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The Economics of Taming Teesta River: Limits the Choice of Agricultural Crop Diversification

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Authors' contributions

This work was carried out in collaboration between both authors. Author AKEH supervised the work. Author EB designed the study and performed the statistical analysis. Author EB wrote the first draft of the manuscript. Author AKEH managed the literature searches and edited the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Taming river flow to facilitate irrigation support for agriculture begets a group of beneficiaries and a group of sufferers. While implementations of such large scale projects are taking place by taming the natural resource hydrology, the economics of net welfare gain must be met. The estimated cost benefit analysis of a trans-boundary river is a complex issue than a river flowing within the domestic territory only. The dynamics of natural resource hydrology of trans-boundary rivers are often influenced beyond the national level policies. Thus, at lower stream, river dependent farmers' often suffer from reduced flow of water for irrigation, if withdrawal of water occurs at upstream. It increases the cost of agricultural production. In addition, limits the choice of river dependent farmers' to reduce their risk of cultivation by adopting crop diversification as a strategy. With reduced flow of water to facilitate adequate irrigation is costly. Hence, diversification of cropping further increases the cost of cultivation, if otherwise; farmers' opt for low water intensive crops.

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Assuming soil condition is not sufficiently favorable for cultivating low water intensive crops, the study attempts to explain how taming (man-made) a river limits farmers' choice to minimize the risk of cultivation by adopting crop diversification. Estimates using Logit and Probit analysis evince that riparian farmers' depending on river water for irrigation are 11 percent more exposed to the risk of production compared to farmers' who usually receive irrigation support from the project. Inadequate water flow in dry season arises the risk for riparian farmers' by limiting their scope of cultivating diversified crops. Besides, the probability of crop diversification drops by 3.5 percent with each event of river erosions in Kharif (Rainy) season at Teesta Valley. These estimates will be useful a priory measures to calculate the overall loss of ecosystem services of a natural hydrology (in the Bangladesh part), which in turn will facilitate Bangladesh to negotiate for a fair distribution of water share in the ongoing trans-boundary water negotiations with India.

Keywords: Teesta River; crop diversification; irrigation; water flow; Logit regression; Probit regression.

1. INTRODUCTION

Taming fresh water resources through physical construction of barrages or dams for hydro power generation to facilitate irrigation support etc. have been widely observed ranging from the Niger basin to Rio Grande basin, from parts of Indus to Great Koyna basin [1]. Worldwide, relentless wild interventions on natural hydrology have started to depict its negative consequences in the form of lost or reduced biodiversity, increasing cost of agricultural cultivation due to scarcity of river water , increased frequency of natural calamities like floods and droughts simultaneous or alternatively in different parts of globe [1]. Envisaging the vehement worrisome consequences of taming natural river hydrology and increasing threat of climate change; global leaders have paid attention towards more sustained agricultural and industrial water use assigning highest priority for river basin conservation [2]. Narrowing down the economic consequences of taming natural river hydrology to the grass root level where people directly experience the consequences would be rather relevant and precise to understand the dynamics.

In absence of clearly defined property rights, there is no incentive for people to conserve natural resources. Thus, it is rationale that, people will use the river hydrology in ways he/she drives maximum benefit out of that. Therefore, any change in the common natural resource hydrology, begets a beneficiary and a non- beneficiary group to formulate their reaction curves towards a change[1] [3].

In the economics of natural resources River is considered to be a common resource[2] as it holds both non-excludable and rival characteristics [3]. More precisely, river is a natural capital and offers two diverse set of resources to the economy. First, provides material resources such as minerals, fish, hydro-energy etc. that are traded in market place [4]. Fishing in a common river is non-excludable, as, to charge fishermen/fishing group for each unit of fishing is difficult but rival as there remain fewer fish stock for the next fisherman / fishing group to catch. Second, river provides environmental resources such as water, flora, fauna etc. which lies outside the market-based system [4]. Riparian farmers' depending on river water for irrigation, finds the 'water-flow' non-excludable as charging rent for per cusec of water use is hard to measure while a cusec withdrawal of water reduces the volume of water available for next farmer/farming group.

Economic incentives that a river offers to riparian community through her services and how diverse interest groups respond to a change in river hydrology (natural/ man-made) depends on the shift of these previously enjoyed incentives. The change in the river hydrology due to the physical construction of barrage/ dam to facilitate irrigation support for agriculture begets a group of beneficiaries and a group of sufferers. Methods of estimating net welfare gain of such large scale intervention in river hydrology are often questioned but mostly met the condition of positive economic return after cost benefit analysis [3]. The scenario become more complex if such estimation has been exercised on a trans-boundary river hydrology compared to a river flowing within the domestic territory.

The dynamics of natural resource hydrology of trans-boundary rivers are often influenced beyond the national policy. Thus, at the lower stream, river dependent farmers' often suffer from reduced flow of water for irrigation if withdrawal of water occurs at upstream and if

[1] *It could be a policy change, any physical or natural change*
[2] *Common Good properties: Non-excludable and Rival*

there remain no agreed negotiation of water share.

In this regard, considering the natural, geographical, political, economic and social attributes finding a suitable common resource is the most important aspect to understand the economics of taming a river. Secondary analysis and literature review on river hydrology of Bangladesh suggests *Teesta[3] River* is one of the suitable common resources to execute the empirical research on.

1.1 Rationale for selecting Teesta River

Teesta is the 4^{th} largest river in Bangladesh and often regarded as the life support for the populace of northeast Bangladesh [5]. The origin of Teesta is on the Pauhunri Glacier near Khangchund lake (27.59'N; 38.48'E at an elevation of 7128'/2173 m) above mean sea level with in the Eastern Himalayas, Sikkim of India [5]. From the Pauhunri Glacier she has traveled across Darjeeling and West Bengal and finally enters into Bangladesh through Dimla Upazila of Nilphamari District. In her long journey she has passed 315 km- 400 km river valley; about 113 km (arguably 172 km) is in Bangladesh covering five northern districts named Gaibandha, Kurigram, Lalmonirhat, Nilphamari, and Rangpur. She has touched about 9,667 square kilometers land and 5,427 villages with an estimated population of 9.15 million in 2011. According to Rashid's study Teesta serves about 21 million people directly or indirectly dependent on the river [6].

Aforementioned discourse clearly states about the trans-boundary nature of Teesta River. From 1930's Teesta River has been a political interest of British Government and received more attention during Pakistan Regime[4]. Since then numbers of dam and barrage[5] have been built on River Teesta from Sikkim to Bangladesh. This man-made endeavor to extract economic benefits by taming the river has caused the river to lose her natural flow. The situation has exacerbated after the construction of Gozaldoba barrage at upstream (India in 1996) which neutralizes the operational benefits of Teesta barrage and its irrigation project (started in 1993). The withdrawal of water at upstream reduces the flow of water flow in dry season at lower stream, especially in the areas outside the teesta irrigation support. Therefore, over time, the river lost the carrying capacity to huge sediment loads. Soon after monsoon months the river literally becomes a dead river with chars and shoals rising up from her bed. Deposit of silts near the barrages are gradually reducing the carrying capacity of water through her main channels and therefore Teesta River became a meandering one as she splits into many channels during dry season. Gradually, Teesta has changed in size and in volume of flow [5]. Inadequate water flow in dry season on Teesta River limits the scope of irrigation for farmers'. The lackluster situation for water has confined farmers' to grow less water intensive crops as well as commercially profitable. The economic incentives that once farmers' used to enjoy by using river water for irrigation has been wiped out these days - in dry season at Teesta Valley.

Fig. 1. Map of the Teesta River (study area is circled in red)

A completely alternative picture arises in rainy season for riparian farmers' (except for the project beneficiaries. During the rainy season, West Bengal Government releases excessive water at upstream [6] and people of northeast

[3] *A Indo-Bangladesh Joint river*

[4] *First dialogue held on establishment of Barrage on Teesta was in 1960*

[5] *Teesta Barrage in Bangladesh at Dalia (operation started on 1993), Teesta Barrage Project at Gajoldoba in West Bengal, two hydro-electricity dams in Sikkim — one at Kulekhani and other at the upstream are the major intervention on river flow. Besides, several hydro-electric dams are built on Teesta(Islam, 2008).*

[6] *In Rainy season, due to excessive rainfall water comes down in bulk with intense turbulence from the Himalayan Mountains (Skkim). To do flood management West government usually open the Gozaldoba Barrage at that time and water further flows down to Bangladesh.*

Bangladesh at downstream suffers from flash-flooding. It suggests annually a significant portion of farming households usually suffered through flash flood at Teesta Valley [5]. Following the natural hydrology of a river, households located to the opposite side of a flood zone are in threat of losing hundreds of acres of agricultural landscapes and dwelling houses due to river erosion. It evinces riparian farmers' who have complete dependency on Teesta River for crop cultivation are remain engaged in farming with severe uncertainty throughout the year. Lack of adequate water availability for irrigation in dry season and potential threat of flash flood in rainy season are forcing farmers' to engage in crop cultivation with uncertainty. In other words, reduced water flow in dry season are making irrigation expensive. Thus, restricting farmers' to use crop diversification as a risk sharing strategy to reduce the degree of uncertainty. Besides, in rainy season river dependent farmers' prefer to be more risk adverse as there prevails constant uncertainty of losing agricultural land in river bank erosion. To the best of knowledge, aforesaid river hydrology of Teesta is unique and meets all the socio economic attributes to conduct the empirical research with a treatment and target group to explain the story of taming a common resource. Consider the river hydrology three farming groups have been defined in the study.

Group A represents farmers' who receive irrigation support in dry season and are enclosed in the flood protected areas during rainy season. In other words, withdrawal of water at upstream (by India) from the common resource do not negatively affect *Group A* in dry season. Therefore, they manage to remain engaged in agriculture with secure flow of water. In addition, they involve in agriculture with more certainty in rainy season by perceiving lower probability of being affected through natural calamities like flood and river erosion.

Group B represents farmers' who reside outside of irrigation support areas and are completely dependent on River Teesta for irrigation. They are primarily affected by the water withdrawal at upstream in the dry season. Thus, in the dry season, *Group B* farmers are expected to be more vulnerable to remain engaged in agriculture relative to *Group A*.

In addition, *Group C* represents a portion of farming households from *Group B* who face constant threat of flash flood and river erosion. Mathematically, *Group C* is the subset of *Group B* and are involved in agriculture round the year. Therefore, in rainy season, *Group C* farmers' are expected to be more vulnerable to remain engaged in agriculture relative to *Group B*.

In the dry season (a) Farmers' belong to *Group A* perceive lower risk of farming than *Group B* and *Group C*. Moreover, *Group B* and *Group C* farmers' perceive similar level of risk to involve in agricultural cultivation.

In the rainy season (b) Farmers' belong to *Group C* perceive higher risk of farming compare to farmers' who belong to *Group A* and *Group B*. Moreover, *Group A* and *Group B* farmers' perceive similar level of risk to involve in crop cultivation.

1.2 Objective of the Research

The endeavor of the study is to understand the economics of common resource (river) and how different interest groups interact with each other to avail the economic incentives of a change in a river hydrology. Several man-made efforts (dams, barrages) have took place to optimize the social welfare by transferring the benefits of natural flow of a river to a target group by arranging irrigation facilities (Bangladesh & India) and hydro-power generation (India). These physical constructions of Dams and Barrages are gradually but relentlessly bringing changes to river hydrology. In tradeoff, large numbers of river dependent households are receiving limited ecosystem services [7] of *Teesta River* while relatively minor populace are enjoying the shifting benefits. Aforementioned discussions are yielding the suspicion of making the *River Teesta* less productive for agriculture (by taming her to opt for short term social welfare ignoring the seminal effect). Thus, the concern lies whether such interventions are making the river dependent farming households more vulnerable? In order to evaluate the consequences of taming River Teesta, the objective of the research is –

To estimate at what extent farming households dependent on river water for irrigation could adopt crop diversification as a strategy for risk (production) migration to augment the possibility of greater marginal gain from cultivation in comparison to the farmers' who receive irrigation support. Specifically, the testable hypotheses

[7] *Standard four ecosystem services are provisioning, regulatory, supportive and cultural*

are- **(a)** Water scarcity limits farmers' choice who belong to *Group B or C* from being involved in crop diversification to gain greater marginal return by producing relatively 'low water intensive' crops. As regards, farming households belongs to *Group B or C* have lower scope for crop diversification as a strategy of minimizing production risk compared to *Group A.* **(b)** In the rainy season at downstream with the sudden release of water, the frequency of flooding *(anticipated by the farmers' belong to Group B or C)* and bank erosion (only farmers' who belong to *Group C*) increases. Thus, the rationale hypothesis is- it further limits farmers' scope to adopt crop diversification as a strategy to minimize production risk separately in response to events like flooding (faced by famers' who belong to *Group B or C)* and river bank erosion (only for *Group C*).

2. LITERATURE REVIEW

2.1 Literature on Crop Diversification

River irrigation system is strategically used in the several East and Southeast Asian economics (Vietnam, China, Thailand, India, Pakistan, Philippines, and Bangladesh etc.) to promote large scale crop intensification as well as to increase the food grain production. In India, Tambiraparani river basin is widely used to increase the food grains by utilizing her river irrigation system. The irrigation facility has enabled farmers' to cultivate diversified crops and minimize the risk of mono cultivation [7].

The use of river water as agricultural irrigation support for crop diversification is evidenced in the case of Ruaha river basin in Tanzania. In this particular river basin, farmers' have adopted tillage methods, agronomic practices and crop diversification approaches to maximize yield from available level of water [8]. It reveals the importance of availability of water in the river basin for diversifying crop cultivation. In Philippines, during the dry season farmers' have extensively adopted crop diversification instead of mono cropping to increase their profitability after the installation of irrigation system at areas like Mindanao and Luzon islands [9].

In Pakistan, a study on crop diversification carried out by Ashfaq et al. [10] found that level of crop diversification were determined by the size of landholding, age of household head, education level, farming experience, and off - farm income of the farmer, the distance of the farm from the main road and from the main market, and farm machinery ownership. An Entropy Index was used to measure the choice of crop diversification by a Multi-Variable Regression model.

Study on the nature and extent of crop diversification in Karnataka state in India done by Acharya et al. [11] has revealed that basic infrastructural facilities such as sustained supply of irrigation water, availability of fertilizer, structure of road network and transportation are the determinants of crop diversification. The study found that crop diversification has a statistically significant positive effect on production by deploying rigorous analyses using the Composite Entropy Index (CEI) and Multiple Linear Regression on a secondary panel data (1982-2008). The CEI for different crop groups showed that nearly all the crop groups has a higher crop diversification index during the post-World Trade Organization (WTO) period (1996 to 2008) than during pre-WTO period (1982 to 1995) period, except for oilseeds and vegetable crops. It suggests that broader policy issues have a bearing on the degree to which farmers' diversify their crop production.

Simwambana et al. [12] by using Rapid Appraisal methods in the Southern province of Zambia has found that most farmers' did not diversify their crop production. Study has focused only on cassava and sweet potato while ignoring crops like groundnut and sunflower (which were important crops in the diversification programme too). Despite the Zambian Government had a policy programme to stimulate crop diversification- this study has found low level of crop diversification as well as undiversified agriculture sector whereas maize being the main staple crop. Similarly, Ibrahim et al. [13] study on crop and income diversification among farming households in north-central Nigeria explained that crop and income diversification were deployed as strategies to reduce rural poverty and to raise income level. The study used the Simpson Index of diversification and Ordinary Least Square Regression approach to identify the determinants of crop diversification[8].

Bhattacharyya [14] study has shown crop diversification helped to raise profitability for

[8] *Determinant were age of household head, level of education of the household head, number of extension visits the farmer received, availability of tractor hiring services, and returns from crop production*

farmer in the state of West Bengal, India. There were gradually diversification towards high value commodities, such as fruits, vegetables, and flowers. Choices of crop diversification came successful through the individual efforts of small farmers', with little support from government (as government policies mainly emphasized cereal based production for household food security). The study has used Simpson Diversity Index as dependent variable to determine the separate effects of each explanatory variables on crop diversification. Major determinant of diversification was a demand-side factor that had induced farmers' to shift towards production of high value crops. Crop diversification was more prominent in rain-fed areas than of irrigated zones. The rain-fed areas are becoming the hub of non-cereals due to the low water requirements of these crops and for abundant labour supply. Cost of cultivation of fruits, vegetables, and flowers are relatively low; the choice of cultivating high value crops are becoming popular among the small farmers' as a risk minimizing strategy.

Bezabih & Sarr [15] has attempted to find at what extent diversification of income portfolio is used as a strategy for shielding against production risk by using Logit and Probit estimations. The study suggests individual risk preferences and weather uncertainty could affect decisions regarding crop diversification. Moreover, covariate shocks from rainfall variability and individual risk aversion are positively corelated with the increased level of diversity. Similarly, Rahman [16] has used Probit model to analyze the impact of diversified production in Bangladesh. In addition, crop diversification is found to be positively influenced by the level of developed infrastructure of a region such as education, experience, farm asset ownership, and non-income ownership of a farmer [17]. Comprehensive literature review suggests numerous analytical approaches can be used to find the determinants of the choice of crop diversification. Acharya et al. [11] employed a Multiple Linear Regression analysis, whereas Ibrahime et al. [13] adopted a Linear Regression approach. Failing to prove causality is one of the limitations of Linear Regression analysis while measuring the choice of crop diversification [18]. Sichoongwe et al. [18] has used Double Hurdle model that allows separate estimation of the probability of participation in crop diversification. Rahman [16] used Probit analysis that allows probability of participation in crop diversification in response to the changes in the dependent variables. In addition, the Herfindahl Index and the Crop Diversification Index can be used to understand the determinants of diversification for those farmers' who diversified their crops.

To the best of our knowledge no study has been conducted on Teesta basin area (Bangladesh) to identify the determinants of the choice of crop diversification among farmers' 'with' and 'without' secure flow of water for irrigation in dry (robi) season and 'affected' and 'non-affected' through flooding and bank erosion in rainy (kharif) season. Therefore, the purpose of the study is to examine *'how far water scarcity and natural disaster occurrences are influencing farmers' choice of crop diversification as a risk migrating strategy'* in the context of *Teesta River* (common resource) by using Logit and Probit analysis.

3. METHODOLOGY AND DATA

3.1 Analytical Framework: Agricultural Crop Diversification

The analytical model used in the study has drawn upon from the theory of crop diversification among diverse farming groups who lives along the main channel of River Teesta. According to Rahm and Huffman (1984) farmer's choice of crop diversification depends on utility maximization [18]. Farmers' who belong to *Group B or C* face water scarcity in comparison to farmers' who belong to *Group A* in the dry season. Thus, on Teesta Valley within farming community there are two types of utility function observed in the dry season due to the differences in 'water availability' for irrigation. So, the hypothesis is:

> *If a reduction in the flow of water in the river pushes an area into water scarcity, it will limit farmers' to minimize their risk of cultivation by adopting crop diversification as a strategy.*

Alternatively, in rainy (Kharif) season farmers' who belong to *Group B* splits and begets another group of farmers' (*Group C)* who anticipate frequent events of flood and river bank erosion. Therefore, in rainy (kharif) season farming community of Teesta basin splits into three diverse groups. *Group A* resides under the flood protected zone; *Group B* are dependent on river water but unaffected by flash flood or bank erosion. In contrast, farmers' who belong to *Group C* are affected by either frequent flooding or river erosion. Normal flow of water in the main channel of Teesta in rainy (kharif) season neutralizes *Group A's* preposition of having comparative advantage of getting secure water support for irrigation in dry season relative to farmers' belong to *Group B* but the situation remain valid for farmers' who belong to *Group C*. Therefore, it is rather logical to examine whether there is any difference in the utility function for farmers' belong to *Group B* and *Group C* in the rainy season. So, the hypothesis is:

> *If an excessive flow of water in the river pushes an area into water logging or bank erosion, it will limit farmers' choice to minimize their risk of cultivation by adopting crop diversification as a strategy.*

The expression U (W_{ji}, Z_{ji}) is a non-observable underlying utility function, which ranks the preference of the k^{th} farmer for the j^{th} diversification process (j = 0, 1; where 0"no diversification" and 1"diversification") from 'i' number of crop choices that are included in the study. Crop diversification is defined as: if a farming household is involved in mono harvesting, for example only on paddy production (regardless of the number of times in dry season) then it is considered to be that farming household/farmer made 'no diversification' choice. In contrast, if a farming household cultivate two or more crops within the same season then it will be considered that the farming household/farmer has made 'diversification' choice. Same definition is valid regardless of dry and rainy season. Thus, the utility derived from crop diversification depends on W stands for water available for irrigation and Z, which is a vector of the attributes associated with crop diversification. Although the utility function is unobserved, the relation between the utility derivable from the j^{th} diversification process is postulated to be a function of the vector of observed farm and farmer, water availability for irrigation and crop diversification specific characteristics and a disturbance term having a zero mean.

Equation 1. General utility function of farmers' choosing crop diversification in dry (robi) season

$$U_{ji}{}^{\mathrm{k}} = \alpha_j F_i(W_i Z_i) + e_{ji}\ ;\ \ j = 0{,}1; i = 1\ to\ 14; k = 1\ to\ 226$$
$$only\ if; i > 1\ than\ j = 1\ and\ if;\ i = 1\ than\ j = 0$$

Equation 2. General utility function of farmers' choosing crop diversification in rainy (Kharif) season

$$U_{ji}{}^{\mathrm{k}} = \alpha_j F_i(W_i Z_i) + e_{ji}\ ;\ \ j = 0{,}1; i = 1\ to\ 14;\quad k = 1\ to\ 156$$
$$only\ if; i > 1\ than\ j = 1\ and\ if;\ i = 1\ than\ j = 0$$

Since the utilities $U_{ij}{}^{k}$ are random, the k^{th} farmer will select the alternative j = 1 if $U_{1i}{}^{k} > U_{0i}{}^{k}$ or if the non-observable (latent) random variable $y^* = U_{1i}{}^{k} - U_{0i}{}^{k} > 0$. The probability that Y^K equals one (i.e., that the farmer practices crop diversification) is a function of the explanatory variables:

$$\begin{aligned} P^K &= P_r(Y^K = 1) = P_r\left(U_{1i}{}^{\mathrm{k}} - U_{0i}{}^{\mathrm{k}}\right) \\ &= \mathrm{P_r}[\alpha_1 F_i(W_i Z_i) + e_{1i} > \alpha_0 F_i(W_i Z_i) + e_{0i}] \\ &= \mathrm{P_r}[e_{1i} - e_{0i} > F_i(W_i Z_i)(\alpha_1 - \alpha_0)] \\ &= \mathrm{P_r}[\mu_i > (-)F_i(W_i Z_i)\beta] = F_i(X_i\beta) \end{aligned}$$

Where X is the (n x k) matrix of the explanatory variables and β is a (k x1) vector of parameters to be estimated, Pr(.) is the probability function, μi is the random error term, and F_i (X_i, β) is the cumulative distribution function for μi evaluated at Xi β. The probability offarmers' choice of crop diversification is a function of the vector of explanatory variables and of the unknown parameters and error term. None of equation 1 and 2 can be estimated directly without knowing the form of F. It is the distribution of μ_i that determines the distribution of F.

The dependent variable of the model is binary (dichotomous variable) and to explain binary model, use of Logit, Probit, and Tobit (Double-Hundle) analyses have been widely noticed. In the estimated model only farming households have been included regardless of the seasonal cultivation. Thus, there is no censored sample of non-farming households. In this regard, Tobit estimation will be erroneous to execute [19]. Therefore, to our best of knowledge use of Logit (follows cumulative logistic function) and Probit (follows cumulative distribution functions) estimation would be rather appropriate. Albeit results under Logit and Probit estimation are quite similar but not comparable. As regards, research findings have been interpreted separately with no harm to logical meaning.

3.2 Data

This study has used cross sectional data and the nature of data is secondary. The primary data set is owned by Asian Center for Development (ACD). Data covers information for 350 households from three districts of Teesta Valley Rangpur, Nilphamari and Lalmonirhat. Among all only farming households who are involved in agriculture have taken into our research sample. In dry season 226 households have mentioned about their involvement in agricultural cultivation while in rainy season the number drops down to 156 households.

4. RESULTS AND DISCUSSION

4.1 Estimation of Agricultural Crop Diversification in Dry Season

Risk management is an integral part of agricultural activities. The uncertainty farmers' face in the production process are driven by various vagarious climatic conditions (drought, flood, storm, cyclone etc.), pests and pathogens, factor and final (market price) price volatility. Now-a-days crop insurance is a deterministic factor behind farmers' choice of crop diversification and it is well documented for developing countries as an option to reduce the risk of cultivation [15]. In the study, farmers' at downstream (Teesta riverside) are exposed to water scarcity for irrigation due to the withdrawal of water at upstream in India. It further illustrates farmers' at down steam are losing economic incentives that they were supposed to receive from provisional services of river ecosystem if there were no withdrawal of water at upstream. In contrast, farmers' within Teesta irrigation support area are enjoying secure flow of water in dry season. Therefore, water as agricultural input is scarce to farmers' at downstream and secure to farmers' at upstream. Utility a farmer gains from the choice of crop diversification is in the form of risk migration. Considering the similar geography, homogenous soil quality and other agricultural inputs available at market place; water availability for irrigation differentiates production function in between downstream and upstream farming. Does water scarcity limit farmers' choice of crop diversification? In order to find the economic explanation empirically the following model has been constructed:

Equation 3. Empirical Logit Model for the farmers' choice of crop diversification in dry (robi) season

$$Prob(CCD_i = j|Z_i) = \frac{\exp(\beta_1 NMM + \beta_2 NIGW + \beta_3 RD + \beta_4 AIS)}{\sum_{j=0}^{1} \exp(\beta_1 NMM + \beta_2 NIGW + \beta_3 RD + \beta_4 AIS)}$$

Equation 4. Empirical Probit Model for the farmers' choice of crop diversification in dry (robi) season

$$Prob(CCD_i = 1) = \varphi(\alpha_1 NMM + \alpha_2 NIGW + \alpha_3 RD + \alpha_4 AIS$$

For both equation 3 and 4, CCD is the dependent variable stands for farmers' choice of crop diversification. Independent variables are: NMM stands for number of male member that illustrates the probability of having more household agricultural labor, NIGW stands for non-income generating wealth to capture the living/socio-economic status of farming household, RD a dummy variable stands for river dependency for irrigation water; where 1 if farmers' who depend on Teesta River for irrigation and 0 if farmers' in support of irrigation project, ALS stands for agricultural land size to capture the scope of crop diversification by famers' who have financial accessibility to take advantage of economies of scale. B_i and α_i $\forall$ i=1, 2, 3, 4 are associated coefficients of explanatory variables. In cases of Logit and Probit analysis (Table 3) the signs of coefficients have greater economic significance while marginal effect analysis carries economic significance in explaining the Logit and Probit estimates.

Table 1 evinces marginal effects of aforementioned empirical models on the farmers' choice of crop diversification. The key independent variable of the model is river dependency by farmers' for irrigation. Albeit results of Logit and Probit coefficients are similar in meaning, they do not mimic each other or even not comparable. Therefore, Logit and Probit coefficients are interpreted separately and distinctively. The Logit coefficient of river dependency for irrigation water -1.38 means households' that are more dependent on river water for irrigation has lower predicted probability of crop diversification in the dry (robi) season (Table 3). It reveals, withdrawal of water at upstream pushes riparian farmers in a water scarce situation and perhaps increasing the cost of agricultural cultivation as they are forced to arrange alternative means of irrigation (for example, sallow machine).

As all other agricultural inputs are similar to both groups of farmers', accessibility of water determines their choice of crop diversification. The marginal effect estimation reveals that the probability of crop diversification are 11 percent lower for riparian farmers' because of lack of secure water flow in the river, keeping other factors constant. One of the major assumptions behind the study is, existing soil quality of Teesta basin is not adequately favorable for producing low water intensive crops. In other words, the reduced probability of crop diversification is indicating towards the yield of production that the riparian farmers' are forgoing by anticipating the uncertainty of cultivation in absence of adequate water accessibility (Table 3). Similarly, Probit coefficient of river dependency for irrigation water is -0.67, means river dependent farming households for irrigation have lower predicted probability of crop diversification in robi (dry) season. The probability of crop diversification status decreases by 0.11 for farming households who are highly dependent on river water for irrigation in robi (dry) season - that is significantly exposing their vulnerability to do agricultural cultivation without secure flow of water in dry season.

On the other hand, agricultural land size is found to be positively related to the farmers' choice of crop diversification and the estimated coefficients are statistically significant. It means, farmers' who have relatively higher ownership of agricultural land are more likely to cultivate diverse crops.

4.2 Estimation of Agricultural Crop Diversification in rainy Season

Seasonality has been observed in the river water flow at Teesta Valley. The variation of river flow in the rainy season depends mostly on the rate of precipitation. In the Teesta Valley, it is quite common that the water scarce situation of the dry season completely turns into a water volume that causes flash flood and river erosion in the rainy season. Increasing siltation on riverbed causes the river to widen and leading to erosion and flooding. Withdrawal of water at upstream in the dry season which leads to the reduced flow of water in the river and increased sedimentations is the primary cause of the aforementioned natural calamities. Alternatively saying, Teesta River gradually has lost the capacity of receiving excessive pressure of water in the rainy season as Bangladesh and Indian Government continues to tame the river. Therefore, vehement water force is either washing away acres of agricultural lands and dwelling houses (river erosion) or finding retention space on the land yards (flood). In the Teesta Valley, river erosion has adverse impact on local livelihoods; washing away the agricultural and dwelling lands, and fostering out migration to neighboring areas and even across the border to India. Flash floods due to the sudden upstream release of water from India have caused considerable damage to local households and livestock. Exposure of natural calamities has increased the vulnerability of farming households. One of common strategies for farmers' is to reduce their state of vulnerability (minimizing production risk) by adopting diverse portfolio of crops. Therefore, in the rainy season two groups of riparian farmers' are found on Teesta basin. One group is 'affected' and other group is 'unaffected' by the natural calamities. An empirical model in this study has been designed to evaluate whether the occurrence of natural calamities like river erosion limits the scope of crop diversification and pushes the state of economic vulnerability of river dependent farming households. The empirical models (Logit and Probit) on farmers' choice of crop diversification are stated below:

Equation 5. Empirical Logit Model for the farmers' choice of crop diversification in rainy (kharif) season

$$Prob(CCD_i = j|Z_i) = \frac{\exp\,(\gamma_1 NMM+\gamma_2 NIGW+\gamma_3 RE+\gamma_4 AIS)}{\sum_{j=0}^{1}\exp(\gamma_1 NMM+\gamma_2 NIGW+\gamma_3 RE+\gamma_4 AIS)}$$

Equation 6. Empirical Probit Model for the farmers' choice of crop diversification in rainy (kharif) season

$$Prob(CCD_i = 1) = \varphi(\delta_1 NMM + \delta_2 NIGW + \delta_3 RE + \delta_4 AIS)$$

For both equation 5 and 6; CCD is dependent variable stands for farmers' choice of crop diversification. Independent variables of the model are: NMM stands for number of male member that illustrates the probability of having more household agricultural labor, NIGW stands for non-income generating wealth to capture the living/socio-economic status of farming household, RE a discrete variable stands for number of time HH faced river erosion in last ten years; ALS stands for agricultural land size to capture the scope of crop diversification by famers' who have financial accessibility to take advantage of economies of scale. γi and δi $\forall i$ =1, 2, 3, 4 are associated coefficients of explanatory variables.

shows marginal effects of empirical model on crop diversification choice. The key explanatory variable of the model is the number of occurrences of river erosion faced by a (agriculture) farming household in last ten years. The Logit coefficient of river erosion -0.66 implies river dependent households who have frequently faced river erosion, their predicted probability of crop diversification is lower in kharif (rainy) season (Table 4).

Table 1. Marginal effect estimation on choice of dry season (robi) crop diversification

Independent variable	Logit (dy/dx)	Probit (dy/dx)
Number of male member	-0.00973	-0.012
Non income generating wealth	-5.63e-07	-5.80e-07
River dependency~	-0.11 **	-0.11***
Agricultural land size	0.00039**	0.00042**

*Level of significance: *** (P≤0.01), ** (P≤0.05) and * (P≤0.10)*

Table 2. Marginal effect estimation on choice of rainy season (kharif) crop diversification

Independent variable	Logit (dy/dx)	Probit (dy/dx)
Number of male member	.0048	0.0034
Non income generating wealth	-4.18e-07	-5.40e-07
River erosion	-0.048 ***	-0.048***
Agricultural land size	0.00063**	0.00077**

*Level of significance: *** (P≤0.01), ** (P≤0.05) and * (P≤0.10)*

The marginal effect estimation reveals that a riparian farmer had lost 4.8 percent probability of crop diversification with each additional events of bank erosion in last ten years, keeping other factors constant. It suggests river erosion in the rainy season further limits the scope of farmers to adopt crop diversification as a strategy to minimize production risk (Table 2). In this case, the uncertainty of losing agricultural land and anticipation of higher lose deter farmers to opt for crop diversification. Similarly, the Probit coefficient of river erosion -0.32 depicts river dependent households that frequently face river erosion, their predicted probability of crop diversification is lower in kharif season (Table 4). River dependent households with each additional event of bank erosion in last ten years had faced reduced probability of crop diversification status by 0.11 which is significantly exposing their vulnerability farmers' to remain involve in agricultural cultivation with each additional shock of river erosion (Table 2).

At the same time, similar results have been found regardless of dry or rainy season in the dry and rainy season for famers who have relatively high agricultural land holding. It is yet again found to be positively related with farmer's choice of crop diversification and the estimated coefficients are statistically significant. It means, farmers' who have relatively higher agricultural land holdings are more likely to cultivate diverse crops regardless of the seasonal variability and other means of factors of production.

5. CONCLUSION

Endeavor to tame Teesta River through the constructions of dams, barrages and other alternative physical interventions have created two contrasting but pessimistic situation for riparian farmers' in two seasons (dry and rainy). In dry season the outcry of the riparian farmers' is for scarcity of water which continues in the rainy season in the form of excessive water flow. Farmers' outcry is driven by the loss they anticipate each year because of the uncertainty of the water flow. That, indeed, limits their scope of risk migration through crop diversification. With the operational start of the barrage in Dalia (1993) - the flow of common resource Teesta has started to divert. Later in 1996 establishment of Gozoldoba barrage at upstream has divided riparian farmers' in three [12] different interest groups at lower stream. Since then, the river only remained to be friendly with the farmers' who belong to first interest group (who gets irrigation support). In contrast, the river continues to offer a large dry landscape to famers who belong to other groups. Farmers' except who belongs to first interest group face about 11 percent reduced probability of crop diversification in the dry season. However, in rainy season Teesta River reestablishes her friendship with the farmers' who belong to the second and third interest groups. And quite frequently over flourish (affect through flood and bank erosion) the third interest group with her friendship and detach farming households from their invaluable mates (causes lot of damage such as washing away agricultural lands and dwelling houses; income and non-income generating asset loss; life loss of HH members). Farmers' of group three have faced 3.5 percent reduced probability of crop diversification with each events of river bank erosion in last ten years. By considering the Teesta River's present contributions to the riparian farmers' it can be safely stated that -the change[13] has already tamed River Teesta.

[12] First interest group-HH receives water for irrigation, second-HH face water scarcity in dry season but face no natural calamity in rainy season, third-HH face water scarcity in dry season and natural calamity in rainy season
[13] Teesta Barrage construction in Dalia

RESEARCH CONTRIBUTION

These estimates will be useful *a priory* measures to calculate the overall loss of ecosystem services of a natural hydrology (in the Bangladesh part), which in turn will facilitate Bangladesh to negotiate for a fair distribution of water share in the ongoing trans-boundary water negotiations with India.

Taming river hydrology has a seminal effect of water scarcity, thus reduces the probability of risk mitigation for riparian farmers' who mostly dependent on river water for irrigation.

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COMPETING INTERESTS

Authors have declared that no competing interest exist.

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APPENDIX

Table 3. Regression results on farmers' crop diversification choice in dry (robi) season

Dependent variable: Choice of dry (Robi) season crop diversification (n=226)				
Independent variables	**Logit coefficient**	**Standard error**	**Probit coefficients**	**Standard error**
Number of male member	-0.17	0.23	-0.10	0.11
Non income generating wealth	$-9.67e^{-6}$	$8.14e^{-6}$	$-4.59e^{-6}$	$4.02e^{-6}$
River dependency	-0.66*	0.41	-.3232**	0.18
Agricultural land size	0.0088**	0.0035	0.0051***	0.0020
Constant	-2.60***	0.64	-1.49***	0.32
Log likelihood	-57.65		-57.74	
LR chi2 (4)	10.31		10.13	
Prob> chi2	0.036		0.038	
Pseudo R2	0.082		0.081	
Akaike Info criterion	125.30		125.48	
Bayesian information criterion	142.41		142.58	

*Level of significance: *** (P≤0.01), ** (P≤0.05) and * (P≤0.10)*

Table 4. Regression results on farmers' crop diversification choice in rainy (kharif) season

Dependent variable: Choice of rainy (kharif) season crop diversification (n=156)				
Independent variables	**Logit coefficient**	**Standard error**	**Probit coefficients**	**Standard error**
Number of male member	0.067	0.20	0.023	0.11
Non income generating wealth	-5.83e-06	$4.11e^{-6}$	$-3.37e^{-6}$	$2.41e^{-6}$
River erosion	-0.66*	0.41	-.3232**	0.18
Agricultural land size	0.0088**	0.0035	0.0051***	0.002
Constant	-2.60***	0.64	-1.49***	0.32
Log likelihood	-46.69		-46.59	
LR chi2 (4)	14.06		14.27	
Prob> chi2	0.0071		0.0065	
Pseudo R2	0.13		0.13	
Akaike Info criterion	103.38		103.17	
Bayesian information criterion	118.63		118.42	

*Level of significance: *** (P≤0.01), ** (P≤0.05) and * (P≤0.10)*

Table 5. Description of variables used in the study for choice of crop diversification in dry (robi) season

Variables	Type	Description	Expected signs	Sign of Logit coefficients	Sign of Probit coefficients
CCD	Dummy	Dependent variable: Choice of crop diversification	X	X	X
NMM	Discrete	Number of male member	(+)	(-)	(-)
NIGW	Continuous	Non-income generating wealth	(+)	(-)	(-)
RD	Dummy	River dependency for irrigation water	(-)	(-)***	(-)***
AIS	Continuous	Agricultural land size	(+)	(+)*	(+)

*Level of significance: *** (P≤0.01), ** (P≤0.05) and * (P≤0.10)*

Table 6. Description of variables used in the study for choice of crop diversification in rainy (Kharif) season

Variables	Type	Description	Expected signs	Sign of logit coefficients	Sign of logit coefficients
CCD	Dummy	Dependent variable: Choice of crop diversification	X	X	X
NMM	Discrete	Number of male member	(+)	(+)	(+)
NIGW	Continuous	Non-income generating wealth	(+)	(-)	(-)
RE	Discrete	Number of times HH faced river erosion in last ten years	(-)	(-)*	(-)**
AIS	Continuous	Agricultural land size	(+)	(+)**	(+)***

*Level of significance: *** (P≤0.01), ** (P≤0.05) and * (P≤0.10)*

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