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## River Research Institute, Faridpur

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# HYDROSTRATIGRAPHIC ANALYSIS TO IDENTIFY THE POTENTIAL GROUNDWATER BEARING ZONES IN THE NORTH OF MEHERPUR DISTRICT

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## Abstract

In this work an attempt has been made to study the hydrostratigraphy of the northern part of Meherpur district using 105 borehole litholog and 15 observation well data to identify the potential groundwater bearing zones for future groundwater resources development. The stratigraphic cross-sections of the area reveals seven distinct hydrostratigraphic features viz. clay-silt-sand, fine sand, fine to medium sand, medium sand, medium to coarse sand, coarse sand and coarse sand with gravel. On the basis of borehole information the groundwater bearing sequence of the area has been divided into two main hydrostratigraphic units- aquitard and aquifer consist of clay-silt-sand and sands of different grain sizes respectively. The aquiferic layer is further divided into two categories namely 'small-scale aquifer' made of fine sand and 'main aquifer' consists of fine-medium to coarse sand-gravels. Groundwater yield potential map for the study area prepared in terms of the ratio of aquifer to aquitard shows that more than 70% area is covered with the yield index greater than five. The presence of thick sandy bed makes the area favorable for future groundwater development.

## Introduction

The water crisis during extreme dry is considered as a national problem in Bangladesh. (BADC 2005). Huge withdrawal of water in the upstream of the Ganges during dry months in recent years has caused widespread scarcity of water resources in the Ganges dependent area of Bangladesh (GoB 2002; Momin 2003). The low river flow in the dry season and rapid expansion of minor irrigation have made the people in the region to make a progressive shift to irrigation-based agriculture (BBS 2002). The study area (Longitude 88°43′13″ E to 88°52′23″ E and Latitude 23°48′44″ N to 23°57′16″ N : Figure 1) situated in the lower Ganges basin completely depends on groundwater for irrigation. More than 95% of the irrigation water in the study area comes from groundwater (BWDB 2000).

One of the major objectives of national water policy of Bangladesh Government is poverty alleviation through the introduction of special groundwater-based irrigation project (MPO 1991). It can be assumed that demand of groundwater resources will increase sharply in near future in the study area (Aktar et al. 2000).

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So, it is essential to identify the groundwater potential zones for future development of groundwater resources and its proper management.

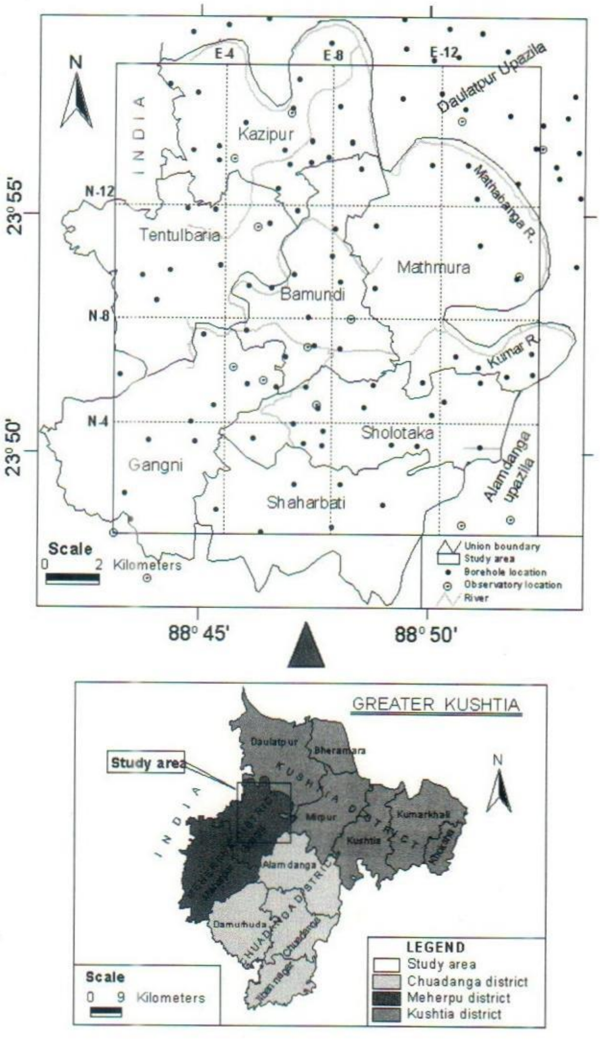


**Figure 1: Location map of the study area showing borehole and observatory positions along with profiles**

Groundwater movements in a geological system are controlled by lithology, stratigraphy and structure of the geologic formations (Karanth 1989). Therefore, hydrostratigraphic study is necessary to identify the groundwater potential zones (Rahman 2006). In the present work, the hydrostratigraphic investigation has been carried out for the identification of groundwater bearing zones for the future development of groundwater resources of the area studied. Borehole lithologs and groundwater fluctuation data have been used for this purpose. Three-dimensional geometry of sub-surface features has been developed to identify the potential groundwater bearing zones. Groundwater yield potential at different locations has also been estimated for spatial assessment of groundwater potential in the study area.

## General Features of the Study Area and Literature Review

The study area is comprised of 264.24 $km^2$. The area is almost plain, but there is a very gentle slope towards the south and southeast from the north. The river Mathabhanga, one of the tributaries of the Ganges, is the major source of surface water in the area. The geology of the area is alluvium type, composed mostly of clay, silt and fine sand, and is gray and brown in color (Haque, 2008).

The study area, like the rest part of Bangladesh, enjoys monsoon climate with seasonal wind reversal. Based on rainfall, temperature and pressure, a yearlong cycle can be broken down into the four seasons: winter (December to February), summer or pre-monsoon (March to June), monsoon (July to September) and autumn or post monsoon (October to November). The study area receives a high amount of rainfall with an average annual rainfall of 1563 mm. More than 72 % of the total rainfall occurs during monsoon (BWDB, 2000). The rest 28 % rainfall occurs due to western and northwestern depressions in winter and early summer. The study area experiences a mean temperature of 23°C with lowest of 6°C in the winter and highest of 43°C. The average relative humidity is 74.33%. As the average relative humidity is comparatively high, wet weather is observed in most part of the year. Therefore, the evapotranspiration is relatively low (Haque, 2008; Haque and Hasan 2001).

Number of works relating to the hydrogeological condition of the study area and its adjoining area has been carried out by several authors (MPO, 1991; Haque and Hasan, 2001, 2002; Momin, 2003; Ali 2006; Haque, 2008). All the previous researches were mostly focused the overall assessment of hydrogeology of the area. No research has been carried out so far on spatial assessment of groundwater potential in the area.

## Materials and Methods

Lithological log is one of the major components of hydrogeological studies. Total 105 borelogs and 15 observation well data distributed over the study area are collected from Bangladesh Agricultural Development Corporation (BADC), Kushtia, for the proposed study. The location of borelogs and observation wells are shown in Figure 1. The data are being processed, analyzed and interpreted with the aid of Rorkworks/2002 and SURFER (version 5.00) for quantitative and spatial hydrogeological study. The sub-surface geology has been studied up to the maximum depth of 97m. Lithological data are used to study the stratigraphy, hydrostratigraphic units, groundwater bearing zone, and spatial assessment of groundwater yield potential in the study area.

## Results and Discussion

### Stratigraphy

The three dimensional stratigraphic model of the study area prepared by using Rorkworks software is shown in Figure 2. The model shows that the area mainly consists of two sub-surface layers, namely a top clay-sit-sand layer and a sandy layer of different grain size. The sandy formation can be clearly sub-divided into fine, fine-medium, medium, medium-coarse, coarse sand and coarse sand-gravel. To observe the cross-sectional views in various parts of the investigated area different representative vertical cross-sections along the profiles of boundary, northeast-southwest, northwest-southeast, north-south and east-west directions have been prepared and presented in Figures 3, 4 and 5 respectively. These figures have been drawn considering the heights of different interfaces with respect to mean sea level (msl). These cross-sections furnish a clear picture of different stratigraphic units or layers underneath. The top clay-sit-sand layer, fine sand and coarse sandy layers are present everywhere, however fine-medium, medium sand, medium-coarse sand and coarse sand with gravel layers are distributed within a single thick sandy layer. From these figures it could be concluded that the sub-surface geology of the area is suitable for groundwater development provided the other conditions are satisfied.

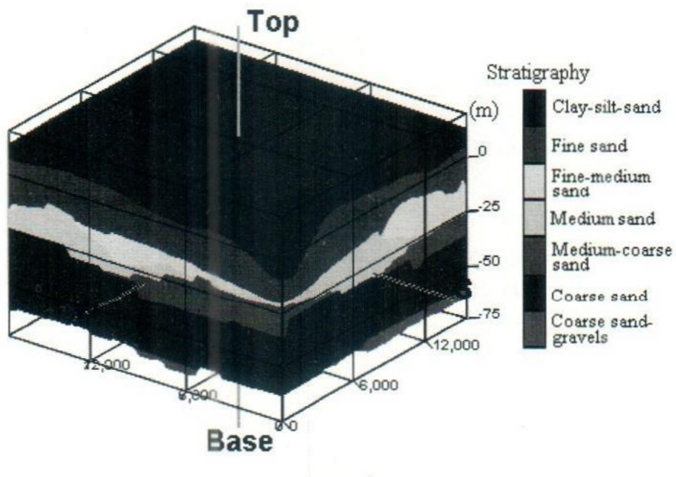


**Figure 2: Three-dimensional stratigraphic model of the study area**

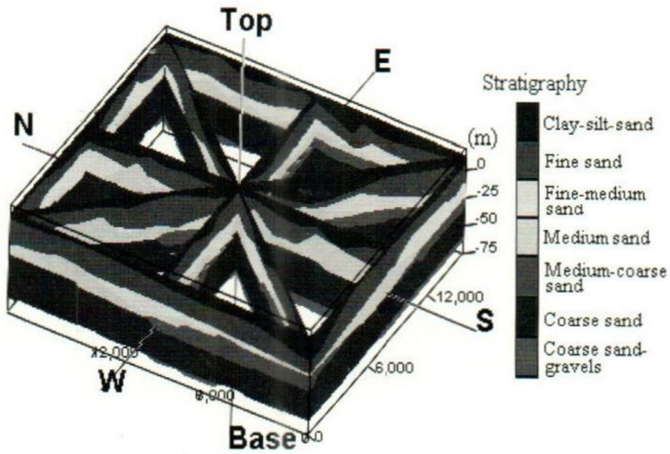


**Figure 3: Fence diagram along the boundary, corners and middle of the edges**

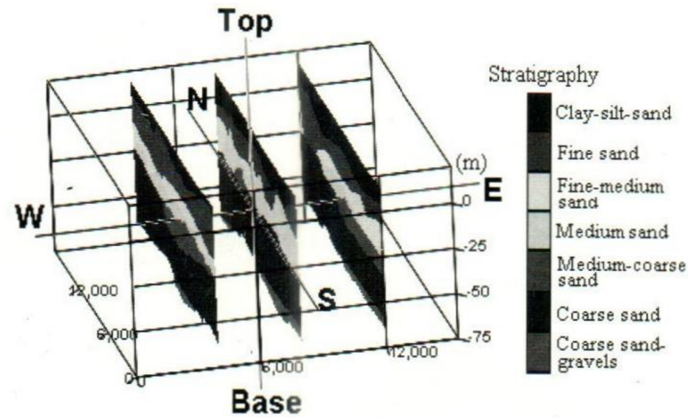


**Figure 4: Fence diagram along profile- E-4, E-8 & E-12 in the north-south direction at easting distance of 4km, 8km and 12km respectively**

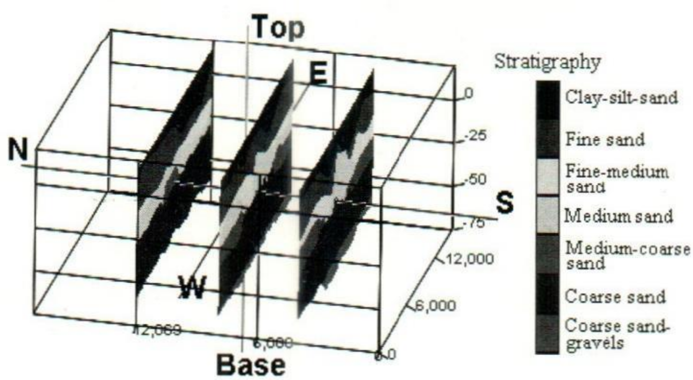


**Figure 5: Fence diagram along profile- N-4, N-8 & N-12 in the east-west direction at northing distance of 4km, 8km and 12km respectively**

**Hydrostratigraphic Units**

Hydrostratigraphy is the element of stratigraphy that deals with the groundwater bearing units. Considering the clay-sit-sand and fine sand as individual units and the rest sandy formations as aquifer materials the three dimensional stratigraphic model has been assembled as shown in Figure 6. Sub-regional stratigraphic sections along the corners and middle of the edges are shown in Figure 7. From the figure, the subsurface formations can be divided into three main layers such as first layer - consists of top clay-silt-sand, second layer - dominantly made of fine sand and third layer - consist of fine-medium, medium, medium-coarse, coarse sand and coarse sand with gravels.

On the basis of borehole information the groundwater bearing sequence of the area has been divided into main two hydrostratigraphic units: Aquitard and Aquifer.

This top layer mainly consists of recent alluvium of Quaternary age of the area is known as Aquitard. The shaded contour map of the thickness of this aquitard layer has been prepared and illustrated in Figure 8(a). In most of the places, the thickness of this layer lies below 16m, however there exists some 30m to 36m distributed mainly in the middle of the area to the middle of the south. The region containing the thick beds is not favorable for well development. This layer may be used as the groundwater source only for the dug wells as the permeability and productivity of this layer is very low.

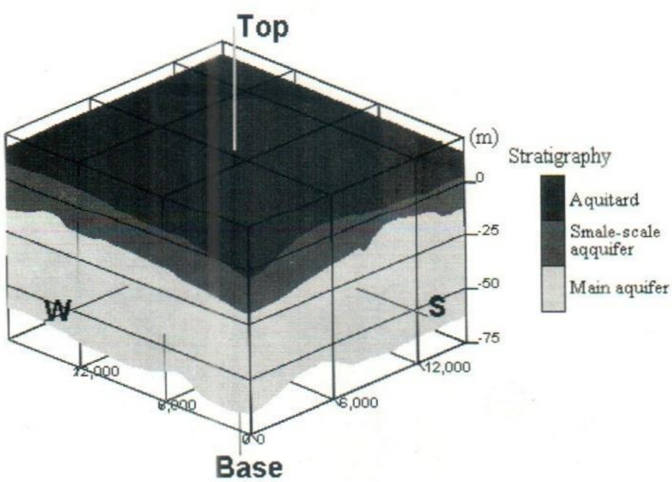


**Figure 6: Reconstructed three-dimensional stratigraphic model of the study area**

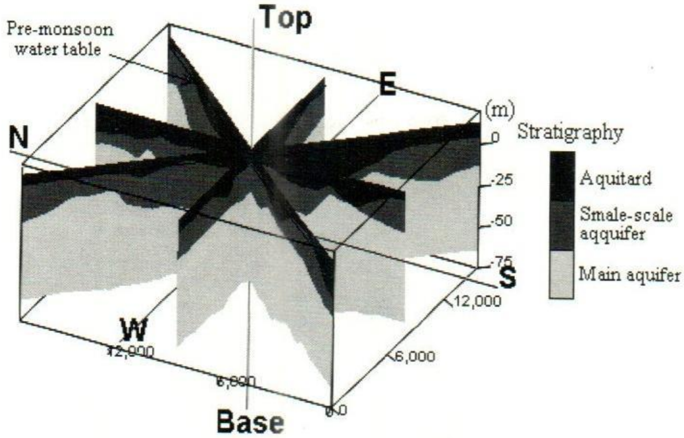


**Figure 7: Reconstructed fence diagram along the boundary, corners and middle of the edges**

The lithological data of the study area have confirmed the presence of aquiferic materials of different granular which may be divided into two categories:

(i) **Small-Scale Aquifer:** The borehole information indicates the existence of a layer consist of fine sand almost presence everywhere just below the surface layer. The shaded contour map of the thickness of this aquifer is shown in Figure 8(b). The thickness of this layer varies from 3m to 36m. However, almost in 50% of the area having thickens up to 14m is distributed along the middle from the north to south. The 36m thick bed is prevailing in the west, south and east sides. This layer may be used as the small-scale groundwater abstracting source for the dug, hand and shallow tube wells because of their medium permeability and productivity.

Groundwater level fluctuation data collected at 15 observation points are used to draw the pre-monsoon groundwater level within this subsurface formation as shown by black line in Figure 7. The positions of the water table of different observation wells confirm that the fluctuation of water table generally occurs within the aquitard, but in the extreme dry, the water table at some places goes down to the small-scale aquifer zone.

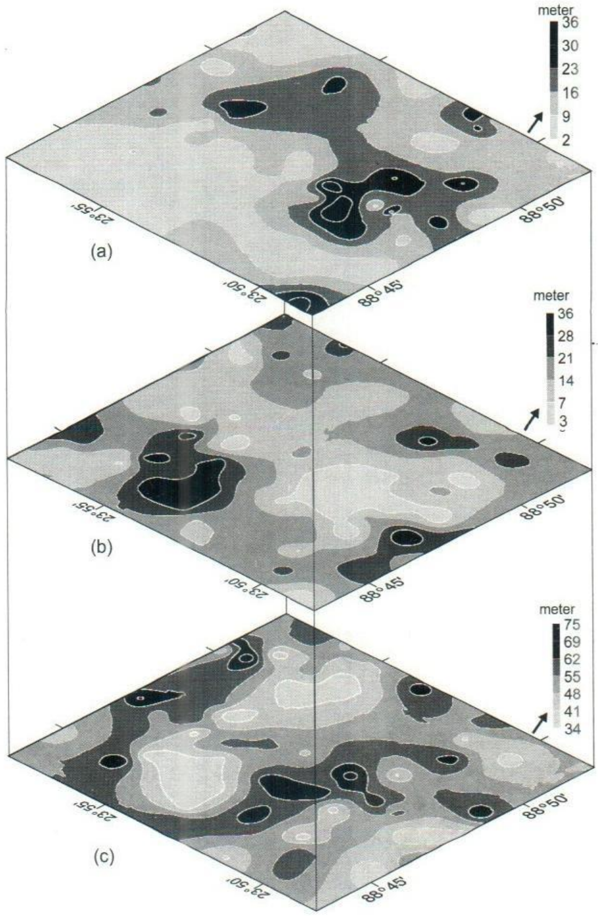


**Figure 8: Lateral variation of the thickness of (a) aquitard, (b) small-scale aquifer and (c) main aquifer**

(ii) **Main Aquifer***:* In the investigated area the main aquifer consists of fine-medium, medium, medium-coarse, coarse sand and coarse sand-gravels. This layer serves as the potential zone for groundwater storage and exploration. The position of the screen of deep tube wells are sunk within this zone. Considering the development potential of groundwater in the area, these formations can be considered as most productive source. Therefore, the assessment of the depth and thickness of this composition is of great importance in groundwater exploration in the area.

The thickness of the main aquifer of the study area has been estimated using the lithological information and presented in Figure 8(c). The thickness of this layer varies from 34m to 75m. However the thickness of this layer in almost 70% of the study area is below 51m. The depth of this layer varies between 6m to 50m in the area. The presence of thick main aquifer reveals the study area favorable for groundwater exploration.

**Hydrostratigraphic Correlation**

The vertical and lateral boundaries of hydrostratigraphic and lithostratigraphic units can be designated on the basis of significant breaks in their characteristics as are identifiable and traceable in the field (Harland et al. 1990). In this section an attempt has been made to group the existing groundwater bearing zones or aquifer system into recognized hydrostratigraphic units. Considering the chronology of different established formations, a generalized hydrostratigraphic succession is proposed and presented in the Table 1.

**Table 1: Hydrostratigraphic Correlation**

| Lithologic Description | Depth (m) | Thickness (m) | Aquifer Types |
|---|---|---|---|
| Clay with silt and fine sand at some places. | 0 | 2 – 36 | Aquitard |
| Fine sand with occasionally fine-medium sand at places. | 2 –36 | 3 – 36 | Small-Scale aquifer |
| Fine-medium, medium, medium-coarse, coarse sand and coarse sand-gravels. | 6 – 50 | 34 – 75 | Main Aquifer |

**Yield Potential Index**

Spatial distribution of combined aquifer to aquitard thickness ratio, termed as groundwater yield index, is presented in Figure 9. From this figure four distinct type yield potential zones have been demarcated in the study area. Predominantly aquitard with poor groundwater potential yield having values in the range of 0.3 to 1.0 occupy very small pocket in the Mathmura union of Gangni upazila. Moderate (1.0 to 15.0) and high (15.0 to 25.0) yield potential indices are distributed in most of the study area indicate a good groundwater yield potentiality. The higher groundwater potential zone of yield index 25.0–38.0 is existed in Daulatpur upazila, northeast corner of the study area. The yield potential index map can be used for selecting suitable well sites.

On the basis of above study, it can be summarized that the sub-surface geology and the aquifer system of the study area and their corresponding hydrogeological characteristics, in general are as follows:

i. Top layer made up of primarily clay and silt is characterized by high porosity, but low permeability. This layer is moderately thick.

ii. An intermediate layer consists primarily of fine sand. This unit is characterized by moderate porosity and permeability. In most places, this layer is exploited to produce water through hand tube wells and other manually operated pumping units for small-scale irrigation.

iii. A deeper layer comprising mainly sand, ranging from medium to coarse sand with gravel is known as the main aquifer. This aquifer is characterized by moderate porosity and high permeability. This layer is capable of providing large quantity of groundwater for irrigation.

The above three units are generally in hydraulic continuity and function as semi-confined to unconfined storage systems.

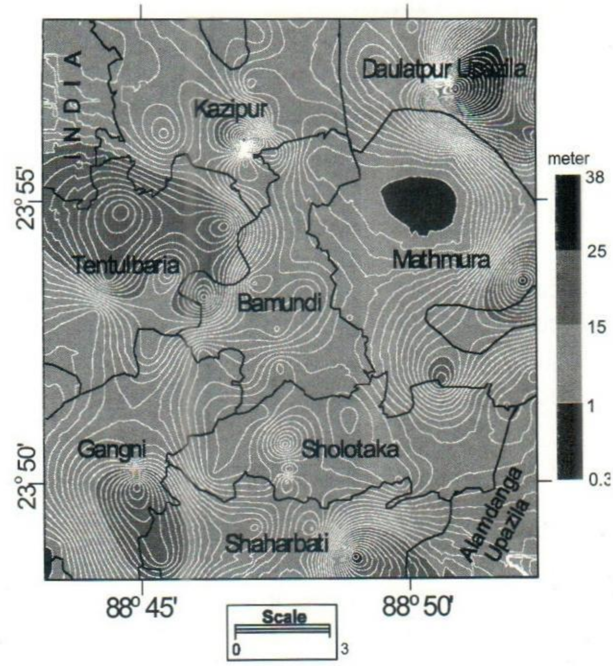


**Figure 9: Groundwater yield index map of the study area**

**Conclusion**

The subsurface discreteness of the investigated area has been studied from borehole lithologs. The stratigraphic cross-sections of the area reveal seven distinct hydrostratigraphic features in accordance of their vertical distribution and lithological composition. Two groundwater bearing sequences have been identified in the study area. The main aquifer consists of fine-medium to coarse sand-gravels with a varying thickness of 34m to 75m is identified at a depth of 6m to 50m. The position of water table at different observation wells confirms that the water table fluctuates within the aquitard in post-monsoon, but in the extreme dry it falls into the upper shallow aquifer at some places. Considering the development potential of groundwater in the area, the main aquifer can be considered as most productive zone. Spatial distribution of groundwater yield potential reveals that the area is favorable for future groundwater development.

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# FORMULATION OF REGRESSION MODELS FOR NUTRIENTS IN HIGHWAY STORMWATER RUNOFF USING EVENT AND SITE SPECIFIC VARIABLES

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**Tasnuva Rouf[4] and Michael K. Stenstrom[5]**

## Abstract

Regression models are formulated for data obtained from the University of California Los Angeles (UCLA) sites located in state of California during the wet seasons of 1999-2003. Three UCLA sites and a total of 59 storm events are used in this study. Rainy season in Southern part of California usually extends from October to May (i.e. mostly in winter season). Regression models were formulated for selected nutrients such as Ammonia, Total Kjeldahl Nitrogen (TKN), Phosphate, Nitrate ($NO_3^-$) and Nitrite based on their event mean concentrations (EMCs). Four event-specific parameters such as total rainfall (T_RAIN), maximum intensity of rainfall (MAX_RAIN), duration of runoff, and antecedent dry days (ADD) and three site-specific parameters such as runoff coefficient, area of the catchment, and average daily traffic were used as independent variables in the regression models. The physical characteristics of the drainage area and vehicular traffic are the dominant factors influencing the site-specific variables. Four forms of regression models, i.e., linear, exponential, semi-log and inverse, are used in the present study. UCLA site 2 exhibited highest minimum, median and mean concentrations for nutrient EMCs; whereas site 1 showed the highest values for maximum concentration. The mean regression coefficient ($R^2$) values for four types of regression models ranged between 0.34 and 0.47. T_RAIN and ADD were the most significant independent variables regarding probability value (p value). Inverse and semi-log forms of regression equations seemed to fit the data better. The $R^2$ values are the highest for TKN and lowest for $NO_3^-$, whereas, On the other hand, $R^2$ values are the highest for model 3 and lowest for model 2. In general for models 1 to 4, ADD has positive and T_RAIN has negative correlations with nutrient EMCs.

## Introduction

Pollutants accumulated on roadway surfaces are washed away by highway stormwater runoff affecting the quality of receiving water bodies. Stormwater runoff includes suspended solids, nutrients, ionic species, metals and organic constituents (Ball et al., 1998).

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Nutrients that reach receiving waters can cause toxicity to aquatic life, reduce oxygen level in water, cause unwanted odor and be responsible for loss of use. It does not attract public attention as it cannot be easily observed as in case of oil or grease and turbidity. Some nutrients present in small concentrations may even cause the water to become toxic (Barrett et al., 1998).

The nutrients measured in each study vary; however, most studies include at least one form of nitrogen and phosphorus. High nutrient loadings to aquatic systems are a concern because they can stimulate excessive algae growth. As this algae dies off and decomposes, dissolved oxygen concentrations in the water may decrease to levels that are harmful to aquatic organisms. Referred to as eutrophication (Beman et al., 2005; Breitburg, 1990; Lehman et al., 2004; Rabalais et al., 2001), this process is contributing to water quality problems.

Landuses with large number of vehicular traffic usually discharge more nutrients than other types of landuses. Hence transportation agencies seem to monitor nutrients level in their stormwater from vehicular-intensive landuses (Ha and Stenstrom, 2003). The vehicular emissions that accumulate on impervious highway surfaces are washed out during a rainfall event. Therefore, integrated management of nutrients in stormwater runoff from vehicular-intensive landuses such as highways has great potential to improve the water quality specifically to the receiving water bodies.

Highway stormwater runoff is discontinuous in time and only happens during and shortly after rainfall events. Highway runoff does not come from a single location, and in addition, depends on surrounding landuse and climatic conditions, and thus a typical non-point source (NPS). Some other examples of NPS pollution are agricultural runoff and atmospheric deposition. Usually the treatment of industrial and domestic wastewaters has been the major concern for the monitoring authorities (Ha and Stenstrom, 2003). Highways are known to be significant sources of NPS as obtained from various studies but in most of the cases, the extent of pollution, specifically that of nutrients is not quantified and often untreated.

To maintain safe and proper driving conditions and to reduce flood risk, highways usually have an efficient drainage system that conveys stormwater to nearby surface water bodies. However, this efficient conveyance system unfortunately delivers pollutants to nearby receiving waters. Typical highway pollutants include automobile and truck residues, for example, exhaust emissions, oil, abraded tire material, and brake dust; dry deposition from surrounding activities; pavement wear and tear; residues from maintenance operations; accidental spills, and litter (Khan et al., 2006). Stormwater pollutants can be divided into various groups, i.e. conventional parameters, organics, nutrients, ions etc. Stormwater runoff from highways often contains considerable amount of nutrients, which is the focus of this study.

Some nutrients are routinely monitored, such as ammonia, total Kjeldahl nitrogen (TKN, which is the sum of organic nitrogen and ammonia), phosphate, nitrate and nitrite. Various sources have been identified for different nutrients. Nutrients in stormwater runoff are present in many forms. Nitrogen is typically measured as ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, TKN, and total nitrogen. Phosphorus is typically measured as orthophosphate phosphorus (also reported as soluble reactive phosphorus, SRP) and total phosphorus. Among the various nutrients, ammonia, nitrate, nitrite, and orthophosphate are of dissolved forms.

Previous researches tried to investigate the relationship between pollutant load arising from highway stormwater runoff and relevant variables. Amount of traffic (such as average daily traffic, ADT), type of traffic (commuter, industrial, or construction), number of vehicles traveling during a storm event, number of vehicles traveled before a storm event, traffic congestion and vehicle speed are some of the important traffic-related factors. Precipitation-related factors include storm duration, amount of precipitation, antecedent dry period, and average or maximum hourly rainfall intensity during the storm event etc. Road conditions such as type of highway surface material and maintenance practices such as deicing, sanding, snow plowing may influence stormwater runoff pollutants. Landuse in the adjoining area also affects the pollutant grading in the stormwater runoff in the form of dry deposition (Khan et al., 2006).

One particularly important factor that may influence pollutant concentrations in highway runoff is the buildup of solids and other pollutants on pavement and in gutters between storms (Ma et al., 2002). This can cause the runoff to display first flush characteristics, meaning runoff in the early stages of the storm has the highest concentrations and a majority of the pollutant load (Gupta et al., 1996).

This research was undertaken to investigate some of the issues related to highway stormwater runoff, and had the following objectives:

1. To determine the event and site-specific independent variables that affect the build-up and wash-off phases of nutrients at three highway sites close to University of California, Los Angeles (UCLA) (hence referred to as UCLA sites 1, 2 and 3) in southern California
2. To develop predictive regression models for the combined UCLA sites that incorporates both the event and site-specific variables

**Literature Review**

The main sources of highway pollutants include atmospheric deposition, vehicular traffic and other direct and indirect depositions and applications. Particulates, Nitrogen, Phosphorus, metals, Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs) are pollutants related to atmospheric deposition.

Vehicular traffic is responsible for pollutants such as particulates, rubber, asbestos, metals, sulfates, bromide, petroleum, and PAHs (Barber et al., 2006). Other direct and indirect deposition and application causes particulates, nitrogen, phosphorus, metals, sodium, chloride, sulfates, petroleum, pesticides, and pathogens to be present in the highway stormwater runoff. Nutrients specifically nitrogen and phosphorus in highway runoff result from atmospheric deposition, fertilizer applications, dead plant material, road-kill, sediments, exhaust etc. (EPA, 1995).

Nutrients are often found in dissolved form. Based on previous studies, only total phosphorus shows a consistent relationship with suspended solids. Studies on factors affecting nutrients in highway runoff have found no correlation between ADT and nutrients (Barrett et al., 1995; Kayhanian et al., 2003). More important predictors of nutrients in highway runoff from previous studies are the number of vehicles during storms (Kerri et al., 1985) and other dry period conditions (Irish et al. 1998). However, because the primary sources of nutrients are atmospheric deposition and agricultural fertilizer applications, landuse is likely the most important factor influencing the concentrations of nutrients in highway runoff (Driscoll et al., 1990; Gupta et al., 1981).

Some forms of nitrogen and phosphorus display first flush characteristics. For example, a study by Yonge et al. (2002) in western Washington concluded that ammonia, TKN, and total phosphorus show strong first flush characteristics; whereas, nitrate and orthophosphate phosphorus do not.

Wu et al. (1998) analyzed stormwater data collected from highway sites in North Carolina and developed regression models for event mean concentrations (EMCs) of several water quality parameters such as total dissolved solids (TDS), total suspended solids (TSS) etc.; nutrients such as total Kjeldahl nitrogen (TKN), phosphorus (P), Ortho-phosphate ($PO_4^{3-}$), ammonia, nitrite ($NO_2^-$), nitrate ($NO_3^-$) etc.; and metals such as Cd, Cr, Cu, Pb etc. as a function rainfall, atmospheric deposition, and traffic counts. Kayhanian et al. (2003) presented regression models for several constituents for the Caltrans sites in terms of some event and site-specific variables. Regression equations were reported with p (probability) values only and developed for all the Caltrans sites as a whole. It did not report $R^2$ values for the regression models. Regression models developed for all the Caltrans sites usually would result in poor $R^2$ values because of differences in climatic, traffic and landuse conditions. The current research considers three UCLA sites with more forms of regression equations and different sets of predictor variables.

Most of the previous works generally used the EMC, which are used to represent stormwater pollutant concentrations (Huber 1993). The EMC is the flow-weighted average concentration collected over the entire storm event, and is equal to the total mass emission, divided the total runoff volume.

Mathematically the EMC can be represented by the following equation (Huber, 1993):

$$EMC = \frac{M}{V} = \frac{\int_0^T c(t)q(t)dt}{\int_0^T q(t)dt}$$

Here, event mean concentrations (EMC) expressed as mass (M) per unit volume (V); whereas, c(t) = concentration of grab sample and q(t) = flow rate associated with grab sample. This can be calculated by quantifying the concentration of flow over a period of time. EMCs are useful because mass discharge can be calculated by multiplying the total runoff volume and EMC, and avoid the high variability that is associated with grab samples (Ha and Stenstrom, 2003). They can also be correlated to landuse (Stenstrom et al., 1984; Sartor et al., 1974; Smullen et al., 1999).

## Methodology

### Data Source

Stormwater runoff at three sites (Table 1) close to University of California, Los Angeles (UCLA) campus was monitored as part of a larger project to determine the characteristics of highway stormwater runoff in California. The freeways are among the busiest in California with average daily traffic (ADT) ranging from 260,000 to 328,000 vehicles/day (Khan et al., 2006). The sites are typical of many freeways all around USA and are highly impervious (i.e. median runoff coefficient, RC = 0.81). The sites were all close to the UCLA campus so that it was convenient for the sampling teams to reach the sites prior to the initiation of runoff. The smallest was 0.39 ha and the largest was 1.69 ha in area. A total 59 storm events at these sites, during the rainy seasons (October to May) of 1999-00, 2000-01, 2001-02, 2002-03, and were used in this analysis. The nutrient EMCs were obtained from the flow-weighted grab samples.

**Table 1: UCLA site characteristics**

| Site | Location | Highway | Area(ha) | RC | Type of surface | ADT (vehicles/day) |
|---|---|---|---|---|---|---|
| 1 | Van Nuys | US-101 | 1.28 | 0.94 | Pavement | 328,000 |
| 2 | Getty Center | IS-405 | 1.69 | 0.71 | Pavement | 260,000 |
| 3 | Santa Monica Blvd. | IS-405 | 0.39 | 0.89 | Pavement | 322,000 |

(Khan et al., 2006)

### Sample Collection

Grab samples were used for this study. Samples were collected at 15 min intervals during the first hour of runoff and at 1 h intervals over the next 7 h. For those few storms that lasted longer than 8 h, additional grab samples were collected to capture the end of the storm. Then the EMC of nutrients were estimated and were used in the regression models.

**Data Analysis**

Linear, semi-log, exponential and inverse regression models were formulated for UCLA sites for various combinations of variables. The variables were classified into event and site-specific categories to study their individual effects. Variables that vary within a site are known as event-specific variables and variables that remain constant for a site but vary among different sites are known as site-specific variables. A 5-step approach was followed for the selection of independent variables for single or multiple sites:

1. The independent variables that have scientific relevance to the dependent variables were identified.
2. The set of independent variables was reduced by eliminating the perfectly collinear (i.e. $R^2 = 1$) variable(s).
3. Variables that cannot be identified with a high degree of accuracy were excluded.
4. Independent variables that revealed a high degree of correlation with other independent variables were recognized.
5. The independent variables with better correlation coefficients to the dependent variables were carefully chosen using a correlation matrix. (Khan et al., 2006)

In the first step, the set of independent variables that influence nutrient concentrations were divided into 5 categories, which included (1) storm-specific, (2) catchment-specific, (3) traffic-specific, (4) climate-specific, and (5) landuse-specific. The variables allied to storm comprise T_RAIN, duration of rainfall (D_RAIN), average intensity of rainfall (AVE_RAIN), maximum intensity of rainfall (MAX_RAIN), total runoff (T_RUN), duration of runoff (D_RUN), average runoff rate (AVE_RUN), and peak flow rate (PEAK_FLOW). RC and AREA are associated with specific catchment area. Traffic characterization variables include ADT, vehicles during a storm event (VDS), antecedent traffic count (ATC), and maximum/average vehicular speed. The ATC is obtained from the product of ADT and antecedent dry days (ADD). The climate-specific variables include ADD and temperature during a storm event. Lastly, the independent variables related to the landuse are atmospheric dry and wet depositions (Khan et al., 2006)

The second step was to identify perfectly collinear variables. Among the storm-specific variables, AVE_RAIN is obtained by dividing T_RAIN with D_RAIN. In the similar way, AVE_RUN is obtained from T_RUN and D_RUN. Therefore, we eliminated AVE_RAIN and AVE_RUN from our analysis.

The third step was eliminating variables that cannot be measured with great precision, e.g. D_RAIN. VDS is a useful parameter (Wu et al., 1998), but was not measured for the UCLA sites.

In the fourth step, the remaining variables were divided into two categories: (1) event-specific and (2) site-specific variables. For our case, the event-specific variables are dependent on the nature of a storm event, climatic and traffic conditions. T_RAIN, T_RUN, MAX_RAIN, PEAK_FLOW, D_RUN, ADD, and ATC were chosen as event-specific factors. Site-specific variables are usually considered constant for a single site but usually vary in among sites. They are dependent on physical characteristics of the drainage area and vehicular traffic. RC, catchment area (AREA), and ADT were identified as site-specific variables. (Khan et al., 2006)

The fifth step was to pick the independent variable from each set. The objective was to select one variable from each group to avoid correlation among independent variables. T_RAIN and MAX_RAIN were preferred over T_RUN and PEAK_FLOW since the former two variables can be obtained from simple rain gage data. ADD was chosen over ATC because ADD is simpler variable. T_RAIN, MAX_RAIN, D_RUN, and ADD were thus selected as event-specific variables, and RC, AREA, and ADT were selected as site-specific variables.

While forming regression equations first the variables were short listed with the aid of correlation matrices and then we selected 4 sets of models [i.e. Models 1 to 4 as shown by Eqs. (1) to (4)] each having four forms (i.e. linear, exponential, semi-log and inverse), and then coefficients of the variables were determined for nutrient EMCs:

$$Model1: EMC = a + b \cdot T\_RAIN + c \cdot MAX\_RAIN + d \cdot D\_RUN + e \cdot ADD \quad (1)$$

$$Model2: EMC = a + b \cdot T\_RAIN + c \cdot MAX\_RAIN + d \cdot D\_RUN + e \cdot ADD + f \cdot RC + g \cdot AREA + h \cdot ADT \quad (2)$$

$$Model3: EMC = a + b \cdot T\_RAIN + e \cdot ADD \quad (3)$$

$$Model4: EMC = a + b \cdot T\_RAIN + e \cdot ADD + f \cdot RC + g \cdot AREA + h \cdot ADT \quad (4)$$

The basis of formulation for models 1 – 4 is briefly explained in the following. Model 1 represents the effect of four of the most significant event-specific variables. Model 2 adds three significant site-specific variables along with the four event-specific variables. Model 3 represents the effect two of the most significant event-specific variables. Model 4 adds three significant site-specific variables along with the two event-specific variables.

Another point to note is that model 3 has only two variables (i.e. T_RAIN and ADD). It is imperative to have at least two causal variables in a stormwater quality regression equation; one representing the build-up mechanism (i.e. ADD) and the other relating the wash-off mechanism (i.e. T_RAIN). In addition, four forms were evaluated: linear form, as shown above; semi-log, where the log of the independent variable was used; inverse form, where the reciprocal of each independent variable was used; and exponential, where the exponential of the independent variable was used. Eqs. (5), (6), (7) and (8) are examples of the semi-log, inverse, exponential and linear forms for model 1.

$$EMC = a + b \cdot \log_{10}(T\_RAIN) + c \cdot \log_{10}(MAX\_RAIN) + d \log_{10}(D\_RUN) + e \cdot \log_{10}(ADD) \quad (5)$$

$$EMC = a + \frac{b}{T\_RAIN} + \frac{c}{MAX\_RAIN} + \frac{d}{D\_RUN} + \frac{e}{ADD} \quad (6)$$

$$EMC = a + b.e^{T\_RAIN} + c.e^{MAX\_RAIN} + d.e^{D\_RUN} + e.e^{ADD} \quad (7)$$

$$EMC = a + b.T\_RAIN + c.MAX\_RAIN + d.ADD + e.D\_RUN \quad (8)$$

Model 1 estimates nutrient concentrations as a function of all four event-specific variables. Model 2 complements model 1 with site-specific variables. The reason for presenting both equations was to show the improvement in the accuracy with the inclusion of site-specific variables. Model 4 complements model 3 with the sites-specific variables as well. After choosing the types and forms of the regression equations, we applied them to combined UCLA sites.

## Results and Discussion

### Characterization of Road Runoff

The results of 59 storm events are given for minimum, maximum, median and mean concentrations as shown in Table 2.

Due to multitude of influential parameters such as atmospheric deposition, varying traffic activities, seasonal changes as well as influences resulting from differing dry weather periods, rainfall intensities, and street sweeping; the runoff constituents are subject to fluctuations with a considerable number of outliers. This has also been observed in other studies (Sansalone et al., 1996; Gnecco et al., 2005; Brown and Peake, 2006). For all nutrients, the concentrations vary in orders of magnitude. In our estimation TKN was the most abundant nutrients followed by Ammonia and Phosphate.

It must be noted that comparability among these studies is limited due to different sample treatments and site specific conditions. For example some studies give their data as mean concentrations, sometimes the median values are given and sometimes the samples are filtered before analysis. Additionally, in many studies only small samples were collected (Gromaire et al., 2001; Gnecco et al., 2005), despite large catchments. Variations in runoff quality during storm events are frequently reported (Young et al., 1996; Mar et al., 1982).

**Table 2: Statistical Summary of Nutrient Concentration (mg/L) Analysis**

| Parameter | Unit | Site | n | Minimum | Maximum | Median | Mean |
|---|---|---|---|---|---|---|---|
| Ammonia | mg/l | 1 | 17 | 0.06 | 4.86 | 1.33 | 1.72 |
| | | 2 | 16 | 0.08 | 26.39 | 3.07 | 5.88 |
| | | 3 | 26 | 0.05 | 20.48 | 1.35 | 2.97 |
| | | Combined | 59 | 0.05 | 26.39 | 1.63 | 3.40 |
| $NO^{-}_{2}$ | mg/l | 1 | 17 | 0.06 | 1.06 | 0.22 | 0.35 |
| | | 2 | 16 | 0.07 | 1.02 | 0.24 | 0.32 |
| | | 3 | 26 | 0.03 | 0.84 | 0.13 | 0.19 |
| | | Combined | 59 | 0.03 | 1.06 | 0.17 | 0.27 |
| $NO^{-}_{3}$ | mg/l | 1 | 17 | 0.83 | 34.74 | 2.40 | 4.64 |
| | | 2 | 16 | 0.58 | 9.67 | 1.07 | 2.02 |
| | | 3 | 26 | 0.30 | 5.87 | 0.78 | 1.24 |
| | | Combined | 59 | 0.30 | 34.74 | 1.13 | 2.39 |
| $PO^{-}_{4}$ | mg/l | 1 | 17 | 0.03 | 1.95 | 0.06 | 0.21 |
| | | 2 | 16 | 0.04 | 1.50 | 0.09 | 0.26 |
| | | 3 | 26 | 0.03 | 0.55 | 0.06 | 0.12 |
| | | Combined | 59 | 0.03 | 1.95 | 0.07 | 0.18 |
| TKN | mg/l | 1 | 17 | 1.02 | 35.68 | 3.21 | 6.19 |
| | | 2 | 16 | 1.24 | 36.92 | 6.03 | 10.16 |
| | | 3 | 26 | 0.81 | 40.60 | 3.79 | 8.25 |
| | | Combined | 59 | 0.81 | 40.60 | 1.82 | 8.25 |

Minimum concentrations of Ammonia, $NO_3^-$ and TKN showed higher values for site 2 (i.e. 0.08, 0.58 and 1.24 mg/l respectively) followed by sites 1 and 3. For $PO_4^{3-}$, though minimum concentration was highest for site 2 (i.e. 0.04 mg/l), yet sites 1 and 3 showed equal values. For $NO_3^-$, highest minimum concentration was observed in site 1 (i.e. 0.83 mg/l) followed by sites 2 and 3. In general, minimum concentrations of ammonia, $PO^-_4$and $NO^-_2$ did not vary much for all the sites; whereas, $NO^-_3$ and TKN displayed some variations.
Maximum concentration of Ammonia showed highest value for site 2 (i.e. 26.39 mg/l) followed by sites 3 and 1. For $NO_2^-$, $NO_3^-$ and $PO_4^{3-}$, higher values of maximum concentrations were observed for site 1 (i.e. 1.06, 34.74 and 1.95 mg/l respectively) followed by sites 2 and 3. Maximum concentration of TKN showed highest value for site 3 (i.e. 40.60 mg/l) followed by sites 2 and 1.In general, maximum concentrations values for $NO^-_2$, $PO_4^{3-}$ and TKN did not vary much among the sites; whereas, Ammonia and $NO_3^-$ exhibited some variations.

Mean and median concentrations of Ammonia, $PO_4^{3-}$ and TKN showed highest values for site 2. For $NO_2^-$, median value was highest for site 2 (i.e. 0.24 mg/l); whereas mean value was highest for site 1 (i.e. 0.35 mg/l). In case of $NO_3^-$, median and mean concentrations showed highest values for site 1 (i.e. 2.40 and 4.64 mg/l respectively).

**Regression Analysis**

Results of regression analysis for various models and parameters along with different forms are presented in the following section. In general, the better the regression coefficient ($R^2$) is, the better is the accuracy of prediction for the dependent variable. On the other hand, the minimum the probability value (p value) is, the less is the impact of that particular independent variable on the overall regression equation.

In case of linear, exponential and semi-log models, the positive values for coefficients of event and site-specific variables indicate their positive correlation (i.e. increase in independent variable results in the increase of dependent variable) with nutrient EMCs. In case of inverse model, positive values for coefficients of event and site-specific variables indicate their negative correlation (i.e. increase in independent variable results in the decrease of dependent variable) with nutrient EMCs.

For model 1 (Table 3), four event-specific independent variables (i.e. T_RAIN, MAX_RAIN, ADD and D_RUN) were used. The average $R^2$ for the five nutrients is 0.44. Regression equation for TKN showed highest accuracy of prediction (i.e. $R^2 = 0.71$); whereas, $NO_3^-$ exhibited lowest accuracy (i.e. $R^2 = 0.24$). Inverse form of regression equation proved to be better for all the nutrients except $NO_2^-$ for which semi-log form was a better fit.

Regarding model 1, T_RAIN is the most prominent parameter for Ammonia (i.e. p value = 0.002) and ADD for $NO_2^-$ (i.e. p value = 0.001). MAX_RAIN exerts most influence on $NO_3^-$, $PO_4^-$ and TKN (i.e. p values of 0.151, 0.001 and <0.001 respectively).

The coefficients of independent variables (i.e. T_RAIN, MAX_RAIN, ADD and D_RUN) indicate that there are positive correlations between ADD and nutrient EMCs. The more the ADD, the more will be the time for nutrients to accumulate on road surface, the more will be the nutrient EMCs. In addition, there are negative correlations between T_RAIN and MAX_RAIN, and nutrient EMCS. The more the T_RAIN and MAX_RAIN, the more will be the dilution effect, the less will be the nutrient EMCs. D_RUN does not show any specific correlations with nutrient EMCs for model 1.

**Table 3: Regression analysis for Combined UCLA sites, Model 1**

| Model | Coefficient | | | | | p value | | | | | $R^2$ | Count | Parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Constant | T_RAIN | MAX_RAIN | ADD | D_RUN | Constant | T_RAIN | MAX_RAIN | ADD | D_RUN | | | |
| I | 0.412 | 15.866 | -1.084 | -0.564 | 4.355 | 0.674 | 0.002 | 0.864 | 0.542 | 0.308 | 0.58 | 59 | Ammonia |
| SL | 0.286 | -0.115 | -0.127 | 0.183 | 0.091 | 0.028 | 0.485 | 0.389 | 0.001 | 0.558 | 0.37 | 59 | $NO_2^-$ |
| I | 0.766 | 8.125 | 11.094 | -0.292 | -4.026 | 0.524 | 0.162 | 0.151 | 0.792 | 0.431 | 0.24 | 59 | $NO_3^-$ |
| I | -0.054 | -0.331 | 1.779 | -0.033 | 0.358 | 0.514 | 0.401 | 0.001 | 0.660 | 0.306 | 0.29 | 59 | $PO_4^{3-}$ |
| I | -0.864 | 13.016 | 43.674 | -0.647 | 9.741 | 0.613 | 0.125 | <0.001 | 0.676 | 0.204 | 0.71 | 59 | TKN |

Model E, I, L, S represents eq. model type exponential, inverse, linear, semi-log respectively.

For model 2 (Table 4), four event-specific (i.e. T_RAIN, MAX_RAIN, ADD and D_RUN) along with three site-specific independent variables (i.e. RC, AREA and ADT) were used. The average $R^2$ for the five nutrients is 0.34. Regression equation for TKN showed highest accuracy of prediction (i.e. $R^2 = 0.54$); whereas, $NO_2^-$ exhibited lowest accuracy (i.e. $R^2 = 0.19$). Semi-log form of regression equation proved to be better fit for Ammonia; linear form for $NO_2^-$ and TKN; and inverse form for $NO_3^-$ and $PO_4^{3-}$.

Regarding model 2, ADT is the most prominent parameter for Ammonia (i.e. p value = 0.017), T_RAIN for $NO_3^-$ (i.e. p value = 0.06) and RC for $PO_4^{3-}$ (i.e. p value = 0.031). ADD exerts most influence on $NO_2^-$and TKN (i.e. p values of 0.031 and 0.024 respectively).

In case of model 2, ADD shows positive correlation with nutrient EMCs. The more the ADD, the more will be the time for nutrients to accumulate on road surface, the more will be the nutrient EMCs. In addition, D_RUN shows negative correlation with nutrient EMCs. The more the D_RUN, the more will be the dilution effect, the less will be the nutrient EMCs. The other independent variables do not show any specific correlations with nutrient EMCs for model 2.

## Table 4: Correlation analysis for Combined site, Model 2

| Parameter | Model | Coefficient | | | | | | | | p value | | | | | | | | $R^2$ | Count |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Constant | T_RAIN | MAX_RAIN | ADD | D_RUN | RC | AREA | ADT | Constant | T_RAIN | MAX_RAIN | ADD | D_RUN | RC | AREA | ADT | | |
| Ammonia | SL | 231.525 | -4.999 | 0.694 | 2.191 | -1.233 | 3.106 | -1.962 | -40.885 | 0.014 | 0.133 | 0.811 | 0.038 | 0.704 | 0.716 | 0.449 | 0.017 | 0.39 | 59 |
| $NO_2^-$ | L | 0.296 | 0.110 | -0.278 | 0.171 | -0.254 | 0.055 | 0.078 | -5.847E-8 | 0.686 | 0.645 | 0.200 | 0.031 | 0.281 | 0.881 | 0.463 | 0.977 | 0.19 | 59 |
| $NO_3^-$ | I | 4.359 | 49.938 | -34.761 | -16.315 | 9.233 | -0.523 | | | 0.723 | 0.060 | 0.251 | 0.260 | 0.692 | 0.951 | | | 0.24 | 59 |
| $PO_4^{3-}$ | I | -1.499 | -0.369 | 2.218 | -0.279 | 0.598 | 1.108 | | | 0.041 | 0.779 | 0.180 | 0.714 | 0.635 | 0.031 | | | 0.34 | 59 |
| TKN | L | 40.286 | -1.100 | -10.144 | 4.586 | -8.057 | -3.690 | -1.023 | -4.504E-5 | 0.038 | 0.866 | 0.082 | 0.024 | 0.201 | 0.703 | 0.721 | 0.385 | 0.54 | 59 |

Model E, I, L, S represents eq. model type exponential, inverse, linear, semi-log respectively.

**Table 5: Regression analysis for Combined UCLA sites, Model 3**

| Model | Coefficient | | | p value | | | $R^2$ | Count | Parameter |
|---|---|---|---|---|---|---|---|---|---|
| | Constant | T_RAIN | ADD | Constant | T_RAIN | ADD | | | |
| I | 0.789 | 18.641 | -0.522 | 0.212 | <0.001 | 0.566 | 0.56 | 59 | **Ammonia** |
| SL | -0.690 | -0.275 | 0.289 | <0.001 | <0.001 | <0.001 | 0.44 | 59 | **$NO_2^-$** |
| SL | 0.148 | -0.239 | 0.269 | 0.326 | 0.008 | 0.002 | 0.30 | 59 | **$NO_3^-$** |
| SL | -1.105 | -0.226 | 0.356 | <0.001 | 0.014 | <0.001 | 0.36 | 59 | **$PO_4^{3-}$** |
| SL | 1.095 | -0.588 | 0.233 | <0.001 | <0.001 | 0.001 | 0.71 | 59 | **TKN** |

Model E, I, L, S represents eq. model type exponential, inverse, linear, semi-log respectively.

For model 3 (Table 5), two event-specific independent variables (i.e. T_RAIN and ADD) were used. The average R2 for the five nutrients is 0.47. Regression equation for TKN showed highest accuracy of prediction (i.e. R2 = 0.71); whereas, NO3- exhibited lowest accuracy (i.e. R2 = 0.30). Semi-log form of regression equation proved to be better for all the nutrients except Ammonia for which inverse form was a better fit.

Regarding model 3, T_RAIN is the most prominent variable for Ammonia (i.e. p value < 0.001) and TKN (i.e. p value < 0.001); whereas, ADD is the most influential variable for NO3- (i.e. p value = 0.002) and PO43- (i.e. p value < 0.001). For NO2-, both T_RAIN and ADD have significant influence (i.e. p value of <0.001 for both).

In case of model 3, ADD shows positive correlation with nutrient EMCs. The more the ADD, the more will be the time for nutrients to accumulate on road surface, the more will be the nutrient EMCs. In addition, T_RAIN shows negative correlation with nutrient EMCs. The more the T_RAIN, the more will be the dilution effect, the less will be the nutrient EMCs.

**Table 6: Regression analysis for Combined ULCA sites, Model 4**

| Model | Coefficient | | | | | | p value | | | | | | $R^2$ | Count | Parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Constant | T_RAIN | ADD | RC | AREA | ADT | Constant | T_RAIN | ADD | RC | AREA | ADT | | | |
| SL | 246.729 | -5.202 | 2.162 | 3.935 | -2.500 | -43.648 | 0.006 | <0.001 | 0.036 | 0.636 | 0.299 | 0.008 | 0.41 | 59 | Ammonia |
| L | -.0532 | -0.153 | 0.192 | 0.450 | 0.144 | $9.064E^{-7}$ | 0.271 | 0.006 | <0.001 | 0.065 | 0.037 | 0.485 | 0.37 | 59 | $NO_2^-$ |
| I | 3.490 | 31.281 | -11.529 | -1.361 | - | - | 0.756 | 0.022 | 0.388 | 0.868 | - | - | 0.27 | 59 | $NO_3^-$ |
| I | -1.238 | 1.360 | -0.601 | 1.087 | - | - | 0.066 | 0.064 | 0.420 | 0.030 | - | - | 0.32 | 59 | $PO_4^{3-}$ |
| L | 34.532 | -11.886 | 5.082 | -1.982 | -1.319 | $-4.946E^{-5}$ | 0.070 | <0.001 | 0.013 | 0.834 | 0.630 | 0.331 | 0.53 | 59 | TKN |

Model E, I, L, S represents eq. model type exponential, inverse, linear, semi-log respectively.

For model 4 (Table 6), two event-specific (i.e. T_RAIN and ADD) along with three site-specific independent variables (i.e. RC, AREA and ADT) were used. The average $R^2$ for the five nutrients is 0.38. Regression equation for TKN showed highest accuracy of prediction (i.e. $R^2 = 0.53$); whereas, $NO_3^-$ exhibited lowest accuracy (i.e. $R^2 = 0.27$). Semi-log form of regression equation proved to be better fit for Ammonia; linear form for $NO_2^-$ and TKN; and inverse form for $NO_3^-$ and $PO_4^{3-}$.

Regarding model 4, T_RAIN is the most prominent variable for Ammonia (i.e. p value < 0.001), $NO_3^-$ (i.e. p value = 0.022) and TKN (i.e. p value < 0.001). ADD exerts most influence on $NO_2^-$ (i.e. p value < 0.001) and RC on $PO_4^{3-}$ (i.e. p value = 0.030).

In case of model 4, ADD shows positive correlation with nutrient EMCs. The more the ADD, the more will be the time for nutrients to accumulate on road surface, the more will be the nutrient EMCs. In addition, T_RAIN shows negative correlation with nutrient EMCs. The more the T_RAIN, the more will be the dilution effect, the less will be the nutrient EMCs. The other independent variables do not show any specific correlations with nutrient EMCs for model 4.

**Table 7: Summary of $R^2$ values for Models 1, 2, 3 and 4 for Various Nutrients**

| Model 1 | Model 2 | Model 3 | Model 4 | Parameter |
|---|---|---|---|---|
| 0.58 | 0.39 | 0.56 | 0.41 | **Ammonia** |
| 0.37 | 0.19 | 0.44 | 0.37 | **$NO_2^-$** |
| 0.24 | 0.24 | 0.30 | 0.27 | **$NO_3^-$** |
| 0.29 | 0.34 | 0.36 | 0.32 | **$PO_4^{3-}$** |
| 0.71 | 0.54 | 0.71 | 0.53 | **TKN** |

The $R^2$ values are the highest for TKN (average value = 0.62) and lowest for $NO_3^-$ (average value = 0.26). On the other hand, $R^2$ values are the highest for model 3 (average value = 0.47) and lowest for model 2 (average value = 0.34).

## Conclusion

Regression models were developed for nutrients such as Ammonia, Nitrite ($NO_2^-$), Nitrate ($NO_3^-$), Phosphate ($PO_4^{3-}$) and total Kjeldahl Nitrogen (TKN) event mean concentrations (EMCs). Four event-specific parameters such as total rainfall (T_RAIN), maximum intensity of rainfall (MAX_RAIN), antecedent dry days (ADD) and duration of runoff (D_RUN) of 59 storm events occurring in three sites (i.e. UCLA sites 1,2 and 3) of Southern California during the rainy seasons (October to May) of 1999-2003 were used in the regression analysis. Finally, a comparison was made between the regression results in terms of regression coefficient ($R^2$), and probability value (p value). Additionally, the models were evaluated using linear, semi-log, exponential and inverse forms of the independent variables.

This paper provided mathematical relations that support the following conclusions:

1. Regarding minimum concentration, among the three UCLA sites, site 2 with the largest catchment area (1.69 ha) showed the highest nutrient EMCs. Site 3 with the smallest catchment area (0.39 ha) showed the lowest EMCs.
2. Regarding maximum concentration, site 1 showed the highest nutrient EMCs.
3. Regarding median and mean concentrations, site 2 once again showed the highest nutrient EMCs.
4. TKN was the most abundant nutrient followed by Ammonia and $NO_3^-$.
5. For model 1, four event-specific independent variables (i.e. T_RAIN, MAX_RAIN, ADD and D_RUN) were used. The average $R^2$ for the five nutrients is 0.44. MAX_RAIN seemed to be the most prominent parameter regarding p value.
6. For model 2, four event-specific (i.e. T_RAIN, MAX_RAIN, ADD and D_RUN) along with three site-specific independent variables (i.e. RC, AREA and ADT) were used. The average $R^2$ for the five nutrients is 0.34. ADD seemed to be the most prominent parameter regarding p value.
7. For model 3, two event-specific independent variables (i.e. T_RAIN and ADD) were used. The average $R^2$ for the five nutrients is 0.47. Both T_RAIN and ADD seemed to exert significant influence regarding p value.
8. For model 4, two event-specific (i.e. T_RAIN and ADD) along with three site-specific independent variables (i.e. RC, AREA and ADT) were used. The average $R^2$ for the five nutrients is 0.38. T_RAIN seemed to be the most prominent parameter regarding p value.
9. Inverse and semi-log forms of regression equations seemed to fit the data better.
10. The coefficients of independent (i.e. T_RAIN, MAX_RAIN, ADD and D_RUN) and dependent variables (RC, AREA and ADT) indicate if there are any positive correlations between them and nutrient EMCs. In general for models 1 to 4, ADD has positive and T_RAIN has negative correlations with nutrient EMCs. The more the ADD, the more will be the time for nutrients to accumulate on road surface, the more will be the nutrient EMCs. On the other hand, the more the T_RAIN, the more will be the dilution effect, the less will be the nutrient EMCs.
11. The $R^2$ values are the highest for TKN and lowest for $NO_3^-$. On the other hand, $R^2$ values are the highest for model 3 and lowest for model 2.

## Notation

AREA: catchment area

ADT: average daily traffic

ADD: antecedent dry days

p: probability value

R: regression coefficient

RC: runoff coefficient

ATC: antecedent traffic count

T_RUN: total runoff

D_RUN: duration of runoff

T_RAIN: total rainfall

EMC: events mean concentration

MAX_RAIN: maximum intensity

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Tech. J. River Res. Inst. 12(2): 34-44, 2014 (December)

# PHYSICAL MODELLING TO SUPPORT HYDRAULIC DESIGN OF RIVER TRAINING WORKS OF GANGES BARRAGE PROJECT

**Pintu Kanungoe[1], A. K. M. Ashrafuzzaman[2], Md. Alauddin Hossain[3] and Md. Johurul Islam[4]**

## Abstract

A physical model study for the river training structure of the proposed Ganges Barrage has been carried out at RRI to investigate the flow pattern and to determine the depth as well as extent of local scour around the groynes under different approach flow conditions. In this study, a stretch of about 9km and part width of the Ganges river covering two T-head groynes have been reproduced in the model. The model is a slightly distorted with horizontal scale of 1:150 and vertical scale of 1:100 and its boundaries are obtained from MIKE21C model. With the worst possible approach flow condition (stronger deflecting flow attack) very high flow concentration occurs near the upstream termination of T-head of both groynes and due to this high flow velocity and large scour depth occur there. The expected maximum velocity near the upstream termination of the T-head of both groynes is 4.2 m/s for the upstream groyne and 3.8 m/s for the downstream groyne. The expected minimum bed level that may occur near the upstream termination of the T-head of both groynes is -13.2mPWD for the upstream groyne and -11.1mPWD for the downstream groyne. For the upstream groyne the possible minimum scour level is found with falling apron in place.

## Introduction

River Research Institute has provided sub-consultancy services for carrying out physical model investigation to support the feasibility study and detailed engineering for Ganges Barrage Project. Under the framework of this study a comprehensive overall model investigation has been carried out covering about 53km reach of the Ganges and 10km stretch of the Gorai.

The suitable location, length and orientation of the proposed Ganges barrage have been determined from the overall model and MIKE21C model. It is observed from the overall model that in order to maintain favourable river approach to the barrage two T-head groynes will be needed along the left bank in the upstream of the barrage. The position, length and orientation of the groynes have been determined from the overall and MIKE21C model (Figure 1). Since both models are not effective in reproducing local details it is decided to conduct a detail model investigation to determine hydraulic design parameters of these structures. In this paper, the results and findings of the detail model study of river training structure of Ganges Barrage Study Project have been discussed. This type of detail model should either be undistorted or slightly distorted. The model covers a long reach with two huge structures. A slight distortion of the model is accepted to accommodate it within the available laboratory space at RRI.

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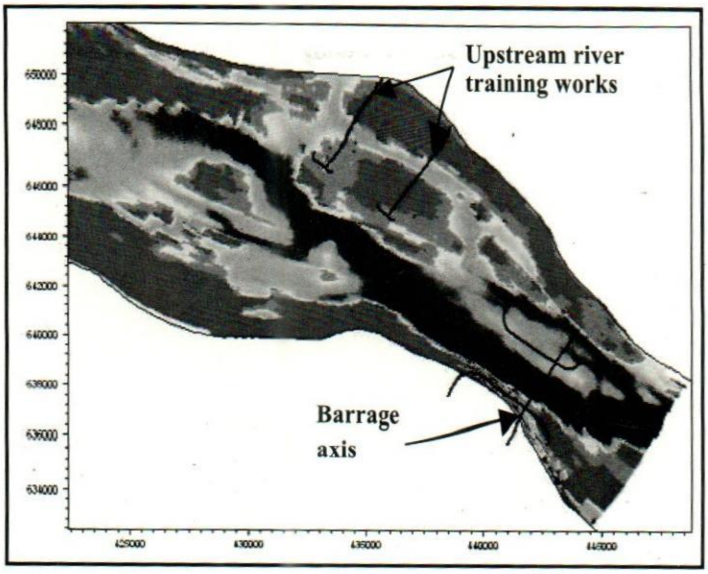


**Figure 1: Position, length and orientation of the upstream river training works**

Moreover, in shallow and long models there would be a significant difference in the actual velocity scale from upstream to downstream due to non-fulfilment of roughness condition. Acceptance of slight distortion helps avoid such problem to some extent. However, further tilting of the model has been done in an attempt to fulfil the roughness condition. The model is calibrated for bankfull discharge mainly to achieve correct distribution of velocity at the inflow section. The investigations are, however, made for 100 year discharge.

## Approach and Methodology

### Model Setup

The outdoor model facilities of RRI have been used for setting up the planned model. The detail model has been constructed in an open-air bed of 125m × 60m. The model setup includes model scale, model discharge, model grid, bathymetry and bank line, re-circulation system, gauging stations, tailgates, Sediment Feeding System, and existing and proposed structures. The layout of the model for river training is shown in Figure 2.

### Model Design

The model has been designed as a slightly distorted model mainly to serve the purposes of accommodating a long stretch of the Ganges covering to T-groynes within the available laboratory space at RRI and to fulfil the theoretical scale condition for roughness to some extent. In a too long sand bed model where model sand is almost similar to prototype sand there could be a significant difference in the actual velocity scale from upstream to downstream in the model due to non-fulfilment of roughness condition. This problem can be avoided by choosing a suitable distortion factor. However, such a large distortion may result in inaccurate reproduction of depth and extent of local scour at and around the structure.

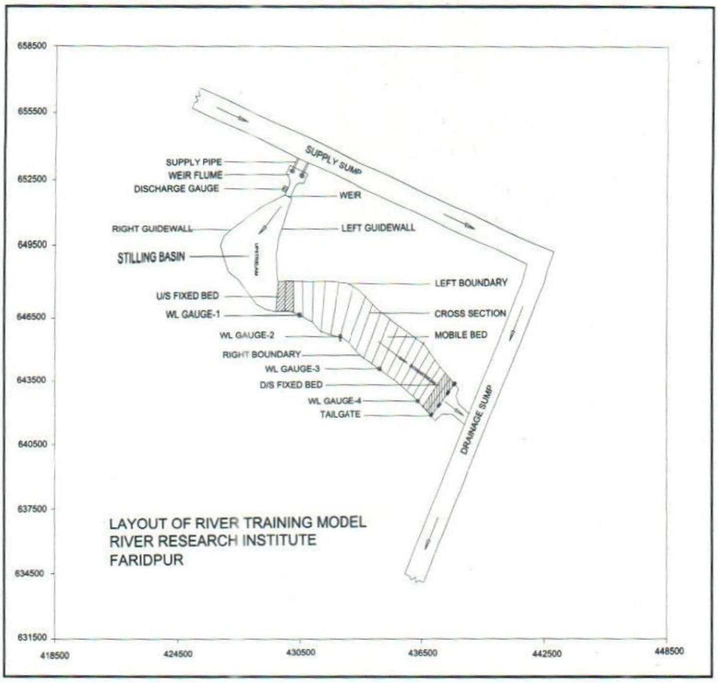


**Figure 2: Layout of the Detail Model for River Training Works**

Acceptance of a slight distortion does not have significant effect on accurate development of local scour but it may not be sufficient enough to fulfil the roughness condition. In order to avoid this problem tilting the model backwards has been considered. The model covers a reach of about 9 km and partial width of the Ganges. The width corresponds to about 15000 $m^3/s$ and 32000 $m^3/s$ of the Ganges bankfull and 100 year discharge respectively. The lateral boundary of the model is the flow line taken from MIKE21C model which corresponds to the above discharges. The model has been designed so that the scale conditions for simulation of flow field, sediment transport and local scour are satisfied. The scale conditions are described below:

*Geometric Condition:* The model should be preferably undistorted but a slight distortion is accepted due to aforementioned reason. It will not have much effect on model results.

*Flow Condition:* In the model the roughness condition ($C_r^2 = L_r/ h_r$) and Froude condition ($V_r = h_r^{0.5}$) should be satisfied.

*Sediment Transport Condition:* In the mobile bed model scale condition for sediment transport should be satisfied when, $V_m > V_{cr}$. $V_{cr}$ in the model is calculated using Van Rijn's formula: $V_{cr} = 0.19(d_{50})^{0.1} \log (12h/3d_{90})$ for $0.0001m \leq d_{50} \leq 0.0005m$. Here, $d_{50}$ = median particle diameter (m) and $d_{90}$ = 90% particle diameter (m). The critical flow velocity for median particle diameter of model bed sand (0.18mm) has been determined from the above equations. The investigations are aimed at the equilibrium scour depth with continuous sediment transport. The river training model, in principle, will not be affected by serious scale effects. A requirement in this type of model is that in the model sediment transport has to be occurred at all locations where sediment transport occurs in prototype. In order to fulfil this condition an increase in the model velocity has been considered so that sediment transport also occurs around the proposed groynes. In this situation the scour hole characteristics are not influenced by the size of the bed material or approach flow velocity. But, like on the prototype, it is influenced only by the flow pattern, the geometry of the structure and cross-section. Thus, live bed scour condition has been occurred in the model at which equilibrium scour depth is reached when, over a period of time, the eroded material equals the supplied material from upstream. The characteristic scale factors for different parameters (basic and derived) according to the Froudian law are shown in Table 1.

**Table 1: Scale factors for the basic and derived parameters**

| Parameter | Unit | Scale |
|---|---|---|
| Length (L) | m | 150 |
| Depth (h) | m | 100 |
| Velocity (V) | m/s | 10 |
| Discharge (Q) | $m^3$ | 150000 |
| Chezy-coefficient (C) | $m^{0.5}/s$ | 1.23 |
| Median grain size ($d_{50}$) | mm | 0.8 |
| Relative density (s) | - | 1 |
| Froude number (Fr) | - | 1 |
| Non-dimensional particle diameter ($D_*$) | - | 0.9 |

**Model Calibration**

The calibration of detail model for river training works is concentrated on the velocity distribution at the inflow section and sediment feeding. The velocity distribution at the inflow section in the model is an upstream boundary condition. For different discharges and approach channel conditions, this boundary condition is obtained from MIKE21C model. In the detail model the velocity distribution at the inflow section has been adjusted using hollow bricks.

The calibration test (T0) is conducted in existing condition i.e. without any proposed structures in place. The model bed is prepared based on 2010 bathymetry. Calibration of the model is done for a discharge of 15,000 $m^3/s$, which corresponds to the bankfull discharge for the selected width of the Ganges river. The velocity distribution at the inflow section is simulated at the upstream boundary of the model. The velocity at the calibration section (CS-13) is measured in the model and compared with the prototype values obtained from MIKE21C model. A comparison between these is shown in Figure 2. From this figure it is evident that the simulated values in the physical model are very close to the same simulated in MIKE21C model.

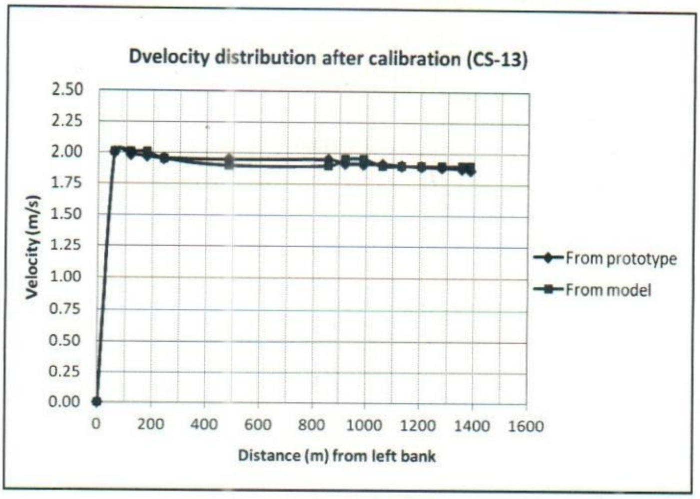


**Figure 2: Comparison of model and prototype (simulated in MIKE21C model) velocity distribution at the inflow section for bankfull discharge**

**Test Procedure**

5 (Five) application tests have been conducted with three possible approach flow conditions and with and without armour material on the upstream groyne in order to investigate flow pattern and depth of scour near the structures and to see stability of the armour material as designed against the flow attacks. The groynes are reproduced in the model as per design. The spacing between groynes is around 3.2km. The shank lengths are 4.2km and 3.81km having T-heads of 835m and 870m respectively. The surface of the groynes is made fixed by cement plaster. During the tests float tracks have been recorded to observe the flow lines. Water levels have been registered at four pre-fixed gauge locations of the model and based on the recorded water levels water surface slope in the model has been determined. It is observed that water surface slope in the model is about 10 (ten) times steeper than that in the prototype. It is happened due to difference in Chezy value between the model and prototype. This problem is, however, overcome by tilting the model. It is observed from the calibration test that the model discharge scaled according to Froude law is not sufficient enough to cause sediment transport in the model at all locations where sediment transport is supposed to occur in the prototype. This is because average velocity in the model with 100 year discharge scaled according to Froude law is 0.18 m/s, which is lower than the critical velocity for sediment transport (0.22 m/s). Therefore, an increase in the model discharge is needed to reproduce local scour phenomena around the structures. Manual sediment feeding has been done in order to assess the required rate of sediment feeding during the model run.

The developments in the river bed have been monitored by taking bed level measurements at 1(one) hour interval. It is a prerequisite that no bed erosion takes place at the inflow sections in the mobile bed. The required rate of sediment feeding has been determined based on bed level monitoring data. When the equilibrium scour condition is reached the model discharge is lowered to Froudian scale discharge and necessary flow measurements have been conducted. Velocity is measured using an A-OTT current meter whereas bed levels have been recorded from wires fixed at a known level.

## Test Results and Discussions

### Flow Pattern

Flow pattern near the upstream groyne for three possible approach flow conditions including existing one is shown in Figure 3. The angle of flow attack in existing condition is about 105°. The two other possible flow attacks include frontal flow attack by a parallel channel (90°) and a stronger deflecting flow attack by an outflanking channel (120°), which is considered as the worst possible approach flow condition for upstream groyne. With these flow attacks on the upstream groyne the downstream groyne is found to have always come under deflecting flow attacks (>90° attack angle) of varying degrees. It is happened due to variation in the extent of flow intrusion in the groyne field under different possible angles of attack on the upstream groyne. The flow lines near the groynes under the worst possible flow attack (120°) on the upstream groyne appear in Figure 4. Parallel flow along the upstream termination of the T-heads is observed for deflecting flow attacks by an outflanking channel. For all possible approach flow conditions the maximum velocity is found to have occurred near the upstream termination of the T-heads. The magnitude of maximum flow velocity for different flow attack conditions appears in Table 2.

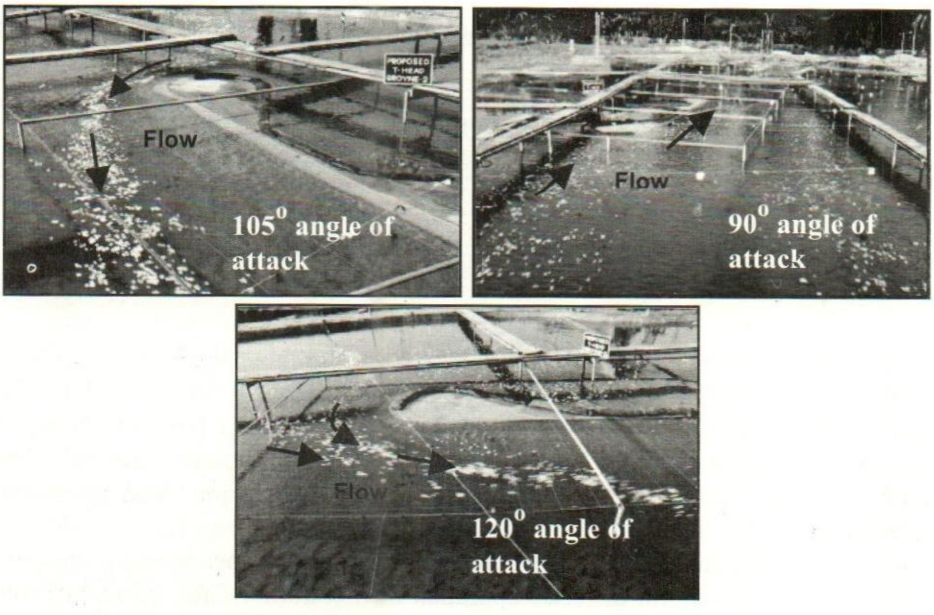


**Figure 3: Flow pattern near the upstream groyne under different approach flow conditions**

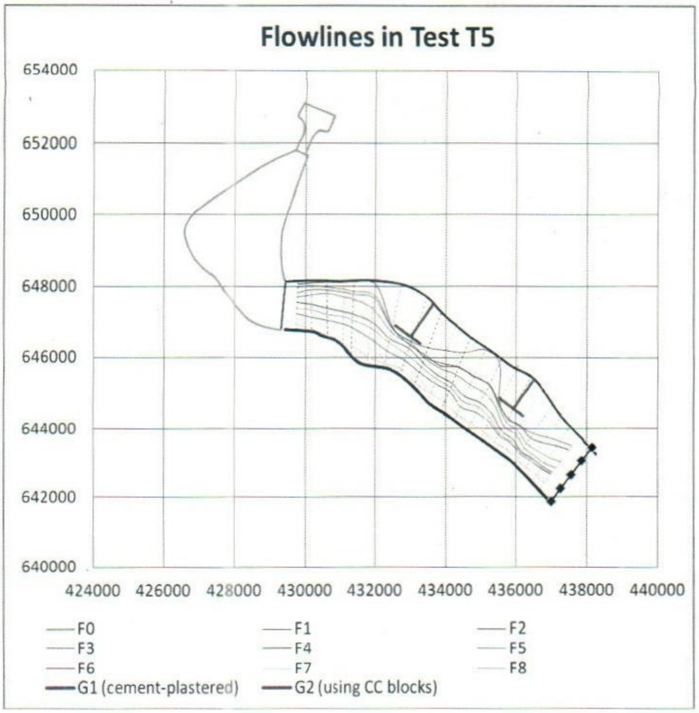


**Figure 4: Flow lines near the groynes for the worst possible angle of attack on the upstream groyne**

**Table 2: Maximum velocity near the upstream termination of T-heads of the groynes for different approach flow conditions**

| Angle of flow attack on the upstream groyne in degree | Maximum velocity at the upstream termination of T-head in m/s | |
|---|---|---|
| | Upstream groyne | Downstream groyne |
| 90 | 2.8 | 3.1 |
| 105 | 3.4 | 3.0 |
| 120 | 4.2 | 3.8 |

**Scour Depths**

During the tests development of bed levels with time at critical locations has been recorded with respect to wires fixed at a known level. When the model has achieved equilibrium scour condition the water depth at maximum scour point has been recorded and corresponding minimum bed level is determined. For $90^{o}$ angle of attack on the upstream groyne the local scour situation near the upstream termination of the T-head of downstream groyne is shown in Figure 5. Maximum water depths recorded near the upstream termination of T-heads and corresponding minimum scour levels for different approach flow conditions are shown in Table 3.

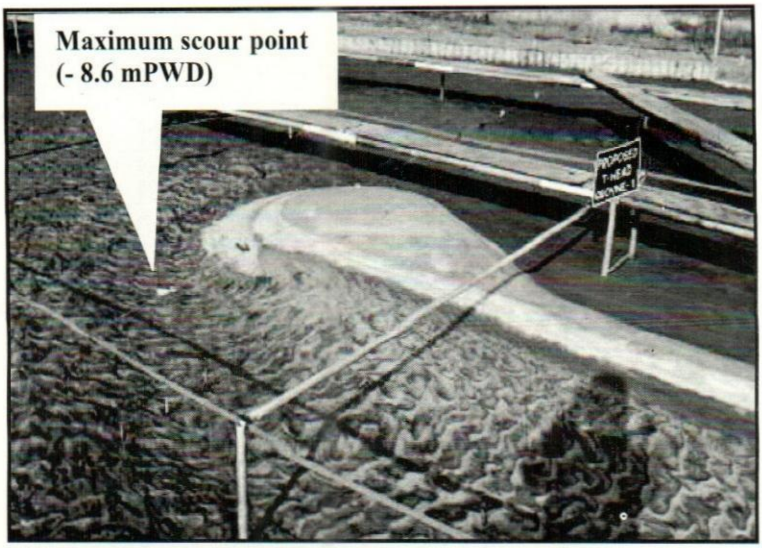


**Figure 5: Scour pattern near the upstream termination of downstream groyne for frontal flow attack ($90^0$) on the upstream groyne**

It is noticeable from the information presented in Table 3 that under the worst possible approach flow condition the minimum scour level near the upstream termination of T-head of upstream and downstream T- groynes can be as low as -13.2mPWD and -11.2mPWD respectively.

**Table 3: Maximum water depths and minimum scour levels near the upstream termination of T-heads of the groynes for different approach flow conditions**

| Angle of flow attack on the upstream groyne in degree | Maximum water depth (m) / minimum scour level (mPWD) at the upstream termination of T-head | |
|---|---|---|
| | Upstream groyne | Downstream groyne |
| 90 | 24/-10.2 | 20/-6.6 |
| 105 | 20/-6.2 | 22/-8.6 |
| 120 | 27/-13.2 | 24.5/-11.2 |

The observed scour depths are not directly comparable to prototype values owing to slightly distorted model and the associated scale effects. Therefore, the results obtained in the model can not be translated directly to the prototype value.

**Stability of Armour Materials**

The upstream groyne is provided with armour materials (cc blocks) and launching apron as per design (Figure 6). Tests have been conducted to observe the stability of the armour materials as designed and also the launching behaviour of the falling apron against the expected velocity and local scour that may occur against different angles of flow attack.

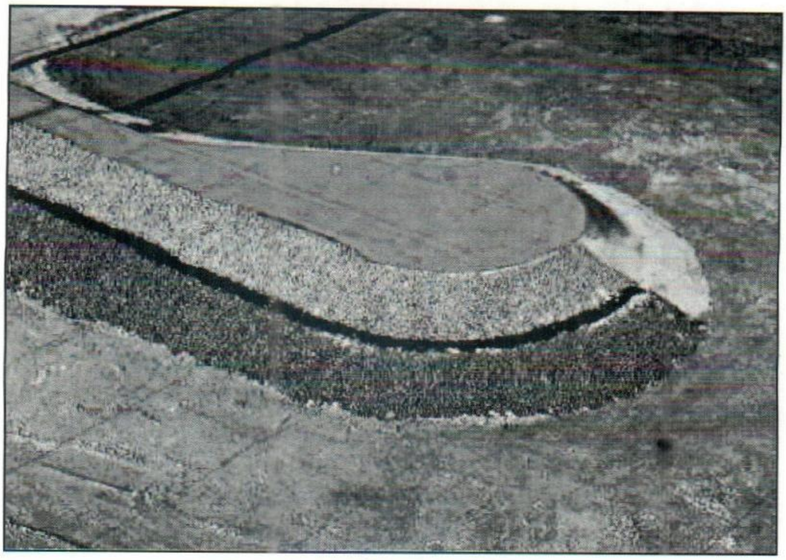

**Figure 6: Placement of armour materials as per design on the upstream groyne**

It is observed that for $90^{0}$ and $105^{0}$ angle of attack the armour materials as designed remain fully intact against flow velocity and the falling apron (laid on bed at a level of -5mPWD) near the upstream termination of T-head only gets partially exposed due to local scour. On the other hand, for the worst possible attack condition the armour materials at the high velocity area remain almost intact barring displacement of a few blocks from their positions. However, the falling apron materials around the upstream termination of the T-head get completely exposed and launch to some extent as shown in Figure 7. It appears from the test results that the adopted slope of the groynes (1V:5H) is appropriately selected for avoiding development of excessively deep scour hole near the groynes.

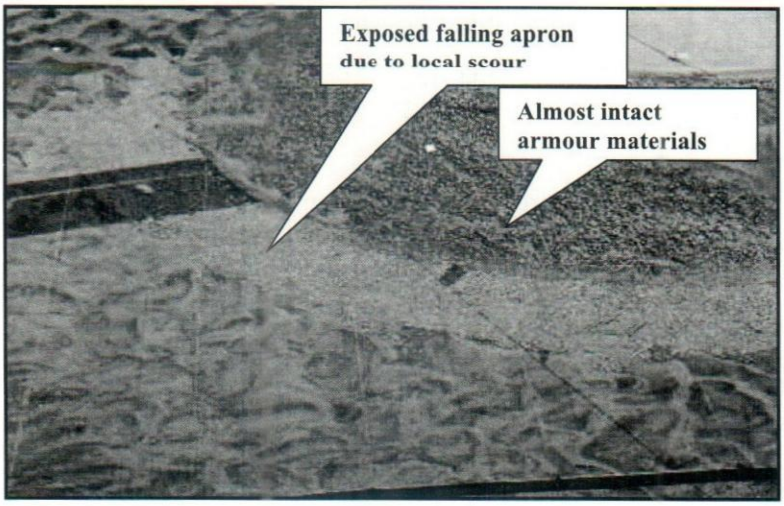


**Figure 7: Scour pattern near the upstream termination of the upstream groyne under the worst possible flow attack condition**

Due to model distortion and the associated scale effects, the observed scour depths are not directly comparable to prototype values. The results found in the model are more qualitative than quantitative. Scale effects are inherent in such type of distorted morphological model that use fine sand as bed material; however, it is notable that the impact of these scale effects will be similar in the tests conducted for different components of River Training Works. These qualitative results can be used in combination with results from the associated numerical model studies. Detailed (undistorted) sectional model is recommended to assist in developing a final design for different components of River Training Works.

## Conclusions and Recommendations

### Conclusions

- For existing approach flow condition, the upstream head of the upstream T-groyne comes under deflecting flow attack. The downstream T-groyne also comes under comparatively weaker similar flow attack. There could be some flow entrance in between the two groynes under this condition.
- Under a possible approach flow condition resulting in frontal flow attack on the upstream groyne more flow enters into the groyne field (in between the groynes). As a result, the downstream groyne comes under comparatively stronger deflecting flow attack.
- Model test results show that the cover layer materials (cc blocks) of the groyne as designed remain stable in both flow attack conditions (deflecting and frontal). On the other hand, against worst possible approach flow (about 120° attack angle and 100 year discharge) condition they remain almost stable.
- The expected maximum velocity near the upstream termination of the T-head of both groynes is 4.2 m/s for the upstream groyne and 3.8 m/s for the downstream groyne.
- The expected minimum bed level that may occur near the upstream termination of the T-head of both groynes is -13.2 mPWD for the upstream groyne and -11.1 mPWD for the downstream groyne. For the upstream groyne the possible minimum scour level is found with falling apron in place.
- The falling apron along the upstream termination of the T-head of upstream groyne gets exposed by bed scouring and launching of the falling apron occurs to some extent for 100 year discharge and at attack angle of 120°.
- The slope at the groyne head (1V:5H) appears to have considerable effect in reducing depth and extent of local scour near the same.

**Recommendations**

- The proposed layout of the river training works (T-groynes) appears to be suitable for guiding the river flow towards the proposed Ganges barrage.
- The hydraulic design of the river training works (T-groynes) may be based on the hydraulic design parameters obtained under this model study.
- Under water constructional aspects of the river training works has not been investigated in this model study.
- If any unexpected developments are observed during the construction and operation phases of the river training work it might be addressed by further physical model testing.

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# TECHNICAL ANALYSIS OF SHALLOW TUBE WELL IRRIGATION EQUIPMENT: A FIELD STUDY IN GHATAIL THANA OF TANGAIL DISTRICT

**Md. Alauddin Hossain[1], Md. Abul Ala Moududi[2], Mohammad Raju Ahmed[3], Rayhan Hayat Sarwer[4], Md. Wakilur Rahman[5] and Afroza Sharmin[6]**

## Abstract

Generally farmers use Shallow Tube Well (STW) equipments for irrigation purpose in Bangladesh. A field survey was carried out in January-March, 2008 in Dighalkandi union (covering five mouza) under Ghatail Thana of Tangail District with a view to examine the technical aspect such as BHP, pump discharge, channel characteristics and performance of STW irrigation equipments in operating the irrigation system. The study revealed that the Brake Horse Power (BHP) for diesel engines varied from 5 to 12 hp and electric motor varied from 5 to 10 hp, though the command areas are more or less equal for both the prime mover. The study also revealed that two types of irrigation equipment viz diesel operated STW (DOS) and electricity operated STW (EOS) were mainly used in the study area for groundwater abstraction. In 1997, DOS was 76% and EOS was 24%; while in 2007, it was 46% and 56% respectively. EOS has been increasing due to upward trend of diesel price. The technical aspect analysis & performance of STW equipments in irrigation business and some policy implications about the development of STW irrigation business have been recommended in this paper.

## Introduction

Bangladesh, the most densely populated country in the world suffers from food deficiency for a long time and it is the major challenge of the Government since liberation for increasing food grain production to meet up the growing demand. Moreover, the economy of the country is dominated by agriculture and the livelihoods of the farmers are largely depended with intensive agriculture production. To meet up the increasing demand, intensive land use is a pre-requisite criterion to overcome this food deficiency. Boro rice is the main crop of the country due to its high production rate. It can be said fairly that increase of Boro rice production remains a significant possible way to increase total food production and ensure food security in the country. Boro rice produced in Rabi season (dry season) and mainly irrigation was used for this crop. The country has abundant water in the wet season but limited water in dry season. There are two major sources of irrigation water in Bangladesh - surface and ground water.

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In 1970s, irrigation was mainly dependent on surface water, but during the last two decades the area irrigated by groundwater increased significantly. Boro rice alone contributed the highest of total rice production in 2007 (BER 2007). About 80% of groundwater used for crop production where Boro paddy alone used 73% of total irrigation. Ground water covers 75% of total irrigated area alone. To extract the ground water, two types of irrigation equipment such as Shallow Tube Well (STW) and Deep Tube Well (DTW) are mainly used for groundwater irrigation where 60% areas are covered by STW (BBS 2006). Coverage of STWs irrigation areas increased by about 17% during last 6 years from 2000/01 to 2005/06 (BER 2006). As a result, it is observed that the farmers singly or jointly used STW to irrigate their land. Although farmers basically install STW to irrigate their own land, but they also sell water to other farmers. This is assumed that they sell water commercially to earn profit like in other businesses. Following the process of STW irrigation development a form of business has been established in rural Bangladesh. These STWs are operated by diesel and electricity. Electricity operated STWs have been increasing due to upward trend of diesel price. In changing situation over time, some issues regarding ground water irrigation extracting by STWs need to be studied thoroughly in order to improve the irrigation business in Bangladesh. Keeping in mind of above-cited issues the following objectives were undertaken to conduct this study. The specific objectives of the study are:

1) To examine the technical aspect and performance of STW in the study area.
2) To assess the implication of mismatches between engines and pumps in operating the irrigation system.
3) To draw recommendations for policy making guidelines for sustainability and cost effective of STW irrigation business.

## Literature Review

Bangladesh is the largest delta in the world. It has fertile agricultural land and abundant water in the wet season but limited water in dry season. There are two major sources of irrigation water in Bangladesh-surface and ground water. In 1970s, irrigation was mainly dependent on surface water, but during the last two decades the area irrigated by groundwater increased significantly. Up to 1992, there was a tube well sitting regulation that required obtaining government permission for sinking irrigation wells and at that time there was 0.389 million STW used for irrigating 1.392 million ha land. But in 1992 when government suspended the sitting regulations and selling of STW was handed over to the private sector, the use of STW increased rapidly. As a result in 2006, 1.129 million STWs were used to irrigate 3.160 million ha of land (MOA, 2006). During the last 14 years (from 1992 to 2006) the irrigation scenario in Bangladesh has changed with more use of ground water and the number of STW has increased many times (MOA, 2006).

Irrigation covered about 34% of total cultivated area of Bangladesh. Moreover, intensive land use is directly related with availability of irrigation facilities to the farmers. The groundwater resource is one of the key factors in making the country self sufficient in food grain production. Groundwater access was increased by about

26% during last 5 years which enhanced the farmers' productivity. Moreover, Boro production is increasing at about 1% annually (BBS 2007). So, developments of irrigation facilities are the crucial issue to increase and sustain Boro production. Different types of irrigation technologies are being used in Bangladesh but the extent of success varies due to geographic location, climatic condition, economic status, soil texture, land elevation, and availability of ground water.

After liberation period, irrigation equipments (STW and DTW) were imported in Bangladesh from different countries by the Government. At that time, the farmer's choices were previously limited to a few brands of diesel engine such as Yanmar 70, Yanmar 105; Kubota 90 and Mitshubishi from Japan, Dongfen from China, Dedong from Korea and Kirloskar from India. But when government suspended importation ban on small engines and selling of STW was handed over to the private sector with the elimination of import duties on irrigation equipment and the relaxation of engine standardization in 1987, these all have promoted the importation of STW engines with cheaper price. As a result, following the liberalization policy, the cheaper and smaller engines from China have developed a large market in the country and are widely used in STW irrigation scheme. These engines have a relatively wide range of horse power and are gradually replacing the aging Japanese ones. Farmers can now choose from a variety of engine capacities to suit their needs at prices which appear to be within the means of many more prospective owners. Although this new breed of inexpensive Chinese engines is reputed to be less durable and more vulnerable to frequent breakdowns (than those which were previously imported), but their low price has been immediately popular amongst farmers (Mandal and et all, 1996).

An issue complicating such as an evaluation, however, is that engines are found at times to be coupled with pumps of different sizes with varying capacities. In attempting to abstract groundwater from various depths (to a maximum total head of 9 m) through STWs, attention is often not paid to the brake horse power requirement. For instance, STW pumps with a design discharge of 20 liters per second and capable of working against a head of 9 m might be found coupled to engines of capacities as low as 3 HP and as high as 18 HP. Obviously, pumping plant efficiency in the field can be expected to vary widely under such conditions. The incidence and implications of such mismatches must be explored in an evaluation of the technical characteristics of minor irrigation equipment and of system management and strategy (Mandal and et all, 1996).

## Methodologies

### Selection of Study Areas

Agriculture is the main driving force of income generated for Gross Domestic Product (GDP) growth of the country. Boro paddy is the main high yielding crop of the country, which alone contributed the highest of total rice production in 2007 (BER 2007) and it is cultivated in winter/dry season by groundwater irrigation. At present, major irrigation system of the country mainly depends on STWs.

Considering this, the study area was chosen from an intensively irrigated area in the north-east Bangladesh, which falls under the Indo-Gangetic basin region. Five adjacent mauzas namely Shekhsimul, Saitapara, Kurmushi, Kaijalipur and Kagmaribeltail of Digar Union under Ghatail Upazila, Tangail were selected for this study. Boro paddy is the main crop of this area, which is cultivated rabi season by groundwater irrigation. The irrigation system of the area mainly depends on STW technology and STW irrigation business has raised up markly in the study area. It is noted here that a detail study about irrigation business was conducted in Dighol Kandi union as one of the study areas in Bangladesh during 1993-96. So, it was a great opportunity to analyze the information in a comparative situation.

**Data Sampling Techniques, Sample Size and Data Collection Procedure**

Both STW owners and irrigators (water buyers) have been chosen as samples for this study. Complete survey technique was used for the STW owners. A total of 71 STW owners were found in the area operating their STW business. Out of 71 STW owners, data were collected from 64. Two-stage stratified random sampling technique was used to collect data from the irrigators (water buyers). Firstly, 20 STW owners were selected randomly from all and then five water buyers were also randomly chosen from each of the selected 20 STWs. During the selection of 20 STWs, equal weight was given to Diesel Operated STWs (DOS) and Electricity Operated STWs (EOS) to assess the performance of business in both cases. So a total of 164 samples (64 STW owners, 50 DOS water buyers and 50 EOS water buyers) were used for this study.

To understand the technical aspect and performance of STW equipments and to assess the implication of mismatches between engines and pumps, between discharge and size of distributional channel in operating the irrigation system the related data (such as BHP, energy consumption, frequency and nature of breakdown of engines & motors, measurement of field channel, flow velocity etc.) were collected from the 30 STW owners through a prescribed questionnaire of the study areas. STW owners were also asked about their opinion on the quality of the equipment and on their preference between different brands. Additionally 4 set of checklist were prepared for conducting Focused Group Discussions (FGD) with rural STW/motor mechanics, spare parts sellers, installation mechanics, local workshop owners, complementary input dealers, irrigation equipment traders and support service providers.

The primary data were collected through two sets of interview schedule from STW owners and water buyers in January and February 2008. The locations of STWs were collected in the field by using Global Positioning System (GPS) and plot them on the mauza maps by identifying each plot. The secondary data were collected from Bangladesh Bureau of Statistics (BBS), Bangladesh Economic Review (BER), Bangladesh Water Development Board (BWDB), Center for Environmental and Geographic Information Services (CEGIS) and Department of Land Records and Survey (DLRS).

## Data Analysis, Result and Discussion

### Location of the Study Area

The study area is within Dighalkandi union, which is under Ghatail Upazila of Tangail district in Bangladesh. The area is situated between latitude $24^0$ 25' 17.5" longitude $89^0$ 57' 26.84" and longitude $89^0$ 59' 10.10" latitude $24^0$ 24' 08.55". The study area comprises five Mauzas of Dighalkandi union (Figure 1). The Mauzas are 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. This Mauza map is actually cadastral map and it is similar to villages in terms of area. The total study area is about 376 hectares (CEGIS Muaza GIS database, 2008).

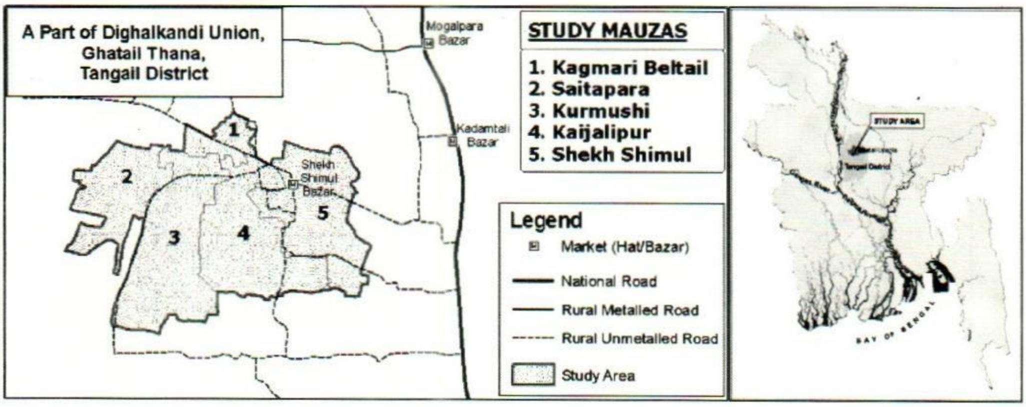


**Figure 1: The location of the study area (*Source:* CEGIS Muaza GIS database, 2008)**

### Spatial Distribution of STWs and Energy Use

The STW business dynamics is changing in the study area like any other business. Therefore, changing phenomenon of tubewell locations and corresponding command areas also took place. There was 68 tubewells in 1997 (Mandal, 1997) in the study area. Among these only two were Deep Tubewells (DTW), one in Kaijalipur and the other one in Saitapara mauza. In 2006-07 irrigation period, the total number of tubewells rose to 71 with only one DTW was working in Kaijalipur mauza. The spatial distribution of the tubewells of 1997 and 2007 are shown in Figure 2a and distribution of diesel and electricity operated tubewells of 2007 are shown in Figure 2b of the study area. Among the 68 tubewells in 1997, 52 tubewells (76 percent) were run by diesel and the remaining 16 (24 percent) by electricity (Table 1). Whereas in 2006-07 irrigation period, only 31 tubewells (44 percent) were run by diesel and 40 (56 percent) by electricity (Table 1). It is evident that electricity driven tubewells are increasing. Table 1 shows that EOS was increased by 32% during the last 10 years.

Table 1: Mauza-wise number of tubewell and their energy use

| Mauza | Number of STW | | Energy Use | | | |
|---|---|---|---|---|---|---|
| | 1997 | 2007 | 1997 | | 2007 | |
| | | | Diesel | Electricity | Diesel | Electricity |
| Kagmari Beltail | 3 | 4 | 2 | 1 | 2 | 2 |
| Kaijalipur | 11 | 11 | 4 | 7 | 0 | 11 |
| Kurmushi | 27 | 21 | 25 | 2 | 10 | 11 |
| Saitapara | 12 | 17 | 12 | 0 | 14 | 3 |
| Shekh Shimul | 15 | 18 | 9 | 6 | 5 | 13 |
| Total | 68 | 71 | 52 | 16 | 31 | 40 |

*Source:* Field survey January, 2008

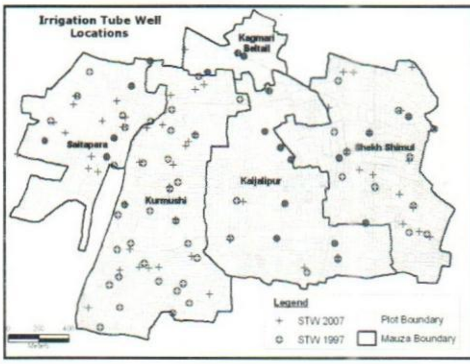


**Figure 2a: Shallow Tubewell (STW) locations of 1997 and 2007.**

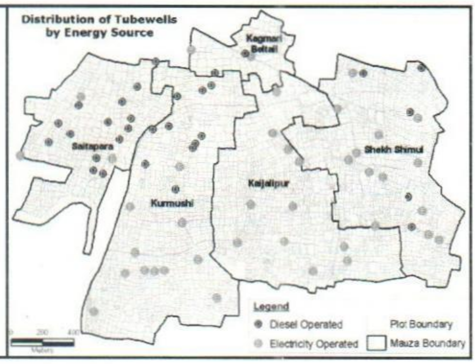


**Figure 2b: Distribution of diesel and electricity operated tubewells in 2007 of the area.**

Figure 2b shows that the diesel operated tubewells are mainly concentrated in the northwestern part of the study area i.e. mainly Saitapara and northern part of Kurmushi mauzas. This is probably because these villages are far away from the existing electricity transformers or point of connection. Other socio economic reasons could not be identified in this study.

## Characteristics of STWs Irrigation Equipment

### Brake Horse Power (BHP)

It is often asserted that, because of the import liberalization policy, engines and motors of different BHP are being imported and that this equipment is being used by farmers without consideration to the actual power requirements under the prevailing field conditions. In this study, the Brake Horse Power (BHP) of the engines and motors did, in fact, varied a great deal. For diesel engines the horse power ranged from 5 to 12 hp for STW (Table 4.1a). Similarly, electric motor power for this system ranged from 5 to 10 hp (Table 4.1b). These wide ranges would indicate a somewhat indiscriminate selection of prime mover power.

**Table 4.1a: Nominal Brake Horse Power (BHP), Revolutions Per Minute (RPM) and fuel consumption by diesel operated STWs in the study area.**

| BHP range (HP) | Country of origin (Number) | Average nominal RPM | Average diesel consumed (liter/hr) |
|---|---|---|---|
| 5.0-6.0 (15) | China (9) | 2041 | 0.568 |
| | Japan (3) | 1864 | 0.934 |
| | Unknown(3) | 2200 | 1.000 |
| 7.0-7.5 (2) | China (2) | 2100 | 1.00 |
| 8.0-12.0 (5) | China (2) | 2088 | 0.871 |
| | Japan(2) | 1940 | 1.004 |
| | Unknown (1) | 2200 | 0.903 |
| Unknown (7) | China (1) | - | 1.000 |
| | Japan (5) | - | 1.130 |
| | Unknown (1) | 1733 | 1.000 |

Note: Figure in parenthesis indicates number of cases.
*Source:* Field survey, 2008

**Table 4.1b: Nominal Brake Horse Power (BHP), Revolutions Per Minute (RPM) and electricity used by electrically operated STWs in the study area.**

| BHP range (HP) | Country of origin (Number) | Average nominal RPM | Average electricity consumed (kwh/hr) |
|---|---|---|---|
| 5.0-5.5 (11) | China (3) | 1426 | 6.00 |
| | Japan (2) | 2500 | 8.00 |
| | England (1) | 1465 | 8.00 |
| | Unknown (5) | 1417 | 7.00 |
| 7.0-7.5 (19) | China (10) | 1440 | 8.00 |
| | Japan (2) | 2500 | 6.00 |
| | England (4) | 2200 | 7.00 |
| | Unknown (4) | - | 7.00 |
| 8.0-12.0 (4) | China (3) | 1448 | 5.12 |
| | Unknown (1) | 1500 | 7.00 |
| Unknown (1) | Unknown (1) | 1500 | 7.00 |

Note: Figure in parenthesis indicates number of cases.
*Source:* Field survey, 2008

**Breakdown of the Diesel Engine**

The breakdowns of engines were either major or minor depending on which part broke or malfunctioned. Failure of bearings or breakage of crankshaft and replacement of piston assemblies were the major ones and affected irrigation. Minor breakdowns such as replacement of oil seals, nozzles, plungers etc. were, however frequent (IIMI-BSERT, 1996). The repairs of major breakdowns were often delayed due to lack of availability of workshop facilities in the rural areas. The repairs of minor breakdowns were easily repairable by the rural mechanic subject to availability of replacement parts in the local market. From the Focus Group Discussion (FGD), it is seen that the aged Japanese engines had broken down more frequently than the cheaper (but newer) Chinese engines. The average breakdown duration was 2-3 days for diesel engines.

## Performance of STWs Irrigation Equipment

### Pump Discharge

The average pump discharge of the 30 STW was 19.31 liter/sec measured in 3rd week of January, 2008. The discharge range of 30 STWs was 10.00 to 26.72 liter/sec in the study area based on pump-engine capacity. For diesel engines, the average discharge was 19.06 liter/sec and for electric motors, the average discharge was 19.69 liter/sec (Table 4.2). Both discharges are similar due to similar characteristic aquifer in the study area. Though same BHP of engine and same diameter of installation pipe, discharge may be varied due to strainer length & position (vertically), type of aquifer, height of drawdown etc.

**Table 4.2: Pump discharge for diesel engine and electric motor in the study area.**

| Type of Prime Mover | Average discharge (liter/sec) |
|---|---|
| Diesel Engine | 19.06 |
| Electric Motor | 19.69 |

*Source:* Field survey, 2008

To determine pump discharge volume method was followed. A simple method of measuring small irrigation streams is to collect the flow in a container of known volume for a measured period of time. An ordinary bucket or barrel is used as the container. The time required to fill the container is recorded with a stop watch. We have used a barrel as a container and stop watch as a time counter. The rate of flow was measured by the following formula.

$$\text{Discharge rate (litres/sec)} = \frac{Volume\ of\ container}{Time\ required\ to\ fill}$$

### Water Productivity (WP)

Water Productivity means the amount of water needed to produce one unit of crop irrigated. The average Water Productivity of the study area was 0.28 Kg/M$^3$ for both engines. For diesel engine, the average Water Productivity was 0.30 Kg/M$^3$ and for electric engine, the average Water Productivity was 0.27 Kg/M$^3$ (Table 4.3). Zahid (2006) research finding stated that the average WP for *Boro* crop was 3.70 Kg/M$^3$, which is almost similar with this study.

**Table 4.3: Water Productivity of 30 STWs in the study area for diesel and motor engines.**

| Type of Engine | Water Productivity (Kg/M$^3$) |
|---|---|
| Diesel | 0.30 |
| Electric | 0.27 |

*Source:* Field survey, 2008

### Land Productivity (LP)

The average command area of STW was 1.74 ha and the average land productivity was 4800 Kg/ha for both engines. There was little difference in paddy yield under diesel and electric engine due to load shading and breakdown of some transformers during the irrigation period (2007) (Table 4.4). But this yield difference was not statistically significant (t=1.6). The average yield of the *Boro* paddy was 5152 Kg/ha was observed from another study (Zahid, 2006), which is almost similar with this study.

**Table 4.4: Land Productivity of 30 STWs in the study area for diesel and electric engine**

| Type of Engine | Average C/A (ha) | Land Productivity (kg/ha) |
|---|---|---|
| Diesel | 1.31 | 4932 |
| Electric | 2.16 | 4668 |

*Source:* Field survey, 2008

## Water Distribution System

### Channel Characteristics

There is almost rectangular/trapezoidal characteristic of channel in the study area. All field channels in the study area were Kutccha (made by clay soil) and it was sufficient to carry the water for irrigation purpose. There was not observed a overtopping during the operation of the pump. However, in some case it seemed that distribution channel (surface area or cross-section area) is higher than required area.

### Measurement of Field Channel

The field channel measurement and flow velocity of 30 STWs (30 command area) were taken in the study area. The channel length depends on command area and shape of command area. The average command area of 30 STW is 3.31 hactares. The average flow velocity was measured 0.614 m/sec. It is also measured that the length of channel ranged from 179.573 to 685.975 m with an average 424.90 m, channel top width ranged from .405 to 0.869 m with an average 0.56 m, average width of channel ranged from 0.360 to 0.765 m with an average 0.5 m, and channel height ranged from 0.152 to 0.229 m with an average 0.18 m (Table 4.5). There is scope for improvement of channel dimension to save land as well as water losses. It is possible to save potential cultivated land and water loss by reducing width of distribution channel, which is shown in Table 4.6.

**Table 4.5: Average channel length, surface area and X-section area in the study area**

| Average C/A (ha) | Surface Area of Channel | | | X-section area of Channel | | | Estimated Discharge ($m^3$/sec) Area*velocity |
|---|---|---|---|---|---|---|---|
| | Length (m) | Top width (m) | Area ($m^2$) | Av. Width (m) | Av.ht (m) | Area ($m^2$) | |
| 3.31 | 424.90 | 0.56 | 244.70 | 0.5 | 0.18 | 0.09 | 0.055 |
| Remarks: 0.055 $m^3$/sec > 0.01913 $m^3$/sec (measured discharge) | | | | | | | |
| 3.31 | 424.90 | 0.28 | 122.36 | 0.25 | 0.18 | 0.045 | 0.027 |
| Remarks: 0.027 $m^3$/sec > 0.01913 $m^3$/sec (measured discharge) | | | | | | | |

*Source:* Field survey, 2008

## Mismatch Analysis among STWs Equipments

The mismatch among the STW equipments settings generally used by the pump owners in the study areas is shown in Table 4.6.

**Table 4.6: Pearson correlation coefficients among engine capacity (HP), pipe diameter, pump discharge and surface area of channel**

| Variables | Discharge | Engine capacity (HP) | Pipe diameter | Surface area of channel |
|---|---|---|---|---|
| Discharge | 1.00 | - | - | - |
| Engine capacity (HP) | 0.03 | 1.00 | - | - |
| Pipe dia | - 0.08 | 0.25 | 1.00 | - |
| Surface area of channel | - 0.32 | 0.11 | 0.33 | 1.00 |

*Source:* Field Survey, 2008

Table 4.6 revealed the following technical silent feature about the STW irrigation system in the study areas.

a) Mismatch between engine and pump capacity happened due to the nominal RPM of many engines/motors were much higher than the designed capacity of the respective pumps. To save the pump or to avoid any breakdown of pump blade, the owners had to reduce the engine speed considerably. As a result, the engines could not run with a full load capacity consuming lower amount of fuel, which caused lower discharge.

b) Mismatch between discharge and engine capacity was found quite higher because the owners purchased their engines in different times and used for different durations, which may reduce pump and engine efficiency.

c) Mismatch between discharge and area of distribution channel, the main reason is the lack of awareness of the farmers. Pump owner makes channel on the other farmers land. On the other hand, farmer has no complain about channel making. He prepares it widely with out any consideration regarding potential cultivated land loss as well as water loss.

d) Maximum matching between HP and pipe diameter was found in the study area, though it was mismatch practically (r=0.25). The overall mismatch mainly occurred due to lack of technical knowledge and information of the farmer, mechanics, equipment traders and installers.

# Conclusions and Recommendations

**Conclusions**

The following conclusions are summarized from the study of STW irrigation business:

a. Most of the engines/motors were found of Chinese due to cheaper and availability in the local market. Chinese engines have taken control over the local markets and replaced the more expensive Japanese engines.

b. Engines/motors belonging wide ranges of capacity were found in use in STW irrigation business, though the discharge, water productivity, land productivity and command area were almost equal. These wide ranges capacity indicates improper selection of engines/motors or prime mover power with the fitted pump due to lack of technical knowledge between the STW owners, mechanics, installers and traders.

c. Mis-matches between engine/motor & pump, discharge with BHP and discharge with surface area of distribution channel were observed in the field.

d. Diesel Operated STW (DOS) are gradually replaced by Electrically Operated STW (EOS) which demands the gradual increase of electric power.

**Policy Implications (Recommendations)**

The following recommendations are made to improve of STW irrigation Business in Bangladesh:

a. Duty free import and free market distribution for required capacity of irrigation equipments should be continued.

b. To minimize mismatch of equipments and to keep the irrigation units (STWs) functioning smoothly, training and technical information should be provided by the government agency to the STW owners, mechanics, installers and equipment traders. This provision would help farmers to minimize/rationalize their costs of irrigation.

c. Diesel price should continue to be subsidized to sustain irrigation water selling business. Availability of diesel and rising in diesel price in peak period of irrigation were reported. The government should monitor the diesel price to ensure diesel supply in proper time at the fixed price.

d. The present situation demands the increase of uninterrupted electricity supply to the study area. To fulfill this demand, government should take necessary steps to minimize cost of electricity connections fee and improve the non-metering billing system.

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# OPTIMIZATION OF GUIDE BUNDS FOR THE PROPOSED GANGES BARRAGE BY PHYSICAL MODELLING

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## Abstract

Ganges Barrage project in Bangladesh is an important project in the water resources sector undertaken by the Government to manage the Ganges water properly for the improvement of the environment and economy of the Ganges Dependent Area. Accordingly a Feasibility study and Detailed Engineering Design of the proposed Barrage is being done by the BWDB. RRI was assigned to conduct physical model modeling of the Ganges Barrage of which Guide Bund models are presented here. Physical model was used to verify the length, location and orientation of Left and Right Guide bunds supplied by the Client as well as to provide some other important design parameters such as maximum local scour, velocity, erosion- sedimentation pattern etc. due to the construction of the Ganges Barrage. Two Detail models were tested with different flow approach and discharge to find out the required information. Maximum local scour measured in the model was upto –30.0 mPWD for left guide band (LGB) and upto – 12.0 mPWD for right guide bund (RGB). Maximum flow velocity was 4.50 m/s for LGB and 4.80 for RGB with flow discharge of 80,000 m3/s. Sedimentation was observed at the u/s of the hydropower which was minimized after modification of the proposed abutment.

## Introduction

Bangladesh as a lower riparian country is situated at the downstream of the major rivers the Ganges, the Jamuna and the Meghna. About one third of the population and nearly 37% of the total area of Bangladesh are fully dependent on the availability of the Ganges water (DDC' 2010). After commissioning of the Farraka Barrage in India, the southwestern region of Bangladesh is facing serious problems in agriculture, fisheries, navigation, salinity, environment, social and others. Ganges water sharing treaty was signed on 12th December 1996 between Bangladesh and India with a view to ensure sufficient water flow during the dry season. Under these circumstances to manage Ganges water, the Government of Bangladesh has undertaken Ganges Barrage Project to address those adverse situations in the South West and South Central region of Bangladesh.

However, the main objectives of the feasibility study and detailed engineering design of the Ganges Barrage is to conduct a detailed feasibility study, socio-economic, environment and other hydraulic and hydro-morphological survey and study; and a detailed engineering design for the construction of Barrage and associated engineering infrastructures across the river Ganges ( DDC' 2011).

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So under the framework of the main project, an agreement was signed between Bangladesh Water Development Board (BWDB) and Design Development Consultant (DDC) to carryout the "Feasibility Study and Detailed Engineering Design for Ganges Barrage Project". Accordingly, a Sub-Consultancy agreement was made between River Research Institute (RRI) and DDC for physical modeling of different issues to support Feasibility Study and Detailed Engineering for the Ganges Barrage Project.

As per agreement, RRI was supposed to carry out one overall model and five detail models Guide bund models were conducted to collect detail design information, which is discussed here. About 7.0 km of river length and partial width was reproduced. Model was undistorted in nature with 1:100 scales. To assess the local scour phenomenon such as scour depth, scour pattern and its extent, velocity field and maximum point velocity etc. quantitatively, detail model study for Right Guide Bund (RGB) and Left Guide Bund (LGB) are carried out. The output of these model studies is helpful for the designer to make the guide bund effective, sustainable and cost effective.

## Objectives of the Study

The objectives of the Guide Bund Models in brief were to investigate:

i) The local scour around the Guide Bund.
ii) Maximum velocity around the structure.
iii) Flow field around the structure.
iv) Morphological changes around the structures.
iv) Investigation of the above issues under different appraoch flow conditions.

## Model Scaling and Its Construction

Hydraulic modelling is form of physical modelling widely used to investigate design and operation issues. An advantage of hydraulic model is its potential capacity to replicate many features of complicated flow situation (ASCE' 2000). The behavior of a river and river system is very complex. The solutions of river engineering problems are largely guided by certain boundary conditions which are very difficult to determine from the prototype conditions. But by close observation to the hydraulic phenomena in the model, it is possible to determine those boundary conditions with reasonable accuracy (RRI' 1995) "Hydraulic Modelling and Scaling Procedure", Technical Journal of RRI, 1995, pp-95.

Selection of scale of any model depends on the objectives of the study, type of bed material to be used, water supply capacity in the model and other physical facilities required for the study. An undistorted scale of 1: 100 was used in both Guide Bund (LGB and RGB) models considering the outputs of the model study and fulfilling certain rules and conditions of the scale modeling. One of the important considerations for the model is the selection of bed material to have roughly similar hydraulic and morphological condition both in model and prototype. Sediment type in the Ganges River is fine sand. So the geometric scaling of fine sand in accordance with model scale would result in the use of silt or clay in the model. However, the properties and transportation characteristics of silt and clay particles are completely different from sand and would not provide a good simulation of the prototype sediment transport conditions. To overcome this problem one alternative is to select a lightweight material such as bakelite, polystyrene, coal dust, walnut shell etc. However, these lightweight materials are not available at RRI and can be sensitive to contamination in an open-air model. On the basis of those considerations, fine sand having $D_{50}$ = 0.18 mm was used for the model study.

The key factor causing displacement and movement of bed material are the near-bed shear velocity and turbulent flow patterns. The standard criterion for initiation of sediment movement is the Shields parameter of Shield diagram. Shields diagram is a plot of dimensionless shear stress against grain Reynolds Number. The model sand has a $D_{50}$ of 0.00018 m; the specific gravity of the model sand (S-1) is 1.65; the average depth of flow in the model was approximately 0.12 m; the average model velocity 0.46 m/s and the model bed slope was about 0.0003. The resulting Shields parameter in the model is calculated to be 0.14. The critical Shields value for initiation of sediment transport in the model was 0.053. It means that sediment transport was ensured in the model. The following considerations were made during scale selection of Guide Bund model. All the important parameters such as geometric condition, minimum water depth for precise measurement, sediment transport confirmation and other relevant conditions were fulfilled

The model was in principle undistorted and mobile bed model with sufficient transport having proposed Guide Bunds in position. The model was scaled with design discharge of 80,000 m3/s and corresponding partial discharge in the model 30% of total design discharge. The model bed was filled upto about 0.6 m of sand all over the area of the model boundary. This sand tray was based on two layers of brick flat soling in such a way that there would not be any scope of seepage vertically. Model area was also enclosed with seepage control wall to resist any seepage also laterally.

**Scale Effects**

Hydraulic models work only with approximate mechanical similarity based on the ratio of forces which determine the type of motion (DHI 1984).The scaling of the guide bund models was carefully done in order to minimize scale effects in the phenomena of interest i.e. local scour and flow velocities as much as possible. A correct prediction of the scour hole dimensions can be obtained when the model is undistorted. This is the case when the horizontal and vertical scales are equal. In this way a geometrical similarity is obtained between the prototype and the model. For flow velocities above the critical flow velocity the local scour only depends on the geometry of the constructions and the flow conditions. For the development of the scour hole the sediment transport needs to be large enough so that the maximum equilibrium scour can be reached within one working day. Moreover the possible errors in the adjustment of the boundary condition each day and the filling and emptying of the model was prevented.

## Model Testing and Interpretation of Results

Guide Bund Models of the Ganges Barrage Project were conducted to determine different design parameters essential for the guide bunds. With a view to achieve those parameters calibration tests as well as several application tests were done with different bathymetry and flow condition. Possible various flow attacks were reproduced for guide bunds to investigate the effectiveness of the proposed structures to severe flow condition. Each test was continued until equilibrium condition is established. Some of the important design issues are discussed here in brief.

### Local Scour

Maximum local scour around the RGB in different tests observed to vary from 4.0 m to 16.0 m. On the other hand for LGB, it was 6.0 m to 22.0 m (RRI' 2014). Maximum local scour was found to occur with 90 degree angle of flow attack at the tip of the Guide bund. Local scour and associated bed level can be seen in plot figure-1 and table - 1. But the value of net local scour was found to reach about 23.0 m at the downstream of the barrage. Morphological changes around the barrage for RGB and LGB are shown in photo-plate-1 & photo-plate-2. A typical cross section of scour is shown in figure-2.

### Flow Field

Flow field for both the guide bunds can be seen in photo-plate-3 & photo-plate-4. Maximum point velocity developed in different tests was between 3.20 - 4.80 m/s for RGB and 2.80 - 4.50 m/s for LGB respectively. Flow field after modification of abutment and divider for RGB is shown in photo-plate-5. A typical velocity profile at maximum velocity section is shown in **Figure 3.** There was no remarkable eddy, vortex or turbulence created in most of the tests except in one for RGB but strong eddy was present for LGB model that requires attention.

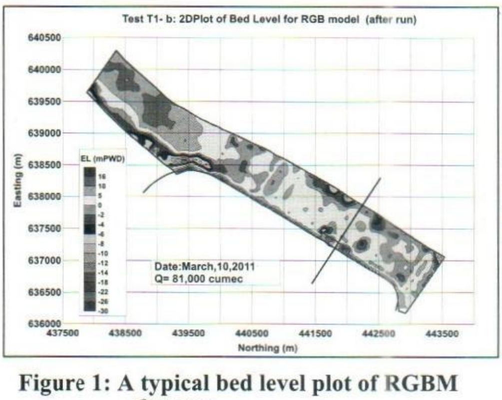


**Figure 1: A typical bed level plot of RGBM after run**

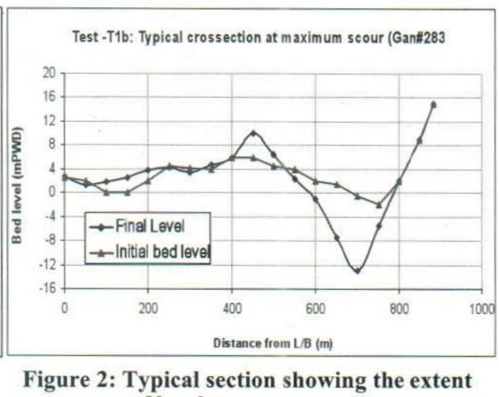


**Figure 2: Typical section showing the extent of local scour**

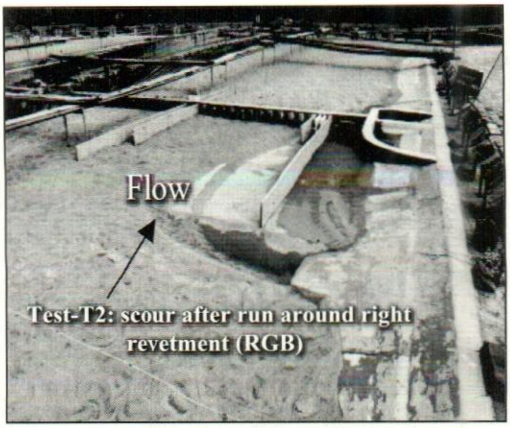


Photo-plate 1: Morphological changes around the barrage for RGB

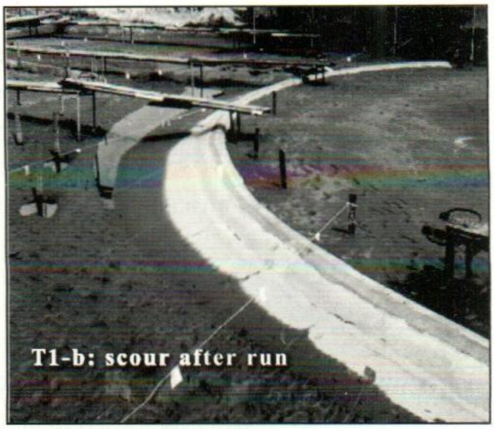


Photo-plate 2: Morphological changes around the barrage for LGB

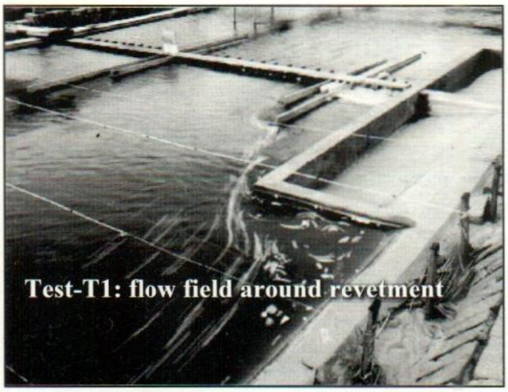


Photo-plate 3: Flow field for RGB model

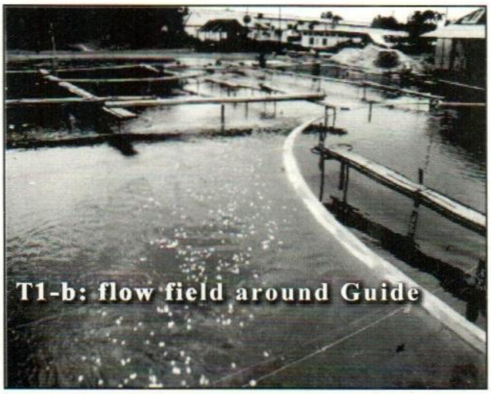


Photo-plate 4: Flow field for RGB model

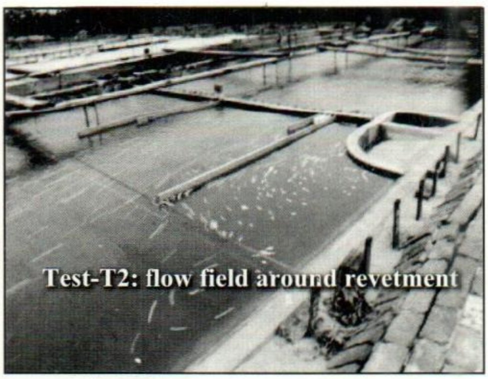


Photo-plate 5: Flow field for RGB model

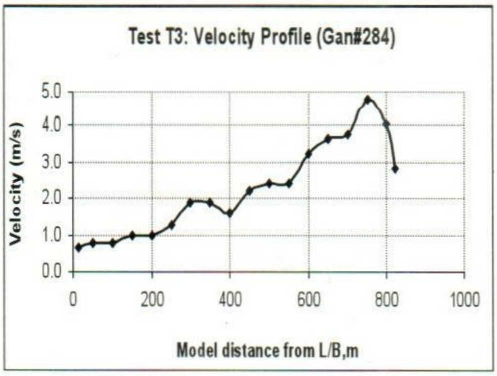


Figure 3: Typical velocity profile across the maximum velocity section

## Other Observation During Model Tests

The shape of the proposed abutment of the barrage and the divider created strong eddy and high turbulence around it, which can be seen from the Photo-plate 3 and as a result big local scour was developed at the upstream of the divider. Due to this adverse situation, significant sedimentation was observed at the upstream of the hydropower. So, the upstream shape of the abutment was modified to reduce the eddy and turbulence to improve the situation. In that case the depth of net scour at the tip of divider was reduced from 23 m to 14 and the eddy was also reduced as shown in photo-plate-5. Moreover, the sedimentation at the upstream of the hydropower unit was reduced. Siltation was also observed at the upstream of under sluice as well as spillway as shown in table-1. The maximum net scour for LGB was measured about 22.0 m (i.e. up to about –29.0 mPWD). So, LGB requires attention.

**Table 1: Comparison of different design parameters between LGB and RGB**

| Scour in meter RGB/LGB | Scour in meter Other Location | Velocity in m/s RGB/LGB | Other Observation |
|---|---|---|---|
| Net scour 4 to 16 m & Maximum16m at the tip of RGB with 90 degree angle of flow/ Net scour 6 to22m & Maximum 22m at the tip of LGB with 90 degree angle of flow | Maximum net scour 23m at the u/s of the barrage/ Maximum net scour 22m at the d/s of the barrage | Maximum velocity 3.2m/s to 4.8 m/s. 4.8 m/s at the tip/ Maximum velocity 2.8 m/s to 4.5 m/s. 4.5 m/s at the tip. | Sedimentation at the upstream of the barrage as well as hydropower was observed. |

## Conclusion and Recommendation

To get the design parameters of the proposed guide bunds in depth physical model studies were done with different test scenarios consulting with the Client and BUET advisors. The conclusion and recommendation made for both the guide bunds are briefly as follows:

- The length, location and orientation of both the guide bunds were found to work well in general except small modification at some places.
- Maximum local scour (net scour) around the RGB and LGB was12.0m and 16.0m respectively at 90 degree angle of flow attack with the tip of the bunds.
- Maximum point velocities developed during the test of LGB and RGB were about 4.80 m/s and 4.50 m/s.
- There was no significant eddy, vortex or turbulence created in most of the tests. Small eddies along with turbulence was created to the right guide bund tip.
- The shape of the bridge abutment and the divider wall itself created strong eddy and high turbulence around it and as a result big local scour was developed at the upstream of the hydropower. Maximum net scour was measured at that location was about 22.0 m (i.e. upto about –29.0 mPWD). Changing the shape

of the abutment it was however reduced to about 14 m (i.e. upto about –20.0 mPWD).

- Significant sedimentation was observed in front of the hydropower unit in initial test, but it was optimized after smoothening the upstream end of the right abutment and flow condition.


## Acknowledgements

The authors are grateful to the Design Development Consultant Ltd. (DDC) the client, Bangladesh Water Development Board (BWDB) who take the Feasibility Study and Detailed Engineering for Ganges Barrage Project and Bangladesh University of Engineering and Technology (BUET) is the sub-consultant of RRI and all the officials and staff of RRI who directly and indirectly associated for the completion of the study.


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# FLUVIAL MORPHOLOGY OF PADMA RIVER BETWEEN CHARGHAT AND PAKSHI AREAS IN BANGLADESH

**Md. Abdur Rahim[1] and Md. Badrul Islam[2]**

## Abstract

The present study deals with the bank erosion and channel shifting characteristics of the Padma River between Charghat and Pakshi areas, Bangladesh (Latitude-24°4' N to 24°12' N and Longitude-88°45'E to 89°0'E). Morphological and morphodynamic maps of the Padma River are constructed using remote sensing techniques. A remarkable change in position of bank and channel as well as bars along with their geometry and morphology during the period of 1977 to 2000 is observed. In the recent years it is found that the bank line is not stable and migrated continuously towards west. The overall width of the Padma River in the study area varied from 4.1 km to 6.2 km during the past 30 years. Bars are also varies from area to area. Different maps and landsat images of the area reveals that the river shifting is abnormal which is alarming for the existence of the area. Bank erosion of recent years is so pronounced that had got significant economic and social impact. Losses of agricultural and urban lands, damage of property including infrastructures were very common and still it is happening.

## Introduction

The Padma is a typical meandering river in Bangladesh, which shifted its course more frequently than any other rivers (Alam, 1996). Presently, Nawabganj, west of Mahananda river, Premtali,. Rajshahi town, Charghat, Bagha, Pakshi etc. areas along its course up to the Hardinge Bridge are worst affected by channel shifting and bank erosion (Hassan and Akhtaruzzaman, 2010) .This phenomenon also forms an individual environment hazard that causes huge loss of life and properties annually along its course. Since prehistoric time, the common peoples know it as "Sharbagrashi" due to its intense channel shifting and high magnitude hazardous bank erosion (Ferdous et. all). Flooding and river bank erosion become very prominent during the monsoon. For the natural activities the river Padma changes its position of chars and the deposition and erosion of bank are occurred each of the year. A number of works was carried out on river bank erosion and channel shifting using remote sensing data in Bangladesh. But no attempt has been made of detailed geomorphology and river shifting in the study area. In this regard, the present research work was aimed to identify the morphological characteristics and channel dynamism of the Padma River for future development plan in the study area.

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## Literature Review

So far as the literature concerned very little information is available regarding the Padma River morphology, shifting and its probable causes in the study area. Kabir, N. and Sultana, N. (2006), Hossain, M.M. (1987) and Hassan, S. and Akhtaruzzaman A.F.M. (2010) studied the morphological changes and land use mapping of some parts of the Padma River. But detail geomorphological mapping has never been done in the study area and these types of information have also never been used for urban planning and land-use purpose. A number of works have been done by different authors for hydrological, geomorphological and geological aspects at a limited scale (Rennel, 1778; Fergusson, 1863; Alam, 1996; Khan, 1991; Morgan and McIntire, 1957; Armstrong, 1965; Alam, 1970; Roy and Islam, 2005; Reddy and Maji, 2003; Haq and Islam, 2000 and Yeasmin and Kabir, 2006). Bangladesh Water Development Board (BWDB) and Geological Survey of Bangladesh (GSB) investigated the areas at different times. Morgan and McIntire (1959) carried out a reconnaissance survey and described geomorphology, sedimentology of the Quaternary deposits of the Bengal Basin. WARRPO (1997) published report on morphological dynamics of the Padma River. Department of Public Health Engineering (DPHE), Bangladesh University Engineering and Technology (BUET), Environment and Geographic Information System (EGIS), Flood Action Plan (FAP-2), Surface Water Modeling Center (SWMC), Soil Resource Development Institute (SRDI) and Bangladesh Agricultural Development Corporation (BADC) carried out several works on different aspects on the area. Bangladesh Water Development Board (BWDB) conducts hydrological, morphological and hydrogeological surveys in the area every year recording rainfall, evaporation, stream discharge, river cross-section, water levels, groundwater tables and bore log data stations throughout the area.

## Methodology

### Study Area

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The study area is located in the channel-bar complex along the bank of the river Padma near Charghat and Bagha Upazilas, Rajshahi district and Pakshi upazilla of Pabna district. The study area lies within the longitude 88°45′ to 89°0′E and latitude 24°4′ to 24°12′N which covers about 45 km length of the Padma River (Figure 1). The study area is well communicated with other parts of country by highways and railways. The basic means of transport available in the study area are bus, rickshaw, tempo etc. Physiographic point of view, the study area falls in the Ganges River Floodplain. Geologically, the study area is lies on the north-northwestern part of the Bengal Basin. The surficial of the area is classified as recent flood plain deposits (Khan, 1991). The recent flood plain deposit consist of clay, silt, fine and medium grain sand and are of relatively loose and more friable in nature (BWDB, 1974).

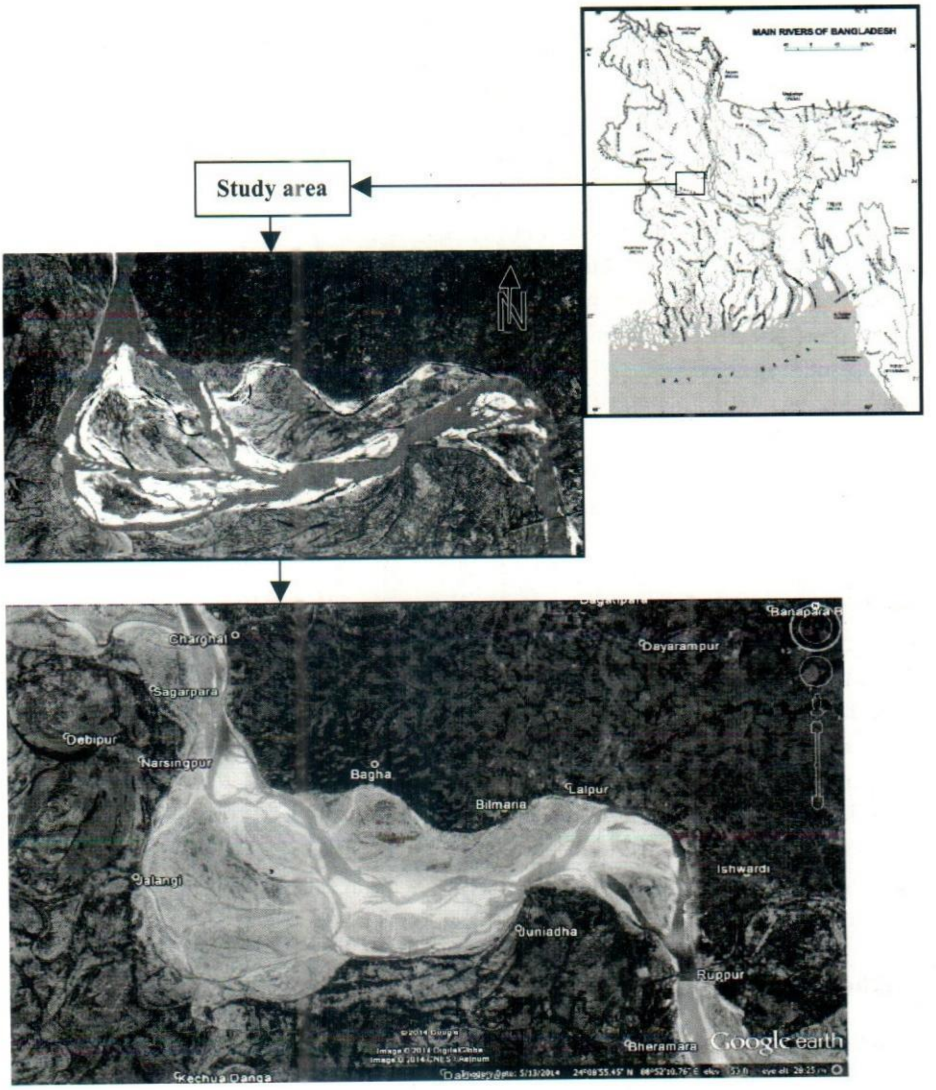


**Figure 1: Location map of the study area.!**

## Materials

The materials, data and information is collected from the different organizations such as department of Geology and Mining (Rajshahi University) and Geological Survey of Bangladesh. ETM+ image of 17 November 2000, TM image of 11 November 1989, MSS image of 09 February 1977 with scale 1:50,000. Base map of scale 1:50000 (2001) was collected from ·Local Government Engineering Department (LGED), toposheet with scale 1:50,000 (1968) was also collected from Bangladesh survey. Different interpretation software and Historical river maps are used in the present study to prepare maps of the river for different time series.

## Methods

For the purposes of this study the data from satellite imagery, topographic sheets and base maps (LGED's) were incorporated first to prepare a geomorphological map (Figure 2, 3, 4) of different time period. Using Adobe Illustrator CS 11 academic software river bank line and bar maps of each satellite image have prepared. Digital data registered with Bangladesh survey toposheets and identified different geomorphic units, mapping with image interpretation techniques, digital image processing and geomorphologic map using Arc GIS software. Superimposition of bank line maps, changes of bank lines, interpretation of bank dynamics (Figure 6, 7, 8 and 9) in terms of fluvial process have carried out using Adobe Illustrator software (version CS 11) with their individual bands.

## Result and Discussion

### Geomorphic Units

The study area is covered by recent alluvium deposited by the Padma River and its numerous tributaries and distributaries. The geomorphological units are identified on the basis of the interpretation of image elements such as tonal variation, texture, size, shape etc, and fluvial features concept (Lillesand and Kiefer, 1987). Geomorphic units are classified on the basis of differential erosion processes (Pike et. all, 2002). Remotely sense data have capability to mapping geomorphic units (Reddy and Maji, 2003). The different geomorphic units are identified on the basis of geomorphological feature and their sedimentological characteristics formed in the area:

**Active Channel (AC):** Active channels have permanent water flow throughout the year. This unit is identified due to its light tone, smooth texture and morphologic position. This unit is the main feature of the study area. It is more prominent feature in the geomorphic map of 1977, 1989, 2000 and Google map of 2014 (Figure 2, 3 and 4).

**Mid Channel Bar (MCB):** This type of channel bar deposits is ephemeral and position of the bars within the channel is likely to change with each sizeable flood. The channel bars are located within the active channel and are only exposed during the late winter and summer. These bars are consists of course to medium grained sand and sand deposits are loose (Figure 2, 3 and 4).

**Lateral Bar Deposits (LBD):** Lateral bars are attached to the main floodplain. These are longitudinal, elongated and transverse to the stream alignment are exposed only during the late winter and summer period (Figure 2, 3 and 4).

**Old Bar Deposits (OBD):** The other bars are dominant morphological units of within the channel area formed due to the formation of bars and shoals in response to migration of the channels. These bars contain several cycles of sedimentation that forms multistoried and are changing sequences (Roy, M.K., Islam, M.S. and Islam, M.S. 2005). These bars are very dynamic and are changing shape, area and position every year. The bar deposits are identified by its geomorphic forms, presence of grain and weeds, light tone etc (Figure 2, 3 and 4).

**New Bar Deposits (NBD):** The new bars are small scale bars within the channel floors, which are characterized morphologically by sand waves without any vegetation. These are mainly consisting of loose, light gray to white, medium to fine-grained sands. These are comparatively lower than that of the older bars and formed recently within the channel and along the older bars. In image these are identified by light tone (Figure 2, 3 and 4).

**Abandoned Channel Deposits (ACD):** The abandoned channels are elongated narrow depressions and shallow discontinuous streams with or without water. The deposits are clay or silty clay, which are underlain by silty sand to fine sand deposits. Vegetation is also elongated shape (Figure 2, 3 and 4).

**Flood Plain Deposits (FPD):** Flood plain lies between natural levee and flood basin bank swamp and is lower in elevation than those of natural levee (Hossain, 1987). This is the largest units of the study area. Flood plains have very quietly sloped towards the flood basin or bank swamp. Flood plain deposits in the study area are composed of gray silty clay to organic rich clay, decomposed to partially decomposed grass roots and organic remains are common in the sediment (Islam et. all, 1998). The study area has been converted to the cultivated lands which exhibit table like geometric shape in the study area on either sides of the Padma River (Figure 2, 3, 4).

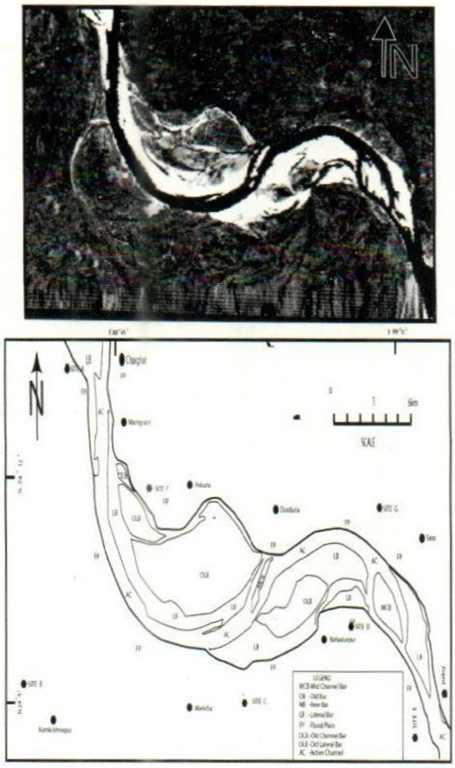

**Figure 2: Geomorphic map from Satellite image of MSS 09 Feb. 1977.**

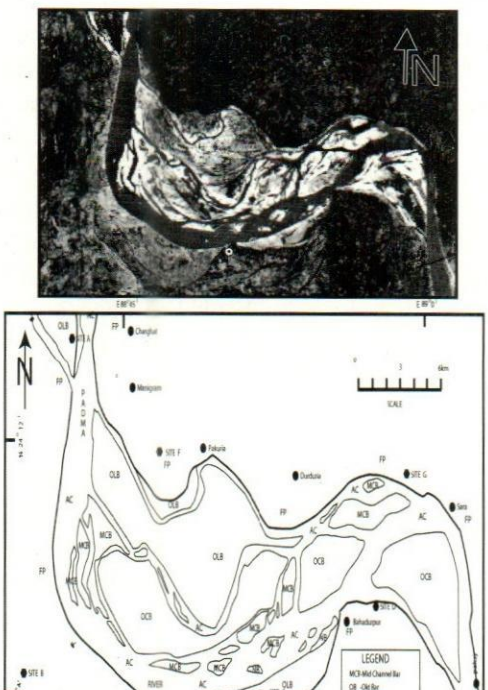

**Figure 3: Geomorphic map from satellite image of TM 11 Nov. 1989.**

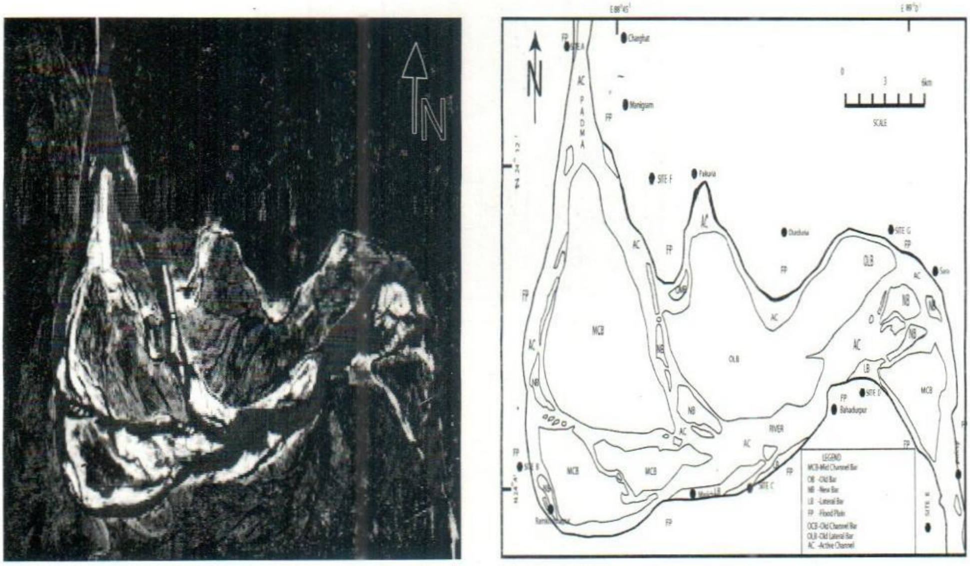

**Figure 4: Geomorphic map from satellite image of ETM+ 17 November 2000.**

## Bank Erosion and Channel Shifting

The Padma is one of the largest rivers in the country. The mighty river has high hydro-dynamic condition, high water discharge and the bank of the river is not stable (Shamsuzzaman et. all, 2004). Erosions are continuously going on the both side of the river (Figure 5). River bank erosion is a complex process in which many factors play a role. Among them, important factors are flood, irregular water flow and earthquake (Islam, 2005). The channel shifting is with time due to natural process and it is to be mention that two great floods events (1988, 1998) occurred in Bangladesh during 1977 to 2000; also played a significant rule in bank line shifting (Alam, 1995). From the study of three satellite images of MSS 1977, TM 1989 and ETM+ 2000 observed that the river bank has been eroded and channel shifted at different places in different times that described as marked in several sites (Figure 6, 7, 8 and 9). The sites are described in below:

**SITE-A**: It is situated in the right bank of the Padma River near Charghat union of Charghat Upazila. During 1977 it was a bar area. In 1989 image it is indicating a sub channel flow to the Padma. About 1.2 km length of the river bank has been shifted towards west during the period of 1977-2000 as a result of total erosion.

**SITE-B:** The area is shifted in the right bank Ramkrishnapur bank of the Padma River near Ramkrishnapur union of Bagha Upazila of Rajshahi district. An assuming river bank erosion and bank line shifting has been occurred during the last 30 years. During this period (1977-2000) as a result of erosion bank line shifted about 6.2 km towards west. A great change of bank line occurred from 1977 to 2000. From satellite image, here existing a prominent channel shifting of the river.

**SITE-C:** Site-C included Marich union of Bagha Upazila at right bank of the river. A great amount of channel shifting also occurred here. The bank line has eroded about 4 km during the period of 1977-2000. The rate of erosion was more during 1977 to 1989, probably for some hard points, the erosion reduced slowly.

**SITE-D:** Bahadurpur and adjacent areas are included here. Site-D is situated at the right bank of Padma. A drastic bar both new and old changing occurred here. The right bank of the river shifted about 2.2 km toward south-west.

**SITE-E:** The right bank of the Padma near Pakshi included in site-E. Comparatively less erosion and channel shifting occurred here. The channel shifted only about 1 km towards west.

**SITE-F:** It is situated at left bank of the river. Pakuria Union of Bagha Upazila and adjacent areas is included in site-F. There is also found a remarkable shifting of bank line in site-F. From the analysis of past few years' data the long term erosion could easily be understood. The rate of erosion widely varies from year to year depending on the flow velocity of the channel. During 1977 to 1989, erosion was slow but after 1989, here observed a great shifting of the bank line toward east about 2.3 km.

**SITE-G:** Site-G is placed at left bank of the Padma River. Sara Union and adjoining areas of the river included in site-G. About 3.5 km of bank line shifting has occurred in here. During this period (1977-1989) erosion was comparatively slower process but during 1989-2000, large erosion taken place and the channel shifted about 3.1 km toward east of the river. The overall rate of erosion is much higher, the river width also increased with impact of this rate of erosion (Figure 5).

During 1977s the bank line movement was relatively slow. The width changes data set collected from the old maps. Digitized width change data from maps made in 1977, 1989 and 2000 were used to calculate the historical width of the river on those years. The rates of width changes were slow at the earlier period and progressively increased. The width of the Padma River almost double in (1989-2000) compared to (1977-1989). Most internal or mid channel bars like Gargari , Chilmari and Bialmaria etc. are eroded greatly and shifted its original position. The bars shifting of the river are also remarkable (Shamsuzzaman, 2004). The channel shifting is varying from place to place due to presence of preventing measurements. In the study area widening is more frequent in site-B, site-C, site-D, and site-G. The bank migration was great in those areas. From the above discussion it is clear that the bank of the Padma River is very much unstable in nature and changes its banks very frequently.


**Figure 5: Padma river bank erosion (a), River bank protection (b), Char erosion (c) and Char bar deposition (d).**

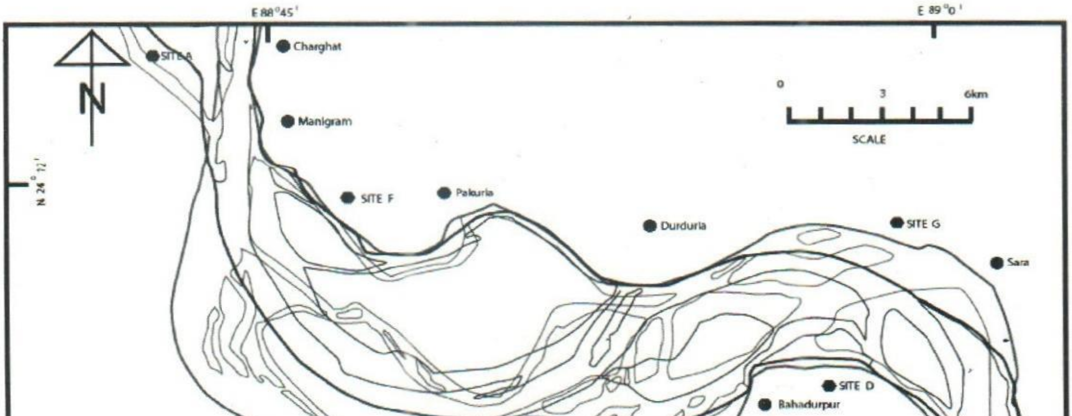


**Figure 6: River bank lines of Landsat MSS 1977 and TM 1989.**

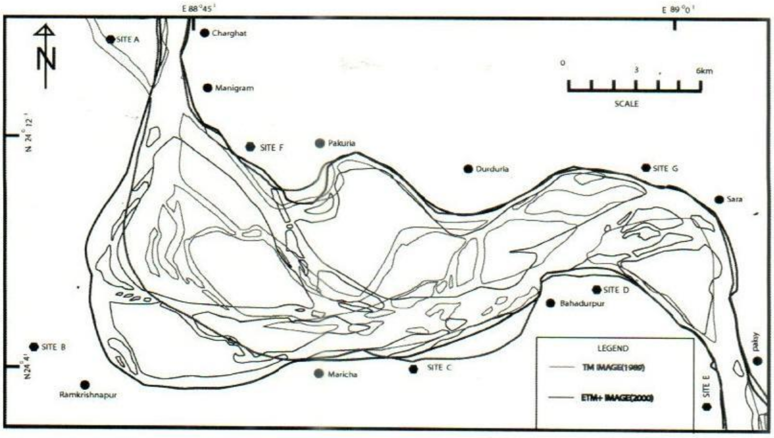


**Figure 7: River bank lines of Landsat TM 1989 and ETM+ 2000.**

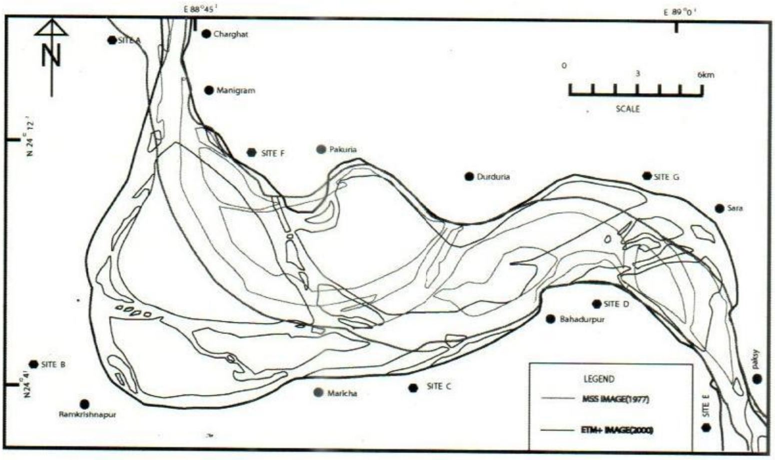


**Figure 8: River bank lines of Landsat MSS 1977 and ETM+ 2000.**

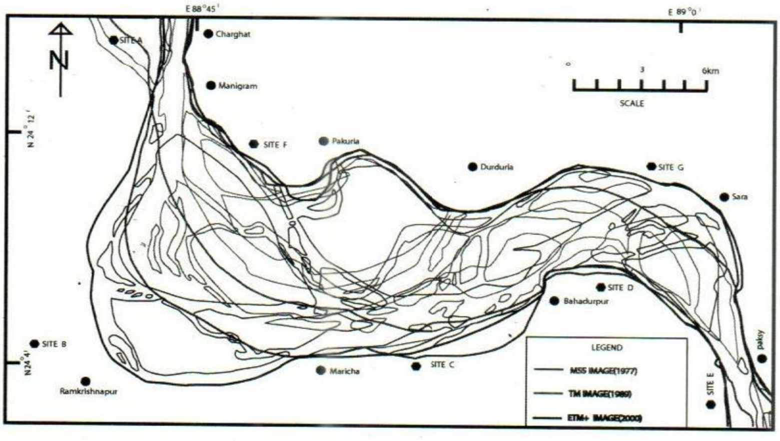


**Figure 9: Superimposed Bank lines of Landsat MSS 1977, TM 1989 and ETM+ 2000.**

## Conclusion and Recommendation

The Padma is a typical meandering river with remarkable wandering nature since prehistoric time but presently it transformed into semi braided river with numerous mid channel bars and meander bends (Hossain, 1987). The river is highly dynamic where bank erosion and accretion occur at extremely high rates through the formation of point bars, channel bars, shifting and erosion of the bank. During last 30 years the Padma River in the study areas shifted progressively from east to west, greatly near Ramkrishnapur and Sara Union. The study area is, one of the most erosion prone areas of the river. Infrastructures and valuable agricultural lands have been lost due to bank erosion along predominantly right-bank and also the left-bank from Charghat to Pakshi during the last decades.

From the three satellite images (1977, 1989, 2000), the trends of right and left bank shifting observed. The maximum amount of shifting at right bank is around 6.2 km near Ramkrishnapur, around 3 km at Maricha Union of Bagha Upazila of Rajshahi district. Mid channel bars namely Chilmari, Gargari and Bialmaria also shifted at around 2-3 km towards west. If the bank erosion and river shifting is continuous with observed character, than the affected area with homesteads will be engulfed into the river within a very short period of time..

The following recommendation should be taken consideration for future development plan in the study area:

- A sustainable bank protection and upstream river water flow control project should be established considering the geomorphic and geologic set up of the region.
- It is important to integrate geological information at early stage for land use planning in order to avoid destruction or damage of properties and lives and to avoid other environmental problem and monetary loss.
- Special long term rehabilitation program should be taken by the government to overcome the effect of flood affected people of the Padma river bank erosion and shifting areas.
- This research work might have some lacking because of limited scope and time. Therefore, a detailed survey should be undertaken for any further development activities in these areas.


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# AN APPLICATION OF 1-D MOMENTUM EQUATION TO CALCULATE DISCHARGE IN TIDAL RIVER: A CASE STUDY ON KALIGANGA RIVER

**Ahmad Asif Reza[1], Shiblu Sarker [2] and Sadia Afrin Asha[3]**

## Abstract

Bangladesh is a large delta formed by the alluvial deposits of the three mighty Rivers: the Ganges, the Brahmaputra and the Meghna with their tributaries and distributaries. By these mighty rivers Bangladesh is subdivided into several zones in which the rivers show mainly non-tidal (flashy, meandering and braided), tidal characteristics. The tidal rivers are situated in the coastal region of Bangladesh. The river network in this south-west costal region is very complex and dominated by semi-diurnal tidal effects. In these tidal rivers periodic changes in water level occurs due to tides. A tide is mainly generated in the deep sea from where it travels into coastal rivers. Discharge measurement is an issue of major importance for the evaluation of water balance and the design of coastal structures. The field measurement of discharge in tidal river is expensive and time consuming. The conventional rating curve (correlation between stage and discharge) is not applicable due to the semidiurnal tidal phenomena. Indirect approaches to generate discharge are more convenient in these cases. In this respect discharge can be generated by applying 1D momentum equation. The momentum equation can be reformed in a way that it can generate discharge by dealing with only water level data, cross-sectional data and roughness values. This method involves convective acceleration and change in water surface slope. The momentum equation can be solved numerically by discretization of cross-sections in respect of water level. But dealing with these enormous calculations and data management is arduous. Thus A numerical program can be developed by using Visual Basic for Applications (VBA). In this consequence developed VBA program was applied on the Kaliganga River as a case study. Results obtained by using this programme for the straight and short reach have been shown to be accurate and reliable sufficient enough with considering back water effect and loop characteristics of unsteady flow and was calibrated only roughness value. And the result has been found quite satisfactory.

## Introduction

Bangladesh is a riverine country. These rivers are both blessing and curse of Bangladesh. The life of peoples of Bangladesh depends on these rivers, on the other hand they have to cope with the natural catastrophes such as flood conveyed by these rivers. Flood prediction can reduce this risk. The water levels and discharge of rivers is extremely important in predicting floods and flood stages. But the field measurement of discharge in river is expensive and time consuming. The usual practice in Bangladesh is to generate discharge data using rating curve from water level data.

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However, the conventional rating curve (correlation between stage versus discharge) is not applicable in tidal rivers due to the semidiurnal tidal phenomena. Hydraulic and Hydrodynamic processes in tidal rivers are complicated. In tidal rivers, water level constantly changes due to the interaction between upstream floods and downstream tides. Consequently, Discharge measurement is a vital issue in tidal rivers. In this respect, application of 1D momentum equation can directly generate the discharge well. This equation can perform well in tidal rivers. The Kaliganga River in the south-west region of Bangladesh is selected for this case study because of the data availability for inputs and calibration of output.

**Literature Review**

Many formulae have been developed for the discharge measurement purposes. Among the formulae Jones formula is the most well-known. Jones (1915) measure discharge of unsteady flow by using the Chezy equation of friction slope and a geometric analysis of the water-surface slope based on the surface velocity and the rate of change of the stage at the gauge. Di Silvio (1969) used a triangular approximation of the flood wave and the hypothesis of narrow loop in the rating curve to obtain a formula for discharge estimation. Henderson (1966) proposed a parabolic approximation of flood wave and modified the Jones discharge measurement formula. Perumal and Ranga Raju (1999), and Perumal et al. (2004) refined the time derivative of the Jones formula by incorporating expressions for the inertial forces of the one dimensional momentum equation. Besides, numerous modelling tools are developed on the basis of 1D momentum equation. For example Mike-11 and HEC-RAS are the two widely used 1D modelling tools that can route both discharge and water level very accurately. But these modelling tools solve the full form of 1D momentum equation using complex numerical schemes. Moreover, composed of greater data base and stable solution schemes, these tools can be used for simulation of much larger and complex river network. Setting up these tools for a single channel of small reach would result in doing some extra work, whereas use of simplified 1D momentum equation in calculating discharge is more efficient. Simplification would compromise the output accuracy. But still it would be within tolerable limit. Moreover the solution can be obtained without complex numerical scheme. The detail methodology and application has been shown in the methodology sections.

**Study Area**

The River Kaliganga, originated from the Madhumati River at gopalganj and Bagerhat district flowing through Gopalganj, Bagerhat and Pirojpur falls into Kacha River in Pirojpur district. Kaliganga is a tidal river situated in southwest region of Bangladesh. The 35km long and 500m wide Kaliganga River is a perennial river. The objective of the study is to generate discharge by using a simplified 1D-momentum equation in between the study area bounded by the station 1 and station 2 as shown in Figure 1.

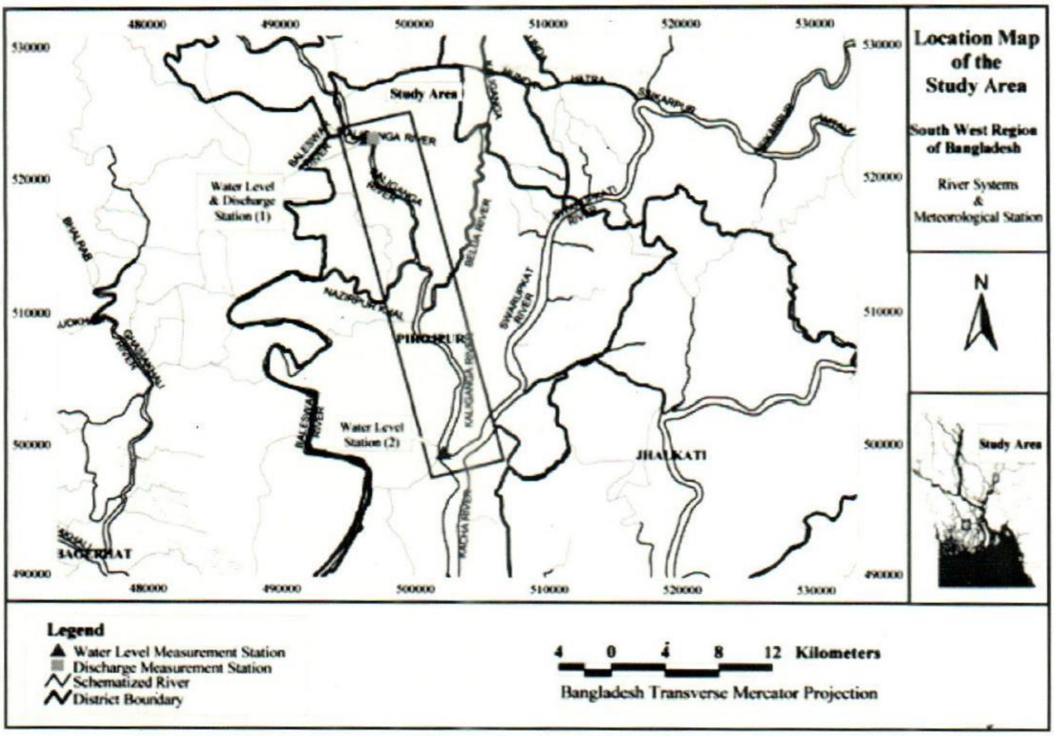


**Figure 1: Schematic Representation of the study area**

## Methodology

This part of the paper consists of simplification and formulation of the governing equation for a small reach. In this reach there will be negligible loss or gain in flow. The equation has been reformed in a way that it can generate discharge by dealing with only water level data, cross-sectional data and roughness values. This method involves convective acceleration and change in water surface slope. The momentum equation is solved numerically by discretization of cross-sections in respect of water level. With this method, calculation for single water level can be done manually with hand calculation. But when a time series of water level is provided it is better to to use a programing tool. Dealing with these enormous calculations and data management is arduous. Thus A numerical program is developed by using Visual Basic for Applications (VBA).

## Governing Equations

The governing equation of this method is 1D momentum equation (Equation 1). The differential form of this momentum equation is simplified in terms of longitudinal direction only. This momentum equation consists of three kinds of force (Pressure force, Gravity force and Friction force) which generates two types of acceleration (Convective acceleration and Local acceleration). This simplified 1-D momentum equation:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{\dot{Q}^2}{A}\right)+gA\frac{\partial h}{\partial x}-gA(S-S_f)=0 \quad \text{..................Equation 1}$$

Considering momentum correction factor, water surface slope with respect to datum and replacing friction slope with discharge and cross section properties finally the equation becomes (Equation 2):

$$\frac{\partial z}{\partial x}+\frac{1}{2g}\frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A^2}\right)+\frac{1}{g}\frac{\partial(\frac{Q}{A})}{\partial t}+\frac{Q^2}{K^2}=0 \quad \text{................Equation 2}$$

Where x is the longitudinal distance along the reach, t is the time coordinate, $z=z_0+h$ is the vertical distance of water surface from the horizontal datum, $z_0$ is the vertical distance of bed from the horizontal datum, β=momentum correction factor, A=cross-sectional area and K= conveyance of the section. For large variation of water level with respect to time this equation can calculate almost correctly the discharge based on cross sectional, conveyance properties. Momentum correction factor depends indirectly on this cross sectional conveyance properties. Each cross section can be discretized into large number of pocket (Equation 3).

$$K=\sum_{j=1}^{N}K_j=\frac{1}{n}\sum_{j=1}^{N}A_jR_j^{2/3} \quad \text{........................Equation 3}$$

Where $K_j$=Conveyance of the small pocket area of each cross section, $A_j$=Area of the small pocket, $R_j$= Hydraulic radius of the small pocket and n=Manning's roughness value. While the momentum coefficient can be estimated as (Equation 4):

$$\beta=\frac{1}{U^2A}\int_0^A u^2dA\cong\frac{A}{K^2}\sum_{j=1}^{N}\frac{K_j^3}{A_j} \quad \text{..........................Equation 4}$$

**Solution of the Equations**

It is assumed that no significant discharge enters or leaves the reach between the two adjacent sections. So the Equation 2 can be simplified for branchless a m,nd close enough two cross sections for a straight reach. So for small longitudinal variation of discharge:

$$(h_u-h_d)+\frac{Q^2}{2g}\left(\frac{\beta_u}{A_u^2}-\frac{\beta_d}{A_d^2}\right)+\frac{(x_u-x_d)}{2}\left(\frac{1}{K_u^2}+\frac{1}{K_d^2}\right)*Q^2+(x_u-x_d)\frac{\partial(\frac{Q}{A})}{\partial t}=0 \quad \text{....Equation 5}$$

By neglecting the local acceleration in Equation 5 the solution becomes into a simple quadratic equation of single unknown discharge. Finally it can be written as Equation 6:

$$(h_u-h_d)+\frac{Q^2}{2g}\left(\frac{\beta_u}{A_u^2}-\frac{\beta_d}{A_d^2}\right)+\frac{(x_u-x_d)}{2}\left(\frac{1}{K_u^2}+\frac{1}{K_d^2}\right)*Q^2=0 \quad \text{............Equation 6}$$

The solution of this quadratic equation for various tidal water level fluctuations is done numerically by Visual Basic Applications. The flow chart of this solution ciphers algorithms are given below:

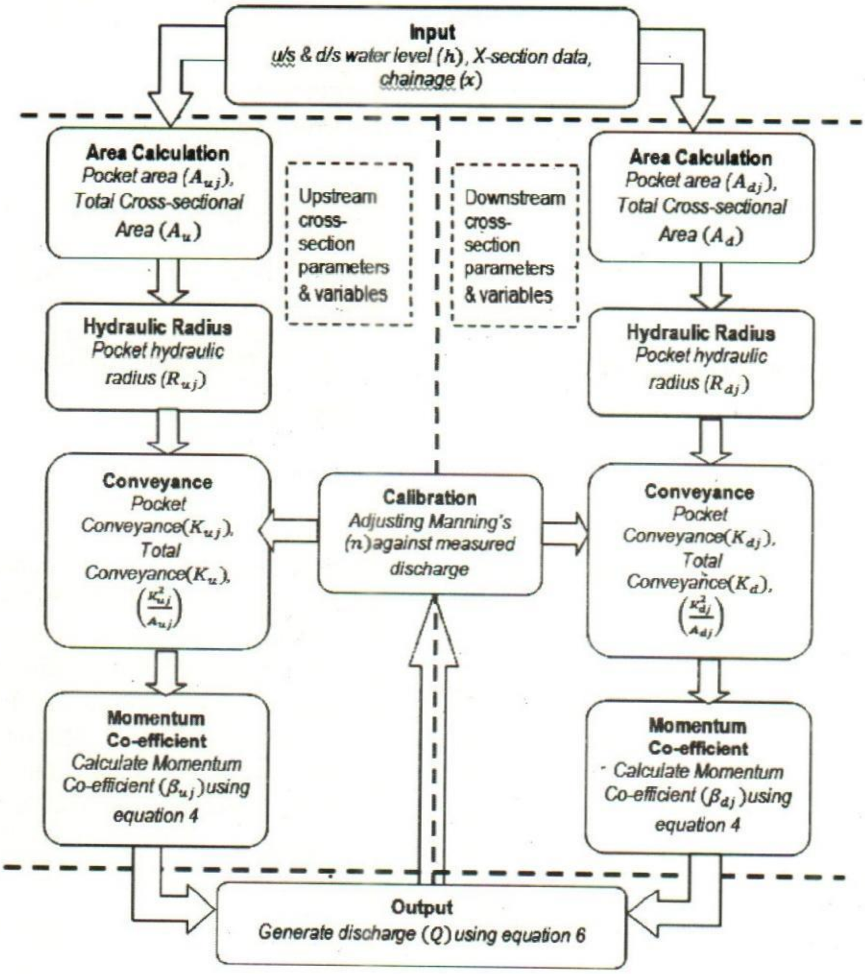


**Figure 2: The flow chart of algorithms**

From above figure it can be seen that for given water level, cross-section and chainage data of upstream and downstream location, the discharge within the reach can be calculated only by calibrating the Manning's "n". The application of this method is shown in the following article.

## Input Data

### Cross-Sectional Data and Chainage

The cross sectional data of the Kaliganga River has been collected from IWM archive. These data were collected by IWM survey team during 1998. Below are the two plots (Figure 3 & 4) of the cross-section at upstream and downstream location (locations has been marked as Station 1 and Station 2 in Figure 1). The chainage between these locations on Kaliganga River is 30.5 Km.

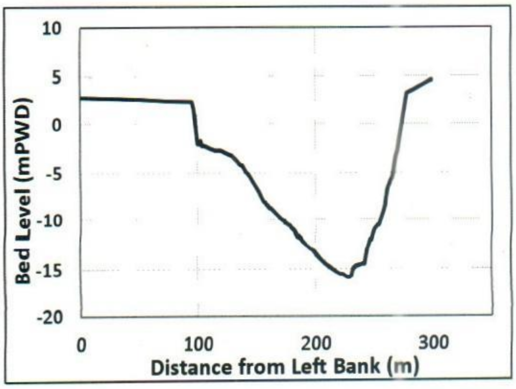


Figure 3: Upstream Cross-Section

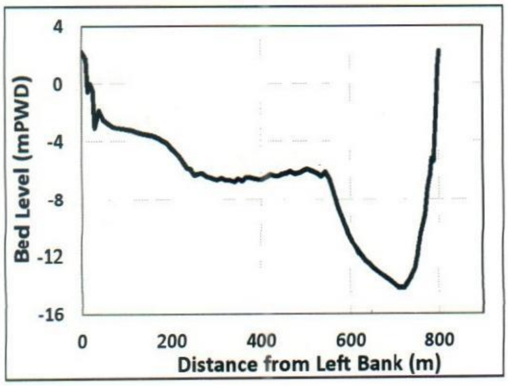


Figure 4: Downstream Cross-Section

**Water Level Data**

IWM was assigned by BWDB to do mathematical modeling in connection of "Gorai River Restoration Project (GRRP)". During project period, IWM Survey Team measured water level and discharge data at several locations of South West Region of Bangladesh. Among those, two stations have been selected for this study. One is at the confluence of Ghagor River and Kaliganga River (Station 1 of Figure 1) and another is at the confluence of Kacha and Kaliganga River (Station 2 of Figure 1). The water level data used to generate discharge covers date from 21/8/2011 to 15/9/2011 (Figure 5). The data is at 30 min interval from 6am to 10pm during dry period. In addition, the discharge data used for calibration is at date of 22/08/2011 and 15/09/2011.

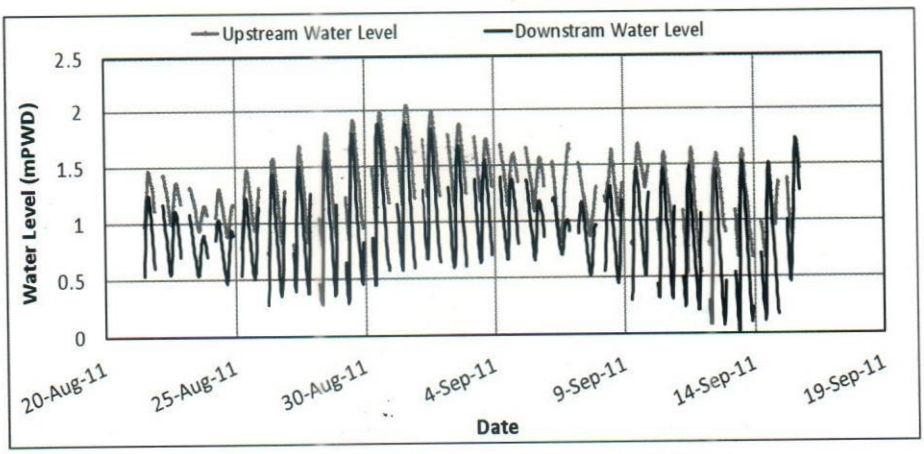


Figure 5: Upstream and Down Stream Water Level

## Results and Discussion

After acquiring all input data, discharge has been generated using the developed VBA program. The discharge has been calibrated in order to achieve desired accuracy by comparing the generated system to actual system behavior. The calibration is done by tuning the bed resistance (Manning's "n"). The comparison plot of generated discharge vs. observed discharge has been given in Figure 6.

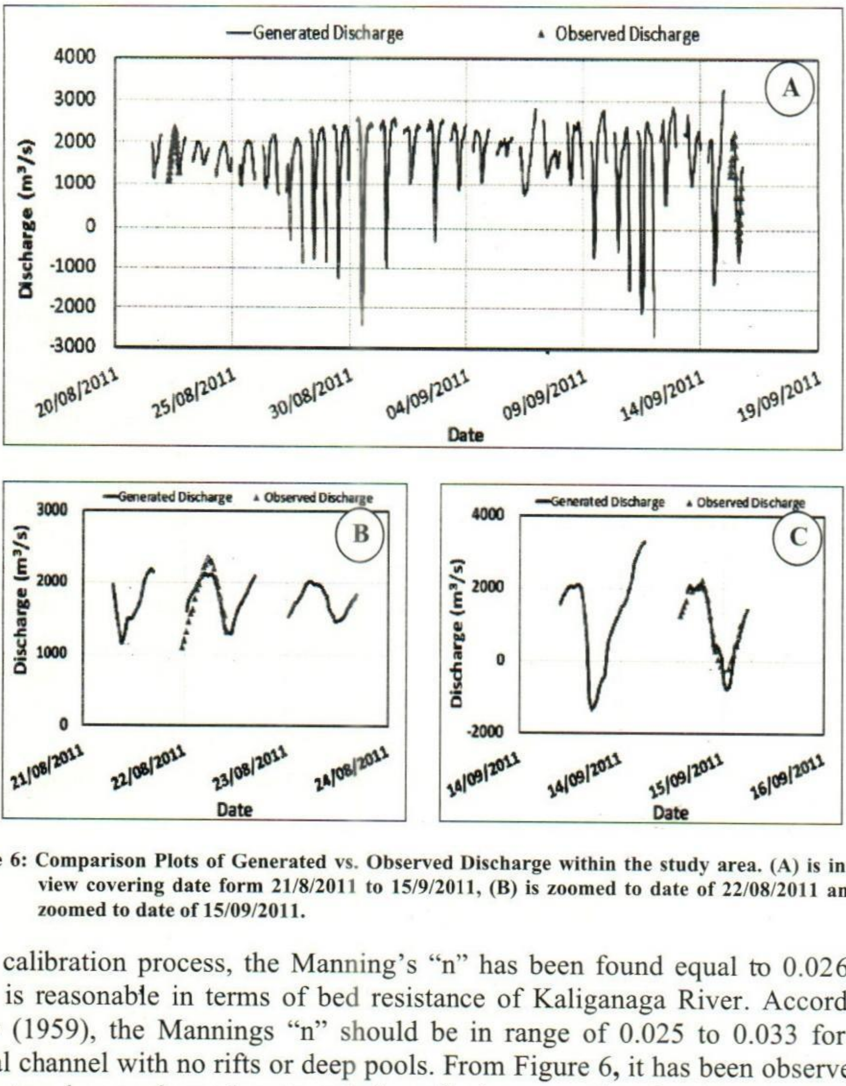


**Figure 6: Comparison Plots of Generated vs. Observed Discharge within the study area. (A) is in the full view covering date form 21/8/2011 to 15/9/2011, (B) is zoomed to date of 22/08/2011 and (C) is zoomed to date of 15/09/2011.**

After calibration process, the Manning's "n" has been found equal to 0.026. This value is reasonable in terms of bed resistance of Kaliganaga River. According to Chow (1959), the Mannings "n" should be in range of 0.025 to 0.033 for clean natural channel with no rifts or deep pools. From Figure 6, it has been observed that the system has performed quite satisfactorily in generating the ebb tide. However, the flood tide has been found slightly over estimated. Nevertheless, the tidal pattern and amplitude of the discharge has been captured agreeably with sufficient accuracy.

## Conclusion and Recommendation

In this study the local acceleration term is neglected. If it is considered the results might have been achieved with more accuracy. Also the contribution of Nazirpur Khal and Belua River connected to Kaliganga River is not considered due to unavailability of input data. Consideration of their contribution might have improved the results. In addition, this method is best suitable for a small and straight reach where the inflow and outflow remains equal. But due to unavailability of input data a reach of 30.5 km has been selected for this study. River bends and branches have been observed within the reach. Selection of small and straight reach is needed to achieve accurate results. In this study the excel VBA programming platform is selected. Excel is the most widely used software for data analysis. But this method can be developed in any other programming platform such as FORTRAN, MATLAB, C, C++ etc.

However, in small and straight reaches with variable or irregular cross sections, it is convenient to use the methodology like described above. Results obtained by this procedure have been shown to be accurate and reliable. Moreover, this approach not only takes into account the back water effect and loop characteristics of unsteady flow, but also reduces the steady flow rating curve extrapolation errors at higher flow regimes. Also for calibration only one parameter is required, which is the roughness coefficient. This reduces the complexity of the system.

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## List of Symbols and Units

**A** Cross sectional area [$m^2$];
**Q** Discharge [$m^3\ s^{-1}$];
**U** Cross sectional mean velocity [$m\ s^{-1}$];
**K** Cross sectional conveyance [$m^3\ s^{-1}$];
**R** Cross sectional hydraulic radius [m];
**h** Water depth [m];
**S** Water surface slope [−];
**$S_f$** Friction slope [−];
**β** Boussinesq momentum coefficient [−];
**n** Manning roughness coefficient [$m^{-1/3}\ s$];

**t** Time coordinate [s];
**x** Longitudinal distance along the reach [m];
**z** Water surface elevation above a horizontal datum [m];
**g** Acceleration due to gravity [m $s^{-2}$];
**u/s** Upstream
**d/s** Downstream

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# EFFECTS OF CLIMATE CHANGE ON RIVER MORPHOLOGY IN BANGLADESH AND A MORPHOLOGICAL ASSESSMENT OF SITALAKHYA RIVER

**Shahadat H.[1], M. Rahman[2], F. Nusrat[3], R. Rahman[4] and N. F. Anisha[5]**

## Abstract

Bangladesh is the largest delta in the world. Himalayas prdduces huge sediment as the young mountain. The Ganges and the Jamuna are draining the southern and northern slopes of the Himalayas which are carrying more than one billion tons of sediment every year.The huge amount of sediment has built up the world's largest delta and made the river and estuary very dynamic and quickly responding. Bangladesh is one of the most vulnerable countries on earth that would be affected by climate change. Global warming with higher associated rainfall and relative sea level rise will likely cause significant changes in sediment and flood regimes. Consequently, large rivers may be disturbed requiring long periods of adjustment in fluvial processes and morphological forms. Being subjected to upstream condition which is beyond control, changes in hydrological and climatic parameters would make these rivers more vulnerable as well as unpredictable. The main issues of climate change that may affect morphological processes are (a) changes in flood regime due to changes in precipitation pattern (b) changes in sediment load due to changes in precipitation (c) changes in base level due to sea level rise. It is now high time to assess the impact of climate change on the morphology of those rivers as well as the subsequent impacts on floodplain dwellers so that the nation can prepare itself to mitigate the effects. It is expected that this sort of study can be replicated for the other large rivers in Asia. The cross sections as well as the model results (from the General Model) have been inspected and parameters derived for the Lakhya River. Numerical modeling using a two-dimensional model is very helpful for assessing the design conditions of physical structures placed in the river.

## Introduction

The Rivers of Bangladesh are generally very active in morphological terms. Annual changes in river profiles as well as bank erosion rates have a scale that is far beyond those in low energy river systems, such as in Europe. The annual river floods, the slope of the river valleys, the sediment properties and the vast amount of upstream sediment supply are the main causes for this. Most of the rivers in Bangladesh are part of a large delta and represents as such an unstable state in the morphological development of river systems. Nevertheless, it has been attempted in the past to quantify river processes in Bangladesh by means of data analysis, analytical assessments and mathematical and physical modelling.The data basis for the Lakhya River provides natural limits to both the understanding and prediction of the morphological river behavior in these rivers.

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Due to this fact, a morphological assessment can't be made on basis of e.g. data analysis or modeling alone. The approach in the present study has therefore been to combine a number of assessment methods and evaluate the combined outcome to provide a ranking of the proposed water intake sites. The various means of determining the suitability in morphological terms are field visit/visual inspection, data analysis, satellite image interpretation, analytical assessments and mathematical modeling.

## Climate Change and River Morphology of Bangladesh

Bangladesh is the largest delta in the world. Himalayas produces huge sediment as the young mountain. The Ganges and the Jamuna are draining the southern and northern slopes of the Himalayas which are carrying more than one billion tons of sediment every year. The huge sediment has built up the world's largest delta and made the river and estuary very dynamic and quickly responding. In Bangladesh, the potential impacts of climate change are of great importance because of global warming. As a result of climate change, river flooding may increase in duration and flash flooding will tend to be more frequent as cyclones. Surge depths will increase, and a sea level rise of 0.5m by 2050 would exacerbate drainage congestion. In the coastal area of Bangladesh the probable impacts of climate change/ sea level rise are more coastal erosion, sedimentation in the estuary will further aggravate drainage congestion, flooding, navigability and cyclones with higher frequencies and intensities. The morphological changes would have severe implications on agriculture, food security, socio-economic development and general livelihood of the coastal communities. [Julien, P.Y., 2006]

***Tectonic Subsidence***: Bangladesh is subject to tectonic induced subsidence which generally is of the order of a few mm per year and reaches its maximum of about 15 mm/year in the Sylhet Basin in north-eastern Bangladesh. [Julien, P.Y., 2006]

***Sea Level Rise:*** With sea level rise a greater part of the upstream sediment load to the coastal zone will deposit near the coast but it is not known to what extend this increased deposition can balance the sea-level rise. This will to a large extend depend on 1) the flow of water and sediment load from upstream 2) the tidal flow and surges and 3) the wave climate in the Bay of Bengal. All these processes will be affected by climate changes – either directly or indirectly and for the first process also to a wide extent by human interference in the basin and in the delta itself. Sea-level rise induced changes of the flow (change in tidal constituents, ebb, flood dominance etc) as well as the change in sediment transport capacity of the delta. The increased penetration of salt water and changes in tidal conditions will move the turbidity maximum and siltation of fine sediments upstream will all have impact on the sediment budget. [Julien, P.Y., 2006]

***Bed Erosion-Deposition:*** Climate change will cause the increment of the flow in rivers which will bring changes in bed erosion and deposition. Higher bed erosion is caused by the higher amount of flow and deposition of eroded materials at downstream is also caused by the climate change. Bridges in the upstream of the river may increase the bed erosion due to this climate change. [SWMC, 2001]

***Flow Velocity:*** Climate change scenario represents the enhancement of the flow, which may cause increment in velocity at certain locations. Maximum velocity causes threat to bank protective structures. [SWMC, 2001]

***Bank Erosion:*** Like other variables, bank erosion is also increase by the climate change. On account of increment of shear stress and bed erosion, bank erosion may increase at some of the important locations. The river Ganges and the Jamuna face increasing bank erosion but interestingly the Padma is not subjected to such consequences. The reason for not having the impact is mainly the geological setting of the Padma that is different from other rivers. The Padma could accommodate the increment of flow by increasing its conveyance area, where bed erosion increment of the Padma is quite higher (6 m erosion) than that of the other rivers. [SWMC, 2001]

**Literature Review**

The following describes in short the key studies in relation to sediment transport and morphology which has been carried out in the past on Lakhya Rivers.

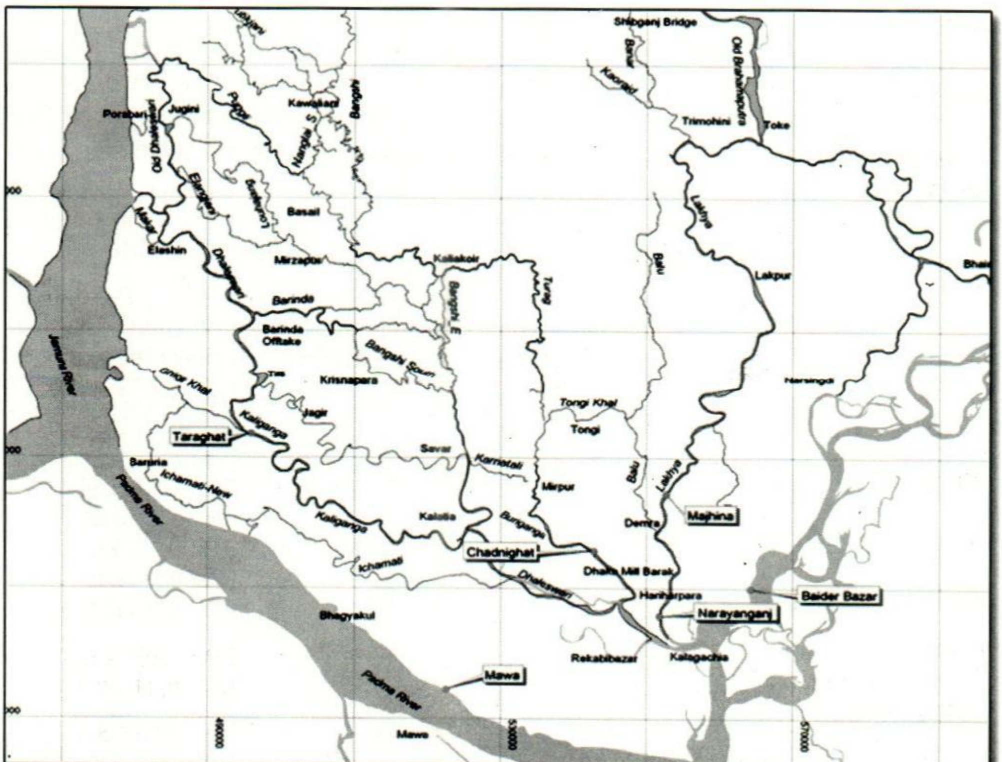


**Figure 1: Rivers around Dhaka City**

*Feasibility study of 2006*

A basic morphological investigation was made on Lakhya, Meghna and Padma Rivers during the Feasibility Study from 2006.The investigation included a review of available data and reports, as well as some basic analysis of cross section development and satellite image interpretation. The study from 2006 is a valuable starting point for the present and also future study.

*FAP studies*

A number of studies were carried out in the 1990's under the Flood Action Plan (FAP). In total 25 studies were carried out. The studies provided new bathymetry, hydraulic and sediment data within the rivers of Bangladesh, as well as analysis of sediment transport and morphology. Basically all main rivers and many secondary Rivers of Bangladesh are covered in the FAP studies. For the main rivers, the primary focus was on Ganges, Jamuna, Padma and Lower Meghna. Hence, only little work was made on the rivers surrounding Dhaka. The specialist reports of FAP24 and FAP6 are useful for the present study [FAP 6, SNC, 1993]

The base line information study by JICA (JICA, 2000) is the only account which describes the morphological changes in the rivers surrounding Dhaka. IWM (IWM, 2004b) also reports on cross section data and sediment transport issues of the rivers. As part of the JICA study, additional cross section surveys were carried out, and historical satellite images retrieved and analysed. With this information the study determined the changes in top width and bank line changes of the river system. The table below summarizes the observed changes in cross section top width and bank line changes as reported in (JICA, 2000). [JICA, 2000]

**Table 1: Morphological changes on the rivers around Dhaka (Source JICA)**

| River Name | Changes in river bed elevation [m] | Changes in top width [m/year] | Left/right bank line change [m/year] *) |
|---|---|---|---|
| Turag (1989-2009) | -0.01 to -9.0 | 0.4 - 3.2 | LB : 0.7 - 3.9<br>RB : 0.1 - 2.5 |
| Buriganga(1989-2009) | -6.3 to -16.2 | 7.3 - 12.4 | LB : 1.7 – 5.8<br>RB : 1.3 – 6.8 |
| Tongikhal (1991,2009) | None | 0 - 0.6 | LB : 0.1 – 3.6<br>RB : 0.2 – 3.4 |
| Balu (1991,2009) | None | 0.2 - 1.8 | LB : 0.3 – 6.6<br>RB : 0.0 – 6.7 |
| Lakhya (1985,1989,1995,1999, 2009) | -0.4 to -14.1 | 3.3 - 9.67 | LB : 0.125 – 6.6<br>RB : 0.04 – 7.3 |
| Dhaleswari (1989,1990,1993, 2009) | -0.25 to -13.4<br>0.15 to -5.6 | 18 – 45<br>10-60 | LB : 0.56 – 5.4<br>RB : 0.4 – 1.5 |

The JICA study (JICA, 2000) reports that even though limited data have been available for the study, the following indications have been obtained: [JICA, 2000]

The river system is not highly morphologically dynamic.
The rivers are more or less stable.
The bank line and top width changes are not high.
The rivers are more or less straight.
Sediment concentrations are not very high.
Bed sediment of most of the rivers is non-cohesive in nature and the rivers are not braided.


**Figure 2: Route of the Lakhya River**

**Figure 3: River bends on the Lakhya and bank erosion at river bend**

## Available Data and Analysis

**Hydraulic Data:** Hydraulic data have been obtained from BWDB from various stations in Lakhya River.

**Water Level:** Water level data exist for 4 stations on the Meghna and 2 stations on the Lakhya River. For all stations except Demra on Lakhya, the period covered is 10 years of daily data. The details of the data are seen in Table 2.

**Table 2: Water level data of Shitalakhya River**

| River name | Station ID | Station name | Period |
|---|---|---|---|
| Lakhya | SW180 | Narayanganj | 01.01.1999-30.11.2009 |
| Lakhya | SW179 | Demra | 01.01.2008-30.11.2009 |

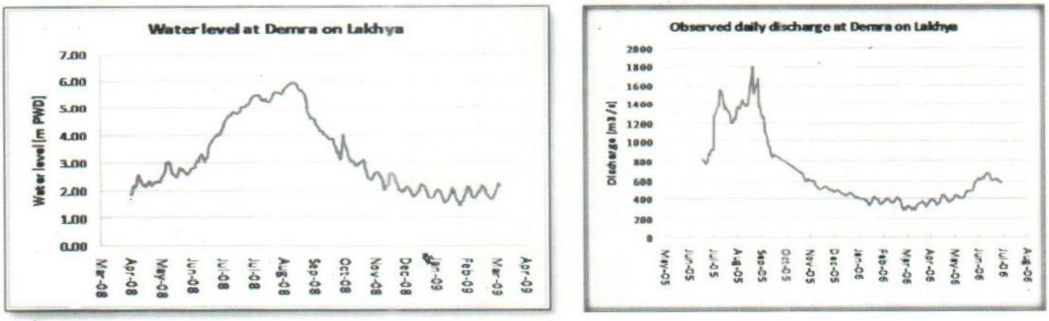


**Figure 4: Water Level and Daily discharge data at Demra on Lakhya**

**Discharge:** Recent discharge data have been received from Demra station on the Lakhya River for the period 04.07.2005 - 09.07.2006 on a daily basis. Weekly discharge data for the same station has been obtained for the period 04.07.2005 - 26.10.2009. (Figure 5)

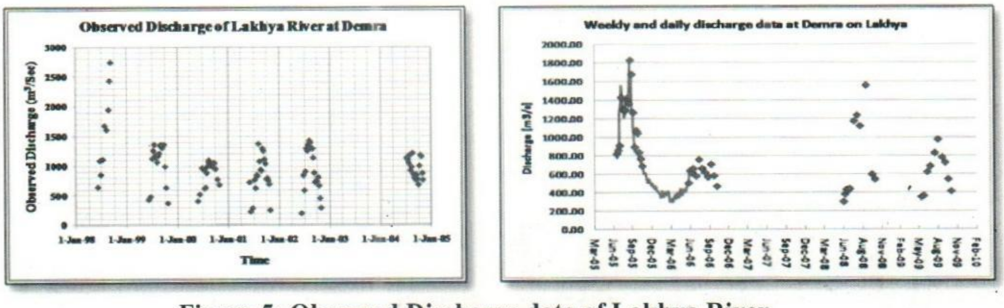


**Figure 5: Observed Discharge data of Lakhya River**

**Velocity:** Velocity data exist from Demra station for the period 04.07.2005 to 26.10.2009 on bi-weekly basis. These velocities are maximum flow velocities in the cross section at Demra and measured approximately in the centre of the river profile.

**Sediment Data:** There are very limited data available on sediment characteristics (grain size, suspended sediment concentration) for the rivers around Dhaka (JICA, 2000). The JICA report (JICA, 2000) only a few data from 1991-92 are available. Based on those data the JICA study came up with concentrations and grain size distribution for the rivers. The table below is a summary of the findings.[ JICA, 2000]

**Table 3: Sediment characteristics of the rivers around Dhaka (from JICA, 2000)**

| River | Sediment grain size $d_{50}$ [mm] | Sediment concentration [mg/l] | Sediment type |
|---|---|---|---|
| Tura | 0.096 - 0.262 | 103 – 583 | Non-cohesive |
| Furigana (1989-2000) | 0.116 | 377 | Non-cohesive |
| Tonga khan (1991,2000) | - | - | - |
| Bale (1991, 2000) | 0.121 | 663 | Non-cohesive |
| Lakhya (1985,1989,1995,1999,2000) | 0.166 | 547 | - |
| Dhaleswari (1989,1990,1993, 2000) | 0.1 – 0.13 | 408-654 | - |

**Bathymetry Data:** Bathymetry data in the form of river cross sections have been obtained from BWDB for various locations on the Lakhya River. All together twelve cross sections on the Lakhya have been received from BWDB. These cross sections are from the years 1998-99 and 2000-01 respectively. Cross sections have likewise been retrieved from the General Model (MIKE11) of Bangladesh by IWM. These cross sections have originally been retrieved from BWDB. The cross sections cover the years 1995-96 in case of Lakhya.A bathymetry survey was conducted in connection with the Meghna Power Plant study (DHI, 2001).[ BWDB, 1990]

**Satellite Images:** Satellite images from the years 1980, 1989, 2000, 2003, 2003 and 2010 have been obtained from the company GRAS A/S in Denmark.

## Methodology

The aim of the morphological assessment is to determine the future changes in river course will significantly affect due to climate change. Since a long term assessment of the rivers in Bangladesh can not be guaranteed, the analysis includes a prioritization of the potential sites. The methodology applied in the present assessment is the following:

| Activity | Description |
|---|---|
| Google Maps Analysis | Qualitative assessment of local conditions from maps |
| Data analysis | • Water levels and discharges<br>• Cross sectional changes<br>• Plan form changes<br>• Sediment data |
| Analytical assessment | Regime analysis/hydraulic geometryMeander stability |
| Numerical modeling | River scale modeling (1D, MIKE11) |

## Hydraulic Data Interpretation and Results

***Implication of the water level and discharge variation***

The water levels in the Lakhya River vary approximately 4-5 meters throughout the year. This has significant impact on the shape of the river channels and the stability. The variation in water level in two distinct seasons, dry and wet season means that a clear dry season and a wet season channel can be identified along the rivers.One effect of this is that the bed shear stress in the vicinity of the banks during the wet season is larger than if the channel was u-shaped. Another effect is that the wet season banks are not as high as if the rivers have u-shaped cross sections.The water level variation of 4-5 meters results in river banks which become saturated during the monsoon, and gradually dry up during the dry season.[ BUET and JICA, 2004]

***Observation in relation to sediment data***

During the analysis it was observed that the Riverhas relatively steep banks. This suggests that the banks have a certain content of silt and clay. The failure of such banks is difficult to predict as the mode of failure are many (shear erosion, tension cracks, rotational collapse etc.) and since the bank material is mixed cohesive (clay and silt) and non-cohesive (sand). The data available show that the sediment concentration in the Lakhya is much higher than in the Meghna. [BUET and JICA, 2004]

***Satellite imagery interpretations***

Plan form changes are obtained by comparing bank line positions from different years. The bank line positions have been processed from the satellite images. The accuracy of the plan form changes is controlled by the resolution of the satellite images which ranges from 15 m to 57 m. Thus any difference in bank line position (from different years) which is less than or similar these figures will not be accurate. The acquired satellite images cover a period of 30 years (1980 to 2010). This is a relatively short period when considering time scales of morphological processes in river systems. The part of LakhyaRiver which is considered in the plan form analysis reaches from Ghorasal Bridge to the present intake channel of the Saidabad treatment plant. In this reach, the river follows a single course with both straight sections and larger and smaller meanders. *Figure 6 shows all bank lines processed* from the satellite images superimposed on the satellite image from 2003.

**Figure 6: Lakhya River from Ghoralsal Bridge to the intake channel at Saidabad**

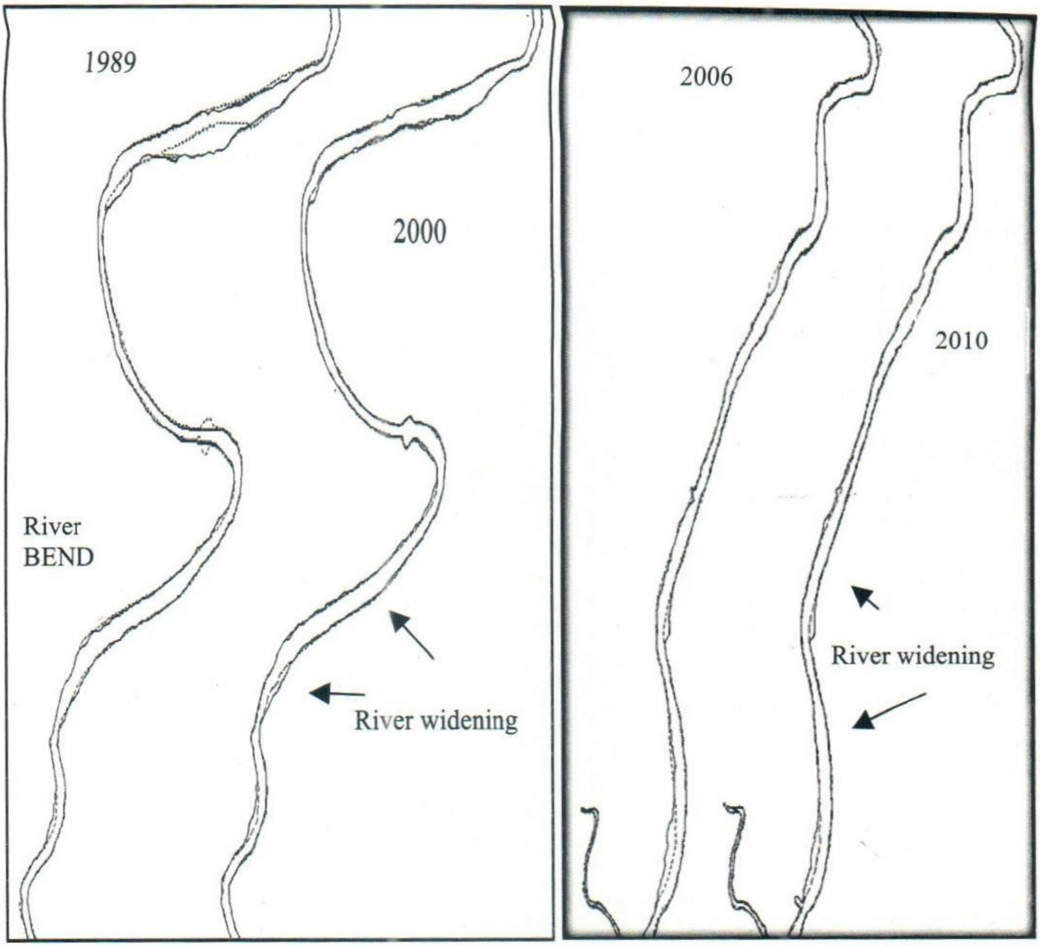


**Figure 7: Bank line positions for the reach between Ghoralsal Bridge and Kanchan Bridge**

A closer inspection of the bank line changes is made separately for two sections: 1) from Ghoralsal Bridge to Kanchan Bridge and 2) from Kanchan Bridge to the channel of Saidabad. In order to compare bank line positions, plots are made for years which have similar resolution of the source image. The bank line position from 1980 have been omitted, as the resolution is 57 m, and judged to be too coarse for comparison with other images. Thus 1989 is compared with 2010 (both 30 m resolution) and 2000 with 2006 (both 15 m resolution).[ BUET and JICA, 2004]

**Cross-section Changes**

River cross sections obtained from different years can be useful for evaluation of the vertical change and stability of rivers. If the cross section have been observed at exactly the same location in a number of years, it is possible to determine a time wise development of the section and calculate erosion/accretion rates. If the horizontal position of the cross sections is available, then the changes in bank position can likewise be obtained from the cross sections. Cross sections have been obtained from BWDB covering all available stations in Lakhya Rivers. The years for which cross sections are obtained are from 1995-1996 and 2000-01 for LakhyaRiver.[ BUET and JICA, 2004]

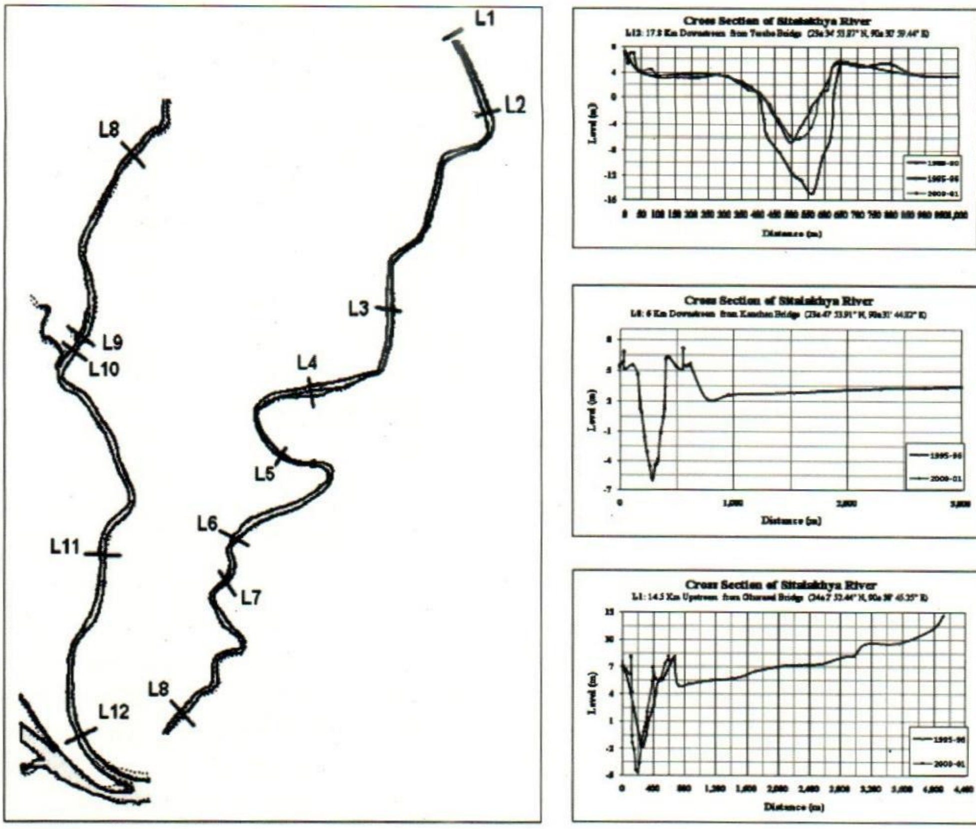


**Figure 8: Locations of observed river cross sections in the Lakhya River**

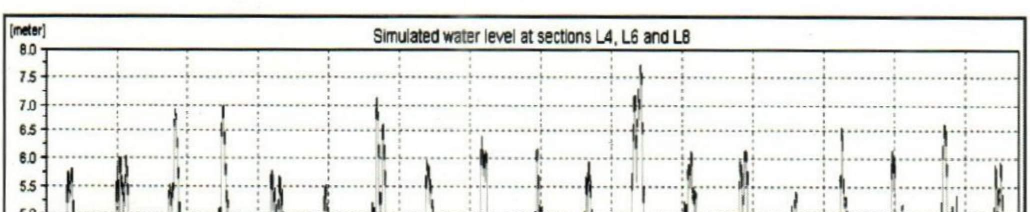


**Figure 9: Simulated cross sectional average flow velocity in Lakhya River from L4, L6 and L8 cross sections are shown.**

## Conclusion

Significant research has been made in the past to identify the stability conditions for various types of rivers and to identify the conditions for which the form or shape of a particular river would change according to the climate change and other effects from environment. There has been much debate on both the validity and the usability of those findings. The present study has attempted to apply the principles for meander stability in order to analyze whether the Lakhya River is likely to be in a transition from one type to another. However, the conclusion when applied to the Lakhya River remains unchanged even if suspended load is included. However true straight rivers do not exist in nature, hence the diagram should be considered as a continuum of shape conditions. The strength of the flow (represented as the dimensionless shear stress) is plotted on the x-axis, while the ratio between the river depth and width appears on the y-axis.The cross sections as well as the model results (from the General Model) have been inspected and parameters derived for the Lakhya River.Numerical modeling using a two-dimensional model is very helpful for assessing the design conditions of physical structures placed in the river.The present morphological assessment has only dealt with the existing situation without a structure. It is highly recommended to deploy two-dimensional mathematical modeling for the future study. This will require a certain amount of bathymetry data, wherefore such data needs to be acquainted.

## Recommendation

According to the results in terms of the parameter variation are plotted on top of the stability diagram, it is seen that the Lakhya River remains in a more clear meandering state due to climate change and erosion accretion process. The results confirm that Lakhya is in a meandering stage for the range of flow and depth condition that it is subjected to.This finding is not surprising when analyzing the river course on satellite images.These types of branches like Lakhya River are usually more stable than typical river braids in e.g. the Jamuna River.The present morphological assessment is concerned with the suitability of climatically changes of river courses along the Lakhya River. The main concern for the study was whether the river reaches with a future changes to remain a stable river.

## Acknowledgement

The authors would like to acknowledge the contribution of all team members of this study. Particularly, Henrik Garsdal, Project Director, Morphological Assessment of Intake Sites, DWASA is appreciated for his kind consent to the authors for this publication and the invaluable support of Anders Refsgaard, Design Engineer, of Morphological Assessment of Intake Sites for safe Drinking Water Source Identification, DWASA.

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# DETERMINATION OF RELEVANT SOIL PARAMETERS AS A BASIS OF PLASTICITY MEASUREMENT

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## Abstract

Plasticity is a useful criterion of engineering soil. It helps us to classify the soil and determining the physical difference between the behavior of clay, silt and sand and determine the physical properties. From this point of view, an attempt has been made for establishing co-relation with plasticity and their relevant parameters. To fulfill the desire, a number of soil testing data of various parameters of Cox's bazar region's soil have been tested in the Soil Mechanics Division (SMD) of River Research Institute (RRI). Laboratory analysis has been accomplished minutely at which it is observed that clay sample mixed with varying amount of fine sand. However, it is also been found that organic clay and clay mixed with organic matter occasionally at the strata in those regions. Here, plasticity index has been varied from (13%-37%) and this wide range of variation is due to the various soil size and presence of organic matter. A number of graphs have been plotted for plasticity vs. liquid limit, compression index compressive strength, cohesion,angle of internal friction, and unit weight. From the graph it is found that compression index($C_C$ ) increases with the increase in plasticity index (PI) whereas compressive strength decreases with the increase in plasticity index. Cohesion decreases with the increase in plasticity index. Unit weight decreases with the increase in plasticity index. Finally, a number of equations have been established. From these equations relative design parameters will be determined in any other regions of similar soils through the measurement of plasticity. So, the findings inform that plasticity is a basis of the most engineering soil parameters.

## Introduction

In geological point of view, Bangladesh soils are still in Pleistocene era containing the ingredients of sand, silt and clay. We know the composition all of the ingredients make soil and contains some water by which soil behaves like a plastic material. As Bangladesh soils are the combination of sand, silt and clay with various sizes and contain water so, they are also plastic soils.

The difference between liquid limit and plastic limit is known as the plasticity index. Soils with high plasticity index are called plastic soils (Garg, 2009). In this paper plasticity index has been chosen as a depending parameter as plasticity is an important property of fine grained soils especially clayey soils. Plasticity in soils is due to the presence of clay minerals.

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In the recent years, the technique of single analysis is arranged for measurement and understands field events have often been attempted (Nakase, 1988). In light of this view, a simplest but most important parameter like plasticity index has been chosen for correlating with other complex parameter from which complex parameters can easily be determined by knowing plasticity index. In this regard, other parameters of soil are also collected from Soil Mechanics Division (SMD) of RRI for same sample. The main objective of this study is to estimate relevant soil parameters such as compression index, compressive strength, angle of internal friction, and unit weight using this established correlation through measuring plasticity.

**Literature Review**

Geologically Bangladesh is a part of the Bengal Basin, one of the largest geosynclines in the world (Sajjadur, 2008).The Bangladesh landmass has gone through several historical ages to arrive to this present formation. The major divisions of these ages are the PreCambrian, the Paleocene, the Eocene, the Miocene, the Pliestocene and the Holocene ages (Inamul, 2008).

Hunt has grouped Bangladesh soil into six units and from the brief soil description of the six units is observed that silts, silty clays and clays of low to medium plasticity occur predominantly in the upper layers and has suggested 3 to 6 percent CBR values for deposits of (1) estuarine and tidal flood plain, (2) raised alluvial terraces, (3) alluvial flood plain (4) alluvial flood plain but including depressions and 10 percent for (5) Himalayan piedmont deposits and (6) hill soils.

Serajuddin and Ahmed have indicated from their study of the soils of different projects areas of Bangladesh occurring up to depths of about 6 to 7 meter that silt and clay materials of low to medium plasticity occur predominantly in many areas in the upper soils strata in Bangladesh (Uma, 2006). In connection of plasticity index, Skempton expressed the relationship,

$$C_u/\sigma = 0.11 + 0.0057PI$$

Where, $C_u$ = *undrained cohesion intercept*

$\sigma$ = *effect of overburden pressure*

$PI$ = *plasticity index* (Arora, 1987)

Some authors have established many of the co-relations by writing the paper and analyzing the soil parameters through the enormous study.

A few of these have been presented herewith. Md. Serajuddin(1964) has established a equation

$$C_c = 0.009(LL-10)$$

Where, $C_C$ = *compression index* $L_w$ = *liquid limit*

Md. Serajuddin and Mr. Alimuddin (1967) have established empirical equations for East Pakistan clays,

$$C_C = 0.0078(W_L - 14)$$

Where, $C_C$ = *compression index*, $W_L$ = *liquid limit*

Serajuddin (2001) established for Dhaka Clays,

$$I_p = 0.74(W_L - 19)$$

Where, $I_p$ = *plasticity index*, $W_L$ = *liquid limit*

$$C_C = 0.009(W_W + 0.005 L_W)$$

Where, $C_C$ = *compression index*, $W_W$ = *natural water content*, $L_W$ = *liquid limit*

$$I_P = 1.0093\ C_P + 0.5238$$

Where, $I_p$ = *plasticity index*, $C_P$ = *clay present*

**Methodology**

In this paper, Cox'sbazar region has been selected as a study area. In order to establish co-relations among some parameters with plasticity index of soil, a good number of soil testing data have been collected from soil mechanics division of Geotechnical Research Directorate of RRI such as natural moisture content, liquid limit, plastic limit, unit weight, loss-on-ignition, compressive strength, cohesion, angle of internal friction and compression index. The soil samples were sent to RRI for testing of different parameters from different construction projects of

Cox'sbazar region by Bangladesh Water Development Board (BWDB). As design needs the soil properties and RRI tests soil samples since 1948.

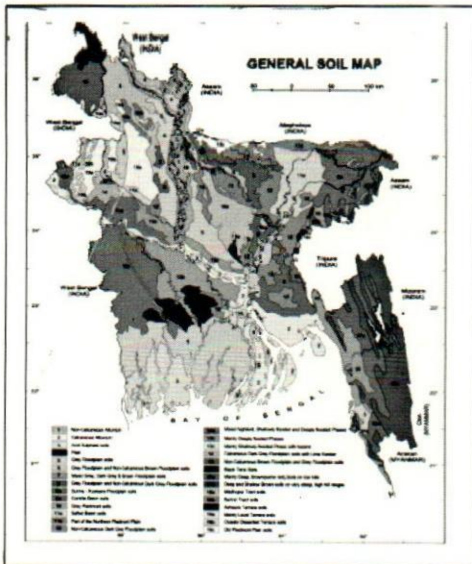


**Figure 1: General Soil map of Bangladesh (Wikipedia, 2014)**

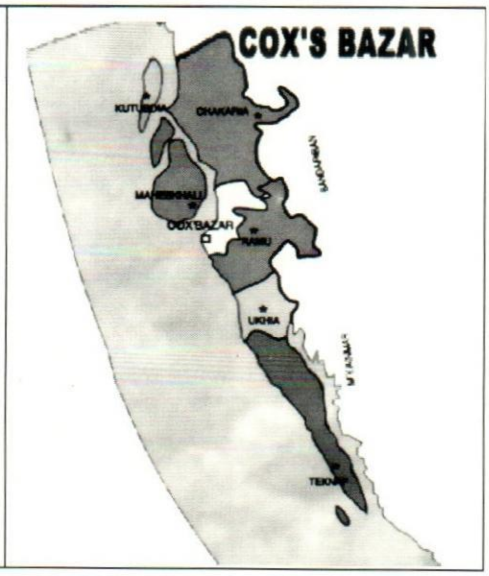


**Figure 2: Study Area (Wikipedia, 2014)**

Figure 1 represents the general soil map of Bangladesh and Figure 2 represents the study area. The drilling was explored in selected region. The maximum explored depth was 72′ and the undisturbed samples were collected from (7′-8′), (10′-12′), (15′-17′), (20′-22′), (35′-37′) and (40′-42′) of Cox'sbazar region of Bangladesh (SMD, 2005, 2006, 007, 2008, 2011).

Desire data have been analyzed by authors using conventional formulas. Liquid limit and plastic limit have been analyzed by Atterberg's limit test and plasticity index has been calculated from these two limits. Compression index has been calculated from the virgin compression line of void ratio and log-pressure curve according to Terzaghi and Peck. For determining shear strength, cohesion and angle of internal friction have determined from Mohr's Circle diagram on unconsolidated undrained triaxial shear test. Unconfined compressive strength has been determined from unconfined compressive test. All soil data have been presented in the tabular form in Table 1.Statistical analysis has been done in conventional method. Statistical Parameters of soil data have been shown in Table 2.

## Results & Discussions

**Table 1: Showing the results of some engineering properties of soil**

| SI No. | Depth in (ft) | N.M.C in % | L.L. in % | P.I. in % | $\gamma_w$ in kN/m$^2$ | $\gamma_d$ in kN/m$^2$ | Ig in (%) | $q_u$ in kN/m$^2$ | c in kN/m$^2$ | ($\phi$)in degree | $C_C$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 15-17 | 27.50 | 56 | 30 | 19.64 | 15.41 | 0 | 131.56 | 27 | 2 | 0.253 |
| 2. | 20-22 | 29.74 | 59 | 32 | 19.40 | 14.81 | 0 | 162.77 | 15 | 5 | .0335 |
| 3. | 20-22 | 40.01 | 42 | 20 | 16.68 | 11.91 | 3 | 0 | 28 | 7 | 0.205 |
| 4. | 30-32 | 35.00 | 48 | 23 | 19.73 | 14.62 | 0 | 83.40 | 46 | 2 | 0.242 |
| 5. | 15-17 | 34.79 | 52 | 29 | 18.38 | 13.63 | 0 | 96.10 | 51 | 2 | 0.287 |
| 6. | 15-17 | 32.68 | 53 | 26 | 18.37 | 13.85 | 0 | 62.48 | 22 | 11 | 0.266 |
| 7. | 15-17 | 57.60 | 66 | 36 | 16.08 | 10.20 | 6.75 | 28.93 | 17 | 2 | 0.555 |
| 8. | 20-22 | 34.82 | 39 | 16 | 19.50 | 14.40 | 0 | 40.93 | 19 | 6 | 0.261 |
| 9. | 13-15 | 38.87 | 47 | 24 | 16.50 | 11.90 | 4.2 | 31.81 | 17 | 5 | 0.282 |
| 10. | 18-20 | 41.33 | 47 | 21 | 17.51 | 12.39 | 4.8 | 55.92 | 22 | 6 | 0.295 |
| 11. | 18-20 | 33.37 | 42 | 20 | 18.02 | 13.31 | 0 | 45.62 | - | - | - |
| 12. | 10-12 | 49.90 | 54 | 27 | 17.61 | 13.41 | 8 | 7.95 | 16 | 2 | 0.412 |
| 13. | 15-17 | 46.40 | 57 | 29 | 17.31 | 10.61 | 0 | 6.44 | 16 | 5 | 0.305 |
| 14. | 10-12 | 55.33 | 58 | 30 | 16.97 | 10.92 | 0 | 0 | 13 | 4 | 0.502 |
| 15. | 15-17 | 57.97 | 55 | 30 | 16.92 | 11.13 | 0 | 28.60 | 13 | 4 | 0.580 |
| 16. | 10-12 | 42.37 | 57 | 30 | 18.25 | 12.82 | 0 | 40.37 | 17 | 4 | 0.405 |
| 17. | 20-22 | 49.89 | 53 | 28 | 17.03 | 11.36 | 0 | 6.67 | 17 | 5 | 0.438 |
| 18. | 20-22 | 33.91 | 40 | 16 | 18.91 | 13.66 | 0 | 18.14 | 6.5 | 4 | 0.525 |
| 19. | 15-17 | 41.88 | 46 | 20 | 18.09 | 12.75 | 0 | 22.20 | 11 | 1.5 | 0.257 |
| 20. | 10-12 | 40.39 | 43 | 18 | 17.84 | 12.71 | 0 | 20.70 | 8.5 | 4 | 0.305 |
| 21. | 15-17 | 40.04 | 45 | 19 | 18.55 | 13.25 | 0 | 22.32 | 10.5 | 2 | 0.283 |
| 22. | 25-27 | 28.28 | 57 | 30 | 18.62 | 14.52 | 0 | 39 | 18 | 2.5 | 0.310 |
| 23. | 10-12 | 35.58 | 56 | 27 | 17.25 | 12.72 | 4.8 | 28.59 | 15 | 10 | 0.345 |
| 24. | 20-22 | 43.81 | 59 | 29 | 17.07 | 12.00 | 5.3 | 19.50 | 9.5 | 2 | 0.330 |

| SI No. | Depth in (ft) | N.M.C in % | L.L. in % | P.I. in % | $\gamma_w$ in kN/m$^2$ | $\gamma_d$ in kN/m$^2$ | Ig in (%) | $q_u$ in kN/m$^2$ | c in kN/m$^2$ | ($\phi$)in degree | $C_C$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25. | 10-12 | 38.70 | 42 | 19 | 17.18 | 12.39 | 0 | 0 | 16 | 7 | 0.360 |
| 26. | 15-17 | 41.25 | 55 | 27 | 17.53 | 12.41 | 5.4 | 17.91 | 15 | 1.5 | 0.323 |
| 27. | 15-17 | 43.26 | 56 | 26 | 18.12 | 12.65 | 6.29 | 15.71 | 15 | 1.5 | 0.325 |
| 28. | 20-22 | 34.23 | 53 | 26 | 17.53 | 13.06 | 0 | 20.02 | 16 | 2 | 0.267 |
| 29. | 20-22 | 37.97 | 44 | 20 | 17.25 | 12.50 | 0 | 22.26 | 7 | 4 | 0.204 |
| 30. | 20-22 | 45.39 | 46 | 24 | 17.78 | 12.23 | 0 | 15.90 | 0 | 0 | 0.317 |
| 31. | 20-22 | 32.89 | 38 | 15 | 18.65 | 14.03 | - | - | 30 | 20 | 0.230 |
| 32. | 10-12 | 42.35 | 48 | 29 | 17.56 | 12.34 | 4 | 41.87 | 20 | .5 | 0.462 |
| 33. | 15-17 | 50.01 | 61 | 33 | 16.82 | 11.21 | 7 | 47.69 | 11 | 6 | 0.480 |
| 34. | 40-42 | 37.04 | 55 | 27 | 16.62 | 12.13 | 0 | 30.98 | 20 | 1 | 0.329 |
| 35. | 35-37 | 30.57 | 34 | 15 | 18.74 | 14.36 | 0 | 53.85 | 35 | 1 | 0.230 |
| 36. | 10-12 | 31.81 | 36 | 18 | 18.19 | 13.80 | 0 | 22.71 | 0 | 0 | 0.205 |
| 37. | 15-17 | 39.18 | 43 | 19 | 16.89 | 12.14 | 0 | 21.90 | 8.5 | 5 | 0.278 |
| 38. | 7-9 | 32.16 | 41 | 19 | 18.37 | 13.97 | 0 | 54.03 | 42 | 7 | 0.362 |
| 39. | 7-9 | 27.46 | 42 | 17 | 18.53 | 14.49 | 0 | 126.16 | 0 | 0 | 0.191 |
| 40. | 12-14 | 34.16 | 55 | 28 | 17.54 | 13.91 | 0 | 97.00 | 0 | 0 | 0.279 |
| 41. | 10-12 | 50.79 | 61 | 32 | 16.38 | 10.84 | 5.08 | 31.41 | 9 | 3 | 0.364 |
| 42. | 5-7 | 56.70 | 76 | 37 | 16.32 | 10.41 | 10.5 | 30.46 | 7 | 8 | 0.580 |
| 43. | | 21.09 | 36 | 13 | 0 | 0 | 0 | 9.88 | 0 | 0 | 0.1625 |

N.M.C= Natural Moisture Content, L.L=Liquid Limit, PI= Plasticity Index, $\gamma_w$ = wet unit weight, $\gamma_d$= dry unit weight, Ig=loss-on-ignition, $q_u$= compressive strength, c= cohesion, $\phi$= angle of internal friction, Cc= compression index

**Table 2: Showing some statistical parameters of soil properties**

| Statistics/Variables | P.I. in (%) | $\gamma_w$ in kN/m³ | $q_u$ in kN/m² | c inkN/m² | $\phi$ in degree | $C_C$ |
|---|---|---|---|---|---|---|
| Mean | 24.51 | 17.35 | 39.52 | 16.35 | 4.05 | 0.32 |
| Median | 26.00 | 17.56 | 28.77 | 15.50 | 4.00 | 0.31 |
| MODE | 30.00 | 18.37 | 0.00 | 0.00 | 2.00 | 0.21 |
| STDEV | 6.13 | 2.86 | 36.61 | 11.66 | 3.68 | 0.12 |
| SKEWNESS | -0.03 | -5.49 | 1.76 | 1.13 | 2.20 | 0.45 |
| KURTOSIS | -0.96 | 33.85 | 3.02 | 1.70 | 7.70 | 0.47 |

Plasticity index vs. liquid limit (LL), compression index ($C_C$ ),compressive strength $q_u$, cohesion, (c), angle of internal friction ($\phi$), and unit weight have been plotted and shown in Figure 3,4,5, 6,7, 8 and 9 respectively.

From Figure 3 i.e. Consistency of soil samples on the plasticity chart, it is visualized that plasticity index increases with the increase in liquid limit and the established equation become

$$PI = 0.6523LL - 8.149$$

From Figure 4 i.e. from relationship between compression index and plasticity index, it is observed that compression index ($C_C$) increases with the increase in plasticity index (PI) and the established equation is,

$$Cc = 0.012719PI + 0.00069356$$

In Figure 5 that is from the relationship between compressive strength and plasticity index it is shown that compressive strength decreases with the increase in plasticity index (PI). The established equation is,

$$q_u = 2.534PI + .00069356$$

From Figure 6, it is observed from the graph between cohesion and plasticity index that cohesion decreases with the increase in plasticity index and the equation is,

$$c = -1.1289PI + 47.928$$

Angle of internal friction (ϕ) decreases with the increase in plasticity index in Figure 7 and the equation is,

$$\phi = -0.44224PI + 16.64$$

From Figure 8 is the relationship between plasticity index and wet unit weight, it is found that wet unit weight decreases with the increase in plasticity index and the equation is,

$$\gamma_W = -0.093812PI + 19.814$$

From Figure 9 that is the relationship between plasticity index and dry unit weight, it is observed that dry unit weight decreases with the increase in plasticity index and the equation is,

$$\gamma_d = -0.014123PI + 16.063$$

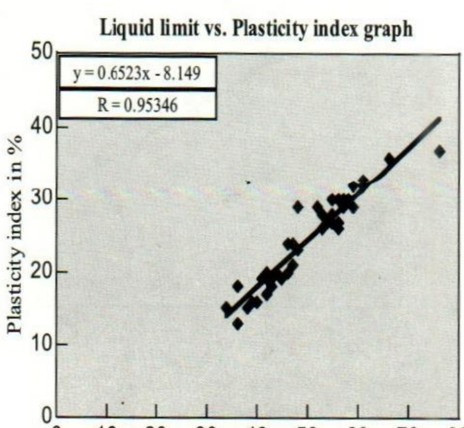


Figure 3: Consistency characteristics of soil samples on plasticity chart and Plasticity index

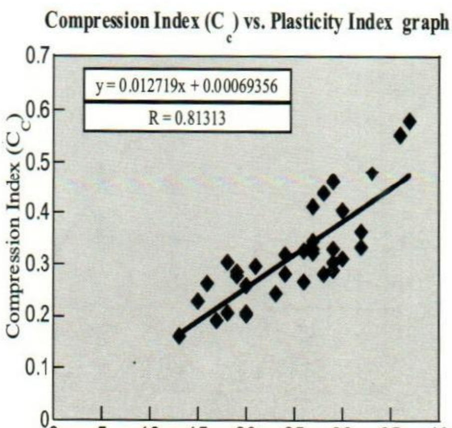


Figure 4: Relation between Compression index and Plasticity index

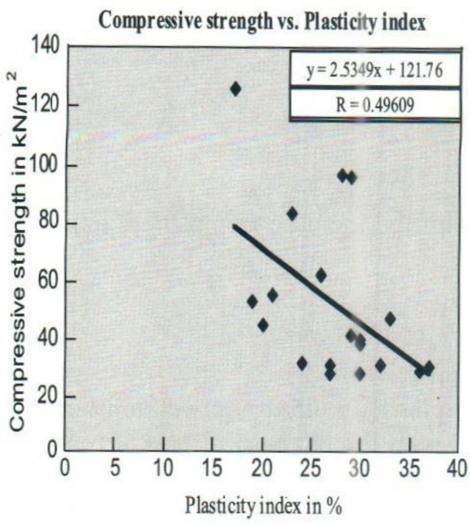


**Figure 5: Relation between Compressive strength and Plasticity index**

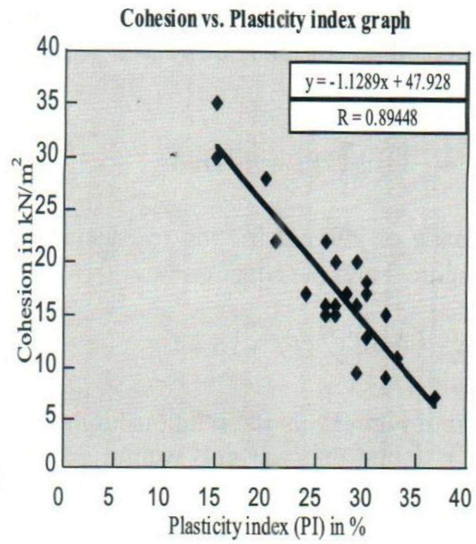


**Figure 6: Relation between Cohesion and Plasticity index**

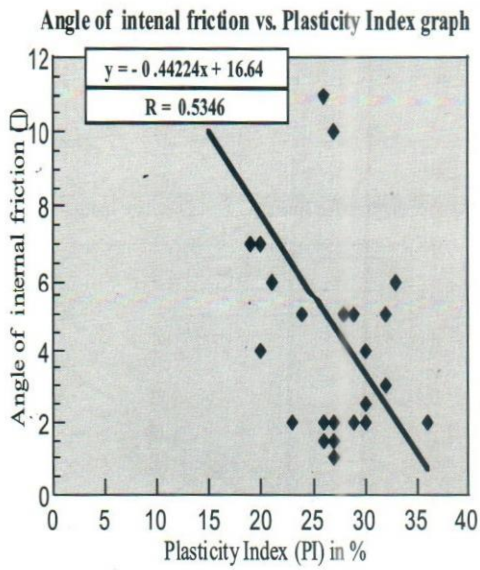


**Figure 7: Relation between Angle of internal friction and Plasticity index**

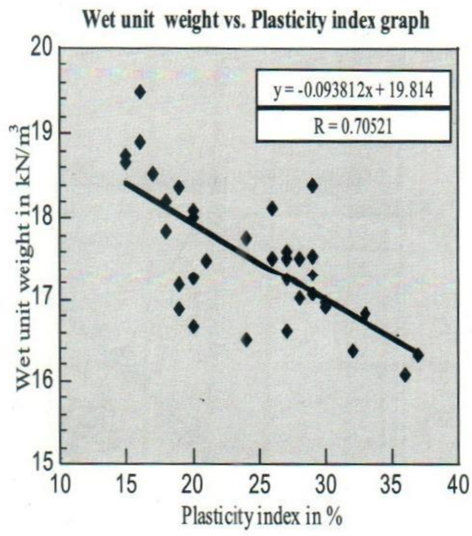


**Figure 8: Relation between Wet unit weight and Plasticity index**

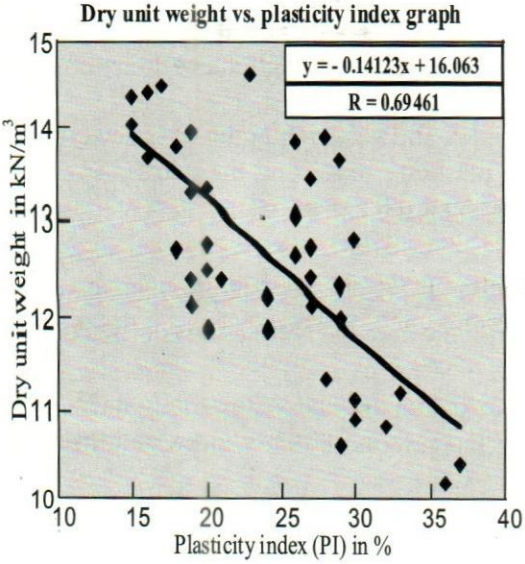


**Figure 9: Relation between Dry unit weight and Plasticity index**

A good number of correlations have been established in this paper and the established equation are presented at a glance in the tabular form in here,

| Established equation | Correlation co-efficient (r) |
|---|---|
| $PI = 0.6523LL - 8.149$ | 0.95346 |
| $Cc = 0.012719PI + 0.00069356$ | 0.81313 |
| $q_u = 2.534PI + .00069356$ | 0.49609 |
| $c = -1.1289PI + 47.928$ | 0.89448 |
| $\phi = -0.44224PI + 16.64$ | 0.5346 |
| $\gamma_W = -0.093812PI + 19.814$ | 0.70521 |
| $\gamma_d = -0.014123PI + 16.063$ | 0.69461 |

In case of compression index, it has been found that compression index varies from (0.1625-0.58). It is depend on particle size, plasticity and presence of organic matter. From the graph it is found that compression index varies with the variation of plasticity index. Here an equation is established wherever correlation coefficient (r) is 0.8.

From the graph of plasticity index and compressive strength, it is observed that compressive strength decreases with the increase in plasticity index and the equation is established where the correlation coefficient (r) is 0.5.

From the plasticity index and cohesion graph, it is seen that cohesion decreases with the increase in plasticity index and the equation is established where the correlation coefficient (r) is 0.9.

Angle of internal friction (ϕ) decreases with the increase in plasticity index and an equation is established where the correlation coefficient (r) is 0.5.

From the wet unit weight and dry unit vs. plasticity index graph that unit weight is decreases with the increase in plasticity index and the correlation coefficient (r) is near about 0.7.

**Conclusions and Recommendation**

Laboratory analysis has been accomplished minutely on a good number of undisturbed samples of Cox'sbazar region of Bangladesh at which it is observed that clay sample mixed with varying amount of fine sand. However, it is also been found that organic clay and clay mixed with organic matter occasionally at the strata in those regions. Here, engineering properties of soils have been determined at which it is seen that moisture content varies from (21%-58%) and plasticity index has been varied from (13%-37%) and this wide range of variation is due to the various soil size and presence of organic matter. A number of graphs have been plotted for plasticity vs. liquid limit, compression index, compressive strength, cohesion, angle of internal friction, and unit weight. From the graph it is found that compression index ($C_C$ ) increases with the increase in plasticity index (PI) whereas compressive strength decreases with the increase in plasticity index. Cohesion decreases with the increase in plasticity index. Unit weight decreases with the increase in plasticity index. Finally, a number of equations have been established. These equations are reasonably close to the other recognized equations. So, it is concluded that plasticity is a basis of the most engineering soil parameters. Here it is recommended that compression index(Cc) and cohesion(c) can easily be determined from the established equation and other relative parameters of soil in this region or any other similar soil can also be calculated by knowing the plasticity index. Moreover, if the relevant design engineer desires more accuracy than they can perform similar study through collecting huge number of soil samples and make arrangement of testing.

## Acknowledgement

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**Notations**

$C_c$ = *Compression index*

$c$ = *cohesion*

$L_L$ = *liquid limit*

$N.M.C$ = *natural moisture content*

$PI$ = *plasticity index*

$\phi$ = *angle of internal friction*

$\gamma_w$ = *wet unit weight*

$\gamma_d$ = *dry unit weight*

$q_u$ = *compressive strength*

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# AN ASSESSMENT OF RIVER WATER QUALITY PARAMETERS: A CASE OF JAMUNA RIVER

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## Abstract

River water quality is a key concern as it is used for drinking and domestic purpose, irrigation and aquatic life including fish and fisheries. The Jamuna is one of the most prominent central rivers in Bangladesh as well as it represents the tapestries line of our riverine country. In toto, the river can play a vital role to contribute social economic structure of development as a developing country like Bangladesh. The study was conducted to assess the water quality parameters of Jamuna River. These parameters were categorized into three classes; Conventional parameters ($P^H$, Temperature, EC and TDS), Organic parameters (DO,BOD,COD) and Other parameters (Nitrate, Ammonia, Sulphate, Chloride , Calcium ) The water samples were collected in plastic container of 2 litre capacity from five different geographic locations along the river in 2012-2013 during both dry and wet season, 25 numbers of samples were collected from surface and 2 feet below from the surface of water at different selective sampling points. A number of physiochemical water quality parameters including Temperature, pH, EC, TDS, DO, BOD, COD, Nitrate ($NO^{2-}$ and $NO^{3-}$), Ammonia, Sulphates, Chlorides, and Calcium were measured in laboratory base analysis. The mean value of such respective parameters in both season were compared with the water quality standards as set by the EQS guideline, ADB, and the guideline of Department of Environment (DoE) in Bangladesh.

## Introduction

River water always acts as an important fresh water resource. Historically most of the development activities flourished depending on them. River water finds multiple uses in every sector of development like agriculture, industry, transportation, aquaculture, public water supply etc. From the very civilization along the rivers, rivers have also been used for clean-up and discarding purposes. Measureless loads of dissipate from industries, household dirt and agricultural practices come across their way into river resulted in outsized extent wear and tear of the water quality. River has now reached to a point of calamity due to spontaneous urbanization and hasty expansion of industrialization. The entire array of life in water is affected due to pollution in water. The problem of water quality deterioration is mainly due to human activities.

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## Literature Review

Water quality criteria are basic scientific information about the effects of water pollutants on a specific water use. Different organizations give a picture of water quality requirements for protecting and maintaining an individual utilize. Many water quality criteria set a maximum level for the concentration of a substance in a particular medium (i.e. water) which will not be harmful when the specific medium is used continuously for a single, specific purpose.

For some other water quality variables, such as dissolved oxygen, water quality criteria are set at the minimum acceptable concentration to ensure the maintenance of biological functions.

Water has become an essential commodity for the development of industrials and agriculture (Kudesia, 1990). Water is absolutely essential not only for survival of human beings, but also for animals, plants and all other living things (Razo *et al.*, 2004). Water is also crucial for the quality of life. The oceans, the rivers, lakes and creeks together with the land constitute the canvas on which life grows and interacts. The ecological balance maintained by the quantity and quality of water determines the way of life of a people.

On the other hand, polluted water is the greatest source of disease and besides debasing the land also becomes unfit to sustain life (Francis, 1994 ). Today the problem is not only of water availability but of environmental quality and ecological balance. With increasing industrialization, urbanization and technological advance in all fields, sources of water are getting more and more seriously polluted. The survival of life on earth will be threatened if the present rate of pollution continues unabatedly. Natural waters are afflicted with a wide variety of inorganic, organic, and biological pollutants. In some cases, such as that of highly toxic cadmium, a pollutant is directly toxic at a relatively low level. In other cases, the pollutant itself is not toxic, but its presence results in conditions detrimental to water quality. For example, biodegradable organic matter in water is often not toxic, but the consumption of oxygen during its degradation prevents the water from supporting fish life (Trivedi, 1992). pH must be controlled within a range favorable to the particular organisms involved. Chemical processes used to coagulate sewage or cyanide ion require that the pH be controlled within rather narrow limits (Nahar, S. 2000). The fluctuation in river water temperature usually depends on the season, geographic location, sampling time and temperature of effluents entering the stream (Ahipathy, 2006). For public health, chlorides up to 250 mg $l^{-1}$ are not harmful but values gather than this are indication of organic pollution (Nahar, S. 2000 ). Oxygen is the single most important gas for most aquatic organisms; free oxygen (O2) or DO is needed for respiration. DO levels below 1 ppm will not support fish; levels of 5 to 6 ppm are usually required for most of the fish population. The average value of DO levels (6.5mg/l) indicates the average quality of river water (APHA, 1995).

The important water quality parameters, such as Color, Odor, Temperature, pH, TSS, TDS, TS, BOD, COD, DO, Turbidity, EC and Salinity etc.

Industrial effluents of different origins containing toxic metals, pesticides, etc and anthropogenic sources (Hatje et al. 1998) create water pollution problems through discharges into river water. The utility of river water for various purposes is governed by physico-chemical and biological quality of the water. The assessment of the changes in river communities as a result of the impact of pollution is particularly interesting issue within the frame work of aquatic ecology, since running waters are becoming increasingly affected by anthropogenic discharge (Whitton et al., 1991). Many workers have studied the impact of anthropogenic activities on the environmental conditions (Kang et al., 2004; Shirodkar et al., 2010; Bhardwaj et al., 2010).

Industrial pollution is one of the major types of water pollutions, as water is an essential raw material in almost all manufacturing plants. Industries that are considered as principal sources of pollution are chemicals, foods, pharmaceuticals, materials and energy. The increased application of commercial fertilizer and widespread use of variety of a new pesticides, insecticides, herbicides and weed killers in agricultural practices are resulting in a host of new pollution problems from land drainage. This type of agricultural pollution has severe impact on water Pollution, as most of pollutants are resistant to natural degradation. Although concentration of the pollutants are still rather low, many of this compounds are toxic to human or animal life; some of them are carcinogenic or have serious ecological implication. (Davis M.L. et al, 1998; APHA 1995; Peavy H. S et al, 1985; Sawyer C.L, et al 1994) .Irrigated agriculture is dependent on adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available (Shamsad and Islam, 2005; Islam *et al.,* 1999). This situation is now changing in many areas. Intensive use of nearly all good quality supplies means that new irrigation projects, and old projects seeking new or supplemental supplies, must rely on lower quality and less desirable sources (Cuena, 1989).

Irrigation water quality is related to its effects on soils and crops and its management. High quality crops can be produced only by using high-quality irrigation water keeping other inputs optimal. Characteristics of irrigation water that define its quality vary with the source of the water. There are regional differences in water characteristics, based mainly on geology and climate. There may also be great differences in the quality of water available on a local level depending on whether the source is from surface water bodies (rivers and ponds) or from groundwater aquifers with varying geology, and whether the water has been chemically treated. The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot, 1985; Rowe *et al.,* 1995).

To evaluate the quality of river water for the purpose of irrigation, health, domestic and fisheries, we need to identify the physiochemical characteristics that are important for respective field, and their acceptable levels of concentrations.

## Materials and Methods

### Study Area

The study was conducted between the Govindashi Ghat, Bamonhata, Nalin bazar, Langra bazar area at Bhuapur Upazila and Gabsarachar Punglipara (Char of Jamuna River).

### Sampling Procedure

The 250 ml plastic bottles were washed well and rinsed with 1-2 ml 2% industrial HCl. The bottles were rinsed again with sampled water and the water samples were collected securely and sealed with proper labeling. Aeration during sampling was avoided as far as possible. The water samples were carefully transported to the laboratory and are preserved for physical and chemical analysis. Samples were collected from river in the distance of about 100 meter from one sample to another.

## Procedures of Parameters Investigation

***$p^H$***

First pH meter was standardized by distilled water and buffer solution. Then 50 ml of sample was taken in clean 100 ml plastic beaker and immersed the pH meter and waited for at least five minutes. Then pH reading was collected from pH meter and wrote down in the notebook. In the same way, for all other samples pH was measured but before every measurement pH meter was sank into distilled water or buffer solution.

***EC, TDS and Temperature***

Firstly conductivity/TDS meter electrode was washed out by distilled water. And then the cell constant of the conductivity meter was checked. Twenty ml sample was taken in 50 ml measuring cylinder and immersed the electrode and waited for at least 10 seconds. Then Electrical Conductivity (EC), Total Dissolved Solid (TDS) and Temperature readings were collected from this meter and wrote down in the notebook.

***DO (Dissolved Oxygen)***

First DO meter was standardized by distilled water and buffer solution. Then 50 ml of sample was taken in clean 100 ml plastic beaker and immersed the DO meter and waited for at least five minutes. Then DO reading was collected from DO meter and wrote down in the notebook. In the same way, for all other samples DO was measured but before every measurement DO meter was sank into distilled water or buffer solution.

***BOD (Biological Oxygen Demand)***

The Biochemical Oxygen Demand (BOD) of polluted water is the amount of oxygen required for the biological decomposition of dissolved organic matter. Usually, the time is taken as 5 days and the temperature 20°C as per the global standard. The BOD test is among the most important method in sanitary analysis to determine the polluting power, or strength polluted water. It serves as a measure of the amount of clean diluting water required for the successful disposal of sewage by dilution. The test has its widest application in measuring waste loading to treatment plants and in evaluating the efficiency of such treatment systems. The test consists in taking the given sample in suitable concentrations in dilute water in BOD bottles. Two bottles are taken for each concentration and three concentrations are used for each sample. One set of bottles is incubated in a BOD incubator for 5 days at 20°C; the dissolved oxygen (initial) content ($D_1$) in the other set of bottles will be determined immediately. At the end of 5 days, the dissolved oxygen content ($D_2$) in the incubated set of bottles is determined.

***COD (Chemical Oxygen Demand)***

COD results are reported in terms of mg of oxygen. N/8 or 0.125 N solution of oxidizing agent is used in the determination. Normality double the strength is used. This allows the use of larger samples. Thus, each ml of 0.25 N solution dichromate is equivalent to 2 mg of oxygen. An excess of oxidizing agent is added, the excess is determined by another reducing agent such as ferrous ammonium sulphate. An indicator ferroin is used in titrating the excess dichromate against ferrous ammonium sulphate. Blanks are used also treated and titrated to get the correct value of COD.

***Nitrate ($NO^{2-}$ and $NO^{3-}$)***

The reaction with the nitrate and brucine produces yellow color that can be used for the colorimetric estimation of nitrate. The intensity of color is measured at 410 nm. The method is recommended only for concentration of 0.1– 2.0 mg/l. All strong oxidizing and reducing agent interfere. Sodium arsenide is used to eliminate interference by residual chlorine; sulphanilic acid eliminates the interferences and chloride interference is masked by addition of excess NaCl. High concentration of organic matter also may interfere in the determination.

***Ammonia***

To a 100mL sample, add a little NAOH to neutralize the acid used for storage and then add 1 ml 10% $ZnSO_4$. $7H_2O$ followed by 1 ml 10% NAOH. Stir and filter. (Ca, Fe, Mg, $S2^-$ are Precipitated). Collect the colorless middle fraction, and 1 drop of 50% EDTA mix well and 2 ml of Nessler's reagent (70gKI+160$HgI_2$+160gNaOH diluted to I liter). Shake well. Measure the resulting yellow color at 420nm. When the sample is colored, distil a 500mL sample with dil. NaOH and collected the distillate in an Erlenmeyer flask containing 200 ml of 0.1 N $H_2SO_4$.. Make up the volume of distillate to 250ml in a volumetric flask. Take 5-10 ml aliquot, neutralize with 0.1N NaOH to pH 4-5, and add 2 ml nessler's reagent .Proceed as above for measurement. Distil as above and collect only 100 ml of the distillate in an Erlenmeyer flask. Titrate with 0.02 N $H_2SO_4$, using a mixed indicator (200 mg methyl red in 100 ml 95% ethyl or isopropyl alcohol + 100 ml methylene blue in 50 ml 95% ethyl alcohol), until the indicator turns a pale lavender. Carry a blank through all the steps.

***Sulphates***

Sulphate is precipitated in hydrochloric acid medium as barium sulphates by the addition of barium chloride. The precipitation is carried out near the boiling temperature and after a period of digestion the precipitate is filtered; washed with water until free of chlorides, ignited and weighed as barium sulphates.

***Chlorides***

If water containing chlorides is titrated with silver nitrate solution, chlorides are precipitated as white silver chloride.
Potassium chromate is used as indicator, which supplies chromate ions. As the concentration of chloride ions Approaches extinction, silver ion concentration increases to a level at which reddish brown precipitate of silver chromate is formed indicating the end point.

***Calcium***

To a 100 ml sample add sufficient KOH (20%) solution to bring the pH to about 12 and precipitate $Mg^{2+}$ as $Mg(OH)_2$. Add 5-10 drops of calconcarboxylic acid indicator (0.4% in methanol) and titrate under Magnetic stirring with 0.05M EDTA solution till the color changes from wine-red to pale blue. Alternatively, add 5 drops of murexide indicator (0.1g stirred with 2.5 ml Deionised water and filtered) and titrate with 0.05M EDTA solution till the color changes from orange to violet.

**Data Processing and Analysis**

The relevant data were processed and analyzed through manually and for computer based analysis MS Excel of Office 2007 version was used.

### Results and Discussions

Irrigation water criteria depend on both the chemical composition and the nature of plants to be irrigated, soil type, climate, amount and method of irrigation and drainage. The suitability of water for irrigation can be determined by the amount and kinds of present salt as well as the soil texture and the salt tolerance of crop. The suitability of surface water for irrigation is restrictive on the effects of mineral constitutes of water on both the plant and soil.

### Conventional Parameters

#### *pH*

The higher values of *pH* represent that there is high chloride, bicarbonate, carbonate etc. that means the water is alkaline. In Jamuna river water there is a significant variation of pH in various sampling station in both seasons (Table 01). pH of the water samples ranged from 8.0 to 9.1 (in dry season) and 8.4 to9.3 (in wet season). In pH average value of samples were found 8.63 and 8.9 where the standard value 7.25 and the standard deviation is 0.98 in dry season and 1.17 in wet season (Table 01). the permissible limit of $p^H$ for irrigation: 6.0 −8.4 (Ayers and Westcot, 1985), 6.5 −8.5 (FAO, 1992), 6.0–8.5 (ADB, 1994) or 6.0 – 9.0 (GOB, 1997).

**Table 1: Comparison the conventional parameters of Jamuna River water during dry and wet season**

| Parameter | Dry season | | Wet season | | Standard (DOE, 2001) | Bangladesh Standard for Fisheries (EQS,1997) | Domestic Standards (De, 2005) | Drinking Standards (ADB ,1994) | Irrigation standard (Ayers and Westcot 1976) |
|---|---|---|---|---|---|---|---|---|---|
| | Avg. (N=5) | Mean±SD (N=25) | Avg. (N=5) | Mean±SD (N=25) | | | | | |
| pH | 8.8<br>8.7<br>8.4<br>8.6<br>8.8 | 8.6±0.98 | 9.1<br>8.9<br>8.6<br>8.9<br>9.0 | 8.9±1.17 | 7.25 | 6.5-8.5 | 6.5-8.5 | 6.5-8.5 | 6.5-8.5 |
| Temperature (°C) | 32.5<br>32.5<br>32.5<br>32.7<br>32.8 | 32.59±1.48 | 35.8<br>35.9<br>35.9<br>35.9<br>36.1 | 35.93±3.84 | 30.5 | 25 | | | |
| EC (µS/cm) | 137.2<br>137.6<br>138.2<br>138<br>138.3 | 137.83±114.67 | 107<br>107<br>106.4<br>105.4<br>105 | 107.70±135.98 | 300 | 800-1000 (µs/cm) | NA | NA | 750 |
| TDS (ppm) | 130<br>129.6<br>130.6<br>130.4<br>129.3 | 130.04±24.72 | 109<br>109.8<br>109.6<br>110<br>109 | 109.48±39.26 | 165 | 500 | 500 | 1000 | < 450 |

*Temperature*

Temperature of water may not be as important in pure water because of the wide range of temperature tolerance in aquatic life, but in polluted water, temperature can have profound effects on dissolved oxygen (DO) and biological oxygen demand (BOD). The fluctuation in river water temperature usually depends on the season, geographic location, sampling time and temperature of effluents entering the stream (Ahipathy, 1995). In Jamuna River different temperatures in various sampling stations during both season (Table 01). The temperature of water samples varies from 32.3 to 33.0 $^0$C (in dry season) and 34.5 to 36.6$^0$C (in wet season). The suitable temperature range of water for irrigation is 20 – 30°C (GOB, 1997).

*EC*

Its value depends on the concentration and degree of dissociation of the ions as well as the temperature and migration velocity of the ion in the electric filed. The electrical conductivity measures the concentration of ions in water. The concentration of ions depends on the environment, movement and sources water. The soluble ions in the surface water originate primarily from solution of rock materials. Specific conductance of most natural water generally ranges from about 50 to 1500 μS/cm. The Electric Conductivity in the study are a ranged between 135 to 141 μS/cm in dry season and 104 to 109 μS/cm in wet season (Table 01) most of which is lying within standard level of EC of most natural waters. The average and standard of EC showed a significant standard deviation. The recommended threshold (TV) EC is 0.70 dS m−1(FAO, 1992), 0.75 dS m−1(ADB, 1994) or 1.2 dS m−1 (GOB, 1997).

*TDS*

Total Dissolve Solids (TDS) refers to the sum of all the components dissolved in water. In natural water dissolved solids are composed of mainly $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, and $Cl^-$, $SO4^{2-}$, $PO4^{3-}$, $H_4SiO_4^{2-}$, and $HCO_3^-$. Water that contains too much dissolve matter is not suitable for common uses. TDS in the study area varies from 129 to 131 ppm in dry season and 106 to 111 ppm in wet season (Table 01). Comparison between average value and standard value shows a small variation and the field value is less than the standard value (Table 01) so the river water is moderately suitable for common uses.

**Organic Parameters**

*DO*

Oxygen is the single most important gas for most aquatic organisms; free oxygen or DO is needed for respiration. The DO levels below 1 ppm will not support fish; levels of 5 to 6 ppm are usually required for most of the fish population. The average value of DO levels (6.5mg/l) indicates the average quality of river water

(APHA 2005). DO values in our study varied between 0.5 to 1.5 ppm in dry season and 0.1 to 1.1 ppm in wet season (Table 02). The average value of DO is 1.01 ppm in dry season and 0.45 ppm in wet season where as the standard value is about 6.5 ppm. So comparison between average value and standard value of DO is highly deviated (Table 02) so that it represents the lower quality of river water for fish life and other aquatic life.

**Table 2: Comparison the organic parameters of Jamuna River water during dry and wet season**

| Parameter | Dry season | | Wet season | | Standard (DOE, 2001) | Bangladesh Standard for Fisheries (EQS,1997) | Domestic Standards (De, 2005) | Drinking Standards (ADB ,1994) | Irrigation standard (Ayers and Westcot 1976) |
|---|---|---|---|---|---|---|---|---|---|
| | Avg. (N=5) | Mean±SD (N=25) | Avg. (N=5) | Mean±SD (N=25) | | | | | |
| COD (ppm) | 97<br>101.6<br>94.8<br>98.8<br>100 | 98.30±66.68 | 9.8<br>8.6<br>9.2<br>8.8<br>8.3 | 8.9±3.46 | 4 | --- | --- | --- | --- |
| DO (ppm) | 0.96<br>1.06<br>1.1<br>0.8<br>1.1 | 1.01±3.88 | 0.3<br>0.6<br>0.3<br>0.4<br>0.8 | 0.45±4.28 | 6.5 | 4.0-6.0 (mg/l) | 4.0-6.0 | NA | NA |
| BOD (ppm) | 33<br>33.8<br>32.4<br>34.4<br>40 | 34.26±20.69 | 52.6<br>49<br>50.8<br>54.4<br>56 | 59.04±38.21 | 5.0 | (-) or below 2 (mg/l) | NA | NA | NA |

***BOD***

Unpolluted, natural waters will have a BOD of 5 mg/l or less. BOD directly affects the amount of dissolved oxygen in rivers and streams. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of high BOD are the same as those for low dissolved oxygen: aquatic organisms become stressed, suffocate, and die. Sources of BOD include leaves and woody debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants; failing septic systems; and urban storm water runoff.

In present study BOD values varied between 20 to 43 ppm in dry season and 40 to 64 ppm in wet season (Table 02). In Comparison between average value and standard value of BOD is showed higher deviation (Table 01) it refers to the lower quality of the river water i.e. the higher rate of pollution of water, it refers that the higher the deviation the lower the quality of water for fish and other aquatic life. ADB (1994) and GOB (1997) proposed BOD of 10 mg $l^{-1}$ in irrigation water quality standards for Bangladesh.

### *COD*

The measure of COD determines the quantities of organic matter found in water. This makes COD useful as an indicator of organic pollution in surface water (King *et al.*, 2003 and Faith, 2006). In the conjunction with the BOD test, the COD test is helpful in indicating toxic conditions and the presence of biologically resistant organic substances (Sawyer *et al.*, 2003). In present study COD values varied between 86 to 112 ppm in dry season and 8 to 10 ppm in wet season (Table 02). Comparison between average value and standard value of COD in dry season shows higher deviation refers to the lower quality of the river water i.e. the higher amount of organic compounds in water which demands higher COD and as a result the lower quality of water for fish and other aquatic life. Where as in wet season it shows moderate values it refers moderate quality of water (Table 02).

**Other Parameters**

*Nitrate ($NO2^{-}$ and $NO^{3-}$)*

Nitrate concentration is low in fresh domestic wastewater but in the effluent of nitrifying biological treatment plants nitrate may be found in concentrations of up to 30 mg. In present study Nitrate ($NO^{2-}$ and $NO^{3-}$) concentration of sample water ranges from 78 to 98 ppm in dry season and 77 to 99 ppm in wet season, this is very high in respect to standard value (Table 02). Comparison between the average value and standard value of Nitrate ($NO^{2-}$ and $NO^{3-}$) is shown higher deviation (Table 03) refers to the lower quality of the river water i.e. the higher amount contamination from fertilizers, municipal wastewaters, feedlots, septic systems in water which causes higher concentration of Nitrate ($NO^{2-}$ and $NO^{3-}$), it refers that the higher the deviation the lower the quality of water for fish and other aquatic life and for common uses. FAO (1992) recommended threshold value (30 mg $l^{-1}$).

**Table 3: Comparison the other parameters of Jamuna River water during dry and wet season**

| Parameter | Sampling site | Dry season | | Wet season | | Standard (DoE, 2001) |
|---|---|---|---|---|---|---|
| | | Avg (N=5) | Mean±SD (N=25) | Avg (N=5) | Mean±SD (N=25) | |
| Nitrate (ppm) | 1 | 86.2 | 88.04±62.18 | 86.6 | 84.83±59.91 | 0.1 |
| | 2 | 89.6 | | 87.6 | | |
| | 3 | 83 | | 84.6 | | |
| | 4 | 94.8 | | 94.4 | | |
| | 5 | 85.7 | | 91.3 | | |
| Ammonia (ppm) | 1 | 11 | 11.22±7.58 | 2.4 | 2.7±1.87 | 0.05 |
| | 2 | 11 | | 2.7 | | |
| | 3 | 10.8 | | 2.3 | | |
| | 4 | 12 | | 3.1 | | |
| | 5 | 11.38 | | 3.2 | | |
| Sulphate (ppm) | 1 | 833 | 832.43±411.84 | 730.4 | 729.69±500.41 | 22 |
| | 2 | 831.6 | | 731.6 | | |
| | 3 | 834.6 | | 730.6 | | |
| | 4 | 830.6 | | 726.6 | | |
| | 5 | 832.3 | | 729 | | |

| Parameter | Sampling site | Dry season | | Wet season | | Standard (DoE, 2001) |
|---|---|---|---|---|---|---|
| | | Avg (N=5) | Mean±SD (N=25) | Avg (N=5) | Mean±SD (N=25) | |
| Chloride (ppm) | 1 | 960.4 | 962.435±03.76 | 860.4 | 865.45±602.77 | 13 |
| | 2 | 969.4 | | 873.4 | | |
| | 3 | 961.8 | | 865.8 | | |
| | 4 | 960.4 | | 862.4 | | |
| | 5 | 958.7 | | 865.3 | | |
| Calcium (ppm) | 1 | 250 | 250.17±106.19 | 247.8 | 248.44±150.22 | 36 |
| | 2 | 251.8 | | 284.8 | | |
| | 3 | 250.4 | | 249.4 | | |
| | 4 | 250.6 | | 249.2 | | |
| | 5 | 246.7 | | 247 | | |

### *Ammonia*

It represents the presence of fecal matter from latrine. In present study Ammonia concentration of sample water ranges from 8 to 13 ppm in dry season and 2.1 to 3.3 ppm in wet season, this is very high in respect to standard value (Table 03). Comparison between average value and standard value of Ammonia is shows higher deviation (Table 03) that refers to the lower quality of the river water i.e. the higher amount organic matter content.

**Table 4: Comparison the average value of Nitrate and Ammonia with their standard value**

| Parameter | Average Value | | Standard (DoE, 2001) |
|---|---|---|---|
| | Dry | Wet | |
| Nitrate (ppm) | 88.04 | 84.83 | 0.1 |
| Ammonia (ppm) | 11.22 | 2.7 | 0.05 |

### *Sulphate*

Effluents from certain industries may also be a major source of sulphate of receiving waters. Another significant source to water systems is airborne industrial pollutants containing oxides of sulphur, which convert to sulphuric acid in precipitation (acid rain). Sulphate can also be produced by bacterial or oxidizing action as in the oxidation of organo-sulphur compounds. The more common sinks are pyrite, gypsum, and sulphate reduction. The generalized formula for sulphate reduction is: $SO_4^{2-} + 2CH_2O \rightarrow 2HCO_3^{-} + H_2S$ Sulphate concentrations in study area ranged between 824 to 843 ppm in dry season and 712 to 743 ppm in wet season (Table 03). Comparison between average value and standard value of Sulphate is shown the higher deviation (Table 03) refers to the lower quality of the river water, unsuitable for common uses and aquatic life. Sulfate salts affect sensitive crops by limiting the uptake of calcium and increasing the adsorption of sodium and potassium, resulting in a disturbance in the cationic balance within the plant.

*Chloride*

Chloride is an indication of salinity in water. Surface water containing significant amount of chloride also tend to have high amount of Na ions indicating the possibility of contacts with water of marine origin. From an environmental standpoint, chloride is basically a conservative parameter and may serve as an index of pollution occurring in natural freshwater from primary sources such as industrial and municipal outlets. The chloride concentrations in the study area of both seasons are presented. Chloride content of samples ranged between 950 to 976 ppm in dry season and 850 to 891 ppm in wet season (Table 03). Comparison between average value and standard value of Chloride is shown the higher deviation (Table 03) refers to the higher impurity of the river water which is unsuitable for common uses and aquatic life.

*Calcium*

The calcium concentrations in study area ranged between 243 to256 ppm in dry season and 243 to 255 ppm in wet season (Table 03). Comparison between average value and standard value of Calcium is shown the higher deviation (Table 03) refers to the higher impurity of the river water which is unsuitable for common uses and aquatic life. Almost all the samples in the study area showed high concentration of calcium that means those concentration falls out of range of natural freshwater. This high concentration may be due to primarily domestic discharges into the river, and the presence of $CO_2$ which cause $CaCO_3$ to dissolve. Calcium and magnesium, if present in the soil in large enough quantities, will counter the effects of the sodium and help maintain good soil properties. Excessive amount of dissolved ions in irrigation water affects plants and agricultural soil physically and chemically, thus reducing the productivity. The physical effects of these ions are to lower the osmotic pressure in the plant structural cells, thus preventing water from reaching the branches and leaves. The chemical effects disrupt plant metabolism.

**Conclusion and Recommendation**

Among the investigated water samples for conventional parameter; $P^H$ and temperature are slightly higher, EC is within the permissible limit. In case of organic parameter DO level is very much lower than acceptable range, BOD and COD are higher than permissible limit. Other parameters like Nitrate, Ammonia, Sulphate, Cloride and Calcium are higher than standard limit. Higher amount of salt revealed that agricultural fertilizer washed to the river Jamuna from its two side's agricultural field.. The overall test results reveal that the water of Jamuna River is suitable for irrigation. Government need to take proper steps to control the effluent discharge to the river. Jamuna is a big river and many cities are situated on the bank of Jamuna. In this industrial era in Bangladesh, the government should take strict measure to maintain of suitability of water in Jamuna river for surface irrigation. Most of our industries established along the rivers as for effluent discharge to the channel without any treatment. On the other hand huge amount of fertilizer waste also discharges to Jamuna make its water more salty. Government should also have to take awareness programme not to over use of fertilizer for agricultural purpose along Jamuna river.

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# EFFECT OF TUBEWELL WATER IRON CONCENTRATION ON ARSENIC REMOVAL PERFORMANCE

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## Abstract

The objective of this study was to investigate the effect of tubewell water iron concentration on arsenic removal performance by comparing the arsenic removal performance data of six individual Multi-Stage Filtration Units (MSFU) treating tubewell water having iron concentrations ranging from 4.6 to 16 mg/L and arsenic concentration ranging from 70 to 410 µg/L). The MSFU, which is connected to the spout of a tubewell with a short piece of PVC / flexible pipe, has three chambers, the 1st chamber (Aerator plus Down-flow Flocculator), 2nd chamber (Sedimentation plus Up-flow Roughing Filter) and 3rd chamber ( Down-flow Roughing Filter).The effectiveness of different chambers of MSFU in removing arsenic from groundwater was investigated adopting the technique of adsorption and co-precipitation of arsenic onto the flocs of ferric hydroxide, making use of the naturally occurring iron of groundwater. The flocculation and roughing filtration processes in the MSFU were accomplished through the use of brick chips. Water samples collected weekly from different location of the Multi-Stage Filtration Units (MSFU) were tested in the laboratory for determining the concentration of iron and arsenic .The result reveals that arsenic removal performance significantly increased with iron concentration of tube well water.

## Introduction

Water is a universal solvent, during percolation through the various strata of soil it dissolves various mineral (chemical impurities) compounds. When the mineral concentration is greater than the acceptable limit then the water becomes unsafe for drinking and not suitable for domestic use. Groundwater in general, has relatively better water quality and usually requires limited treatment with relatively low capital and operational cost. Many countries in the world consequently rely on groundwater to a large extent as a source of drinking water. Groundwater has qualitative problems that could be of natural and / or anthropogenic origin. Many arsenic containing ground water also contain significant level of iron and manganese due to natural geochemistry (Ohio EPA, 2008). The presence of iron and arsenic in groundwater beyond the permissible limit is now considered to be a major problem throughout the world and produce numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply .In some places of Bangladesh the concentration of iron and arsenic in ground water are at much higher level than the limit acceptable to the rural people. People of those areas generally refuse to use tubewell water and inclined to use pond and river waters (Mondol, 2009).

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At present arsenic contamination of groundwater is a major public health problem in Bangladesh. The presence of arsenic above the Bangladesh limits of safe drinking water of 50 μg/L was first detected in groundwater of the Bengal Delta Plain (BDP) aquifers in Bangladesh in 1993. This has resulted in a severe environmental disaster affecting several million people in the region, as groundwater is the main source of potable water for nearly 98% of the population in Bangladesh. It is unfortunate that the presence of arsenic in addition to iron in drinking water has emerged as a serious threat to public health challenge (Ahmed, 2005).

Arsenic toxicity has no known effective treatment, but drinking of arsenic contamination free water can help the arsenic affected people to get rid of the symptoms of arsenic toxicity (Ahmed, 2005). Hence, provision of arsenic contamination free water is urgently needed for mitigation of arsenic toxicity and protection of health and well being of people living in acute arsenic problem areas(NAMIC and BAMWSP, 2004).

The iron problem has long been recognized in Bangladesh, and many technologies have been developed for iron removal at municipal, community and household levels. Municipal Iron Removal Plants (IRPs) were first installed in Bangladesh during the early 1980s. After the detection of arsenic in ground water, many municipal IRPs are now being designed and used for removal of both iron and arsenic. In the backdrop of the discovery of arsenic in many areas of the country, community treatment units designed for removal of both arsenic and iron are becoming popular. Many NGOs are now installing different types of such community-based iron/ arsenic removal plants. However, most of the plants have been constructed without following any technical design parameters (BRTC, 2006).

**Literature Review**

In nature, arsenic is generally found only in the trivalent and pentavalent states. $H_3AsO_3$, an un-dissociated weak acid, is predominant in the pH range of 2-9. Therefore, any As(III) present in a typical water supply would occur as $H_3AsO_3$., On the other hand, As(V) in water occur as a strong acid and dissociates into ions according to the pH value (Mondol,2009).

Arsenate[As(V)] and Arsenite[As(III)] are common oxidation states of arsenic in water. Arsenate is dominant in oxygenated water while arsenite is dominant in non-oxygenated water. In groundwater, both the arsenate and arsenite usually exist in soluble form and unlike iron they can not be oxidized into insoluble precipitates through aeration process, as result their removal from groundwater through simple aeration, precipitation and Solid Transfer Unit Operations (e.g. flocculation, sedimentation followed by sand filtration processes) is not feasible (Ahmed,2005).

Arsenic can be chemically precipitated as arsenic (III) sulfide, calcium arsenate, or ferric arsenate. The sulfide $As_2S_3$ has its lowest solubility at pH value 4.0. A number of calcium arsenates [e.g., $Ca_3(AsO_4)_2$] can be precipitated from As(V) solutions by lime addition to high pH. Arsenic (V) can also be precipitated from process solutions at about pH value 2.0 with Fe(III) to form ferric arsenate, $FeAsO_4.2H_2O$. Therefore, at neutral pH range removal through chemical precipitation is not feasible. Effective removal of arsenic from water requires the complete ionization/dissociation of arsenic species. Arsenite[As(III)] dissociates in to arsenite ions at pH value greater than 9.0. While arsenate [As(V)] dissociates in to different species of arsenate ion at wide range of pH from less than 7 to greater than 11.5 (Mondol, 2009).

The oxidation of As(III) in to As(V) spices is the primary step in the removal process of arsenic. In the oxidation processes with dosing of chemicals, effective oxidants are free chlorine, hypochlorite, ozone, permanganate, and Fenton's reagent ($H_2O_2/Fe^{2+}$), but not the chloramines. These oxidants can convert As(III) into As(V) in the absence of oxygen (Hasan, 2003).

Adsorption-desorption reactions are very important in determining the mobility of arsenic in nature as well as its removal in many treatment systems. Both arsenate and arsenite adsorb to surfaces of a wide range of solids including iron, aluminum and manganese oxides (e.g., iron oxyhydroxides) and clay minerals (Mondol,2009).

Arsenic is a metalloid, exhibiting metallic as well as non-metallic characteristics and corresponding chemical processes. Unlike many heavy metals (e.g., lead, zinc, cadmium) which exist in water primarily as cations, arsenic exists primarily as oxyanions (e.g., $HAsO_4^{2}$, $H_2AsO_4^{-}$) and adsorb on hydrous oxide surfaces as anions (Hasan, 2003).

Adsorption-desorption of arsenic onto iron oxide surfaces are important controlling reactions in the subsurface because iron oxides are widespread in the hydro-geologic environment as coatings on other solids, and because arsenate adsorbs strongly to iron oxide surfaces in acidic and near-neutral pH conditions. Desorption of arsenate is favored at higher (i.e., alkaline) pH values (Mondol, 2009).

It has been noticed that the removal efficiency of trivalent arsenic increased significantly with increasing contact time. This is simply because when the contact time was long arsenic species in the influent had more chance to be adsorbed on the adsorption surface (Hasan, 2003).

If the alkalinity of tubewell water is very low (less than 130 mg/L as $CaCO_3$) and iron concentration is less than 1 mg/L then, oxidation and precipitation of iron flocs will very negligible which will affect the co-precipitation and passive sedimentation processes (Mondol,2009).

Up-flow coarse media (gravel/brick khoa) bed has been found to be effective in the removal of both arsenic and iron from ground water through flocculation, sedimentation and adsorption processes while the water containing both arsenic and iron flows through the interstices of coarse media (Ahmed,2005).

ITN-Bangladesh under a research program has developed a combined arsenic- iron removal unit (AIRU) adopting the technique of adsorption and co-precipitation of arsenic onto the flocs of ferric hydroxide, making use of the naturally occurring iron of groundwater. The AIRU, which is attached to a tubewell, has mainly two chambers, down-flow flocculator and up-flow roughing filter. The flocculation and roughing filtration processes in the AIRU were accomplished through the use of coarse media gravel beds (Ahmed, 2005).

Over 75% arsenic removal can be achieved through AIRU without using any chemicals through adsorption on to natural iron oxides surfaces provided that the raw water arsenic concentration is within 200ppb and the iron-arsenic concentration ratio is around 30 .For higher arsenic concentration above 200ppb and iron-arsenic concentration ratio less than 30; intermittent dosing of oxidizing agent is necessary to convert the As(III) into As(V) to ensure more adsorption of arsenic and hence maintaining the treated water within the acceptable limit(Ahmed,2005).

In order to develop appropriate design criteria for multi-stage filtration (MSF) units for use in Bangladesh a research was undertaken by ITN Center, BUET for the Arsenic Policy Support Unit (APSU). The MSF system considered under the research comprised of three units; Dynamic Roughing Filter (DyRF) unit, Up-flow Roughing Filter(URF) unit and Slow Sand Filter (SSF) unit(Ahmed,2006).

Mondol (2009) conducted a study "Effectiveness of Multistage Filtration in removing Iron, Manganese and Arsenic from groundwater of Bangladesh" .With the help and constant guidance of the second author of this paper he constructed several numbers of Multistage Filtration Units (MSFU) in three different places of Bangladesh (different hydro-geological conditions) .The MSFU, which is connected to the spout of a tube well with a short piece of PVC / flexible pipe, has three chambers. The 1st chamber (Aerator plus Down-flow Flocculator), 2nd chamber (Sedimentation plus Up-flow Roughing Filter) and 3rd chamber ( Down-flow Roughing Filter).The effectiveness of different chambers of MSFU in removing arsenic from groundwater was investigated adopting the technique of adsorption and co-precipitation of arsenic onto the flocs of ferric hydroxide, making use of the naturally occurring iron of groundwater. He mentioned that over 92% arsenic removal can be achieved through MSFU without using any chemicals through adsorption on to natural iron oxides surfaces. He established that higher the iron concentration, greater is the iron oxide precipitation and this greater amount of iron precipitations provide more adsorption surface for arsenic ion adsorption. According to this study arsenic removal performance was observed to be a function of initial iron concentration.

Followings are the summary of arsenic dissociation, adsorption and removal theory (Mondol, 2009):

a) Both arsenate and arsenite (less efficient) adsorb strongly on hydrous oxide surfaces of a wide range of solids including iron (e.g., iron oxy- hydroxides), aluminum and manganese oxides-hydroxides and clay minerals.
b) Therefore, oxidation & ionization of non-ionized As(III) to ionized As(V) through adding oxidizing agents or direct ionization of As(III) through increasing of pH > 9, is the first step of As removal.
c) Arsenic ions are also absorbed on solid chemical flocs surfaces, which are subsequently removed through co-precipitation.
d) Through aeration of iron content water or Alum coagulation process macro-flocs of Fe(OH)3 / Al(OH)3 are produced which can be used for the co-precipitation of ionized arsenic contaminants.

**Materials and Methods**

Water quality analysis of this study was conducted at the laboratory of Environmental Engineering Laboratory, Department of Civil Engineering, BUET, Dhaka.. To conduct the study the authors selected six individual Multi-Stage Filtration Units (MSFU) treating tubewell water having iron concentrations ranging from 4.6 to 16 mg/L and arsenic concentration ranging from 70 to 410 μg/L) in three different hydro-geological conditions of Bangladesh. Actually these filtration units were constructed by Mondol (2009) for his research "Effectiveness of Multistage Filtration in removing Iron, Manganese and Arsenic from groundwater of Bangladesh". The effectiveness of different chambers of MSFU in removing arsenic from groundwater was investigated adopting the technique of adsorption and co-precipitation of arsenic onto the flocs of ferric hydroxide, making use of the naturally occurring iron of groundwater. The flocculation and roughing filtration processes in the MSFU were accomplished through the use of brick chips.

At each treatment plant location, tubewell (raw) and treated water samples were collected weekly from different location of the Multi-Stage Filtration Units (MSFU) for subsequent analysis of iron, arsenic and other selected water quality parameters in the laboratory. At each location, raw and treated water samples were collected in pre-washed 500 ml plastic bottles. Water samples in pre-washed bottles were acidified with 1 ml concentration Nitric acid, which were later used for analysis of dissolved arsenic and iron in the laboratory. In the laboratory, arsenic and iron concentrations of water samples were determined using Flame-AAS (Atomic Absorption Spectrophotometer).The pH, arsenic and Iron contents of the water samples were determined also in the field regularly. In this process iron and arsenic concentrations were determined using HACH field kit and pH were determined by field pH meter. The alkalinity of tubewell water of each treatment plant location was also determined.

## Results and Discussions

The data collected in the field and laboratory test results have been analyzed and presented in table no.1.

**Table1: Plant location, raw water quality, treated water arsenic concentration and overall arsenic removal performance**

| Location of MSFU | Raw water (tube well water) quality | | | | Treated water quality | |
|---|---|---|---|---|---|---|
| | pH | Alkalinity (mg/L as $CaCO_3$ | Iron (mg/L) | Arsenic (µg/L) | Residual arsenic concentration (µg/L) | Overall Arsenic Removal % |
| Kodda,Sirajgonj (MSFU-1) | >6.5 | 174 | 16 | 70 | 7 | 90 |
| Chala,Sirajgonj (MSFU-2) | >6.5 | 134 | 15 | 120 | 13 | 89 |
| Homna,Comilla (MSFU-3) | >6.5 | 286 | 16 | 336 | 32 | 90.5 |
| Polua,Jessore (MSFU-4) | >6.5 | 470 | 8 | 410 | 64 | 84.5 |
| Sadipur,Jessore (MSFU-5) | >6.5 | 220 | 8 | 216 | 35 | 84 |
| Sonakur,Jessore (MSFU-6) | >6.5 | 292 | 4.6 | 337 | 71 | 79 |

Overall arsenic removal performance of different MSFU (installed at different zones) has been determined and comparison among these units on the basis of overall arsenic (As) removal performance has been presented in Figure1. Similar type of arsenic removal performance have been observed in the MSFUs (1 & 2) installed at Sirajgonj. This is due to environmental conditions (pH, alkalinity, initial iron content of tubewell water) of both the locations are almost same. The overall arsenic removal performance of MSFU-3 was found to be similar to those of MSFU-1 and MSFU-2 . This was because that the tubewell water iron concentration of Homna and Sirajgonj were almost same.

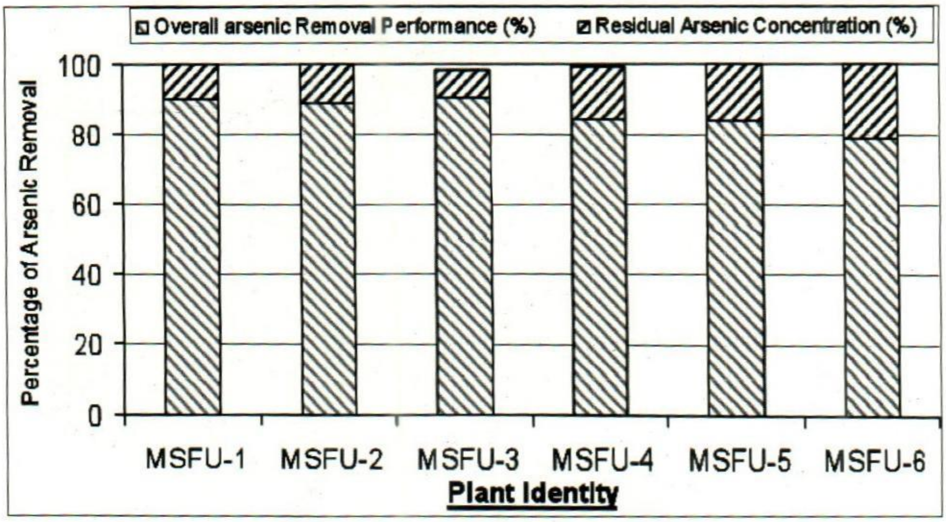


**Figure1: Comparison among different MSFU on the basis of overall arsenic Removal performance**

The arsenic removal performance of MSFU-4 (Polua,Jessore) was not observed as efficient as Sirajgonj & Homna. Because the tubewell water iron concentration of Polua was less than Sirajgonj and Homna. As the tubewell water iron concentration of MSFU-4 and MSFU-5 were same, so the arsenic removal performance of both the units were observed almost same. Finally, as the tubewell water iron concentration of Sonakur (MSFU-6) was less than those of Sirajgonj, Homna, Polua and Sadipur, so the arsenic removal performance of this unit was less than Sirajgonj, Homna,Polua and Sadipur.

The effect of tubewell water iron concentration on arsenic removal performance has been determined by comparing the arsenic removal performance data of six individual MSFU treating tubewell water having different iron and arsenic concentrations. The results have been presented in figure 2. The result reveals that arsenic removal performance significantly increased with iron concentration of tubewell water, because higher the iron concentration, greater is the iron oxide precipitation and this greater amount of iron precipitations provide more adsorption surface for arsenic ion adsorption.

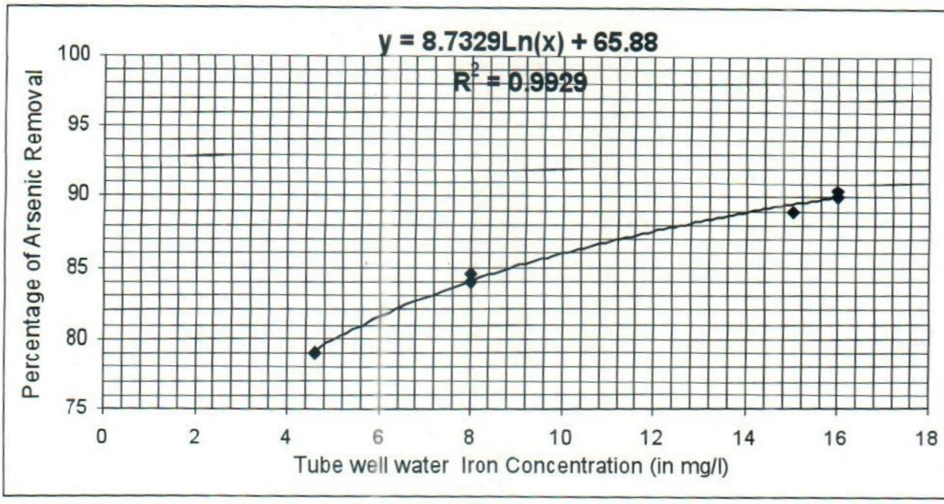


**Figure 2: Effect of tube well water iron concentration on arsenic removal performance**

The trend of the arsenic removal performance with respect to initial iron concentration of tubewell water can be expressed by the following equation

**y = 8.7329 Loge(x) +65.88**

Where,

y =Percentage of Arsenic Removal
x = Tubewell water Iron Concentration (mg/L)

## Conclusion

Arsenic removal performance was observed to be function of initial Iron concentration. The trend of the arsenic removal performance with respect to initial iron concentration of tubewell water achieved through the MSFU have been expressed through the equation y = 8.7329 Loge (x) + 65.88, where, y =Percentage of Arsenic Removal, x = Tubewell water Iron Concentration (mg/L). Using this equation it will be easy to determine the residual arsenic concentration in the final effluent achieved through properly designed MSFU treating tubewell water of different initial iron and arsenic concentration.

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# DEVELOPMENT OF MANUALLY OPERATED LOW LIFT BLOWER PUMP

Syed Md. Anwaruzzaman[1]


## Abstract

A hand operated Blower pump consisting of a single trapezoidal shaped suction chamber has been developed. The suction chamber is made of 18 gauge steel sheet. The diaphragm is prepared by rubber tube. The pump is simple, cheap and light weight. It is suitable for small and fragmented small land holdings. The power required for operation at 4.0m (total lift) is only 0.1 hp. The pump has an optimum suction lift of 3.75m with a discharge of 1700 liters per hour. It is operated by one man and needs no fuels or external power. It can be easily fabricated using local available materials and skills.


### Introduction

Irrigation is one of the most important factors required for increasing food production which is attains the top list among the policy of the Bangladesh government. To make the above program successful there is a great need for introducing High Yielding Variety (HYV) crops in the existing cropping system. In Bangladesh various crops are grown round the year. Due to the lack of proper irrigation facilities irrigated crops are only grown during the dry season in small scale. Pumps like power pump, Low Lift Pump (LLP), Shallow Tube Well (STW), BRRI pump are being used by the farmers in Bangladesh, for irrigated crop production during dry period. But large number of poor farmers still can not afford such type of pumps due to higher cost.

Considering the above factors this study program has been under taken to develop a low cost pump using mainly indigenous resources and available skills to enable the poor farmers to be the owner of such type of pump.

### Back Ground of the Study

Irrigation in Bangladesh nowadays is done mainly by manually operated Low Lift Pumps (LLP), Shallow Tube Wells (STW), Deep Tube Wells (DTW), Power Pump etc. On the basis of the available manufacturing facilities, cost, socio-economic conditions, repair and maintenance facilities; and sources of water, manually operated pumps are still considered as the main machineries for irrigation. Several manually operated diaphragm pumps have recently been developed by different organizations. Most of them are operated by action of lever principle. The Rangpur-Dinajpur Rural service introduced a pump discharging 13,608 liter of water per hour. Since the pump is made of wood its life time is short. More over the energy loss is high because of its complicated suction and delivery systems. The International Rice Research Institute developed a bellows pump with a discharge capacity of 1800 liter per hour at a head of one meter (IRRI - 1971).

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The main purpose of the study was to develop a pump using indigenous resources and local skills so that poor farmers can use it with a low investment. Required materials were collected from the local market and the pump was constructed and tested in the hydraulic laboratory of the Department of Irrigation and Water Management (IWM), Mymensingh.

**Objective of the Study**

- To design and construct a low cost simple diaphragm pump with locally available materials.
- To study the performances characteristics of the constructed pump under different head.

## Literature Review

Use of manually operated tube wells in irrigating agricultural land has been infact increasing each year in Bangladesh. In 1980, a hand operated diaphragm pump was developed by the Agricultural Engineering Division of Bangladesh Rice Research Institute (BRRI) for low lift irrigation (Baqui, 1980). The pump consists of two suction chambers, each of which is made of 14 gauge steel sheet of course with the best one. It is cheap and simple and light in construction and easy to operate. Only 0.5 hp is required to operate the pump for a total lift of 5.l8m. The optimum suction lift of the pump is 2.74m with a capacity of 4.73 liter per second. It can be fabricated locally available materials with local mechanic and is operated by two men. The Agricultural section of Rangpur- Dinajpur Rural Service developed a low cost pump in 1978 using bamboo pipe and strainer (RDRS, 1980). The pump has been improved by RDRS in which a fly wheel with piston rod was used and effective operation was obtained. In the light of the above principles, RDRS has made a small portable pump in order to lift surface water to a height of 1.5m to 3.0m. The discharge of the pump ranges from 2.51 to 3.16 liter per second and its cost is Tk. 350.00. Another low cost pump has also been developed by RDRS and is called treadle pump. About 0.13 hectare of land can be irrigated by this pump in 3 to 4 hours. Construction of the pump is simple and easily repairable and the cost is also less than Tk. 300.00. MCC with jointventure of Mirpur Agricultural Workshop and Training School has developed a Power pump whose action is receprocating ( Spare and Weins, (1981). This pump is manually operated and is made of PVC pipe having 5.08cm diameter. The piston movement within the cylinder is governed by aT-handle at the end of the piston rod. The pump is installed at an inclined angle of 30° from the horizontal to a well. A suction chamber has been provided for the purpose of compenseting the velocity variation produced by water column traveling in the well pipe and provides a steader upward flow of water in the ground pipe enabling the operator make easier and smooth stroke. The discharge of the pump varies 1.45 to 0.78 liter per second with the variation of suction lift. The pump can operate at a maximum suction lift of 7.6m.

Sree Narendra Nath an inhabitant of village Kashir Khamer, under upazilla Ulipur, Rangpur, has developed a low cost pump (1979). He used only bamboo blined pipes and strainers. It had two cylinders (made of concrete) on a concrete block. The action of this pump is also reciprocating. The two piston rods are connected with a long bamboo, the center of which is placed over a support. So the down ward and up ward movement of the end of the bamboo causes the movement of the pistons in the cylinder. The discharge capacity of the pump is about 2.51 liter per second and can easilly operated by one man. One unit of the pump is cost Tk.850.00 and can irrigate 0.80 hectare of land Boro rice.

A manually operated wheel pump for five different sizes were developed by Bangladesh Agricultural University (BAU) for low lift irrigation. The sizes were 8.9, 9.3, 10.8, 12.0 and 13.0cm. The pumps were tested at different suction lifts of upto 5.48m. The discharge capacities of the smallest and largest sizes ranged from 21.1 to 74.7 liter per min and 44.0 to 137.4 liter per min. respectively, at suction lifts of 1.29 to 5.48m.

The International Rice Research Institute has developed a Bellows pump with a discharge capacity of 5.0 liter per second, at lift of 1 m (lRRI, 1971).

**Materials and Methods**

For the construction of the blower pump the materials, such as 18 gauge steel sheet, rubber tube, 1.25" GI pipe, angle bar, flat bar, lever, plastic rope, 1.5" and 1" nuts and bolts, hinges, joint screw etc. were used.

If a volume of confined air is evacuated in contact of free water would rise in the evacuated space up to the equivalent height of 76 cm of mercury i.e. is 10.36m of water. In practical purpose water could be lifted up to a height of 7.8m depending upon degree of created vacuum.

Figure 1 to Figure 4 shows the main component of the pump. The suction chamber is made of 18 gauge steel sheet with trapezoidal shaped of length 55.0 cm and the length of the parallel sides are 42.0cm and 13.5cm respectively at the base and the depth of the suction chamber is 11.0cm. The inlet and outlet valves were made from M.S plate sandwiched together with rubber diaphragms with nuts and bolts. The valves are hanged from elevated portion attached to the pipes so that could operate easily over the inclined faces of the inlet and outlet manifolds. The diaphragm is attached to the suction box and its covering plain sheet by nuts and bolts. For easy movement of the upper portion of the suction chamber it is attached to the suction box by hinge at the delivery side. A lever stand made by angle bar is attached to the pump base over which operating lever exists. Pan cover is connected to the operating lever by a plastic rope. Photographic view of the blower pump is shown in Figure 5.

The operation of the pump is simple and one man can operate the pump easily. Pulling the operating lever down ward causes the pumps diaphragm to expand and thus draw water from a pond through a inlet pipe to the pump chamber. A weight of about 5.0 kg is placed on the extended portion of the pan cover at the suction; which pushes the upper cover down ward causing compression in the diaphragm and forces the water to come out through the out let pipe from the chamber. Direction and movement of the water is controlled by a set of simple flapper valves. The period of operation and energy requirement to operate the pump is dependent on the total lift and quantity of water to be pumped.

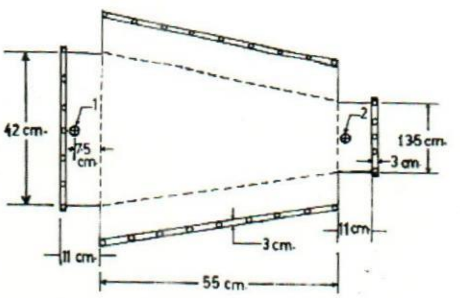


FIG. 1 Shape and Size of the Mild Steel (M/S) Sheet used for the Construction of the Pump (Top View)

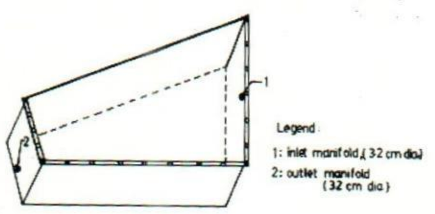


FIG. 2 Suction Pan
(N.B.- not in scale)

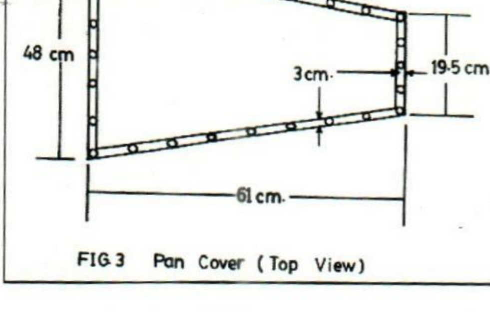


FIG 3 Pan Cover (Top View)

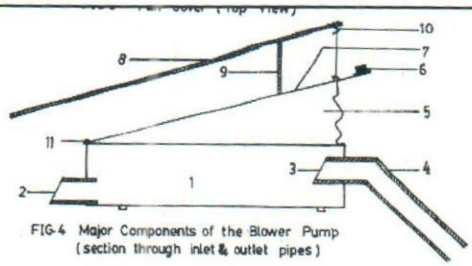


FIG-4 Major Components of the Blower Pump
(section through inlet & outlet pipes)

Legend:

1- suction pan/chamber
2- delivery valve
3- suction valve
4- suction pipe
5- diaphragm
6- counter weight
7- pan cover
8- operating lever
9- lever stand
10- operating rope
11- hinge

(N-B- - not in scale)

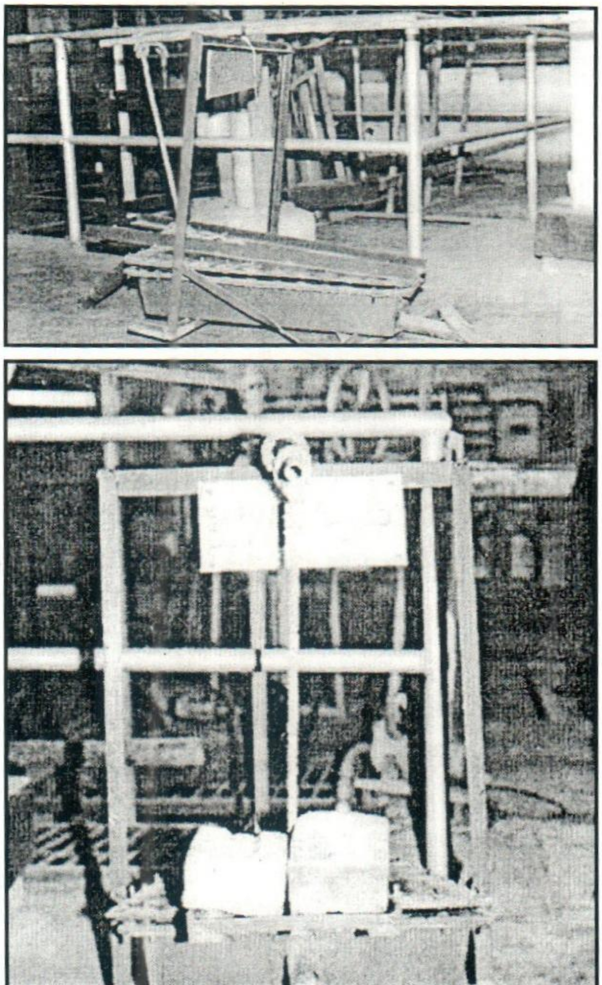

**Figure 5: Photographic view of the Blower Pump**

## Results and Discussion

The tests of the blower pump were conducted at the hydraulic laboratory at 5 different heads. The pump was operated manually for 4 hours and average values of three observation of each test were taken. To collect the water a rectangular tray was used. Time was recorded by a stop watch. The head, discharge and other necessary parameter are shown in the following table. Frictional loss of pipe is approximated from the bulletin 1.481, Oregon Agricultural Experimental Station (Israelson and Hansen)

**Table1: Lift, frictional loss, discharge and efficiency in case of blower pump**

| Sl. No. | Vertical lift (m) | Frictional Loss (m) | Total Lift (m) | Discharge (Lit./min) | Efficiency (%) |
|---|---|---|---|---|---|
| 1 | 0.91 | 2.13 | 3.04 | 35 | 24.5 |
| 2 | 1.82 | 1.72 | 3.54 | 30.5 | 24.2 |
| 3 | 2.74 | 1.27 | 4.01 | 23 | 19.2 |
| 4 | 3.35 | 1.22 | 4.57 | 12 | 10.2 |
| 5 | 3.81 | 0 | 4.61 | 6.5 | 6.15 |

It is observed from the above table that the efficiency decreased with the increased of head. The maximum efficiency of about 24.5% is obtained at a total lift of 3.04m. The head-capacity and efficiency relationship is shown in Figure 6. From the efficiency curve it is shown that the efficiency is increased with the increase of lift and discharge up to a certain limit.

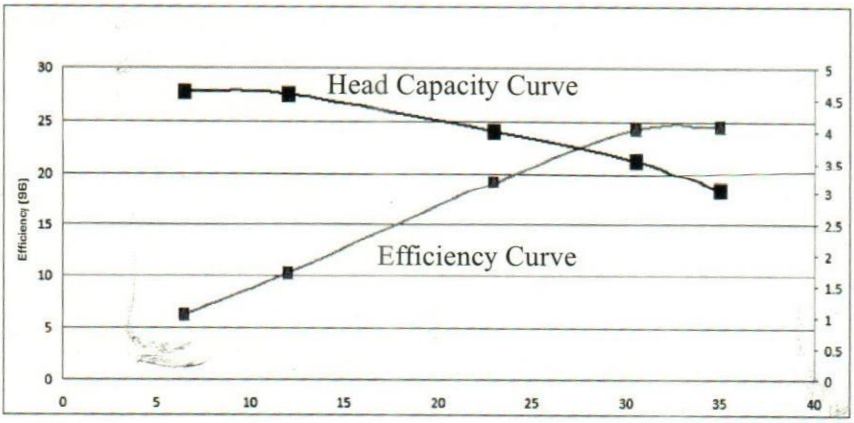


**Figure 6: Pump Characteristic Curves**

## Conclusions

The cost for the construction of the pump is Tk.770.00. This pump is light weight and easily portable. The pump has an optimum suction lift of 3.75m with a discharge of 1700 liters per hour and efficiency 22.5%. It is operated by one man and needs no fuels or external power. It can be easily fabricated using local available materials and skills. So the poor farmers and fragmented land owners can use this type of pump for irrigation purpose.

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# CALIBRATION AND SENSITIVITY ANALYSIS OF HEC-HMS MODEL FOR JAMUNESSWARI RIVER BASIN OF BANGLADESH

**Nishan Kumar Biswas[1] and Manashi Paul[2]**

## Abstract

Runoff estimation from a given rainfall event is a difficult task due to various influencing factors. Sometimes it is impossible to determine actual field values of numerous parameters of hydrological events in developing countries like Bangladesh. Though Hydrological modelling is a complex task, if it is well calibrated, then it makes the application of the model effective for climate change, flood forecasting, irrigation engineering and other type of watershed and water resource studies. Assessment of impact of climate change on water resources in river basin requires a proper estimation of availability of water and that can be achieved by hydrological modelling of the basin. In this study a basin named Jamunesswari with three sub-basins located in the North-West region of Bangladesh is considered. Basin model is developed by using computer based Hydrological model HEC-HMS (Hydraulic Engineering Center, Hydrological Modelling System). The model is calibrated with the discharge data of Basin outfall Badarganj. The model performance and sensitivity analysis is studied by altering the four most sensitive parameters. Thus, the model may be applied to other hydro-meteorologically similar river basins. This model can also be used as a baseline study for future water resources planning and management.

## Introduction

HEC-HMS is one of the computer models for simulation of rainfall-runoff correlation. The hydrologic modeling system is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. Hydrographs produced by the program are used directly or in conjunction with the other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and systems operation. Assessment of water resources is a prime requisite in order to frame long term sustainable management strategy for water to combat this situation. Hydrologic models which comprise integration of key hydrologic processes are appropriate tools for such studies. However, hydrological modeling is a simplified representation of the real situation which is a challenging task particularly for regions with limited data and hydrologic models should be well calibrated and its performance should be evaluated to provide reliable result for any study. The purpose of this study is to optimize the probable loss parameters for soil moisture for study area.

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## Literature Review

It is also worth mentioning that the HEC-HMS model has been used successfully worldwide by researchers (Beighley and Moglen (2003), Fleming and Neary (2004), Chris McColla and Graeme Aggett (2005), Yusop *et al.* (2007)).

## Methodology

The study comprises data acquisition, processing of meteorological data, delineation of sub-basin area and boundary, development of an HEC-HMS Model for study area, calibration of model with the observed data and finally calculation of variation of discharge volume for changing four parameters such as Surface Storage, Maximum Infiltration Rate, and Tension Zone Storage and as percentage of calibrated parameters.

The HMS Model represents the watershed with five storage layers viz., canopy - interception, surface-depression, soil profile, groundwater storages (1 and 2) involving twelve parameters viz., canopy interception storage, surface depression storage, maximum infiltration rate, soil storage, tension zone storage and soil zone percolation rate and groundwater 1 and 2 storage depths, storage coefficients and percolation rates. Rates of inflow to, outflow from and capacities of the layers control the volume of water lost from or gained by each of these storage layers.

In this background, a study on the calibration and evaluation of a watershed simulation model viz., Hydrologic Modeling System, developed by the Hydrologic Engineering Center, USA (HEC-HMS) has been carried out for Jamunessawri river basin situated in the North-West Hydrological Region of Bangladesh for proper assessment and management of water resources in the basin area. The Jamunessawri river (140 km long), having originated in Chilahati, Bangladesh (26° 6' N, 88°51' E) drains a sizable portions of the three catchments named NW01U, NW01M, NW01L and finally debouches into the Karatoya River. The Jamunessawri basin extends over 1124.03 $km^2$, covering 0.76% of geographical area of the country. Average annual rainfall in the basin is 175 mm. The annual yield of water within the basin constitutes about 0.4% of the country's total surface water resources. The annual utilizable water resources in the basin have been estimated to be 106704954 $m^3$.

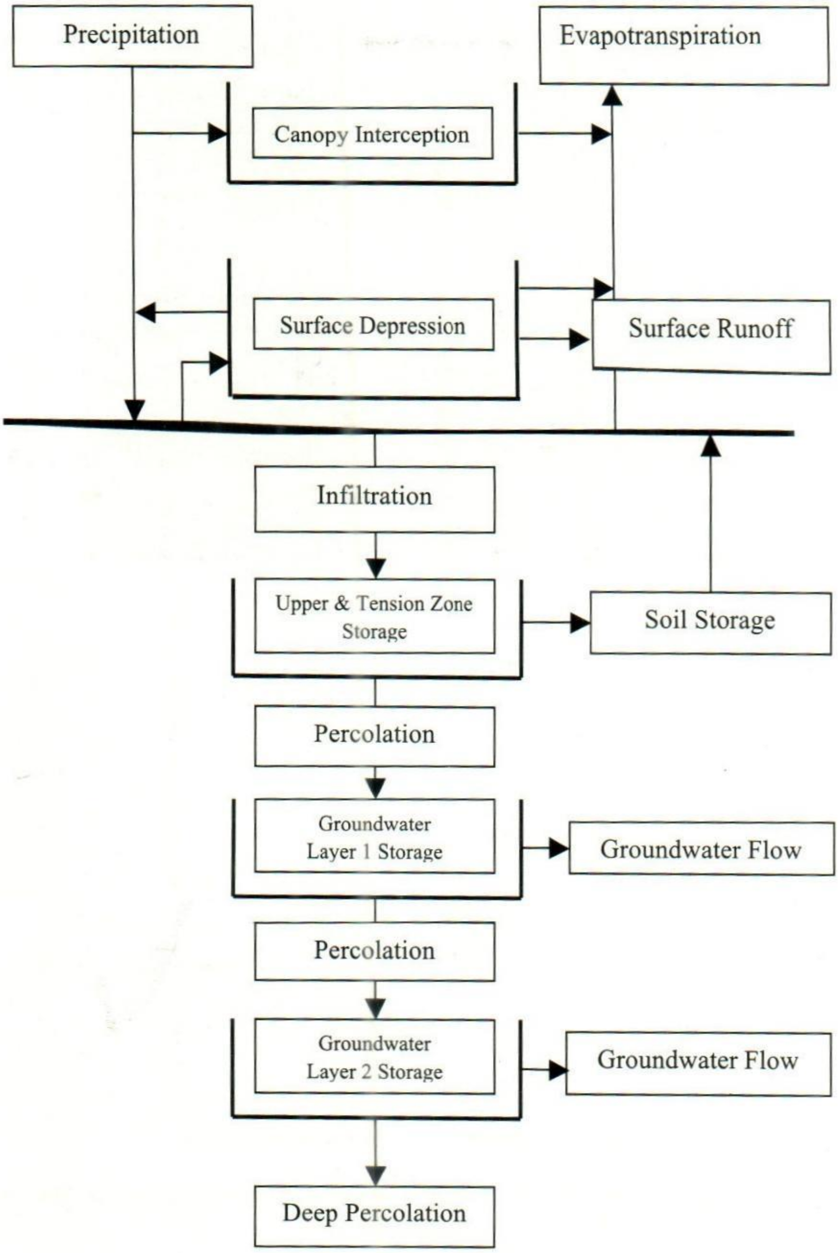



**Figure 1: Schematic Diagram of HEC-HMS Algorithm**

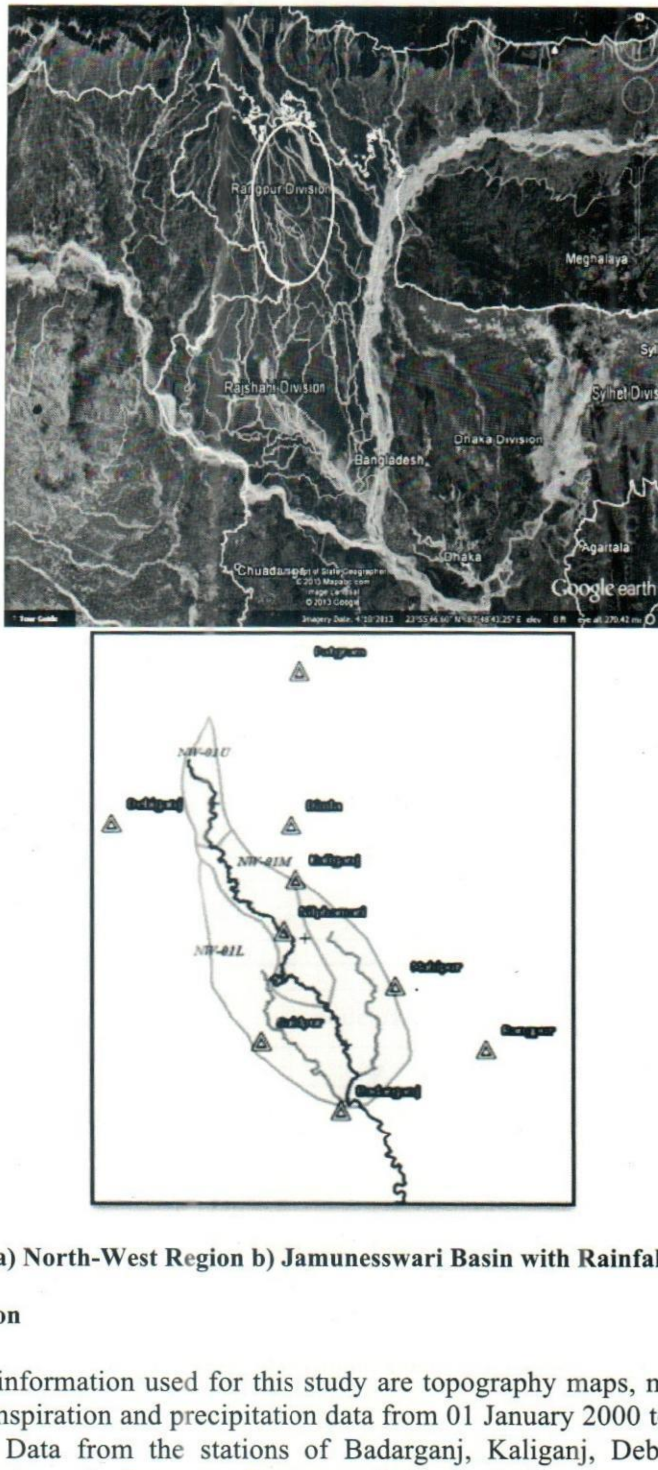



**Figure 2: a) North-West Region b) Jamunesswari Basin with Rainfall Stations**

**Data Acquisition**

The data and information used for this study are topography maps, meteorological data, evapotranspiration and precipitation data from 01 January 2000 to 29 February 2012.Rainfall Data from the stations of Badarganj, Kaliganj, Debiganj, Dimla, Mohipur, Nilphamari, Patgram, Rongpur, Saidpur station are collected from Bangladesh Meteorological Department. Also the location coordinate is collected. Discharge data for Badarganj station, situated at the outfall of Jamunesswari Basin is collected from Bangladesh Water Development Board. The discharge data of

Badarganj from 31 March 2002 to 30 March 2006 at three hours interval is used for calibration of model.

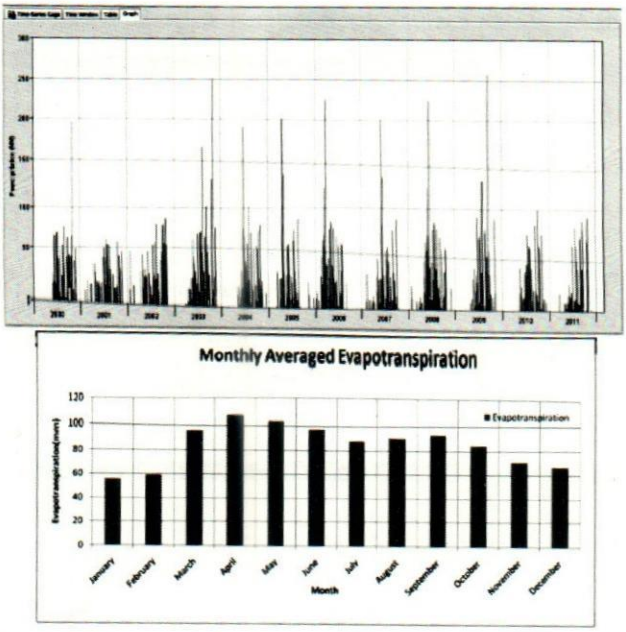



**Figure 3: a) Rainfall Pattern and b) Average Evapotranspiration of Jamunesswari Basin**

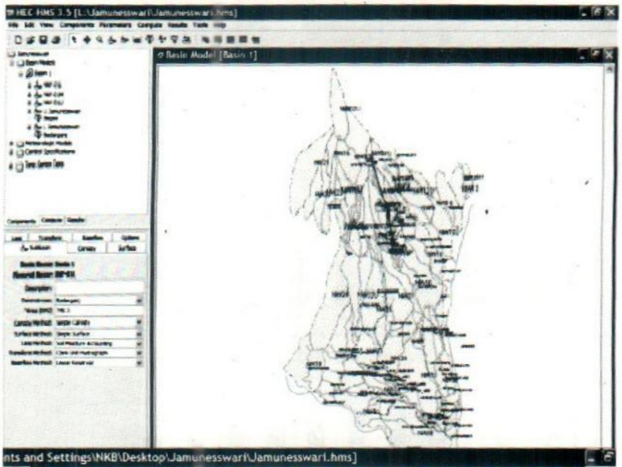
### Processing Meteorological Data

For each sub-basin, area and boundary is collected from the North-West Hydrological Model developed by Institute of Water Modelling. The river channels Bullai, Jamunesswari and B-Chikley was digitized in the Google Earth. The evapotranspiration data was processed as monthly monthly averaged data. The weightage of each precipitation gauge for each sub-basin is calculated by using Theissen Polygon feature in ArcGIS 10.

### HEC-HMS Model Development

By using the processed meteorological data such as precipitation, gauge weightage, monthly averaged evapotranspiration data, catchment area, observed discharge data of Badarganj station, HEC-HMS Model is developed. Control specification is kept from 01 April 2004 00:00 am to 31 March 2006 00:00 am. Calculation time interval is used as 1.5 hours. For canopy storage, Simple Canopy Method is used. Here for North-West Region of Bangladesh, the effect of canopy is negligible. Simple Surface Method is used for Surface Storage. For the loss calculation Soil Moisture Accounting Method and Clark Unit Hydrograph Technique with the peak and time to peak computed by Snyder's Unit Hydrograph Method was adopted to compute stream flow hydrograph. Linear Reservoir Method is used for Base-flow.

Muskingum Method of channel routing was used to generate discharge hydrograph at downstream point in all three river channel.



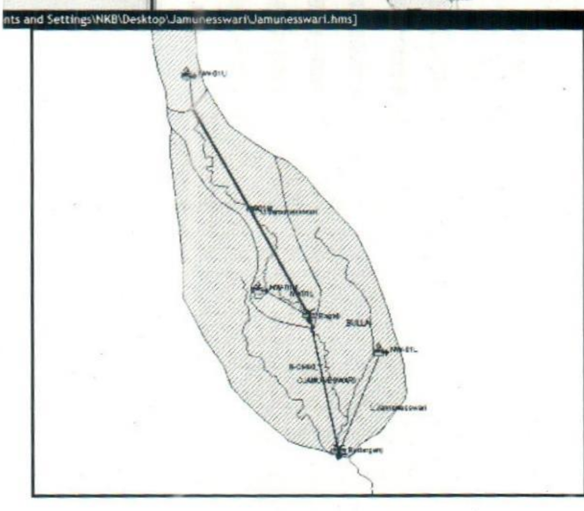


**Figure 4: a) HEC-HMS Model Setup b) Model schematic View**

After setting up, the model is simulated using an initial value of all the parameters. Then manual calibration is carried to calibrate the model with observed discharge data of Badarganj. After a significant improvement of simulated discharge hydrograph, auto calibration feature of the model is used for the purpose of obtaining the optimum discharge hydrograph.

**Model Calibration**

Before the application of any model, it is necessary to calibrate it with the observed data. Model Calibration is a process of comparing the model to actual system behavior until model accuracy is judged to be acceptable. The model is calibrated using the observed discharge data of Badarganj station from April 2004 to March 2006. The following figure shows the calibration of model:

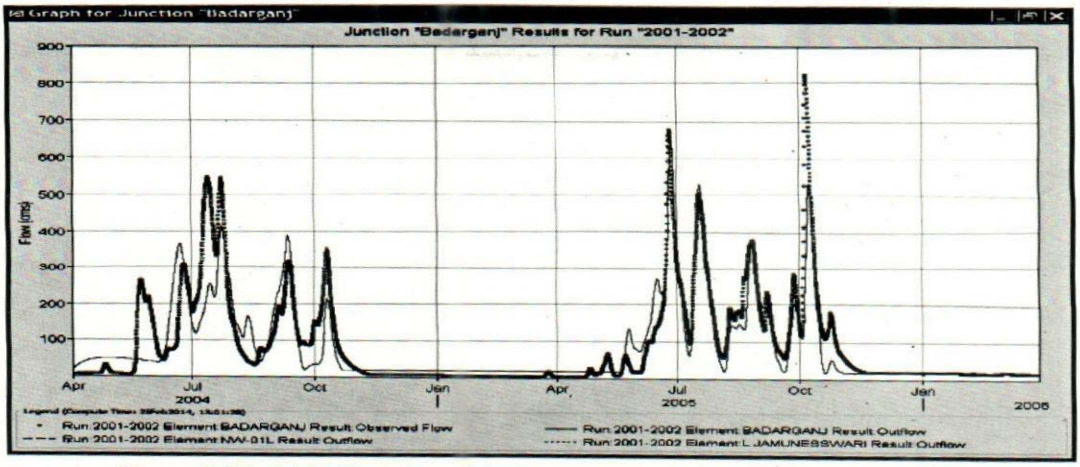



**Figure 5: Model Calibration with Observed Discharge of Badarganj station**

### Sensitivity Analysis

After getting the optimized parameters, their sensitivity is also observed. Among the most sensitive parameters, Maximum Soil Infiltration Rate and Surface Storage Capacity, Initial Surface Storage, Maximum Infiltration Rate, Tension Zone Storage Capacity are both increased and decreased 10%, 20% and 30% from the optimized value and change in total volume of runoff is observed.

### Result & Discussion

After completing model calibration, the calibrated parameters of the three different sub-basins are obtained. They are shown in the table below:

**Table 1: Optimized HEC-HMS parameters of Jamunesswari Basin**

| Hydrological Parameters | | NW-01L | NW-01M | NW-01U |
|---|---|---|---|---|
| Simple Canopy | Initial Storage (%) | 0 | 0 | 0 |
| | Maximum Storage (mm) | 0 | 0 | 0 |
| Simple Surface | Initial Storage (%) | 0 | 0 | 0 |
| | Maximum Storage (mm) | 1000 | 1000 | 1000 |
| Soil Moisture Accounting Loss | Soil (%) | 20 | 20 | 20 |
| | Ground Water 1 (%) | 75 | 75 | 75 |
| | Ground Water 2 (%) | 20 | 20 | 20 |
| | Maximum Infiltration(mm/HR) | 0.1 | 0.1 | 0.1 |
| | Impervious (%) | 0 | 0 | 0 |

| Hydrological Parameters | | NW-01L | NW-01M | NW-01U |
|---|---|---|---|---|
| | Soil Storage (mm) | 250 | 250 | 250 |
| | Tension Storage (mm) | 50 | 50 | 50 |
| | Soil Percolation (mm/hr) | 0.5 | 0.5 | 0.5 |
| | Ground Water 1 storage(mm/hr) | 300 | 600 | 600 |
| | Ground Water 1 percolation (mm/hr) | 0.5 | 0.5 | 0.5 |
| | Ground Water 1 coefficient (mm/hr) | 700 | 500 | 500 |
| | Ground Water 2 storage(mm/hr) | 350 | 250 | 250 |
| | Ground Water 2 percolation (mm/hr) | 0.5 | 0.5 | 0.5 |
| | Ground Water 2 coefficient (mm/hr) | 3500 | 2000 | 1000 |
| Clark Transform | Time of Concentration (hr) | 150 | 300 | 300 |
| | Storage Coefficient (hr) | 30 | 20 | 10 |
| Linear Reservoir Base Flow | Initial Type | Discharge per Area | | |
| | Ground Water 1 Initial($m^3/s/km^2$) | 0.005 | 0.005 | 0.005 |
| | Ground Water 1 Coefficient (hr) | 1000 | 1000 | 1000 |
| | Ground Water 1 Reservoir | 1 | | |
| | Ground Water 2 Initial($m^3/s/km^2$) | 0.01 | 0.01 | 0.01 |
| | Ground Water 2 Coefficient (hr) | 1000 | 1000 | 1000 |
| | Ground Water 2 Reservoir | 1 | | |
| lag routing | Reach- U Jamunesswari (minute) | 180 | | |
| | Reach- L Jamunesswari (minute) | 180 | | |

Generated Runoff of Individual sub-basin with the precipitation is observed as following:

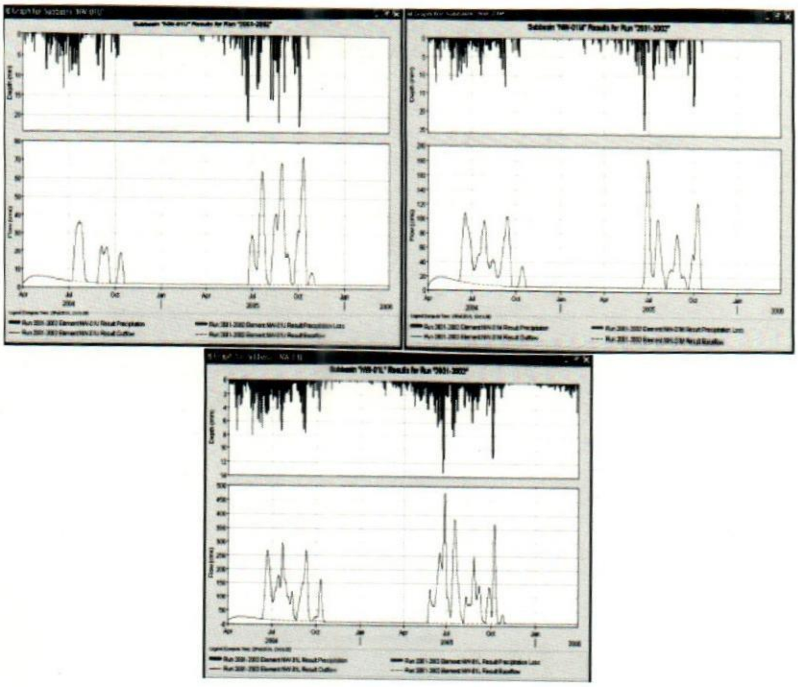


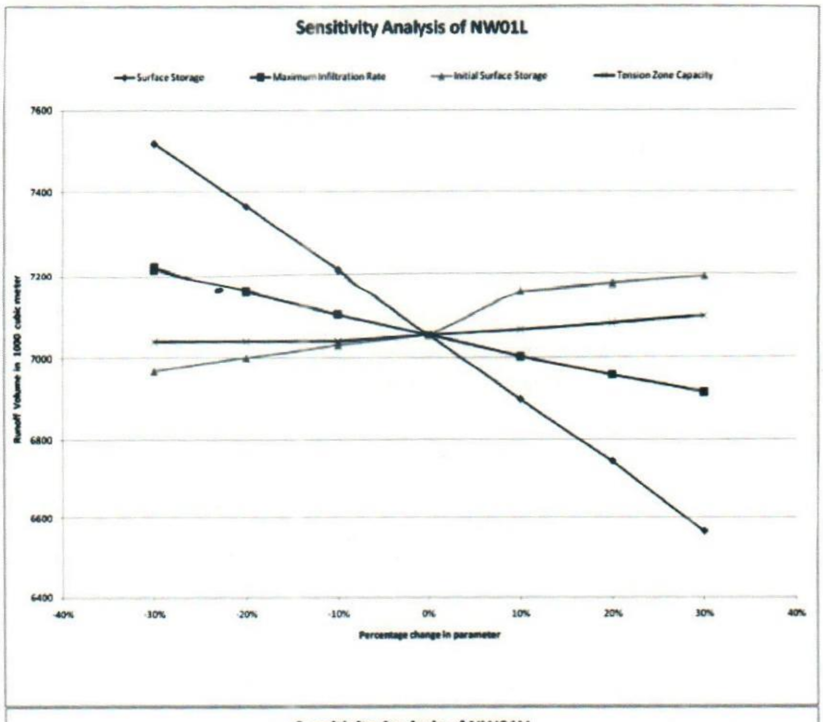
**Figure 6: Runoff along with Rainfall of Individual Catchment a) NW01U b) NW01M and c) NW01L**

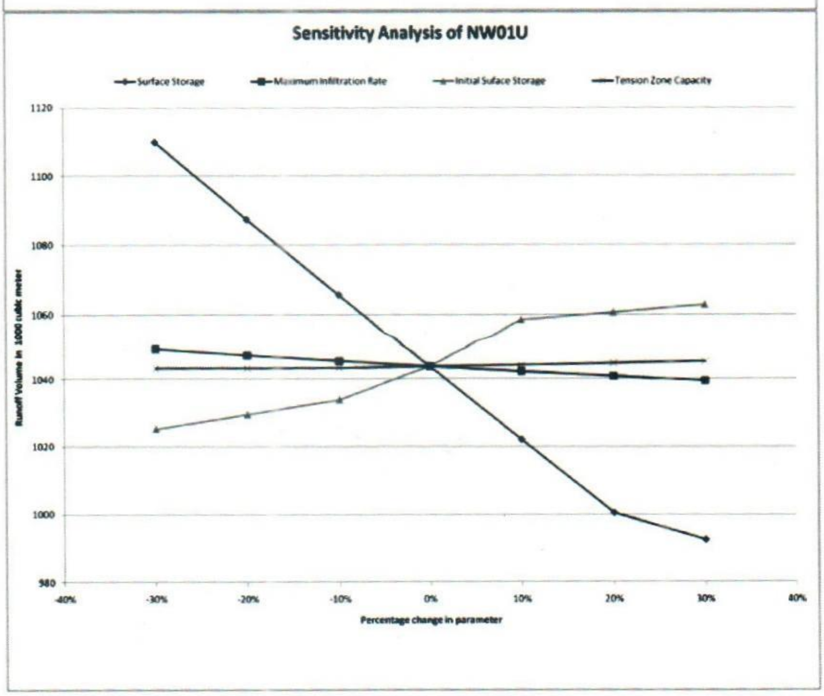
The total runoff of the Jamunesswari Basin is as follows:

**Table 2: Global Summary of Model Result**

| Hydrological Element | Area(km$^2$) | Peak Discharge(m$^3$/s) | Time of Peak | Volume(m$^3$) |
|---|---|---|---|---|
| NW-01L | 749.5 | 479.5 | 26Jun2005, 15:00 | 6984.9 |
| NW-01M | 263.7 | 183.1 | 29Jun2005, 09:00 | 2657.813 |
| NW-01U | 110.83 | 72.5 | 10Oct2005, 21:00 | 1033.291 |

Maximum Soil Infiltration Rate and Surface Storage Capacity, Canopy Storage Capacity, Tension Zone Storage Capacity, Soil Profile Storage Capacity are both increased and decreased at a rate of 5%, 10%, 20% and 30% from the optimized value and change in total volume of runoff is observed as following graph:


Sensitivity Analysis of NW01L
Surface Storage
Maximum Infiltration Rate
Initial Surface Storage
Tension Zone Capacity
Runoff Volume in 1000 cubic meter
Percentage change in parameter


Sensitivity Analysis of NW01U
Surface Storage
Maximum Infiltration Rate
Initial Suface Storage
Tension Zone Capacity
Runoff Volume in 1000 cubic meter
Percentage change in parameter

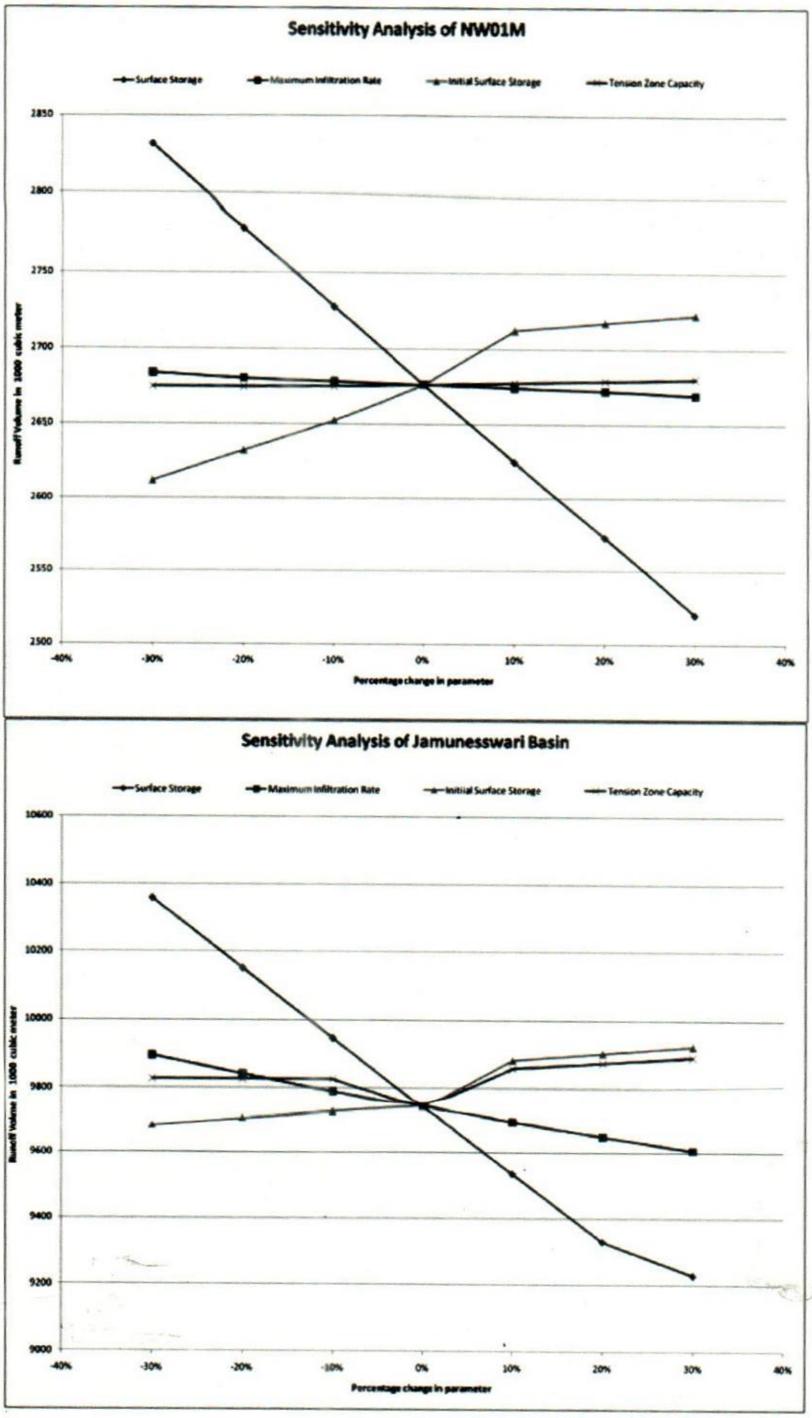



**Figure 7: Sensitivity of a) NW01L, b) NW01U, c) NW01M and d) Jamunesswari Basin**

## Conclusion and Recommendation

The model study shows that the most sensitive parameters of HEC-HMS Model for Jamunesswari basin is Maximum Surface Storage as its sensitivity is maximum. Again a low sensitive parameter like Tension Zone Capacity changes the volume of runoff a negligible amount. The study shows that the calibrated model performs well in simulating stream flow and the model may be applied to other watersheds in the Jamunesswari river basin and other hydro-meteorologically similar river basins.

Despite the good performance of the models, development of model parameterization methodology using geographic information systems is highly recommended. More hydrological data and satellite images are highly needed to take into account the climatic, hydrological and soil characteristics spatial variability in basins for better and accurate modeling of the hydrological processes in the catchment. Semi-distributed versions of these models may also improve their performance and reproduce the peak better than the lumped versions. However, more data will be needed.

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