Monitoring of Channel Morphology of Ganga River Using Remote Sensing and GIS Data

Vishal Kamboj, Aditi Bisht, and Nitin Kamboj

Abstract The present study deals with the dynamics of channel morphology of river Ganga in Haridwar region during the last two decades (1992–2019). Land Use/Land cover classification and channel geometry characteristics of river Ganga were assessed using remote sensing and GIS analysis approach. The LULC classification was divided into three classes: River, Dry Riverbed and River Ganga catchment or floodplain covering an area of 8366.22 ha. Moreover, channel geometry was calculated using sinuosity index and geomorphological features. The study area is divided into 10 segments showing the different types of channel patterns. It was found that LULC classification of river banks depends on water flow and seasonal ecological and anthropogenic activities. The channel pattern of river Ganga is modified by natural processes such as heavy rainfall, floods, bank erosion and anthropogenic processes such as dams, riverbed mining and agricultural activities near the banks.

Keywords Channel morphology · Ganga river · Remote sensing and GIS · Sinuosity index · Haridwar

1 Introduction

Rivers serve as geological agents that transfer material from one ecosystem to another and are also responsible for the formation of various landforms on the earth's surface [1]. Flowing water serves as a constant erosional factor and shapes the channel pattern of a river [2, 3]. Moreover, the process of erosion and deposition of river sediments creates, destroys and recreates the channel pattern, landforms and finally habitat [1, 3]. The shape of the riverbed depends on some geomorphological features such as point bars, bars, islands and natural dams [1, 4]. Basically, a river system is a combination of corridors such as channel patterns, bars, levees, floodplains,

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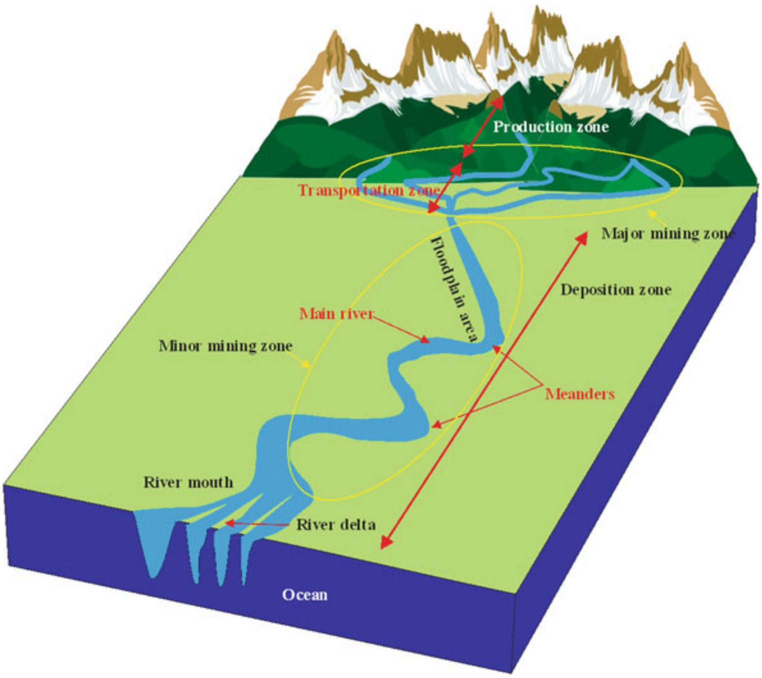

Fig. 1 Showing the river corridors from upland to lowland area

riparian zones, etc., extending from the uplands or mountains to the lowlands or plains (Fig. 1).

2 Geological Characteristics of the River System

The river bed consists of a combination of stones, boulders, gravel, sand and silt known as bed material and depends on the depositional areas [5]. A fluvial water system is divided into three zones based on its function and structure: Production zone, Transport zone and Deposition zone. In all three zones, the most affected part of the fluvial system is the channel pattern [1, 6]. The production zone is very steep and eroded. The eroded material is transported by flowing water through the transport zone and later deposited in the depositional zone under favourable conditions [1].

2.1 Substrate Structure and River Channelization

According to [7, 8], the composition of sediments in fluvial systems is classified according to the size of boulder (>256 mm), cobble (64–256 mm), pebble (16–64 mm), gravel (2–16 mm), sand (0.0625–2 mm), silt (0.0039–0.0625 mm) and clay (0.000244–0.0039 mm). Sediments are non-cohesive, granular particles composed mainly of a mixture of rocks and minerals that move with the flow in quartz form [3, 9, 10]. The availability of larger sediment particles is higher in the upper reaches than in the lower reaches. The small particles are deposited in the lower reaches due to their size and gravity and form the floodplain [4]. The amount of sediment depends on the erosion rate and water flow of the river and forms and maintains the channels and floodplains [11]. The river channels are continuously damaged due to natural and anthropogenic disasters all over the world.

In the present era, the changes in the rivers are studied with the help of remote sensing images and GIS applications. These scientific tools are inexpensive and efficient for mapping and monitoring the geomorphological features of river systems [12, 13]. These tools and techniques provide spatial and temporal data for evaluating the detection of changes in river channels [14].

In Northern India, most of the rivers are glacier fed rivers like Ganga and Yamuna. Ganga is also affected by natural and anthropogenic disasters in the form of floods, bank erosion, high runoff, mining, agricultural and industrial activities. Due to these disasters, the river bed of the rivers is destroyed and altered. The objective of the present study is to map and monitor the changes in the river flow of Ganga during the last two decades at Haridwar District. The results obtained indicate that the changes in channel pattern and floodplain are important for the conservation of river Ganga.

2.2 Description of the Study Area

Haridwar district (29° 56′ N and 78° 09′ E) is located in the southwestern part of Uttarakhand and covers an area of about 2360 km^2. Haridwar is the most famous holy place and also known as Gangadwara because the river Ganga touches the plains after a distance of 267 km in the mountains [15]. Due to the geological features of the river system, Haridwar is located in both the transport and deposition zones of the river Ganga. River Ganga provides a large amount of raw material such as sand, boulders, gravel and paving stones for construction purposes in Haridwar district [5, 16]. In recent decades, excessive extraction of these materials has altered the channel pattern and degraded the aquatic habitat, which has affected the biotic community of river Ganga.

Table 1 Satellite data used to analyse the LULC of the study area

S.No.	Data/Satellites name	Path:Row	Spatial resolution (m)	Years
1.	Landsat 4–5 TM C1	146:39	30	1992
2.	Landsat 4–5 TM C1	146:39	30	2001
3.	Landsat 7 ETM + C1	146:39	15	2011
4.	Landsat 8 OLI/TIRS	146:39	15	2019

Source Earth explorer (USGS)

3 Data and Methodology

3.1 Data Sources Used for Preparation of LULC Maps

Land Use/Land Cover (LULC) and channel pattern was done using various data sources i.e. satellite imagery, toposheet and ground surveys over two decades (1992–2019). The cloud-free satellite image was obtained from the official website of the United States Geological Survey (USGS; Earth Explorer) for the years 1992, 2001, 2011, and 2019 (see Table 1).

3.2 Methodology Adopted for Preparation of the LULC Maps

LULC change detection was performed using Arc GIS 10.5 software with a supervised classification method. First, the area of interest (AOI) was cropped from the downloaded satellite data of the respective years 1992, 2001, 2011 and 2019. For this classification, training samples were obtained during a field visit using Garmin GPS MAP Model No. 76CSx. During the study, the area is classified into three classes: Water body, river bed and river basin or floodplain. The classified image was validated using Arc GIS (10.5) accuracy assessment function (see Fig. 2).

3.3 Methodology Applied for the Channel Pattern

Channel pattern refers to the water flow paths of a river system. The study of channel pattern was carried out using sinuosity index and geomorphological features of the river [17, 18].

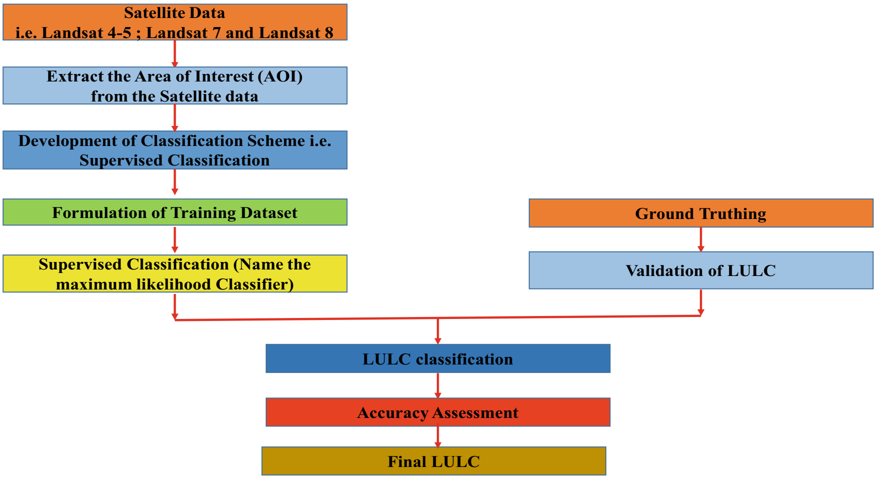

Fig. 2 Flow chart for preparation the land use/land cover

3.3.1 Identification of Channel Pattern Based on Sinuosity Index

Sinuosity index is the length of the watercourse divided by the shortest distance between two points (Fig. 3). The sinuosity index is calculated according to the following formula.

$$Sinuosity\,index\,(SI) = \frac{lenght\,of\,water\,course\,(Lw)}{shortest\,length\,of\,the\,river\,(SLw)}$$

Based on the sinuosity index, the river channel is divided into three types: straight channel, sinuous channel and meandering channel (Table 2).

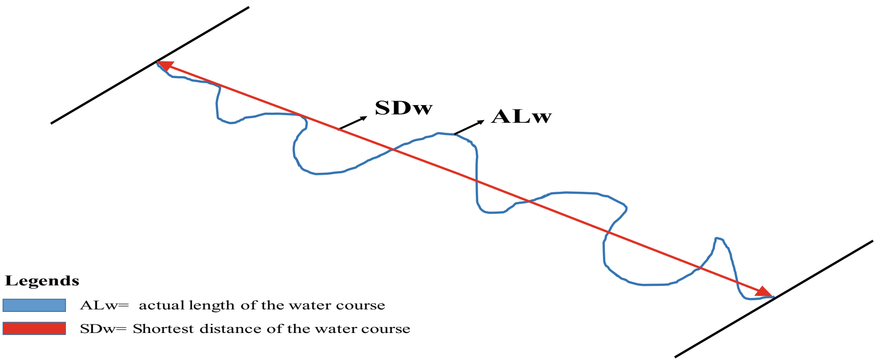

Fig. 3 Methods for calculating the sinuosity index [19]

Table 2 Types of the river channel based on sinuosity index

S.No.	Types of river	Sinuosity index
1.	Straight channel	<1.05
2.	Sinuous channel	1.05–1.50
3.	Meandering channel	>1.50

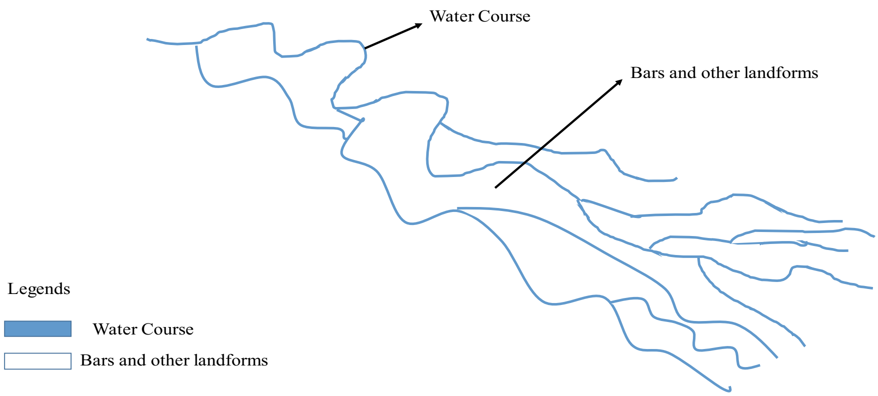

Fig. 4 Sketch map showing the braided channel condition [19]

3.3.2 Identification of Channel Patterns Based on Geomorphological Features

On the basis of geomorphological features, channel patterns are classified into two types, namely braided channel and Anabranching. Braided channel is a fragmentation of the river channel by permanent and temporary bars and islands, which are shown in Fig. 4 [20]. Moreover, Anabranching channel is a separation of the river into different channels by vegetation, an alluvial island in the active channel and not in the floodplain [21].

4 Results and Discussion

4.1 LULC Classification to Detect the Changes in River Morphology in the Catchment Area of Ganga River

In the present study, the total area of 8366.22 ha of the river Ganga was analysed to detect the changes in the river basin in Haridwar (see Table 3). The LULC was classified into three classes: River or Water, Dry Riverbed and Basin or Floodplain of the selected years 1992–2019 (Figs. 5, 6, 7 and 8). The river or water covers an area of 781.92 ha, 1463.49 ha, 856.89 ha and 934.92 ha in the respective years 1992,

Table 3 LULC classes of Ganga river basin for river morphology in selected study zones

S.No.	Classes name	1992		2001		2011		2019	
		Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
1.	River	781.92	9.35	1463.49	17.49	856.89	10.24	934.92	11.17
2.	Dry river bed	2324.43	27.78	2109.60	25.22	4025.52	48.12	2978.55	35.60
3.	River basin	5259.87	62.87	4793.13	57.29	3483.81	41.64	4452.75	53.22
	Total area (ha)	8366.22	100.00	8366.22	100.00	8366.22	100.00	8366.22	100.00

ha = hectares, % = percentage

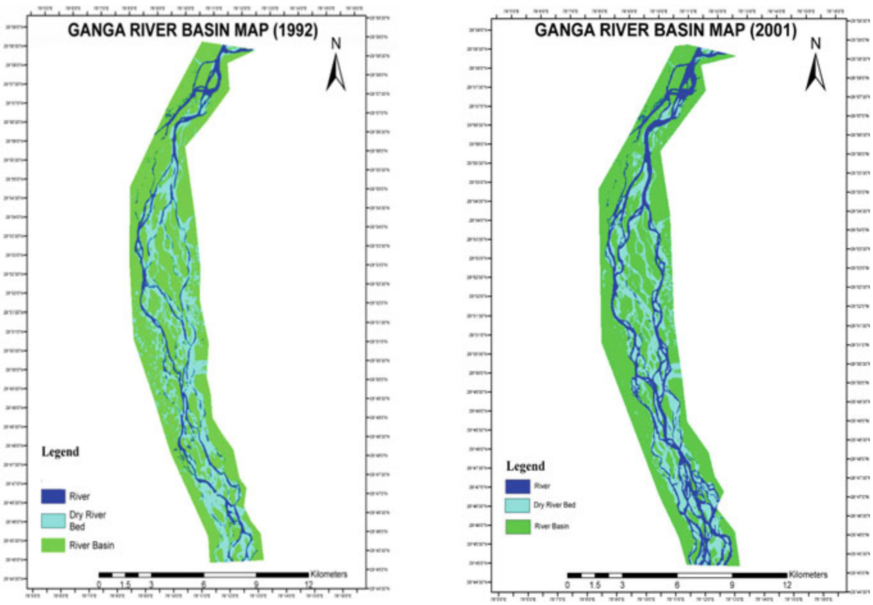

Fig. 5 LULC map of Ganga river basin during 1992–2001

2001, 2011 and 2019. In addition, the dry riverbed covers an area of 2324.43 ha, 2109.60 ha, 4025.52 ha and 2978.55 ha in the years 1992, 2001, 2011 and 2019. In addition, the floodplain or river basin covers an area of 5259.87 ha, 4793.13 ha, 3483.81 ha and 4452.75 ha in the respective years 1992, 2001, 2011 and 2019.

The LULC results of Ganga Basin show that the selected classes, i.e., water or river, dry riverbed and floodplain or river basin, depend on the flow discharge of the river and other environmental factors. Water covers a large area in the monsoon

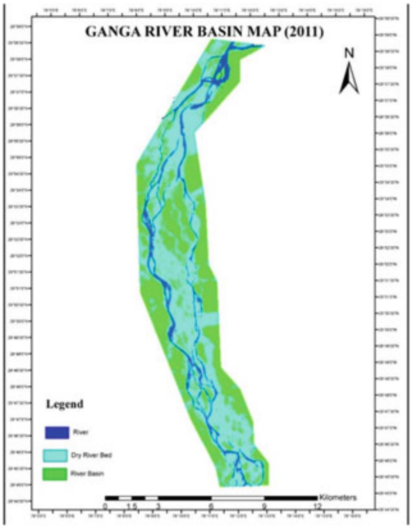

Fig. 6 LULC map of Ganga river basin during 2011–2019

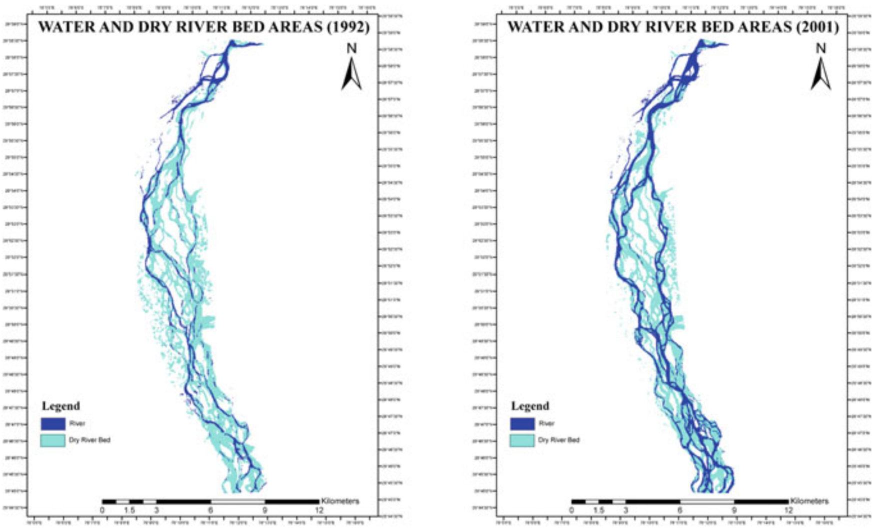

Fig. 7 Water and dry river bed areas during 1992–2001

season due to heavy rainfall and high runoff. The dry riverbed and floodplain or river basin cover a large area in summer and winter as the discharge of river water is less.

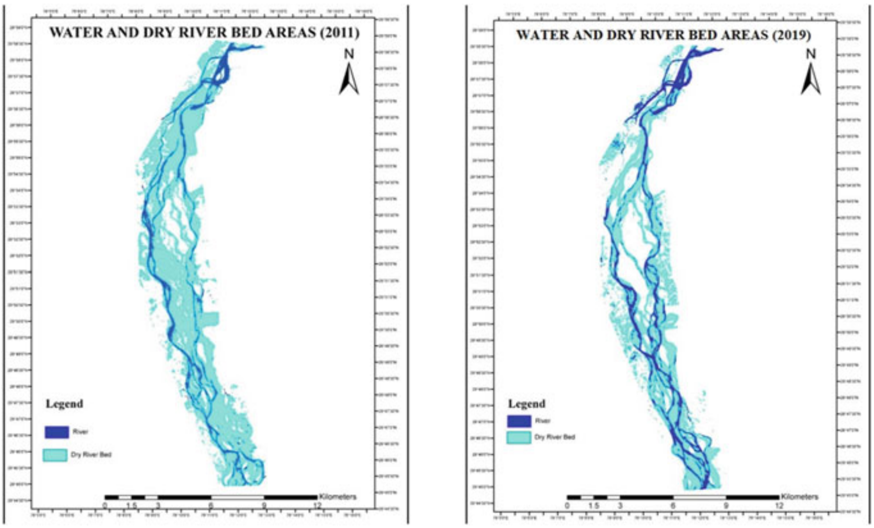

Fig. 8 Water and dry river bed areas during 2011–2019

4.2 Detection of Changes in Channel Morphology

Channel morphology refers to the shape, size, length, depth, width, slope, cross-sectional area, and presence of bed material. The characteristics of channel morphology depend on the geologic setting and discharge of a river. Most rivers have a cross-sectional area, also known as traverse section, which shows unique features of the river. At the cross-section site, the channel forms in the form of valleys and terraces and increases the width, depth, sediment character, gradient and floodplain area of the channel.

During the study, satellite data of selected years from two decades were used to analyse the changes in the channel, discharge pattern and river flow (see Figs. 9 and 10). Then, the current channel pattern was analysed using sinuosity index and geomorphological features of the river.

To study the current channel morphology, geometry and stream type, the selected stretch of Ganga was divided into 10 segments based on the channel pattern shown in Table 4 and Figs. 11 and 12. In the selected 10 segments, segment I shows the straight channel with sinuosity index of 0.89 while the six segments II, III, IV, VI, VII and X show the sinuous channel. Moreover, the left segment namely V, VIII and IX, shows the braided channel. The result shows that the formation of straight channel is possible due to the short length of the segment I. However, the formation of sinuous and meandering channel depends on the cross-sectional areas. In this area, riffles are mostly present in the cross section and pools in the bands. Many researchers also reported the higher number of pools and riffles in the cross section and bands of a river system [1, 4, 10, 14]. However, based on the geomorphological features,

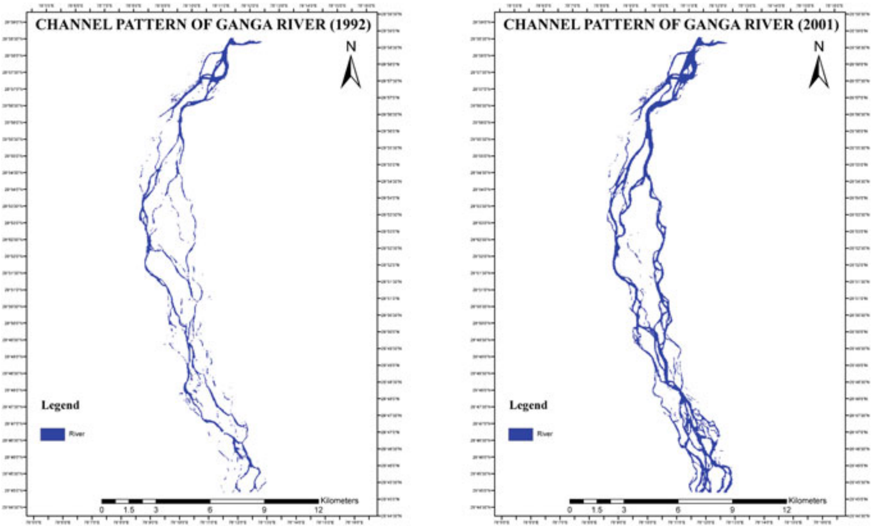

Fig. 9 Channel pattern of Ganga river during 1992–2001

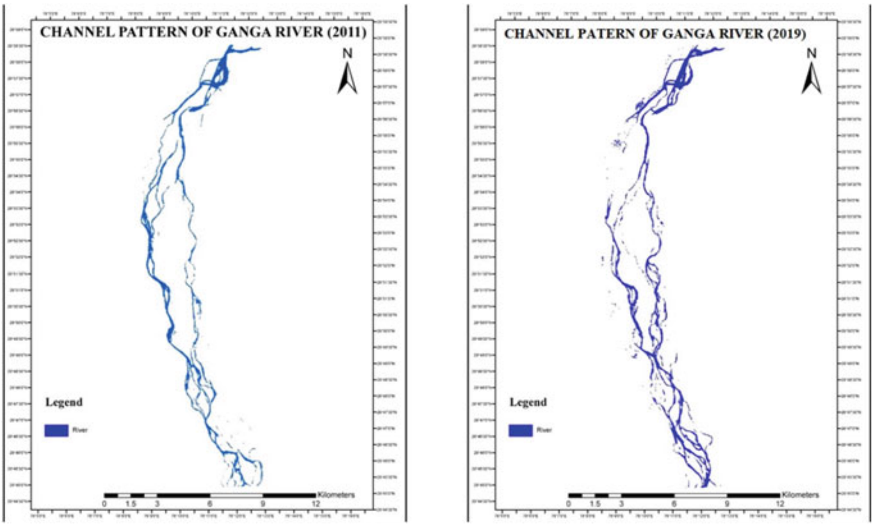

Fig. 10 Channel pattern of Ganga river during 2011–2019

braided conditions were found in the downstream sections. The braided condition is due to the unstable bars and numerous channels. The braided condition depends on the natural and anthropogenic activities and changes from day to day, month to month and season to season [4, 10]. In the present study, it was found that the braided channel formed in the river Ganga may be due to the unplanned mining of river bed

Table 4 Channel geometry of the Ganga river in selected stretch

S.No.	Segment name	Segment code	Width (m)	Depth (ft) (range)	Length of stream channel (m)	Length of straight-line distance (m)	Sinuosity index value	Type of channel
1	Bhimgoda barrage to Chandi bridge	I	517.42–594.54	5–8	1653.5	1853	0.89	Straight channel
2	Chandi bridge to upstream of Kangri village	II	547–1072.13	6–12	3158	2822.90	1.12	Sinuous channel
3	Kangri village to Gajiwala (left bank)	III	274.54–711.71	4–9	3089.06	2,858.19	1.08	Sinuous channel
4	Gajiwala to Shyampur (left bank)	IV	180.55–798.37	5–8	2241.86	1909.25	1.17	Sinuous channel
5	Shyampur to Sajanpur Peeli	V	775.53–991	4–9	2761.58	2511.23	1.09	Sinuous and braided channel
6	Kangri village to Ajitpur (right bank)	VI	311.05–654.92	4–8	3941.28	3757.06	1.05	Sinuous and braided channel
7	Ajitpur to Bisanpur	VII	654.92–805.47	4–12	3778.89	3282.22	1.15	Sinuous and braided channel
8	Bisanpur to Tanda	VIII	805.47–991.37	4–11	2403.23	2264.19	1.06	Sinuous and braided channel
9	Tanda to Bhogpur	IX	991.37–1145	4–13	2683.13	2530.55	1.06	Sinuous and braided channel
10	Sajanpur to Bhogpur	X	991–1145	4–13	3192.33	2849.77	1.12	Sinuous and braided channel

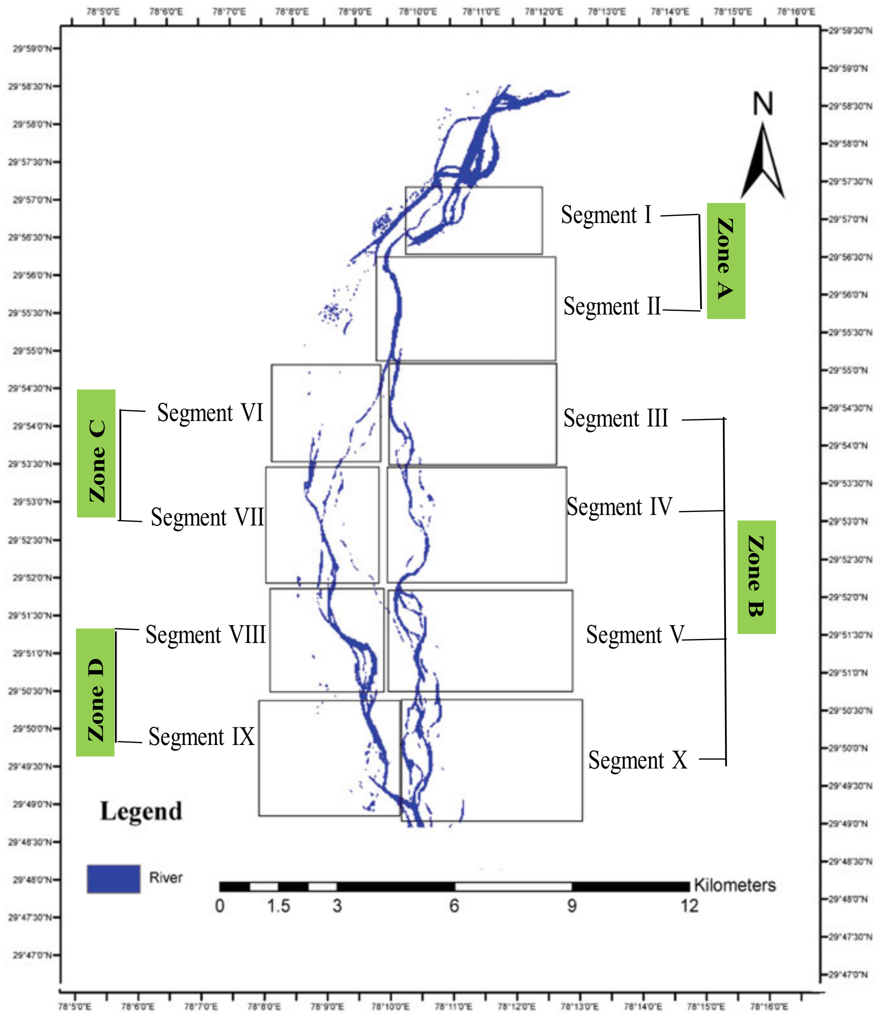

Fig. 11 Map showing the channel pattern with segment number I–X of river Ganga

in this area as well as natural flooding and flood discharges in the monsoon season. The study conducted by [22, 23] showed the conditions of river Ganga due to mining activities in the area (see Fig. 13) and reported that river Ganga is changing its actual water course and water quality and aquatic biodiversity due to mining activities.

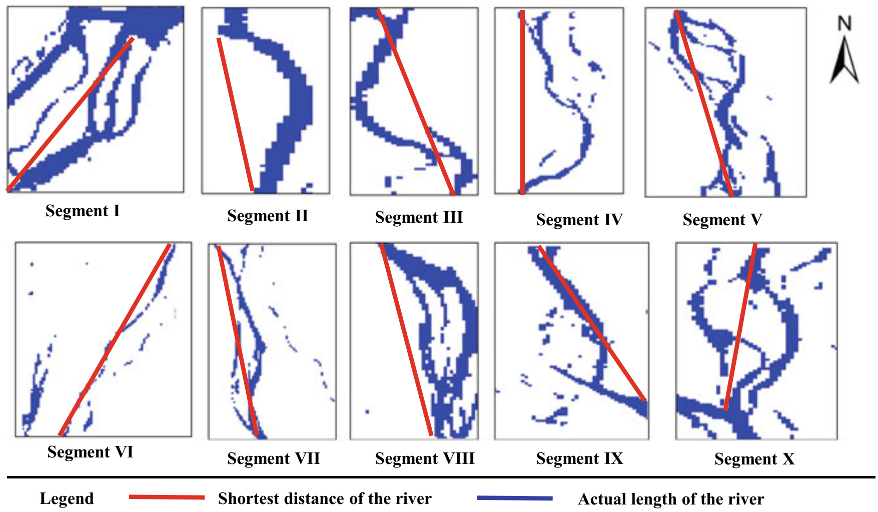

Fig. 12 Segments of river Ganga

5 Conclusion

The present study focused on the changes in LULC and channel pattern in the catchment area of River Ganga in Haridwar during the last two decades (1992–2019). The present study covers a total area of 8366.22 ha in the catchment area of river Ganga. It is to be noted that the three classes selected for LULC mapping of Ganga catchment mainly depend on the discharge of the river. Moreover, the study of channel pattern of river Ganga is divided into ten segments on the basis of morphological characteristics. Out of the 10 river segments, segments I have straight channel, II–IV have sinuous channel and segments V–X have both sinuous and braded channel. The reasons for channel alteration may be natural processes i.e. bed load and sedimentation, floods and anthropogenic activities like unscientific mining in the selected catchment.

Fig. 13 Mining activity at selected stretch of Ganga river at Haridwar

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Conflict of Interest There is no conflict of interest.

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