CHARACTERIZATION OF URBAN STORM WATER QUALITY FOR DIFFERENT LAND USES

Anupam Chowdhury[1], Protik Chakraborty*[2] and Tamanna Tanjum[3]

[1]Assistant Professor, Department of Civil Engineering, RUET, Rajshahi, Bangladesh. e- mail: anupam.19ce@gmail.com
[2]Undergraduate Student, Department of Civil Engineering, RUET, Rajshahi, Bangladesh. e-mail: protikchakraborty77@gmail.com
[3]Undergraduate Student, Department of Civil Engineering, RUET, Rajshahi, Bangladesh. e-mail: ttturin1996@gmail.com

***Corresponding Author**

ABSTRACT

Urbanization results in the diversification of land use with large natural vegetated lands converted into impervious areas such as roofs, roads and other paved surface. The increased fraction of impervious surfaces leads to generation of pollutants through various anthropogenic activities during dry periods and washout these pollutants during rainfall events which finally enter into the receiving water bodies. This further deterioate the water quality and unbalance the aquatic ecosystem. Hence, characterisation of urban stormwater quality is critically important to select treatment system to safeguard the water sources. The research study focused on the characterisation of urban stormwater quality for three different land uses such as residential, commercial and industrial. The storm water samples were collected from three different land use areas in Rajshahi city. Collected samples were tested in the laboratory by using standard quality control and test methods specified in APHA 1999. The test results showed that suspended solids (SS), turbidity, electric conductivity was found higher for industrial areas where pH and BOD were found higher in residential and industrial areas respectively. The study results will provide guideline to the storm water management authority for selection of suitable treatment system or management system for different land uses in Rajshahi city.

Keywords: *Storm water runoff, Storm water quality, Land use, Rajshahi City, Principal component analysis.*

1. INTRODUCTION

Water pollution is a crucial concern now- a -days. It has created many problems to 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 study on categories, causes and control of water pollution. The study results showed that water pollution affects the entire biosphere of plants and organisms living in the water bodies as well as the plants that might be exposed to the water.

Currently, stormwater runoff has become one of the major source of water pollution. Due to rapid urbanisation process natural land turns into impervious surface which are suitable platform for pollutant buils-up and wash-off by rainfall events (Goonetilleke et. al., 2015). The stormwater runoff enter into the nearby water bodies through drainage systems or overland flow without treatment and deteriorate the receiving water quality. The type and amount of pollutant generation depend on many factors such as geology of the land, topography, geography, rainfall intensity and pattern, and land use type (Sarukkalige, 2011). Guzman et. al. (2018) conducted study on influence of land use on urban runoff quality in Bogota, Colombia. This study has evaluated the influence of land use on the concentrations of physical-chemical parameters in urban runoff. For this, an artificial rain was used at three points with different land uses such as residential, industrial and vehicular parking in the city of Bogotá. They showed that industrial sector presented higher concentrations of all parameters such as nitrates, nitrites, suspended solids, COD and alkalinity and residential area and recreational areas represented the similar variations due to the presence of traffic and vegetal species.

Lucke et. al., (2018) conducted study on urban stormwater characterization and nitrogen composition from a large scale catchment. This study investigated the pollutant concentrations variability of pollutant build-up parameters in different land use types such as seven residential areas 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. Maharjan et. al., (2017) conducted study on modeling of stormwater runoff, quality and pollutant loads in a large urban catchment. Their study mainly focused on development of build-up model for the Mustoja basin in Tallinn. The build-up rate was slightly higher in commercial area than in the residential area and the industrial area had slightly higher than the commercial area. Khatun et. al., (2014) conducted study on variability of pollutant build-up in different land uses of Guwahati city, Assam, India. For this study, stormwater samples were collected from five different land use types; residential, commercial, recreational, heavy traffic and industrial, around Guwahati city, Assam (India). They analysed the collected samples to measure different build-up parameters to investigate the variability of pollutant build-up parameters in five different land use types. They showed that industrial areas had higher value of co-efficient of variations.
Jarvelainen (2014) studied on land use based storm water pollutant load estimation and monitoring system design in Lahti city, Finland. In this study, the quality and quantity of storm water being generated in city areas was estimated. He found that industrial and commercial areas had higher amount of heavy metals and pollutants.

Based on above review it was understood that the types and amount of pollutants generated varies with diferrent land use types. Hence, proper characterization of urban stormwater quality for different land use type is essesntial for selection of suitable treatment method. 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.

2. METHODOLOGY

2.1 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 4th largest among the eight divisions in Bangladesh. It's being developed day by day due to many industries and educational institutes. Due to rapid urbanization process, stormwater gets polluted by the pollutants generated in road surfaces and washout during rainfall events. The sample collection point were six different road surface runoff such as Alokarmor, New market; Belderparamor; 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.

1(a)

1(b)

1(c)

2(a) 2(b) 2(c)

Figure 1: Study area

Table 1: Characteristics of Study Sites

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

2.2 Sample Collection

The sample collection was undertaken based on the standard procedure recommended by EPA, 1992. Sample was collected three times from selected location at different rainfall events (Table-2) to understand the effect of dry periods on the variability of stormwater quality. After sample collection, the bottle was properly sealed and leveled for future identification.

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

2.3 Data Analysis Method

Univariate and multivariate analysis techniques were used.

2.3.1 Univariate Analysis Tools

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

$$\bar{X} = \frac{\sum x_n}{N} \tag{1}$$

Here, $\sum x_n$= sum of data values.
N = total number of data points.
$\bar{X}$ = mean

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

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

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.

$$CV = \frac{\sigma}{\bar{X}} \tag{3}$$

Here, σ= Standard deviation.
$\bar{X}$=mean

2.3.2 Multivariate Analysis Tools

Principal Component Analysis:

A statistical procedure that convert a set of observations of possibly correlated variables into a set of values that linearly uncorrelated variables. This transformation is defined in such as a way that the first principle component has the largest variance and each succeeding component in turn has the highest variance. The resulting vectors are an uncorrelated orthogonal basis set. PCA is sensitive to the relative scaling of the original variables.

3. RESULT AND DISCUSSION

Table 3 shows the summary of the analysis results for selected stormwater quality parameters for each individual land use category. It can be seen that these pollutants concentrations vary considerably for each land use, which indicates that pollutant distribution throughout the catchment is highly dependent on the land use. Suspended solids are one of the main indicators of water quality. Most of the pollutants absorbed by suspended solids and transport by stormwater runoff.

Table 3: Average pollutant loading for each specified land use

Land use type	Sites	pH			TURBIDITY (NTU)			CONDUCTIVITY (mg/L)			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

Storm water in residential area demonstrated the cleanest appearing storm water with lowest average amounts of suspended solids within the storm water. With a low variance for suspended solids (SS) and turbidity, residential sites are cleanest among the other sites.

The stormwater quality in industrial area was found highly polluted than other land use. This is due to recording the highest amounts of SS and turbidity in the storm water when compared to the other land use. The industrial location also recorded the higher BOD value than the residential sites. Presence of organic matter in industrial area causes the highest BOD value in industrial area than residential area. Commercial storm water resulted in containing low concentrations of suspended solids and turbidity value then industrial sites. But commercial area are recorded the highest BOD value than the other sites. This is due to the generation of highest organic waste which decomposed on road surfaces and washout through storm water runoff. The organic wastes in commercial areas are produced from local market, fruit seller, decomposed fruit bunch or vegetable waste and distribute along road side. In contrast, industrial area produces small amount of organic waste that's why the value of BOD is lower than the commercial areas.

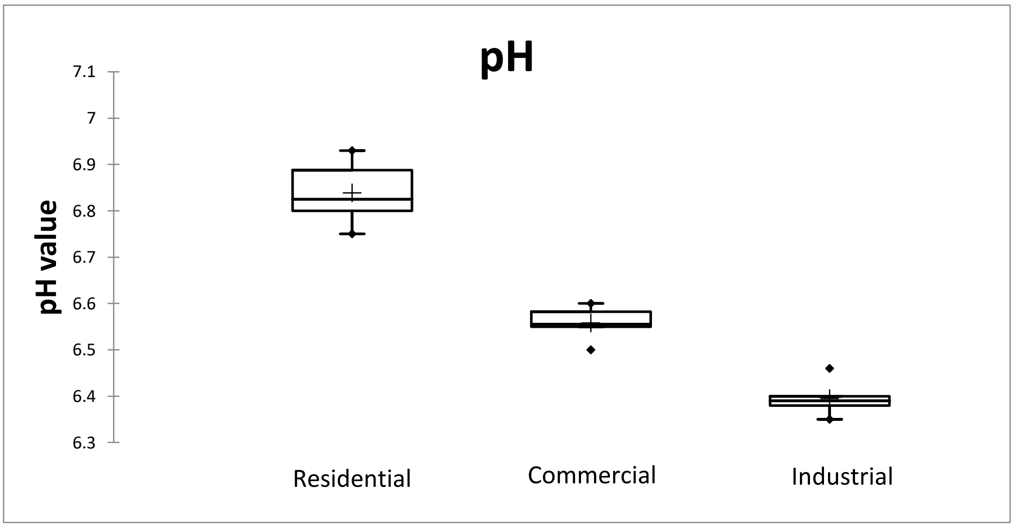

Figure 2: Variation of pH for different land uses

The variation of water quality parameters for three land use are presented by Box Whisker plot in Figures 2-6. As seen in Figure 2, the highest pH value was found 6.93 in residential area where mean value was 6.83. Commercial area shows the highest value of 6.6 and mean value is about 6.55. Residential area has the higher concentration compared to industrial and commercial areas. From Table 3, pH value in residential area displays the highest standard deviation among the three different land use areas. This indicates a 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.

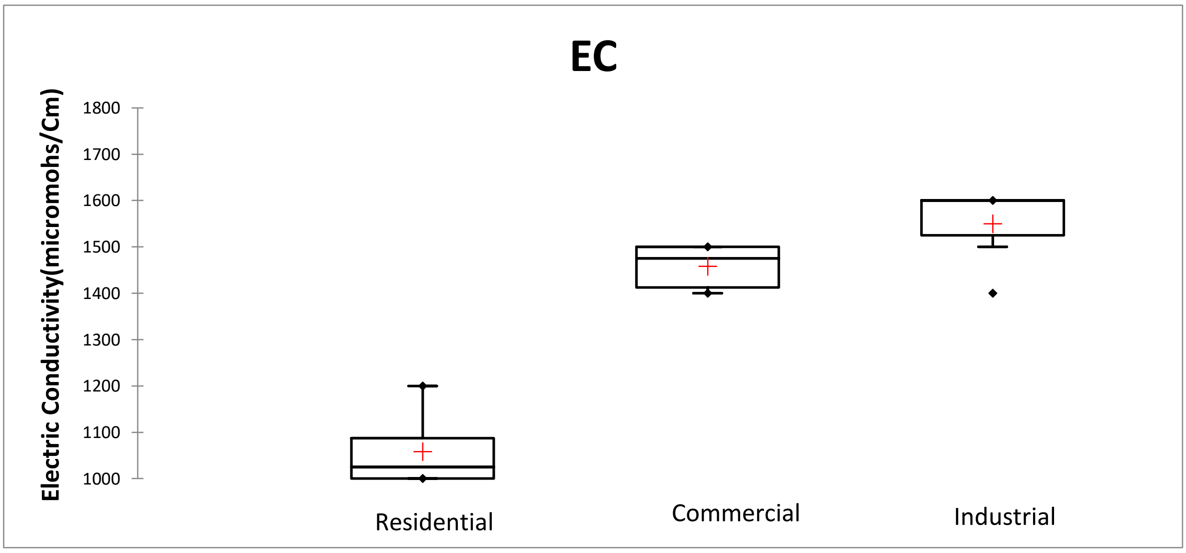

Figure 3: Variation of Electric Conductivity for different land uses

The variation of Electric Conductivity (EC) is shown in Figure 3. 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 industrial area is the reason of having higher value of EC in industrial area.

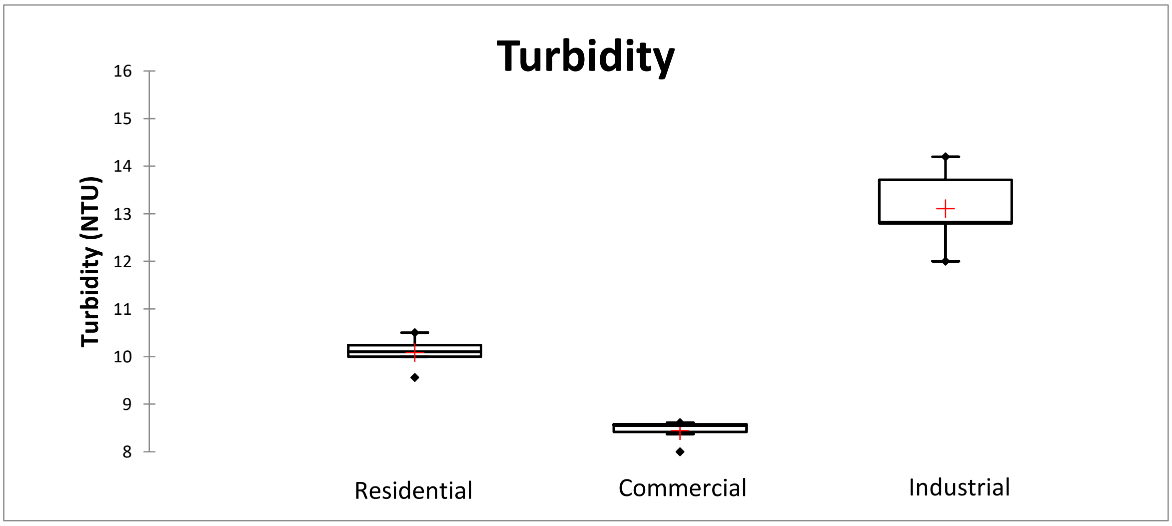

Figure 4: Variation of Turbidity for different land uses

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 industrial area (mean value 13.15 NTU). This can be due to the presence of the fine particles from production process of goods and distributed on the road surface by traffic, wind, workers during loading and unloading time.

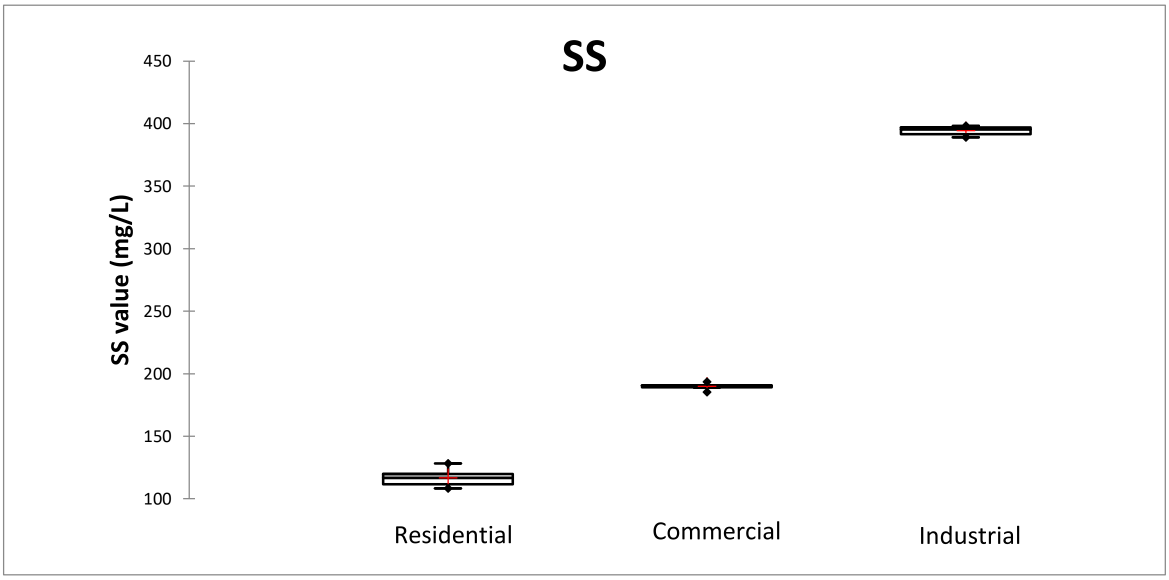

Figure 5: Variation of Suspended Solids for different land uses

The variation of SS for three different land uses shown in Figure 5. The residential area has 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 industrial area (394.25 mg/l) was almost two and a half times the values for residential areas. The commercial and industrial area produces 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.

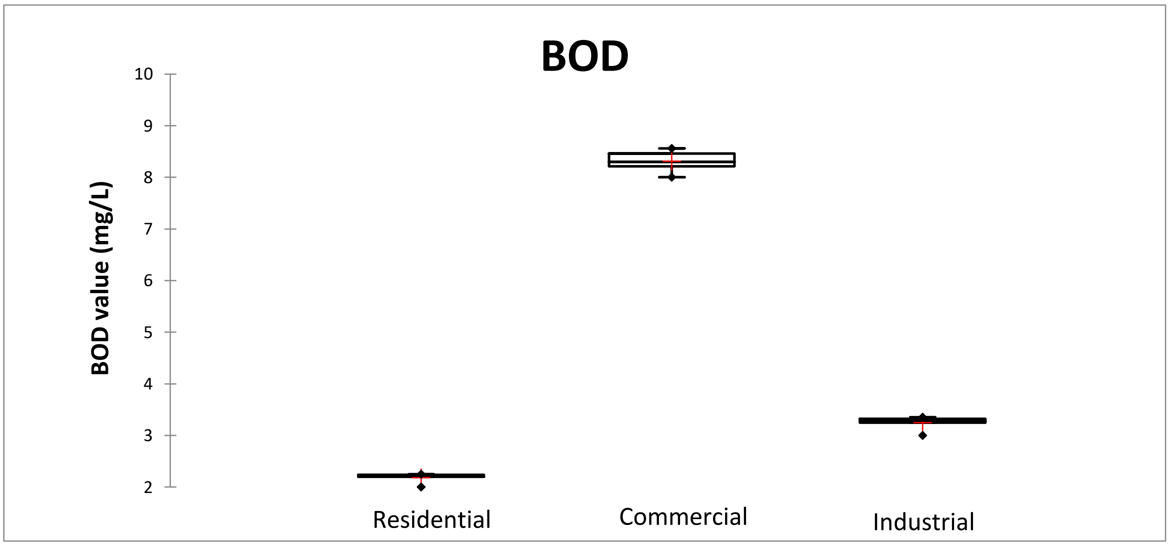

Figure 6: Variation of BOD for different land uses

The variation of BOD concentration is shown in Figure 6. The highest BOD value in residential area is found 2.25 mg/l and mean value is 2.18 mg/l. Commercial area shows the highest value of 8.5 mg/l mean value is about 8.3 mg/l. Residential area has the lower concentration compared to industrial and commercial areas. From Table 3, BOD value in commercial area displays the highest standard deviation. This indicates a high variability in the value of BOD concentration. As we know, BOD value measures the amount of dissolved oxygen to biologically decompose the organic matters. The presence of organic matter is higher in commercial area that are produced from local market, fruit seller, decomposed fruit bunch or vegetable waste and distribute along road side. Residential area produces 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	ADD
pH	1	-0.913	-0.464	-0.888	-0.302	-0.051
EC	-0.913	1	0.278	0.789	0.472	-0.009
Turbidity	-0.464	0.278	1	0.792	-0.638	-0.020
SS	-0.888	0.789	0.792	1	-0.102	-0.007
BOD	-0.302	0.472	-0.638	-0.102	1	-0.016
ADD	-0.051	-0.009	-0.020	-0.007	-0.016	1

The correlation among water quality parameters is essential to identify possible relationship between them. Table 4 shows the pearson correlation co-efficient between each water quality parameters.
From the correlation matrix, the pearson correlation co-efficient value greater than 0 indicates a positive correlation; that is, as the value of one variable increases, so does the value of the other variable. A value less than 0 indicates a negative correlation; that is, as the value of one variable increases, the value of the other variable decreases. A value of 0 indicates that there is no relation between the two variables. The highest negative correlation shows between pH and EC. That means if the value of pH increases, the EC decreases. Turbidity and SS shows highest positive relation. That indicates the proportional relation between them. As the value of turbidity increases, the value of SS also increases. SS has similar relationship with EC and Turbidity. pH has negative correlation with other water quality parameters. EC has positive correlation with Turbidity, SS and BOD. on the other hand, BOD has only positive correlation with EC.

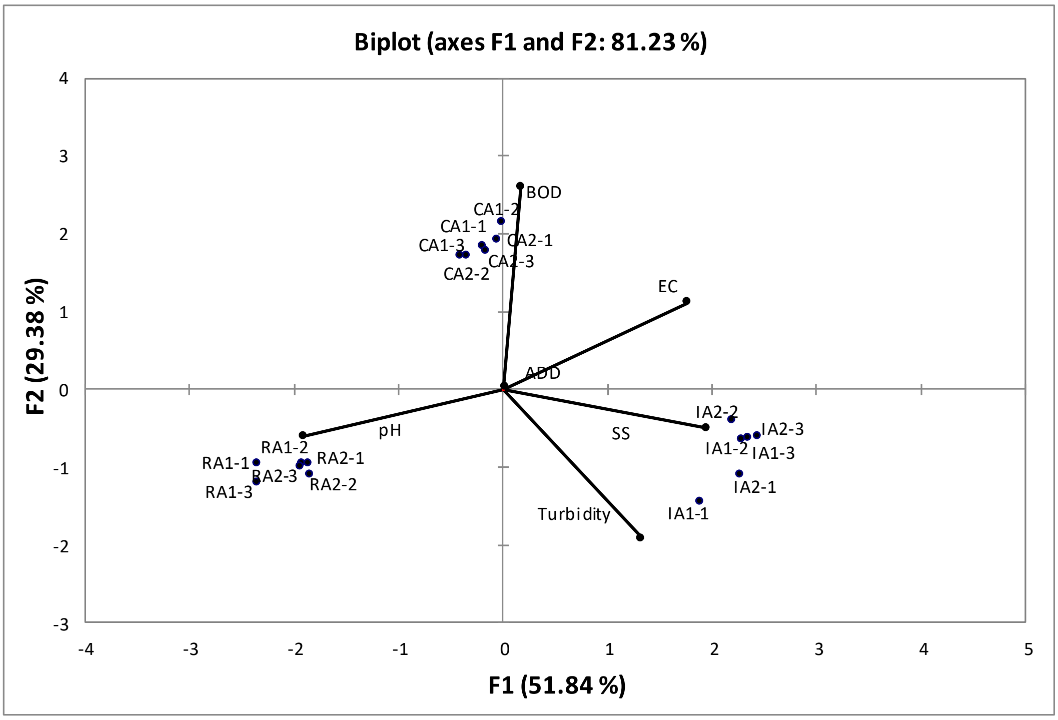

Figure 7: Component Bi-pots

Multivariate techniques were applied to identify linkage between various water quality parameters for three different land use. Using the principal components PC1 which described the largest data variance and PC2 the next largest amount of data variance, it was possible to develop biplots for the three different land uses.

The principal component analysis of the water quality parameter resulted in the most of the data set variance being contained in the first two components. 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 represent variables that are highly correlated while orthogonal vectors represent variables that are uncorrelated.

The realtive distance travelled along the attribute vectors from different areas represent the relative differences in performances among them. Residential areas perceived to be similar as they are close to each other. They perform similarly with respect to the pH and EC. For commercial and industrial areas the relative distance from EC and pH are much greater then residential areas. In that case rasidential areas and commercial areas are perceived to be dissimilar to each other.

Water quality parameters such as SS and turbidity are very close to each other. Thats why they are highly correlated with each other. Industrial areas are close to SS and turbidity. So, they exibited high correlation with SS and turbidity. Residential areas and commercial areas perform similarly withb respect to SS and turbidity. Residential and industrial areas are performed similar with respect to BOD value as their relative distance from attribute vector are same. Commercial areas are highly influecend by BOD as they are very close to each other.

From the discussion, in short, for residential area pH is the most influential factor, where in commercial area BOD is the most significant water quality parameter. Industrial areas are highly influenced by suspended solids and tyrbidity. Industrial sites contributed substantially higher value of SS compared to the other. For example, mean SS from the industrial sites were comparable around 395mg/L while mean SS from residential area was 116.75 mg/L (Table 3).

4. CONCLUSIONS

There are differences in the results of the data analysis among the land uses. A number of reasons behind to this situation. Comparing the three different urban forms, industrial area has the most adverse footprints. This is based on the concentration of various pollutants, their high variability etc.
Turbidity and SS are the major pollutant from surface runoff. Turbidity and SS value of industrial area is comparatively higher than the other areas. Excessive use of chemical, industrial production of fine particles such as cement, lime etc. increases the value of water quality parameters such as SS, turbidity, conductivity in industrial area. For the residential areas, the variance of pH is more than other water quality parameters. pH is the prime influencing factors for residential areas. The highest BOD value was recorded in commercial lands. The BOD value was recorded in commercial area is greater than residential and industrial areas. The study results will provide guideline to the storm water management authority for selection of suitable treatment system or management system for different land uses in Rajshahi city.

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