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USABLE WATER ASSESSMENT FOR NORTH-EASTERN PART OF BANGLADESH: A CASE STUDY

E. Shaik[1*] and M. T. Islam[1]

Abstract

The agro-based north-eastern haor region of Bangladesh is very important for crop production and food security of the country. The irrigated crop of dry season faces useable water scarcity. So usable water assessment during the dry season is very important for agro-based Haor area to know the extent of necessary surface water development measures for the study area. At the same time, Haor area is engulfed with various water-related problems and constraints viz. pre-monsoon flash flood and seasonal flood due to excess rainfall, climatic variability, river capacity reduction; water logging due to unplanned road construction and canal or creek filled up, disruption of hydraulic connectivity between Haor and river and dry seasonal water scarcity. The study intends to explore the dry season water security which one of the major concerns for the development of agro-based north-eastern Haor region of Bangladesh. The distinct water scenarios like status of usable water in terms of stream flow, static flow, dependable rainfall, and usable groundwater during dry season is estimated which necessitate assessment of crop water demand and supply requirement to know the spatio-temporal scenario of water whether surplus or deficit is important for regional policy planning and water management of the study area.

Keywords: *rainfall, evapotranspiration, crop production, crop water demand, usable water.*

Introduction

The unique hydro-ecological characteristics of the study area are large bowl-shaped floodplain depressions which cover about 2372.67 sq. km within 19,998 sq. km of total area and accommodating about1.99 million people within 19.37 million (BHWDB, 2012; Bevanger *et al.,* 2001; IUCN, 2002). There are 373 Haor located in the north-eastern part including the study area of Sunamganj, Netrakona, and Kishoreganj (Hossain, 2013). These 373 Haors cover an area of about 859,000 ha which is around 43% of the total area of the Haor districts and in the study purposes 1527.16 sq. km is considered that is actually the agro-based area (BHWDB, 2012). It is a mosaic of wetland habitats including rivers, streams, canals, large areas of seasonally flooded cultivated plains and beels. It is difficult to foresee the country's overall progress without the development of the Haor region as it covers a major part of the country and population which deserves special development initiatives. Both BRRI dhan 28 and 29 were being the widely adopted rice varieties. On an average, about 33% of the haor areas were under mechanized irrigation, but in Kishoregonj, the coverage of mechanized irrigation was 87% that helped increasing cropping intensity. In Kishoregonj and Habigonj, nearly 94 and 87% areas were devoted to Modern Variety (MV) Boro rice production. Alam *et al.* (2010) studied on Crop Production in the Haor Areas of Bangladesh; assess the land utilization status, delineate the productivity and profitability of growing modern rice, evaluate the existing cropping patterns and depicts the prospect of possible cropping patterns.

Khan *et al.* (2012) conducted a study on the Impacts of Flood on Crop Production in Haor Areas of Two Upazillas in Kishoregonj. Haor is a basin-like structure where water remains either stagnant or in flash flooding condition during the months of June to November. In Bangladesh, Haor areas are covered by Boro rice and produce a large amount. Severe flood damage the boro crop, so that the study was conducted to know the land use pattern and impact of the flood on boro rice production. Flood control measures would be taken to prevent a huge loss of boro rice. Hossain *et al.* (2017) also conducted an experiment about the impact of Flash Flood on Agriculture Land in Tanguar Haor Basin. The most diversified ecosystem Tanguar haor, is not only ecologically but also socio-economic important for supporting livelihood to around 70,000 people. Geographical location has made it vulnerable to adverse impacts by a flash flood in almost every year.

The future challenges in the context of climate change are also a major concern for the sustainable development of the region. Haor resources have been broadly grouped into three categories: human, economic and natural resources based on an understanding of the possible size, composition, resource management and growth potentials for resources in the area

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(BHWDB, 2012). The physiography of the study area is Old Brahmaputra Floodplain, Sylhet Depression and Meghalaya Foothills within eleven physiographic units. The climate of the study area is classified as tropical. The summer has a good deal of rainfall, while the winter has very little. The mean temperature during the summer months remains within 23°C to 30°C. April and May are the hottest months. Over the rest of the country, it ranges from 41°C to 43°C. The post-monsoon months of October and November are transition months from summer to winter and it is quite hot in October (Khatun *et.al.* 2016). The average annual rainfall ranges from 2222 mm to 4961 mm whereas maximum 1337 mm rainfall in Bishwamvarpur, Sunamganj in July. The major rivers of these districts are Bhatta, Baulai, Dhanu, Dahuka, Derai, Ghorauta, Kalni, Kangsha, Meghna, Nawa, Old Brahmaputra and Surma (WARPO, 2016). The usable water in the dry season is not sufficient to meet the demand despite available river and perennial of water bodies. Dey *et al.* (2017) studied on the recent flash flood'17 in the north-east region which was triggered by heavy rainfall has breached parts of embankments and resulted in huge loss of assets and income of Haor dwellers. The aim of the study was to investigate the impact of flash flood'17 in different sectors, such as agricultural production, livelihood including food security, education system, social and gender vulnerability, water, sanitation and health, and economic groups. Nowreen *et al.* (2015) also monitored the Haors as large, round-shaped floodplain depressions located in the North-Eastern region of Bangladesh. Extreme events such as heavy rainfall routinely affect the Haor basin with flash floods. These Haors are predicted to experience severe stress because of changes in rainfall and temperature patterns.

The study area lies in the Meghna Basin which is part of the Ganges-Brahmaputra-Meghna (GBM) basins. Flow from about 66,640 km^2 of the Meghna basin is drained ultimately into the Bay of Bengal through the Kalni-Kushiyara and Surma-Baulai river system. The estimated outflow of water from this region into the Bay amounts on average is 162,619 million-m^3 year. Fifty seven (57) percentage of this flow is generated at the upstream of Bangladesh while 43% is generated within the country. Transboundary flow from India to Bangladesh varies from time to time whereas the inflow (mainly pre-monsoon flow) from India into Bangladesh is the main cause of flash flood in the Haor area (BHWDB, 2012).

The main objectives of the study is to explore the spatio-temporal potentialities of utilizable surface water and groundwater availability whether surplus or deficit from the demand and supply requirement of Austagram, Bajitpur, and Bhairab Upazila of Kishoreganj district; Atpara, Barhatta, and Durgapur Upazila of Netrokona district and Bishwamvarpur, Chhatak, and Dakshin Sunamganj Upazila of Sunamganj district.

Methodology

Study site

The study was conducted at Austagram, Bajitpur, and Bhairab Upazila of Kishoreganj district; Atpara, Barhatta, and Durgapur Upazila of Netrokona district and Bishwamvarpur, Chhatak, and DakshinSunamganj Upazila of Sunamganj district which lies in Mymensingh, Dhaka and Sylhet division respectively (Fig. 1). The study areas i.e. nine upazilas of three districts are located (91°0'00" E and 25°0'00"N) mostly north east and a little part in the north central hydrological region of Bangladesh.

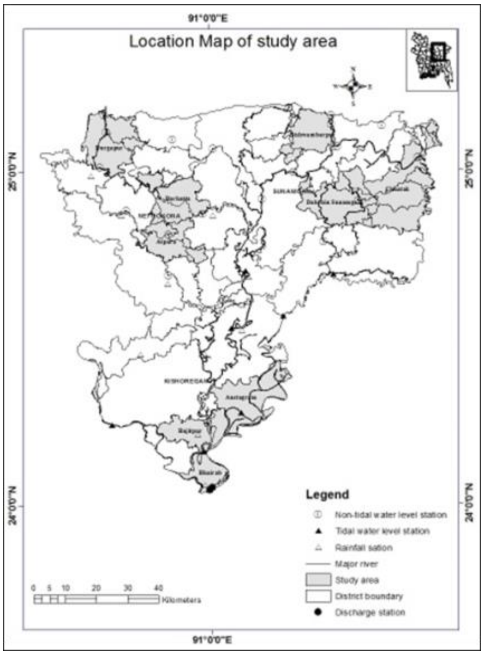

Fig. 1. Location map of the study area

The geographical feature of the study area is plain terrain with a mild slope, riverine, vegetative cover, and distinct scenario of perennial water bodies like haor, baor and beels etc,

Data processing approach

In this study all secondary data are used to assess the surface water condition specifically like rainfall, evaporation, surface water level and discharge, groundwater level has been updated in terms of validation test i.e. randomness test, consistency test, correlation test; compilation test i.e. normal distribution, T-test, F test; frequency test and goodness of fit test i.e. chi-square test etc. Due to the lack of data, groundwater analysis in Sunamganj district, utilizable river flow volume analysis at Bhairab and Durgapur Upazila have been omitted. Overall data quality is best fitted and consistent to analysis.

Rainfall analysis

In this study, the rainfall data of BWDB stations over a longer period of time from 1965 to 2012 have been analyzed as the gridded value of uniformly squared interval from which subsequent monthly average rainfall has been depicted in the graph to represent the temporal trend, availability, and variability of rainfall.

From the mean and standard deviation of monthly rainfall, monthly 80% dependable Rainfall (mm) was calculated as follow,

80% Dependable Rainfall = Mean - 0.84 × Standard Deviation

Evapotranspiration analysis

The dynamic process by which water is transferred from the soil and land surfaces to the atmosphere and by transpiration from plants. In this study, Assessment of Evapotranspiration has been calculated from Jan 1965 to Dec 2012 by using Penman-Monteith method from five parameters namely maximum and minimum temperature, relative humidity, wind speed and sunshine for study area from the adjacent meteorological stations of BMD.

Utilizable surface water

Stream flows and static water are considered the main source of surface water resources during the dry season. Median flow leaving the 80% dependable flow in the stream is considered as available or utilizable stream flow. Median static water leaving the 80% dependable static water in the natural storage system is considered as available or utilizable static water.

Crop water demand

The crop water requirement ETc in dry season has been calculated in mm from the product of crop coefficient Kc and reference crop evapotranspiration (ETo) as follows

$ET_c = K_c \times ET_o$

Where,

K_c = crop coefficient (crop type, stage of growth)

ET_o = reference crop ET

From the arable land area of each Upazila and crop water requirement ET_c, monthly crop water demand have been calculated for dry season in volume in MCM.

Usable groundwater

Resultant Ground Water Resource less 25% of it in account of limitations (e.g. drainage, abstraction difficulty etc.) is considered as Usable Groundwater Resource.

Results and Discussion

The results and discussion are based on the monthly average rainfall, 80% dependable rainfall, average evapotranspiration, utilizable river flow, static water, water supply requirement, crop water demand, useable groundwater, accumulative surplus or deficit water resources in the dry season of the study area.

Rainfall

The long-term monthly average rainfall (1965 to 2012) trend in the study area is the same for all the Upazila. Most of the rainfall peaks occur from June to August and mostly in July. All of the rising limbs is extended up to the month of July and after that recession starts. About 19% to 29% of rainfall of study areas occurs from November to May which covers dry season. The completely dry season is November to February when monthly average rainfall is less than 40 mm which necessitate dry seasonal surface water augmentation to reduce the stress on groundwater. The maximum annual rainfall 5649 mm occurred at Bishwamvarpur and minimum rainfall 2180 mm occurred at Bajitpur. The monthly maximum rainfall 1337 mm occurred at July at Bishwamvarpur Upazila (Fig. 2). The total rainfall of all the Upazila is near about or more than the national annual mean rainfall. The rainfall scenarios show potentialities of surface water storage in wet season for subsequent use in the dry season for agriculture and other uses. The change of rainfall pattern is remarkable in the study area.

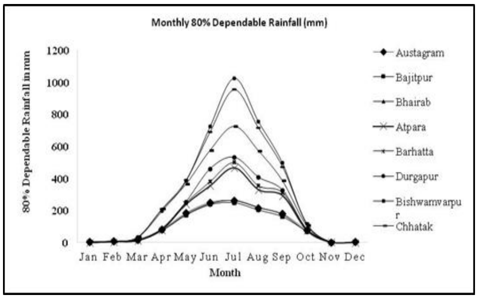

Fig. 2. Monthly Average Rainfall (mm)

Dependable rainfall

The 80% Dependable Rainfall is the value of monthly rainfall that indicates exceedance may occur 80% of the time. This value ensures that on average there will be enough available water to meet the crop's need four out of every five years. The highest 80% dependable rainfall 1026 mm was found in Sunamganj district (Fig. 3).

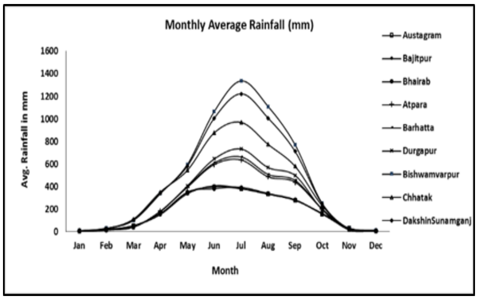

Fig. 3. Monthly 80% Dependable Rainfall (mm)

Evapotranspiration

The long-term monthly evapotranspiration trend is the same for all Upazila. The rate of evapotranspiration depends on the climatic condition. With seasonal variation, the rate of evapotranspiration fluctuate. This study shows that in the month of March, April and May rate is higher where April shows maximum rate 150 mm and average about 139 mm. In this study Kishoreganj district indicates higher evapotranspiration rate in comparison with Netrokona and Sunamjganj. The study indicates that from June to December the rate is decreasing whereas from January to April it indicates an increasing pattern. The long-term monthly evaporation trend was also the same for all of the Upazila. Evapotranspiration showed an increasing trend during the dry season which was about 57% to 58% of total evapotranspiration spanning from November to May. Total evaporation of the study area ranges from 1219 to 1323 mm respectively (Fig. 4).

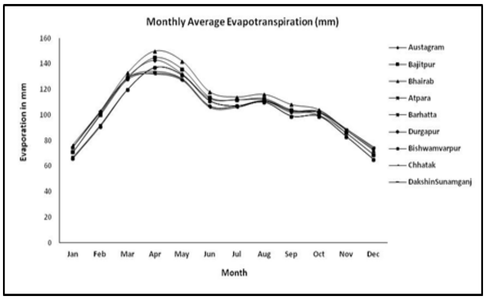

Fig. 4. Monthly Average Evapotranspiration (mm)

Utilizable river flow

In the study area, the total utilizable static water volume of the dry season is only 2% of total utilizable river flow volume. Utilizable static water sources like ponds, artificial lake, and perennial lakes are not a significant amount in this study area to fulfill the demand. In Kishoreganj, the highest river flow in the dry season in the month of November is 2382 million cubic meter (MCM) at Bajitpur Upazila whereas the lowest river flow was 321 MCM (Table 1). From April to upward till November the river flow shows an increasing pattern whereas from December to March it indicates a decreasing pattern. In this point of view, it is clearly shown in the rainy season; the river flow is higher compared to dry season. Netrokona and Sunamganj indicate lower river flow in comparison with Kishoreganj which is 04 MCM in Dakshin Sunamganj.

Utilizable static water

It is evident that water volume increases in the wet season whereas it decreases in the dry season. Since this study based on a dry period where April and May show the maximum water volume in comparison with rest of the month. The highest static water is utilized at Chhatak in Sunamganj district is about 95.6MCM whereas in Kishoreganj and Netrokona is used lower amount (Table 2). However, Poor storage depicts the demand of irrigation.

Water supply requirement

The water supply requirement is the highest at Bhairab in Kishoreganj is 1.2 million cubic meter in comparison with another district (Table 3). The increase of water supply requirement indicates either the more water is used in crop productivity or more water is used in domestic purposes. In Sunamganj, excessive water is used at Chhatak Upazila is 1.0 MCM related to Bishwamvarpur and Dakshin Sunamganj Upazila. Therefore, besides using surface water, the withdrawal of groundwater is increasing

Table 1. Utilizable river flow volumes in the dry season in MCM

District	Upazila	Nov	Dec	Jan	Feb	Mar	Apr	May
Kishoreganj	Austagram	1,915	404	405	327	706	1,069	2,074
	Bajitpur	2,382	219	348	347	383	321	986
Netrokona	Atpara	43	22	17	13	13	33	165
	Barhatta	118	19	7	8	9	52	283
Sunamganj	Bishwamvarpur	124	139	96	82	96	99	106
	Chhatak	256	46	37	45	157	520	705
	Dakshin Sunamganj	147	15	6	4	17	81	120

Note: Utilizable River Flow Volumes in Dry Season for Bhairab and Durgapur is not estimated due to lack of data.

Table 2. Utilizable static water volumes in the dry season in MCM

District	Upazila	Nov	Dec	Jan	Feb	Mar	Apr	May
Kishoreganj	Austagram	0.2	0.0	0.0	0.0	0.0	0.7	35.5
	Bajitpur	0.0	0.0	0.0	0.0	0.0	0.1	5.7
	Bhairab	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Netrokona	Atpara	0.2	0.0	0.0	0.0	0.0	0.8	9.6
	Barhatta	0.2	0.0	0.0	0.0	0.0	1.4	8.4
	Durgapur	0.0	0.0	0.0	0.0	0.0	0.0	5.4
Sunamganj	Bishwamvarpur	7.2	9.7	3.6	4.1	3.8	13.9	56.7
	Chhatak	0.0	0.0	0.0	0.0	0.0	0.2	95.6
	Dakshin Sunamganj	1.0	0.0	0.0	0.0	0.0	7.8	56.7

Table 3. Water supply requirement in the dry season in MCM

District	Upazila	Nov	Dec	Jan	Feb	Mar	Apr	May
Kishoreganj	Austagram	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Bajitpur	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Bhairab	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Netrokona	Atpara	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Barhatta	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Durgapur	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Sunamganj	Bishwamvarpur	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Chhatak	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Dakshin Sunamganj	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Crop production

Crop production of the study area has been calculated according to BBS data collected from the National Water Resources Database (NWRD), WARPO. In this research, the crop production data from 1974-1990 has used. Therefore, the data shows that the highest avg. production of the crop is at Chhatak, Sunamganj district in 1980-81 which is approximately 5284 metric tonnes (Table 4) and no crop has produced at Bishwamvarpur, Sunamganj in 1974-83. After 1983 the area gradually started cultivation and in 1983-84 the crop production is approximately 574 metric tons. According to area and production of rice crops of BBS, 2013 (Aus, Aman, and Boro) in 2009-2011, it has been noticed that Aus production is decreasing in comparison with Aman and Boro (Table 5)

Table 4. Crop Production (in M.ton)

District	Upazila	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Kishoreganj	Austagram	3399	3986	3874	3239	2741	3293	3740	3982
	Bhairab	1106	1330	1093	998	868	973	895	1111
Netrokona	Durgapur	2855	3704	4436	3328	3991	3098	3789	4044
	Atpara	1092	1129	1446	1459	1121	1094	172	1564
	Barhatta	1634	1869	1529	444	1544	1368	2040	2011
Sunamganj	B.pur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chhatak	3321	3537	2943	4251	4441	5039	5284	4873

contd.

contd.

District	Upazila	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90
Kishoreganj	Austagram	3560	3560	4211	3230	3400	3558	3112	3112
	Bhairab	1369	1628	1695	1420	1749	1712	1659	2083
Netrokona	Durgapur	3914	4000	4086	2819	3542	3768	2988	3190
	Atpara	1278	1278	995	1337	1714	2290	1918	2083
	Barhatta	1777	2535	1601	2104	2148	2999	1379	1556
Sunamganj	B.pur	0.00	574	549	1048	673	1241	1206	1179
	Chhatak	4758	5009	1326	1509	3924	1559	1633	2424

Note: B.pur: Bishwamvarpur

Table 5. Area and production of rice crops in the study area (Mton)

District	Upazila	2009-2010					
		Aus		Aman		Boro	
		Area	Production	Area	Production	Area	Production
Kishoreganj	Austagram	0	0	397	348	56181	81039
	Bajitpur	74	67	4347	4556	16974	28070
	Bhairab	550	560	17000	19880	3700	53400
Netrokona	Atpara	1547	1268	25179	23651	27608	44083
	Barhatta	145	113	37504	37171	33777	49862
	Durgapur	15	25179	22	27960	4044	580
Sunamganj	Bishwamvarpur	988	1080	20501	18675	27664	33210
	Chhatak	469	367	21390	14868	37565	26494
	Dakshin Sunamganj	0	0	41891	3986	43767	35314

contd.

contd.

District	Upazila	2010-2011					
		Aus		Aman		Boro	
		Area	Production	Area	Production	Area	Production
Kishoreganj	Austagram	0	0	327	4010	60665	103126
	Bajitpur	91	98	3507	3692	16166	26808
	Bhairab	600	600	18000	20880	3500	52257
Netrokona	Atpara	495	375	24166	21128	28053	45907
	Barhatta	50	40	37505	36156	34025	53975
	Durgapur	51	33	40714	38626	45085	93904
Sunamganj	Bishwamvarpur	1750	1740	21000	17609	27605	35042
	Chhatak	617	526	23082	16995	37664	59696
	Dakshin Sunamganj	0	0	4710	6807	45201	73314

Crop water demand

Crop water demand depends on soil, meteorological and crop physiological factor and important in irrigation scheme design. In the studied agro-based area, monthly crop water demand during the dry season is crucial due to being stapled consuming sector of water use. The irrigated area in Kishoreganj is 55.14% which indicate the importance of irrigation in the Haor region (BBS, 2012). The total demand for the study area is found about 712 MCM and maximum water demand 127 MCM for Chhatak and minimum water demand 41 MCM for Bhairab (Table 6). Monthly utilizable surface water volume is enough to meet the demand. But due to the lack of surface water based irrigation system management, groundwater is also lifted for irrigation purpose. The net cultivable area in Austagram, Bajitpur, and Bhairab are 243.53, 132.56 and 87.34 sq. km respectively. Statistically, crop water demand in some month of a year may be zero due to no irrigation. The monthly crop water demand is highest in a drier month due to higher evaporation demand. The maximum crop water demand was found in March for Austagram. The minimum crop water demand indicates the sufficiency of dependable rainfall.

Table 6. Monthly crop water demand in the dry season in MCM

District	Upazila	Nov	Dec	Jan	Feb	Mar	Apr	May
Kishoreganj	Austagram	0.0	0.3	18.0	25.4	36.7	32.2	0.0
	Bajitpur	3.5	0.4	8.7	12.0	17.3	17.7	2.9
	Bhairab	2.9	0.3	5.5	7.6	10.9	11.6	2.3
Netrokona	Atpara	4.5	0.2	8.7	12.1	17.5	15.7	0.4
	Barhatta	6.6	0.2	9.5	13.3	19.2	17.3	0.5
	Durgapur	8.5	0.3	11.8	16.5	23.8	21.5	0.7
Sunamganj	Bishwamvarpur	5.0	0.1	0.1	11.0	17.3	17.8	14.5
	Chhatak	4.5	0.1	0.1	22.7	35.6	35.6	28.6
	Dakshin Sunamganj	1.4	0.0	0.0	17.4	27.2	26.9	21.6

Usable groundwater

The concept of monthly usable groundwater volume is recognized by the Bangladesh Water Act 2013 which permits groundwater use within safe yield limit (WARPO, 2013). Groundwater is the only source of drinking water in haor and entire Bangladesh except metropolitan areas where surface water treatment plant available. The spatial utilizable groundwater volume for all the study Upazila is very limited with a total maximum of 83.5 MCM at Atpara and total minimum 6.5 at Durgapur (Table 7). There is no usable groundwater in April-May for all the study area. The use of groundwater during April-May due to unavailability of alternative sources may cause mining. Both the usable groundwater and surface water sources are very limited at Durgapur. The usable groundwater shows decreasing trend at dry season (Nov to May) for all the data analyzed Upazila due to low recharge, groundwater withdrawal by Low lift Pump, deep tube well, Hand tubewell and shallow tubewell. Usable groundwater volume indicates the storage and yielding capacity of the aquifer. In respect to storage availability, Atpara Upazila indicates good quality aquifer compared to others.

Table 7. Monthly usable groundwater volume in the dry season in MCM

District	Upazila	Nov	Dec	Jan	Feb	Mar	Apr	May
Kishoreganj	Austagram	10.1	9.6	9.1	3.1	0.0	0.0	0.0
	Bhairab	21.7	17.6	16.1	9.4	0.7	0.0	0.0
Netrokona	Atpara	26.0	21.7	21.2	13.0	1.6	0.0	0.0
	Barhatta	19.6	14.6	14.0	6.8	0.0	0.0	0.0
	Durgapur	6.5	0.0	0.0	0.0	0.0	0.0	0.0

Note: Usable groundwater volume for Bajitpur Upazila and Sunamganj District is not estimated due to lack of data

Accumulative surplus/deficit

The surplus or deficit depends on how much water is used or how much water is a shortage in the mentioned time frame November to May. The maximum shortage of water shows -34.5 million cubic meters at Bajitpur in Kishoreganj following -28.7 and -27.7 million cubic meters at Austagram and Bhairab respectively. The shortage of water also noticeable in February, March, and April whereas Bajitpur shows the entire time frame. Besides the deficit in November, December and January show a surplus of water. The present study indicates that the sufficient water supply in November to January is 21.7 MCM whereas from February to May the shortage of water is noticeable which are -80.5 MCM at Atpara and Durgapur respectively (Table 8). In comparison with Netrokona to Kishoreganj, the maximum shortage of water shows Durgapur, Netrokona district which indicates either environmental flow of water is disrupting or the withdrawal of water is increasing. The entire time frame in Sunamganj from November to May shows the shortage of water where in May indicates maximum -81.0 at Chhatak and in November minimum -0.4 at Bishwambarpur Upazila. This means withdrawal of an excessive amount of groundwater not using surface water or water supply disruption by constructing a dam or such type of structure.

Table 8. Monthly (accumulative) surplus or deficit water resources in the dry season (MCM)

District	Upazila	Nov	Dec	Jan	Feb	Mar	Apr	May
Kishoreganj	Austagram	9.6	9.1	3.1	-5.4	-17.6	-28.2	-28.7
	Bajitpur	-2.4	-3.3	-8.2	-14.5	-23.4	-32.4	-34.5
	Bhairab	17.6	16.1	9.4	0.7	-11.4	-24.2	-27.7
Netrokona	Atpara	21.7	21.2	13.0	1.6	-14.6	-29.2	-29.9
	Barhatta	14.6	14.0	6.8	-3.2	-17.3	-30.1	-30.9
	Durgapur	-2.6	-3.4	-15.8	-32.8	-57.2	-79.2	-80.5
Sunamganj	Bishwambarpur	-0.4	-0.8	-1.2	-5.3	-17.3	-29.6	-39.7
	Chhatak	-3.6	-4.7	-5.7	-19.9	-41.6	-63.3	-81.0
	Dakshin Sunamganj	-0.5	-1.0	-1.4	-15.1	-26.3	-37.4	-46.3

Conclusion

The Haor area is considered as the most productive wetland resources of Bangladesh which depend on the availability and high potentiality of surface water storage and use. About 19% to 29% of rainfall of study areas occurs from November to May. Evapotranspiration showed about 57% to 58% of total evapotranspiration spanning from November to May. The highest river flow in the dry season in the month of November is 2382 million cubic meter (MCM) whereas the lowest river flow was 321 MCM. The highest avg. production of the crop is at Chhatak, Sunamganj district in 1980-81 which is approximately 5284 metric tonnes. The present study indicates that the sufficient water supply from November to January is 21.7 MCM whereas from February to May the shortage of water is noticeable which is -80.5 MCM. Groundwater use in April-May, therefore, may tend to mine.

Due to a shortage of both surface and groundwater in Durgapur necessitate development activities to prevent mining. Further study is necessary to find out the scope of surface water storage, distribution and use due to the availability of streamflow, static flow, and rainfall. The food production is essential in the study area by utilizing groundwater or surface water for the development of national economy. Since the study area faces enough shortage of water, therefore, it is necessary to change the cropping pattern, to introduce water conserving and drought tolerant crops. Rainfall or evapotranspiration is a natural process so this flows cannot possible to impede by human beings rather using rainwater or as much as possible by harvesting. The construction of a dam or structures over the channel may hamper the static flow of the river. Since water is a valuable national resource, therefore, the public awareness should increase and proper implementation of the Bangladesh Water Act is essential to ensure the maintenance of usable water.

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SHIFTING OF ENERGY SOURCE FOR SHALLOW TUBEWELL IRRIGATION SYSTEM: A FIELD STUDY

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Abstract

Shallow tube well (STW) is the main device for groundwater abstraction for irrigation purpose in Bangladesh. This paper focuses shifting of STW energy source used in the study area. Field survey was carried out in Digholkandi Union comprises five mauzas under Ghatail Thana of Tangail district in 2017 with a view to examine the quantity and type of energy used of STW, to identify the trends line of energy type from a base line and to address the causes of shifting from one to another. Primary and secondary data were used in this study. Primary data were collected through questionnaire survey and financial as well as sensitivity analysis were done to predict the profitability of STW irrigation business. The study revealed that two types of irrigation equipment were mainly used in the study area for groundwater abstraction. In 2007, diesel operated STW (DOS) was 44% and electricity operated STW (EOS) was 56% in the study area. In 2017, field survey data showed that DOS was only 4% and EOS was 96% in the study area. Last ten years using of DOS and EOS has been decreased and increased 40% respectively. DOS is in abolition stage and EOS has been reached tends to 100%. Study findings showed that EOS was highly profitable than DOS due to lower electric charges compared to fuel and lubricant cost and coverage of higher command area by EOS promoted the irrigation business. Some recommendations have been included in this paper for the sustainability of STW irrigation business.

Keywords: *GIS application, location and mapping of STW, cropping pattern, command area.*

Introduction

Bangladesh is an agricultural country and 80% people live in rural area and their livelihood based in agriculture (BER, 2015). The economical development of the country is depends on the agricultural development of the country and agricultural development is depends on groundwater based irrigation to a large extent. Groundwater widely used as irrigation for the production of rice. Rice is the main and staple food of Bangladeshi people that constituted about 90% of the total food grain production in Bangladesh (Huda, 2001).

Of the three types of rice Aus, Aman and Boro, the *Boro* rice alone contributed the highest share (55%) of total rice production since 1998-99 to till now (BBS, 2015). About 80 percent of groundwater was used for crop production in which Boro paddy consumed 73 percent of total irrigation (Rahman and Ahmed, 2008).

Groundwater is the main source of irrigation in Bangladesh, although surface water is also used on limited scale in some rural areas. (Shirazi *et al.*, 2010). The total area under irrigation in Bangladesh is 5,049,785 ha and 78.9% of this area is covered by groundwater sources including 3,197,184 ha with 1,304,973 shallow tube wells and 785,680 ha with 31,302 deep tube wells (DTW) (DPHE and JICA, 2010). It is estimated that, out of 9.03 million ha of total cultivable area, 7.56 million ha (84 %) are suitable land for irrigation (Shahabuddin and Rahman 1998). To meet up the different requirements of growing population, the using of agricultural land for the non-agricultural purpose has been increased a large extent. As a result, total cultivable land of the country has been reached to 8.50 million ha and approximately 7.41 million ha (87%) land is under irrigation (BBS, 2015). Two types of irrigation equipment such as STW and DTW were mainly used to abstract groundwater in Bangladesh where 60% areas are covered by STW [Halcrow and Partners, 1998; BADC, 2015].

That is STW irrigation system or technology has utmost importance for food production and food security and lifting millions of poor farmers out of poverty in Bangladesh. As STW irrigation is the only system/technology for further intensification of agriculture, its rational use should be ensured with sustainability in relation to the profitability.

Hossain and Moududi (2009) conducted a field study regarding STW irrigation system in Bangladesh and it was reported that the farmers sell pumped water commercially for producing

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Boro rice to other farmers to earn money like other business and following the process, STW irrigation system or technology has been established as a form of business in rural Bangladesh. Study revealed that electricity operated STW (EOS) irrigation business was more profitable than diesel operated STW (DOS) with respect to the then price of inputs and paddy. But the business will be unprofitable for DOS in uncertain situation considering 10% increase of O & M cost or 10% decrease of benefit or 10% increase of diesel price. They stated that it would be fairly unable to sustain the STW irrigation business in severe uncertain situations with rising of diesel of fuel prices without commensurate rising of paddy prices.

In 2007, diesel price was Taka 35.00 per liter, while in 2017 (and from the earlier) diesel price has risen to Taka 65.00 per liter. In changing situation over time, it is essential further study in order to examine the present situation about DOS and EOS irrigation system in that area. So, the overall objectives of the study were to examine existing number of STW and their energy type, to identify the trends line of energy type from a base line (year) and to draw recommendations for the improvement of STW irrigation system.

Methodology

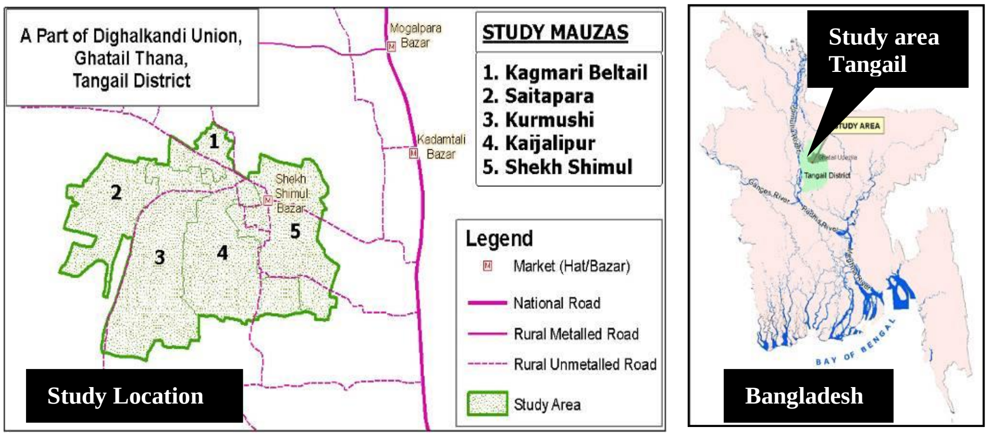

Fig. 1. The location of the study area

Location of the Study Area

The study area was within Dighalkandi union, which under Ghatail Upazila of Tangail district in Bangladesh. The area is situated between latitude 24^0 24’ 08.55”, longitude 89^0 57’ 26.84” and latitude 24^0 25’ 17.5”, longitude 89^0 59’ 10.10”. The study area comprises five Mauzas of Dighalkandi union (Fig. 1). The Mauzas were Saitapara, Kurmushi, Kagmari Beltail, Kaijalipur and Shekh Shimul. The Mauza is the revenue boundary and it is the smallest land boundary unit available in Bangladesh. The study area was chosen from an intensively irrigated area in the north central region of Bangladesh, which falls under the Indo-Gangetic basin region. Boro paddy was the main crop of this area, which cultivated in rabi season by groundwater irrigation. The entire irrigation system of the area mainly depended on STW irrigation technology.

Data collection and approaches

Primary and secondary data were used in this study. The primary data were collected through questionnaire survey in 2017 during irrigation periods and interviewed with farmer (STW owner). Complete survey technique was used for the STW owners to examine the existing number of STW and their energy type. Required secondary data (regarding STW used in the past) was collected from a baseline (1997 and 2007) in study area and data analyzed to understand the trend line of energy type, i.e. changing pattern of energy type of STW irrigation system in the study area. The locations of STWs were collected in the field by using Global Positioning System (GPS) and plotted them on the mauza maps according to energy type by identifying each plot. To examine the causes of shifting by energy source, the relevant data was collected and financial analysis was done to understand the profitability of STW irrigation business both for DOS and EOS. Sensitivity analysis was done to predict the STW irrigation business for future in changing input and output price.

Results and discussion

Number of STW with energy type

There were 68 tube wells in 1997 irrigation periods in the study area (Mandal, 1997). In 2007 irrigation periods, the total number of tube wells rose to 71 in the study area (Hossain and Moududi, 2009). In 2017 irrigation periods, the field survey data revealed that the total number of shallow tube wells down to 50 in the study area. The spatial distribution of the shallow tube wells of 2007 and 2017 is shown in Fig. 2. Among the 68 tube wells in 1997, 52 STWs (76%) were run by diesel and the remaining 16 STWs (24%) by electricity (Table 1). On the other hand, in 2007 irrigation periods, only 31 STWs (44%) were run by diesel and 40 STWs (56%) by electricity [Table 1 and Fig. 2 (left one)] and in 2017 irrigation periods, there were found almost EOS in the study area, only 2 STWs (4%) were run by diesel and 48 STWs (96%) by electricity [Table 1 and Fig. 2 (right one)], which proved the sensitivity analysis conducted by Hossain and Moududi (2009). The minimum tube well density of a mauza in the study area was 10 per km^2 at Kurmurshi mauza and the maximum was 20 at Kagmari Beltail mauza in 2017. The average tube well density of the study area was 15 STW per km^2 (Table 2).

Shifting and trend line of STW energy type

From the above discussion it is evident that last 20 years (from 1997 to 2007) DOS has been decreased from 76% to 44% and EOS has been increased from 24% to 56% (Fig. 3). On the other hand, last ten years (from 2007 to 2017) using of diesel engine has been decreased and using of electricity driven STWs has been increased 40% respectively (Fig. 3). It can be said that DOS is in abolition stage and EOS has been reached tends to 100%. Farmers informed the investigator that the causes for shifting the farmers from DOS to EOS were high price of diesel cost, high operation and maintenance (O & M) cost of diesel engine, less operation cost of EOS, larger command area of EOS system and the electric bill has to be paid after harvesting the crop. During survey investigator observed that there was no metering system at all except few STW in the study area. Concern authority made electricity bill on an average based on motor horse power. The STW owner informed the investigator that this average bill was much higher than the metering system bill. EOS owners opined that they got electricity connection with the help of middle man, who had good linkage with some of the concern officials. Middle man charged fixed cash to arrange electricity connection. The owners claimed that the major portion of electricity connection charges goes to middle man and concern officials. Miah and Mandal (1993) reported that the STW owners had to pay bribes to the concern officials for getting electricity connections.

Table 1. Mauza-wise number of STW and their type of energy source

Mauza	Number of STW			Type of Energy source					
				1997		2007		2017	
	1997	2007	2017	D	E	D	E	D	E
Kagmari Beltail	3	4	4	2	1	2	2	0	4
Kaijalipur	11	11	12	4	7	0	11	0	12
Kurmushi	27	21	11	25	2	10	11	0	11
Saitapara	12	17	8	12	0	14	3	2	6
Shekh Shimul	15	18	15	9	6	5	13	0	15
TOTAL	68	71	50	52	16	31	40	2	48

Note: D: Diesel; E: Electricity

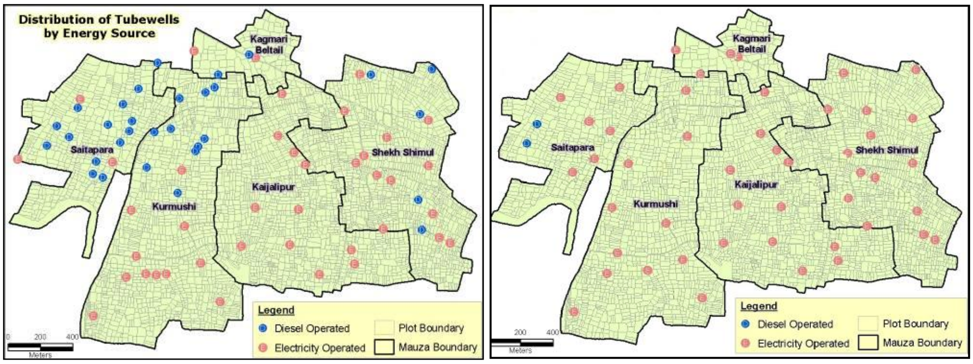

Fig. 2. Distribution of STWs by Energy Source in mauza map of the study area in 2007 (left) and 2017 (right) respectively.

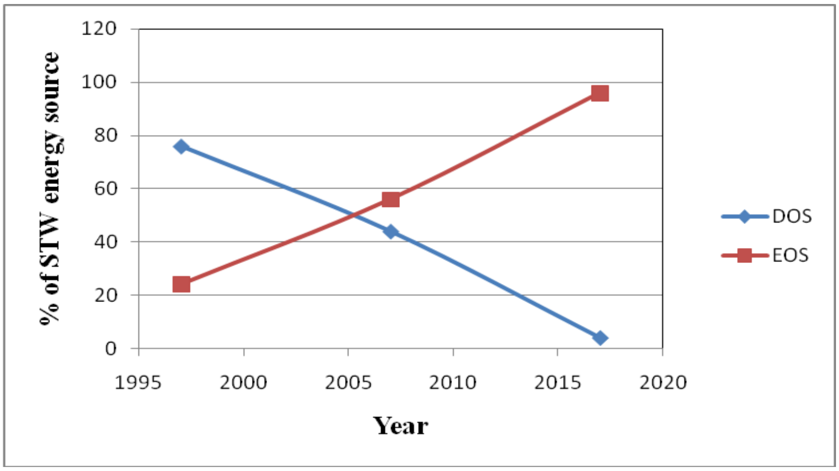

Fig. 3: Shifting and trend line of STW energy type

Table 2. Density of the STW in 2016 in the study area

Mauza	Number of STW	Area (Hectares)	Area in km²	Density/km²	Average Density/km²
Kagmari Beltail	4	20	0.20	20	15
Kaijalipur	12	95	0.95	13	
Kurmushi	11	109	1.09	10	
Saitapara	8	62	0.62	13	
Shekh Shimul	15	90	0.90	17	

(Source: Field survey, 2016)

Investment Cost, O & M cost of STW and return from STW irrigation system

Investment cost of STW included purchase of diesel engine/electric motor, pump, pipe and strainer, STW installation, construction of STW shed, irrigation channel making, registration fee for electric connection, switch board, connection cable, iron / wood made base, electric light etc. Investment cost of STW both for DOS and EOS is shown in Table 3. O & M cost of STW included fuel (diesel or electricity), mobil, spare parts and mechanics fee, operator's salary, irrigation channel repairing, STW shed repairing, labor for collection of rice from field etc. O & M cost of STWs both for DOS and EOS is shown in Table 4. Return or benefit included Boro rice and Boro straw of STW Irrigation system which is shown in below Table 5. From the field survey data revealed that the average command area was 2.82 ha and 3.57 ha for the DOS and EOS system respectively and the yield was 5.48 t/ha in both cases. As payment of water charge, DOS owner got on average 15.45 ton rice @ Tk. 21620 per ton (considering average 2.82 ha command area and 5.48 t/ha yield), while EOS owner got 19.56 ton rice @ Tk. 21620 per ton (considering average 3.57 ha command area and 5.48 t/ha yield); though return depends on command area to a large extent. Total return from DOS was lower than EOS in the study area due to smaller command area.

Table 3. Investment cost of STW irrigation technology, 2017

Cost Item	DOS Tk.	EOS Tk.
a. Purchase of diesel engine/electric motor	12800	12000
b. Purchase of pump, pipe and strainer	6000	7780
c. Installation	1400	1700
d. Construction of STW shed	2050	2590
e. Irrigation channel making	2145	2750
f. Others (Registration fee for electric connection, switch board, cable, iron / wood made base, electric light)	3000	20000
g. Total investment cost [a+b+c+d+e+f]	27395	46820

(Source: Field Survey, 2017)

Table 4. O & M cost per season of STW irrigation technology, 2017

Cost Item	DOS Tk.	EOS Tk.
a. Diesel cost [450 liter/season@65 Tk./liter]	29250	-
b. Mobil cost [10 liter/season@250 Tk./liter]	2500	-
c. Electricity cost	-	30000
d. Spare parts and mechanics fee	1800	800
e. Operator's salary	32000	31000
f. Irrigation channel repairing	1000	1100
g. STW shed repairing	900	1150
h. Others (Labor for collection of rice from field)	17116	16673
I. Total O & M cost (Tk.) [a+b+c+d+e+f+g+h]	84566	80723

(Source: Field Survey, 2017)

Table 5. Return or Benefit per season of STW irrigation technology, 2017

Return or Benefit Item	DOS Tk.	EOS Tk.
a. Value of rice (5.48 t/ha@21620Tk./t*CA/4)	83527	105741
b. Straw from rice	10000	11115
c. Charge for watering the vegetables plots and others	1000	500
d. Total return (Tk./season) [a+b+c]	94527	117356
e. Salvage value of STW	6600	8250

(Source: Field Survey, 2017)

Financial and sensitivity analysis of STW irrigation business

Benefit-Cost ratio was calculated (Table 6) from investment cost, O & M cost and return or benefit mentioned in Table 3, Table 4 and Table 5 respectively. Average life span is assumed for both engine and motor 10 years. Details analysis was shown in Annexure 1-9**.** From financial analysis, Table 6 showed that the irrigation business by EOS was highly profitable in the current situation (2017), because Internal Rate of Return (IRR) was quite higher than bank rate (10 percent) and DOS system. Though the IRR of DOS was 56 % (higher than bank rate), but it was much lower than the IRR estimated in other study (Mandal and Parker, 1995). This lower IRR rate in present situation clearly proved that the IRR rate decreased over time mainly due to increase of diesel price and maintenance cost. Again, lower electric charges compared to fuel and lubricant cost and coverage of higher command area by EOS promoted the irrigation business, which proved to be more profitable than DOS.

Last ten years, both diesel and electricity price and output price has gone up and down in Bangladesh. In 2007 diesel price was Taka 35.00 per liter, while in 2017 (and from the earlier) diesel price has risen to Taka 65.00 per liter. In case of electricity and output (paddy), the price has gone up and down. In this regard sensitivity analysis was done considering the both certain and uncertain situations. Sensitivity analysis showed that for a 10 % increasing of O & M cost or 10% decreasing of benefit when other cost remain the same, DOS business runs as unprofitable, while the EOS business still remains profitable (Table 6). The main reason is lower profit from DOS was the significant increased of diesel price. Again, other things remaining the same, only diesel price increased by 10% will still give a marginal profit for the DOS owners (IRR 32%) (Table 6). Moreover, if both diesel and rice price increased by 10% keeping other thing remaining the same; the irrigation business will be profitable. If diesel price increased by 20% and output price increased by 20%, the STW business will be even more profitable (Table 6).

Table 6. IRR, NPV and BCR in current and different uncertainty of STW irrigation business

Different certain and uncertain situations	Diesel operated STW			Electricity operated STW		
	IRR (%)	NPV (Tk)	BCR	IRR (%)	NPV (Tk)	BCR
In 2017 (current situation)	56	38499	1.07	360	184288	1.34
If O&M cost increased by 10%	-6	-14521	0.98	156	134692	1.23
If benefit decreased by 10%	-12	-20896	0.96	113	111866	1.21
If diesel price increased by 10%	32	19465	1.03	-	-	-

Different certain and uncertain situations	Diesel operated STW			Electricity operated STW		
	IRR (%)	NPV (Tk)	BCR	IRR (%)	NPV (Tk)	BCR
If diesel and output price increased by 10%	151	77797	1.14	-	-	-
If diesel price increased by 20% and output price increased by 20%	526	118158	1.20	-	-	-

(Source: Field Survey, 2017); NPV indicates Net Profit Value, BCR indicates Benefit-Cost Ratio.
Note: Calculations were done on the basis of data provided in Annexure 1-9.

Conclusions

The study revealed that two types of irrigation equipment (DOS and EOS) were mainly used in the study area for groundwater abstraction in the study area. In 2007, DOS was 44% and EOS was 56% in the study area. Last 10 year's scenario was totally changed. In 2017, field survey data showed that DOS was only 4% and EOS was 96% in the study area. Last ten years (from 2007 to 2017) using of diesel engine has been decreased and using of electricity driven STWs has been increased 40% respectively. Study findings showed that EOS was highly profitable than DOS. EOS has been increased due to upward trend of diesel price. Sensitivity analysis showed that for a 10 % increasing of O & M cost or 10% decreasing of benefit when other cost remain the same, DOS business runs as unprofitable, while the EOS business still remains profitable. Again, other things remaining the same, only diesel price increased by 10% will still give a marginal profit for the DOS owners (IRR 32%). Moreover, if both diesel and rice price increased by 10% keeping other thing remaining the same; the irrigation business will be profitable. If diesel price increased by 20% and output price increased by 20%, the STW business will be even more profitable.

Recommendations

In case of EOS, government should take steps to minimize cost of electricity connections fees and to review existing electricity connection procedure which might be improved the present situations. Concern authority should give priority to facilitate the provision of required electricity, metering systems and should ensure uninterrupted power supply. On the other hand, for DOS the government should monitor the diesel price and to ensure diesel supplying at the fixed price in time. Diesel price should continue to be subsidized to sustain irrigation water selling business as well as Boro rice production. To sustain the Boro rice cultivation, paddy price should be increased at least 20%.

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Annexure 1: Benefit-Cost analysis of EOS

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	46820	80723	127543	117356	-10187	0.909	115937	106677
2	0	80723	80723	117356	36633	0.826	66677	96936
3	0	80723	80723	117356	36633	0.751	60623	88134
4	0	80723	80723	117356	36633	0.683	55134	80154
5	0	80723	80723	117356	36633	0.621	50129	72878
6	2500	80723	83223	117356	34133	0.564	46938	66189
7	0	80723	80723	117356	36633	0.513	41411	60204
8	0	80723	80723	117356	36633	0.467	37698	54805
9	0	80723	80723	117356	36633	0.424	34227	49759
10	0	80723	80723	125606	44883	0.386	31159	48484
			Total				539931	724220

Note: DF indicates discount factor

Annexure 2: Benefit-Cost analysis of DOS

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	27395	84566	111961	94527	-17434	0.909	101773	85925
2	0	84566	84566	94527	9961	0.826	69852	78079
3	0	84566	84566	94527	9961	0.751	63509	70990
4	0	84566	84566	94527	9961	0.683	57759	64562
5	0	84566	84566	94527	9961	0.621	52515	58701
6	2500	84566	87066	94527	7461	0.564	49105	53313
7	0	84566	84566	94527	9961	0.513	43382	48492
8	0	84566	84566	94527	9961	0.467	39492	44144
9	0	84566	84566	94527	9961	0.424	35856	40079
10	0	84566	84566	101127	16561	0.386	32642	39035
			Total				545886	583321

Annexure 3: Sensitivity Analysis of EOS at 10 percent increases of O & M costs

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	46820	88795	135615	117356	-18259	0.909	123274	106677
2	0	88795	88795	117356	28561	0.826	73345	96936
3	0	88795	88795	117356	28561	0.751	66685	88134
4	0	88795	88795	117356	28561	0.683	60647	80154
5	0	88795	88795	117356	28561	0.621	55142	72878
6	2500	88795	91295	117356	26061	0.564	51491	66189
7	0	88795	88795	117356	28561	0.513	45552	60204
8	0	88795	88795	117356	28561	0.467	41467	54805
9	0	88795	88795	117356	28561	0.424	37649	49759
10	0	88795	88795	125606	36811	0.386	34275	48484
			Total				589528	724220

Annexure 4: Sensitivity Analysis of EOS at 10 percent decreases of benefits

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	46820	80723	127543	105620	-21923	0.909	115937	96009
2	0	80723	80723	105620	24897	0.826	66677	87242
3	0	80723	80723	105620	24897	0.751	60623	79321
4	0	80723	80723	105620	24897	0.683	55134	72139
5	0	80723	80723	105620	24897	0.621	50129	65590
6	2500	80723	83223	105620	22397	0.564	46938	59570
7	0	80723	80723	105620	24897	0.513	41411	54183
8	0	80723	80723	105620	24897	0.467	37698	49325
9	0	80723	80723	105620	24897	0.424	34227	44783
10	0	80723	80723	113045	32322	0.386	31159	43636
			Total				539931	651798

Annexure 5: Sensitivity Analysis of DOS at 10 percent increases of O&M costs

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	27395	93023	120418	94527	-25891	0.909	109460	85925
2	0	93023	93023	94527	1504	0.826	76837	78079
3	0	93023	93023	94527	1504	0.751	69860	70990
4	0	93023	93023	94527	1504	0.683	63534	64562
5	0	93023	93023	94527	1504	0.621	57767	58701
6	2500	93023	95523	94527	-996	0.564	53875	53313
7	0	93023	93023	94527	1504	0.513	47721	48492
8	0	93023	93023	94527	1504	0.467	43442	44144
9	0	93023	93023	94527	1504	0.424	39442	40079
10	0	93023	93023	101127	8104	0.386	35907	39035
			Total				597843	583321

Annexure 6: Sensitivity Analysis of DOS at 10 percent decreases of benefits

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	27395	84566	111961	85074	-26887	0.909	101773	77333
2	0	84566	84566	85074	508	0.826	69852	70271
3	0	84566	84566	85074	508	0.751	63509	63891
4	0	84566	84566	85074	508	0.683	57759	58106
5	0	84566	84566	85074	508	0.621	52515	52831
6	2500	84566	87066	85074	-1992	0.564	49105	47982
7	0	84566	84566	85074	508	0.513	43382	43643
8	0	84566	84566	85074	508	0.467	39492	39730
9	0	84566	84566	85074	508	0.424	35856	36072
10	0	84566	84566	91014	6448	0.386	32642	35132
			Total				545886	524989

Annexure 7: Sensitivity analysis of DOS at 10 percent increases of diesel price

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	27395	87491	114886	94527	-20359	0.909	104431	85925
2	0	87491	87491	94527	7036	0.826	72268	78079
3	0	87491	87491	94527	7036	0.751	65706	70990
4	0	87491	87491	94527	7036	0.683	59756	64562
5	0	87491	87491	94527	7036	0.621	54332	58701
6	2500	87491	89991	94527	4536	0.564	50755	53313
7	0	87491	87491	94527	7036	0.513	44883	48492
8	0	87491	87491	94527	7036	0.467	40858	44144
9	0	87491	87491	94527	7036	0.424	37096	40079
10	0	87491	87491	101127	13636	0.386	33772	39035
			Total				563857	583321

Annexure 8: Sensitivity analysis of DOS at 10% increases of both diesel and benefit price.

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	27395	87491	114886	103980	-10906	0.909	104431	94518
2	0	87491	87491	103980	16489	0.826	72268	85887
3	0	87491	87491	103980	16489	0.751	65706	78089
4	0	87491	87491	103980	16489	0.683	59756	71018
5	0	87491	87491	103980	16489	0.621	54332	64571
6	2500	87491	89991	103980	13989	0.564	50755	58645
7	0	87491	87491	103980	16489	0.513	44883	53342
8	0	87491	87491	103980	16489	0.467	40858	48559
9	0	87491	87491	103980	16489	0.424	37096	44087
10	0	87491	87491	111240	23749	0.386	33772	42939
			Total				563857	641654

Annexure 9: Sensitivity analysis of DOS at 20% increases both of diesel and benefit

Year	Investment cost (Tk.)	O&M cost (Tk.)	Total cost (Tk.)	Benefit (Tk.)	Incremental benefit (Tk.)	DF at 10%	Cost at 10% df	Benefit at 10% df
1	27395	90416	117811	113432	-4379	0.909	107090	103110
2	0	90416	90416	113432	23016	0.826	74684	93695
3	0	90416	90416	113432	23016	0.751	67902	85188
4	0	90416	90416	113432	23016	0.683	61754	77474
5	0	90416	90416	113432	23016	0.621	56148	70442
6	2500	90416	92916	113432	20516	0.564	52405	63976
7	0	90416	90416	113432	23016	0.513	46383	58191
8	0	90416	90416	113432	23016	0.467	42224	52973
9	0	90416	90416	113432	23016	0.424	38336	48095
10	0	90416	90416	121352	30936	0.386	34901	46842
			Total				581828	699986

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FLOOD HAZARD MAPPING OF SURMA RIVER BASIN IN SYLHET CITY

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Abstract

As flood is one of the major disasters of Bangladesh and does immense damage to the lives and livelihood of locals living near or in the flood prone zones, it is necessary to study all possible water bodies and their nearby areas. The popularity of using software based data management tools to justify existing vulnerabilities and the overall status of flood and flood hazard in Bangladesh has been observed in recent years while many studies of flood hazard have been found in the literature. It was therefore aimed in this current study to determine the status of flood throughout the years 2006 to 2015 in the district of Sylhet. The discharge capacity of Surma River has been calculated for 25 year return period and a flood hazard map has been generated using GIS which shows the river has not sufficient capacity to carry all the water during peak flow which results in water logging in Sylhet city. Although the overall capacity of the Surma River is much larger than the total yearly discharge and runoff, caution is necessary for a flash flood. At the end, the digital elevation model has been used to understand the elevation of the study area.

Keywords: *flood, geo-statistics, GIS map, hazard, ordinary kriging, Surma River*

Introduction

Floods are one of the highly devastating natural hazards in South-Asia. It is the most common natural disaster of Bangladesh. The country is deltaic in shape and is situated at the Ganges-Brahmaputra-Meghna (GBM) basin which is the third largest fresh water outlet of the world's oceans. The country has to bear the enormous pressure of this flow whereas only 7% of the total catchment of the GBM basin lies within the territory of Bangladesh. This unique geographical feature makes Bangladesh more susceptible to regular flooding. Bangladesh is expected to be one of the most affected countries of global climate change. So, the flood characteristics are likely to be changed with the changing climate. Characteristics study of the flood is fundamental for planning the proper adaptation strategy and effective flood management. Sylhet city is vulnerable to flooding because of having heavy rainfall during the monsoon season. It is located in the north-eastern zone of Bangladesh. The area of Sylhet city is 26.5 km^2 with a population about 479,837 (BBS, 2011). Built out of hilly areas this city is situated in an area that is higher than sea level, from 1 meter to 7 meters (Tanjil, 2016). As the city is on higher land than most another part of the country it has very low chances of long duration flood. But the heavy rainfall throughout the rainy season and most of the year, chances of a flash flood are high. In this manner, flood hazard maps can be of various use. Flood hazard maps are designed to increase awareness of the likelihood of flooding among the public, local authorities and other organizations. They also encourage people living and working in flood-prone areas to find out more about the local flood risk and to take appropriate action (Environment Agency, 2010). Flood hazard maps can be used by developers to determine if an area is at risk of flooding, and by insurers to determine flood insurance premiums in areas where flood insurance exists. The creation of flood maps usually combines topographic data with historic or modeled information on extreme sea levels and wave heights. This allows the determination of the water level at the coast under extreme conditions and shows how this water could flood inland. This is likely to involve the deployment of storm surge and wave models. Geographic Information Systems (GIS) are frequently used to produce flood hazard maps. They provide an effective way of assembling information from different maps and digital elevation models (Sanyal and Lu, 2003). Using GIS, the extent of flooding can be calculated by comparing local elevations with extreme water levels. Flood Hazard maps will give information on the spatial and temporal flood depth and water logging situation at different climate condition.

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Methodology

Selection of study area

The study area is Sylhet city which is the main city of Sylhet district. River Surma, the primary river of Sylhet flows through it. As one of the basic requirements of the study area is a Digital Elevation Model (DEM) and SRTM Digital Elevation Model of the study area, was used in taking the decision of selection of the low laying flood pone area. In a broader sense, the investigated area is lack of any remarkable stream of Bangladesh, but the area is well drained by a network of locally important streams most of which are both structurally lithologically controlled and dendritic in pattern. The relatively major streams are fewer in number and are of perennial type, that is they flow even in the dry season, but during rainy season they flow with their full strength and become able to carry large boulders to distant places whereas the minor streams are large in number and of intermitted type, that is they are seasonal in their flow, and water ceases to flow during the dry spell.

The basic idea is to find out how much water spills out of the river Surma. For that purpose, Data of the annual rainfall, discharge of river Surma and the capacity of the river are necessary.

Water level data

The daily water level data were collected from BWDB for the years 2006 up to 2015 (10 years). This dataset was then converted to monthly water level data by selecting the peak/maximum water level of a month. This gives a better overview of the river Surma water level. These data set then plotted in a graph to show the water level across different time. The Menn-Kendall analysis was also carried out to see if the river showed any trend.

Rainfall data

The daily rainfall data was collected from BWDB for the year's 2006 up to 2015 (10years). This dataset was then converted to monthly rainfall data by selecting the peak/maximum rainfall of a month. This gives a better overview of the Sylhet city rainfall. Then the data was converted into a format (.xlsx) suitable for use in the Arc map software. Rainfall was then converted to Runoff and was used for Kriging in the Arc map software.

Runoff calculation

The expected volume of monthly runoff for 50% probability was estimated for Surma river using the total Table 1) monthly rainfall depth in Sylhet station for the period (2006-2015)

Table 1. Expected runoff depth of monthly rainfall for 50% possibility

Probability	Monthly Rainfall (mm)	Monthly Rainfall (MCM)	Monthly Runoff* (MCM)	Equivalent Runoff depth (mm)
50%	210	87.15	40.96	98.7

*Using runoff coefficient method

R=k P Eq. (1)

Where,

R = runoff depth (mm)

K = coefficient of runoff (Sogreah, 1978)

P = Rainfall depth (mm)

Runoff volume calculation

Runoff volume is the total rainfall depth of a catchment area. Therefore, runoff volume is obtained by the following formula:

V= R * A Eq. (2)

Where A is the catchment area and V is the runoff volume.

The study area had a catchment area about 1 km^2 and the runoff depth was calculated in mm. To simplify, the following was obtained with the unit (m^3)

$$V = \frac{R}{1000} * 1 * 1000 * 1000 = 1000R$$

Digital Elevation Model (DEM)

Digital Elevation Model is one of the essential data for flood study of an area. DEM data of the study area were collected from the NASA Shuttle Radar Topographic Mission (SRTM). The NASA Shuttle Radar Topographic Mission (SRTM) digital elevation data (DEMs) were downloaded from the SRTM FTP server (ftp://e0srp01u.ecs.nasa.gov/srtm/version2/) for the study area. The resolution of DEM is 90 meter. The DEM data were further processed using ArcGIS 10.0 to fill in the no-data voids or cells. The processing involved the production of vector contours and the re-interpolation of these derived contours back into a raster DEM using ILWIS contour interpolation tool. DEM was used to develop flood inundation maps and land types classification. Difference between water level data obtained from the interpolated water level surface of different return periods and land surface values have been considered as inundation depth in the study area. The DEM is also used for the preparation of a vulnerability map for different flood risk elements.

Discharge data

The daily discharge data were collected from BWDB for the year, 2006 upto 2015 (9years). This dataset was then converted to monthly discharge data by selecting the peak/maximum Discharge of a month. This gives a better overview of the river Surma discharge. Then the data was converted into a format (.xlsx) suitable for use in the Arc map software.

Reservoir capacity calculation

In order to understand the total capacity of River Surma, calculation of the total volume of the study area is necessary. Calculating the reservoir capacity requires estimating the shape of the reservoir. As the reservoirs are irregular both in cross sections and in long sections it is not easy to calculate. In many cases reservoirs are estimated from the reservoir width, the throwback and maximum impounded water depth (Lawrence and Cascio, 2004). The formula is based on the equation below with different values for the two constants.

$$C = k_1 * k_2 * D * W * T \quad \text{Eq. (3)}$$

Where, C = Capacity, D = Depth, W = Width, T = Throwback

And k_1 k_2 are constants that have different values based on the shape of the reservoir
Following formula is used from the dam design manual (Lawrence and Cascio, 2004).

$$C = 0.25*1*D*W*T$$

(Fowler, 1977), where k_1 = 0.25 and k_2 = 1, for valley cross section shapes.
The study area has a roughly estimated 11.3km throwback which was later reduced to 10km for the calculation of capacity. This provides a marginal volume left out of calculation which gives a better safety check.
The formula was then simplified as below with the unit m^3

$$C = [0.25 * 1 * D * W * T(= 10) * 1000] = 2500DW$$

Width and depth (cross section) of the river was obtained from BWDB for 3 stations, namely S#29 (Sheikhghat), S#30 (Mendibag) and S#33 (Kanaighat). Among these, the width in the S#30 station was almost double compared to the other two which increased the over-all capacity of the study area.

Geostatic analysis steps

The methodology of this study begins with the selection of the study area. The Discharge data of the Surma river and the Rainfall data of Sylhet city were obtained from BWDB. This data was then processed into the monthly maximum dataset. The geostatic analysis is done under the kriging method using Arc GIS platform. Various kriging methods were used to find better visual representation.

Geo-statistics

The theory of Geo-statistics has been expressed in many textbooks, including those of Issaks and Srivastava (1989) and Goovaerts (1977). Here a brief discussion of the geo-static methods that were used in the study is presented. In geo-statics, a semi-variogram is used to quantify the differences between sampled data values as a function of their separation distance, h. In practice, the experimental semi-variogram *(h), is calculated as follows

$$y * h = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - Z(x_i + h)]^2 \quad \text{Eq. (4)}$$

Where, N(h) is the number of sample pairs that are separated by a vector h, and Z(x) and $z(x_i{+}h)$ are the values of the variable z at locations of x_i

and x_i+h, respectively. However, for kriging analysis, an appropriate theoretical model should be used to fit the experimental data. The most widely used models include the spherical, exponential and Gaussian models. The spherical model used in the study is defined as follows:

$$\gamma(h) = C_0 + C[\frac{3h}{2a} - \frac{1}{2}(\frac{h}{a})^3] \text{ where, } h \leq a; \quad \text{Eq. (5)}$$

$$\gamma(h) = C_0 + C \text{ when, } h > a; \quad \text{Eq. (6)}$$

Where, C_0 is the y-axis intercept (the nugget effect), $C_0 + C$ is the "sill", which is near the sample variance, and a represents the range of influence.

Among many kriging procedures, Ordinary Kriging was chosen due to the lack of sufficient data.

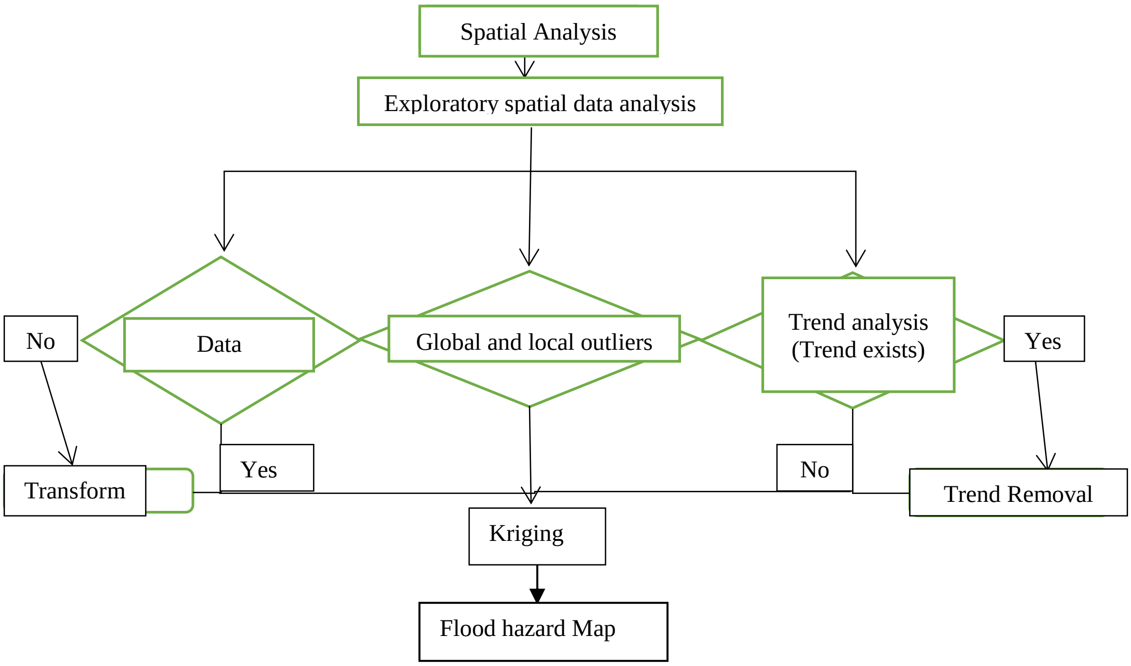

Fig. 1. Flow chart of the geo-static analysis steps

Ordinary Kriging (OK)

OK assumes that the mean is stationary but unknown. In addition, the OK estimator is known as the best linear unbiased estimator (BLUE) and is defined as follows (Journel and Huijbregts, 1978)

$$z^*(x_0) = \sum_{i=1}^{n(u)} \lambda_i z(x_i) \text{ with } \sum_{i=1}^{n(u)} \lambda_i = 1 \quad \text{Eq. (7)}$$

Where $z^*(x_0)$ is the OK estimator at location x_0, $z(x_i)$ is the observed value of of the variable at location x_i, λ_i is the weight assigned to the known values near the location to be estimated and n(u) is the number of neighboring observations. The values of λ_i are weighted to obtain a sum of unity, and the error variance is minimized as follows:

$$\left\{\sum_{j=1}^{n(u)} \lambda_i \gamma\ (x_i, x_j) - \mu = \gamma(x_i, x_j)\right\} \quad j = 1, \dots, n(u) \sum_{j=1}^{n(u)} \lambda_j = 1 \quad \text{Eq. (8)}$$

Where, μ is the Lagrance co-efficient for minimizing the OK estimation variance, $\gamma(x_i, x_j)$ is the average semivariogram value between the observed values and $\gamma(x_i, x_j)$ represents the average semivariogram value between the location x_i and the location to be estimated. The OK estimation variance (or standard deviation) can be used as a measure of the estimation uncertainty as follows:

$$\sigma^{2*}(x_0) = \sum_{i=1}^{n(u)} \lambda_i \, \gamma\,(x_i, x_0) + \mu \qquad \text{Eq. (9)}$$

Results and discussion

There are several statistical tests available for testing stationary-ness of time series (Hirsch Et Al 1993). In the present study, the regression test for linear trend has been carried out for the annual water level series from 2006 to 2014 at Kanaighat SW-266 station, Sylhet SW-267 station of Surma-Meghna River and Islampur SW-332 station of Dhala River. These tests start from a null hypothesis (H0) that the observations are samples from a stationary process. The likelihood of this hypothesis is evaluated based on the value of a test statistic, a property of the data set. A large deviation of the test statistic from the stationary value is unlikely to be coincidental. The P-value is the probability that the deviation of the test statistic from the homogeneous case is coincidental. If the p value is less than the significance level α (alpha) = 0.05, H0 is rejected. Rejecting H0 indicates that there is a trend in the time series while accepting H0 indicates no trend was detected. The p-value is a percentage. It tells you how likely it is that the coefficient for that independent variable emerged by chance and does not describe a real relationship. A p-value of .05 means that there is a 5% chance that the relationship emerged randomly and a 95% certainty that there is indeed a positive trend. This is the "Significance F" value in Excel; some other statistical programs call it by other names. This measures the likelihood that the model as a whole describes a relationship that emerged at random, rather than a real relationship. As with the p-value, the lower the significance F-value, the greater the chance that the relationships in the model are real.

Arc-Map analysis

Results were produced in the form of maps. These maps include Capacity of Surma river, Discharge pattern in Surma river, Rainfall affecting the existing flow and Digital Elevation Model (DEM) of the study area.

River capacity: From the equation, the corresponding capacity at that point of river Surma in m^3 can be obtained and plot them in the arc map software. After that, Geostatic analysis was carried out with Kriging which gave the following map (Fig. 2)

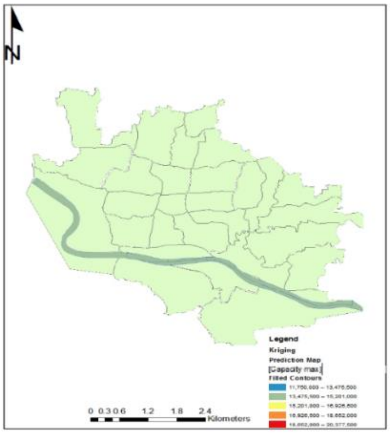

Fig. 2. The average capacity of Surma River

Here we can see that on an average, the river has a capacity of about 15 thousand m^3 with a maximum of about 20 thousand m^3 in the Machimpur region.

Water discharge through River Surma

Originating from the Barak River of eastern India, Surma river's discharge data of three different stations are featured in the following Fig. 3, where discharge rate decreases from east to north-west.

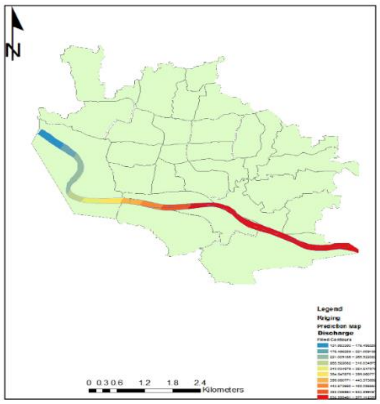

Fig. 3. Water discharge (2006-14) pattern in the River Surma.

Discharge of the river with additional rainfall water

Rain water runoff has been induced in the following Fig. 4 along with discharge. Here the total discharge is lessened by the rainfall.

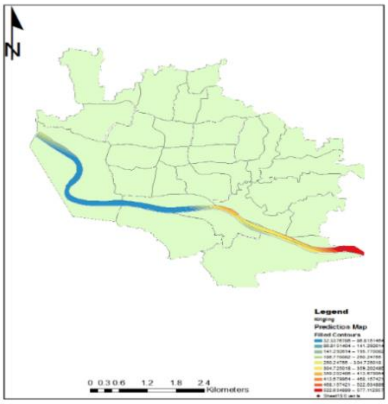

Fig. 4. Water discharge with rainfall (2006-2014) induced pattern in the river Surma

The following map (Fig. 5) contains information about the elevation of the study area with respect to mean sea level. As the study area is mostly in between -101inch to 291inch or -3 meters to 7.5 meters. It is comparatively on higher land than the rest of the country, which helps in flushing out the excess discharge through the river or through the smaller water ways in the study area.

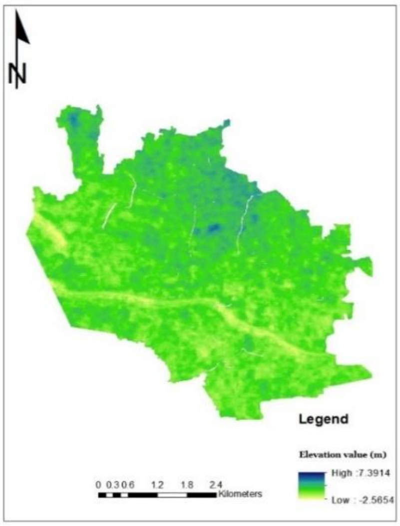

Fig. 5. DEM of the study area

Again Fig. 6 shows a comparison between the models created in the Arc map with the DEM. It can be noted that there are low lying areas quite next to the river.

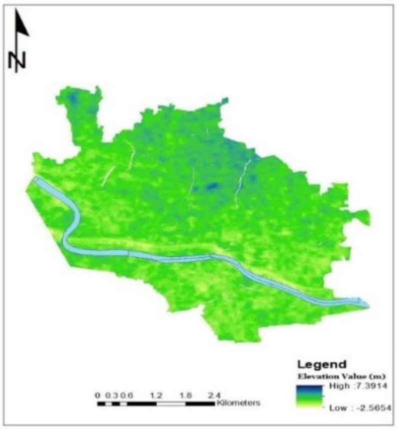

Fig. 6. DEM compared with the study area of Surma River

Flood hazard mapping

The total maximum peak discharge through Surma River at Sylhet City Corppration (SCC) is calculated as 321.35 m^3/s. Based on discharge a flood hazard map (for 25 year return period) has been generated using GIS (Fig. 7)

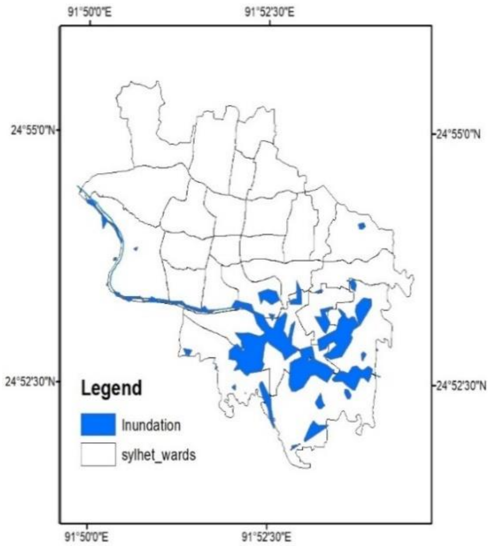

Fig. 7. Flood hazard map for Sylhet City

Conclusion

There is a decreasing trend of water level in Islampur SW332 station and there is no linear trend that could be detected at the 5% significance level in Kanaighat SW 266 and Sylhet SW267 stations. River capacity is sufficiently large enough to keep the flow within the channel throughout most of the year.

Rainfall increases overall precipitation count in the river throughout the year. A hypothetical ten times the regular rainfall induced map shows a significant rise in the precipitation count of the river which shows that the river is quite sufficiently large to support the excess water.

The tri-yearly analysis shows the discharge trend changes in recent years. The years 2006-08 shows the high discharge near the Eastern region of the study area. The years 2009-11 follows a similar trend with slight shifting to the western part. The years 2012-14 drastically shifted toward the west and to the middle region of the study area as well as the heart of the city. From the DEM, low lying lands near the study area are in the primary risk of flash floods.

From flood inundation mapping it is clear that the water bodies in SCC are not sufficient enough to carry all the water during the peak flow in near future. So, water logging will be a major suffering to the people. Moreover, some parts of the city will be inundated due to flooding of Surma River. Taking some flood control management and designing a proper storm water drainage system facility in all across Sylhet City Corporation must be done in order to get rid of these vicious sufferings.

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FEASIBILITY OF PREPAID IRRIGATION AT RAJSHAHI REGION IN BANGLADESH

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Abstract

Since water is scarce and essential resource for crop production, Barind Multipurpose Development Authority (BMDA) in Bangladesh has invented and has implemented prepaid irrigation program -a new an efficient irrigation program. This study was conducted to identify the better irrigation program for crop production. BRRI-Dhan-28 was selected and cultivated using equal quantity and ratio of similar fertilizers for all the sample plots. The results showed that per Bigha (1350 m^2) average irrigation charge for prepaid irrigation program was Tk. 699 and for private irrigation program was Tk.1480 which was about 112% higher than the prepaid irrigation program. The amount of water per Bigha for Boro rice cultivation were 59 and 82 bigha-inches for prepaid and private irrigation programs, respectively. It showed that about 39% excess water was used by the private irrigation program. Volumetrically the loss of water for using the private irrigation was about 780 m^3 per bigha. Average yield per bigha was increased about 9% in the prepaid over private irrigation. Net income per bigha in the prepaid and private irrigation programs were Tk.5700 and Tk.4000, respectively. Benefit–cost ratios of prepaid and private irrigation programs were 2.36 and 1.79, respectively. Total loss of irrigation water due to private irrigation program was found about 19830 million cubic meters per year which could produce about 9.46 Million Metric Ton rice. This study confirms that prepaid irrigation program is an economic and environment friendly program to grow more rice in the study area.

Keywords: *feasibility, prepaid irrigation, economic.*

Introduction

About 80% percent peoples depend on agriculture and agricultural works in Bangladesh. Among the total employment on agriculture, 42 percent generates from own farm, 35 percent from other farm and the remaining 23 percent from other agricultural services (Habibul, 2005). So, the development in agriculture and agricultural production technology in Bangladesh is very essential for growing more food for her rapidly growing population. The proper amount of water and its application is a key factor for crop production. Tushaar *et al.* (2008) urged that "Getting prices right" is the silver bullet widely advocated to developing countries in fighting waste, misallocation and scarcity of water (Tushaar *et. at.*, 2008). Kaldellis and, Kondili (2007) found that increased water demand due to economic growth, irrigation needs, declining precipitation levels and over-abstraction of groundwater are all factors that create fresh water shortage problems in the Aegean Archipelago islands (Kaldellis and Kondili, 2007). Fischer *et al.* (2007) commented that mitigation reduced the impacts of climate change on agricultural water requirements by about 40% or 125-160 billion m^3 (Gm^3) compared with unmitigated climate. Simple estimates of future changes in irrigation efficiency and water costs suggest that by 2080 mitigation may translate into annual cost reductions of about 10 billion USD. Hossain (2010) discussed the benefits of using the modelling tools for optimum utilization of water resources in irrigation and drainage management of command area development projects. In the Teesta Barrage Project, he observed that during Kharif-II season, the full supply levels (FSL) could not be achieved in a dynamic head for the required water flow in both the Teesta and the Rangpur main canals. FSL was also not achieved during Rabi and Kharif-I as the water flow was not optimal in the Teesta. After modelling study he stated that to achieve FSL and required flow in the canal system, some interventions are required. TBP phase-I is now flood free and the annual return from paddy in that area is about Tk. 300.0 crore. Islam et al. (2004) observed that expansion of cropped area and use of HYV rice in the TBP have contributed to labor demand which increased wage rate by 24.5% and also increased purchasing power of landless households. They investigated that Teesta River water reduced the irrigation cost by one-fifth. They found that increase in rice yield level together with the decrease in irrigation cost, has doubled the farm income. They further studied that the present flow in the Teesta River is inadequate to meet the present irrigation requirement, while the fluctuation in the flow rate affects directly the availability of water in the TBP area. To give easement to the farmers for crop production, the irrigation and agricultural specialists developed the schedule of irrigation which save the irrigation water, reduce irrigation cost and get higher yield. From the starting

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to till now all the organizations Bangladesh Agricultural Development Corporation, Bangladesh Water Development Board, Local Government Engineering Department (LGED), deliver irrigation water to farmers land by seasonal contract irrigation charge basis. The farmers receive and use more water for crop production. They misuse the irrigation water. For using more irrigation, the yield of crops reduces, cost of production increases, profit of crops decrease, storage of water decreases and starts ecological imbalance. Moreover, at every irrigation scheme a lot amount of irrigation charge keeps as arrear, which is never possible to realize from the farmers. Considering all the factors BMDA has been developed a new eco-friendly, more profitable, easy to operate and sophisticated prepaid irrigation program in Bangladesh. It is a water delivering program where irrigation charge is taken instantly and the specific amount of water is provided to the farmers on the basis of prepaid card given to them. Using this card, total amount of water can be taken by splitting according to the irrigation scheduling of crops. The prepaid irrigation program is become very popular to the farmers for its various types of merits.

A comparative study of prepaid and private irrigation programs was taken to find out the merits and economics of the prepaid irrigation programs over the private irrigation program.

Methodology

The prepaid irrigation is conducting through BMDA of government irrigation equipment and the private irrigation is conducting through the private owners of the irrigation equipment. At first 25 Upazilla of three districts of Bangladesh named- Rajshahi, Chapai Nawabgonj and Naogaon districts had been taken as the main sample stations and under every station 10 numbers of sample plots had been chosen from prepaid Deep Tube Wells (DTWs) and private irrigation equipment especially from private Shallow Tube Wells (STWs) or private DTWs. The sample plots of prepaid and private irrigation programs had been selected at the nearby two separate irrigation equipment’s command area of two irrigation programs. The 250 sample plots having 5 different soil types were cultivated with BRRI Dhan 28 following the recommended fertilizer doses for the prepaid and private irrigation program. Field data were taken by direct measurement and field survey with pretested questionnaire for the sample plots.

Results and discussion

Table 1. Irrigation charge per bigha in the prepaid and private irrigation program

Soil Texture	Average irrigation charge (Tk.)		Increment of irrigation charge	
	Prepaid	Private	(Tk.)	%
Silty clay	660	1334	674	102
Silty clay loam	687	1435	748	112
Silt loam	720	1517	797	111
Clay loam	655	1432	777	119
Loam	770	1684	914	119
Average	699	1480	781	112
SD	63.12	284.13		

The prepaid irrigation program of the BMDA has opened a new chapter to maximize yield and profit by reducing production costs for cultivating crops against the private irrigation program to the farmers. The obtained results on the basis of different specific objectives of prepaid irrigation program and the private irrigation program are discussed below:

Irrigation cost

The amount of irrigation cost per bigha at the private irrigation program over the prepaid irrigation program for Boro rice production was Tk. 699 and for private irrigation program was 1480. It shows that on and average Tk.781 per bigha excess irrigation cost required in the private irrigation program. This amount is about 112% higher than the prepaid irrigation program. So, farmers choose the prepaid irrigation program (Table 1). At the silty clay type soil per bigha average irrigation charge for prepaid and private irrigation program were Tk. 660 and Tk. 1334, respectively. That is per bigha irrigation cost Tk. 674 required more in the private irrigation program. Some of the locations the irrigation charge at the private irrigation program is showing very higher than the average. This happened due to the local water lords of private irrigation program. At the silty clay loam type soil per Bigha average irrigation charge for prepaid and private irrigation program were Tk.

687 and Tk. 1435, respectively. That is per bigha irrigation cost Tk. 748 required more in the private irrigation program. Average irrigation charges for prepaid and private irrigation program per bigha were Tk. 720 and Tk. 1517, respectively, for silt loam type soil. That is per bigha irrigation cost Tk. 797 required more in the private irrigation program. The private irrigation program required more amount of irrigation charge on comparison to the prepaid irrigation program to cultivate one bigha of Boro rice for clay loam soil (per bigha average irrigation charge for prepaid and private irrigation program were Tk. 655 and Tk. 1432, respectively). Maximum average irrigation charge for prepaid and private irrigation program were found (Tk. 770 and Tk. 1684, respectively) for loam type soil.

Table 2. Water used per Bigha in the prepaid and private irrigation program

Soil Texture	Average irrigation (in)		Increment of irrigation amount	
	Prepaid	Private	(in)	%
Silty clay	51	74	23	45
Silty clay loam	57	80	23	40
Silt loam	63	87	24	38
Clay loam	55	76	21	38
Loam	68	91	23	33
Average	59	82	23	39
SD	8.91	13.88		

Irrigation depth

The quantity of irrigation water which applied in the sample plots of prepaid and private irrigation programs also measured and calculated. The used irrigation water per bigha for Boro rice cultivation was 59 in and 82 in for prepaid and private irrigation programs, respectively in depth. It shows that about 39% excess irrigation water was used by the private irrigation program (Table 2). It was found that the minimum and maximum irrigation depth (51in, 74 in) and (68 in, 91 in) were needed for silty clay and loam soil, respectively. For using more irrigation water than the required quantity the tillers of the rice reduced in numbers. These less number of tillers hampers the yield of the rice. So, the results prove the prepaid irrigation is better than the private irrigation program. The Table 2 shows the at a glance result of the two irrigation programs about the quantity of irrigation used per bigha for producing Boro rice in different types of tested soil textures.

Table 3. Rice yield per Bigha in the prepaid and private irrigation program

Soil Texture	Average yield (Kg)		Increment of average yield	
	Prepaid	Private	(Kg)	%
Silty clay	799	737	62	8
Silty clay loam	891	817	73	9
Silt loam	944	856	88	10
Clay loam	866	800	66	8
Loam	952	893	59	7
Average	891	821	70	9
SD	76.26	77.88		

Yield of rice

Average yield per bigha in the prepaid and private irrigation programs were 891 and 821 Kg, respectively. That is about 70 Kg rice reduced in the private irrigation program which was about 9% less in production of rice in the private irrigation program. The prepaid irrigation produced more yield. Maximum yield (952 kg, 893 kg) were found in loam soil for prepaid and private irrigation program. The yield at two irrigation programs in different types of soil text ures are shown in Table 3.

Table 4. Per Bigha yield per Bigha-inch of irrigation water

Soil Texture	Average yield (Kg)		Increment of average yield	
	Prepaid	Private	(Kg)	%
Silty clay	16	10	6	60
Silty clay loam	16	11	5	45
Silt loam	15	10	5	50
Clay loam	16	11	5	45
Loam	15	10	5	50
Average	16	11	5	45
SD	1.97	1.73		

Average production of rice per inch of irrigation

The sample plots and schemes were 41 for silty clay type soil of each number of programs. It is identified that the private irrigation program unable to produce higher yield than the prepaid irrigation program for cultivating per bigha of Boro rice. At the silty clay soil per Bigha average yield per bigha-inch of irrigation water for prepaid and private irrigation programs were 16 Kg and 10 Kg, respectively. Per bigha average yield reduced per bigha-inch irrigation water was 6 Kg in the private irrigation program than the prepaid irrigation program. The private irrigation program was unable to produce higher yield than the prepaid irrigation program for cultivating per bigha of Boro rice. At the silty clay loam soil per Bigha average yield per bigha-inch of irrigation water for prepaid and private irrigation programs were 16 Kg and 11 Kg, respectively. That is per bigha average yield reduced per bigha-inch irrigation water was 5 Kg in the private irrigation program than the prepaid irrigation program (Table 4).

Table 5. Amount of water used to produce one Kg Boro rice in prepaid and private irrigation program

Soil Texture	Average irrigation required (L)		Excess water used	
	Prepaid	Private	(L)	%
Silty clay	2156	3425	1269	59
Silty clay loam	2200	3313	1032	47
Silt loam	2281	3438	1157	51
Clay loam	2171	3353	1182	54
Loam	2402	3495	1093	46
Average	2250	3400	1150	51
SD	282.44	519.17		

Table 6. The Benefit-Cost Ratio of the prepaid and private irrigation program

Soil Texture	Average Gross income (Tk.)		Average Production cost (Tk.)		Benefit- Cost Ratio	
	Prepaid	Private	Prepaid	Private	Prepaid	Private
Silty clay	9047	8209	3962	4691	2.28	1.71
Silty clay loam	10024	9099	4143	4929	2.42	1.85
Silt loam	10458	9525	4456	5364	2.35	1.78
Clay loam	9491	8643	4224	5045	2.25	1.71
Loam	10569	9741	4211	5180	2.51	1.88
Average	9900	9050	4200	5050	2.36	1.79
SD	1037.9	1045.3	467.1	647.4	0.085	0.067

Quantity of water

The private irrigation program required more irrigation water to produce one Kg rice production than the prepaid irrigation program. On average 2250 L and 3400 L water were required in the study are for the prepaid and private irrigation program, respectively. Details water required are shown in Table 5. At the silty clay soil requirement of irrigation water for one Kg rice production for prepaid and private irrigation programs were 2156 L and 3425 L respectively. That is per Kg rice production required 1269 L excess irrigation water in the private irrigation program. At the silty clay loam soil requirement of irrigation water for one Kg rice production for prepaid and private irrigation programs were 2200 L and 3313 L, respectively. That is per Kg rice production required 1032 L excess irrigation water in the private irrigation program. For the silt loam soil, irrigation water needed for one Kg rice production for prepaid and private irrigation programs were 2281 L and 3438 L, respectively. That is per Kg rice production required 1157 L excess irrigation water in the private irrigation program. At the loam soil requirement of irrigation water for one Kg rice production for prepaid and private irrigation programs. The 2402 L and 3495 L water were required for prepaid and private irrigation programs, respectively.

Average gross income

It is identified that the private irrigation program failed to produce maximum gross income than the prepaid irrigation program. At the silty clay type soil total Gross Income generated for prepaid and private irrigation programs were Tk. 9047 and Tk. 8209, respectively per Bigha. That is per bigha gross income increased Tk. 838 in the prepaid irrigation program. It is identified that the private irrigation program failed to produce maximum gross income than the prepaid irrigation program. At the silty clay loam type soil gross income generated for prepaid and private irrigation programs were Tk. 10024 and Tk. 9099, respectively per bigha. Gross income was increased Tk. 925 in the prepaid irrigation program. The private irrigation program failed to produce maximum gross income than the prepaid irrigation program. At the loam type soil total gross income generated for prepaid and private irrigation programs were Tk. 10569 and Tk. 9741, respectively per Bigha. Gross income increased Tk. 828 in the prepaid irrigation program (Table 6). Average production cost per bigha for producing Boro rice among the prepaid and private irrigation program were (Tk. 3962 and Tk. 4691), (Tk. 4143 and Tk. 4929), (Tk. 4456, Tk. 5364), (Tk. 4224, Tk. 5045), and (Tk. 4211, Tk.5180), for silty clay, silty clay loam, silty loam, clay loam and loam soil, respectively (Table 6).

Benefit –Cost Ratio(BCR)

The benefit –cost ratio is one of the main criteria to distinguish the irrigation program which one is better than the others. Table-6 shows the benefit –cost ratio of the two irrigation programs. It is found that the benefit –cost ratio of prepaid irrigation program always higher than the private irrigation program for all types of soils. The maximum and minimum BCR values were (2.51, 1.88), (2.28, 1.71) for Loam soil and silty clay soil for the prepaid and private irrigation programs, respectively. Only for the beauty and profitable corners of the of the prepaid irrigation program the numbers of the irrigation equipment of the prepaid irrigation program are increasing day by day. But the number of irrigation equipment of private irrigation program and alike to private irrigation program are decreasing day by day. The irrigated area also increased in the prepaid irrigation program.

The major problems with prepaid irrigation are found by the farmers in this study are: (i) faulty prepaid card and faulty card reader, (ii) Maintenace need special type technician (iii) may loss as it is very small in size and difficult to carry by the farmers. (iv) may damage by different ways i.e. fire, scratch, breaking, (v) difficult to pay all money at a time in advance, (vi) handling of prepaid card needs knowledge about irrigation scheduling.

Conclusion

The field data of the two irrigation programs were analyzed to compare them. The prepaid irrigation program proved that it is better than the private irrigation program. Irrigation costs per bigha rice production were Tk. 699 and Tk. 1480 for prepaid and private irrigation program, respectively. About 112% excess irrigation was required in the private irrigation program. This excess amount was the additional burden to the farmers. In this study it was also found that about 39% more irrigation water required in the private irrigation program. About 780 cubic meter water lost per bigha in the private irrigation program, which affects the eco-system. The yield of cultivated rice of the two programs were found 891 kg, 821 kg, which show that the prepaid irrigation program produced 9% more rice on comparison to the private irrigation program. Cultivation of Boro rice through prepaid irrigation, the state would achieve additional 9% of rice which can reduce the food crisis to some extent. On average 16 Kg and 11 kg rice were produced using 1 bigha-inch of water for prepaid and private irrigation. Prepaid irrigation program was able to increase of 45% yield over private irrigation. The benefit –cost ratios of the prepaid and private irrigation program were found 2.36 and 1.79, respectively, in the study area which was about 32% more than the private irrigation program. Loam soil in that area had maximum BCR (2.51, 1.88) for prepaid and private program and minimum BCR (2.25, 1.71) was found in clay loam soil. From this result it was proved that the farmers could earn more profit from the prepaid irrigation program. The production cost per Bigha was found lower (prepaid-Tk.4200, private- Tk.5050) and benefit was found higher (prepaid-Tk.9900, private-Tk.9050) in the prepaid irrigation program on average in the study area. It was found that about 43% income was saved in the prepaid irrigation program. The obtained results finally confirmed that the prepaid irrigation has the positive impact for cultivating Boro rice economically and environmentally. To improve the prepaid irrigation program, (i) development of more effective prepaid card, and (ii) more detail study should be done.

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HYDRODYNAMIC SCENARIO'S TO REDUCE THE SALINE WATER INTRUSION IN THE SOUTHWEST REGION OF BANGLADESH

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Abstract

Salinity in Bangladesh coastal area is dependent on tidal flow, rainfall intensity, evaporation, freshwater flows from upstream and the impact of climate change like sea level rise (SLR). Due to the reduction in freshwater flow from the upstream rivers in the dry season, the average salinity concentrations in the coastal part are higher in dry season than in the monsoon. The flow of Ganges River within Bangladesh reduced significantly due to the withdrawal of water in the upstream boundary. The simulation of the calibrated salinity model for the Southwest region in Bangladesh has been carried out in this study to explore the hydrodynamic scenarios which may reduce the salinity level at the above mentioned area. The scenarios are based on different flow conditions and have been simulated with the calibrated and validated hydrodynamic and salinity model. The scenario considering the increase in upstream flow through Ganges and its connected rivers has been simulated to identify the saline free zone at the most southern end zone. Salinity level remains higher in the western part of the Southwestern region than that of the eastern part. The eastern part remains less saline since it receives freshwater flow through Arial Khan, Bishkhali and Buriswar Rivers. As a result, salinity levels in the region decreases from west to east. It was observed that the some of the major rivers of Southwest would be saline free and all other rivers will have significant reduction of salinity due to increase in flow of fresh water through the Ganges and its distributaries.

Keywords: *augmentation, Bay of Bengal, freshwater, hydrodynamic, MIKE 11, MIKE 21 FM, salinity, southwest.*

Introduction

Bangladesh is a low-lying, riverine country located in South Asia with a largely marshy land coastline of 710 km (441 mi) on the northern littoral of the Bay of Bengal, formed by a delta plain at the confluence of the Ganges (Padma), Brahmaputra (Jamuna), Meghna Rivers and their tributaries. About 700 rivers including tributaries flow through the country constituting a waterway of total length around 24,140 km.

The flow of the Ganges in Bangladesh reduced significantly due to withdrawal of water in the upstream at the Farakka Barrage. India commissioned the Farakka Barrage in West Bengal in 1975 to divert 40,000 cusec water of the Ganges River into the Bhagirathi-Hooghly Rivers for flushing silt and improve navigability of Kolkata Port connected to the Bay of Bangal on the south (BWDB, 2012). The main impact of reduced low flow values has been the drop in hydraulic head of the Ganges River system, and the consequent increase in salinity in Southwestern Bangladesh rivers (Rahman and Ahsan, 2001).

The study area encompasses the entire Southwest (SW) area of Bangladesh bounded by the Ganges and the Padma in the north and in the east extending into the Bay of Bengal to the south and the international border to the west. The Gross Area of the Southwest (including South central) region is 41,500 km2 (IWM, 2003). The increase of salinity in the Ganges distributaries has also led to ecological impacts on the world's largest mangrove forest; the Sundarbans is about 10,000 km2 in southwest Bangladesh and West Bengal of India (Siddiqi, 2001; Lacerda, 2001). The Bangladesh portion of Sundarbans covers an area of 6017 km² of mangrove forests, wildlife sanctuaries and sand bars, out of this 1905 km² are made up rivers, creeks and canals (Wahid, 1995; Katebi, 2001). Salinity levels increased in the Sundarbans when intake-mouths of the Mathabhanga, Kobadak and other rivers that used to bring fresh water from the Ganges to the south were silted up and thus lost their connection with the Ganges. Therefore, the result of increase salinity and alkalinity has damaged vegetation, agricultural cropping pattern and changing the landscapes in the Sundarbans region (Hoque *et al.,* 2006).

In the recent years, groundwater based water supply in coastal area is suffering from a number of major problems mainly arsenic contamination, lowering of the water table, salinity and non-availability of suitable aquifers (PDO-ICZMP, 2004).

Salinity in the river system of southwest coastal region increases steadily from December through February, reaching maximum in the late March and early April (EGIS, 2001). About 20% of the net cultivable land of Bangladesh coastal region

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is affected by different degrees of salinity (Karim *et al.,*1990). Most of the lands remain fallow in the dry season (January–May) because of soil salinity (Mondal, 1997). In dry season, when the flows of upstream water reduce drastically, the saline water goes up to 240 kilometers inside the country and reaches to Magura district. Presently around 31 Upazilas of Jessore, Satkhira, Khulna, Narail, Bagerhat and Gopalganj districts are facing severe salinity problem. Agricultural activities as well as cropping intensities in those Upazilas have been changing; as a result farmers cannot grow multiple crops in a year (Shamsuddoha and Chowdhury, 2007).

Methodology

The approach of the study is to develop hydrodynamic scenario to reduce the saline water intrusion in the southwest region of Bangladesh.

a) Data collection on precipitation, evaporation, water level, discharge, salinity and river cross-section

b) The principal modelling tools used in the study was the one-dimensional and two-dimensional (1-D and 2-D) modelling systems, MIKE11 and MIKE 21FM of DHI. The salinity developments of southwest region of Bangladesh take place during the dry period.

c) To achieve the objectives, the simulation of the calibrated and validated salinity model has been carried out by increasing upstream flows which are connected with Ganges River for limiting salinity of Southwest region of Bangladesh.

d) Scenario-1 (baseline condition, 2011-2012) has been simulated to explore the present salinity intrusion. Scenario-2 (Minimum flow through Gorai River) has been simulated to understand the worst condition for salinity intrusion. Finally, Scenario-3A, Scenario-3B and Scenario-3C (flow through Ganges connected Rivers) has been conducted to identify the saline free zone with improved upstream flow and dredged river bathymetry condition. Three simulations have been done under this study which is described in Table 1.

Table 1. Summary of the scenarios used in the study

Scenario	Flow	Condition	
Scenario 1	Base line Scenario	Simulation of calibrated and validated Southwest Regional Model (Nov 2011 to June 2012) No upstream connection with Ganges River Apply existing upstream and downstream flow condition (2011-12)	
Scenario 2	Minimum flow through Gorai River	Baseline Model (Scenario-1) simulated with minimum flow through Gorai River All other river (Hisna, Mathabhanga and Chandana) are disconnected at dry season with Ganges River	
Scenario 3	Flow through Ganges connected Rivers	3A	Flow through Gorai, Hisna and Chandana based on Ganges barrage study Restoration of flow through the channels with dredged X-sections
		3B	20% flow increase of Gorai, Hisna and Chandana River
		3C	20% flow decrease of Gorai, Hisna and Chandana River

Based on irrigation water demand, navigational requirement, fisheries requirement, salinity intrusion prevention criteria BWDB has fixed the seasonal flow diversion amount from the Ganges to link channels through Ganges barrage operation. In our study the flow data of the right bank of Ganges River been collected and used for increasing the upstream flow and presented below in Table 2. The Gorai River Hydrograph for different flow scenario is shown in Fig. 1.

Table 2. Monthly Flow Diversions (m^3/s)

River	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Hisna	400	300	231	234	232	242	184	300	400	500	500	400
Gorai	2500	1000	225	227	225	230	194	500	2500	7600	7600	2500
Chandana	300	200	46	57	77	80	44	50	200	300	300	300
Total	3200	1500	502	518	534	552	422	850	3100	8400	8400	3360

(Source: BWDB, 2012)

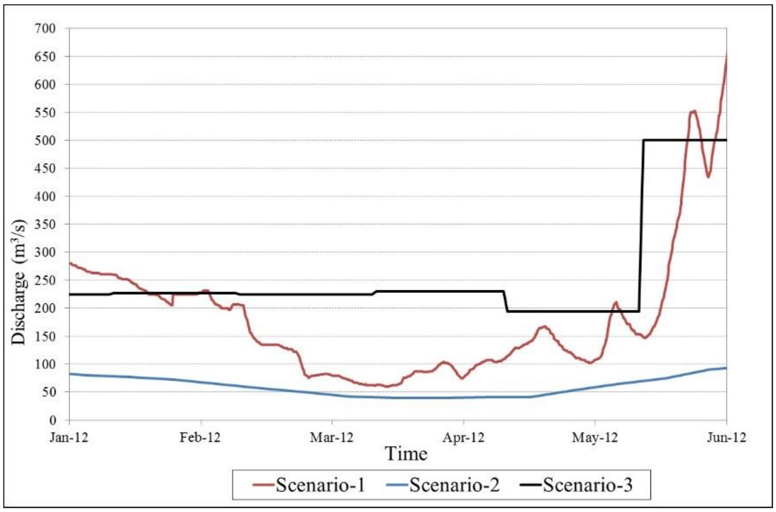

Fig. 1. Gorai River Hydrograph at different flow scenario

Data and Model used in the study

Data on salinity, water level, river cross-section and discharge were collected for consecutive two years considering monsoon and dry season under GRRP project by IWM. The bathymetric survey data were collected by IWM from different study. Historical hydrometric data such as water level and discharge were also collected from IWM, BWDB. Rainfall data were collected from BMD. In this study MIKE has been used for One-Dimensional and Two-Dimensional Modelling. MIKE11 was used for One-Dimensional model. Subsequently, MIKE21 FM was used for Two-Dimensional model. The salinity model, based on this hydrodynamic model, will describe the transport and advection of salinity. Fig. 2 shows the overall methodology of the salinity model. The existing one-dimensional Southwest Regional Model (SWRM) developed by MIKE 11 has been extended and updated with the dredged X-sections cross-sections to restore the flow thorough Ganges connected River of Southwest Regional rivers (Fig. 3). The calibrated and validated Bay of Bengal model (BoB) (Fig. 4) developed by MIKE 21FM has been used to generate the d/s boundary condition (Salinity) for southwest regional model.

The existing SWR Model has 230 river branches and 32 boundaries of which 12 are directly connected to the sea at the downstream. Whereas, the developed SWRM under this study contains total 39 boundaries, of which 27 are upstream and 12 are downstream boundaries. The 12 downstream salinity boundary for 1-D model will be used from the output of Bay of Bengal salinity model simulation.

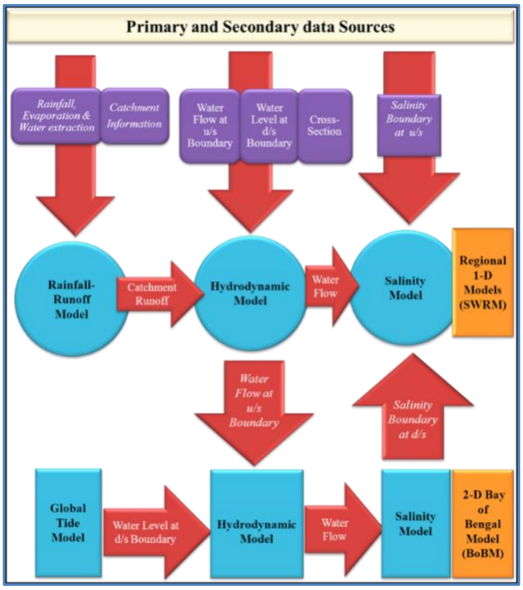

Fig. 2. Methodology of the salinity modeling.

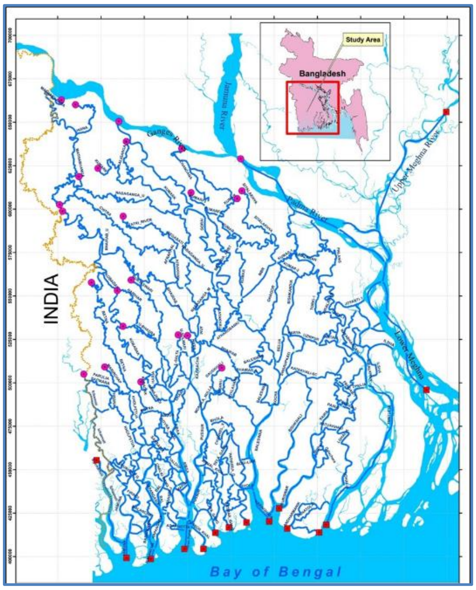

Fig. 3. Southwest Regional Model Domain.

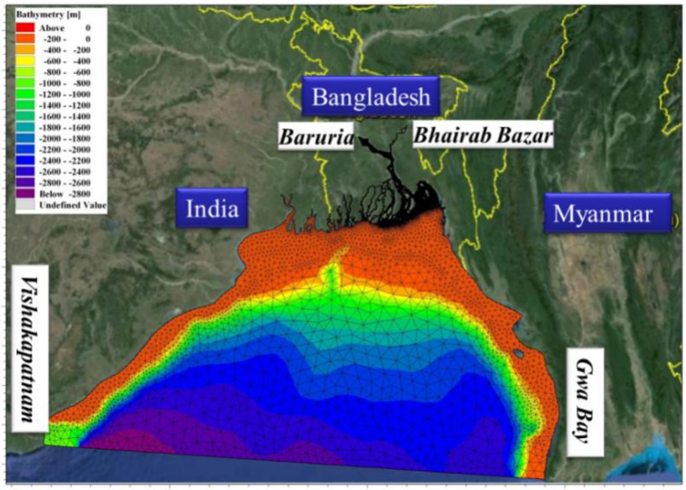

Fig. 4. Bay of Bengal Model Domain (BoBM)

MIKE 11 hydrodynamic equations

The equations which are solved for the flow simulations are called Saint Venant equation. These are derived from the Navier Stokes equation. Saint Venant equations are:

$$\frac{\delta q}{\delta x} + \frac{\delta A_{fl}}{\delta t} = q_{in} \qquad \text{Eq. (1)}$$

$$\frac{\delta q}{\delta t} + \frac{\delta\left(\alpha \frac{q^2}{A_{fl}}\right)}{\delta x} + gA_{fl}\frac{\delta h}{\delta x} + gA_{fl}I_f = \frac{f}{\rho_w} \qquad \text{Eq. (2)}$$

Where, q (Discharge); A_{fl} (Flow area); q_{in} (lateral inflow); h (water level); α (momentum distribution coefficient); I_f (Flow resistance); f (Momentum forcing) and ρ_w (Density of Water). Equation (1) is called the continuity equation; Equation (2) is called the momentum equation

MIKE 11 advection-dispersion equations

The advection-dispersion equation is solved numerically using an implicit finite difference scheme, which, in principle, is unconditionally stable and has negligible numerical dispersion. It solves the following advection-dispersion formula:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = -K.A.C + q_L.C_L$$

Eq. (3)

Where, C (concentration); D (dispersion coefficient); A (cross-sectional area); K (linear decay coefficient); C_L (source/sink concentration) and q_L (lateral inflow). The Equation (3) is presented above briefly described in Reference Manual, DHI (2014).

Model calibration & validation

Flow roughness is the major parameter for the calibration of hydrodynamic model. Manning's M (Inverse of Manning's roughness n) is used as the calibration parameter for the calibration of the one dimensional mathematical models. Hydrological year of 2012 has been used for the calibration of the base model. The locations of water level, discharge and salinity calibration are given in Fig. 5.

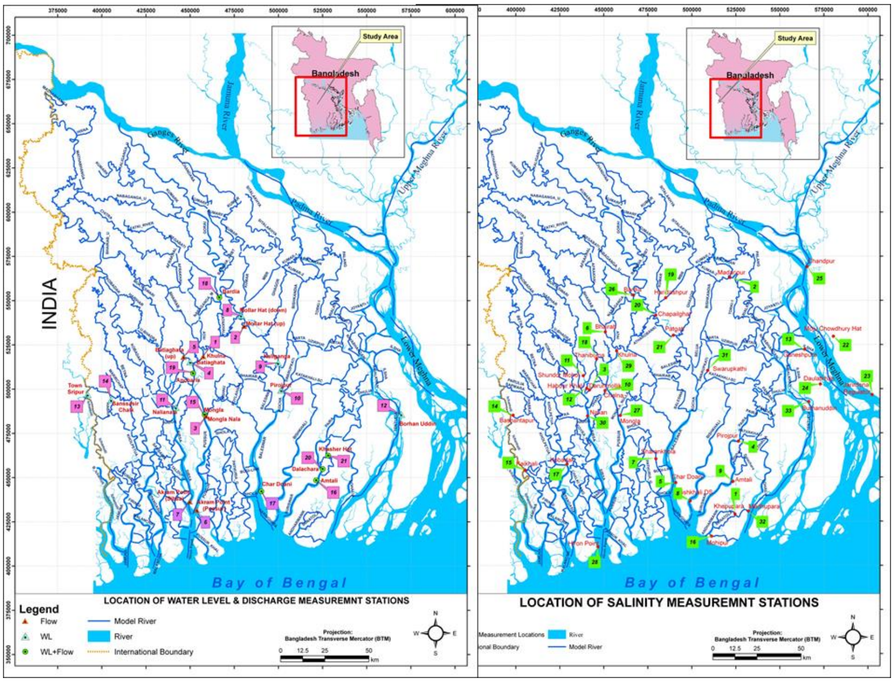

Fig. 5. Location of Water Level, Discharge & Salinity measurement Stations (Source: IWM)

Sample of water level, discharge and salinity Calibration plots of Southwest Regional Model against water level are shown in Fig.6. Under this study all the units of water lever are in (m PWD), discharge and salinity flow are in (m^3s^{-1}) and all the units of salinity are in (ppt). Calibrated hydrodynamic model for year 2012 is validated for year 2011 hydrological year. The validation location and Correlation factor "R".

Table 3. Validation Location and Correlation factor "R".

SI No	Calibration	River Name	Station	R
1		Kocha	Pirozpur	0.91
2	Water Level	Lower Shoilmari	Batiaghata	0.90
3		Kazibachar	Ancharia	0.95

SI No	Calibration	River Name	Station	R
4		Rupsa	Khulna	0.92
5	Flow	Pussur	Akran Point	0.94
6		Sibsa	Akram Point	0.90
7		Pussur	Mongla	0.90
8	Salinity	Pussur	Mongla	0.99
9		Sibsa	Nalian	0.97

Results and discussion

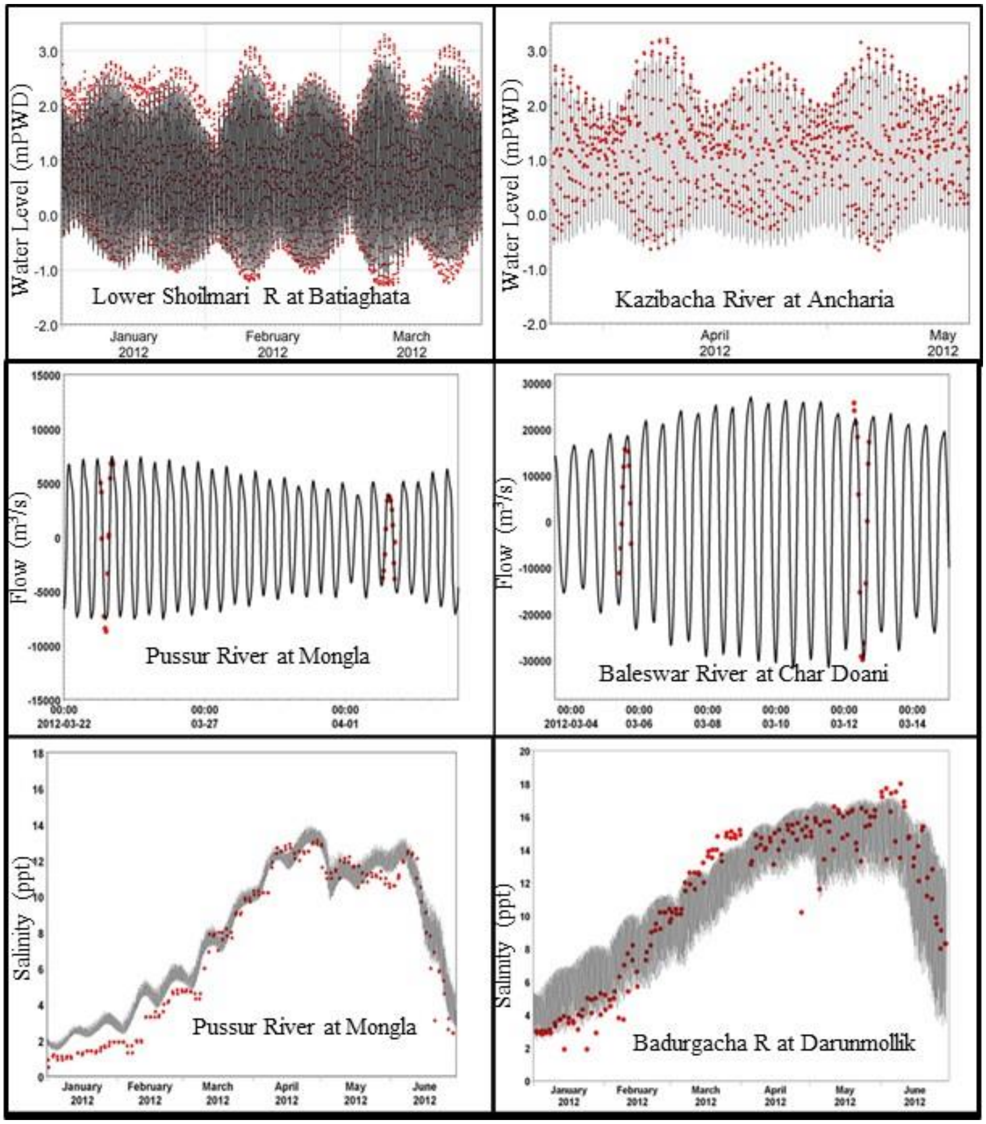

Fig. 6. Calibration of the Southwest regional model against water level, flow and salinity (2012).

Under this study, the one-dimensional hydrodynamic model is applied in order to evaluate the trans-boundary flow that will be sustaining the major rivers in the Southwestern region of Bangladesh. The Hydrograph of Ganges connected river represents the trans-boundary flow through Ganges River. It is assumed that the Ganges River flow distribute in Gorai, Madhumati and Chandana River. The Gorai, Madhumati, Mathabhanga and Chandana Rivers are now disconnected from the Ganges River in the dry season due to river bed aggradations at the mouth of their off-takes. All those rivers become dry or nearly zero flow under existing river condition. Flow Hydrographs of the Southwest major rivers for Scenario-3A are shown in Fig.7.

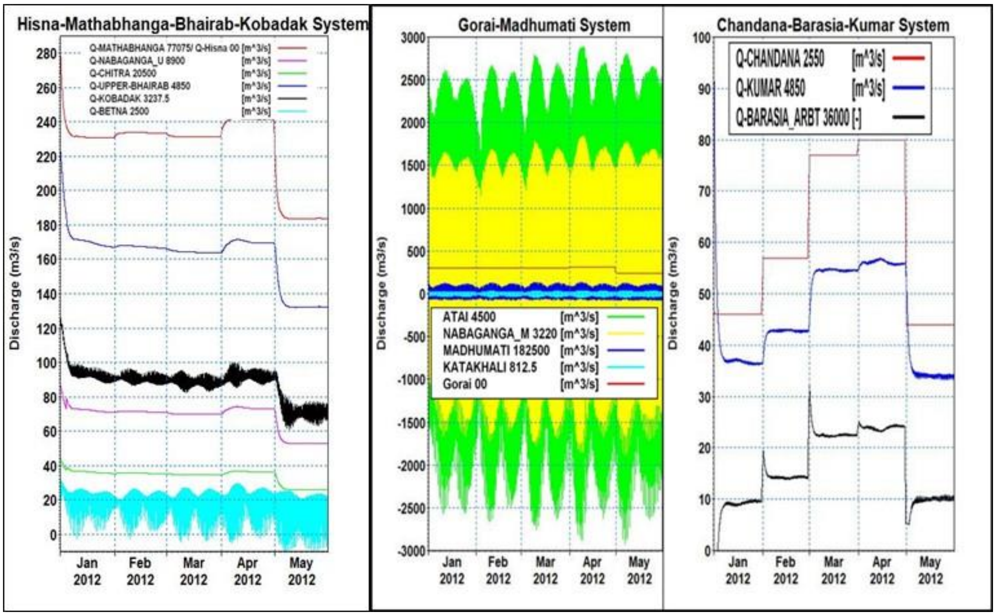

Fig. 7. Flow hydrograph for increased flow Scenario

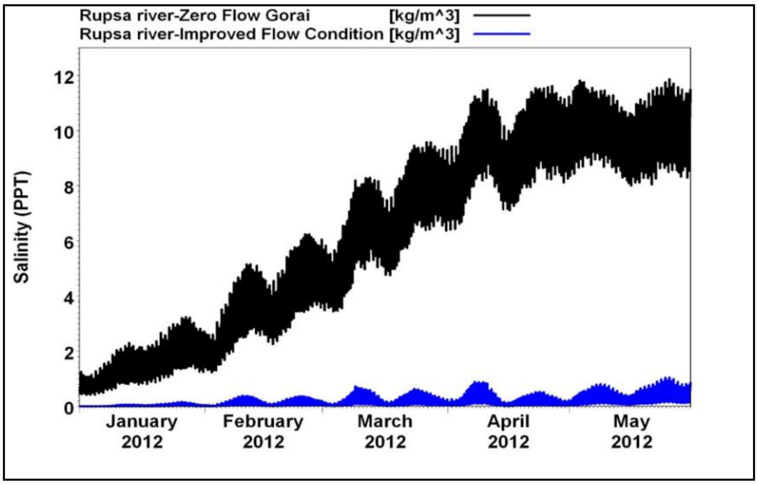

Fig. 8. Significant reduction of salinity in the improved flow condition

The model results indicate that in Scenario-3A (increased upstream flow condition), some of the major rivers such as Gorai-Madhumati, Nabaganga, Chitra, Atai, Bhairab Upper, Rupsa would be saline free and all other rivers will have significant reduction of salinity due to increased upstream flow in Gorai River, Hisna River & Chandana River. Augmentation in the Gorai River flow reduces the salinity in the Pussur River and Sibsa River.

Due to diversion of a considerable fraction of the freshwater discharge from the Padma River, salinity level in the eastern part of the south-west area remains less saline. As a result, salinity levels in the region decreases from west to east as well as from south to north. Fig. 8 shows the significant reduction of salinity in the improved flow condition.

From the sensitivity analysis of Ganges connected River flow by model results indicate that with Scenario-3B (20% flow increase of Gorai, Hisna and Chandana River) and Scenario-3C (20% flow decrease of Gorai, Hisna and Chandana River) the saline free zone similar to Scenario-3A.

Conclusion

Salinities in the Bangladesh coast are dependent on the volumes of freshwater flows discharging from upstream. In 1975, India commissioned Farakka Barrage on the Ganges at about 17km upstream of the Indo-Bangladesh border to divert about 40,000 m3/s of flow into Bhagirathi-Hoogly river system. As a consequence of such a large-reduction of the available flow, the Ganges dependent area in Bangladesh was exposed to serious fresh water shortage. The withdrawal of freshwater flow has resulted in landward movement of salinity front in the Ganges dependent coastal area of Bangladesh. From this research paper, it can be revealed that some of the major rivers such as Gorai-Madhumati, Nabaganga, Chitra, Atai, Bhairab Upper, Rupsa would be saline free and all other rivers will have significant reduction of salinity due to increased upstream flow in Gorai River, Hisna River & Chandana River. Augmentation in the Gorai River flow reduces the salinity in the Pussur River and Sibsa River.

Acknowledgment

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SELECTION OF A BRIDGE LOCATION OVER THE RIVER LOHALIA: AN ASSESSMENT USING MIKE 21C MODEL

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Abstract

Choosing the ideal site for a bridge is as important as constructing the bridge itself appropriately. There is a range of location suitability criteria and models that assist in analyzing site suitability. This study is an attempt to determine the suitable location of a proposed bridge along with its alignment as well as approach road using MIKE 21C model over the Lohalia river in Patuakhali district. This study also provides hydraulic design parameters of the bridge as well as its approach roads. A field survey campaign has been conducted to collect field data necessary for model development and hydro-morphological study. The model was calibrated using field data and then applied for different scenario simulations in the base and with bridge conditions. It is revealed from the study that the bridge should be located at the inflection point between two consecutive meander bends near the Boga ferry terminal from hydro-morphological considerations. The suggested bridge length of 980m is much larger than that obtained from regime equation in order to fulfil specified navigational requirements. For the bridge pier and abutment, the design scour level is found as -16.46mPWD and -6.9 mPWD respectively. The study also comes up with design discharge, water level, girder bottom level and deck level of the bridge. Moreover, location and dimension of the approach road, slope protection works, river training works and design variables of the same have also been suggested from the study.

Keywords: *approach road, BIWTA, bridge, hydraulic design, MIKE 21C, thalweg.*

Introduction

River bridges play a fundamental role in road construction project. The choice of the right site is a crucial decision in the planning and design of a bridge. It may not be always possible to have a wide choice of sites for a bridge. For river bridges in rural areas, usually, a wider choice may be available. The location suitability of a river bridge consists of a comprehensive study of preliminary engineering, hydrology, and hydraulics, roadway alignment, along with environmental and geological surveys (Groenier and Gubernick, 2007). The characteristics of an ideal site for a bridge across a river are:

a) A straight reach of the river.
b) Steady river flow without cross-currents:
c) A narrow channel with firm banks
d) Suitable high banks above high flood level on each side.
e) Rock or other hard in erodible strata close to the river bed level.
f) An economical approaches, danger of floods; the approaches should be free from obstacles such as hills, frequent drainage crossings, sacred places, graveyards or built-up areas or troublesome land acquisition
g) Absence of sharp curves in the approaches;
h) The absence of expensive river training works;
i) Avoidance of excessive underwater construction.

Foregoing studies of site suitability have used a representation of static, dynamic, deterministic or stochastic mathematical programming models to determine the optimal site location. Groenier and Gubernick (2007) discusses a commonsense approach, combined with science, to help select the best locations for bridges. Ardeshir, *et al.* (2014) selected a bridge construction site using fuzzy analytical hierarchy process. Wimmer (2015) conducted another study to assess alternative proposed bridge crossing locations over the Merrimac river in the U.S using a GIS approach. Each method has its own criteria in finding the best alternatives.

In this study, MIKE 21C model is used to simulate the river processes. It is a special module of the MIKE 21 software package based on a curvilinear (boundary-fitted) grid, which makes it suitable for detailed simulation of rivers and channels, where an accurate description of bank lines is required. The MIKE 21C is particularly suited for river morphological studies and includes modules to

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describe flow hydrodynamics, helical flow, sediment transport, scour and deposition, bank erosion and planform changes (DHI, 2017)

In Bangladesh, the rural road network is essential for improving the health, education, and the livelihoods of about 66 percent of the county's people. As part of the strategy to expand transport and communication infrastructures in the country, Government has planned to construct a bridge over the river Lohalia in Patuakhali, the south-central region of Bangladesh.

The Lohalia river is tidally affected, meandering and dynamic in nature. It takes off from the Pandab-Paira river which is also a tidally affected river. The hydrological setting of the study area is very complex. Therefore, selection of a suitable bridge location requires investigation of the past and present erosion trend as well as likely future developments in the river planform under different hydrological scenarios. In case of the proposed bridge over the Lohalia river a number of issues have been identified first namely stability of the river at the bridge location, vertical and lateral stability the bridge, hydraulics of bridge opening, design discharge and flood level, navigational requirements and likely impacts of the bridge on river hydraulics and morphology particularly in terms of flooding potential in the upstream of the bridge. Selection of appropriate bridge length requires detailed analysis of hydraulics of bridge opening together with consideration of other relevant issues.

On the other hand, due to tidal influence, the total scour at a bridge crossing can be evaluated using the scour equations recommended for inland rivers and the hydraulic characteristics can be determined using flow modelling and coastal engineering methods. However, it should be emphasized that the scour equations and subsequent results need to be carefully evaluated considering other information from the existing site, other bridge crossings, or comparable tidal waterways or tidally affected rivers in the area. The hydrology of the study area is very complicated as four types of climatic factors influence its hydrology. These climatic factors are cyclonic surge, tidal flow, monsoon flow and sea level rise due to global warming (BUET and IWM, 2008). Thus to investigate the combined effect of these four factors are very important to determine the vertical and horizontal clearances of the bridge. Implementation of the proposed bridge may cause an adverse impact on tide, sedimentation, and erosion. Therefore, these issues should be addressed carefully. The objective of this study is to find out a suitable bridge location together with its appropriate length and alignment taking all the relevant issues in view and to suggest measures for protecting the bridge and approach roads from being outflanked by the river.

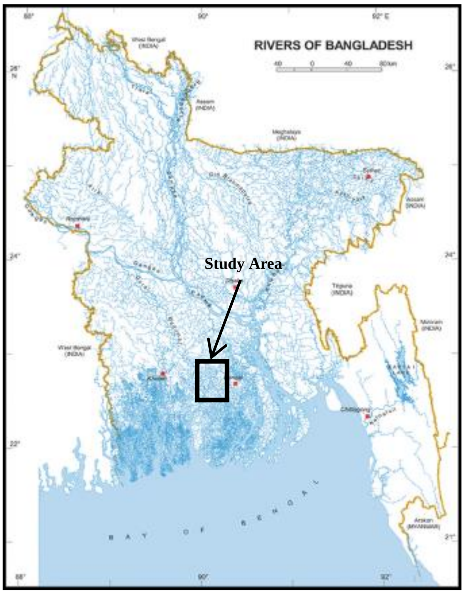

Fig. 1. Location of study area

Methodology

Study site

The study area is in the district of Patuakhali which is situated in the south-central region of Bangladesh. The Zilla (district) road Lebukhali to Amragachia starts from Lebukhali on Dhaka-Barisal-Patuakhali National Highway and headed to the Amragachia through Dumki, Bauphal, Dasmina, Galachipa and Amtali Upzillas (units that form a district).

This thoroughfare is the only way of road communication for the people of the area with Patuakhali, Barisal, and Dhaka. The proposed Boga Bridge over the Lohalia river is located at 14th K.M. of Lebukhali-Amragachia road (Fig. 1). At present, ferry service has been provided by the Roads and Highways Department (RHD) to cross the river. The Lebukhali-Amragachia Road plays a very important role in road communication network of this area. A good number of villages, bazaars, and trade centres are connected to this road through LGED (Local Government Engineering Department) and other village roads. A large number of light and heavy vehicles move on this road and also the traffic volume is increasing day by day. The river at the likely bridge location is a boundary between Dumki and Bauphal upzillas. The west part of the proposed bridge is situated at Muradia union (on the right bank of the river) of Dumki upzilla. On the other hand, east part of the same is situated at Boga union (on the left bank of the river) of Bauphal upzilla (RRI, 2014). The distance of the off-take from the proposed Boga Bridge is about 3.5 km (along the river). The total length of the river from off-take to outfall is about 85 km (along the river).

Data collection and model development

In order to conduct the study, necessary historical hydrological data of the river, time series and satellite imageries of the study area were collected from the Water Resources Planning Organisation, Dhaka (WARPO) and The Centre for Environmental and Geographic Information Services (CEGIS), Dhaka. A field survey campaign was conducted to collect the recent bathymetric and bankline data of the river, nearby existing road alignment data, water level, discharge and sediment data etc. The collected data was processed and analysed to the extent of gaining an understanding of the present physical conditions of the river at the bridge location and also deriving information to use as model inputs. A two-dimensional model covering an extent of about 20km of the river was developed using modelling software MIKE 21C (DHI, 2017). The initial bathymetry (Fig. 2) of the model was formed using recently surveyed bathymetric data.

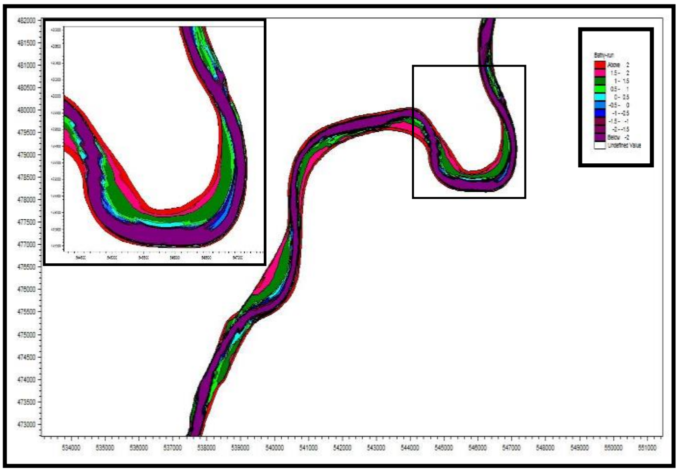

Fig. 2. Initial bathymetry of the model using MIKE 21C

Calibration of the model

The model was calibrated for measured discharge and water level under the framework of the study since there was no historical discharge data available on the Lohalia river. The calibrated model was then applied for different scenario simulations in the base and with bridge conditions. Since the measured discharges at the proposed bridge location was insufficient for deciding about design discharge, indirect method was adopted for computation of design discharge. In this case, slope area method was used for calculating discharges corresponding to different return period water levels because the river has a defined channel. Standard manuals on hydraulic and hydrologic design of bridge and BIWTA guidelines for navigational clearances was consulted for deciding about design flood level and discharges, standard high and low water levels, bridge height, bridge span length, approach road formation level etc. (BUET and IWM, 2008).

Results and Discussion

Suitable Bridge location and approach road alignment

It appears from the analysis of collected bathymetric data of the river and time series satellite images of the study area and also from the model simulation results that the crossing between two consecutive meander bends at the Boga ferry terminal is almost stable in terms of lateral migration and bed degradation. At present, the thalweg is almost in the middle of the river at this location and the maximum velocity also occurs almost in the middle of the river. The suitable river stretch for siting of the bridge is shown in Fig. 3.

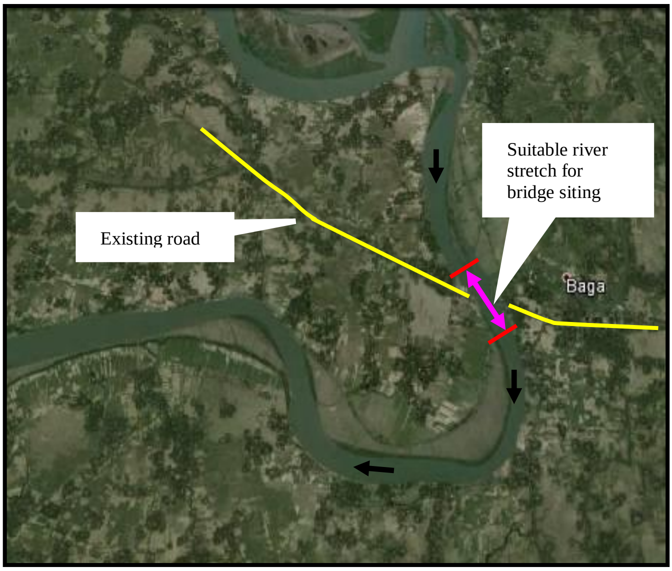

Fig. 3. Suitable river stretch for siting of the bridge

It is observed from the study that a longer bridge compared to that needed from the hydrological and morphological point of view has to be adopted to fulfil the BIWTA requirements for navigational clearance and to restrict the abutment height within a reasonable limit. Considering the issues related to the selection of suitable bridge location and approach road alignment namely proximity to and alignment of the existing RHD Zilla road, river approach to the bridge, skew in the bridge, proportion of displaced households etc. only one option is found for bridge and left link road (approach and access road). The appropriate bridge location is at somewhat downstream of the meander crossing. However, for the right link road, four options have been identified. Considering all relevant issues namely, length of the link road (approach and access road), curve of the approach road etc.,option-3 has been selected (Fig. 4).

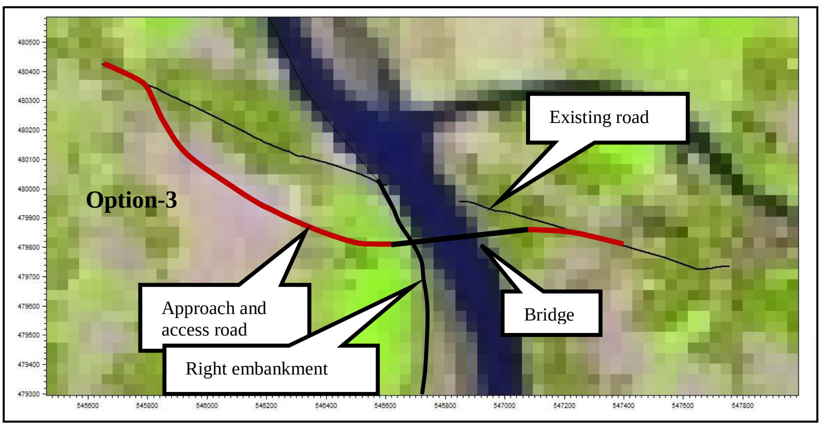

Fig. 4. Proposed alignment of the bridge and approach road over Lohalia river at Boga ferry terminal

Suitable Bridge length

The bend in the upstream of the selected bridge location is still in the process of development, however, the rate of bank erosion is rather low. The right bank of the river in the downstream of the bridge location is part of a compound bend and is experiencing erosion. The hydrodynamic simulations of different return period discharges show similar velocity distribution pattern along the cross-sections at and in the immediate upstream and downstream of the proposed bridge location. The design discharge for the bridge has been estimated as 1972 m^3s^{-1} and based on the design discharge and other relevant issues in view appropriate length for the bridge has been determined as 980m.

The model simulations with different return period discharges have been conducted with the bridge in place to see the effects of bridge constriction caused by bridge piers on existing hydraulics at and around the bridge. It is found from the simulation results that the bridge causes a local increase in flow velocity around the bridge piers and some extent upstream and downstream of the same but has negligible effects on the water level upstream compared to the base condition. It means with the selected bridge opening the free passage of flood flow will not be hampered. The velocity field in the vicinity of the bridge for 50-year and 100-year discharges and with the bridge in place is shown in Fig. 5. The bridge is introduced in the model as accurately as possible as per decision as to the number of spans, pier width etc.

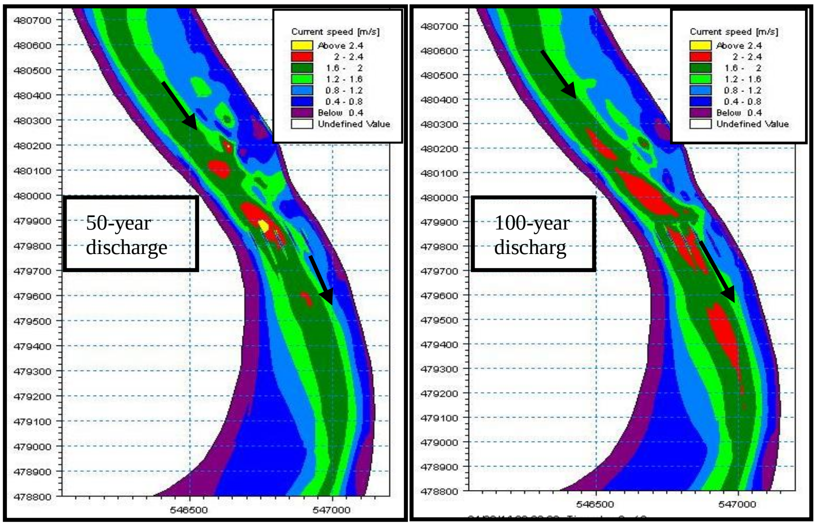

Fig. 5. Velocity field at and around the bridge for 50-year and 100-year return period

Hydrological and hydraulic design parameters

Table 1. The hydrological and hydraulic design parameters of the bridge and approach road obtained from the study.

Design parameters		Specifications
Design discharge for bridge substructure	:	2165 m^3s^{-1}
Discharge for bridge	:	1972 $m^3 s^{-1}$
Design flood level for bridge substructure	:	3.35 mPWD
Design flood level for bridge	:	3.22 mPWD
Standard Low Water Level	:	-0.45 mPWD
Standard High Water Level	:	2.44 mPWD
d_m of soil material	:	0.18 mm
Formation level of the approach road	:	3.95 mPWD
The bottom level of the bridge girder	:	21.0 mPWD
Deck level at centreline of the bridge	:	23.5 mPWD
Length of the bridge	:	980 m
Number of bridge spans (main bridge)	:	4
Number of bridge spans (viaduct)	:	24
Design scour level for abutment	:	-6.90 mPWD
Design scour level for pier	:	-16.46 mPWD
Length of the approach road	:	302.5 m

[Note: Bangladesh Water Development Board and other government departments refer water levels to the Public Works Datum (PWD). PWD is a horizontal datum believed originally to have zero at a determined Mean Sea Level (MSL) at Calcutta. PWD is located approx. 1.5 ft below the MSL established in India under the British Rule and brought to Bangladesh during the Great Trigonometric Survey (FFWC, 2017).]

Velocity information at and in the Vicinity of the Bridge

Velocity information at and in the vicinity of the bridge location in base and with bridge conditions are shown respectively in Table 2 and Table 3 below.

Table 2. Velocity information at the bridge location in base condition

Return Period (year)	Discharge (m^3s^{-1})	Maximum velocity (ms^{-1})	Cross-sectional mean velocity (ms^{-1})
50	1972	2.04	1.36
100	2165	2.13	1.40

Table 3. Velocity information with bridge in place and for 100-year discharge

Location	Maximum velocity (ms^{-1})	Near bank velocity (ms^{-1})
Along right bank upstream of Dumki ferry terminal	-	1.80 to 2.15
Near left abutment (over left floodplain)	Not applicable	-
Near right abutment	Not applicable	-
Along left bank in the immediate downstream of the bridge	-	1.70 to 2.10
At the left pier of the middle span	2.70	-
At the right pier of the middle span	2.38	-
Along right bank in the immediate downstream of the bridge	-	1.10 to 1.40

Bridge height and span arrangements

According to BIWTA navigation route classification, the Lohalia river in the study area falls under the Class I navigation route(BUET and IWM, 2008). It means minimum vertical clearance should 18.3m with reference to Standard High Water Level (SHWL). The SHWL determined by BIWTA at Kaitpara which is about 3.5km upstream of the Boga ferry terminal is 2.45mPWD. On the other hand, the same at Patuakhali (16.5km downstream of Boga ferry terminal) is 2.40 mPWD. The bottom level of the bridge girder, in this case, is the summation of Standard High Water Level, minimum vertical clearance as specified by BIWTA and anticipated sea level rise due to global warming. The bottom level of the girder is thus 21.5 mPWD. The minimum horizontal clearance for Class I navigation route is 76.22m (BIWTA, 2018). The entire length of the bridge (980m) is divided into main bridge and viaducts. The main bridge length is divided into 4(four) spans. An 80m long span is considered in the middle of the dry flow channel to meet the BIWTA navigational requirements. The other three spans of the main bridge are of the length of 60m each. For the remaining length, 24 (twenty-four) viaducts of an equal span length of 30m are considered (11 in the right side and 13 in the left side).

Need for river training works

The proposed bridge is located at the crossing of two consecutive meander bends. Examination of satellite images of the study area and consultations with the local people point to the fact that substantial right bank erosion did occur in the upstream of the Dumki ferry terminal and at present, the rate of erosion is rather low. The left bank in the immediate downstream of the bridge is still being eroded and there is potential for future bank erosion. The Lohalia river originates from the southern branch of the Paira river and its off-take is only about 3.5km upstream of the proposed bridge location. Based on the planform analysis of the Lohalia and its parent river it can be concluded that there is a degree of uncertainty as to future morphological developments at and around the proposed bridge location. In consideration of the long-term safety of the bridge, bank protection works in the form of bank revetment has been proposed in the upstream of the Dumki ferry terminal (along the right bank) and in the downstream of the bridge (along the left bank). The suggested length of bank revetment is 300m in the upstream of the Dumki ferry terminal and 200m in the downstream of the bridge (RRI, 2014a). The location and placement of the bank protection works are shown in Fig. 6.

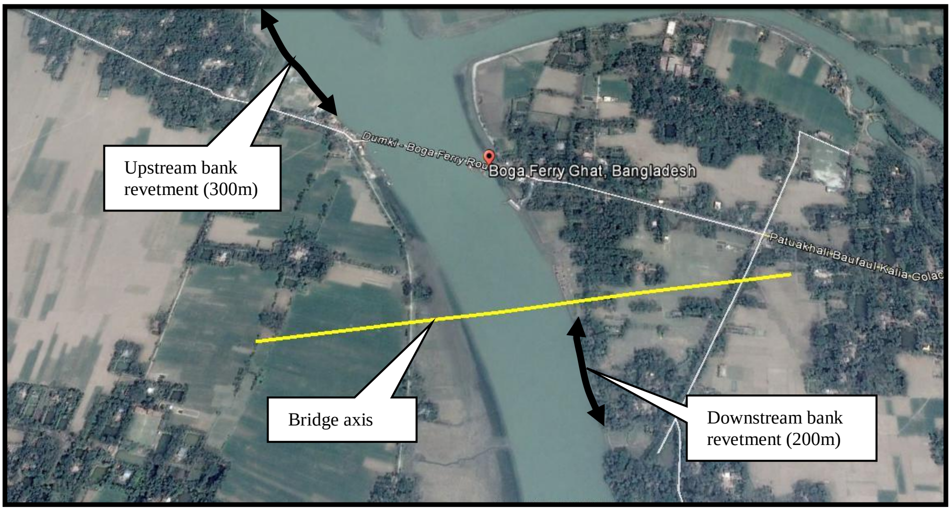

Fig. 6. Placement and length of suggested bank revetments upstream and downstream of the bridge

Conclusions

The length of the bridge is selected as 980 m which is aligned at an angle of about 10° with the river. The design discharge for the bridge and bridge substructure is 1972 m^3s^{-1} and 2165 m^3 s^{-1} respectively. The design water level for the bridge and bridge substructure is 3.22 mPWD and 3.35 mPWD respectively. The Standard High Water Level (SHWL) and Standard Low Water Level (SLWL) is 2.44 Mpwd and -0.45 mPWD respectively.

Besides, the approach road formation level at access road and at abutment is 3.95 mPWD and 10.0 mPWD respectively. The length of the approach road is 302.5 m on both sides of the bridge. The bottom level of the bridge girder at the centre of the bridge should be kept at 21.0mPWD. The bridge deck level at centreline of the bridge is 23.5 mPWD.

The main bridge consists of one 80m long span in the middle and three 60m long spans (two in the right side and one in the left side). There will be 24 (twenty-four) viaducts (eleven in the right side and thirteen in the left side) of 30m length each.
The design scour level at the abutment is -6.9 mPWD. The bottom level of the pile foundation for the abutment should be placed well below this level. The design scour level for the bridge pier is suggested to be -16.46 mPWD. The bottom level of the pile foundation should be set well below this level.

Furthermore, suggested length of the bank revetment along the right bank is 300 m in the upstream of the Dumki ferry terminal and 200 m along the left bank in the downstream of the bridge. The required length of the link roads on right and left side of the bridge is 1952 m and 300m respectively.

The results of this study can encourage public participation in the decision-making process and assist various planners and authorities to formulate a suitable plan for sustained transportation development of the region. Economic, social, political and public support, as well as environmental concerns, will all be challenges that will need to be addressed and overcome. While the conclusions formulated here may be more helpful in ascertaining a more suitable bridge location across the Lohalia, it also demonstrates that continued analysis and up-to-date data as well as developing new criteria for site selection can benefit the analysis process and overall result.

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COMPARISON OF POLLUTANT REMOVAL EFFICIENCY BETWEEN SUB-SURFACE FLOW WETLANDS FOR MUNICIPAL WASTEWATER

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Abstract

Constructed wetlands have been used for decades mostly for the treatment of domestic or municipal wastewater. It is a treatment system that uses natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality, which is low in energy consumption, requiring minimal maintenance. The overall objective of this study was to assess the performance of two subsurface flow constructed wetland to treat municipal wastewater. The specific objectives were a comparative study of pollutant removal efficiency between horizontal and vertical flow wetland system using stone chips, coal and sawdust as media evaluate the removal performance of pollutants from municipal wastes such as pH, alkalinity, turbidity, TSS, TDS, BOD_5, fecal coliform, $NO^{-2}$and NO^{-3}. The two systems had an identical configuration; each consisted of a subsurface vertical flow (VF) wetland and a horizontal flow (HF) wetland. The wetlands were planted with *Canna indicia* and employed with stone chips, coal and sawdust media. The results were impressive. Vertical flow constructed wetlands are more efficient in reducing pH, turbidity, and E.coli from water than horizontal flow systems. The removal efficiency of total suspended solid varies in the range from 30-40%, BOD_5 ranges from 75-90%. Horizontal flow constructed wetlands are more efficient in removing dissolved solids from water and provide efficient color removal under predominantly anaerobic condition. The results provided a strong evidence to support widespread research and application of the constructed wetland as a low-cost, energy-efficient, wastewater treatment technology in Bangladesh.

Keywords: *coal, constructed wetland, horizontal flow, removal efficiency, sawdust, stone chips, vertical flow*

Introduction

Constructed wetlands are engineered to duplicate the processes occurring in natural wetlands, where the main purpose of the structure is to remove the contaminant or pollutant from the wastewater (Aremu and Ojoawo, 2012). The constructed wetland is an integrated system consisting of water, plants, microorganisms and the environment, which can be manipulated to improve water quality. It has been widely used for treating a variety of wastewater in many sectors because of its multiple values and functions. Constructed wetlands are artificial wastewater treatment system consisting of shallow (usually less than 1 m deep) ponds or channels, which have been planted with aquatic plants, and rely upon natural microbial, biological, physical and chemical processes to treat wastewater (Sandeep *et al.,* 2005). These systems of wastewater treatment offer several potential advantages as compared to the conventional treatment system, this includes; simple construction (can be constructed with local materials), require less skill to operate and maintain, process stability under varying environmental conditions.

As the nation's population continues to grow, development is pushed further into rural areas where septic systems must be used for wastewater treatment. Constructed wetlands for wastewater treatment are an inexpensive and technologically appropriate solution for wastewater treatment in developing countries (El-Bahrawy, 2013). There are two basic types of constructed wetland namely; free water surface flow constructed wetland in which the flow of water is above the sediment surface, and subsurface flow constructed wetland in which the flow of water is primarily below the sediment surface. These systems use wetland plants, soils, and their associated microorganisms to remove contaminants from wastewater (Baskar, 2008). In developed temperate-climate countries, the horizontal sub-surface flow constructed wetlands (HSF-CWs) have been successfully used for the treatment of various types of wastewater for more than four decades (Vymazal, 2010). However, to date, there has been limited information about CWs in developing countries (Zhang *et al.,* 2014). The adoption of

CWs has been surprisingly slow there due to the lack of understanding of CW's potential benefits, actual performance, and appropriate design features (Zhang *et al.,* 2014).

Bangladesh is the ninth most populous country & twelfth most densely populated countries in the

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world. With the population growth, there is an increasing problem of wastewater management. Currently, according to a UNFPA report, Dhaka is one of the most populated cities in the world and one of the issued concerned in the management of municipal wastewater. An easy, cheap and efficient water purification system is needed to resolve this problem. Constructed wetlands have shown to successfully control organic material, nutrients, and pathogens (Greenway, 2005). It is reported that constructed wetland technology is a viable option that not only reduces nutrients but it performs the function of disinfection, rendering the treated wastewater a resource to irrigate crops, playing arenas, gardens or golf courses. Constructed wetlands are achieving prominence as an active and low-cost alternative for the treatment of wastewater in both the developed and developing world (Mustafa, 2013).

For this assessment, the actual source of the influent water is the municipal wastewater from Babu Bazar canal which is connected to Buriganga River. The Buriganga River is witness to many historic and cultural events of the capital city which thrive on the banks of its water. It stretches only 27 kilometers originating from the Dholeshwary (also known as Shitalakkhya) near Kalatia and meeting Turag at Kamrangirchar, near Hazaribagh. Because of its course, the Buriganga receives all the wastewater from Turag, which flows through industrial Tongi, Savar and Hazaribagh areas and receives it also from households besides industries and vessels. The Buriganga river is afflicted by the noisome problem of pollution. The city of Dhaka discharges about 4,500 tons of solid waste every day and most of it is released into The Buriganga. A recently published report has pointed out that there are over 7,000 industrial units including- dyeing mills, tanneries, rubber and plastic product factories, pesticide factories in the Dhaka metropolitan area. Of these, the dyeing factories and the tanneries are the biggest polluters. Each day about 900 cubic meters of untreated domestic and industrial effluents are discharged into the Buriganga-Turag system. Industries at these areas discharge untreated washing and clinical wastes, used batteries, plastic bottle sand containers, and other discarded plastic materials and burnt oil into the river water. At present, Buriganga is the most polluted river in Bangladesh.

The rationale of this paper is to advance the use of constructed wetland technology for wastewater treatment and reuse in developing countries like Bangladesh. The overall goal of this paper is to assess the performance of a pilot-scale constructed wetland through studying its treatment performance. And the specific objectives are to notify the capacity of removal of the various wastewater parameters from the horizontal subsurface flow and vertical subsurface flow using coal, stone chips, and sawdust media and to compare the removal percentage of various wastewater parameters between horizontal and vertical subsurface flow.

Methodology

The methodological approach of this study consists of the description of the experimental area, equipment and elements.

Source area and water

Babu Bazar Khal which comes from Buriganga River was the source of municipal wastewater. Sample water was collected from Babubazar Khal at Old Dhaka in 40 sunlight insulation barrel drum which contains 30 liters of municipal wastewater. It was collected in every Saturday morning and the drums were filled up by labors. It was transported from collection point to Bangladesh University of Engineering and Technology.

Dosing system

The outlet of the tank was being opened for 1.5-2 minutes to check the whole system and workability of the filtering process. Each tank received a container of wastewater. This process was continuously repeated 3 times a week.

Description of tanks

Two rectangular steel tanks were used to replicate the lake on a large scale. A media is used for the growth of the microbial community. It was constructed in such a way, so as to facilitate the growth of roots underwater.

Horizontal tank

The HF had a rectangular shape tank. This tank is made with high strength steel materials. The dimension consist depth of 3'5", a width of 1'8", a length of 3'4" shown in fig1. The outlet was located at the 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor. In outlet, the water came out and passed into the farther stage of the hybrid system. Another outlet pipe is used to remove excess water from the tank and to provide a certain level of water for the research.

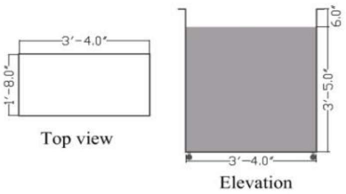

Fig. 1. The dimension of horizontal sub-surface flow tank

Vertical tank

The HF had rectangular shape also made with high strength steel materials. The dimension consist depth of 3'11", a width of 1'8", a length of 1'8" shown in fig 2. The outlet was located at the 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor. In outlet, the water came out and passed into the farther stage of the hybrid system.

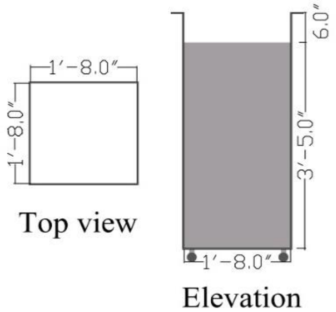

Fig. 2. The dimension of vertical subsurface flow tank

Preparation of coal media bed

Two constructed wetlands consist of coal as the media. It is available almost everywhere. It is an organic material which is used in two tanks. At first, we took a sufficient amount of coal and washed it with clean water to remove other organic and inorganic substances, harmful elements, oils, and impurities. Next, we crushed the coal into small pieces of 9.5mm to 2.75mm. Then a thin shit of wooden board is placed under the tank below the outlet. After that, we put all the coal into the tank and filled it, for horizontal tank we filled 2'11" and for vertical tank 3'2". The top of the tank left open and planted Canna Indica plant above the coal media. After all this, we filled the tank with our collected municipal wastewater from Babu Bazar canal up to a certain level. Canna indica is collected from the local market. This constructed wetland technology is based upon the treatment power of three main mechanisms: microorganism, optimizing the system, the physical and chemical properties of the media and finally the plants themselves.

Preparation of stone-chips media bed

Two constructed wetland is consists of Stone chips as the media. Crushed stone is one of the most accessible natural resources, and is a major basic raw material used by construction, agriculture, and other industries. It is an organic material which is used in two tanks. At first, we took a sufficient amount of stone chips and washed it with clean water to remove other organic and inorganic substances, harmful elements, oils, and impurities. Next, we crushed them into small pieces. Then a thin shit of wooden board is placed under the tank below the outlet. After that, we put those crushed stone chips into the tank and filled it, for horizontal tank we filled 2'11" and for vertical tank 3'2". The top of the tank left open and planted Canna Indica plant above the media. After all this the tank was filled with collected municipal wastewater from Babu Bazar canal up to a certain level. In this project, stone chips are collected from a construction site of Mahakali. It was collected from a river bank in Sylhet. At least 20 kg of stones are used in each container of both vertical and horizontal flow. This constructed wetland technology is based upon the treatment power of three main mechanisms: microorganism, optimizing the system, the physical and chemical properties of the media and finally the plants themselves.

Preparation of sawdust media bed

Two constructed wetland is consists of sawdust as the media. At first, we took a sufficient amount of sawdust and washed it with clean water to remove other organic and inorganic substances, harmful elements, oils, and impurities. Then a thin shit of wooden board is placed under the tank below the outlet. After that, we put all the sawdust into the tank and filled it, for horizontal tank we filled 2'11" and for vertical tank 3'2". The top of the tank left open and planted Canna Indica plant above the media. After all this, we filled the tank with our collected municipal wastewater from Babu Bazar canal up to a certain level. Canna indica is collected from the local market. This constructed wetland technology is based upon the treatment power of three main mechanisms: microorganism, optimizing the system, the physical and chemical properties of the media and finally the plants themselves.

Wetland vegetation

Constructed wetlands can be planted with a number of adapted, emergent wetland plant species. Wetlands created as part of compensatory mitigation or for wildlife habitat typically include a large number of planted species. Commonly used plants are Phalarisarundinacea (reed canary grass), Typha spp. (cattails), Scirpusspp, (bulrushes) and Glyceria maxima (sweet mannagrass) (Chadde, 2011). However, the most frequently used plant species worldwide is Phragmites australis (common reed) (Wallace, 2009). Canna Indica is the plant which was used for our experiment. These plants are used because they help transform wastewater constituents so that quality standards for their discharges are met. Macrophytes play an important role in the treatment of wastewater. The biomass of the plants shows the pathway of the wastewater enhancing sedimentation of solids. There is also uptake of some pollutants in wastewater as nutrients by these plants. The extensive root system provides a huge surface area to act as a filter for suspended solids and debris. The root zone also provides an extensive surface area for attached growth of microorganisms, which in turns are involved in the transformation of pollutants. Oxygen diffused through the root zone membranes into the surrounding water environment creates an oxygen-rich area around the root zone of the plants that drive many chemical transformations and results in the degradation of the pollutants. Diffusions of oxygen through the root zone also helps to maintain a partially aerobic condition in the water columns

Operation and maintenance

After the preparation for bed for the constructed wetland, the actual performance of the bed was started. The raw wastewater is collected from a drain beside BUET and put them into the wastewater container. The raw wastewater characteristics were determined using procedure mentioned in standard methods. After the analysis, wastewater was allowed to pass through the reactor, as the time progress the percolation of wastewater start into the reactor. Percolated water from the bed passed into the next stage of the hybrid system and finally collected into the effluent container. The dosing frequency of wastewater is two times a day with four hours' interval. The purified wastewater characteristics also studied by using standard methods.

Results and Discussion

During the three weeks, monitoring period samples were collected from the constructed wetland system and analyzed for each of the various physical, chemical, and microbiological parameters. Table 1, Table 2 and Table 3 represents the inlet and outlet concentrations of each monitored parameter of coal, stone chips, and sawdust media.

Analysis of pH

The pH values of effluent in coal media, from 6.7 to 7.1 meets up with WHO standard from drinking water which is between the ranges of 6.5-8.5 and for stone chips media the values, from 6.5-8 are also in WHO standard for both horizontal and vertical flow. It also meets up with the irrigation standard. If pH is less than 6.5 in crop yield, there would be increased foliar damage and may corrode irrigation equipment. But for sawdust media, though the vertical flow pH values were within WHO standard for horizontal flow, it exceeded the WHO range. It was reported that vegetated free-water surface wetlands produce effluent with pH just above neutrality (Wallace, 2009).

Table 1. Summary of the test scenarios of coal media and key results

Parameter	Unit	Bangladesh standard	Sample type	Week 1	Week 2	Week 3
pH		-	Raw	7.1	8	7.3
			Horizontal	7.1	7	6.7
			Vertical	6.9	7.1	6.5
Color	Pt-co	15	Raw	40	10	60
			Horizontal	25	30	30
			Vertical	20	28	35
Turbidity	NTU	10	Raw	0.91	1.05	8.9
			Horizontal	2.36	4.58	10.25
			Vertical	1.6	3.32	9.6
Alkalinity	mgL^{-1}		Raw	364	236	260
			Horizontal	236	212	204
			Vertical	208	212	208
TSS	mgL^{-1}	10	Raw	.001	.002	.001
			Horizontal	.002	.003	.003
			Vertical	.002	.001	.001
TDS	mgL^{-1}	1000	Raw	.032	.033	.028
			Horizontal	.027	.023	.035
			Vertical	.021	.030	.024
BOD_5	mgL^{-1}	0.2	Raw	16	14	19
			Horizontal	14	10	12
			Vertical	6	7	8
Fecal coliform (20ml)		0 CFU (N/100mL)	Raw	30	26	37
			Horizontal	Uncountable	Uncountable	14
			Vertical	11	7	4
Nitrate (NO^{-3})	mgL^{-1}	10	Raw	5.9	7.5	9
			Horizontal	1	3.2	2.4
			Vertical	3.6	2.9	2
Nitrite (NO^{-2})	mgL^{-1}	<1	Raw	11	9	13
			Horizontal	13	6	3
			Vertical	4	1.7	2.5

Table 2. Summary of the test scenarios of stone chips media and key results

Parameter	Unit	Bangladesh standard	Sample type	Week 1	Week 2	Week 3
pH		-	Raw	7.1	8	7.3
			Horizontal	6.9	6.5	6.8
			vertical	7.2	7.4	6.7
Color	Pt-co	15	Raw	36	10	60
			Horizontal	47	70	20
			vertical	26	20	20
Turbidity	NTU	10	Raw	0.91	1.05	8.9
			Horizontal	25.36	20.87	19.23
			vertical	0.29	0	.36
Alkalinity	mgL^{-1}	- -	Raw	364	236	260
			Horizontal	240	280	215
	–		vertical	216	320	210
TSS	mgL^{-1}	10	Raw	.001	.002	.001
			Horizontal	.001	.003	.002
			vertical	.002	.001	.001
TDS	mgL^{-1}	1000	Raw	.033	.035	.029
			Horizontal	.026	.022	.020
			vertical	.026	.037	.022

BOD_5	mgL^{-1}	0.2	Raw	16	14	19
			Horizontal	2	3	2
			vertical	1	1	2
Fecal coliform (20ml)		0 CFU	Raw	30	26	37
			Horizontal	38	50	59
			vertical	16	11	19
Nitrate (NO^{-3})	mgL^{-1}	10	Raw	5.9	7.5	9
			Horizontal	1.8	2.1	1.3
			vertical	5.5	3.7	2.6
Nitrite (NO^{-2})	mgL^{-1}	<1	Raw	11	9	13
			Horizontal	1.8	1.2	2.7
			vertical	6	5	8.4

Table 3. Summary of the test scenarios of sawdust media and key results

Parameter	Unit	Bangladesh standard	Sample type	Week 1	Week 2	Week 3
pH		-	Raw	7.1	8	7.3
			Horizontal	9.3	9.7	9.6
			Vertical	7.3	7.5	7.6
Color	Pt-co	15	Raw	36	10	60
			Horizontal	21	30	35
			Vertical	29	33	35
Turbidity	NTU	10	Raw	0.91	1.05	8.9
			Horizontal	0.08	1.62	2.10
			Vertical	1.98	5.32	0.94
Alkalinity	mgL^{-1}		Raw	364	236	260
			Horizontal	128	120	126
			Vertical	380	244	460
TSS	mgL^{-1}	10	Raw	.001	.002	.001
			Horizontal	.001	.003	.002
			Vertical	.002	.001	.001
TDS	mgL^{-1}	1000	Raw	.033	.035	.029
			Horizontal	.025	.020	.021
			Vertical	.041	.038	.033
BOD_5	mgL^{-1}	0.2	Raw	16	14	19
			Horizontal	3	2	3
			Vertical	2	2	2
Fecal coliform (20ml)		0 CFU	Raw	30	26	37
			Horizontal	Uncountable	13	6
			Vertical	Uncountable	4	4
Nitrate (NO^{-3})	mgL^{-1}	10	Raw	5.9	7.5	9
			Horizontal	1.2	2.8	1.5
			Vertical	4.3	5.1	3.4
Nitrite (NO^{-2})	mgL^{-1}	<1	Raw	11	9	13
			Horizontal	2	2.7	2.5
			Vertical	8	7	8.1

Analysis of color

Spatially within each treatment, the performance of both coal media and sawdust media was not up to the mark as demonstrated in table1 and 3, the highest removal efficiency was 50% for vertical flow. In 2^{nd} week, coal media failed to decrease color concentration but increased the concentration. For stone chips, the highest removal percentage was 66% for horizontal flow. The effluent values of this parameter were higher than Bangladesh standard which is 15 Pt-co.

Analysis of turbidity

For coal media, the turbidity value has been seen increasing throughout the monitoring period. For stone chips, the turbidity effluent value was higher than the influent value in case of horizontal flow. But in vertical flow, the removal percentage was very impressive. Removal percentage range for the stone chips vertical flow was between 68-100%. For sawdust media, the removal efficiency was insignificant except 3rd week where horizontal flow had up to 76% and vertical flow had up to 89% maximum efficiency rate.

Analysis of alkalinity

Alkalinity removal rate was around 35-43% for coal media for the observation period. Highest removal percentage was 42.23% for vertical flow as a reference to table 1. For stone chips, the removal range was between 35-41%, where the highest removal rate was 40.65% for vertical flow. The removal rate was good in saw dust media, ranged between 49-65%, having the maximum removal rate of 64.83% as demonstrated in table 3.

Analysis of TDS and TSS

TSS removal rate was not good in coal media as for table1, removal percentage rate was between 0-50% for both horizontal and vertical flow. The effluent TDS values were consistently low, degrading the removal rate between 9-35%, having the highest value of only 34.38%. The TSS effluent value of stone chips media showed no greater difference than coal media effluent value. For TDS, the removal rate was not satisfactory, as the removal percentage range was between 21-38%, the highest removal rate was 37.14%. For saw dust, the TSS removal percentage is below average as the range was 21-49% with highest removal percentage of 85% for horizontal flow. As for TDS effluent values, they were not significantly higher than TDS influent values.

Analysis of BOD_5

The reduction in BOD_5 concentrations over the monitoring period was reasonable, 62.5% for vertical flow of coal media, while horizontal flow was not much productive in reducing BOD_5concentrations. For stone chips, BOD_5 removal percentage was eminent as the range was between 89-93% with the highest percentage rate of 92.85% for vertical flow. For sawdust, degradation of BOD_5 ranged between 84-90% where the highest removal efficiency was found 89.47% for vertical flow. Performance of these constructed wetland showed that the system had a good buffer capacity and was able to tolerate organic shock loads.

Analysis of fecal coliform

Fecal coliform for coal media had the highest value of removal percentage of 89.78% for vertical flow but for horizontal flow, the removal percentage was dissatisfactory. Stone chips were not that successful in removing fecal coliform as compared to the other parameter. The highest percentage was 57.69% for vertical flow. For sawdust the values were unexpectedly good as the highest percentage was 89.18% for vertical flow.

Analysis of nitrite (NO^{3-}) and nitrate (NO^{-2})

Coal media showed better performance in removing NO^{3-} because removal percentage ranged from 38-84% with the maximum percentage of 83.05%. NO^{2-} removal percentage was also good, had the highest rate of 81.11% for a vertical flow having a range of 18-82%. For stone chips media NO^{3-} removal range was from 8-86% with a peak rate of 85.55%. NO^{2-} removal range was from 35-87%, had the highest rate of 86.67% for horizontal flow. For sawdust media, NO^{3-} had a removal percentage rate of 27-84% and the maximum value was 80.77% for horizontal flow.

Conclusion

The monitoring of horizontal flow constructed wetland shows that the general performance of the system was good and it successfully reduced contaminants system so, constructed wetlands. clearly can be an effective treatment facility for polluted water. The initial result of this research work, however, found that the ability of a wetlands system to treat such polluted water is highly influenced by the media and the flow pattern used in it. After observing the tanks performance, it can be highlighted that stone chips media and coal media performs exceedingly well in vertical flow wetland when saw dust media is highly appreciable in horizontal flow wetland, especially stone chips media with vertical flow showed a prominence performance for maximum water quality parameters. The results indicate that if constructed wetlands are appropriately designed and operated, they could be used for secondary and tertiary wastewater treatment under local conditions, successfully. The main advantage of these systems is they do not require any power as well as addition of chemicals. Hence constructed wetlands can be used in the treatment train to upgrade the existing malfunctioning wastewater treatment plants, especially in developing countries. The treated wastewater from these wetlands can be used for landscape irrigation and also for other beneficial uses. The goal of this study was to explore the potential public benefits and quality improvement of wastewater by the constructed wetland. The result provides an easy and low-cost way of treating wastewater from environmentally friendly elements and a certain process that is reliable to all kind of people.

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EFFICACY OF DIFFERENT LAUNCHING MATERIALS IN RIVERBANK PROTECTION: A LABORATORY-SCALE MODEL STUDY

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Abstract

There are many different types of materials that are utilized for slope protection nowadays to save the riverbank against the wave action, current of the river or surface run-off. In general, cement concrete (CC) blocks, stone chips, geo-textile bags (geo-bags) filled with sand are widely used in revetment works in Bangladesh. A study was undertaken to determine the launching behaviour of these bank protection materials to find out the cost-effective and sustainable solution for riverbank protection using scale model. In order to fulfil the objectives, an undistorted model having a scale of 1:30 was designed using Froude's model law. The model consists of two channels namely, the main channel and oblique or shoot channel. Discharges had been fed in the model with the discharge ratio of Q_{shoot}/Q_{main}= 0.8 and 1. The study showed that the scour decreases once the discharge ratio changes from 0.8 to 1.0. However, scour was augmented, under full oblique flow condition (i.e. only shoot channel was opened while the main channel remain closed) than that of under oblique flow condition (when both channels were opened). Moreover, it was observed that the combined apron (geo-bags and CC blocks) works better as compared to single geo-bags or even only CC blocks as launching materials. Finally, the study showed that the cost involved in case of launching apron of composite materials was around 34-35% less than that of the single composition of CC blocks provided.

Keywords: *CC blocks, geo-bags, launching apron, launching material, oblique flow, spur, stone chips*

Introduction

There is active bank erosion cropped up in almost all of the major rivers in Bangladesh causing damage to valuable land, properties and infrastructures from year to year. Because of high density of population along the riverbanks, a great number of people have been displaced due to this continuous bank erosion process. These poor people migrated to nearby towns and cities and live a sub-human life in the slum areas. This has created a great nuisance and social problem in the country. Bank protection work is one of the prime necessities for poverty alleviation and national growth. The issue is the safety of lives, land and sustainability of the infrastructures against the forces acting in the rivers (RRI, 2016).

As Bangladesh is a lower riparian country, the large variation in discharge and the huge amount of sediment load is very difficult to manage. Therefore, major emphasis should be given to the design parameters. Moreover, the design parameters such as design flow velocity, design scour depth can be obtained through the present research work by physical modelling.

A number of studies have been conducted on riverbank management so far. Bhuiyan *et al.* (2002) examined bank erosion processes. Klassen and Masselink (1992) studied bank erosion rates using satellite images. Hasan (2011) has conducted an investigation of river erosion protection by submerged vane in a river bend. Ahmed (1989) carried out an experimental study on dumping of bank protection materials under flowing water to investigate the launching characteristics of C.C. block and geo-bags with different launching configuration. Oberhagemann and Hossain (2011) studied the effectiveness of geo-textile bag revetments for large rivers in Bangladesh. However, a cost-effective and sustainable solution for riverbank protection in Bangladesh still necessitates investigation in a more holistic approach.

Launching Apron (LA) is an important part of river training structures. Without LA of appropriate launching materials, revetment and spurs cannot be stable and may collapse. Therefore, a research work was undertaken to combat riverbank erosion effectively. Through the research work, the performance of

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launching materials for riverbank protection has been assessed to determine their efficacy and to find out the cost-effective material.

Methodology

A closed shed hydraulic laboratory was used for model development. It provides all kinds of facilities related to scale model study. A preliminary layout of the model was given with the reference grid points in the model. Channel planform was given using these grid points and the bed and bank levels were fixed up by levelling instrument as per bathymetry using Rise and Fall method. This requires some cutting and filling of sand from the model.

The model was investigated on a mobile bed and hydraulic similarity was established in the model with an undistorted scale. The scale ratio was selected as 1:30. The model was a Froude model and was studied over a generalized plain bathymetry. The model was carried out to investigate the local scour and velocity field at and around the revetments under different likely approach flow conditions. The model has been designed to fulfil both the flow and sediment transport criterion simultaneously. It means the model velocity would be higher than the critical flow velocity for the initiation of sediment movement. This is because for any velocity higher than the critical, the scour dimensions are the only function of flow direction and structure geometry. The model will, therefore, reproduce the scour holes correctly.

In this physical model, various types of instrument and facilities are needed such as, a sharp-crested weir for measuring flow, point gauge for measuring water level, 3-D current meter for measuring velocity, high resolution camera for taking video and photographic view of model, stopwatch for taking instant time and floats for identifying flow path of flowing water.

The required discharge was estimated using sharp-crested weir in the inflow section using Rebock's formula. Model velocity was measured by a 3D velocity meter. Water slope was calculated by analysing the water level measured at different position using point gauges installed in the model. Flowlines of the stream were identified by dropping floats from the upward calibration section and catching them at the downward ending section of the model. A stopwatch was used to calculate the surface velocity of the flow. Finally, model data was collected, analyzed and each test results was interpreted.

Similarity condition of the Model

The model has been designed such that the scale conditions for the simulation of flow field, sediment transport and local scour are satisfied. The scale conditions (Sharp, 1981) are described below:

i) Geometric condition

The model should be undistorted: $L_r = h_r$

Where, L_r= horizontal scale and h_r = vertical scale

ii) Roughness condition

In the model the following roughness condition should be satisfied in order to reproduce the flow field in principle:

$C_r^2 = L_r / h_r = 1$ Where, C_r = roughness scale

iii) Froude condition

The Froude condition should be fulfilled which holds when: $V_r = h_r^{0.5}$

iv) Sediment Transport Condition

In the movable bed model following scale condition for sediment transport should be satisfied:

$V_m > V_{cr}$

V_{cr} in the model will be calculated using the following formula:

$V_{cr} = 0.19(d_{50})^{0.1} \log (12h/3d_{90})$ for $0.0001m \leq d_{50} \leq 0.0005m$ Eq. (1)

(van Rijn, 1984)

Where,
d_{50}= median particle diameter (m), d_{90} = 90% particle diameter (m)

The critical velocity for sediment transport can also be calculated from the critical Shields value. The critical velocity in the model has been calculated from the following equations.

$$D_* = d_{50}\{(s-1)\, g/v^2\}^{1/3} \qquad \text{Eq. (2)}$$

$$\theta_{cr} = 0.14D^*\text{^}(-0.64) \text{ for } 4<D^*<10 \qquad \text{Eq. (3)}$$
(Van Rijn, 1984)

$$\theta_{cr} = 0.24D^*\text{^}(-1) \text{ for } 1<D^*<4 \qquad \text{Eq.(4)}$$
(Van Rijn, 1984)

$$V_{cr} = \{\theta_{cr}(s-1)d_{50}C^2\}^{½} \qquad \text{Eq. (5)}$$

Where, D_* = Particle parameter, d_{50} = Median grain size, s = Relative density of the sediment v = Kinematic viscosity, C = Chezy co-efficient and, θ_{cr} = Critical shields parameters

The critical flow velocity for the median particle diameter of model bed sand (0.085mm) has been determined from the above equations. The investigation is aimed at the equilibrium scour depth with continuous sediment transport. A requirement in this type of model is that in the model, sediment transport has to be occurred at all locations as it occurs in the prototype. In order to fulfil this condition, an increase in the model velocity was considered to ensure the sediment transport in the model.

Model set-up

The hydraulic scale model was set up (Fig. 1) using the existing facilities of RRI. A closed tidal shed of RRI having a dimension of 80m X 25m was used for setting up the model. The area reproduced in the model was about 1.20 km (channel length) and about 0.18 km (channel width). The model set-up includes model bed preparation, water circulation system, construction of stilling pond and instalment of point gauges in the model etc. Two types of design were maintained for the main channel as well as shoot channel. In case of main channel, one end was kept trapezoidal at the left bank while the other end was vertical (Fig. 2). The shoot channel was the rectangular type (Fig. 3).

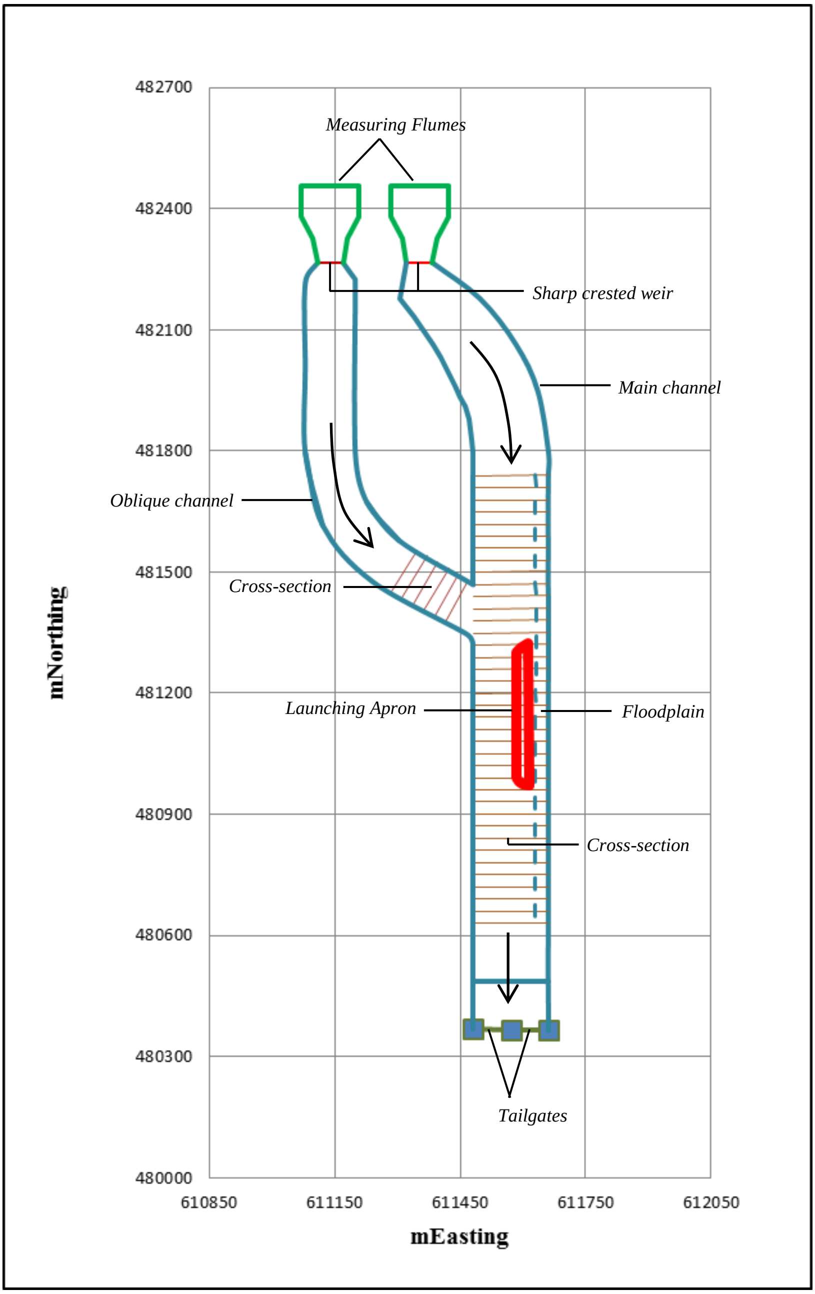

Fig. 1. A layout of the model

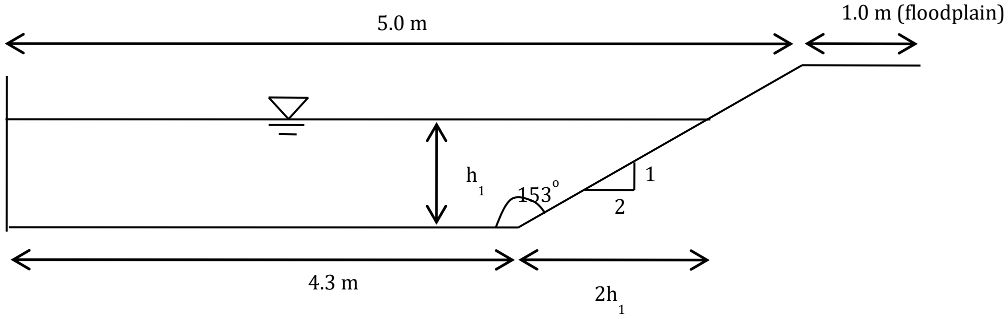

Fig. 2. Section for the main channel

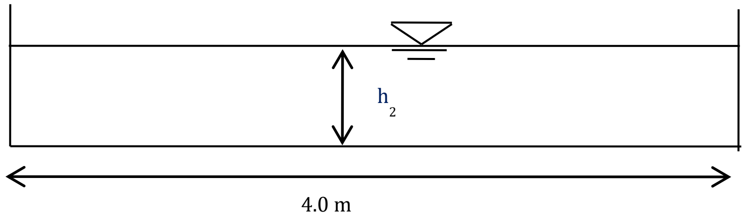

Fig. 3. Section for shoot channel

Test scenarios

The calibration test together with 25 application test runs with various structural intervention along the left bankline was conducted in the model. Test T0 contributed to the calibration of the model. The application tests T1 through T22 are carried out (Table 1) with a view to observing the performance of the bank protection structure (revetment) to prevent riverbank erosion. Each application test was run with both Froude's discharge to determine flow velocity, flow lines etc. and scour discharge to determine the scour depth. Scour discharge was run until equilibrium bed level was reached in the model.

Table 1. Test scenarios and objectives of the model

Test No.	Test ID	Test Scenarios	Angle of flow attack	Discharge Condition
1	T0	Calibration test. Plain bathymetry is used	No oblique flow condition	Discharge in the main channel only. Q_{main}=2025m^{3}s^{-1} (q=450 m^{3}s^{-1})
2	T1	Test with geo-bags as launching materials (LM)		
3	T2	Test with CC blocks as LM		
4	T3	Test with stone chips as LM		
5	T4.1	Test with stone chips as LM	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
6	T4.2			Q_{shoot}/Q_{main}= 1.00 Q_{main}=1012.5 m^{3}s^{-1} (q=225 m^{3}s^{-1}) and Q_{shoot}=1012.5 m^{3}s^{-1} (q=253 m^{3}s^{-1})
7	T5.1	Test with geo-bags as LM	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
8	T5.2			Q_{shoot}/Q_{main}= 1.00 Q_{main}=1012.5 m^{3}s^{-1} (q=225 m^{3}s^{-1}) and Q_{shoot}=1012.5 m^{3}s^{-1} (q=253 m^{3}s^{-1})
9	T6.1	Test with CC blocks as LM	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
10	T6.2			Q_{shoot}/Q_{main}= 1.00 Q_{main}=1012.5 m^{3}s^{-1} (q=225 m^{3}s^{-1}) and Q_{shoot}=1012.5 m^{3}s^{-1} (q=253 m^{3}s^{-1})
11	T7	Test with CC blocks as LM. The shoot channel feeds total discharge to the main channel.	60º	Q_{shoot}= 2025 m^{3}s^{-1} (q=506 m^{3}s^{-1}) Fully oblique flow
12	T8	Test with stone chips as LM. The shoot channel feeds total discharge to the main channel.	60º	Q_{shoot}= 2025 m^{3}s^{-1} (q=506 m^{3}s^{-1}) Fully oblique flow
13	T9	Test with geo-bags as LM. The shoot channel feeds total discharge to the main channel.	60º	Q_{shoot}= 2025 m^{3}s^{-1} = 411 l s^{-1} (model) (q=506 m^{3}s^{-1}) Fully oblique flow
14	T10	Test with 3 spurs: Spur S1 (solid), Spur S2 (CC blocks) and Spur S3 (geo-bags)	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{Shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
15	T11	Test asper design proposed by BWDB (LA consists of 50%CC block and 50%geo-bag and apron length 30m)	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{Shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
16	T12	Same as test T11 but the shoot channel feeds total discharge to the main channel	60º	Q_{shoot}= 2025 m^{3}s^{-1} (q=506 m^{3}s^{-1}) Fully oblique flow

Test No.	Test ID	Test Scenarios	Angle of flow attack	Discharge Condition
17	T13	Same as test T12 but length of LA = 25m	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
18	T14	Same as test T13 but length of LA = 35m	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
19	T15	Same as test T14 but LA consists of 40%CC block and 60%geo-bag and LA length = 35m	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
20	T16	Same as test T14 but LA is shifted u/s by 60m at CS26-CS14.	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
21	T17	Test as per design proposed by BWDB. But CC block portion of LA consists of 45cm cube 50% and 35cm cube 50%. LA placed at CS26-CS14.	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
22	T18	Same as test T17 but CC block portion of LA consists of 45cm cube 40% and 35cm cube 60%.	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
23	T19	Test with 2 spurs S1 and S2 having shank length = 30m and LA length = 30m. The LA of S1 has two layers. Top layer consists of 45cm cube 40% and 35cm cube 60%. Bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%. The LA of spur S2 consists of 125kg geo-bag.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})
24	T20	The u/s part of LA of spurs S1 and S2 is same as test T19 (top layer consists of 45cm cube 40% and 35cm cube 60% & bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%). The d/s part of LA of spurs S1 and S2 consists of stone-chips only.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})
25	T21	The u/s part of LA of spurs S1 and S2 is same as test T20 (top layer consists of 45cm cube 40% and 35cm cube 60% and bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%). The d/s part of LA of spurs S1 and S2 consists of 60cm cube 60% and 45 cm cube 40%.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})
26	T22	The u/s part of LA of spurs S1 and S2 is same as test T21 (top layer consists of 45cm cube 40% and 35cm cube 60% and bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%). The d/s part of LA of spurs S1 and S2 consists of 60cm cube 60% and 45cm cube 40% at the top layer and 500kg geo-bags at the bottom layer.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})

Results and Discussions

Comparison of launching

(i) Comparison of launching pattern for different launching materials

A comparison is made among tests T7, T8, T9 and T18 showing the launching behaviour of CC blocks, stone-chips, geo-bags and composite materials (CC blocks + geo-bags) for revetment under oblique flow condition (60-degree) for discharge 2025 $m^3 s^{-1}$(Fig. 4). From the figures it is evident that stone chips have the best launching pattern as there is no bare space on the launching slope. The composite material, CC blocks and geo-bags stand 2nd, 3rd and 4th position respectively with respect to launching pattern.

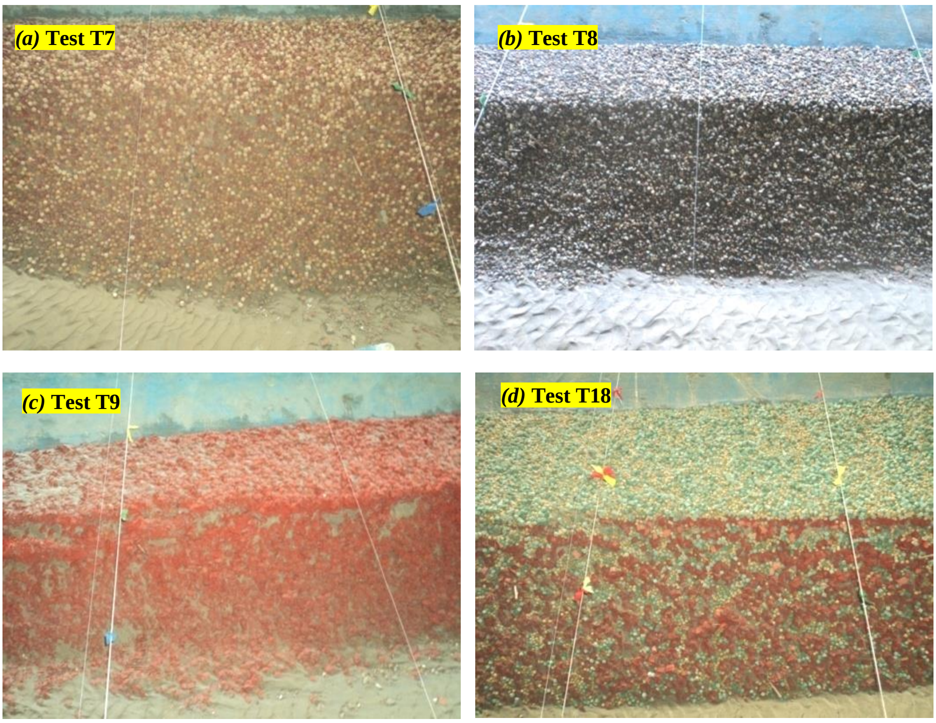

Fig. 4. Launching pattern of different launching materials (a) CC blocks (b) stone-chips (c) geo-Bags (d) CC blocks + geo-bags at various tests

(ii) Comparison of launching behavior for composite materials having different apron length and thickness when CC blocks (top) + 50% geo-bags (bottom) in case of the revetment

Fig. 5 shows the launching behavior of composite materials comprises of CC blocks and geo-bags with the variation of apron length of revetment for tests T12, T13 and T14 (discharge 2025 m^3s^{-1}) under fully oblique flow condition (60-degree). It is evident from these figures that test T12 provides better launching pattern in comparison to tests T13 and T14.

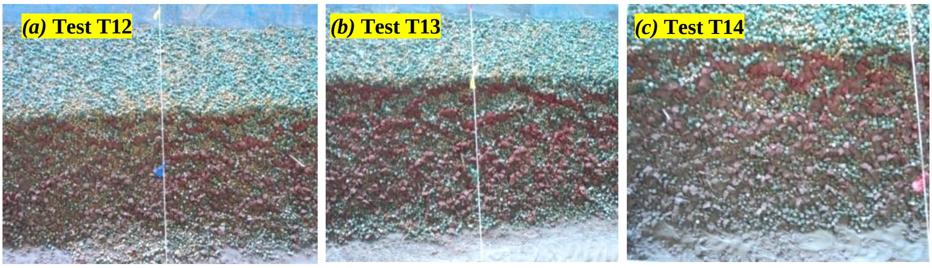

Fig. 5. Launching behavior of composite materials with different apron length and thickness

Note: (a) Apron length 30 m &thickness 2 m; (b) Apron length 25 m &thickness 1.4 m; (c) Apron length 35m &thickness is 1.71 m.

(iii) Comparison of launching behavior for composite materials with different proportion of CC blocks in the launching apron in case of the revetment

A comparison is made among tests T12, T17 and T18 showing the launching behavior of composite materials (CC blocks and geo-bags) with different CC block proportion for revetment under oblique flow condition (60-degree) for discharge 2025 m^3s^{-1} (Fig. 6). It is evident from the figures that test T18 provides the best result as bare space is relatively lower. Channel developed around the LA is well shaped. The numbers of CC blocks rolled in the developed channel are less. More numbers of CC blocks are retained on the developed slope.

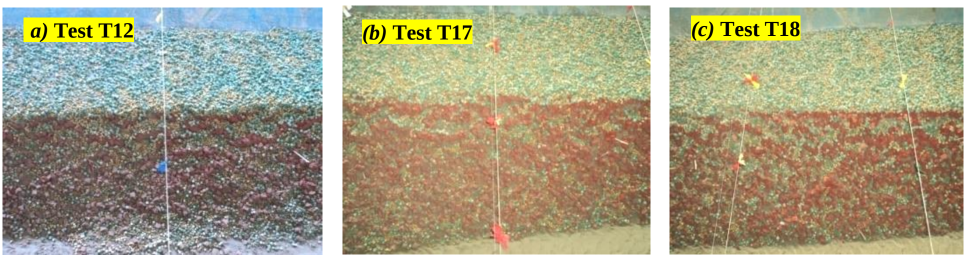

Fig. 6. Launching behavior of composite materials with different CC block proportion

Note: (a) 60% of 45 cm cube & 40% of 35 cm cube; (b) 50% of 45 cm cube & 50% of 35 cm cube; (c) 40% of 45 cm cube & 60% of 35 cm cube.

(iv) Comparison of launching pattern with the variation of the material composition of launching apron in the d/s part of spur S1

Fig. 7 shows the launching pattern with the variation of material composition for d/s part of launching apron of spur S1 (start from spur axis) when the material composition in the u/s part remains the same for tests T19, T20, T21 and T22 under fully oblique flow condition (60-degree) in case of spur.

Test 20 provides best results as the launching characteristics of stones are much better than other materials. Because the scour developed at the toe of the LA of stones is less than that of other materials. Stones are capable to resist scour development but other materials have no such ability. From the d/s part of LA of spur S1, few stone-chips was displaced towards d/s. Bare space is much less than test T19.

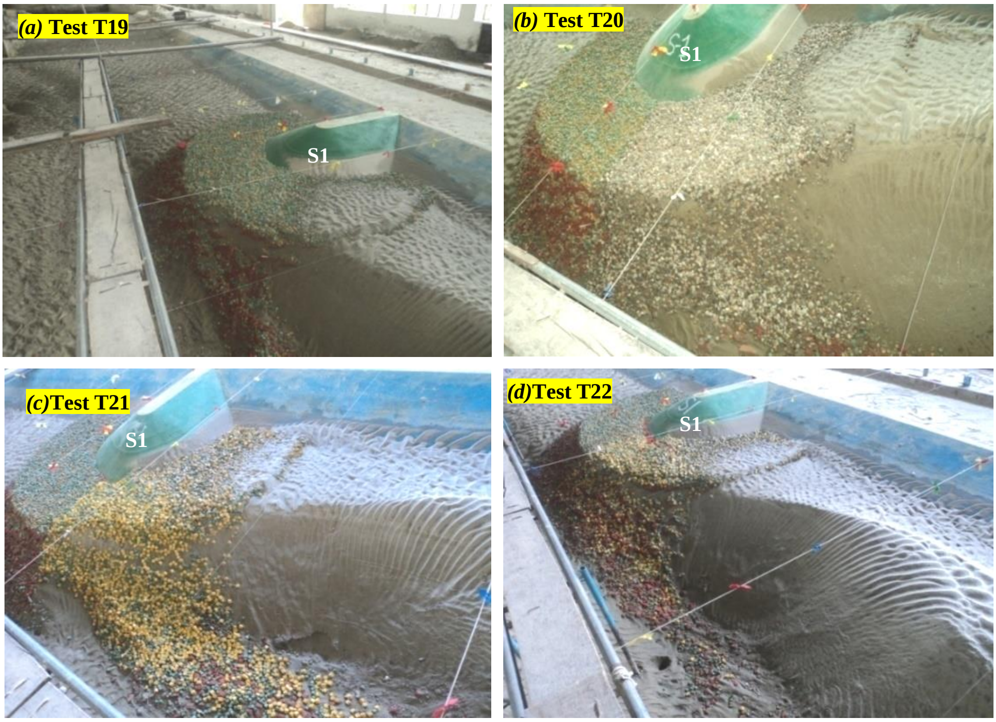

Fig. 7. Launching behaviour of composite materials with different material compositions in the d/s part of spur S1.

Note: (a) U/S part of S1: Top layer constitutes 40% of the 45cm cube and 60% of the 35cm cube, Bottom layer consists of 50% of 250kg geo-bag and 50% of 175 geo-bag (b) U/S part of S1: same as previous. D/S part of S1: Stone-chips (c) U/S part of S1: same as previous. D/S part of S1: 60% of the 60cm cube and 40% of the 45cm cube. (d) U/S part of S1: same as previous. D/S part of S1: 60% of the 60cm cube and 40% of the 45cm cube.

Developed launching slope

i) Launching slope at a section across the revetment after the test run along CS20 (T18) for the low-cost material composition

Fig.8 shows that for the low-cost material composition (T18) for LA of the revetment, the launching slope is 28.15 degree (1:1.87) and launched 27% out of 30m.

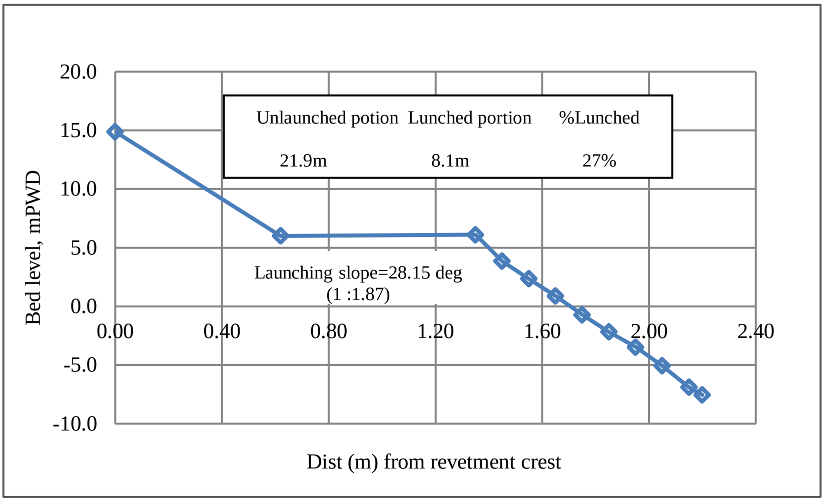

Fig. 8. A section perpendicular to the revetment after test run

ii) Launching slope at a section across the revetment after the test run along the spur S1 axis (CS20) [T22]

Fig.9 shows that for the low-cost material composition (T18) for LA of spur S1, the launching slope is 32.14 degree (1:1.59) and launched 40% out of 30m.

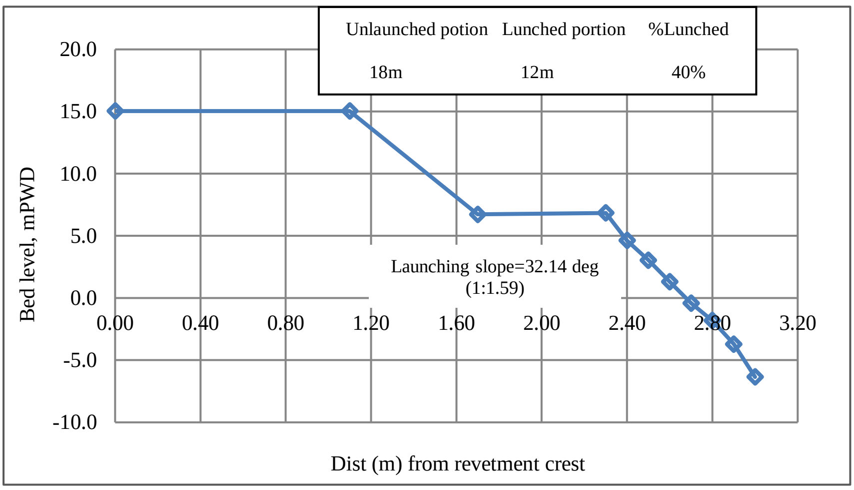

Fig. 9. A section perpendicular to the revetment after the test run along spur S1 axis

Cost analysis

Cost analysis is made based on Standard Schedule of Rates Manual, 2012-13, O & M Circle, BWDB, Faridpur for different material composition (tests T12, T17, T18 and T22) in case of revetment and spur. The cost is around 34-35% is less for LA of composite materials than providing the single composition of CC blocks in case of revetment and spur.

Table 2. Cost analysis for revetment and spur

Test No.	LA for Revetment	Costing (Tk.m^{-1})	In case of CC blocks used	% Savings
T12	Top: 45cm cube 60% + 35cm cube 40% + bottom: 250kg geo-bag50% + 175kg geo-bag 50%	378495	573365	33.99%
T17	Top: 45cm cube 50% + 35cm cube 50% + bottom:250kg geo-bag 50% + 175kg geo-bag 50%	375756	567887	33.83%
T18	Top: 45cm cube 40% + 35cm cube 60% + bottom: 250kg geo-bag 50% + 175kg geo-bag 50%	373017	562409	33.68%
T22	LA (u/s part) for Spur			
	Top: 45cm cube 40% + 35cm cube 60% + bottom: 250kg geo-bag 50% + 175kg geo-bag 50%	373017	562409	33.68%
	LA (d/s part) for Spur			
	Top: 60cm cube 60% + 45cm cube 40% + bottom: 500kg geo-bag100%	360376	558099	35.43%

[Note: 1 USD= Tk. 83.05 BDT]

The summary table which shows observational facts and key results is shown in Table 3.

Table 3. Summary table of test results

Sl. No.	Observational facts	Key results	Test No.
1	Launching pattern of different launching materials	The launching materials such as CC blocks, stone-chips, geo-bags and composite materials (CC blocks + geo-bags) tested under fully oblique flow condition (60-degree) shows that stone chips have best launching pattern as there is no bare space on the launching slope. The composite materials, CC blocks and geo-bags possess 2nd, 3rd& 4th position respectively with respect to launching pattern.	T7, T8, T9 & T18
2	Launching behavior of composite materials having different apron length and thickness	The composite materials (CC blocks + geo-bags) tested under fully oblique flow condition (60-degree) shows that the LA having length 30m & thickness 2m shows better launching behavior relative to other options.	T12, T13 & T14
3	Launching behavior of composite materials having different CC block proportion	The composite materials (CC blocks + geo-bags) with different CC block proportion tested under fully oblique flow condition (60-degree)shows that the LA with CC block proportion 40% of 45 cm cube & 60% of 35 cm cube provides the best result as bare space is relatively lower. Channel developed around the apron is well shaped. The numbers of CC blocks rolled in the developed channel are less. More numbers of CC blocks are retained on the developed slope.	T12, T17 & T18
4	Development of launching slope	For the low-cost material composition: In case of LA of revetment, the launching slope 28.15 degrees (1:1.87) having launched 27%. In case of LA of spur S1, the launching slope 32.14 degrees (1:1.59) having launched 40%.	T18 & T22
5	Costing	The cost was found 34-35% less for LA of composite materials (CC blocks + geo-bags) than providing the single composition of CC blocks in case of revetment and spur**.**	T12, T17, T18 & T22

Conclusions and Recommendations

It can be concluded that insignificant scour or launching pattern was observed around the launching apron of different materials particularly in case of parallel flow (*i.e*. no oblique flow). Moreover, it was observed that the scour decreases when the discharge ratio of shoot to main channel changes from 0.8 to 1.0.Scour was augmented under full oblique flow condition than that of under oblique flow condition at discharge ratio either 0.8 or 1.0.The best composition of materials for revetment: LA consists of 45 cm cube 40% and 35 cm cube 60% at the top layer and 250 kg geo-bag 50% and 175 kg geo-bag 50% at the bottom layer. In this case, maximum scour and velocity is found around 12.09 m and 2.46 ms^{-1} respectively under fully oblique flow (60^0).

Maximum absolute (without LA) scour was found 19.62 m around spur (shank length=30 m) under oblique flow condition. The suitable composition of materials for u/s part of LA of spur: LA consists of 45 cm cube 40% and 35 cm cube 60% at the top layer and 250 kg geo-bag 50% and 175 kg geo-bag 50% at the bottom layer. The suitable composition of materials for d/s part of LA of spur: LA consists of 60 cm cube 60% and 45 cm cube 40% at top layer and 500 kg geo-bag at the bottom layer. In this case, maximum scour and velocity was found around 13.56 m and 2.52 ms^{-1} respectively under oblique flow condition (60^0).

Furthermore, it was evident that the combined apron (geo-bags and CC blocks) works better than the simple geo-bag (as per Standard Schedule of Rates Manual, 2012-13, O & M Circle, BWDB, Faridpur) or even only CC blocks as launching materials. Among the 3-LA materials, stone chips are the best as it provides effectual launching pattern. However, it is too much expensive and unavailable in the developing country like Bangladesh. CC blocks have better launching capabilities but it is expensive relative to geo-bags. Geo-bags can be made easily, available and is less costly. Although it (made as per design manual of BWDB) has relatively poor launching compared to CC blocks or composite material (geo-bag and CC bags). The cost is around 34-35% is less for LA of composite materials than providing the single composition of CC blocks in case of revetment and spur.

Performance of composite launching material (geo-bag and CC block) in straight revetment construction in terms of attained areal coverage, developed slope and scour depth is found to be good under generalized bathymetry. Before implementation of the composite launching material, the result may be verified using real bathymetry.

At the d/s part of the spur, the launching material (geo-bag and CC block) used in this study needs more test to get optimum results considering a variation of the size of geo-bag and CC block. In this study, only single-sized geo-bag and CC block have been tested. The composite launching material may be tested at u/s termination of the revetment by simulating the flow condition.

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QUALITY ASSESSMENT OF IRRIGATION WATER OF BIRGANJ UPAZILLA UNDER DINAJPUR DISTRICT

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Abstract

Water with adequate quality and quantity is very important for irrigation to ensure the crop yields and quality. Keeping in mind it, an investigation was carried out in Birgonj Upazilla under Dinajpur district of Bangladesh in 2017 to assess the extent of groundwater quality and suitability for irrigation purpose. In this connection 50 groundwater samples were collected during irrigation period from eleven unions at different locations and analyzed the samples in the laboratory with respect to international irrigation water quality standards and Bangladesh standards. Analyses were included the determination of pH, EC, TDS, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Mn^{2+}, Fe^{3+}) and anions concentration (HCO_3^-, SO_4^{2-}, PO_4^{3-} and Cl^-). In addition, some water quality determining parameters such as sodium adsorption ratio (SAR), soluble sodium percentage (SSP), hardness (H_T), permeability index (PI), potential salinity and Kelly's ratio were computed to assess the suitability of groundwater for irrigation. Results showed that almost all the water samples were within the recommended value for irrigation as GoB and WHO standards. Based on results from the laboratory analyses it was observed that the groundwaters of the study area were suitable for irrigation and safely be used for irrigation and would not affect the soils, crop yield and quality**.** The results also provided base line data for water quality of groundwater resources of the study region to match national and international standards for irrigated agricultural requirements.

Keywords: *quality assessment, irrigation water, suitability, analysis, cations, anions*.

Introduction

Groundwater is the main source of irrigation (Shirazi *et al.*, 2010). The contribution of groundwater in relation to total irrigated area increased significantly from 41% in 1983 (Ali *et al*., 2003) to 86% in 2002 (BADC, 2002; Hasan *et al.*, 2007). The total area under irrigation in Bangladesh is 5,049,785 ha and 78.9% of this area is covered by groundwater sources including 3,197,184 ha with 1,304,973 shallow tubewells and 785,680 ha with 31,302 deep tubewells (DPHE and JICA, 2010), but heavy pumping of groundwater may create agro-ecological problems (Shirazi *et al.*, 2010).

Groundwater seems to be pure and free from suspended material in comparison to surface water, yet many compound and/or ions in varying amounts may be present in dissolved and/or ionic forms at toxic levels are generally regarded as water pollutants. There are several factors such as ions, salts, heavy metals, toxic elements, fertilizers, pesticides, insecticides, and industrial wastages etc. that affect water quality and make the water quality poor. Using this poor quality water, it might deteriorate soil properties, crops yield and quality (Sarker *et al.*, 2000, Sarker *et al*., 2009). Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and miscellaneous (Ayers and Westcot, 1985).

EC and Na^+ play a vital role in suitability of water for irrigation (Rao, 2005). Soil containing a large proportion of Na^+ with HCO_3^- or Cl^- /SO_4^{2-} are turned alkaline or saline soil, respectively (Todd, 1980). Higher salt content in irrigation water causes an increase in soil solution osmotic pressure. Since plant roots extract water through osmosis, the water uptake of plants decreases. The osmotic pressure is proportional to the salt content or salinity hazard. The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. In addition, high Na^+ content can cause displacement of exchangeable Ca^{2+} and Mg^{2+} from the clay mineral of the soil (Matthess, 1982). Ayers and Westcot (1985) reported that soil containing high levels of exchangeable Mg^{2+} causes an infiltration problem. The presence of excessive Na^+ in irrigation water promotes soil dispersion and structure breakdown when Na^+ to Ca^{2+} ratio exceeds 3:1. Such a high Na:Ca ratio (>3:1) results in severe water infiltration problems, mainly due to lack of sufficient Ca^{2+} to counter the dispersing effect of Na^+. Excessive Na^+ also

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creates problems in crop water uptake, poor seedling emergence, lack of aeration, plant and root diseases etc. (Ayers and Westcot, 1985).

Haque (2006) analyzed that the severity of salinity problem in the coastal area increases with the desiccation of the soil. It affects crops depending on degree of salinity at the critical stages of growth, which reduces yield and in severe cases; total yield is lost. About 53% of the coastal areas are affected by salinity.

Agriculture mostly depends on suitable supply of water for irrigation. Before application of water, water quality must be measured because of secure in-toxic food production. If the Poor quality of irrigation water is not managed properly then it poses many hazards to plant production. So for the better plant and crop production the quality of the water need to be analyzed properly and improving further management (Haque *et al.*, 2017)

Thus, groundwater quality assessment for irrigation has become a necessary and important task for present and future groundwater quality management and sustainability of groundwater. Moreover, formulation of a base line data for the study area, an investigation was conducted to assess suitability of groundwater for irrigation usage in Birgonj upazilla under Dinajpur district with the following specific objectives.

a) To assess the degree of ionic toxicity of irrigation water from groundwater source.

b) To categorize groundwaters on the basis of GoB and WHO standard criteria.

c) To predict the suitability and acceptability of groundwater for irrigation usage.

Mathodology

Study area selection

Locations of the study area as well as groundwater sampling sites were selected different places of eleven (11) unions under Birgonj upazila in Dinajpur district (Fig. 1). The eleven unions were namely Satair, Maricha, Vognagar, Paltapur, Sibrampur, Sujalpur, Nijpara, Shatagram, Mohammadpur, Palasbari and Mohanpur. There are different water sources for irrigation in the study area, but groundwater is the major source of irrigation water and most of the farmers are beying utilized Deep Tube Well (DTW) to abstract groundwater for irrigation in the study area.

Fig.1. Representation of study area map (Birganj Upazilla).

Water quality with respect to irrigated agriculture

Water quality analysis for irrigation mainly includes the determination of (1) the total concentration of soluble salts, (2) the relative proportion of sodium to the other cations, and (3) the carbonate and bicarbonate concentration with respect to the concentration of calcium and magnesium. To assess the suitability of groundwater of the study area for irrigation, GoB standard (Annexure 1) was followed by the Ministry of Environment and Forest with respect to the socio-economic conditions in Bangladesh. In this study, water quality parameters for irrigation such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (H_T), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), potential salinity, Kelly's ratio (KR), Carbonate (CO_3), Bicarbonate (HCO_3), Sulphate (SO_4), Phosphate (PO_4), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Sodium (Na) and Potassium (K), Iron (Fe), Manganese (Mn), and Copper (Cu) were estimated by standard methods (APHA, 2000). SAR, SSP, H_T, PI and KR were computed of water samples using the following formulae for determining the rating of irrigation water classess, where all ionic concentrations are in milli equivalent per liter (meq/l) [In all cases, i.e. for a, b, c, d and e].

Samples collection and testing

A total of 50 water samples were collected from 50 deep tube wells during irrigation time in 2017 (January-May) and used for the study purposes. Water samples were collected in litre plastic bottles. These bottles were cleaned and washed with tap water followed by distilled water. Before sampling, containers were rinsed 3 to 4 times with water to be sampled. The groundwater samples were carried out to the laboratory of the Department of Agricultural Chemistry, Hajee Mohammed Danesh Science and Technology University (HSTU), Dinajpur for required testing. Collected samples were carefully tested in the laboratory following standard methods (APHA, 2000). Tested sample results were analyzed to asses the quality of the groundwater for irrigation. Finally, conclusions are presented in this paper.

a) According to Rechards (1954), Sodium Adsorption Ratio (SAR) is expressed as:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad \text{Eq. (1)}$$

b) Todd (1980) defined Soluble Sodium Percentage (SSP) as:

$$SSP = [(Na^{+} + K^{+})/ (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}]*100 \qquad \text{Eq. (2)}$$

c) Doneen (1962) defined Permeability Index as:

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \qquad \text{Eq. (3)}$$

d) Hardness or Total Hardness (H_T) as per Golterman and Clymo (1971).

$$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+} \qquad \text{Eq. (4)}$$

e) The Kelly's Ratio was calculated using the equation (Kelly's 1963) as:

$$KR = Na^{+} / (Ca^{2+} + Mg^{2+}) \qquad \text{Eq. (5)}$$

Kelly (1963) suggested that KR for irrigation water should not exceed 1.0. That means that a good balance of Na^{+}, Ca^{2+} and Mg^{2+}, which also indicates a good tilth condition of the soil and no permeability problem of the soil.

Results and discussion

In this section, the groundwater quality during irrigation period of the study area with respect to irrigation is illustrated. The calculated values of the water samples are presented in Table 1.

The ionic concentration of Ca, Mg, Na, K, Fe, Mn, Cu, Cl, HCO_3, SO_4, and PO_4 were existed in variable quantities in the collected 50 groundwater samples. The minimum, maximum and average concentration of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{3+} , Mn^{2+}, Cu^{2+}) of 50 samples is presented in Table 1. The investigation expressed that a good proportion of these cations existed in waters which was 'suitable' for good structure and tilth condition of soil and which would improve the soil permeability. As per GoB (1997) [Annexure 1] and Ayers and Westcot (1985) [Annexure 2] based on Ca, Mg, Na, K, Cu, Mn and Fe content, the entire water samples can safely be used for long-term irrigation without the harmful effects on soils and crops.

Table 1. Physico-chemical parameters of 50 groundwater samples

	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Na^{+} (mg L^{-1})	K^{+} (mg L^{-1})	Fe^{3+} (mg L^{-1})	Mn^{2+} (mg L^{-1})	Cu^{2+} (mg L^{-1})
Min	5.61	5.83	5	2.5	0.064	0.03	0.01
Max	37.68	32.08	20	20	1.19	0.71	0.14
Mean	14.96	15.19	9.1	7.35	0.47	0.298	0.03

Table 1. Continued

	P^{H}	EC (µS cm^{-1})	TDS (mg L^{-1})	Cl^{-} (mg L^{-1})	HCO_3^{-} (mg L^{-1})	SO_4^{2-} (mg L^{-1})	PO_4^{3-} (mg L^{-1})
Min	6.39	131	64	0.014	0.8	0	0
Max	8.49	686	343	0.037	3.6	11.72	0.02
Mean	7.54	325.42	159.58	0.023	1.69	1.97	0.01

Table 1. Continued

	SAR	SSP %	Hardness (mg L^{-1})	PI (mg L^{-1})	Potential Salinity (mg L^{-1})	Kelly's ratio
Min	1.41	9.68	39.93	0.17	0.02	0.17
Max	5.14	25.59	225.73	0.43	5.89	0.66
Mean	2.36	15.53	99.66	0.27	1.01	0.32

Note: All parameters are expressed in milligrams per liter (mg L^{-1}) except pH (units). The electrical conductivity (EC) is expressed in micromohs/cm. (µS cm^{-1}) at 25^{0}C.

The minimum, maximum and average concentration of major anions (P^{H}, EC, TDS, Cl^{-}, HCO_3^{-}, SO_4^{2-} and PO_4^{3-}) is presented in Table 1. On the basis of pH values, almost all the water samples were within the recommended pH value .42 µS cm^{-1}. According to GoB (1997) guidelines (Annexure 1) and the water classification by Ayers and Westcot (1985) [Annexure 3**]**, 15 samples were excellent, 35 samples were good for irrigation purposes. The amount of total dissolved solids (TDS) of groundwater samples in the investigated area varied from 64 to 343 mg L^{-1} with mean value of 159.58 mg L^{-1} (Table 1). According to GoB (1997) guidelines (Annexure 1) and the water classification by Freeze and Cherry (1979) based on TDS (Annexure 4), suitability rating of all the collected groundwater samples was considered as 'fresh' for irrigation. These waters would not affect the osmotic pressure of soil solution and cell sap of the plants when applied to soil as irrigation water. for irrigation as per GoB and WHO guidelines (Annexure 1). The EC of all water samples (Table 1) was within the ranges of 131 to 686 µS cm^{-1} with the mean value of 325

According to GoB (1997) guidelines (Annexure 1) and Ayers and Westcot (1985) based on Cl, HCO_3, SO_4 and PO_4 (Annexure 2), all tested groundwater samples were found within the recommended limit (except 50% samples for HCO_3).

The minimum, maximum and average concentration of groundwater samples on the basis of SAR, SSP, Hardness, Permeability Index (PI), Potential Salinity and Kelly's ratio is presented in Table 1. The SAR of groundwater samples was within range of 1.41 to 5.16 with the mean value of 2.36. That is all value is less than 10. According to the water classification by Todd (1980) in respect to SAR (Annexure 3), all the groundwaters were classified as 'excellent' (SAR<10) for irrigation. Similarly, the SSP of all water samples varied from 9.68 to 25.59% with the mean value of 15.53%. According to the water classification by Wilcox (1955) in respect to SSP (Annexure 3), all the groundwaters (47 samples) were classified as 'excellent' (SSP<20%) and 3 samples were 'good' for irrigation. The H_T of all water samples was within the ranges of 39.93 to 225.73 mg L^{-1} with a mean value of 99.66 mg L^{-1}. According to the water classification by Sawyer and McCarty (1967) in respect to hardness (Annexure 5), 14 samples were 'soft', 29 samples were 'moderately hard' and 7 samples were 'hard' for irrigation.

Table 1 showed the computed Permeability Index (PI) of collected goundwater samples. The PI of water samples was within the ranges of 0.17 to 0.43 with a mean value of 0.27 mg L^{-1}. Permeability problem occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops. Two factors such as salinity of water and its sodium content relative to calcium and magnesium is responsible for infiltration. The Potential salinity of all water samples was within the range of 0.02 to 5.89 with a mean value of 1.01mg L^{-1} (Table 1). Highly saline water increases the infiltration rate. The Kelly's ratio for all water samples was ranged from 0.17 to 0.66 with the mean value 0.32 (Table 1). Kelly's ratio is used to find whether groundwater is suitable for irrigation or not. Groundwater having Kelly's ratio more than one is generally considered as unfit for irrigation. According to Kelly's ratio, all of the water samples were suitable for irrigation.

Quality classification and suitability assessment of groundwater samples for irrigation is shown in Table 2 based on EC, TDS, SAR, SSP and H_T. In respect to EC, 15 samples were excellent and 35 samples were good for irrigation purposes. In respect to TDS, suitability rating of all the collected groundwater samples was 'fresh' for irrigation. In respect to SAR, all the groundwaters were classified as 'excellent' for irrigation. In respect to SSP, 47 samples were classified as 'excellent' and 3 samples were 'good' for irrigation. In respect to hardness, 14 samples were 'soft', 29 samples were 'moderately hard' and 7 samples were 'hard' for irrigation.

Table 2. Quality classification and suitability assessment of groundwater samples for irrigation.

Sl.	EC	TDS	SAR	SSP	H_T
1	Good	Fresh	Excellent	Excellent	Moderately hard
2	Good	Fresh	Excellent	Excellent	Moderately hard
3	Good	Fresh	Excellent	Excellent	Moderately hard
4	Good	Fresh	Excellent	Excellent	Hard
5	Good	Fresh	Excellent	Excellent	Moderately hard
6	Good	Fresh	Excellent	Excellent	Moderately hard
7	Good	Fresh	Excellent	Excellent	Moderately hard
8	Good	Fresh	Excellent	Excellent	Moderately hard
9	Good	Fresh	Excellent	Excellent	Moderately hard
10	Good	Fresh	Excellent	Excellent	Moderately hard
11	Good	Fresh	Excellent	Excellent	Moderately hard
12	Good	Fresh	Excellent	Excellent	Moderately hard
13	Good	Fresh	Excellent	Excellent	Moderately hard
14	Good	Fresh	Excellent	Excellent	Moderately hard
15	Good	Fresh	Excellent	Excellent	Moderately hard
16	Good	Fresh	Excellent	Good	Soft

Sl.	EC	TDS	SAR	SSP	H_T
17	Good	Fresh	Excellent	Good	Soft
18	Excellent	Fresh	Excellent	Excellent	Moderately hard
19	Excellent	Fresh	Excellent	Excellent	Soft
20	Excellent	Fresh	Excellent	Excellent	Soft
21	Excellent	Fresh	Excellent	Excellent	Soft
22	Excellent	Fresh	Excellent	Excellent	Soft
23	Excellent	Fresh	Excellent	Excellent	Soft
24	Excellent	Fresh	Excellent	Excellent	Soft
25	Excellent	Fresh	Excellent	Excellent	Soft
26	Good	Fresh	Excellent	Excellent	Moderately hard
27	Good	Fresh	Excellent	Good	Moderately hard
28	Good	Fresh	Excellent	Excellent	Hard
29	Good	Fresh	Excellent	Excellent	Hard
30	Good	Fresh	Excellent	Excellent	Moderately hard
31	Excellent	Fresh	Excellent	Excellent	Soft
32	Excellent	Fresh	Excellent	Excellent	Soft
33	Excellent	Fresh	Excellent	Excellent	Soft
34	Excellent	Fresh	Excellent	Excellent	Soft
35	Excellent	Fresh	Excellent	Excellent	Soft
36	Good	Fresh	Excellent	Excellent	Moderately hard
37	Good	Fresh	Excellent	Excellent	Moderately hard
38	Good	Fresh	Excellent	Excellent	Moderately hard
39	Good	Fresh	Excellent	Excellent	Moderately hard
40	Good	Fresh	Excellent	Excellent	Moderately hard
41	Good	Fresh	Excellent	Excellent	Moderately hard
42	Good	Fresh	Excellent	Excellent	Moderately hard
43	Excellent	Fresh	Excellent	Excellent	Soft
44	Excellent	Fresh	Excellent	Excellent	Moderately hard
45	Good	Fresh	Excellent	Excellent	Moderately hard
46	Good	Fresh	Excellent	Excellent	Moderately hard
47	Good	Fresh	Excellent	Excellent	Hard
48	Good	Fresh	Excellent	Excellent	Hard
49	Good	Fresh	Excellent	Excellent	Hard
50	Good	Fresh	Excellent	Excellent	Hard

Conclusions

Different physico-chemical properties of groundwater were matched with the GoB standards water quality for irrigation. The concentrations of total cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Mn^{2+}, Fe^{3+}) and total anions (pH, EC, TDS, Cl^{-}, HCO_3^{-}, SO_4^{2-} and PO_4^{3-}) under study were within the safe limit for soils and crops for irrigation. There was no ionic toxicity of the collected water samples and the groundwater samples had no Mn and Cu toxicities for irrigation. Based on water quality determining parameters such as SAR, SSP, H_T, PI, potential salinity and Kelly's ratio for suitability assessment, all the tested water samples were suitable for irrigation usage. Based on EC, 30% samples fall under the category Excellent and 70% samples fall under the category Good. Based on TDS and SAR, 100% samples fall under the category of Fresh water and Excellent respectively. As per SSP indices 94% samples fall under the category of Excellent and 6% samples fall under the category of Good. As per H_T indices 30% samples fall under the category of Soft and 56% samples fall under the category of Moderately hard and 14% samples fall under the category of Hard. In the study area, groundwater might safely be applied for irrigating agricultural crops.

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Annexure 1. Water quality standard for irrigation in Bangladesh [Source: GoB (1997) and WHO (2004)]

Sl. No.	Parameters	GoB-Limit (1997)	WHO (2004)	Sl. No.	Parameters	GoB-Limit (1997)	WHO (2004)
1	Temp (°C)	20-30		10	Mg^{2+} (mg L^{-1})	30-35	50
2	pH	6.0-9.0	6.5-8.5	11	Cl^{-} (mg L^{-1})	150-600	250
3	EC (µS cm^{-1})	2250		12	HCO_3^{-}(mg L^{-1})	200	
4	TDS (mg L^{-1})	2100	1000	13	NO_3^{-}(mg L^{-1})	10	50
5	H_T (mg L^{-1})			14	SO_4^{2-} (mg L^{-1})	400	250
6	Na^{+} (mg L^{-1})	200	200	15	PO_4^{3-}(mg L^{-1})	10	
7	K^{+} (mg L^{-1})	12		16	B^{+} (mg L^{-1})	2	
8	Ca^{2+} (mg L^{-1})	75		17	As^{+} (mg L^{-1})	1	
9	Mn^{2+} (mg L^{-1})	5		18	Fe^{3+} (mg L^{-1})	1-2	

Annexure 2. Suggested maximum concentration of chemical constituent in irrigation water by Ayers and Westcot (1985)

Elements	Symbol	Suggested maximum concentration
Sodium	Na	30.00 mg L^{-1}
Potassium	K	20.00 mg L^{-1}
Calcium	Ca	60.00 mg L^{-1}
Magnesium	Mg	25.00 mg L^{-1}
Iron	Fe	5.00 mg L^{-1}
Manganese	Mn	5.00 mg L^{-1}
Copper	Cu	0.20 meq L^{-1}
Chloride	Cl	4.0 meq L^{-1}
Carbonate	CO_3	0.10 meq L^{-1}
Bicarbonate	HCO_3	1.50 meq L^{-1}
Sulphate	SO_4	20.00 meq L^{-1}

Annexure 3. Limits of some important parameter indices for rating groundwater quality and its suitability in irrigation use

Category	Groundwater quality indices*			Suitable for irrigation
	EC (µS/cm)	SAR	SSP	
I	<700	<10	<20	Excellent
II	700-3000	10-18	20-40	Good
III	>3000	18-26	40-80	Fair
IV	-	>26	>80	Unsuitable

* According to Ayers and Westcot (1985), Todd (1980) and Wilcox (1955), respectively

Annexure 4. Irrigation water classification based on TDS by Freeze and Cherry (1979)

Water class	Total dissolved solids (TDS), mg L^{-1}
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Annexure 5. Irrigation water classification based on hardness by Sawyer and McCarty (1967)

Water class	Hardness mg L^{-1}
Soft	0-75
Moderately hard	75-150
Hard	150-300
Very hard	>300

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EXPLORING ORGANIC MATTER PRESENCE IN SOILS AND ITS EFFECT ON ENGINEERING PROPERTIES OF GOPALGANJ DISTRICT

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Abstract

The presence of organic matter (OM) in soils changes its behavior in engineering practice. The design engineer should take concern for this and that's why it is important to ensure the presence of either OM is in soil or not. So, laboratory investigation of presence of OM in soils is of great importance for designing structures. In Bangladesh, Gopalganj district is one of the low lying depression areas where OM presents in the sub-surface soil. Under these circumstances this paper has been attempted to explore the presence of OM in soil in Tungipara, Gopalganj sadar and Kotalipara upazila of Gopalganj district. Soil samples have been collected from Bangladesh Water Development Board (BWDB) and the engineering properties of soils have been determined at the Geotechnical Research Directorate of River Research Institute (RRI). After the analysis of data, organic matter has been found up to 32´ at Tungipara, up to 17´ at Gopalganj sadar and up to 22´at Kotalipara upazilla. It has also been observed that the natural moisture content, liquid limit and plasticity have been increased with the increases of organic matter content. Here it is remarkable that organic matter contents in Tungipara are 5% to 32% and their corresponding SPT values are 1 to 6, organic matter contents in Gopalganj sadar are 5% to 20% and their corresponding SPT values are 2 to 4 and Kotalipara 5% to 16% and their corresponding SPT values are 2 to 4. Though effect of organic matter presence in soils on SPT has been demonstrated here but not remarkable effect has been observed.

Keywords: *liquid limit, natural moisture content, organic matter content, plasticity index, standard penetration test.*

Introduction

Bangladesh is a small country occupying 56,977 square miles. However, it has wide varieties of soils both in surface as well as sub-surface. There are 500 soil types in Bangladesh which has been classified in ranging from juvenile alluvium or man-made soils at one extreme to old and deep weathered red soils. The extensive range of environmental situation has generated many kinds of soils and its strata.

The most comprehensive soil classification of Bangladesh with complete information on soil characteristics has been envisaged. The formation of soil with its structural phenomena such as factors, processes as well as spatial coverage of different soil types have provided by this classification. According to this coverage, a total of 21 general soil types have been recognized where peat is one of the important soil type (Sajjad, 2008).

Peat Soils are partially or fully decomposes of organic matter which constitutes more than half of the uppermost 80cm of the profile in these soils. Peat soils occur extensively in the wet depressions of flood plain areas like the Gopalgonj and Khulna beels and some perennially wet sites in the Sylhet Basin. It has limitations such as deep flooding and low natural fertility (Sajjad, 2008).

The soils contain organic matter at the surface or buried under a mineral soil layer below at a depth of up to 40 cm. The organic material that forms the Histic horizon known as Histosol and it is varies from dark brown, fibrous peat to semi-liquid black muck (Banglapedia).

The organic soil is also found in the marsh land. The marsh lands all over the country have clay soils highly rich in organic materials. Its colour is blackish. The marshlands are found in Gopalgonj, Khulna, Narail, Netrokona and Sunamgonj areas and have black peat soils (Inamul, 2008).

In Bangladesh, the floodplains of the rivers are covered with sandy, or silty, or silt mixed sandy soils. It has some clay soils at patches, carried and deposited by the rivers. But, the all season wetlands have thick deposit of clay mixed organic soils. This happens because of carrying finer particles and clay soils from distant sources, and accumulating in deep inland, away from the rivers. The all season wetlands also accumulate suspended organic solids, and have deposition of the fossils of aquatic plants. At certain areas, where the fossil percentage is higher, the soil is called peat. These are unconsolidated deposits of semi-carbonized plants, containing about 60% carbon, and about 30% oxygen (Inamul, 2008).

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Madaripur, Gopalganj, Narail, Khulna, Bagerhat, Pirojpur, Sunamgonj, Netrokona, Kishoregonj and Habigonj districts have peat soils near the ground or just few meters below the ground. Peat soils are also found at the fringes of some other lowlands, under a layer of silt or sandy topsoil. All these happened because of morphological changes in the adjacent rivers, when they started carrying sand and silt during floods, and deposited them over the subsiding fossil soil (Inamul, 2008).

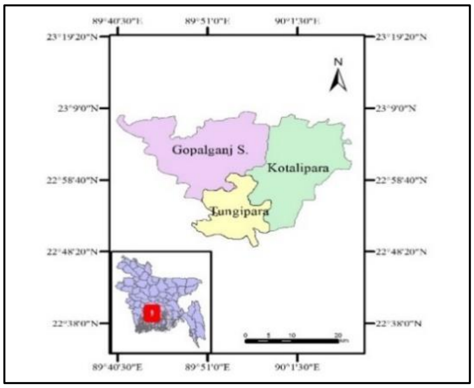

Fig. 1. Study area using ArcGIS 10.3

Peat and organic matter content have significant effect on engineering properties of soils as well as on its structure. So, considerable design should be done through duly study of organic matter of soil. No doubt, some scientists and engineers have studied. The following authors' studies could be taken for this case.

Ekwue (1990) studied Organic-matter effects on soil strength properties. He showed organic matter reduced bulk density and increased moisture retention of soil. Effect of Organic Content on the Index Properties and Compaction Parameters of Soil was investigated by Sen *et al.* (2014). The test results indicated that the organic content significantly alter the geotechnical properties of soil.

Abdi *et al.* (2016) tried to assess the influence of organic matter on the physical properties and mechanical behaviors of Hyrcanian forest soil, Iran. They also explored the relation between the amount of organic matter and the behavior of forest soil as road material. The results showed that soil plasticity increased linearly with increasing organic matter. Increasing the organic matter from 0% to 15% resulted in an increase of 11.64% of the plastic limit and15.22% of the liquid limit after drying at 110°C. Also, increasing the organic matter content reduced the soil maximum dry density and increased the optimum moisture content.

Develioglu and Pulat (2017) studied on geotechnical engineering properties and compressibility behavior of dredged soil. They obtained the samples with four different organic matter contents. From this study they has shown that OMC has an important effect on the engineering properties of dredged soils. Moreover, Rabbee and Rafizul (2012) have found that the shear strength has decreased with the increase of organic content and the stress-strain behavior is similar for all the reconstituted soils.

The Gopalgonj Sub-Region covers the areas of Gopalgonj District and north of the Perojpur and Barisal districts. The Gopalgonj sub region has many low-lying depressions, good for shallow tube well and subsoil irrigation. The ground elevation varies from 5m to 2m above mean sea level. The land is sloping at an average rate of 0.06m/km from north to south. The total area covered by this sub-region is about 1600sq.km out of which 1400 sq.km is vulnerable to flood (Inamul, 2008).

Though Gopalganj district is an organic prone area however, no dominant study has been carried out to investigate the relationship among soil properties of Gopalganj District in Bangladesh. Aim at this point, this study was attempted to reveal the relationship between organic matter content (OMC) (as independent variable) and engineering properties (as dependent variables) of soil including natural moisture content (NMC), plasticity index (PI), liquid limit (LL) and standard penetration test (SPT) of Goplaganj district. It is sanguine the study will bring help for design engineers for construction purposes who will work at low lying areas such as Gopalganj district.

Methodology

In context of organic matter presence in soils, Gopalganj district has been selected for this study as this area's soil contains highly rich organic matter. In search of organic matter content, only three upazillas of Gopalganj district namely Tungipara, Gopalganj sadar and Kotalipara have been selected as a study area which has been shown in Fig-1.

Soils including boring logs have been collected from Ground Water Hydrology Division of Bangladesh Water Development Board (BWDB). The samples were received by River Research Institute (RRI) up to 72 ft from the existing ground surface for each location. However, only organic matter content layer were considered along the soil profile in this study.

Soil samples have been tested at Geotechnical Research Directorate (GRD) of RRI. In order to detect organic matter content soils, the soils have been selected through its characteristics such as odour and dark colour (Lambe, 2004). Soil OMC, NMC, LL and PL has been quantified following ASTM procedure. SPT values have been taken from boring logs supplied by BWDB. Statistical analyses have been done between parameters using SPSS software (version 21).

Results and Discussion

This study has been carried out to reveal the relationship between OMC and NMC, PI, LL and SPT of the soil of the Upazilas of Gopalganj District. The data have been presented in the tabular form in Table-1 and the graphical presentation has been illustrated in Fig-2 and Fig-3 respectively.

In Tungipara upazila, soils of three locations namely, Char Boyria Gonapara, North Basuria and Kuchimara Khal have been identified containing organic matter presence up to 9.32% and the organic matter was observed up to the maximum depth of about thirty two feet (32´) from the existing ground surface. The sequence of presence of organic matter is not continuous for all the holes and their corresponding depth. These discontinuities have been occurred due to the percentage of the fossils of aquatic plants were accumulated in deep and light inland at variable range as the theory and practical concern.

Linear regression analysis has been done between organic matter content (independent variable) and natural moisture content (dependent variable) and it has showed linear relationship with a coefficient of determination, $R^2 = 0.804$. Similar relationships were obtained for the case of liquid limit and plasticity index. Both liquid limit and plasticity displayed linear relationship with organic matter content. The obtained coefficients of determination, R^2 for LL VS OMC and PI VS OMC are 0.8729 and 0.9079 respectively.

These results have been shown in the Table-2. They have resemblance to that of Develioglu and Pulat (2017), where they found the liquid and plastic limits increased with increasing OMC. Different result has been observed from the analysis between SPT and OMC. Using SPSS software (version 21) correlation coefficient (Pearson) of SPT and OMC was obtained equal to -0.374, according to Evans (1996) which indicates a weak correlation between the two parameters. Effective diameter of the samples have been observed in the range 0.001mm to 0.007mm while organic matter content ranged from 5% to 9.32% and natural moisture content ranged from 48.27% to 64.55%. All the corresponding illustrations have been shown in Fig- 3.

In Gopalganj sadar upazila, Dattadanga Khal, Vogergati Khal, and Shibpur Khal had been identified regarding organic matter presence up to 11.95% and the organic matter is observed up to the maximum depth of about only fifteen feet (15´) from the existing ground surface in this three locations which is lower than Tungipara upazilla. However, the organic matter content have been found greater amount in Gopalganj upazilla than the Tungipara upazilla though there is no sequence of presence of organic matter content for all the holes and their corresponding depth as the same reasons as Tungipara Upazilla.

The highest organic matter was found in Kotalipara Upazila (Table-1). The three locations of this upazilla namely Depuar Khal, Pukuria Khal and Panchuramer Khal have been identified regarding organic matter presence up to 15.85%

and the organic matter is observed up to the maximum depth of about twenty two feet (22´) from the existing ground surface. There is also absent the sequence of continuous presence of organic matter for all the holes and their corresponding depth as the due same reasons as Tungipara upazilla.

Table 1. Soil organic matter according to soil profile and its corresponding NMC, LL, PI, SPT and soil texture including D_{10}, D_{30}, D_{60} in Tungipara, Gopalganj sadar and Kotalipara upazilla

Upazila	Location	Hole No.	Sample No.	Depth	OMC	N.M.C	LL	PI	Clay (%)	Silt (%)	Sand (%)	SPT	D_{10} (mm)	D_{60} (mm)	D_{30} (mm)
Tungipara	Char Boyria Gonapara	2	D1	5-7'	5.4	51.08	59	29	22	73	5	1		0.0375	0.00375
		3	D1	5-7'	9.32	64.55	76	38	15	83	2	1		0.0475	0.005
	North Basuria	2	D1	5-7'	6.96	55.03	66	32	16	81	3	2		0.016	0.0045
		3	D5	25'-27'	5.4	50.22	61	31	10	84	6	6		0.02	0.007
			D1	5-7'	6.08	48.59	60	30	16	76	8	2		0.018	0.0055
	Kuchiamara Khal	1	D1	5'-7'	6.8	51.86	65	32	4	77	19	2		0.0105	0.0035
		2	D1	5'-7'	6.4	50.13	63	30	18	80	2	2		0.0105	0.004
		3	D3	15'-17'	7.13	52.787	62	32	10	82	8	2	0.002	0.015	0.0058
			D4	20'-22'	5	48.27	55	27	18	75	7	2		0.012	0.004
			D6	30'-32'	8.54	56.01	68	35	16	77	7	2		0.014	0.0045
Gopalganj Sadar	Dattadanga Khal	1	D2	10'-12'	11.6	56.64	72	36	10	82	8	4	0.0025	0.055	0.009
					9.72	53.7	62	33	12	82	6	3	0.0014	0.016	0.0058
		3	D2	10'-12'	10.24	59.43	75	34	8.5	83.5	8	5	0.0025	0.0525	0.0075
	Vogergati Khal	3	D2	10'-12'	5.75	45.04	53	27	10	82	8	4	0.002	0.025	0.008
	Shibpur Khal	3	D3	15'-17'	11.95	66.38	85	42	11	84	8	4	0.0018	0.065	0.0075
Kotalipara	Depuar Khal	1	D1	5'-7'	5.82	50.31	55	27	21	78	1	2		0.0078	0.0031
		2	D2	10'-12'	15.85	74.86	86	45	11	80	9	4	0.002	0.025	0.0055
	Pukuria Khal	2	D3	15'-17	14.85	60.15	78	40	7	84	9	2	0.003	0.024	0.009
			D4	20'-22'	15	69.99	63	36	9.5	83.5	7	2	0.0021	0.016	0.006
	Panchuramer Khal	2	D1	5'-7'	7.65	49.12	58	30	17	80	3	3		0.009	0.00355

Note: Organic layer do not found in all holes or locations towards the whole soil profile (0´-72´). Here only consider the depth which contain organic layer in each hole/location. So, there is difference in hole no. sample no. and depth in each location.

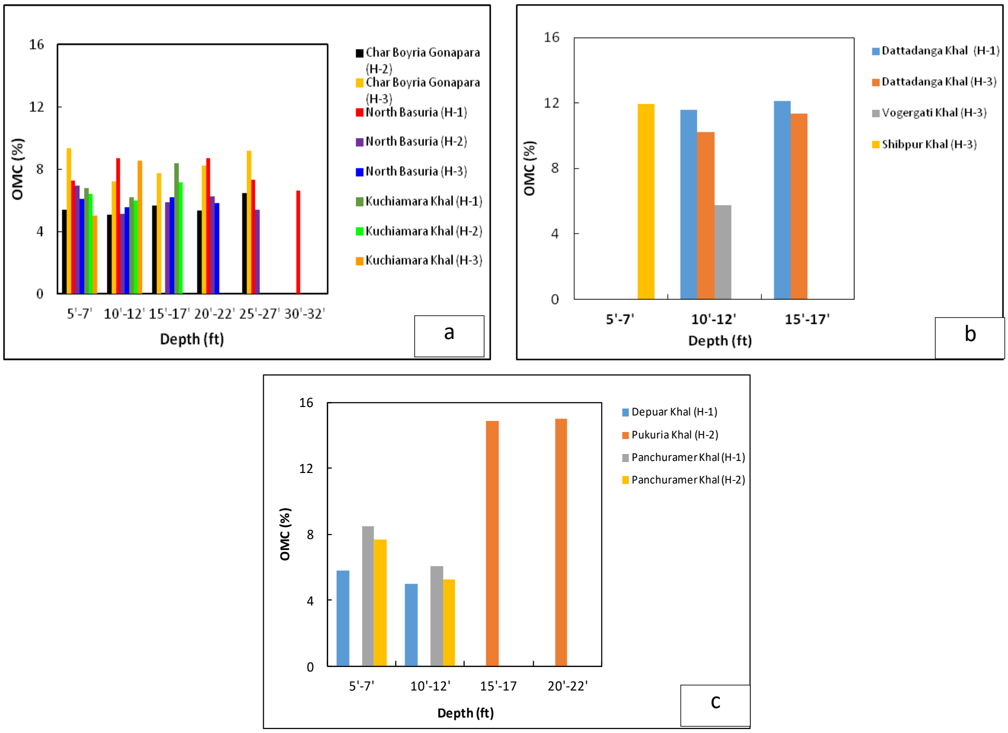

Fig. 2. The amount of OM (in %) according to depth a) for Tungipara, b) for Gopalganj Sadar, c) for Kotalipara. Note that here only consider the depth which contain organic layer in each hole/location. Organic layer do not found in all holes or locations towards the whole profile (0-72´).

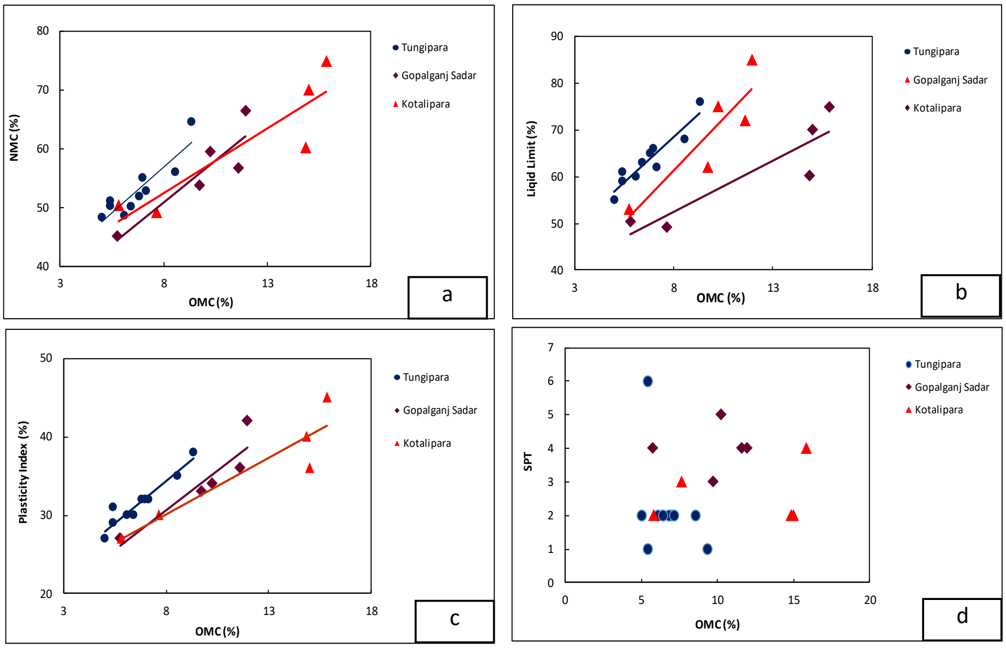

Fig. 3. Relationship between OMC and engineering properties of soils a) OMC vs NMC, b) OMC vs Liquid limit, c) OMC vs Plasticity Index, d) OMC vs SPT

Table 2. Obtained values of Coefficient of determination, R^2 and equation

Location	Parameter		Coefficient of determination, R^2	Equation
	Independent (x)	Dependent (y)		
Tungipara	OMC	NMC	0.8040	y = 3.1218x + 31.927
		LL	0.8729	y = 3.8857x + 37.454
		PI	0.9079	y = 2.132x + 17.309
Gopalganj Sadar		NMC	0.8059	y= 2.8419x + 28.24
		LL	0.7838	y = 4.4045x + 26.007
		PI	0.8422	y = 2.0091x + 14.606
Kotalipara		NMC	0.8254	y=2.1992x + 34.861
		LL	0.8130	y = 2.1992x + 34.861
		PI	0.8556	y = 1.4331x + 18.64

Table 3. Obtained values of Correlation coefficient (Pearson), R

Location	Parameter		Correlation coefficient (Pearson), R
	Independent (x)	Dependent (y)	
Tungipara	OMC	SPT	–0.374
Gopalganj Sadar		SPT	0.0743
Kotalipara		SPT	−0.228

Linear regression analysis between OMC and NMC showed that there is linear relationship with coefficient of determination ($R^2 = 0.0.8254$).

Similar relationships were also obtained for the case of LL and PI. Similar to Tungipara and Gopalganj sadar Upazilla, both LL and PI displayed linear relationship with OMC. The obtained coefficients of determination, R^2 for LL VS OMC and PI VS OMC were $R^2 = 0.813$ and $R^2 = 0.8566$ respectively. Like as Tungipara and Gopalganj Sadar different results were observed from the analysis between SPT and OMC. The correlation coefficient (Pearson) of SPT and OMC was obtained equal to -0.228. These results have been shown in the Table-2 and Table-3 respectively. The amount of organic matter varied from 5.82% to15.85 % and NMC from 49.12% to 78.86%, effective diameter of the samples has been observed in the range 0.002mm to 0.025mm. Lower than this range of organic matter, the effective diameter of soil particles had not been identified in hydrometer test of grain size analysis. All the corresponding illustrations have been referred to Table-1.

After all the analysis of the data of the selected locations, it has been found that natural moisture content, plasticity and SPT value of soil samples have been varied with the variation of amount of organic matter content. However, the variation of organic matter content would not vary with effective diameter of the representative soil samples. Here it is clear that the variation of effective diameter has been varied due to the presence of percentage of clay, silt and sand particles.

Conclusions

In this study a number of areas of Gopalganj district have been selected to explore the presence and effect of organic matters in soils on its engineering properties. From this study it has been concluded that soils in all the locations of three Upazilas of Gopalganj District contain various amount of organic matter at the depth from ground level to the maximum depth of 12´. However exceptions have been observed at North Basuria and Kuchiamara of Tungipara Upazila where organic matter has been found depth up to 27´and 32´ respectively. The highest organic content (15.85%) has been found in Kotalipara Upazila and the lowest organic content (5.00%) has been found in Tungipara Upazila. The average organic content has been found 6.70% for Tungipara, 9.85% for Gopalganj Sadar and 11.83 for Kotalipara. However, organic layer is absent in some of the boreholes. It is mentionable that the natural moisture content, liquid limit and the plasticity have been increases with the increases of organic matter content. The measurement of other properties has not been conducted due to various reasons. That's why only SPT values could not demonstrate the original phenomena in this study.

Recommendations

The study will be helpful for design engineer especially who will work on organic matter containing low-lying area like Gopalgonj. In this study, most of the layers content organic matter up to maximum depth of about 32´ and there is some effects on natural moisture content and plasticity even it is recommended that knowing engineering properties of soil through laboratory test is obligatory.

Acknowledgement

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