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Unstable Behavioral Pattern of Teesta River and Its Impact on Riverine Dwellers: A Case Study of Confluence Area of Teesta and Dharala River, India

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Abstract

The power of the river does not always work to the benefit of living things; rather, it has the ability to destroy human society and has negative effects on the environment. River Teesta has a prodigious significance on the riverine dweller and its changing precarious behavior has repercussions on the lives of millions. Utilizing satellite images and 41 years of temporal analysis, the mapping of channel extraction and channel shifting has been demonstrated. Delineating the exact channel boundary is a laborious operation, but MNDWI technique is really valuable in this situation to produce valuable results. Descriptive statistics are used to analyze the Teesta River’s active flow line migration trend and channel migration behavior. A particular river's oscillating character over time has both beneficial and detrimental power, destroying important resources for environmental sustainability and human society while also providing fertile mother earth as a source of wealth. As a result, another goal of the current study was to determine how vulnerable riverine residents were. A Livelihood Vulnerability Index (LVI) based on the riverine inhab-itants’ exposure, sensitivity, and capacity for adaptation was created. According to the findings, the river’s erratic behavior is putting the people who live beside it in danger. Therefore, it is vitally necessary to implement a capable management strategy to stop bank failure at the Teesta-Dharala confluence in order to save the riverine residents.

Keywords: *Channel migration, Riverine landscape, Riverine dwellers, Livelihood Vulnerability Index (LVI), River confluence, RS-GIS*

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1. Introduction

Bank erosion is a natural geomorphic process or disturbance that occurs during or immediately after floods. Riverbanks act as ecotones, or transitional borders, between aquatic and terrestrial ecosystems, and they frequently change in response to the hydrologic conditions of the environment. Although bank erosion is a normal natural mechanism (Piegay *et al*., 1997). River bank erosion and migration frequently destroys cultivable fields, displaces human settlements, ruins growing crops, and severely disrupts road and transport networks. It is among the most aggressive, violent and unpredictable sorts of disasters, which basically rely on amount of rainfall, soil texture, river geometry, and terrain (Islam and Husain, 2020). About 16.1 million people were relocated worldwide in 2018 due to weather-related catastrophes, with floods accounting for 33% (5.4 million people) (Laha and Bandyopadhyay, 2013). To explore the unstable behavior of Teesta River along the confluence area with the Dharala River which leads to channel migration, bank erosion, and it adverse effect on the lives of riverine dwellers has been examined exclusively in this research work. Instantaneous responses to environmental changes can be seen in the riverine areas. At various geographic and temporal scales, rivers can adjust to changes brought on by water and sediment sources, dynamic tectonics, and human activity (Ophra *et al*., 2018). However, river form changes often and regionally as a result of shifting ecological conditions (Takagi *et al*., 2007; Heitmuller, 2014; Akhter *et al*., 2019; Dewan *et al*., 2017; Bordoloi *et al*., 2020). Teesta River tends to exhibit this dynamic change more frequently during the monsoon season (Lanzoni *et al*., 2018). As a result of geomorphic processes along the bank of this river is frequently coupled with channel migration, braiding pattern which leads to unstable behavior of the channel, since they are related to variations in the severity of bank line erosion and channel modifications. River Teesta has extremely dynamic landscapes that change channel shape and flow pattern frequently (Stanford and Ward, 1993).

When a river undergoes a number of morphological changes both longitudinally and transversely as a result of multiple hydraulic works, spillways, and embankments over a considerable amount of time, it becomes an intriguing case study (Geria *et al*., 2018). Migration along riverbanks is a frequent and endemic environmental hazard. The velocity of the river when decrease it helps to develop meander bends as they mature. These changes have a detrimental effect on riverbanks and the lives of the riverine dwellers (Das and Bhowmik, 2013; Rahman, 2010). The process of lateral migration of river has potential to cause drastic local or regional changes (Hickin and Nanson, 1984; Thakur *et al*., 2012), creates a socioeconomic risk for those living in the riverine areas (Debnath *et al*., 2017). All the tributaries of river Teesta bring with it a huge amount of sediment load (Richards *et al*., 2021) as they flow down from the Himalayas and deposit its load at the confluence area of Teesta-Dharala River. Numerous factors, such as mainstream morphology in terms of river width changes, the sinuosity index, braiding trends (Chakraborty and Mukhopadhyay, 2014; Laha and Bandyopadhyay, 2013; Dey and Mondal, 2019), discharge variability, sediment transport, slope, channel obstacle, vegetation cover, bank stability, bedrock nature, construction of short-length bridges, and floods have an impact on channel behavior (Dhari *et al*., 2015; Dey and Mondal, 2019). Sediments are deposited on the convex side of a river bank while severe erosion can be observed on the concave side of the river which leads to river bank failure and flooding in the riverine areas (Afreen, 2009).

People who have been evacuated consistently experience socioeconomic instability, health crisis, an employment recession, homelessness, and social isolation (Das, 2017; Ferral *et al*., 2019; Maria, 2021). The loss of farmland, fertile land, and animals, as well as human displacement, has a significant effect on people's socioeconomic and environmental well-being (Mallick, 2016; Rahaman and Gain, 2020). The majority of the respondents of the study area are engaged in agriculture, hence they favor living in the flood plain area (Debnath *et al*., 2016; 2017; Eniolorunda *et al*., 2017). Consequently, one of the major causes of rural poverty, landlessness, and population displacement brought on by floods and channel migration (Ahmed, 1991). Rivers are highly susceptible to environmental influences and have had a huge impact on the land of river bank areas, leading to a vulnerable consequences (Chatterjee and Mistri, 2013, Debnath *et al*., 2016; Ophra *et al*., 2018).

Contemporary river management practices and even restoration plans call for channel bank infrastructure, or hard structural characteristics that prevent bank erosion (also called revetment, erosion control, or bank stabilization structures concerns (Piegay *et al*., 1997; Casagli *et al*., 1999), and potential effects on aquatic habitat from contributions of fine bank silt. Often, "restoration" programs are primarily concerned with bank stabilization. Static banks, on the other hand, are not typical, because ecosystems cannot survive in rivers and streams that are still. Despite this, the construction of bank infrastructure has grown commonplace in response to the notion that bank erosion is damaging as a growing population and associated development encroach on riparian areas. Controlling bank erosion is therefore a significant ecological issue. Policymakers will be able to target suitable measures for securing poor farmers to ensure their livelihoods and access to food. Furthermore, from the perspective of an unstable morphological behaviour and the character of the river, the current study intends to analyze the relationship between hazardous phenomena such as temporal shifting pattern of the river bank, insecurity, and the riverine settlement displacement.

2. Study Area

The River Teesta, which is part of the Brahmaputra River system, is one of the important rivers in North Bengal. The people of North Bengal live under the immense influence of the River Teesta. It has a major influence in the fields of drinking water, power, and irrigation (Rudra, 2021). It is very economically valuable and quite aggressive during the peak of the monsoon. The general characteristics of rivers have included bank failure, channel avulsion, and a horizontal oscillating pattern of the river course. However, the natural river also degrades or loses riverine resources, which is risky from an economic and environmental perspective. The research area has been focused in and around the confluence of Teesta and Dharala River in the Jalpaiguri district, West Bengal (Figure 1). In this study, a 25 km river stretch from the village of Purba Dolaicaon, located at 26°41’05" North and 88°39’49" East, in the upstream section of the Dharala confluence, to the village of Paschim Bara Gharia, located at 26°29’35" North and 88°45’58" East, in the downstream section, was considered to represent the vulnerability of river bed settlements as well as neighboring dwellers of the flood plain areas. Two railway bridges and two road bridges that have been constructed between the villages of Balapara and Dakshin Marichbari are impeding the natural flow of the Teesta River. Therefore, riverine settlements of this area are suffering from numerous issues, i.e., natural hazard like flood and bank erosion; economic aspects like losses of standing crops, destroying agricultural fields, collapsing of river bed settlements and agricultural job insecurity; and socio-cultural fields also suffering from local point of view. The study area covers 86 villages near the confluence of Teesta-Dharala River, which are under three blocks namely Kranti, Maynaguri, and Malbazar. Out of which 20 villages have direct experience of active flow condition throughout the year (Appendix).

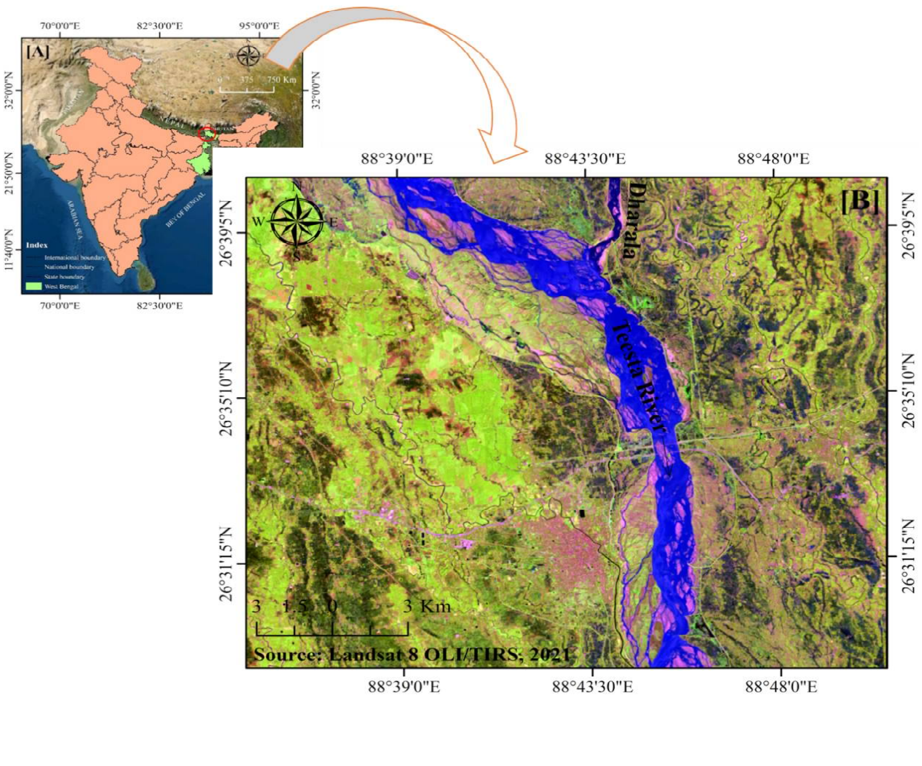

Figure 1: Locational Personality of the Study Area. (A) Location under the Indian Administrative Boundary (B) Teesta River Course at the Dharala River Confluence with Adjacent Quasi-natural Riverine Landscape

The study area, which is where the Dharala River and the Teesta River confluence, is always under water owing to flooding, despite the fact that morphology of the River Teesta changes during the monsoon season. This region experiences extremely intense rainfall, and all of the Teesta River's tributaries gushe into it, flooding it and triggering bank failure. The river embankment, a man-made barrier, is used to prevent bank erosion and manage flood conditions. However, it has frequently been observed that the barrier itself collapsed under the weight of the water and penetrated the community, demolishing numerous homes and claiming many lives. Due to flooding, the residents of the study area are forced to live on the river bund after losing their homes and other property. They led dismal lives and found it difficult to obtain necessities like food, water, and employment. They are prone to water-borne illnesses and do not receive adequate care. To address the issue of flooding for those who live along the bank of the river, it is necessary to study the Teesta River's erratic behavior and take appropriate action.

3. Materials and Methods

In order to connect theoretical information with practical applications and to evaluate our comprehension in a professional setting, field research is a crucial part of all types of research. Therefore, a field study was carried out by an expert researcher to gather the primary data and assemble them in order to investigate the Teesta River's erratic behaviors and their effects on the riverine people.

3.1. Data Used

The research was accomplished using different sources of data collection and image processing approaches to analyze the channel morphology, mapping of active flow line alteration and its impact on riverine dwellers. Purposive sampling and simple random sampling techniques were used to choose three villages and individual families for the interview respectively. Three villages, namely Basusuba, Chat Rarpar and Purbba Sangapara, were chosen from the study area as sample villages, and the majority of the households in these locations belonged to the category of migrant workers. In our study region, a dweller is considered to have migrated if it has moved at least once as a result of river bank migration. Since the population is homogeneous, the primary data was gathered using a sample size (n) of 126 people, with 42 emanating from each of the villages. From September to November (just ending period of Monsoon and post Indian Monsoon), a cross sectional survey was conducted to collect the data, utilizing a pre-designed schedule, site observations and face-to-face interviews throughout the study area (Just ending period of Monsoon and post Indian Monsoon) to investigate the migration behaviors and adaptation strategies of riverine dwellers. The survey schedule includes a number of questions about household income sources, health status, housing information, land ownership, flood coping measures, preparedness, and perceptions of river instability (Mondal *et al.*, 2020).

On the other hand, topographical maps (Survey of India) and satellite images (Landsat) were taken from various years, also were employed to determine the changing pattern of morphology and unstable character of the investigated river over time. Remote Sensing and GIS aid in the identification of changes in landscapes, particularly in terms of spatio-temporal scale (Dutta and Das, 2020; Das and Saha, 2022), and these techniques reduce the usage of traditional human methods and equipment while also saving time. In this research, we have used geospatial technologies to evaluate the effects of bank erosion in a specific location. Also the aim of the current work is to analyze the riverbank shifting and identify high erosion susceptible zones using temporal multispectral remote sensing images from the Landsat series of satellites. Multiple-dated Landsat photos from the dry (post-monsoon) period from the website http://earthexplorer.usgs.gov representing 1980, 1990, 2000, 2010, and 2021 were gathered (Table 1).

Table 1: Details about the Satellite Imageries

Category	Path & Row	Spatial Resolution	Acquisition date	Datum & zone
Landsat 8 OLI	139 & 42	30 m	August 6, 2021	WGS-84, 45 N
Landsat 7 ETM +	139 & 42	30 m	November 4, 2010	WGS-84, 45 N
Landsat 7 ETM +	139 & 42	30 m	December 10, 2000	WGS-84, 45 N
Landsat 5 TM	139 & 42	30 m	October 20, 1990	WGS-84, 45 N
Landsat 3 MSS	149 & 42	30 m	January 17, 1980	WGS-84, 45 N

Source: USGS Earth Explorer (https://earthexplorer.usgs.gov/)

Remote sensing and GIS are essential tools for studying the fluvial channel dynamics over a vast area and the river migration in different years (Yang *et al*., 1999; Thorne *et al*., 1993). Without the help of remote sensing and GIS, getting empirical solutions to existing problems involving historical and present-day structural alterations in river channels would be difficult due to time and area coverage limitations. Utilizing widely accessible, inexpensive, and freely available remote sensing data enables the identification of morphological changes and their effects on riverbanks (Langat *et al*., 2019; Momin *et al*., 2020). ArcGIS 10.5 was used to conduct mapping analysis for evaluating river instability, while SPSS was used to analyze the gathered data to create a tabular analysis and graphical representation in order to accomplish the research objectives. To understand the relationships between different variables, these data were interpreted by using cartographic tools together with statistical and quantitative methodologies including cross tabulation, binary logistic regression, livelihood vulnerability index, and others.

3.2. Image Processing

The various satellite imageries were collected from the USGS Earth Explorer, including Landsat MSS for the year 1980, the TM for the years 1990, ETM + for the year 2000 and 2010, and OLI for the year 2021 were used to quantify the rate of riverbank shifting over time and identify the areas with the highly eroded and changing LULC as well (Figure 2). Sharp distinction between Land and water, active flow of the channel, braiding, and channel bar imagery were obtained during the dry period and are eligible for analysis.

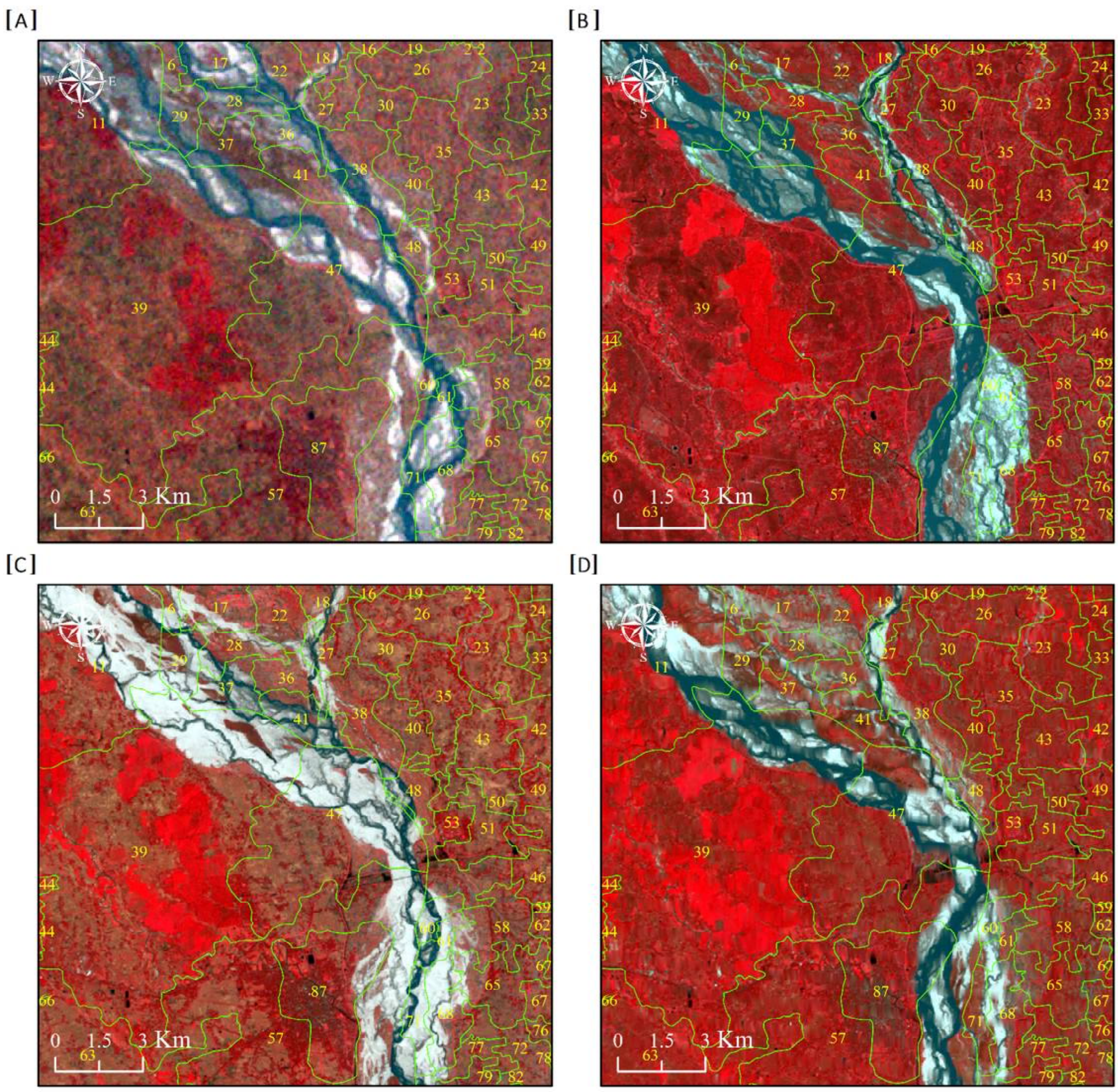

Figure 2: Spatio-temporal scenario of the Teesta River course at Dharala River confluence (A) 1980 (B) 1990 (C) 2000 (D) 2010 (E) 2021 (F) Referenced Cross-section line

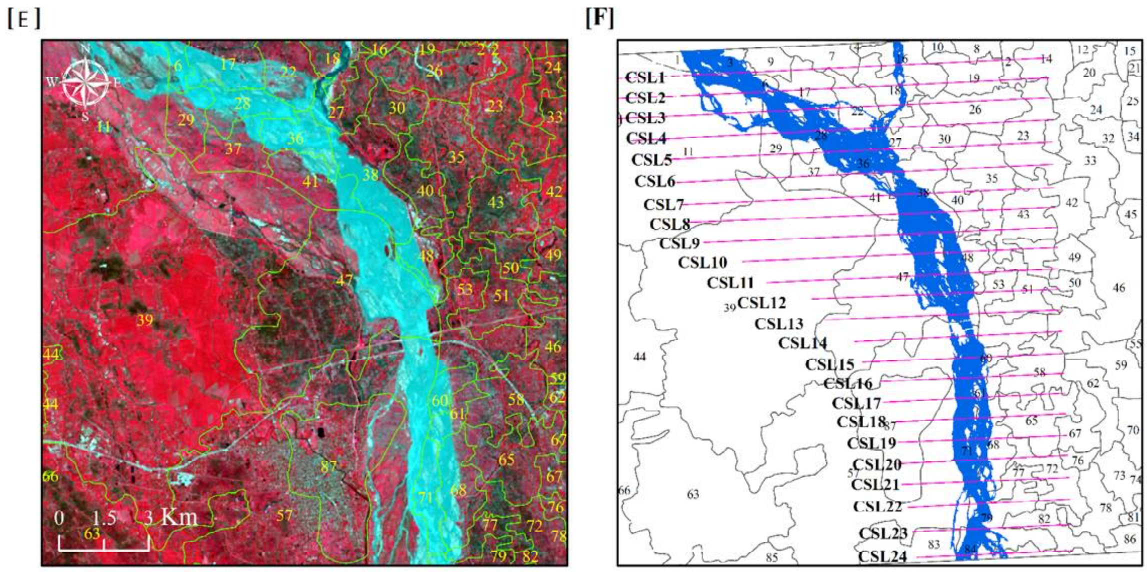

Figure 2 (Cont.)

There are several sandbars along the river beds, dispersed in character, as a result of low discharge in the river channel during the dry seasons. Digital image processing methods have typically been employed by researchers to separate the active river channel from other land cover groupings. Additionally, because it is difficult to delineate the active river channel, the researcher manually digitized it as a polygon form in ArcMap (Version 10.5). This same technique was applied for the all-temporal satellite images which were mentioned in Table 1.

The temporal range fluctuated between the times examined since cloud-free photos were not available at predictable intervals. However, the images taken on or around those dates are essential for the spatiotemporal analysis of land cover change. The noise and haze effect are prevalent defects when remote sensing data is presented in its raw form. As a result, in ERDAS imagine tool, atmospheric and radiometric corrections were applied to the collected satellite images. All data from Landsat 8OLI, Landsat 7ETM+, Landsat MSS and Landsat TM are in Level 1, which has previously been geometrically rectified, for geometric adjustment. The WGS 84 UTM Zone 45 N projection system was used to georeferenced all of the photos. Erdas Imagine 2014 and ArcMap 10.5 environment were used to do image processing such as layer stacking, mosaicking, image enhancement, and geo-processing.

3.3. Channel Extraction Using Modified NDWI

In order to increase water body reflectance in the green band while reducing it in the NIR band, McFeeters developed the NDWI formula in 1996. However, the primary drawback of NDWI is that it is unable to efficiently reduce signal noise emanating from built-up area land cover features (Du *et al*., 2016). Furthermore, in 2006, Xu discovered that the watercourse has a higher rate of absorption in the SWIR band than the NIR band, and the built-up class has a higher radiation in the SWIR band than the NIR band (Xu, 2006). The MNDWI was proposed as a result of this discovery, and it is defined as follows:

$$MNDWI = \frac{\rho green - \rho SWIR}{\rho green + \rho SWIR} \quad ...(1)$$

where ρgreen is the TOA reflectance value of the green band and where ρSWIR is the TOA reflectance of the SWIR band. Furthermore, water bodies have higher positive values in MNDWI than NDWI because SWIR light absorbs more of it than NIR light; soil, vegetation, and built-up classes have smaller negative values because SWIR light reflects more of them than green light; and soil, vegetation, and built-up classes have higher positive values in MNDWI than NDWI because SWIR light reflects more of it than green light (Sun *et al.*, 2012).

3.4. Statistical Analysis for Active Flow Line Migration (1980-2021)

The dynamics of channel migration patterns, the relationships between variables, and the extension of the observation around the center value have been analyzed with the help of descriptive statistics. For this purpose, mean, Standard Deviation (SD), Coefficient of Variation (CV), skewness and kurtosis were used to explain the finding (Das and Saha, 2022; Mandal *et al.*, 2018; Das, 2017; Dey and Mandal, 2019).

The IBM SPSS statistics 25 program was used to analyze the statistical techniques. Rivers commonly change direction laterally in the natural world. The variability of bank line migration is commonly measured using the standard deviation. High standard deviation suggests migration rates are dispersed throughout a variety of scales, and their low standard deviation indicates that they are likely to be rather comparable to regular migration. A larger coefficient of variation for bank line migration denotes more erratic or inconsistent lateral migration. A more uniform pace of bank line migration would indicate a reduced coefficient of variation. Kurtosis is used to show where a distribution curve for a migratory channel peaks (Saha and Basu, 2013). Kurtosis is used to assess the properties of the distributional pattern of Teesta River. The degree of the asymmetry in the lateral migration of the temporal bank lines was expressed using skewness, which was utilized as a final measure.

3.5. Calculation of Livelihood Vulnerability Index

Vulnerability is a combination of the three factors exposure, sensitivity, and adaptability (Liu *et al.*, 2013; Fischer and Frazier, 2018). A balanced weighted technique, which has been used by various academicians worldwide in a variety of fields, to evaluate the livelihood vulnerability (Pandey *et al.*, 2017; Hahn *et al.*, 2009; Alam *et al.*, 2017) of riverine dwellers. The livelihood vulnerability index was carried out utilizing the below formula:

$$Index K_a = \frac{K_v - K_{\min}}{K_{\max} + K_{\min}} \quad \ldots(2)$$

where, K_a is an original area of a sub-component, and K_{max} and K_{min} are the maximum and minimum values of each sub-component, respectively. To convert the indicator into a standardized index, the maximum and minimum values were employed 0 and 100 and utilized as minimum and maximum values to standardize the process of this method (for example, percent of female headed families, percent of agricultural laborers, percent of orphans, etc.). To generate the index of each major component, each indication was standardized and then averaged are calculated by using the Equation (2).

$$LVI_c = \frac{\sum_{f=1}^{7} W_{MZ} M_{az}}{WM_z} \quad \ldots(3)$$

Which can also be expressed as:

$$LVI_c = \frac{W_{SDP}SDP_a + W_{LS}LS_a + W_{SN}H_a + W_H H_a + W_F F_a + W_W W_a + W_{NDC}ND_a}{W_{SDP} + W_{LS} + W_{SN} + W_H + W_F + W_W + W_{NDC}}$$

From the collected data, the relationship among different determinants of socio-economic factors were calculated by using the conversion factor to understand the livelihood vulnerability (Shetu *et al.*, 2016).

3.6. Binary Logistic Regression

Binary Logistic Regression analysis is used to assess the influence of independent factors on the probability that a binary dependent variable would fall into one of the alternative categories and the impact of variables on the human component was investigated and determined (King, 2008; Sakinc and Ugurlu, 2013; Zewude and Ashine, 2016; Magalhães *et al.*, 2014). To investigate the Binary Logistic Regression age, occupation, shifting of land, loss of land, and income all are taken as independent variables while security status utilized as the dependent variable.

Suppose, there are n individuals, some of them respond "secure" and the others respond as "not secure". If the response variable is the status security, then the two categories may be respondent is secure and not secure. After the tabulation it was analyzed through the SPSS using the formula given below (Monahan *et al.*, 2007):

$$P = \frac{exp(a + b_1x_1 + b_2x_2 + b_3x_3 + ...)}{1 + exp(a + b_1x_1 + b_2x_2 + b_3x_3 + ...)} \quad ...(4)$$

where,

P = The probability that a case is in a particular category,

exp = The exponential function (approx. 2.72),

a = The constant (or intercept) of the equation and,

b = The coefficient (or slope) of the predictor variable.

4. Results and Discussion

4.1 Status of Bank Erosion

The Teesta River's propensity for lateral channel mobility and its governing elements together constitute a significant challenge in the identification and prediction of the spatial distribution of river bank erosion. The relationship between stream energy and boundary resistance can be linked to the distribution of lateral mobility at the scale of a river network. The fact that the bank retreat is an integrated result of three interacting groupings of activities is also well acknowledged (sub-aerial processes, erosion processes, and mass wasting). Together, these point to the possibility of shifting bank process dominance within a fictitious drainage basin in response to changes in the energy, bank material, and climatic circumstances further downstream (see, Lawler, 1992). In more recent years, Fonstad and Marcus (2003) have proposed the possibility of self-organized riverbank systems, which are capable of changing internally (i.e., organizing themselves) without altering the volume and frequency of external inputs to the system.

The east bank of the Teesta River is primarily subject to severe bank erosion and bank failure, the river channel has a propensity to migrate towards the east, and as a result, the river has already consumed up to 8.44 km^2 of land in the study area, whereas in the west bank the rate of erosion is quite low and after the monsoon there is a vast land with fresh alluvial deposits can be seen. An extensive large riverine area has already been washed away by the channel migration and there is a serious threat that the barrier bund can be broken at any time if the pressure of water exceeds the threshold level. Six years (2015) ago this barrier was broken due to the excessive pressure of water, and the entire village was drowned. Another important problem that has been observed is the extremely inadequate drainage infrastructure in the study area. The bed of the river and the surface of the village land is at the same altitude, so during the monsoon the water gets accumulated in the study area and cannot pass out.

4.2. Lateral Migration of the Teesta River Course

The lateral displacement of the Teesta River channel has been computed from 1980 to 2021 while using 1980 as a base year (as illustrated in Figures 2 and 3). In this study, the total number of 24 cross-sections were taken into consideration to understand the nature of channel migration both quantitative as well as qualitative manners. In the upper portion of the investigated stretch, it was found that the maximum river course had been shifted. Cross-sections 1, 2, 4, 5, 6, 7, and 8 have been shown to be the most noticeable cross-sections where river courses were often changed between 1980 and 2021 (Figure 2). Between 1980 and 2021, the study area's average lateral displacement was calculated to be 642.72 m on the left bank and 1605.05 m on the right bank, whereas the actual average lowest lateral shift is calculated as 1140.90 m (right bank) in the period between 1980 and 1990 (Table 2) and 569.36 m (left bank) in the period between 2010 and 2021 (Table 2). On the other hand, average maximum lateral shift is calculated as 1934.30 m on the right bank and 1011.17 m on the left bank (2000-2010). From a statistical point of view, coefficient of variation is 0.93 (right bank) and 0.95 (left bank) during the period between 1980 and 2021 which indicates a comparatively high migration rate in both the river banks (for details see Tables 3, 4, 7 and 8). But within the successive time, there was several variability; whereas, between 2010 and 2021, the right bank has the largest coefficient of variance of channel shifting pattern (0.99) and 2010-2021 (1.33), 2000-2010 (1.15) and 1980-1990 (1.14) on the left bank (Table 2). However, the pattern of lateral migration was more stable between 1990 and 2000 (coefficient of variation: 0.53) on both the right bank and the left bank (coefficient of variation 0.88). Indicating discrete uniform distribution of the bank line shifting pattern away from the center line, the kurtosis value of the lateral shift for the right bank for the years 2000-2010 and 1980-2021 displayed a negative sign. It is interesting, in case of overall bank line

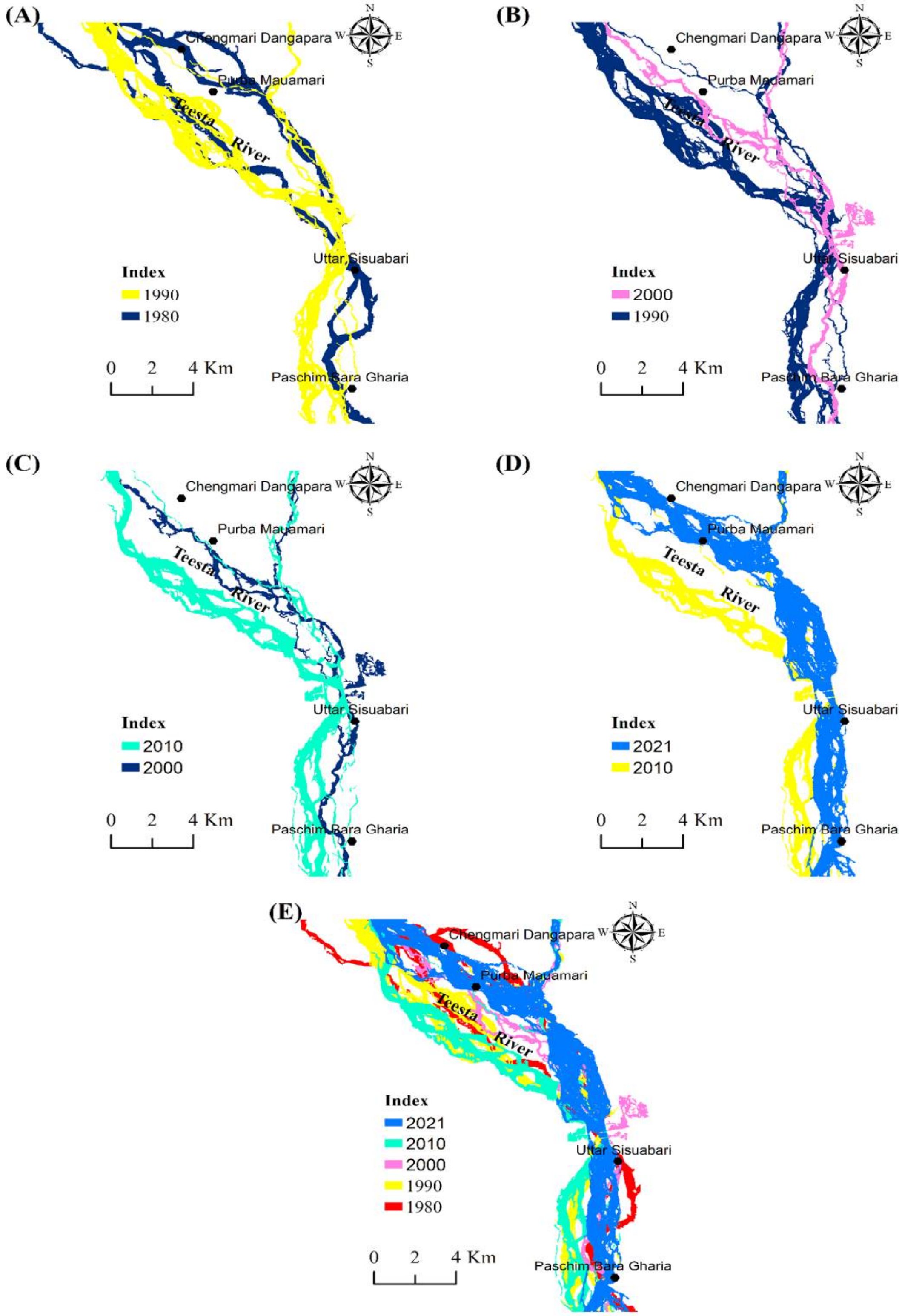

Figure 3: Temporal Shifting of the Active Flow Boundary (A) 1980-1990; (B) 1990-2000; (C) 2000-2010; (D) 2010-2021; and (E) 1980-2021

migration as the kurtosis value is -0.85 (right bank) and on the left bank 3.70 (Table 2) which indicates the platykurtic pattern (flat topped) and leptokurtic pattern of river course migration more or less prolonged migratory nature. Moreover, river course shifting directly affects the localized natural and human resources. According to 41 years of temporal analysis about oscillating behavior of the river course it is experienced that adjacent villages are prone to economic loss i.e., fertile agricultural land, standing crops, houses, and short-term human displacement. In the studied area several villages (i.e., Purbba Dolaicaon, Chengmari Dangapara, Chengmarihat, Dakshin Chengmari, Paschim Sangapara, Purbba Sangapara, Basusuba, Sisuabari, Barapatina Nutunbus, Paschim Mauamari, Paschim Premganj, Premganj Majhiali, Kharia, and Mandalghat) have a greater vulnerable experienced (Tables 5 and 6).

Table 2: Descriptive Statistics of Bank Line Migration (1980-2021)

Year	Mean	SD	CV	Skewness	Kurtosis
Left Bank					
1980-1990	784.36	893.39	1.14	1.63	2.36
1990-2000	873.08	766.08	0.88	1.17	0.60
2000-2010	1011.17	1159.07	1.15	1.41	0.68
2010-2021	569.36	757.23	1.33	3.77	16.46
1980-2021	642.72	609.91	0.95	1.90	3.70
Right Bank					
1980-1990	1140.90	974.48	0.85	0.98	1.63
1990-2000	1577.12	837.18	0.53	0.42	0.02
2000-2010	1934.30	1152.35	0.60	0.83	-0.22
2010-2021	1818.99	1802.36	0.99	1.16	0.15
1980-2021	1605.05	1498.36	0.93	0.79	-0.85

Note: *Standard deviation **Co-efficient of variation

Source: Satellite imageries (https://earthexplorer.usgs.gov/)

4.3. Causes of River Bank Erosion in River Teesta

The main cause of river bank erosion in the river Teesta is huge hydraulic pressure due to excessive monsoonal rainfall and foothills landscape. It is a vigorous river which has a very strong current and carries a lot of sediment with it (O'Malley, 1999). Both during the monsoon and non-monsoon seasons, it features turbulent flow. During the monsoon, enormous amounts of water flow at extremely high velocities have enough force to uproot the top soil layers or possibly induce mass failure (Tucek and Marek, 2008). Centrifugal force raises the level of the water, causing the outside bend to experience the deepest flow, and gravity force drags the water downward, and the erosive force acting against the river bank is towards downward velocity (Das, 2014). The width of the river has been narrowed due to the construction of the Teesta Bridge that connects Jalpaiguri and Maynaguri. However, at the junction of the two rivers, the actual width of the river is 2209 m (data taken from Google Earth, 2021), due to the construction of the Teesta Bridge, its breadth has narrowed to reduce the construction cost of the bridge and thus the width of the river has been decreased to 956 m only. Therefore, there is an abrupt rise in water level between the confluence point and the Teesta Bridge, the velocity of the river increases at an alarming rate during the monsoon period. The main erosional mechanism responsible for river Teesta bank erosion in the study area is abrasion. It is a process in which loose rock material is removed from valley walls and valley floors using erosional tools, such as boulders, pebbles, cobbles, gravel, etc. The erosional agents go down the gradient of the channel with the water and impact the rocks that come into contact with them as a result (Lawler, 1992). River bank erosion occurs both naturally and as a result of human activities. Rivers and streams follow dynamic systems in the sense that they are always changing their pattern of water flow (Nasermoaddeli and Pasche, 2008). The extensive floods, excessive rainfall, imprudent water flow with strong wind, and inadequate land cover along the bank line all are responsible for riverbank erosion (Baki, 2014; Nur and Siddiqi, 2021) in the studied area. In the area where North Bengal is located, especially in

Table 3: Descriptive Statistics for Right Bank

Transects	Mean	SD	CV	Skewness	Kurtosis
CSL1	1932.170	1660.940	0.86	0.277	-2.122
CSL2	1731.918	844.546	0.49	-0.211	-0.896
CSL3	1199.816	741.512	0.62	-1.265	1.332
CSL4	2565.248	1328.994	0.52	-1.413	2.038
CSL5	3441.910	1943.260	0.56	-1.937	3.977
CSL6	3118.928	1799.197	0.58	-0.269	0.366
CSL7	3341.914	1829.979	0.55	-0.121	0.055
CSL8	2985.442	2235.879	0.75	-0.531	-3.152
CSL9	2074.852	1134.157	0.55	-2.123	4.602
CSL10	1881.880	722.001	0.38	-1.437	1.263
CSL11	537.088	356.380	0.66	-0.540	0.135
CSL12	453.202	543.527	1.20	0.626	-3.201
CSL13	214.222	192.474	0.90	0.814	-0.852
CSL14	471.876	264.966	0.56	-1.541	2.659
CSL15	611.154	343.500	0.56	0.146	-1.741
CSL16	1131.386	357.797	0.32	-0.386	-0.523
CSL17	1586.678	452.401	0.29	-0.776	0.354
CSL18	1523.052	643.983	0.42	-1.702	2.797
CSL19	1432.278	666.259	0.47	-1.788	3.156
CSL20	97–2.252	472.035	0.49	-1.836	3.308
CSL21	1094.802	557.744	0.51	-0.285	1.004
CSL22	1280.696	544.851	0.43	-2.030	4.282
CSL23	1588.598	503.758	0.32	-0.260	-2.583
CSL24	1595.134	557.585	0.35	-0.191	2.016

Source: Satellite imageries (https://earthexplorer.usgs.gov/)

Table 4: Descriptive Statistics for Left Bank

Transects	Mean	SD	CV	Skewness	Kurtosis
CSL1	1508.414	1120.331	0.74	0.727	-2.524
CSL2	1612.154	1106.503	0.69	0.988	-0.699
CSL3	1845.082	1307.568	0.71	0.749	1.431
CSL4	1589.636	1428.011	0.90	0.858	-1.163
CSL5	1399.944	1658.831	1.18	0.734	-2.339
CSL6	1157.250	1247.699	1.08	0.594	-2.789
CSL7	1026.070	1208.148	1.18	2.099	4.515
CSL8	798.758	496.805	0.62	0.378	-0.331
CSL9	431.890	339.284	0.79	1.394	2.822
CSL10	344.978	213.385	0.62	0.023	-2.575
CSL11	290.516	95.630	0.33	-0.553	-1.358
CSL12	351.868	220.768	0.63	1.361	1.323
CSL13	20.384	15.077	0.74	0.305	-2.946
CSL14	64.372	63.066	0.98	0.469	-3.026

Table 4 (Cont.)

Transects	Mean	SD	CV	Skewness	Kurtosis
CSL15	336.840	242.792	0.72	1.528	2.587
CSL16	690.224	435.389	0.63	0.759	0.563
CSL17	961.408	687.317	0.71	-0.436	-2.112
CSL18	633.686	261.001	0.41	-0.167	-0.825
CSL19	656.386	283.246	0.43	-1.783	3.696
CSL20	624.304	406.722	0.65	0.677	-0.160
CSL21	1119.078	504.684	0.45	-1.218	1.908
CSL22	376.154	203.443	0.54	-2.023	4.208
CSL23	286.960	193.062	0.67	0.403	-1.451

Source: Satellite imageries (https://earthexplorer.usgs.gov/)

Table 5: Vulnerability Status of Riverine Villages Along the Teesta River Course at Dharala River Confluence and Surrounding (Left Bank)

S. No.	Vulnerability Zones Based on Active Flow Line Migration*	Villages
1	High (>1000 m.)	Purbba Dolaicaon, Chengmari Dangapara, Chengmarihat, Dakshin Chengmari, Paschim Sangapara, Purbba Sangapara, Basusuba, and Sisuabari
2	Moderate (<1000 m.)	Ulladabri, Dakshin marichbari, and Gopalganj
3	Low (<500 m.)	Paschim bara Gharia, Uttar sisnabari, Uttar marichbari, and Domohani

Note: *Temporal scenario 1980 to 2021.

Table 6: Vulnerability Status of Riverine Villages Along the Teesta River Course at Dharala River Confluence and Surrounding (Right Bank)

S. No.	Vulnerability Zones Based on Active Flow Line Migration*	Villages
1	High (>1000 m.)	Barapatina Nutunbus, Paschim Mauamari, Paschim Premganj, Premganj Majhiali, Kharia, and Mandalghat
2	Moderate (<1000 m.)	North eastern side of Kharia village, and some part of Paharpur village
3	Low (<500 m.)	Paharpur, and some part of Kharia village

Note: *Temporal scenario 1980 to 2021.

the riverine zone, the ongoing threat of flooding and riverbank erosion has caused a tremendous catastrophe. River bank erosion occurs in two ways which are physically and anthropologically. Rivers and streams are

Table 7: Temporal Shifting Characteristics (1980-2021) of the Right Rank

CSLRB	1980-1990	Direction	1990-2000	Direction	2000-2010	Direction	2010-2021	Direction	1980-2021	Direction
CSL1	4010.03	Left	1579.14	Left	766.4	Right	59.3	Left	3245.98	Left
CSL2	2091.29	Left	1982.84	Left	1177.23	Right	619.75	Left	2788.48	Left
CSL3	14.24	Right	1904.39	Left	1590.07	Right	979.74	Left	1510.64	Left
CSL4	387.78	Right	2359.4	Left	3744.19	Right	3455.53	Left	2879.34	Left
CSL5	61.05	Right	3672.56	Left	4169.19	Right	4933.91	Left	4372.84	Left
CSL6	594.39	Right	2327.18	Left	3422.7	Right	5437.09	Left	3813.28	Left
CSL7	836.5	Right	2636.81	Left	3194.43	Right	5714.16	Left	4327.67	Left
CSL8	684.38	Right	436.36	Left	4472.96	Right	5077.59	Left	4255.92	Left
CSL9	66.67	Left	2448.64	Left	2780.33	Right	2686.95	Left	2391.67	Left
CSL10	1641.31	Right	2353.8	Left	2345.75	Right	2355.16	Left	713.38	Left
CSL11	22.23	Right	645.94	Left	964.51	Right	681.59	Left	371.17	Left
CSL12	73.67	Right	994.07	Left	1099.74	Right	29.76	Left	68.77	Right
CSL13	78.78	Left	324.28	Left	494	Right	146.58	Left	27.47	Left
CSL14	493.6	Right	652.84	Left	699.54	Right	29.57	Left	483.83	Right
CSL15	1029.09	Right	461.54	Left	484.05	Right	187.85	Left	893.24	Right
CSL16	1566.63	Right	924.33	Left	1258.1	Right	637.13	Left	1270.74	Right
CSL17	1887.59	Right	1629.71	Left	2077.01	Right	1432.06	Left	907.02	Right
CSL18	1820.42	Right	1901.3	Left	2011.08	Right	1447.27	Left	435.19	Right
CSL19	1784.19	Right	1923.51	Left	1772.03	Right	1386.45	Left	295.21	Right
CSL20	1296.04	Right	947.57	Left	1221.06	Right	1233.93	Left	162.66	Right
CSL21	1219.62	Right	903.81	Left	1226.79	Right	1827.62	Left	296.17	Left
CSL22	1552.58	Right	1378.34	Left	1666.89	Right	1481.32	Left	324.35	Right
CSL23	1807.58	Right	1853.14	Left	2165.7	Right	1029.64	Left	1086.93	Right
CSL24	2361.85	Right	1609.41	Left	1619.39	Right	785.85	Left	1599.17	Right

Source: Satellite imageries (https://earthexplorer.usgs.gov/)

dynamic systems in the sense that they are always changing. Riverbank erosion can have beneficial consequences, constructing alluvial terraces and agricultural floodplains, for instance. Even though certain rivers with stable banks experience a healthy amount of erosion, unstable rivers and the erosion that takes place on their banks are cause for concern.

4.3.1. Physical Factor

There are many factors that play an important role in bank erosion in river Teesta are: (i) Stream bed in fill, River Teesta carries a huge amount of river load, so every post monsoon the bed of the river rises which leads to overflow of water (Wolman, 1959); (ii) During the rainy season, bank material gets easily washed away due to heavy rainfall (2500-3000 mm) (Rudra, 2018; Rudra, 2021); (iii) Saturation of banks from off-stream sources can be seen in the study area; (iv) because of the river's rapid movement and depth in the channel's midsection, the flow within the channel is frequently redirected and accelerated; (v) With a very poor drainage system, the water remains accumulated in the study area for over weeks. There is no passage that the water can pass out as the region is a low-lying region and its altitude is below the level of the river bed; and (vi) another influencing and powerful cause is the wave action, strong and loud waves generated at the river bank due to the rise and fall of water level during monsoon season (Das, 2014).

Table 8: Temporal Shifting Characteristics (1980-2021) of the Left Rank

CSLRB	1980-1990	Direction	1990-2000	Direction	2000-2010	Direction	2010-2021	Direction	1980-2021	Direction
CSL1	2990.5	Right	820.43	Right	635.67	Right	657.26	Left	2438.21	Right
CSL2	3257.66	Right	1050.99	Right	867.88	Right	647.44	Left	2236.8	Right
CSL3	1842.67	Right	1227.57	Right	2019.79	Right	3846.45	Left	288.93	Left
CSL4	553.87	Right	2475.61	Right	3652.32	Right	305.43	Left	960.95	Left
CSL5	32.26	Left	2724.09	Right	3625.86	Right	155.68	Left	461.83	Left
CSL6	77.38	Right	2266.54	Right	2728.52	Right	557.37	Left	156.44	Left
CSL7	274.32	Right	650.25	Right	3160.46	Right	709.28	Left	336.04	Left
CSL8	188.4	Left	1489.27	Right	628.77	Left	1072.79	Left	614.56	Left
CSL9	80.7	Left	296.36	Right	371.31	Right	993.04	Left	418.04	Left
CSL10	99.97	Left	173.13	Left	532.37	Right	584.47	Left	334.95	Left
CSL11	158.41	Left	229.93	Left	359.67	Right	313.27	Left	391.3	Left
CSL12	419.1	Left	707.61	Right	205.47	Left	259.42	Left	167.74	Left
CSL13	4.66	Right	8.71	Left	15.98	Left	35.71	Right	36.86	Right
CSL14	10.02	Right	138.54	Left	125.26	Right	39.68	Right	8.36	Right
CSL15	740.95	Right	363.01	Left	113.06	Right	219.37	Left	247.81	Right
CSL16	1348.02	Right	747.08	Left	382.82	Right	217.43	Left	755.77	Right
CSL17	1619.8	Right	459.62	Left	1574.27	Right	60.58	Left	1092.77	Right
CSL18	952.51	Right	616.27	Right	283.44	Left	505.35	Left	810.86	Right
CSL19	723.46	Right	907.25	Right	169.86	Left	704.88	Left	776.48	Right
CSL20	727.68	Left	1225.06	Right	245.78	Left	244.93	Right	678.07	Left
CSL21	1069.5	Left	1631.87	Right	1418.84	Left	306.03	Left	1169.15	Left
CSL22	497.03	Left	406.45	Right	449.79	Left	19.48	Right	508.02	Left
CSL23	67.42	Right	165.58	Left	418.17	Right	545.04	Left	238.59	Left
CSL24	1088.35	Right	172.71	Right	282.62	Left	664.26	Right	296.79	Right

Source: Satellite imageries (https://earthexplorer.usgs.gov/)

4.3.2. Anthropological Factors

The construction of dams and bridges are the most important anthropological factors, narrowing of rivers at the confluence of river Teesta and Dharala due to the construction of bridges is responsible for bank erosion (Das, 2014). Another significant factor is the sudden opening of Teesta Barrage at Gajoldoba which causes a sharp rise in water level because of heavy rainfall during the monsoon period.

4.4. Impact of River Bank Erosion on Socioeconomic Determinants

Bank erosion is a cause of great concern among the dwellers of the riverine area. Every year, it affects millions of people who live near riverbanks and its surrounding areas (Ferdous and Mallick, 2019). Erosion has compelled millions of people to leave their homes and move to new locations, posing a significant threat to society. As a result of these circumstances, people who live near riverbanks are very much vulnerable to erosion. Residents on floodplains and char land are constantly subjected to river due to bank erosion (Islam *et al.*, 2017). The Teesta River experiences a great deal of erosion and channel migration as a result of its swift current, lack of vegetation, and loose debris and silt that make up its banks (Islam *et al.*, 2017; Khan and Islam, 2003).

4.4.1. Migration Status of Respondents

Erosion-caused displacement typically involves the relocation of entire households. The respondents were classified into two categories based on their migration types which are temporary migration and permanent migration (Zaman, 1989). However, the majority of respondents opted for temporary migration due to financial constraints as well as to fulfil the needs of their family (Maria, 2021). Despite the fact that the majority of people's occupations are tied to rivers and agricultural land, most people choose temporary migration, but at the time of extreme unrepairable impacts occur on that particular land, most people migrate permanently (Mondal *et al.*, 2021). After being displaced, villages along the Teesta River relocated to safer areas such as riparian villages or other safe places (Islam and Rashid, 2011). A small number of displaced individuals sought refuge in the river embankment, which are Khash and government land (Ghosh and Sahu, 2019). People migrated to other locations as a result of riverbank erosion, such as shelter on the river's embankment, neighboring villages, neighboring towns, char villages, or other places (Islam and Rashid, 2011).

People who lose their jobs as a result of bank erosion go to other areas as migratory workers to meet their fundamental requirements (Das, 2014). People are mostly fleeing to neighboring villages and surrounding char land for safety (Mollah and Ferdaush, 2015). Even if a family has one or more male family members, they are accustomed to relocating to new locations for work and other reasons in order to improve their lives. 82% of the population are going to live in nearby char land and 63% of people arranged their settlement in neighboring villages (Figure 4).

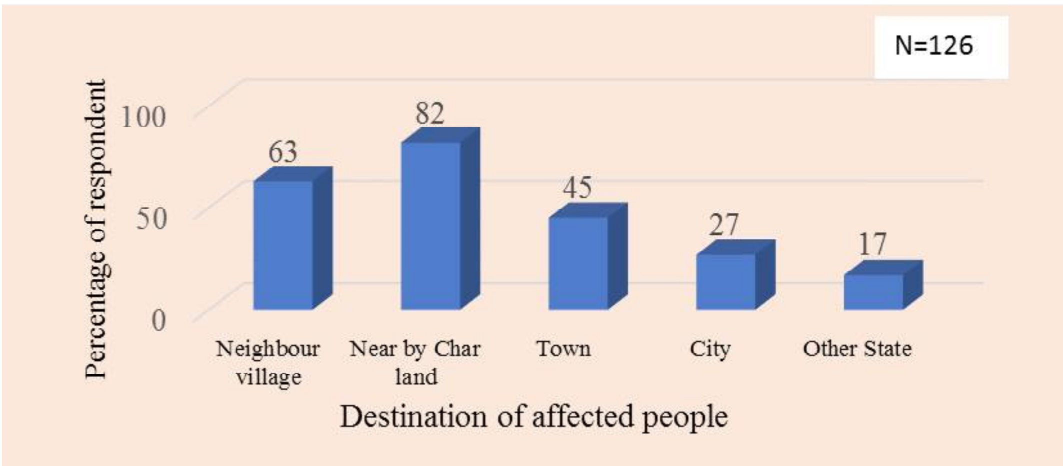

Figure 4: Respondent's Choice of Destination During Flood

Source: Primary Data, 2021

4.4.2. Loss of Land

It was found that the amount of land that is submerged and eroded is substantially more than the amount of land that rises from the riverbed owing to accretion (Akhter *et al.*, 2019). Those who have lost their assets and must rely on their savings which typically leads to greater debate (Barua *et al.*, 2019). Homestead land, housing constructions, farms, livestock, trees, and other household items are all impacted by land loss. People are forced to move to a new place after losing their homesteads, putting them in dangerous situations (Shetu *et al.*, 2016; Mutton and Haque, 2004).

In the study area, the quantity of land lost was classified into three groups (Table 9). The majority of respondents (37%) said they lost 0-3 acres of land, people (20%) agreed to a loss of 3-6 acres, 34.52% said they lost 6-9 acres of land, and 10% said they didn't lose any land.

Table 9: Loss of Land of Respondent (In Acre)	
Loss of Land (acre)	**Percentage of Respondent**
0-3	37.00
3-6	20.00
6-9	34.52
No loss	10.00
Source: Primary Data, 2021	

4.4.2.1. Changing Pattern of the Income Source of Respondent Owing to Erosion of the Riverbank

According to the data gathered, just 21% of respondents were engaged in farming activities after riverbank erosion, while 63% of respondents were engaged in farming activities before riverbank erosion. Because of riverbank erosion, there were significantly more day workers and unemployed people in the study region (Roy *et al.*, 2017). After the river bank erosion, 35% of respondents were day laborers, compared to just 12% before the bank erosion, and 14% of respondents were unemployed, compared to only 7% before the bank erosion. Prior to the hazard of riverbank erosion, non-farming activities were related with 22% of respondents (Table 10). Riverbank erosion obviously restricts people's employment opportunities. In addition to changing the population's patterns of employment along the rivers, Rahman and Gain (2020) also claim that as a result of river bank erosion, the majority of people lose their access to land for agriculture and end up landless and homeless (Paul *et al.*, 2020). This results in a high rate of non-farming activities, day labor, and unemployment in the research region.

Table 10: Occupation Pattern in the Affected Area		
Occupation Pattern	**Before Bank Erosion (%)**	**After Bank Erosion (%)**
Farming	63	21
Day labors	35	12
Unemployed	14	7
Non farming	22	25
Source: Primary Data, 2021		

Table 11: Status of Health of Respondent due to Flood and Other Affect	
Health Attributes	**Affected People (%)(n=126)**
Has any member of your family ever suffered from psychological issues such as stress, nervousness, anxiety, or insomnia? (percentage)	84
Having affected by any water borne disease?	92
Due to fool anyone in your family member effected by heart attack?	21
Did anyone injured?	62
Any family member ever been diagnosed by a doctor as having pink eye? (%)	24
Others e.g., drowning	56
Vector borne disease	24
Lung related disease	65
Gastro related disease	89
Source: Primary Data, 2021	

4.4.3. Health Consequences of Unstable Riverine Attitude

Apart from the amount of water present, a variety of additional elements influence the severity and scale of erosion, due to this uncertainty flood, drought also took place as well as their effects on human health (Noji, 2000). Flood-related health effects can be classified as either direct or indirect. Direct effects of being in the water and in an area that has been inundated include drowning, injuries from debris, chemical contamination, and hypothermia (Choudhury *et al.*, 2006; Du *et al.*, 2010). Examples of indirect effects linked to dangers associated with water damage to the built and natural environment include infectious diseases, malnutrition, poverty-related illnesses, and illnesses linked to displaced populations (Ahern *et al.*, 2005).

Health attributes among the sample has been recorded among the respondents who support that 89% of the population has been affected by the gastro related problem due to the consumption of unhygienic food and unsafe drinking water during the flood situation. People majorly affected by the water borne diseases and psychological issues 92% and 84% respectively. Although 62% of the population have been injured due to the flood outbreak (Table 11).

4.5. Livelihood Vulnerability

Vulnerability is a term which is used to describe the susceptibility to stress of any person or the people of society as a result of changes in the different environmental or socioeconomic situations that disrupt lives (Sarker *et al.*, 2019; Hahn *et al.*, 2009). Determiners of who is susceptible to natural disasters and socioeconomic changes can be identified using the assessment of livelihood vulnerability based on the crisis they have been going through, lack of opportunities to fulfilment there basic needs and the restriction created by the nature itself.

The vulnerability score of the livelihood strategies component showed (Table 12) on the basis of several components which are indicating the situation by comparing the components to each other (Thakur *et al.*, 2012). Values based on a 95% significance level allow for a clear observation of the research area's susceptibility. Based on the analysis value, the crisis facing the people is more appropriate. As the area is highly affected by the flood during the last 10 years. And also, the whole area is facing a crisis due to the uncertain behavior of the river.

Table 12: Indexed Value of Sub-Component of LVI

Sub-Component	Units	Study Area
Dependency ratio	Ratio	0.151
Percentage of female household	Percent	0.095
Average livelihood diversification index	1/ number of livelihoods	0.174
Ration of non-agricultural income to total income	Ratio	1.200
Average time to health facility	Time	0.562
Average crop diversity index	1/ number of crops	0.107
Percentage of household that does not save crops	Percent	0.585
Loss of agricultural land	Percent	0.270
Percentage of household using unsafe drinking water	Percent	0.653
Average number of reported floods, last 10 years	Percent	0.765
Percentage of households affected by bank erosion	Percent	0.565
Percentage of households affected by flood	Percent	0.464

Source: Primary Data, 2021

4.6. Relationship Between the Socioeconomic Determinants Based on Respondent Security

There are several determinants like education, income, food security, land loss etc. which are also affected due to the erosion. The households were determined by questioning respondents about their experience of various determinants which have a high impact on the livelihood of the population in the study area.

There was a total of 126 responders, nearly 78.9% indicating they were facing lack of security due to the impact of determinants. Based on the cross-tab analysis there are 5 parameters used to find out the security among the occupation, value of cultivable land, shifting of agriculture, losses due to erosion and income. Due to the uncertainty of the river bank most of the respondents are in a vulnerable situation regarding every determinate. They are not secure about their income, occupation, agriculture, land erosion and Income. Annual income was not powerful at all but it's not significant (at 0.01 significance level) which determined that the household is facing a crisis as their income is not secure so they are not getting food security also (Table 13). The lower-income segment was not in the same predicament.

Table 13: Test of the Independence of Attributes

***n*=126**	**Security Status**		
Name of Independent Variables	***N***	**NO**	**YES**
Age (p=0.0001)			
Below 40 years	61	32(52.46%)	21(36.51%)
Above 40 years	59	38(65.41%)	29(48.55%)
Occupation			
Agriculture	42	12(28.6%)	29(73.21%)
Non-Agriculture	61	32(52.46%)	21(36.51%)
Value of cultivable land (p=0.378)			
Less than 50,000 (in ₹)	96	58(61%)	39(39%)
Above TK.100,000 (in ₹)	11	8(59.32%)	5(42.62%)
Shifting of agriculture land(p=0.651)			
Single time	72	42(59.52)	28(42.43)
More time	53	30(59%)	22(42.10)
Losses due to erosion p=0.175			
Less than 80,000 (in ₹)	48	37(80.21%)	11(22.51)
Above 80,000 (in ₹)	69	31(50.6%)	14(82.25)
Income p=0.001			
Below 30,000 (in ₹)	82	38(47.27%)	47(54.02%)
Above 30,000 (in ₹)	35	42(62.21%)	8(22.22%)

Source: Primary Survey, 2021

Including these important variables, the researcher additionally included the time of shifting as well as the area of arable lands (in value) for the binary logistic regression because they were thought to have an impact on their security (Shetu *et al.*, 2016).

5. Conclusion

It has been concluded that locations where river banks are prone to erosion are a particularly sensitive zone for bank failure, this may cause flooding and negatively affect the quality of life for those who live in the research region. The investigation discovered that while certain cross barriers have been constructed to slow the flow of water and prevent riverbank erosion, the bank is severely eroded when the cross barriers are lacking. There are some patches of land where river deposition can be found. People practice paddy cultivation, which is on the verge of getting washed away if the water level rises. High river braiding is found in the middle of the river with fresh sand deposits. Sand bars change their positions according to the flow of water. The barrier bund is made of sand filled with boulders outside, but they are not wire meshed. Owing to flooding and erosion of the riverbanks, people have been relocated, facing several crises on their basic needs, lack of goods etc. River bank erosion also influences natural resources and the displaced population's socio-economic situation and their livelihood condition. On another side, it was destroying the dwellers' settlement and infrastructure, causing damage to people's crops, land, occupation, and increasing poverty in general (Photo plate 1). There were a number of plausible causes for the food insecurity in these places. Their large family size, lack of education, and meagre money were the main causes of their uneasiness. Their social and health situations deteriorated as a result of their food insecurity. Beside this, the consequences of river bank erosion have a serious consequence in the overall aspect of natural, economic, and social problems for the riverine dwellers. Presently some places of the barrier bund are in the verge of breaking, the soil underneath have already been washed away in this monsoon, if not repaired soon then in the next monsoon the water might enter to the study area and there is a huge possibility of a catastrophic damage to the people of the study area because of bank failure if the government does not come out with a proper solution. To prevent bank failure, it is suggested that sustainable embankment construction and maintenance are needed to be carried out. In order to prevent bank erosion and depth loss due to siltation of river beds, comprehensive management measures must be implemented. The government should engage people for training on disaster management and involvement of local institutions and local governments. Opening and closing of Teesta barrage must be properly regulated by the experts. The rapid and proper implementation of a relief and rehabilitation program for the displaced individuals is urgently required and their basic needs must be fulfilled as soon as possible.

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Informed Consent Statement

Not applicable.

Data Availability Statement

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Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Photo Plate 1: Overview of the Riverine Landscape and Human Lifestyle: (a) Bank Failure at During Monsoon; (b) Flood Protection by Embankment Construction Along the Left Bank of Teesta River; (c) Water Lodging After Overflow of River Water; (d) Fishing Activity by Riverine Dwellers During Monsoon; (e) Agricultural Practice on Fertile Riverine Landscape; (f) Permanent Settlements Displacement After Land Lost Due to Channel Shifting

Appendix (Cont.)

Code	Village Name	Code	Village Name	Code	Village Name
1	Junglee Mohal	30	Bidurerdanga	59	Uttar Madhabdanga
2	Jhar Matiali	31	Guzrimari	60	Uttar sisuabari
3	Purbba Dolaicaon	32	Dakshin Baragila	61	Dakshin marichbari
4	Uttar Saripakuri	33	Banglajhar	62	Madhabdanga
5	Jharbaragila	34	Amguri	63	Bahadur
6	Chengmari Dangapara	35	Baulbari	64	Uttar Bhuskadanga
7	Dakshin Khalpara	36	Purbba Premganj	65	Dakshin Ulladabari
8	Chak Maulani	37	Paschim Premganj	66	Satkhamar
9	Chengmarihat	38	Basusuba	67	Uttar Dangapara
10	Adabari	39	Patkata	68	Gopalganj
11	Barapatina Nutanbus	40	Chat Rarpar	69	Satkhamar
12	Kajaldighi	41	Premganj Majhiali	70	Dakshin Madhabdanga
13	Shikarpur	42	Paitkakhocha	71	Dakshin sisuabari
14	Chengmari	43	Singimari	72	Barnes
15	Satvendi	44	Bhelakoba	73	Dakshin Dangapara
16	Dakshin Saripakuri	45	Uttar Khagrabari	74	Dakshin Bhuskadanga
17	Dakshin Chengmari	46	Mainaguri (CT)	75	Kukurjan
18	Chapadanga	47	Paharpur	76	Uttar Putimari
19	Dakshin Chak Maulani	48	Domohani	77	Sisuabari
20	Dakshin Kalamati	49	Bagjan	78	Dakshin Putimari
21	Purbba Baragila	50	Uttar Mauamari	79	Paschim Bara Gharia
22	Paschim Sangapara	51	Kanthalbari	80	Bara Kamet
23	Kumarpara	52	Chhat Guzrimari	81	Purba Sisuabari
24	Paschim Baragila	53	Uttar Marichbari	82	Gaurgram
25	Chapgar	54	Madhya Khagrabari	83	Mandalghat
26	Dakshin Matiali	55	Dakshin Khagrabari	84	Dharmmapur
27	Purbba Sangapara	56	Sukani	85	Garalbari
28	Purbba Mauamari	57	Kharia (P)	86	Penchahahi
29	Paschim Mauamari	58	Ulladabri		

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