783.03	1650.43	1591.57	0.43	0.31	1.04	-2233.58	-0.0004	0.0000	92358.45
30	92433.47	6454.66	5256.12	0.89	1.22	1.23	3059.01	0.00	0.00	98061.88
31	98888.13	2996.65	1837.42	0.97	1.87	1.63	-1055.74	-0.0009	0.0000	99261.15
32	101884.78	1938.33	1486.72	0.80	1.32	1.30	914.15	0.00	0.00	103300.04
33	103823.11	1046.45	975.66	0.60	0.49	1.07	-959.59	-0.0010	-0.0004	104794.16

Okhla to Gokul : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
34	104869.56	1943.71	1531.43	1.01	0.93	1.27	1002.53	0.00	0.00	105543.40
35	106813.27	3295.60	1860.59	1.20	1.98	1.77	-1038.42	-0.0010	0.0000	106888.90
36	110108.87	2690.97	1644.08	1.31	1.79	1.64	866.36	0.00	0.00	112276.94
37	112799.84	4511.33	3165.23	1.79	0.93	1.43	-1657.05	-0.0006	0.0000	116626.98
38	117311.18	786.31	579.48	0.95	0.85	1.36	394.45	0.00	0.01	117650.65
39	118097.48	3009.95	2729.74	0.73	0.58	1.10	-2306.89	-0.0004	0.0000	121032.50
40	121107.43	5852.39	4824.57	0.92	1.31	1.21	2620.93	0.00	0.00	126285.67
41	126959.82	4351.00	3715.76	1.30	0.74	1.17	-2130.88	-0.0005	-0.0001	131235.94
42	131310.82	1500.79	1404.29	0.47	0.53	1.07	1496.39	0.00	0.00	132135.74
43	132811.61	1950.48	1904.32	0.35	0.25	1.02	-3234.39	-0.0003	0.0000	132886.75
44	134762.09	2551.80	2519.34	0.25	0.19	1.01	5803.66	0.00	0.00	135737.79
45	137313.89	3302.16	3185.06	0.35	0.37	1.04	-4601.94	-0.0002	0.0000	137388.93
46	140616.06	4051.70	3428.08	0.70	0.97	1.18	2428.92	0.00	0.00	142492.24
47	144667.76	1650.68	1575.78	0.41	0.39	1.05	-2061.10	-0.0005	0.0000	146243.79
48	146318.44	2099.80	1893.27	0.71	0.48	1.11	1773.25	0.00	0.00	147143.42
49	148418.24	4650.39	2570.75	1.24	2.02	1.81	-1428.32	-0.0007	-0.0001	148493.43
50	153068.63	6300.82	4557.02	1.54	1.06	1.38	2423.93	0.00	0.00	155091.94
51	159369.45	1649.34	1530.25	0.46	0.56	1.08	-1623.59	-0.0006	0.0000	159444.34
52	161018.80	1349.17	1153.77	0.83	0.68	1.17	895.40	0.00	0.00	161689.98
53	162367.96	4052.46	3321.99	1.02	1.13	1.22	-1879.78	-0.0005	0.0000	166339.15
54	166420.42	1179.60	844.20	1.25	0.84	1.40	549.88	0.00	0.00	166925.51
55	167600.03	3738.16	1893.21	1.37	2.30	1.97	-1019.93	-0.0010	-0.0002	167674.92
56	171338.18	3893.67	1930.09	1.64	1.58	2.02	1208.48	0.00	0.00	173504.45
57	175231.86	2695.47	1879.04	1.14	1.52	1.43	-1014.01	-0.0010	-0.0002	177851.90
58	177927.33	1347.56	1306.84	0.32	0.38	1.03	1922.01	0.00	0.00	178750.94
59	179274.89	1198.75	1118.29	0.52	0.55	1.07	-1126.86	-0.0009	-0.0003	179350.58
60	180473.64	4199.72	2948.00	1.68	1.14	1.42	1489.68	0.00	0.00	180999.43

Okhla to Gokul : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
61	184673.36	4199.59	2709.72	1.19	1.54	1.55	-1546.67	-0.0006	0.0000	184748.01
62	188872.95	7652.54	6589.87	1.33	0.74	1.16	3698.96	0.00	0.00	189548.00
63	196525.48	5101.05	4939.06	0.49	0.51	1.03	-5089.11	-0.0002	0.0000	197650.06
64	201626.53	822.62	799.15	0.31	NaN	1.03	NaN	NaN	0.00	202152.86

Gokul Barrge to Chambal Yamuna Cofluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
1	0.00	3632.28	2962.50	1.74	0.67	1.23	1501.43	0.0007	0.0030	256.98
2	3632.28	1348.91	1341.04	0.12	0.17	1.01	-4564.93	-0.0002	0.0000	3707.55
3	4981.19	300.19	300.19	0.00	0.00	1.00	113366.62	0.0000	0.0000	5055.67
4	5281.38	5695.16	2619.33	2.47	1.07	2.17	-1607.70	0.00	0.00	10901.41
5	10976.53	4047.64	2853.23	0.90	1.58	1.42	1630.83	0.0006	0.0017	13452.92
6	15024.17	3146.88	2364.96	1.04	1.40	1.33	-1293.23	-0.0008	0.0000	15100.72
7	18171.05	3278.41	1422.45	1.14	2.67	2.30	849.64	0.0012	0.0030	20925.84
8	21449.46	2087.87	1093.61	1.58	1.38	1.91	-707.31	0.00	0.00	23462.69
9	23537.33	148.09	148.09	0.00	0.00	1.00	57313.61	0.0000	0.0000	23611.97
10	23685.42	296.58	296.58	0.01	0.01	1.00	-21075.39	0.0000	0.0000	23758.87
11	23982.00	1650.05	1615.49	0.29	0.30	1.02	2791.43	0.0004	0.0007	24659.52
12	25632.06	300.77	300.76	0.00	0.01	1.00	-25953.58	0.00	0.00	25704.55
13	25932.82	845.82	754.43	0.47	0.83	1.12	623.05	0.0016	0.0031	26450.77
14	26778.64	3157.29	2259.46	1.24	0.96	1.40	-1437.11	-0.0007	0.0000	29860.33
15	29935.93	2696.89	2610.49	0.43	0.50	1.03	2890.44	0.0003	0.0008	32260.27
16	32632.81	4051.00	3527.22	0.70	0.82	1.15	-2670.88	0.00	0.00	36608.67
17	36683.81	1650.93	1631.03	0.18	0.27	1.01	3724.61	0.0003	0.0005	37809.32
18	38334.74	297.40	297.39	0.01	0.01	1.00	-14820.89	-0.0001	-0.0001	38556.65
19	38632.14	1941.52	1315.86	1.17	1.39	1.48	760.05	0.0013	0.0020	39307.02

Gokul Barrge to Chambal Yamuna Cofluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
20	40573.65	3002.70	2237.53	1.44	1.05	1.34	-1200.37	0.00	0.00	43499.04
21	43576.36	2085.65	1424.96	1.11	1.31	1.46	858.34	0.0012	0.0024	44846.74
22	45662.01	151.48	151.48	0.01	0.01	1.00	-11318.45	-0.0001	-0.0001	45737.20
23	45813.49	749.29	734.64	0.23	0.28	1.02	1449.09	0.0007	0.0013	46191.06
24	46562.78	1198.01	542.62	1.39	1.88	2.21	-368.91	0.00	0.00	46642.03
25	47760.78	605.16	598.26	0.16	0.24	1.01	1480.36	0.0007	0.0012	48148.50
26	48365.94	303.43	303.43	0.00	0.01	1.00	-30565.46	0.0000	0.0000	48440.04
27	48669.37	2397.22	1909.14	0.78	1.19	1.26	1221.18	0.0008	0.0021	50393.45
28	51066.59	1643.99	1456.63	0.65	0.62	1.13	-1302.73	0.00	0.00	51141.22
29	52710.58	1493.15	1006.49	1.07	1.02	1.48	698.86	0.0014	0.0034	53389.13
30	54203.73	4644.93	2964.88	1.53	1.14	1.57	-1738.54	-0.0006	0.0000	58773.60
31	58848.66	2379.25	1511.20	0.84	1.92	1.57	862.02	0.0012	0.0025	60869.19
32	61227.92	4954.41	3959.96	1.56	0.99	1.25	-1934.86	0.00	0.00	61305.47
33	66182.33	301.77	301.76	0.01	0.01	1.00	12983.40	0.0001	0.0001	66409.91
34	66484.10	607.56	601.26	0.20	0.19	1.01	-1551.91	-0.0006	-0.0003	67009.59
35	67091.66	1432.84	711.71	2.08	1.38	2.01	415.56	0.0024	0.0051	67449.42
36	68524.49	597.21	592.35	0.19	0.15	1.01	-1739.25	0.00	0.00	69044.26
37	69121.70	304.81	304.78	0.02	0.01	1.00	8702.88	0.0001	0.0002	69199.14
38	69426.51	4338.29	1482.08	1.11	2.89	2.93	-1087.68	-0.0009	0.0000	73689.21
39	73764.79	2996.73	2473.42	1.09	0.82	1.21	1574.50	0.0006	0.0012	74436.72
40	76761.53	2401.72	2207.37	0.59	0.47	1.09	-2250.97	0.00	0.00	79087.03
41	79163.25	2835.62	1328.69	1.09	2.01	2.13	904.78	0.0011	0.0025	80437.29
42	81998.86	2380.04	1129.01	1.33	2.35	2.11	-650.66	-0.0015	-0.0005	82078.09
43	84378.91	1790.32	1205.79	1.19	1.22	1.48	736.69	0.0014	0.0028	85498.43
44	86169.22	2243.89	1952.89	0.95	0.77	1.15	-1303.31	0.00	0.00	88338.03
45	88413.11	1799.77	1760.92	0.29	0.27	1.02	3263.33	0.0003	0.0006	89237.51
46	90212.88	2402.29	2323.95	0.36	0.40	1.03	-3147.67	-0.0003	0.0000	90287.81

Gokul Barrge to Chambal Yamuna Cofluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
47	92615.17	150.02	150.02	0.00	0.00	1.00	316177.30	0.0000	0.0000	92690.74
48	92765.19	757.62	754.12	0.11	0.13	1.00	-3064.06	0.00	0.00	92839.65
49	93522.81	853.17	743.09	0.78	0.58	1.15	604.83	0.0017	0.0034	93870.98
50	94375.98	306.46	306.37	0.03	0.03	1.00	-4572.97	-0.0002	-0.0002	94455.78
51	94682.44	2996.45	2951.12	0.28	0.23	1.02	5866.08	0.0002	0.0004	95951.44
52	97678.89	3450.89	3333.71	0.32	0.39	1.04	-4881.75	0.00	0.00	97753.75
53	101129.79	2401.30	2214.62	0.46	0.62	1.08	2230.68	0.0004	0.0010	102704.88
54	103531.09	2992.42	2003.22	0.95	1.81	1.49	-1084.34	-0.0009	0.0000	103606.23
55	106523.51	3311.40	1868.90	1.60	1.72	1.77	1000.30	0.0010	0.0016	109287.60
56	109834.91	634.25	512.79	1.02	0.62	1.24	-361.12	0.00	0.00	110387.77
57	110469.16	1658.25	1605.39	0.40	0.45	1.03	1949.23	0.0005	0.0009	111754.29
58	112127.41	1650.52	1520.61	0.56	0.50	1.09	-1550.00	-0.0006	-0.0001	113703.58
59	113777.93	1947.64	1843.46	0.44	0.41	1.06	2309.76	0.0004	0.0010	114751.34
60	115725.58	2842.40	1748.56	1.13	1.77	1.63	-979.03	0.00	0.00	115800.12
61	118567.97	3580.72	2060.95	1.40	2.02	1.74	1043.28	0.0010	0.0022	121784.91
62	122148.69	1564.14	1080.28	0.87	1.58	1.45	-584.71	-0.0017	-0.0003	123631.20
63	123712.83	1805.49	1511.40	0.76	1.02	1.19	1015.51	0.0010	0.0019	124993.33
64	125518.32	2244.78	1632.70	1.08	1.36	1.37	-918.77	0.00	0.00	127687.26
65	127763.10	297.79	297.77	0.01	0.02	1.00	8861.48	0.0001	0.0001	127987.10
66	128060.89	1800.37	1764.94	0.36	0.21	1.02	-3169.93	-0.0003	0.0000	129785.38
67	129861.26	2990.10	1875.56	1.05	1.73	1.59	1075.19	0.0009	0.0020	131285.16
68	132851.35	1048.40	917.93	0.67	0.72	1.14	-750.24	0.00	0.00	132929.97
69	133899.75	3298.18	2521.06	1.22	1.06	1.31	1449.24	0.0007	0.0012	135321.89
70	137197.94	1947.73	1737.75	0.55	0.66	1.12	-1617.68	-0.0006	0.0000	139070.64
71	139145.66	2850.06	2478.99	0.85	0.68	1.15	1870.05	0.0005	0.0011	140720.39
72	141995.72	5956.81	1775.77	1.81	2.57	3.35	-1327.48	0.00	0.00	147878.69
73	147952.53	4194.47	1614.40	2.03	1.47	2.60	1199.38	0.0008	0.0017	150422.48

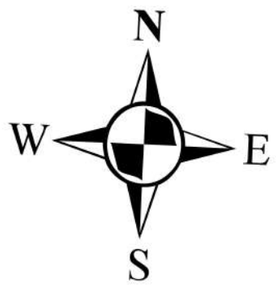
Gokul Barrge to Chambal Yamuna Cofluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
74	152147.01	1346.50	1313.32	0.31	0.30	1.03	-2188.33	-0.0005	0.0000	153418.37
75	153493.51	1931.12	1689.13	0.73	1.04	1.14	1080.09	0.0009	0.0019	155070.53
76	155424.62	2697.64	1844.38	1.69	0.86	1.46	-1062.17	0.00	0.00	157897.97
77	158122.26	2250.62	2047.55	0.55	0.56	1.10	2013.79	0.0005	0.0010	159248.12
78	160372.88	4042.61	1953.16	1.08	2.54	2.07	-1113.09	-0.0009	0.0000	164337.84
79	164415.49	2093.55	1868.51	0.82	0.70	1.12	1382.07	0.0007	0.0012	165686.81
80	166509.04	1348.11	1116.47	0.86	0.78	1.21	-822.49	0.00	0.00	167782.18
81	167857.16	5694.45	1873.83	2.09	2.06	3.04	1374.14	0.0007	0.0014	172428.42
82	173551.61	149.90	149.90	0.00	0.00	1.00	-25056.55	0.0000	0.0000	173626.37
83	173701.51	1650.13	1628.28	0.23	0.19	1.01	3845.30	0.0003	0.0006	174376.45
84	175351.64	3449.04	2822.83	0.84	1.01	1.22	-1872.10	0.00	0.00	175426.62
85	178800.68	2698.86	2090.18	0.97	1.09	1.29	1310.80	0.0008	0.0017	180673.56
86	181499.55	3743.70	2165.24	1.31	1.52	1.73	-1326.31	-0.0008	-0.0001	185167.46
87	185243.24	3447.03	2137.13	1.61	1.20	1.61	1230.42	0.0008	0.0018	187414.25
88	188690.27	2549.90	2351.09	0.50	0.53	1.08	-2483.10	0.00	0.00	191165.18
89	191240.17	1650.74	1615.16	0.27	0.31	1.02	2844.32	0.0004	0.0006	192065.82
90	192890.92	4801.17	4335.13	0.73	0.62	1.11	-3546.12	-0.0003	0.0000	192965.89
91	197692.09	3450.70	3256.14	0.48	0.40	1.06	3935.03	0.0003	0.0006	199117.55
92	201142.78	2550.05	2052.68	0.62	1.16	1.24	-1441.79	0.00	0.00	201217.59
93	203692.84	1497.81	1374.43	0.43	0.72	1.09	1306.39	0.0008	0.0015	204666.74
94	205190.65	2548.37	2151.10	0.86	0.81	1.18	-1526.23	-0.0007	0.0000	207664.06
95	207739.01	3591.18	1467.24	1.61	1.64	2.45	1106.90	0.0009	0.0021	209761.00
96	211330.19	1351.36	1319.86	0.34	0.28	1.02	-2163.39	0.00	0.00	212607.05
97	212681.55	1342.79	1318.51	0.24	0.30	1.02	2508.38	0.0004	0.0007	213509.07
98	214024.34	153.52	153.52	0.00	0.00	1.00	-28404.07	0.0000	0.0000	214099.32
99	214177.86	1000.21	841.15	0.65	0.82	1.19	650.27	0.0015	0.0032	214697.09
100	215178.08	2705.02	2476.83	0.60	0.67	1.09	-2127.08	0.00	0.00	217809.27

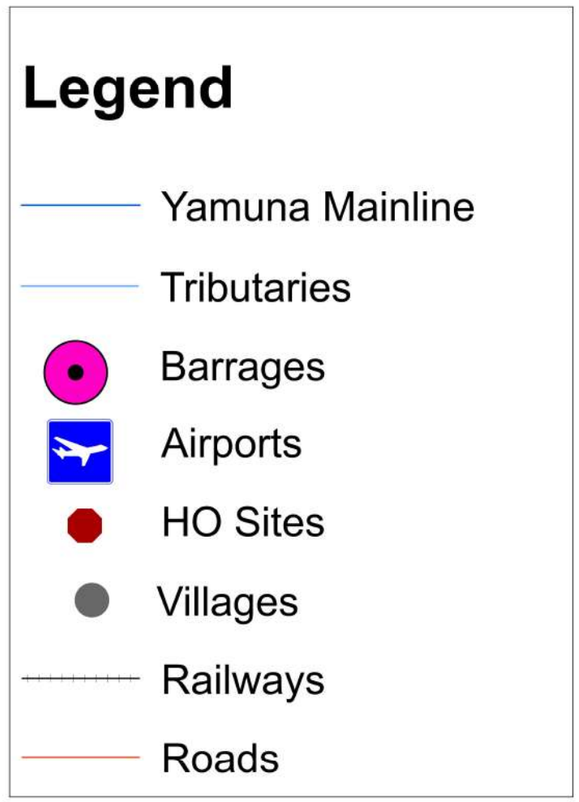
Gokul Barrge to Chambal Yamuna Cofluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
101	217883.10	1499.57	1242.97	0.70	0.88	1.21	951.48	0.0011	0.0021	218707.44
102	219382.67	7494.17	1943.53	3.07	1.78	3.86	-1502.48	-0.0007	-0.0002	223500.70
103	226876.84	2840.49	1706.51	1.51	1.50	1.66	942.30	0.0011	0.0020	228296.36
104	229717.33	5093.81	3052.01	2.39	1.10	1.67	-1458.65	0.00	0.00	234736.45
105	234811.14	5398.25	2826.87	1.73	1.48	1.91	1688.82	0.0006	0.0014	237584.75
106	240209.38	5393.12	1840.33	1.15	3.01	2.93	-1299.48	-0.0008	0.0000	240283.99
107	245602.50	7344.36	2473.01	2.36	2.50	2.97	1514.38	0.0007	0.0013	251225.88
108	252946.86	2096.73	1744.60	1.07	0.53	1.20	-1307.11	0.00	0.00	254968.06
109	255043.59	5401.14	4551.57	1.06	0.91	1.19	2746.78	0.0004	0.0008	255868.75
110	260444.74	6297.23	4239.84	1.28	1.47	1.49	-2292.76	-0.0004	0.0000	260519.59
111	266741.96	2250.82	2143.37	0.43	0.54	1.05	2330.92	0.0004	0.0007	268318.00
112	268992.79	3600.98	3464.80	0.51	0.37	1.04	-4116.67	0.00	0.00	272518.66
113	272593.77	3600.04	3179.02	0.67	0.87	1.13	2345.41	0.0004	0.0008	275669.59
114	276193.81	5851.31	4850.50	1.35	0.83	1.21	-2687.44	-0.0004	0.0000	281970.07
115	282045.12	5386.79	2741.68	1.44	1.62	1.96	1752.86	0.0006	0.0017	285117.94
116	287431.91	13197.38	7440.26	1.20	2.68	1.77	-2747.58	0.00	0.00	287507.16
117	300629.28	10346.41	3230.34	3.05	1.28	3.20	2297.00	0.0004	0.0014	303101.82
118	310975.70	1799.59	1790.35	0.11	0.21	1.01	-5527.42	-0.0002	0.0000	311050.94
119	312775.29	304.42	304.42	0.00	0.01	1.00	30997.70	0.0000	0.0001	313004.34
120	313079.71	2510.05	1188.72	1.54	1.66	2.11	-774.92	0.00	0.00	313155.08
121	315589.76	1647.29	1522.45	0.71	0.55	1.08	1307.68	0.0008	0.0014	315968.81
122	317237.05	2700.05	2182.92	0.74	1.03	1.24	-1533.26	-0.0007	0.0000	319862.88
123	319937.10	7497.87	2247.36	2.32	1.77	3.34	1835.86	0.0005	0.0011	321811.25
124	327434.97	10796.70	3687.34	1.61	2.83	2.93	-2132.49	0.00	0.00	327509.99
125	338231.67	7496.45	2249.61	2.97	1.76	3.33	1478.38	0.0007	0.0018	338904.50
126	345728.11	4199.58	3257.15	0.95	1.08	1.29	-2070.18	-0.0005	-0.0001	345803.08
127	349927.69	10776.44	8497.93	1.14	1.96	1.27	3433.62	0.0003	0.0022	360341.82

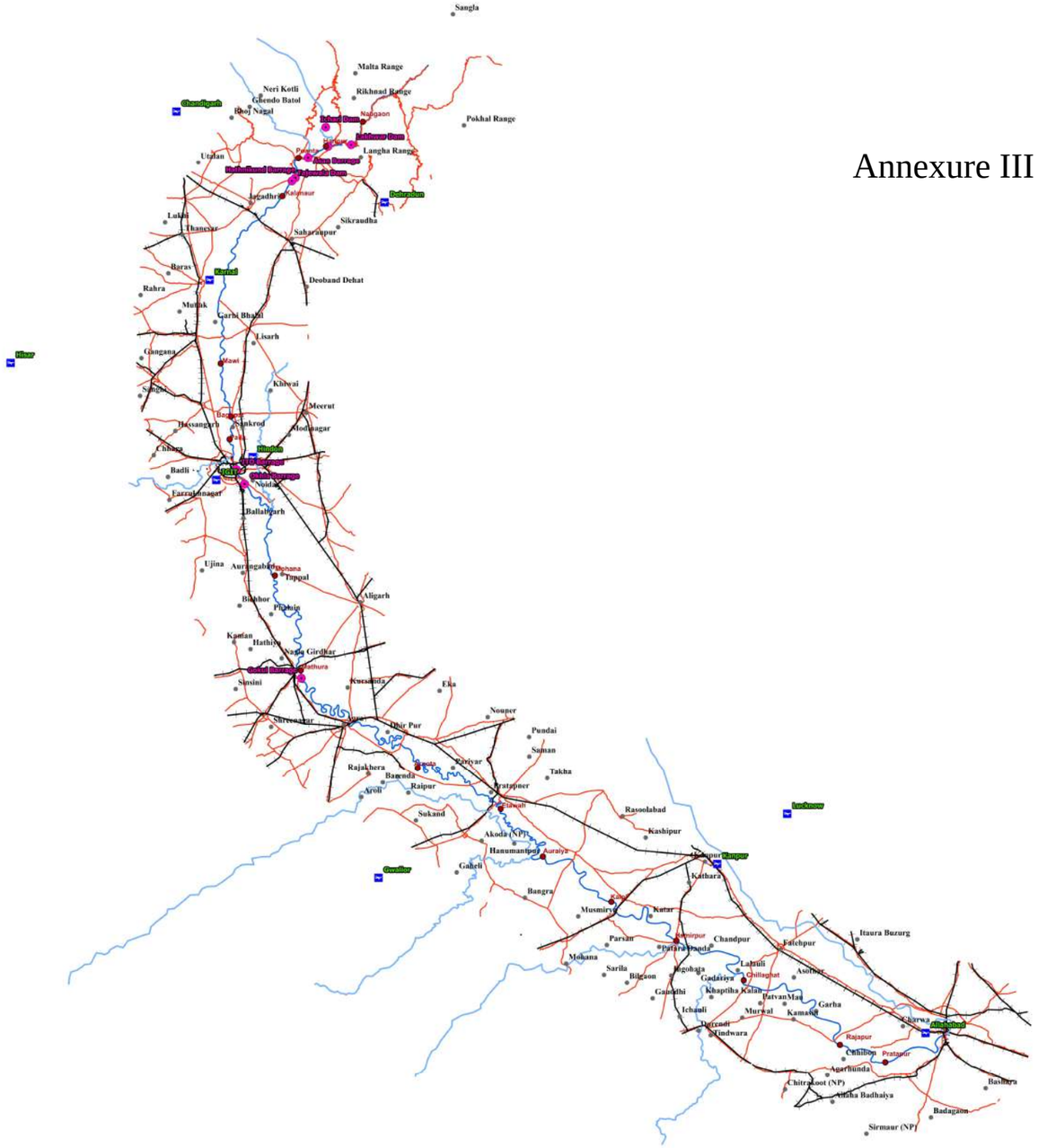
Gokul Barrge to Chambal Yamuna Cofluence : Year 2000										
Bend	start_s	arclength	line_dist	entranceangle	exitangle	sinuosity	avg_radius	avg_curve	max_curve	max_curve_s
128	360704.13	7203.19	2344.82	2.30	1.71	3.07	-1799.66	0.00	0.00	367831.89
129	367907.32	4945.51	2104.08	1.41	1.81	2.35	1533.88	0.0007	0.0016	370983.83
130	372852.83	5248.69	4292.65	1.09	1.23	1.22	-2264.19	-0.0004	0.0000	378026.91
131	378101.53	3974.89	3147.50	1.06	NaN	1.26	NaN	NaN	0.0010	380276.38

Annexure III

Annexure III









Proceedings of Dissemination Workshop of Morphology Study of Kosi, Bagmati, Yamuna Project held on 15th Jan 2024 at New Delhi

The Civil Engineering Department, IIT Delhi, organized final workshop for the project: "Morphological Studies of Kosi, Bagmati, and Yamuna Rivers using Remote Sensing Techniques", at the Auditorium, Research & Innovation Park, IIT Delhi, on 15th January, 2024. The project outcomes were presented to the participants of the workshop who were from a range of concerned organizations. Invitation to participate was sent to the State Govt of Bihar, UP, Haryana and their research institutes like IRI, WALMI. Central agencies and academic institutes such as Central Water Commission (CWC), Ganga Flood Control Commission (GFCC), National Institute of Hydrology (NIH), National Remote Sensing Centre (NRSC), Ministry of Jal Shakti (MoJS), IIT Roorkee, IIT Guwahati, IIT Mumbai, IIT Chennai, IIT Kharagpur, IIT Hyderabad, SVNIT Surat, WWF India, etc were also invited to attend the workshop. List of Participants: Annexure I

Prof A.K. Nema, Head of Civil Engineering Department, IIT Delhi, and Mr. D.P. Mathuria, Chief Engineer, CWC, welcomed the participants. It was followed by a short briefing about the project by Prof. A. K. Gosain.

Prof Rakesh Khosa gave an overview of the project and also presented genesis, morphological signatures, quasi-statism of a river course, the concept of the ergodynamics and the river corridor, shifting in a real sense, asymmetry in river drainage network, and various nuances of Kosi's morphological behavior. It was followed by a presentation by Mr. Gaurav Pakhale on methodology and system-specific outcomes of morphological study using remote sensing techniques in Yamuna, Baghmati, and Kosi Basin.

After the presentations, the floor was opened for discussion and comments and questions were invited from the participants. A very intense discussion pursued wherein most of the participants engaged in conversations, shared their views and experiences, and also provided feedback on the study done by IIT Delhi. A few observations were made on the final reports such as providing further clarity on the areal retreat of erosion deposition and to provide additional information, such as the location of nearby villages and the geographical context while discussing various indices and stable or unstable reaches.

Dissemination Workshop of Morphological Studies of Kosi, Bagmati & Yamuna Rivers Using Remote Sensing Techniques

Research & Innovation Park, IIT Delhi
15th January, 2024

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