Using Turbidity to Determine Total Suspended Solids in an Urban Stream: A Case Study

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Abstract ***—*** *A high concentration of total solids will make drinking water unpalatable and might have an adverse effect on people who are not used to drinking such water. Levels of total solids that are too high or too low can also reduce the efficiency of water treatment plants, as well as the operation of industrial processes that use raw water. The estimation of Total Suspended Solids (TSS) is very much important in relation to the selection of proper treatment process. The direct measurement of TSS is relatively costlier and time consuming than turbidity measurement. Though universal correlation does not exist, there are many investigations showing that turbidity is in relation with suspended sediments. For example, Model developed for Turbidity & TSS for the Sitnica river, Kosovo, shows the coefficient of determination* R^2 *= 0.8687, for fourteen rivers around Singapore* R^2 *= 0.80 & for urbanizing streams at Washington, USA,* R^2 *= 0.96. The aim of this work is to establish a regression model that would enable the measurement of TSS in the Shitalakhya river at Dhaka through the measurements of turbidity. TSS & Turbidity concentration was measured daily throughout the year 2017 and the regression model was developed to surrogate turbidity for TSS. It is found that for the year 2017 as a whole the* R^2 *= 0.48, for the dry and wet season they were 0.51 & 0.59 respectively, which are not excellent but fairly good correlation. When calculating the regression equation for every month we found that* R^2 *varies from 0.04 to 0.79, and half of the twelve values fall below 0.2. Thus for this particular site, the use of turbidity as a surrogate to TSS for individual monthly measurement is not effective throughout, however, to get an instantaneous idea of pollution during dry and wet season as a whole, the model can be used.*

Keywords — *Correlation, surface water, turbidity, total suspended solids.*

I. INTRODUCTION

All streams carry some SS under natural conditions. However, if concentrations are enhanced through, for example, anthropogenic perturbations, this can lead to alterations to the physical, chemical and biological properties of the water body. Physical alterations caused by SS include reduced penetration of light, temperature changes, and infilling of channels and reservoirs when solids are deposited. These physical alterations are associated with undesirable aesthetic effects, higher costs of water treatment, reduced navigability of channels and decreased the longevity of dams and reservoirs [1]. Dawson and Macklin [2] and Haygarth et al. [3] mentioned that chemical alterations caused by SS include the release of contaminants, such as heavy metals and pesticides and nutrients such as phosphorus into the water body from adsorption sites on the sediment. Furthermore, where the SS have a high organic content, their in-situ decomposition can deplete levels of dissolved oxygen in the water, producing a critical oxygen shortage, which can lead to fish kills during low-flow conditions pointed out also by Bilotta and Brazier [1].

Turbidity can be caused by the presence of suspended solids, such as clay, silt, sand, from inorganic materials and organic matter such as algae and/or plankton. The presence of dissolved organic matter, fluorescent dissolved organic matter, and other dyes will also contribute towards the turbidity of water. As the turbidity is a function of particle shape, size, and composition it follows that if two waters have the same turbidity they may not necessarily contain the same concentration of suspended solids. Fig. 1 is a photograph of two waters with differing turbidity. The water on the left is visually cloudier (higher turbidity) than the water on the right. The cloudy water on the left contains very small particles that have a strong ability to reflect and scatter light. The sample on the right has a smaller number of larger particles giving the water a lower turbidity. However, these two waters contain the same mass of suspended solids that is they contain the same concentration of total suspended solids. The difference between these two samples is particle size. In the left sample there are a large number of small (low mass) particles and in the right, we have a much smaller number of large (higher mass) particles. For each sample, if we multiplied the number of particles by the mass of the particles we would get the same answer. This was explained in Watery News [4].

For most waters containing suspended particles, there will typically be a defined relationship between Turbidity (Measured in NTU) and Total Suspended Solids (mg/L)

The universal correlation between turbidity and TSS does not exist [5], however, there are some investigations showing that turbidity is in relation with suspended sediments. It is known that the eventual relationship between TSS and turbidity is affected by density, size, and shape of particles and water colour. However, if a good correlation between TSS and turbidity is developed, then turbidity may serve as a proxy for suspended solids and pollutant concentrations within a chosen basin. This was observed by Nasrabadi et al. [6] and Holliday et al. [7].

Many researches have been conducted in this field. The relationship between suspended sediment and turbidity along the Elbe River was investigated by The German Federal Institute of Hydrology. This study took place from June 1996 until February 2001 and involved 1405 measurements of turbidity, suspended matter, and flow rates. The study showed that large streambed particles and water colour adversely affected the measurements and the measurement error was found to increase with increasing flow rate. A linear relationship between TSS and turbidity was found for naturally suspended sediments in rivers in South Germany. Another investigation was conducted in Kansas River and Little Arkansas River. About twenty samples were collected at eight stream-gauging stations between 1998 and 2001 in order to document the effectiveness of turbidity as a surrogate. Results from this study showed a coefficient of determination of 0.987 between the turbidity and suspended sediments. This was due to the favourable condition of turbidity measurement, noticed by Kusari [8], that the particle size for the test sites was 95 percent fines.

The Shitalakhya river is the lifeline of Dhaka city. At least three million city dwellers are directly dependent on the drinking water produced and supplied by treating water from this river at the largest treatment plant in Bangladesh. Raw water quality of this river is very vital to the sustainable development of the city as well as the sustainable supply of drinking water to the citizens. In general, around fifteen thousand samples are tested annually for quality assessment including TSS and turbidity in relation to the operation of the treatment plant, which involves considerable time and cost. No such study correlating different quality parameters has been conducted recently with Shitalakhya water. The correlation study between turbidity and TSS may help to ascertain TSS from turbidity information, thus saving time and money.

With this background the aim of this study is to establish, if feasible, a regression model that would enable the measurement of TSS in the Shitalakhya river at Dhaka through the measurements of turbidity

II. MATERIALS AND METHODS

A. Study Area

The study area is Dhaka the capital city of Bangladesh, which has a distinct monsoonal season, with an annual average temperature of 26°C and monthly means varying between 19°C in January and 29°C in May, sometimes reaching to 40°C. Approximately 87% of the annual average rainfall of 2,123 millimetres occurs between May and October. Dhaka is located at 23° 42′ N and 90° 22′ E, on the banks of the Buriganga river and surrounded by other peripheral rivers. The largest water treatment plant of the country is situated near the river Shitalakhya in the eastern periphery of Dhaka city at Latitude N 23° 43' 11.25" and Longitude E 90° 26' 14.25" [9].

B. Sample collection and analysis

Raw Water samples were collected from the treatment plant intake from a depth of 0.6 d of the channel. Samples were collected in clean plastic cans of 2 litres capacities for physicochemical analysis. The collected samples were transferred to the laboratory of the plant, by following the precautions laid by standard methods [10]. Turbidity (Nephelometric Method), DO, temperature, were determined within the field of collection, the other parameters including TSS (Gravimetric Method) were analysed in the laboratory within the stipulated period.

III. RESULTS AND DISCUSSIONS

The concentration of two important physical water quality parameters is tested taking the raw water of the Shitalakhya river extracted at the intake of the largest water treatment plant in Dhaka. The study covers a period of one full year in 2017 and the concentrations of both the parameters were recorded on daily basis throughout the year and are analysed. All the test result values are utilized in this study. The global number of the sample tested in this study period is around 730 comprising almost equally in each month covering all seasons. The results of the analysis for the average, minimum and maximum concentration values for all the parameters used as test data during the study period are presented in Table 1.

The regression analyses have been carried out to relate Turbidity with TSS. The regression is carried out first for the whole year taking all the daily measurements. Secondly, the regression is done for the dry season and wet season separately comprising respectively the months of November to April and May to October. Lastly, it is carried out for each month of the year in order to get a comprehensive picture of the whole year across the months. The investigation of and relationships between the parameters in the form of scatter graph are shown in Fig. 2 to 4. Their mathematical expression & the coefficient of determination are also shown in Fig. 2 to 4, which present apparently linear correlation between the variables.

As it can be noticed from Fig. 2 and Table 2, the correlation between turbidity and total suspended solids for the study period for the year as whole gives a positive relationship and it is as follows: TSS (mg/l) = 0.2711 * Turbidity (NTU) + 5.3798 ($p < 0.01$), but the coefficient of determination is only 0.48, which we cannot call excellent.

Similarly, from the depicted graph of wet and dry season (Fig. 3 to 4) we can notice that their relationship is positive and it follows the regression equation TSS (mg/l) = 0.2089 * Turbidity (NTU) + 8.009 ($p < 0.01$) and TSS (mg/l) = 0.5307 * Turbidity (NTU) + 1.1151 ($p < 0.01$) respectively and the coefficient of determination is 0.51 and 0.59 respectively, which cannot be termed as excellent.

Lastly, the calculated regression equations and their respective coefficient of determinations for each month are shown in Table 2. We notice that there is a wide range of variations in the R^2 values, ranging from 0.04 to 0.79. Half of the R^2 values lie below 0.20 and even the lowest value stands to 0.04. The highest R^2 is found in July with a value of 0.79.

An explanatory variable, such as turbidity in this relationship, cannot be used confidently throughout the year to compute the response variable Total Suspended Solids. Since the predictive ability of the relationship can be assessed based on the coefficient of determination (R^2), then for the selected location there is no strong correlation between turbidity and TSS throughout. As it is evident from the graphs and tables, we can conclude that prediction of TSS based on turbidity readings, for this given site in any part of the year is not reasonable and thus it would be wise not to use such correlations in lieu of measuring the parameter conventionally for this site and for this river water throughout the year.

Nevertheless, the outcome of the present study is not abnormal. Because though Turbidity has the advantage that it can be measured at higher solution time-steps, however, there are limitations when using turbidity as a surrogate measure of SS. First, turbidity is a measure of only one of the many effects of SS. Second, turbidity responds to factors other than just SS concentrations. Turbidity readings are influenced by the particle size and shape of SS, the presence of phytoplankton, the presence of dissolved humic substances and the presence of dissolved mineral substances. Consequently, a high turbidity reading can be recorded without necessarily involving a high SS concentration. Therefore, if relying solely on turbidimeter data, it is not straightforward to know exactly what is causing the turbidity. Whilst time-series of turbidity may do well at describing the reduction in light penetration and aesthetic issues surrounding SS, it is likely that their use will lead to underestimation of the broader effects of SS in the aquatic environments.

Tab. 1 Average & maximum monthly concentration of Turbidity and Total suspended solids

Months	Total Suspended Solids (mg/L)			Turbidity (NTU)		
	Max.	Average	Min.	Max.	Average	Min.
January	23.7	14.0	8.2	58.9	29.5	6.2
February	22.0	18.4	9.8	72.4	48.2	30.6
March	38.0	20.5	15.5	96.0	57.4	38.2
April	25.3	10.3	1.8	69.3	19.5	6.1
May	13.3	7.5	4.4	16.8	13.9	9.4
June	13.0	7.3	2.4	22.4	18.3	11.3
July	35.0	15.6	6.6	53.9	25.8	14.7
August	29.6	14.3	7.0	47.4	20.7	10.8
September	32.6	12.0	3.6	31.7	16.6	7.9
October	23.6	12.9	4.8	52.3	23.2	11.8
November	9.2	4.0	1.0	19.0	7.0	3.4
December	14.6	5.4	2.8	18.6	7.6	3.6

Fig. 1 Waters with differing levels of turbidity with same amount of TSS [4]

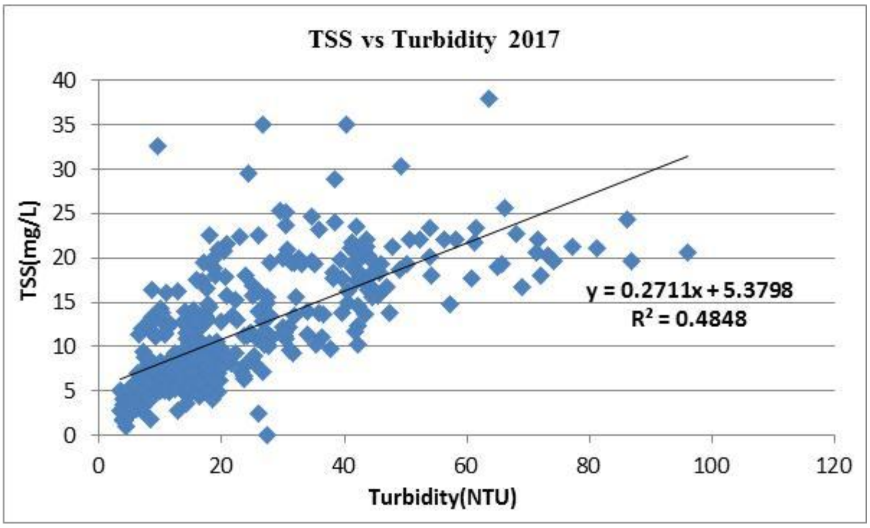

Fig. 2 Regression analysis of turbidity and TSS for 2017

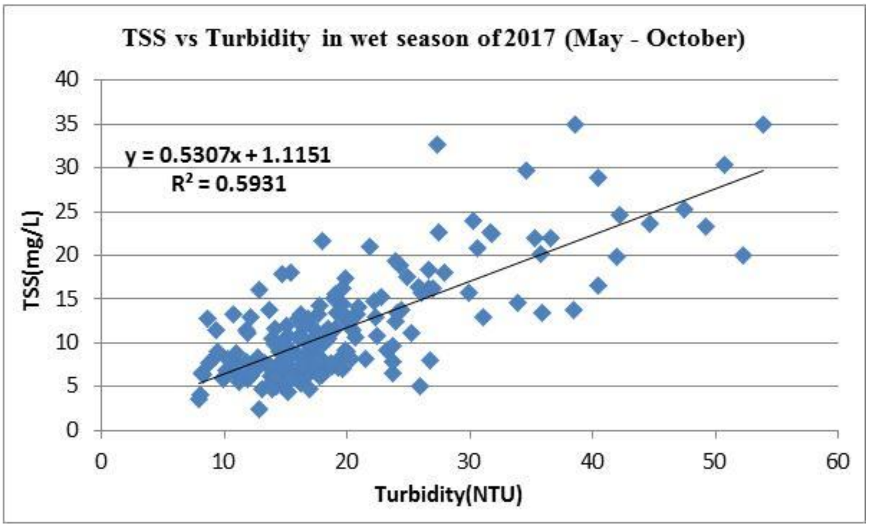

Fig. 3 Regression analysis of turbidity and TSS for the wet season in 2017

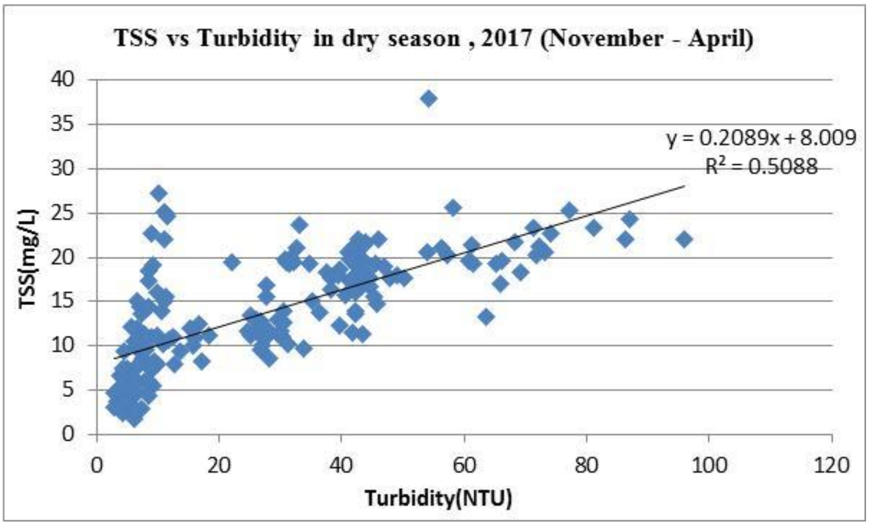

Fig. 4 Regression analysis of turbidity and TSS for the dry season in 2017

Tab. 2 Correlation equations between Turbidity and TSS in each month in 2017

Months	**Correlation Equation**	**Coefficient of Determination (R^2)**	***p* value**
January	TSS (mg/l) = 0.165 * Turbidity (NTU) + 9.1828	0.0684	>0.05
February	TSS (mg/l) = 0.0791 * Turbidity (NTU) + 14.751	0.0957	>0.05
March	TSS (mg/l) = 0.173 * Turbidity (NTU) + 14.34	0.1794	>0.01
April	TSS (mg/l) = 0.1857 * Turbidity (NTU) + 6.6561	0.5261	< 0.01
May	TSS (mg/l) = 0.1754 * Turbidity (NTU) + 4.942	0.0456	>0.05
June	TSS (mg/l) = 0.1981 * Turbidity (NTU) + 3.675	0.1589	>0.05
July	TSS (mg/l) = 0.6348 * Turbidity (NTU) - 0.7308	0.7945	< 0.01
August	TSS (mg/l) = 0.426 * Turbidity (NTU) + 5.5006	0.4919	< 0.01
September	TSS (mg/l) = 0.7042 * Turbidity (NTU) + 0.3302	0.6409	< 0.01
October	TSS (mg/l) = 0.3905 * Turbidity (NTU) + 3.8692	0.6363	< 0.01
November	TSS (mg/l) = 0.3747 * Turbidity (NTU) + 1.3598	0.6961	< 0.01
December	TSS (mg/l) = 0.3313 * Turbidity (NTU) + 2.9035	0.1696	>0.01

IV. CONCLUSIONS

With a continuous daily data over the year of 2017 of turbidity and TSS an effort was made to correlate them with an intention if turbidity can be used as a surrogate to TSS as is done in many rivers in other countries.

From the result of the study, it is evident that the developed regression model for the analysed river water does not indicate an excellent linear correlation between TSS concentrations and turbidity levels throughout the year at this sampling point, since the correlation coefficient of R^2 is mostly lower than expected. However, in many studies in other countries the correlations between turbidity with TSS were found excellent, like study done in Sitnika river (R^2 = 0.87) [11], study done in Singapore rivers (R^2 = 0.80) [12]. Another higher correlation coefficient (of R^2 = 0.979), was developed by a log-linear model while using the turbidity to determine Total Suspended Solids in storm water runoff from green roofs [13]. Also, a study focusing on using turbidity to determine Total Suspended Solids in urbanizing streams in the Puget Lowlands, Washington, USA derived a correlation coefficient as high as of R^2 = 0.96 [14], in a study in Kelantan river, Malaysia, the coefficient of determination was found 0.96 [15].

In this reach of Shitalakhya river, it would be better not to use the turbidity values to determine the TSS throughout the year consistently. However, to have an instantaneous rough idea of TSS the relation developed may be used by the plant operator in dry and wet season as a whole and separate experiment may be conducted on other reaches of the river to determine the relation with extensive sample analysis.

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