Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 1 ~ Issue 3 (2014) pp: 17-31
ISSN(Online) : 2348-2532
www.questjournals.org

Research Paper

Study of Geomorphological Changes in Upper Gangetic Flood Plain from 1973 To 2013

Vikas Kamal, Saumitra Mukherjee*
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India

Received 21 November, 2014; **A**ccepted 06 December, 2014 © The author(s) 2014. **P**ublished with open access at **www.questjournals.org**

ABSTRACT:- *Upper Gangetic flood plain lies at the door steps of Himalayas i.e. Haridwar. The present study is based on visual interpretation of LANDSAT satellite images of the year 1973, 1999, 2009, 2011 and 2013. Identification of features along the channel is done on ARCGIS platform after image enhancement. The disadvantage of large area is dealt by dividing it into thirteen parts based on features and mapability. Spatial calculation has been performed for each part separately and color coding is done to maintain the coherency. The cross tabulation matrix approach is followed to study the swap change and net change, which helps in studying the change in detail. The results show that during 1973, braidation was a common phenomenon in all divisions, which was superseded by erosion and broadening of main channel with migration during 1999 to 2011. Finally in 2013 the pattern show that river area has gone down due to narrowing and further appearance of depositional features in the channel, indicating reduced water flow. Results show that the second reach is the most geomorphically disturbed part of the river with average percentage change of 59.7 for all features and the midchannel bars have suffered the maximum changes among all features in the study area. So, the study has brought out what changes have occurred which helps to ascertain the probable cause of such changes.*

Keywords:- *Cross-tabulation matrix, Geomorphology, active flood plain, chute channel, channel migration.*

I. INTRODUCTION

Remote sensing and Geographical Information Systems (GIS) are powerful tools to derive accurate and timely information on the spatial distribution of land use/land cover changes over large areas (Carlson 1999; Guerschman et al. 2003; Rogana et al. 2004; Zsuzsanna et al. 2005; Mukherjee, 2008). Satellite remote sensing is the most common data source for detection, quantification, and mapping of LULC patterns and changes because of its repetitive data acquisition, digital format suitable for computer processing, and accurate georeferencing procedures (Chen et al. 2005; Clemmens 2000; Jensen 1996; Lu et al. 2004). LULC changes have been widely studied across the globe at various scales to demarcate the changes produced over time in a very efficient and reproducible manner. The technique basically involves using the satellite data of an area and carrying out the digital image processing to bring out the features by virtue of its reflectance values. It involves various preprocessing steps like georeferencing, atmospheric correction, main steps of classification which can be either supervised or unsupervised, and post processing steps like merging of classes to get the best output results (Ekstrand 1994).

But applying the same procedures for fluvial features is bit difficult because of the following points:

a. Non availability of high resolution data which can observe features with great precision.
b. Non availability of cloud free temporal data e.g. in IRS LISS3.
c. Fluvial features classification yields intermingled classes, which is unacceptable.
d. It is difficult to obtain spatial attributes like length, area and parameter from classified result.

In order to overcome these problems, manual digitization of fluvial features for different time period was done. The spatial attributes particularly the area was calculated using inbuilt tools in ARCGIS 10.1 software. Then the further processes were carried out to see the reachwise geomorphic changes in the study area. Now-a-days the access to satellite data is very easy through ISROs Bhuvan geoportal web service as well as through USGS Earth Explorer satellite portal service. The need of temporal data is rising day by day and these facilities help a lot to academicians and private stakeholders in general. In order to keep the database coherent, satellite images of LANDSAT for different time were downloaded and processed for digitization.

Upper Gangetic Flood plain witnesses the transition part of river life. It lies near the doorsteps to the Himalayas and is filled with vigour and power in this stretch. The stretch is highly braided and valley width is high due to incision and oscillatory movement of the mainstream. The amount of bedload and suspended load carried by the river has varied largely due to building of dams and barrages along the river. This has impacted the river course to a huge extent which is further enhanced by anthropogenic activities in the recent time. Construction of bunds for managing the river flow during peak flood situation has changed the face of floodplain (Rahaman, 2009). The present study is done to find out which reach of this stretch is highly disturbed and has witnessed the maximum geomorphological changes. Dynamic nature of the river forces the geomorphological features to change its character from one to another depending on the degradation and aggradation happening in the region.

Active floodplain is defined as an area that gets regularly flooded along the riverside with an average return period of 2.33 years (Report 2010). In the present situation active flood plain boundary is taken as the study area boundary and is derived from overlapping the river channels of different time periods and merging the outer margins of channel. There have been instances when river water has overtopped this boundary also, for example in the floods of September 2010, when the floodwater occupied the valley margins of the river. So, to avoid confusion between the valley area and active flood plain, the above methodology was adopted. Alluvial islands are the compound mid channel bars that may be elongated, with length greater than river width and surrounded by flow on all sides. They are generally found in anastomosing channels (Report 2010). The alluvial islands are marked in the study area keeping these facts in mind. Mid channel bar, lateral bar and tributary bar are the elongated features formed from bed load and suspended load deposition in the middle of channel, along the banks and at the confluence of tributary. They are formed due to drop in stream energy and increase of load in the channel.(Brierley and Fryirs 2005). Braid bar are bars that are deposits of bed load and suspended load in the braided stream part of the river. They are former point bars or lateral bars that have been cut through chute channels or transverse channels. They mostly escape flooding. (Smith 1974). They have been distinguished into two types; BB (braid bars) and VBB (vegetated braid bars) in this study to account for vegetation which is mostly local cultivation in some parts. Secondary Channels are low width –depth ratio open channels in the anastomosing region of river valley that bifurcate and rejoin the main channel. (Report 2010).

II. STUDY AREA

The study area is derived from coalescing together the river channel for different time period together which is taken here as active flood plain. It extends from Haridwar at 29.94 N latitude and 78.16E longitude to Narora at 28.11 N latitude and 78.45 E longitudes. The total area is 929 square kilometer. The major cities are Bijnor, Garhmukteshwar, Haridwar and Narora. The tributaries joining in this stretch of the river are namely, Mithawali, Rawasan Nadi, Kotawali Rao,Begam Nadi, Banganga river, Malin Nadi, Chhoiya Nadi, Solani river, Bagad Nadi, Tikta Nadi, Burdwan Nadi and Burh Ganga. Many of these rivers are ephemeral and are lost in active flood plain because of cultivation in this area and construction of checkdams in the upper reaches. Besides, there were many oxbow lakes which have dried out at present, namely Bagad Jhil, Sinda Jhil, Jabda Jhil, Bhiraoti Jhil, Khiara Jhil on the left margin in older flood plain. The study area comprises of the Haridwar district of Uttarakhand and Bijnor, Moradabad, Muzaffarnagar,JP Nagar, Bulandshahr, Meerut and Ghaziabad districts of Uttar Pradesh. Geologically, the area is covered by Quaternary alluvium. Atypical Humid subtropical climate (Koppen "Cwa") prevails in this region with foggy, dry cold winter, hot summer with dust storms and humid warm monsoon seasons. The population density is very high and stands at 800 person per square kilometer. Ganga river has been the cradle of Vedic civilization and is the life line for the nation. The area is also drained by canal system, namely Upper Ganga canal starting at Haridwar (Bhimgoda barrage), Madhya Ganga canal starting at Bijnor barrage and Lower Ganga canal starting at Narora barrage. The command area of these canals covers huge area of interfluves region between Ganga and Yamuna and fulfills the demand of irrigation in these areas (Fig.1).

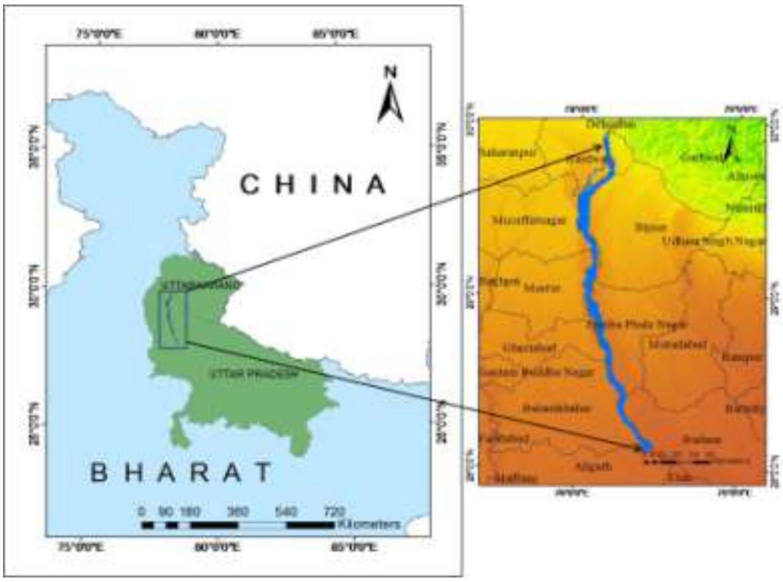
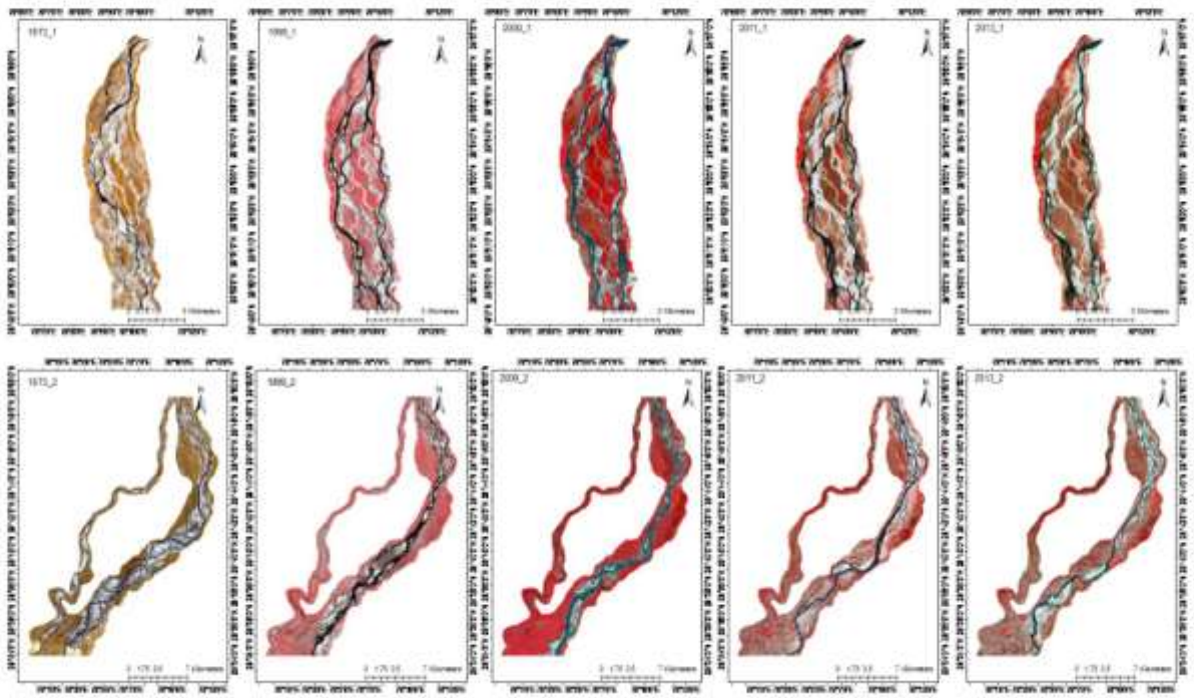


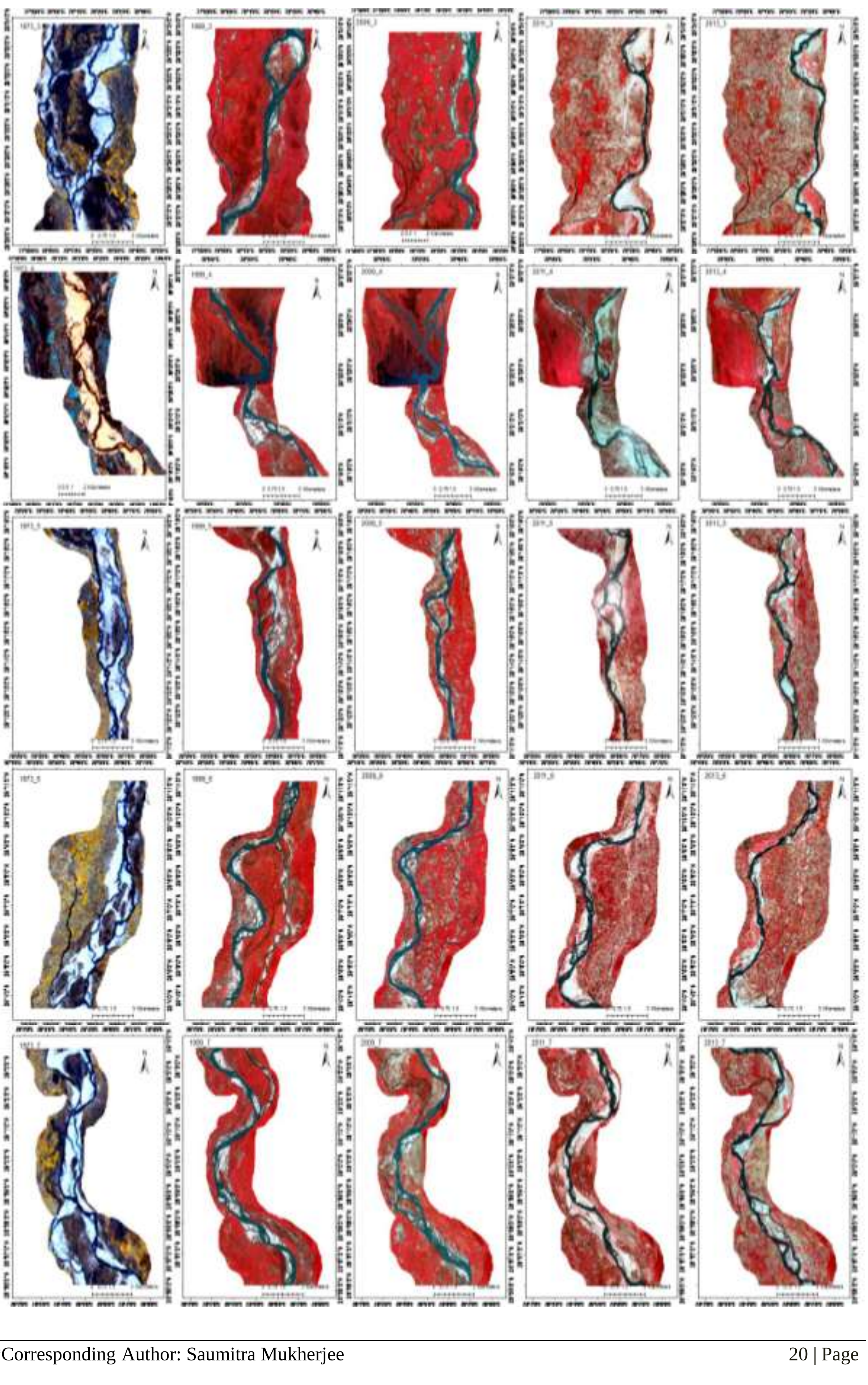
Figure 1. Study area showing the active flood plain along Ganga from Haridwar to Narora.

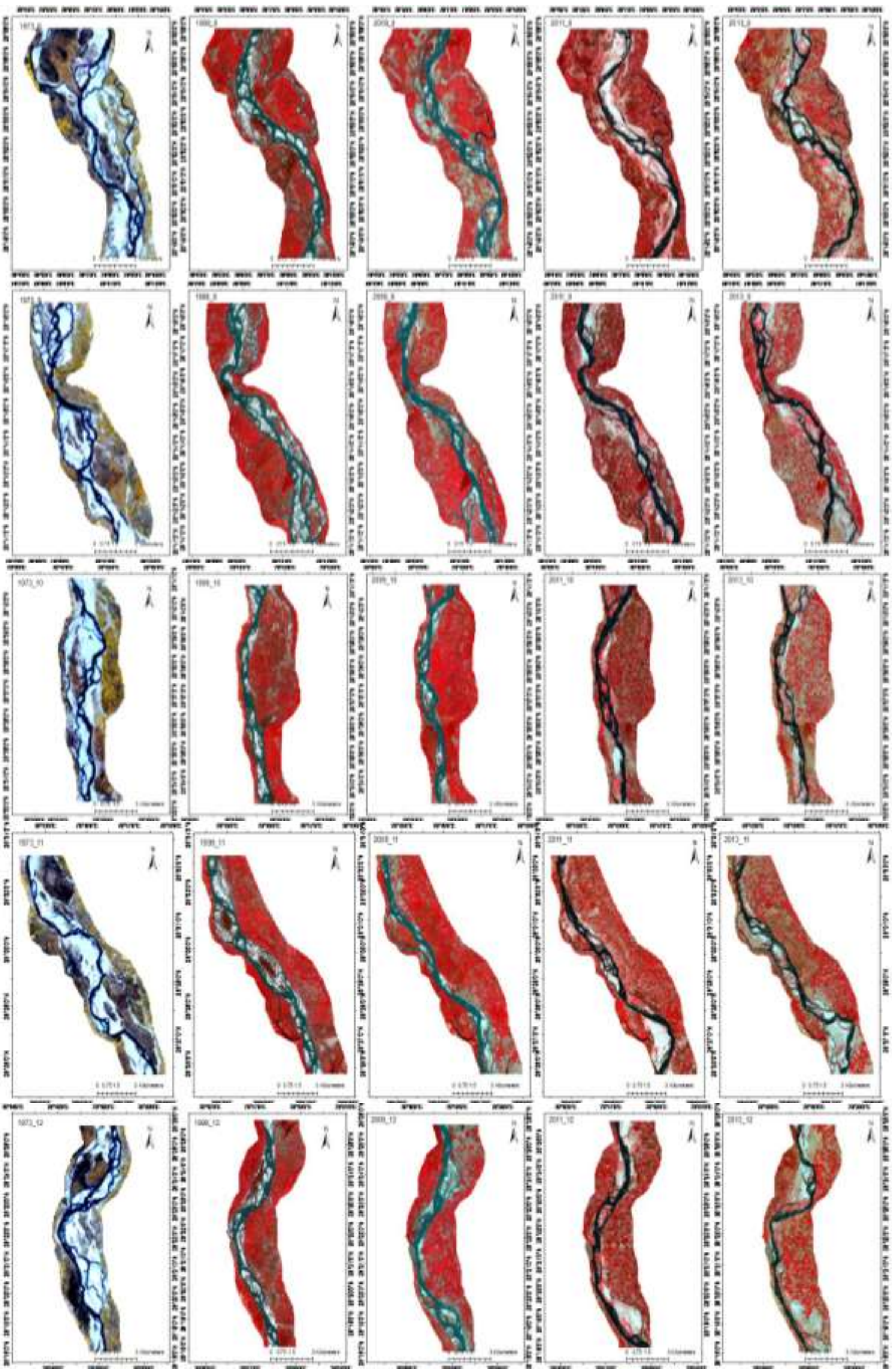
III. MATERIALS AND METHODS

The data used for the study were Landsat MSS (1973) mosaic acquired on 25th January 1973, Landsat TM (1999) acquired on 22nd October 1999, Landsat TM (2009) acquired on 25th October 2009, Landsat TM mosaic of 22April 2011 and 6 April 2011 for the year 2011 and Landsat 8 Level 1 OLI data (2013) acquired on 7th December 2013. These data are freely available from USGS Earth Explorer site to download. (http://glovis.usgs.gov) (http://edcsns17.cr.usgs.gov). The toposheets available for the area were georeferenced and used to cross check the accuracy of Landsat images. The river channel was digitized from Haridwar to Narora and overlaid for all five time periods. The outer boundary is roughly digitized as the active flood plain boundary which is used as study area. Since the study focused only on changes in the river geomorphology, this approach was adopted.

The total length of the river in this reach is about 225km. So, to study the geomorphic changes, the area was subdivided into smaller reaches, depending on the uniformity of the area and mapability.







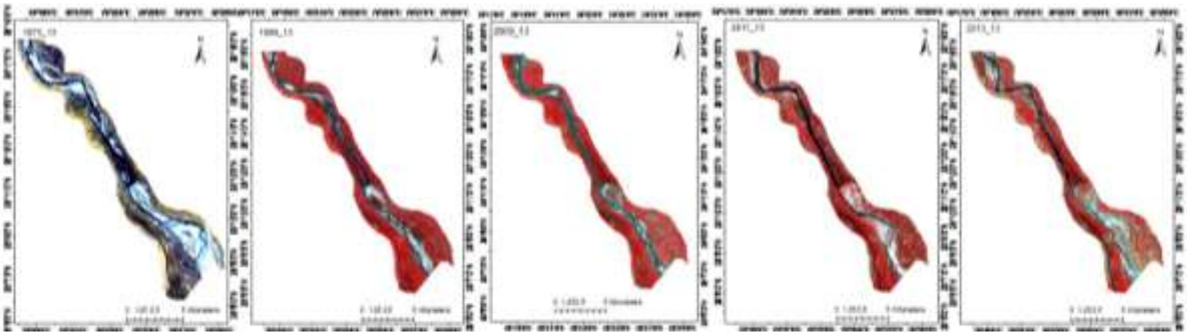


Figure 2. Satellite images (13 parts of the active flood plain) used for geomorphic classification.

Following is the table showing the division of area:

Reach No.	Length(km)	Start location	End location
1	14	Haridwar	Shahpur Shitala Khera
2	35.6	Shahpur Shitala Khera	Majilishpur
3	13.8	Majilishpur	Bhuwapur
4	15	Bhuwapur	Siali
5	14.3	Siali	Behbalpur
6	14.5	Behbalpur	Akbarpur Garhi
7	15.9	Akbarpur Garhi	Tarbiyatpur Janubi
8	15	Tarbiyatpur Janubi	Garhmukteshwar
9	15.2	Garhmukteshwar	Paindapur Ahatmali
10	14	Paindapur Ahatmali	Faridpur Khadar
11	16	Faridpur Khadar	Mubarikpur Bangar
12	14.3	Mubarikpur Bangar	Mohammadabad urf Meria Haridwar
13	26	Mohammadabad urf Meria Haridwar	Pesari

Table 1. Divisions of study area

Image enhancement renders image useful by making the features distinct and visible to eyes (Das, 2009). The image processing ability is inbuilt in ARCGIS which involves contrast change, band change and stretching through histogram equalization and other statistical approaches. In this study, contrast stretching was applied for visual interpretation. Digitization was done manually using ARCGIS. The spatial reference chosen for working is WGS_1984_Zone 44N, linear unit (meter 1.000), angular unit (0.01745), false easting (500000), false northing (0), central meridian (81), scale factor (0.996), latitude of origin (0) and Datum (D_WGS_1984). The following features were digitized for each time period:

S.No.	Features	Abbreviation
1	Active Flood Plain	AFP
2	Alluvial Island	AI
3	Braid Bar	BB
4	Canal	CANAL
5	Chute Channel	CC
6	Flood Basin Swamp	FBS
7	Lateral Bar	LB
8	MidChannel Bar	MCB
9	Ox bow lake	OBL
10	Point Bar	PB
11	River	R
12	Secondary Channel	SC
13	Tributary	T

14	**Tributary Bar**	**TR**
15	**Vegetated Braid Bar**	**VBB**

Table 2. Abbreviations used for geomorphic features in the study area classification.

After making the vector files color coding was given to distinguish the features. A uniform coding was maintained for all reaches. Area of features was calculated in the attribute column itself utilizing inbuilt geometry function of ARCGIS. Then to compare the two time period maps produced from visual interpretation, popular cross-tabulation matrix approach was adopted. First, for every reach an intersect shape file was prepared that has attributes containing feature name for each time period and final area. This database file was used to generate cross-tabulation matrices in excel sheet. Thus we got total 52 sheets (four per reach: 1973 vs 1999, 1999 vs 2009, 2009 vs 2011 and 2011 vs 2013).

Cross tabulation matrix or pivot table allows comparison between two thematic layers provided they have same areal extent. This matrix has cells which show value of coincidence corresponding to a feature class. Thus it covers the areal difference between two classes for two time periods. The matrix follows the format as shown in the following table (Table 3). The rows correspond to time 1, and the columns to time 2. Diagonal enteries indicate the persistence between the time-period, whereas the other entries indicate a transition from category “i” to category “j”.

	Time 2				**Total (Time 1) (A)**	**Change for time1 categories (Loss) (B)**	**Change (with trend) (C)**	**Percent change (With trend) (D)**
Time 1	**Category1**	**Category 2**	**Category 3**	**Category 4**				
Category1	**P11**	**P12**	**P13**	**P14**	**P1+**	**P1+ - P11**	**±(P1+ - P11)**	**±100*{(P1+ - P11)/ P1+}**
Category 2	**P21**	**P22**	**P23**	**P24**	**P2+**	**P2+ - P22**	**±(P2+ - P22)**	**±100*{(P2+ - P22)/ P2+}**
Category 3	**P31**	**P32**	**P33**	**P34**	**P3+**	**P3+ - P33**	**±(P3+ - P33)**	**±100*{(P3+ - P33)/ P3+}**
Category 4	**P23**	**P24**	**P25**	**P26**	**P4+**	**P4+ - P44**	**±(P4+ - P44)**	**±100*{(P4+ - P44)/ P4+}**
Total (Time 2) (A’)	**P+1**	**P+2**	**P+3**	**P+4**	**1**			
Change for time 2 categories (Gain) (B’)	**P+1- P11**	**P+2-P22**	**P+3-P33**	**P+4-P44**				

Table 3. Cross tabulation matrix representation

As seen in the matrix for each category in time 1 change was calculated in column (B). Then looking at the difference between total (A – A’) in both the time, a negative sign or positive sign is placed as prefix in values of (B) in column (C) which denotes the trend. Then in the last column percentage change was calculated by dividing ‘B’ by ‘A’. Swap is calculated as twice the minimum of gain or loss. The total change is the sum of gain and loss and net change is the difference of total change and the swap (Pontius et al. 2004)

IV. RESULTS AND DISCUSSION

The digitized layers were generated in ARCGIS interface using Editor Tool. All thirteen parts were color coded uniformly to maintain the data uniformity. Following are the thematic diagrams that were generated for different time periods (Fig.3).

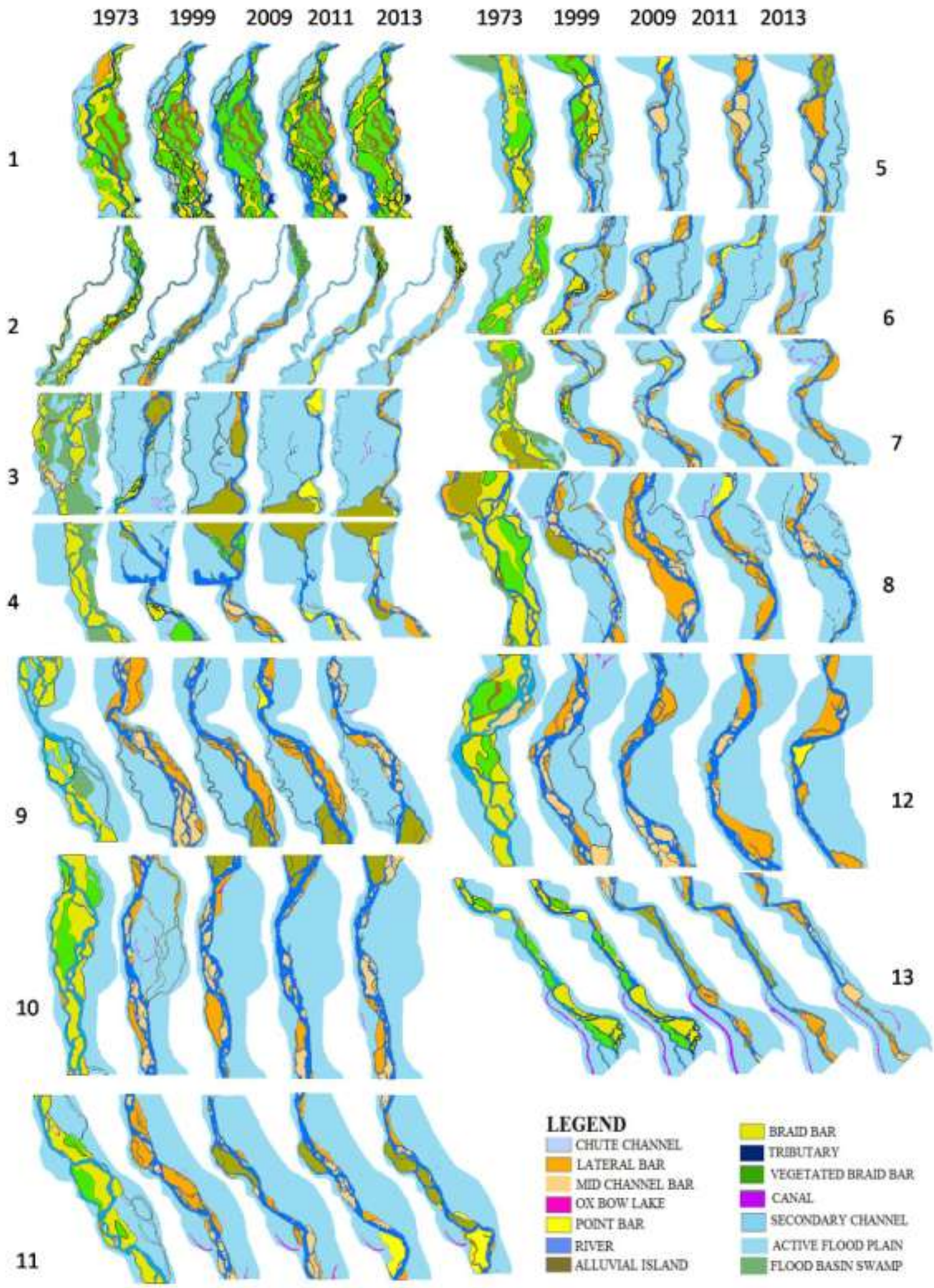


Figure 3. Geomorphological map of 13 reaches for five different years.

Since the data is digitized manually, there is no need for accuracy check through error matrix as generally done in LULC generation through unsupervised classification. The vector layers were given uniform legend for all the temporal maps. The total area of each layer remains the same for different time images as evident in the Fig.4. The blank cells in the table show that the feature is non-existent in that reach for that time.

	REACH 1					REACH 2				
	1973	1999	2009	2011	2013	1973	1999	2009	2011	2013
AFP	8.80	9.13	9.49	9.15	9.00	64.90	92.15	98.80	105.60	183.59
AI		0.03					4.93	1.79	5.59	3.01
BB	11.23	5.95	2.61	7.05	7.28	41.23	13.76	0.31	3.57	10.26
CANAL										
CC	3.06	2.70	2.63	2.55	1.42	7.77	1.38	3.50	2.21	0.34
FBS						7.40				
LB	1.41	1.36	0.09	1.53	1.05	0.64	6.51	7.71	5.57	3.72
MCB		1.60	1.15	0.97	1.00	1.44	4.80	5.25	3.17	8.38
OBL							0.10			
PB						0.08	0.95		6.15	1.06
R	3.04	6.02	7.01	6.40	5.87	17.84	21.13	20.17	15.28	13.69
SC	1.55	0.73	0.59		0.19	8.17	7.05	8.01	7.35	3.88
T	0.14	0.36	0.34	0.49	0.34	0.20	0.07	0.16	0.08	0.29
TB									0.31	1.10
VBB	7.78	9.13	13.10	8.86	10.85	7.92	4.79	11.92	2.73	2.31

	REACH 3					REACH 4				
	1973	1999	2009	2011	2013	1973	1999	2009	2011	2013
AFP	30.24	73.00	69.43	74.65	76.81	38.41	52.53	42.10	56.40	50.69
AI		5.91	15.60	7.69	9.17		1.29	11.23	8.36	10.72
BB	17.81	2.12				19.98	2.78			
CANAL										
CC	1.12	0.61	0.13	0.30	0.44		0.20	1.00	0.43	0.20
FBS	34.49					15.11				
LB	0.42	1.06	2.64		3.60		0.96	3.23	0.10	5.56
MCB	4.02	0.87	0.56	0.69	0.50	0.13	0.59	2.97	2.84	2.49
OBL		0.43	0.16		0.38		0.13			0.03
PB		0.85		7.40	0.59		0.96	0.54	2.41	1.69
R	5.06	8.78	6.65	5.17	5.29	4.94	14.06	15.15	8.09	7.24
SC	3.53	3.30	2.46	1.72	0.92	0.05	0.69			
T	0.12	0.05	0.06	0.06						
TB										
VBB	0.88	0.72					4.44	2.40		

	REACH 5					REACH 6				
	1973	1999	2009	2011	2013	1973	1999	2009	2011	2013
AFP	16.71	23.15	32.93	29.70	29.38	36.56	47.19	55.56	54.22	56.68
AI					3.63		0.77			
BB	11.94	4.52				12.55	6.20			
CANAL		1.62	0.31	0.56	0.26					
CC							0.87	0.78	0.77	0.45
FBS	3.89			5.42	4.86		0.18			
LB	1.93	1.15	1.16	3.92	1.39	1.60	4.24	3.14	2.51	7.24
MCB	0.45	1.42	2.91	0.24	0.27	0.24	1.56	2.91	1.57	0.76
OBL		0.00					0.11			0.51
PB	0.24	0.27	1.09	5.29	4.95		1.27	0.62	4.71	0.33
R	5.83	5.79	5.95	0.81	1.20	5.28	7.38	7.05	6.77	4.47
SC	1.02	1.16	1.60			1.79	2.17	1.88	1.38	1.51
T										
TB										
VBB	3.94	6.85				13.92				

	REACH 7					REACH 8				
	1973	1999	2009	2011	2013	1973	1999	2009	2011	2013
AFP	14.63	45.37	48.10	47.64	48.53	12.96	48.09	35.88	47.56	51.69
AI	7.72					7.81	3.20			
BB	17.43	1.39	1.41			23.55				
CANAL						0.05	0.19	0.07	0.42	0.06
CC		1.69	2.35	1.13	0.97	0.35	1.82	1.69	0.98	0.85
FBS	13.18					2.75				
LB	1.74	7.28	2.52	9.52	7.52	2.24	3.55	16.60	9.12	3.09
MCB	0.31	2.07	3.68	0.29	1.39	0.05	3.82	3.49	0.52	3.93
OBL		0.01		0.34	0.53		0.03			0.02
PB		0.42	0.20	0.91	0.07	0.50	0.09	0.02	2.31	
R	6.37	6.43	7.40	5.82	6.65	9.14	7.70	9.93	6.69	7.60
SC	0.89	0.53					0.27	1.10	1.17	1.53
T										
TB										
VBB	3.39	0.47				9.37				

	REACH 9					REACH 10				
	1973	1999	2009	2011	2013	1973	1999	2009	2011	2013
AFP	28.6	30.2	38.3	35.3	40.0	21.0	34.0	33.5	35.0	34.3
AI	0.2		3.3	3.5	3.4			1.3	1.7	1.6
BB	13.8					13.2				
CANAL										
CC		1.4	1.3	1.9	0.7		2.1	0.5	0.3	0.4
FBS	2.6									
LB	0.0	10.2	5.7	6.6	1.3	0.5	3.2	3.5	1.3	2.1
MCB		7.8	1.1	1.0	4.4	0.3	2.7	2.3	1.9	3.2
OBL		0.0			0.1		0.1	0.1		0.0
PB		0.0	0.2	0.9						
R	7.5	9.1	8.3	9.2	8.3	6.7	6.2	7.1	7.9	6.5
SC	1.5	0.4	0.8	0.8	0.9	0.7				
T										
TB										
VBB	4.9					5.7				

	REACH 11					REACH 12				
	1973	1999	2009	2011	2013	1973	1999	2009	2011	2013
AFP	33.4	44.4	49.9	46.7	44.2	18.7	32.7	34.8	33.5	36.2
AI			2.9	2.0	5.4	12.8				
BB	16.0									
CANAL						0.7	0.5	0.5	0.3	0.5
CC		1.1	0.8	0.0	0.7					
FBS						0.6	3.6	3.1	6.6	5.7
LB		10.0	1.2	2.4	1.1	1.7	4.7	3.3	1.4	0.4
MCB	0.9	2.3	2.6	2.1	1.0		0.1	0.0		
OBL		0.3	0.4	0.2	0.3					1.0
PB			0.1	3.5	5.0	8.3	6.4	7.1	7.0	4.9
R	7.4	7.3	7.6	8.5	7.8					
SC	3.1									
T										
TB						6.0	0.9			0.1
VBB	4.6									

	REACH 13				
	1973	1999	2009	2011	2013
AFP	49.5	59.6	60.2	62.4	66.6
AI		2.4	4.8	2.2	
BB	13.7				
CANAL	1.7	1.0	2.6	1.4	1.2
CC		1.2	1.0	0.9	1.2
FBS					
LB	0.5	8.1	5.5	9.1	6.5
MCB	0.1	3.6	2.6	0.1	3.1
OBL		0.1			0.3
PB	1.4			0.3	0.1
R	13.1	10.2	10.2	10.3	7.7
SC		0.7			0.2
T					
TB					
VBB	6.9				

Figure 4. Areal changes in the 13 reaches.

Reach 1 extends from Haridwar in the North to Shahpur Shitala Khera in the South and is about 14 km in length. The reach shows an increase in river, vegetated braid bar and active flood plain over time due to the change in river course from a single channel to a braided river course. The high braidation observed in this reach during 26 years can be due to decrease in stream power which has led to dumping of bed load and suspended load on the river bed. Stream power decrease is commonly attributed to the dam construction in the upper reaches and sediment load has increased due to heavy urbanization in the area.

Reach 2 extends from Shahpur Shitala Khera to Majilishpur and is about 35.6km in length. This reach is marked by a prominent disappearance of a secondary channel with time, due to overexploitation of river bed for boulders and cobbles by mining *mafias* in the area (Fig.5). Mid channel bar, point bar and active flood plain have increased in this reach over time showing aggradation regime in the region. Also, one can easily notice the river migration in this stretch. In the upper part river major channel is shifted towards left bank, in the middle part it has shifted towards right bank and in the lower part the river seems to revert back to its original bank during 2013 after detaching in 2009. Further calculations, revealed that it is the most geomorphologically disturbed part of the river.

Figure 5. Mining of river bed material in Haridwar

Reach 3 extends from Majilishpur to Bhuwapur and is about 13.8km in length. This reach is showing a marked river migration from west to east leaving behind oxbow lake. Also, a marked decline in natural forest is visible in the form of loss of flood basin swamp to active flood plain which is highly cultivated zone in the region. This migration has given rise to formation of alluvial islands and secondary channels in the stretch.

Reach 4 extends from Bhuwapur to Siali village and is about 15 km in length. Bijnor barrage constructed in this stretch has modified the face of river. Water ponding increased the river area in 1999 and 2009 but later the ponding is reduced in 2011 and 2013. River bifurcation due to alluvial island is seen in the upper part and downstream of barrage, major landform changes in the form of lateral bars and point bars appearance is visible. Formation of depositional features is representing the increased suspended load derived from nearby agricultural land, which is not observed in the 1973 image.

Reach 5 extends from Siali to Behbalpur and is about 14.3km in length. The major change that is observed here is the conversion of a main braided stream to a secondary channel which is later left as a remnant river because of embankment and *bund* constructed at the junction to prevent flood. Gradual formation of midchannel bar, lateral bar and alluvial islands is seen in the river channel.

Reach 6 extends from Behbalpur to Akbarpur Garhi village and is about 14.5 km in length. The river has completely migrated towards right margin of the active flood plain. The original river is reduced to a secondary channel in 1999-2009. It started disappearing in 2011 but was recouped in 2013. Formation of point bar, lateral bar and midchannel bar is seen in the later time period and river area is reduced.

Reach 7 extends from Akbarpur Garhi to Tarbiyatpur Janubi village and is about 15.9km in length. In upper part of this reach river shows migration towards left margin and formation of oxbow lake in the left out part. Forested swamp was lost in 1999 and active flood plain enlarged with formation of lateral bars and midchannel bars.

Reach 8 extends from Tarbiyatpur Janubi to Garhmukteshwar and is about 15 km in length. The river is converted from braided to single channel from 1973 to 2013. Midchannel bar formed in 1999 gradually convert into lateral bar in 2013. The secondary channel formed in the 1999 period is seen disappearing in 2013. Channel seems to oscillate over a small distance from 1999 to 2013.

Reach 9 extends from Garhmukteshwar to Paindapur Ahatmali village and is about 15.2km in length. The river channel shows migration towards left margin in 1999 and gradual disappearance of secondary channel in 2013. Formation of midchannel bar in 1999 is seen which gradually convert to lateral bar in 2011 and again one can see midchannel bar in the 2013 image. The difference of size of midchannel bars suggest that river flow has reduced in 2013 and suspended load is increasing from agricultural areas due to erosion.

Reach 10 extends from Paindapur Ahatmali to Farid Khadar and is about 14km in length. The river channel shows migration towards right margin in 1999 leaving a secondary channel which later is inconspicuous in 2011-13. Formation of alluvial island in the upper part and lateral bar in lower part is seen.

Reach 11 extends from Farid Khadar to Mubarikpur Bangar and is about 16km in length. Here we see that river is trying to move towards its past channel seen as secondary channel in the 1973 image, but is forced to remain in between because of anthropogenic activities like bunds to control flood. Gradual formation of alluvial island from midchannel bar and lateral bar is seen in 2013.

Reach 12 extends from Mubarikpur Bangar to Mohammadabad urf Meria Haridwar and is about 14.3km in length. The channel has shifted towards the right margin and formation of midchannel bar and lateral bar is seen. The secondary channel seen in 1999 is inconspicuous in 2011-13.

Reach 13 extends from Mohammadabad urf Meria Haridwar to Pesari village and is about 26km in length. This reach is highly affected by human interference due to construction of Narora barrage and embankments. Narrowing down of rive course is seen downstream and with time. This stretch is strategic due to nuclear power facility which is situated on the banks of Ganga river.

The quantitative assessment of percentage change is done through cross tabulation matrices. The results derived from them are shown in terms the annual rate of percent change (Table 4,5,6,7).

The annual rate of change in 1973 to 1999 period shows that AFP area increased in all reaches with maximum in the 9th reach. Alluvial island area decreased in all reaches to nil. Braid bar area decreased in first 7 reaches and disappeared in last 6 reaches. Chute channel decreased in reaches 1, 2, 3, 12 and increased in the eighth reach. Flood basin swamp is lost in all reaches. Lateral bar decreased in reach 1 and 5, but increased in the rest. Midchannel bar decreased in 3, 5 and 11th reach and increased in the rest. Point bar increased in 2nd and 5th reach but decreased in 8th and 13th. River area increased till 9th except in 5th and 7th and then decreased in all downstream reaches. Secondary channel decreased in all except 4th, 5th and 6th reach. Vegetated braid bar decreased to nil in all reaches except in 1st and 5th reach. The overall trend that comes out is that the area has lost largely in terms of braid bars, vegetated braid bar and flood basin swamp in this period, meanwhile gained in terms of lateral bars and midchannel bar throughout the stretch. Specifically, alluvial islands were lost from 2nd, 7th, 8th and 9th reaches. Chute channel and secondary channel area declined in 1st, 2nd and 3rd reaches due to gain by the river channel. River lost in 10th, 11th, 12th and 13th because of shift, which converted into LB and MCB. Active flood plain gained in this period in all reaches due to conversion of flood basin swamp and braid bars to cultivation land and decrease of water supply in this region from upstream areas. The main characteristics have been that the main channel has broadened, braidation declined and more depositional features came up with measurable migration of river. Ox bow lake and point bar formation is also observed in this period (Table 4).

Annual rate of change

FEATURES (1973_99)	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11	Reach 12	Reach 13
AFP	1.26	0.79	0.80	1.03	1.32	1.39	1.21	1.02	2.13	0.54	0.71	1.01	0.31
AI	0.00	-3.85	0.00	0.00	0.00	0.00	-3.85	-3.85	-3.85	0.00	0.00	0.00	0.00
BB	-2.98	-3.17	-3.69	-3.64	-2.99	-3.77	-3.82	-3.85	-3.85	-3.85	-3.85	-3.85	-3.85
CANAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.00	0.00	0.00	0.00	2.75
CC	-2.92	-3.82	-3.80	0.00	0.00	0.00	0.00	3.85	0.00	0.00	0.00	-3.72	0.00
FBS	0.00	-3.85	-3.85	-3.85	-3.85	0.00	-3.85	-3.85	-3.85	0.00	0.00	0.00	0.00
LB	-3.80	3.85	3.85	0.00	-3.71	3.69	3.71	3.85	3.85	3.70	0.00	3.85	3.70
MCB	0.00	3.81	-3.80	3.85	-3.85	3.73	3.85	3.85	0.00	3.38	-3.85	3.76	3.85
OBL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PB	0.00	3.85	0.00	0.00	3.85	0.00	0.00	-3.85	0.00	0.00	0.00	0.00	-3.85
R	2.76	2.98	3.00	2.95	-3.27	3.45	-3.44	3.15	2.94	-2.92	-3.13	-3.20	-2.47
SC	-3.16	-2.60	-3.57	3.85	3.67	3.85	-3.85	0.00	-3.85	-3.85	-3.85	0.00	0.00
TRIBUTARY	2.07	-3.83	-3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VBB	1.76	-2.95	-3.85	0.00	3.79	-3.85	-3.85	-3.85	-3.85	-3.85	-3.85	-3.85	-3.85

Table 4. Annual rate of percent change (1973-1999)

The annual rate of change in 1999 to 2009 period shows that AFP declined and lateral bar gained in 3rd, 4th and 10th reach. Ox bow lake and point bar area declined in many places, meanwhile LB and MCB gained. River channel gained in many reaches indicating more erosion in this period. Alluvial island and braid bar continue losing their area (Table 5).

Annual rate of change

FEATURES (1999_09)	*Reach 1*	*Reach 2*	*Reach 3*	*Reach 4*	*Reach 5*	*Reach 6*	*Reach 7*	*Reach 8*	*Reach 9*	*Reach 10*	*Reach 11*	*Reach 12*	*Reach 13*
AFP	0.9	1.6	-2.8	-3.3	0.8	1.1	1.5	-3.2	1.0	-1.0	0.7	1.1	0.9
AI	-10.0	0.0	-10.0	-10.0	0.0	-10.0	0.0	-10.0	0.0	0.0	0.0	0.0	10.0
BB	-8.2	-9.9	10.0	-10.0	-10.0	-10.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
CANAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-7.6	0.0	0.0	0.0	0.0	0.6
CC	-4.3	9.8	10.0	9.6	-10.0	-10.0	9.8	-9.0	-9.4	-9.5	-9.5	9.9	-9.6
FBS	0.0	0.0	0.0	0.0	0.0	-10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LB	-9.8	8.1	10.0	7.4	10.0	-10.0	-8.8	8.1	-8.5	6.6	-9.7	-9.3	8.3
MCB	-9.0	8.9	-9.7	6.7	9.0	9.9	6.5	-8.5	-9.7	-8.3	7.7	-9.2	9.3
OBL	0.0	-10.0	-10.0	-10.0	-10.0	0.0	-10.0	-10.0	-10.0	-10.0	1.8	-8.2	-10.0
PB	0.0	-10.0	-10.0	-10.0	10.0	-10.0	-10.0	-10.0	10.0	0.0	0.0	0.0	0.0
R	3.2	-6.5	-8.8	5.0	6.5	-7.0	7.6	6.4	-6.7	5.8	5.9	5.6	-4.3
SC	-5.4	4.2	-7.8	-10.0	6.9	-8.1	-10.0	10.0	5.5	0.0	0.0	0.0	-10.0
TRIBUTARY	-4.9	4.7	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VBB	1.5	4.2	0.0	-10.0	-10.0	0.0	-10.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5. Annual rate of percent change (1999-2009)

2009 to 2011 period has more activity within a smaller area and one observes the changes in LB, MCB, CC and river channel. Point bar gained in 6th to 9th reach indicating a depositional phase in this stretch. So it indicates that a channeling pattern is being established (Table 6).

Annual rate of change FEATURES (2009_11)	*Reach 1*	*Reach 2*	*Reach 3*	*Reach 4*	*Reach 5*	*Reach 6*	*Reach 7*	*Reach 8*	*Reach 9*	*Reach 10*	*Reach 11*	*Reach 12*	*Reach 13*
AFP	-5.8	6.0	2.0	2.9	-7.3	-5.0	-5.4	3.6	-5.2	3.4	-4.1	3.6	3.4
AI	0.0	7.1	-25.7	-14.7	0.0	0.0	0.0	0.0	11.3	6.6	-21.1	0.0	-27.5
BB	26.1	25.1	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0
CANAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	26.2
CC	-26.2	-45.1	31.7	-49.4	-45.1	49.7	-45.5	-48.6	36.0	-49.0	-50.0	-50.0	-49.3
FBS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LB	3.8	-49.5	-50.0	-50.0	25.9	48.5	32.3	-42.3	20.4	-49.2	38.2	36.7	32.5
MCB	-30.1	-44.0	50.0	-48.2	20.1	47.7	-50.0	-48.1	-49.2	-40.9	-46.6	-47.4	-49.9
OBL	0.0	0.0	-50.0	0.0	0.0	0.0	0.0	0.0	0.0	-50.0	-26.9	-50.0	0.0
PB	0.0	0.0	0.0	50.0	-47.0	41.7	50.0	50.0	50.0	0.0	50.0	0.0	0.0
R	-16.3	-32.1	-35.1	-38.6	-35.3	31.1	-37.2	-33.9	23.0	22.0	27.3	-29.3	20.7
SC	-50.0	-7.6	-15.1	0.0	-31.4	28.4	0.0	27.7	26.2	0.0	0.0	0.0	0.0
TRIBUTARY	7.7	-37.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VBB	-19.6	-42.7	0.0	-50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6. Annual rate of percent change (2009-2011)

2011 to 2013 period shows that the previous pattern continued with more midchannel bar and lateral bar deposition. Chute channel area increased in the last reaches showing that they linked to mid channel bar and lateral bars. River area declined due to less water in the main channel (Table 7).

Annual rate of change *FEATURES (2011_13)*	*Reach 1*	*Reach 2*	*Reach 3*	*Reach 4*	*Reach 5*	*Reach 6*	*Reach 7*	*Reach 8*	*Reach 9*	*Reach 10*	*Reach 11*	*Reach 12*	*Reach 13*
AFP	-3.7	4.8	2.6	-6.9	-3.6	3.2	4.5	3.7	3.3	-2.4	-3.3	3.9	4.2
AI	0.0	-50.0	1.5	6.6	0.0	0.0	0.0	0.0	-20.7	-13.0	6.6	0.0	-50.0
BB	22.7	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CANAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-44.2	0.0	0.0	0.0	0.0	-20.4
CC	-32.7	-49.9	45.8	-49.0	-50.0	43.3	-45.0	-48.8	-46.6	48.3	50.0	47.9	47.2
FBS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LB	-29.4	-49.5	0.0	50.0	-44.9	30.7	-35.4	-43.4	-45.2	20.5	-44.4	-35.4	-34.3
MCB	25.7	47.0	-44.9	-48.3	-49.6	-45.4	42.6	34.6	34.2	33.4	-47.5	-50.0	50.0
OBL	0.0	0.0	0.0	0.0	0.0	0.0	29.5	0.0	0.0	0.0	9.7	0.0	0.0
PB	0.0	-49.9	-48.7	-50.0	42.6	-50.0	-50.0	50.0	-50.0	0.0	9.9	0.0	-50.0
R	-15.1	-30.8	34.4	-32.2	-37.7	-36.7	34.8	27.3	31.0	-22.0	-28.8	-32.5	-27.4
SC	0.0	-28.8	-24.8	0.0	0.0	50.0	0.0	27.1	21.5	0.0	0.0	0.0	0.0
TRIBUTARY	-22.6	39.5	-50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRIBUTARY BAR	0.0	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VBB	6.5	-39.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7. Annual rate of percent change (2011-2013)

Thus we see that river changed from braided to straight during the 26 year period from1973 to 1999, with a noticeable migration and formation of oxbow lake and point bar. In 1999 to 2009 erosional phase is visible. In 2009 to 2011, confinement is seen with more depositional changes but in 2011 to 2013, river shortening is seen.

The cross tab matrix between 1973 and 2013 has been used to calculate swap change and net change (Table 8). The graphical layout for net change during this 40 years duration shows that FBS, OBL and Tributary bar either disappeared or appeared from different features. Swap change shows that the order is AFP>R>FBS>BB>AI>VBB>LB>CC>MCB>SC, meaning AFP, R and FBS changed maximum and CC, MCB changed less. Net change order follows as AFP>BB>VBB>LB>MCB>AI>SC>R>PB>CC ,meaning that though river changed a lot but in terms of net change it turns out to be less (Fig. 6). This helps us understand the dynamic nature of any feature. It comes out that the river channel is most dynamic followed by chute channel. Rest of the features are not dynamic they either decrease or increase in the same place but don’t change their location. If we compare the net change for different categories for different time period (Fig.7), it turns out that there is an abnormal pattern in 2009-2011 period for AFP, PB, R and MCB which points to the fact that this period has more disturbance associated with depositional changes.

Sum of Shape_Area	**Column (2013)**														
Row (1973)	**AFP**	**AI**	**BB**	**CANAL**	**CANAL TRIBUTARY**	**CC**	**LB**	**MCB**	**OBL**	**PB**	**R**	**SC**	**TRIBUTARY**	**TRIBUTARY BAR**	**VBB**
AFP	267.4	11.0	1.2	0.5	0.0	2.4	14.9	7.2	0.7	2.7	26.5	3.3	0.3	0.3	0.5
AI	13.1					0.1	0.9	0.2		0.1	1.2	0.1			
BB	134.4	10.9	7.8			2.8	14.7	13.0	0.6	4.7	28.7	2.4	0.1	0.3	4.8
CANAL	1.0			0.7							0.0				
CANAL TRIBUTARY	0.0				0.0										
CC	6.1	0.2	0.6			0.7	1.4	1.2		0.0	2.0		0.1		0.8
FBS	59.8	8.6				0.2	4.3	1.2	0.3	0.8	4.0	0.3			
LB	9.2	0.3	0.0			0.2	0.5	0.3	0.1	0.1	0.8	0.2			
MCB	6.9	0.3				0.1	1.2	0.3			0.6	0.1			
PB	0.7					0.1	1.1	0.0			0.2	0.0			
R	57.8	3.0	4.6			1.6	9.0	4.7	0.2	1.5	16.0	0.6	0.1	0.5	1.0
SC	17.7	0.7	0.0			0.1	0.6	0.5	0.1	0.1	1.2	1.3			0.0
TRIBUTARY	0.1		0.1			0.0		0.0		0.0	0.1	0.0	0.1	0.0	
VBB	44.0	2.1	3.1			1.6	4.7	3.4	0.2	0.1	9.6	0.4			6.1

Table 8. Cross tabulation matrix for 1973-2013 time period.

	Loss	**Gain**	**Minimum**	**Swap change**	**Total change**	**Net change**
AFP	71.6	350	71.68	143.35	422.49	279.13
AI	15.7	36.9	15.74	31.48	52.68	21.20
BB	217.37	9.72	9.72	19.44	227.09	207.65
CANAL	1.05	0.54	0.54	1.07	1.58	0.51
CANAL TRIBUTARY	0.04	0.04	0.04	0.07	0.08	0.01
CC	12.3	9.22	9.22	18.45	21.53	3.08
FBS	79.3		79.38	158.77	79.38	-79.38
LB	11.1	52.8	11.16	22.33	63.99	41.66
MCB	9.25	31.6	9.25	18.49	40.89	22.40
OBL	0.00	2.20	0.00	0.00	2.20	2.20
PB	2.18	10.0	2.18	4.35	12.24	7.89
R	84.5	74.9	74.95	149.90	159.47	9.57
SC	21.9	8.50	8.50	17.00	30.47	13.47
TRIBUTARY	0.36	0.53	0.36	0.72	0.89	0.17
TRIBUTARY BAR	0.00	1.10	0.00	0.00	1.10	1.10
VBB	69.1	7.09	7.09	14.17	76.24	62.07

Table 9. Swap and Net change calculated for 1973-2013 using cross tabulation matrix.

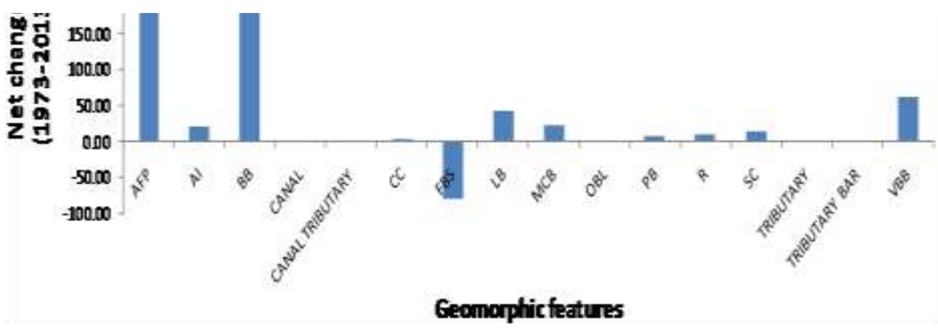


Figure 6. Variation of net change for different categories for time period 1973-2013.

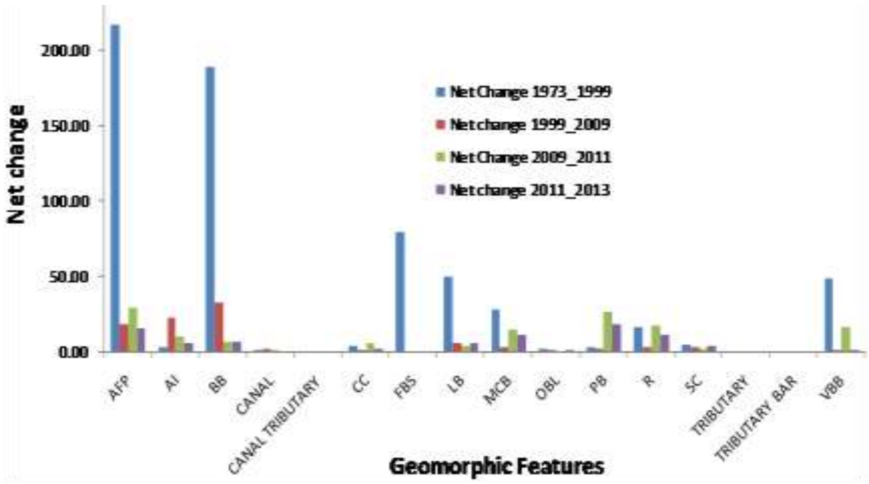


Figure 7. Variation of Net change for different categories over different time period.

	AVERAGE VALUES OF CHANGE PERCENTAGE FOR DIFFERENT FEATURES for time from 1973 to 2013										TRIBUTARY	TRIBUTARY BAR	VBB	AVERAGE FOR EACH REACH (MOST DISTURBED REACH)
	AFP	AI	BB	CC	LB	MCB	OBL	PB	R	SC				
Reach	15.1	25.0	64.3	59.2	65.7	50.4	0.0	0.0	41.7	59.0	40.7	0.0	28.2	34.6
Reach	14.5	53.5	61.4	96.9	94.8	92.4	25.0	75.0	67.1	45.6	75.2	4.3	70.7	59.7
Reach	14.5	38.6	49.0	88.4	75.0	96.4	50.0	49.3	76.3	62.7	56.3	0.0	25.0	52.4
Reach	19.9	35.6	48.6	73.3	68.5	89.9	25.0	75.0	67.0	50.0	0.0	0.0	50.0	46.4
Reach	16.1	0.0	44.4	72.6	84.5	82.5	25.0	94.8	74.0	56.7	0.0	0.0	49.7	46.2
Reach	15.8	25.0	49.5	71.5	88.6	95.6	0.0	70.8	73.8	84.4	0.0	0.0	25.0	46.2
Reach	16.6	25.0	74.9	69.8	80.0	87.5	39.7	75.0	77.4	50.0	0.0	0.0	50.0	49.7
Reach	18.3	50.0	25.0	96.2	88.0	87.5	25.0	100.0	67.1	52.4	0.0	0.0	25.0	48.8
Reach	20.5	41.0	25.0	64.8	79.0	66.0	25.0	75.0	62.7	62.7	0.0	0.0	25.0	42.1
Reach	8.9	9.8	25.0	72.3	75.4	79.9	50.0	0.0	55.5	25.0	0.0	0.0	25.0	32.8
Reach	10.0	13.9	25.0	73.6	65.6	91.5	22.8	30.0	63.2	25.0	0.0	0.0	25.0	34.3
Reach	13.1	0.0	25.0	97.9	84.2	96.1	45.4	0.0	65.7	0.0	0.0	0.0	25.0	34.8
Reach	8.0	63.8	25.0	72.2	78.3	98.1	25.0	50.0	50.9	25.0	0.0	0.0	25.0	40.1
	14.7	29.3	41.7	77.6	79.0	85.7	27.5	53.5	64.8	46.0	13.2	0.3	34.5	

Table 10. Overall average change percentage (1973-2013)

Table 10 is an attempt to calculate the geomorphic disturbance in the study area in terms of overall average change percentage. Firstly, an average of percentage change was calculated for each feature for each reach over the 40 years time period. Then final average for each reach and each feature was calculated. The results show that the second reach is the most geomorphologically disturbed reach and the tenth reach is the least disturbed reach.

V. CONCLUSION

Visual interpretation and cross tabulation matrix for geomorphological change detection has been rarely used. The results found show that the active flood plain of the Ganga river is increasing with time due to loss of forested swamps, disappearance of braid channels and confinement of river channel due to man-made embankments and bunds. Reduction in the river area over time shows that water input into the main channel has gone down due to construction of canals in the study area. Agriculture intensification and settlement in the active flood plain has led to loss of features like oxbow lake and rivers fed by groundwater in the vicinity of main channel. Based on this study, it can be said that if on one hand landscape manipulation and irrigation project has promoted the economic health of the region, on the other hand, it has led to loss of geomorphic diversity in the region. In the near future, if the condition of secondary channels is not restored, then the area may witness the decline of groundwater level.

ACKNOWLEDGMENTS

The authors are thankful to Quest Journal for the support to develop this document. Author express thanks to CSIR SRF for financial assistance and labmates Dr. S. Shashtri, Ms. Neha, Ms. Harshita, Mr. Chandrasekhar, Mr. Payam, Mr. Ratan Sen, Ms. Priyadarshini, Vikas Rena, Sakshi Rana and Yadavji for help and assistance. Sincere thanks to Dr. M. S. Chauhan (Scientist F at Birbal Sahni institute of Palaeobotany) for considering the abstract in National Conference on quaternary climate change:new approaches and emerging challenges 2014.

REFERENCES

[1]. T. N. Carlson, S.G.A. Azofeifa, "Satellite Remote Sensing of land Use changes in and around San José, Costa Rica, " Remote Sensing of Environment, 70, 1999, 247–256.

[2]. J. P. Guerschman, J. M. Paruelo, C. D. Bela, M. C Giallorenzi, F. Pacin, "Land cover classification in the Argentine Pampas using multi-temporal Landsat TM data," International Journal of Remote Sensing 24, 2003, 3381–3402.

[3]. J. Rogana, D. Chen, “Remote sensing technology for mapping and monitoring land-cover and land-use change,” Progress in Planning, 61, 2004, 301–325.

[4]. D. Zsuzsanna, J. Bartholy, R. Pongracz, Z. Barcza, Analysis of land-use/land-cover change in the Carpathian region based on remote sensing techniques. Physics and Chemistry of Earth, 30, 2005, 109–115.

[5]. X. Chen, L. Vierling, & D. Deering, “A simple and effective radiometric correction method to improve landscape change detection across sensors and across time,” Remote Sensing of Environment, 98(1), 2005, 63-79.

[6]. A. J. Clemmens, “Measuring and improving irrigation system performance at the field level,” Melbourne: Irrigation Association of Australia, 2000.

[7]. J. R. Jensen, “Introductory digital image processing,” (3rd ed.) Upper Saddle River, NJ: Prentice Hall, 1996.

[8]. D. Lu, P. Mausel, E. Brondizio, & E. Moran, “Change detection techniques.” International Journal of Remote Sensing, 25(12), 2004, 2365-2407.

[9]. S. Ekstrand, “Assessment of forest damage with Landsat TM: correction for varying forest stand characteristics,” Remote Sens. Environ., 47, 1994, 291-302,.

[10]. Active Floodplain Mapping:Defining the “River Space” Report Code: 005_GBP_IIT _FGM_DAT_01 _Ver 1_Dec 2010.

[11]. Gary J. Brierley and Kirstie A. Fryirs, “Geomorphology and River Management: Applications of the River Styles Framework,” Blackwell Publishing, Oxford, UK, 2005, 398, ISBN 1-4051-1516-5.

[12]. N. D. Smith, “Sedimentology and bar formation in the Upper Kicking Horse river, a braided outwash stream,” J. of Geol., 82, 1974, 205-223.

[13]. T. Das, “Land Use / Land Cover Change Detection: an Object Oriented Approach, Münster, Germany,” Thesis Master of Science in Geospatial Technologies. Institute for Geoinformatics University of Münster. 2009, 18.

[14]. R.G. Pontius, E. Shusas, M. McEachern, “Detecting important categorical land changes while accounting for persistence,” Agriculture, Ecosystems and Environment, 101, 2004, 251–268.

[15]. M. M .Rahaman, “Integrated Ganges basin management: conflict and hope for regional development,” Water Policy 11, 2009, 168–190.

[16]. Saumitra Mukherjee, “Role of Satellite Sensors in Groundwater Exploration,” Sensors, 8, 2008, 2006-2016.