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Does anthropogenic upstream water withdrawal impact on downstream land use and livelihood changes of Teesta transboundary river basin in Bangladesh?

Zia Ahmed · Rafiul Alam · Mufti Nadimul Quamar Ahmed · Shrinidhi Ambinakudige · Mansour Almazroui · M. Nazrul Islam · Piash Chowdhury · Md. Najmul Kabir · Sakib Mahmud

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Abstract This article evaluates the impact of upstream water withdrawal on downstream land use and livelihood changes in the Teesta River basin, using a combination of geospatial and social data. Results show that water bodies gradually decreased, indicating a low volume of water discharge from upstream of the Teesta River basin due to the construction of several barrages. During the study period, a significant change in the area of water bodies was observed between 2012 and 2016, from 881 to 1123 Ha, respectively. The cropland area increased because farmers changed their cropping practice due to water scarcity and floods. Trend analyses of riverbank erosion and accretion patterns suggest an increase in accretion rates compared to the rate of riverbank erosion. A household survey was conducted using a self-administered questionnaire where 450 respondents have participated (farmers: 200 and fishermen: 250). Survey results show that most of the farmers (65.5%) and fishermen (76.8%) think that the construction of upstream barrages caused harm to them. The majority of farmers and fishermen feel water scarcity, mainly in the dry season. We found that a large number of participants in the study area are willing to change their occupations. Furthermore, participants observed that many local people are migrating or willing to migrate to other places nowadays. Our study also found that farmers who face water scarcity in their area are more likely to change their location than their counterparts, while those who face problems in their cultivation are less likely to move. On the other hand, upstream barrages, fishing effects, and getting support in crisis significantly predict fishermen's occupation changes. We believe our results provide essential

Z. Ahmed (✉) · P. Chowdhury · M. N. Kabir
Department of Geography and Environment, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh
e-mail: ziaahmed-gee@sust.edu

R. Alam
BRAC James P Grant School of Public Health, BRAC University, Dhaka 1212, Bangladesh

M. N. Q. Ahmed
Department of Applied Sociology and Social Work, North East University Bangladesh, Sylhet, Bangladesh

Present Address:
S. Ambinakudige
Department of Geosciences, Mississippi State University, Starkville, MS-39762, USA

M. Almazroui · M. N. Islam
Centre of Excellence for Climate Change Research/ Department of Meteorology, King Abdulaziz University, Jeddah 21589, Saudi Arabia

M. Almazroui
Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, UK

S. Mahmud
Department of Economics, Shahjalal University of Science & Technology, Sylhet-3114, Bangladesh

information on the significance of transboundary water-sharing treaties, sustainable water resource management, and planning.

Keywords Land use · Livelihoods · Water Scarcity · Barrage · Migration · Bangladesh

Introduction

More than 200 rivers in Bangladesh have their origin in other countries, and almost all those rivers flow through India before entering Bangladesh. Among these rivers, the Teesta is important, as sharing the water between India and Bangladesh is still being negotiated (Islam & Higano, 2001). A total of 35 Upazilas and 5427 villages are located along the Teesta River comprising five northern districts of Bangladesh: Gaibandha, Kurigram, Lalmonirhat, Nilphamari, and Rangpur (Prasai & Surie, 2013). After the Ganges, Brahmaputra, and Meghna, Teesta is the fourth most important river in Bangladesh. The Teesta River floodplain in Bangladesh accounts for 14% of the total cropped area, and over 9.15 million people of the country depend on it (Mondal & Islam, 2017). The water demand upstream and downstream of a transboundary river basin varies based on water use by irrigation projects, dams, hydroelectricity, ecosystems, livelihood practices, and household activities of the people (Arfanuzzaman & Syed, 2018). The availability of water in the Teesta River has been reduced due to several developments in the upstream of India making Bangladesh vulnerable to dry season water scarcity (Zannah et al., 2020).

Around 100-km upstream from the Teesta Barrage, India built a barrage across the Teesta River at Gazoldoba (Bangladesh). During the rainy season, excess water is released via the Gazoldoba Barrage into Bangladesh, resulting in floods. However, during the dry season, India retains water from the Teesta River for usage in agricultural fields and for navigation needs on their lands (Sarker et al., 2011). Bangladesh is losing considerable food production from the Teesta catchment area due to a lack of availability of irrigation water in the dry and lean period because of unilateral water withdrawal in the upstream country, India (Arfanuzzaman & Ahmad, 2016). A high-rate flow diversion near Gozoldoba is used mostly for surface water agriculture, resulting in water scarcity in the Bangladeshi portion of the Teesta River. Furthermore, during the monsoon season, the flow of water causes flooding and bank erosion downstream. The availability of water for irrigation, particularly during the lean or dry season, has been at the heart of a long-running disagreement between the two countries about water allocation (Khan & Ali, 2019).

In many river basins, upstream development and interannual variations in rainfall can cause both episodic and chronic shortages in water supply downstream (Gaur et al., 2008). Globally, nearly 11% of current croplands and 10% of existing grasslands could be vulnerable to a reduction in water availability and may lose some productive capacity, with Africa and the Middle East, China, Europe, and Asia particularly at risk (Fitton et al., 2019). Upstream–downstream linkages include environmental, socio-economic, institutional, and cultural factors. Upstream impacts on hydrological processes can be broadly divided into two types: (i) human-influenced activities related to land use and (ii) natural impacts related to climate (Nepal et al., 2014). Land-use changes have potentially large impacts on socio-economic development. Particularly in regions where water availability is limited, land-use changes can result in increased water scarcity and thus contribute to a deterioration of living conditions (Wagner et al., 2013). Lacking a sufficient flow of water in the Teesta River, environmental and socio-economic conditions of the surrounding region have become very severe, and the socio-economic and environmental problems of the area are growing day by day (Islam & Yoshiro, 1999).

Damming and large-scale river diversion projects can result in far-reaching consequences for downstream river discharge and delta maintenance (Higgins et al., 2018). The impact of dam construction caused a shift from rice to lower value millet and sorghum crops in the wet season and an enormous reduction in the extent of dry season cultivation (Adams, 1985). A large river basin is a mosaic of different land uses and practices with varying vegetative patterns in all stages of growth and with heterogeneous geology, soils, and climate. In a large catchment, it is not always easy to identify clear changes when analyzing time-series data on land use. Many modifications may be taking place, some more relevant from a water resource point of view, but these may not always be captured with the available land-use data (Wilk & Hughes, 2002).

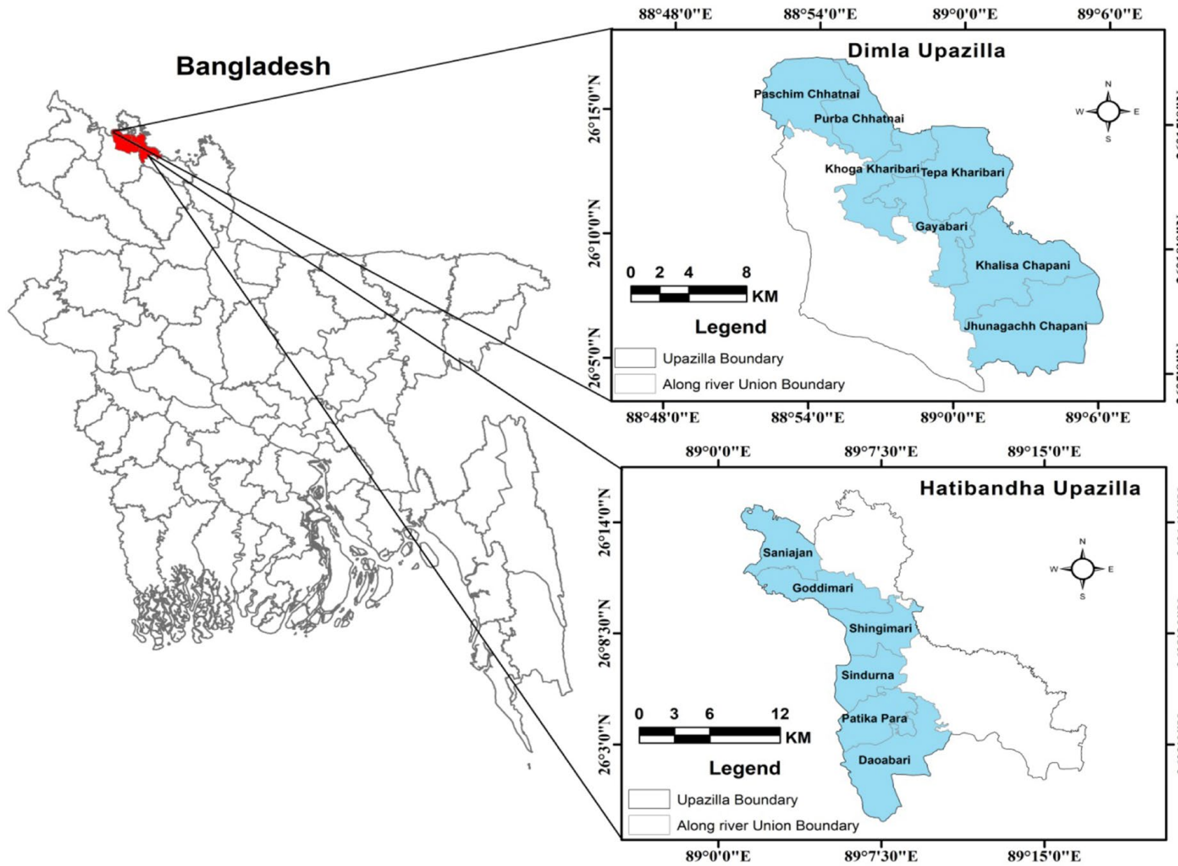

Fig. 1 Study area of Teesta River basin

This article identifies the adverse impact of upstream anthropogenic water withdrawal of a transboundary river on downstream land use and socioeconomic changes, by focusing on farming and fishing communities in the Teesta River basin between India and Bangladesh. Two other specific objectives were to discover the changing patterns of agricultural land due to water scarcity and to examine the contribution of an upstream barrage on the occupational shift in farming and fishing communities downstream. The construction of the article follows several sections started with the "Introduction" where we explained our study background and specific objectives of this study. In the next section titled "Materials and methods," we elaborated our study areas' selection, data collection procedure, and data analysis tools and techniques used in this study. Then, we explained our findings in the sect. "Result." Finally, we conclude the article with a discussion and suggest further studies in this regard.

Materials and methods

Selecting the study area

The study areas (Fig. 1) are Dimla and Hatibandha Upazilas (sub-districts) of Bangladesh. In both Upazilas, the main source of income is from agriculture, at 78.02% and 75.36%, respectively. Farming and fishing are the two main occupations. The main reason for selecting this study area was that the inhabitants there depend mainly on the Teesta River for agriculture and fishing purposes.

Data collection procedure and analysis techniques

Primary data were collected utilizing a questionnaire survey. The survey was conducted in two Upazilas, namely, Dimla Upazila and Hatibandha Upazila of Bangladesh. Four hundred and fifty respondents were selected randomly from two Upazilas, and among them, 200 were farmers, and 250 were fishermen. Farmers were chosen primarily from the Dimla Upazila, and the fishermen mainly were from Hatibandha Upazila. Initial draft of our survey questionnaire was written in the participant's native language (Bangla), hoping that this would make it easier for them to comprehend the study's objectives. If any of our participants had difficulty understanding what we were asking them, we, therefore, explained a few questions vocally to them. We translated our questionnaire into English (from Bangla) for analysis effectively after data collection. The questionnaire was designed in a manner that was easy to navigate to fulfill the aims of this study. Every household head served as a responder, and we asked every one of them a variety of crucial and relevant questions to achieve our research objectives. There were two parts to our questionnaire. In the first portion of the survey, we asked about the respondents' real challenges in their respective localities. We inquired whether they believed that opening the Gozoldoba barrage was harmful to them or created difficulties for their employment. We also asked them about water scarcity, problems in cultivation/fishing, getting supports (financial, social, etc.) from government or NGOs, or other sources during crises. In this part, we also added some other questions. Then, in the second part, we wanted to know whether the government could solve water distribution problems through proper negotiation. We also wanted to see whether participants are changing or willing to change their principal occupation in the coming days and whether they are migrating or ready to migrate to other places shortly. The respondents were given categorical options and were free to choose from either "agree" or "disagree" (see Table 6).

The primary data in this study were analyzed using descriptive statistics and binary logistic regression techniques. In order to indicate the level of agreement or disagreement on various issues that participants were asked about, descriptive statistics such as percentages and frequencies were used to display the results (see Table 6). Furthermore, binary logistic regression was used to examine the factors that affected the respondent's decision regarding changing their occupation and migration. Two separate models were developed for farmers and fishermen regarding their migration and occupation decisions. For farmers, five independent variables were used for both models: opening of Gozoldoba barrage, water scarcity, impacts on cultivation, problems in cultivation, and getting supports in crisis. Dependent variables for farmers were whether or not respondents changed their occupation (occupation) for the first model and whether or not respondents were willing to migrate to another place (migration) for the second model. We used the same dependent variables in the two models developed for fishermen. The five independent variables were the opening of Gozoldoba barrage, water scarcity, impacts on fishing, problems in fishing, and getting supports in crisis (see Tables 7 and 8). We used SPSS (Statistical Package for Social Science) version 23, Microsoft (Office, Excel), and other software programs to evaluate our survey data. Moreover, secondary data were collected to determine land-use change, mainly from the United States Geological Survey (USGS). Landsat images were taken at 4-year intervals. The collected years were 1992, 1996, 2000, 2004, 2008, 2012, 2016, and 2020, respectively (Table 1). Each satellite image reflects the dry season, and the sensor was Landsat OLI, TM, and ETM.

Table 1 Landsat satellite data used in this study

Satellite	Sensor type	Paths/rows	Acquisition date	Resolution
Landsat 8	OLI/TIRS	138/42	04/06/2020	30 m
Landsat 8	OLI/TIRS	138/42	01/06/2016	30 m
Landsat 7	ETM	138/42	02/04/2012	30 m
Landsat 5	TM	138/42	03/04/2008	30 m
Landsat 5	TM	138/42	03/09/2004	30 m
Landsat 7	ETM	138/42	02/19/2000	30 m
Landsat 5	TM	138/42	03/03/1996	30 m
Landsat 5	TM	138/42	03/08/1992	30 m

Selected images have radiance values which can be converted into top of atmosphere (TOA) planetary reflectance values.[1] For that, reflectance coefficient values are needed, which are available in the metadata file of the image. To convert radiance value to TOA reflectance, the following Equations are used.

[1] USGS (2016) Landsat 8 (L8) Data Users Book. United States Geological Survey.

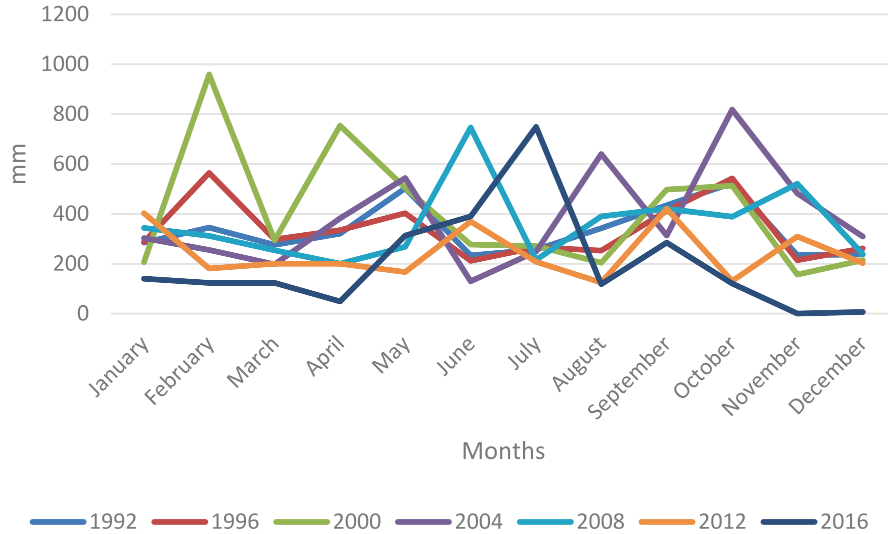

Fig. 2 Monthly precipitation in the Teesta catchment. Source: Bangladesh Meteorological Department

Figure 2 depicts the monthly precipitation for years that correspond to the years of satellite images collected. These precipitation data were collected from the rainfall stations located in the Teesta catchment areas. As the satellite images were obtained during the dry period, the precipitation trend justifies the seasonal uniformity of that period. Furthermore, the obtained precipitation data support the nature of the dry seasons. According to Fig. 2, from February to April, the precipitation rate was shown to have a declining trend in the catchment. Besides, Fig. 3 shows the monthly river flows of the years similar to the years of satellite images obtained. It demonstrates that the river flow was comparatively lower during the dry period than the monsoon period. Therefore, the study has adopted the dry period's recurrent years having lower monthly precipitation and lower monthly river flow, which can justify the obtained date of satellite images.

Eq. (1) converts digital number (DN) into TOA reflectance values, while Eq. (2) uses the sun angle to correct the reflectance values (USGS, 2016):

$$\rho\lambda = M\rho \times Qcal + A\rho \quad (1)$$

Here,

ρ = (TOA) planetary reflectance, without correction of solar range.

$M\rho$ = band-specific multiplicative recalling factor.

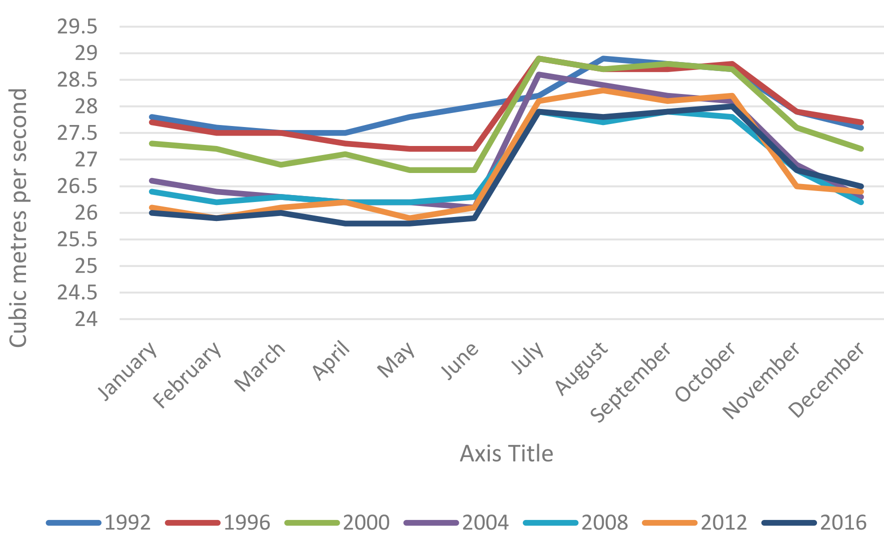

Fig. 3 Monthly river flow of the Teesta river

$Qcal$ = pixel values (DN).

$A\rho$ = band-specific additive recalling factor.

Correcting the reflectance values using the sun angle:

$$\rho\lambda\mathbf{corrected} = \mathbf{p\lambda/sin\theta SE} \quad (2)$$

Here,

$\boldsymbol{\rho\lambda}\mathbf{corrected}$ = reflectance values after sun angle correction.

$\boldsymbol{\rho\lambda}$ = TOA planetary reflectance.

$\boldsymbol{\theta SE}$ = local sun elevation angle (sun angle).

Image classification and change calculation method

This study uses the supervised maximum likelihood classifications (Ahmad & Quegan, 2012). The means and variances of the training data are used to estimate the probability that a pixel is a class member. The pixel is then placed in a class with the highest probability of membership.

The main topic of concern for this study was the land-use changes in the Teesta transboundary river basin in Nilphamari and Lalmonirhat districts of Bangladesh. The supervised ML classification was based on the signature file (training data) provided by band combination-based knowledge of Landsat. Four land-use classes were identified in the study area, namely: barren land, water bodies, cropland, and dense vegetation (Fig. 1). Classified raster data was converted into vector data to calculate geometry, and land-use change was detected by using the "intersect" tool in ArcGIS 10.7 software. Next, water bodies and the sum of other lands (barren land, cropland, and dense vegetation) were overlaid with each other by using the "erase" tool in ArcGIS 10.7 to estimate erosion accretion of the study area. To ensure that the classification exercise was of the highest quality and reliability, an accuracy assessment was carried out. Random sample points, field knowledge, and Google Earth were used to prepare some positions. During field visits, a GPS (global positioning system) was utilized to visually identify the exact location, latitude and longitude, and type of the location under investigation. The ground control points obtained in this way were used to evaluate the classification accuracy.

Results

The land-use scenarios in the Teesta transboundary river basin from 1992 to 2020 are depicted in Fig. 4. Table 1 shows the land-use area from 1992 to 2020 and shows that water bodies were progressively reduced from 1996 to 2020. Since 2004, there has been less water available for fishing, and the situation got worse in 2012 and 2016. The number of water bodies certainly indicates a low volume of water release from the Teesta River upstream. Because of the construction of the Gozoldoba barrage in the upper Teesta River, after 1996 the amount of discharge was very low and has altered downstream socio-economic conditions and cropping patterns.

Figure 5 depicts the spatial scale of different classes as well as the evolving pattern where water bodies were found decreasing significantly (R^2 = 0.63). The sum of barren land (Table 2) in relation to water bodies shows that barren land fluctuates due to cropping trend changes (from filed survey data) and was highest in 2004. Table 2 also reveals that cropping land rose from 1996 to 2004 but was at its lowest in 2004. In the case of crop ground, the quantity increased because farmers altered their cropping practices as a result of water shortages in dry seasons and flooding in wet seasons. The majority of farmers now grow maize rather than rice because maize needs less water than rice. Maize produces consistently higher output yields than boro rice[2] and also requires far less water than boro rice (Ali et al., 2009). Most farmers are not financially solvent because they only plant maize once a year and the rest of the time they grow vegetables and peanuts, which are not lucrative. There is also the risk of flash flooding whenever India discharges a large amount of water from upstream. Due to water shortages, land remains dry for four to five months. Rice production has declined at considerable rate in the Teesta River basin, which is very concerning in terms of food security.

[2] Boro rice refers to a method of rice cultivation that takes advantage of residual or stored water in low-lying areas following the harvest of Kharif rice.

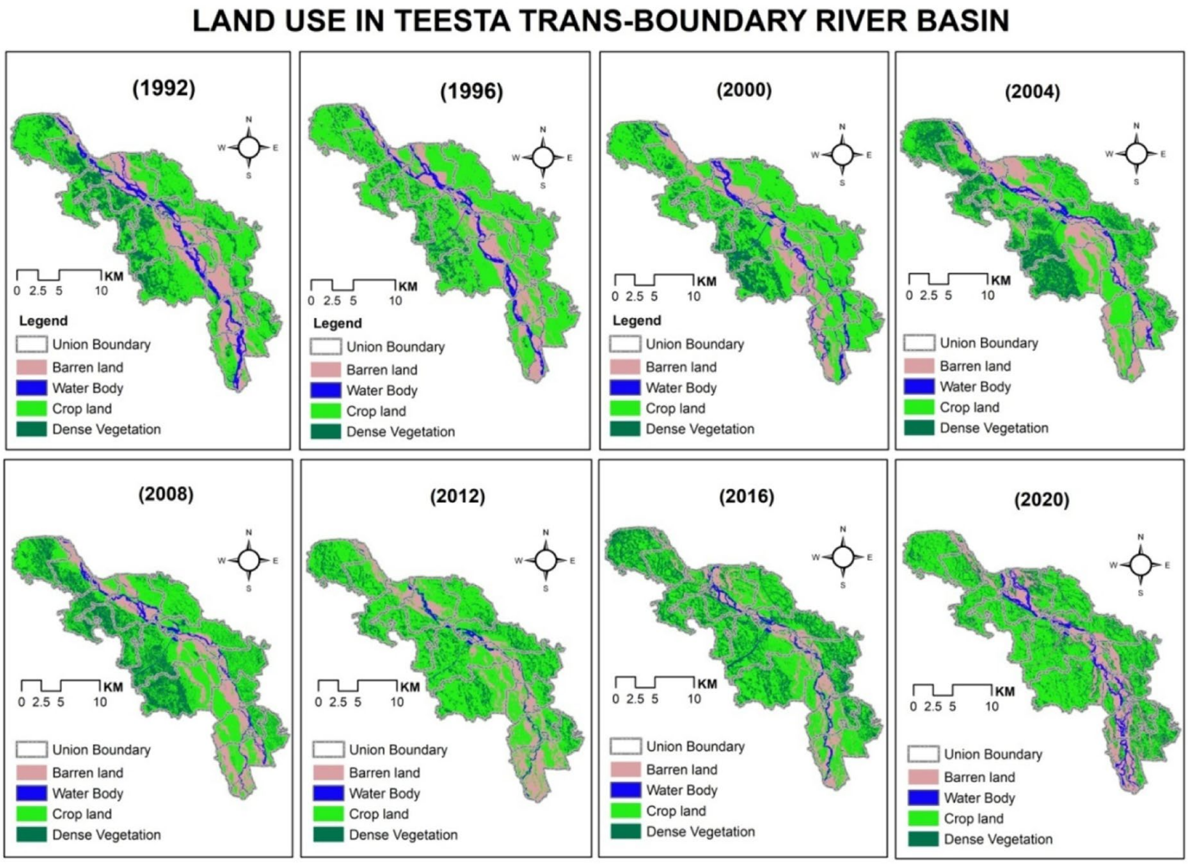

Fig. 4 Land-use scenarios in Teesta transboundary river basin from 1992 to 2020

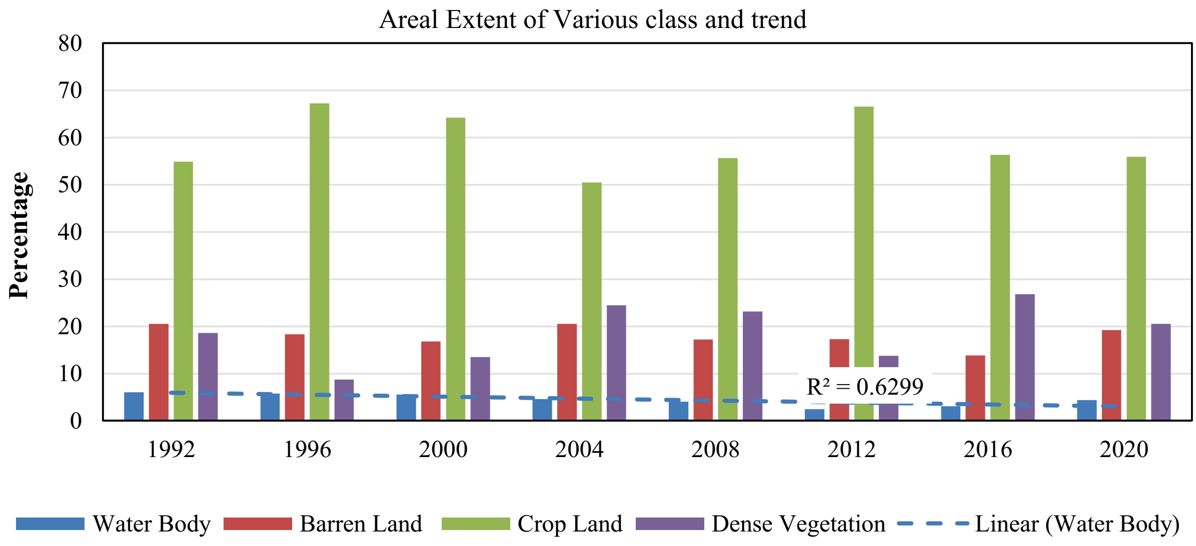

Fig. 5 Area of land use (%) at $p \leq 0.05$

Table 2 Area of land use (ha)

	1992	1996	2000	2004	2008	2012	2016	2020
Water body	2190.11	2089.01	2004.23	1665.94	1464.86	881.352	1125.8	1580.682
Barren land	7432.17	6649.6	6097.41	7444.07	6242.29	6279.63	5018.98	6974.17
Cropland	19,910.1	24,379.6	23,279.9	18,296.4	20,167.2	24,121.3	20,418.9	20,284.3
Dense vegetation	6737.91	3153.04	4893.39	8860.97	8392.4	4990.87	9708.99	7432.74

Table 3 Statistical table showing the aerial change of the study area from 1996 to 2020

	Final Stage (2020)				
		Waterbody	Barren land	Cropland	Dense vegetation
Initial stage (1996)	Water body	311.91	917.87	553.19	304.24
	Barren land	661.78	2818.19	2119.81	1045.97
	Cropland	595.46	3165.54	14,662.14	5917.46
	Dense vegetation	10.80	65.95	2917.86	153.99

Table 4 Statistical table showing the change percentage of the study area from 1996 to 2020

	Final stage (2020)					
		Waterbody	Barren land	Cropland	Dense vegetation	Column total
Initial stage (1996)	Water body	14.94	43.98	26.50	14.58	100
	Barren land	9.96	42.41	31.90	15.74	100
	Cropland	2.45	13.01	60.24	24.31	100
	Dense vegetation	0.34	2.09	92.67	4.89	100
	Row total	4.36	19.24	55.91	20.49	100

Change detection statistics

A change detection technique was used to accumulate a detailed tabulation of changes between two classification images and to identify the classes changed in the final state image (2020). The statistics tables list the initial state classes (1996) along the rows and the final state classes down the columns (Tables 3 and 4). The tool measured the transition dynamics of a land-use class to another class at a given extent. The initial state image was entered as the time 1 image and the final state image as time 2. Table 4 reveals that around 44% of initial water bodies were converted into a final state of barren land. It also indicates that only 14.94% of the initial water body remained unchanged. Table 4 shows that about 31.90% of the original barren land was turned into final cropland, with the cropland part remaining largely unchanged and 60% of the initial cropland remaining unchanged. Finally, 13% of initial cropland became final barren land, while 24% of initial cropland became vegetation[3] by successive processes (Fig. 6).

Overall classification accuracy of the study area for the years 1992, 1996, 2000, 2004, 2008, 2012, 2016, and 2020 are 74%, 75%, 81%, 79%, 79%, 82%, 85%, and 85%, respectively.

River erosion and accretion in Teesta River basin

Table 5 reveals the amount of erosion and accretion in the study area of the Teesta River basin. In the study period, there was a net gain of land from 1992 to 2011, but from 2012 to 2020 erosion was dominant in the Teesta River basin, and there was an increasing

[3] Vegetation contains mainly grassland and forests. Although settlement and vegetation surrounding building and road are included in vegetation class.

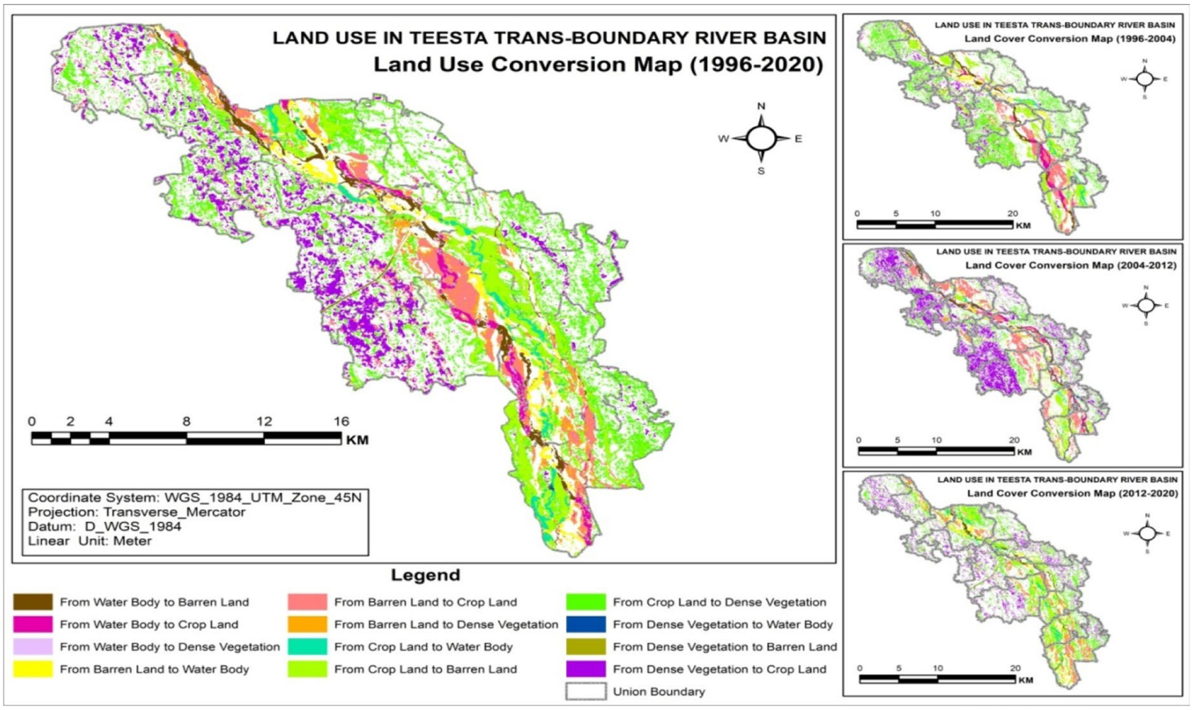

Fig. 6 Land-use conversion map from 1996 to 2020

trend towards net loss of land (Fig. 7). Table 1 also demonstrated that the amount of cropland increased in the study period because the land which was formed by accretion processes was also used for various types of agricultural purposes such as the cultivation of maize, potato, nut, and wheat. The trend analyses of erosion and accretion patterns clearly suggest an increase in the rates of accretion compared to the rate of erosion. Change in land-use patterns along with the integration of river dynamics can be effectively used to evaluate the socio-economic impact of riverine hazards on human beings. The river morphology and land use are intricately related, while the increased human interventions upstream of a trans-boundary river are a potential agent for altering the land used and socio-economic pattern in the Teesta River basin. As land-use changes forced by interventions upstream intensify the fluvial hazard, dwellers near the river basin area would further modify the land-use pattern, an adjustment which can lead to changes in the cropping patterns, hydrology, and socio-economic patterns of the riverside area.

Respondent's opinion regarding various issues

Table 6 shows that most farmers (65.5%) and fishermen (76.8%) think that the opening of the Gozoldoba barrage caused harm to them. Moreover, many participants agree that the government can solve

Table 5 Statistical table showing accretion and erosion of the study area from 1992 to 2020 (ha)

	1992–1996	1996–2000	2000–2004	2004–2008	2008–2012	2012–2016	2016–2020
Accretion	3164.3	3405.6	3300.31	2328.37	2515.97	1281.148	1616.764
Erosion	2961.06	3232.44	2631.29	1926.839	1342.474	1770.606	2530.65
Unchanged	33,208.137	32,954.103	33,305.355	34,139.384	34,340.756	34,747.014	34,180.072
Net loss/gain	203.24	173.16	669.02	401.531	1173.496	−489.458	−914.65

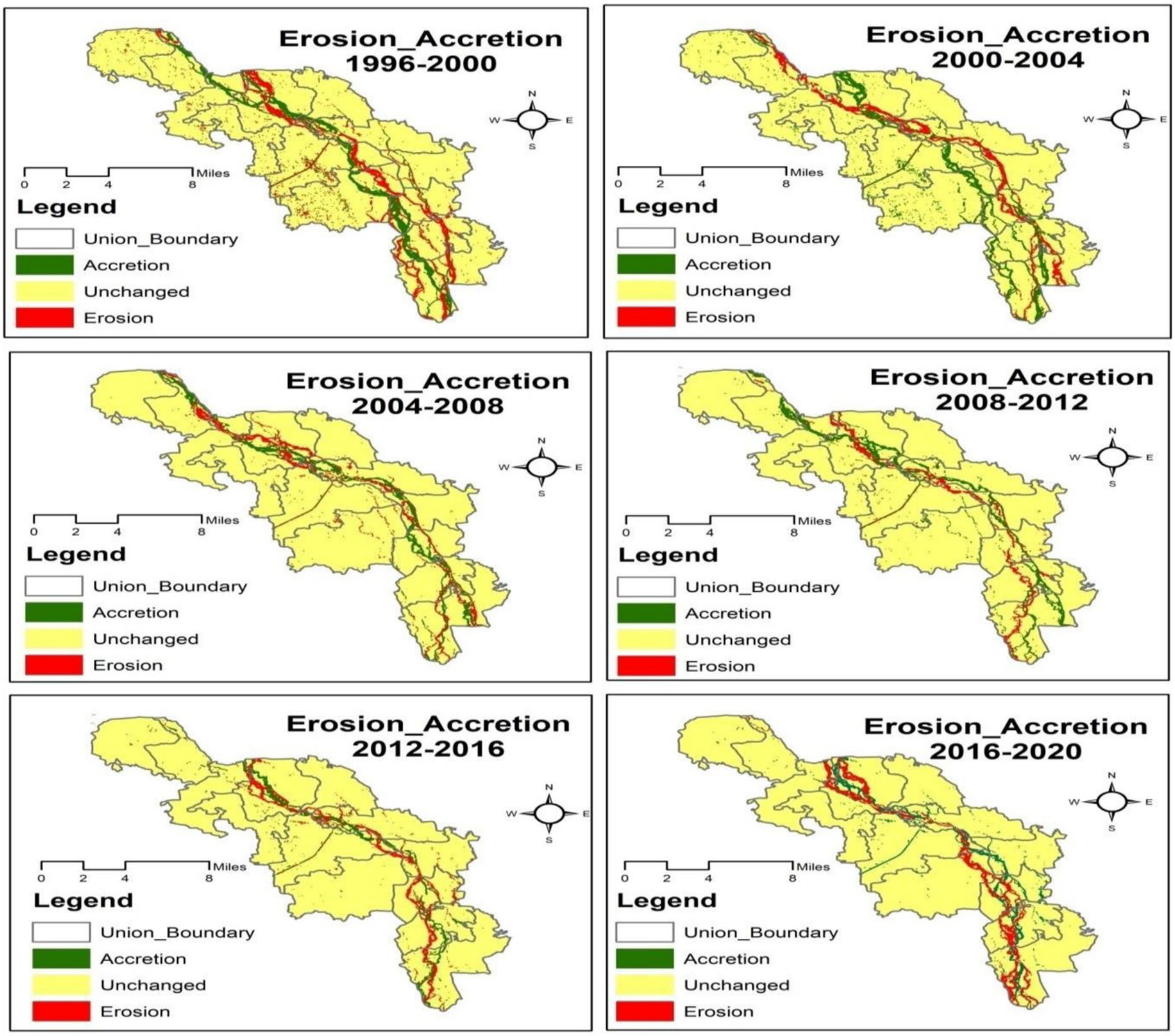

Fig. 7 River erosion and accretion in Teesta transboundary river basin from 1996 to 202

water distribution problems through negotiation (farmer: 72.5%; fisherman: 80.8%). Sixty-one percent of farmers opined that the water problem persisted after 1996, while 75.6% of fishermen believe the water problem existed before 1996. Both farmers and fishermen mostly feel water scarcity in the dry season. 61.5% and 60% of farmers think that people are changing/willing to change their occupation and people are migrating recently or willing to migrate to other places soon, respectively. However, the percentages are 75.2% and 71.2%, respectively, for fishermen. Many farming and fishing community participants also said that their cultivation/fishing was affected by a lack of river water and that they faced problems in their work due to the barrage. Over half of our studied farmers and fishermen get any kind of supports from anywhere during a crisis (farmers: 54.5%; fisherman: 64%).

Results show that, for the farmers, the first model as a whole explained between 18.1% (Cox & Snell R square) and 26.2% (Nagelkerke R-square) of the variance in occupation and correctly classified 74% cases. In comparison, the second model as a whole explained between 33.8% (Cox & Snell R square) and 47.4% (Nagelkerke R-square) of the variance in migration and correctly classified 82.5% cases

Table 6 Respondent's opinion regarding various issues

Questions	Response	Farmer % (*n*)	Fisherman % (*n*)
Do you think that opening of Gozoldoba barrage causes any harm to you?	Yes	65.5 (131)	76.8 (192)
	No	34.5 (69)	33.2 (58)
Do you think that government can solve water distribution problem through negotiation?	Before 1996	72.5 (145)	80.8 (202)
	After 1996	27.5 (55)	19.2 (48)
From when water problem is persisting as you think?	Yes	39.0 (78)	75.6 (189)
	No	61.0 (122)	24.4 (61)
Do you feel scarcity of water in the dry season?	Yes	61.0 (122)	78.0 (195)
	No	39.0 (78)	22.0 (55)
Do people recently changing/willing to change their Occupation	Yes	61.5 (123)	75.2 (188)
	No	38.5 (77)	24.8 (62)
Do people recently migrate or are willing to migrate to other places for surviving?	Yes	60.0 (120)	71.2 (178)
	No	40.0 (80)	28.8 (72)
Do your cultivation/fishing affects for lack of enough water in the river?	Yes	82.0 (164)	78.4 (196)
	No	18.0 (36)	21.6 (54)
Do you face problems in your work due to the barrage?	Yes	84.5 (169)	77.2 (193)
	No	15.5 (31)	22.8 (57)
Do you get any supports from anywhere during a crisis?	Yes	54.5 (109)	64.0 (160)
	No	45.5 (91)	36.0 (90)

(as shown in Table 7). On the other hand, the first model developed for fisherman as a whole explained between 19.0% (Cox & Snell R square) and 23.4% (Nagelkerke R-square) of the variance in occupation and correctly classified 77.2% cases. The second model as a whole explained between 16.6% (Cox & Snell R square) and 18.9% (Nagelkerke R-square) of the variance in migration and correctly classified 66.6% cases (as shown in Table 8).

The first model for farmers showed that only two predictors were significant in explaining their decision to change their occupation. The two

Table 7 Parameter estimates for farmer's decision of changing occupation and migration

Explanatory variables	Occupation Coefficient (odd ratio)	Migration Coefficient (odd ratio)
Opening of Gozoldoba barrage		
Yes (Ref = no)	0.048 (1.049)*	0.883 (2.419)
Water scarcity		
Yes (Ref = No)	0.021 (1.021)	1.267 (3.552)***
Affects in cultivation		
Yes (Ref = no)	−0.902 (0.406)	0.071 (1.074)
Problems in cultivation		
Yes (Ref = no)	0.910 (2.403)**	−0.73 (0.196)*
Getting supports in crisis		
Yes (Ref = no)	−0.078 (1.081)	−3.307 (0.969)

Occupation: observation = 200; chi-square = 16.49; R^2 (Nagelkerke) = 26.2%, R^2 (Cox and Snell) = 18.1%, classification = 74.0%

Migration: observation = 200; chi-square = 17.93; R^2 (Nagelkerke) = 47.4%; R^2 (Cox and Snell) = 33.8%, classification = 82.5%

Reference category: no

*$p < 0.05$; **$p < 0.010$; ***$p < 0.005$

Table 8 Parameter estimates for fisherman's decision of changing occupation and migration

Explanatory variables	Occupation	Migration
	Coefficient (odd ratio)	Coefficient (odd ratio)
Opening of Gozoldoba Barrage		
Yes (Ref = No)	1.320 (3.742)*	1.027 (2.792)
Water scarcity		
Yes (Ref = No)	−0.173 (0.841)	0.658 (1.932)*
Affect in fishing		
Yes (Ref = No)	0.047 (1.048)**	0.650 (1.916)
Problems in fishing		
Yes (Ref = No)	−0.770 (0.463)	0.075 (1.078)*
Getting supports in crisis		
Yes (Ref = No)	−0.708 (0.493)*	−0.264 (0.768)

Migration: observation = 250; chi-square = 27.56; R^2 (Nagelkerke) = 18.9%, R^2 (Cox & Snell) = 16.6%; classification = 66.6%. Reference category: no

*$p < 0.05$; **$p < 0.010$; ***$p < 0.005$

most important predictors were the opening of the Gozoldoba barrage and problems in cultivation. The above result (shown in Table 7) indicates that farmers who think that the opening of the Gozoldoba barrage caused any harm to them are more likely to change their occupation than those farmers who do not feel any harm from the opening of Gozoldoba barrage. Meanwhile, farmers who face various problems in their cultivation are 2.4 times more likely to change their occupation than farmers who do not face any difficulties in cultivation. Although the result is not statistically significant, the responses suggest that farmers who face water scarcity in their area are 1.02 times more likely and who get support during any crisis are 1.08 times less likely to change their occupation than their counterparts. Table 7 also indicates that two predictors significantly explain farmers' migration decisions. The significant predictors are water scarcity and problems in cultivation. Farmers who face water scarcity in their area are 3.5 times more likely to migrate to other places than those farmers who do not meet water scarcity. On the other hand, farmers who face problems in their cultivation are less likely to change their area than those who do not face such issues. The odd ratio suggests that farmers who believe that the opening of Gozoldoba barrage causes any harm to them are 2.4 times more likely to migrate to another place than those who do not think so.

Three predictors, namely, opening of Gozoldoba barrage, affect in fishing, and getting supports in crisis, were found statistically significant for explaining the first model, that is, whether fishermen are willing to change their occupation. Table 8 indicates that fishermen who think opening of Gozoldoba barrage causes harm to them are 3.7 times more likely to change their occupation. Further, fishermen who believe that their fishing is affected due to lack of water in rivers are more likely to change their occupation than those who do not believe so. In contrast, fishermen who get support during a crisis are found less likely to change their occupation than others who do not get such help. We found that water scarcity and problems in fishing are the two most significant predictors for explaining fishermen's migration decisions. Fishermen who face water scarcity in their area and face problems in their fishing are more likely to migrate to other places than their counterparts. Although results are not statistically significant, the odd ratio suggests that respondents who think that opening of the Gozoldoba barrage causes harm to them, and respondents who believe that the lack of water in river affects their fishing, are 2.7 and 1.9 times, respectively, more likely to migrate to other places than their counterparts.

Discussion

This study revealed that water bodies significantly decreased from 1996 to 2020. From 2004, minimum amount of water was available for fishing, while conditions were very severe in 2012 and 2016. After construction of the Gozoldoba barrage in the upper portion of Teesta River in 1996, the amount of discharge has been meager. Hussain (2015) identified drought and flood-induced critical moments and coping strategies in the hazard-prone area of the Lower Teesta River. Our findings indicate that drought and flooding have occurred almost every year after the building of Gozaldoba barrages on the Teesta River. The severity and duration of these disasters change livelihoods and land-use patterns in the downstream part of Teesta River. Khan et al. (2015) investigated the dam's impact on the Teesta riverbed; his results suggest that the discharge capability of the Teesta River has been dramatically reduced due to water depletion and the discharge of heavy silts from the upper catchments. Mbugua (2011) studied water scarcity in the northern part of Bangladesh. From 1960 to 1991, there were 19 drought spells in Bangladesh, and twelve of these occurred in the Teesta River basin. In 1996, the dry season water discharge of the Teesta was 6500 cusecs in the Bangladesh portion, but this was reduced to 1380 cusecs in 2007, and 794 cusecs in 2014. Economic losses of river-dependent people increased due to irrigation collapse, production loss, crop damage, and socio-economic changes (Arfanuzzaman, 2015).

Present research on land use and land cover change has shown that the amount of cropping land increased from 1996 but it was lowest in 2004. Cropland quantity increased because farmers changed their cropping practice due to water scarcity in dry seasons and floods in wet seasons. Most farmers now cultivate maize instead of rice because maize requires less water than rice. Land remains barren due to water scarcity over 4 to 5 months. Raihan et al. (2017) studied the impact of water shortage on crop production in the Teesta River basin, Bangladesh, and found that most farmers opined that irrigation costs were increasing continuously due to the shortage of water; they were also more intent on cultivating maize, tobacco, and wheat compared to rice, due to water shortages.

During the current study period, there was a net gain of land from 1992 to 2011, but, in recent years, 2012 to 2020, erosion was dominant in the Teesta River basin, and there was an increasing trend towards a net loss of land. We also found that land which was formed by accretion processes was also used for various types of agricultural purposes such as cultivation of maize, potato, nuts, and wheat. Mukherjee and Saha (2016) found that the normal channel pattern of the river Teesta has been heavily impacted by a significant number of dam constructions on the river in recent years, causing the main river channel to shift, which ultimately increased erosion and sedimentation.

Dilshad et al. (2019) examined social vulnerability in Hindu Kush Himalaya (HKH) area and found that agriculture and fisheries are the major livelihood options in the downstream part of the river basin. After the building of the Gajolzobba barrage on the Teesta River, the availability of irrigation water in Bangladesh was restricted. The barrage was also responsible for altering the Teesta River hydrology and ecosystem, which ultimately impacted peoples' livelihood.

Binary logistic regression result suggests that predictors, namely, the opening of Gozoldoba barrage and problems in cultivation, were significant in explaining farmers' decisions regarding changing their occupation. Farmers who confront water scarcity in their area are more inclined to relocate, but farmers who face cultivation problems are less likely to relocate, when compared to their counterparts. Additionally, this study also found that fishermen who think the opening of Gozoldoba barrage causes harm to them, and who think that their fishing is affected due to lack of water in the river are more likely to change their occupation. Meanwhile, fishermen who get support during crises are found less likely to change their occupation compared to others who do not get such support. On the other hand, fishermen who face water scarcity in their area and who face problems in their fishing are more likely to migrate to other places compared to their counterparts. Miletto et al. (2017) provide valuable insight in their work about migration and its dependency on water shortage. Their study found that there is a close relationship between water scarcity, food insecurity, and social instability, which intensifies the patterns of migration throughout the world (WWAP UNESCO World Water Assessment Programme, 2016). Agriculture sectors use the most water and the trends towards increased water scarcity demonstrate that this will impact heavily on water-dependent jobs.

Conclusions

The study demonstrated the impact of upstream anthropogenic water withdrawal on downstream land use and livelihood changes. Our investigation indicates that land use and land cover can change rapidly in the downstream area and that the volume of river water gradually decreases after the construction of a major barrage upstream. Since the construction of the Gozoldoba barrage in the upper portion of the Teesta River in 1996, the amount of water discharge has been very low and has seriously changed the downstream socio-economic conditions and cropping patterns. Barren land amounts associated with water bodies reveal that barren land fluctuated because of cropping pattern changes. In cropland, the area increased because farmers changed the cropping practice due to water scarcity in the dry seasons and floods in the wet seasons. Trend analyses of erosion and accretion patterns clearly suggest an increase in the accretion rates compared to the rate of erosion. The river morphology and land use are intricately related. Increased human intervention upstream of a transboundary river is potential agents for altering the land used and socio-economic patterns in the Teesta River basin downstream. Spatiotemporal information about land use and land cover change patterns and water discharge in the transboundary downstream part helps to identify water scarcity scenarios and its impact on the downstream dwellers. This study found that most farmers and fishermen are willing to change their primary occupation as their principal occupation is affected by many factors. Many farmers and fishermen also want to move to other places for better livelihoods. However, the present study is limited to only small areas and by taking only 450 samples. It is difficult to generalize such scenarios for the entire country based on these small areas and sample size. A comparative study among different locations and a large sample size would be much more fruitful. This study provides a practical understanding for future research. Combined with land use and land cover change and water discharge data will be helpful for the decision-makers to formulate a water-sharing treaty for sustainable transboundary river management.

Data availability Data will be available upon request to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

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