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Characterization of Urban Storm Water Quality for Different Land uses in Rajshahi City, Bangladesh

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Abstract- Urbanization results increased fraction of impervious surfaces, which leads to the generation of pollutants through various anthropogenic activities during dry periods and washout these pollutants during rainfall events that finally enter into the receiving water bodies. This further deteriorate the water quality and unbalance the aquatic ecosystem. Hence, characterization of urban stormwater quality is critically important for selecting a suitable treatment system to safeguard the receiving water sources. The paper focused on the analysis of urban stormwater quality parameters (e.g., pH, turbidity, electric conductivity (EC), suspended solids (SS) and bio-chemical oxygen demand (BOD) for three different land uses such as residential, commercial and, industrial. The stormwater samples were collected from three different land-use areas in Rajshahi City. The laboratory test results showed that SS, turbidity, EC were found significant for industrial areas where pH and BOD show higher value in residential and industrial areas, respectively. The study results will provide guidelines to the stormwater management authority for the selection of suitable treatment systems to protect the receiving water quality for different land types in Rajshahi city.

Keywords: *stormwater runoff, stormwater quality, land use, rajshahi city, principal component analysis.*

GJSFR-H Classification: *FOR Code: 040699*

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I. Introduction

Water pollution is a crucial concern now- a -days. It has created many problems for human beings and water bodies. People are suffering from a lot of water-born diseases. It has become a threat to the fishes and other water bodies. Soni et al. (2019) conducted a study on categories, causes, and control of water pollution. Their study results showed that water pollution affects the aquatic ecosystem, including plants that are exposed to the water.

Currently, stormwater runoff has become one of the major sources of water pollution. Due to the rapid urbanization process, natural land turns into the impervious surface, which is a suitable platform for pollutant build-up and wash-off by rainfall events (Goonetilleke et al., 2005). The stormwater runoff enters into the nearby water bodies through drainage systems or overland flow without treatment and deteriorates the receiving water quality. The type and amount of pollutant generation depend on many factors such as the geology of the land, topography, geography, rainfall intensity and pattern, and land use type (Sarukkalige, 2011). Guzman et al. (2018) conducted a study to examine the physical-chemical parameters of urban stormwater runoff using artificial rain for different land uses in Bogota, Colombia. They showed that nitrates, nitrites, alkalinity, COD and suspended solids concentration were found higher in the industrial area compared to residential and recreational areas. Also, they showed a similar variations of these pollutants for residential and recreational areas due to the presence of traffic and vegetal species.

A similar study conducted by Lucke et. al. (2018), where the variability of pollutant build-up parameters was investigated for seven residential and five commercial areas in Australia. They showed that the values of suspended solid, nitrogen, and phosphorus were higher in urban residential areas than the commercial areas. In another study, Maharjan et. al. (2017) focused on the development of the build-up model for a large urban Mustoja catchment in Tallinn for different land-use types. Their study results showed that the build-up rate was found higher in the industrial areas compared to commercial and residential areas. Also, commercial areas showed a higher build-up rate than a residential area. A similar study conducted by Khatun et al. (2014), where the variability of pollutant build-up parameters was investigated in five different land uses such as industrial, commercial, residential, heavy traffic, and recreational around Guwahati city, Assam, India. They showed that industrial areas had a higher value of co-efficient of variations compared to other land-use types. In another study, Jarvelainen (2014) estimated the stormwater pollutant load and designed the monitoring system for different land-use types in Lahti city, Finland. In this study, the quality and quantity of stormwater being generated in different land-use areas were estimated. He found that industrial and commercial areas had a higher amount of heavy metals and pollutants compared to other land uses. In another study, Liu (2011) investigated the influence of rainfall and catchment characteristics on urban stormwater

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quality in Gold Coast, Australia. In this study, pollutants build-up samples that were collected from twelve road surfaces in residential, industrial, and commercial areas. Study results showed that commercial and residential areas had relatively higher variations of nutrients and organic carbon build-up than an industrial areas.

Based on the above review, it was understood that the types and amount of pollutants generated vary with different land-use types. Hence, proper characterization of urban stormwater quality for different land-use types is essential for the selection of suitable treatment methods. The aim of this study is to characterize the urban stormwater quality for three different land uses, such as residential, commercial, and industrial areas in Rajshahi City. The study will show us the variation among the parameters of urban stormwater in residential, commercial, and industrial areas after a regular time interval.

II. Methodology

a) *Study Site Selection*

The stormwater samples were collected from three different land-use, such as residential, commercial, and industrials areas in Rajshahi city. Rajshahi is the 4^{th} largest among the eight divisions in Bangladesh (RCC, 2006). It's being developed day by day due to many industries and educational institutes. Due to the rapid urbanization process, stormwater gets polluted by the pollutants generated in road surfaces and washout during rainfall events. The sample collection point was six different road surface runoff such as Alokarmor, New market; Belderpara Mor; Zero-point, Shaheb Bazar; Moni Chattar; BSCIC, Sapura and Match Factory Mor in Rajshahi City (Figure 1). The characteristics of these study sites are discussed in Table 1.

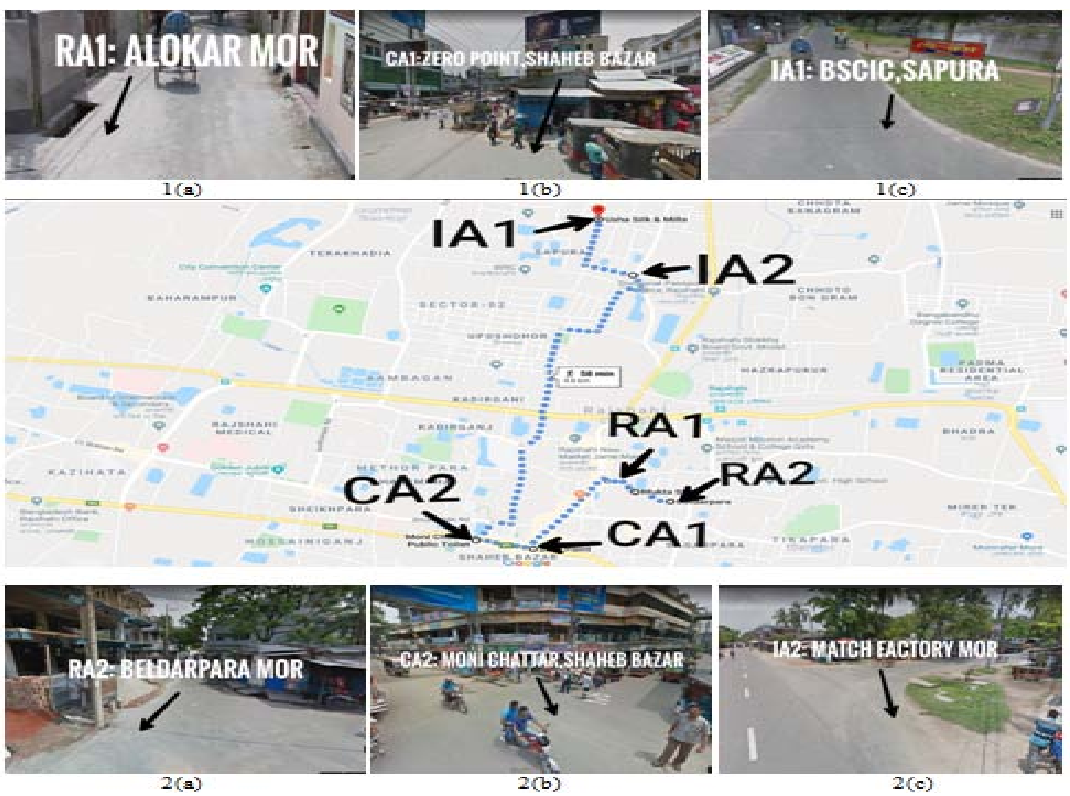

Figure 1: Study sites

Table 1: Characteristics of Study Sites

Land use type	Site Name	Road type	Texture depth (mm)	Location Coordinate
Residential	Alokarmor	Main road	1.78	24°22′1.0″N 88°36′10.8″E
	Belderparamor	Branch road	1.63	24°22′7.1″N 88°36′22.5″E
Commercial	Zero- point, Shaheb Bazar	Main road	2.67	24°21′55.5″N 88°35′59.9″E
	Moni chattar	Main road	2.39	24°21′58.0″N 88°35′50.8″E
Industrial	Bscic, Sapura	Branch road	2.58	24°23′14.3″N 88°36′19.8″E
	Match factory mor	Main road	2.92	24°23′12.8″N 88°36′20.6″E

b) Sample Collection and Laboratory Testing

The stormwater samples were collected from selected six locations (see section II (a)) for three consecutive rainfall events according to the schedule mentioned in Table 2. This further enables to investigate the effect of antecedent dry days on pollutants deposition rate on the road surfaces. The standard sample collection procedure recommended by Simpson et al. (2017) were followed during sample collection. The collected sample bottles were sealed with airtight tape. A permanent marker was used to level each sample bottle for future identification. The collected samples were tested in the public health Engineering laboratory of RUET using the standard test method specified by APHA (2017). Accordingly, stormwater quality parameters such as pH, turbidity, electric conductivity, total suspended solids, and BOD were tested and results were recorded for further data analysis.

Table 2: Sample collection time

Sample collection date	Sample no.
02/06/2019	RA1-1, CA1-1, IA1-1
09/06/2019	RA1-2, CA1-2, IA1-2
25/06/2019	RA1-3, CA1-3, IA1-3
29/08/2019	RA2-1, CA2-1, IA2-1
04/09/2019	RA2-2, CA2-2, IA2-2
09/09/2019	RA2-3, CA2-3, IA2-3

c) Data Analysis Method

To understand the variation of stormwater quality parameters for three different land-use types, univariate analysis was undertaken. However, the correlation among the parameters and their influence on land use types were investigated using a multivariate analysis technique.

i. *Univariate Analysis Tools*

Mean: The average of a set of data points is measured by it.

$$\bar{X} = \frac{\sum x_n}{N} \qquad (1)$$

Here, $\sum x_n$ = sum of data values.

N = the total number of data points.

$\bar{X}$ = mean

Standard Deviation (SD): The dispersion of the data set is measured from its mean.

$$\sigma = \sqrt{\frac{\sum(x-\bar{X})^2}{N-1}} \qquad (2)$$

Here, x= individual data points

$\bar{X}$=mean/average of the data points

N = total number of data point,

σ= standard deviation

Coefficient of variation (CV): The level of dispersion around the mean is measured by CV.

$$CV = \frac{\sigma}{\bar{X}} \qquad (3)$$

Here, σ= Standard deviation.

$\bar{X}$=mean

ii. *Multivariate Analysis Tools*

Principal Component Analysis (PCA) is a multivariate data analysis technique. PCA is generally used to identify the correlations among the variables and objects which are of similar characteristics. PCA transforms the large datasets into independent new variables called principal component (Abdi & Williams, 2010). The total number of variables influence the number of principal components to be reproduced during transformation. In this transformation, the first principal components represent the highest variance and gradually decrease to end components. Hence, the first two principal components are used to produce PCA bi-plot (Huang et al., 2007). PCA bi-plot is the two-dimensional graphical representation where any two principal components are plotted in the x and y-axis, respectively. The correlations among the variables and data points can be determined from the PCA bi-plot.

III. Result and Discussion

The summary of the analysis results for different land-use type is presented in Table 3. As seen in Table 3, stormwater pollutants concentration was found variable for different land-use types. This suggests that the distribution of pollutants throughout the catchment is not uniform and significantly influence by different land use types.

Suspended solids (SS) can be considered as one of the main indicator pollutants due to their capacity to absorb other pollutants such as heavy metals, nutrients, hydrocarbons, and transport them into stormwater runoff (Herngren et al., 2006). The amount of SS was found lower for residential areas compared to commercial and industrial areas. This indicates comparatively clear water in residential area than other sites.

Table 3: Average pollutant loading for each specified land use

Land use type	Sites	Ph			Turbidity (Ntu)			Ec (Ms/Cm)			Suspended Solids (Mg/L)			Bod (Mg/L)		
		MEAN	SD	CV (%)	MEAN	SD	CV (%)	MEAN	SD	CV (%)	MEAN	SD	CV (%)	MEAN	SD	CV (%)
Residential	Alokar Mor	6.90	0.20	1.95	10.00	0.40	3.58	1066.7	115.5	10.82	115.73	10.8	9.39	2.22	0.02	1.82
	BeldarPara Mor	6.78	0.02	0.29	10.16	0.28	2.76	1050.0	50.00	04.76	117.85	2.65	2.25	2.15	0.13	6.04
Commercial	Zero Point	6.57	0.10	1.64	08.52	0.10	1.54	1433.3	57.74	04.02	189.99	4.30	2.26	8.23	0.30	3.06
	Moni-Chattar	6.55	0.05	0.76	08.36	0.26	3.11	1483.3	28.86	01.94	189.87	0.93	0.49	8.32	0.16	1.92
Industrial	Bscic, Sapura	6.42	0.10	0.80	13.17	0.90	6.85	1533.3	57.72	03.76	394.45	4.32	1.09	3.17	0.30	9.11
	Match Factory Mor	6.38	0.02	0.31	12.93	0.02	0.15	1566.6	57.73	03.68	394.31	03.67	0.93	3.27	0.02	0.62

The stormwater runoff from industrial area represents highly polluted compared to other land-use. This can be due to the presence of high amount of SS and turbidity in the industrial area. Also, the BOD value was found slightly higher in the industrial area compared to the residential area. This can be due to the presence of fine organic matters produce from industrial processes and distributed by wind during loading and unloading conditions.

Commercial stormwater resulted in containing low concentrations of suspended solids and turbidity value than industrial sites. But commercial areas are recorded the highest amount of BOD compared to other land uses. This may be due to the generation of the highest organic waste, which decomposed on road surfaces and washout through stormwater runoff. The organic wastes in commercial areas are produced from the local market, fruit seller, decomposed fruit bunch or vegetable waste and distribute along the road side. In contrast, the industrial area produces small amount of organic waste, that's why the value of BOD is lower than the commercial areas.

The comparison of stormwater quality parameters among three different land uses was presented by Box Whisker plot in Figures 2-6.

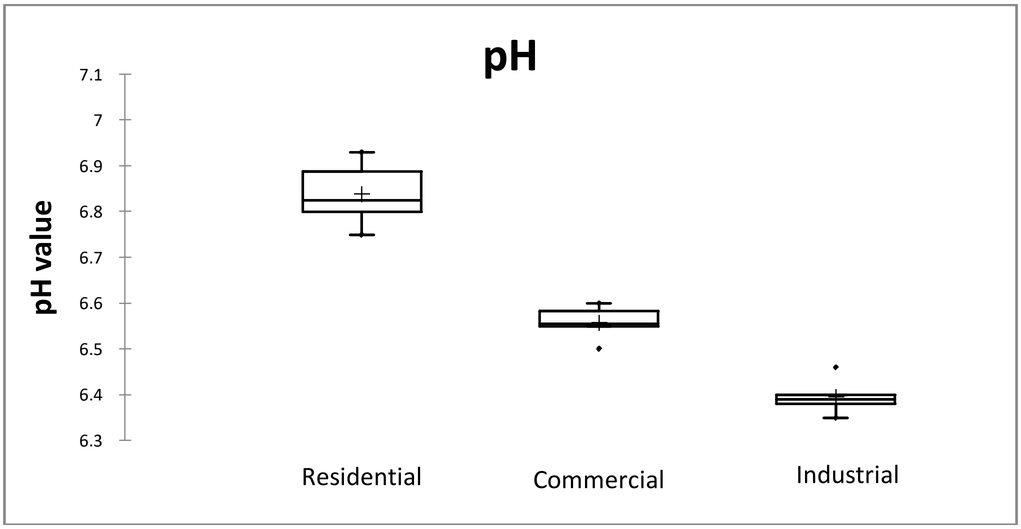

Figure 2: Variation of pH for different land uses

As seen in Figure 2, the highest pH value was found 6.93 in the residential areas where the mean value was 6.83. The commercial area shows the highest value of 6.6, and the mean value is about 6.55. The residential area has a higher concentration compared to industrial and commercial areas. From Table 2, pH value in residential area displays the highest standard deviation among the three different land uses. This indicates high variability in the value of pH concentration. pH value was found lower for both commercial and industrial areas. This can be due to the presence of chemical and metal that reacts with water and decrease the pH value.

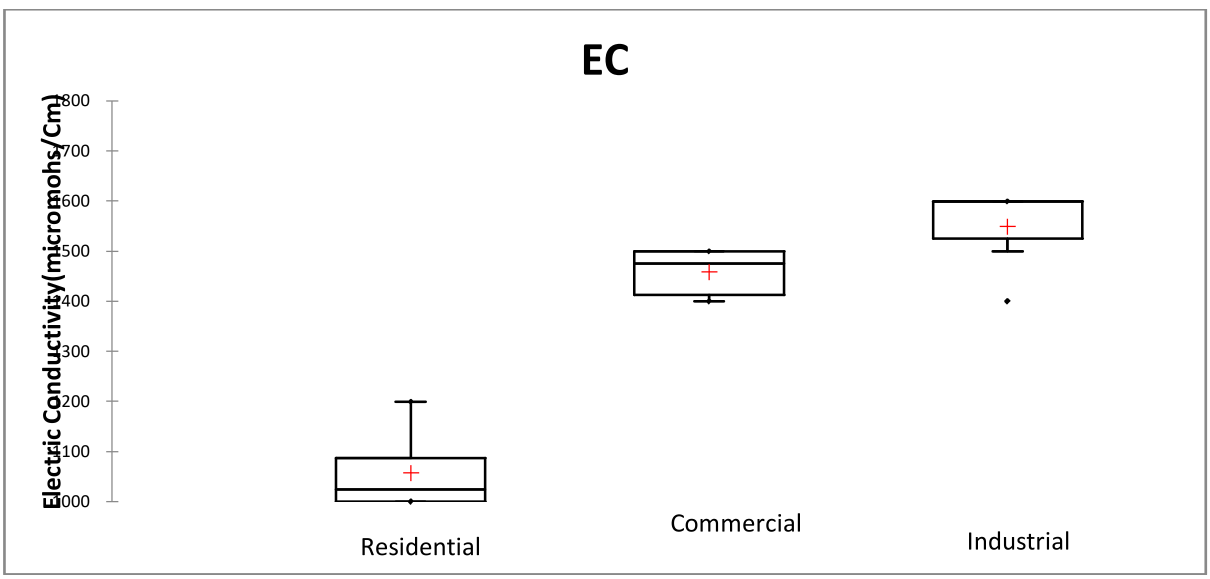

Figure 3: Variation of Electric Conductivity for different land uses

The variation of Electric Conductivity (EC) is shown in Figure 3. The industrial area has the highest conductivity (mean 1550 micromohs/Cm) than residential (mean 1060 micromohs/Cm) and commercial (mean 1460 micromohs/Cm) areas. The reaction of chemical and metal substances with the water flowing from the industrial area is the reason for having a higher value of EC in the industrial area.

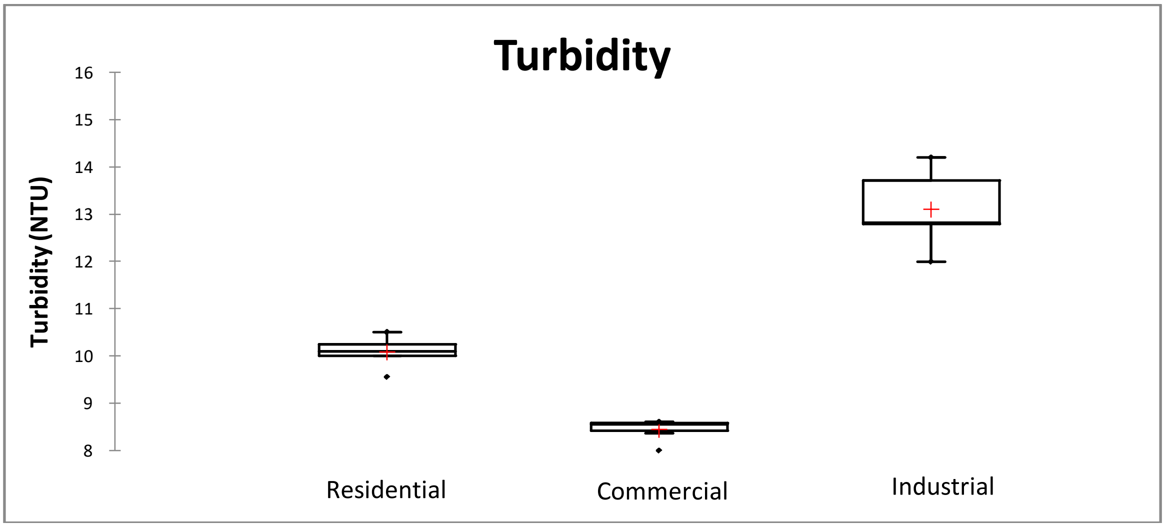

Figure 4: Variation of Turbidity for different land uses

The significant differences of turbidity among three land uses are presented in Figure 4. Water turbidity is directly caused by the presence of suspended matters such as clay, silt, etc. The overall patterns of SS and turbidity concentration in different land uses were similar. Commercial land-use type was significantly less turbid (mean value is 8.45 NTU) than all other land use types. The highest turbidity was found in the industrial area (mean value 13.15 NTU). This can be due to the presence of the fine particles from the production process of goods and distributed on the road surface by traffic, wind, workers during loading, and unloading time.

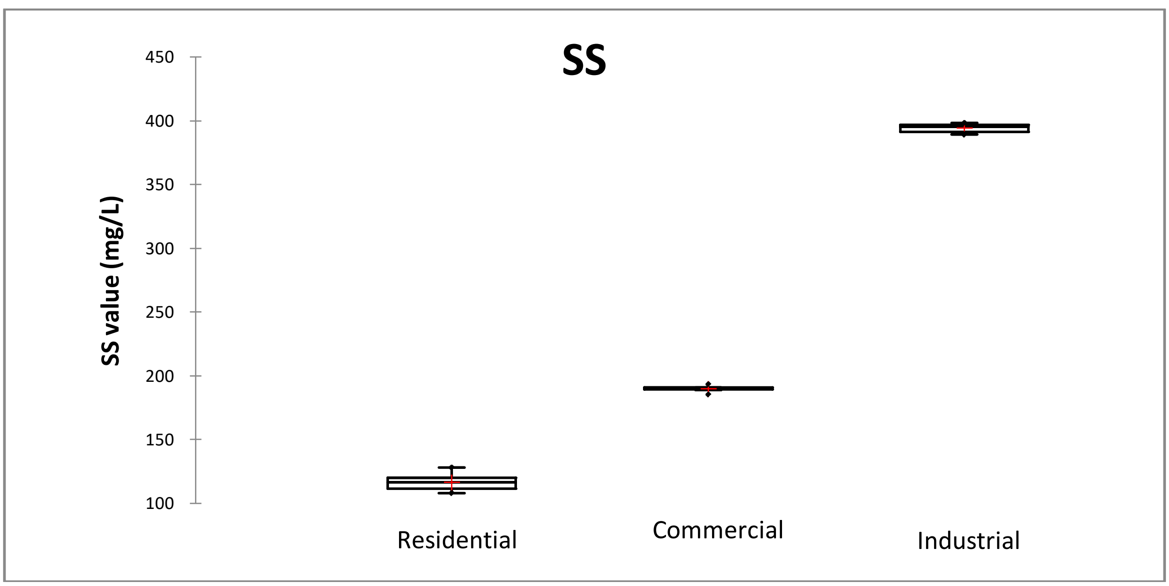

Figure 5: Variation of Suspended Solids for different land uses

The variation of SS for three different land uses shown in Figure 5. The residential area has a lower mean SS value (116.75 mg/l) compared to other land uses. This can be due to the periodic cleaning of road surfaces by street sweepers. It can be seen that the average concentration of SS in the industrial area (394.25 mg/l) was almost two and a half times the values for residential areas. The commercial and industrial area produces a high level of SS. This is due to high population density, traffic density and various anthropogenic activities occur by human and distribute by traffic and wind.

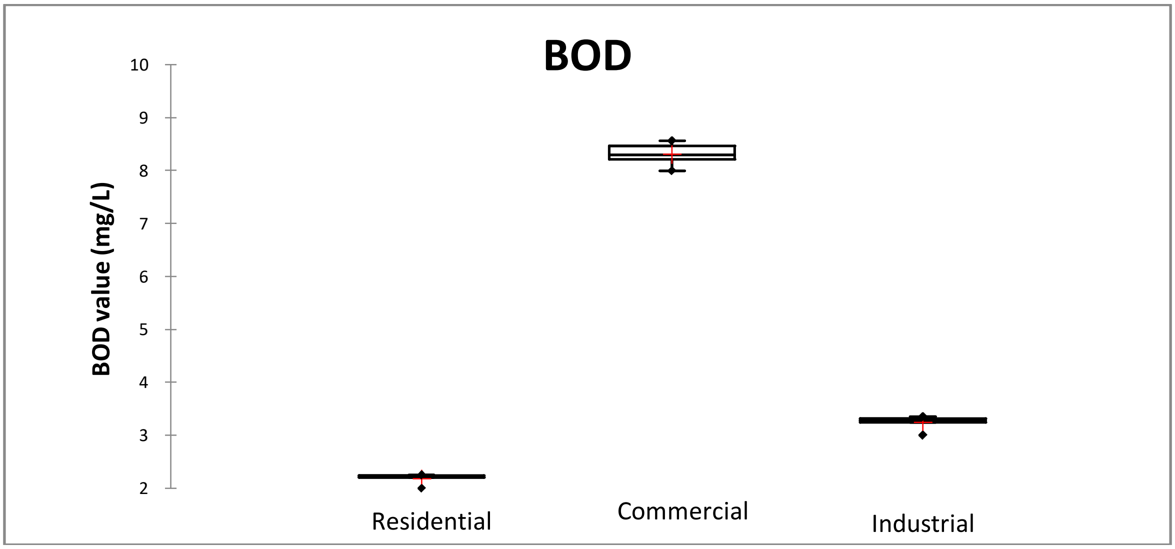

Figure 6: Variation of BOD for different land uses

The variation of BOD concentration is shown in Figure 6. The highest BOD value in a residential area is found 2.25 mg/l, and the mean value is 2.18 mg/l. The commercial area shows the highest value of 8.5 mg/l mean value is about 8.3 mg/l. The residential area has a lower concentration compared to industrial and commercial areas. From Table 3, BOD value in commercial area displays the highest standard deviation. This indicates high variability in the value of BOD concentration. As we know, the BOD value measures the amount of dissolved oxygen to biologically decompose organic matter. The presence of organic matter is higher in a commercial area that is produced from the local market, fruit seller, decomposed fruit bunch or vegetable waste and distribute along the road side. The residential area produces a small amount of organic waste. That's why the value is lowest among the others.

Table 4: Pearson correlation matrix

Variables	pH	EC	Turbidity	SS	BOD
pH	1	-0.913	-0.464	-0.888	-0.302
EC	-0.913	1	0.278	0.789	0.472
Turbidity	-0.464	0.278	1	0.792	-0.638
SS	-0.888	0.789	0.792	1	-0.102
BOD	-0.302	0.472	-0.638	-0.102	1

The correlation among water quality parameters is essential to identify a possible relationships between them. Table 4 shows the Pearson correlation co-efficient between each water quality parameter. The correlation between variables would be positive if the correlation co-efficient becomes greater than zero. When the correlation co-efficient value becomes greater than zero, then a negative correlation exists. When the value becomes zero, then no relationship exists between the variable. The highest negative correlation is between pH and EC. That means if the value of pH increases, the EC decreases. Turbidity and SS shows the highest positive relationship. That indicates the proportional relation between them. As the value of turbidity increases, the value of SS also increases. SS has a similar relationship with EC and Turbidity. pH has a negative correlation with other water quality parameters. EC has a positive correlation with turbidity, SS and BOD. However, BOD has only a positive correlation with EC.

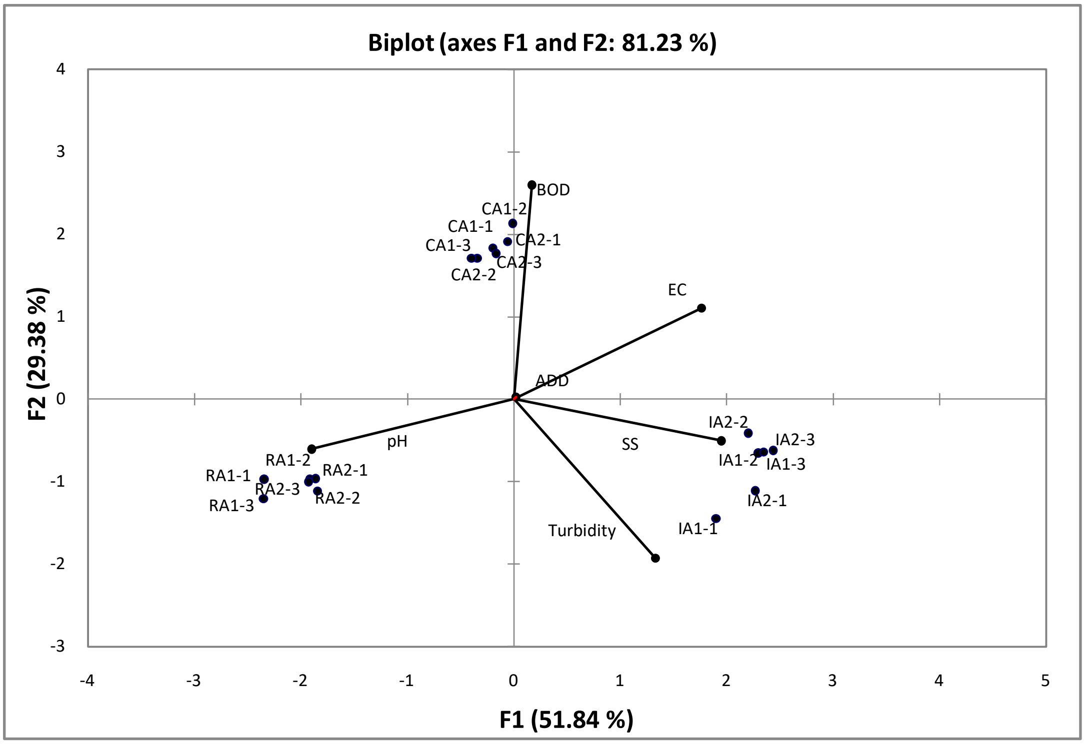

Figure 7: Principal component analysis bi-pots

Multivariate techniques were applied to identify linkage among various water quality parameters for three different land use. The principal component analysis bi-plot of the first two components is presented in Figure 7. This is because the first two components explain most of the data variance. As seen in Figure 7, principal component F1 and F2 explain 51.84% and 29.38% data variance, respectively. Both components explain 81.22% variance of the total dataset.

The angle between the loading vector is significant as the degree of correlation between water quality parameters is inversely related to it as the angle reduces the degree of correlation increases. Vectors situated closely together indicate those variables are highly correlated, while orthogonal vectors represent variables that are uncorrelated. The relative distance traveled along the attribute vectors from different areas represent the relative differences in performances among them.

Commercial and industrial areas perceived to be similar as they are close to each other. They perform similarly concerning the pH and EC. For commercial and industrial areas, the relative distance from pH is much greater than residential areas. In that case, pH has much influence on residential areas. Commercial and industrial areas are performed similarly concerning EC value as their relative distance from the attribute vector are the same.

Water quality parameters such as SS and turbidity are very close to each other. That's why they are highly correlated with each other. Industrial areas are close to SS and turbidity. So, they exhibited a high correlation with SS and turbidity. Residential areas and commercial areas perform similarly concerning SS and turbidity. The residential and industrial areas are performed similarly concerning BOD value as their relative distance from the attribute vector are the same. Commercial areas are highly influenced by BOD as they are very close to each other.

IV. Conclusions

This paper characterises the urban stormwater quality for three different land-use types. pH is the most influential parameter in the residential area, where in commercial areas BOD is the most significant water quality parameter. Industrial areas are highly influenced by suspended solids and turbidity. Also, EC has an almost similar influence on commercial and industrial areas compared to residential areas. Industrial sites contributed substantially to higher value of SS, turbidity, EC compared to commercial and residential areas. The study results will provide guidelines to the stormwater management authority for the selection of suitable treatment systems or management systems for different land uses in Rajshahi City.

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