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Three Decades of River Bank Erosion and Accretion Appraisal along Bank Line Shifting Trend in a Transboundary River, Teesta Floodplain of Bangladesh

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Abstract

As the world's largest delta, Bangladesh possesses distinctive geomorphology dominated by transboundary rivers, making it vulnerable to climatic hazards such as river erosion that causes severe loss of land and other resources. Using four Landsat imageries of 1991, 2001, 2011 and 2021 the current study analyzed the amount and trend of river erosion and accretion on the Teesta Floodplain of Bangladesh for three decades. Findings indicate that the Teesta River experiences severe bank erosion and accretion regularly, causing bank line shifting and thus significant affecting the land-use/land-cover (LULC) change of the area. Between 1991 and 2021, approximately 194 square kilometers of land were eroded, while an equivalent area of land was accreted. Approximately 1072 km^2 of agricultural land was converted into other categories, with the settlement area gradually increasing. This trend of changes shows that agricultural land and water-bodies will reduce in the next two decades while barren land and settlement areas will increase. The agricultural lands and barren lands have a greater chance of being occupied by settlement areas. At the same time, crop production patterns will move to those crops that require less water due to the reduction of water-bodies. Reduced flow during the dry season and massive discharge during the monsoon from India's Gajoldoba barrage caused massive siltation and erosion. Comprehensive river management and restoration with an intergovernmental treaty or understanding between India and Bangladesh is required to resolve this crisis in the long run.

1. Introduction

Bangladesh is one of the largest active deltas in the world with unique landscape features and biodiversity (Zevenbergen et al., 2018; Hasan et al.,2020; Masum et al., 2023). The entire country of Bangladesh is made up of a generic hilly terrain, a small amount of high land, and a large expanse of plain land inundated by river water (Rasul et al., 2004). The Bangladesh Delta is a highly dynamic region that is vulnerable to natural disasters and climate change due to unique geographical location, landscape features, large number of rivers, and monsoon climate (Mutahara et al. 2018; Sharma et al. 2010).

The majority of Bangladesh's lands are represented by Quaternary deltaic deposits (Zevenbergen et al., 2018). Bangladesh's natural location lies between the Himalayas and the Bay of Bengal, with a tropical monsoon climate that is prevalent throughout the country (Rasul et al., 2004). The catchment area of the main rivers is around 1.65 million square kilometers, of which only 7.5 percent lies inside Bangladesh's periphery, spawning 1200 km of run-off yearly, of which only 10% is generated within Bangladesh (Afroz & Rahman, 2013). These rivers carry around 1.1 billion tons of silt every year in addition to massive amounts of water, and are responsible for flooding and shoreline erosion in Bangladesh (Agaton et al., 2016). The combination of large ejections and heavy sediment masses with high water substances from the annual wet monsoon, a low grade of compaction, and a massive amount of runoff materials results in vastly variable and dynamic channel morphologies to adjust their bed configurations (Alam, 2017; Bandyopadhyay, 2007). In any season, the river channel might alter by more than 300 meters (Akhter et al., 2019). Bangladesh has almost 2,400 kilometers of bank line along 700 rivers (including tributaries and distributaries).

The process of bank erosion is strongly influenced by river dynamics. The river's dynamic feature produces riverbank erosion, a terrible natural hazard in Bangladesh (CEGIS.,2015). According to satellite pictures, the rivers consume over 6,700 hectares of agricultural land each year, affecting approximately 8,00,000 people (DMB, 2017; CEGIS, 2015). The use of satellite remote sensing to examine fluvial channel dynamics over a vast area is particularly successful (Leigh, et. Al., 2004). Although this technique has been frequently utilized to study fluvial channel movement and discover paleo-braided channels on terraces surfaces, it has not been generally employed to study fluvial channel migration (Leigh, et. Al., 2004). Several researches have used geospatial tools to explore basic channel alteration, such as overlaying a set of historical channel maps in various types of river systems (Akhter et al., 2019).

The Teesta is Bangladesh's one of the most dynamic river and the country's fourth largest river system (Akhter et al., 2019). The Teesta floodplain area is one of Bangladesh's major geomorphic units, including fourteen districts in the country's north (Raihan et al., 2018). The Teesta is one of the 54 transboundary rivers crisscrossed across the Bangladesh periphery. It is the most disputable river, over which Bangladesh and India wrangled over for the 50 years (Afroz & Rahman, 2013). India constructed Gajoldoba barrage in upper course of Teesta without considering the situation in Bangladesh. Sudden discharge from Gajoldoba barrage creates enormous havoc in downstream with massive flooding and excessive river erosion (Islam, 2016). The erosion and shifting of rivers in Bangladesh have long been a dominant environmental problem (Ferdous &Mallick, 2019) with negative impact on riverside dwelerssecurity and shelter, along with their means of subsistence (Brouwer et al., 2007).

This study is intended to estimate the extent of riverbank erosion and accretion in the Teesta Floodplain along bank line shifting during 1991 to 2021.During the last few decades, the Teesta River has changed its plan form from braided to straight through meandering and back (Akhter et al., 2019). This process includes changes in width, braiding intensity and extent of annual bank erosion. The objective is to understand better the erosion and accretion mechanisms of the Teesta River by estimating the spatial extent and patterns of bank line alterations and island area by remote sensing.

No specific research has explored the bank erosion and accretion along bank line shifting trend in this transboundary river, Teesta floodplain of Bangladesh. Akhter et al. (2019) has worked with the spatiotemporal changes in five districtsin the reach of Teesta river. Several other researchers have explored basic channel alteration in otherbig river systems like Padma and Meghna (Hasan et al., 2017, Ophra et al., 2018, Hossain et al., 2013). Therefore, this paper aims to assess the extent of riverbank erossion and accretion as well as channel dynamics of the Teesta River.

The outcome of this study will contribute to understand the prediction of the morphological behavior (channel sifting, erosion and deposition) of the Teesta River. Then a Land Use/Land Cover (LULC) has developed, and finally, based on the trend of land use changes, a prediction has been given which predicts the land pattern in the next two decades if any steps are not undertaken.Moreover different government and non-government organizations related with river can develop different planning and create models for mitigating the bank line erosion. The predicted map will help policy makers to take the necessary steps in the future for sustainable development activities, conservation of recourse. Finally it will assist to implement 'Teesta River Comprehensive Management and Restoration Project' which Bangladesh Government planned to execute with the Collaboration of Chinese government.

2. Data and Methods

This chapter explains how to validate the use of specific processes and techniques to discover, select, and evaluate data in order to better understand the study problem. Several literature reviews were used to guide the design of this study. This chapter also discusses the challenges of putting methods into practice. Because the study aims to determine the trend of riverbank shifting, erosion, and deposition of the Teesta River in chosen regions, the research methodologies used in this study are analytical in nature. This study is both quantitative and qualitative in character. To conduct this research, the necessary data were mainly collected from satellite image analysis.

2.1. Study Area

The Teesta floodplain area is Bangladesh's largest geomorphological unit, covering a considerable portion of northern Bangladesh. The Teesta is Bangladesh's most active river and the country's fourth largest river system. The Teesta River originates in India's Sikkim, from the Pauhunri Glacier in the Eastern Himalayas. The Teesta River flows across Bangladesh's northern area (Figure 1). This river is recognized as the lifeline of Bangladesh's northern territory. Around 21 million in Bangladesh are directly and indirectly depend on the river, which covers nearly 14 percent of Bangladesh's total agricultural area and offers 7.3 percent of the country's livelihood prospects (Statistics, 2015). The Teesta floodplain is located between 25.30° and 26.18° N latitudes and 88.52° and 89.45° E longitudes, and it flows through five districts in Bangladesh's Rangpur Division (Nilphamari, Kurigram, Lalmonirhat, Gaibandha and Rangpur districts). As shown in the 2011 population census, the population is predicted to be 10.42 million (Statistics, 2015). The Teesta River basin is around 2,000 sq.km and is made up of fine to medium – grained typical of an alluvial floodplain. The shallow depressions and valleys of defunct river channels impacted by the monsoon climate, which formed long morphological alterations in the Teesta River's reach.

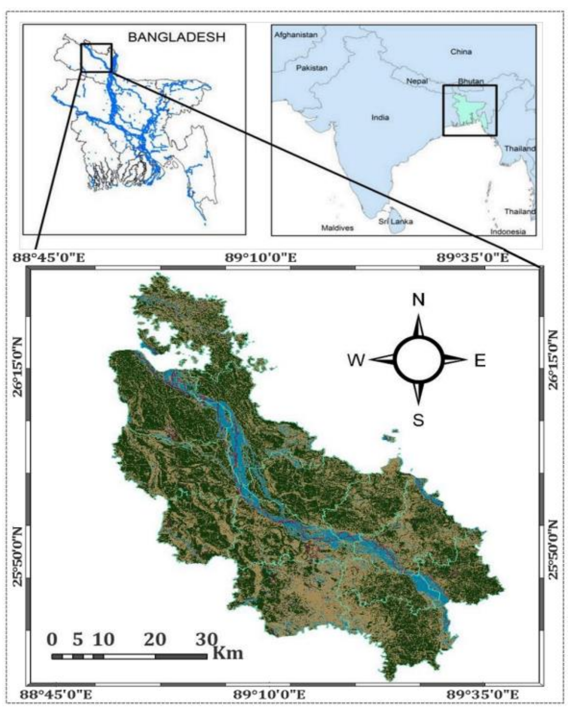

Figure 1. Location of the Study Area (Teesta Floodplain)

Flooding is a risk in the research area. Each year, flash floods occur, with the biggest flooding occurring during the monsoon season in that area due to a sudden surge of water from India's Gajoldoba barrage (Islam 2016). The Teesta River is a vital source of water in the northern drought-prone region, and millions of people rely on it for their livelihoods. The study area is in a sub-tropical monsoon climatic region where rainfall occurs only during monsoon months (June to September), with the rest of the year being dry (Islam, 2016). Despite the fact that the northern region remains dry during the post- and pre-monsoon seasons, the area receives more than 1900 mm of yearly rainfall. Summer and winter mean temperatures in the Teesta River basin are around 35 °C and 15 °C, respectively (Rahman et al., 2011).

2.2. Research Design

Research design is the conceptual frame work within which the research is conducted; it is the blueprint of the research. The method and techniques that are used to conduct this research are analytical in nature. Overall research design is showed in Figure 2.

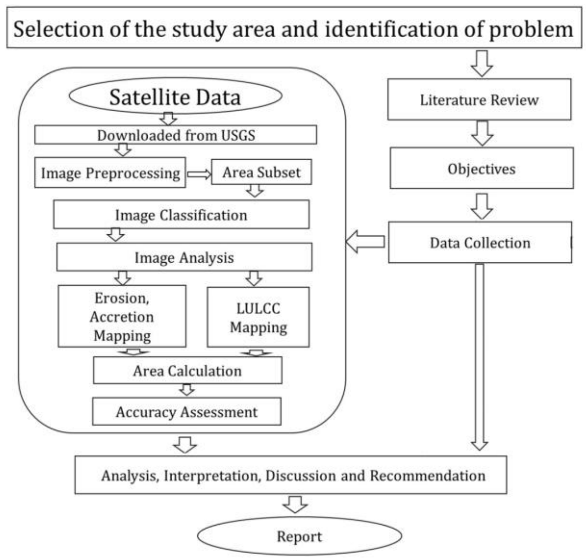

Figure 2. Research Design

2.3. Satellite Image Analysis

Freeware Landsat satellite data were collected from archive of United States Geological Survey using Earth Explorer (http://earthexplorer.usgs.gov), a user friendly online dynamic data visualization and procurement tool from USGS. As the Gajoldoba barrage in the upper steam were constructed in 1985, for clear understanding of the long term (three decades) effect, availability of cloudless images for the same month at every ten years interval and finally for facilitating trend analysis4 satellite images of 1901,2001,2011 and 2021 were using for assessment (Table 1). Other images with different seasonal variation also investigated for ensuring the perfection of the study. Images from Landsat-7 were avoided because of its scanline error.ArcGIS Version: 10.5, Erdas Imagine 2014, Google Earth; Version: Pro were used to complete the analysis.

Table 1. Collected Satellite Image Details

Acquisition Date	Satellite ID	Sensor ID	Path/Row	Spatial Resolution
08-03-2021	Landsat 8	OLI &TIRS	138/42	30 meters
13-03-2011	Landsat 5	TM	138/42	30 meters
17-03-2001	Landsat 5	TM	138/42	30 meters
06-03-1991	Landsat 5	TM	138/42	30 meters

Pre-processing operations were used to correct for data distortions caused by sensor and platform-specific radiometric and geometric errors. All preprocessing methods namely geometric correction, radiometric correction and atmospheric correction were done with due care. The DN values of Landsat TM were converted to radiance data using the following Eq. 1:

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$$L_\lambda = \frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN} \times (QCAL - QCALMIN) + LMIN\lambda \text{……..(Eq.1)}$$

Where, Lλ = is the cell value as radiance, QCAL= digital number, LMINλ= spectral radiance scales to QCALMIN, LMAXλ = spectral radiance scales to QCALMAX, QCALMIN = the minimum quantized calibrated pixel value (typically = 1), QCALMAX = the maximum quantized calibrated pixel value (typically = 255).

Then, the radiance data was converted into at sensor reflectance or TOA reflectance using the following Eq. 2,

$$\rho_\lambda = \frac{\pi \times L_\lambda \times d^2}{ESUN_\lambda \times \cos\theta s} \text{……..(Eq.2)}$$

Where, ρλ = Unitless planetary reflectance, Lλ= spectral radiance (from earlier step), d= Earth-Sun distance in astronomical units, ESUNλ= mean solar exa-atmospheric irradiances, θs = solar zenith angle.

Enhancements were used to make it easier for visual interpretation and understanding of imagery. Image classification uses the reflectance statistics for individual pixels. The images were analyzed through histogram equalization, supervised, unsupervised and NDVI classification. The quality of the downloaded cloud-free Landsat images was improved using a histogram equalization procedure. The study region was classified as supervised, unsupervised, and NDVI to distinguish between water and land features, or to put it another way, to demarcate the river line/bank from the water. The unsupervised classification of the research area was chosen to assess the changes since it provided an explicit scene of the water and land feature among the three categories of supervised, unsupervised, and NDVI. There were made 20 to 25 classes of the study area and then these classes were reclassified into 4 major classes as, Agriculture, Barren, Settlement and Waterbody (Table 2).

Table 2. LULC Classification Scheme Used in this Study

Class Name	Description
Agriculture	Crop fields, farmlands and sparsely vegetated area
Barren	Land areas of exposed soil and barren area influenced by human impact
Settlement	Residential, commercial, industrial, transportation, roads, mixed urban Land, homestead tree and playground
Waterbody	River, open water, lakes, ponds and reservoirs

2.3.1. Change Detection with LULC Trajectories

The LULC trajectory matrices were used to perform a change detection analysis (Ahmed, 2006; Chen et al., 2005; Sejati et al., 2023; Zaki et al., 2022). Processing time series data from the research area from 1991 to 2021 yields LULC trajectories (Banskota et al., 2014; Mosammam et al., 2017). In this work, supervised classification has been done by selecting training zones. As a supervised image classifier, a maximum likelihood classifier (MLC) was used ArcGIS 10.8 was used to transfer the classified images to the GIS layer for quantification of eroded and deposited land covers. Boundary of river areas in 1991,2001,2011 and 2021were digitized through visual interpretation of the converted layers of the classified images in 1991,2001,2011 and 2021 respectively.

2.3.2. Quantification of Erosion and Deposition

The river boundary was then superimposed, followed by converted layers of classified images. The converted layers from classified images from 1991, 2001, 2011, and 2021 were clipped based on digitized river boundary layers from 1991, 2001, 2011, and 2021. The clipped layers in 1991, 2001, 2011, and 2021 correspond to the river areas in 1991, 2001, 2011, and 2021, respectively. The Teesta's eroded and deposited areas were calculated by superimposing and comparing river layers from 1991 to 2001, 2001 to 2011, and 2011 to 2021. The river area in 1991 was subtracted from the river area in 2001, and the converted layer of the classified image of 1991 was clipped on the basis of this subtracted layer. This clipped layer depicts the eroded areas between 1991 and 2001. The same method was used to sort out the eroded areas from 2001 to 2011 and 2011 to 2021.

The attribute tables of these clipped layers were summarized to quantify the eroded land covers from 1991 to 2001, 2001 to 2011, and 2011 to 2021. When deposition was used, the river area in 2001 was subtracted from the river area in 1991, and the converted classified image in 2001 was clipped based on this subtracted layer. This clipped layer indicates the deposited land cover from 1991-2001. The same process was also followed to sort out the deposited land covers from 2001-2011 and 2011-2021. The attribute tables of these clipped layers are summarized for calculation of the deposition from 1991-2001, 2001-2011 and 2011-2021.

2.3.3. Movement of Channels

Due to erosion and deposition of the banks of the Teesta, the river channels are changing. To visualize the movement of channels, the river channels were selected using the attribute tables from the river areas in1991, 2001,2011 and 2021. The river channels were visualized and compared with the river area.

2.3.4. Accuracy Assessment

In Arc Map 10.8, the accuracy of each map was assessed by taking around 260 random points, known as reference points. A valid accuracy assessment map must have a minimum of 30 points for each class and a total score of more than 250 (Congalton and Green, 1999). With the use of these reference locations and the categorized map, a combine table was built. Using the pivot table tool box, a confusion matrix table was created from this combine table. The relationship between the categorized map and the reference data is summarized in an error matrix (Jensen, 2005) and used to calculate the controller and explainer's dependability (Gerard et al., 2010). This matrix table exported in MS Excel was used to calculate omission percent, commission percent, producer accuracy, and user accuracy. With the use of this derived data, the overall accuracy and Kappa coefficient were tested. The Kappa coefficient is always in the range of 0 to 1 (Appendix 1).

2.4. Secondary Data Collection

Secondary data were gathered from various sources in accordance with the study's requirements. Data such as the total area of the study sites, population of the area, cultivable land of the site, past data on flooding and river erosion, and so on were gathered from the union parishad Office, BWDB (Bangladesh Water Development Board), and so on. Furthermore, supporting data and materials were gathered from a variety of sources, such as the internet, previous studies, and survey reports. The data collected for this study was subjected to statistical and cartographic processing in preparation for further analysis and synthesis.

2.5. Result Evaluation and Report Writing

The overall scenario of Riverbank erosion was evaluated with satisfactory precision. After successful evaluation of all findings this report finds a way to be alive. Knowledge, findings and recommendation from previous relevant study was taken in count wisely during the completion of this report.

2.6. Forecasting of LULC for the Next Two Decades

The values for LULC have forecasted for 2031 and 2041 (Ten years intervals) based on the current trend of changes. This forecasting is based on the assumption that the current trend of changes will continue at the average rate, which is found between 1991- 2021. These trend lines have been drawn by the EXCEL forecasting function, which is the simple statistical relationship between the dependent variable, Y (Area) the independent variable, X (Area), were used. The linear equation is as follows (Eq. 3):

$$y = a + bx \ldots. \textit{(Eq.3)}$$

Where, $a = \bar{y} - b\bar{x}$ and $b = \frac{\sum (x-\bar{x})(y-\bar{y})}{(x-\bar{x})^2}$, $\bar{x} = Mean\ of\ Year, \bar{y} = Mean\ of Area$

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3. Results and Discussion

3.1. Teesta River Course

Teesta is one of the most dynamic rivers of Bangladesh. It changes its course very frequently. To investigate morphological changes of the Teesta River, the four satellite images have been analyzed in this study. River courses were extracted with a series of methods using ArcGIS 10.8. In this study images from 1991, 2001, 2011 and 2021 have been taken to show the dynamic shifting of the Teesta River. The following figure 3 shows how the course of Teesta was in different years.

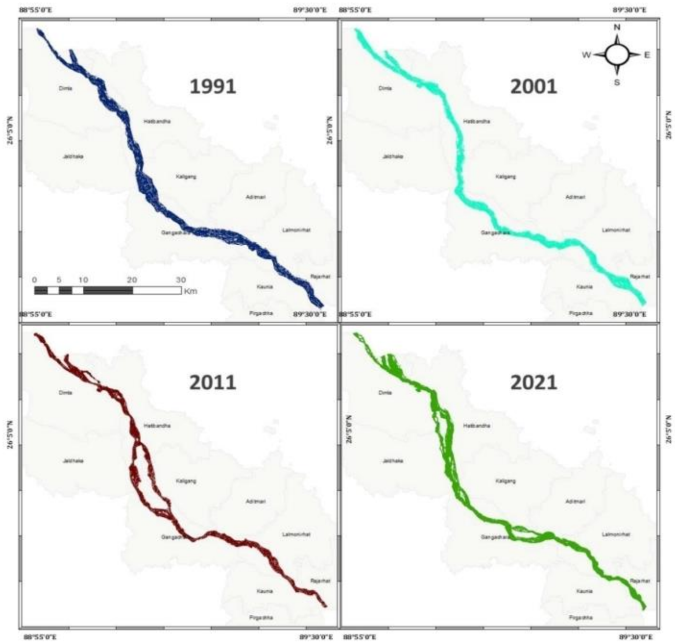

Figure 3. Course of Teesta River in Different Years

Most rivers in humid and sub-humid areas complete their processes in three stages: young, mature, and older. The river flows in a meandering course due to the gradual slope in the first of these three stages. As a result, the river basin has seen lateral erosion and channel shifting. Widening of river Teesta was very conspicuous in 2011 and in 2021 like all big rivers (Hasan et al., 2017, Ophra et al., 2018) which was mainly for the formation of island. Bank failure (the separation and entrainment of bank materials in the form of grains, aggregates, or blocks due to fluvial, subaerial, and geotectonic processes) is a common occurrence in the lower reaches of all rivers (Bandopadhyay, 2007).

3.2. Shifting Nature of the Teesta River Channel

The changing nature of the Teestariver in our study area is a common fluvio-geomorphic phenomenon that can be seen in any part of the river. This shifting nature is like the pendulum of a wall clock, and it occurs along the river's left and right banks. To demonstrate the shifting nature, a map of the Teesta channel's position has been created based on maps from 1991, 2001, 2011, and 2021, respectively (Figure 4). From Figure 4 it is seen that, the river had rightward movement in upper portion and leftward movement in lower portion during 1991-2001 period. In 2011 river have divided into two braided channels in the middle portion. It shows overall rightward movement. The river course of 2011 and 2021 shows the split in channel. According to Akhter et al. (2019) sudden surges of water from Gajoldoba barrage have causes lateral shifting of Teesta River channel. Channel shifting of Teesta River placed within 2 km to 8.5 km in the period of last 30 years (Figure 4). However, the common river channel from 1991 to 2021 showed in figure 5 proves the lateral shifting of Teesta River course. Channel migration is evident in study area however it doesn't follow any predictable manner. This unpredictability happened due to the Gajoldoba barrage constructed in upstream of the river. They haven't follow any rules and regulations towards transboundary rivers (Sharma & Goyal, 2020). This unpredictable channel shifting causes enormous river erosion and thus accretion (Afroz & Rahman, 2013).

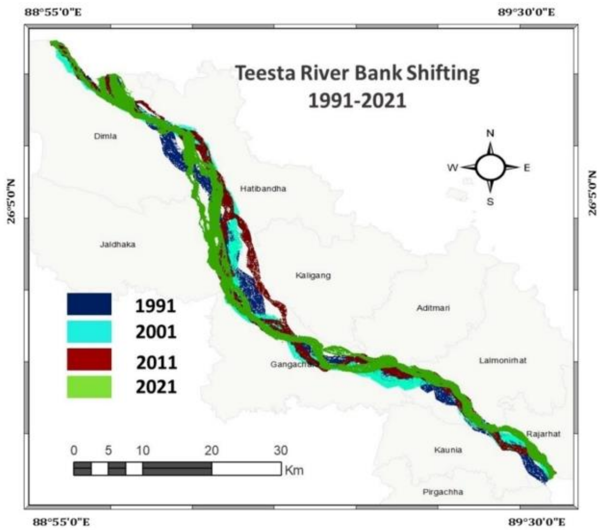

Figure 4. Shifting Nature of the Teesta River Channel in 1991-2021

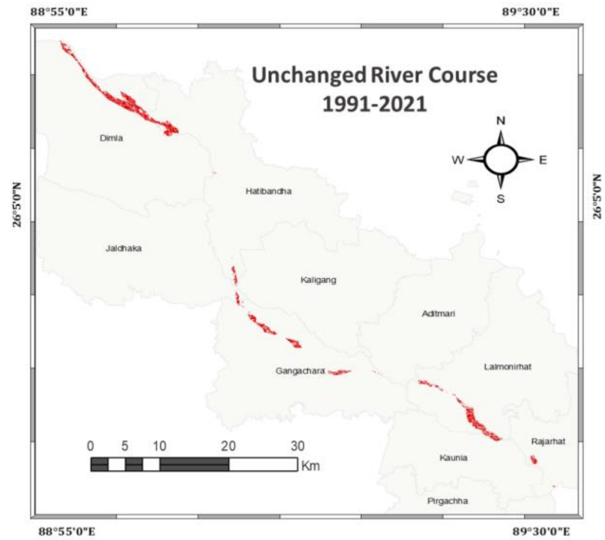

Figure 5. Unchanged River Course Since 1991

3.3. Assessment of Riverbank Erosion and Accretion

Riverbank erosion and accretion assessment has been done using remote sensing (RS) and geographic information system (GIS) approach. Eroded and deposited areas of the Teesta between the years are calculated by superimposition and pairwise comparison of river layers in 1991-2001, 2001-2011 and 2011-2021.Figure 6 represents the Teesta River erosion and accretion for different periods. The erosion of the river Teesta was calculated in this study during three ten-year intervals, from 1991 to 2021 (Figure 7). The river Teesta is degraded and accreted simultaneously. On the one hand, the riverbank is eroding, while on the other, new chars are appearing like other big river systems (Hasan et al., 2017, Ophra et al., 2018).

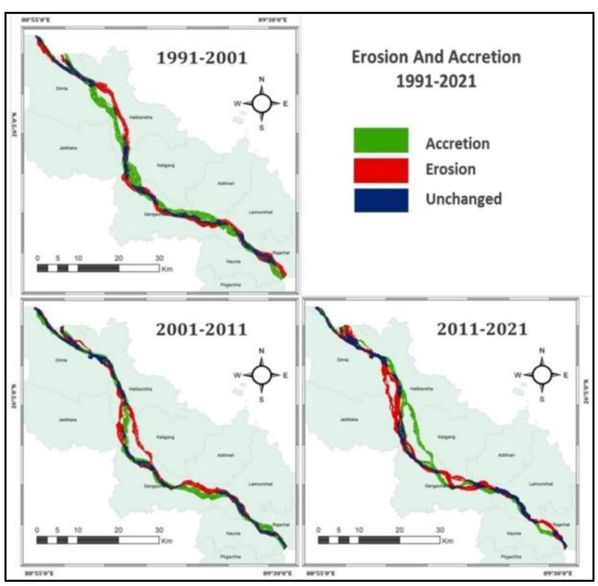

Figure 6. Riverbank Erosion and Accretion in Different Periods

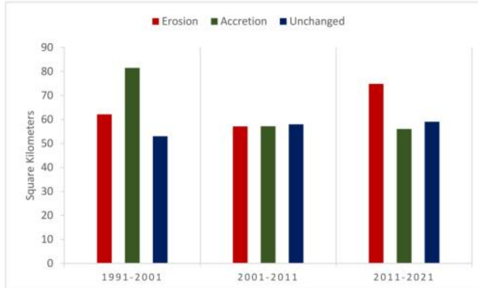

Figure 7. Riverbank Erosion and Accretion during 1991-2021

River erosion occurred over a 62square-kilometer area between 1991 and 2001. New chars have sprouted up in an area of 61 square kilometers at this time. In a 53square-kilometer stretch, the river has remained unchanged. The river's erosion and accretion were nearly equal (57 square-kilometer) from 2001 and 2021. And the analogous location remained the same. In 2011, river erosion damaged 75 square kilometers, with sedimentation concealing 56 square kilometers. The foregoing finding (Akhter et al., 2019) show that the river Teesta is being eroded and accreted at the same time. The vulnerable people who live along the Teesta River's bank are the ones who suffer the most from the erosion and accretion (Brouwer et al., 2007). The Teesta is a mighty and flashy river with a long history. River erosion has historically been, which was normal and people were accustomed to it. But in the nineties, the Indian government was trying to control the flow of the Teesta by constructing the Gajoldoba Barrage on the upstream of the river Teesta (Afroz & Rahman, 2013).

3.4. LULC Changes in Teesta Floodplain

The study area was characterized and mapped into four major Land use/Land cover (LULC) classes, and the spatiotemporal patterns of these LULC dynamics were demonstrated. These included; agriculture, barren, settlement and waterbody. LULC map 05 1991,2001,2011 and 2021 are shown in Figure 8.

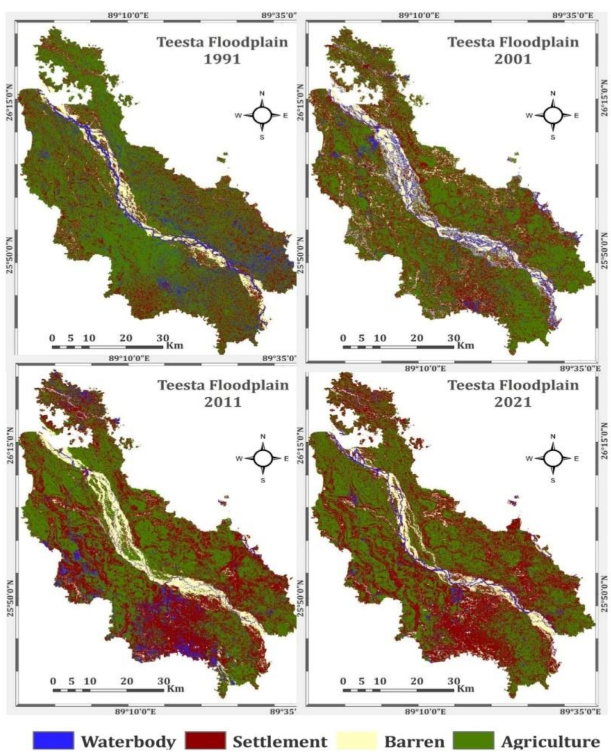

Figure 8. Classified LULC map of Teesta Floodplain for Different Years

Analysis revealed a significant change in the proportions of the various LULC types of the study area in different years (Table 3 and Table 4). The results of the image classification showed that the total land area of TF is 3280 square kilometers. Individual class area and change statistics are summarized in Table 4.

Table 3. Area Statistics and Percentage of the LULCC Units During 1991-2021

LULCC Classes	1991		2001		2011		2021	
	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area(%)	Area (km²)	Area(%)
Agriculture	2060	63%	1758	54%	1543	47%	1544	47%
Barren	181	6%	371	11%	301	9%	263	8%
Settlement	763	23%	934	28%	1260	38%	1362	42%
Waterbody	276	8%	217	7%	175	5%	110	3%

Table 4. Change of Land Use Class from 1991-2021 ('+' indicates increase and '- 'indicates decrease)

LULC	Change in Extent in km² 1991-2021
Agriculture	-516
Barren	+82
Settlement	+599
Waterbody	-165

The percentage area of each class in different years showed that Agriculture had the largest share in 1991 representing 63 % (2060 sq km) of the total LULC categories assigned. This class faced a decreasing shift and it was reduced to 47 % (1544 sq km). But this decreasing rate is not reflected in the period of 2011 to 2021. It is happened because of different factors like, technological innovation i.e., development of drought resistant varieties of food crops. Because of that new varieties people are now able to cultivate the harsh land like char areas. They converted lot of bare land into agricultural land. The government provide incentives to the farmers, and took several initiatives to develop the crop production of the study area (Ferdous & Mallick, 2019). The COVID 19 pandemic situation also shows a positive notion of crop production in the study area (Economic Review 2020).

The other class which faced decline during the study period was waterbody. The area of this class in 1991 was 8% (276 sq km) of the total area and in 2021 it was reduced to 3% (110 sq km)). The major increment was faced by settlement area. Its share was increased from 23% (763sq km) in 1991 to 42% (1362 sq km) in 2012.This study revealed that there was about more than 179 % increase of settlement area i.e., from 1991 to 2021. This figure represented the dramatic change in land cover in the built-up surface category, putting tremendous pressure on non-built-up surfaces, particularly agricultural fields.

3.5. Trend Analysis

Figure 9 shows forecasting using Excel forecasting function that if the current rate of change continues at the average rate seen between 1991to 2021, the agricultural land will be 1285.5 km2 and 1109.2 km2 in 2031 and 2041, respectively. In contrast settlement area will be 1610.5 km2 by 2031 and 1822.8 km2 by 2041. Along with decreasing rate of agricultural land, the water bodies were at a decreasing rate. The trend showed that the area of water bodies will be 59.5 km2 by 2031 and 5.5 km2 by 2041. Figure 10 showed that the transition from agricultural lands to settlement areas was higher than any other transitions. It indicates that though agricultural lands were in a stable condition from 2011-2021 due to technological innovation but the huge increasing rate of settlement area will create a huge pressure on agricultural lands, which may force the agricultural lands to decrease in the next two decades due to conversion from agricultural lands to settlement areas.

Due to the declining rate of water bodies, the available lands are used for producing crops that require lower amounts of water, such as wheat and maize. These wheat and maize are gradually taking up more land although the lands used for rice production were in static condition (Mahmud et al. 2021). If the current trend of decreasing waterbodies continues as per the prediction, there is a chance of complete conversion of rice production to wheat and maize production. According to the changing pattern of barren lands, it will be 323 km2 in 2031 and 340.6 km2 in 2041 (Figure 9). From 1991-2021, most of the barren areas were converted to settlement areas, then some of the barren lands were converted to agricultural lands and the minimum amount was converted to waterbodies (Figure 10). So, as the trend analysis of barren lands are showing an increasing rate in the next two decades, there is a greater chance to increase settlement areas by occupying the barren lands as per the previous records, and the trend pattern of settlement areas also supports this.

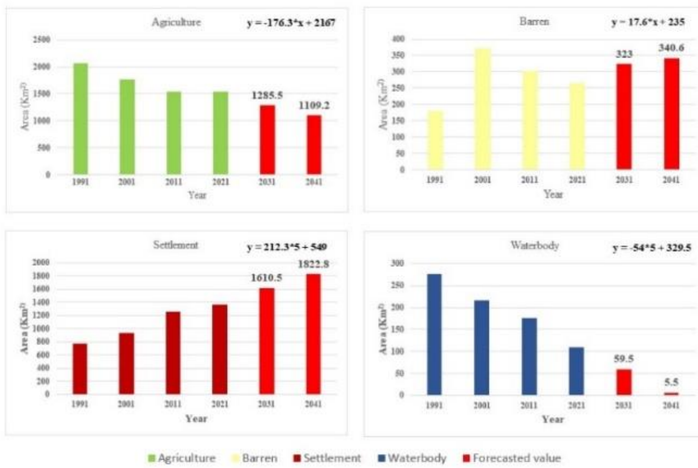

Figure 9. Projected Net Change between 1987 and 2037 for each of the Major Land Use.

3.6. Accuracy of Classified Images

To determine the accuracy of a classified map, an error/confusion matrix is constructed (Appendix 1). This is the most frequent method for determining per-pixel classification (Lu & Weng, 2007). For each classed map, the Kappa statistics/index was calculated to assess the accuracy of the results. The accuracy of the resulting classification of land use/cover maps from 1991, 2001, 2011, and 2021 was 83%, 82%, 79%, and 81%, respectively. For the years 1991, 2001, 2011, and 2021, the Kappa coefficient was 0.76, 0.75, 0.71, and 0.73, respectively. For a dynamic area like Teesta floodplain, this level of overall accuracy is acceptable for subsequent analysis and change (Lei & Zhu, 2018).

3.7. Transitions between LULCC classes

There is an enormous transition between LULCC classes in the Teesta floodplain because it is such a dynamic place. Figure 10 illustrates the temporal transitions between different LULCC classes in the different period from 1991 to 2021. Trajectory matrices were formed with data table of these change maps. Using the trajectory matrix, this study investigates the transformation between different LULC classes. These trajectory matrices are summarized in Table 5.

There is a significant number of spatial changes among the land use classes in the study period. The majority of agricultural lands in the Teesta floodplain are being changed into other land classifications. As a result, agricultural land is disappearing at an alarming rate similar to Padma basin (Ophra et al., 2018). Between 1991 and 2001, approximately 681 sq km of agricultural land was turned into settlements, and 139 square kilometers have been converted into barren land, with the remaining 90 square kilometers becoming waterbodies. Between 2001 and 2011, around 554 sq km of agricultural land was converted to settlement, and between 2011 and 2021, roughly 364 sq km of agricultural land was converted to habitation. In the 30 years between 1991 and 2021, around 920 sq km of agricultural land was transformed into settlement. The study found that about 400 sq km area has been converted from settlement area to agricultural land between 1991 and 2021. However, since the Teesta floodplain is a dynamic region, all kinds of transitions are possible there.

A large area of land was lost in the river as a result of river erosion; nevertheless, a large amount of land was discovered in the aftermath of the char, and the hardworking people of North Bengal began cultivating it again, resulting in the conversion of the settlement area into agricultural land. People have also begun farming in the surroundings of their houses in order to suit the requirements of an expanding population (Akhter et al., 2019). As a result, settlement could also be converted into agricultural land. Approximately 158 sq km of land was converted from water to agricultural land between 1999 and 2001. The river Teesta dries out in the winter due to a lack of water, and many huge regions along the river become suitable for agriculture. Furthermore, due to the rise of chars in the river, people are farming in those areas, resulting in a changeover (Brouwer et al., 2017).

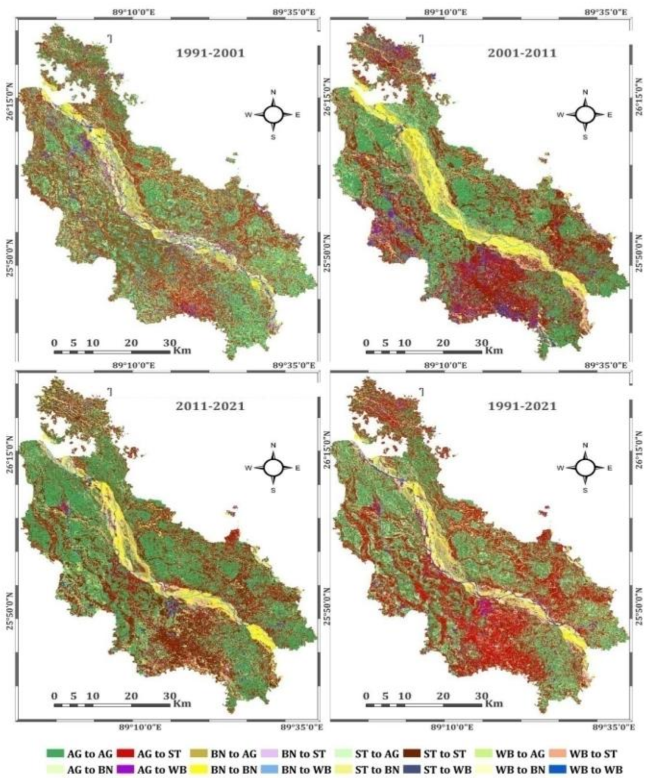

Figure 10. Transition between LULC Classes (AG=Agriculture, ST=settlement, BN= barren and WB=waterbody)

Table 5. Transition between Different Classes

From Class	To Class	1991-2001	2001-2011	2011-2021	1991-2021
		Area (km)	Area (km)	Area (km)	Area (km)
Agriculture	Barren	139	42	39	97
	Settlement	681	554	364	920
	Waterbody	90	88	27	55
Barren	Agriculture	24	85	40	38
	Settlement	24	119	93	59
	Waterbody	44	15	30	15
Settlement	Agriculture	426	314	320	400
	Barren	109	39	65	67
	Waterbody	59	40	23	25
Waterbody	Agriculture	158	69	70	117
	Barren	33	68	21	30
	Settlement	61	46	53	113

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3.8. Seasonal Variation of Teesta River Flow

The flow of the river Teesta has fluctuated dramatically with seasonal variation. In this study we have tried to find out the change in the flow of the river Teesta by remote sensing method. During the dry season and monsoon of 2011 and 2021, the flow of Teesta River has been taken out using satellite image (Figure 11). As can be seen from the Figure 12, the flow of the river Teesta in the rainy season in 2011 was 238 sq km, while in 2021 the flow was 236 sq km. And the dry season the river flow moved from an area of 44 sq km in 2011 to 31 sq km in 2030. During the monsoon season, the flow of water in the river Teesta does not change greatly, but during the dry season, the flow of water in the river Teesta decreases day by day.

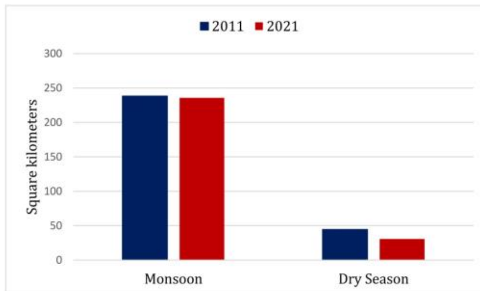

Figure 12. Seasonal Variation of waterflow

Seasonal variations in the Teesta's water flow are more man-made than natural. The Gajoldoba Barrage, which was built on the upper upstream of the Teesta River, caused unusual abnormalities in the changes of water flow. During the dry season, when water is needed for agriculture in North Bengal, Bangladesh, almost all the gates of Gajoldoba Barrage remain closed. When the TeestaRiver overflows during the monsoon season, they opened all the gates. The area was thereafter flooded as a result of the water onslaught, and river erosion became rampant (Khan & Islam, 2015; Hassan et al., 2016).

The river Teesta eroded even before the construction of the Gajoldoba Barrage, but the residents of the area were able to adapt. However, the people of the area are now unable to cope with the unpredictable erosion induced by the Gajoldoba Barrage's sudden and unexpected release of water. It causes plenty of severe catastrophes for the inhabitants of the region (Rahman, 2013). The socioeconomic impact of Teesta River erosion is discussed in the next section of this paper (Brouwer et al., 2017).

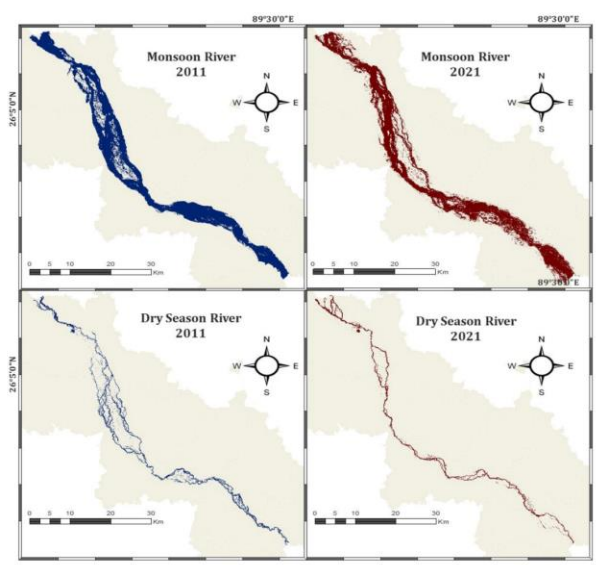

Figure 11. Seasonal Variations in River Flow

4. Conclusion

Bangladesh is a riparian country with 57 transboundary rivers, including the Teesta, which is Bangladesh's fourth largest river after the Ganges, the Brahmaputra and the Meghna. The majority of transboundary rivers entering the country from India encounter one or more upstream diversions basically in drought period. As a result, Bangladesh has year-round water-related socio-economic and environmental issues due to excessive water during the monsoon and scarcity during the non-monsoon months. Because Bangladesh has a lengthy dry season, which lasts around 7 to 8 months each year, these transnational rivers are vital to Bangladesh's agricultural production, navigation, underground water supply, and fishery resources. Throughout the research period, the Teesta River has been found undergoing severe erosion and siltation during 2011 to 2021, widening of rivers forming island inside, rightward movement in upper portion and leftward movement in lower portion and finally splitting in channel.

The rapid release of surplus water from the Gajoldoba Barrage during dry season is the main reason for causing significant erosion and flooding, resulting in massive losses for the population. Reduced flow during the dry season, as well as the rapid release of water, might have far-reaching social and environmental consequences for Bangladesh by transforming riverside agriculture to temporary settlement and damage of agri-crop resulting from rapid discharge consecutively. The disappointing situation has been forecasted in trend analysis that the massive decrease of waterbody and agriculture with the significant increase of barren area by the year 2041. The findings of this study would provide researchers and decision makers with elementary but essential information for resilient and comprehensive management of the Teesta Floodplain in lower riparian Bangladesh, as well as assist top management in Bangladesh and India in understanding the situation associated with upstream transboundary River water withdrawal. Because our country is heavily populated and the majority of its citizens are directly or indirectly dependent on agriculture, a comprehensive riverbank erosion management measures should be developed urgently on a national scale. On the basis of our research findings, the recommendations have proposed that a firm agreement with Indian government for the distribution of water is crucial. Moreover, successful implementation of Teesta River Comprehensive Management and Restoration will help to protect the river and the people from the erosion and drought. Finally, afforestation programs should be motivated and proper steps for relief and rehabilitation for the victims should be taken including the setting embankments in areas prone to severe erosion.

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