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# TEMPORAL AND SPATIAL DISTRIBUTION OF SUSPENDED SEDIMENT CONCENTRATION IN BHAIRAB RIVER, BANGLADESH

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**ABSTRACT**

*In this study the water samples were collected from different depth and width wise locations in Shiromoni and Raligate Point of Bhairab River in Khulna Division of Bangladesh. Using the data-set for a period of twelve months in the Bhairab River, the variability of suspended sediment concentration at different temporal scales (monthly) was analyzed. The water samples were collected in three depth wise and three width wise sections. So, each month nine water samples were collected in each site. After collecting the water samples, its $P^H$, salinity and suspended sediment concentration were determined. The depth wise variation of suspended sediment concentration was fitted with theoretical standard distributions and the unknown coefficients are determined and compared with that of Jamuna River in Bangladesh. Using the estimated values of coefficients, the value of suspended sediment concentration for any depth of Bhairab River can be calculated for any season without performing the field measurements.*

**Keywords:** *Bhairab River, High Tide and Low Tide Period, Salinity, Suspended Sediment Concentration.*

## 1. INTRODUCTION

Bangladesh is a land of rivers. Country's most of the land is formed through silt brought by the many rivers that flow through it. Khulna is a port city of Bangladesh surrounded by several rivers. The Bhairab River on northern side, Rupsha River in the middle part and Pasur on the southern side, and Mayur on the northern and Hatia River on the southern side of the city. The life in Khulna largely depends on waterways. Our study location is situated at Shiromoni and Raligate Point of Bhairab River. Figure 1 shows the location of Bhairab River running besides the Khan Jahan Ali Thana under Khulna district. The study points are indicated as P1 and P2 in the figure for Shiromoni and Railigate sites respectively. Shiromoni point is at upstream side and Railigate at downstream. Two sites are about 2 km apart.

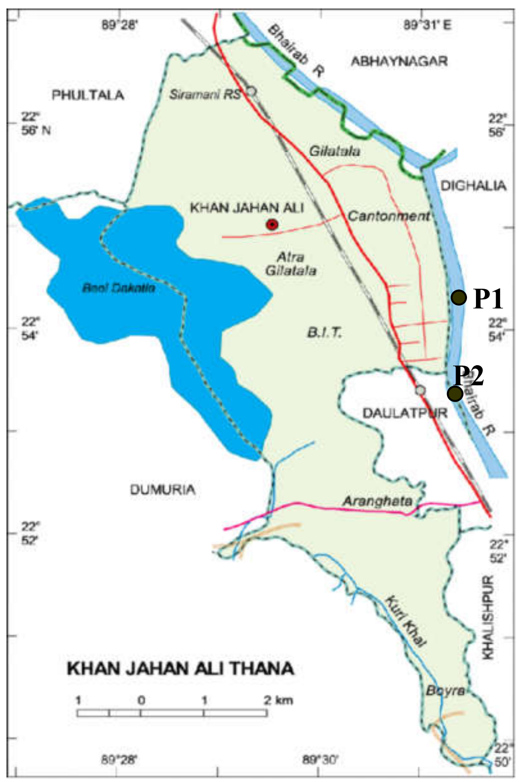


**Figure 1** Location of Bhairab river in Khulna district and two study points P1 (Shiromoni) and P2 (Raligate).

Bhairab River is one of the tidal rivers in Bangladesh, which is the branch of Gorai River that originated from Ganga River. In the region of Rupsha in Khulna city, its name is Rupsha River. The flow of Bhairab River depends on upstream flows comes from Gorai River which plays an important role on its suspended sediment concentration. The characteristic of a river depends on the sediment concentration. The flow path of the river changes due to excessive sediment, and also erosion of the river occurs due to excessive sediment transport.

The transport of salinity and $P^H$ are important elements

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to determine the water quality in a river. Although this type of research can contribute to the country's environmental and river morphological database, very few research have been done on the morphology of Bangladeshi rivers. Sarker and Klassen (2011) reported the distribution of measured suspended sediment concentration of Jamuna river at Bahadurabad point, which will be used in this study for comparison. The objectives of the study were to determine the variation of suspended sediment concentration along depth and width wise directions and to determine the temporal variation of suspended sediment concentration (SSC). The temporal variation of salinity and $p^H$ were also studied. The measured SSC were fitted with the available theoretical standard distributions and the coefficients in the equations are compared with that of Jamuna River.

## 2. EXPERIMENTAL TECHNIQUES

Water samples were collected by locally made sampler. After collecting sample water, suspended sediment concentration, $P^H$, and salinity were determined in the laboratory.

### 2.1 Water Samples Collection

Along the depth wise direction, the water samples were collected in three sections: from just below the surface, at $1/3^{rd}$ of river depth and at $2/3^{rd}$ of river depth below the surface. Along the width wise direction, samples were collected in three points in each horizontal section and they are at $1/4^{th}$ of river width, at 1/2 of river width and at $3/4^{th}$ of river width. Sample collecting points are shown in Figure 2. The horizontal sections are denoted as H1, H2, and H3 and vertical sections are denoted as V1, V2 and V3, respectively.

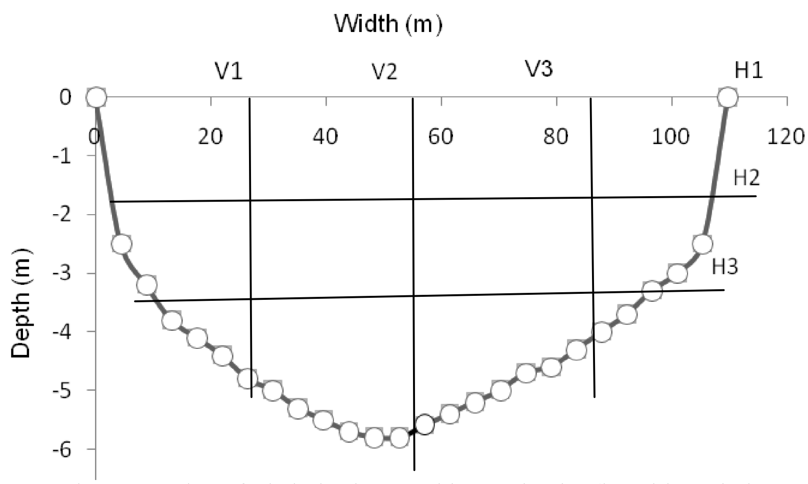


**Figure 2** Measured cross-section of Bhairab River at Shiromoni point (low tide period, Dec. 14, 2010)

**Table 1** Summary of water quality test of collected water samples at different months.

| Month | Collection of water sample | SSC | Salinity | $P^H$ | Remarks |
|---|---|---|---|---|---|
| June 2010 | Yes | Yes | Yes | Yes | High tide |
| July 2010 | Yes | Yes | Yes | Yes | High tide |
| August 2010 | Yes | Yes | Yes | Yes | Low tide |
| September 2010 | One point | Yes | No | No | High tide |
| October 2010 | Yes | Yes | Yes | Yes | High tide |
| November 2010 | Yes | Yes | Yes | Yes | High tide |
| December 2010 | Yes | Yes | Yes | Yes | Low tide |
| January 2011 | Yes | Yes | Yes | Yes | Low tide |
| February 2011 | One point | Yes | Yes | Yes | High tide & Low Tide |
| March 2011 | Yes | Yes | Yes | Yes | High Tide |
| April 2011 | Yes | Yes | Yes | Yes | High Tide |

### 2.2 Laboratory Tests

After collecting the water its pH and salinity were determined. The suspended sediment concentrations of the samples were measured by filter paper method. At first blank filter paper was being weighed. Then water samples were filtered and then the filter paper were dried and weighed again. The difference of these two weights was the weight of suspended sediment concentration. In the oven dry method, the samples of water with suspended sediments were kept in an oven for 2 days at a temperature of 100º-120ºC and the settled sediments were decanted and weighed using electronic balance. The details of water sample collection and the name of performed laboratory tests are presented in Table 1.

To assess the authenticity of results obtained by filter paper method, the SSC for three water samples in different depths were measured by both filter paper method and oven dry method. Figure 3 shows the comparison of measured SSC between oven dry method and filter paper method. The difference between two results is negligible. Reasonably, the amount of SSC of oven dry method is slightly (about 1.9%) greater than that of filter paper method.

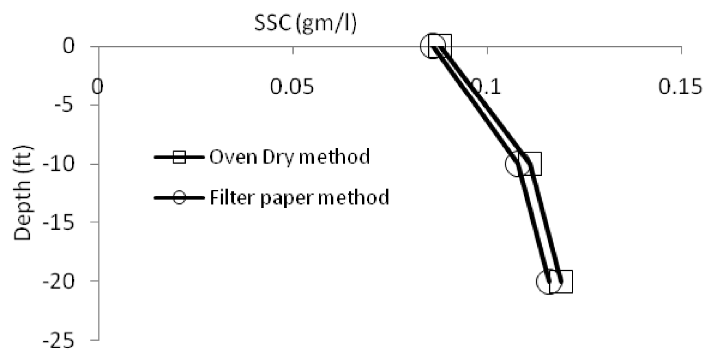


**Figure 3** Comparison of suspended sediment concentration measured by oven dry and filter paper method.

## 3. RESULTS AND DISCUSSION

### 3.1 Temporal Variation of Suspended Sediment Concentration

Figure 4 shows the temporal variation of suspended sediment concentration. It shows that the SSC is higher during June to September and low during October to March. Therefore, the suspended sediment concentration (SSC) of Bhairab River in rainy season is higher than dry season. In rainy season water comes in Bhairab River from upstream Gorai River which carries a lot of sediment particles. On the other hand rain water from catchment area also carries a lot of sediment. So in rainy season suspended sediment concentration is higher. But in dry season SSC is lower, because there is no upstream water flow and no rainfall in catchment area. In rainy season the average suspended sediment concentration in Raligate and Shiromoni points were found as 0.945 gm/l and 0.982 gm/l, respectively. In dry season, the suspended sediment concentration in Raligate point and Shiromoni points were found as 0.534 gm/l and 0.571 gm/l, respectively.

### 3.2 Temporal Variation of Salinity

Figure 5 shows the temporal variation of salinity. It shows that the salinity is low in rainy season from June to September and high in dry season from October to April. In comparison to Figure 4, it is observed that when the SSC is high the salinity is low and when SSC is low the salinity is high. In other words, salinity is lower in rainy season and higher in dry season. Average suspended sediment concentration during rainy season at Shiromoni and Raligate points were found as 1.55 gm/l, and 1.525 gm/l, respectively. During dry season, average SSC at Shiromoni and Raligate points were found as 4.3 gm/l and 4.15 gm/l, respectively.

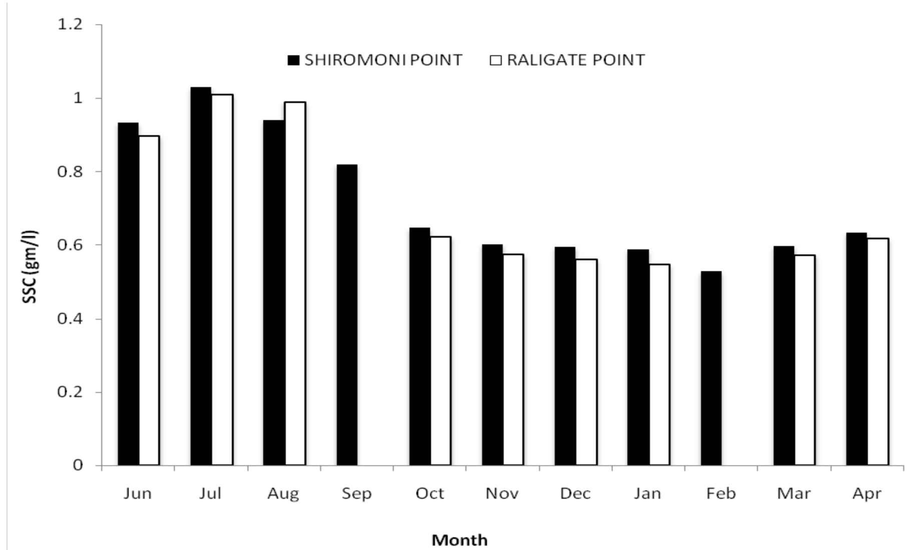


**Figure 4** Temporal variation of suspended sediment concentration at two sites in Bhairab River

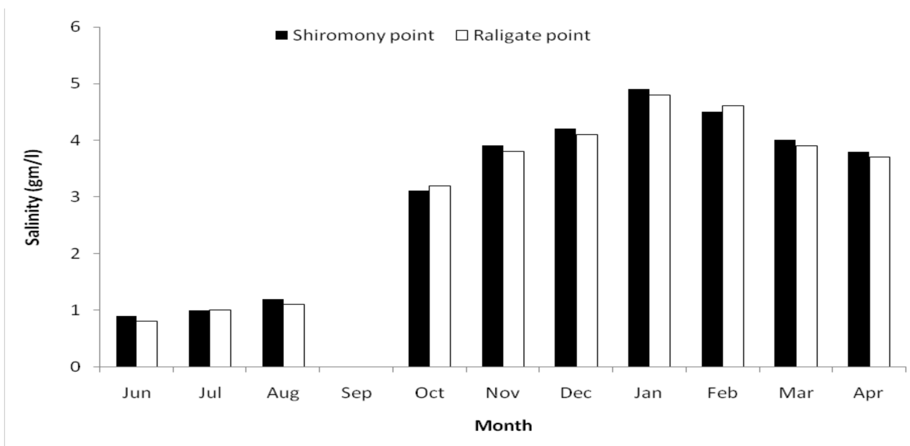


**Figure 5** Temporal variation of salinity at two sites in Bhairab River

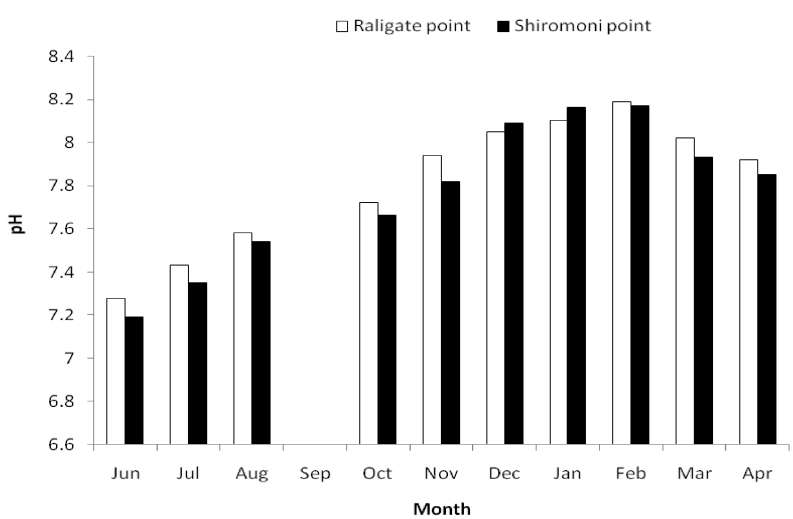


**Figure 6** Temporal variation of pH in the water of Bhairab river at Raligate and Shiromoni points

### 3.3 Temporal Variation of P$^H$

Figure 6 shows the temporal variation of pH in the water of Bhairab river at Raligate and Shiromoni point. The pH distribution of the river water showed that in dry season the water is slightly alkaline. High pH values of 8.0-8.2 were recorded during the dry season while pH dropped to values of 7.3-7.7 during the rainy season. This drop in pH from 8.2 to 7.3 was probably due to stirring effect of the incoming flood and rain water from the rivers and streams.

### 3.4 Spatial Distribution of SSC

Figure 7 illustrates spatial distribution of the seasonally averaged SSC along depth wise direction in rainy season and dry season in the year of 2011 at Shiromoni point. The experimental data revealed that the variation of suspended sediment concentration increases with depth from surface. That means, if the vertical depth from water surface increases then the SSC also increases. Every month shows same pattern of variation. Although the SSC in dry season is lower than the rainy season, they showed similar variation with depth as two profiles are seen to be nearly parallel to each other.

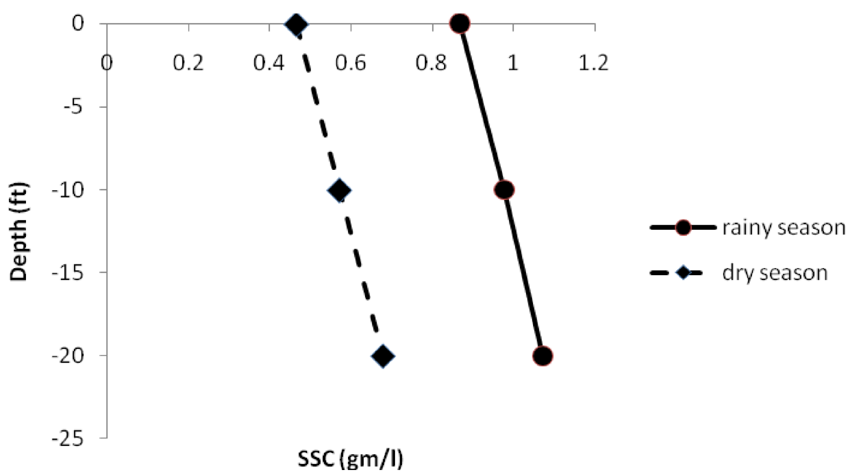


**Figure 7** Depth-wise distribution of the seasonally averaged SSC for rainy and dry season in the year of 2011 at Shiromoni point of Bhairab river.

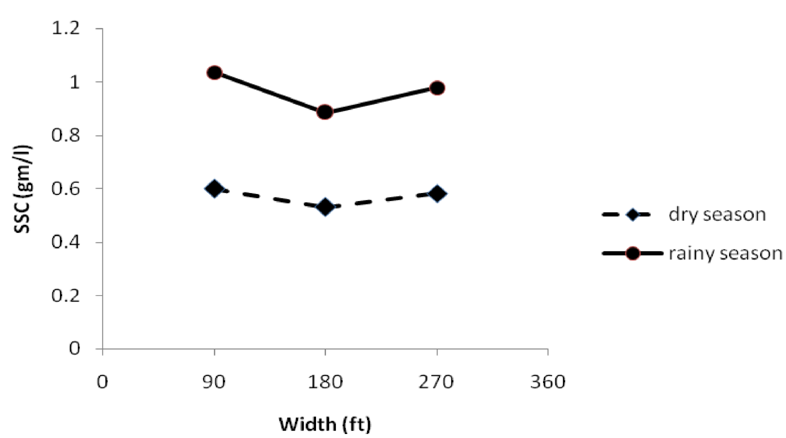


**Figure 8** Width-wise distribution of the seasonally averaged SSC for rainy and dry season in the year of 2011 at Shiromoni point of Bhairab river

Figures 8 illustrates the average spatial distribution of SSC along width wise direction in rainy season and dry season in the year of 2011at Shiromoni point of Bhairab river. From observed data it is seen that the suspended sediment concentration at middle of the river is lower than two sides of the river for all the horizontal section. This type of variation is also observed in depth wise direction. The velocity of water in the middle of the river is higher than the bank of the river. On the other hand turbidity is higher near the bank of the river and relatively fresh water can be found in the middle of the river.

### 3.5 Variation of $P^H$ and Salinity with Suspended Sediment Concentration

Figure 9 shows the variation of pH with Suspended Sediment Concentration. It is observed that when pH is higher, then SSC is low and when pH is low, then SSC is higher. So pH shows an inverse relationship with SSC. Figure 10 shows the variation of Salinity with Suspended Sediment Concentration. It is observed that when salinity is high, then SSC is low and when salinity is low, then SSC is high. So salinity has also an inverse relationship with suspended sediment concentration.

### 3.6 Comparison of SSC with High Tide and Low Tide Period

Figure 11 shows the comparison of SSC with High Tide and Low Tide period in February 2011 at Raligate point of Bhairab river. In comparison of SSC between high tide and low tide period it is observed that the average SSC in high tide period is 0.573gm/l and in low tide period is 0.518gm/l. It is found that the SSC in high tide period is 9.63% greater than that of low tide period.

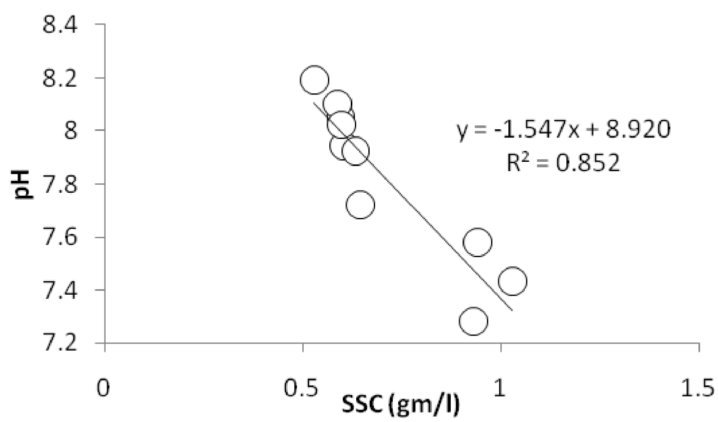


**Figure 9** Variation of pH with Suspended Sediment Concentration

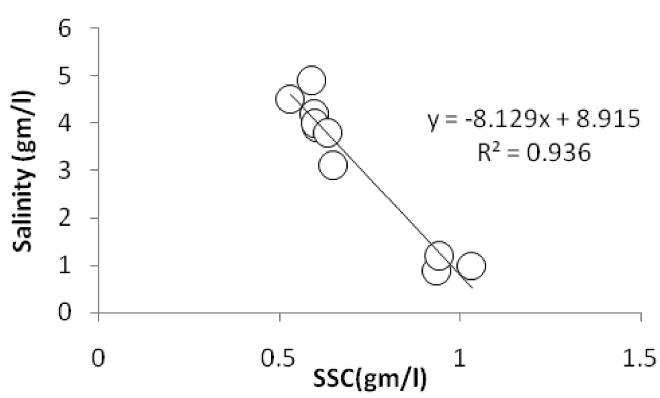


**Figure 10** Variation of Salinity with Suspended Sediment Concentration

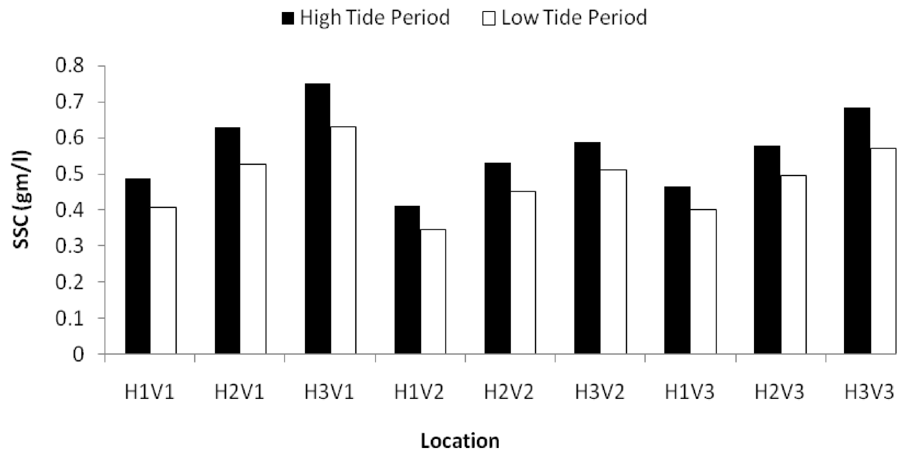


**Figure 11** Variation of suspended sediment concentration in high tide and low tide period at Raligate point in February 23, 2011.

### 3.8 Correlation of Experimental SSC with Theoretical Standard Distribution

Theoretical distribution of suspended sediment concentration in a river can be written in the form of Equation (1) and Equation (2) as shown below (Garde and Ranga Raju, 2006):

$$C = Ca \times e^{\left(-\left(\frac{W_0}{\varepsilon_s}\right)\times(y-a)\right)} \quad (1)$$

$$\frac{C}{C_a} = \left(\frac{a(d-a)}{y(d-a)}\right)^{z} \quad (2)$$

The parameters in the equations are defined in Figure 12. Here, C indicates suspended sediment concentration at any depth y from river bed (mg/l), 'a' is the depth from river bed where upward and downward sediment movement is in equilibrium (m), '$C_a$' is sediment concentration at depth 'a' from river bed (mg/l), $W_0$ is Fall Velocity (m/s) and $\varepsilon_s$ is Sediment Diffusion Coefficient for the diffusion along any distances. In this study, the measured distribution of SSC is compared with equation (1) and (2), and the unknown coefficients a, $C_a$, $w_0/\varepsilon_s$ and z are determined for Bhairab River.

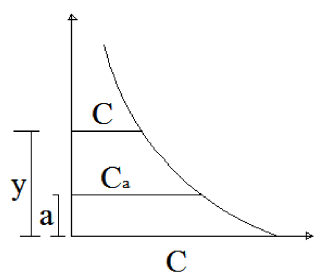


**Figure 12** Typical suspended sediment concentration profile along vertical direction.

#### *3.8.1 Calculation of $C_a$ for Equation (1) & (2) from fitted experimental profile*

Since the vertical distribution of suspended sediment concentration can be expresse in expoential form as shown in Equation (1), the measured SSC is also plotted with exponantial trend line. The objective is to determine the value of '$C_a$' from this trend line, which will be used to calculate the other unknown coefficients ($w_0/\varepsilon_s$ and z) for Bhairab river. Figure 13 shows the vertical distribution of measured suspended sediment concentration for dry season and rainy season. Here each profile is fitted with exponential trend line and '$C_a$' is calculated. From the trend line for any value of y (=a), the value of SSC (= $C_a$) can be calculated.

### *3.8.2 Comparison of depth wise distribution of SSC*

Figure 14 shows the correlation of measured suspended sediment concentration at rainy season and dry season with theoretical standard distribution (Equation 1). Comparing theoretical distribution with measured suspended sediment concentration, the value of coefficient $w_0/\varepsilon_s$ was calculated by trial. Its value was found as 0.035 and 0.089 for rainy season and dry season, respectively. From this graph, the value of suspended sediment concentration for any depth of any point of Bhairab River can be calculated without performing any field and laboratory tests.

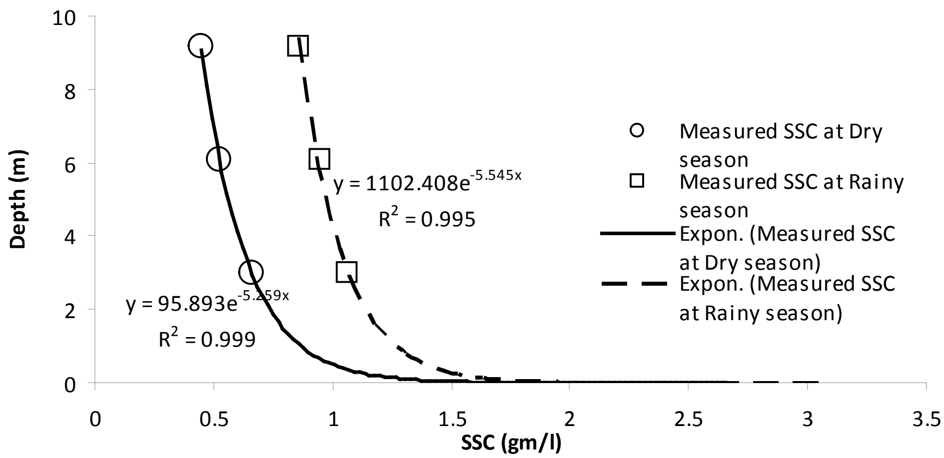


**Figure 13** Vertical distribution of measured SSC for Bhairab River with exponential trend line

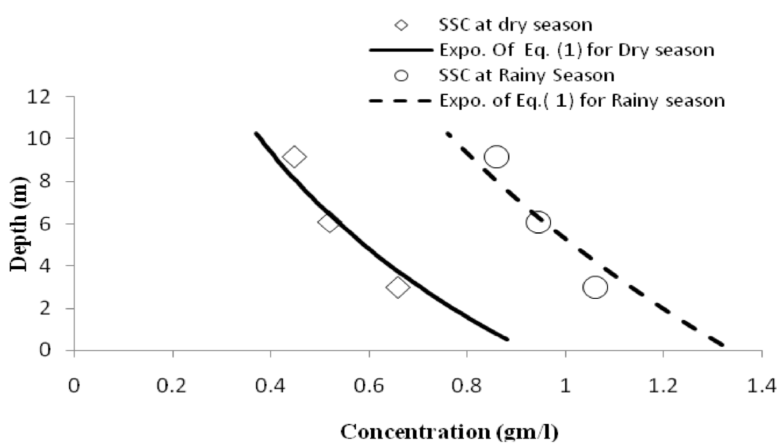


**Figure 14** Correlation of measured SSC with theoretical standard distribution (Equation 1)

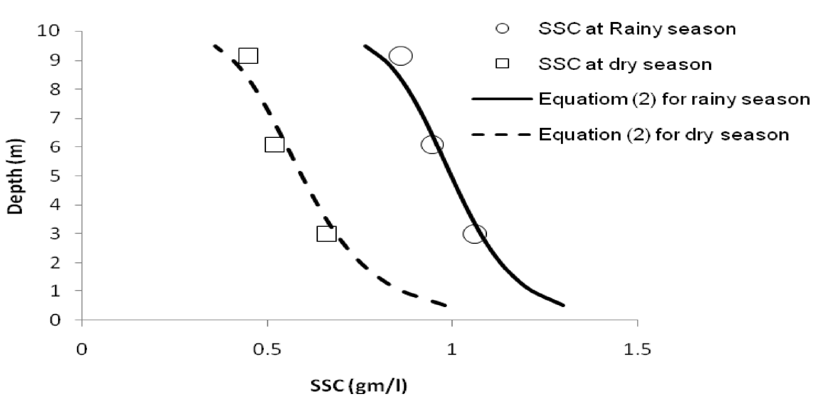


**Figure 15** Correlation of experimental SSC with theoretical standard distribution (Equation 2)

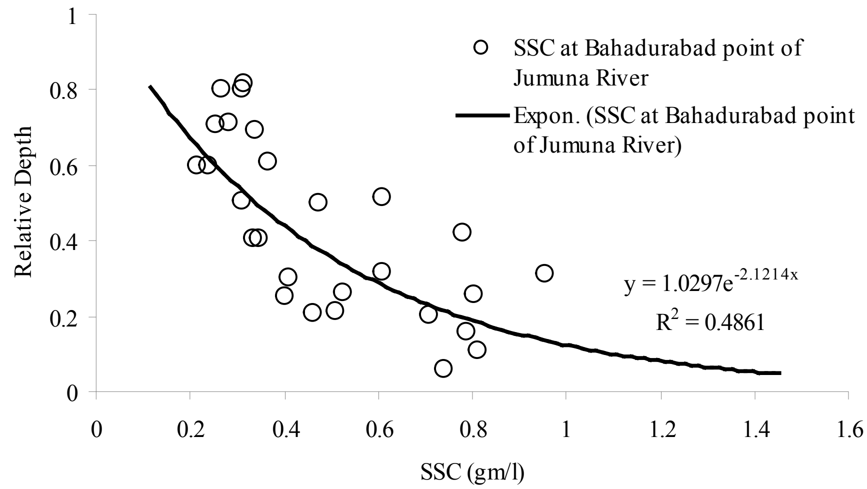


**Figure 16** Vertical distribution of measured SSC for Jamuna River (Sarkar and Klaassen, 2011) with exponential trend line

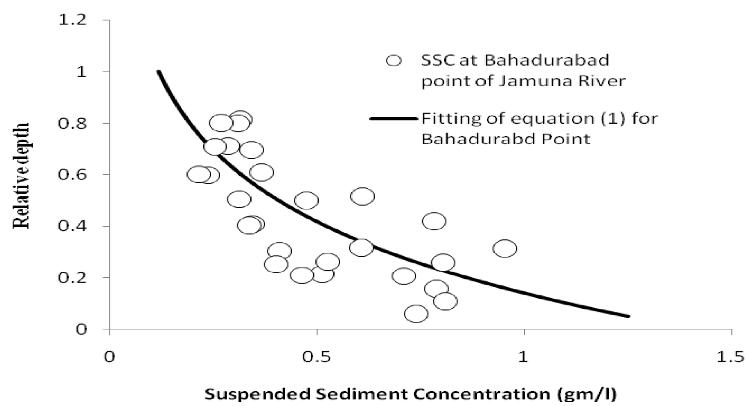


**Figure 17** Correlation of SSC of Jamuna River with theoretical standard distribution (Equation 1)

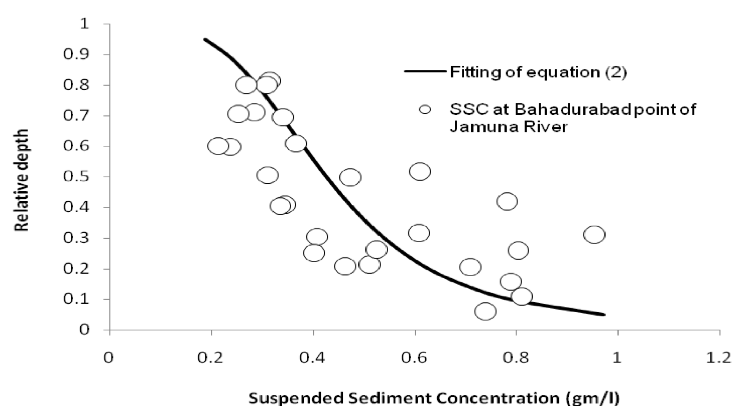


**Figure 18** Correlation of SSC of Jamuna River with theoretical standard distribution (Equation 2)

### *3.8.3 Calculation of exponent z in Equation (2)*

Figure 15 shows the correlation of measured SSC with theoretical standard distribution (Equation 2). Using the same procedure as described before, the values of z in Equation (2) were estimated both for dry and rainy seasons, and their values were found as 0.09 and 0.17, respectively. The distribution in Figure 13 was used to estimate the value of '$C_a$' and finaly the values of z were estimated by trial for best fit of equation (2) with measured SSC profile.

### 3.9 Correlation of Measured SSC of Jamuna River with Theoretical Distributions

Figure 16 shows the distribution of measured SSC for Jamuna river (Sarker and Klassen, 2011) with exponential trend line. Using the same procedure described for Bhairab river, the measured distribution of SSC for Jamuna River is compared with equation (1) and (2), and the unknown coefficients a, $C_a$, $w_0/\varepsilon_s$ and z were determined for Jamuna. After estimating coefficients, the theoretical standard distribution was calculated using those two Equations. Figure 17 shows the correlation of suspended sediment concentration of Jamuna river at Bahadurabad point with the calculated theoretical distribution (Equation 1). The distribution in Figure 16 was used to estimate the value of '$C_a$'. Comparing theoretical distribution with measured suspended sediment concentration, the value of coefficient $w_0/\varepsilon_s$ was calculated by trial. Its value was found as 0.25 for Jamuna river with a value of $C_a$ as 1.40 gm/l at 0.05 m above the bottom.

Figure 18 shows the correlation of measured SSC of Jamuna river at Bahadurabad point with the calculated theoretical distribution (Equation 2). For this river, the value of z in Equation (2) was estimated as 0.28. The distribution in Figure 16 was used to estimate the value of '$C_a$' and finaly the value of z was estimated by trial for best fit of equation (2) with measured SSC profile.

Table 2 shows the comparison of coefficients of Equation (1) and (2) for Bhairab River with that of Jamuna River. Although the seasonal variation of these coefficients are estiamted for Bhairab river, due to lake of available SSC data, those coefficients are calculated only for dry season for the Jamuna river. It is observed that the value of SSC in Bhairab River is comparable with that of Jamuna River.

**Table 2** Comparison of coefficients of equation (1) and (2) for Bhairab River with that of Jamuna River

| River | Season | SSC (gm/l) | a (m) | $C_a$ (gm/l) | $w_0/\varepsilon_s$ | z |
|---|---|---|---|---|---|---|
| Bhairab | Rainy Season | 0.955 | 2.0 | 1.10 | 0.035 | 0.17 |
| | Dry Season | 0.543 | 1.30 | 0.82 | 0.089 | 0.09 |
| Jamuna | Dry Season | 0.484 | 0.05 | 1.40 | 0.25 | 0.28 |

## 4. CONCLUSIONS

In the Bhairab River the suspended sediment concentration is found to be varied temporally as well as spatially. The suspended sediment concentration during rainy season is found higher compared to dry season. The reason behind this is, in rainy season there is high upstream flow and runoff due to rain, which carry a lot of sediments. The value of pH is found lower during rainy season and higher during dry season. In comparison between high tide and low tide period, it is observed that the suspended sediment concentration in high tide period is about 10% higher than that of in low tide period. The variation of suspended sediment concentration is found to be increased with depth and the suspended sediment concentration at middle of the river is found lower than two sides of the river. The experimental data are fitted with standard theoretical distribution of suspended sediment concentration. The coefficients in the equations of standard distribution are estimated for Bhairab River. The experimental results are found to be comparable with that of other rivers (such as Jamuna) in Bangladesh. Using the estimated values of coefficients, the value of suspended sediment concentration for any depth of Bhairab River can be calculated for any season without performing any measurements.

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