IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402, p- ISSN: 2319-2399.Volume 20, Issue 10 Ser. II (October 2026), PP 46-59
www.iosrjournals.org

The Teesta River and Barrage Projects: A Review of Hydrology, Water Management, and Environmental and Socioeconomic Impact

Dr. Mst. Shifat Rumana[1]

Abstract:
The Teesta River is one of the major transboundary rivers in Bangladesh, with immense importance for Bangladesh's agricultural, fishery, ecosystem, and socio-economic activities in the northern region. This study aims to review the geographic and hydrological characteristics of the Teesta, analyze the features and benefits of the Gajoldoba and Dalia Barrages, assess downstream water availability, address transboundary water-management concerns and their environmental and socio-economic impacts. The reviewed articles report significant seasonal variability in the river's flow, with strongly expressed monsoon peaks and significant deficits during the dry season. This pattern is closely related to the observed trends of flood surges, riverbank erosion, siltation, irrigation water shortages, and alterations in aquatic and livelihood resources. The Teesta Barrage Irrigation Project contributes to higher cropping intensity and production in the irrigated areas. Overall, the reviewed articles reveal the interdependence of the problems related to the transboundary nature of the Teesta River. Therefore, it is essential to prioritize integrated, interrelated measures, focused on sustainable water management practices downstream, improved water storage capacity, flood and erosion risk reduction, ecological considerations, and long-term water and socio-economic assessments.

Keywords*: Teesta River; Teesta Barrage; irrigation; riverbank erosion; flooding; water scarcity; climate change*

Date of Submission: 12-10-2026 Date of Acceptance: 24-10-2026

I. Introduction

The Teesta River is one of the major transboundary rivers of Bangladesh and is regarded as the fourth major river of the country in terms of its importance within the national river system (Mondal et al., 2017). The river originates in the Himalayan region of Sikkim, India, flows through the Indian state of West Bengal, and subsequently enters Bangladesh at Chatnai in Nilphamari District (Islam & Higano, 2000; Mondal et al., 2017). The river basin is shared by India and Bangladesh, making the Teesta an important transboundary water system in South Asia, where upstream water management directly influences downstream water availability and riverine conditions (Arfanuzzaman, 2020; Momen, 2023).

The Teesta has undergone substantial historical changes in its course and channel system. Historical accounts indicate that the river was formerly connected with the Karatoya–Atrai–Jamuneswari river system before major changes in its course during the late eighteenth century (BWDB, 1999). Its present-day floodplain in Bangladesh supports extensive agricultural activities and a large population whose livelihoods are closely associated with river water and floodplain resources. Mondal et al. (2017) estimated that the Teesta floodplain accounts for approximately 14% of Bangladesh's total cropped area and is associated with about 9.15 million people, demonstrating the river's considerable agricultural and socioeconomic significance.

The hydrological behaviour of the Teesta is characterized by pronounced seasonal variability, with relatively high flows during the monsoon and reduced flows during the dry season. Analysis of discharge records at the Dalia and Kaunia stations has identified considerable variability in both maximum and minimum flows, with declining low-flow conditions and recurrent high-flow events affecting communities along the river (Mondal et al., 2017). Such variability contributes to a contrasting set of water-related challenges, including seasonal flooding, dry-season water scarcity, riverbank erosion, and difficulties in maintaining reliable water supplies for agriculture and other uses.

Human interventions have further influenced the hydrological and socioeconomic characteristics of the river. The construction of the Gajoldoba Barrage in India and the Teesta Barrage Project at Dalia in Bangladesh introduced major water-control and irrigation structures within the transboundary river system. Earlier studies

[1] Professor, Department of Geography and Environmental Science, Begum Rokeya University, Rangpur Bangladesh. Email:shifatrumana@gmail.com

documented concerns regarding the effects of upstream water regulation on downstream irrigation and environmental conditions, while more recent research has examined how upstream water withdrawal is associated with changes in land use, water bodies, and livelihoods in the lower Teesta basin (Islam & Higano, 2000; Ahmed et al., 2022).

The transboundary nature of the Teesta has therefore made water allocation a persistent issue in Bangladesh–India relations. Research has identified downstream water scarcity and agricultural impacts as important consequences of unequal or uncertain water availability, while recent studies have emphasized the need for cooperative and institutionally supported approaches to transboundary water management (Arfanuzzaman, 2020; Gupta, 2025; Hossen et al., 2024).

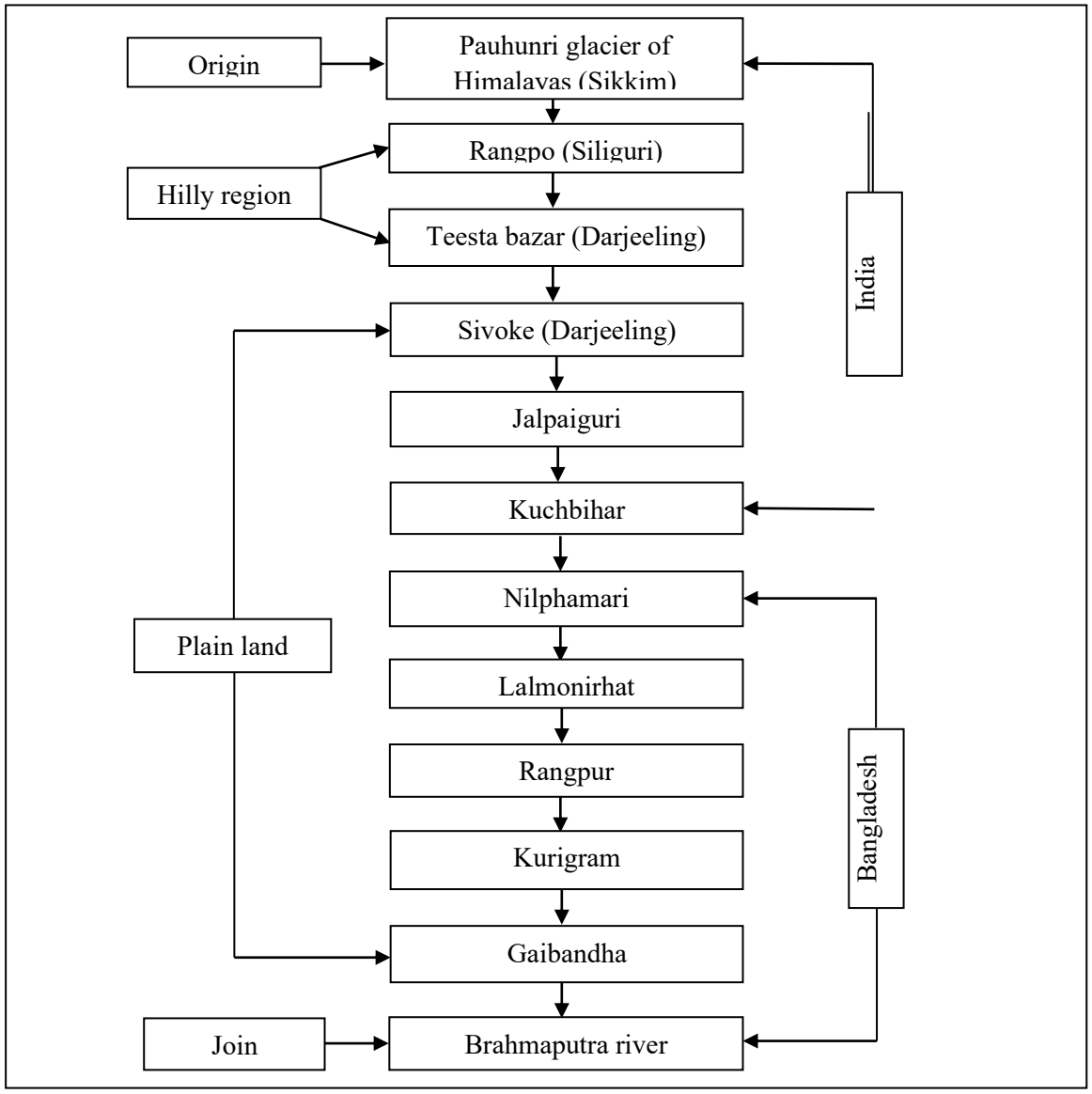
The environmental and socioeconomic dimensions of the Teesta problem are also closely interconnected. Studies have documented flood risk and household vulnerability along the river. Drought risk and its implications for farming communities (Sultana et al., 2021), and livelihood changes associated with upstream water withdrawal (Ahmed et al., 2022). Recent geomorphological research has examined long-term riverbank erosion and accretion along the Teesta floodplain, highlighting the continuing instability of the riverine landscape (Parvej et al., 2024).

Although some studies have examined individual aspects of the Teesta River including hydrology, barrages, water sharing, flooding, erosion, agriculture, livelihoods, and climate-related changes these dimensions are often addressed separately. A comprehensive synthesis is therefore necessary to understand how hydrological variability, upstream and downstream water management, transboundary governance, environmental change, and socioeconomic vulnerability interact within the Teesta River system. Accordingly, this review brings together existing evidence on the geographical and historical development of the Teesta, its hydrological and river dynamics, the role of the Gajoldoba and Dalia barrages, transboundary water-sharing issues, environmental and socioeconomic impacts, and emerging challenges associated with climate variability. The review further identifies major knowledge gaps and potential directions for more integrated and sustainable management of the Teesta River.

II. Geographical and Historical Overview

The Teesta originated from the Teesta source Glacier-Pauhunri Glacier, Teesta kangse near Khangchung lake (27°59' N; 38°48' E at an elevation of 7128©/2173 m.). Out of its 250 miles about 100 miles (170 km.) lies in Bangladesh (Hanif, 1995). The Teesta was the most important river of the northern region till 1787 and it was the principal source of supply for the Karatoya, Atrai, Jamunaswari and other rivers. Considerable structural changes in the *barind* region affected the Karatoya, which rapidly dwindled. The Teesta with a large amount of water left over could not pass down the Atrai without causing floods. The excessive rains of 1787 suddenly brought down a vast flood of sand and choked the Atrai channel, with the result that the Teesta burst into very small Ghaghat river, and not finding sufficient outlet, overflowed the swept nearly the whole Rangpur district. The flood or rather deluge happened in a single day, August 27, 1787 (Verghese, 1990).

The major flood in 1987 in northwest Bangladesh was mainly caused by excessive rainfall occurring throughout the monsoon season, and was aggravated at times by flash floods passing down the Teesta river as well as other rivers entering Bangladesh from the northwest (Ahmed, 2006). The 1987 flood was intensified by the above normal level of rainfall starting in July throughout the country with heaviest fall occurring around Rangpur (Elahi, 1991a). The Teesta river basin lie in two countries named India and Bangladesh. From the figure-2.8 it is seen that, the Teesta river originates in the glaciers of the Himalayas in Sikkim. It flows in hilly region before emerging into the alluvial plains of North Bengal in India. The river crosses in Indian plains before it enters into the extreme northwest region of Bangladesh. It crosses five district of Bangladesh named Nilphamari, Lalmonirhat, Rangpur, Kurigram, Gaibandha and finally join to Brahmaputra river. Through the mountainous area before emerging at Sivoke on the alluvial plains of North Bengal (India) across which it follows in a braided course for a further 50 miles/80 km., and then crosses the Bangladesh-India border. After a further length of 100 miles/160 km., it joins the Brahmaputra river at kamarjani village near Chilmari thana (Mukhopadhya, 1982). Top to bottom basin area of the Teesta river is shown in a figure-1 below:



Source: Author

Figure: 1 Basin area of the Teesta river

Catchment, Tributaries and Floodplain Characteristics

The flow of the Teesta river first moves south from Jalpaiguri (India) in three channels, namely the Karatoya to the east, the Punarbhaba to the west and the Atrai to the center. These perhaps account for the name *trisrota* and ultimately the Teesta. The name Teesta, it may be mentioned, has been derived from the *sanskrit* word *trisrota* (three currents), and the river according to Hindu mythology is said to flow from the breasts of the goddess *Parvati* (Rahman et al., 1994).

Table: 1 Catchments area of the Teesta river

Landscape	State/region	Area (Sq. km.)	Total (Sq. km.)
Hilly region	1. Sikkim 2. West Bengal	6930 1121	8051
In plain	1. West Bengal 2. Northern Bangladesh	2104 2004	4108
Total in India			10155
Total in Bangladesh			2004
Total			12159

Source: Rahman, 2013

The Teesta river flows the Himalayan to plain land in West Bengal (India) and it receives drainage from a number of tributaries which are listed in the table-2:

Table: 2 Major tributaries of the Teesta river in India

Left-bank tributaries	Right-bank tributaries
Lachung chhu Chakung chhu Dik chhu Rain khola Rangpo chhu	Zemu chhu Rangyong chhu Rangit river

Source: Rahman, 2013

In Bangladesh Dhum is a tributariy of the Teesta river (Ministry of Establishment 1990). On the other hand major distributaries of the Teesta river are Ghaghat, Manas, Ganga and Bullai.

The Teesta dependent area is one of largest sub-regions of the Bengal basin, which covers almost the entire greater Rangpur district. In Bangladesh portion, the Teesta flood plain is bounded by latitudes 25°30' to 26°18' north and longitudes 88°52' to 89°45' east which includes the north-eastern part of the country. It covers the area about 1062 sq. miles/ 2750 km^2 (Survey of Bangladesh, 1976).

Before 1787, Teesta was the main stream of North Bengal and it is still an important river in this region. After 1787, though the Teesta river has changed its course as well as the system as a whole, it has had direct and indirect impact on its river systems and the entire floodplain (Hanif, 1995)

Table 3. Teesta river flow (left and right bank upazila)

	District	**Upazila**
Teesta river left bank flows	Lalmonirhat	Patgram
		Hatibandha
		Kaligonj
		Lalmonirhat Sadar
	Kurigram	Ulipur and Rajarhat
		Chilmari
Teesta river right bank flows	Nilphamari	Dimla
		Kishorgonj
	Rangpur	Gangachara
		Kaunia
		Pirgacha
	Gaibandha	Sundorgonj
		Sadar upazila

Source: (Sheikh, 2012), page.10-12.

III. Hydrological Characteristics and River Dynamics of Teesta River

3.1 Basin and Physical Characteristics

The area of Teesta sub catchment in Bangladesh is about 2000 km^2. The riverbed is comprised of fine to medium sand common to an alluvial floodplain. This area is classified as shallow depressions and valleys of moribund river channels formed by long morphological history of changes in the river courses. The general slope of the river varies from 0.47 to 0.55 m./km. The Teesta sub catchment is vulnerable to flooding in each year. There are two main tributaries of the river Teesta, namely Naotara and Buri-Teesta. Flash floods are caused by the Teesta river and if the peaks are observed in rivers Jamuna and Teesta simultaneously. The worst flood situation occurs in the area (Rahman et al., 2011).

3.2 Seasonal Flow Variability

The Teesta River exhibits pronounced seasonal variability in discharge, with higher flows during the monsoon months and considerably lower flows during the late winter and pre-monsoon periods. The discharge records from the Dalia station for 2008–2017 show that the annual maximum discharge occurred mainly between June and August, whereas the annual minimum discharge was generally recorded between February and March (BWDB, 2018). The highest discharge during the observed period was 94,106 cusecs in June 2014, while the lowest was 232 cusecs in March 2015. This represents a very large seasonal contrast in river flow.

Table: 4 Annual water discharge at Dalia (Nilphamari) station of the Teesta river (2008-2017)

Year	Month	Highest water discharge (Cusec)	Month	Lowest water discharge (Cusec)
2008	June	60411	March	1050
2009	July	64462	February	545
2010	June	73958	February	1680
2011	September	70966	March	697
2012	June	70966	February	1468
2013	July	68461	February	944
2014	June	94106	March	409

2015	June	65049	March	232
2016	July	75834	February	713
2017	August	70231	March	1552

Source: BWDB, 2018

The maximum annual discharge exceeded 60,000 cusecs in every year during 2008–2017, ranging from 60,411 cusecs in June 2008 to 94,106 cusecs in June 2014. In contrast, minimum annual discharge varied considerably, from only 232 cusecs in March 2015 to 1,680 cusecs in February 2010. The records therefore indicate a highly variable flow regime, characterized by substantial monsoon flows followed by sharply reduced discharge during the dry season. Such strong seasonal fluctuations are an important characteristic of the Teesta River and have implications for both flood management during high-flow periods and water availability for irrigation and other downstream uses during the dry season (BWDB, 2018).

3.3 Flood Characteristics and Water-Level Variability

The Teesta River experiences recurrent flooding during the monsoon season, with substantial variations in river water levels recorded at both the Dalia and Kaunia stations. The available records of major flooding periods show that the highest water levels at Dalia generally occurred between July and August, while the corresponding peaks at Kaunia were also concentrated mainly during July and August (BWDB, 2017b). However, the timing of peak water levels was not identical in every year, indicating variability in the occurrence and propagation of high-flow events along the river.

At Dalia station, the recorded water levels ranged from 52.487 m in 1980 to 52.950 m in 2007 among the listed major flood events. Importantly, all recorded peak water levels in the table exceeded the reported danger level of 52.40 m at Dalia, indicating that these events reached flood-critical conditions at the station. The highest recorded level in the dataset occurred on 8 September 2007 (52.950 m), followed by 52.890 m on 8 July 1988 and 52.780 m on 27 August 2014 (BWDB, 2017b).

Table: 5 Highest water level of some major flooding period at Dalia (Nilphamari) and Kaunia (Rangpur) station of the Teesta river

Year	Date	Highest water level of Dalia station (m.)	Date	Highest water level of Kaunia station (m.)
1980	20.7.80	52.487	21.7.80	30.082
1981	4.7.81	52.761	Na	Na
1987	13.8.87	52.765	14.8.87	30.470
1988	8.7.88	52.890	26.8.88	30.430
1990	13.8.90	52.690	14.8.90	30.100
2004	8.7.04	52.600	9.7.04	29.080
2007	8.9.07	52.950	4.9.07	29.660
2009	20.8.09	52.760	21.8.09	29.340
2012	16.7.12	52.700	17.7.12	29.310
2014	27.8.14	52.780	27.8.14	28.950
2016	22.6.16	52.650	25.7.16	28.900

Source: BWDB, 2017b Na=Data is not available N.B: Danger level of Dalia station is 52.40 m. and danger level of Kaunia station is 30.00 m.

At Kaunia station, the recorded peak water levels varied from 28.900 m in 2016 to 30.470 m in 1987. Several of the listed events exceeded the reported danger level of 30.00 m, particularly in 1980 (30.082 m), 1987 (30.470 m), 1988 (30.430 m), and 1990 (30.100 m). In contrast, the peak levels recorded in 2004, 2007, 2009, 2012, 2014, and 2016 remained below the stated danger level at Kaunia, despite being identified as major flooding periods in the dataset (BWDB, 2017b).

Overall, the records demonstrate that flooding in the Teesta basin is predominantly associated with high river stages during the monsoon season, although the timing and magnitude of peak water levels vary between years and monitoring stations. The difference between Dalia and Kaunia also indicates spatial variability in river-stage behaviour along the downstream course of the river. Such variability is important for understanding flood risk because the occurrence of high water levels depends not only on the magnitude of river discharge but also on the spatial and temporal characteristics of river flow and channel conditions.

3.4 River Morphology

The Teesta River is characterized by a highly dynamic and predominantly braided channel system, with continuous changes in channel width, bar and island formation, bank position, and channel alignment. Recent sedimentological evidence indicates that the river contains extensive sand bars and floodplain deposits, with fine- to medium-grained sediments being transported mainly through bedload processes and, to a lesser extent,

suspension. The presence of different sedimentary structures and fining-upward sequences also indicates repeated changes in flow velocity, channel position, and depositional conditions over time (Sohan et al., 2023).

Riverbank erosion and accretion are therefore persistent geomorphic processes along the Teesta floodplain. Using Landsat imagery from 1991, 2001, 2011, and 2021, Parvej et al. (2024) found recurrent erosion and accretion along the Teesta floodplain over three decades. Their analysis estimated approximately 194 km² of land erosion and a broadly comparable area of accretion between 1991 and 2021, demonstrating that the river has undergone considerable lateral adjustment during this period. These processes have contributed to continuous bankline shifting and changes in surrounding land-use and land-cover patterns, particularly affecting agricultural land and settlement areas (Parvej et al., 2024).

Human interventions can further modify these natural morphological processes. Uddin et al. (2024), examining the influence of bridge infrastructure on the Teesta, reported noticeable changes in bar area, channel width, and bankline position following road-bridge construction. Their analysis of Landsat imagery from 2001 to 2021 showed an increase in average bar area of approximately 32.45 km² during the post-construction period, while erosion became dominant along both banks within the investigated reach. The findings suggest that river-crossing infrastructure can locally influence flow patterns and sediment redistribution, thereby contributing to morphological adjustment of the channel (Uddin et al., 2024).

3.5 Sediment and Channel Dynamics

Sediment transport is a fundamental process controlling the morphology and channel behaviour of the Teesta River. The river transports substantial quantities of sediment from the Himalayan catchment toward the Brahmaputra–Jamuna system, while deposition within the river channel contributes to the formation and migration of bars and islands. A sedimentological investigations indicate that Teesta sediments are predominantly fine- to medium-grained sands and are transported mainly as bedload through saltation, with a subordinate contribution from suspended transport. The occurrence of different sedimentary structures and fining-upward sequences reflects variations in flow energy, sediment deposition, and channel and bar migration (Sohan et al., 2023).

Sediment transport and deposition are closely linked to changes in channel morphology. A study of fluvial processes in the Bangladesh reach estimated a mean annual sediment load of approximately 31.4 million tonnes and reported that the Teesta is characterized by a wide and shallow channel with frequent changes in its main course, accompanied by aggradation and channel contraction in recent years (Shi et al., 2019). Multi-temporal analysis has also demonstrated a strong relationship between bar formation and channel braiding, indicating that sediment deposition within the channel contributes directly to channel bifurcation and lateral shifting.

3.6 Dry-Season Flow and Water Scarcity

The Teesta exhibits a strong seasonal contrast between monsoon and dry-season flows. The discharge records presented in Section 3.2 demonstrate that annual minimum discharge at Dalia occurred mainly during February and March, whereas maximum discharge generally occurred during the monsoon months. More recent discharge analysis similarly demonstrates a pronounced seasonal concentration of flow: one recent assessment found that approximately 94.9% of annual discharge occurred between May and November, leaving only about 5.1% for December–April (Rahman et al., 2024).

Low dry-season flow is particularly important because the downstream Teesta basin depends on river water for irrigation and agricultural production. The reduction in downstream water availability during the dry season has been associated with changes in surface-water bodies and land-use patterns in the lower Teesta basin. Ahmed et al. (2022), examining the effects of upstream water withdrawal, reported a gradual reduction in water bodies and identified upstream withdrawal through barrage development as an important factor associated with changes in downstream water availability and livelihoods.

The implications of dry-season scarcity extend beyond irrigation. Reduced river flow can constrain agricultural water availability and alter aquatic and floodplain environments that depend on seasonal river connectivity. At the same time, the relationship between upstream withdrawal and downstream scarcity should not be interpreted as being controlled by a single factor. Natural seasonal variability, rainfall, upstream regulation, irrigation demand, and other basin processes interact to determine the amount of water reaching downstream areas. Therefore, dry-season flow represents an important link between the hydrology of the Teesta, barrage-based water management, transboundary water allocation, and agricultural vulnerability.

3.7 Long-Term Hydrological and Climate-Related Changes

Long-term hydrological behaviour in the Teesta is influenced by both climatic variability and changes in land use and land cover. Recent modelling research by Rahman and Islam (2024) indicates that projected changes in land use and climate could modify future discharge patterns across the Teesta basin. Their

simulations suggest that wet-season discharge may increase under several future scenarios, while winter discharge may experience a comparatively smaller but generally negative change toward the end of the century. The study therefore indicates that future changes may be expressed differently across seasons rather than as a uniform increase or decrease in river flow.

Changes in the upstream Himalayan portion of the basin may also influence both water and sediment yield. A recent modelling study in the Sikkim part of the Teesta basin found that combined climate and land-cover changes could increase water yield by approximately 3–5% and sediment yield by 15–61% during the assessed historical and near-future periods. The study further found that climate change had a stronger influence on water yield, whereas land-cover change had a comparatively greater influence on sediment yield (Sharma et al., 2024). These findings suggest that the future hydrological regime of the Teesta may become increasingly variable, with potential changes in both high-flow and low-flow conditions and corresponding implications for sediment transport. However, these results are primarily based on hydrological modelling and future scenarios rather than direct observations of future conditions. Therefore, they should be interpreted as projections rather than established future trends.

IV. Teesta Barrage and Water Management

4.1 Teesta Barrage, India

India has constructed Rambhi dam, Kalijhora dam, Gajoldoba barrage, Mahananda barrage etc. on over the Teesta river to produce electricity and increase agricultural production. Above all Gajoldoba barrage (Jalpaiguri) is a big project which is the burning issue for the relationship between India and Bangladesh.

Table: 6 At a glance Gajoldoba barrage in India

Subject	Description
Location	Jalpaiguri (India)
Opening	19 January, 1987
Length	1000 m.
Height	87 m.
Agriculture	Irrigated area only 14 % out of total proposed area

Source: Dainik Prothom Alo, 2017

The Teesta Barrage Project (TBP) in India is a major multipurpose water-resource development project constructed on the Teesta River at Gajaldoba in Jalpaiguri District, West Bengal. The project was initiated in the mid-1970s, with the first phase beginning in 1976. It was designed primarily to utilize the water resources of the Teesta for irrigation, while also incorporating hydropower generation, navigation, and flood-moderation objectives (Hossen et al., 2024).

The main structure of the project is the Teesta Barrage at Gajaldoba, which diverts river water into an extensive canal network. The first sub-stage includes the Teesta–Mahananda Link Canal, Mahananda Main Canal, Dauk–Nagar Main Canal, Nagar–Tangon Main Canal, and Teesta–Jaldhaka Main Canal. The project also includes pickup barrages on the Mahananda and Dauk rivers, regulators, canal falls, cross-drainage structures, bridges, and an extensive distribution network (Hossen et al., 2024). Through these interconnected structures, water from the Teesta is transferred to agricultural areas beyond the immediate Teesta floodplain. An important component of the project is its hydropower-generation system. Three hydropower plants with a combined installed capacity of 67.5 MW (3 × 22.5 MW) were developed along the canal-fall system of the Mahananda Main Canal. These facilities depend on water transferred from the Teesta through the Teesta–Mahananda Link Canal and associated canal infrastructure (Hossen et al., 2024). Thus, the project illustrates the multiple and sometimes competing uses of Teesta water, particularly for irrigation and hydropower generation.

The project has been developed to support irrigation and other water-related benefits in northern West Bengal; on the other hand, downstream Bangladesh depends on the same river for irrigation, fisheries, ecosystem functions, and other livelihood-related uses. Consequently, the Gajaldoba barrage should not be considered only as an irrigation structure but as a major component of the wider Teesta River management system.

4.2 Dalia/Teesta Barrage, Bangladesh

Bangladesh has constructed a barrage in 1990 on the Teesta river at Doani in Lalmonirhat district to provide irrigation water in three crop seasons from the river through canal networks in the Teesta Barrage Project (TBP) area. The major physical components of the TBP comprise a 615 m. barrage, a 110 m. canal head regulator, 708 km. irrigation canal networks, 380 km. drainage channels and 80 km. flood embankment. The TBP was designed to provide irrigation water, flood protection and drainage facilities for 749000 ha of cultivated land. The project was planned to be completed in two phases. Phase 1 was completed in June 1998. The main conveyance system completed under this phase includes 307 km. main canals, 1450 km. secondary

canals, 2735 km. tertiary canals and 8000 field outlets. Phase 1 targets irrigation of 111406 ha, particularly as supplementary irrigation in the monsoon season (Islam et al., 2004).

Teesta barrage was completed successfully in August 1990. The irrigation facilities were provided from January 1993 and during the year an area about 65000 *bigha* (16000 acres) was brought under High Yielding Variety (HYV) paddy cultivation in the dry season. The project was also being implemented for flood control and drainage for a command area of 750,000 hectares, of which 540,000 hectares were irrigable (BWDB, 1993).

Table: 7 At a glance Teesta barrage or Dalia barrage in Bangladesh

Subject	Description
Name of project	Teesta barrage project (phase-1)
Type of project	Irrigation, drainage and flood mitigation
Location	Doani, Hatibandha, Lalmonirhat
Area coverage	Nilphamari district (Nilphamari sadar, Jaldhaka, Saidpur, Kishorganj and Dimla) Rangpur district (Rangpur sadar, Gangachara, Badarganj and Taraganj) Dinajpur district (Chirirbandar, Parbatipur, and Khansama)
Project area	Total project area 154,250 ha (Actual 126,310 ha) and Irrigation applicable area 111,406 ha (Actual 91,226 ha)
Length	615 m.
Total gate of barrage	44
Canal head regulator	1 (110 m.)
Power of water supply	283 cusec[2] (Main irrigated canal)
Silt trap	1 (45 ha)
Closer dam	1 (2870 m.)
Flood by-pass	1 (610 m.)
Embankment of flood mitigation	80 km.
Main canal	33.67 km.
Major secondary canal (Dinajpur, Rangpur, Bogra)	74.43 km.
Secondary canal	214.70 km.
Tertiary canal	387.65 km.
Drainage canal	380.00 km.
Irrigation structure, bridge, culvert	1110
Drainage structure	120
Field turn out	2000
Inspection road	20.67 km.
Project road	74 km.
Group of water user	1756

Source: BWDB, 2017a

The Dalia barrage is not only an irrigation structure but also forms part of an integrated flood-control, drainage, and agricultural water-management system. The BWDB project brief identifies the principal objective of Phase-I as increasing agricultural production through supplementary irrigation together with flood protection and drainage improvement. The project brief reports a gross project area of 154,250 ha, of which 111,406 ha was identified as irrigable, while the executed areas were reported as 126,310 ha and 91,226 ha, respectively (BWDB, 2017a). These figures indicate that the physical development of the project and its irrigation potential should be distinguished from the area actually brought under the completed project infrastructure.

The effectiveness of the barrage is also closely related to the seasonal availability of Teesta water. Islam et al. (2004) reported that the TBP began operation with limited conveyance infrastructure in 1993 and that irrigation water supply substantially increased agricultural benefits in the project area. However, increasing agricultural demand for irrigation also made the availability of river water increasingly important. Their assessment further identified upstream withdrawal of Teesta water as a constraint on irrigation-water availability in the Bangladesh project area.

Subsequent research has demonstrated that the difference between the designed irrigation potential and the area that can actually be irrigated is particularly important during the dry and lean seasons. Das et al. (2016) reported that the cultivable area under Phase-I was 111,406 ha, whereas water scarcity restricted the irrigated area to approximately 79,378 ha. The study linked the resulting irrigation shortage with limitations on agricultural production and regional food security.

Thus, the Dalia barrage illustrates an important characteristic of the Teesta water-management system: the construction of extensive irrigation infrastructure does not by itself guarantee the availability of irrigation water. The effectiveness of the project depends on the quantity and seasonal timing of river flow reaching the

[2] 1 cusec = 990[2] metric ton of water flow per second.

barrage. This creates a direct connection between the operation of the Dalia barrage, upstream water regulation, dry-season flow, agricultural production, and transboundary water sharing. These interconnected issues are considered further in the following section on India–Bangladesh water-sharing issues.

4.3 Comparison between Gajoldoba and Dalia Barrage

The main purpose of Teesta Barrage Project (TBP) is to increase agricultural production by both Gajoldoba (India) and Dalia (Bangladesh) barrage. Comparative description of Gajoldoba (India) and Dalia (Bangladesh) barrage is given in table-2.9 below:

Table: 8 Comparison between Gajoldoba barrage (Teesta river, India) and Dalia barrage (Teesta river, Bangladesh)

Criteria	Gajoldoba (India)	Dalia (Bangladesh)
Landscape	Mixed (hilly and plain land)	Plain land
Climate	Tropical; mild winter, hot, humid summer (March to June); humid, warm rainy monsoon (June to October)	Tropical savanna and humid subtropical
Target area	922000 ha	750000 ha
Irrigation potential	527000 ha	540000 ha
Type of soil	Sandy or clayey loam	80% alluvial
Currently under irrigation	527000 ha	111000 ha
Power generation	67.50 MW	No
Link cannels	210.79 km.	275 km.
Beneficiaries	8 million people	21 million people

Source: Rahman, 2013

Both barrages included link cannels for water distribution over the irrigation project area but only Gajoldoba project (India) has 67.50 MW hydropower. Nevertheless, the big difference with the numbers of beneficiaries; in upstream it is including 8 million people and in downstream almost three times higher than upstream is about 21 million consequently (Islam and Yoshiro, 2001).

4.4 Irrigation and agricultural implications

The development of the Teesta Barrage Project (TBP) has significantly influenced agricultural practices and irrigation systems in northern Bangladesh. The primary objective of the project was to provide surface-water irrigation to agricultural land through a network of canals, thereby reducing dependence on rainfall and supporting crop production in the Teesta floodplain. The project initially provided supplementary irrigation during the aus and aman seasons, while irrigation facilities were later extended to the boro season from the 2006–07 cropping year (Arfanuzzaman & Ahmad, 2016).

The availability of irrigation water has contributed to the expansion and intensification of agricultural production within the TBP area. The three major rice-growing seasons in the region are aus, aman, and boro, but their dependence on irrigation differs considerably. During the aus and aman seasons, rainfall provides an important component of crop-water requirements. In contrast, boro cultivation takes place during the dry season and is therefore highly dependent on irrigation water. Consequently, the availability of Teesta water during the dry and lean periods is particularly important for maintaining boro cultivation in the project area (Arfanuzzaman & Ahmad, 2016).

Recent research has also reported positive agricultural outcomes associated with the TBIP. Shahen and Momen (2024) found increased crop production in their study area in Nilphamari following the implementation of the irrigation project. Their assessment reported that crop production in the study area increased from approximately 88,280 metric tons before the project to about 202,150 metric tons at the time of their assessment. The authors also reported that 99.3% of surveyed farmers perceived an increase in crop production and that the availability and productivity of TBIP water were major factors influencing agricultural production. However, their study also found that the benefits were not distributed equally among all categories of farmers, with marginal farmers receiving fewer benefits than middle- and upper-level producers (Shahen & Momen, 2024).
The major agricultural implications identified in the literature can therefore be summarized as follows:

Table: 9 Major irrigation and agricultural implications of the Teesta Barrage Project

Agricultural aspect	Major implication	Supporting evidence
Irrigation availability	Provides surface-water irrigation and reduces dependence on rainfall and alternative water sources	Arfanuzzaman & Ahmad (2016)
Boro cultivation	Dry-season *boro* production is particularly dependent on adequate irrigation water	Arfanuzzaman & Ahmad (2016)
Irrigated area	Designed irrigable area of 111,406 ha, but actual irrigation was reported to be lower because of water scarcity	Arfanuzzaman & Ahmad (2016)

Crop production	Irrigation availability has contributed to increased crop production in studied TBIP areas	Shahen & Momen (2024)
Crop diversification	Water shortages have encouraged greater cultivation of maize, wheat, tobacco and vegetables in some downstream areas	Raihan et al. (2017)
Irrigation cost	Water shortages have increased irrigation and agricultural production costs	Raihan et al. (2017)
Rice production	Reduced irrigation availability can constrain rice production, particularly during the dry season	Arfanuzzaman & Ahmad (2016)
Farmer benefits	Agricultural benefits from TBIP are not distributed equally among different categories of farmers	Shahen & Momen (2024)
Food security	Irrigation shortages can reduce agricultural production and consequently affect regional food security	Arfanuzzaman & Ahmad (2016)

4.5 Downstream water availability

The availability of water in the downstream section of the Teesta River is characterized by strong seasonal variability, with relatively high flows during the monsoon and substantially reduced flows during the dry and lean seasons. This seasonal contrast is particularly important for Bangladesh because agricultural irrigation, fisheries, navigation, and riverine ecosystems depend on the availability of sufficient downstream flow. Hydrological analyses based on long-term observations at the Dalia and Kaunia stations have documented a declining tendency in Teesta discharge, particularly during the dry season (Mondal et al., 2018). Such reductions can increase pressure on water resources in the downstream basin, especially during the Boro cultivation period when irrigation demand is high.

The availability of downstream water is influenced by the interaction between upstream diversion, natural inflow, groundwater contribution, and water abstraction at the Dalia barrage. Hossen et al. (2024) described the flow reaching Dalia as consisting mainly of water released from the Gajaldoba barrage together with groundwater regeneration between Gajaldoba and Dalia, with only a small contribution from tributary inflows. Similarly, the flow available at Kaunia is influenced by the outflow from Dalia and additional groundwater or baseflow contribution between Dalia and Kaunia. Therefore, downstream discharge cannot be considered solely as a direct continuation of upstream river flow; it is also affected by hydrological processes occurring along the intervening river reach (Hossen et al., 2024).

The dry-season situation is particularly critical. Earlier hydrological assessments estimated that approximately 90–120 m^3/s of flow during January and February may be required to sustain important environmental functions of the Teesta. However, during 2001–2006, the mean flows during January, February, and March were reported as approximately 40, 24, and 57 m^3/s, respectively, indicating substantial deficits relative to the estimated environmental-flow requirement (Mondal et al., 2018). These low-flow conditions can reduce the availability of surface water for irrigation and can also affect fisheries, navigation, sediment transport, and other river-dependent functions.

Reduced downstream flow has consequences beyond irrigation. Ahmed et al. (2022), examining downstream land-use and livelihood changes in the Teesta basin, reported that water scarcity was particularly perceived during the dry season and that many farmers and fishermen associated upstream barrage development with adverse effects on their livelihoods. Their findings also indicated occupational and migration-related responses among affected communities. These observations suggest that changes in downstream water availability can propagate through agricultural production, fisheries, employment, and livelihood decisions.

V. Environmental and Socioeconomic Impacts

5.1 Agriculture and irrigation

Agriculture is one of the sectors most directly affected by the seasonal variability of Teesta River flow. The Teesta Barrage Irrigation Project (TBIP) has substantially increased agricultural production in parts of the command area by providing irrigation water and enabling more intensive cultivation. A recent study of the TBIP area in Nilphamari reported that 99.3% of surveyed farmers perceived an increase in crop production after the development of the irrigation project. The same study found changes in cropping patterns and cultivation frequency, indicating that reliable irrigation can increase the intensity and diversity of agricultural production (Shahen & Momen, 2024). These findings demonstrate the agricultural benefits of the barrage infrastructure, but they should be interpreted as evidence from the surveyed TBIP area rather than as a basin-wide estimate.

The benefits of irrigation, however, are constrained by inadequate dry-season river flow. Arfanuzzaman and Ahmad (2016) estimated that Phase-I of the TBIP had a cultivable area of 111,406 ha, while water scarcity restricted the irrigated area to approximately 79,378 ha. Consequently, a substantial portion of the cultivable area could not receive sufficient irrigation during the Boro season. Farmers outside or inadequately served by the project have increasingly depended on groundwater, which raises production costs and increases vulnerability to dry-season water scarcity. A field study in four Teesta-basin villages found that 100% of surveyed farmers reported increasing irrigation costs associated with water shortages, while many reported

shifting toward relatively less water-intensive crops such as maize, wheat, tobacco and vegetables, particularly during the dry season (Raihan et al., 2017).

The evidence therefore indicates a dual agricultural effect of the Teesta water-management system. Irrigation infrastructure has increased cropping intensity and production where water is available, while insufficient and seasonally variable river flow limits these benefits and increases dependence on alternative water sources. Recent research also suggests that future reductions in effective rainfall and increasing irrigation demand may further intensify this seasonal imbalance in the Teesta floodplain (Mondol et al., 2022). Thus, agricultural vulnerability in the Teesta basin is determined not simply by the existence of irrigation infrastructure, but by the timing, reliability and spatial distribution of available water.

5.2 Flooding

Flooding is a recurrent environmental hazard in the Teesta floodplain, but its impacts are highly uneven across locations and households. Flood risk results from the interaction of high monsoon discharge, low-lying floodplain conditions, channel dynamics and the exposure of settlements and agricultural land to the river. A household-level study of 377 households along the right bank of the Teesta found significant spatial differences in flood risk: risk was highest in the downstream cluster, followed by the upstream and midstream clusters (Haque et al., 2020).

The socioeconomic effects of flooding extend beyond direct physical damage. In the same 377-household study area, 97% of surveyed households reported that their houses were inundated during the 2017 flood, while agriculture was the dominant livelihood for approximately 63% of households. Following flood events, households used multiple coping mechanisms, including borrowing money, reducing consumption, selling assets and temporary migration (Haque et al., 2021).

Recent research further demonstrates that flood risk in the Teesta is not static. A 2026 participatory assessment found that the area classified as having high vulnerability increased from 607.76 km² in 2000 to 761.22 km² in 2022**, while the very-high-vulnerability area increased from 441.30 to 654.87 km². The study achieved 85% agreement between its flood-vulnerability assessment and field observations, suggesting that increasing vulnerability is associated with both physical flood characteristics and differences in local adaptive capacity (Monir et al., 2026).

5.3 Riverbank erosion and land loss

Riverbank erosion is one of the most persistent geomorphic hazards affecting communities along the Teesta. Multi-temporal satellite analysis has documented substantial lateral migration of the river and recurrent erosion and accretion across the Teesta floodplain. Parvej et al. (2024), analysing Landsat imagery from 1991 to 2021, estimated approximately 194 km² of land erosion during the study period, demonstrating the magnitude of long-term bankline instability. Such erosion is accompanied by compensating accretion elsewhere, but newly deposited land does not necessarily occur at the same locations or provide an immediate substitute for lost agricultural and settlement land.

The socioeconomic consequences arise primarily from the loss of agricultural land, homesteads and productive assets. A 2025 study of 385 erosion-vulnerable households in four upazilas of Lalmonirhat District found repeated loss of homesteads and agricultural land, declining agricultural production and increasing food insecurity among affected households (Ali et al., 2025). Localized evidence from Tepa Kharibari Union in Nilphamari also indicates that erosion contributes to occupation change, migration and disruption of social networks (Rumana et al., 2023).

Erosion therefore represents more than a physical change in riverbank position. Repeated land loss progressively reduces household asset bases and can transform formerly land-based livelihoods into wage labour, petty trade or other less secure activities. The impacts are particularly important for households with limited land and financial resources because they have fewer options for relocating or replacing productive assets. Consequently, erosion acts as a cumulative socioeconomic stressor rather than a single-event hazard.

5.4 Fisheries and aquatic resources

The Teesta River and its associated channels, floodplain wetlands and seasonal water bodies provide habitat for fish and support capture fisheries in northern Bangladesh. However, the fishery is sensitive to changes in river discharge, habitat connectivity, water depth and seasonal inundation. A field assessment conducted in Rangpur and Nilphamari during 2018–2019 identified 45 fish species belonging to 17 families and 10 orders. Of these species, 24.44% were classified as commonly available, 26.66% as moderately available, 22.22% as less available and 26.66% as rarely available (Aktar et al., 2020).

The same study found considerable seasonal variation in fish production. Estimated production was highest in April (592 ± 65.30 kg/day) and lowest in July (112 ± 12.24 kg/day), while Shannon–Weaver diversity values ranged from 1.11 to 2.42. The authors identified habitat degradation, fishing pressure and other

anthropogenic disturbances as important threats to fish biodiversity and production (Aktar et al., 2020). These results demonstrate that fisheries are strongly seasonal and that the ecological condition of the river is important for sustaining fish resources.

Changes in downstream water availability may further influence aquatic resources. Ahmed et al. (2022), based on geospatial analysis and a survey of 250 fishermen and 200 farmers, reported widespread perceptions of dry-season water scarcity and adverse effects associated by respondents with upstream barrage development. Among surveyed fishermen, 76.8% perceived upstream barrages as harmful to their livelihoods, although this represents respondent perception rather than a direct measurement of the causal effect of barrage operation (Ahmed et al., 2022).

Overall, the available evidence suggests that fisheries vulnerability in the Teesta is associated with the combined effects of seasonal flow variation, habitat alteration, fishing pressure and changing water availability. However, long-term quantitative monitoring linking specific flow changes to fish population trends remains limited. This represents an important research gap for assessing the ecological consequences of Teesta water management.

5.5 Livelihoods

Livelihoods in the Teesta floodplain are closely connected with agriculture, fisheries, agricultural wage labour and access to riverine land and water. Consequently, changes in river flow, flooding, erosion and dry-season water scarcity can affect several livelihood components simultaneously. Ahmed et al. (2022) used geospatial and household-survey evidence to examine downstream changes, the study found that dry-season water scarcity was widely reported and that many respondents considered changing their occupation or migrating to other locations.

Riverbank erosion creates an additional pathway of livelihood loss by removing the physical assets on which rural households depend. Evidence from Teesta erosion-prone communities shows that households respond through occupational diversification, asset sales, borrowing and migration. In one field study,99% of respondents reported livelihood or income diversification as a response to erosion-related vulnerability, while 80.1% of reported cases involved migration for occupation (Sultana et al., 2020). These figures should be interpreted as case-study evidence rather than representative estimates for the entire Teesta basin.

The combined effects of water scarcity, flooding and erosion therefore increase livelihood uncertainty. Households with land-based livelihoods may experience crop losses or loss of farmland, while fishing households may be affected by reduced access to suitable aquatic habitats. Poorer households are particularly exposed because their limited financial and physical assets reduce their capacity to absorb repeated shocks. Recent research on Teesta charland communities similarly identifies limited human, social, physical, natural and financial livelihood assets as major components of vulnerability (Shamim et al., 2025).

Thus, the livelihood impacts of the Teesta are best understood as cumulative: hydrological variability affects productive resources, repeated hazards reduce household assets, and declining asset security encourages livelihood diversification and mobility.

5.6 Migration and socioeconomic transformation

Migration in the Teesta basin is closely associated with repeated loss of land, livelihood disruption and seasonal water-related stress. Riverbank erosion can require households to relocate their homes repeatedly, while loss of agricultural land may reduce the viability of farming as a primary occupation. Sultana (2022) documented several forms of erosion-induced displacement in Teesta communities, including temporary, stepwise and permanent relocation. Such displacement can alter household economic conditions as well as social networks and access to services.

Empirical evidence also shows that migration is used as an economic coping strategy rather than only as permanent displacement. In a study of erosion-affected Teesta communities, 53.1% of reported migrants were identified as seasonal migrants and 46.9% as temporary migrants in response to livelihood disruption (Sultana, 2022). Another study found that 80.1% of reported coping cases involved migration for occupation, demonstrating the importance of mobility as a livelihood strategy in erosion-prone communities (Sultana et al., 2020).

Water scarcity can also contribute to occupational and spatial mobility. Ahmed et al. (2022) found that farmers experiencing water scarcity were more likely to consider changing location, while factors including upstream barrages and fishing-related impacts were associated with occupational changes among fishermen.

Overall, the evidence indicates that environmental change in the Teesta can produce a chain of socioeconomic transformation: erosion and water scarcity → loss of productive assets → occupational diversification → temporary or permanent migration → changes in household and community structure. The scale and permanence of these transformations, however, vary considerably among locations and socioeconomic groups.

VI. Conclusion

The Teesta River is a highly dynamic transboundary system where seasonal flow variability, upstream and downstream water management, flooding, erosion, sediment dynamics, and climate variability interact to influence agriculture, ecosystems, and livelihoods. The Gajoldoba and Dalia barrages have supported irrigation and agricultural production, but dry-season water scarcity limits the effective use of downstream irrigation potential and contributes to pressure on water-dependent livelihoods. Recurrent flooding, riverbank erosion, and land loss further increase household vulnerability, while changes in fisheries, food and water security, occupational patterns, and migration demonstrate the wider socioeconomic consequences of river-system changes. Recent studies also indicate that climate and land-use changes may further modify future flow and sediment regimes. Overall, the evidence highlights the need for **integrated basin-scale management, improved dry-season water availability, flood and erosion risk reduction, ecological consideration, and effective transboundary cooperation**. Further long-term research integrating hydrological, environmental, and socioeconomic data is essential for developing sustainable and resilient management strategies for the Teesta River.

Reference:

[1]. Ahmed, A. U. (2006). *Bangladesh. Climate Change Impacts and Vulnerability. A Synthesis*. Climate Change Cell, Department of Environment, Dhaka.

[2]. Ahmed, Z., Alam, R., Ahmed, M. N. Q., Ambinakudige, S., Almazroui, M., Islam, M. N., Chowdhury, P., Kabir, M. N., & Mahmud, S. (2022). Does anthropogenic upstream water withdrawal impact on downstream land use and livelihood changes of Teesta transboundary river basin in Bangladesh? Environmental Monitoring and Assessment, 194, 59. https://doi.org/10.1007/s10661-021-09726-3

[3]. Aktar, M. J., Islam, M. J., Barman, S. K., & Kunda, M. (2020). Assessment of fish biodiversity in the Teesta River of Bangladesh. Journal of the Sylhet Agricultural University, 7(2), 95–114.

[4]. Alam, E., Afreen, S., & Ahmed, F. (2020). Assessing the flood risk of riverine households: A case study from the right bank of the Teesta River, Bangladesh. International Journal of Disaster Risk Reduction, 51, 101758. https://doi.org/10.1016/j.ijdrr.2020.101758

[5]. Ali, M. H., Khan, F. U., Rahman, M. R., & Fatema, M. R. (2025). Assessing the impact of riverbank erosion on livelihood and household food security in the Teesta riverine areas of Bangladesh. i-Manager's Journal on Economics & Commerce, 5(1), 19. https://doi.org/10.26634/jecom.5.1.21354

[6]. Arfanuzzaman, M. (2020). Upstream downstream divergence and hydro-socioeconomic distress in South Asia. World Food Policy, 7(1), 41–61. https://doi.org/10.1002/wfp2.12022

[7]. Arfanuzzaman, M., & Ahmad, Q. K. (2016). Assessing the regional food insecurity in Bangladesh due to irrigation water shortage in the Teesta catchment area. Water Policy, 18(2), 304–317. https://doi.org/10.2166/wp.2015.072

[8]. BWDB. (1993). Teesta Barrage Project 1993. vol. 1V. BWDB (Bangladesh Water Development Bosard), Rangpur, Bangladesh.

[9]. BWDB. (1999). Operation and maintenance manual of Teesta Barrage and its canal head regulator, Interim Report, April 1999, BWDB (Bangladesh Water Development Board), Dhaka. Bangladesh.

[10]. BWDB. (2017a). Teesta Barrage Project, Phase-1 (Leaflet). BWDB (Bangladesh Water Development Board), Rangpur. Bangladesh.

[11]. BWDB. (2017b). (Official report). BWDB (Bangladesh Water Development Board), Rangpur, Bangladesh.

[12]. BWDB. (2018). (Official report). BWDB (Bangladesh Water Development Board), Rangpur, Bangladesh.

[13]. Dainik Prothom Alo. (2017). May 18, 2017 (In Bengali). Dhaka, Bangladesh.

[14]. Das, B., Hossain, M. S., & others. (2016). Assessing the regional food insecurity in Bangladesh due to irrigation water shortage in the Teesta catchment area. Water Policy, 18, 304–317. https://doi.org/10.2166/wp.2015.072

[15]. Elahi, K. M. (1991a). Riverbank Erosion, Flood Hazard and Population Displacement in Bangladesh: A Overview. In: Elahi, K. M; Ahmed, K. S., and Mafizuddin, M. (eds.) *Riverbank Erosion, Flood and Population Displacement in Bangladesh.* Riverbank Erosion Impact Study (REIS). Dhaka, Bangladesh.

[16]. Gupta, K. (2025). Resolving Teesta River conflicts: Harnessing institutional solutions for cross-border water cooperation. Journal of Asian and African Studies, 60(4). https://doi.org/10.1177/00219096231218436

[17]. Hanif, S. A. (1995). *Hydro-geomorphic characteristics of the Teesta floodplain, Bangladesh.* Unpublished Ph.D Thesis, Department of Geography, University of Rajshahi. Bangladesh.

[18]. Haque, M. M., et al. (2021). Determinants of household-level coping strategies and recoveries from riverine flood disasters: Empirical evidence from the right bank of Teesta River, Bangladesh. Climate, 9(1), 4. https://doi.org/10.3390/cli9010004

[19]. Hossen, M. A., Connor, J., & Ahammed, F. (2024). Valuation of the Teesta River water by hydro economic model. Water Conservation Science and Engineering, 9, 17. https://doi.org/10.1007/s41101-024-00250-2

[20]. Islam, M. F. and Yoshiro, H. (1999). International Environmental Issue between India and Bangladesh: Environmental and Socio-economic Effects on the Teesta River Area. In 39th Congress of the European Regional Science Association, ERSA: *Regional Cohesion and Competitiveness in 21st Century Europe.* August 23-27, 1999, Dublin, Ireland.

[21]. Islam, M. N., Azam, M. A. and Islam, Q. R. (2004). Teesta River Water Sharing: A Case Study in Teesta Barrage Project. Local Government Engineering Department (LGED), Dhaka. Bangladesh.

[22]. Islam, M. F. and Yoshiro, H. (2001). Equitable Sharing of Bilateral International Water: A Policy Measure for Optimal Utilization of the Teesta River. *Studies in Regional Science,* 32 (1), 17-32.

[23]. Islam, M. F., & Higano, Y. (2000). Environmental problems and water resource management in floodplains: Evidence from the Teesta River Basin, Bangladesh. Studies in Regional Science, 31(1), 31–39. https://doi.org/10.2457/srs.31.31

[24]. Islam, M. N., Azam, M. A., & Islam, Q. R. (2004). Teesta River water sharing: A case study in Teesta Barrage Project. In Irrigation in a total catchment context sharing the river: Proceedings of the 2nd ICID Asian Regional Conference on Irrigation and Drainage (pp. 36–42).

[25]. Ministry of Establishment. (1990). *Bangladesh Zila Gazetter, Rangpur.* (In Bengali). Khan, M. N. I (ed.), Bangladesh Government Prees. Government of the People's Republic of Bangladesh.

[26]. Momen, M.N., & Rahman, M. M. (2023). The impoverishment of political discourse and legal rights in transboundary Teesta water management. World Water Policy, 9(1), 11–28. https://doi.org/10.1002/wwp2.12093

[27]. Mondal, M. S. H., Jalal, M. R. A., & Hossain, M. A. A. (2017). Chronological trends in maximum and minimum water flows of the Teesta River, Bangladesh, and its implications. Jàmbá: Journal of Disaster Risk Studies, 9(1), a373. https://doi.org/10.4102/jamba.v9i1.373

[28]. Mondol, M. A. H., et al. (2022). Changing occurrence of crop water surplus or deficit and the impact of irrigation: An analysis highlighting consequences for rice production in Bangladesh. Agricultural Water Management.

[29]. Monir, M. M., Sarker, S. C., & Akhter, S. (2026). Participatory flood vulnerability assessment in the Teesta floodplain of Bangladesh using GIS-based AHP and frequency ratio models. Next Sustainability, 7, 100251. https://doi.org/10.1016/j.nxsust.2026.100251

[30]. Mukhopadhya, S. C. (1982). *Geomorphology of the Subarnarekha Basin.* West Bengal: University of Bardwan. India.

[31]. Rahman, A., Rana, H., Saleemul, H., and Eirck, G. J. (1994). *Environment and development in Bangladesh*. Dhaka: University Press Limited. (UPL).

[32]. Rahman, M. M., Arya, D. S., Goel, N. K. and Dhamy, A. P. (2011). Design Flow and Stage Computations in the Teesta River, Bangladesh, Using Frequency Analysis and MIKE 11 Modeling. *Journal of Hydrologic Engineering*. ASCE.

[33]. Parvej, K., Masum, K. M., Fahim, M. S. I., & Redowan, M. (2024). Three decades of river bank erosion and accretion appraisal along bank line shifting trend in a transboundary river, Teesta floodplain of Bangladesh. Geoplanning: Journal of Geomatics and Planning, 11(1), 1–16. https://doi.org/10.14710/geoplanning.11.1.1-16

[34]. Prapti, M. T. M., & Rahman, M. M. (2026). A probabilistic multi-return-period framework for integrated flood risk assessment in the Teesta River Basin, northern Bangladesh. Applied Computing and Geosciences, 31, 100394. https://doi.org/10.1016/j.acags.2026.100394

[35]. Rahman, M. A. (2013). *Water scarcity-induced change in vegetation cover along Teesta River catchments in Bangladesh: NDVI, Tasseled Cap and System Dynamics Analysis.* Unpublished Master's thesis. Department of Physical Geography and Quaternary Geology. Stockholm University.

[36]. Rahman, S., & Islam, A. K. M. S. (2024). Hydrological response to climate and land use and land cover change in the Teesta River basin. Hydrology Research, 55(11), 1123–1142. https://doi.org/10.2166/nh.2024.055

[37]. Raihan, M. L., Sarker, M. A., & Miah, M. A. M. (2017). Shortage of water in Teesta River basin and its impact on crop production in northern Bangladesh. SAARC Journal of Agriculture, 15(2), 113–123. https://doi.org/10.3329/sja.v15i2.35163

[38]. Rumana, M. S., Ghosh, B. K., & Akhter, S. (2023). Assessing the impacts of Teesta riverbank erosion on livelihood pattern: A case study of Tepa Kharibari Union of Dimla Upazila, Nilphamari in Bangladesh.

[39]. Shahen, M. A., & Momen, M. N. (2024). Assessing the nexus between irrigation project and crop production: A study on Teesta Barrage Irrigation Project (TBIP) in Bangladesh. In The Palgrave Handbook of Environmental Policy and Law. https://doi.org/10.1007/978-3-031-30231-2_35-1

[40]. Shahen, M. A., & Momen, M. N. (2025). Assessing the nexus between irrigation project and crop production: A study on Teesta Barrage Irrigation Project (TBIP) in Bangladesh. In The Palgrave Handbook of Environmental Policy and Law. Springer. https://doi.org/10.1007/978-3-031-55387-5_35

[41]. Shamim, M. A. S., Islam, S., Podder, T., & Runa, M. S. S. (2025). Poor livelihood assets and adaptive strategies of the riverbank erosion induced charland people in Bangladesh: A study on the Teesta riverine ecosystem.

[42]. Sharma, P., et al. (2024). Quantification of the impact of land cover and climate change on water and sediment yield in sub-tropical Himalayas in upstream Teesta River basin, Sikkim. Remote Sensing Applications: Society and Environment, 34, 101146. https://doi.org/10.1016/j.rsase.2024.101146

[43]. Shi, H., Ji, Z., Lu, Q., & Wang, D. (2019). Study on fluvial processes and sediment transport capacity of Teesta River in Bangladesh. In World Environmental and Water Resources Congress 2019: Hydraulics, Waterways, and Water Distribution Systems Analysis. American Society of Civil Engineers. https://doi.org/10.1061/9780784482353.038

[44]. Sohan, M. S. R., Yeasmin, R., Rahman, M. J. J., Sayem, A. S. M., & Rana, M. S. (2023). Sedimentological characterizations of recent sediments from the Teesta River, Bangladesh: Implication for sediment transportation and depositional conditions. Bangladesh Geoscience Journal, 29(1), 1–20. https://doi.org/10.59185/bgj.v29i1.186

[45]. Survey of Bangladesh. (1976). p. 507.

[46]. Sultana, R. (2022). Dislocation and involuntary migration: Lessons from the Teesta River bank erosion in Bangladesh. In Regional Development Planning and Practice (pp. 121–147). https://doi.org/10.1007/978-981-16-5681-1_6

[47]. Sultana, R., Hassan, M. Z., & Paul, S. K. (2020). Mitigation of erosion-induced disaster through indigenous practices: Evidence from rural community of Teesta river bank.

[48]. Sultana, S., et al. (2021). Perceived and actual risks of drought: Household and expert views from the lower Teesta River Basin of northern Bangladesh. Natural Hazards, 108, 2569–2587. https://doi.org/10.1007/s11069-021-04789-4

[49]. Uddin, M. J., Shakik, A., & Mim, F. B. (2024). Understanding the impact of bridge structure on river morphology through geospatial techniques: Case on Teesta River, Bangladesh. Discover Environment, 2, Article 91. https://doi.org/10.1007/s44274-024-00136-z

[50]. Verghese, B. G. (1990). *Waters of hope*. Dhaka: Academic Publishers.