Report Code: 021_GBP_IIT_FGM_DAT_02_Ver 1_Dec 2011

Delineation of Valley Margin and Geomorphic Mapping

of Channel Belt and Active Floodplain of the Ganga River

GRB EMP : Ganga River Basin Environment Management Plan

by

Indian Institutes of Technology

IIT Bombay | IIT Delhi | IIT Guwahati | IIT Kanpur | IIT Kharagpur | IIT Madras | IIT Roorkee

Preface

In exercise of the powers conferred by sub-sections (1) and (3) of Section 3 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government has constituted National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring and coordinating authority for strengthening the collective efforts of the Central and State Government for effective abatement of pollution and conservation of the river Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin Management Plan (GRBMP).

A Consortium of 7 Indian Institute of Technology (IIT) has been given the responsibility of preparing Ganga River Basin Management Plan (GRBMP) by the Ministry of Environment and Forests (MoEF), GOI, New Delhi. Memorandum of Agreement (MoA) has been signed between 7 IITs (Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee) and MoEF for this purpose on July 6, 2010.

This report is one of the many reports prepared by IITs to describe the strategy, information, methodology, analysis and suggestions and recommendations in developing Ganga River Basin Management Plan (GRBMP). The overall Framework for documentation of GRBMP and Indexing of Reports is presented on the inside cover page.

There are two aspects to the development of GRBMP. Dedicated people spent hours discussing concerns, issues and potential solutions to problems. This dedication leads to the preparation of reports that hope to articulate the outcome of the dialogue in a way that is useful. Many people contributed to the preparation of this report directly or indirectly. This report is therefore truly a collective effort that reflects the cooperation of many, particularly those who are members of the IIT Team. A list of persons who have contributed directly and names of those who have taken lead in preparing this report is given on the reverse side.

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Contents

1. Preamble

In the first report (005_GBP_IIT_FGM_DAT_01_Ver 1_Dec 2010) of the Fluvial Geomorphology Thematic Group, the 'active floodplain' was mapped from satellite imagery to define the 'river space'. This report presents the mapping of the valley margin and geomorphic features in the channel belt as well as active floodplain. As has already been emphasized, it is important to recognize and document the various hydrological and ecological functions of the river valley and floodplains for developing a sustainable river management plan.

A river valley is a wider and more extensive area, compared to active floodplain, and is primarily defined on the basis of a topographic 'break' across the river. The course of the river may not be necessarily symmetric to its valley. The valley margin primarily defines:

a) the 'water divide' which is the line dividing neighbouring drainage basins (catchment) on a land surface. It can be visualized as a line on the ground on either side of which water droplet will start a journey to different rivers and even to different sides of the region. It is analogous to the 'hydrological boundary' between two watersheds.

b) the limit of 'lateral connectivity' between the river channel and floodplain or in other words, the hydrological and functional connection between the river and the riparian zone.

c) the 'recharge area' of the river in question i.e. the area in which the surface water infiltrates and is added to the groundwater because of the topographic low. It is important to note here that the areas for any 'artificial recharge' (reservoirs/ditches) must be located within the river valley margin.

In addition, the geomorphic features within the active floodplain delineated earlier have been mapped with an idea to document river character and behavior for understanding the distinctive physical processes operating in different reaches.

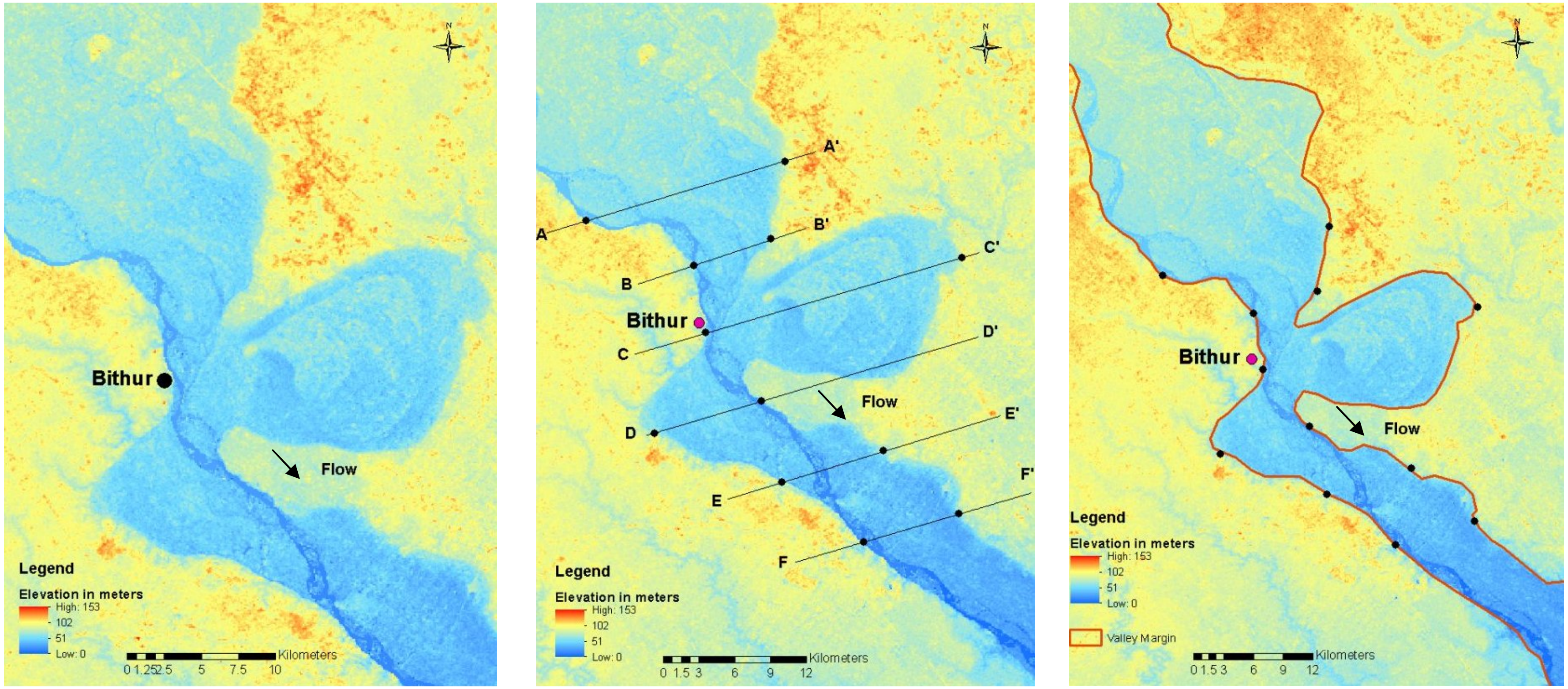
2. Data used and Methodology

2.1 Mapping of Valley Margin using SRTM data

The Shuttle Radar Topography Mission (SRTM) launched in February 2000 obtained digital elevation data at 90 m resolution for most parts of the world. Elevation changes can be identified by classifying the SRTM into multiple classes, and then assigning a color code. Figure 1(a) shows such a color-coded map for the Kanpur area of SRTM data, classified into 4 classes. The valley margin was marked based on the profiles from generated SRTM data (Figures 2a-f). Figure 1 (b) shows the profile lines and the black dots represent the topographic break indicating the valley margin and the mapped valley margin is shown in Figure 1 (c).

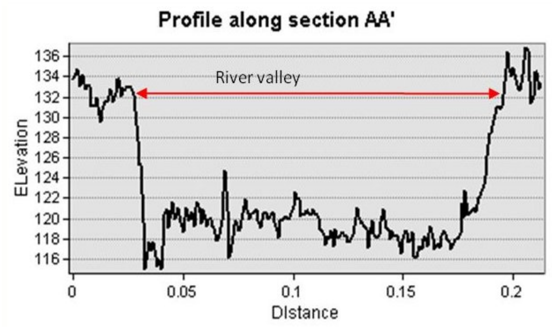
2.2 Mapping of geomorphic features

The Landsat TM data of pre-monsoon period 2010 was used to map the different geomorphic features using the false color composite (432 band combination on RGB planes). Figure 2(g) shows the Landsat data for the Kanpur city area. Table 1 lists the different geomorphic features that were mapped with their definitions. Google Earth images were also used for identification of features. Figure 2(h) shows a snapshot of the same area as given in the Landsat imagery.

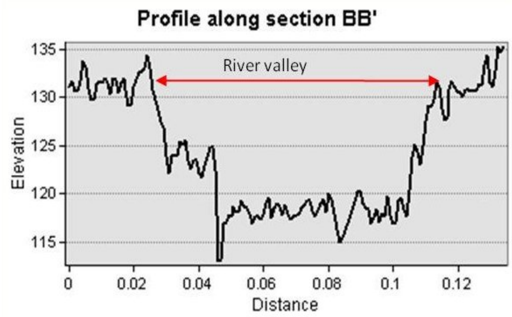


(a) (b) (c)

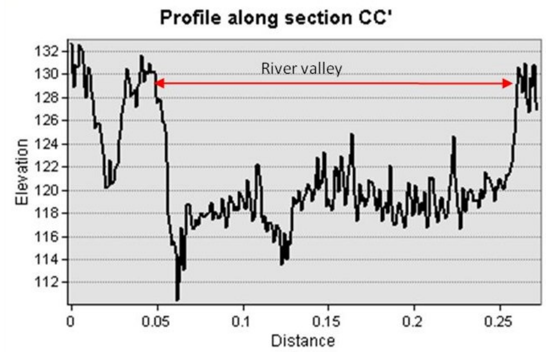
Figure 1: (a) Color coded SRTM data, (b) sections across which profiling have been done, (c) final valley margin of the area



(a)



(b)



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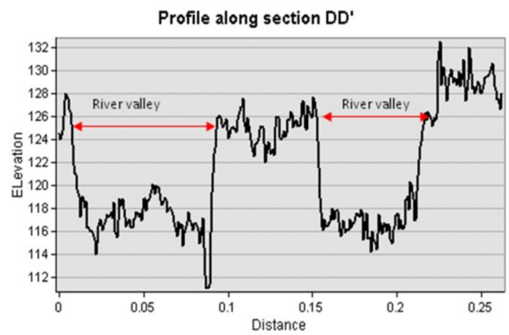

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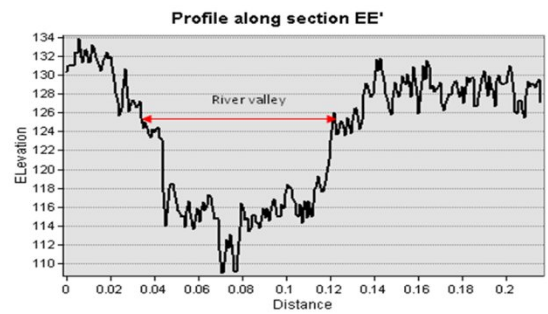

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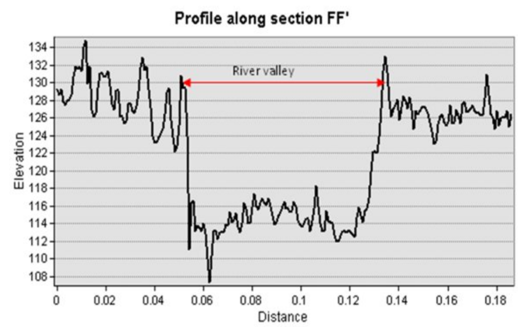

(f)

Distance in decimal degrees vs Elevation in meters

Figure 2 (a-f): Showing the profiles along the selected sections

(g) (h)

Figure 2 (g-h): (g) a snapshot of Landsat imagery, (h) snap shot of the same area in Google Earth

Table 1: List of Channel belt and Floodplain geomorphic units

Major Geomorphic Unit, Channel belt

Feature	Definition and characteristics
Mid channel bar or longitudinal bar	Mid channel tear drop shaped unit bar, elongated in flow direction in gravel and mixed bed channels. Bar deposits typically decrease in size downstream away from a coarser bar head. This can be vegetated.
Transverse bar or linguoid bar	Mid channel unit bar oriented perpendicular to flow generally in sand bed channels. Reflects downstream movement of sand as ribs. If crescent form then it is linguoid bar.
Point bar	Bank attached arcuate shaped unit bar developed along convex banks of meander bends. Bar forms follow the alignment of the bend with differing radii of curvature. The bar surface is typically inclined towards the channel. Grain size typically fines down bar (around the bend) and laterally (away from the channel). Typically these unit bar forms are largely unvegetated.
Tributary bar	Formed at, and immediately downstream of, the mouth of tributaries. Generally poorly sorted gravels and sands with complex and variable internal sedimentary structures.
Alluvial island	Vegetated mid channel compound bars that generally comprise an array of smaller scale geomorphic units. Elongate ridge forms are commonly aligned with flow direction along these major in channel sediment storage units. Scaled to one or more channel widths in length. Especially found when river is anastomosing. Also, size is much larger than mid channel bar.
Lateral bar	Bank attached unit bar developed along low sinuosity reaches of gravel and mixed bed channels. Bar surface is generally inclined towards the channel.
Chute channel	Elongate channel that dissects a bar surface. A common feature on compound point bars, islands and mid channel bars.
Secondary channel	Pattern of coexistant multiple-anastomosing channels (repeated bifurcating and rejoining) with low width/depth ratio. Open channels that remain connected to the trunk stream or the main channel.
Abandoned Braid bars	At places the paleobars that are now part of the flood plain, clearly display accretion surfaces of braid bars. The accretion surfaces within them cannot be related to growth and abandonment of point bars rather they show clear pattern of a braided mid-channel or lateral bars.

Table 1 continued to next page … … … …

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Feature	Definition and characteristics
Alluvial terrace	Typically a relatively flat (planar), valley marginal feature that is perched above the contemporary channel and/or floodplain. Generally separated from the floodplain by e steep slope (a terrace riser). Can be aired or unpaired. Often present as a flight of terraces.
Ox bow lake	Channel depressions of arcuate or sinuous planform (generally one meander loop). Horse show or semi circular in planview, reflecting the morphology of the former channel bends with water.
Levee	Raised elongate asymmetrical ridge that borders the channel, with steeper proximal margins. Best developed along concave banks and in some confined settings. Scaled in proportion to the adjacent channel, levee crests may stand several meters above the floodplain surface. Composed almost entirely of suspended load sediments, i.e. dominantly silt, often sandy.
Flood channel	Gently curved, subsidiary channel to a primary channel. Generally of low sinuosity. Entrance height near bankfull floodstage. May exist as a depressed tract of the floodplain that occasionally conveys floodwaters.
Water body/Wetland	Stagnant water bodies in the flood plain which are of permanent nature. Is distinguishable from Ox bow lake as it does not have the typical shape of ox bow.
Accretion surfaces	These are curved lines occurring within a bar or in the floodplain within the abandoned bar deposits (similar to meander scrolls). They represent different paleo-position of an accreting bar (both meander and braided bars). Whereas some of them can be related to the accretion surfaces of meander bars (meander scrolls), many of them cannot be related to accretion surfaces of point bars. Some of them are related to mid-channel braid bar or lateral bar accretion surfaces.
Meander cut off	Channel depressions of arcuate or sinuous planform (generally one meander loop). Horse show or semi circular in planview, reflecting the morphology of the former channel bends without water.
Meander scroll	Ridge like morphology associated with successive migrating channel. Difference with meander cut-off is they are multiple and in a succession.
Abandoned meander belt	Especially in the stretch of Ganga downstream of Allahabad; coalesce of abandoned successive meandering channel resulting in a unique geomorphic unit.
Abandoned Meander Bars	These occur in the flood plain with point bar accretion surfaces and with/without ox bow lakes.
Abandoned channel	They are dry channels which were active in the past but at present have become dry.
Abandoned meander loop	These features are similar to ox bow lake but at a much larger scale.
Sand patch (flood deposits)	Occurring typically along the stream these are areas of dry sand which have been deposited during flooding. They do not have any distinct shape and can be distinguished from channel bars.

3. Results and Discussions

3.1 Delineation of basin scale Valley margin along the Ganga River

Figure 3 shows the 'valley margin' for the river Ganga from Haridwar to Farakka. The 'valley width' is not uniform along the entire stretch. Based on this, distinct reaches were identified as shown in Table 2.

Table 2: Valley Margin of the Ganga River

Stretch	Maximum and minimum width, km	Major characteristics
Haridwar to Narora	28/9.7	North-south trending valley suddenly widens immediately downstream of Haridwar to a maximum of 28 km on the western side; river is flowing at the eastern edge of the valley; valley width narrows down considerably around Bijnor (9.7 km) and the river swings to the western edge upstream of Bijnor forming a wide valley; river valley widens again downstream of Bijnor and maintains a similar width up to Garmukteshwar; downstream of Garhmukteshwar, the river is characteristically flowing along the western edge all the way to Narora and a wide NNW-SSE trending valley is mapped dominantly on the eastern side
Narora to Fatehgarh	27.8/12.7	Fairly symmetric, NW-SE trending valley with wide valley margins on both sides of the river; Just upstream of Fatehgarh, the river swings to the western edge of the valley and a wide valley is mapped on the eastern side.
Fatehgarh to Kanpur	27.4/3.8	Highly asymmetric valley trending NW-SE, much wider along the eastern valley margin; incised valley margin along the western bank; a large meander around Kanpur causes a significant widening of the valley; valley margin coincides with the active floodplain boundary in a large part of this reach.
Kanpur to Allahabad	11.3/~1	Wide valley along the eastern bank continues to ~ 42.8km downstream of Kanpur and then suddenly narrows down to ~ 1km around Dalmau and Unchahar region with only a few patches of wide valley on the eastern side close to Allahabad; valley margin merges with active floodplain in most parts.

Table 2 continued to next page … … … …

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Stretch	Maximum and minimum width, km	Major characteristics
Allahabad to Varanasi	14.2/1.8	Valley width quite variable and extends to both banks of the river, sinuous course of the river frequently swings from the right edge to the left edge of the valley.
Varanasi to Munger	36.1/7	Valley widens significantly downstream of Varanasi and is evenly distributed on left and right bank of the river; valley width reduces significantly downstream of Patna and also becomes asymmetric, mostly spread along the left bank.
Munger to Farakka	39.2/7.3	Large parts of the valley are spread towards the left bank and the river is flowing at the southern edge of the valley up to 95 km downstream of Munger after which it swings to the northern and southern edges alternately.

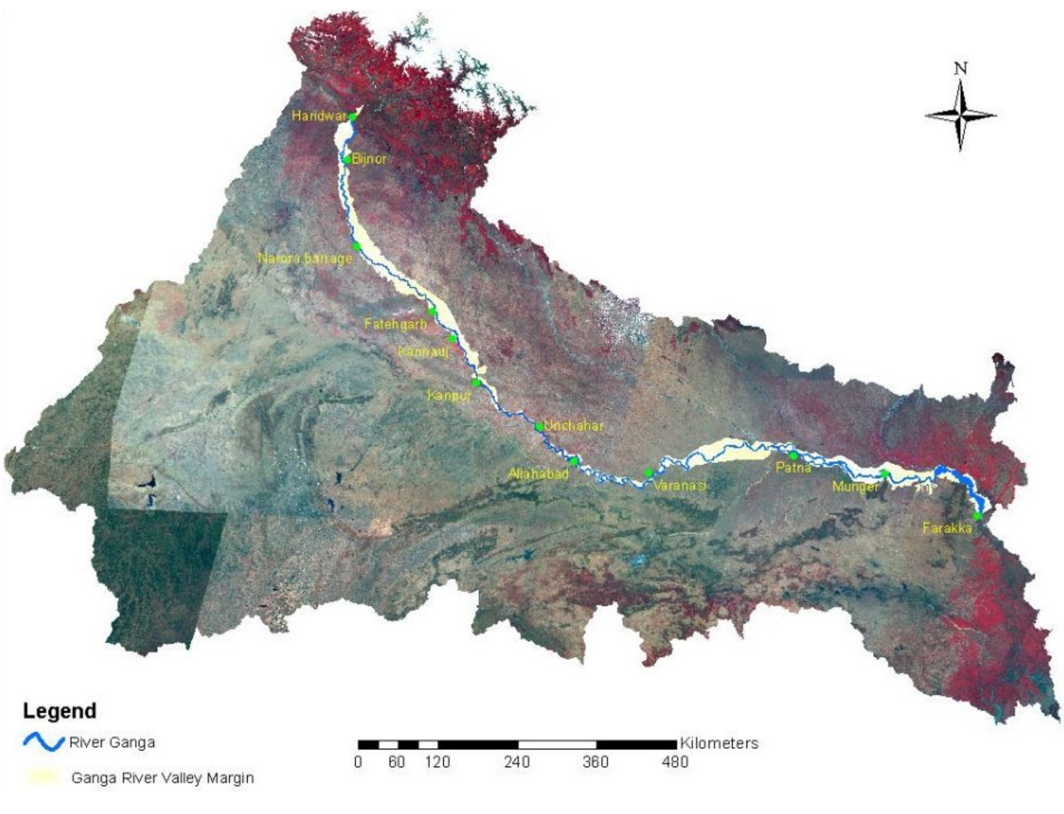

Figure 3: Ganga river valley margin from Haridwar to Farakka plotted in AWiFS image

3.2 Geomorphic Mapping

This section presents the important geomorphic features in the channel belt and active floodplain along the Ganga River. At this stage, diagnostic features are discussed in windows for the sake of clarity but eventually the data will be integrated into distinct zones based on ecological characteristics and biodiversity. We will then characterize River Styles in each zone.

3.2.1 Gangotri to Haridwar

The major part of the Gangotri to Haridwar extent is occupied by structural ridges, valleys and at some places features of fluvial origin. This extent mainly shows the highly and moderately dissected hills of Himalayan range. This stretch of the Ganga River between Gangotri to Haridwar has significantly narrow valley on both sides of the river and the river itself is quite narrow with a much thin water line which is clearly shown in the satellite image. Very narrow flood plain has been observed. The geomorphic fluvial origin features include lateral bar, mid channel bar, alluvial island, chute channel and point bar. Valley margin has also been marked along the Ganga River. Figure 4 shows the geomorphic mapping of the stretch.

3.2.2 Haridwar to Narora

A major part of the Haridwar to Narora stretch is occupied by fluvial geomorphic features. In this stretch, wide flood plains have been marked. The flood plain is composed of sand, gravel, silt and clay. This stretch of the Ganga River has a considerably wide valley on either side of the river. The river channel in this stretch is highly braided. As a result, mid channel braid bars form a significant geomorphic feature followed by lateral bars, and point bars. For the mapping clarity, the geomorphic map in this stretch has been shown into two parts. Figure 5a shows from Haridwar to Mawana in which the river is flowing towards the eastern edge of the valley in the upper parts and then swings to the western and eastern parts alternately. An extremely wide valley immediately downstream of Haridwar is due to a sudden decrease in slope as the river debouches into the plains and forming a large depositional area (piedmont fan). A large number of paleochannels on the western side of the main channel suggest an eastward migration of the river in recent times. In the reach upstream of Bijnor has a large alluvial island which splits the channel into two parts. Downstream of Bijnor, the river has a wide floodplain on both sides. However, this situation changes dramatically downstream of Garhmukteshwar. The river now flows close to the western edge of the valley and has developed a wide valley on the eastern side (Figure 5b). The active floodplain is much narrower compared to the valley all the way to Narora where a barrage is located. The river channel as well as active floodplain have simple forms composed of a few mid-channel bars and fewer meander cut-offs.

3.2.3 Narora to Fatehgarh

This stretch of the river has significantly wide valley on both sides of the river but the river itself is quite narrow with a much thin water line (Figure. 6a) which is clearly a manifestation of the Narora barrage. The river is highly braided but with significant sinuosity in several reaches. As a result, abandoned braid bars form a significant geomorphic feature followed by lateral bars. A number of abandoned channels are mapped which bound the abandoned braid bars and therefore representing the secondary channels of the Ganga. Some of them probably get activated during the high flows. Frequent sand patches on the southern side represent flood deposits.

3.2.4 Fatehgarh to Kanpur

In this stretch, two important tributaries, the Ramganga and the Garra join from the northern side and the river Kali from the southern side around Kannauj. The Ganga river flows along the southern margin of the valley (Figure 6b) and is incised in most reaches with a cliff line varying in height from 10-15 meters. As a result, a wide floodplain runs along the northern bank and very narrow floodplain along the southern bank. The channel is multi-thread with frequent and large mid-channel bars and infrequent lateral bars. Abundant meander cutoffs, scrolls and abandoned meander loop in the active floodplain on the northern side suggests that the river has been gradually shifting towards the south. The presence of an abandoned meander loop upstream of Kanpur is conspicuous because of which the valley width suddenly widens.

3.2.5 Kanpur to Allahabad

Downstream of Kanpur, the river continues to flow along the western edge of the valley for ~ 30 km and 12.8 km further downstream the valley narrows down considerably (Figure. 6c). The river starts swinging to the northern and southern edge within the limited space and narrow floodplains have developed on both sides alternately. From a point ~ 71 km downstream of Kanpur the river flows in an east-west trend for ~ 21.2 km and then resumes NW-SE trend at Dalmau. The river valley also narrows down downstream of Dalmau and attains a minimum width of ~1 km at Unchahar. A wide abandoned meander belt is mapped at Dalmau but apart from this, there is very little evidence of channel migration suggesting this to be a relatively stable stretch. The valley starts widening again downstream of Unchahar (Figure 6d) and attains a width of ~ 7 km at Allahabad. Pockets of wide floodplain have developed in the stretches upstream of Allahabad which are as wide as the valley margin in this region. Frequency of abandoned channels and meander cut-offs also increases and a large abandoned meander belt is noted at Allahabad.

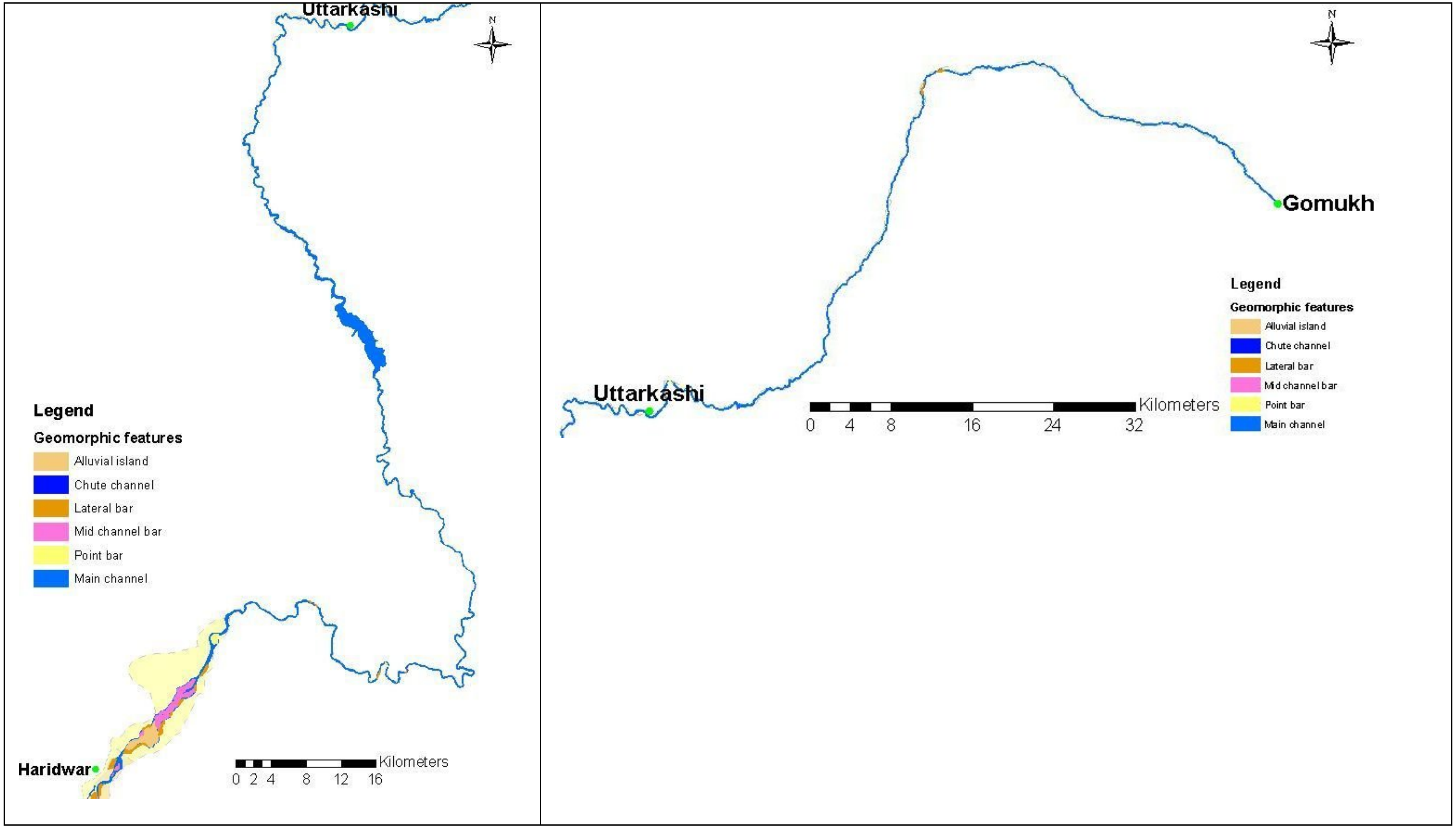

Figure 4: Geomorphic mapping of Ganga between Haridwar to Gomukh

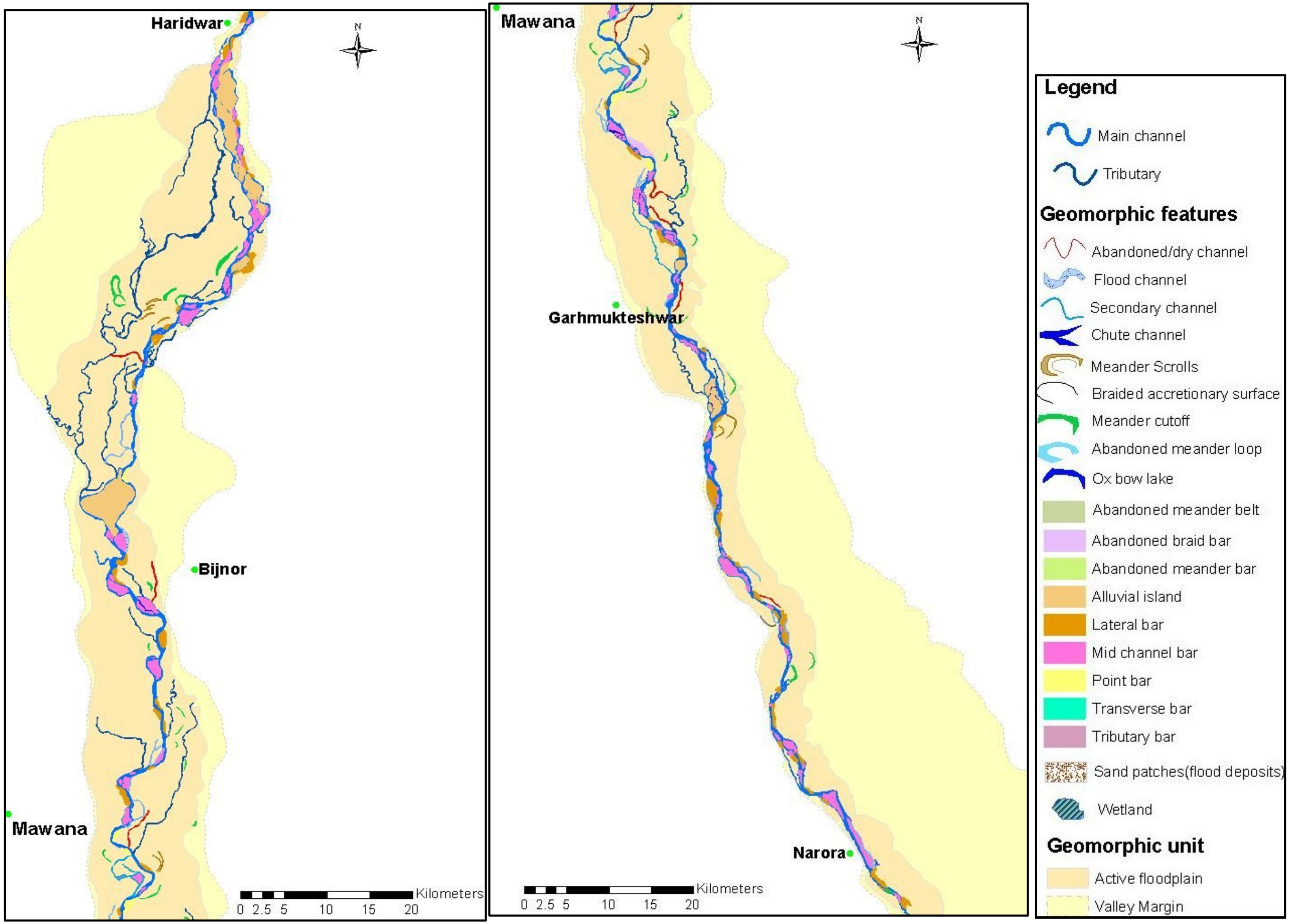

Figure 5 (a-b): Geomorphic map of the Haridwar to Narora stretch

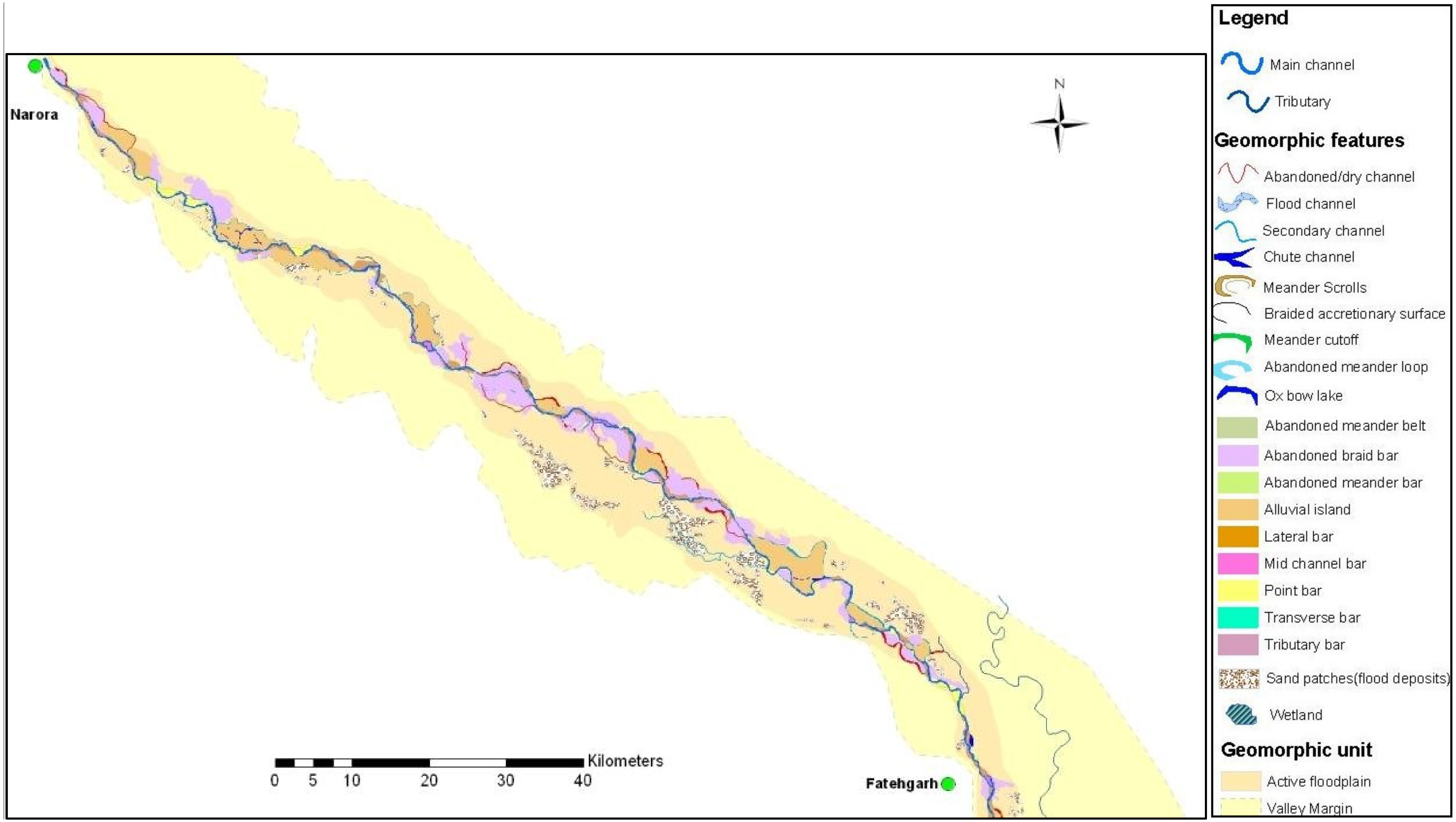

Figure 6a: Geomorphic map of the Narora to Fatehgarh stretch

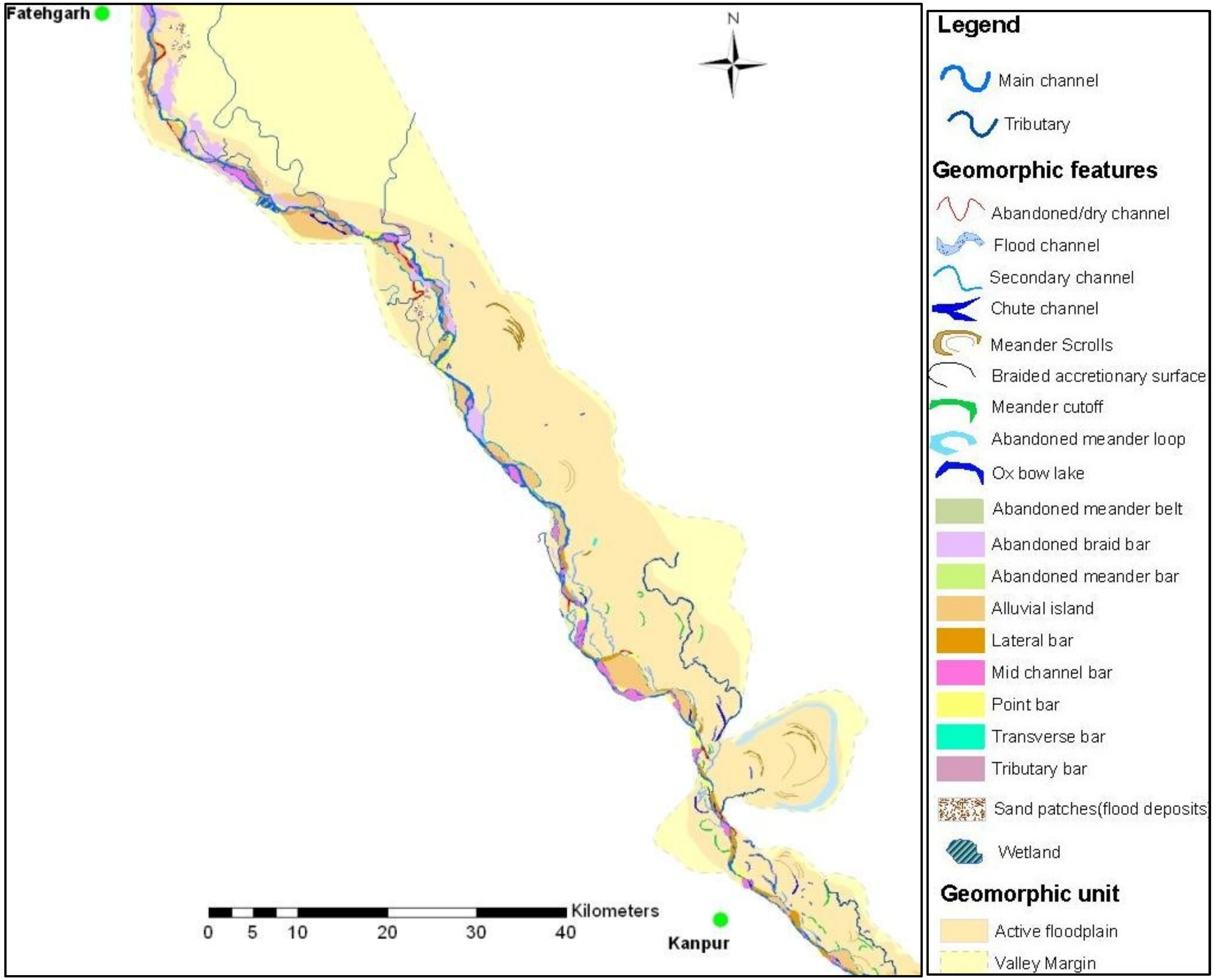

Figure 6b: Geomorphic map of the Fatehgarh to Kanpur stretch

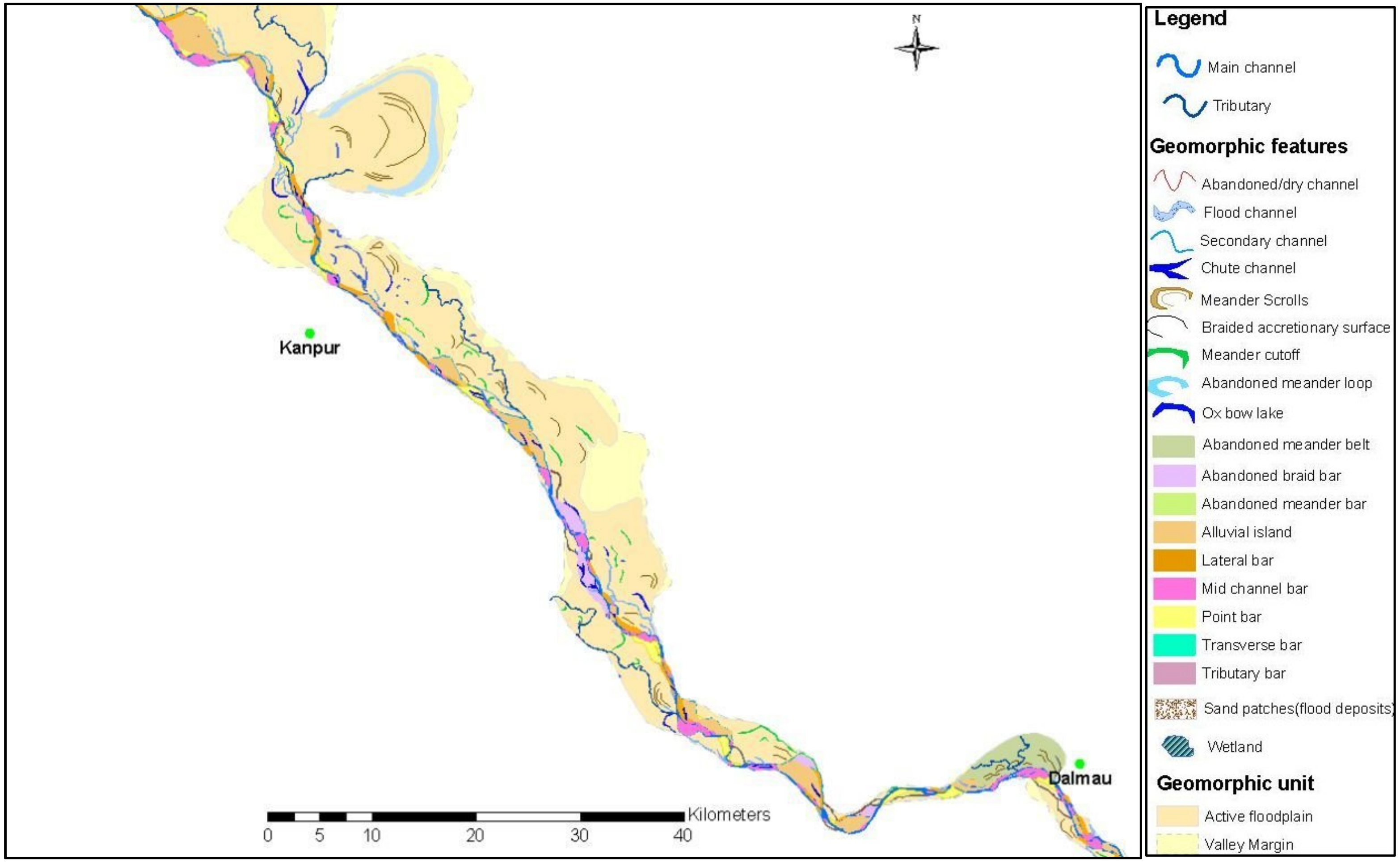

Figure 6c: Geomorphic map of the Kanpur to Dalmau stretch

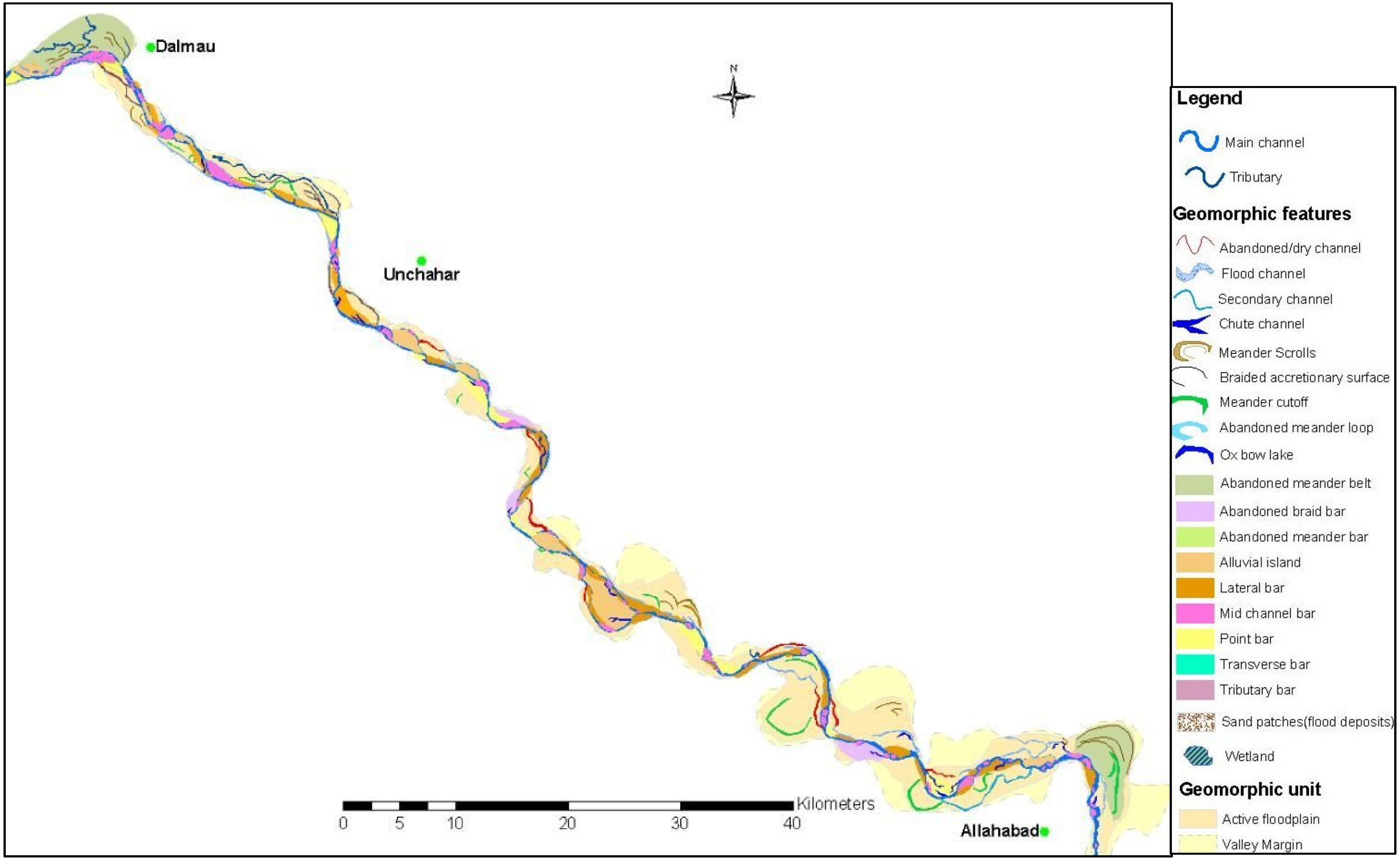

Figure 6d: Geomorphic map of the Dalmau to Allahabad stretch

3.2.6 Allahabad to Varanasi

The river stretch between Allahabad and Varanasi (Figure 7) over a length of 245 km is a unique segment of the Ganga River as it nearly approaches (~7 km; near Meja) the peninsular shield and exhibits a strong basement/tectonic control with a maximum sinistral shift of about 16 km towards SSE (Allahabad). In addition, these two cities are the most popular religious centers along the river course. The mapping of the river course based on remote sensing data with limited field checks has shown the various geomorphic units with their respective numbers and areal coverage which includes mid-channel bars (134.59 sq km), point bars (110.76 sq km), alluvial islands (56.17 sq km), lateral bars (245.34 sq km), meander scrolls (3.18 sq km), flood channels (9.42 sq km), and vegetation patches (69.17 sq km). The width of the flood plain varies between 1.4 (SE of Handia) and 8.4 km (near Mirjapur). The maximum (14.2 km) and minimum (1.8 km) valley margin width have noted ~ 63 km downstream of Allahabad and Varanasi, respectively. The distinctive feature of this stretch of the Ganga River is its partly confined valley fills (cratonic) nature between Chunar and Mirjapur and the remaining part is grouped under unconfined alluvial valley.

3.2.7 Varanasi to Munger

For the sake of clarity, the geomorphic map in this stretch has been presented into two parts, one from Varanasi to Madhubani (Figure. 8a) and then from Madhubani to Munger (Figure. 8b). The minimum width of floodplain in this stretch is 1.8 km downstream Varanasi, while the maximum width went up to 28 km near Ara. The minimum Valley margin width is 7 km d/s Varanasi, while the maximum Valley margin width increases to 36.1 km at the location 23 km d/s Buxar. Alluvial Islands are a significant geomorphic characteristic in this reach of Ganga river (Figure 8a, b). While the first island 30 km downstream of Buxar is only 3.0 km in width, 2 major islands of over 12 km. maximum width are present u/s and d/s Patna and there are 2 more islands further downstream -- between Barh-Mokama (5.5 km max. width) and upstream of Munger (2.0 km wide). Alluvial islands seem to gain prominence in width / area downstream of the confluence of Ghaghra and Gandak rivers from the North and Son river from the South, probably due to the contribution of a huge sediment load from the Himalayan terrain. Two major areas of meandering belts, one each on the northern and southern banks of Ganga river, d/s of Varanasi between Zamania and Buxar, have been identified. Another special stretch between Buxar and Ara (downstream) and confined only to the southern bank of river Ganga, is a zone of meander scrolls, meander scars and ox-bow lakes.

3.2.8 Munger to Farakka

Total along channel length of the studied area is about 330 km and the valley setting is semi-confined (Figure 9). The southern margin is controlled by basement rocks of the craton whereas the northern valley margin is unconfined and merges with/bound by the alluvium of Kosi and Mahananda river. Maximum floodplain width in the study stretch is about 23.3 km and minimum width 7.2 km. The sinuosity of the stretch has increased a little bit as compared to the immediately upstream stretch, but the river is braided all through the sector with many mid-channel bar or large islands, lateral bar, etc. The increase in sinuosity is plausibly related to irregular configuration of the basement block on the southern margin of the valley (e.g. Munger-Bhagalpur-Sahibganj stretch).

The major geomorphic characteristic of the river in this stretch is the braided-sinuous pattern, with numerous fine-grained sandy bars in channel (Fig. 9). These channels are extremely mobile and the active channel is seen to migrate more than a km within a year. Active floodplain is marked by abandoned meander and braided bars. Abandoned channel and bar accretion surfaces at places marked fine clayey fine-grained sediment. Levees, newly grown bars and many abandoned slough channels (flood channels) over braid bars are marked by dry sandy patches. Most of these abandoned bars (now part of the floodplain) and in channel large islands are now agricultural fields.

4. Endnote

The mapping of valley margin and geomorphic features in the active floodplain along the Ganga river shows significant diversity in terms of valley width and geomorphic features in different reaches of the river. These differences have important implications for water resource management and ecological restoration. The stretches with wide valleys and active floodplains could provide sites for creating artificial recharge sites keeping in view the present-day landuse. The channel-belt and floodplain features should provide important insights to the possible habitats for aquatic and land biota. These maps should be integrated with the present distribution of biodiversity along the river and the causal factors for their abundance/absence can be ascertained. In terms of hydrology, the geomorphic features such as the variety of bars are suggestive of river processes which would ultimately relate to the hydrological regime and would provide an important input for E-Flows assessment.

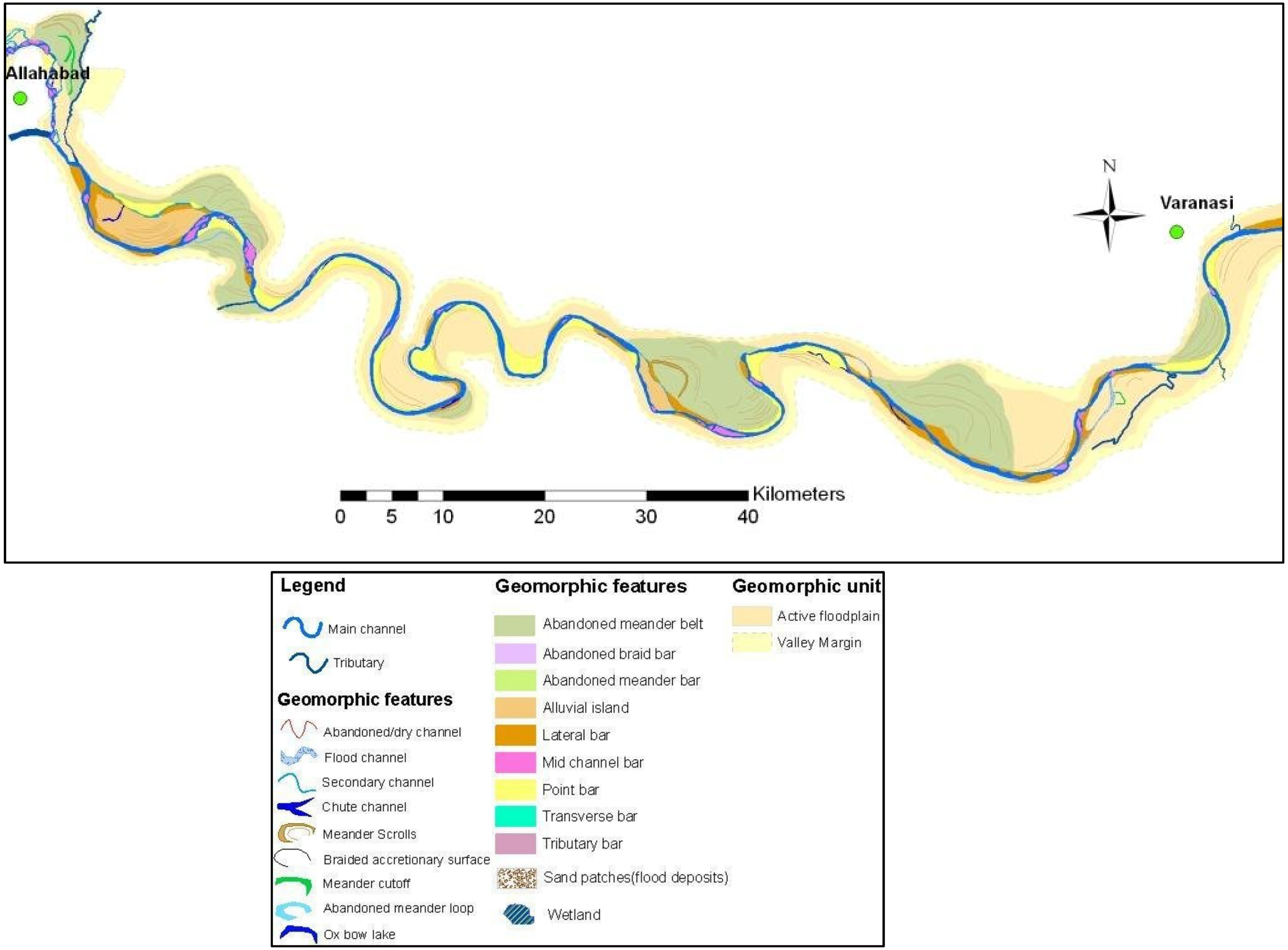

Figure 7: Geomorphic map of the Allahabad to Varanasi stretch

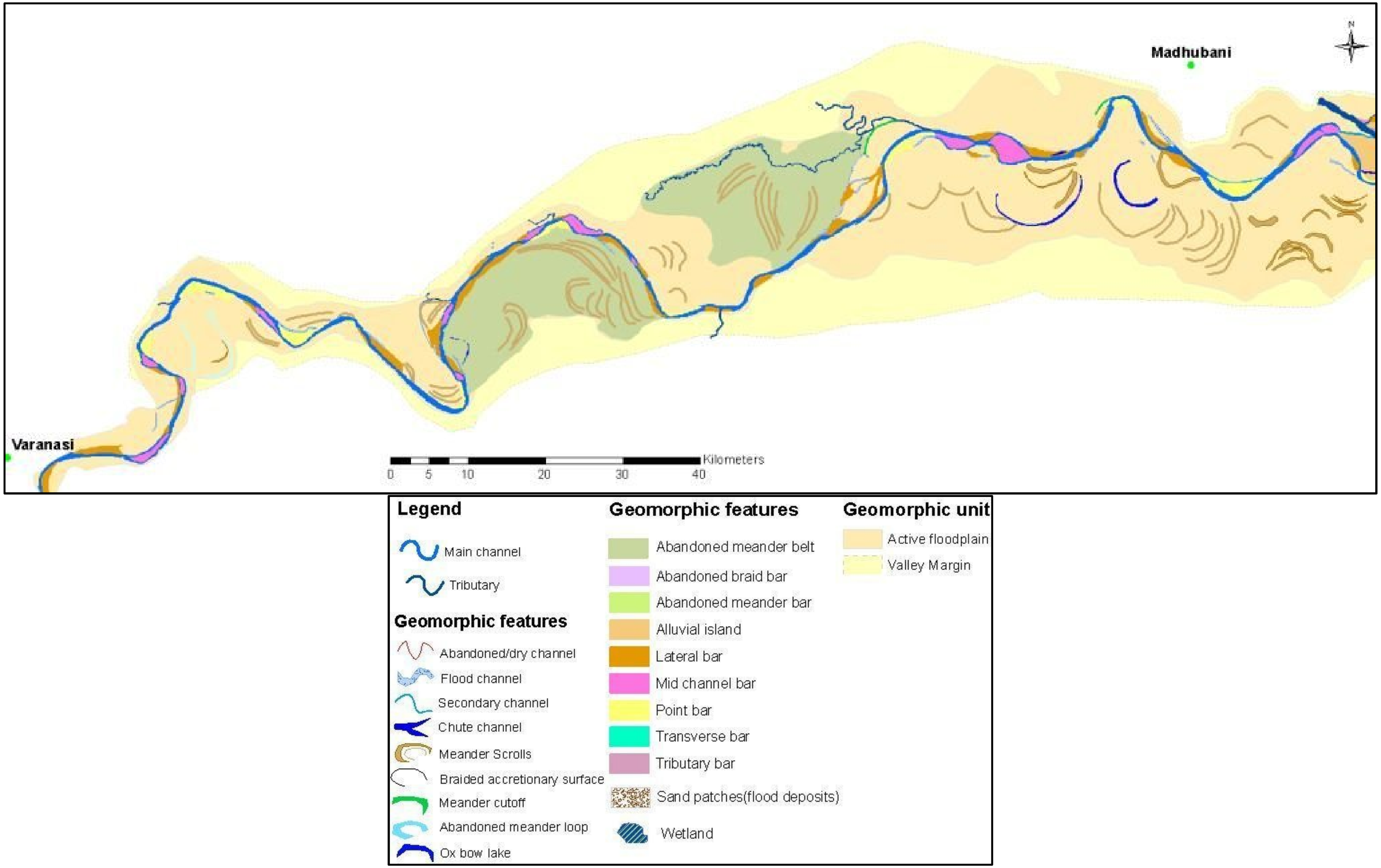

Figure 8 (a): **Geomorphic map of the Varanasi to Madhubani stretch**

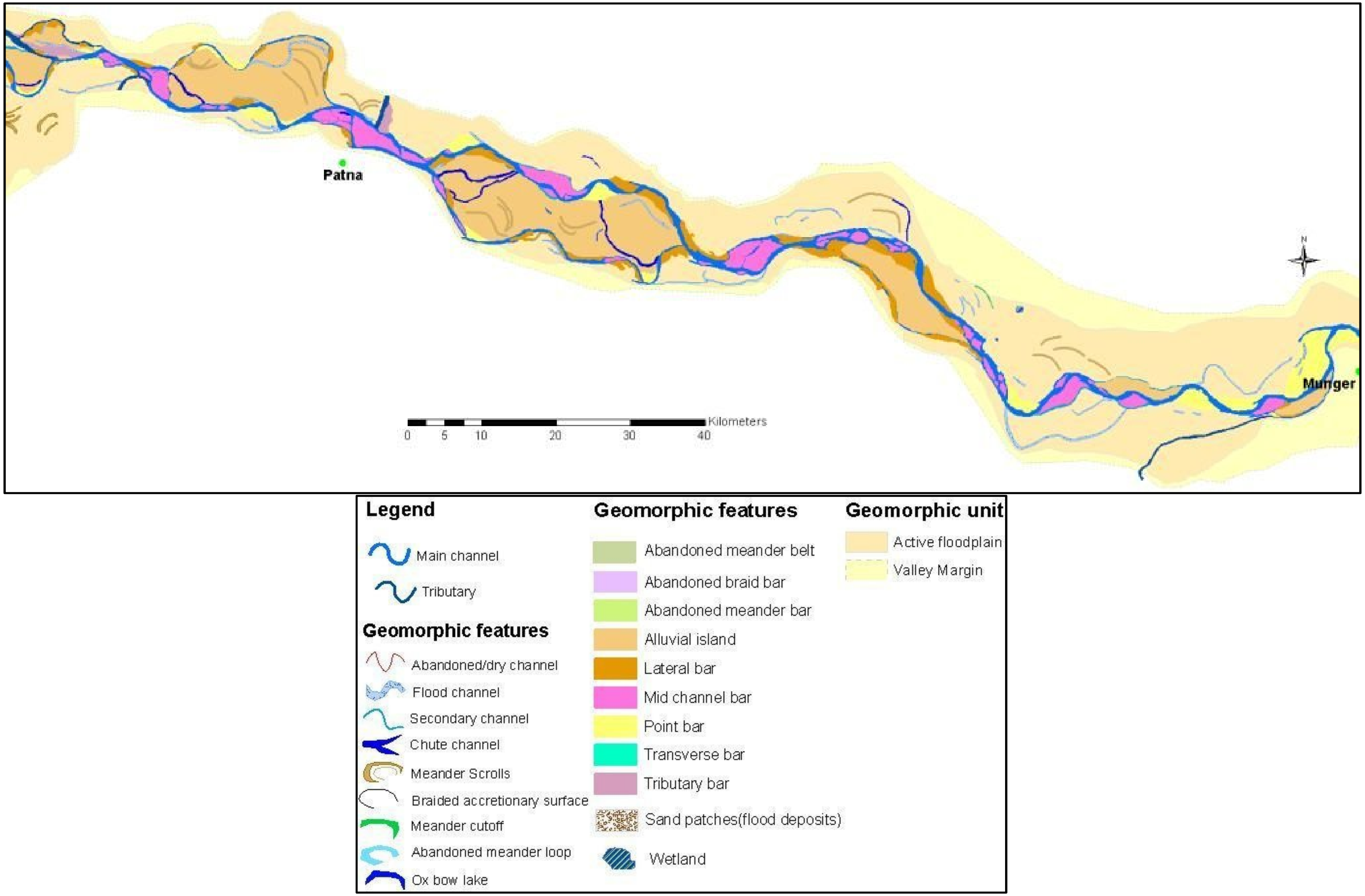

Figure 8 (b): Geomorphic map of the Madhubani to Munger stretch

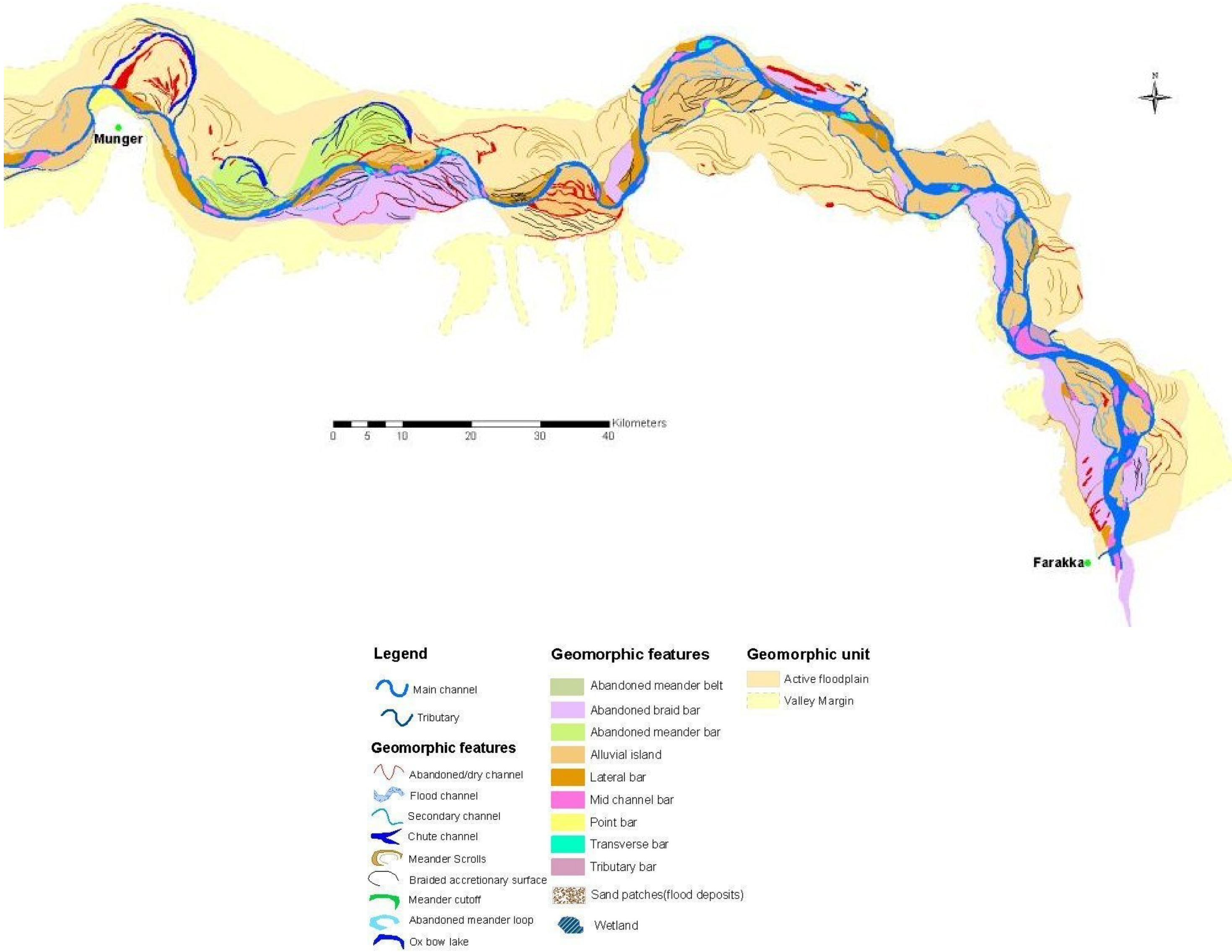

Figure 9: Geomorphic map of the Munger to Farakka stretch