

Impact of Structural Interventions on Morphological Changes of Teesta River Using River Sensing Approach

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Abstract Bangladesh, a predominantly riverine country, is characterized by a complex network of approximately 405 rivers, including 57 transboundary waterways. The Teesta, one of the country's major transboundary rivers, traverses 115 kilometers of its total 315-kilometer length within Bangladesh, significantly impacting the livelihoods of its riparian populations. To address irrigation demands, a barrage was constructed across the Teesta River in 1998. This study investigates the morphological alterations induced by the Teesta Barrage on the river's dynamics, specifically focusing on bar formation, sinuosity index, and river width. Employing Landsat satellite imagery from 1988 to 2020 and GIS analysis, the research reveals a substantial increase in bar area post-barrage construction. While the maximum sinuosity index has risen, the minimum and average values have declined, indicative of altered channel patterns. Concurrently, the river's width has expanded, with an increasing disparity between its maximum and minimum dimensions, signifying heightened channel dynamism. These findings underscore the adverse impacts of the Teesta Barrage on the river's morphology. Consequently, comprehensive studies on the river's morphological evolution are imperative to develop effective mitigation strategies for the affected communities.

Keywords: Teesta River, Teesta Barrage, GIS, remote sensing, morphology, bar dynamics, sinuosity

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1. Introduction

Bangladesh, a nation characterized by its extensive river network, is geographically positioned within the Ganges-Brahmaputra-Meghna (GBM) deltaic region. This deltaic formation is globally recognized for its vast expanse and the formidable force of its river systems [1]. Bangladesh possesses a dense and complex network of approximately 405 rivers, a significant proportion of which, numbering 57, extend beyond its national boundaries [2]. Of these 57 transboundary rivers, a substantial number, precisely 54, originate from India, while the remaining three trace their source to Myanmar [3]. The Teesta River, a significant transboundary river shared between India and Bangladesh, serves as the primary focus of this investigation. Recognizing the imperative to enhance agricultural output, the construction of a barrage commenced at Dalia Point along the river's course in the year 1979. This infrastructural project culminated in its completion during the period spanning 1997 to 1998 [4,5]. The introduction of hydraulic structures, such as barrages, is widely recognized to disrupt the natural equilibrium of river channels, often inducing morphological transformations. Given its role as an obstruction to the river's flow, the construction of the Teesta Barrage is expected to have precipitated alterations

in the river's morphology.

Previous research has extensively explored the dynamics of river channels, with a particular focus on bar formation and evolution. Khan et al. (2021) conducted a wide-ranging study on the Dharla River, employing multi-temporal satellite imagery to analyze erosion, accretion rates, and channel morphology, including the quantification of sinuosity index and average river width [6]. Khan (2018) showed the complex interplay between climate change and upstream developments within the Teesta River basin, with a particular focus on their cumulative impact on the basin's water balance [7]. Rahman et al. (2017) conducted a comprehensive analysis of the Dudhkumar River, focusing on the complex interplay of erosion, accretion, and bar formation processes [8]. To trace the historical evolution of the Meghna River's course, Nabi et al. (2016) studied research spanning a period from the 1760s onwards, and utilized Geographic Information Systems (GIS) and remote sensing techniques to analyze changes in the river's Bankline's [9]. Khan (2014) employed GIS and remote sensing techniques to analyze the erosion patterns of the Jamuna River [10], while Chisty et al. (2014) focused on the erosion and deposition processes within the Karnaphuli River [11]. Nath et al. (2013) contributed to the understanding of riverbank erosion trends in the Chandpur region [1]. Moreover, the seismic event of 1950, centered in Assam, and its subsequent impact on the

Brahmaputra, Padma, and Lower Meghna rivers were investigated by Sarker et al. (2009) [12]. In the context of the Teesta River, Khan (2001) examined the morphological alterations induced by the construction of the Teesta Barrage, providing valuable insights into the river's response to human intervention [13]. Mazumder et al. studied the Island Dynamics of the selected reach of the Chandpur confluence [14]. These preceding studies collectively contribute to a broader understanding of river dynamics within the Bangladeshi landscape.

While previous research, such as that conducted by Saha et al. (2021) [15], has investigated the phenomenon of banking shifting in response to barrage construction, the subsequent impacts on bar dynamics, river width, and other pertinent morphological parameters using 33-year continuous data remain relatively unexplored. This study aims to fill this knowledge gap by comprehensively examining these critical aspects of river channel evolution in the context of the Teesta River and its barrage. The primary objectives of this research encompass a comprehensive assessment of bar dynamics within the Teesta River, meticulous determination of the sinuosity index curve to characterize the river's meandering behavior, and precise quantification of average and maximum river width to clarify channel evolution and morphological transformations over time due to the construction of this barrage.

2. Materials and Methodology

2.1. Study Area

The Teesta River, a transboundary hydrological entity, originates from the Pahunri Glacier, nestled within the Eastern Himalayas. Its course traverses the Indian states of Sikkim and West Bengal before entering the territory of Bangladesh, where it ultimately merges with the Brahmaputra River, discharging its waters into the Bay of Bengal. The river's journey encompasses the Indian districts of Sikkim, Kalimpong, Darjeeling, Jalpaiguri, and Cooch Behar, assuming the status of Sikkim's largest river and West Bengal's second largest. Within Bangladesh, the Teesta significantly contributes to the country's hydrological regime [5]. This River stands as the fourth largest transboundary river coursing through Bangladesh [16]. With a total length of 315 kilometers, the Teesta River traverses a distance of 115 kilometers within the territory of Bangladesh [17]. Its basin encompasses an approximate area of 2004 square kilometers [18] and enters the territory of Bangladesh at the Kharibari border, situated within the Nilphamari district [17]. The Teesta River traverses five districts within Bangladesh, namely Gaibandha, Kurigram, Lalmonirhat, Nilphamari, and Rangpur, encompassing approximately 35 Upazilas and impacting the lives of over 5427 villages. Its influence extends to a significant portion of the nation's population, affecting approximately 7.3% of the total citizenry. Moreover, the river's floodplain supports a substantial portion of the country's agricultural sector, contributing to 14% of the cultivated area [16].

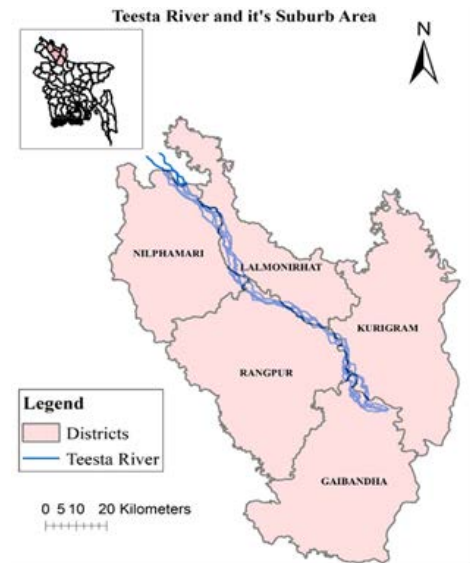


Figure 1. Teesta River and its Suburb Area [15]

To address the irrigation demands of the region's extensive agricultural lands, a barrage was constructed across the Teesta River at Dalia Point during the period 1997-1998. This hydraulic structure was designed to divert approximately 280 cubic feet of water per second for agricultural purposes [4]. The Teesta River exhibits a wide range of discharge, with an average maximum flow rate of 280,000 cubic feet per second and an average minimum flow rate of 100,000 cubic feet per second [19]. A map that shows the representation of the study area is presented in the accompanying Figure 1.

2.2. Data Collection

All spatial data utilized in this study were procured from the publicly accessible United States Geological Survey (USGS) Earth Explorer platform. Landsat satellite imagery, specifically from sensors 4, 5, 7, and 8, was acquired for the designated study period. To ensure optimal image quality for analysis, cloud-free scenes were prioritized. In consideration of post-monsoonal conditions, January imagery was preferentially selected; however, due to data availability constraints, December images were incorporated for certain years. All downloaded imagery was in Tagged Image File Format (.tif) with a spatial resolution of 30 meters by 30 meters. The study period spanned from 1988 to 2000.

2.3. Quantification of Bar Dynamics

To ascertain the temporal evolution of bar formation and expansion within the river channel, a methodological framework was established. Initially, raster imagery encompassing the study area was integrated into the Geographic Information System (GIS) environment. Subsequently, a meticulous process of digitizing the discernible bars within the river channel was undertaken for each specified year. The resultant polygon shapes representing the bars were subjected to area calculations to quantify their spatial extent.

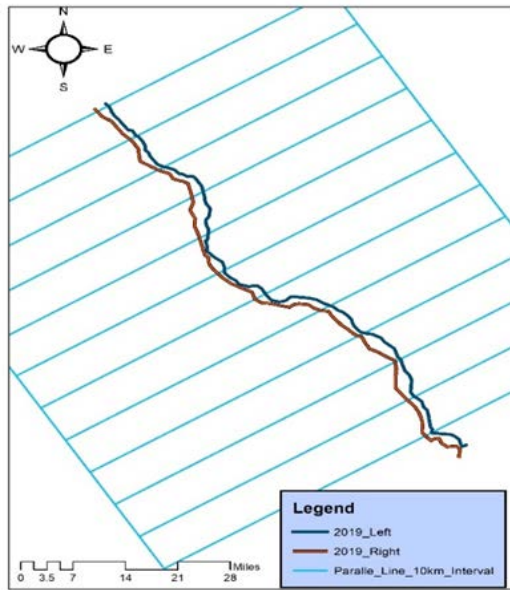


Figure 2. Methods for the Determination of River Width

2.4. Determination of Sinuosity Index

The sinuosity index, a quantitative measure of river meandering, was calculated through a series of sequential steps. The delineation of both riverbanks for each study year was collected from [15]. The calculated lengths of these digitized bank lines were averaged to derive the channel length. Concurrently, the valley length, representing the overall length of the river course, was determined using appropriate GIS tools. The ratio of channel length to valley length yielded the sinuosity index value for each respective year.

2.5. Analysis of River Width

To characterize changes in river width over time, a systematic approach was implemented. Twelve equidistant transverse lines were established at ten-kilometer intervals across the river channel. The width of the river was digitized along each of these transects, resulting in a series of width measurements. Statistical analysis of these measurements provided insights into the temporal variability of river width and its potential correlation with other morphological parameters (Figure 2)

3. Result and Discussion

3.1. Bar Dynamics

Figure 3 presents a comparative analysis of bar area evolution within the Teesta River before and after the construction of the Teesta Barrage. The data reveals a pronounced increase in the overall bar area after the barrage's construction. While a gradual upward trend in the bar area is evident before barrage implementation, a significantly steeper increase is observed post-1998.

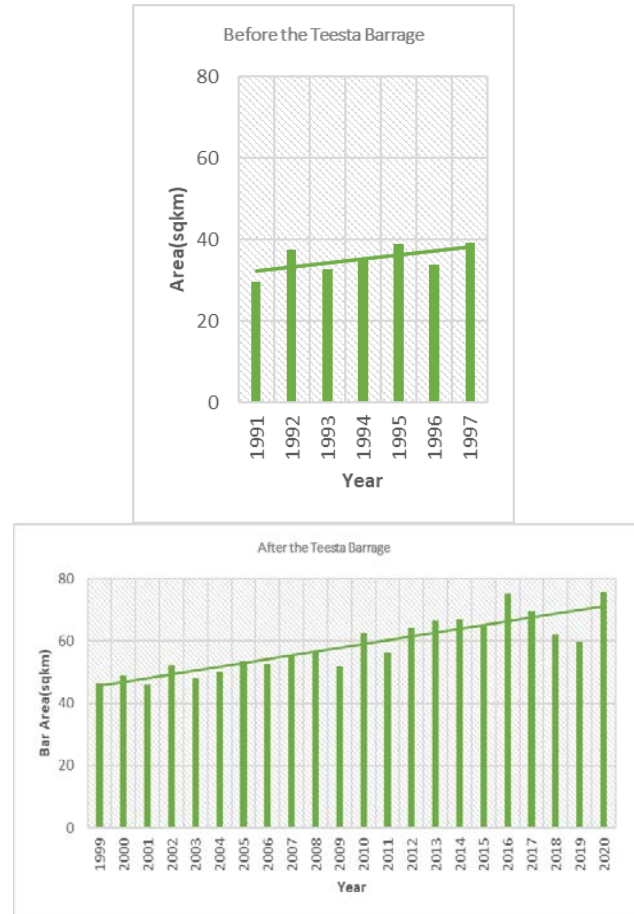


Figure 3. Bar Area Before and After the Teesta Barrage

Notably, the maximum bar area recorded before barrage construction was 39.09 square kilometers, whereas the minimum bar area observed post-barrage construction reached 46.10 square kilometers, representing an approximate 18% increase. A comprehensive analysis of the data indicates that the average, maximum, and minimum bar areas experienced increases of approximately 66%, 94%, and 56%, respectively, relative to pre-barrage conditions (Figure 4).

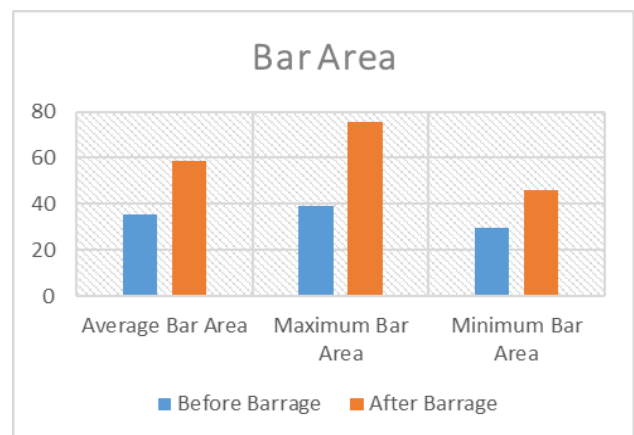


Figure 4. Variation of Overall Maximum, Average, and Minimum bar area (sqkm) before and after the construction of Teesta Barrage

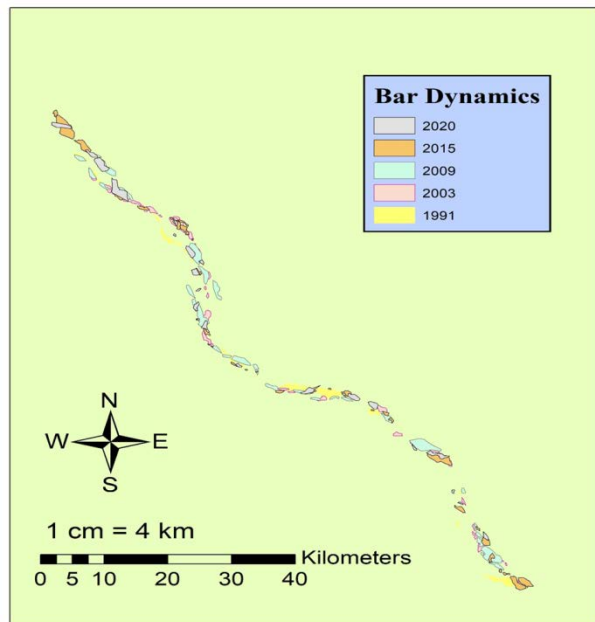


Figure 5. Change of locations of bars every 6 years

The spatial distribution of bar areas over six-year intervals is graphically depicted in Figure 5. The findings of this analysis underscore the substantial impact of the Teesta Barrage on the river's morphological dynamics, particularly concerning bar formation and expansion.

3.2. Analysis of Sinuosity Index

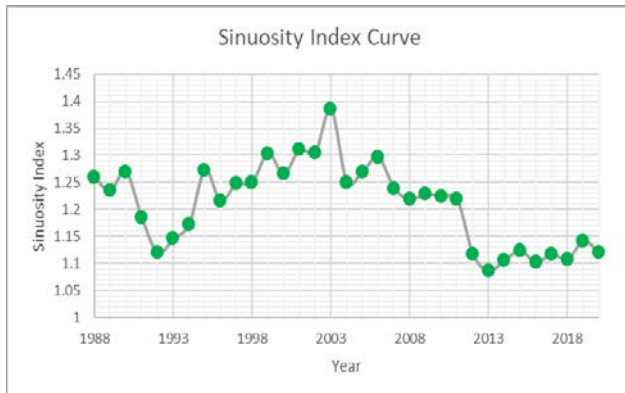


Figure 6. Sinuosity Index Curve of Teesta River Over 34 Years

Figure 6 presents a detailed temporal analysis of the sinuosity index, a quantitative measure of a river's meandering tendency, over a thirty-four-year period. The calculated values consistently exceeded unity, unequivocally classifying the Teesta River as a sinuous channel, a categorization congruent with Charlton's (2008) established typology (Table 1) [20].

Table 1. Classification of Sinuosity

Type	Sinuosity
Straight	<1
Sinuuous	1-1.5
Meandering	>1.5

While a marginal increase of approximately 9% in the maximum sinuosity index was observed post-barrage construction, the overall trend in average and minimum

sinuosity values exhibited a slight decline, approximating 0.50% and 3%, respectively. These nuanced changes suggest a complex interplay of factors influencing the river's morphological evolution. Notably, the expanded range of sinuosity index values following barrage construction, from 1.08 to 1.38 compared to the pre-barrage range of 1.12 to 1.27, signifies an increased propensity for channel instability and a more dynamic riverine system (Figure 7).

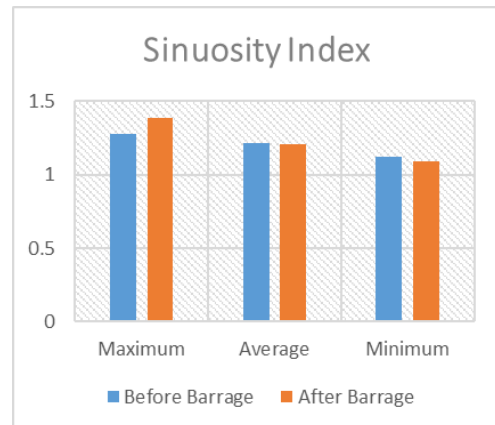


Figure 7. Variation of Overall Maximum, Average, and Minimum SI value before and after the construction of Teesta Barrage

4. Analysis of the Width of the River

To assess changes in river width, measurements were conducted at twelve distinct locations along the Teesta River at three-year intervals. The resulting data were subsequently analyzed to derive average and maximum width trends over time. The graphical representation of these trends indicate a consistent increase in both average and maximum river width throughout the study period. This observation suggests that erosional processes have predominated over depositional activities, leading to a progressive widening of the river channel (Figure 8).

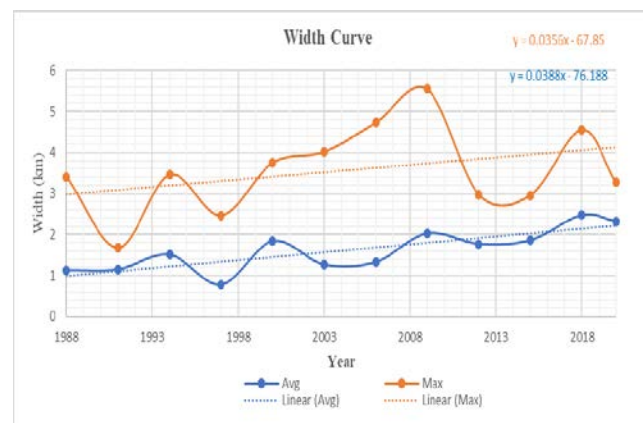


Figure 8. Average and Maximum Width Curve

A comparative analysis of river width data reveals a substantial increase of approximately 62% in the average width following the construction of the Teesta Barrage. Before barrage implementation, river width exhibited a range of 200 to 3500 meters, while this range expanded to 110 to 5550 meters in the post-barrage period. These

findings indicate a complex pattern of channel adjustments, with localized widening in certain reaches and narrowing in others. Furthermore, the increasing disparity between maximum and minimum width values highlights the growing dynamism of the river channel over time (Figure 9).

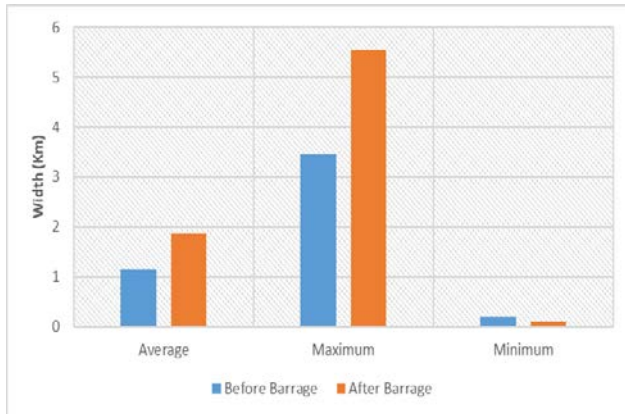


Figure 9. Variation of Overall Maximum, Average and Minimum value of river Width before and after the construction of Teesta Barrage

5. Conclusion and Recommendations

The present study has systematically analyzed the impacts of the Teesta Barrage on river morphology. Key findings reveal significant alterations in river dynamics after barrage construction. Notably, an increase in the bar area, coupled with an elevated maximum sinuosity index and average river width, has been observed. Conversely, a decline in the minimum sinuosity index indicates a reduction in channel curvature. These findings collectively suggest an intensification of river dynamism.

It is imperative to acknowledge the limitations imposed by the 30-meter spatial resolution of the Landsat imagery utilized in this study. To enhance the accuracy and precision, of future investigations, the incorporation of higher-resolution satellite data is recommended. While Landsat 7 provided valuable information, the presence of data gaps due to sensor anomalies necessitates cautious interpretation of results in areas affected by these deficiencies.

The findings of this study serve as a foundation for subsequent research endeavors aimed at comprehending the intricate processes governing the morphological evolution of the Teesta River. A more in-depth exploration of the barrage's influence on river hydraulics, sediment transport, and bank erosion is warranted to develop effective management strategies for this vital waterway.

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