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Economics of transboundary water: an evaluation of a glacier and snowpack-dependent river basin of the Hindu Kush Himalayan region

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Abstract

The Himalayan rivers are recognized as a reliable source of water supply in the countries of the Hindu Kush Himalayan (HKH) region. Increasing need for food and energy for the growing population of the HKH region has stimulated water harvesting from the transboundary rivers and triggered water conflict, environmental degradation and socio-economic turmoil among the riparian nations. Teesta is one such mighty trans-Himalayan river flowing through India and Bangladesh and is recognized as a basin where there is increasing tension between these two nations. Due to upstream interventions including barrage, dam and hydropower construction, the lower riparian region of Bangladesh faces acute water stresses, which hamper the agricultural, fisheries and livelihood activities of the river-dependent communities and impede the economic prosperity of the greater north-west region. The study provides a robust outline of the transboundary nexus between India and Bangladesh, and identifies upstream intervention-induced economic loss and ecological deterioration in the lower Teesta basin. To encourage water collaboration between the riparian states, the study estimates the benefit of transboundary co-operation for the larger socio-economic prosperity and environmental sustainability in the Teesta basin of the Himalayan region, which is decidedly applicable to similar basins in the HKH region and the rest of the world.

Keywords: : Ecological economics; Ecosystem services flow; Hindu Kush Himalayan; Natural resource management; Regional water cooperation; Teesta river basin; Transboundary conflict

1. Introduction

Transboundary rivers are imperative to foster economic activities in the large catchment areas of the beneficiary countries. Economies of such transboundary basins are highly reliant on the water resources of the river for agriculture, energy and livelihood opportunities of the people. The Himalayan ranges are the sources of major rivers such as Indus, Ganges, Brahmaputra, Meghna, Yangtze and Mekong of

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South and South-east Asia, delivering fresh water supply to 1.4 billion people (FAO, 2012). Lack of water cooperation, inappropriate planning and management, and climate-induced hydrological changes put the river basin countries of the Hindu Kush Himalayan (HKH) region in a situation of conflict (Ahmed, 2012; Asia Foundation, 2013; Vij *et al.*, 2017). Vasily *et al.* (2015) expressed concern that, despite having a good number of Himalayan-sourced mighty rivers, South Asia is now recognized as the world's most water-stressed region. South Asia's population is growing by 25 million per year but its per capita water availability is found to have fallen by 70% since 1950. The study fears that the vast ice mass of the HKH mountain range, storing water and providing continuous river flows during dry periods, is highly susceptible to the adverse effect of climate change. Thus, the water, energy and food supply of this region is at high risk (Bandyopadhyay, 2007; Rasul, 2014). Joint effort, transboundary cooperation and strategic use of water resources can support the sustainable development of agriculture and hydropower, and river health in South Asia (Dyson *et al.*, 2003; Ghosh, 2008). It has been argued that increasing demand for water in the transboundary basin may cause conflict and war in the face of water scarcity. Serageldin (1995) fears that as populations grow and demand increases, dispute over water resources may lead to international conflict, especially where water is already a scarce resource (Falkenmark, 1990; Gleik, 1993; Fisher *et al.*, 2005). In contrast, others argue that scarcity will promote increased cooperation (Giordano *et al.*, 2002; Giordano & Wolf, 2003; Wolf *et al.*, 2003; Dinar & Dinar, 2004). Giordano & Wolf (2003) and Wolf *et al.* (2003) support the hypothesis based on the extensive database of transnational river basins that cooperation is enhanced when scarcity increases. They nuance this by arguing that water scarcity may be both a cause of conflict and a stimulus for cooperation. Besides, Dinar & Dinar (2004) argue that although water wars have been rare, this does not mean that they will never occur. Serageldin (2009) also urges that, 'The wars of this century have been on oil, and the wars of the next century will be on water … unless we change the way we manage water.' Thus, risk of water war will always be there until equal rights over the water resources are established in the shared river basin (Falkenmark *et al.*, 2000; Wichelns *et al.*, 2003).

In the present situation of water stress and conflict in the river basin of the HKH region, the study uses a multidisciplinary lens on the Teesta river basin of South Asia to assess the drivers and conditions leading to water tension and its consequences between the riparian states and finally sketches possible solutions for greater water integration. Teesta is a Himalayan-sourced transboundary river and a key tributary of the mighty river Brahmaputra-Jamuna, which flows through India and Bangladesh with a total beneficiary of 29 million people (Mungpoo, 2012). The Teesta river begins as Chhombo Chhu at Khangchung Chho, a glacial lake situated at the tip of Teesta Khangse glacier, at an elevation of 5,280 metres in the state of Sikkim. There are approximately 84 glaciers in the Teesta river basin, covering an area of 440.30 km^2, which are distributed in 10 sub-basins. Moreover, total permanent snowfields are measured at 251.22 km^2. Hence, total area under glaciers and permanent snowfields is approximately 691.52 km^2 (Waslekar *et al.*, 2013). The total glacial and snow cover stored water in the Teesta river basin is about 145.05 km^2. Both riparian nations, India and Bangladesh, have built irrigation infrastructure in this river basin for the optimum utilization of water resources with a view to improving the socio-economic condition and well-being of the river basin communities (Arfanuzzaman & Abu Syed, 2017). It has emerged that the irrigation and hydropower plant of the upstream country (India) often control the Teesta's water and tend to receive the maximum benefit at the cost of Bangladesh's loss (Rahman *et al.*, 2010; Arfanuzzaman & Ahmad, 2015a). Consequently, water discharge appears to be on a continuous downward trend in Bangladesh, which fuels the water tension between

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both countries. A river has many natural functions. When a river's water flow is lower than the minimum required level, all the environmental functions and ecosystem services such as freshwater supply, water regulation, water cycling, primary production, water purification, flood control, climate regulation, CO_2 sequestration, soil formation, nutrient cycling, air quality regulation, and photosynthesis are hampered badly, which ultimately disrupts the social–ecological resilience and livelihood activities of the river-dependent people. Since water resource management in transboundary river basins is a key link between water and economic prosperity in the river basin, effective management of freshwater resources helps sustain agriculture, industries, ecosystems and communities (Malivar & Missimer, 2012; Arfanuzzaman, 2015; Arfanuzzaman & Abu Syed, 2017). Bangladesh is regularly facing water crises in the dry and lean seasons in the Teesta river because the upstream country has control over the water resources of the Teesta (Mullick *et al*., 2011; Arfanuzzaman, 2015). Since the Teesta river is believed to be a lifeline for agricultural production in north-western Bangladesh, the people of this region are highly reliant on this fourth-largest transboundary river for their livelihood activities.

Although there has been much effort and bilateral conventions between the nations, no momentous progress has yet been made on dispute resolution and equitable water sharing of Teesta river basin, which signifies greater socio-economic cost in the lower Teesta basin of Bangladesh. India is utilizing the water resources of Teesta river through the irrigation barrage at Gazaldoba and hydropower plant at Sikkim without any assent by Bangladesh, which throws the north-west region of Bangladesh into a water-insecure situation (Mirza *et al.*, 2008; Ahmed, 2012; Arfanuzzaman, 2017b). Against this backdrop massive economic loss and environmental damage have taken place in Bangladesh, partly in the form of irrigation failure, production loss and damage, livelihood disruption and ecosystem distortion in the river-dependent areas (Arfanuzzaman *et al*., 2016). Groundwater recharge of the Teesta river is also hampered and the level of groundwater is falling 1.2 m per year in many parts of this river basin due to increased tube-well-based alternative irrigation together with low recharge, poor management and land-use change (Mondal & Saleh, 2003). Waslekar *et al*. (2013) found that the long-awaited Teesta treaty would have broader implications for the holistic management of all shared water resources of the 54 transboundary rivers between India and Bangladesh. They conclude that, if the Teesta treaty is implemented, farmers across the entire Teesta basin will benefit in the short and long run, and two important states in South Asia will share better prospects and hopefully set a paradigm for others. Rahman *et al*. (2010) revealed that there are more than 4,000 dams around India, which have an adverse effect on river ecosystems. This study expressed concern that the Farakkah barrage would create tremendous ecological damage on the Bangladesh side which will take 50–60 years to repair with great effort and international assistance. The study maintains that the Ganges, Meghna and Teesta are the most affected rivers in Bangladesh due to Indian barrages, canal networks, dams, hydropower and irrigation footprint. Additionally, for about two decades, India has diverted 1,133 cubic metres per second out of 1,728 m^3/s during the dry season, which has had serious impacts on the Ganges basin ecosystems. Islam & Higano (2002) emphasized optimum water sharing of Teesta river for the maximum benefit of India and Bangladesh. They also revealed that when water is available at the 425 cumec (m^3/s) level, crops worth $44 million can be produced and at the 227 cumec level $20 million worth of crops can be produced in lower Teesta basin of Bangladesh. Sarker *et al*. (2011) found that excessive water withdrawal in the dry season and release water in the rainy season by India are a problem for Bangladesh. In their words, in the rainy season India is releasing water through Gazaldoba barrage which causes flooding in Bangladesh, and in the dry season India is diverting maximum water for irrigation, power generation and navigation purposes in their project area. Consequently, the Teesta Barrage Project (TBP) of

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Bangladesh cannot fulfil its objective and the climatic conditions of the surrounding region are deteriorating day by day. In this study, I intend to provide credible, relevant and justifiable information and knowledge on water resources-related issues, concerns and development pattern of the transboundary river Teesta to facilitate better trade-offs and policy formulation in water-scarce critical economic moments when loss and damage are relatively higher. Further, the study endeavours to divulge the hydroelectric and agricultural water demand of two riparian nations against the water availability, anticipated benefit of different water-sharing agreements (WSAs) based on the virgin and post-project discharge, and develop an outline of water collaboration for larger socio-economic advantage and prosperity in the Teesta river basin. In addition, the study attempts to find out the net benefit in terms of different water flows of Teesta river and provide intellectual support to the water-sharing agreements for mutual regional and transboundary benefits in the HKH region.

2. Methodology and data

Both qualitative and quantitative research techniques have been used in this paper to produce robust information and scientific knowledge on transboundary water resource management, water collaboration and socio-economic prosperity in the Teesta basin. In order to analyse the net gain, a baseline is formulated for the comparison between desired irrigation area and actual irrigation. Baseline irrigation area is formulated on the basis of average decadal water flow (ADWF) in the pre-project period and irrigation in per cumec water. The baseline irrigation is estimated based on the following equation.

$$\text{Baseline irrigation: } BI = \frac{ADWF}{2} * 1\ cumec * CA \quad (1)$$

where, BI = baseline irrigation per hectare, CA = cultivation area (ha) per unit of water, 1 cumec (m^3/s) = 35.3147 cusec.

$$\text{More explicitly, } BI = \frac{ADWF}{2} * 35.3147 * 21$$

Here, ADWF is divided by 2 by assuming the 50% share of water by the two countries. To convert cumec into cusec, 50% ADWF is multiplied by 35.3147, and 21 hectares of land can be cultivated by 1 cusec of water.

To estimate the agricultural water demand of the river basin, the study endeavours to adopt the water productivity and accounting method. Currently available discharge and virgin flow of the Teesta river were considered in the analysis for the water demand calculation.

$$W_d = \frac{A_l}{Wp_l} \quad (2)$$

Here, W_d signifies the demand of water, Wp_l is the water productivity of the land and A_l indicates the quantity of agricultural land in the river basin.

According to the environmental impact assessment of the Ting Ting hydroelectricity project of the Upper Teesta, 46 cumec water will be required to generate 99 megawatts of hydropower from the

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Teesta river. On this basis the following formula has been used in this study to estimate the water demand of the hydropower projects of the upstream region.

$$\text{Water demand of the hydropower projects: } WDh = \frac{CHP}{MWr} \tag{3}$$

where, CHP indicates the capacity of currently operational hydropower plants, and MWr represents the marginal requirement for water per unit of hydropower produced. Since 46 cumec water is required to produce 99 MW, MWr = 2.15 cumec. Currently, 510 MW hydropower plant is operational against the installed 3,405 MW.

Further, in order to derive the loss and gain against the virgin water flow in the pre-project or pre-barrage period, a baseline is considered. The pre-project water flow is also called the natural or virgin flow of Teesta river. A baseline is estimated based on the decadal discharge of Teesta river in the pre-project period. Here, the baseline water flow is the average water flow of Teesta river during 1973 to 1983, measured at Dalia station in the Bangladesh basin. Since the Teesta is a transboundary river the analysis is made based on 50% virgin flow of the river. The analysis of net gain is carried out based on average and minimum virgin flow. Considering the average virgin flow, the baseline irrigation is 63,506 hectares of land during the Boro rice season and based on the minimum virgin flow, baseline irrigation is 54,137 hectares. Moreover, the benefit of different water-sharing agreements has been calculated based on the water productivity principle. According to the Bangladesh Water Development Board (BWDB), 370 hectares of land can be cultivated by a single cumec of water in TBP area. Based on this standard, the total land cultivation is calculated by available water resources of Teesta river.

Extensive primary and secondary data were used to conduct this study. Secondary data have been collected from BWDB, Joint Rivers Commission (JRC), local government institutions, the Government of Sikkim, Indian Space Research Organisation and other scientific literatures. Primary data have been collected from Teesta basin areas through key informant interview, focus group discussion and stakeholders' meeting. In addition to quantitative assessment, the Geographic Information System (GIS) technique has been used in the study to prepare the land-use pattern map of upper and lower Teesta catchment region.

3. Overview of the Teesta river basin

The total catchment area of Teesta river is 12,159 km^2 in India and Bangladesh. The catchment area comprises hilly and plain regions. Here, the hilly region is dominant throughout the catchment, covering 8,051 km^2. Geologically the whole hilly area falls into Indian territory whereas the plain area covers both west Bengal of India and north Bengal of Bangladesh almost equally. Both riparian nations of this transnational river have already implemented massive irrigation projects in the floodplain to utilize the water resource for the socio-economic development of the people. In the upstream areas India has built many dams for hydropower, which degrades the river ecosystem and lowers the water availability in the downstream nation (International Rivers, 2013).

As shown in Figure 1, the entire Teesta basin is 404 km long, out of which 270 km falls in Indian terrain and the remaining 134 km is in Bangladesh. The distance between the two barrages is 105 km. The water availability of the Bangladeshi barrage mostly depends on the released water

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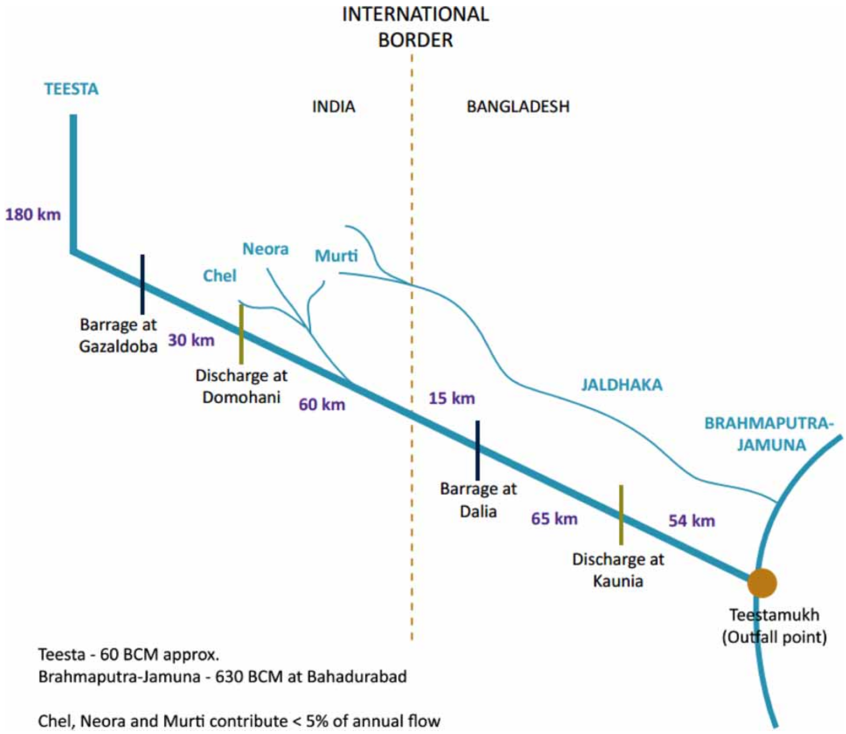

Fig. 1. The Teesta river basin at a glance. *Source*: Adapted from Waslekar *et al*. (2013).

from the upstream barrage. There are eight major tributaries in the Himalayan region of the Teesta basin. Lachung Chhu, Chakung Chhu, Dik Chhu, Rani Khola, and Rangpo Chhu are the left-bank tributaries and Zemu Chhu, Rangyong Chhu, and Rangit River are the right-bank tributaries. In the flood plain, three tributaries of Teesta are found, namely Chel, Neora, and Murti, which discharge water after the Gazaldoba barrage in India. But the annual contributions of such rivers are found to be less than 5% of the annual flow of the Teesta.

Table 1 postulates the total number of glaciers and snowfields with their prevailing areas across the upper Teesta basin. There are 84 glaciers in the Teesta basin, which are distributed in 10 sub-basins and cover an area of 440.24 km^2. Goma Chu, Chumbo Chu and Lachung Chu are the most vital basins holding 22, 15 and 11 glaciers, respectively, and collectively embracing more than 50% of the total number of glaciers over an area of 174 km^2. In addition, total permanent snowfields were also mapped and their total extent was measured as 251.244 km^2. These are distributed across 12 sub-basins. Out of 197 permanent snowfields, 113 snowfields are held by Lachung Chu, Goma Chu and Chumbo Chu basins with a coverage of 118 km^2. Here, Lachung Chu basin is the largest basin with 49 snowfields. Total glacial and permanent snow cover stored water in Teesta basin is estimated as 145.05 km^3. Average altitude of snow line is 5,093 m. This is 342 m lower than the average middle altitude for the glaciers of the basin.

As shown in Table 2, Chhungthang, Sankalang and Dikchu cover 57%, 51% and 53% of the snowpack of the Teesta basin, respectively. Moreover, there are 1,189, 1,900 and 2,020 km^2 of rain-fed areas over Chhungthang, Sankalang and Dikchu, respectively. In Teesta basin the total rain-fed and snowpack catchment areas are recorded as 10,877 km^2.

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Table 1. Total glacier and snowfield areas in each sub-basin of Teesta basin.

Glaciers			Permanent snowfields		
Sub-basin	No. of glaciers	Total area (km^2)	Sub-basin	No. of snowfields	Total area (km^2)
Tsakchurong Chu	8	30.8	Tsakchurong Chu	1	1.263
Prek Chu	3	20.37	Chakung Chu	3	0.909
Rilli Chu	2	1.3	Rangyong Chu	8	17.233
Rangyong Chu	8	71.15	Umaran Chu	20	22.959
Umaran Chu	4	25.93	Ringi Chu	3	1.501
Zemu Chu	2	80	Tista River	11	20.86
Goma Chu	22	82.72	Zemu Chu	14	36.87
Chumbo Chu	15	41.81	Goma Chu	35	30.67
Lachung Chu	11	49.15	Chumbo Chu	29	40.389
Sebuzung Chu	9	37.01	Lachung Chu	8	21.96
			Lachung Chu	49	47.474
			Sebuzung Chu	16	9.156
Total	**84**	**440.24**	**Total**	**197**	**251.244**

Source: Glacier Atlas of Teesta Basin, ISRO 2001.

Table 2. Snow-covered and rain-fed area of Teesta basin.

	Catchment area (km^2)			
Location	Snow-covered	Rain-fed	Total	Snow-covered area as % of total area
Chhungthang	1,598	1,189	2,787	57
Sankalang	1,939	1,900	3,839	51
Dikchu	2,240	2,020	4,260	53

Figure 2(a) and 2(b) explain the land-use pattern of the upper Teesta catchment of India and the Teesta catchment of Bangladesh, respectively. It can be seen that the extent of agriculture, human settlement and vegetation is much higher across the lower Teesta basin. Whereas in the upper Teesta catchment, glaciers, rocky land, and moraines are dominant in the higher altitude and forest, alpine scrub, and scrub are extensive at lower elevations.

3.1. Barrage and hydropower structures in the Teesta basin

Gazaldoba barrage of India is nearly 100 km from the Dalia-Doani point where Bangladesh also constructed a barrage to fulfil the irrigation demand of its north-western region. The discussion of this largest irrigation project (TBP) started in Bangladesh in 1955 to provide a timely irrigation facility in the drought-prone areas of this constituency. As a downstream country, Bangladesh is now more severely affected by extraction and diversion of the river's water by the upstream country, India, through the grand barrage and hydropower station at Gazaldoba. Therefore, Bangladesh is receiving very low water flow, and the benefits of building TBP to meet the country's irrigation demand in the north-western region have not materialized.

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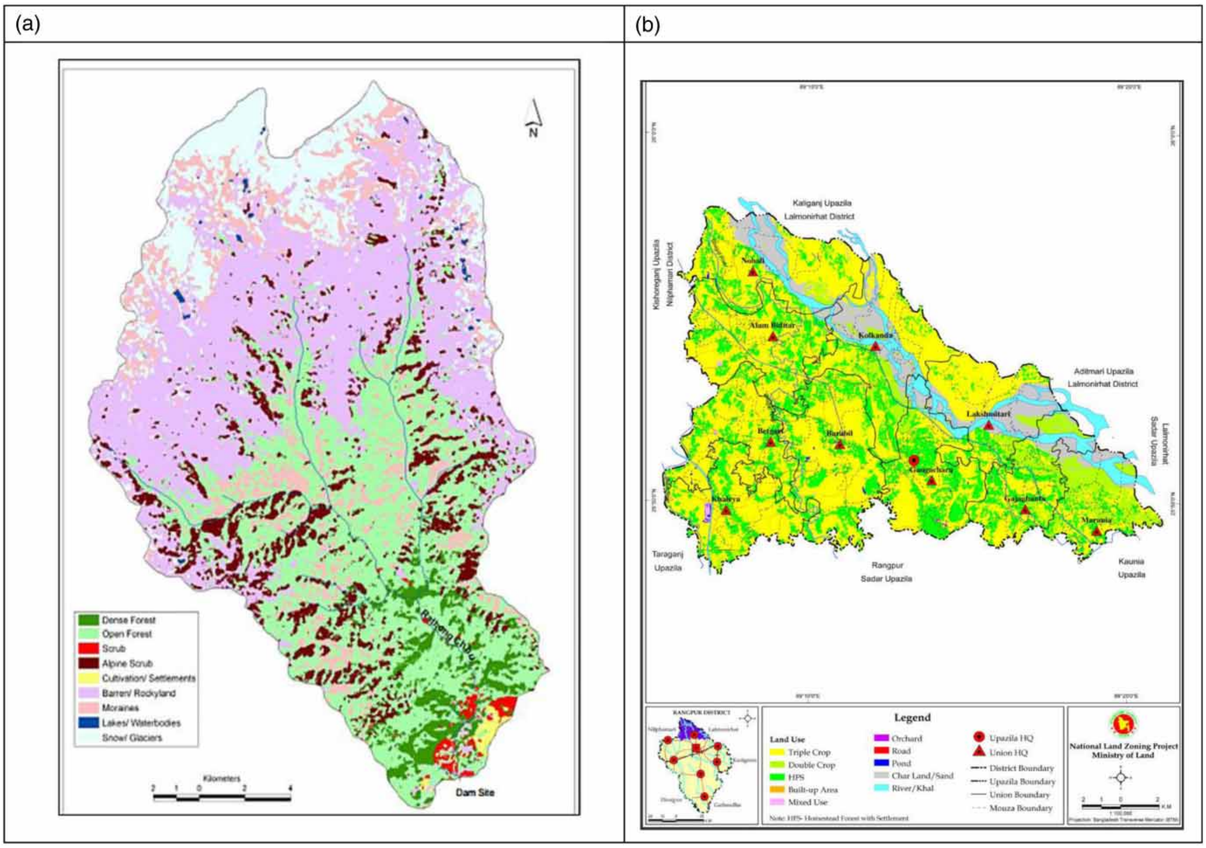

Fig. 2. Land-use pattern map of (a) Sikkim, India (upstream catchment) and (b) north-west Bangladesh (downstream catchment). *Sources*: (a) Govt. of Sikkim, India and (b) Ministry of Land, Govt. of Bangladesh.

Table 3 exhibits the climatic condition, geographical elements, and other technical features of two barrages of upper and lower Teesta basin. It appears that except for the hydropower plant all the features of the two barrages are identical. It is reported in the table that the upper riparian nation, India, has already brought about 58% of its total irrigable area under irrigation while the lower riparian nation, Bangladesh, has been able to bring only 20% of its total irrigable area under the irrigation scheme. This is because of unequal water resource distribution in the upstream and downstream basins. Bangladesh cannot bring the entire potential area under irrigation coverage because it is not getting sufficient water from upstream as water is diverted by India at Gazaldoba barrage. At the same time India is not releasing an equal share of water because it is using the maximum amount of water to irrigate its large-scale agricultural lands. Although the number of beneficiaries is relatively higher in Bangladesh, most of them are deprived of the benefit of the river's water resources. Only 8 million people of India are getting irrigation service in 922,000 hectares. In contrast, 21 million people of Bangladesh are the beneficiaries of 540,000 hectares of irrigable land but due to water unavailability from the upstream just 111,406 hectares of land can be irrigated, which forces a large number of people out of the irrigation advantage.

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Table 3. Barrage structures in the Teesta floodplain.

	India	Bangladesh
Location	Gazaldoba	Dalia-Doani
Landscape	Hilly and plains	Plain land
Climate	Tropical, mild winter, hot humid summer, warm rainy monsoon	Tropical savanna, and humid subtropical
Command area	1,214,000 ha	750,000 ha
Irrigable area	922,000 ha	540,000 ha
Under irrigation	540,000 ha	111,406 ha
Soil type	Sandy or clayey loam	Sandy and alluvial
Hydropower	67.50 MW	N/A
Link canals	210.79 km	275 km
Beneficiaries	8 million	21 million
Year of operation	1989	1993

Sources: BWDB and Government of Sikkim.

Along with the barrage in the floodplain, India also constructed several hydropower plants in the upper Teesta region. Table 4 illustrates that, to date, six massive hydropower projects with 3,405 MW installed capacity have been constructed in the Sikkim state of India throughout 2006–2013. At present Teesta Hydel Project Stage-V is in operation, which is consuming vast amounts of water resources throughout the year. It emerges that, as an upstream state, India is extracting all the possible benefits of water resources by disregarding the water rights of Bangladesh. In addition, there is an inter-river linking project undertaking by India through the upstream Teesta river which will further exacerbate water scarcity in Bangladesh (Rahman *et al*., 2010).

4. Results and discussion

Table 5 demonstrates that the total agricultural demand for water in the upstream and downstream nations is 2,885, 2,208, and 1,115 cumec for command, irrigable and under irrigation areas, respectively, against the virgin flow of 198, 1,472 and 793 cumec in the dry (pre-monsoon), wet (monsoon) and lean (post-monsoon) periods, respectively. Here, it is evident that the overall demand for water

Table 4. Installed hydropower projects in the upstream basin of India.

Name of project	Installed capacity (MW)	Year of completion
Teesta Hydel Project Stage-I	280	2012–13
Teesta Hydel Project Stage-II	480	2011–12
Teesta Hydel Project Stage-III	1,200	2011–12
Teesta Hydel Project Stage-IV	495	2011–12
Teesta Hydel Project Stage-V[a]	510	2006–07
Teesta Hydel Project Stage-VI	440	2011–12
Total installed capacity	3,405	

[a]Operational power plant.

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Table 5. Estimates of water demand in upstream and downstream nations.

	Water demand in entire Teesta basin (m^3/s)				Virgin flow:1973–1985 (m^3/s)			Post-project water flow in Bangladesh:1996–2009 (m^3/s)		
Category	Agri. water demand in India	WDH in India	Agri. water demand in Bangladesh	Total demand	Dry season	Wet season	Lean season	Dry season	Wet season	Lean season
Command area	1,637	237	1,011	2,885	198	1,472	793	95	1,136	514
Irrigable area	1,243		728	2,208						
Under irrigation	728		150	1,115						

Note: WDH indicates water demand of hydropower.

generated through immense agricultural irrigation projects and hydropower plants is beyond the supply capacity of the Himalayan-sourced River Teesta. It appears that the command and irrigable areas are both developed ahead of the decadal virgin discharge in the different periods of the upper Teesta river basin. Total demand for water in the upstream and downstream basins can only be met in the wet season, particularly for the area that is presently under irrigation. Apart from the wet season, the virgin water flow is insufficient to meet the irrigation demand of the entire irrigable and under irrigation area. Thus, extreme water deficit occurs in the dry and lean seasons in the Teesta basin regions.

Since there is no hydropower plant in the downstream basin, only agricultural water demand is predominant here, whereas upstream water demand is led by massive irrigation and hydropower projects. The estimation illustrates that the upstream demand is 815 cumec or 85% higher than the downstream demand, which causes severe disruption of the water availability in the downstream basin. Furthermore, the operation of hydropower plants requires an additional 237 cumec water around the year in the upstream basin. Currently one out of seven hydropower plants is operational in the Sikkim, which requires 237 cumec water to produce 510 MW of electricity. It is perceptible that the agricultural demand of Bangladesh is much lower than the demand of the hydropower plant of the upstream region. The total water demand in the Indian part of the basin is estimated at 965 cumec against the 198 cumec decadal virgin flow. Though the current water discharge condition is unknown, it can be said that whatever the water discharge available at present it is inclusively harnessed by the upstream consumption, which is detectable by the post-irrigation project water discharge situation in downstream Bangladesh throughout 1996–2006. As the water discharge condition becomes acute during the dry season, the upstream nation may set the priority or trade-off between agricultural and hydropower water consumption.

In these circumstances, as the upstream nation, India tends to withdraw the maximum water resources for its own consumption; the amount of water Bangladesh receives is nevertheless at the very least to meet its irrigation demand only. After meeting the water demand in Indian barrage and dam areas, the trickle-down water Bangladesh receives is very scarce. It appears that, during India's post-barrage period (1996–2009), Bangladesh has received less than half of the water resource in the dry season than the virgin flow and a little more than half of the virgin flow in the lean season. Such unequal resource distribution triggers water conflict in this transboundary basin, which puts the relationship between these two close neighbours under profound suspicion.

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4.1. Impact of unilateral water diversion in the downstream region

It appears in Figure 3 that decadal water discharge of Teesta river has declined significantly in the post-project period. Here, water discharge in the downstream part of Bangladesh is found to be reduced by almost half throughout the year. This is due to excess water demand and withdrawal in the upstream sites. The Indian and Bangladeshi barrage construction was accomplished in 1989 and 1993, respectively. The period 1996–2009 saw the introduction of full-fledged operation of the Bangladeshi irrigation project, which experienced squeezed water flow during the dry and lean seasons and even during the monsoon compared with the natural or pre-project flow, which was due to the immense upstream intervention over the water resource of the trans-Himalayan River Teesta. It is found that the net change in water discharge is very substantial during this period compared with the decadal virgin flow. Except in June, each month experienced a severe decline in the water discharge, most prominently during July to December in the Bangladesh basin. Consequently, the lower Teesta region of Bangladesh experienced comprehensive water stresses and emerged in a helpless position to meets its water demand in the cropping seasons. Thus, irrigation failure, as well as project failure, has occurred and water-dependent agricultural production has been severely hampered.

Due to regular diversion and extraction of Teesta's water by India, water discharge has decreased steadily in Bangladeshi territory. Consequently, lower catchment areas of Bangladesh are deprived of the utilization of valuable water resources. As the dry season is considered critical in the Teesta basin areas due to prevailing higher water demand for agriculture, fishing and other livelihood activates, the lower discharge exacerbates the situation in both upper and lower riparian regions. Water demand is relatively higher in the dry season when Boro rice is mostly cultivated in the entire Teesta basin. In monsoon agriculture, only supplementary irrigation is required to grow crops but in the dry season full irrigation is obligatory for obtaining an optimum level of production. It is apparent that recent water

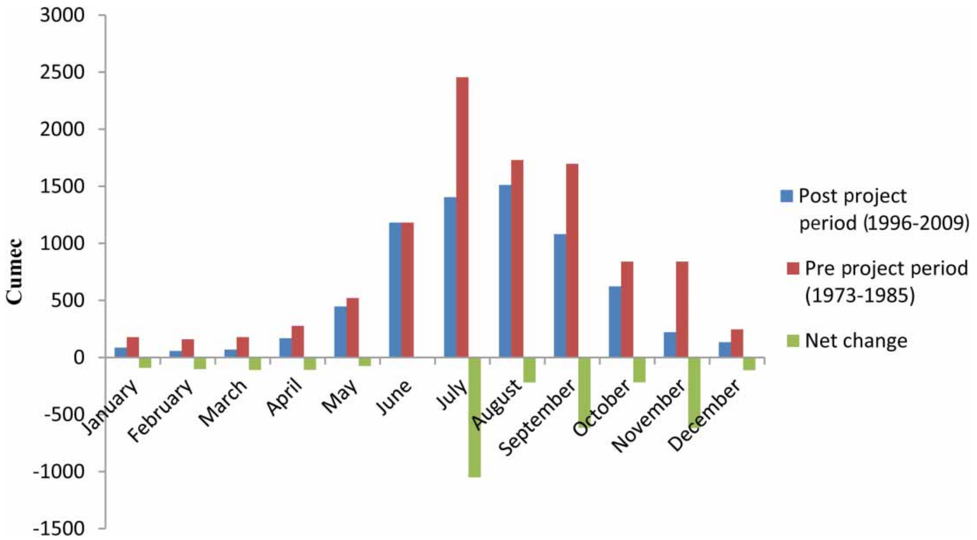

Fig. 3. Decadal water discharge in pre- and post-project period in the lower Teesta basin of Bangladesh. *Source*: Author's estimation based on the collected data.

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discharge in the lower Teesta basin of Bangladesh has faced remarkable volatility compared with the historical discharge, which reduces water availability to subsistence farmers and fuels the water uncertainty situation in downstream Bangladesh. After meeting water demand in upstream areas, the amount of water Bangladesh receives is insufficient to meet its agricultural water demand. Consequently, large-scale crop loss and damage occur in the downstream Teesta basin.

4.2. Ecological impact in the upper Teesta basin due to hydropower plant

Construction and operation activities of a series of mega hydropower, dam and irrigation projects cause immense disruption to the river basin ecology and environmental amenities of the upper Teesta mountain region and extensively squeeze the water availability and degrade the rich ecosystems of the lower Teesta basin of Bangladesh. The Indian Government and the Central Electricity Authority have prioritized the development of hydropower projects throughout the region, which is seismically vulnerable, rich in biodiversity, and home to many tribal communities.

Already over 71 km of the river, which flows through earthquake-prone, ecologically and geologically fragile terrain, is either in reservoirs or diverted through tunnels for hydropower generation. Construction of dams may cause river-stimulated seismicity and exert a higher strain on an active fault region of the upper Teesta basin. The 3,405 MW hydropower projects already installed impose a threat to river communities and the rich biodiversity of the Himalayan region. The upper Teesta river has become a contested battleground between the government and the indigenous Lepcha and Bhutia communities in Sikkim, India, as the ecology of Teesta river has seriously deteriorated. This has resulted in human and biodiversity displacement and destruction of species including the golden mahseer (*Tor putitora*) and the snow trout (*Schizothoraicthys progastus*), as well as affecting the livelihood opportunities of indigenous people (CISHME, 2007; FEWMD, 2013).

CISHME (2007) expressed concern that the dam areas hold considerable cultural and ecological value. Over 100 mammal species, over 230 bird species, 34 reptile species, 10 amphibian and 345 butterfly species, a good number of fish species and 7,500 trees are endangered due to construction of dam and hydropower plants. In the mountain ranges of the upper Teesta basin, 36 species are currently in the threatened category and 10 species at the near-extinction stage, and many ecosystems are at high risk of serious disruption due to anthropogenic action and infrastructure projects (CISHME, 2007; Acharjee & Barat, 2013). The intermediate catchment between Teesta Hydel project Stage-III and Stage-IV harbours a rich diversity of mammalian and bird fauna in addition to being a zone of diversity for butterflies. Therefore, any increased human activity in this critical zone would have an adverse impact on the habitats of these species. There is a possibility of reservoir-induced seismicity in the region owing to its geological setting, which clearly shows that no pondage of any duration should be allowed in this area as it would lead to geological instability resulting in the increased incidence of landslides.

The Indian Government has recently awarded contracts for the construction of an additional 26 hydropower projects along the Teesta which will further deteriorate the physical environment, natural processes, bio-physical drivers, ecological balance, mountain and Himalayan hydrology, ecosystems, human health, and biodiversity of the upper Teesta basin and downstream floodplains (International River, 2012; FEWMD, 2013; Arfanuzzaman & Mallick, 2016). The previously constructed and currently proposed hydropower projects will cause large-scale loss of cultivable land and forests, displace the population due to acquisition of private and community properties, and increase the

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incidence of water-related diseases including vector-borne diseases. Further, the land-use pattern, hydrologic regime, water quality, riverine fisheries including migratory fish species, air pollution and noise level during project construction phase, and terrestrial and aquatic ecology will be immeasurably impacted due to the construction and operation of hydropower plants (T.T. Energy, 2010).

4.3. Ecological impact in the lower Teesta basin due to barrage and hydropower plant

Due to the operation of upstream infrastructure, irrigation and production failure and ecological disturbance occur frequently to a larger extent in the downstream region of Bangladesh. In the dry and lean periods, the volume of water Bangladesh receives after the Indian demand is met is diverted into the main canal of TBP to serve agricultural irrigation. Since the upstream intervention, water discharge is much reduced in the dry and lean seasons and Bangladesh utilizes the entire available volume of water for irrigation during the Boro cropping period. As a result, for several years no water is found in the downstream river basin. Therefore, the Teesta river is dried up during the Boro cropping period in Bangladesh. In this circumstance, a large portion of the Teesta river basin becomes waterless and the river cannot perform its environmental and ecological functions smoothly. Hence, the ecological balance is disturbed and the river's ecosystem services, for instance provisioning and regulatory services, are severely inhibited. Further, reduced water flow in the lower Teesta extensively harms biodiversity, livelihood opportunities and food security in the river basin areas, which has a comprehensive cost in the short run and long run (Mullick *et al*., 2012; Acharjee and Barat, 2013; Arfanuzzaman & Ahmad, 2015b). In addition, river-bed rise, dryness, and river-bank erosion become a regular phenomenon, and availability of fish such as *Hilsha, Boal, Pabo, Rhui, Chengti, Tepa, Darka,* and *Kawa* is considerably reduced due to serious reduction of the water discharge upstream (Arfanuzzaman & Mallick, 2016). Water scarcity in the lower Teesta river basin affects groundwater recharge tremendously in the north-western region of Bangladesh, which forces the groundwater level to go lower. In Rangpur region, where people used to find water at 15–17 m deep, they are now getting water from 21–23 m below ground. Consequently, the moisture of the topsoil shrinks and the cost of water withdrawal increases significantly, which is very hard for the poor and marginal farmers to afford.

Figure 4 illustrates that initially the water discharge of Teesta river was nearly 170 cumec in the dry season. Then the water flow was observed to have reduced significantly during 2000 to 2014. In the extreme dry season, as well as in February and March, water levels have reached a critical level and even dropped to zero in some years. From 2005 to 2014 the lower Teesta basin of Bangladesh was found to be waterless five times in February, three times in March and once in April.

During the dry season, particularly from February to April, the necessity of irrigation is much higher due to Boro crop cultivation. It is evident that as the last decadal water discharge rate in the dry season is reduced comprehensively in the lower basin due to upstream intervention, water flow in Bangladesh is vastly insufficient for its irrigation scheme. Thus, all the water ought to be diverted in the TBP areas in different years, which can meet only some part of the irrigation demand in Bangladesh. Besides, an empty Teesta river cannot perform its ecological functions and fails to provide the provisioning, regulatory and cultural ecosystem services in the lower basin region during the dry season, which puts nature and the river-dependent community of lower riparian Bangladesh in great distress. As Teesta is the largest river in north-western Bangladesh, river-bed drying is expected to hamper its water, environment, and climate regulation activities, which will result in greater environmental cost in future

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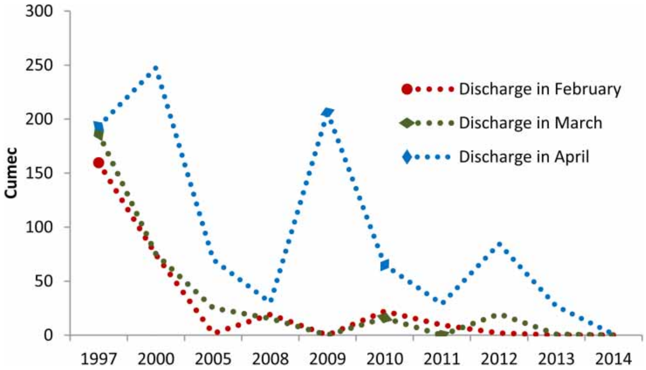

Fig. 4. Dry season flow in lower Teesta basin after meeting the demand of India and Bangladesh. *Source*: Author's calculation based on the collected data.

(Arfanuzzaman, 2016). If the required water discharge is not available in the lower Teesta basin from upstream in years to come, the Teesta river in Bangladeshi territory will experience dryness for a much longer period and hence the ecosystem services and ecological balance will both be compromised in the long run, which may bring irreversible effects on the environment and climate of the downstream region. Simultaneously, the livelihood, agriculture and fishing activities of poor and marginal groups will be impacted severely in these areas due to water and climate stresses (Arfanuzzaman, 2017a). Furthermore, Teesta river is a key tributary of another mighty river system, the Brahmaputra-Jamuna of Bangladesh, which is largely reliant on the Teesta river for water resource. If Teesta become waterless itself in the dry and lean seasons, it therefore cannot supply water to the Brahmaputra-Jamuna. Thus, the water flow of Brahmaputra-Jamuna river will also be affected. In this way the adverse consequences will be circulated from one basin to another basin and from region to region.

4.4. Net gain in terms of virgin flow in the lower Teesta basin of Bangladesh

When no infrastructure was built in Gazaldoba and different elevations of the upper Teesta Himalayan region to divert the water of Teesta basin, Bangladesh received consistent water flow. In the case of unavailability of the virgin or pre-project water discharge, the extent of the yearly benefit forgone in TBP area of the lower Teesta basin of Bangladesh is exhibited in Table 6.

It is apparent from Table 6 that during 2006–07 it was possible to cultivate only 11,323 hectares of land in the TBP of Bangladesh against the baseline of 63,506 hectares using the water resource of the Teesta. Hence, the loss was 52,183 hectares which equates to 339,190 metric tonnes of rice forgone in the Boro season. At current market price, the cost of this forgone production is nearly US$81.6 million. Negative gain can be seen each year due to unavailability of the expected 50% water in the Teesta river during the dry period. More explicitly, Bangladesh never received 50% of the virgin flow during the dry season when irrigation was started for Boro production in TBP area. It emerges that total production loss is 1,277,478 metric tonnes and the estimated cost is US$307.3 million for the unavailability of water from the upstream region. In some cropping years less than half of the 50% virgin flow was available in the lower Teesta basin, which increases the amount of negative gain in different cropping periods. It appears that water unavailability devastates the overall irrigation achievement in the irrigable area of the

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Table 6. Net gain in Boro production based on the virgin flow.

Cropping year	Baseline[a] (ha)	Achievement (ha)	Difference (ha)	Production gain (metric tonnes)	Net benefit (million US$)
2006–07	63,506	11,323	−52,183	−339,190	−81.6
2007–08	63,506	44,408	−19,098	−124,137	−29.8
2008–09	63,506	29,425	−34,081	−221,527	−53.3
2009–10	63,506	42,980	−20,526	−133,419	−32.1
2010–11	63,506	46,004	−17,502	−113,763	−27.4
2011–12	63,506	50,154	−13,352	−86,788	−20.9
2012–13	63,506	59,733	−3,773	−24,524	−5.9
2013–14	63,506	27,486	−36,020	−234,130	−56.3
		Total	−196,535	−1,277,478	−307.3

[a]Baseline is estimated on the basis of ADWF in Teesta river during the pre-project period and based on minimum water flow in the cropping season.

lower Teesta catchment during Boro season. The baseline irrigation was never achieved in the lower Teesta basin due to substantial shortfall of water discharge.

4.5. Estimated benefit of different WSAs

The water rights and win–win situation will subsist in the transboundary River Teesta only if both riparian nations receive an equal share of water for the inclusive economic growth and development of the basin region. Otherwise, only the upstream country will benefit at the cost of the downstream country's share of the water resources of Teesta. The upstream interventions not only restrict the water discharge in the lower basin but also degrade the rich Himalayan ecology and biodiversity and river ecosystem, and also obliterate the community interest of the upper Teesta catchment region to a large extent. Thus, to protect the interest of river basin communities upstream and downstream and maintain ecosystem health and sustainability of the Teesta river basin, detrimental dam and hydropower plant development needs to be controlled and prevented in ecologically critical areas. An equitable WSA can diminish the water stress from the riparian nations and help to sustain the larger socio-economic gain across the Teesta river basin. Table 7 illustrates the anticipated benefit for India and Bangladesh under different WSAs in the water-stressed dry and lean seasons where water demand is relatively higher in both basins. In order to estimate the expected benefit of different WSAs the virgin flow of the river is taken into account. The virgin flow is counted during the period 1973–1985 when there was no dam and barrage infrastructure. It is found that during the dry and lean seasons the virgin flow of Teesta river was 198 and 368 cumec, respectively. If Bangladesh and India receive equal shares of the virgin flow, they can cultivate 73,322 ha in the dry or pre-monsoon periods and 136,626 ha in the lean or post-monsoon periods, respectively. If Bangladesh receives 45% of the water, it can cultivate 66,003 ha in the dry season and 122,955 in the lean season, whereas India can cultivate 80,665 ha and 150,276 ha in the dry and lean seasons, respectively, if it receives 55% of water resources from the river, and so on. The benefit of one nation will be increased with an increase in the amount of water it receives over the equal share of transboundary water and vice versa.

If the dependable flow of the pre-project period is considered, the estimation differs to some extent. The estimates based on the 75% dependable flow of Table 8 point out that if both countries agree on a

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Table 7. Estimated benefit based on the virgin flow.

Different scenario of water treaty and its anticipated benefit	Bangladesh cultivated area (ha)		India cultivated area (ha)	
	Dry season	Lean season	Dry season	Lean season
Cultivating area in case of 50–50 WSA	73,322	136,626	73,322	136,626
Cultivating area in case of 45–55 WSA	66,003	122,955	80,665	150,276
Cultivating area in case of 40–60 WSA	58,674	109,284	87,998	163,947
Cultivating area in case of 35–65 WSA	51,324	95,634	95,340	177,597
Cultivating area in case of 30–70 WSA	43,995	81,963	102,669	191,268
Cultivating area in case of 25–75 WSA	36,666	68,313	109,935	204,918

Table 8. Estimated benefit based on the dependable flow.

Different scenario of water treaty and its anticipated benefit	Bangladesh cultivated area (ha)		India cultivated area (ha)	
	Dry season	Lean season	Dry season	Lean season
Cultivating area in case of 50–50 WSA	60,270	131,082	60,270	131,082
Cultivating area in case of 45–55 WSA	54,243	117,957	66,297	144,179
Cultivating area in case of 40–60 WSA	48,216	104,853	72,324	157,286
Cultivating area in case of 35–65 WSA	42,189	91,750	78,351	170,393
Cultivating area in case of 30–70 WSA	36,162	78,643	84,378	183,500
Cultivating area in case of 25–75 WSA	30,135	65,536	90,405	196,607

Note: In the Teesta floodplain 21 ha of land can be cultivated by 0.028 cumec of water.

50–50 water sharing treaty, India and Bangladesh will receive 80 cumec in the dry or pre-monsoon periods and 176 cumec in the lean or post-monsoon periods. Under this circumstance both countries will be able to cultivate 60,270 and 131,082 ha of land, respectively. If equal share of water is not ensured in the treaty, Bangladesh will be deprived of optimal crop cultivation and socio-economic well-being of a large number of people compared with the upper Teesta basin. Here, the expected benefit of Bangladesh will shrink along with the lower volume of water it receives from the 50% share. Here, the upstream nation will benefit at the cost of Bangladesh's exclusion from the water resources of Teesta. It depends on the negotiation capability of the downstream nation as to how much water resources it will receive from the upper riparian control. It deserves special mention that, apart from water harvesting, both nations must keep the minimum required water flow in the Teesta river to sustain the life and livelihood of the river basin region in the long run, which will help to attain the Sustainable Development Goals as well as ensure climate-resilient development pathways.

5. Conclusion and recommendation

The Himalayan region is recognized as a water tower of South and South-east Asia. In order to benefit from the water resources of the Himalayan-sourced transboundary rivers, river basins need to be managed jointly in a sustainable manner. Unilateral withdrawal of water in the upstream restricts economic gain and prosperity of the lower riparian people around the HKH region as well as around the world. This creates basin-level conflict and impedes transnational cooperation among the riparian regions. In

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the case of Teesta, transboundary conflict, exclusion, water stress, non-cooperation and ecosystem degradation are taking place due to over-extraction of water resources and immense upstream intervention through massive hydropower and irrigation infrastructures. Both countries need to work collectively to reduce water losses, increase water productivity, reallocate water for agricultural water demand management and promote healthy ecosystems in the river basin areas by ensuring minimum flow in the dry and lean seasons. It is evident that water demand of the irrigation and hydropower projects is much higher than the supply capacity of the trans-Himalayan River Teesta, which can be optimized by proper planning, managing and reserving the surplus water of the monsoon period, increasing irrigation efficiency, promoting fewer water-consumptive crops in the dry season and rain-fed crops in the monsoon season, and controlling the operation of hydropower during the dry season. Due to constant intervention in the upper Teesta basin it becomes a challenging task for the lower riparian country, Bangladesh, to acquire an equal share of water for the benefits of its riparian communities. Here, Bangladesh must put the emphasis on effective negotiation, strengthening the Joint River Commission, holding regular meetings with upstream authorities and political parties along with people-to-people communication to get an equitable share of water as an urgent need from the upper riparian control. At the negotiation table Bangladesh should also claim the cost of water scarcity at the basin level, which arises due to diversion of water in the Indian part of the basin. In order to sustain the ecosystem services' flow and water-reliant livelihood options of the lower Teesta basin, minimum environmental flow is required. In this regard the water-sharing treaty can be designed in such a way that a certain amount of water will always flow in the entire basin to meet the ecosystem requirement as well.

Upstream water withdrawal and comparative economic gain over the well-being of the downstream nation will fuel the sub-regional tension, conflict, and mistrust between these two close neighbours and hinder water prosperity in the HKH region. Himalayan-sourced rivers are a blessing for economic growth and well-being among the communities living across the river basin areas. The riparian nations of Teesta should treat the transboundary river as a single unit for sustainable river basin management and restore the river's ecosystem by terminating environmentally damaging dam and hydropower projects upstream. To achieve greater socio-economic benefit and sub-regional water cooperation in the Teesta basin, both neighbour countries should engage in sustainable river basin management and mitigate the shock of extreme climate events such as flooding, flash flooding, drought etc., collectively. At the superficial level, relations between India and Bangladesh seem to be sailing through troubled waters. The failure to sign the Teesta WSA is apparently the most visible example of the lack of reason in the relations between Bangladesh and India. The reality is that the problem of water scarcity in the dry and lean seasons can be solved only through a joint endeavour for basin-level planning, management, augmentation and conservation of valuable water resources. Considering the Teesta as a source of cooperation, instead of conflict, can provide environmental, political and economic benefit to both nations and serve as an ideal example to other riparian nations of the HKH region and the rest of the world.

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