

Bank Erosion and Accretion along the Putharjhora- Kranti Reaches of the Chel River, Piedmont Sikkim Himalaya from 1955 to 2017

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ABSTRACT

We have studied bank erosion and accretion along the Putharjhora-Kranti reaches of the Chel River, piedmont Sikkim Himalaya using SOI topographical maps of 1955 and 1970, and Landsat images of 1976, 1987, 1994, 2005, 2010 and 2017. Extensive field survey was also conducted to supplement the study and thereby verify the findings derived from GIS analysis. We have deployed overlay method for determination of areas of bank erosion and accretion by superimposing and comparing sequential changes in the position of banks in these years. We identified 342 erosion plots (all plots >1m² has been considered, plots <1m² were neglected). The total area of bank erosion from 1955-1970 equaled 34.77 km², of which 12.4 km² occurred along the left bank and 22.4 km² along the right bank. The total area of bank retreat amounted to 13.65 km² during 1955 to 1970, 9.61 km² from 1970 to 1976, 1.45 km² from 1976 to 1987, 3.43 km² from 1987 to 1994, 3.55 km² from 1994 to 2005, 1.93 km² from 2005 to 2010, and 1.15 km² from 2010 to 2017. The annual rate of bank erosion from 1955 to 1970 averaged 0.92 km²/y, and increased to the highest value of 1.61 km²/y during 1970 to 1976, then decreased to the lowest derived value of 0.13 km²/y during 1976 to 1987, 0.5 km²/y from 1987 to 1994, 0.33 km²/y during 1994-2005, 0.38 km²/y from 2005 to 2010, and 0.17 km²/y from 2010 to 2017. Spatially, the Oodlabari Bazaar-Nipuchapur Tea Garden section has suffered the most extensive bank erosion whereas Rajadanga-Kranti section of the study reach sustained minimal bank erosion. Further, right bank has recorded larger erosion compared to the left. A brief analysis of possible sources of error in estimation for bank erosion area has also been provided.

Keywords: Bank erosion and accretion, River Chel, Putharjhora-Kranti, Overlay method.

INTRODUCTION

Rivers are highly sensitive to environmental conditions, and alluvial channels can respond and readjust at a range of rates to the variations caused by water and sediment inputs,

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active tectonics and human activities at a range of spatial and temporal scales (Sinha and Ghosh, 2012; Heitmuller, 2014). Any changes, whether natural or anthropogenic, can initiate a departure from a state of dynamic equilibrium (Winterbottom, 2000; Petts and Gurnell, 2005). This may in turn, result in channel instability causing changes in channel form and pattern (Yang *et al.*, 1999; Surian and Rinaldi, 2003; Wellmeyer *et al.*, 2005; Kummur *et al.*, 2008; Yao *et al.*, 2011; Gupta *et al.*, 2013; Midha and Mathur, 2014).

Channel migration with bank erosion, accretion, and down cutting is a natural phenomenon for an alluvial river. However, with the growth of human population world over the impact is evident. Humans are emerging as rather dominating factor than the natural ones. Developmental activities like reservoir construction, restricting the lateral movement of river through embankments, sand and boulder mining, land use alterations and infrastructure construction along the river banks have altered the natural geomorphological dynamics of river (Gregory and Park, 1974; Knighton, 1989; Kondolf, 1997; Surian, 1999; Surian and Rinaldi, 2003; Batalla *et al.*, 2004; Vanacker *et al.*, 2005; Wellmeyer *et al.*, 2005). The consequent channel instability cause damage to various socio-economic and environmental in terms of flood hazards, damage to riparian vegetation and infrastructure, inland navigation, and alteration of aquatic and riparian ecosystems. Thus, it poses challenges for engineers, scientists, and managers on how to best accommodate societal needs with the structure and processes of nature. Understanding the planform dynamics of river channels has important implications for maintaining biodiversity (Naiman *et al.*, 1993; Hughes, 1997; Ward *et al.*, 1999) and minimizing flood damage (Holburt, 1984). Investigations of historical channel change provide insight into how stream channels respond to such flood events. With this information, land and resource managers are able to make decisions that minimize social costs (*e.g.*, flood damage to property) and maximize the ecological benefits of flooding (*e.g.*, rehabilitating riparian vegetation and deterring the proliferation of exotic species) (Tiegs and Pohl, 2005). Thus, an improved understanding of river channel change processes is imperative for improving river engineering and environmental management as well.

The Chel basin is a part of the region popularly known as 'Dooars' which falls in the zone of transition between the dissected upper Himalayan hill surface and the lower gently rolling Teesta- Brahmaputra plains, and is popular for notorious incidents of channel avulsion and river capture activities (Chakraborty and Mukhopadhyay, 2014). Because of its straddle like situation with two distinct physiographic units, Chel basin has varied geomorphologic problems. The hilly terrain in the north above the elevation 350m experience rapid overland flow, erosion and landslides whereas its piedmont in the intermediate and alluvial plain in the south is observing large scale sediment deposition, rise in valley floor and consequent shifting of channels (Lama and Maiti, 2019). Channel dynamism of river Chel is causing large scale erosion along its course and is damaging Tea Gardens, forests and agricultural lands (Fig. 5). Therefore, a study on the erosion and accretion along a reach (Putharjhora - Kranti) of river Chel has been attempted herein over the period of 62 years (1955-2017) using Topographical sheets, multi-temporal Landsat images, and supplemented by fieldwork.

STUDY AREA

Chel lies to the left of river Tista after Lish and Gish and joins Neora to become Dharala Nadi at 88° 44' 13"E, 26° 41' 45.6" N which ultimately merges with mighty Tista about 13 kms downstream. The study area extends between 26° 41' 30" and 27° 5'15" north latitudes and

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longitudes 88° 37'00" and 88° 45' 15" east (Fig. 1). The entire watershed covers an area of 321 km² with a watershed perimeter of 115.21 km. Elevation ranges from 92 m to 2449 m. Geomorphologically, the basin comprises of the alluvial plain, piedmont surface, terrace surfaces, lesser Himalayan surfaces etc. Agriculture in the watershed is largely Tea plantation. Chel is one among many other rivers (Gish, Diana, Chamurchi, Rehti, Gabur-Basra, Jainti etc.) that are dissecting the southern part of Lesser Himalaya with catchment sizes between 50–100 km² and are located in the belt of higher precipitation and form large alluvial fans. "Aggradation follows upstream into the hills, while farther downstream the braided channels changes into meandering ones". The distribution of rainfall is such that 80-90% of the total rainfall amount is concentrated in five summer months from May to September and almost no rainfall during winter. Mean monthly temperature ranges between 18.2°C – 29.3°C (Lama and Maiti, 2019).

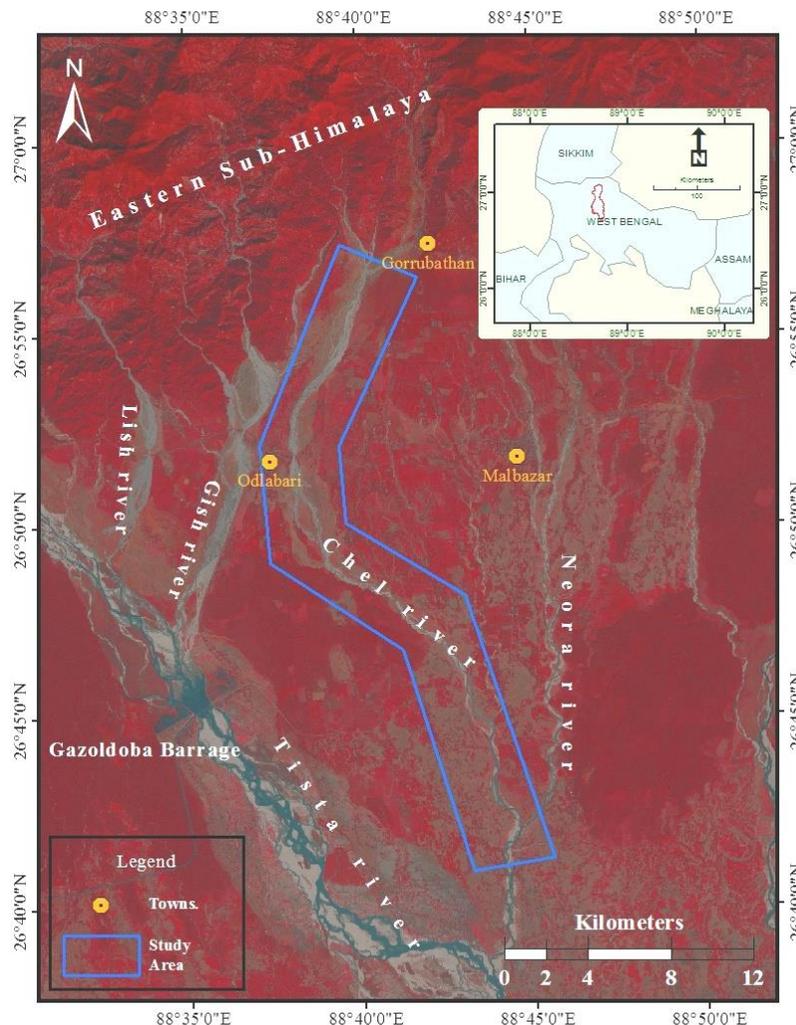


Fig. 1. Pan Sharpened Landsat 8 OLI/ TIRS image (1 December 2017, Path and Row- 139/41) showing the study reach of river Chel (Map of part North- East India showing location of Chel river basin in the inset). Note: The image is a standard false color composite where the Red, Green and Blue band has been assigned Green, Red and Near Infrared colors, respectively.

DATA AND METHODOLOGY

In this study we applied overlay analysis methodology of seven temporal datasets using a combination of topographic maps and Landsat Images spanning 62 years (from 1955 to 2017). This study uses topographical maps and multi temporal Landsat data to quantify and analyze the dynamics of River Chel from 1955 to 2017. A single Landsat scene (Path/ Row: 139/41; 149/41 for 1976 image) covers the entire study area. Similarly, one US AMS Series–U502 topographical map too covers the entire study area. Whereas two sheets of Survey of India topographical maps (78B/9 & 78B/10) topographical maps covers the study area. Therefore, six Landsat scenes (1976, 1987, 1994, 2005, 2010, and 2017) were collected from the USGS site (<http://earthexplorer.usgs.gov/>). One 1: 250,000 scale U.S. Army corps of Engineers NG 45-8, Series –U502 topographical map (1955) was acquired from the University of Texas site (<https://legacy.lib.utexas.edu/maps/india.html>) and two 1:50,000 scale topographical maps (Map no.- 78 B/9 and 78B/10) surveyed during 1969-71 were obtained from the Survey of India (SOI). Therefore, the study will confine with six epochs (1955-1970,1970-1976, 1976-1987,1987-1994,1994-2005,2005-2010, and 2010-2017). There exists a large data gap from 1855 until 1970, from 1976 to 1987 and from 1994 until 2005. Variation in the length of epochs is due to availability of topographical maps and cloud-free Landsat scenes. All the Landsat scenes were downloaded from the USGS through their data visualization tool GloVis. (Table-1). All the images were acquired for months of October to December as this time of the year generally the region is cloud free being dry season and the discharge is sufficient to fill the main channel normal (non-flood water level of the river) and at the same time relatively constant from year to year.

Table-1: Map sources used in the study.

Types of data	Publisher	Index/ map no.	Survey year	Scale	Spatial coverage		
Edition-2 Army Map Service (AMS) Series-U502	USArmy Corps of Engineers	NG 45-8	1955-1956	1:2,50,000	Jalpaiguri and Kochbehar District		
Topographical maps	Survey of India	78 B/9 and 78 B/10	1969-1971	1:50,000	Darjiling, Jalpaiguri and Dinajpur District		
Satellite images	Satellite/ sensor	Path/Row	Date of acquisition	Resolution (Meter)	Projection	WRS type	Bit depth
	Landsat 1-5 MSS	149/41	30.11.1976	60	UTM/WGS 1984	1	8
	Landsat 4-5 TM	139/41	31.12.1987	30	UTM/WGS 1984	2	8
	Landsat 4-5 TM	139/41	18.12.1994	30	UTM/WGS 1984	2	8
	Landsat 4-5 TM	139/41	13.10.2005	30	UTM/WGS 1984	2	8
	Landsat 4-5 TM	139/41	14.12.2010	30	UTM/WGS 1984	2	8
	Landsat 8 OLI/TIRS	139/41	01.12.2017	30 (15m for PAN)	UTM/WGS 1984	2	16

ArcGIS (version 10.1; ESRI, Redlands, CA) software package have been used for preparation of GIS database relating to historical channel position and movement throughout the entire study period of 62 years. All the images were processed through ERDAS imagine (v. 9.0) software and then were georeferenced based on Universal Transverse Mercator (UTM) projection system (Northern hemisphere 45 zone and world geodetic system (WGS) 84) manually using GCPs collected during GPS survey. All the GCPs representing permanent features like, road intersections, corners of large buildings, bridges etc were well distributed

throughout the scenes, and the registration resulted a Root Mean Square Error (RMSE) of <0.5 pixels. A first-order polynomial transformation with nearest neighbor resampling technique was applied to analyze channel planform dynamics of river Chel from 1972-2017. Finally, each image was clipped using an area of interest (AOI) file derived from a vector dataset. All the datasets were brought to a common spatial reference system of UTM-45, WGS 84. By superimposing active channel banklines during seven different periods between 1955-2017, we created polygons depicting areas of erosion and accretion for different epochs. The earliest and most recent data corresponds to years 1955 and 2017 respectively. Based on the derived polygons, we have attempted to quantify areas of erosion, areas of accretion and their spatio-temporal variation. With the objective of computation of channel migration change, we considered the earliest channel bank line (1955) as the origin. The banklines of later date were superimposed on previous ones. Native knowledge about the area was also applied.

DELINEATION OF CHANNEL BOUNDARY

A bunch of previous studies demonstrate the availability of techniques ranging from manual digitization to automatic digitization to extract river boundaries from Landsat images. We attempted automatic technique for extraction of river banks but dropped the idea as the results were unreliable due to similarities in spectral reflectance of several riverine features. Studies done in other parts of the world (Yang *et al.*, 1999; Gupta; 2013) have similarly found manual digitalization superior than the automatic digitization for delineation of river bank from Landsat multispectral data. So we preferred manual digitization technique over automatic one and digitized the channel boundaries from each Landsat image, using a combination of bands (1-6-7) which has been found by Yang *et al.* (1999), an effective band combination to display river channels at normal water level. Now there is some division of opinion in defining the channel-bank limit among the geoscientists. Nicoll and Hickin (2010) digitized the channel outlines of confined meandering rivers at 23 locations in Alberta and British Columbia, Canada to understand planform geometry and channel migration using a strict geomorphologic approach wherein boundary of water limit was taken as edge of the channel because this boundary is clearly visible in multispectral Landsat image. However, this approach cannot be used in our study area having low discharge and braiding nature of flow. Almost in entire study reach, the channel cross sections are broad and shallow. So a small change in water level can therefore give misleading large changes in the positions of the channel boundaries. To get rid of this problem, we defined channel bank limits using a non-morphological variable, namely soil-vegetation limit. This method of defining channel bank limits was adopted by Lawler (1993), Gurnell (1997); Yang *et al.* (1999), Tiegs and Pohl (2005), Dewan *et al.* (2017) etc. Soil-vegetation limit approach presume that river channel limit is an elongated area wherein stream flow occurred with sufficient frequency, energy and duration to prevent the incidence of vegetation, and therefore 90% of this area is either bare soil or water (Gurnell, 1997; Yang *et al.*, 1999, Tiegs and Pohl, 2005). This method effectively overcomes the problem of inconsistencies in channel planform delineation due to varying water levels (Gurnell, 1997). Due to its simplicity and practicality, this method has been used successfully and widely in different climatic regions of the world (Lawler, 1993, Gurnell, 1997; Yang *et al.*, 1999, Tiegs and Pohl, 2005, Midha and Mathur, 2014, Dewan *et al.*, 2017). A single operator performed digitization of channel boundary on-screen from each Landsat image at 1:5000. Finally, a georeferenced spatial dataset, representing Channel banklines, for each topographical map and Landsat image was created (Fig. 2). Bhunia *et. al.* (2016) have used single sensor Landsat-Thematic Mapper (TM) of 1989,1999,2005 and 2010 to show the channel dynamics of a reach of river Ganga in

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the southern Vaishali district of Bihar. They argue that observing images of common projection minimizes the error due to temporal changes.

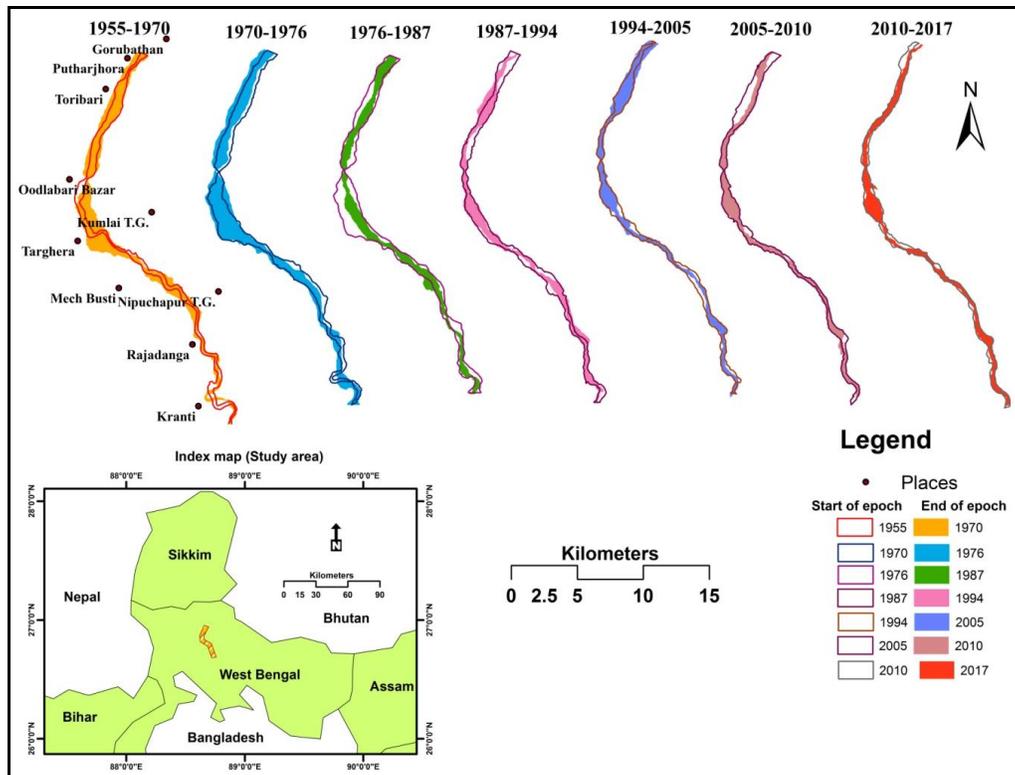


Fig. 2: Channel configuration map of Chel River, showing epochal change in channel location. Channel at the start of the epoch are shown by hollow polygon, at the end with solid fill.

RESULTS AND DISCUSSION

Determination of erosion and accretion areas

River bank changes were analysed by superimposing the digitized banklines for each of the seven data sets using the ArcGIS software and its extensions. The seven periods are 1955 to 1970 (15 years), 1970 to 1976 (6 years), 1976 to 1987 (11 years), 1987 to 1994 (7 years), 1994 to 2005 (11 years), 2005 to 2010 (5 years), and 2010 to 2017 (7 years). The overlaying of banklines for each time period revealed the areas of erosion and accretion.

We then digitized the areas of erosion and deposition thus revealed after superimposition for each time period to create polygons that represented the difference between the two bank lines. If the developed polygon was positioned to right of the right bank of base year, it represented an erosion polygon: if the polygon was positioned to the left of the right bank of base year, it represented the accretion polygon. For the left bank, the same process was repeated but unlike right bank, here polygons to the right and left of the base year represented accretion and erosion polygons (Fig. 3). Adding the areas of these polygons gave the total eroded and accreted areas of the time period.

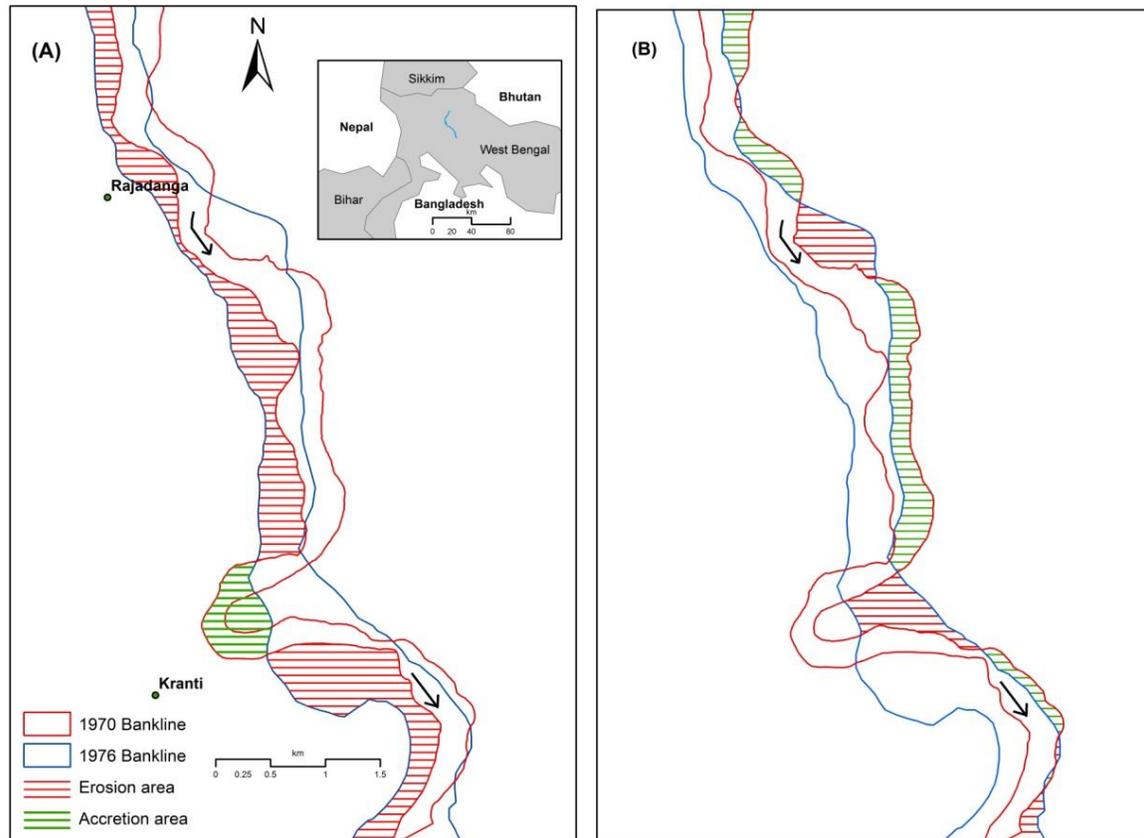


Fig. 3: Enlarged area demonstrates an example for the identification of erosion and accretion areas between transects 27 and 35. (A) Erosion and accretion areas along the right bank of river Chel during 1970-1976. (B) Erosion and accretion areas along the left bank of river Chel during 1970-1976.

Area of erosion

The total area of bank erosion from 1955-1970 equaled 34.8 km^2 , of which 12.36 km^2 were on the left bank and 22.4 km^2 were on the right bank (Table-2) Further, we identified 342 erosion plots (all plots $>1\text{m}^2$ has been considered, plots $<1\text{m}^2$ were neglected). On the left bank there are 166 erosion plots smaller than 1 km^2 which totaled 8.52 km^2 (69.16 % of the total area). In contrast, there are only 2 erosion plots larger than 1km^2 but their area equaled 3.8 km^2 (30.84 % of the total area).

Along the right bank there are 168 erosional plots are larger than 1 km^2 of size which equaled 8.07 km^2 (35.8 % of the total area). In contrast, there are only six erosional plots larger than 1km^2 but their area totaled 14.17 km^2 (64.2 % of the total area).

Table-2: Area of riverbank erosion along the study reach of River Chel from 1955-2017.

Time span	Area of erosion (sq.km.)		
	Left Bank	Right Bank	Total
1955-1970	5.77	7.88	13.65
1970-1976	1.77	7.84	9.61
1976-1987	0.31	1.14	1.45
1987-1994	1.344	2.082	3.426
1994-2005	1.81	1.741	3.551
2005-2010	0.76	1.172	1.932
2010-2017	0.6	0.546	1.146
Total (1955-2017)	12.364	22.401	34.765

Area of accretion

The total area of bank accretion from 1955-1970 equaled 35.16 km², of which 18.99 km² were along the left bank and 16.17 km² were on the right bank (Table-3) Further, we identified 363 accretion plots. On the left bank there are 166 erosion plots smaller than 1 km² which totaled 14.26 km² (76.13 % of the total area). In contrast, there are only 3 erosion plots larger than 1km² but their area equaled 4.47km² (23.86 % of the total area).

Along the right bank there are 191 erosional plots are larger than 1 km² of size which equaled 8.68 km² (52.93 % of the total area). In contrast, there are only 3 erosional plots larger than 1km² but their area totaled 7.72 km² (47.07 % of the total area).

Table- 3: Area of riverbank deposition along the study reach of River Chel from 1955-2017.

Time span	Area of accretion (sq.km.)		
	Left Bank	Right Bank	Total
1955-1970	0.794	1.527	2.321
1970-1976	4.72	0.45	5.17
1976-1987	5.23	6.62	11.85
1987-1994	3.67	1.734	5.404
1994-2005	1.6	1.1	2.7
2005-2010	1.632	2.763	4.395
2010-2017	1.34	1.98	3.32
Total (1955-2017)	18.986	16.174	35.16

Annual rates of bank erosion and accretion

The total area eroded along the study reach totaled 13.65 km², from 1955 to 1970; 9.61 km², from 1970 to 1976; 1.45 km², from 1976 to 1987; 3.43 km², 1987 to 1994; 3.55 km², from 1994 to 2005; 1.93 km², from 2005 to 2010 and 1.15 km², from 2010 to 2017. These total figures give way to annual bank erosion rates of 0.92 km²/y, 1.6 km²/y, 0.13 km²/y, 0.49 km²/y,

0.33 km²/y, 0.38 km²/y, 0.17 km²/y respectively (Table-2 & 4). The total area accreted along the study reach equaled 2.32 km², from 1955 to 1970; 5.17 km², from 1970 to 1976, 11.85 km², from 1976 to 1987; 5.4 km², 1987 to 1994; 2.7 km², from 1994 to 2005; 4.4 km², from 2005 to 2010 and 3.32 km², from 2010 to 2017. These figures translate into annual accretion rates of 0.15 km²/y, 0.88 km²/y, 1.08 km²/y, 0.77 km²/y, 0.25 km²/y, 0.88 km²/y, and 0.47 km²/y, respectively (Table-3 & 4).

Table- 4: Mean annual rates of bank erosion and accretion along the study reaches from 1955 to 2017.

Time span	Erosion rate (sq.km/y)	Accretion rate (sq.km/y)
1955-1970	0.92	0.15
1970-1976	1.61	0.88
1976-1987	0.13	1.08
1987-1994	0.5	0.77
1994-2005	0.33	0.25
2005-2010	0.38	0.88
2010-2017	0.17	0.47

Spatial and temporal distribution of erosion and accretion along the study reach

Areas of erosion and accretion along the right and left banks of Chel River are shown in (Fig. 4). The table depicts that during the period 1955-1970, erosion exceeded far more than accretion along the left bank. Rest of the assessment periods record accretion values are greater than the erosion values, except during 1994-2005 wherein the erosional area is 1.81 km² against the accretion area of 1.6 km². The maximum amount of erosional area (5.8 km²) was recorded during 1955-1970, while maximum accretion area (5.13 km²) was recorded during 1976-1987 along the left bank. Over the entire 62 years of assessment period, 12.32 km² area was eroded against the 18.81 km² of accretion period along the left bank. This means that during the last 62 years 6.49 km² of land has been gained along the left bank of river Chel. In contrary to left bank, the right bank of river Chel is more prone to erosion. Except during 1976-1987 and last two epochs (2005-2010, 2010-2017), right bank erosion exceeded deposition. The maximum area of erosion (8.09 km²) occurred during 1955-2017 whereas maximum area of accretion (6.5 m²) occurred during the same time period along the right bank. Altogether 22.54 km² of area was eroded against 16.32km² of accretion during the entire assessment period. This implies that an area equivalent to 6.22 km² was lost along the right bank of river a Chel during 1955-2017 (Table-2 and 3).

ACCURACY OF RESULTS

We have selected cloud free Landsat images of minimum water level differences and a single operator digitized multi-temporal channel boundary to achieve highest level of accuracy yet there can't be scope for denial of the fact that while working with multi-temporal dataset on Remote sensing and GIS, positional inaccuracies may crop up due to procurement of maps and images from different time period and at different scale. In our case, one of the possible error

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source is the different map scale of Topographical maps (1955 AMS with 1:2,50,000 and 1970 SOI with 1:50,000 map scale) and the different spatial resolutions of the Landsat MSS (60m) and ETM & OLI/TIRS (30m) images.

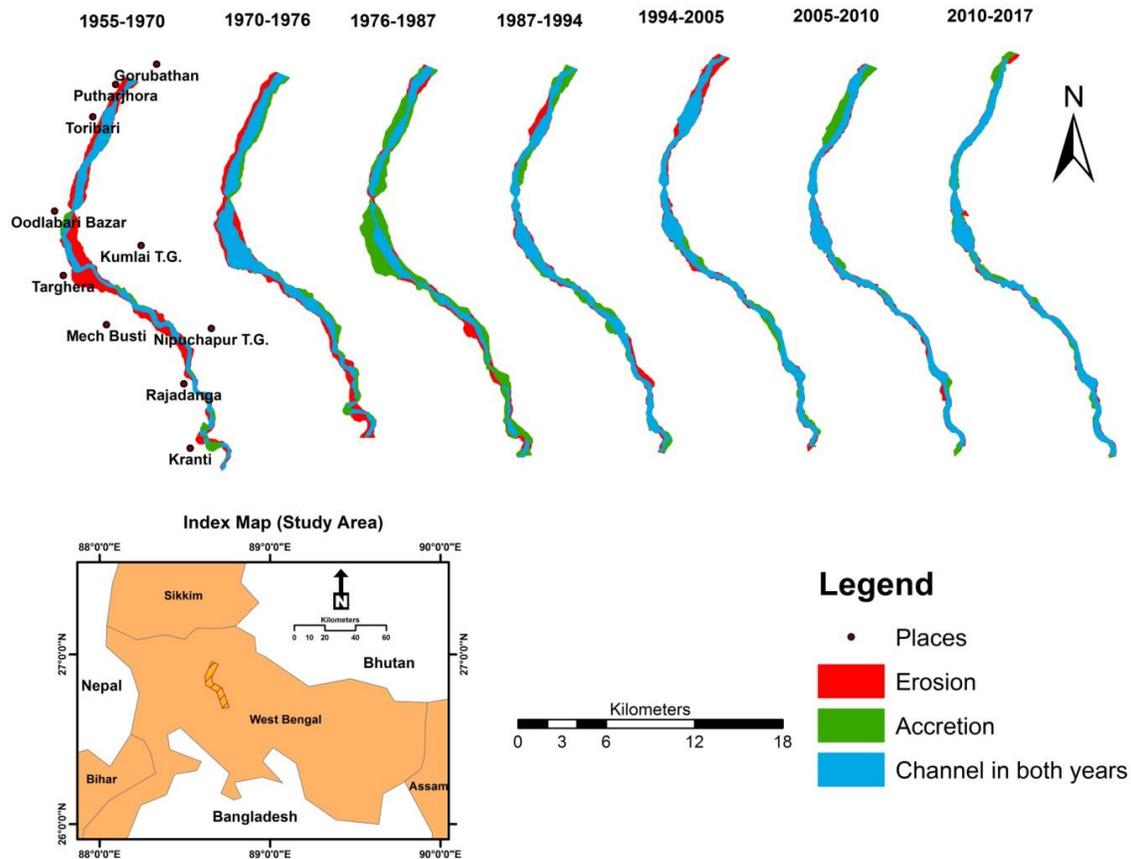


Fig. 4: Spatial patterns of erosion and accretion areas along the Chel River.

Further, systematic and random errors of the sensors themselves could have affected the delineation of channel boundary (Dewan *et al.*, 2017). Mixed color composition of pixels in multispectral Landsat images along the transition zones posed as a challenge and can be considered as another source of error that precluded us from deciding the exact line of channel boundary along some reaches. This misjudgment of channel boundary can have a significant implication in area calculation whether erosional or accretional.

Other sources of error inherent in our methods include those associated with polygon delineation and variability in the time that elapsed between the cessation of flood events and the collection date of the image data. Despite everything, we believe the work embodies measurement accuracy of satisfactory level and documents information on erosion-accretion scenario of the River Chel along its alluvial reach.

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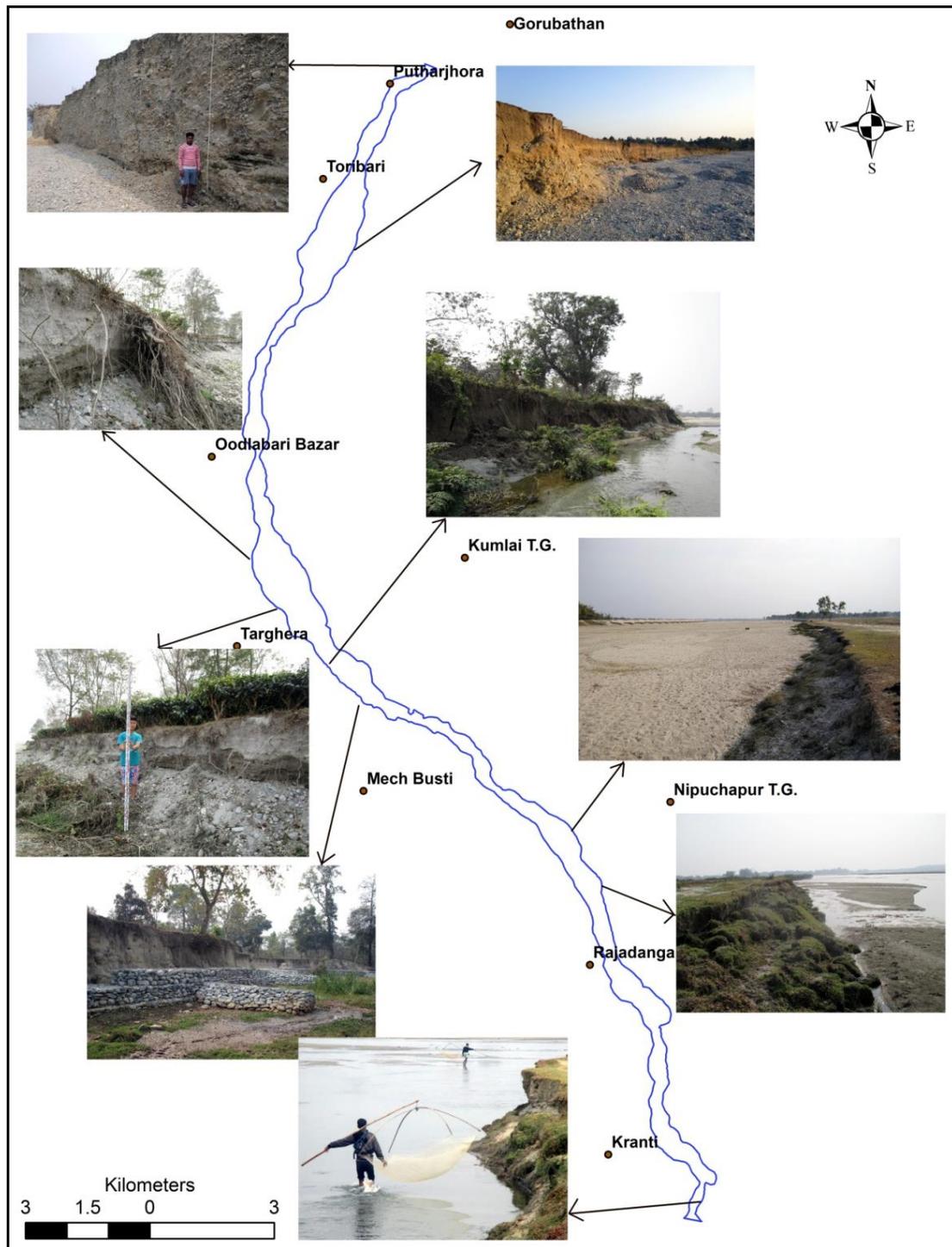


Fig.5: Field photographs showing bank erosion along the entire study reach of Chel River.

CONCLUSION

The present study attempted to show channel dynamism of river Chel from 1955 to 2017 spanning 62 years. Thereby it computed the temporal and spatial variation in the amount of areas of erosion and accretion along the Putharjhora- Kranti reach.

In the studied reach of Chel River, the area of bank retreat from 1955-2017 totaled 34.77 km², of which 22.4 km² was recorded along the right bank whereas 12.36 km² were along the left bank. The total areas eroded were 13.65 km² during 1955 to 1970, 9.61 km² during 1970 to 1976, 1.45 km² from 1976-1987, 3.43 km² from 1987-1994, 3.55 km² from 1994-2005, 1.93 km² from 2005-2010, and 1.15 km² from 2010-2017. The total areas accredited were 2.32 km² from 1930 to 1970, 5.17 km² from 1970 to 1976, 11.85 km² from 1976-1987, 5.4 km² from 1987-1994, 2.7 Km² from 1994-2005, 4.4 km² from 2005-2010 and 3.33 km² from 2010-2017. There is no noticeable trend in the mean annual rates of erosion and deposition in the study reach. The values are all fluctuating during the study period. Spatially, the right bank Oodlabari Bazaar-Nipuchapur Tea Garden section has suffered the most extensive bank erosion, whereas Rajadanga- Kranti section of the study reach sustained minimal bank erosion. Lastly the study also underscores the immense potentiality and utility of freely available Landsat images coupled with GIS technology in quantitative fluvial geomorphology.

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