Progressive Agriculture 30 (4): 395-404, 2019 **ISSN: 1017 - 8139**

Progressive Agriculture

Journal homepage:http://www.banglajol.info/index.php/PA

Yield gap, profitability and inefficiency of *Aman* rice in coastal areas of Bangladesh

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Abstract

Despite of being an extremely overpopulated country with a limited land resource, Bangladesh has managed to increase its food production to a viable level. Yet it is necessary to increase production of food crop in order to cope with the growing population in a sustainable way. Closing yield gap is a means of attaining sustainability of agricultural intensification to keep pace with the growing crop demand. The objective of the present study is to assess the inefficiency and the yield gap of Aman rice production in climate vulnerable areas in Bangladesh. The study was conducted in Shaymnagar and Kaliganj Upazilas of Satkhira district in Bangladesh and data were collected using a stratified random sampling technique from 110 Aman cultivating farmers. Descriptive statistical techniques as well as Stochastic Frontier model were used to achieve the objectives of the study. The study revealed that, Aman rice cultivation was profitable in the study area. We estimated the model based yield gap, highest recorded yield gap and experimental yield gap. The mean efficiency analysis revealed that farmers could increase their production with optimal use of inputs and proper management systems. Absence of proper knowledge about the optimum input use and lack of institutional training as well as inadequate extension services were responsible for the reduced yield in most farmers' fields. Salinity has reduced the overall productivity of the region, but it is believed that by popularizing the practice of saline tolerant rice variety and addressing the above mentioned issues the potential production can be achieved in the coastal region.

Key words: Yield gap, efficiency, climate change, vulnerable, coastal, Bangladesh

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Introduction

Agriculture is the most important sector of the economy of Bangladesh due to its role in food security, employment and livelihoods (Habiba, 2015). It accounts for 14.74% of the sectoral share of GDP and about 41% of the total labor force (BBS, 2016). As Bangladesh is the 8th populous country in the world, provides for 2.11% of global population with very limited land resource of 130,170 sq. km and agriculture in Bangladesh is already under pressure (worldometers, 2020). The country's agriculture suffers from huge and increasing demands for food and from problems of land and water resource depletion (Ahmed *et al.*, 2000). To cope with the population growth, the total production must be increased every year to a certain level; estimated to be to an additional amount of 2.6 million tons of husked rice every year compared to that of the previous year to feed the extra millions (Sultana, 2017).

Climate change is considered to be the greatest threat towards attaining this objective. Salinity intrusion, atmospheric temperature, rainfall, humidity, solar radiation etc. are dominant climatic factors closely linked with agricultural production that forms the economic base of underdeveloped Bangladesh, which is considered as the most vulnerable country facing climate change (Basak, 2012). The people of Bangladesh, especially in the coastal zone, are struggling with these adverse impacts of climate change. Therefore, there is a significant chance that a huge amount of rice yield may hamper for only fluctuations of those climatic parameters (Basak, 2012). For example, the catastrophic cyclone *Sidr* which hit the southern region of Bangladesh in November 2007 affected 33 districts with an economic impact of $1.7 billion. Approximately 2.5 million acres of agricultural land were damaged accounting for about 70% loss of the annual Aman rice production in the most affected area which is the main crop of coastal area [FAO/GIEWS Global Watch, 2007]. According to the estimate by the Department of Agricultural Extension of Bangladesh, the loss in rice due to the cyclone is found equivalent to 1.23 million tons, with 535,707 tons in the 4 severely affected districts, 555,997 tons in badly affected 9 districts and 203,600 tons in moderately affected 17 districts in Bangladesh [Habiba, 2015]. Therefore, Climate change is adversely affecting the agricultural production and farmers' livelihoods and, consequently, increasing risks to food security of Bangladesh [Ahmed and Chowdhury 2006; FAO 2006; Sarker *et al*. 2012; Al-Amin *et al*. 2017, Al-Amin *et al*. 2019].

The concern has received added importance, especially with the estimation of sea level rise, which would affect the southern part, about 47,000 km in coastal areas of Bangladesh that is equivalent to 32 % of the total landmass [CEDR, 2009]. A recent report shows that more than 1 million hectares of arable land in Bangladesh are affected by salinity intrusion caused by slow- and rapid-onset events [SRDI, 2010]. It also indicates that production of the principal rice crop (Aman rice) in Satkhira decreased substantially, from about 0.3 million tons in 2008 to 0.2 million tons in 2010. The impact of climate change in rice production seems to be negative and thus alarming because rice has contributed most to self-sufficiency in food grain production in Bangladesh.

Bangladesh produced about 50.1 million tons of rough rice from 11.7 m ha of land in 2010 with a productivity of 4.3 t/ha (FAO, 2012). Yet the present productivity is far below the attainable yield of 8–10 t/ha in the dry season (Boro) and 5–6 t/ha in the wet season (Transplanted Aman) in farmers' field experiments (Mamun et al., 2015). This difference in yield in farmer's fields between farmer-managed and researcher-managed trials is mainly due to the differences in management practices adapted by researchers and farmers. However, a large portion of this yield gap remains unexplained. An understanding of yield gap and development of appropriate practical technologies to minimize the causes of the yield gap are therefore, critical for meeting the challenges of continued gains in rice production. As the coastal population of Bangladesh is characterized as the most vulnerable population due to climate change, there was a need to look for the present yield gap in the area which led us to this study where we tried to assess the efficiency of Aman rice production in climate vulnerable coastal areas of Bangladesh and estimate the yield gaps.

Materials and Methods

Households were selected using stratified random sampling from Shaymnagar and Kaliganj Upazilas of Satkhira district in Bangladesh (Figure 1). Total 110 households were selected in which 54 were selected from Joynagar, Gangati and Kashimari village of Shyamnagar Upazila and 56 were selected from Gandhulia, Raghurampur, Teghoria and Dulobala villages of Kaliganj Upazila as sample. In Shyamnagar Upazila 18 households were selected from each village of Shyamnagar Upazila and from Kaliganj Upazila 14 households were selected from each of the four villages, depending on the availability of farming households in those Upazilas. Interview schedule was prepared to collect data by face to face interview method. Data were collected from the study area by face to face interview method using the structured and pre-tested interview schedule in the months of November-December, 2017. Information was collected for the immediate previous month of data collection that is for October 2017. The objective of the research was clearly stated to the respondents prior to collect data. Secondary data were obtained from existing publications, BBS, research reports etc.

Figure 1. Map of study area.

***Analytical techniques*: **The yield gap of a crop grown in a certain location and cropping system is defined as the difference between the yield under optimum management and the average yield achieved by farmers (Cassman *et al.*, 2003) (Figure 2). Yield under optimum management is labeled as potential yield under fully irrigated conditions or water-limited yield under rainfed conditions. The difference between yield potential and actual yield achieved by farmers represents exploitable yield gap (Cassman *et al.*, 2003). To fulfill the objective III, three kinds of yield gap were determined, these were: modeled yield gap (YG_M), highest recorded yield gap (YG_R) and experimental yield gap (YG_E). These yield gaps were calculated as;

YG_M=Modeled yield potential−Average farmer's yield….(1)

YG_R=Highest recorded yield−Average farmer's yield…...(2)

YG_E=Experimental yield−Average farmer's yield ………(3)

Model-based yield represents the highest potential yield attained by farmers through favorable combinations of soil, climate and crop management in selected locations (Meng *et al*., 2013). The model has been shown to be reasonably accurate at estimating yield potential (Yang *et al*., 2004, 2006). The highest recorded yield is the yield achieved by farmers at the selected locations under the most favorable ecological conditions with extensive inputs regardless of the economic cost and environmental risk (Chen *et al.*, 2012). The experimental yield is the yield published in literature was those with good ecological conditions and extensive inputs, farmers may have great difficulty in attaining comparable yields. The attainable yield was collected from field experiments which conducted on farmer's field using recommended management by local agronomists (Meng *et al*., 2013).

Modeled yield gap was calculated by subtracting farmer's average yield from modeled potential yield. At the same time, the highest recorded yield gap was calculated through subtracting farmer's average yield from highest yield recorded in the area among farmers. On the other hand, the experimental based yield gap calculated by subtracting average yield from the experimental yield in research institutions.

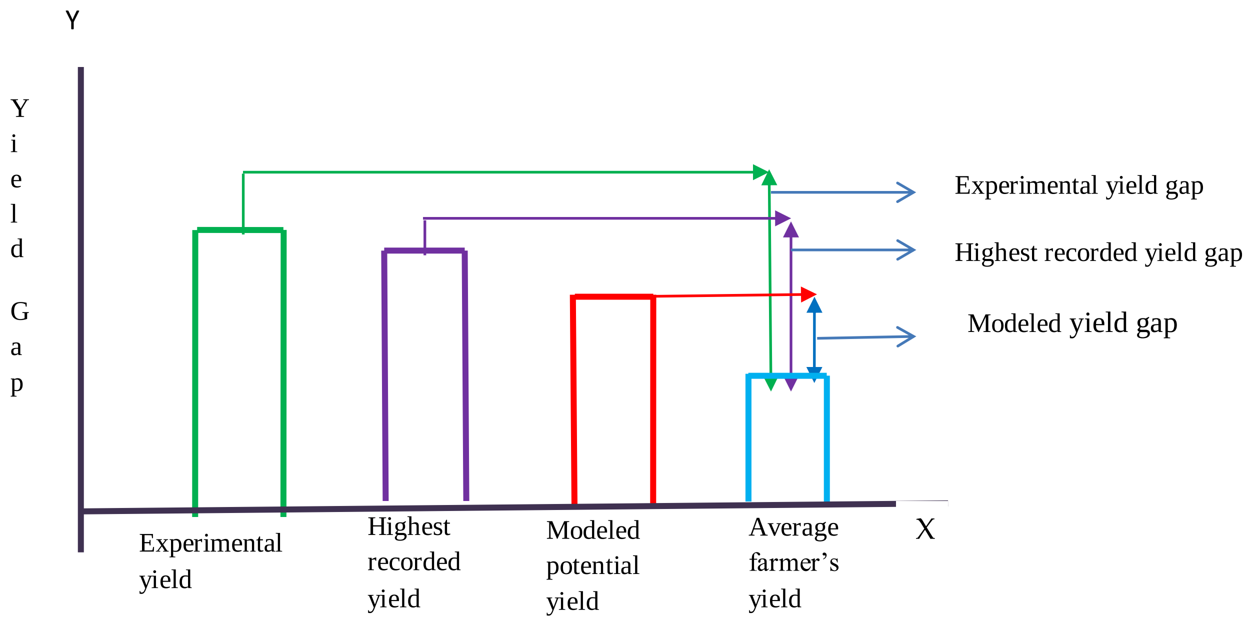

Figure 2. Conceptual framework of yield gaps.

The average yield in the study area was calculated through dividing total yield by the number of sample farmer's yield i.e.

Average farmer's yield= $\frac{\text{Total Yield}}{\text{Total number of farmers}}$ ……..(4)

To estimate the highest recorded yield gap, highest yield was identified from the data set gathered by researcher. To estimate the experimental yield gap, experimental yield of Aman production was collected from BRRI website which is 4.66 ton/ hectare for variety BRRI – 49 (BRRI, 2017).

Technical efficiency analysis**:** Technical efficiency analysis is required to find out modeled yield estimation. To estimate the modeled yield, technical efficiency (TE) analysis with appropriate functional form (Cobb-Douglas or Translog) needs to be used. In this case, stochastic frontier production function (SFP) was employed.

Following Aigner et al., (1977) the stochastic frontier production with two error terms can be modeled as:

$Y_i = f(X_i,\beta)exp(V_i\text{-}U_i)$……………………………(5)

Where,

Y_i is the production of the i-th farm (i=l. 2, 3 ...n); X_i is a (l×k) vector of functions of input quantities applied by the i-th farm.; β is a (k×l) vector of unknown parameters to be estimated; V_i's are random variables assumed to be independently and identically distributed $(N(0, \delta^2))$ and independent of U_i*'s* and the U_i*'s* are non-negative random variables, associated with technical inefficiency in production assumed to be independently and identically distributed. The first error component V is intended to capture the effects of random shocks outside the farmer's control, measurement error and other statistical noise and the second error component U is intended to capture the effects of technical inefficiency.

Following Battese and Coelli (1998), the technical inefficiency effects, U_i can be expressed as:

$U_i = Z_i\delta+W_i$ ………………………………………………………………(6)

Where, *W* are random variables, defined by the normal distribution with zero mean and variance σ^2, u. *Zi* is a vector of farm specific variables associated with technical inefficiency and δ is a (mxl) vector of unknown parameters to be estimated.

After estimating this model, potential yield is estimated from the model. The technical efficiency (TE) shows the farm's ability of maximizing output with a set of given input. The range of TE is 0 to 1. TE = 1 implies that the farm is producing on its production frontier and is said to be technically efficient. Hence, (1–TE) represents the gap between actual production and optimum attainable production that can be achieved by moving the firm towards the frontier through readjusting inputs (Chaves and Aliber, 1993).

***Empirical Cobb-Douglas Frontier Production Model*:** Two types of functions namely Cobb-Douglas and Translog dominate the technical efficiency literature. The stochastic production function for the sample rice farmers was specified as:

$$\ln Y = \ln \alpha + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + \cdots + b_i \ln X_i + V_i - U_i \ldots \quad (7)$$

Where,

Y = yield of Aman rice (kg/ha)
α = parameters
β = coefficients
X_1= labor (man per day/ha)
X_2 = seed (kg/ha)
X_3 = fertilizer (kg/ha)
X_4 = insecticides (tk/ha)
i = 1, 2, 3, 4………..
$V_i - U_i$ = disturbance term

***Technical Inefficiency Effect Model*:** The technical inefficiency effect in equation (7) are defined as,

$$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + W_i \ldots (8)$$

Where,

U_i = inefficiency
δ_0 = parameter
Z_1 = age
Z_2 = education of farmers
Z_3 = access of training
Z_4 = access of extension service
Z_5 = experience
W_i = random variable

Results and Discussion

***Socio-economic profile of farmers*:** The socio-economic characteristic of an area represents the extent of development and also helps to take appropriate policies for further development. The socio-economic environment also greatly determines the nature and extent of participation of people in the development programs. In this section, an endeavor was thus made to evaluate the major socio-economic characteristics of respondents such as age, family size, education, dependency ratio, access of training, access of extension service, access to credit, cultivated land area etc. in the study area (Table 1).

The majority of the study sample was middle aged and had spent a considerable number of years in farming, therefore were experienced. Although, the literacy rate of the study population was not very high, with only 60 percent of the population achieving formal education. The sample households have received training and extension services on a regular basis and therefore were concerned about the related advancements. But it was found that, credit service was unpopular among the farmers as they were not much interested to take up loans to meet their financial needs for rice cultivation and was rather inclined to make various adjustments in their cultivation practices. Most of the household surveyed was dependent on agricultural activities solely and some households were engaged in other activities such as driving van, small business or day laboring along with rice cultivation to support family expenses.

Table 1. Socio-economic characteristics of respondents.

Socioeconomic characteristics	Average	Standard deviation
Age (years)	44.27	13.99
Experience (years)	26.21	15.53
Family size (persons)	5.10	2.10
Number of earning members in family (persons)	1.28	0.57
Education (years)	4.92	4.68
Availed extension services (%)	81.81	0.38
Availed training (%)	61.86	0.488
Credit	10	
Total cultivated land(ha)	24.89	
Dependency ratio	3.33	

***Productivity analysis*:** Farmers in the study area did not maintain any written records of costs and returns of rice cultivation. It is therefore assumed that farmers have sharp memory and calculate everything associated with rice farming. Both family and hired labor were used for rice cultivation and farmers purchased all necessary inputs. Both inputs and outputs were valued at market price during the period of survey. Although it was easy to obtain cost of seed, fertilizers, insecticides and power tiller; it was quiet difficult to make a numerical figure of family labor for which no payment was made. To solve this problem, principle of opportunity cost was employed (Table 2).

The undiscounted BCR in the study area was 1.22 which indicates that Aman rice farming was profitable in the study area. The largest share of cost was incurred by hired labor. This result is consistent with a study carried on by Sultana (2017) in Dacope upazila of Khulna district, which revealed that Aman rice cultivation was profitable and BCR was 1.14. But this is lower to some extent than the findings of Khan (2017) which indicated the BCR in Satkhira district was 1.25.

Table 2. Per hectare average cost and return of Aman Rice cultivation.

Particulars	**Quantity /ha**	**Price per unit (Tk./unit)**	**Cost/ Returns (Tk./ha)**
A. Total Cost of production			
B. Variable Cost			
Seed (Kg)	63.99	60	3850
Urea (Kg)	184.33	18	3316
TSP (Kg)	133.47	25	3337
MoP (Kg)	117.60	16	1881
Gypsum (Kg)	98.75	12	1184
DAP (Kg)	97.92	30	3138
Zinc (Kg)	6.85	200	1372
Insecticides (Tk)	-	-	4594
Power tiller (Tk)	-	-	5384
Hired labor (Man-day)	95	350	33250
Total Variable Cost			61306
Family labor (Man-day)	30	350	10500
Land use cost (Tk)			8785
Total fixed Cost			19285
Total Cost of Production (B+C)			80591
D. Total return			
Main product (Paddy) (Kg)	4663.82	19.42	90571
By-product (Straw) (Tk)			8097
Total return			98668
Gross Margin (D-B)			37362
Net Return (D-A)			18077
Undiscounted BCR (D÷A)			1.22

Source: Author’s estimation, 2018.

***Inefficiency analysis*:** In the way of finding out the yield gap, the stochastic frontier analysis was done to measure the technical efficiency and then efficient yield was found out. For that, both the production inputs and socio-economic characteristics were used in the analysis. The maximum likelihood estimates for parameters of Cobb-Douglas stochastic production function and the technical inefficiency effect for Aman rice farmers is presented in Table 3. It has been found that most of the coefficients of input variables or output elasticity of input variables has expected sign. The coefficient of labor, seed and fertilizer in the stochastic frontier model were statistically significant at 1% level which implies that by 1% increase in labor, seed and fertilizer the yield increases 0.095%, 0.068% and 0.153% respectively. This indicates that farmers in the study area used labor, seed and fertilizer accurately which helped them to increase the yield of Aman rice and those were very important for rice production.

Table 3. Maximum likelihood estimates for parameters of Cobb-Douglas stochastic production function and the technical inefficiency effect for Aman rice farmers.

Variables	**Parameters**	**Coefficients**	**Standard error**	**t-ratio**
Intercept	β_o	6.352***	0.461	13.763
Labor	β_1	0.095***	0.031	2.967
Seed	β_2	0.068***	0.026	2.549
Fertilizer	β_3	0.153***	0.032	4.658
Insecticides	β_4	0.135	0.015	0.227
Inefficiency model				
Intercept	δ_0	0.320***	0.056	5.622
Age	δ_1	-0.002**	0.001	-2.109
Education	δ_2	0.001	0.002	0.7474
Access of training	δ_3	-0.057***	0.019	-2.966
Access of extension service	δ_4	-0.054***	0.0171	-3.187
Experience	δ_5	0.001	0.001	1.485
Variance Parameter				
Sigma-square	σ^2	0.005***	0.001	4.933
Gamma	Γ	0.999***	0.091	10.966
Mean efficiency	0.8189			

*** =*Significant at* 1%, ** = *Significant at* 5%, * = *Significant at* 10%; Source: Author's estimation, 2018.

On the other hand, the coefficient of insecticide was not significant. In the technical inefficiency model, farmer's age was statistically significant at 5% level whereas access of training and access of extension services are statistically significant at 1% level of significance respectively.This indicates that age, training and credit had significant effect on increasing yield of Aman rice. The more the farmers accessed training and extension service, the more yield of Aman rice increased. The farmers of more age also contributed to increased yield of Aman rice due to their relatively enriched understanding of farming. The education and experience of farmers were however found insignificant. This means that there was no significant effect of this inefficiency factors on yield. Although, the sign of experience and education found were unexpected. But it can be due to the soil fertility or use of unique doses of inputs by farmers whatever the soil quality or farm location nearer to saline water.

Besides, the gamma (γ) parameter was 0.999 at 1% level of significant and very closer to 1 indicating that inefficiency factors had significant impact on rice production. So, the maximum likelihood estimate was the adequate estimate on. The gamma parameter (γ) also implies that about 99.90 percent of the difference between observed output and maximum production frontier output is caused by differences in farmers' level of technical efficiency.

The mean efficiency 81.89% revealed that the farmers were producing Aman rice which is 18.11% lower than frontier production. That means that the production gap was 18.11% and the yield per hectare can be increased, on an average, by 18.11% without incurring any additional production cost. The estimated result also showed that there is a greater scope of increasing yield, breaking the frontier of Aman rice production in the study area through increasing efficiency if the existing resources are efficiently managed and modern varieties of seed and technology are made available to the farmers.

According to Roy and Hamid (2014), there was technical efficiency in rice production ranges from 28% to 97% with mean efficiency of 75% in southern Khulna region, which is consistent with our findings. Sultana (2017) found that overall mean efficiency level of Aman rice producer in Dacope Upazila of Khulna district was about 85% implying that farmers could increase production by 15% more with optimal use of input and proper management system.

***Yield gap measurement*:** Yield gap is a powerful method to reveal and understand the biophysical opportunities to meet the projected increase in demand for agricultural products, and to support decision making on research, policies, development and investment are needed. The yield gap of a crop grown in a certain location and cropping system is defined as the difference between the yield under optimum management and the average yield achieved by farmers.

The study attempted to find out three kinds of yield gap of Aman rice production to estimate the yield gap: the farmer's average yield, modeled potential yield, highest obtained yield and experimental yield. The yield gaps are presented in Table 4.

Table 4. Yield gap of Aman rice in the study area.

Particulars	**Yield (ton/ha)**	**Average yield (ton/ha)**	**Yield gap (ton/ha)**
Modeled potential yield (Y_M)	4.798	4.663	0.135
Highest recorded yield (Y_R)	5.677	4.663	1.014
Experimental yield (Y_E)	5.500	4.663	0.837

Source: Author's estimation, 2018.

Table 4 clearly represents that the highest recorded yield gap was the highest (1.014 ton/ha). The modeled yield gap was 0.135 ton/ha, which was the lowest. In this respective year, the rainfall was quiet good which reduced the effect of salinity in the study area and no climatic hazard occurred which was quite a rare phenomenon; which in return resulted in higher than usual yield. Sultana (2017) looked into the Yield gap and associated risk factors in Dacope Upazila of Khulna District and found significant amount of yield gap for Aman rice production. Experimental yield gap was higher (1.93 ton/ha) compared to highest recorded (1.37 ton/ha) and modeled (0.497 ton/ha) yield. Climatic disaster may increase the salinity in the area which may increase the yield gap. The difficult task is to reduce the experimental yield gap. Because experimental yield is obtained from good agronomic conditions and with proper doses of fertilizers and other inputs. But, the study area's soil and environment condition does not always remain same. The highest recorded yield gap in the study area indicated that prevailing yield gap in the area can be eliminated as some farmers have obtained a much higher yield than the average yield.

Conclusion

Even Aman rice cultivation in the climatically endangered area of Bangladesh is a profitable agribusiness venture; the farmers can get more yields if they can increase their efficiency level. The estimated yield gaps in the research area were ranged from 0.134 to 1.014 tons per hectare. The present natural situation of the coastal area is suitable for rice cultivation despite having lower yield potential in general. However, constraints on yield, such as, salinity intrusion, tidal surge, water logging, irregular rainfall and temperature will continue to be present in those areas. Yet, it is possible that, by increasing the technical knowledge of the farmers the production of rice can be improved. Training programs aimed at optimum input use should be more emphasized and extension services should be more accessible and available to the farming community. This may lead to higher yields of rice production. There is proof that high yield can be obtained in the study area as far as 5.67 tons per hectare, which is even higher than the experimental yield. Therefore, there is opportunity for lower yielding farmers to improve their production by following the high yielding farming practices. Also, as the maximum farmers in the study area are not cultivated salt tolerant rice varieties and are experiencing a lower yield altogether due to increasing salinity, henceforth, emphasis should be given to disseminating and popularizing the use of new salt tolerant rice varieties among the farmers. Government's extension office, NGO's and other GO's can prescribe the appropriate doses of fertilizer and insecticides to farmers along with ensuring regular supply of inputs at subsidized price to the poor farmers. Expanding research, monitoring, knowledge management and development and transfer of technology, especially on saline-resistant crop varieties are needed to manage climate change and its impacts in the study area.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgements

The first author gratefully acknowledges the Ministry of Science and Technology of the Government of People's Republic of Bangladesh for funding this research project.

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