River Style® Framework for the Ganga River

FLUVIAL GEOMORPHOLOGY GROUP*

GANGA RIVER BASIN ENVIRONMENTAL MANAGEMENT PLAN

SUBMITTED TO

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1. PREAMBLE

River Styles framework explains the mutual linkages between the river forms and the geomorphic processes within a specific zone in the river. It consists of attributes at different scales that provide a platform to distinguish different types of rivers. According to the practical set of objective criteria used in river reach analysis by Kellerhals et al. (1976), and the nested hierarchical framework proposed by Frissell et al. (1986), the River Styles framework provides a physical basis to describe and explain within a catchment distribution of river forms and processes, and predict future river behavior. Within a catchment, River Style framework gives a holistic framework for data collection and organization and provides a framework to interpret its behavior and the adjustment potential over time.

Scale is very important to define the hierarchical River Style framework. The nested hierarchical River Styles framework consists of five scales: catchment, landscape, reach, geomorphic and hydraulic. Catchment scale explains the geological setting and climatic condition over the entire catchment. Similarly, the landscape setting defines the large-scale landforms that directly impact the processes operative in different reaches. River reaches are stretches over which the basic riverine processes are more or less uniform. River Styles are identified and interpreted at the reach scale using valley setting and assemblage of geomorphic units. Geomorphic units and their sedimentology is defined for both the channel and the floodplain of the river. Within the geomorphic units, homogeneous sets of flow type and substrate define the hydraulic units that are used to interpret aquatic habitat patches along the river.

River Styles classification is accomplished in different steps. For the identification of distinct River Styles three parameters namely, valley setting, geomorphic units and bed material texture are necessary. Each parameter plays a major role in defining one style. For an example, channel plan form of an alluvial river shows distinct behaviour between different valley settings whereas the bed material texture is important in defining the processes operative in a particular river reach. Sedimentological composition and the mutual association of channel planform and channel geometry with the geomorphic units provide the distinct attributes for the different River Styles. Sinuosity and braid channel ratio are important from channel morphometry point of view.

Field investigation assists the River Style framework by providing some necessary data. Bed material texture can be interpreted from the field data. In general terms, bed material size and texture reflects regional geology, flow energy and sediment flux from upstream. Confined valley settings are dominated by bed rock with coarse textured geomorphic units. In Partly confined valley settings bed rock may or may not be present and bed materials are of variable sizes. Fine-grained suspended deposits are encountered in the floodplain pockets. Unconfined valley settings comprise all kinds of textures with locally significant bedrock. Bed material textures and its relation to the bank composition translate to the river character and behaviour.

River Styles concept has primarily been developed for a smaller river system and in this work we attempt to apply this for a large river system such as the Ganga for the first time. Our efforts so far have

shown that for a large tropical river such as the Ganga, the River Styles framework can be very useful to define geomorphic diversity from the source (Gangotri) to sink (Ganga sagar). The Ganga River basin has significant diversity in terms of landscape setting, valley setting, valley morphology, geomorphic features; morphometric parameters that will be reflected in the River Style based classification. Additionally, River Style is a hierarchical approach, which includes geomorphic characteristics at different scales. The large scale attributes for the Ganga River include landscape setting, valley setting, valley morphology, valley confinement and the small scale (reach scale) attributes consist of bar area, bar percentage, sinuosity, braid channel ratio etc.

The Ganga river is not just a large river in terms of area, length, discharge and sediment load, it also traverses through very diverse settings through its journey from the source to th sink. The Bhagirathi is the source stream of the Ganga which originates from the Gangotri Glacier at Gomukh. At Devprayag, where the Alaknanda joins the Bhagirathi, the river acquires the name Ganga. The course of the Ganga river up to Haridwar falls into the mountainous reach and it then debouches into the plains. The Ganga river is joined by numerous tributaries in the plains before flowing into the Bay of Bengal. The River Ramganga joins the Ganga near Kannauj, and the Yamuna confluences the Ganga at Allahabad, making a major contribution to the river flow. Beyond Allahabad, the Ganga is joined by several tributaries, most of which are from the north and a few from the south. At Farakka, the barrage diverts some of the water into a feeder canal. Downstream of this barrage, River Ganga splits into two, the Bhagirathi (Hooghly) on the right and Padma on the left. The Bhagirathi (Hooghly) meets the Bay of Bengal about 150 km downstream of Kolkata. The Padma enters Bangladesh and meets the Brahmaputra and Meghna before finally joining the Bay of Bengal. The complexity and diversity of the Ganga river are important to understand the ecological diversity in the system and the River Style Framework provides a good opportunity to document such variability in the system from the source to the sink.

In the Ganga River, landscape setting is determined on the basis of position and the physiographic characters of the basin. Similarly, valley setting is characterized with respect to the type of the valley such as bedrock, alluvial or mixed. The next step is to determine channel confinement from the mutual relation between the channel and the adjacent floodplain. This is followed by the identification of geomorphic units. In the Ganga River, the various geomorphic units like mid channel bar, side bar, point bar, alluvial island, confluence bar in the channel belt area and meander cut off, meander scrolls, meander loop, abandoned meander bar, ox bow lake, abandoned braid bars, flood channels, chute channel, abandoned channel, flood channel have been interpreted in the active flood plain region. These geomorphic units vary in spatial and temporal scale in different River Styles framework. Some features may be used as geomorphic indicators to define certain geomorphic status of the river.

From the application point of view, River Styles framework will provide a present base line to evaluate the physical status of a river with respect to the geomorphic character, its present day condition in terms of geomorphology, flow characteristics and biota and allow us to develop a framework for comparison with the past condition and future trends of the river. On the basis of

characterization of the river following the River Style framework approach we propose to approach the work of river restoration and management.

2. DATA USED

2.1 *Geomorphic maps*

The key geomorphic units that have been mapped for the river Ganga are valley margin, active floodplain and channel belt each characterized by several geomorphic features. Landsat imagery, SRTM generated DEM along with Google Earth images were used to prepare these maps. Details of the procedure used for geomorphic mapping have already been discussed in the previous report. These geomorphic maps for the entire stretch of the Ganga River have been used as one of the inputs to define the different River Styles for the Ganga. The geomorphic maps were also used to calculate different parameters such as sinuosity, braid channel ratio, the bar area, etc and has been used for characterizing the River Styles.

2.2 *Field Observation*

While characterizing a river reach, several parameters are needed such as bed material character, types of riparian vegetation; these were recorded during field visits to key points along the river. Field trip was organized in June-July 2011 and November 2011 to study these parameters. Cross section survey was carried by professional surveyors along with participants from FGM and WRM group members, along pre-defined section lines and cross sectional parameters like depth, bankfull width, wetted perimeter, etc were computed.

2.3 *DEM (ASTER/SRTM)*

ASTER DEM data of the year 2009 has been used to generate the slope data in the hilly terrain. ASTER has a spatial resolution of 30 m in comparison to SRTM's 90 meter and is thus better suited for computing slope in the high altitude areas. It has been used to compute slope between Gomukh (source of Ganga) to Haridwar. But ASTER data has much more noise and is totally unsuitable in the plains area. So, for computing slope in the low altitude area (downstream of Haridwar) SRTM has been used.

3. METHODOLOGY

In order to characterize the stretches of Ganga River and divide it into geomorphologically significant and distinctive portions, the guidelines outlined in the River Style® framework (Brierly & Fryirs, 2005) have been used. However, as Ganga is a much larger and complex system as compared to smaller drainages of Australia studied by Brierly and others, we have designed a set of parameters and criteria that can be applied in the present scenario to document geomorphic diversity and function of the Ganga River. This has formed the basis for differentiating the Ganga River into distinct River Styles.

The River Style® framework has a nested hierarchical top-down approach and is arranged in three key scales. The following section describes the key parameters at each scale that are assessed to define a River Style.

1. **Landscape/Valley setting:** Landscape setting is readily identifiable from topographic features with a characteristic pattern of landforms through which the river flows. In the Ganga River five landscape units have been identified based on landscape position and physiographic character. Usually, ***the valley setting constitutes the next hierarchy but in the case of the Ganga River, this is inclusive in the landscape setting***. They are: -
    - *Himalayan Bedrock*: when the river is flowing through the Himalayan mountain range.
    - *Piedmont*: a terrain close to the mountain front as the river leaves the mountainous terrain and enters the plain.
    - *Alluvial Valley*: an alluvial plain where the river flows through its own alluvium.
    - *Craton Margin*: a low-lying plain where the river is flowing through an area that is flanked or underlain partly by the Indian cratonic basement rock and partly by its own alluvium.
    - *Valley-Interfluve*: when the river flows through an alluvial terrain that has been deposited in the interfluve region of the two major river valleys.
    - Fan-Interfan: when the river emerges from mountain front and flows out onto a more gently sloping plain resulting into a distinct landform called fans. The area between two fans is called interfan.
    - Badland: this is typical for the Yamuna and Chambal rivers that flow through the Vindhyans creating ravines. Badlands are highly dissected regions.
2. **Channel confinement:** This describes the relationship between the channel and its adjacent floodplain and can be divided into:
    - *Confined*: When more than 90% of channel abuts the valley margin and there is no active floodplain on both the banks of the channel.
    - *Partly confined*: When 10% to 90% of channel is hugging the valley margin; active floodplain is present only in parts of the study reach and is absent or very poorly developed on the other parts.
    - *Unconfined*: Where less than 10% channel abuts the valley margin or the channel mostly flows centrally; active floodplain extends on both the banks of the channel.
3. **Floodplain boundation:** The nature of floodplain boundation defines the relationship between the active floodplain and the valley margin. They can be divided into:
    - *Confined*: Active floodplain boundary coincides with the valley margin on both the sides of the channel.
    - *Partly confined*: Active floodplain boundary coincides with the valley margin in certain reaches of significant length but remains unconfined in the remaining reaches.
    - *Unconfined*: Active floodplain boundary and the valley margin are usually separated by an older floodplain.

In addition to these three parameters that formed the first level of differentiation, channel type (braided, sinuous or anabranching) was also added to the River Style description, although it did not always formed the basis for distinction.

After the River Style® boundary was marked on the geomorphic map, each stretch of a particular style was further divided into reaches for which various channel morphometric and meander parameters were calculated. Cross sectional parameters were calculated at specific field locations. Table 1 lists the different parameters that were calculated and Figures 1 and 2 illustrate the planform and meander parameters respectively.

Table 1: Planform and cross-sectional parameters

Parameters	Term	Definition	Expression	Figure
Planform	**Sinuosity (P)**	Ratio of valley gradient to channel gradient over a stream reach.	**Lcmax/Lr** where, Lcmax is the length of the midline of the channel (for single-channel rivers), or the widest channel (for multi-channel rivers) and Lr is the overall length of the reach	1 a
	Braid-channel ratio (B)	It distinguishes between rivers with single and multiple thalwegs. Higher value indicates that the stream has a network of small channels separated by small sediment deposition called bars.	**Lctot/Lcmax** where Lctot is the total of the mid-channel lengths of all the channels in a reach	1 b
	Average Channel width	Average width of the trunk (primary) channel.		
	Channel area	Area occupied by water in the stream.		
	Bar area	Area occupied by different depositional units like mid channel bar, side bar, point bar, alluvial island and confluence bar.		
Meander	**Radius of curvature (Rc)**	Radius of a best-fit circle passing through points on a meander curve.		2 a
	Axial wavelength (L)	Distance between two consecutive inflection points.		2 a
	Amplitude (Am)	Width of the meander bends measured perpendicular to the straight line axis.		2 a
Cross-sectional	**Bankfull width (w)**	Maximum width that the stream can attain before flooding.		2 b
	Maximum depth (dmax)	Depth at which the deepest point (thalweg) of the stream is found.		2 b
	Left sub area (Al)	The sub area or zone formed by a vertical line drawn from the surface of the water to the thalweg on the left side of water flow.		2 b
	Right sub area (Ar)	The sub area or zone formed by a vertical line drawn from the surface of the water to the thalweg on the right side of water flow.		2 b
	Channel capacity (A)	Cross sectional area of the channel at bankfull discharge.	**Al + Ar**	
	Channel	Quantifies the asymmetry of the channel cross	**(Ar - Al) /A**	

	asymmetry (A*)	section. If negative then the left sub area is bigger than the right sub area. If positive then vice versa.		
	Wetted perimeter (P)	Surface of the channel bottom and sides which is wet i.e. which is in direct contact with water during bankfull discharge.		2 b
	Hydraulic radius	Measure of channel efficiency. The greater the efficiency of the channel, the less likely it is to flood. The highest values occur when channels are deep, narrow and semi circular in shape.	**A/P**	

Based on the geomorphic maps prepared for different stretches of Ganga, ARCGIS 10.0 has been used for calculating different parameters. Representative geomorphic maps and field photographs are given in Appendix I. Appendix II shows the reaches in the Ganga River along with the position of the meanders for which parameters have been calculated. Appendix III lists the channel morphometric data with diagramatic representation and Appendix IV shows the meander parameter data and the bar plot of the parameters reach wise..

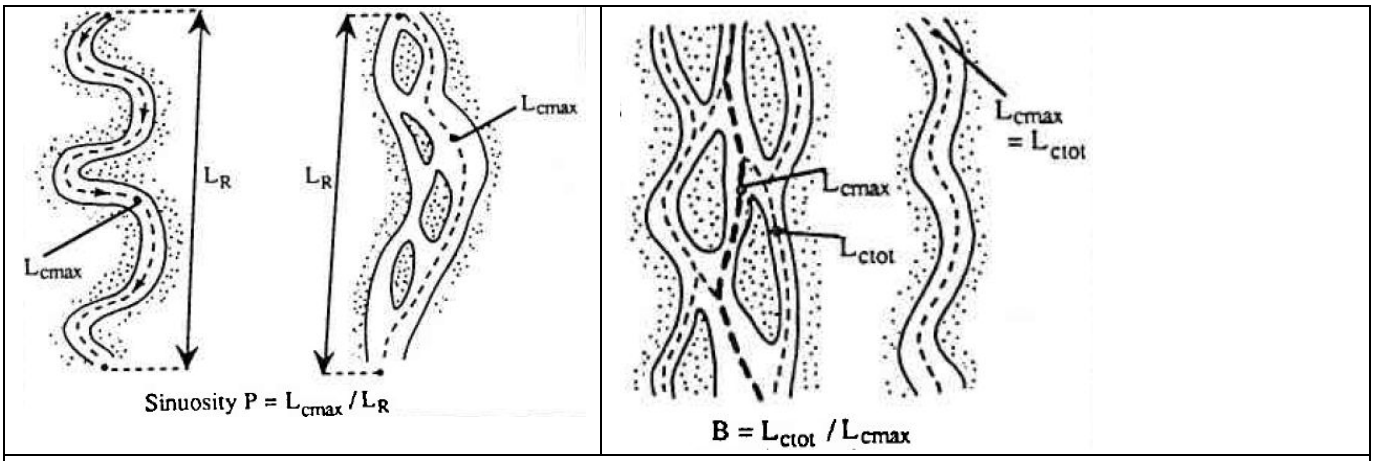

Figure 1 a, b: Sinuosity and Braid Channel ratio of a meandering and braided river **after Friend and Sinha, (1993).**

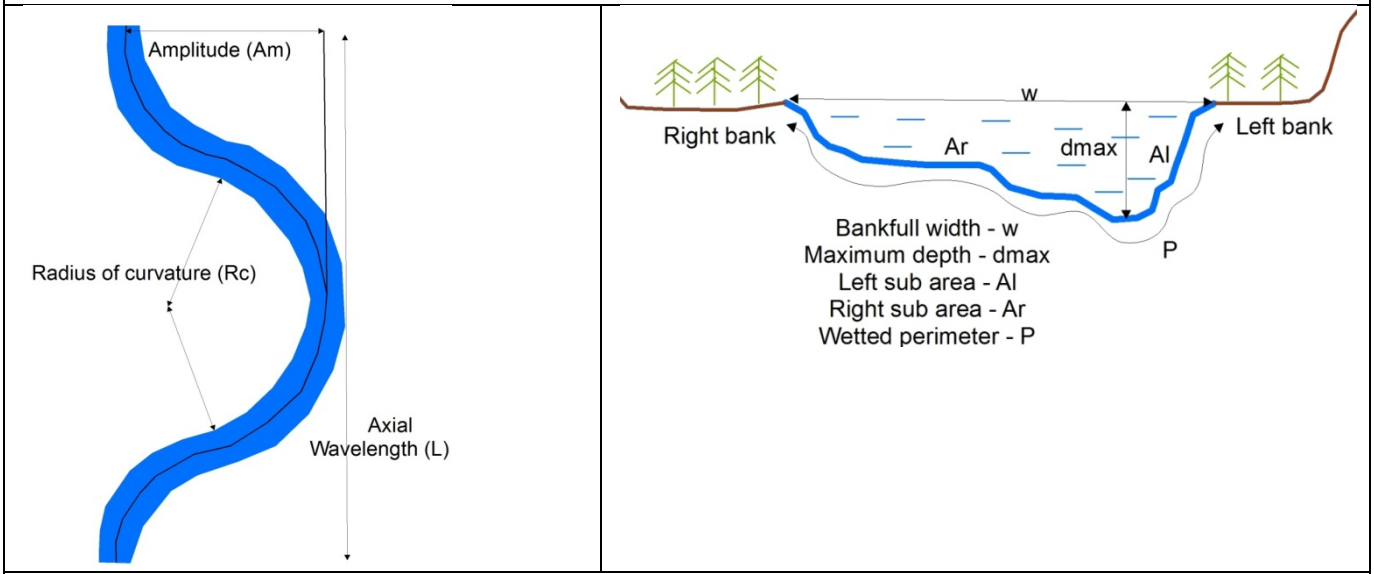

Figure 2 a, b: Meandering and cross sectional parameters of a channel

We have followed slightly different approaches to develop the River Style Framework of the Ganga river in the Himalayan catchment and in the plains. Two parameters that form the major point of distinction are:

- **Slope**: It is an important parameter that has been used in characterizing the river in the Himalayan catchment where it varies remarkably. It is of little importance in the plains area as the slope remains more or less uniform with very little variation. Slope has been calculated using the hydrology tools of ARCGIS.
- **Active Floodplain**: It is a prominent feature in the plains area but it is either absent or patchy in the mountainous terrain.

The template for documenting the characteristics of the different River Styles of Ganga River is based on the documentation by Brierley and Fryirs (2005) with some modifications. Table 2 shows the template designed for documenting the River Style description for the Ganga River.

Table 2: Template for River Style description of the Ganga River

Defining attributes: A brief synopsis about the particular River Style®. **Stretch:** Location names giving the extent of the particular style.	
DETAILS OF ANALYSIS	
Data used: The data that was used for interpretation **Date:** **Analyst:** Name of the person creating the template.	
RIVER CHARACTER: The different factors that characterize a particular stretch of river .	
Landscape setting	Broad terrain characteristics as defined above (p.4 of the report)
Valley Morphology	Here the river valley width and its general configuration are documented. Based on the average valley width, the valley is characterised as : <1 km – very narrow, 1 to 3 km – Narrow, 3 to15 – moderate, 15 to 35 km – wide, > 35 km – very wide
Channel confinement	Channel confinement by the flanking floodplains and may be confined, partly confined or unconfined.
Active Floodplain characteristics	The morphology of the active floodplain along with its width and its relation (boundation) with valley margin.
Channel Characteristics	The different parameters that are calculated are given here corresponding to the particular style.
Diagnostic Geomorphic Features	*Channel belt- alluvial/Himalayan Bedrock* Document all the geomorphic features of the main channel and its active floodplain.

(geometry, sedimentology)	*Flood plain*
Land Use/Land Cover association	*Flood plain* The land utilization in active floodplain as well as in the different bars as observed in field/Google Earth/LULC map of NRSC.
	Channel belt
Channel and Floodplain material	The grain size of the bed material as well as the active floodplain as observed and measured in field.
RIVER BEHAVIOUR AND PROCESS ZONE	
Document the river dynamics, bank erosion/stability, sediment supply and tectonic processes that have influenced the River Style® along with the river characteristics during low flow, bankfull flow and overbank flow.	
ECOLOGICAL SIGNIFICANCE The ecological diversity that is present in the particular River Style.	

4. RIVER STYLE® FRAMEWORK FOR THE GANGA RIVER

Using the first order parameters and the channel characteristics, the Ganga has been divided into 10 distinct river styles. Distinguishing attributes of River Style® are summarized in Table 3. Figure 3 shows the distribution of the River Styles for the Ganga River from source to Farakka. A brief description of each River Style® is presented below. The templates describing characteristics of each style are given in section 5.

1) ***Himalayan, Steep Valley*** River Style® has been defined for the stretch of the Ganga from Gomukh to Rishikesh where the valley margin is adjacent to the active channel, and consequently, no floodplain has formed. The Ganga River in this stretch is mostly a single channel. Channel bed and valley walls consist of Himalayan bedrock, providing the key control on the path of the river. The river gradient varies from moderate to steep (2 degree). Riffles and pools are the dominant geomorphic features. Bed material consists of boulders, cobbles, pebbles and coarse sand.

2) ***Himalayan, Partly Confined Floodplain and Channel, Braided*** River Style® occurs at the transition of alluvial and Himalayan bedrock confined channel reach. This style between Rishikesh and Haridwar differs from Style 1 mainly in terms of development of narrow floodplain pockets. The floodplain as well as the channel is partially confined by the valley. The river is highly braided, multichannel and of low sinuosity. It is characterized by a gentle gradient (0.518 degree). Bed material is dominated by gravel/ coarse sand.

3) ***Piedmont, Partly Confined Floodplain and Channel, Braided*** River Style® is observed when the Ganga River leaves the confines of Himalayan mountainous region downstream of Haridwar and enters the alluvial plain. The river is highly braided in this style between Haridwar and Bijnor and both valley and active floodplain widths show a remarkable increase. Both the floodplain and the channel are partly confined.

4) ***Valley-Interfluve, Partly Confined Floodplain and Channel, Braided*** River Style® from Bijnor to Narora is characterized by an interfluve setting where the channel is restricted on one side (in this case on the right bank) by a cliff or the valley margin itself and the active floodplain has developed only on the opposite (left) bank of the river in this style. In some reaches, the channel is unconfined as the floodplain has developed on both banks but the floodplain is partly confined on the left bank by the valley margin. Side bars and mid channel bars are the dominant in-channel geomorphic feature here whereas abandoned braid bars are common in the active floodplain. Asymmetry is very much pronounced here. Channel bed is composed of fine sand and the banks are muddy.

5) ***Valley-Interfluve, Unconfined Floodplain and Channel, Braided*** River Style® between Narora and Fatehgarh has similar features as the previous style except that both the active floodplain and channel are unconfined and the valley margin is quite wide on both sides. The stretch of the Ganga between Sirathu and Allahabad also shows the same style except that the channel is a little more sinuous. Abandoned braid bar is the dominant geomorphic feature. Bed material in this River Style varies from very fine sand to coarse sand and the bank comprises an alternate succession of mud and fine sand. The sandy bars appear more common in the channel belt downstream of the Narora barrage.

6) ***Valley-Interfluve, Unconfined Floodplain, Partly Confined Braided*** River Style® between Fatehpur and Sirathu is characterized by incised channel and very narrow, discontinuous active floodplain on either side. Channel is partly confined by the cliffs (mostly on the right bank) but the active floodplain, where present, is bordered by a narrow but continuous valley margin (inactive floodplain). Channel is braided and mid channel bars and alluvial islands are noted. Bed material comprises of fine to medium grained sand and the floodplain is muddy.

7) ***Alluvial Valley, Unconfined Floodplain and Channel, Sinuous*** River Style® has been defined between Allahabad and Gopiganj and this stretch marks a sharp transition from valley interfluve setting to alluvial setting. The stretch between Chunar and Chapra also shows the same River Style. The river is highly sinuous and large point bars are present bordered by adequately wide active floodplain. Valley margin is narrow and mimics the channel sinuosity. Numerous scrolls, abandoned meander loops and ox-bow lakes are common. Fine-grained sand is the bed material in this style.

8) ***Craton Margin, Partly Confined Floodplain and Channel, Sinuous*** River Style® is marked between Gopiganj and Chunar when the river is bordered by the craton margin along its right bank. Further downstream, the stretch between Pansalla and Kursela also shows the same style. Active floodplain

has developed only along the left bank. Point bars are common and so is abandoned meander belt. Though the river is mostly sinuous (1.27-2.03), some reaches in this river style show multi-thread braided morphology where abandoned braid bars are found. Medium to fine grained sand is the bed composition with clayey, silty to fine grained sand as the floodplain material.

9) ***Valley-Interfluve, Partly Confined Floodplain and Channel, Anabranching*** River Style® defined between Chapra and Pansalla again marks a sharp change from craton margin setting to valley-interfluve setting. A large part of the valley is occupied by the channel belt and floodplain. The most diagnostic geomorphic features in this river are large, stable alluvial islands dividing the channel into anabranches that rejoin downstream. Some stretches in this style show significant sinuosity.

10) ***Craton Margin, Confined Floodplain, Partly Confined Braided*** River Style® between Kursela to Farakka is similar to River Style 8 above except that the floodplain is confined by valley side and the channel is partly confined. Alluvial islands and large braid bars are the dominant geomorphic features. Channel sediments comprise of very fine-grained sand and floodplains have silt and clay.

The following sections of the report present the systematic description of each of the river styles in the form of detailed templates.

Table 3: Distinguishing attributes of River Styles in the Ganga River

River Style® No.	River Style® Name	Stretch (Length in Km.)	Landscape Setting	Channel Confinement	Flood Plain Boundation	FP:VW	Nature of Symmetry	Channel type	Mean Slope	Sinuosity	Braid Channel Ratio	Bar %	Special feature/Defining attribute
1	Himalayan, Steep Valley	Gomukh to Rishikesh (~236)	Himalayan Bedrock	Confined	No floodplain	-	Symmetric	Sinuous	2˚	1.03 - 2.39	1.0 - 1.25	13-64	Incised channels in Himalayan bedrock. No floodplain with none to very few bars.
2	Himalayan, Partly Confined Floodplain and Channel, Braided	Rishikesh to Haridwar (~27)	Himalayan Bedrock	Partly confined	Partly confned	1:5	Asymmetric	Braided	0.518˚	1.18 - 1.40	1.21 - 2.78	63	Discontinuous floodplain in Himalayan bedrock confined channel with dominant mid channel bars and alluvial islands.
3	Piedmont, Partly Confined Floodplain and Channel, Braided	Haridwar to Bijnor (~79)	Piedmont	Partly confined	Partly confined	1:1.8	Asymmetric	Braided	0.124˚	1.15 - 1.25	1.8 - 3.7	68	Abrupt increase in valley and floodplain width. Channel width also increases significantly with very high braiding index.
4	Valley-Interfluve, Partly Confined Floodplain and Channel, Braided	Bijnor to Bugrasi (~110.7)	Valley-Interfluve	Unconfined	Partly Confned	1:1.5	Symmetric	Braided	0.034˚	1.2 - 1.43	1.4 - 2.4	60	Active Floodplain is dominantly on the left bank of the river with abundant floodplain features. Valley is prominent on the left side of the river and the river flows very close to the right valley margin.
		Bugrasi to Narora (~59)	Valley-Interfluve	Partly confined	Partly confned	1:5	Asymmetric	Braided		1.12 - 1.27	1.72 - 2.1	72	
		Fatehgarh to Fatehpur (~224)	Valley-Interfluve	Partly confined	Partly confined	1:1.6	Asymmetric	Braided	0.027˚	1.07 - 1.25	1.2 -2.3	71	

River Style® No.	River Style® Name	Stretch (Length in Km.)	Landscape Setting	Channel Confinement	Flood Plain Boundation	FP:VW	Nature of Symmetry	Channel type	Slope	Sinuosity	Braid Channel Ratio	Bar %	Special feature/Defining attribute
5	Valley-Interfluve, Unconfined Floodplain and Channel,Braided	D/S Narora to Fatehgarh (~201)	Valley-Interfluve	Unconfined	Unconfined	1:3.8	Symmetric	Braided	0.24˚	1.13 - 1.42	1.27 - 2.25	85.5	Abandoned braid bar common. The valley margin is highly irregular.
		Sirathu to Allahabad (~82)	Valley-Interfluve	Unconfined	Unconfined	1:1.9	Symmetric	Braided	0.055˚	1.1 - 1.5	1.96 - 2.18	66	
6	Valley-Interfluve, Unconfined Floodplain, Partly Confined Braided	Fatehpur to Sirathu(~102)	Valley-Interfluve	Partly confined	Unconfined	1:2.4	Symmetric	Braided	0.035˚	1.22 - 1.63	1.54 - 2.27	68.9	Narrowest portion of active floodplain and valley margin in plain area with discontinuous floodplain. Only style with an unconfined floodplain but with a partly confined channel.
7	Alluvial, Unconfined Floodplain and Channel, Sinuous	Allahabad to Gopiganj(~115)	Alluvial	Unconfined	Unconfined	1:1.3	Asymmetric	Sinuous	0.018˚	1.4 - 2.4	1.15 - 1.95	70.5	Valley margin shows alternate widening and narrowing. Meander scrolls are abundant. Big patches of abandoned meander belt with meander scrolls are the prominent feature without the influence of Indian craton. Big patches of abandoned meander belt with meander scrolls are the prominent feature without the influence of Indian craton.
		Chunar to Chapra (311)	Alluvial	Unconfined	Unconfined	1:1.3	Asymmetric	Sinuous	0.010˚	1.11 - 2.6	1.0 - 2.59	38 - 60	

River Style® No.	River Style® Name	Stretch (Length in Km.)	Landscape Setting	Channel Confinement	Flood Plain Boundation	FP:VW	Nature of Symmetry	Channel type	Slope	Sinuosity	Braid Channel Ratio	Bar %	Special feature/Defining attribute
8	Craton Margin, Partly Confined Floodplain and Channel	Gopiganj to Chunar(~74)	Craton Margin	Partly confined	Partly confined	1:1.8	Asymmetric	Sinuous	0.019˚	1.27 - 2.03	1.22 - 1.44	58.4	Big patches of abandoned meander belt with meander scrolls are the prominent feature with a cratonic setting.
		Pansalla to Kursela(~141)	Craton Margin	Partly confined	Partly confined	1:1.7	Asymmetric	Braided	0.024˚	1.36-1.4	1.7-1.76	62	
9	Valley-Interfluve, Partly Confined Floodplain and Channel, Anabranching	Chapra to Pansalla (~183)	Valley-Interfluve	Partly confined	Partly confined	1:1.3	Asymmetric	Anabranching	0.028˚	1.13 - 1.25	1.03-2.09	67 - 80	Alluvial islands are prominent and formed by the anabranches of the main channel.
10	Craton margin, Confined Floodplain, Partly Confined Braided	Kursela to Farakka (~145)	Craton Margin	Partly confined	Confined	1:1.7	Symmetric	Braided	0.011˚	1.61	3.57	64	Wide floodplain and valley margin totally coinciding, Big patches of alluvial island.

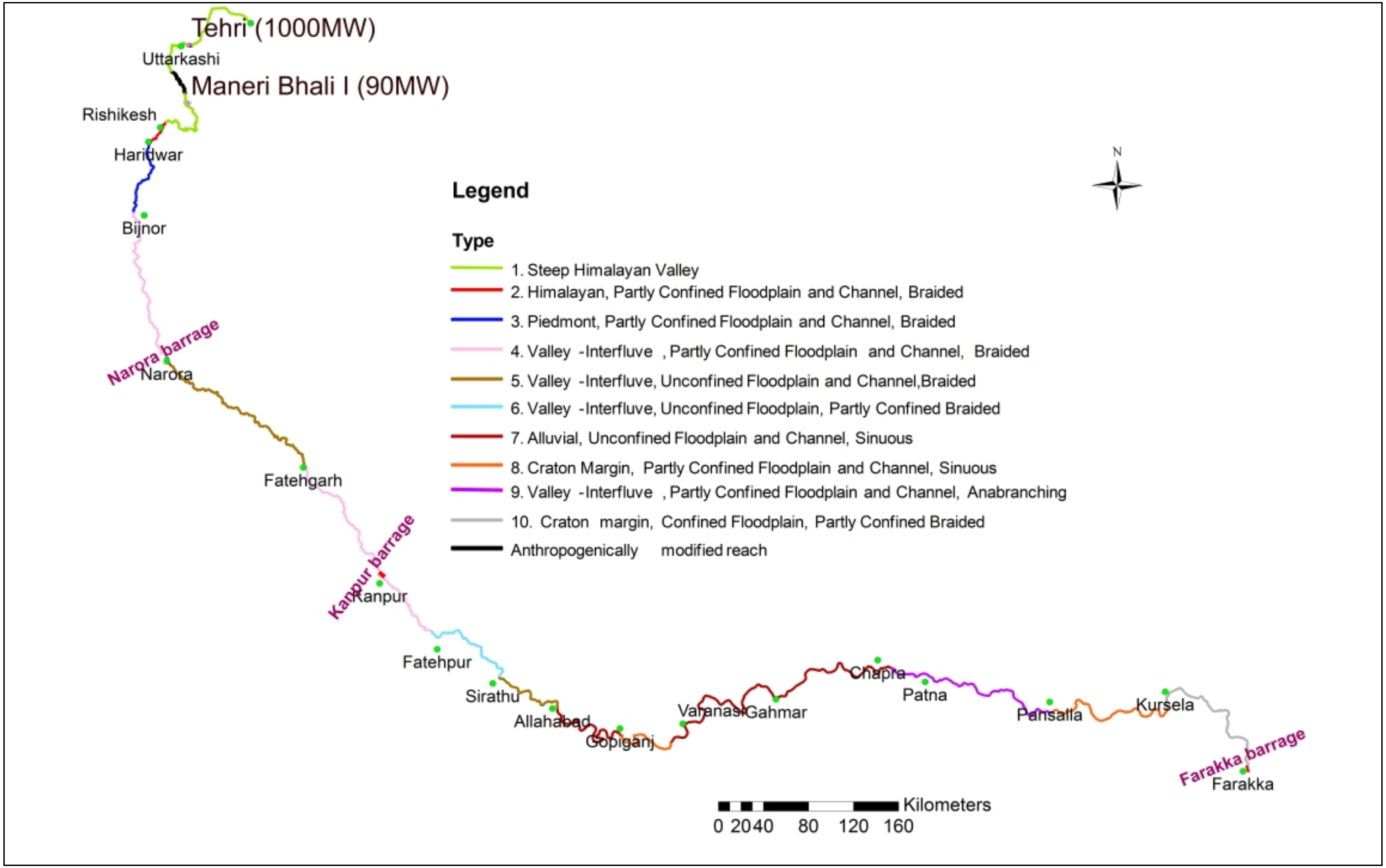

Figure 3: Distribution of River Styles in Ganga River from Gomukh to Farakka

5. TEMPLATES OF THE DIFFERENT RIVER STYLE® OF GANGA RIVER

5.1 River Style 1: Himalayan Steep Valley

Defining attributes: This river style covers a stretch of ~236 km in Himalayan bed rock valley setting. Channel belt geomorphic features are negligible or absent in this river style except in a small stretch between Dharali to Sunagarh. Valley is relatively narrow in upper reaches from Gomukh to Tehri while it becomes wider near Dharali and downstream from Tehri to Rishikesh. Channel follows the central position mostly except near Uttarkashi and Kaudiyala where it moves in oscillating manner. In this part, channel is characterized by high sinuosity ranging up to 2.42 otherwise channel shows low sinuosity. The braid channel ratio ranges from 1.0 to 1.4.

Stretch: Gomukh to Rishikesh - 236 Km

DETAILS OF ANALYSIS	
***Data used*:** Geomorphic feature mapped from Google earth, LISS IV MX and Landsat TM (5th May 2010)*; Valley margin delineated from SRTM 90m DEM (2000).* ***Analysts*:** Ritesh Sipolya, Vikas Kamal *and Dr.Rajesh Kumar* ***Date*:** 8th May, 2012	
RIVER CHARACTER	
Landscape setting	Himalayan bed rock: • Greater Himalayan Mountains of central crystalline with undifferentiated metamorphic rocks. • Lesser Himalayas of undifferentiated metamorphic/igneous rocks, containing quartzite with associated argillaceous bands and calcareous hard sedimentary and slate phyllite, low grade schists.
Valley Morphology	• Moderate valley width, average width 3.12 km (max.7.74 km and min1.23 km). • Valley showing a maximum width at downstream of Devprayag and minimum at downstream of Maneri. • Valley is deep with moderate width. It is generally narrow in upper reaches from Gomukh to Tehri while the valley becomes wide downstream from Tehri to Rishikesh.
Channel confinement	• Confined channel in the entire river style.
Channel Characteristics	• Sinuosity (P): 1.03-2.42 • Total channel area = 12.86 sq.km. • Average channel width = 113.42 m • Braid channel ratio (B): 1.0-1.25 • Total bar area = 3.14 sq.km. • Side bars: ~2.49 sq.km, Length:58m –1.12km; Width: 6.2 m – 256 m • Alluvial islands: none • Mid channel bars: ~0.325 sq.km; Length: 22.7m - 412m Width: 8.1 m –103m • Point bars: ~0.283 sq.km; Length: 118m - 204m; Width: 45 m - from 106km • Confluence bars: 0.11 sqkm • Meandering parameters: o 81 meanders o Radius of curvature (rc) : 0.06 km to1.24km o Wavelength (L):0.4 to 17.63km o Amplitude (Am):0.14 km to 2.54km. • It is mostly single channel with few near-emergent bars comprising 10-12% of the channel reach excepting in few reaches where bar percentage exceed 50%

Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – Himalayan Bedrock* • Incised symmetrical channel without floodplain. • Depositional features are in few stretches only. • Moderate to steep slope ranges from 0.625° to 2.48°. a. Gomukh to Dharali ~ 2.48˚ b. Dharali to Sunagarh ~0.625˚ c. Sunagarh to Maneri ~ 2.22˚. d. Maneri to Tehri dam~ 2.10˚. e. Tehri to Rishikesh~1.83˚ • Riffle and pools are present along entire stretch except at dam sites.
Land Use/Land cover association	*Channel belt* Mostly barren land with some patches of grass.
Channel and floodplain material	Boulders, cobbles, pebbles and coarse sand in channel belt.
RIVER BEHAVIOUR AND PROCESS ZONE River channel width decreases and as a consequence, side and mid channel bars are exposed during low flow stage. The bankfull stage is attained during south west summer monsoon; mid channel bars are submerged while side bars are partly inundated. Diurnal variations in discharge due to snow melt are observed in upper reaches. Overbank stage is never attained as there is no flood plain. Geomorphologically, this style is characterized by degradational regime.	
ECOLOGICAL SIGNIFICANCE From an ecological point of view, following species dominate in their respective groups: 1. Phytoplankton- diatoms and green algae 2. Zoobenthos –Stone fly (Plecoptera), May fly, Diptera (Two wing fly), Dragon fly and Damsel fly. 3. Fishes- Trout fish, Mahseer fish	

5.2 River Style 2: Himalayan, Partly Confined Floodplain and Channel, Braided

Defining attributes: This river style is ~ 26.85 km long. This river style has the maximum valley width of 9.2 km and minimum of 2.9 km and is set within an alluvial-Himalayan bedrock transition valley setting. Large alluvial island and mid channel bar are prominent channel belt geomorphic features. The channel is characterized by partly confined and braided channel with low sinuosity ranging from 1.18 to 1.40. The braid channel ratio ranges from 1.21 to 2.78, highest value recorded in the reach between Raiwala and Rishikesh. Narrow active flood plain pockets are observed in this river style. Ganga River is flowing along GTF (Ganga Tear Fault) in the eastern margin of Doon valley.

Stretch: Rishikesh (Ramjhula) to Haridwar (27 Km)

DETAILS OF ANALYSIS	
***Data used*:** Geomorphic and active floodplain mapped from Landsat *4-5TM imagery 5th May 2010; Valley margin delineated using SRTM-90m (2000)* *Analysts*: Ritesh Sipolya,Vikas Kamal and Dr.Rajesh Kumar *Date*: 15th November, 2011	
RIVER CHARACTER	
Landscape setting	• Transition zone of alluvial and Himalayan bed rock with following: – Alluvium, unconsolidated sand, silts with/without clay (cumulative high permeability, low bearing capacity and poor foundation characteristics). – Piedmont deposits with non-calcareous hard sedimentaries (low permeability, medium to high bearing capacity and good foundation characteristics) – Sub Himalayan moderately hard sedimentaries of sandstone, shale, boulder conglomerate (Low to moderate permeability, fair bearing capacity and poor foundation characteristics).

Valley Morphology	• Moderate valley width, average width 6.5 km • Valley showing a maximum width between Rishikesh and Raiwala (9.2 km) and minimum near Haridwar (2.9 km). • Nearly linear valley bulges in elliptical shape at right margin between Raiwala and Rishikesh
Channel confinement	• Partly confined except in the upper reach.
Active floodplain characteristics	• Maximum floodplain width is ~ 0.66 km and minimum ~ 0.32km with an average width of 0.52km. • Approximately, 1/5th of Active floodplain margin oscillates within valley margin. The active floodplain is partly confined similar to the channel confinement. • Continuous active floodplain is present along either side of bank. • Ratio of Active flood plain to Valley width is 1:5
Channel Characteristics	• Sinuosity (P): 1.18-1.40 • Total channel area = 7.47 sq.km. • Average channel width =826.7m • Braid channel ratio (B): 1.21-2.78. • Total bar area = 13.152sq.km. • Side bars: ~1.83 sq.km, Length:265.37m – 2.09km; Width: 82.52m – 486.13m • Alluvial islands: ~7.9 sq.km ; Length: 1.23 km – 4.96km; Width: 590.69m – 1.79km • Mid channel bars: ~3.412 sq.km; Length: 161.58m – 2.14km; Width: 46.6m –766.3m • 7 tributaries • Meandering parameters: o 4 meanders o Radius of curvature (rc) : 0.32 km to 0.66km o Wavelength (L):2.62 km to 4.21km o Amplitude (Am):0.93km to 1.37km.
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – alluvial, bedrock transition.* • Transition zone of alluvial and Himalayan bed rock • Valley is narrow at rishikesh and Haridwar • Alluvial Island is prominent. • Rishikesh to Haridwar ~0.518˚
	Floodplain • Flood plain pockets are visible.
Land Use/Land cover association	*Floodplain* Flood plain is covered by agricultural land, vegetation and settlements.
	Channel belt • Alluvial islands are covered with dense natural vegetation. • Mid channel bars are slightly vegetated. • Side bars are mostly barren.
Channel and floodplain material	Sand, Pebble, Cobble and conglomerates.
RIVER BEHAVIOUR AND PROCESS ZONE River channel width decreases considerably and therefore, vegetated alluvial islands, side bars and chute channels are exposed in low flow stage. River attains the bankfull stage regularly during monsoon season; alluvial islands are marooned whereas side and mid channel bars are inundated. River water inundates either side of bank in over bank stage. A good lateral connectivity with active flood plain is observed specifically in lower reaches. Geomorphologically, this style is characterized by an aggradational regime.	
ECOLOGICAL SIGNIFICANCE	

From an ecological point of view, following species dominate in their respective groups:

1. Phytoplankton- diatoms and green algae.
2. Zoobenthos –Dragon fly and Damsel fly.
3. Fishes- Mahaseer fish

5.3 River Style 3: Piedmont, Partly Confined Floodplain and Channel, Braided

Defining attributes: This River Style occur in a stretch of ~79 km in an alluvial valley setting. As soon as river Ganga leaves the mountainous region and comes in the plain area in Haridwar, valley width and floodplain width abruptly increases and a wide valley and active floodplain formed. Low to moderate sinuosity channel follow the left and right margin of the valley alternatively. Channel is highly braided and wide in the upper reach and it is partly confined by valley margin. Channel belt is comprised of number of big mid channel bars, alluvial islands and small side bars dissected by chute channels and some dry channels. Occasionally abandoned braid bars and sand patches are also present. Floodplains are characterized by flood channels, dry channels, and few meander scrolls and meander cutoffs. Long anabranch channels follow the main trunk; some tributaries originating from Himalaya also join the river Ganga.

Stretch: Haridwar to Bijnor (79 Km)

DETAILS OF ANALYSIS	
Data used : Landsat 4-5TM Apr and Oct 2010; Valley margin maps from SRTM 2000 *Analysts*: Ritesh Sipolya,Vikas Kamal and Dr.Rajesh Kumar *Date*: 28 April, 2012	
RIVER CHARACTER	
Landscape setting	• Piedmont setting, unconsolidated sand, silts with/without clay (cumulative high permeability, low bearing capacity and poor foundation characteristics).
Valley Morphology	• Wide valley with an average width of 17.7 km. • Valley width is narrow (2.7 km) in Haridwar, and abruptly bulges into the centre and attains max width of 28.3 km in Laksar, again width reduces downstream.
Channel confinement	• Partly confined by valley margin and approaches the left margin of the floodplain in the entire river style from Haridwar to Bijnor.
Channel Characteristics	• Max and min channel width is 2.4 km and 0.4 km respectively covering an area of ~18.9 sq.km. • Sinuosity (P) value ranges between 1.15-1.25 • Braid Channel ratio (B) ranges between 1.8 - 3.7. Channel is highly braided (B=3.7) in the upstream. • Total channel belt area is ~100.96 sq.km in which bars cover ~72.6 sq.km of area • Side bars up to 1.5 km in length and 0.6 km width covers 5.84% of total channel belt area. • Small to large mid channel bars having 4.2 km in length and 2 km in width are the most prominent unit and cover max area of 21.88% of total channel belt. • Big alluvial islands the second prominent unit are 10 km in length and 2.7 km in width cover 44.17% of channel belt. They are dissected by chute channels and dry channels. • Long anabranch channel follow the right margin and left margin alternatively. • Meandering parameters (2 meanders): o Radius of curvature (rc) : 1.2 km to 1.6 km o Wavelength (L) : 7.2 km – 8.6 km o Amplitude (Am) : 1.8 km – 2.9 km
Active floodplain characteristics	• Active floodplain is present only on right bank of river; on the left bank very small patches are present at few places. • Average floodplain width is ~9.9 km; max width14.9 km and min width 1.2 km.

	• Approximately 2/3rd of Active floodplain margin coincides with the valley margin on the left bank. • Active floodplain width:Valley margin width = 1:1.8
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – alluvial* • High Braid Channel ratio (B=3.7), braiding gradually decreases towards downstream. • Big alluvial island and mid channel bars are dominated and covered 66.06% of total channel belt area. • Partly confined channel in the entire river style. 27.04% of the channel belt has water and rest is covered with bars.
	Floodplain • Active floodplain present only along the right bank of the river and it is confined by valley margin on left bank
Land Use/Land cover association	*Floodplain* • A large part of flood plain is used for agricultural purpose.
	Channel belt • Alluvial islands are covered with vegetation and cultivated land. • Mid channel bars have mixed landuse i.e. agricultural land and barren land. • Side bars are used for agricultural purpose.
Channel & floodplain material	Pebbles and sand are found in channel while silt and clay are prominent in floodplain.
RIVER BEHAVIOUR AND PROCESS ZONE In low flow stage, channel width reduces to considerable size and most of the mid channel bars and alluvial islands are exposed which are used for seasonal cultivation. At bankfull stage, most of the mid channel bars and side bars are submerged fully and alluvial islands fully or partly on regular basis during monsoon. Anabranch channels filled with water supplying water and sediment during this stage. Low-lying floodplain is also affected in bank full stage. At most places, right bank is high and steep and generally not submerged but left bank is inundated during bankfull stage. Geomorphologically, this style is characterized by aggradational reach. The translation of meanders occurs along valley slope and therefore an eastward shift is observed.	
ECOLOGICAL SIGNIFICANCE From an ecological point of view , following species dominate in their respective groups: 1. Phytoplankton- diatoms and green algae. 2. Zooplanktons- Rotifers and Cladocera. 3. Phytobenthos-Pediastrum and Scenedesmus 4. Zoobenthos-Trichoptera (Caddish fly) and Beetle (Coleoptera). 5. Fishes- Major Carps and Minor Carps. 6. Higher vertebrates- Turtles and Ghariyals.	

5.4 River Style 4: Valley-Interfluve, Partly Confined Floodplain and Channel, Braided

Defining attributes: This river style is set within a valley-interfluve setting. The river valley width is variable which is more prominent in the lower reaches than in the upper reaches. The channel mostly follows the right valley margin having an active floodplain dominant only on left bank of river. In reaches where it flows centrally, active floodplain is present on both banks. The right margin of the floodplain, almost totally, coincide with valley margin except downstream of Kanpur. The channel shows low sinuosity and high braid channel ratio. Channel belt is comprised of number of bars; mid channel bars, side bars and prominent, alluvial islands are dominant only in the lower stretch. Big patches of abandoned braid bars are present in both stretches. Small to big tributaries including Ramganga join the main trunk in FGFP stretch and confluence bars formed.

Stretch: 1. Upper Reach: Bijnor to Narora - 170 Km
2. Lower reach: Fatehgarh to Fatehpur - 224 km

DETAILS OF ANALYSIS	
***Data used*:** Geomorphic and active floodplain mapped from Landsat *4-5TM and Awifs imagery April 2010; Valley margin maps from SRTM 2000* *Analysts*: Ritesh Sipolya,Vikas Kamal, Dr.Rajesh Kumar and Shamiuddin Ahmad *Date*:13Dec, 2011	
RIVER CHARACTER	
Landscape setting	• Valley-Interfluve setting
Valley Morphology	• Wide valley having an average width ranges between 15.2 km • Valley width is variable and controlled by cliff line at places. Max width is in upstream of Narora (28.39 Km) and near Kanpur (27.44 Km) whereas near Fatehpur valley shows min width of 7 km. The width is quite unofrm in the upper stretch. • The valley is oriented in N-S direction in the upper reach while in the lower reach it is oriented along NW-SE direction.
Channel confinement	• Channel is mostly partly confined, either by valley margin or by cliff. • Channel is symmetric in the upper reaches(till Bugrasi) after which it flows along the southern boundary of the valley resulting in an asymmetric channel.
Active floodplain characteristics	• Active floodplain of variable width is dominantly present on left bank of river except in few reaches where it is present on both banks. • Active floodplain is partly confined by valley/cliff on the right bank of the river. • Average width of active floodplain is 7.57 Km with the minimum value of ~ 2.5 Km (downstream of Kanpur) and maximum value of 17 Km (at Kanpur). • Between Narora to Kanpur floodplain is quite wide. • Nearly 40% of floodplain margin coincide with valley margin (southern side), resulting in a partly confined floodplain. • Active floodplain: Valley margin width = 1:2 (average)
Channel Characteristics	• Channel is quite wide in the upper reaches while the lower reaches are narrow. The average width of the channel is ~ 356 m. • The channel is not sinuous with the sinuosity(P) value ranging from 1.07 to 1.5 • Braiding is quite prominent and the braid channel ratio ranges from 1.21 to 2.31 • In the upper reaches till the Narora barrage mid channel bar is the dominant unit (covers maximum area of 23% of the channel belt) along with side bar (20%). • In the lower reaches, alluvial islands (18%) cover an equally large area as mid channel bars (16%). As in the upper reaches side bars(29%) are very common. • Abandoned braid bars are also quite dominant in both upper and lower reaches. • Numerous chute channels are present that dissect the bar surfaces. • Secondary channels are more prominent in the lower reaches than in the upper reaches. • Point bars are quite few and occupies about 2% in the upper reaches and 4% in the lower reaches. • Kannauj is a major confluence point where the Ramganga, Garra and Kali joins Ganga. In the lower reaches small rivers like Pandu, Khar nadi, Isan nadi flows into Ganga near Kanpur. • Meandering is not prominent and the different values recorded for the different meandering parameters are: – Radius of curvature: 0.7 to 2.9 Km – Axial wavelength: 2.6 to 11.9 Km – Amplitude: 1.1 to 4.5 Km
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – alluvial* • Channel is multiple with very low sinuosity and high braid channel ratio. • The main channel occupies 38% of the area while the rest is covered by bars. • The area covered by the main channel is higher in the upper reaches (64 sq. km.) than in the lower reaches(47 sq. km.). This is due to the presence of the Narora barrage downstream of the upper reach.

	Floodplain • Small to big abandoned channels, flood channels are quite common on the floodplain. • Patches of sand deposition are present in the lower reaches. • Meander cutoffs, meander scrolls and Ox bow lake are common on the left bank of the river suggesting that the river has a southward shift in the lower reaches. There is an abandoned meander loop near Kanpur.
Land Use Land cover association	*Floodplain* • The whole of floodplain in this style is covered by agricultural/fallow land. Rabi wheat, Kharif rice, Zaid pulses, rice are the major crops. • In Safipur, marsh is present that supports crane.
	Channel belt Most of bars are used for seasonal cultivation like cucurbita. In the upper reaches, most mid channel bars are vegetated. In the lower reaches, cultivation of watermelon on bars are more common.
Channel and floodplain material	• The channel bed material in the lower reaches are composed of fine sand and both banks are muddy. There is very little riparian vegetation with thorny plants. At some exposed sections near Kanpur, silt and clay sediments alternate (levee sequence).
RIVER BEHAVIOUR AND PROCESS ZONE During lean period or the low flow stage the bars are exposed as the river width decreases. Due to this these bars are used for seasonal cultivation in the lower reaches. While in the upper reaches vegetation is present on the bars. At bankfull stage the bars get submerged partly or fully. In the overbank stage the left bank is inundated in the lower reaches while both banks are flooded in the upper reaches. this is beacuse at most places the right bank is high and steep. Geomorphologically, the upper stretch is characterized by an aggradational regime and the lower stretch by degradational regime as evidenced from high cliff line all along the right bank. The upper stretch is marked by a major confluence zone between the Ganga and Ramganga. The confluence zone has been dynamic at historical-scale as reported in the literature and a shift upto 10-12 km has been documented.The presence of meander scrolls, cutoffs and ox bow lake in the floodplain in the lower stretch suggest a significant river dynamics and a dominant southward movement of the river.	
ECOLOGICAL IMPORTANCE From an ecological point of view, Phytoplanktons dominate (diatoms/green algae); Zooplanktons are characterized by Protozoans, Rotifers and Cladocera; Among the fishes, Indian major Carps are 40-50% and Cat fishes are 10-15% as estimated from their catch; Forage and other fishes are also found; Among the higher vertebrates are characterized by soft/hard shelled turtles are present, Ghariyals are very rare/scarce and dolphins are spotted.	

5.5 River Style 5: Valley-Interfluve, Unconfined Floodplain, Unconfined Braided

Defining attributes: This river style is set in a valley-interfluve, alluvial valley setting. The Ramganga flows from North and joins Ganga at Kannauj (downstream of Fatehgarh) while Yamuna flows from south west and joins Ganga at Allahabad. The channel occurs centrally within the valley with floodplain on both banks of the river. Although there is a continuous floodplain on both banks of the river, the floodplain widths are quite variable and controlled by the position of the channel with respect to the valley margin. The channel in general has lower sinuosity and higher braid channel ratio.

Stretch: 1. Upper reach: Narora to Fatehgarh - 201 Km
2. Lower reach: Sirathu to Allahabad - 82 Km

DETAILS OF ANALYSIS	
***Data used*:** Geomorphic and active floodplain mapped from Landsat *4-5TM and Awifs imagery April 2010; Valley margin maps from SRTM 2000* *Analysts*: Haridas Mohanta and LipiBasu *Date*:5th Dec, 2011	
RIVER CHARACTER	
Landscape setting	• Valley-Interfluve setting
Valley Morphology	• Valley width varies from 2.26 km to 35.67 km • Valley width is variable controlled by the interfluve and cliffs at few places • The valley boundary is irregular with alternate widening and narrowing at places.
Channel confinement	• Unconfined channel • Symmetric channel, river flows centrally to valley.
Active floodplain characteristics	• Active floodplain on both banks of varying width. • Width of active floodplain varies from 2.26 km to 13.45 km. • Active floodplain: Valley margin width varies from 1:1.9 to 1:3.78
Channel Characteristics	• The average width of channel in the upper stretch is ~130 m compared to ~ 265 m in the lower stretch due to the presence of Narora barrage. There is no effect of any man made structure in the lower stretch. • Sinuosity ranges from 1.1 to 1.5 • Braid channel ratio ranges from 1.27 to 2.25(dominantly braided) • In the upper stretch, alluvial islands (45%) cover a large area and side bars (25%) and mid channel bars (13%) are distributed almost in all reaches. • In the lower stretch, side bars (26%) cover a large area and alluvial islands (20%) are very common. • Alluvial islands are present in the upper reaches and mid channel bars characterize the lower reaches . • Side bars are common in both the stretches. • There are no confluence bars in either of the stretches. • Point bars are relatively rare. • The meanders in upper stretch are relatively tighter (smaller wavelengths) compared to the ones in lower stretch which have a greater wavelength. • Meanders are very prominent in both the stretches. – Radius of curvature: 0.73 to 2.49 Km – Axial wavelength: 3.65 to 12.32 Km – Amplitude: 1.6 to 5.8 Km
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – alluvial* • The presence of alluvial islands and mid channel bars results in high braiding value of the river in both the stretches. • The main channel occupies 19% of the area while the rest is covered by bars.
	Floodplain • Abandoned braid bars, sandy patches and meander scrolls are the most dominant geomorphic feature in this style suggesting a dynamic river. • Abandoned channels, flood channels are quite common on the floodplain. • The lower reaches have meander cutoffs, abandoned meander belt which are relatively less in the upper reaches.
Land Use Land cover association	*Floodplain* • The whole of floodplain in this style is covered by agricultural/fallow land. Rabi wheat, Kharif rice, Zaid pulses, rice are the major crops. • Mid channel bars are used for seasonal cultivation. • Small plants of babool, sheesham, chilbil, parthenium and small shrubs with grasses

	constitute the riparian vegetation in this style. • Above HFL vegetation is mixed trees, Juliflora (small babool like plants), babools, and shrubs.
	Channel belt Lateral and point bars and few mid channel bars are used for agriculture. At some places these bars have vegetation along with alluvial islands.
Channel and floodplain material	• The bed has loose materials and the grain size increases from very fine sand to coarse sand. Floodplain is mostly muddy. • Alternate succession of mud and sand is observed on the bank. • Bank is steep in the lower reaches compared to upper ones.
RIVER BEHAVIOUR AND PROCESS ZONE River channel width decreases at the low flow stage and more mid channel bars are exposed. Large mid channel bars are used for seasonal cultivation. The flood channels dry up and in some cases is used for cultivation. Every monsoon river attains bankfull stage. Mid channel bars, alluvial islands, side bars are partly submerged and the average width of the channel increases. The flood channels fills with water. During the bankfull stage, river floods both the banks regularly. Places where the river flows near the valley margin, a narrow floodplain has developed due to restricted overtopping of the river on that side. In some cases abandoned braid bar and abandoned channel gets filled with water. Geomorphologically, the upper stretch is characterized by an aggradational regime. The lower reach has a sinuous channel belt which suggests a dominance of lateral erosion processes and influences the floodplain width significantly. The downstream end is a major confluence zone between Ganga and Yamuna.	
ECOLOGICAL IMPORTANCE From an ecological point of view, Phytoplanktons dominate (diatoms/green algae); Zooplanktons are characterized by Protozoans, Rotifers and Crustaceans. Among the fishes, Indian major Carps are 40-50% and Cat fishes are 10-15% as estimated from their catch; Forage and other fishes are also found; Among the higher vertebrates are characterized by soft/hard shelled turtles are present. Ghariyals are very rare/scarce and dolphins are spotted.	

5.6 River Style 6: Valley-Interfluve, Unconfined Floodplain, Partly Confined Braided

Defining attributes: - This river style occurs in a stretch of ~102 km in an alluvial valley setting. River valley is relatively narrow, nearly linear and of uniform width except near Dalmau area where it attains a larger width. Floodplain width also follows a similar trend. Low to moderate sinuosity river channel follows the left and right margins of the floodplain alternately, and as a consequence, discontinuous floodplain occurs on either side of the river. Channel is highly braided in most reaches and channel belt is comprised of a number of bars. Mid channel bars, side bars, abandoned braid bars and alluvial islands are most frequent and dissected by small to large chute channel. Point bars are very few in this stretch. Floodplains are characterized by flood channels, abandoned channels and occasional meander cutoffs.

Stretch: Fatehpur to Sirathu (~ 102 Km)

DETAILS OF ANALYSIS	
Data used: Landsat 4-5 TM 2009-10 ***Analysts****:* Lipi Basu, Shamiuddin Ahmad and Haridas Mohanta *Date:*17Aug2011	
RIVER CHARACTER	
Landscape setting	• Valley-interfluve setting between Ganga in the north and Yamuna in the south.
Valley Morphology	• Moderate valley with an average width of 5.02 km. Valley width is fairly uniform except near Dalmau where it attains a width of 9.0 km. The minimum width recorded is 2.4km. • Nearly linear valley oriented in NW-SE direction except near Dalmau where it is W-E

	trending.
Channel confinement	• River channel at places is partly confined by cliff/valley margin. It swings from northern to southern boundary of the valley alternately.
Active floodplain characteristics	• Narrow active floodplain (discontinuous) prominent only on one side of the river (either on the left or right bank of the river) due to the swinging nature of the river. • Average flood plain width is 2.13 km (excluded channel width). Max. floodplain width is 4.3 km and min. width recorded is 0.8 km. • The floodplain is unconfined as the valley margin is at a distance from the active floodplain boundary, separated from it by inactive floodplain. • Flood plain width:valley margin width=1:2.4
Channel Characteristics	• A continuous channel having an average width of 201.5 m (min and max channel width is 66 m and 451 m respectively) covering an area of 21.25 sq.km. • Sinuosity (P) value ranging between 1.22 – 1.63 • Braided channel system with Braid channel ratio (B) ranges from 1.54 – 2.27, maximum braiding in reach near Dalmau area. • Total Channel belt area is 76.8 sq.km in which bars covers 52.95 sq.km. area. • Side bars up to 6.5 km in length and 1.0 km in width are the most prominent unit and cover max area of 33.9% of total channel belt. • Small to large mid channel bars (prominent in reach 1) having 2.5 km length and 0.96 km width cover 12.1% of total channel belt area. • Sharp-edged point bars up to 3.6 km length and 1.1 km width are very rare and cover 3.5% of the channel belt area. • Comparatively large oval-shaped patches of alluvial island with max length of 5.5 km and 1.9 km width are the second most prominent unit and cover an area of 19.4% of total channel belt. • Large patches (up to 6.0 km length and 1.03 km width) of abandoned braid bars are most prominent along the main channel. • Chute channels (mostly <1 km in length and average width of 30m) dissect the bars and island. • Occasionally flood channels follow the outer margin of bars, but sometimes dissect the alluvial island. • Secondary channels are prominent in upstream reaches and follow the outer margin of bars and alluvial island. • Meander cutoff are scarce; large patch of abandoned meander belt near Dalmau. • Short, discontinuous, anabranching abandoned channels mostly dissect the abandoned braid bar, elongated to river somewhere are seen. • Meandering parameters (4 meanders): o Radius of curvature (rc) : 0.74 km - 2.15km o Wavelength (L) : 8.3km – 16.5km o Amplitude (Am) : 2.7km – 5.4km • River Cross Sectional Parameters (average): o Channel Asymmetry {A*=(Ar-Al)/A}= 0.04 (highly asymmetric channel) o Bankfull Width (w) = 819.4 m o Max Depth (dmax) = 6.5 m o w/ dmax =126.2 o Wetted Perimeter(bankfull) (P) = 933.4 m (standard deviation is 258.6) o Hydraulic radius (bankfull) (A/P) = 3.3
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – alluvial* • The main channel occupies 38% of the area while the rest is covered by bars. • Low to moderately sinuous channel flowing along the margins of flood plain; highly braided in upper reaches and braiding gradually decreases downstream and attains the maximum sinuosity in lower reaches.
	Floodplain Narrow and fairly uniform width extending only on one side of the river resulting in discontinuous floodplain. Near Dalmau there is abandoned meander belt suggesting

	that the river shifted from North to South in that area. Abandoned channels are abundant in the narrow floodplain.
Land Use Land cover association	*Floodplain* • Most of the floodplain are muddy and used as single cropland. Flat muddy flood plain are used for wheat, mustard, bajra (chari) etc. whereas on sloping and silty flood plain vegetables like pointed gourd (parwal), bitter gourd (karela) are very common. • At many places floodplains are covered with open scrub land and plants like parthenium (Gandhak in local language). • Loose sand deposits are also present at a few places.
	Channel belt Mid channel bars and side bars are commonly cultivated with zaid crops like watermelon, cucumber, pumpkins etc. On alluvial islands wheat, mustard and coarse grain crops are cultivated.
Channel and floodplain material	• River bed is composed mostly of fine to medium grain loose sand. • Floodplain is mostly covered by muddy sediments underlain by silty/sandy sediments.
RIVER BEHAVIOUR AND PROCESS ZONE In low flow stage, channel width reduces to considerable size and most of the mid channel bars are exposed which are used for zaid cultivation. On alluvial islands, wheat and mustard crop cultivation is common with seasonal zaid crop. At bankfull stage, most of the mid channel bars and side bars are submerged fully and alluvial islands fully or partly on regular basis during monsoon. Low-lying floodplain is also affected in bank full stage. During overbank stage the river floods in restricted pockets. Geomorphologically, the degradational regime continues as in the upstream reaches as evidenced from high cliff line along the right bank. Pockets of aggradational reaches are characterized by alluvial islands.	
ECOLOGICAL SIGNIFICANCE Phytoplanktons (diatoms/green algae/blue algae) common but in reduced numbers compared to upstream reaches; Zooplanktons are characterized by Protozoans, Rotifers and Crustaceans and their numbers are higher compared to upstream reaches; Among the fishes, Indian major Carps reduced to 30% and Cat fishes increase marginally to 15-20% as estimated from their catch; Forage and other fishes are also increased; Among the higher vertebrates soft/hard shelled turtles are reported upto Allahabad; Ghariyals are very rare/scarce and reported upto Allahabad; dolphins are frequent.	

5.7 River Style 7: Alluvial, Unconfined Floodplain and Channel, Sinuous

Defining attributes: This river style extending nearly WNW-ESE Is characterized by moderately sinuous channel the channel flow predominately along the central valley except for few reaches where it swings from one bank to other bank; however there are wide flood plains in either side of river. The channel belt comprises various geomorphic unit and they are fairly stable on the temporal scale. The alluvial island vegetated. In some reaches upto Ghagra confluence bar the river is sinuous with meanders in a valley characterized by three large asymmetrical abandon meander belts with flood plain feature like Oxbow lake meander scars meander cutoff and scrolls. These meander belts are located at alternate banks of river channel highlighting prominent migrating of river channel.

Stretch: Upper Reach: Allahabad to Gopiganj (115Km)
Middle reach: Chunar to Chapra (321.17 Km)

DETAILS OF ANALYSIS	
Data used: Geomorphic and active floodplain mapped from Landsat 4-5TM,February 2010 and Valley margin maps from SRTM 2000 ***Analysts:*** Sanjeet Sharma and Desh Deepak Pandey *Date:*17Aug2011	
RIVER CHARACTER	
Landscape setting	• Alluvial valley setting with valley margin extending on either side of the river

Valley Morphology	• Valley width is highly variable in this river style • Maximum valley width is 35.80 km near Ballia and minimum is 3.57 in Handia
Channel confinement	• Channel is Unconfined but at a few reaches it is partly confined by a cliff
Active floodplain characteristics	• Flood plain width is very variable the max active flood width is 28.87 km and min width is 2 km. • Flood plain is distributed symmetrically at both side of channel. • FP:VM width = 1:
Channel Characteristics	• Sinuosity (P): value ranging between 1.11 to 2.6 • Braid channel ratio (B) ranges between 1 to 2.59 • Total bar area is 477.83Km^2 while the total channel area is 295.65 Km^2 • The individual bar area is given as below: o Alluvial islands: 103.07 Km^2 o Mid channel bars: 31.00 Km^2 o Point bars: 102.28 Km^2 o Side Bar: 110 Km^2 Four tributaries joins the Ganga in this stretch of which two are very significant Tons and Ghaghra
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt – alluvial* Moderately sinuous carrying dominantly fine silt to sand sized sediment and in channel there are large number of mid channel bars which are used as cultivation land.
	Floodplain Flood plain is characterized by the presence of Abandoned meander belts, Meander scrolls and Abandoned braid bars. It is present in both side of channel but at few reaches it's become narrow.
Land Use/Land Cover association	***Floodplain*** Here the large part of flood plain is used cultivation land , Most of the flood plain is muddy and used as cultivation as a different types of vegetable.
	Channel belt Most of the exposed bars are used as cultivation.
Channel and Floodplain material	• Channel carry fine to slit sized sediment • Floodplain material is dominantly clayey and muddy.

RIVER BEHAVIOUR AND PROCESS ZONE

In low flow stage the river channel width decreases and alluvial island bar are exposed and the bars are used for cultivation and agriculture. During bankfull stage there is increased water level and the bars get submerged. In overbank stage, the river floods water submerges left and right bank alternatively. During most of the flood, lateral bars are nearly submerged. Similarly, many of the mid channel bars are also submerged; In the long term the sinuous reaches and bars shifts, giving rise to meander scrolls and abandoned braid bars.

Geomorphologicaly, the degradational regime continues in the upstream reach as evidenced from the high cliff line along the both banks. Pockets of aggradational reaches are characterized by alluvial islands and bars, in upstream stretch at Allahabad Yamuna joins in the Ganga and it increase the sediment load with water. So in this stretch channel always contain significant amount of water. In this style river is so much dynamic, flow is high and depth is deep which is good for cultivation and fish population**.** Dolphin are recorded during field survey.

ECOLOGICAL SIGNIFICANCE

At Varanasi, the water quality is very poor. This is probably because of the reduction of the water volume and the subsequence increase in concentration of chemicals. Trichopterans dominate the benthic population here. Major carps and catfish are dominant.

5.8 River Style 8: Craton Margin, Partly Confined Floodplain and Channel, Sinuous

Defining attributes: This river style, comprising of two discontinuous stretches, extending nearly East-West, is characterized by moderately sinuous channel. While abandoned meander bars are observed in the floodplain, the in-channel features include both mid-channel and lateral bars. Thus, in spite of its sinuous nature, the river here is characterized by moderate Braid Channel Ratio. Channel flows symmetrically within the valley in the lower stretch excepting near Munger and Bhagalpur where basement rocks laps on its southern margin. In the upper reach, the channel flows close to the southern boundary of the valley. Active flood plain is better developed towards the northern side of the river.

Stretch: Upper Reach: Gopiganj to Chunar - 74Km
Lower reach: Pansalla to Kursela - 142 Km

DETAILS OF ANALYSIS	
Data used: Geomorphic and active floodplain mapped from Landsat 4-5TM,February 2010 and Valley margin maps from SRTM 2000 ***Analysts***: Sanjeet Sharma, Sayan Sinha, Haridas Mohanta and Lipi Basu *Date:*17Aug2011	
RIVER CHARACTER	
Landscape setting	• Craton Margin in an alluvial bedrock transition setting
Valley Morphology	• Maximum valley width is 36 Km. and minimum is 4.09 Km. with an average width of 16.74 Km (wide valley) • The maximum width is observed near Kursela while the minimum width is downstream of Gopiganj. • In the upper stretch the valley alternately widens and narrows, while in the lower stretch the valley narrows down significantly near Munger before widening out again.
Channel confinement	• The channel is partly confined by valley margin, mostly. At a few locations in the lower stretch, the channel is unconfined with floodplain on both banks. • Vindhyan rocks are exposed in southern side of river bank at few places like Chunar. • FP:VM width = 1:1.4
Active floodplain characteristics	• Maximum floodplain width is 20.85 km and minimum is 2.15 km with an average FP width of 11.24 km. • The southern margin is mostly marked by basement rocks. • Active floodplain is partly confined coinciding at few places with the valley margin. • Floodplain is dominantly present on the northern side of the river.
Channel Characteristics	• Sinuosity (P): value ranging between 1.27 to 2.03 • Braid channel ratio (B) ranges between 1.22 to 1.76 with the maximum braiding near Munger. • Total bar area is 230.29Km^2 while the total channel area is 198 Km^2 • The individual bar area is given as below: o Alluvial islands: 69.56 Km^2 o Mid channel bars: 16.91 Km^2 o Point bars: 32.46 Km^2 o Abandoned Braided Bar: 230.75 Km^2 o Abandoned Meander Bar: 158.27 Km^2 o Side Bar: 110 Km^2 o Transverse Bar: 1.63 Km^2 o Confluence Bar: Nil • Two major tributaries join the Ganga in the lower stretch.
Diagnostic geomorphic features (geometry,	*Channel belt – alluvial* • The main channel occupies 41% of the area while the rest is covered by bars. • Slightly sinuous carrying dominantly fine sand sized sediment. In spite of sinuous nature and fine-grained channel sediments size, the reach is characterized by

sedimentology)	moderately high braid channel ratio. The channel has many side bars. Transverse bars are also present in the lower reaches.
	Floodplain The floodplain is characterized by the presence of abandoned meander belt. Abandoned braid bars dominate in the lower stretch.
Land Use/Land Cover association	*Floodplain* • Large part of flood plain is used as cultivated land. Most of the flood plain is muddy and used as single cropland. Flat muddy flood plain are used for wheat, mustard, Bajra etc. whereas on sloping and silty flood plain vegetables like pointed gourd, bitter gourd is common. • Many places the unused flood plain is covered by Parthanium and straw. • Few permanent structures have been constructed on the floodplain and there are only a few settlements close to the river bank in the lower stretch..
	Channel belt Most of the exposed bars are vegetated and at places cultivated or used for grazing. Pisiculture is well developed. Most of the bars, particularly the bank attached lateral ones, are extensively mined for brick kiln and construction. In the upper reaches the bars are used for seasonal cultivation.
Channel and Floodplain material	• Channels carry medium to fine grained sand. • Floodplain material is dominantly clay or silt to very fine sand.
RIVER BEHAVIOUR AND PROCESS ZONE In low flow stage the river channel width decreases and alluvial island bar are exposed and the bars are used for cultivation and agriculture. During bankfull stage there is increased water level and the bars get submerged. In overbank stage, like in 2011 monsoon, the river has flooded most of the floodplain and inundated the villages situated on the active flood plain requiring the administration to start relief measures. During most of the flood, lateral bars are nearly submerged. Similarly, many of the mid channel bars are also submerged; In the long term the sinuous reaches and bars shifts, giving rise to meander scrolls and abandoned braid bars. Geomorphologicaly, the degradational regime continues in the upstream reach as evidenced from the high cliff line(~20m) along both the banks. Pockets of aggradational reaches are characterized by alluvial islands and bars . The river style is characterized by exposure of bed rock in the channel in the right bank, which make channel partly confined. In the lower stretch, the bars are extremely dynamic over a period of few to several years	
ECOLOGICAL SIGNIFICANCE The benthos is very low at Bhagalpur and the insect population is dominated by hemipterans. Fish yield (major carps, ilish) have reduced over a period of time. Phytoplankton and zooplankton are common.	

5.9 River style 9 -Valley Interfluve, Partly Confined Floodplain and Channel, Anabranching

Defining attributes: The river style stretches for 183 Km, is trending West-East and is set within an alluvial setting. It attains a maximum valley width of 20.0 kms across Patna and minimum of 8.10 km downstream Gandak confluence. Active floodplain almost totally coincides with valley margin except for the most downstream reaches. Active flood plain is mainly limited to left bank while the right bank is devoid of flood plain because of a southern embankment near Patna up to the confluence of river Punpun from south. The channel has a low sinuosity of 1.21.It is characterized by presence of mid channel bars (31) and large alluvial islands (max. length – 34km, width – 12.5km). Alluvial islands seem to have gained prominence in width and area downstream of the confluence of Ghagra and Gandak rivers from the north and Son river from the south.

Stretch: Chapra to Pansalla (183 Km)

DETAILS OF ANALYSIS	
Data used: Geomorphic and active floodplain mapped from Landsat 4-5TM and Awifs imagery April 2010; Valley margin maps from SRTM 2000**.** Analysts: K.N Mishra and Anubhav Rathee Date:18.9.2011	
RIVER CHARACTER	
Landscape setting	• Alluvial setting and is trending W-E
Valley Morphology	• Wide valley with an average width of 15.88 km.; valley width : max. 25.56 km, min 8.19 km. • Valley showing maximum width at Pansalla and minimum near Patna downstream of the Gandak confluence. • Valley narrows down across Patna and upstream Mokama and widens downstream in the central stretch and near Mokama.
Channel confinement	• Partly confined by the embankment on the right bank of the river.
Active Floodplain characteristics	• Average floodplain width is 13.04 km. (max. width 21.03 Km; min. width 7.45 Km). • Active flood plain is mainly limited to left bank while the right bank is devoid of flood plain because of a southern embankment in the stretch near Patna up to the confluence of river Punpun from south. • Floodplain width: valley margin width = 1: 1.2
Channel Characteristics	• Min. Channel width: 540m • Max. Channel width: 1550m • Channel Area : 170.68 sqkm • Sinuosity (P): 1.08 -1.31 • Braid channel ratio (B) : 2.09 - 2.48. • Total bar area: 720.54 sq.Km. • Side bar: 79.46 sq.Km. ; Length: 2.20 km-12.80 km; width: 0.66km-3.29 km. • Alluvial Island : 552.09sq.Km. ; Length: 5.02 km-35.40 km; width: 2.47km-11.72 km. • Mid channel bar : 60.63 sq.Km. ; Length: 0.36 km-4.92 km; width: 0.20 km-2.53 km. • Point bars: 22.87sq.Km. ; Length: 2.50 km-5.17 km; width: 0.55 km-01.60 km. • Confluence bars: 5.49 sq.Km.; Length: 2.69 km-4.12 km; width: 1.30 km-1.32 km. • Flood channels: varying length from 1.93 km to 14.07 km. • Chute channels: Of varying lengths (6.37 km to 14.11 km), dissecting bars/ island. • Meandering parameters: o 4 meanders o Radius of curvature (rc): 1.92 km-3.32 km. o Wavelength (L): 5.25 km-12.19 km. o Amplitude (Am): 2.52 km-4.88 km. • Anabranches resulting in large alluvial islands characterizes this river style. A number of flood and chute channels dissects the island. • The lower reaches are dominated by mid channel bars and side bars and there are smaller patches of alluvial islands and other floodplain features like meandering scrolls. • Oxbow lakes, more conspicuous downstream, indicate distinct shifting / migration of the channel. • Gandak River joins Ganga from the north, with a distinct patch of confluence bar in the floodplain. • Sone and Punpun river joins the Ganga from South.
Diagnostic geomorphic features (geometry, sedimentology)	*Channel belt- alluvial* • ~ 20 % of the channel belt has water and the rest is covered by bars. • Partly confined by artificial embankment on the right bank of the river. • Alluvial island cover more than 75% of the channel belt. • Mid channel bars, side bars increases downstream.

	• Braiding is maximum in the middle.
	Flood plain • Active floodplain almost totally coincides with valley margin except for the most downstream reaches. • Mainly limited to left bank while the right bank is devoid of flood plain because of a southern embankment near Patna up to the confluence of river Punpun from south.
Land Use Land cover association	*Flood plain* • Large part of flood plain is used as cultivated land.
	Channel belt • Alluvial islands are used for agriculture throughout the year; side bars are also used for agriculture during low flows.
Channel and floodplain material	• River Bed Material consist of loose sediments. • Floodplain material is silty sand.
RIVER BEHAVIOUR AND PROCESS ZONE River channel narrows down in width, mid channel bars and alluvial islands are well exposed and used for seasonal agricultural activities during low flow stage. The river attains bankfull stage during monsoon, the sidebars and point bars are submerged and alluvial island are partly submerged. The river flood water submerges left bank overtopping it regularly in overbank stage. Geomorphologically this style is characterized by an aggradational regime and a major confluence zone between the Ganga and Gandak and also between Ganga and Son. The confluence zone has been dynamic at historical scale.	
ECOLOGICAL SIGNIFICANCE Water degradation is less due to less variation of water volume. Ganga is fed here by the tributaries Ghagra, Sone, Punpun and Gandak. The ecosystem of this region comprises of phytoplanktons, zooplanktons, other invertebrates and macro fauna including fishes. Benthos is more at Patna with less insects and high molluscs. Due to the presence of barrage, fish yield have decreased. Major carps, large catfish and Ilisha have reduced significantly over the years.	

5.10 River Style 10: Craton Margin, Confined Floodplain, Partly Confined Braided

Defining attributes: This part of the river is ~ 145 km long and is typified by high braiding index low sinuosity and presence of many large islands and mid-channel bars. The setting is semi-confined with the presence of the cratonic basement rock on one side. Floodplain has developed asymmetrically. Downstream of Kursela it is on the right bank of the river while 52 Km downstream of Kursela the floodplain is well developed only on the left bank. Floodplain typically consists of abandoned braid bars and two major tributaries (Kosi and Mahananda) joins Ganga in this stretch.

Stretch: Kursela to Farakka (145 Km)

DETAILS OF ANALYSIS	
Data used: Geomorphic and active floodplain mapped from Landsat 4-5TM,February 2010 and Valley margin maps from SRTM 2000 ***Analysts:*** Lipibasu and Sayan Sinha *Date:*17Aug2011	
RIVER CHARACTER	
Landscape setting	• Craton Margin on the southern side of the river
Valley Morphology	• Maximum valley width is 26.6 Km near Farakka and minimum is 7.72 km. with an average width of 15.83 Km(wide valley)

Channel confinement	• Partly confined by the valley margin. In very short stretches river is confined by cratonic basement on its southern side.
Active Floodplain characteristics	• Maximum floodplain width is 18.23 Km and minimum-6.01 Km. with an average width of 12.31 Km. • Floodplain is confined by cratonic basement on its right bank while left bank is confined by alluvium. • FP:VM width = 1:1.2
Channel Characteristics	• Sinuosity (P) in this style is 1.61 • Braid channel ratio (B) is high with a value of 3.57 • Two tributaries joins Ganga in this stretch • The total bar area is 406.58 sq km and channel area is 224.08 sq km. The area of the individual units are: o Alluvial islands: 331.56 sq km o Mid channel bars: 32.13 sq km o Point bars: 4.77 sq km o Abandoned Braided Bar: 157.64 sq km o Abandoned Meander Bar: Nil o Side Bar: 33.81 sq km o Transverse Bar: 4.31 sq km o Confluence Bar: 5.02 sq km
Diagnostic Geomorphic Features (geometry, sedimentology)	*Channel belt- alluvial* • High braiding index • The main channel occupies 35% of the area while the rest is covered by bars. • Large sandy islands with braided accretion surfaces • Medium to fine sand size dominant component of the bars/islands
	Flood plain • Floodplain marked by abundant meander scrolls.
Land Use/Land Cover association	*Flood plain* Many large villages occur on the active floodplain with permanent structures.
	Channel belt Most of the large islands have been extensively cultivated. In some islands small villages have been built that are subject to flood hazard. Many of the uncultivated bars show dense growth of grassy vegetation.
Channel and Floodplain material	Channel and channel bars are mostly made up of fine grained sand; floodplains comprise clay, silt and very fine sand.

RIVER BEHAVIOUR AND PROCESS ZONE

In-channel bars are very dynamic in this part of the river and changes remarkably within a period of 1 to 6 years, resulting in loss of cultivated land and appearance of new emergent bars. During flood most of the bars and large part of the islands remains submerged.

This part of the river channel appears to be aggrading rapidly by depositing sandy sediments as bars and island. Two tributaries that join Ganga in this stretch probably carry a lot of sand resulting in the braided pattern and aggradational regime of the river.

ECOLOGICAL SIGNIFICANCE

Phytoplanktons are more dominant than zooplankton at Farakka. The major fish was ilish here but after the construction of the Farakka barrage the ilish has been replaced by other species (common carp and telapia) and the ecosystem changed. Tenualosa ilisha and Pangasius pangasius are badly affected in this region. Birds have been reported in the area adjoining the Farakka barrage as below:

- Near threatened bird: Black-bellied Tern, Darter, Ferruginous Pochard

- Vulnerable bird: Baer's Pochard, Indian Skimmer, Lesser Adjutant
- Critically endangered bird: Long-billed Vulture, Oriental White-backed Vulture

6. CONCLUSIONS AND RECOMMENDATIONS

This report has presented the different River Styles® of the Ganga River some of the major findings are as follows:

1. The Ganga River displays significant morphological diversity from the source (Gangotri) to Farakka which has been documented as 10 different River Styles. Primarily, such morphological diversity should translate into different physical habitat. This data should therefore be integrated with the ecological diversity recorded in the Ganga river for understanding the present distribution of biota and for planning the restoration/rehabilitation activities.
2. The Himalayan (mountainous) part of the River (Gomukh to Haridwar) is distinctly different from the reaches in the plains. Two River styles identified in the mountainous reaches primarily differ in terms of presence or absence of floodplains and channel morphology. While the upper part is sinuous with no floodplains, the lower part shows discontinuous floodplain and braided morphology. This differentiation reflects strong control of bedrock valley walls in the upper reaches; the valley walls guide the river course and provide no space for sediment storage due to high slopes. In the lower reaches, slope decreases a bit and a part of the sediment flux is stored in the floodplains and within the channels as bars.
3. The first major change in River Style is observed at Haridwar where the river debouches into the plains and an abrupt change in slope results in a sharp increase in valley as well as floodplain width. The Ganga River seems to be quite unstable in this reach and has been swinging across the valley as evidenced by several paleochannels.
4. The stretch of the Ganga River from Bijnor to Allahabad is characterized by valley-interfluve setting and we have recognized three distinct River Styles in this stretch which are differentiated in terms of valley-floodplain relationships and reach-scale channel morphology. A major and common feature in this stretch is that the river is incised dominantly along the right bank and floodplain is preferentially developed along the left bank. This reflects the differential stability of the banks and also implies that flooding characteristics would also be different along the two banks. Such differences would mean that lateral connectivity of the river would be quite different on the left and right banks which should in turn be manifested in terms of floodplain ecology.
5. The stretches from Allahabad to Gopiganj and then from Chunar to Chapra fall into alluvial setting and include the confluence of the Yamuna and the Ganga at Allahabad channel morphology shows a sharp change in these stretches. The River Style for both these stretches is characterized by abundant meander scars and sinuous channel suggesting a dynamic regime where meander migration is a common mechanism of river dynamics. Downstream of Chapra and upto Pansalla, the valley-interfluve setting takes over again and the most diagnostic feature in this style is the presence of large alluvial islands and anabranching channel. Overbank flooding along both banks of the river is common and an aggradational regime dominates in this style. Such morphological variability in River Styles should characterize distinct physical habitats. It is also clear that river management strategy in these stretches will need a strong focus on flooding and sediment control.
6. The lower reaches of the Ganga river have a distinct river style as the southern bank of the river coincides with the craton margin. The diagnostic features of this river style include wide valley and floodplain, large patches of abandoned meander belt, and alluvial islands. Large scale dynamics of the channel has been recorded in these stretches and a prominent aggradational regime is inferred.

Similar work on River Style Framework has been carried out on the major tributaries of the Ganga which will be presented in the next report. River Style Framework developed for the Ganga River has provided a valuable document to highlight the geomorphic diversity along the Ganga. This has also provided a database for reach-scale morphological characteristics which can be easily related to the habitat conditions of the indicator species of the reaches or an individual river style. Apart from providing a descriptive documentation of geomorphic diversity, this data will be of immense value in geomorphic assessment of the river condition in different reaches and also for the assessment of E-flow at different points along the river.

7. REFERENCES

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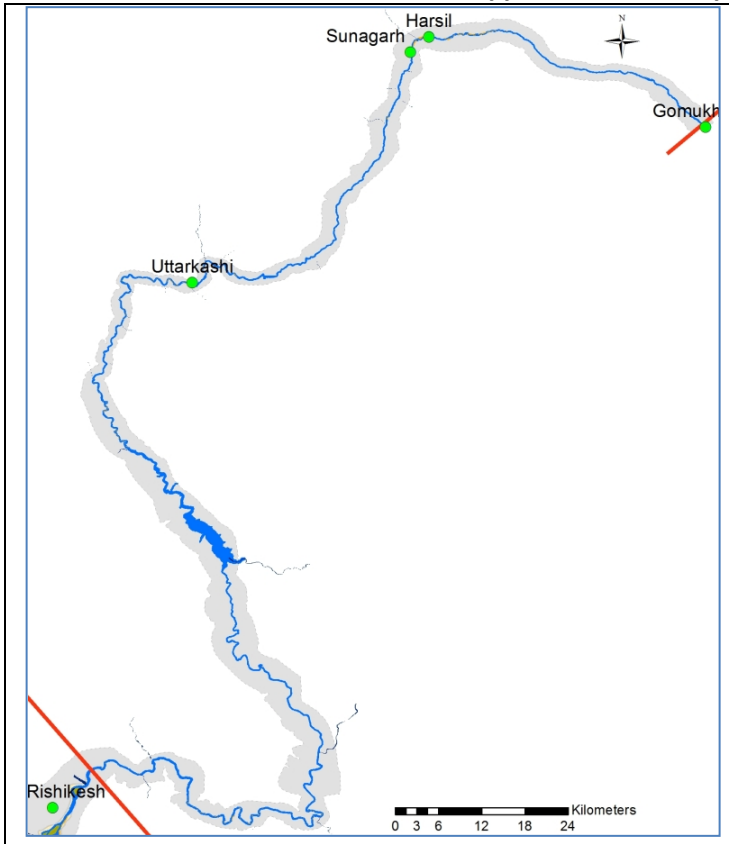
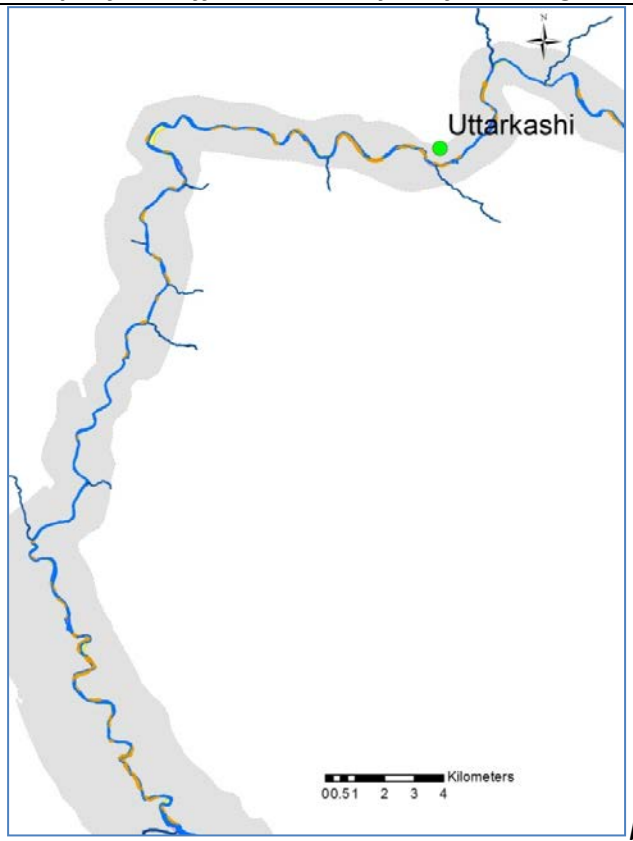
Appendix I- Geomorphic maps of the different River Styles of the Ganga River and field characteristics



a



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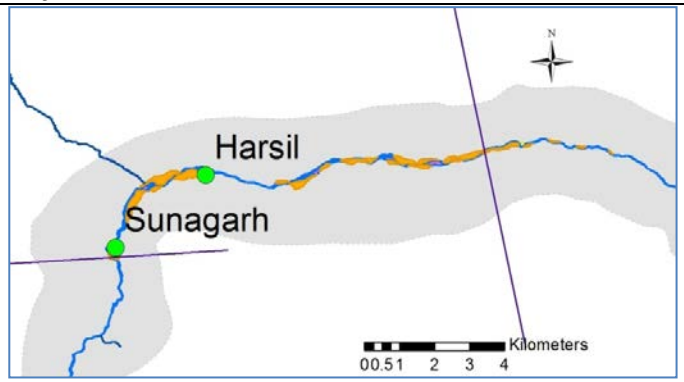
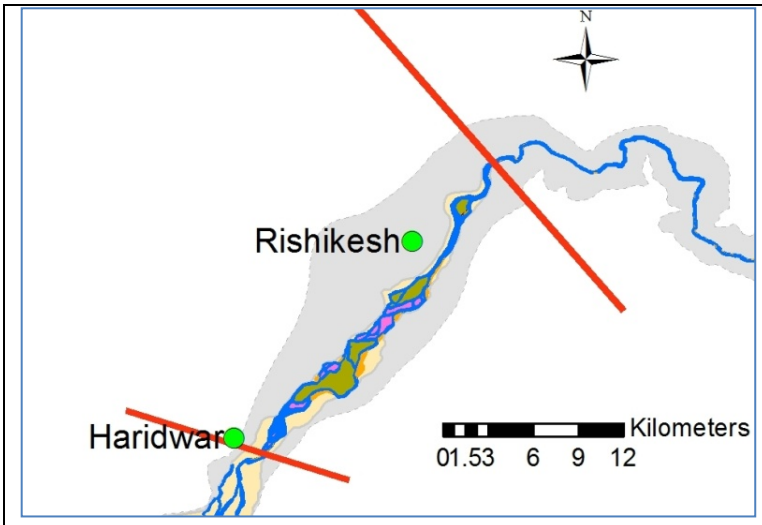


c

d

e

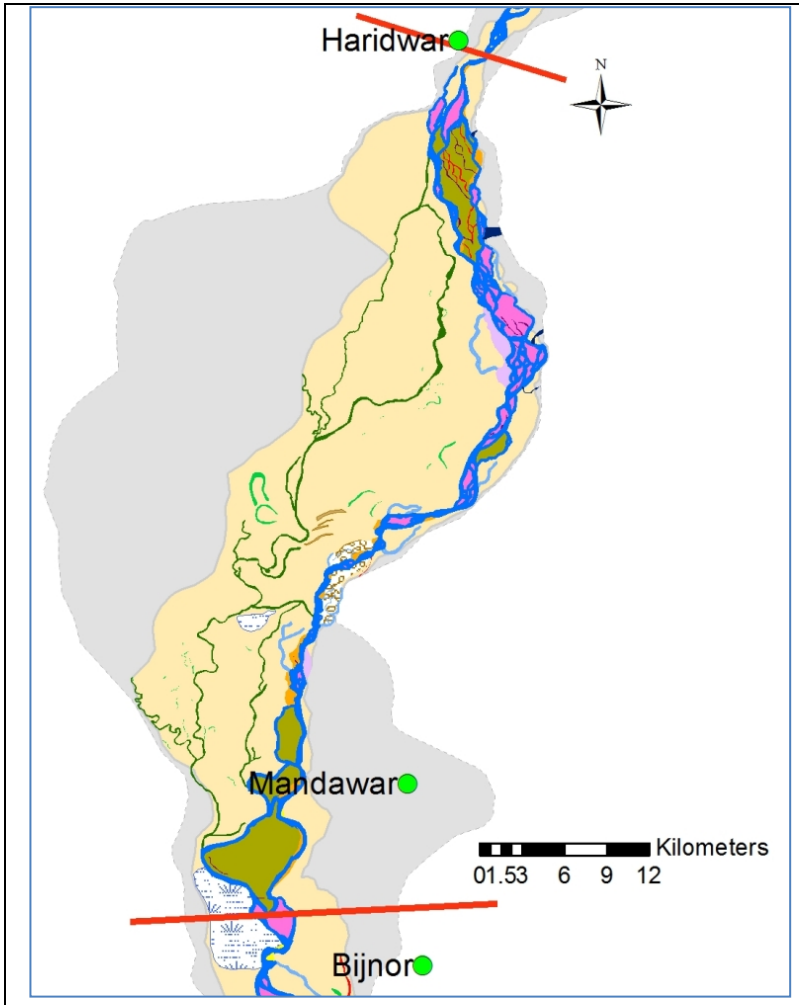
Figure 4 a, b c, d, e: River Style 1 entire view; Zoomed view of River style 1 near Uttarkashi; Zoomed view of River style 1 near Sunagarh; actual field photographs showing bed material and the river valley along with the channel belt



a

b

Figure 5 a, b: River Style 2 entire view and actual photograph showing the channel belt



a

b

c

Figure 6 a, b, c: River Style 3entire view with the actual field photographs

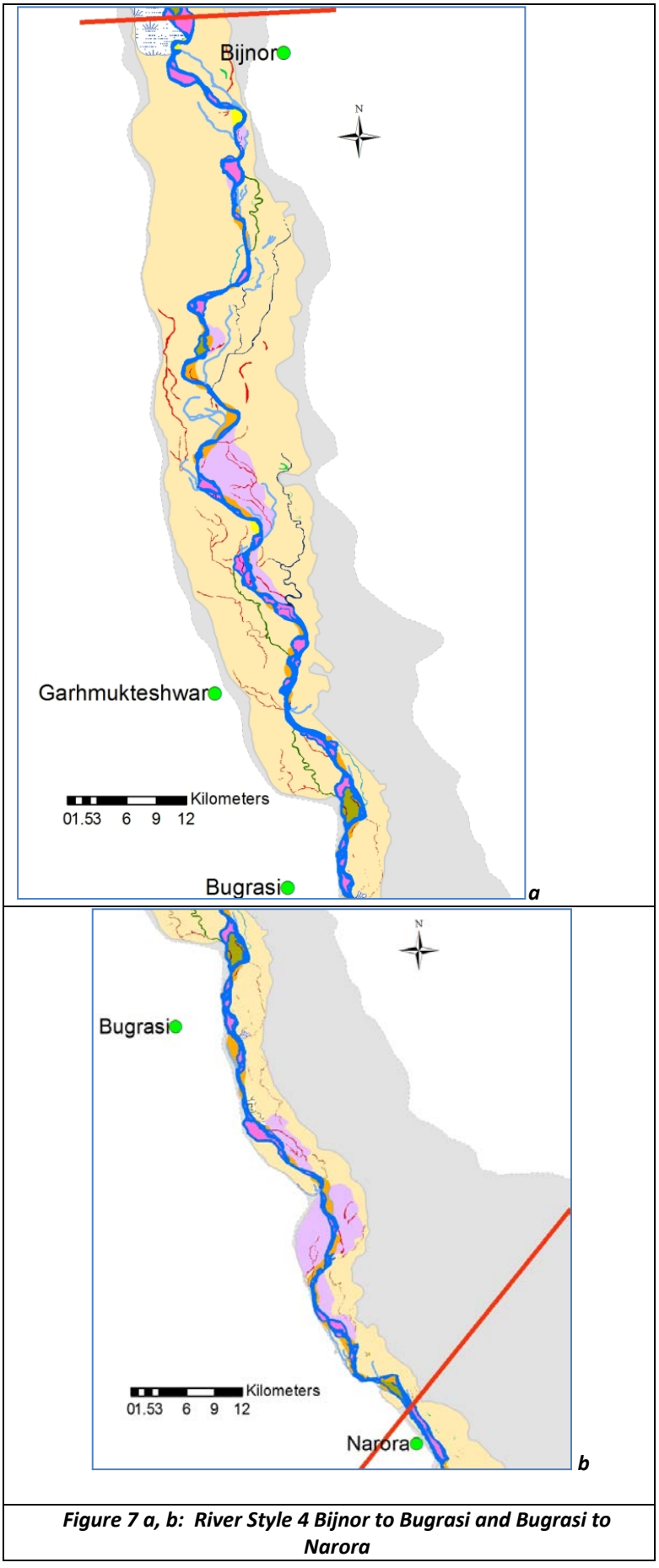
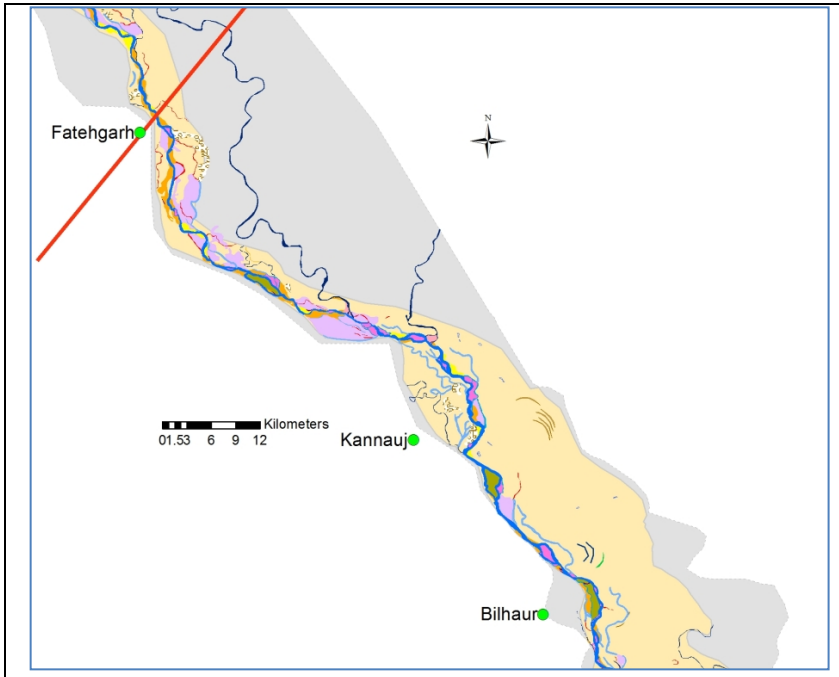


Figure 7 a, b: River Style 4 Bijnor to Bugrasi and Bugrasi to Narora



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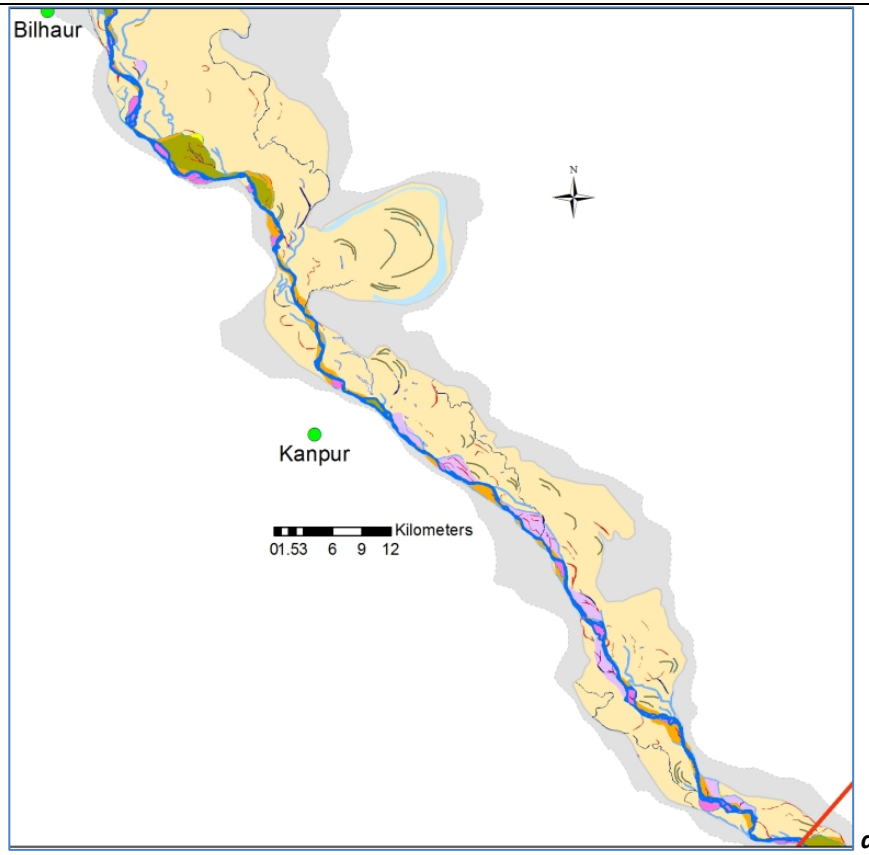


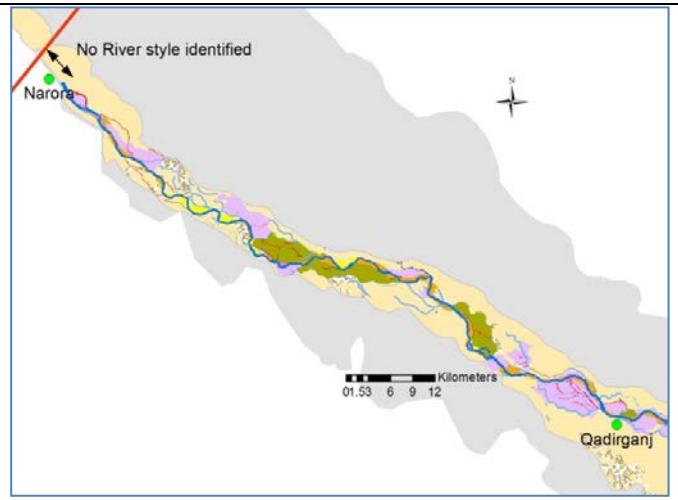
d

e

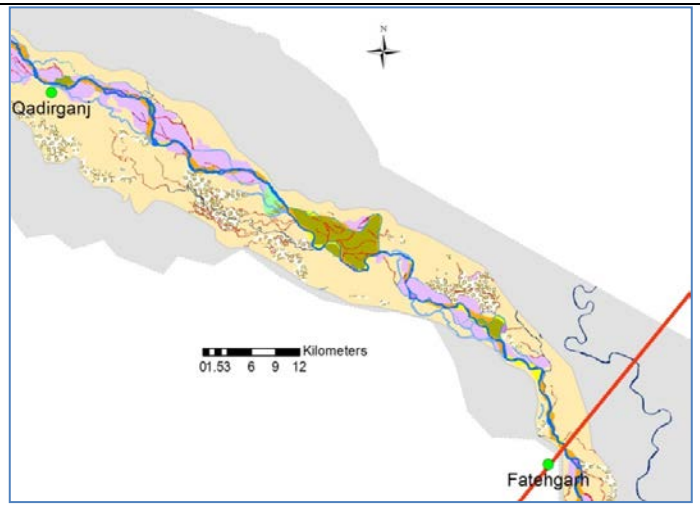
f

g

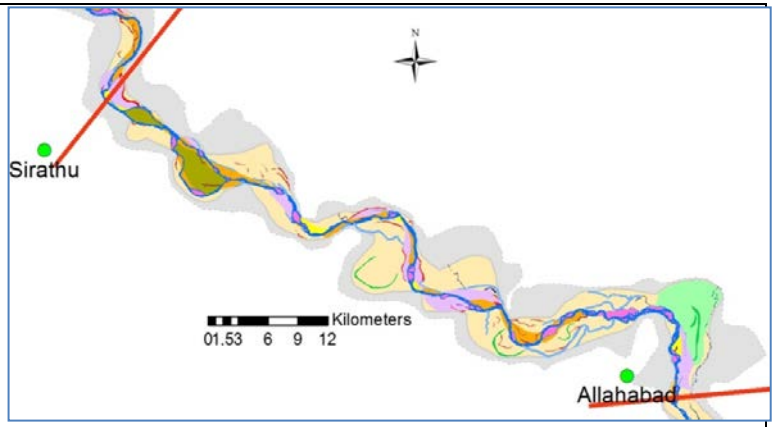
Figure 7 c, d, e, f, g: River Style 4 from Fatehgarh to Bilhaur, River Style 4 from Bilhaur to Fatehpur, actual field photograph showing the river bank, cultivated mid channel bars and the high cliffs near Jajmau



a



b

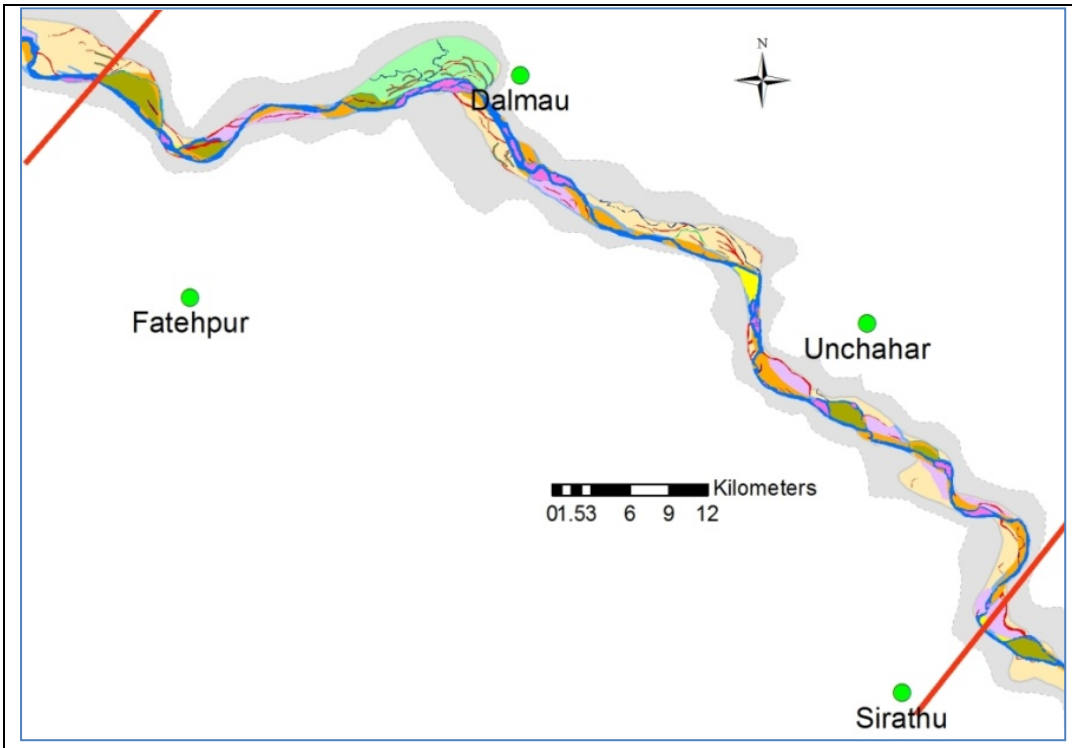


c

d

e

Figure 8 a, b, c, d, e: River Style 5(Narora to Qadirganj); River Style 5(Qadirganj to Fatehgarh); River Style 5(Sirathu to Allahabad); actual field photograph showing the cultivated side bar and the extensional view of the river

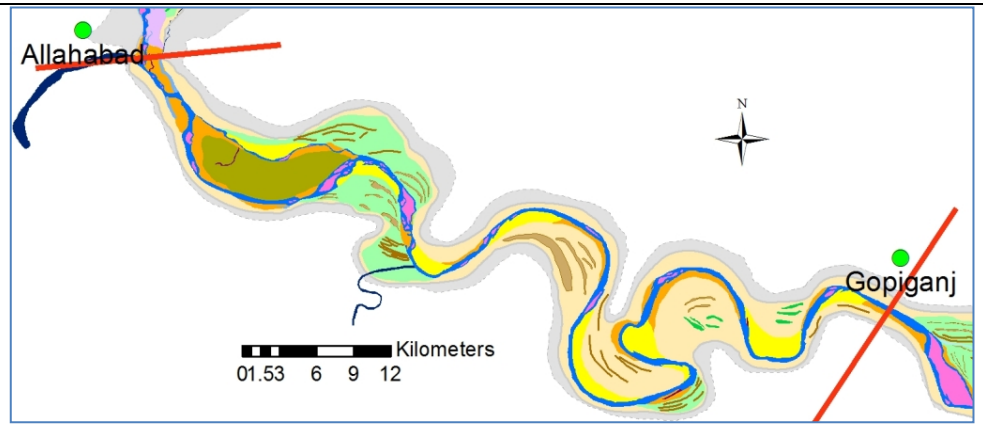


a

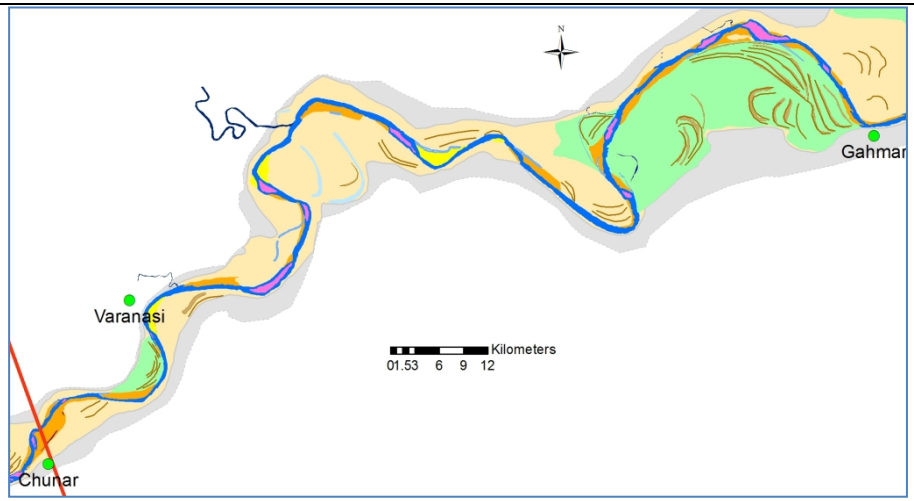
b

c

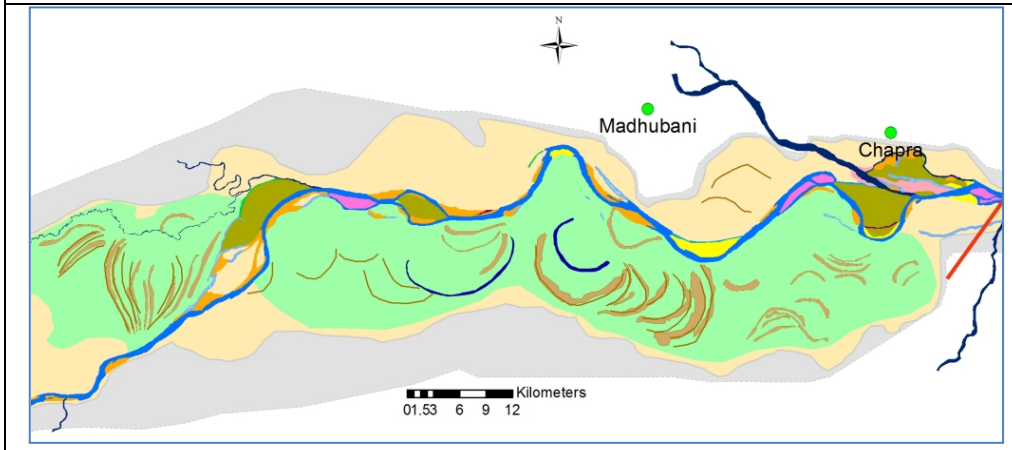
Figure 9 a, b, c: River Style 6(Fatehpur to Sirathu) and actual field photographs showing the cultivated mid channel bars and an extensional view of the river



a



b



c

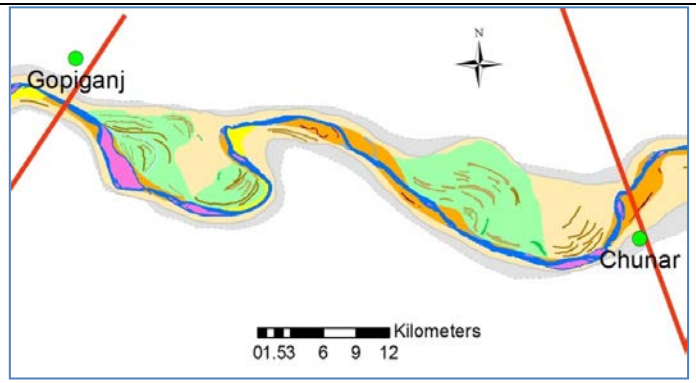
d

e

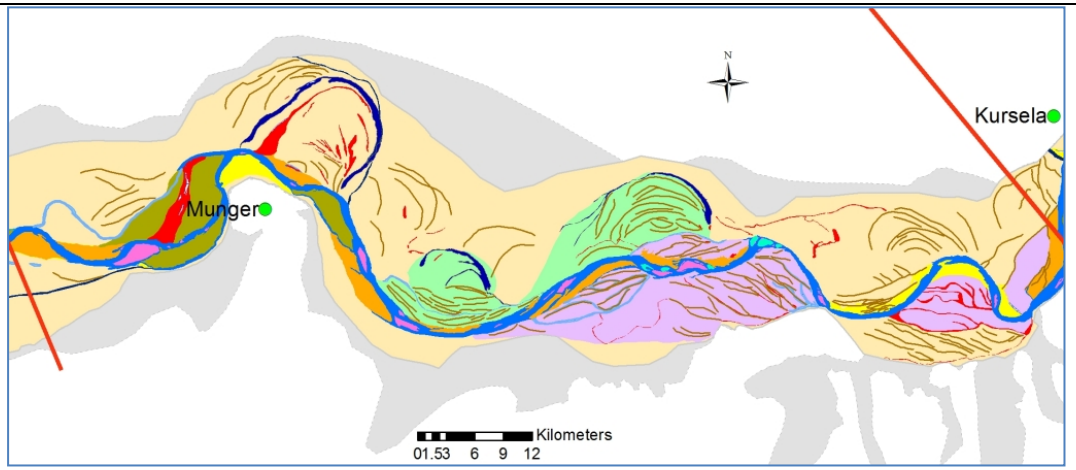
f

g

Figure 10 a, b, c, d, e, f, g: River Style 7(Allahabad to Gopiganj), River Style7(Chunar to Gahmar), River Style 7(Gahmar to Chapra); actual field photographs showing unconfined nature of channel, cultivated active floodplain, unused active floodplain covered with vegetation and calcrete cliffs near Rudauli(~ 15 Km upstream of Varanasi)



a

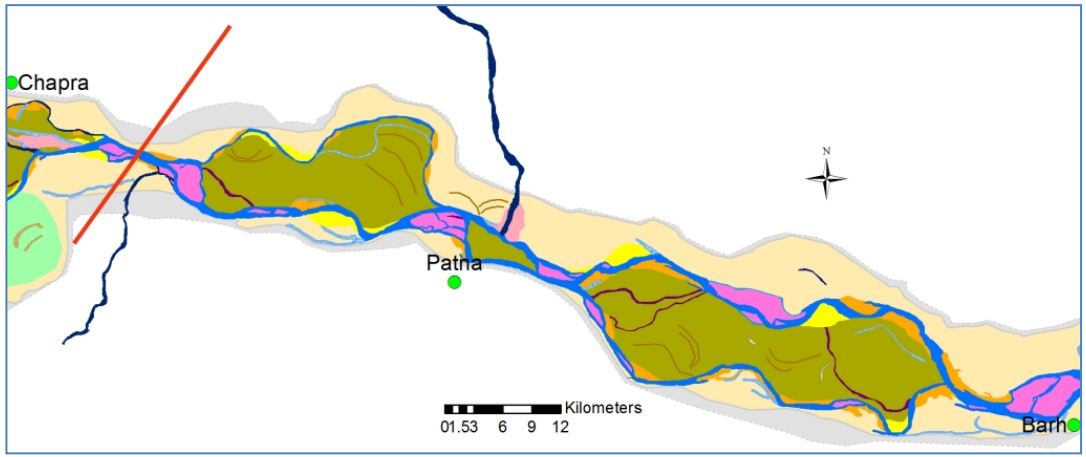


b

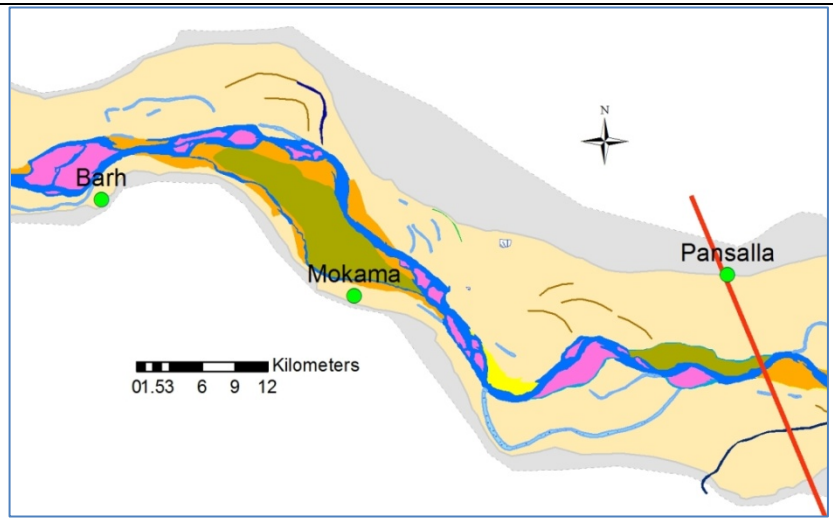
c

d

Figure 11 a, b, c, d: River Style 8(Gopiganj to Chunar), River Style 8(Pansalla to Kursela), Actual field photograph showing the active floodplain coinciding with the valley margin defined by the craton boundary and muddy river bank



a

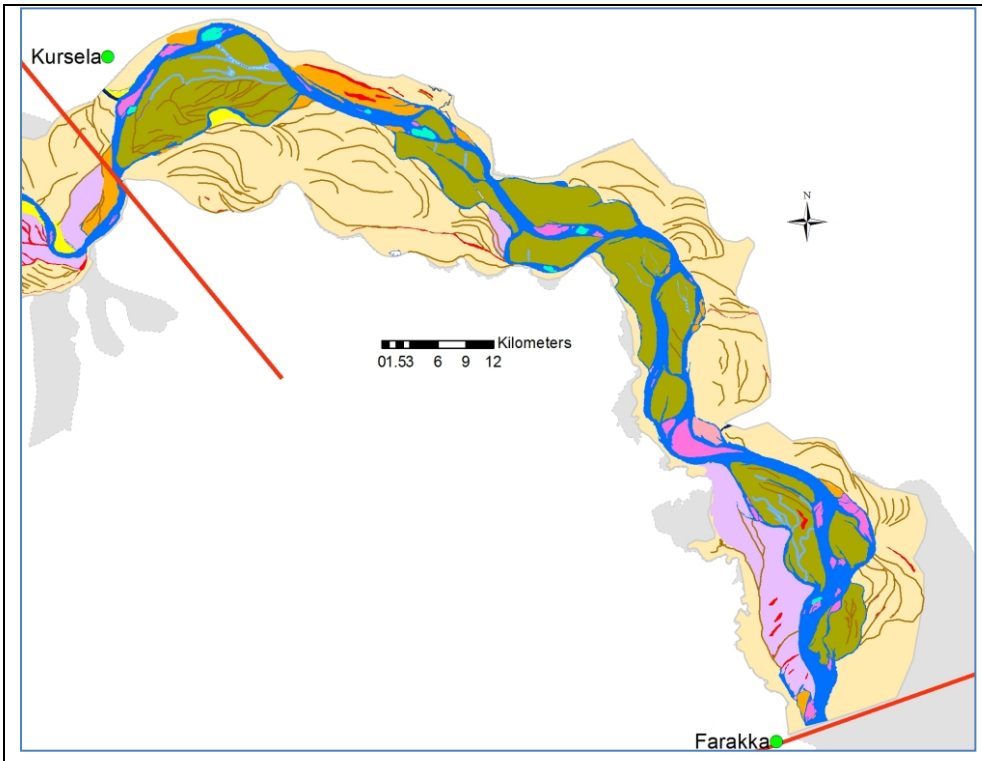


b

c

d

Figure 12 a, b, c, d: River Style 9(Chapra to Barh), River Style 9(Barh to Pansalla); actual field photographs showing loose unconsolidated material in the river bank and the extensional view of the river



a

b

c

Figure 13a, b, c: River Style 10(Kursela to Farakka); actual field photographs showing extensively cultivated floodplain and vegetated alluvial islands with settlements and the extensional view of the river

Appendix II- Reach divisions and meander position for the Ganga River

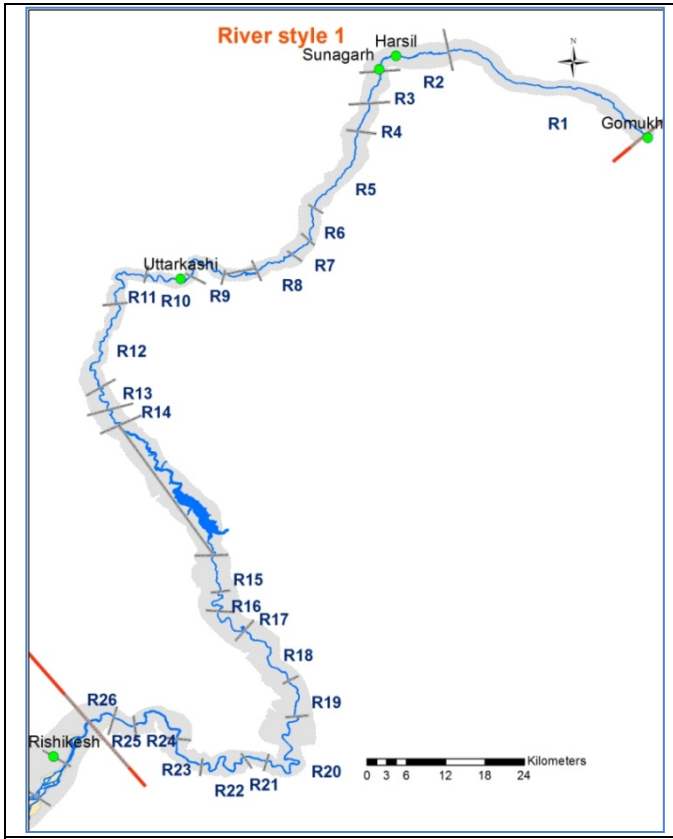


Figure 14 (Reach 1 to 26)

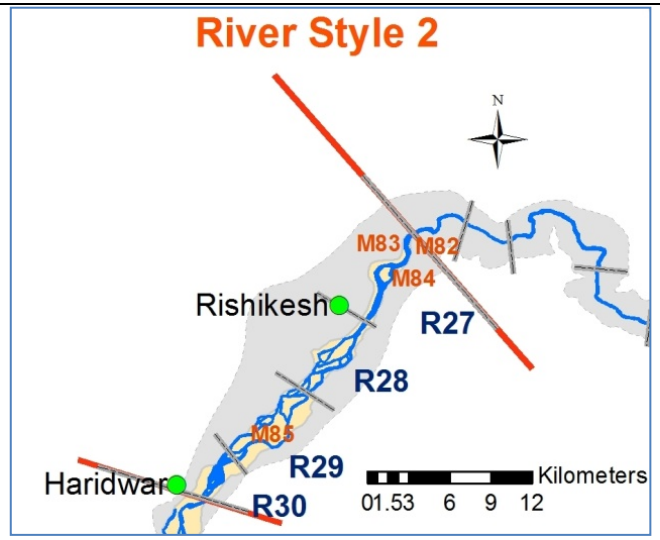


Figure 15(Reach 27 to 30)

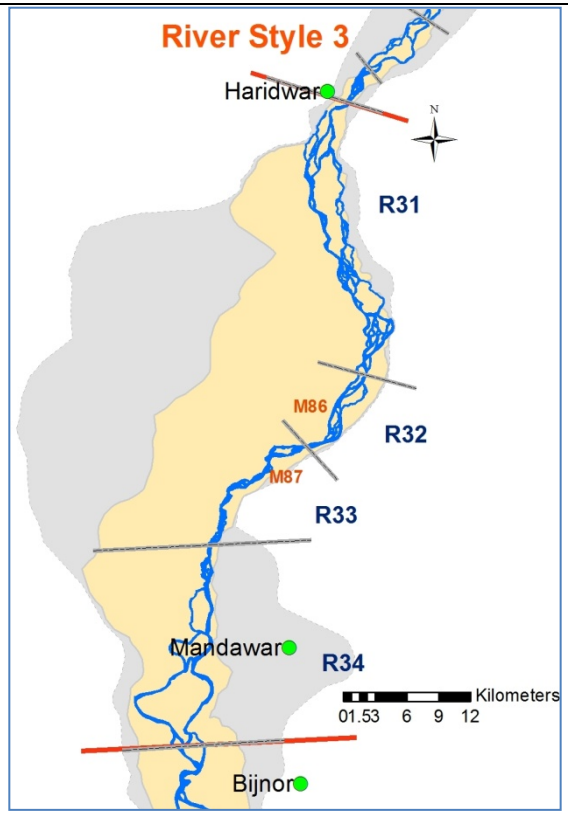


Figure 16 (Reach 31 to 34)

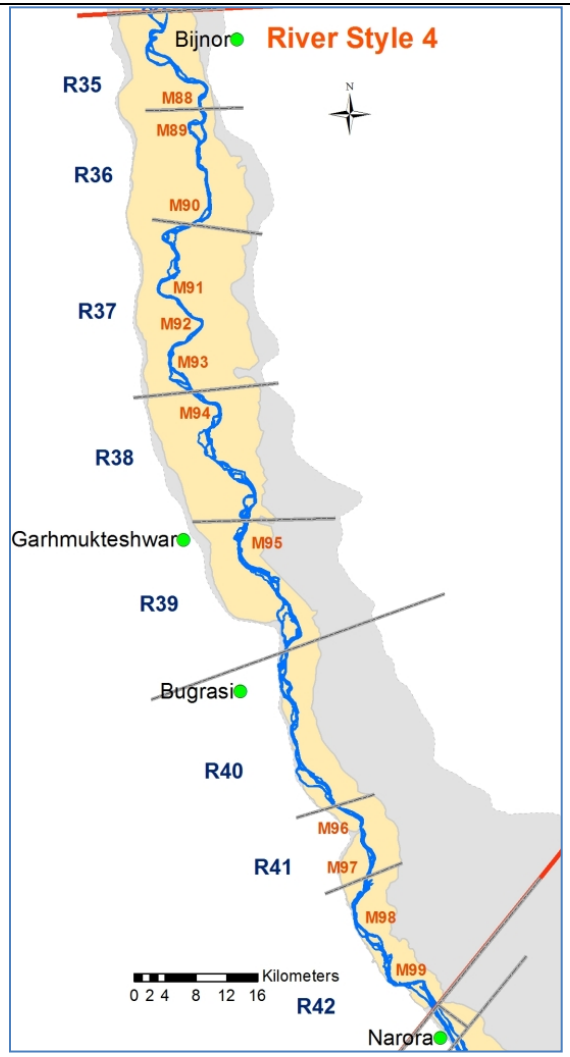


Figure 17 (Reach 35 to 42)

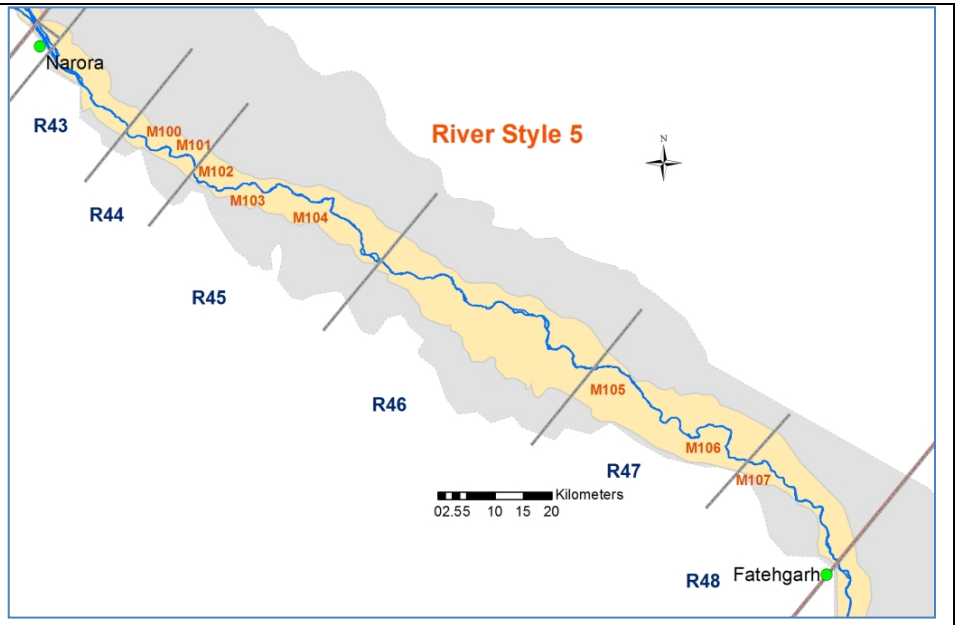


Figure 18 (Reach 43 to 48)

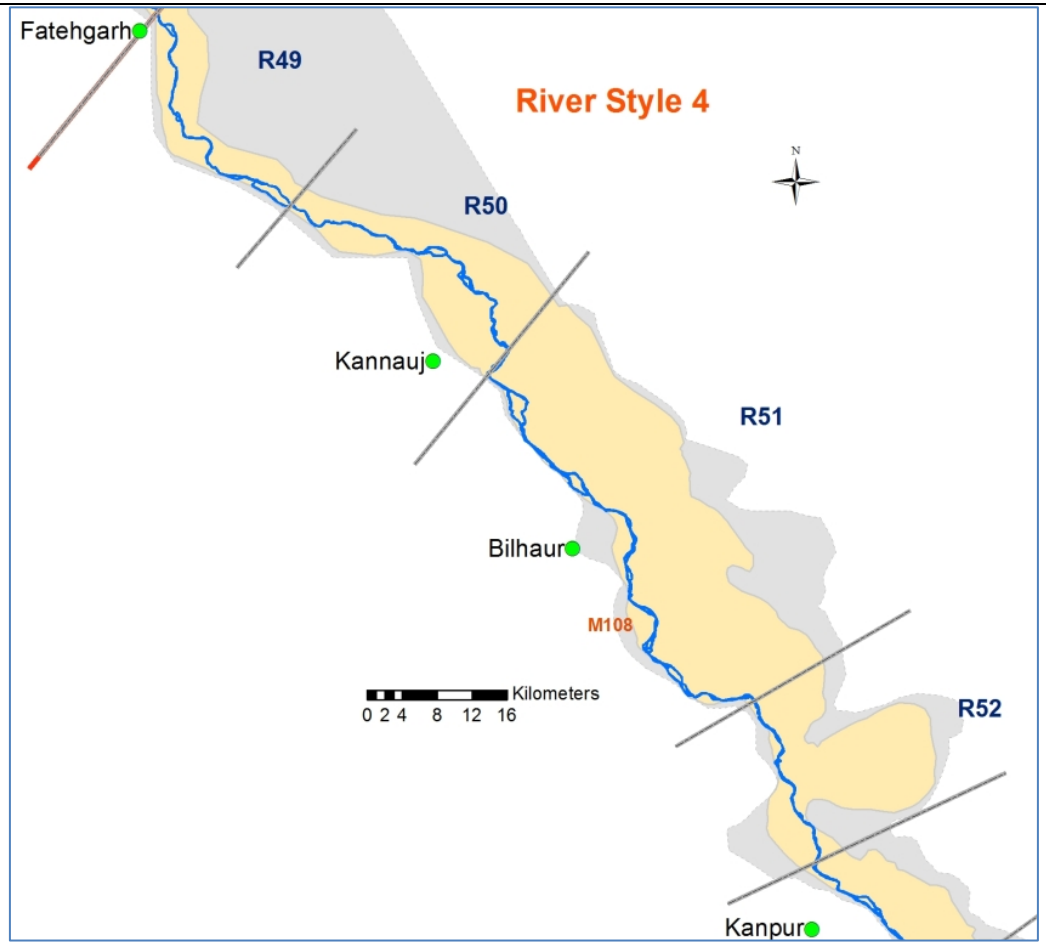


Figure 19 (Reach 49 to 52)

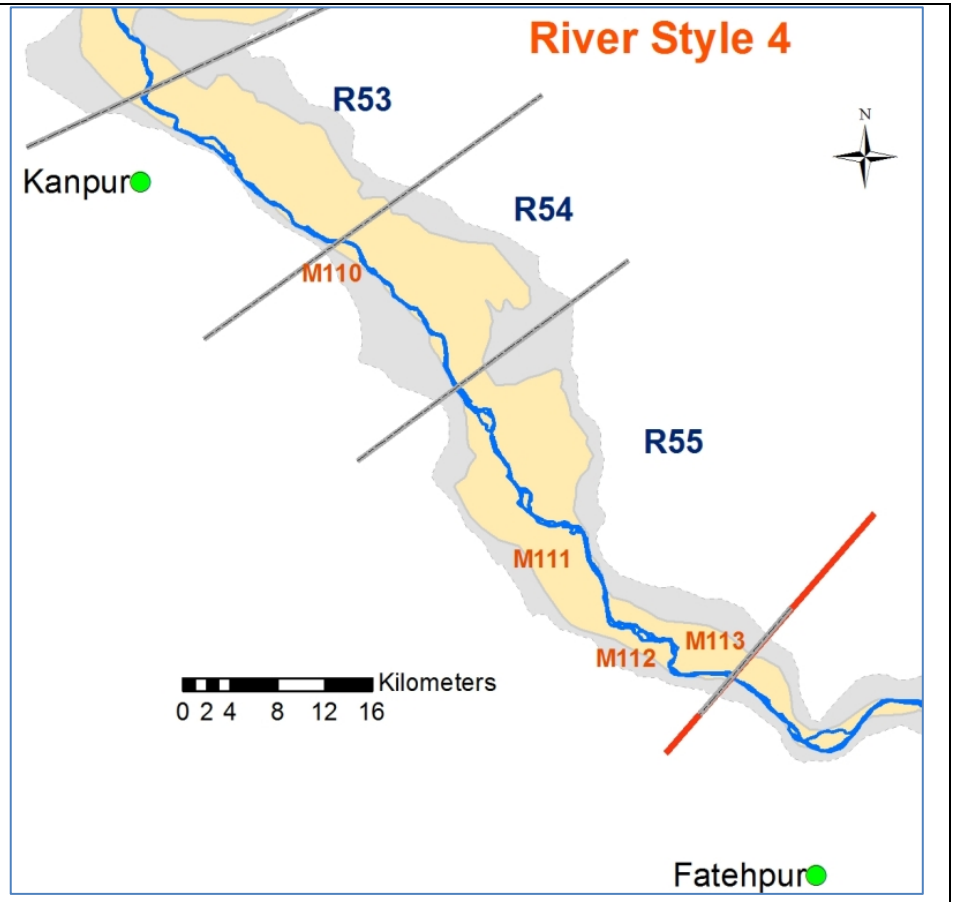


Figure 20 (Reach 53 to 55)

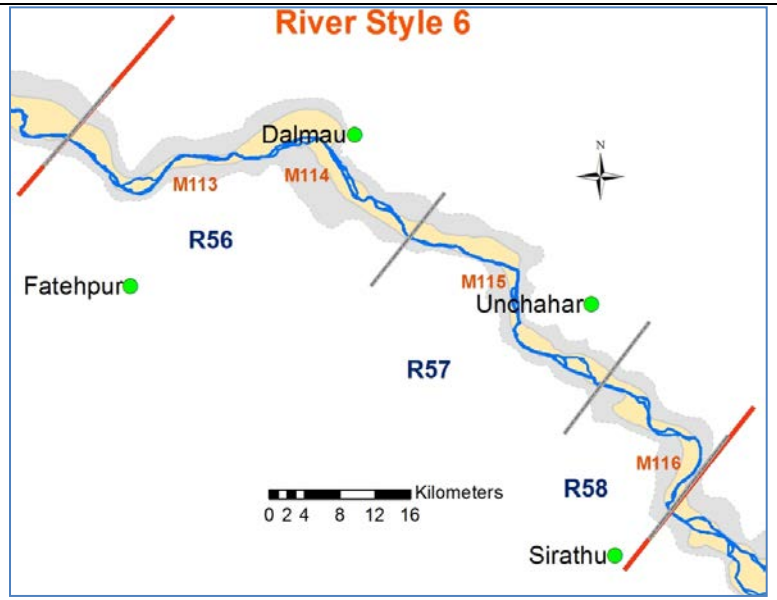


Figure 21 (Reach 56 to 58)

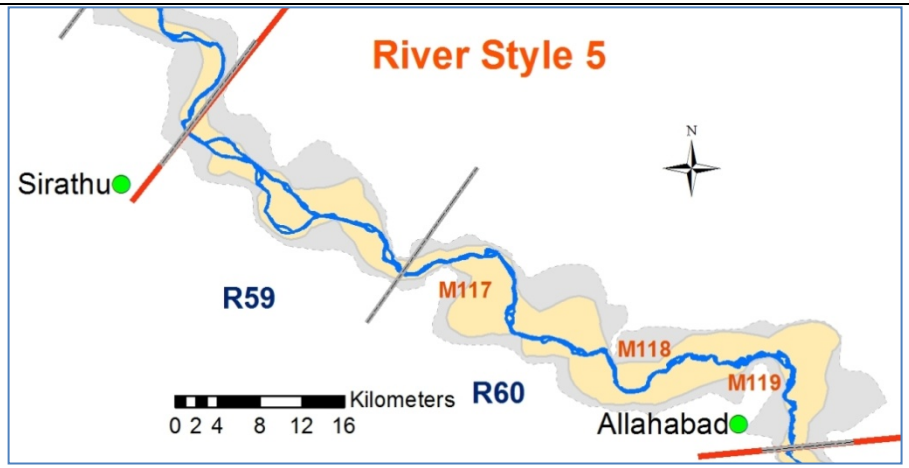


Figure 22 (Reach 59 and 60)

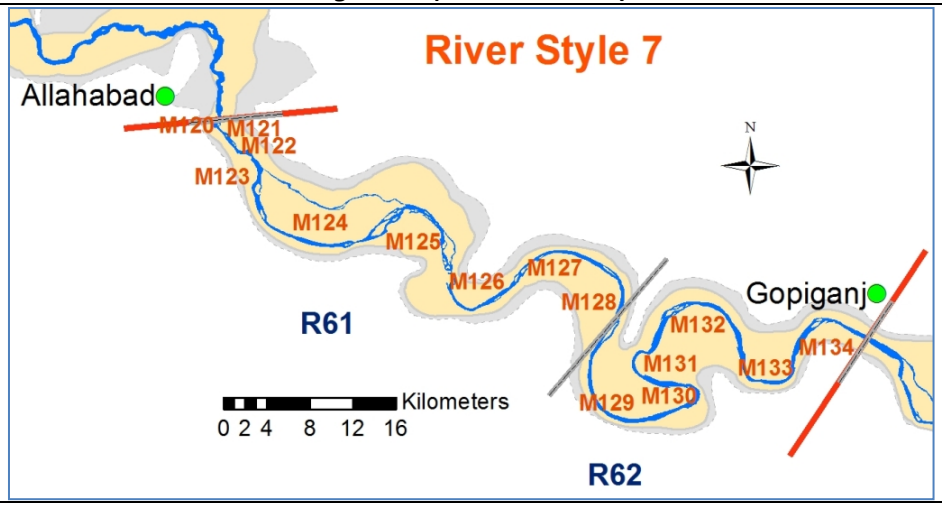


Figure 23 (Reach 61 and 62)

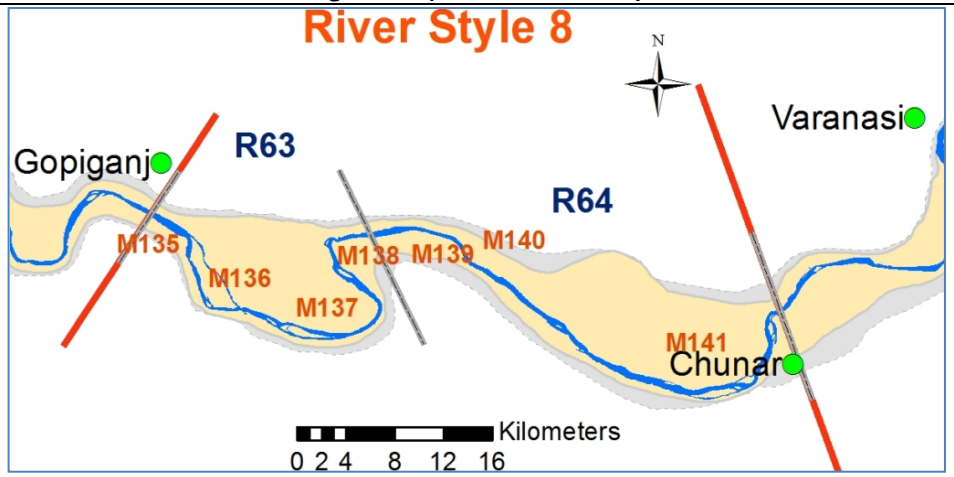
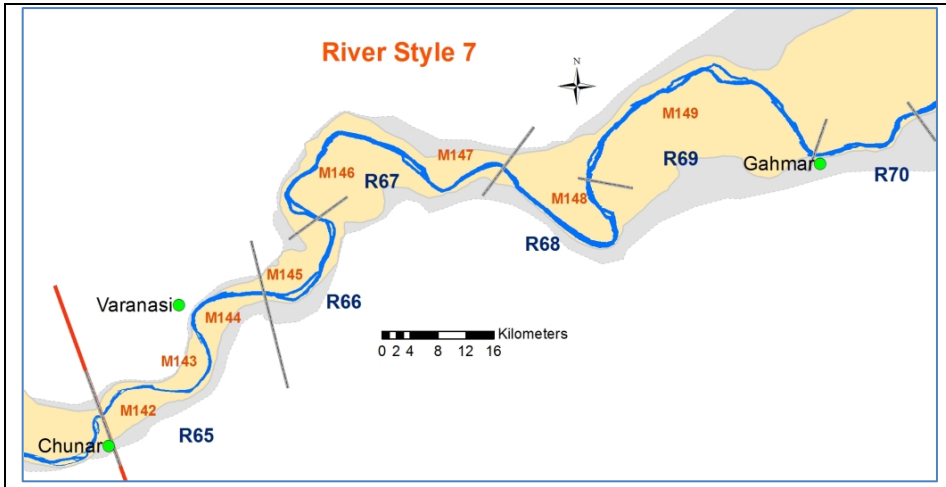


Figure 24 (Reach 63 and 64)



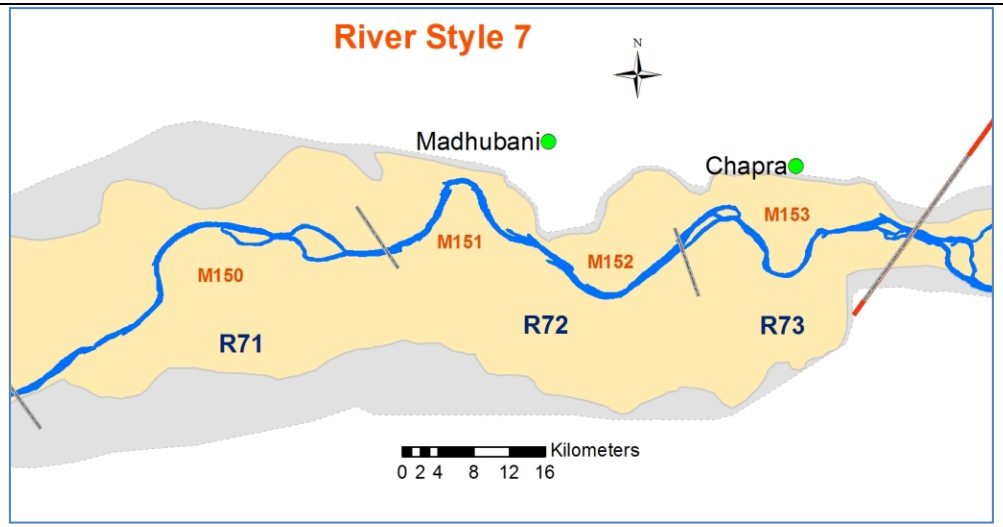


Figure 25 (Reach 65 to 70)

Figure 26 (Reach 71 to 73)

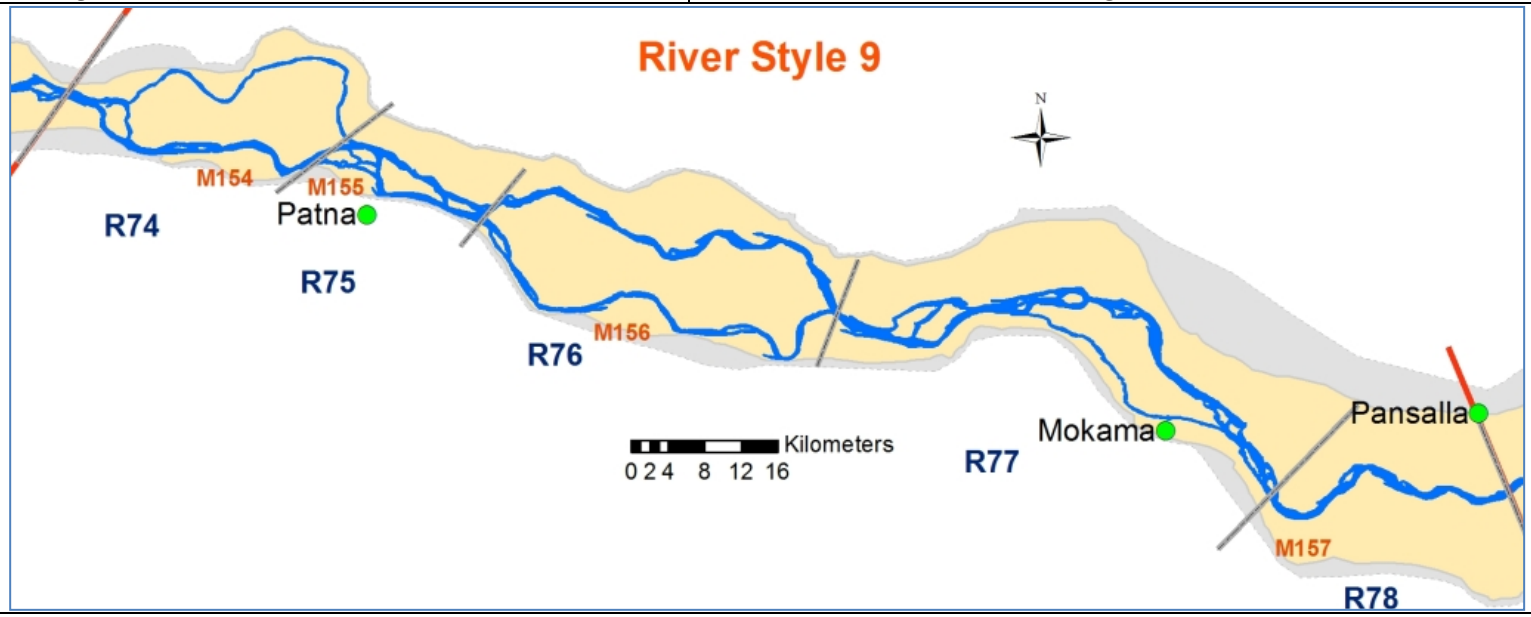


Figure 27 (reach 74 to 78)

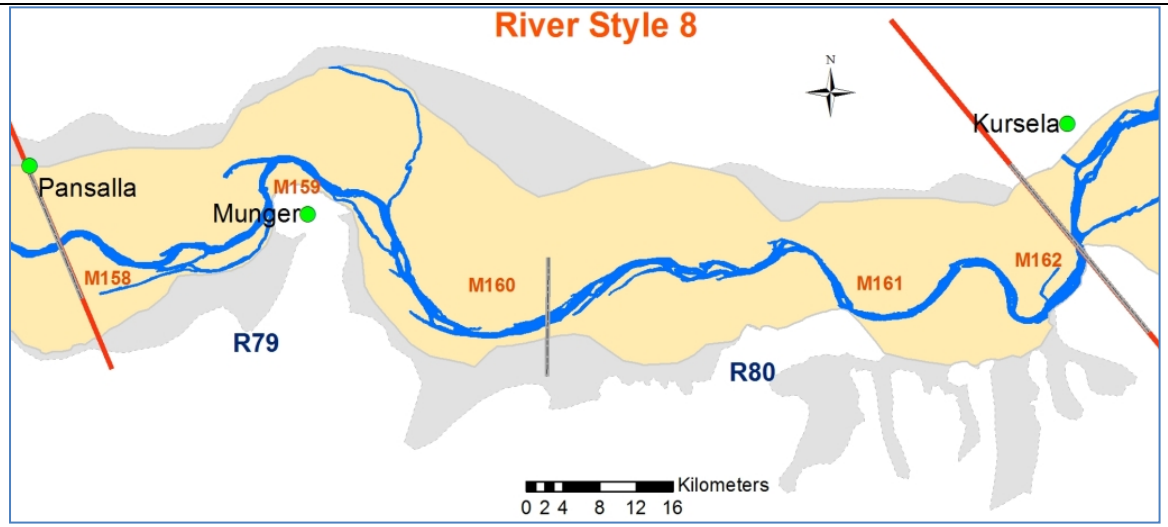


Figure 28 (Reach 79 and 80)

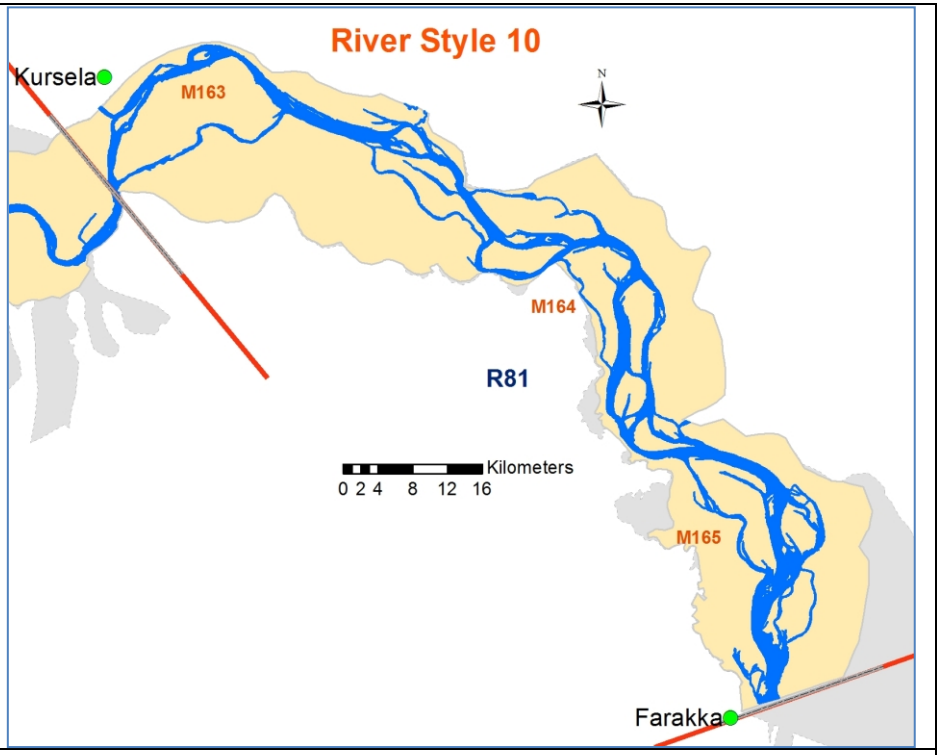


Figure 29 (Reach 81)

Appendix III - REACH-WISE MORPHOMETRIC DATA FROM GOMUKH TO FARAKKA

a) Table of morphometric parameters and bar area

River Style No.	River Style name	Stretch name	Reach No.	Total Length of Reach (km)	Sinuosity (P)	Braid Channel Ratio (B)	Average Channel width (m)	Channel Area (sq. km.)	Bar Area (Sq km)					Total Bar Area
									Mid Channel Bar	Point Bar	Confluence Bar	Alluvial Island	Side Bar	
1	Himayan Steep valley	Gomukh - Rishikesh	1	33.48	1.14	1.01	105	0.99	0.04	0.01	0	0	0.1	
			2	11.78	1.24	1.25	90	0.63	0.14	0	0	0	0.98	
			3	5.83	1.15	1	98	0.19	0	0	0	0	0	
			4	4.78	1.06	1.06	165	0.19	0.005	0	0	0	0.07	
			5	14.4	1.11	1	150	0.42	0	0	0	0	0	
			6	5.71	1.12	1.06	150	0.14	0.003	0	0	0	0.012	
			7	3.26	1.05	1	44	0.09	0	0	0	0	0.0003	
			8	6.5	1.21	1.03	38	0.26	0.003	0	0	0	0.003	
			MANERI DAM											
			9	8.81	2.01	1.14	106.5	0.4	0.03	0.03	0.01	0	0.09	
			10	8.69	1.45	1.16	109.7	0.43	0.02	0.02	0.02	0	0.19	
			11	10.42	1.99	1.12	125.5	0.54	0.03	0.13	0.01	0	0.1	
			12	16.41	1.26	1.1	191.8	0.77	0.04	0.01	0	0	0.08	
			13	5.27	1.47	1.09	61.4	0.29	0.003	0.043	0	0	0.134	
			14	4.31	1.56	1	40.8	0.22	0	0.03	0	0	0.11	
			TEHRI DAM											
			15	6.2	1.107	1	160	0.2	0	0	0	0	0	
			16	5.94	1.99	1	108	0.27	0	0	0	0	0.004	
			17	7.99	1.77	1.01	146.1	0.38	0.001	0.01	0	0	0.01	
			18	11.52	1.19	1	68.02	0.68	0	0	0	0	0	
			19	6.2	1.13	1	154.5	0.38	0	0	0	0	0	
			20	18.69	2.42	1.01	107.3	1.57	0.003		0.072		0.147	

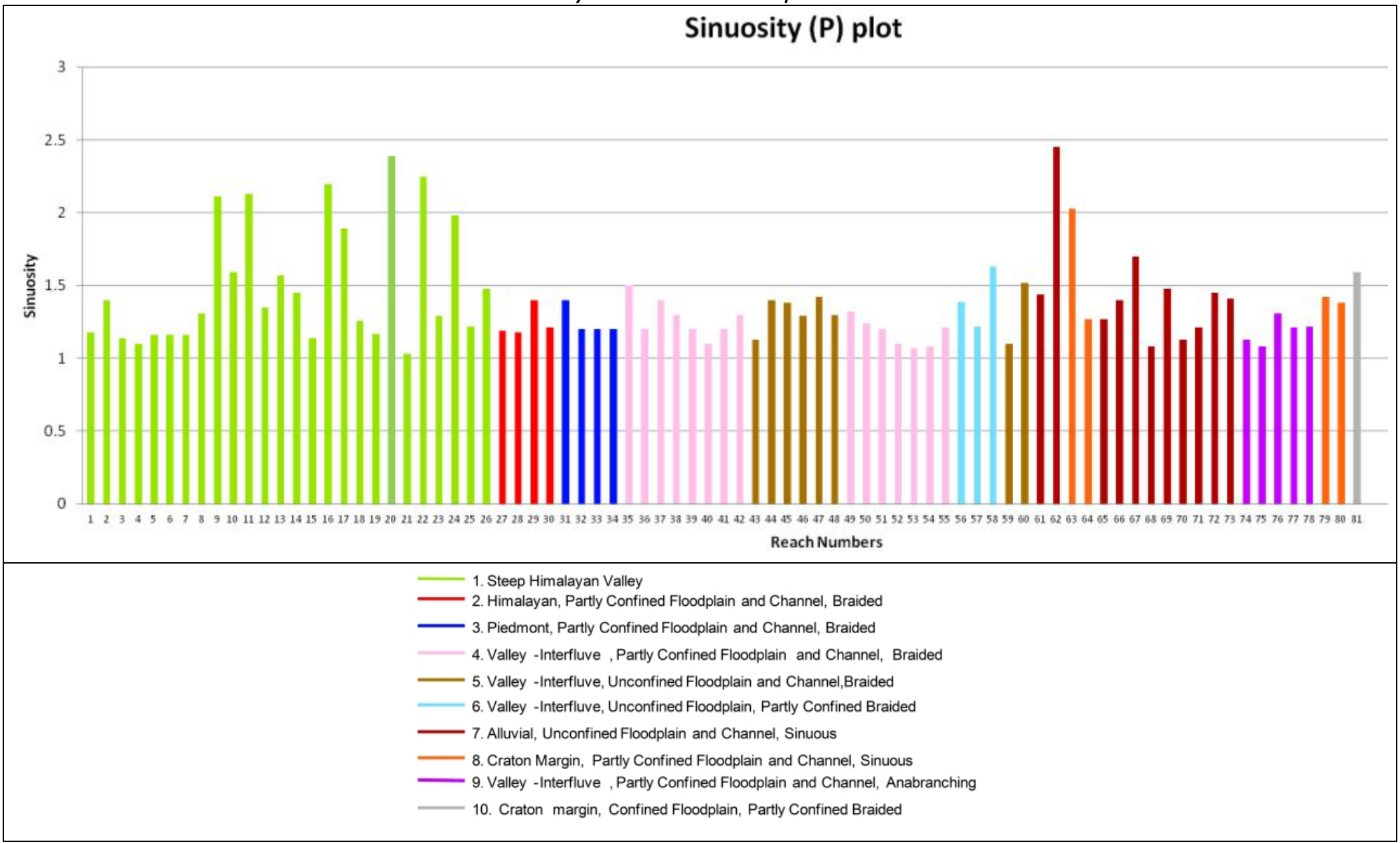
River Style No.	River Style name	Stretch name	Reach No.	Total Length of Reach (km)	Sinuosity (P)	Braid Channel Ratio (B)	Average Channel width (m)	Channel Area (sq. km.)	Bar Area (Sq km)					
									Mid Channel Bar	Point Bar	Confluence Bar	Alluvial Island	Side Bar	Total Bar Area
			21	3.18	1.03	1	84.5	0.27	0	0	0	0	0.011	
			22	12.09	2.11	1.03	143	1.13	0.009	0	0	0	0.24	
			23	6.13	1.18	1	121.5	0.6	0	0	0	0	0.13	
			24	10.83	1.85	1	121	1.55	0	0	0	0	0.006	
			25	3.21	1.04	1	105	0.27	0	0	0	0	0.017	
			26	4.48	1.32	1	131	0.63	0	0	0	0	0.04	**3.13**
2	**Himalayan, Partly Confined Floodplain and Channel, Braided**	**Rishikesh (Ramjhula) - Haridwar**	27	8.21	1.17	1.21	1319	1.97	0.01	0	0	0.63	0	
			28	6.98	1.09	2.78	1192	1.49	1.95	0	0	1.88	0.45	
			29	8.37	1.25	2.7	1079	1.59	1.17	0	0	5.4	0.9	
			30	3.83	1.11	1.26	633	2.42	0.28	0	0	0	0.48	**13.15**
3	**Piedmont, Partly Confined Floodplain and Channel, Braided**	**Haridwar - Bijnor**	31	32.34	1.25	3.7	1820	10.7	16.7	0	0	13.7	1.6	
			32	9.76	1.18	2.9	800	3.3	2.3	0	0	2	0	
			33	14.46	1.18	1.8	600	4.9	1.4	0	0	0	1.4	
			34	22.12	1.15	2.4	575	8.4	1.7	0	0	28.9	2.9	**72.6**
4	**Valley-Interfluve, Partly Confined Floodplain and Channel, Braided**	**Bijnor - Narora**	35	18.76	1.37	1.6	1100	6.7	5.1	1.8	0	0	0.06	
			36	17.34	1.15	1.7	720	5.5	3.2	0	0	0	1.5	
			37	30.9	1.43	1.4	525	10.4	3.2	0	0	1	7.1	
			38	22.59	1.27	2.2	970	9.3	5.9	0.9	0	0	2.5	
			39	21.14	1.2	2	800	10.1	3.3	0	0	3.7	2.4	
			40	23.44	1.12	2.1	870	9.2	6.4	0	0	0	4.4	
			41	11.6	1.17	1.7	480	3.6	0.7	0	0	0	3.4	
			42	23.83	1.27	1.9	590	9.2	2.9	0	0	1.7	5.1	**66.26**

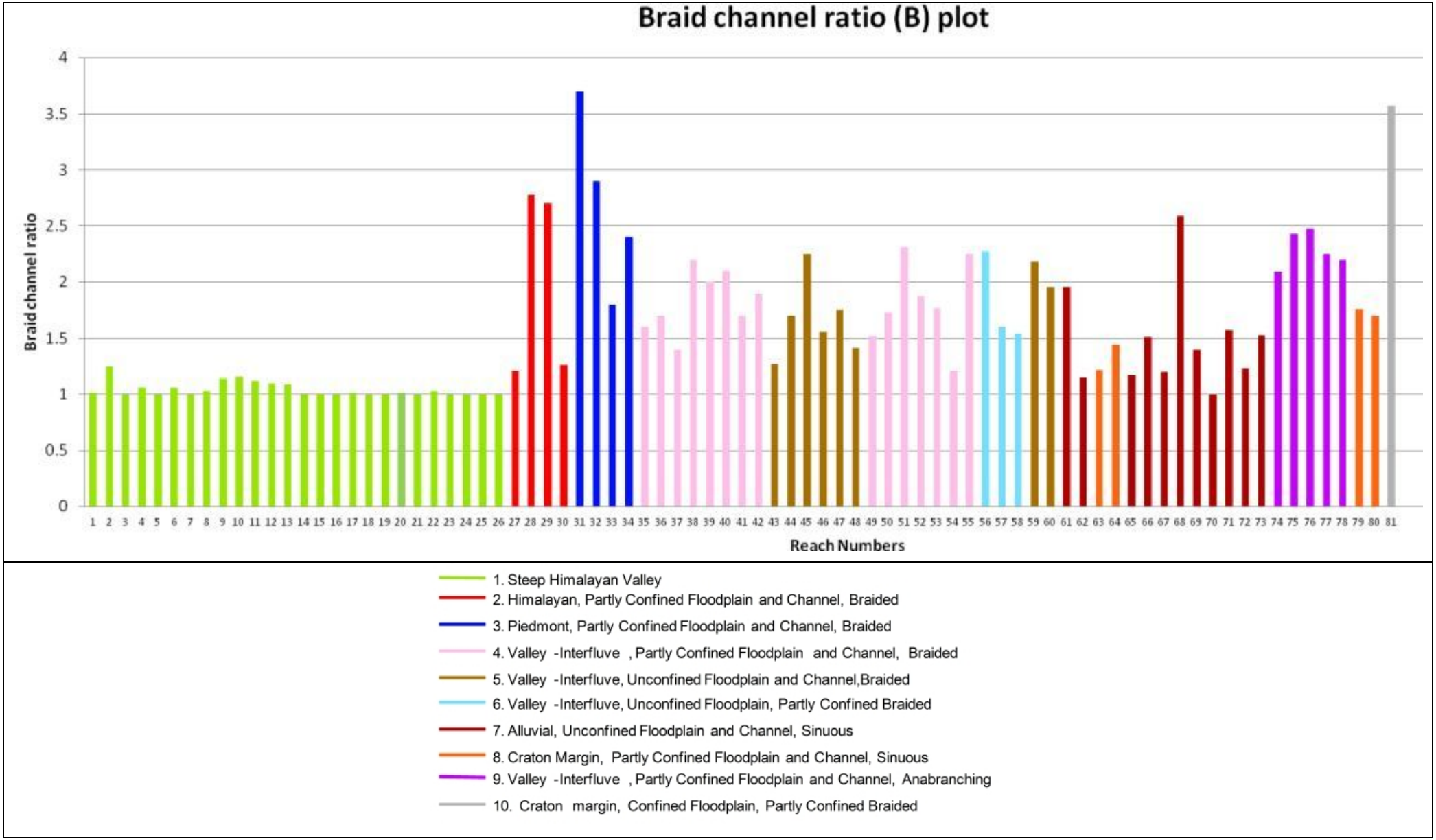
River Style No.	River Style name	Stretch name	Reach No.	Total Length of Reach (km)	Sinuosity (P)	Braid Channel Ratio (B)	Average Channel width (m)	Channel Area (sq. km.)	Bar Area (Sq km)					Total Bar Area
									Mid Channel Bar	Point Bar	Confluence Bar	Alluvial Island	Side Bar	
			NARORA BARRAGE											
5	Valley-Interfluve, Unconfined Floodplain and Channel, Braided	Narora - Fatehgarh	43	20.29	1.11	1.27	123	2.5	0.11	0	0	0	5.3	
			44	17.39	1.37	1.7	133	1.9	0.06	5.3	0	0	1	
			45	45.66	1.38	2.25	128	5.9	1.15	4.32	0	46.24	12.86	
			46	48.7	1.27	1.56	132	6.3	1.5	0.57	0	5.77	15.68	
			47	40.45	1.39	1.75	144	5.2	0.9	2.62	0	30	7	
			48	28.37	1.25	1.41	152	4	0.5	5.06	0	3.48	6.6	**156.02**
4	Valley-Interfluve, Partly Confined Floodplain and Channel, Braided	Fatehgarh - Fatehpur	49	32.36	1.25	1.52	144	5.31	2.14	2.09	0	3	10.81	
			50	34.45	1.24	1.73	146	7.34	4.44	3.75	1.46	1.07	7.23	
			51	58.76	1.24	2.31	341.3	14.02	9.07	1.08	0	20.6	6.07	
			52	21.42	1.1	1.87	199.5	4.02	1.23	0	0	3.38	7.8	
			KANPUR BARRAGE											
			53	21.04	1.07	1.77	196	4.23	1.23	0	0	1.14	3.29	
			54	16.46	1.08	1.21	176.5	2.83	0.87	0	0	0	3.87	
			55	39.38	1.22	2.25	288.4	8.92	6.38	0.08	0	0.205	8.37	**110.7**
6	Valley-Interfluve, Unconfined Floodplain, Partly Confined Braided	Fatehpur - Sirathu	56	47.56	1.39	2.27	222.3	10.5	6.6	0.24	0	10.88	11.02	
			57	31.23	1.22	1.6	189.8	6.36	1.45	2.11	0	3.06	8.85	
			58	23.1	1.63	1.54	192.4	4.39	1.27	0.32	0	0.95	6.2	**52.95**
5	Valley-Interfluve, Unconfined Floodplain and Channel, Braided	Sirathu - Allahabad	59	25.03	1.1	2.18	261.6	6.87	1.85	1	0	13.21	6.2	
			60	56.22	1.52	1.96	270.7	13.3	6.14	2.46	0	0	10.68	**41.54**

River Style No.	River Style name	Stretch name	Reach No.	Total Length of Reach (km)	Sinuosity (P)	Braid Channel Ratio (B)	Average Channel width (m)	Channel Area (sq. km.)	Bar Area (Sq km)					Total Bar Area
									Mid Channel Bar	Point Bar	Confluence Bar	Alluvial Island	Side Bar	
7	Alluvial, Unconfined Floodplain and Channel, Sinuous	Allahabad - Gopiganj	61	57.11	1.44	1.96	480	65.36	3.32	16.71	0	30.33	23.89	
			62	57.72	2.45	1.15	510	56.31	0.62	29.55	0	6.63	11.06	**122.11**
8	Craton Margin, Partly Confined Floodplain and Channel, Sinuous	Gopiganj - Chunar	63	34.14	2.03	1.22	430	33.38	1.99	4.73	0	6.85	28.92	
			64	40.26	1.27	1.44	540	20.38	2.34	0	0	0	16.82	**61.65**
7	Alluvial, Unconfined Floodplain and Channel, Sinuous	Chunar to Chapra	65	36.17	1.32	1.17	280	36.33	0.21	8.1	0	0	13.52	
			66	18.74	1.47	1.51	426	8.09	3.04	0	0	0	0.54	
			67	43.4	1.72	1.2	586	20.18	1.39	10.02	0	0	7.55	
			68	28.87	2.6	2.59	530	14.96	0.45	0	0	0	8.97	
			69	43.72	1.48	1.4	490	20.95	6.73	0	0	0	20.29	
			70	16.1	1.11	1	400	6.61	0	0	0	0	3.83	
			71	49.37	1.21	1.57	485	25.53	4.38	3.2	0	35.13	23.35	
			72	42.2	1.42	1.23	753	24.39	0	9.88	0	0	9.38	
			73	32.79	1.38	1.53	731	18.12	7.01	4.17	7.71	37.68	7.8	**220.83**
9	Valley-Interfluve, Partly Confined Floodplain and Channel, Anabranching	Chapra - Pansalla	74	32.05	1.18	2.09	965	28.67	1.93	5.39	0	169.69	6.23	
			75	19.07	1.13	2.43	1131	20.93	14.98	0.85	5.49	13.56	1.2	
			76	43.79	1.21	2.48	1236	48	3.53	5.71	0	272.4	24.46	
			77	59.47	1.25	2.25	1161	58.9	23.87	1.44	0	79.64	47.57	
			78	28.8	1.22	2.2	715	22.18	16.32	9.48	0	16.8	0	**720.54**

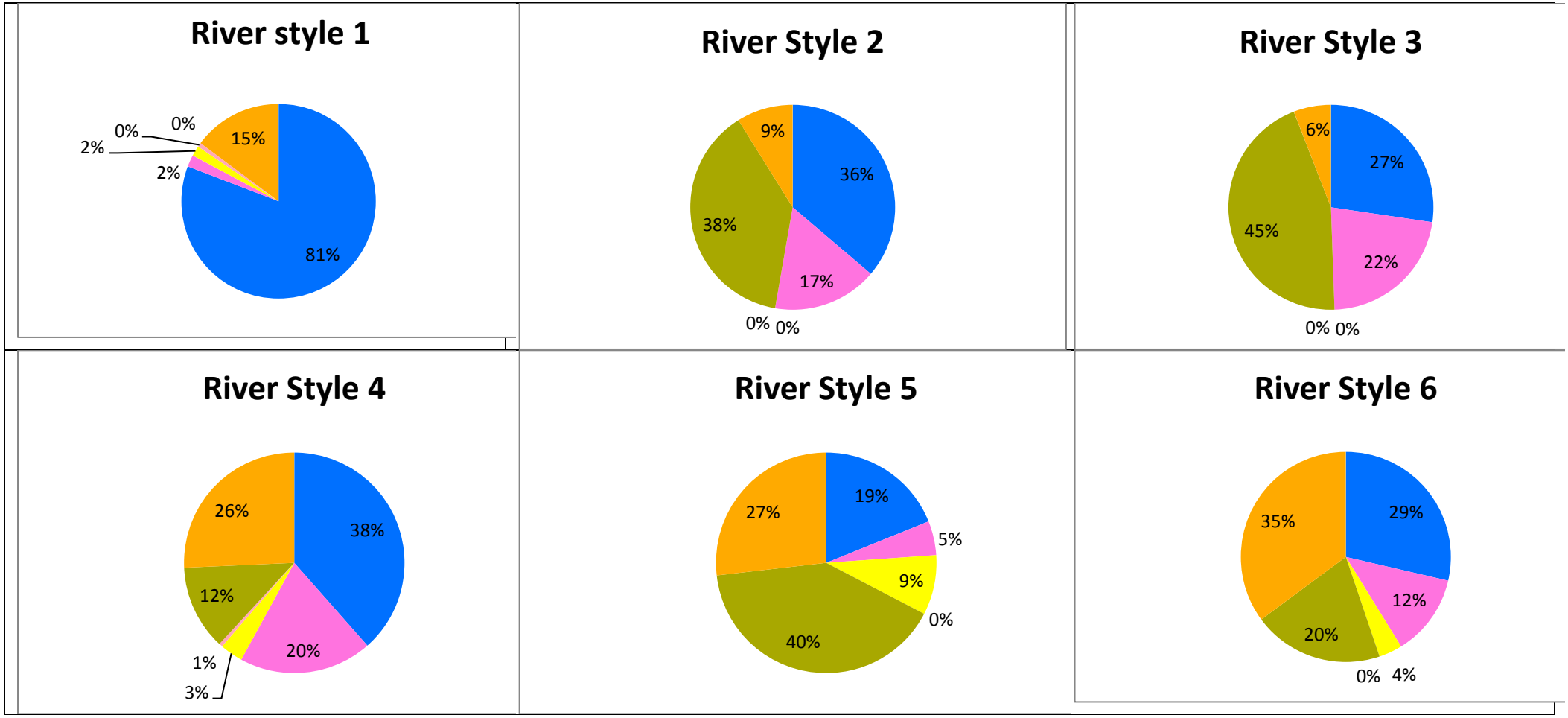
River Style No.	River Style name	Stretch name	Reach No.	Total Length of Reach (km)	Sinuosity (P)	Braid Channel Ratio (B)	Average Channel width (m)	Channel Area (sq. km.)	Bar Area (Sq km)					Total Bar Area
									Mid Channel Bar	Point Bar	Confluence Bar	Alluvial Island	Side Bar	
8	Craton Margin, Partly Confined Floodplain and Channel, Sinuous	Pansalla - Kursela	79	69.01	1.4	1.76	3170	50.62	7.95	10.17	0	62.71	36.85	
			80	72.9	1.36	1.7	1210	52.76	4.63	17.56	1.63	0	27.14	**168.64**
10	**Craton margin, Confined Floodplain, Partly Confined Braided**	**Kursela - Farakka**	81	145.36	1.61	3.57	6170	224.08	32.13	4.77	4.31	331.56	33.81	**406.58**
			FARAKKA BARRAGE											

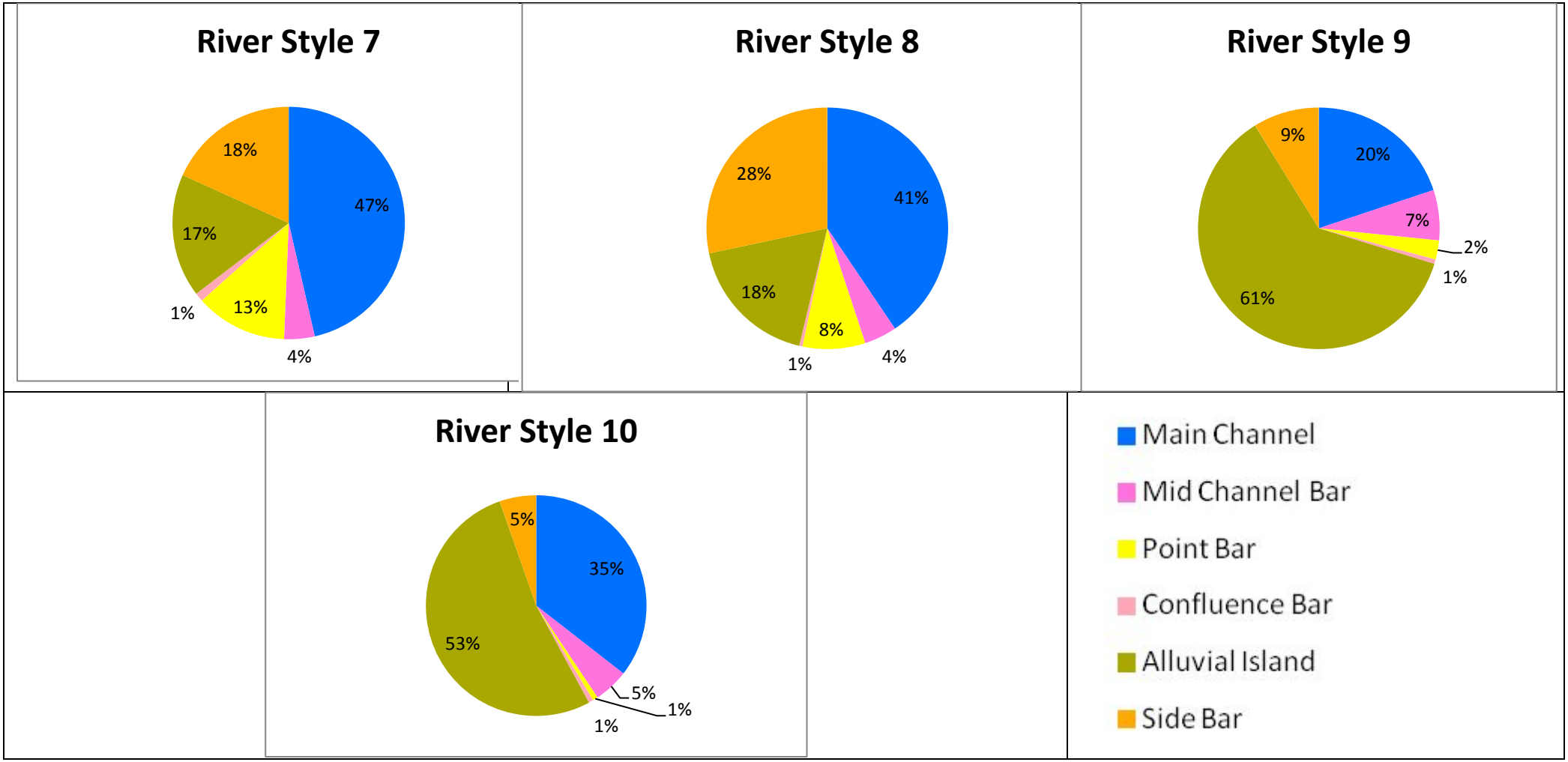
b: Sinuosity and Braid channel ratio plot reach wise




Braid channel ratio (B) plot
Braid channel ratio
Reach Numbers
1. Steep Himalayan Valley
2. Himalayan, Partly Confined Floodplain and Channel, Braided
3. Piedmont, Partly Confined Floodplain and Channel, Braided
4. Valley -Interfluve , Partly Confined Floodplain and Channel, Braided
5. Valley -Interfluve, Unconfined Floodplain and Channel,Braided
6. Valley -Interfluve, Unconfined Floodplain, Partly Confined Braided
7. Alluvial, Unconfined Floodplain and Channel, Sinuous
8. Craton Margin, Partly Confined Floodplain and Channel, Sinuous
9. Valley -Interfluve , Partly Confined Floodplain and Channel, Anabranching
10. Craton margin, Confined Floodplain, Partly Confined Braided

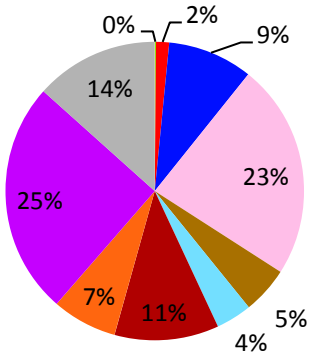
c: Main channel and bar distribution percentage for each River Style



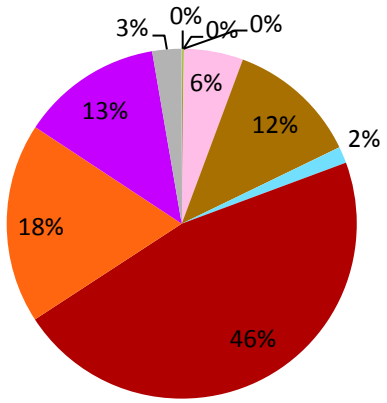

River Style 7
47%
4%
13%
1%
17%
18%
River Style 8
41%
4%
8%
1%
18%
28%
River Style 9
20%
7%
2%
1%
61%
9%
River Style 10
35%
5%
1%
1%
53%
5%
Main Channel
Mid Channel Bar
Point Bar
Confluence Bar
Alluvial Island
Side Bar

d: Bar distribution percentage for different River Style

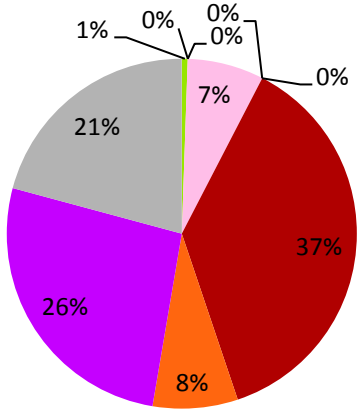
Mid Channel Bar Distibution in different River Style



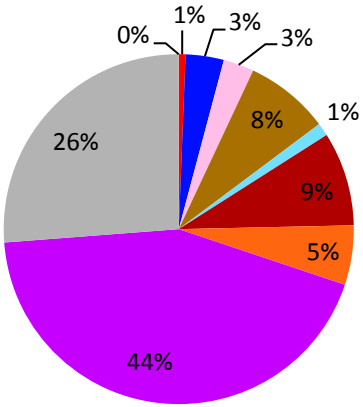
Point Bar Distibution in different River Style



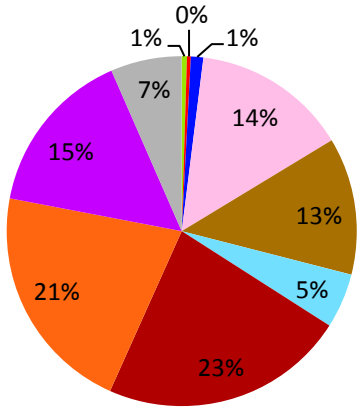
Confluence Bar Distibution in different River Style



Alluvial Island Distibution in different River Style



Side Bar Distibution in different River Style



1. Steep Himalayan Valley
2. Himalayan, Partly Confined Floodplain and Channel, Braided
3. Piedmont, Partly Confined Floodplain and Channel, Braided
4. Valley -Interfluve , Partly Confined Floodplain and Channel, Braided
5. Valley -Interfluve, Unconfined Floodplain and Channel,Braided
6. Valley -Interfluve, Unconfined Floodplain, Partly Confined Braided
7. Alluvial, Unconfined Floodplain and Channel, Sinuous
8. Craton Margin, Partly Confined Floodplain and Channel, Sinuous
9. Valley -Interfluve , Partly Confined Floodplain and Channel, Anabranching
10. Craton margin, Confined Floodplain, Partly Confined Braided

Appendix IV- REACH-WISE MEANDER PARAMETERS FROM GOMUKH TO FARAKKA

a) Table of meander parameters reach wise

River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (r_c) Km	Axial wavelength(L) Km	Amplitude(Am) Km
1	Himalayan steep valley	Gomukh - Rishikesh		1	1.08	13.33	2.34
			1	2	1.24	17.63	2.54
				3	0.24	3.37	0.52
			2	4	0.82	4.29	1.66
			3	5	0.09	0.58	0.18
			4	6	0.06	0.61	0.14
			5	7	0.09	0.55	0.19
				8	0.15	1.25	0.34
			6	9	0.15	1.16	0.37
			7	10	0.12	0.83	0.25
				11	0.08	0.54	0.19
				12	0.13	0.6	0.34
				13	0.07	0.6	0.17
				14	0.08	0.7	0.17
			8	15	0.11	0.83	0.25
			MANERI DAM				
				16	0.14	0.68	0.27
				17	0.26	0.93	0.59
			9	18	0.37	1.9	0.89
				19	0.52	2.66	1.11
				20	0.29	1.84	0.57
				21	0.34	1.7	0.68
				22	0.33	1.43	0.86
				23	0.33	1.46	0.88
			10	24	0.24	1.19	0.62
			11	25	0.21	0.89	0.47

River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (r_c) Km	Axial wavelength(L) Km	Amplitude(Am) Km
1	Himalayan steep valley	Gomukh - Rishikesh		26	0.17	0.8	0.41
				27	0.11	0.71	0.23
				28	0.34	0.88	0.64
				29	0.23	1.16	0.49
				30	0.09	0.43	0.2
				31	0.17	0.66	0.35
				32	0.25	1.24	0.5
			12	33	0.19	1.4	0.39
				34	0.1	0.4	0.36
				35	0.17	0.89	0.35
				36	0.21	0.98	0.47
				37	0.36	1.4	0.74
				38	0.29	1.76	0.67
			13	39	0.23	1.68	0.49
				40	0.15	0.85	0.38
			14	41	0.15	0.67	0.35
				TEHRI DAM			
			15	42	0.22	2.19	0.44
				43	0.23	1.11	0.54
				44	0.25	1.37	0.59
				45	0.31	1.48	1.27
			16	46	0.41	1.89	0.93
				47	0.58	1.81	1.18
				48	0.36	1.82	0.97
				49	0.54	1.95	1.08
			17	50	0.18	0.86	0.42
				51	0.38	3.73	0.77

River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (r_c) Km	Axial wavelength(L) Km	Amplitude(Am) Km
1	Himalayan steep valley	Gomukh - Rishikesh		52	0.55	3.43	1.19
				53	0.64	4.37	1.26
			18	54	0.33	3.22	0.71
			19	55	0.41	3.53	0.85
			20	No Meander			
				56	0.28	1.72	0.9
				57	0.41	2.28	0.9
				58	0.36	2.13	0.72
				59	0.31	2.62	1.05
				60	0.53	3.28	1.1
				61	0.55	2.44	1.55
				62	0.3	0.73	1.06
				63	0.39	1.97	0.82
				64	0.32	1.32	1.31
				65	0.33	2.12	0.65
				66	0.25	1.38	0.55
			21	67	0.25	1.9	0.54
				68	0.28	1.72	0.5
				69	0.34	1.9	0.7
				70	0.19	1.36	0.58
				71	0.23	1.64	0.64
				72	0.36	1.72	1.23
				73	0.34	2.39	2.07
			22	74	0.36	1.82	1.03
			23	75	1.12	6.19	2.38

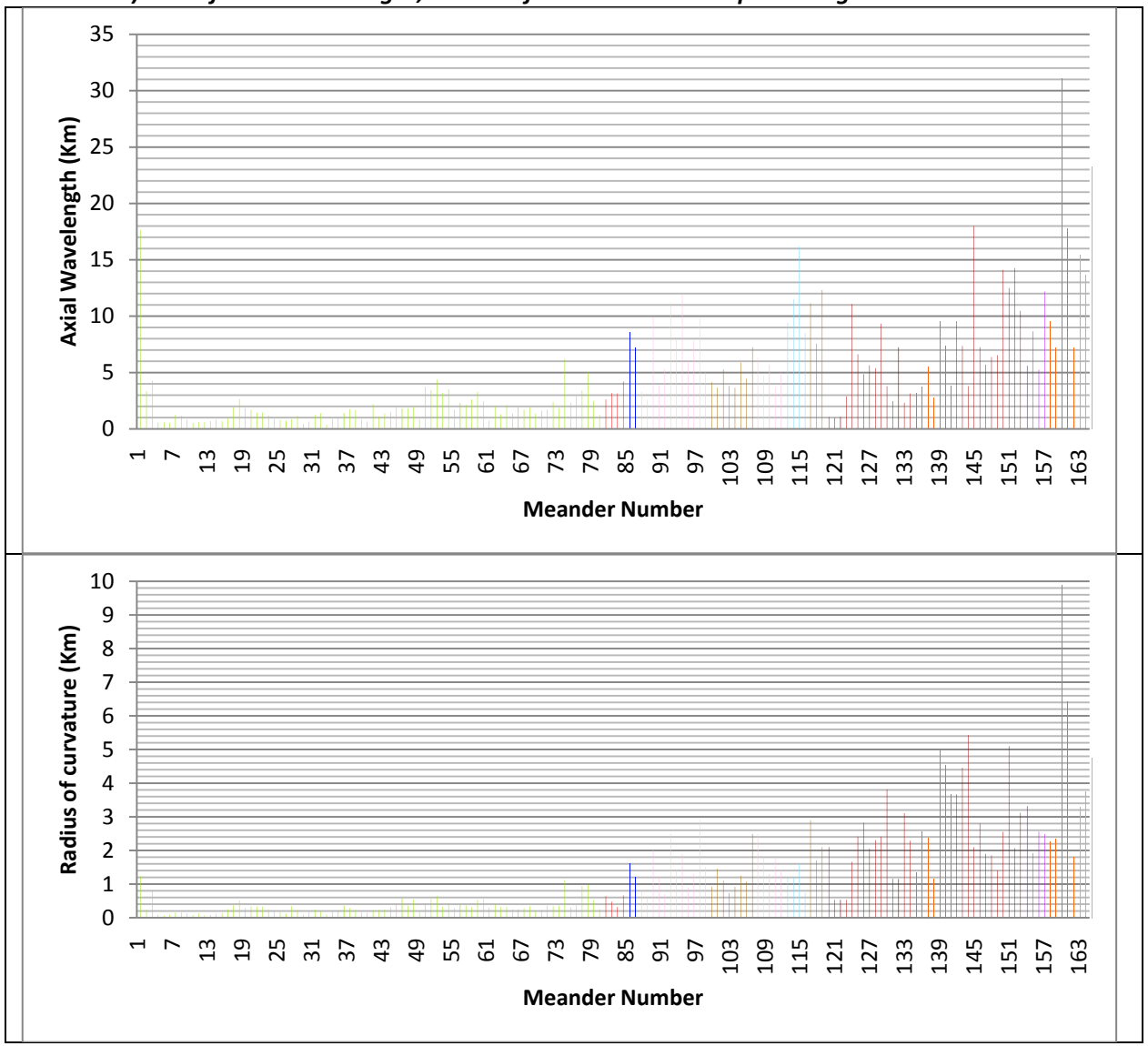
River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (r_c) Km	Axial wavelength(L) Km	Amplitude(Am) Km
1	Himalayan Steep Valley	Gomukh - Rishikesh	24	76	0.31	2.32	1.11
				77	0.37	2.91	0.77
				78	0.94	3.42	1.88
			25	79	0.98	5.02	2.03
			26	80	0.52	2.48	1.05
				81	0.26	1.23	0.56
2	Himalayan, Partly Confined Floodplain and Channel, Braided	Rishikesh (Ramjhula) - Haridwar	27	82	0.64	2.62	0.96
				83	0.48	3.18	0.93
				84	0.32	3.13	1.07
			28	No Meander			
			29	85	0.66	4.21	1.37
			30	No Meander			
3	Piedmont, Partly Confined Floodplain and Channel, Braided	Haridwar - Bijnor	31	No Meander			
			32	86	1.6	8.6	2.9
			33	87	1.2	7.2	1.8
			34	No Meander			
4	Valley-Interfluve, Partly Confined Floodplain and Channel, Braided	Bijnor - Narora	35	88	0.8	3.3	1.8
				89	0.6	2.6	1.5
			36	90	2	9.9	3.7
				91	1.2	3.9	2.4
				92	0.7	5.3	3
			37	93	2.5	11.2	4.5

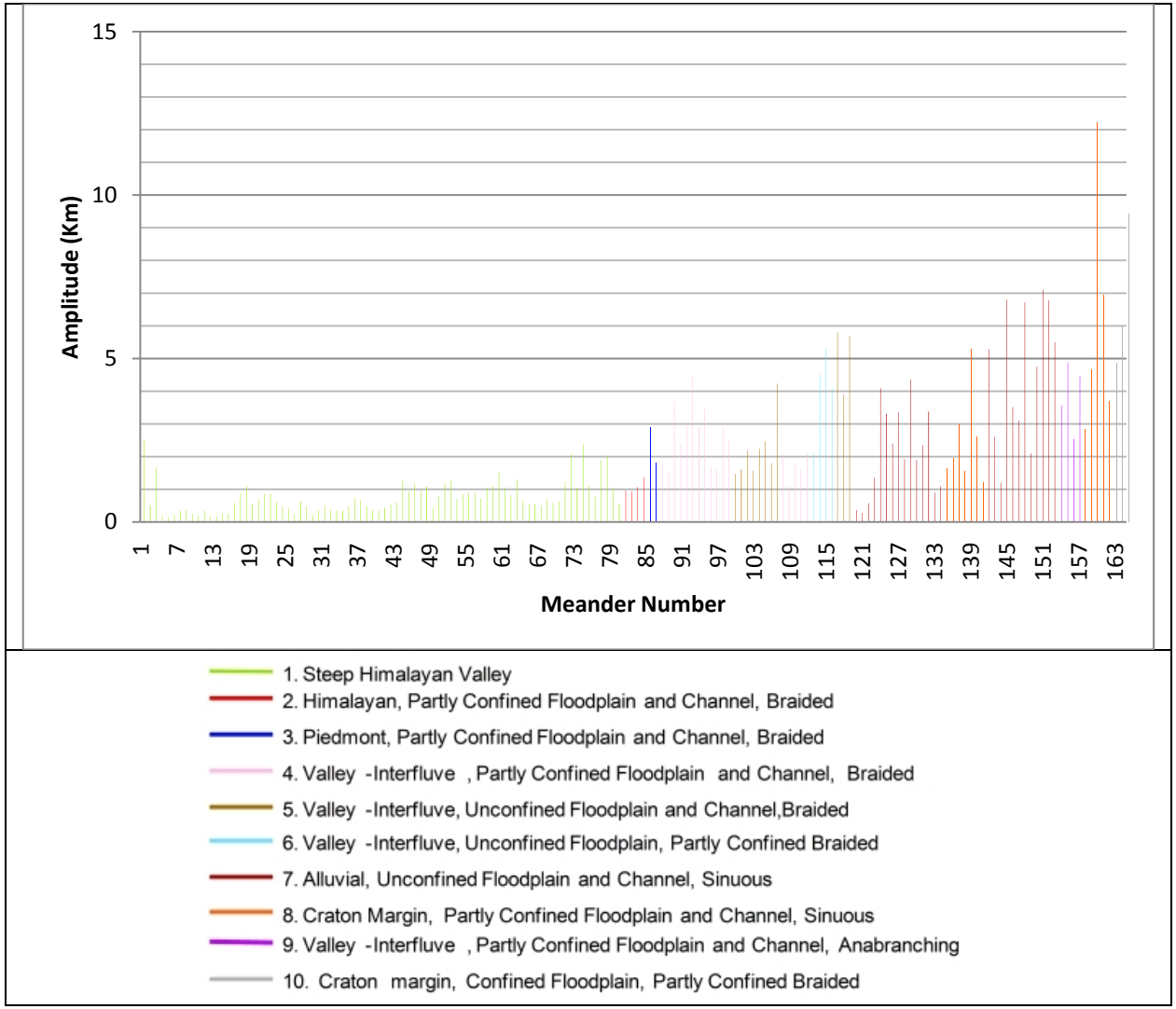
River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (r_c) Km	Axial wavelength(L) Km	Amplitude(Am) Km
4	Valley-Interfluve, Partly Confined Floodplain and Channel, Braided	Bijnor - Narora	38	94	1.4	8	2.9
			39	95	1.9	11.9	3.5
			40	No Meander			
			41	96	0.9	6	1.7
				97	1.3	7.8	1.6
			42	98	2.9	9.8	2.9
				99	1.5	5	2.5
			NARORA BARRAGE				
5	Valley-Interfluve, Unconfined Floodplain and Channel, Braided	Narora - Fatehgarh	43	No Meander			
			44	100	0.92	4.14	1.47
				101	1.46	3.67	1.6
				102	1.1	5.27	2.2
			45	103	0.73	3.81	1.57
				104	0.92	3.65	2.24
			46	105	1.25	5.9	2.47
			47	106	1.07	4.46	1.8
				107	2.49	7.26	4.23
			48	No Meander			
4	Valley-Interfluve, Partly Confined Floodplain and Channel, Braided	Fatehgarh - Fatehpur	49	No Meander			
			50	No Meander			
			51	108	1.8	6.3	2.1
			52	No Meander			
			KANPUR BARRAGE				
			53	No Meander			
			54	109	1.3	4.7	1.1
			55	110	1.8	5.7	1.8
				111	1.4	3.7	1.6
				112	1.2	5	2.1

River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (r_c) Km	Axial wavelength(L) Km	Amplitude(Am) Km
6	Valley-Interfluve, Unconfined Floodplain, Partly Confined Braided	Fatehpur - Sirathu	56	113	1.2	9.4	2.1
				114	1.6	11.5	4.5
			57	115	0.74	16.2	5.3
			58	116	2.2	8.5	4.1
5	Valley-Interfluve, Unconfined Floodplain, Unconfined Braided	Sirathu - Allahabad	59	No Meander			
			60	117	2.9	11.14	5.8
				118	1.7	7.57	3.9
				119	2.1	12.32	5.7
7	Alluvial, Unconfined Floodplain and Channel, Sinuous	Allahabad - Gopiganj	61	120	0.53	1.06	0.36
				121	0.53	0.99	0.28
				122	0.53	1.07	0.58
				123	1.66	2.89	1.35
				124	2.41	11.08	4.1
				125	2.82	6.62	3.31
				126	2.05	4.85	2.4
				127	2.3	5.64	3.35
				128	2.41	5.4	1.92
			62	129	3.81	9.33	4.36
				130	1.16	3.8	1.9
				131	1.15	2.46	2.35
				132	3.11	7.24	3.38
				133	2.29	2.32	0.9
				134	2.47	3.13	1.09
8	Craton Margin, Partly Confined Floodplain and Channel, Sinuous	Gopiganj - Chunar	63	135	1.34	3.15	1.64
				136	2.56	3.71	1.95
				137	2.38	5.54	2.98
				138	1.16	2.74	1.56
			64	139	5.01	9.58	5.28
				140	4.54	7.36	2.61
				141	3.67	3.8	1.21

River Style No.	River Style name	Stretch Name	Reach No.	Meander number	Radius of curvature (rc) Km	Axial wavelength(L) Km	Amplitude(Am) Km
				142	4.46	9.57	5.29
				143	5.43	7.36	2.61
			65	144	2.1	3.8	1.21
			66	145	2.8	18	6.8
			67	146	1.9	7.25	3.52
				147	1.85	5.71	3.1
			68	148	1.4	6.36	6.72
			69	149	2.55	6.55	2.1
			70	No Meander			
			71	150	5.1	14.1	4.75
	Alluvial, Unconfined Floodplain and		72	151	2.07	12.5	7.1
				152	3.12	14.26	6.78
7	Channel, Sinuous	Chunar - Chapra	73	153	3.24	10.47	5.5
			74	154	3.32	5.6	3.58
	Valley-Interfluve, Partly Confined Floodplain and		75	155	1.92	8.65	4.88
			76	156	2.56	5.25	2.54
	Channel,		77	No Meander			
9	Anabranching	Chapra - Pansalla	78	157	2.49	12.19	4.47
			79	158	2.273	9.547	2.824
				159	2.342	7.178	4.664
	Craton Margin, Partly Confined Floodplain and			160	9.882	31.09	12.22
			80	161	6.414	17.754	6.953
8	Channel, Sinuous	Pansalla - Kursela		162	1.799	7.246	3.682
			81	163	3.274	15.41	4.856
	Craton margin, Confined			164	3.737	13.694	5.98
	Floodplain, Partly			165	4.756	23.253	9.434
10	Confined Braided	Kursela - Farakka		FARAKKA BARRAGE			

b) Plot of Axial wavelength, Radius of curvature and Amplitude against Meander Number




15
10
5
0
Amplitude (Km)
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
103
109
115
121
127
133
139
145
151
157
163
Meander Number
1. Steep Himalayan Valley
2. Himalayan, Partly Confined Floodplain and Channel, Braided
3. Piedmont, Partly Confined Floodplain and Channel, Braided
4. Valley -Interfluve , Partly Confined Floodplain and Channel, Braided
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10. Craton margin, Confined Floodplain, Partly Confined Braided