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SOIL EROSION AND ITS EFFECTS ON MAIZE FIELD AS MODIFIED BY AMENDMENTS IN SOUTHWESTERN COASTAL BANGLADESH

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Abstract

The coastal soils of Bangladesh are preferentially dominated by silt content and stressed by salinity (Na^+) as well as low humus content . Hence, these soils are moderately to extremely vulnerable to water erosion, which is a major form of land degradation. The aim of this study was to estimate the soil erosion rate from maize fields in the southwestern coastal region. A field experiment was conducted on maize grown field, which is nearly level, moderately saline, and silt dominated coastal land. The plots were amended with inorganic fertilizer, sieved sand, and decomposed cow dung. Each runoff plot was connected to separate reservoirs and was exposed to rainfall. From the erosive rainstorms, representative critical rainfall intensity was determined. The entrapped eroded material in the reservoirs was collected to estimate the loss of soil. The efficacy of the applied amendments was studied in terms of lowering seasonal (maize growth period) soil loss and erosion associated deterioration of relevant soil parameters. This study revealed that CRI was ≥15 mm h^{-1}. The soil loss during the maize growth period from inorganic fertilizer, cow dung, and sand amended runoff plots were 64(±7) t ha^{-1} y^{-1}, 51(±5) t ha^{-1} y^{-1}, and 23(±2) t ha^{-1} y^{-1}, respectively. The changes in soil properties indicated that after initial erosion, vulnerability to further erosion increased.

Keywords: Soil erosion; Soil erodibility; Critical rainfall intensity; Soil physical properties

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Introduction

Soil erosion occurs when soil particles are detached by the force of water or wind and are transported and deposited elsewhere. Erosion also starts when the irrigation or rainwater detaches the soil particles from soil aggregates (Hann and Morgan, 2006). Soil erosion depends largely on both the erosivity of rainfall and erodibility of the soil (Akintola, 2010). Soil erodibility can be determined from some soil properties, which are correlated with erosion (Stanchi *et al.* 2013). Soil loss is not only related to the erosivity but also erodibility because stable soil aggregates can resist the beating action of rain in an efficient way and can save soils even when runoff occurs (Toy *et al.*, 2002). There are four soil erodibility classes based on K value, which described that values >0.45, 0.35 – 0.45, 0.25 – 0.35, and <0.2 were classified as very high, high, moderate, and low soil erodibility, respectively (Amangabara *et al.*, 2014). Soil loss is negatively correlated with clay content, but it is positively correlated with very fine sand and silt contents (Duiker *et al.*, 2001; Wischmeier and Smith, 1978).

Soils with relatively low organic matter content are more vulnerable to water erosion (Brady and Weil, 2002) since organic matter increases the stability of the soil. The presence of organic carbon and clay coatings increases soil aggregate stability and makes it more resistant to water erosion (Kodešová *et al.*, 2009). Organic carbon also plays a significant role in aggregate stability (Liu *et al.*, 2003). Soils having dispersion ratio > 0.15 or 15% are erodible in nature (Dabral *et al.*, 2016; Middleton, 1930). Furthermore, these limits of critical organic matter content for characterizing soil structure: <5% indicates high susceptibility to erosion; 5 to 7% indicates the risk of soil degradation, and >9% indicates stable soil structure (Pieri, 1991). The application of cow dung can reduce soil dispersion ratio, bulk density, and increase total porosity and other physical properties (Adekiya*et al.*, 2016; Rasoulzadeh and Yaghoubi, 2010). Both clay ratio and modified clay ratio are positively correlated with soil loss (Singh and Khera, 2008), and a higher value of modified clay ratio indicates higher susceptibility to erosion. Besides, soils with high silt contents are very vulnerable to water erosion (Bonilla and Johnson, 2012; Romero *et al.*, 2007). The values of clay ratio (3.44-9), modified clay ration (mean value of 6.9), critical level of organic matter content (<5%) indicate that the soils are highly erodible in nature (Kusre*et al.*, 2018).

Soil erosion often causes an increase in the sand fraction and reduction in the silt and clay fraction (Abdullahi, 2018). Furthermore, it has also been observed that the soils of the eroded field have higher bulk density and lower porosity (Rosen, 2009; Jagdale and Nimbalkar, 2013). The changes in soil properties after erosion indicate that already eroded soil is more susceptible to further erosion and eroded faster compared to the non-eroded soils (Pimental, 2006).

In Bangladesh, around 75% of the areas have *very high* susceptibility to erosion, 20% have *high* susceptibility to erosion and 5% have *moderate* susceptibility to erosion (Hossain and Rahman, 2015). Coastal erosion is the wearing away of the coastal land, which is mainly a natural process. Coastal erosion has now become a great problem in Bangladesh since the land of the coastal area is decreasing day by day. The total cultivable land is declining at an alarming rate in the coastal areas because 16 coastal districts, out of 19, have experienced the loss of net cultivable land due to erosion (Mishu and Zaman, 2013). Bhola island has been reduced from 6400 km^2 to 3400 km^2 since 1960 (Shamsuddoha and Chowdhury, 2007), and it has been estimated that the erosion rate in this coastal area is up to 120t ha^{-1} y^{-1} (Sarwar and Woodroffe, 2013). The southwestern part of Bangladesh, including Khulna, Bagerhat, and Satkhira are also coastal areas of Bangladesh dominated by silt content and affected by high Na^+ content.

Therefore, this study was undertaken to determine - a) changes of soil properties caused by 'inorganic fertilizer', 'cow dung' and 'sand', b) critical rainfall intensity for the coastal region (Na^+ and silt dominated) of Bangladesh, c) soil erosion rate from land subjected to each amendment, and d) to evaluate the impact of soil erosion on soil properties.

Methods

The study area lies between 22° 48' 12.10" to 22° 48' 12.86" North latitude and 89° 32' 2.22" to 89° 32' 2.14" East longitude. It falls under Batiaghata Upazila in Khulna district. Runoff plots of (5m × 4m) area were prepared and reservoirs of (3m × 4m × 1m) dimension were constructed adjunct to each plot and connected by a channel. Amendments (inorganic fertilizer, sieved sand, and decomposed cow dung) were applied on 23rd January 2018. After 90 days of application of the amendments, the seeds of BARI Hybrid Maize (*Zea mays* L.) were sown on 28th April 2018. The recommended amount of inorganic fertilizer was applied as suggested in the fertilizer recommendation guide (FRG, 2012) in inorganic fertilizer treated plots. The rate of the application of inorganic fertilizer was – 85 kg ha^{-1} Nitrogen, 25 kg ha^{-1} Phosphorus, 40 kg ha^{-1} Potassium, 18 kg ha^{-1} Sulfur, and 5 kg ha^{-1} Magnesium. In cow dung treated plot, 6 kg decomposed cow dung per 100 kg of soil was applied. In sand treated plot, 40 kg sand per 100 kg of soil was applied. The location of the area is shown in Fig. 1.

The experiment was run in the same field where the soil properties of the plots were all the same before amendments application, and there were three replications for each amendment. Complete randomized block design (CRBD) was used to set up the experimental plots. The layouts of the plots are illustrated in Fig. 2.

Initial soil samples were collected from the runoff plots before applying the amendments to determine the inherent characteristics of the soil. After 90 days of amendment application (25th April 2018) but before seeds sowing, soil samples were again collected from the runoff plots to observe the changes in soil properties caused by the amendments. Finally, samples were collected (on 5th August 2018) from the field after erosion to observe the changes in soil properties due to erosion. The slope steepness of every plot was the same since our study area was nearly level.

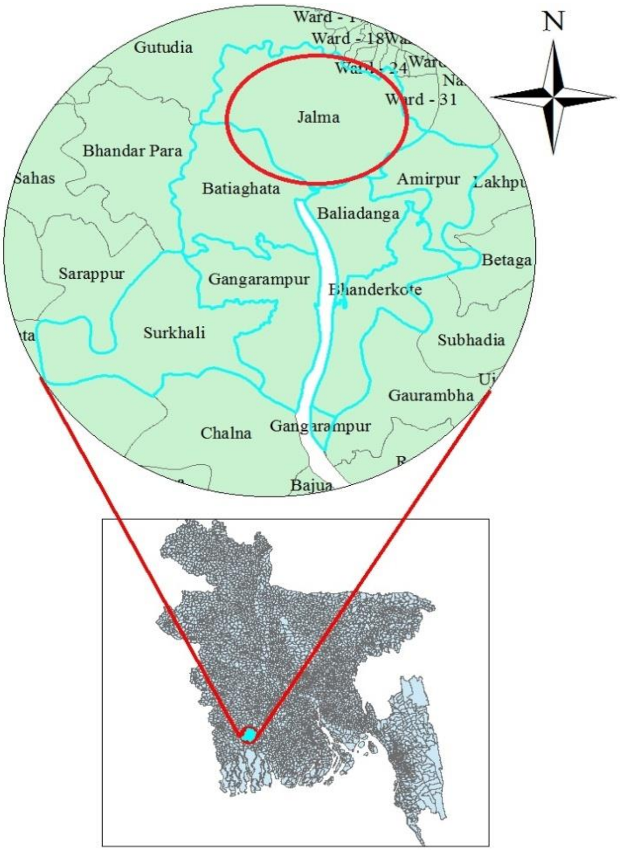

Fig. 1: Location of the area.

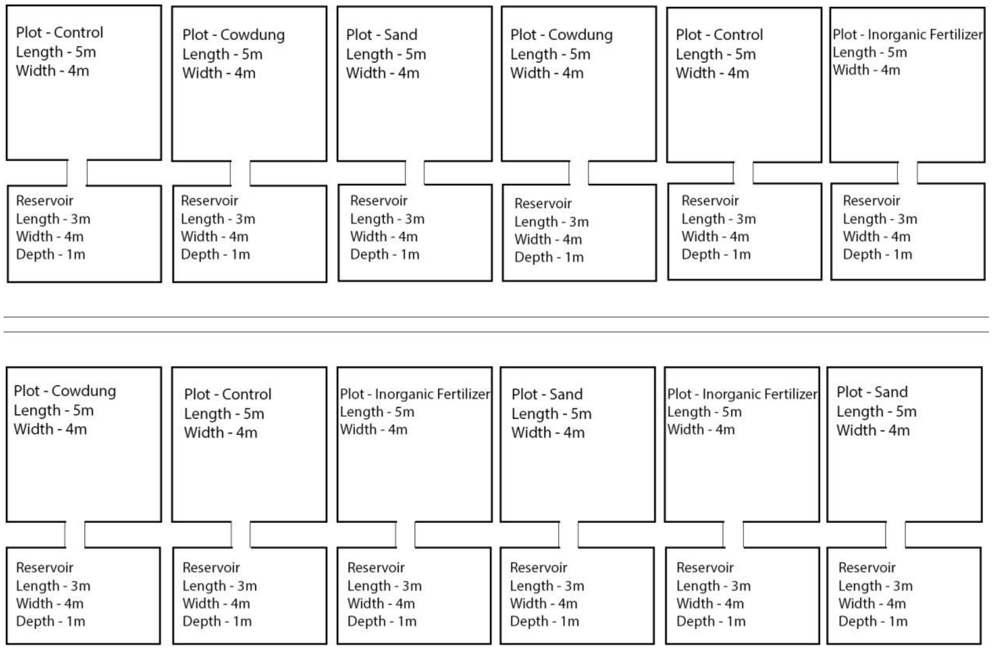

Fig. 2: A schematic diagram of the runoff plots and their collection reservoirs.

Plots were exposed to natural rainfall, and the runoff volume of water from each plot was caught in the reservoirs for determining soil loss and other erosion related parameters. The data of rainfall amount, duration, and intensity were collected from the nearby meteorological station, Khulna. The meteorological center was 546 meters away from the experimental field. After each rain event, the sediments trapped in the reservoir were collected. Before collecting the sediment samples, the runoff water in the reservoir was stirred and homogenized properly.

Following parameters were determined in this investigation: organic matter (%) (Walkley and Black wet oxidation method), particle size analysis by soil hydrometer and wet sieving method (Gee and Or, 2002), permeability by constant head method (Klute, 1965), clay ratio (Bouyoucos, 1951), modified clay ratio (Kumar *et al.*, 1995), dispersion ratio (Middleton, 1930), critical organic matter content (Pieri, 1991), bulk density by core sampling method (Blake and Hartge, 1986), particle density by pycnometer method (Black, 1965) and total porosity (Strickling, 1956). soil erodibility factor (K) (using the equation of erodibility and nomograph), and soil structure by visual observation.

The erodibility factor (K) of the study area was determined to be 0.31 as calculated by the erodibility equation(Eq. 1) below:

$$K = \frac{\mathbf{2.1 \times M^{1.14} \times 10^{-4} \times (12-a) + 3.25 \times (b-2) + 2.5 \times (c-3)}}{\mathbf{100}} \qquad \text{(Eq. 1)}$$

Dispersion ratio was calculated by Eq. 2,

$$\text{Dispersion ratio} = \frac{(\%silt+\%clay)\,in\ undispersed\ soil}{(\%silt+\%clay)\,in\ dispersed\ soil} \qquad \text{(Eq. 2)}$$

Undispersed soil means "samples which were not treated with H_2O_2 and Sodium-hexametaphosphate."
Dispersed soil means "samples which were treated with H_2O_2 and Sodium-hexametaphosphate."
Clay ratio was calculated by Eq.3.

$$\text{Clay ratio} = \frac{(\%sand+\%silt)}{\%clay} \qquad \text{(Eq. 3)}$$

Modified clay ratio was calculated by Eq. 4.

$$\text{Modified clay ratio} = \frac{(\%\mathbf{sand}+\%\mathbf{silt})}{(\%\mathbf{clay}+\%\mathbf{organic\ matter})} \qquad \text{(Eq. 4)}$$

S_t (critical organic matter content) was determined by Eq.5.

$$\text{Critical soil organic matter content} = \frac{\%\mathbf{soil\ organic\ matter}}{(\%\mathbf{clay}+\%\mathbf{silt})} \qquad \text{(Eq. 5)}$$

The statistical analysis was conducted using SPSS 16 – One-way ANOVA, and Tukey's HSD was used for the post hoc comparison of means.

Results

Amendments (inorganic fertilizer, cow dung, and sand) were used to observe the changes in soil separates of the field after 90 days of amendments application. Table 1 indicated expectantly that the sand fraction significantly increased after the application of sand. On the other hand, the percentage of sand, silt and clay did not change significantly for inorganic fertilizer and cow dung.

There was no significant difference in the dispersion ratio between inorganic fertilizer and control treated plots, but the difference was significant between cow dung and sand treated plots. The dispersion ratio in cow dung and sand treated plots was 69% and 55%, respectively (Table 1). The clay ratio was similar (with a value of about 2) in the control, inorganic fertilizer and cow dung treated plots, but it increased in sand treated plots. Modified clay ratio in sand treated plots changed significantly compared to the control, inorganic fertilizer, and cow dung treated plots. The highest value of clay ratio and modified clay ratio was observed in the sand treated plots, which were 2.4 and 2.1, respectively. It is important to address that in control plots, where no amendments were used, showed similar results like inorganic fertilizer treated plots

Table 1: Changes in soil properties after 90 days of amendments (inorganic fertilizer, cow dung, sand) application compared to control.

	%Sand†	%Silt†	%Clay†	%Sand‡	%Silt‡	%Clay‡	DR%	CR	MCR	OM%	S_t%	D_b	Porosity%
CN	11a	56a	33a	34a	63a	3a	74a	2a	1.8a	3.75a	4.2a	0.9ab	60a
INf	11a	56a	33a	33a	63a	4a	75a	2a	1.8a	3.75a	4.2a	0.9ab	60a
CD	10a	56a	34a	38b	58b	4a	69b	1.9a	1.7a	3.91b	4.3a	0.7a	67b
S	17b	54b	29b	33a	63a	4a	55c	2.4b	2.1b	3.75a	4.5b	1.22b	49c

CN= Control, INf= Inorgnic fertilizer, CD= Cow dung, S= Sand, DR= Dispersion ratio, CR= Clay ratio, MCR= Modified clay ratio, OM= Organic matter, S_t= Critical organic matter content, D_b= Bulk density

†% Soil separates using dispersing agent (Na-hexametaphosphate) and H_2O_2; ‡% Soil separates not using any dispersing agent; According to Tukey's HSD mean test, values of each fraction under each treatment followed by different lowercase are significantly different ($P<0.05$)

The organic matter content and critical organic matter content (S_t) was found to be 3.75% and 4.2% respectively, in the control and inorganic fertilizer treated plots. Organic matter (%) and S_t increased to 3.91% and 4.3%, correspondingly in cow dung treated plots. The D_b of the control plots initially was 0.9 gm cm^{-3}, which increased to 1.22 gm cm^{-3} after sand addition. In cow dung treated plots, the D_b decreased to 0.7 gm cm^{-3} (Table 1). The porosity of cow dung treated plot increased from 60% to 67%. The total porosity reduced significantly in sand treated plots, which was 49%. In the control plots, the total porosity was expectantly observed to remain at 60%. The CRI was determined to be ≥15mm h^{-1} in this area. CRI for every plot was the same because the cow dung and sand did not bring about significant changes in the soil properties in 90 days.

The annual soil loss (t ha^{-1} y^{-1}) is presented in Table 2, which shows that sand application reduced soil erosion more effectively compared to cow dung and inorganic fertilizer. The soil loss from control treated plots was 61t ha^{-1} y^{-1}, and soil loss from inorganic fertilizer, cow dung, and sand treated plots was 64t ha^{-1} y^{-1}, 51t ha^{-1} y^{-1}, and 23 t ha^{-1} y^{-1}, respectively.

Table 2: Soil loss estimation from different treatments.

Treatments	Loss of soil (t ha^{-1} y^{-1})
Control	61c
Inorganic fertilizer	64c
Cow dung	51b
Sand	23a

According to Tukey's HSD mean test, values of each fraction under each treatment followed by different lowercase are significantly different ($P<0.05$).

A reduction in clay content was seen by 3%, 4%, and 1% from inorganic fertilizer, cow dung, and sand treated plots, respectively, and the change in silt content is similar to that of clay reduction (Table 3). Due to the loss of particles, changes were found in dispersion ratio, clay ratio, and modified clay ratio**Table 3**. Dispersion ratio increased in all plots by 1%, 2%, and 15% from inorganic fertilizer, cow dung and sand treated plots, respectively. Similarly, clay ratio also increased by 15%, 21%, and 8% from inorganic fertilizer, cow dung and sand treated plots, respectively.

Table 3: Changes in soil properties of each plot after erosion as affected by inorganic fertilizer, cow dung, and sand amendments in maize plots in batiaghata Upazila, Khulna, 2019.

Parameters	**Treatment**					
	Inorganic fertilizer		Cow dung		Sand	
	Before erosion	After erosion	Before erosion	After erosion	Before erosion	After erosion
%Sand†	11a	17b	10a	17b	17a	20a
%Silt†	56b	53b	56b	53b	54a	52a
%Clay†	33b	30b	34b	30b	29a	28a
%Sand‡	33a	38b	38b	41b	33a	44b
%Silt‡	63b	60b	58	58	63a	55b
%Clay‡	4b	2b	4a	1b	4a	1b
DR (%)	75b	76b	69b	71b	55a	70b
CR	2a	2.3b	1.9a	2.3b	2.4b	2.6b
MCR	1.8b	2.1b	1.7a	2.1b	2.1b	2.3b

OM (%)	3.75a	3.62b	3.91a	3.31b	3.75a	3.53b
OM (%) in sediments	0.11		0.4		0.19	
S_t (%)	4.2a	4.3a	4.3a	4b	4.5a	4.4b
D_b	0.9a	1.15b	0.7b	0.88b	1.22a	1.28b
Porosity (%)	60a	51b	67a	60b	49a	37b

† % Soil separates using dispersing agent (Na-hexametaphosphate) and H_2O_2

‡ % Soil separates not using any dispersing agent

According to Tukey's HSD mean test, values of "before erosion and after erosion" of each parameter under each treatment followed by different lowercase are significantly different ($P<0.05$). The statistical difference is shown between the 2 values "before erosion" and "after erosion" in each treatment.

The soil organic matter decreased by 0.11%, 0.4% and 0.19% from inorganic fertilizer, cow dung and sand treated plots, respectively (Table 3).Critical organic matter content was lower for sand and cow dung treated plots due to the loss of organic matter, silt, and clay fractions. The results indicate that after erosion, the bulk density of soil in every plot increased (Table 3). In the inorganic fertilizer treated plots, the bulk density increased the most (by 28%); whereas, in cow dung treated plots, D_b increased by 25%, and it increased the least for sand treated plots (by only 5%).

Discussion

The results clearly indicate that the application of cow dung improved soil properties like –dispersion ratio, clay ratio, organic matter, critical organic matter content, bulk density, and porosity compared to control and inorganic fertilizer amendment. Cow dung is an excellent source of soil organic matter, which stabilizes soil structure and improves bulk density and porosity. According to the studies conducted by Adekiya *et al.*, (2016); Rasoulzadeh and Yaghoubi (2010), the incorporation of cow dung can decrease soil bulk density, dispersion ratio and increase total porosity, modified clay ratio and critical organic matter content as it aids in stable aggregate formation. Soils with high dispersion ratio are structurally weak and easily eroded (Igwe *et al.*, 1995). According to the criterion of Middleton (1930); soils having dispersion ratio >0.15 or 15% are erodible. Moreover, the incorporation of cow dung reduces the dispersion ratio by binding soil particles leading to increased soil stability. Sarkar *et al.*, (2003), in their study, found that the sole application of inorganic fertilizer to farm fields decreased the stability of macro-aggregates while increasing the bulk density, which agrees with the findings of this experiment. The addition of inorganic fertilizer affects the chemical composition of the soil solution that causes flocculation or dispersion of the clay particles, thereby affecting soil aggregate formation (Haynes and Naidu, 1998).

CRI was observed to be about 15 mm h^{-1} and was similar for all plots because the amendments were not so effective at changing the soil properties significantly. If the amendments caused a significant change in soil properties, soil properties would be more improved, and the soils could resist the beating action of raindrops. As a result, CRI would vary for each plot.

Cow dung significantly reduced soil erosion compared to control and inorganic fertilizer treated plot because cow dung actually improved most of the physical properties. Sand particles are larger than silt and clay particles, and that's why these particles are hard for water force to wash away. Soil loss is negatively correlated with the sand percentage (Bonilla and Johnson, 2012). In addition, sand particles are responsible for larger pores, which increases water infiltration rate and reduces runoff (Ostovari *et al.*, 2018). This study indicated that sand can reduce soil erosion more effectively (for short-run) than cow dung and inorganic fertilizer. Cow dung is an excellent source of organic matter, which can increase soil aggregate stability and can provide better protection against water erosion. After erosion, the percentage of sand increased for all plots, and the findings of this experiment agrees with the findings of Abdullahi (2018). Due to the losses of silt and clay, the dispersion ratio of the plots increased for every plot. Increase in the clay ratio and modified clay ratio also occurred due to the decrease in particle sizes. These results indicate that already degraded soils have a higher risk of erosion. Pimental (2006) also reported that an eroded field becomes more vulnerable to further erosion. The reduction in organic matter, clay, and silt fraction should intuitively reduce the critical organic matter content in the inorganic fertilizer treated plot, but instead, it increased. The loss of organic matter was much less in this case, which could be the reason why critical organic matter content increased only in the inorganic fertilizer treated plots. More research is needed on the relationship between critical organic matter, %organic matter, and soil particles. According to the limits shown by Pieri (1991), the magnitude of critical organic matter content indicates that the plots are highly susceptible to erosion. After erosion, the soil bulk density of every plot increased while total porosity decreased, which is corroborated by the findings of Jagdale and Nimbalkar (2013).

Conclusion

The critical rainfall intensity above which soil erosion occurred in the study area wasdetermined to be 15 mm h^{-1}. The addition of sand reduced soil loss but did not improve soil physical properties, while cow dung improved soil physical quality through soil stabilization. But inorganic chemical fertilizers did not show any positive effects on soil physical properties and in reducing soil loss. The percentage of sand fraction increased after erosion, while silt and clay fraction decreased. Significant loss of organic matter was found in cow dung treated plot. The porosity decreased after erosion, corresponding to an increase in bulk density. The dispersion ratios of the eroded plots were higher than before erosion occurred. Both clay ratio and the modified clay ratio increased with erosion. A Long-term research should be conducted using a combined treatment of sand and cow dung, which could be more effective at reducing soil erosion while enhancing soil productivity.

Conflict of interest

None.

Author contribution statements

Md. Sanaul Islam designed the entire work and played his role as the supervisor. He also checked and evaluated all the laboratory data and analysis. **Baig Abdullah Al Shoumik and Md. Sanaul Islam** jointly prepared different sections of the manuscript.

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