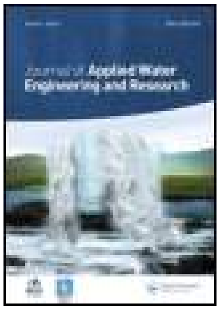

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# Benefit functions for instream water uses - a case of the Teesta River, Bangladesh

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# Benefit functions for instream water uses – a case of the Teesta River, Bangladesh

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The functional relationship between bene“t level and resource availability, which is demonstrated in a marginal bene“t (MB) function but not in a total bene“t (TB) function, is mostly absent in environmental valuation studies. This paper aims to establish the total and MB functions for instream water direct uses. Incomes of the bene“ciaries considered as the water-use bene“t and its seasonal variation within a year obtained from a semi-structured primary survey are used to establish a quadratic TB and subsequently a linear MB function. The Teesta River from Bangladesh is taken as a case study where capture “shery and small-scale navigation are the instream water direct uses on which many riparian poor rely for their livelihood. Despite several challenges including data paucity, the study carries importance to persuade instream ”ow provision and safeguard the livelihoods of the poor riparian communities in a developing country perspective.

**Keywords:** bene“t function; instream water uses; “shery; navigation; instream ”ow values; basin water management; Teesta River, Bangladesh

## 1. Introduction

Water carries both commodity bene“ts and environmental values (Dinar et al. 1997; Young 2005). Securing in particular the commodity bene“t of water resources, human intervention on natural ”ow is a common phenomenon around the world (Richter et al. 2006). Such modi“cations of the natural ”ow have brought humanity many bene“ts; however, it has broken the river…human linkage markedly observed in developing countries. Modi“cation and alteration of natural ”ow have resulted in the degradation of river health, loss of ecosystem goods and services leading to signi“cant economic damage to society (King 2009). Minimum instream ”ow is imperative for sustenance of the scattered, informal, small-scale uses even though traditional water management often neglects such uses and prioritizes of o stream human demands ( Kashaigili et al. 2005; Richter et al. 2006). Yet recent researches argue that a better understanding of bene“ts and costs involved with instream water provisioning is necessary to ensure instream ”ow and river health (Moore 2004; Scatena 2004). Economic bene“t of instream uses, such as “sheries, navigation, recreation and wetlands, is the fundamental along this line to institute instream ”ow and o er appropriate balance between environmental needs and human consumption.

The value of water depends largely on so-called use-dimensions that re”ect the circumstances of water uses, i.e. the place (o - or insteam), economic role (private or public good) and form of water uses (consumptive or non-consumptive use) (Agudelo 2001; Lange 2007). Instream water uses are mostly non-consumptive with direct and/or indirect uses. Techniques based on market and non-market approaches are available for measuring the economic bene“ts of water uses at di erent use-dimensions combining the established economic theories and applied economic practices. The dimension and signalling of economic bene“t of instream water uses are markedly at variance with o stream uses (Daubert & Young 1981). Relatively accurate information on marginal bene“ts (MBs) of o stream, consumptive uses are available; however, measuring economic bene“ts of instream, non-consumptive uses at di erent ”ow levels are a challenging problem.

To date, there have been a number of researches that have tried to “nd bene“ts of instream water uses, mainly recreational boating, “shing, rafting and the like. Majority of these researches applied contingent valuation method (CVM) and/or travel cost method (TCM). CVM is a stated preference technique based on hypothetical market using surveying of a sample of persons asking individual willingness to pay (WTP); whereas TCM is a revealed preference technique, which accounts cost of travel incurred for visiting a recreation site is considered. Majority of these studies estimating the bene“t of recreational use of instream water or ecosystem services are found predominantly in developed regions (Daubert & Young 1981; Du eld et al. 1992 ;

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Booker & Colby 1995; Douglas & Taylor 1998; Loomis 1998; Weber & Berrens 2006 all from the USA) except few in developing countries, e.g. Xu et al. (2003) in China and Ojeda et al. (2008) from Mexico. Studies related to valuation of water for navigation use are rare. Gibbons (1986) provided a comprehensive treatment of the topic and mentioned the short-run average bene“t of water for navigation in six di erent cases from the USA.

Majority of instream water-use valuation studies estimated total bene“t (TB) of the instream water and associated services rendered to society rather than the bene“t function. A certain “gure of TB is not able to depict the changes in bene“ts at di erent ”ow levels. Currently practiced measure of the total economic bene“t at a given level of water use is typically inadequate (Gri n 2006 ) and does not help much to the water managers in managing the resource e ciently due to its failure in re”ecting equitable distribution of gains and losses among individual uses (Turner et al. 2004). TB quanti“cation may provide limited justi“cation for water investment decision ( Young 1996), but the e cient resource management often involved in trade-o analyses calls for equating MBs of the resource in its alternative uses (Dinar et al. 1997; Agudelo 2001; Turner et al. 2004; Gleick et al. 2006; Moran & Dann 2008). Moreover, only single-point measurement of the MB does not enable the same level of managerial power as does knowing the MB function (Gri n 2006 ).

Daubert and Young (1981) and Du eld et al. (1992) are among the very few studies that estimated the MB function for the recreational uses of instream water in the USA. Study measuring the total and MB functions for instream water uses mainly by the informal and poor riparian users in developing countries is extremely rare and no study is available in particular from Bangladesh. Struggling with considerable data paucity, this paper intends to “ll the research gap by using a case study. The aim of this paper is to provide a simple and easily adaptable method to assess the total and MB functions of small-scale riparian instream water direct uses with its application for the Teesta River in Bangladesh.

## 2. Concepts and procedures

Since this study focuses on developing a method to assess instream water direct uses bene“ts and further application of the method to the Teesta River, Bangladesh, direct uses of instream water in Teesta are only considered hereafter. Likewise overall country situation, capture “shery and navigation are the main instream water direct uses in the Teesta that carries signi“cant economic interest. The “sheries sector with its high level of biodiversity and food value plays a signi“cant role to the overall economy of Bangladesh. The sector contributes about 60% of the animal protein to the daily diet, 5.24% of country•s gross domestic product (GDP), 7% of export earning and provides livelihood to about 10% of the total population (Oliver 2002; Ahmad 2005). Navigation is an important mode of transportation especially in a country like Bangladesh having many rivers. In Bangladesh, transport accounts for about 8% of the overall GDP and water transport generates about 15% of total transport-GDP (World Bank 2005). The following sections address the concepts and procedures adopted to estimate “shery and navigation bene“t.

### *2.1. Concepts*

Either of the two basic approaches of revealed and stated preference is predominantly used to determine economic bene“t of environmental goods and services ( Daubert & Young 1981). The former approach involves analysing relevant market transactions in goods and services, whereas the latter one uses survey to identify individual•s WTP from a hypothetical setting. Despite having advantages and disadvantages for obtaining economic bene“t using those approaches, most economists prefer to use market data, since such analyses are based on the actual behaviour rather than a hypothetical situation. This paper uses actual market bene“t of “sh production and navigation to estimate the instream ”ow bene“ts where “shermen and boatmen income data act as the basis.

Fishery … Towards looking into “sh production at different ”ow levels in the river, a deep-rooted hydrological… ecological link is a requisite; however, such a link is not yet well established in contemporary literature (IWMI 2005; Arthington et al. 2006). The physical habitat simulation model (PHABSIM) developed by Bovee (1982) calculates an index related to the amount of microhabitat available for di erent life-stages at di erent ”ow levels. The method was especially focused at protecting a single species (sport “sheries in North America). Nevertheless, developing a relation between river discharge and all species• habitats, in an integrated form for a complex tropical “shery, with high level of biodiversity using PHABSIM is again hard to approach.

Instead, the overall habitat can be considered as a proxy to total “sh production or catch which can easily be incorporated further into an economic term. Then it needs a relation between overall habitat and hydrological parameters. Few literature worked on this issue. Recently, the World Bank (2004) developed a •feeding opportunity index• for Mekong as a surrogate of “sh production and tested for the Cambodian Dai “sheries. This index calculates the productive habitat as the product of area inundated (from water level) and number of inundation days. Baran et al. (2001) modelled a logarithmic water level…catch relation for the Cambodian Dai “sheries and found a relation between water level and Dai catches. Such researches provide a background on hydrology-habitat inter-dependency. This paper considers the link between ”ow (hydrology)-habitat-production for “shery water valuation.

Navigation … For short-run and at-source valuation of water for inland transport, all operating costs subtracted from the estimated gross bene“ts of the water transport facilities yield the economic bene“ts for water in navigational use (Gibbons 1986). The short-run bene“t would be justi“ed due to the high seasonality of navigation, where a negligible MB is realized at the high ”ow period and vice versa. Based on these principles water bene“t for navigation is derived. The boatmen income is considered as the gross bene“t from navigation water use.

### *2.2. Procedures*

Bene“t of the “sh production or navigation is considered equal to “shermen /boatmen income for a certain time period, e.g. month or season. A primary survey was administered to the riparian “shermen and boatmen group to identify their income as well as income variation at di erent ”ow levels. Total numbers of bene“ciaries are deduced from demographic information. Aggregated incomes of the groups over alternative instream ”ow levels map out the total instream ”ow bene“t function. Its “rst-order derivative gives the MB function.

Fishing e ort and its associated cost is the fundamental economic component in the biological production of a “shery (Ahmed 1991; Tietenberg & Lewis 2009). Each unit of e ort is composed of a standard size of labour, gear, vessel and some other necessary inputs per unit of time. The market prices of these inputs constitute the cost of the e ort. Since each unit of e ort is capable of catching certain amount of “sh, the cost of a particular unit of e ort is equivalent to the cost of producing the corresponding amount of “sh. In the case of navigation several cost items are involved namely, O&M of boats, food, oil, etc. Operating costs for the cases of “shermen and boatmen are considered and deducted from their income to reach the bene“t of the corresponding water use.

Considering a single input, such as river discharge, and a single output, i.e. “sh catch or “shermen income or boatmen income, a quadratic function (synonymously used as TB function hereafter) would re”ect suitably the usual shape of the relationship: while resource mobilization increases, output “rst increases then stabilizes and then decreases. Such a principle refers to setting a marginal physical product curve (or simply put, a marginal product curve), commonly used in microeconomics, and was followed in earlier studies of natural resource economic valuation, e.g. Daubert and Young (1981), Bishop (1989 cited in Booker & Colby 1995), etc. Moreover, the Tennant (1976) method for assessing environmental ”ow requirement (such as 50% and 40% of mean annual ”ow is, respectively, excellent and good for “sh even in the high ”ow season) implicitly indicates that “shes do not need complete virgin ”ow but the virgin ”ow is not at all detrimental, which indicates a decreasing marginal utility of ”ow for “sh habitat. Brown (1991) mentioned that this perception can be applied for any time or over an entire year assuming a favourable time distribution of ”ow. Considering all these arguments, TB function is developed as a quadratic function in terms of ”ow as shown in Equation (1).

$$\mathrm{TB} = \beta_0 + \beta_1 {}^{*}\, \text{”ow} + \beta_2 {}^{*}\, \text{”ow}^2, \qquad (1)$$

where TB is the total bene“t from the water used in particular instream use, $\beta_0$ is the constant, $\beta_1$, $\beta_2$ are the coe cients and ”ow indicates the river ”ow ($m^3\,s^{-1}$). The average income for the respondents for a speci“c time period and mean discharge for the stated period are used in estimating the bene“t functions. The theoretical set-up of such a model is quite robust; however, empirical validation is really tricky. No such literature is found at this moment. This paper “rst attempts to validate the model while faced with several challenges such as small sample size, very limited number of points to run the regression, scarcity of resources and secondary information.

## 3. Study site

Teesta, the fourth main river in terms of discharge in Bangladesh, is chosen for this study. The Teesta originates from the glaciers in Sikkim, India, at an elevation of 7128 m in the Eastern Himalayas. The river enters into Bangladesh at Chatnai, Nilphamari district and meets the Brahmaputra known as the Jamuna in Bangladesh. The total length of the Teesta is about 315 km of which about 113 km fall inside Bangladesh (Bari & Marchand 2006). It is a sandy braided river with a steep slope, exhibiting high seasonal ”ow variability and cause inundation of ”oodplains in monsoon and low ”ow conditions in dry season. Teesta is the main source of water in northwest drought-prone yet agricultural potential region of Bangladesh. River ”ow has been regulated since 1987 when India constructed an irrigation barrage at Gazaldoba. Afterwards another barrage was established at the Dalia-Doani point inside Bangladesh in 1990 to supply water to Teesta Irrigation Project (TIP) (Figure 1).

In recent years a drastic ”ow reduction has been observed resulting in an alarming situation for agriculture as well as for instream users downstream to the barrage in Bangladesh part. Bangladesh Water Development Board (BWDB) provided daily mean discharge for the period of 1967…2006 at Kaunia which is the only ”ow gauge station downstream to the barrage and before Teesta•s con”uence with the Jamuna. Table 1 depicts the long-term ”ow characteristics of the Teesta based on last 40 years discharge at Kaunia. The ”ow characteristics are presented in a seasonal form breaking into three time periods, pre-barrage from 1967 to 1990, post-barrage-1 from 1991 to 2000 (low impact) and post-barrage-2 from 2001 to 2006 (severe impact). The seasons are categorized as the high ”ow season for the months of June to September, the intermediate ”ow season for October, November, April and May and the low ”ow season for months of December to March. Table 1 shows that the ”ow in the Teesta distinctly varies in between the seasons; however, the ”ow is decreasing with time for almost all the seasons. Highest ”ow is observed in July and the lowest is in February.

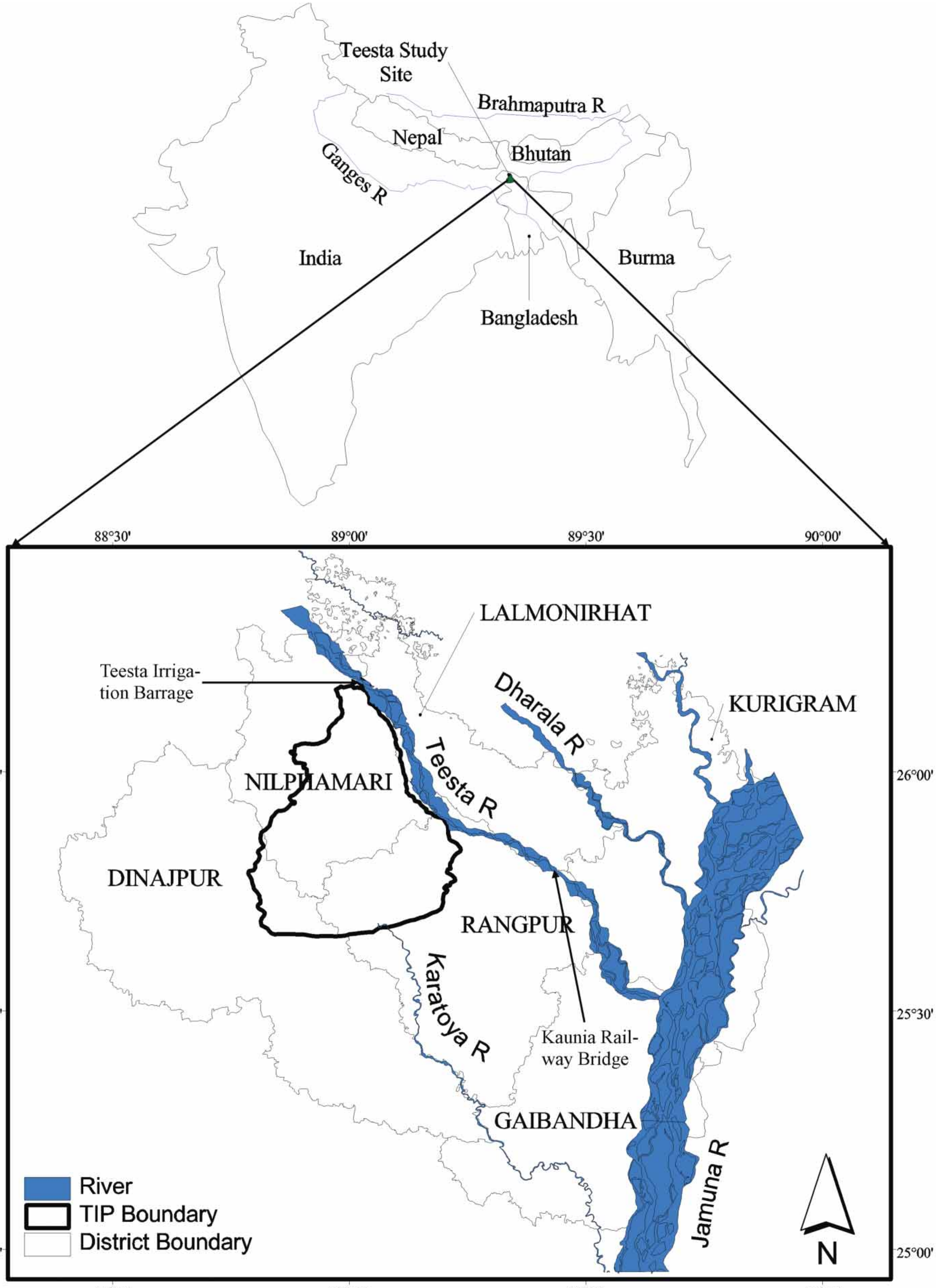


Figure 1. Location map of the study site along the Teesta River, Bangladesh.

Table 1. Estimated selected long-term ”ow characteristic of the Teesta at the Kaunia point.

| Period | High ”ow season | | | Intermediate ”ow season | | | Low ”ow season | | | Annual ”ow |
|---|---|---|---|---|---|---|---|---|---|---|
| | MMX | MMF | MMN | MMX | MMF | MMN | MMX | MMF | MMN | Mean |
| 1967…1990[a] | 3674 | 1970 | 1031 | 1159 | 519 | 310 | 228 | 169 | 139 | 886 |
| 1991…2000 | 3647 | 2140 | 1271 | 926 | 500 | 275 | 226 | 152 | 110 | 931 |
| 2001…2006 | 2259 | 1548 | 966 | 770 | 408 | 174 | 114 | 80 | 50 | 679 |

Notes: All ”ows are measured in $m^3 s^{-1}$. MMX, mean monthly maximum ”ow; MMF, mean monthly ”ow; MMN, mean monthly minimum ”ow.
[a]Pre-barrage period.



In addition to the proper functioning of the riverine ecosystem, ”ow in the Teesta is important for capture “shery and small-scale navigation mainly by the riparian poor. Instream water requirements set forth in di erent management plans until now are based on some rudimentary judgment (Bari & Marchand 2006) even though National Water Management Plan (2001) and National Water Policy (1999) recognized the environmental water needs for the rivers to some extent.

The study site is a section of the Teesta River between the barrage (Bangladesh side) at the upstream and Kaunia (Rangpur district) at the downstream that is about 70 km in length (Figure 1). The study site covers three administrative districts of the country, namely Lalmonirhat, Nilphamari and Rangpur. For administrative purposes, Bangladesh is divided into districts, sub-districts (Upazila) and unions and the latter one is the smallest unit.

Overall the socio-economic condition of the study area (the three districts) is extremely poor. Agriculture is central to the economy and the main occupations of the inhabitants are farming, labour selling, “shing, rickshaw pulling and to a lesser extent small-scale navigation. Literacy rate is only about 40% concentrated in young and children (BBS 2005). Along both the river banks, no domestic or industrial water abstractions from the river exist. The adjacent areas of the river banks are completely rural with poor accessibility due to the ill-developed transportation system. A number of people at the site are engaged in “shing and boating as their prime livelihood activities. However, data and information related to these livelihood activities were not available from any source. No information was on hand on “sh production, varieties of instream water uses, number of instream water users and their life or income pattern based on river ”ow.

## 4. Primary survey and underlying assumptions

### *4.1. Delineation of the site*

Total income from the bene“ciaries would be considered as the bene“t from instream water direct uses; however, administering the primary survey among the bene“ciaries needs “rst to draw the boundary of the study site within which the bene“ciaries live in. Given that demographic information database will be used to “nd out the total number of bene“ciaries, delineation based on administrative unit is necessary. Since •union• is the smallest administrative unit in Bangladesh, only the riparian union along both the banks of the river is considered as the study area. From the barrage at upstream to Kaunia at the downstream (i.e. the study site), 26 riparian unions are found at both the banks of Teesta.

### *4.2. Total number of beneficiaries and sample size for the survey study*

The available information from the national demographic database (i.e. BBS 2005) is the number of households and persons engaged in “shing and transportation activity, respectively, at the union level. To “gure out the total number of “shermen and boatmen is quite tricky here and few assumptions were undertaken. In the case of the “shermen group, it is assumed that (i) the “shermen who are working at the Teesta study site live in the riparian unions, (ii) this “shermen are engaged only in capture “shery and (iii) one person from each household is engaged in “shery work. Based on the assumptions and using data from BBS (2005), total 920 “shermen were found working in 26 riparian unions of the study site. Sample size for the primary survey is estimated to be 90 based on Equation (2) as suggested by Israel (2009).

$$n = \frac{N}{1 + N(e^2)}, \quad (2)$$

where $n$ is the sample size, $N$ is the population size and $e$ is the level of precision which is considered as 10% in this case.

The case of boatman is more intricate because the available information at the union level is the number of persons working in the transportation sector but not speci“cally for water transport. Bangladesh Labour Force Survey (2005) provided the number of people engaged in the transport sector as well as in inland water transport separately for mechanized and non-mechanized groups. Since the boats in the study site are mostly non-mechanized, the proportion of the number of people working in the inland water transport non-mechanized sector to the total number of people working at the transport sector was used in estimating the total number of boatmen at the study site following Equation (3).

$$\mathrm{TNB} = \sum_{j} \mathrm{PWT}_U^* \frac{\mathrm{PWWT_{NM}}}{\mathrm{PWT}_C}, \tag{3}$$

where TNB is the total number of boatmen, PWT indicates the people working at the transport sector, $\mathrm{PWWT_{NM}}$ is the number of people working in the inland water transport non-mechanized sector, $U$ is the riparian union, $C$ indicates whole country, $j = 1, 2, \ldots, n$ the number of riparian unions. The values of $\mathrm{PWT}_C$ and $\mathrm{PWWT_{NM}}$ are 2,670,000 and 56,587, respectively, as obtained from Bangladesh Labour Force Survey (2005). Using union-speci“c data from BBS (2005), total 51 boatmen were estimated working at the site. Calculation based on Equation (2), the sample size appeared as 34 considering $e = 10\%$. However, Israel (2009) mentioned that if the population is small, the sample size can be reduced slightly. This is because a given sample size provides proportionately more information for a small population than for a large population. In such cases, the adjusted sample size ($n_0$) can be adjusted using Equation (4) given by Israel (2009).

$$n_0 = \frac{n}{1 + (n-1)/N}, \tag{4}$$

where $n$ is the previously calculated sample size and $N$ is the population size.

The population size 51 can be considered small and in this case the adjusted sample size for the primary survey on the boatmen group is 20.

### *4.3. Questionnaire survey*

A semi-structured primary survey was administered (in local language) to the “shermen and boatmen group in arbitrarily selected 11 riparian unions out of 26 in May and June 2008. Ninety-seven “shermen and 23 boatmen were approached randomly where responses were collected from 91 “shermen and 21 boatmen.

The questionnaire was focused on two parts, “rstly the dependency (livelihood) of the target groups on river discharge and the variations of their income level with the changes in river ”ow within a year (open-ended questions), secondly the socio-demographic with few other questions (close-ended questions). An in-depth conversation was held with the individual for the “rst question matter and the latter part was structured and focused into speci“c questions on name, address, age, experience, education, sex, working days per week, family size and “shing mode in the case of “sherman (individual or group “shing) of the respondents. Instead of looking into gears, individual or group catching was queried for the “shermen for the simplicity since it was observed at the site that individual catching relates with simpler gears than group catching. For the “rst part, individuals were asked to respond on their income within a year dividing into as small time slice (e.g. month or season) as possible. Questions were also asked on alternative employment opportunity and corresponding income in the case when regular income falls very short. Income value is then related with corresponding mean ”ow for that time slice. Mean discharge data at Kaunia as obtained from BWDB are used in this case.

## 5. Results

While answering the question related to income and its variation over ”ow ”uctuation within a year, all the respondents answered their income as daily and for three di erent seasons. The seasons are (i) the dry or low ”ow season from December to March, (ii) the wet or high ”ow season from June to September and (iii) the intermediate ”ow season for the months of April, May, October and November. The observed average daily income in a season of an individual from the target group is considered uniform over the entire season. The boatmen receive the highest income in the high ”ow season and the the lowest in the dry season. Three income values therefore are recorded for this group. Respondent boatmen also mentioned that at the severe low ”ow condition people usually walk across the river and boatmen income falls tremendously whereas ”ood occurrences are good for them if only the income from boating is considered.

In the case of the “shermen group, seasonal breakdown of their answers on income was bit di erent even though they also identi“ed exactly three seasons. However, “ve income values in three seasons were reported from all respondent “shermen. Exception happened only in the dry season. Survey shows that the dry season is favourable for “shing; however, very dry condition is not encouraging. According to the respondents early dry season (“shermen were not able to mention the exact month rather they said early or post season; early dry is considered as December and January) has the highest income whereas income falls to the lowest in the mid of the dry season, i.e. that the driest time in the season and which normally happens in February. The late dry season month (March) normally follows an income pattern similar to the intermediate ”ow season. Wet season months (June to September) have normally low daily income. Hence, the “ve daily income values for “ve periods (December…January, February, March, Intermediate ”ow season and Wet season) are obtained from the respondent “shermen.

The post-barrage period (1991…2006, 16 years) average ”ow is considered to develop the quadratic bene“t function for both the water uses. Experiences of “shermen and boatmen from primary survey were obtained as 20 and 18 years, respectively, which indicates that most of the “shermen and boatmen working at the study site are working in the post-barrage period. Table 2 represents seasonal mean ”ow and corresponding daily income in taka[1] of an individual “sherman and boatman as obtained from the survey analysis.

Table 2. Seasonal ”ow and income of the “shermen and boatmen.

| Season | Months | Mean ”ow ($m^3\,s^{-1}$) | Average (for $n = 91$) daily income (Tk) for “shermen | Average (for $n = 21$) daily income (Tk) for boatmen |
|---|---|---|---|---|
| Dry (low ”ow) | December and January | 152 Seasonal average $= 125$ | 207 | 68 |
| | February | 88 | 54 | |
| | March | 107 | 123 | |
| Intermediate ”ow | April, May, October and November | 466 | 123 | 190 |
| Wet (high ”ow) | June to September | 1918 | 73 | 464 |

Note: Tk, taka, the national currency of Bangladesh worth 70 taka ≈1 USD.

Table 3. Descriptive statistics of the boatmen and “shermen surveys.

| Variable | Average value for the “shermen group ($n = 91$) | Average value for the boatmen group ($n = 21$) |
|---|---|---|
| Respondent age (year) | 37 | 31 |
| Experience (year) | 20 | 18 |
| Education (yrs of schooling) | 2 | 1 |
| Family size (members) | 5 | 5 |
| Working days in week | 6 days, $n = 16$<br>7 days, $n = 75$ | 6 days, $n = 4$<br>7 days, $n = 17$ |
| Individual or group “shing | Individual $n = 29$<br>Group $n = 62$ | |
| Sex | Male $n = 91$ | Male $n = 21$ |

Average values obtained for the other questionnaires are reported in Table 3.

The study targets to estimate the short-run bene“t that relates to operating costs only; however, the operating costs of the poor “sher group in the Teesta consist of own labour and time. Survey on the “shermen and boatmen reveals that they are mostly landless (>90%) and very poor (daily income in odd situation fall below one dollar a day). Agriculture labour selling is the only option for them to switch the livelihood. The key question is the timing; agriculture labour demand is high in the dry season while the dry season is favourable for the “shermen. Boatmen can switch to agriculture labour selling since their income falls tremendously in the dry season from boating; however, all of them do not do that. In general, the boat is run by two persons mostly from the same family and one person sometime goes for labour selling but the other remains with the boat. The reason behind is they do not want others to take up the same job. Considering all the situations, opportunity costs of labour and time are regarded as insigni“cant. The other operating costs are minor too since most of the boats including “shing boats are manually operated. Marginal cost of “shing and boating also would not be very high. Cost is therefore omitted in bene“t calculation.

Question was also asked on “shermen•s views on the low income at the high ”ow season. Fishes breed and migrate to ”oodplain in the wet season and the local group is aware of the fact. Fishermen acknowledge the importance of the wet season ”ow despite their low income. In the wet season density of “sh (no. of “sh per unit volume of water) decreases, this probably results in less catch with the same e ort in a certain period of time. Fishermen also added that the number of “sh catcher increases in the wet season. The modest agricultural activity in the wet season as well as frequent ”ooding constrain the poor•s livelihood and impel them to go for “shing or boating as their daily livelihood in high ”ow season. Increased number of “shermen and lower concentration of “sh in high ”ow reduce the per capita income in this season. Moreover, the inherent meaning of economic bene“t implies a resource scarcity which is not at all the case for Teesta water in the wet season. Balance of this argument implies that the wet season income of the “shermen is a ected by some external factors and of less of interest from an economic point of view, therefore this income value is dropped in estimating the TB function of “shery water use.

The estimated quadratic function between individual “sherman income and mean ”ow for the respective income period represents the TB function for the water in “shery use (Equation (4a)). While estimating the TB function, an intercept indicating nil bene“t from a certain ”ow is considered which is practically an obvious case. Such an intercept is found in earlier researches related to instream water use, e.g. Ringler and Cai (2006), Baran et al. (2001) for “shery and Jager and Bevelhimer (2007) for hydropower. This critical ”ow value for “shery use is taken from a PHABSIM study for the Teesta River by Bari and Marchand (2006). The study presented the monthly habitat duration curve for the main “sh species (Boirali, *Aspidoparia morar*) of the Teesta River and weighted usable area (WUA) against di erent discharge levels. For the 100% habitat exceedence probability (i.e. zero habitat) for the driest month February, the WUA was determined and the corresponding discharge was found to be about 50 $m^3/s$. The present study therefore considers an average ”ow of 50 $m^3/s$ as the critical ”ow that results in zero catch meaning zero bene“t. The “rst-order derivative of the TB function with respect to •”ow• generates the MB function (Equation (4b)). TB and MB are measured in taka.

$$\mathrm{TB}_F = -0.0055 * \text{”ow}^2 + 3.181 * \text{”ow} - 158.06, \qquad (4a)$$

$$\mathrm{MB}_F = -0.011 * \text{”ow} + 3.181. \qquad (4b)$$

Based on the calculated bene“t function, a ”ow of 287 $m^3\,s^{-1}$ gives the maximum daily income or the maximum bene“t in the “shery sector, which implies the zero MB. Figure 2 portraits the TB and MB functions for the instream water use in the “shery sector.

The approximated quadratic TB function for individual boatman was established in a similar way as the “shery case was done. Boatmen responded that in the driest condition people cross the river by walking and their income goes closer to zero, which helps to consider the intercept in this case. They added that such a situation is happening in recent years most likely in February. Considering their responses, mean ”ow of the driest month, February (24 $m^3\,s^{-1}$) for the period of 2001…2006 is considered as critical ”ow when boatmen daily income is considered as zero. Total and MB functions are reported in Equation (5a) and (5b), respectively. The maximum bene“t-generating ”ow for the boating sector in this case is 2400 $m^3\,s^{-1}$. Figure 3 represents the total and MB function for the instream water in navigation use.

$$\mathrm{TB}_F = -0.0001 * \text{”ow}^2 + 0.477 * \text{”ow} - 2.24, \qquad (5a)$$

$$\mathrm{MB}_F = -0.0002 * \text{”ow} + 0.477. \qquad (5b)$$

For both the “shery and navigation cases, the quadratic TB function was found to be the best “t; however, the number of observations is very limited. The negative coe cient of $\text{Flow}^2$ in the TB function for both the instream water uses indicates a downward sloped MB functions and the positive value coe cient for Flow in the same function indicates an initial positive MB.

Table 4 represents the total and MBs for the whole “shermen and boatmen group at some representative ”ow levels. At a very low ”ow level such as 50 $m^3\,s^{-1}$ “shermen income practically becomes zero whereas it becomes negative from the model calculation. Around 300 $m^3\,s^{-1}$ ”ow is optimum

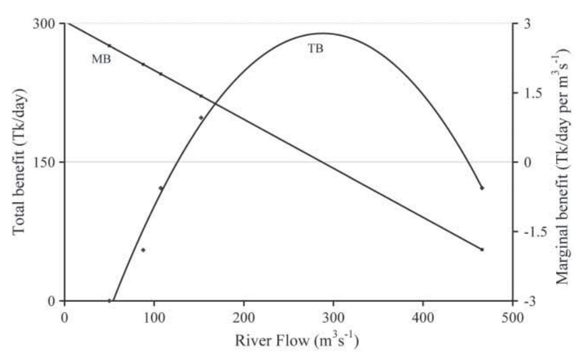


Figure 2. Estimated total and marginal bene“t function for individual “sherman.

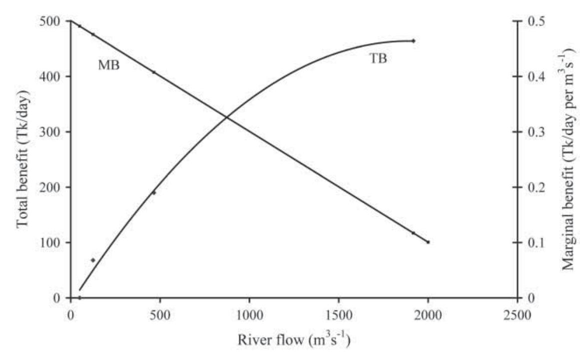


Figure 3. Estimated total and marginal bene“t function for individual boatman.

Table 4. Total bene“t (TB) and marginal bene“t (MB) for the instream water uses, “shery and navigation at several representative ”ow levels.

| | Fishery water use | | | | Navigation water use | | | |
|---|---|---|---|---|---|---|---|---|
| Flow ($m^3\,s^{-1}$) | Individual TB ($Tk\,d^{-1}$) | Aggregated TB ($Tk\,month^{-1}$) | Individual MB ($Tk\,m^{-3}\,s^{-1}\,d^{-1}$) | Aggregated MB ($Tk\,m^{-3}\,s^{-1}\,month^{-1}$) | Individual ($Tk\,d^{-1}$) | Aggregated TB ($Tk\,month^{-1}$) | Individual MB ($Tk\,m^{-3}\,s^{-1}\,d^{-1}$) | Aggregated MB ($Tk\,m^{-3}\,s^{-1}\,month^{-1}$) |
| 50 | −13 | −352,176 | 2.63 | 72,616 | 21 | 32,692 | 0.47 | 715 |
| 100 | 105 | 2,899,104 | 2.08 | 57,436 | 44 | 68,051 | 0.46 | 700 |
| 150 | 195 | 5,391,384 | 1.53 | 42,256 | 67 | 102,644 | 0.45 | 684 |
| 200 | 258 | 7,124,664 | 0.98 | 27,076 | 89 | 136,472 | 0.44 | 669 |
| 300 | 301 | 8,314,224 | −0.12 | −3284 | 132 | 201,834 | 0.42 | 638 |
| 400 | 234 | 6,467,784 | −1.22 | −33,644 | 173 | 264,135 | 0.40 | 608 |
| 500 | 57 | 1,585,344 | −2.32 | −64,004 | 211 | 323,377 | 0.38 | 577 |

Notes: TB, total bene“t; MB, marginal bene“t; Tk, taka, the national currency of Bangladesh worth 70 taka ≈1 USD.

for the “shermen group whereas boatmen income is the highest at a very high ”ow level. Analyses show that “shery bene“t is much higher than navigation bene“t for the Teesta, which demands more attention in water management for “shery water use.

## 6. Discussions and conclusion

Low ”ow season, except severe low ”ow, for the “shermen and high ”ow season for the boatmen are economically bene“cial. Maximum bene“ts that can be realized from the “shery and navigation are about 8.33 million and 0.87 million taka per month, respectively, if optimal ”ow for the concerned uses can be ensured. However, the maximum bene“ts from both sectors are not achieved simultaneously due to the opposite seasonal occurrence of the maximum bene“ts of individual uses. Nevertheless, the highest MB for both groups lie at very low ”ow such as Tk 72,616 per $m^3 s^{-1}$ per month for “shery and Tk 715 per $m^3 s^{-1}$ per month for navigation at a ”ow level of 50 $m^3 s^{-1}$. Dry season ”ow management, therefore, demands special attention because the o stream irrigation demand is also very high at the same time.

In estimating the “shery bene“t, ”oodplain “shery, which is a completely river hydrological phenomenon, is not accounted. Floodplain “shery is more important in monsoon and post-monsoon periods mostly related to ”ood events from high ”ow season; however, this study is more interested on estimating the MB of the river discharge, which is more critical at low ”ow period when MB from instream uses are high as well as demands from o stream side are also high.

Instream water use particularly the “sheries largely depends on water quality; however, the water quality aspect is not considered explicitly in this study for the economic valuation. In the study site no major industrial or urban activities exist; water quality issues may therefore only arise from agricultural pollution. However, the return ”ow path of TIP is looked into and it is found that the return ”ow is mainly draining into the Jamuna River.

In a study by Mullick et al. (2010a), the environmental ”ow requirements for the same study site are estimated using the Tennant method, ”ow duration curve (FDC) method and range of variability approach (RVA) method. FDC method recommends a ”ow range, 108…151 $m^3 s^{-1}$ for the low ”ow season which is in the range of •fair to good• according to the Tennant method. RVA gives monthly ”ow targets and based on the RVA analysis range of ”ow for the dry season four months should be in the range of 118…279 $m^3 s^{-1}$. Particularly, the RVA analysis results show that maintaining environmental ”ow can generate almost the highest bene“t from instream water direct uses in the case of Teesta. Table 1 shows that currently (2001…2006) discharge at the low ”ow season does not comply with the environmental water requirements, which obviously will result in environmental as well as social degradation by jeopardizing poor•s livelihood. In a wider perspective, such a situation may lead to malnutrition in this region by tapping the main protein supply through “shery.

Mullick et al. (2010b) found in other study on the Teesta site in Bangladesh that o stream water use (i.e. only irrigation) from the Teesta generates huge bene“t of about Tk 3260…3520 million per year. Analyses show that instream bene“t cannot compete with o stream bene“t if only direct uses are counted. However, from a societal point of view, instream water uses also carry signi“cance because it generates a considerable number of employments to the riparian poor.

In addition, the study focuses on the short-term bene“ts calculated based on only cross-sectional data set in a yearly basis. Time series data for each season will generate more accurate results for the bene“t function. However, due to “nancial and time constraints long-term survey was not carried out. Alternatively, “sh production information was looked from secondary sources such Department of Fishery (DoF). Unfortunately no related data from secondary source were obtained. DoF only collects “sh production data in a yearly basis and district wise but not river wise. Since more than one river may exist in a district or one river ”ows into several districts, district base “sh production data cannot be used for such an analysis.

The developed model is fully a static one. Time values of money and in”ation parameter were not incorporated in the model. Considering all these parameters and inclusion of cost (both capital and operation) in a dynamic model will result in more accurate result. This study is merely a “rst attempt to estimate instream water direct use bene“ts in a data poor developing country perspective.

Results from such a study will signi“cantly in”uence the forging connection between the •triple bottom line parameters•, namely: economy, society and ecosystem. Realizing and acknowledging such multifaceted bene“cial aspects of instream water, the study provides an important insight towards a pro-poor and environmentally sound approach to river management.

## Note

1. Taka is Bangladesh national currency; 70 Taka ≈1 USD.

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