WASTEWATER CHARACTERISTICS OF KHULNA MUNICIPAL AREA IN BANGLADESH

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ABSTRACT

This study was conducted to assess the physico-chemical characteristics of wastewater that is generated in Khulna Municipal Area and deliberately discharged to the nearby rivers, canals, etc. without treatment. Wastewater samples were collected from 10 sampling spots on the drainage network at monthly interval from January to March, 2011 following standard guidelines. Some quality parameters of wastewater i.e. Temperature, pH, EC, DO, TDS, Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, CO_3^{2-}, HCO_3^-, NO_3^-, SO_4^{2-} and PO_4^{2-} were selected based on the agriculture and health significances. The quality parameters of wastewater samples were analyzed following standard methods and techniques. The results of the study reveal that high temperatures in wastewater were recorded during the warm month (March) following the February and January. The nearly neutral to slight acidic pH values were found in all the observation spots during the study period. The observed values were within the range to permit reuse in agriculture. The average monthly DO concentration decreased gradually from January to March, which might be due to the increasing trend in temperature in the same months. The values of DO were found to be below the permissible level recommended for irrigation. The conductivity and TDS values increased first from January to February and finally decreased in the subsequent month. Some observed values of EC and TDS exceeded the irrigation water quality standards. Chloride was the dominant anion following bicarbonate, sulfate, phosphate and nitrate whereas calcium was the dominant cation following magnesium, sodium and potassium in wastewater generated in KCC area during the dry season. Some anions and cations were found to be exceeded the irrigation water quality standards. The wastewater is not totally safe for reuse in agriculture in terms of some physico-chemical parameters. This domestic effluent dominated wastewater flow through the numerous concrete and earthen drains which finally dispose of to the nearby water bodies, i.e. the Mayur River, Rupsha River, etc. without treatment. As the quality of wastewater is not fully satisfactory, there are valid probabilities for occurring pollution problems in river waters, becoming alarming situation in health and sanitation sectors, deteriorating environmental conditions, etc. However, the Mayur River, located at western fringe of Khulna City, have already become a dumping ground for untreated wastewater coming from municipal area of Khulna.

1. INTRODUCTION

Khulna, the third largest city in Bangladesh and the second largest in the coastal zone, is located on the banks of the Rupsha and Bhairab Rivers in Khulna District. It is the capital of Khulna Division and a major industrial and commercial center. Population of the Khulna City Corporation (KCC) area is about 1.7 million and the growth rate is 5% which is mainly due to rural-urban migration. Economic activities in Khulna are mainly centered on its rich natural resources – fisheries and forestry. Around 1.9 % of the population of Bangladesh lives in Khulna, however, it contributes a slightly higher percent in terms of Gross Domestic Product (GDP) (2.5% of national GDP) (ADB, 2009). The service sector dominates the economic activities of the area (54%) following agriculture (26%) and industries (20%) (BBS, 2007).

According to the land use survey undertaken for Khulna's Master plan (Aqua-Sheltech, 2002), about 46% of the built-up area is occupied by residential housing. Near about 15% land is under industrial use, small percentage (about 5%) of land is under commercial use. The remaining land use in the built-up area consists of transport infrastructure, official buildings, community and defense, facility parks and water bodies. The land use pattern of Khulna has been substantially influenced by the flow of the Rupsha and Bhairab Rivers. As a deltaic plain the land is flat and poorly drained. The whole metropolitan area is approximately 2.5 m above the mean sea level. Such low topography of the city is an obstacle to the development of a proper land use structure.

Dwellers of the KCC area, usually, consume water for domestic purpose, commercial and industrial purposes, and public sector. The coverage is only 30% of households with piped water supply. The rest is self-managed and many of the people face water crisis. Considering other demands as 10% of the consumer demand and leakage through the network as 20% of water supply, it was estimated that the water supply requirement was 165 liter per capita per day (lcd) (IWM, 2007). As such, the water supply requirement was found to be 242 million liters per day (MLD) for 1.47 million people in 2007. IWM (2007) also assumed that the prevailing population growth would continue and the population of Khulna would be around 2.9 million by the year 2030, which would make the water requirement 478 MLD. Groundwater is the main source of water supply in KCC area. Total 56 production wells operated by Khulna Water Supply and Sewerage Authority (KWASA) and about 12,000 hand tubewells (deep and shallow tubewells) operated by private owners have combined production of around 125 MLD. However, the actual total production is about 90 MLD considering low production efficiency, malfunctioning of wells, etc. The critical situations with water supply becomes more critical each day, regarding that the demands for quality water are constantly increasing and the available water of satisfactory quality is shorter in supply, because of its uneven distribution in terms of space and time, and because of the intensive pollution.

Expansion of urban populations and heterogeneous land-use pattern, improved standard of livings, and increased coverage of water supply and sewerage give rise to greater quantities of municipal wastewater (MWW) in Khulna. MWW means domestic wastewater or the mixture of domestic wastewater from commercial establishments and institutions including hospitals with industrial wastewater and storm water run-off, which flow into the sewerage system. It contains a broad spectrum of contaminants resulting from the mixing of wastewaters from aforesaid sources. Due to limited industrial development, d*omestic* effluent and urban run-off now contribute the bulk of wastewater generated in KCC area. Domestic wastewater usually contains *greywater (sullage)* which is generated from washrooms, laundries, kitchens etc. and can also contain *blackwater*, which is generated in toilets. *Blackwater* might contain besides urine and faeces/excreta (together sometimes called nightsoil) also some flush water. However, providing safe and sufficient drinking water and proper sewerage system remains as the challenging tasks in the city.

Drainage system in Khulna City is not well-developed. The wastewater effluents, generated in KCC area, flow through the numerous concrete and earthen drains which finally dispose of to the nearby water bodies, i.e. the Mayur River, Rupsha River, etc. There are about 18 big and small canals and drains that drain out the effluents from KCC area to the Mayur River which is located at western fringe of the city. This triggered the reduction in fish population, increased the prevalence of disease, etc. The wastewater is now polluting the river water as the treatment facilities are not yet established in Khulna. As the quality of wastewater is not satisfactory, problems like pollution of surrounding rivers and the streams, deterioration of the environment, and health sanitation have become alarming.

Obviously, an understanding of the nature of wastewater is essential in the design and operation of collection, treatment, and disposal facilities; in the engineering management of environmental quality; and in assessing the reuse potential of wastewater in agriculture. Though, a number of studies have investigated the characteristics of wastewater in different municipal areas of Bangladesh such as Dhaka, Chittagong, Sylhet and Rajshahi, no study was conducted to identify the nature and composition of wastewater in Khulna municipal area. Consequently, this study was conducted to determine the characteristics of municipal wastewater particularly during the dry season (November-May) of 2011 and its management in Khulna City. The specific objectives of the study are: (i) to assess the physioco-chemical characteristics of wastewater that is discharged to the different water bodies and soils in and around Khulna; (ii) to evaluate the suitability of municipal wastewater for irrigation purposes comparing the results with existing water quality standards; and (iii) to find out the existing management system of wastewater in Khulna City.

2. MATERIALS AND METHODS

2.1 Study Area

Khulna, the headquarters of Khulna division, is the third largest city in Bangladesh and the second largest in the coastal zone. It is located in the south-west of the country and on the banks of two tidal rivers i.e. the Rupsha and the Bhairob Rivers **(Figure 1).** Geographically, the city along with its surrounding lies between 22°47´16´´ to 22°52´ north latitude and 89°31´36´´ to 89°34´35´´ east longitude. Khulna Pouroshava was stablished on 12 December, 1884 during the British colonial regime, which further promoted to Municipal Corporation just 100 years later and finally declared as City Corporation on 6 August, 1990 (Official website of Khulna City Corporation (KCC)). It has total 31 wards which cover an area of 45.65 square kilometers with a population of 17,84,623 as of 2010 and constituting 2.06% of the national population. The density of the population is 15,429 square kilometer. The rate of literacy is 60.49%. Most of the peoples are Muslims (89%) and other religious groups include Hindus (10%), Buddhists and Christians (01%).

About 46% of the built-up area is occupied by residential housing. Near about 15% land is under industrial use, small percentage (about 5%) of land is under commercial use. The remaining land use in the built-up area consists of transport infrastructure, official buildings, community and defense, facility parks and water bodies. As a deltaic plain the land is flat and poorly drained. The whole metropolitan area is approximately 2.5 m above the mean sea level. Such low topography of the city is an obstacle to the development of a proper land use structure. Dwellers of the KCC area, usually, consume water for domestic purpose, commercial and industrial purposes, and public sector. The coverage is only 30% of households with piped water supply and the rest is self-managed. This leads to the greater quantities of MWW in Khulna. Due to limited industrial development, d*omestic* effluent and urban run-off now contribute the bulk of wastewater generated in KCC area. However, drainage facilities are not yet well-developed. The wastewater effluents, generated in KCC area, flow through the numerous concrete, semi-concrete and earthen drains which finally dispose of to the nearby water bodies, i.e. the Mayur River, Rupsha River, etc. Total length of the drains, which convey the most domestic effluents, is about 642.18 km in KCC area.

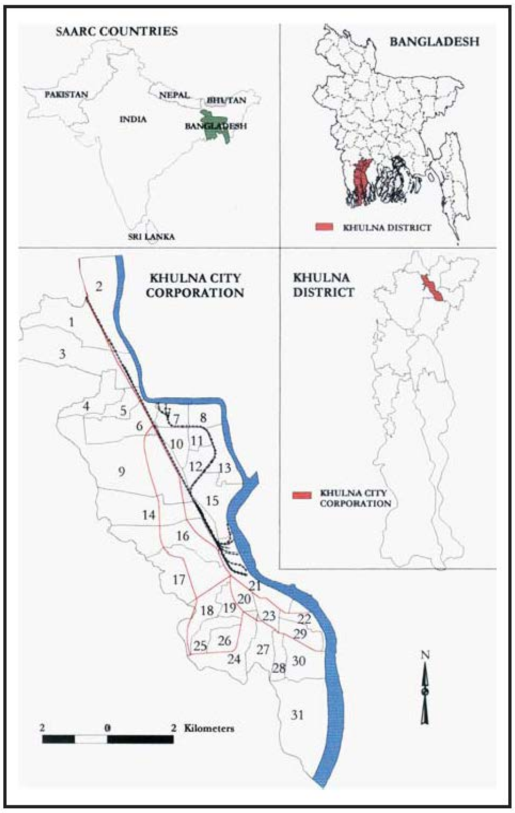

Figure 1: Khulna City Corporation (KCC) area (Source: KCC, 2010)

2.2 Collection of Wastewater Samples

Before samplings of wastewater 10 sampling spots on the drainage system in the KCC area were selected (Table 2.1), most of which are trunk drains that are located near the left bank of the Mayur River at western fringe of the Khulna City (Figure 2.1).

Table 2.1 Sample station and GPS locations.

S.I	Station name	Waste water Characteristics	*GPS Location*
1	Kasamnagor	Urban mixed waste water	(22°49'906"N-89°31'533"E)
2	Gollamari	Mainly slaughter house waste	(22°50'01"N-89°31'237"E)
3	Iskon Sasanghat	Urban mixed waste water	(22°49'606"N-89°31'790"E)
4	Ali Club	Urban mixed waste water	(22°49'722"N-89°32'175"E)
5	Nobopolli	Urban mixed waste water	(22°49'827"N-89°31'803"E)
6	Karimnagor	Urban mixed waste water	(22°48'636"N-89°32'477"E)
7	Khulna Medical Collage	Medical waste	(22°48'515"N-89°32'414"E)
8	Sasanghat Boyra	Urban mixed waste water	(22°48'222"N-89°32'447"E)
9	Andhairghat	Urban mixed waste water	(22°48'048"N-89°32'448"E)
10	Mirardanga	Urban mixed waste water	(22°48'091"N-89°32'487"E)

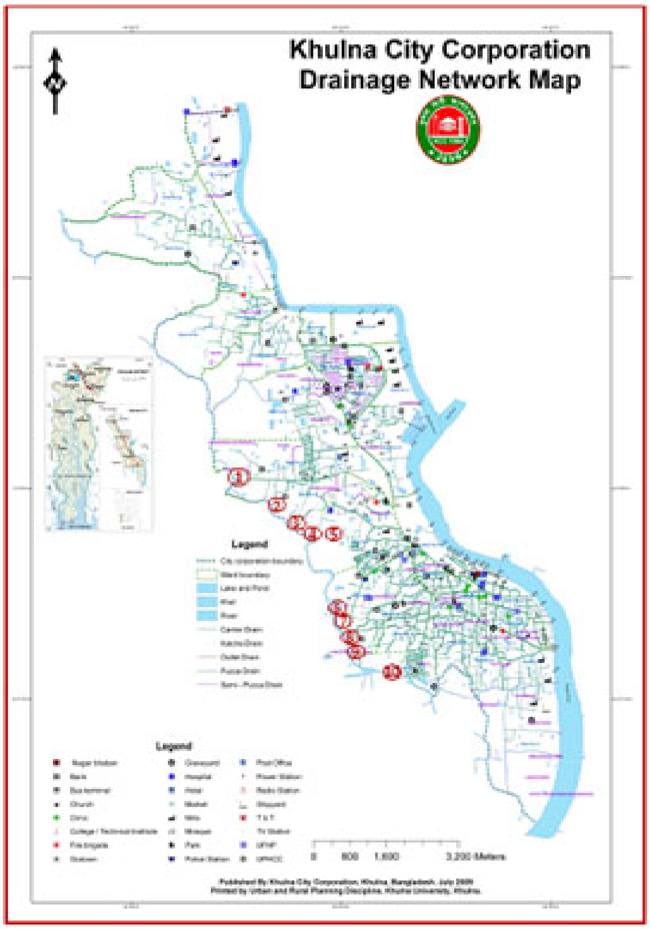

Figure 2.1: Drainage Network Map of KCC area showing the sampling spots (Source: KCC, 2010)

Samples of wastewater were collected from aforesaid sampling spots during the months of January-May, 2011. Total 50 wastewater samples, one from each spot in each month, were collected following standard guidelines. New plastic bottles with hard plastic screw caps were used for wastewater sample collection. The bottles were properly cleaned before using and washed 2-3 times with the wastewater to be sampled before sampling. Wastewater samples were collected from the midpoint of the trunk drains by dipping each sample bottle approximately 15-20 cm below the water surface, opening the bottle and allowing it to fill in and closing with its cap under water (UNEP/WHO, 1996). Wastewater sample was collected, placed in an ice box and transported to the laboratory on the same day. The samples were then preserved in a refrigerator at about 4°C until analysis.

2.3 Methods of Wastewater Sample Analysis

Some quality parameters of wastewater i.e. Temperature, pH, EC, DO, TDS, Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, NO_3^{-}, SO_4^{2-} and PO_4^{2-} were selected based on the agriculture and health significances. Among these parameters, pH, EC/TDS and DO were measured on spots by using portable pH meter, EC/TDS meter and digital oxygen meter, respectively. Temperature was also measured along with those parameters on spots. The remaining parameters were analyzed following Standard Methods and instruments at Chemical Laboratory of Environmental Science Discipline, Khulna University, Khulna, Bangladesh.

3. RESULTS OF THE STUDY

The results for the various physico-chemical parameters determined in the wastewater samples are presented in Tables 1, 2 and 3 (See Appendix-A). The quality of wastewater is influenced by chemical, biological and environmental factors. Physico-chemical parameters for the dry season (January-March) are discussed as below:

3.1 Physioco-chemical Characteristics of Wastewater

3.1.1 Temperature

The temperatures of the wastewater samples ranged from 15.5 to 18.5, 19.0 to 21.0 and 25.6 to 27.7 °C in January, February and March, respectively. The lowest temperature was found in January at Spot-6: Karimnagar whereas the highest value was found in the month of March at Spot-10: Mirardanga. The mean monthly temperature was found to be 17.5 °C in January and it increased to 20.0 °C in February and 26.5 °C in the following month. It is seen that the temperatures gradually increased concurrently with the subsequent dry months. However, there were little variations in temperature between the sampling spots in each month. These variations might be due to the variable meteorological conditions during the dry months in the study area.

3.1.2 Hydrogen ion concentration (pH)

The pH values of all the wastewater samples varied from 6.32 to 6.86, 6.63 to 6.85 and 6.35 to 6.89 in January, February and March, respectively. The lowest pH value was found to be in February at Spot-4: Ali Club. However, the highest value was found in March at Spot-1: Kasamnagor, which might be due to the outstanding concentration of bicarbonate in wastewater. The average values of pH were 6.72, 6.74 and 6.61 in the subsequent studied months, respectively. It is found that the average values slightly increased from January to February and then decreased in the following month. It is also observed that there were insignificant variations in pH values between the sampling spots during the studied months. The nearly neutral to slight acidic pH values were found in all the observation spots during the study period.

3.1.3 Dissolved oxygen (DO)

For all the sampling sites, DO values of the wastewater samples ranged from 0.6 to 1.4, 0.7 (constant), 0.3 to 0.8 mg/L in January, February and March, respectively. The lowest concentration was found to be 0.3 mg/L at Spots-1,2,5: Kasamnagor, Gollamari, Nobopolli in the month of March, which was likely due to the higher temperatures in wastewater, intense algal growth and decay during this period. However, the highest value was observed in January at Spot-6: Karimnagor. The average concentration was found to have 1.0 mg/L in January and it decreased gradually in the subsequent dry months (0.7 mg/L in February and 0.49 mg/L in March). The gradual decreased average concentrations were likely due to the gradual increased in temperatures from January to March. The significant decrease in DO during the warm period coincides chronologically with a great increase in algal blooms causing degradation of habitat for other life, and a change in the competitive balance between species leading to loss of biodiversity (Cooper *et al*., 2002).

3.1.4 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The EC is the capacity of water to conduct current, which is caused by the presence of salts, acids and bases, called electrolytes, capable of producing cations and anions (Goel, 2006). The conductivity increases with the increase of ions. It is also effectively a surrogate for total dissolved solids (TDS) and is important for irrigation because it is a measure of the salinity of the water. Salinity restricts the availability of water to plants by lowering the total water potential in the soil. Salinity also has an impact on crop physiology and yield with visible injury occurring at high salinity levels.

In the present study, the conductivity of wastewater samples varied from 1.49 to 2.42, 1.47 to 2.82 and 1.40 to 2.06 dS/m in January, February and March, whereas the average values were found to be 1.72, 1.76 and 1.62 dS/m in the same months, respectively. The minimum value was observed in March at Spot-3: Iskon Sasanghat whereas the maximum value was found in the month of February at Spot-5: Nobopolli. It is clearly observed that the conductivity value increased first from January to February and finally decreased in the subsequent month. This might be due to the variable mixing of ion producing electrolytes in wastewater from the background concentrations present in supplied salts dominated water in the Khulna City, the dilution caused by direct runoff (atmospheric precipitation) and by wastewaters from less solute laden drains, the higher evaporation in summer, etc. (Kazmi, 2000).

The TDS results obtained for all sites ranged from 842 to 1403, 833 to 1313 and 733 to 1140 mg/L in January, February and March, respectively. The average TDS values were found in the same months as 1059.1, 1004.2 and 908.3 mg/L, respectively. The highest value was observed at Spot-10: Mirardanga in January whereas the lowest value was in Spot-3: Iskon

Sasanghat in March. The variations in TDS results at all the observation spots during the study period are found to be same as the aforementioned variations in EC results.

3.1.5 Carbonate ion (CO_3^{2-}) and Bicarbonate ion (HCO_3^-)

Carbonate and Bicarbonate are major ions in describing the alkalinity of any water or wastewater. Alkalinity is the buffering capacity of a water body, which measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH. It represents the presence of bicarbonate, carbonate and hydroxide in the water. The concentrations of CO_3^{2-} were found to be nil at all the observation spots during the study period. The HCO_3^- values of wastewater samples varied from 311.6 to 378.2 (average of 333.27), 253.2 to 378.3 (average of 322.60) and 269.3 to 385.2 (average of 330.51) mg/L in January, February and March, respectively. The highest HCO_3^- result was found in March at Spot-2: Gollamari following in February at Spot-5: Nobopolli and January at Spot-3: Iskon Sasanghat. It is observed that the mean monthly HCO_3^- results increased gradually from January to the month of March, which might be due to the lower level of wastewater in carrier drains and the gradual accumulations of bicarbonate ions through increased rate of decomposition caused by temperature gradually increased from January to the following months.

3.1.6 Chloride ion (Cl^-)

Chloride, a hardness producing anion, occurs in water and wastewater in varying concentration. The concentration of chloride normally increases as the mineral content increase. Salts of chlorides are highly soluble in water and wastewater, which do not precipitate and cannot be removed by biological methods of wastewater treatment (Goel, 2006). It was also reported that domestic sewage and industrial effluents are significant sources of chloride in natural waters. A rise of chloride concentration in surface waters caused by the disposal of wastewater can be indicative of pollution. The most common toxicity in the irrigation water is from chloride (Ayers and Westcot, 1994).

The high concentrations of chloride were found in wastewater generated from the KCC area. The concentrations at all the sampling spots varied from 132.93 to 646.96, 138.14 to 525.21 and 158.32 to 597.23 mg/L in January, February and March, respectively. The average concentrations were found to be 316.34, 261.03 and 335.07 mg/L in the aforesaid months, respectively. Both minimum and maximum values of chloride were found in comparatively colder month (January) at spots-3 & 10: Iskon Sasanghat & Mirardanga, respectively. In addition, the concentration decreased first from January to February and then increased in the subsequent warmer month (March). These variations could be attributed to input of highly variable soluble salts from the urban supplied water, liquid portion of septic tank, etc.

3.1.7 Calcium ion (Ca^{2+}) and Magnesium (Mg^{2+}) ion

The calcium and magnesium are the most abundant elements in surface and groundwater which exist mainly as bicarbonate and to a lesser degree in the form of sulphate and chloride (Ramesh and Anbu, 1996). Generally weathering of rocks, industrial effluents and municipal sewage are the principle sources of these elements in natural waters. They are the principle hardness producing cations as hardness of water and wastewater is mainly due to the presence of calcium and magnesium salts as bicarbonates, carbonates, sulfate and chlorides.

The Ca^{2+} and Mg^{2+} results found for all observation sites ranged from 16.0 to 38.0 and 10.80 to 34.40 mg/L; 10.91 to 36.30 and 10.80 to 31.25 mg/L; and 12.36 to 33.25 and 11.16 to 25.47 mg/L in January, February and March, respectively. The average values of both ions were 23.6 and 22.5 mg/L, 21.03 and 20.31 mg/L, and 23.25 and 17.17 mg/L in the abovementioned months, respectively. The maximum values for both ions were found to be in January at Spot-10: Mirardanga and Spot-3: Iskon Sasanghat, respectively. However, the minimum values for both ions were found to be in the month of February at Spot-8: Sasanghat Boyra, respectively. It is also observed that the mean monthly Ca^{2+} concentration decreased first from January to February and afterward increased in the following month and reached nearly stable conditions as in the colder month. However, the mean monthly Mg^{2+} concentrations decreased progressively from January to the following months. These variations might be due to the background concentrations in supplied water, variable composition of greywater and blackwater, etc.

3.1.8 Sodium ion (Na^+) and Potassium ion (K^+)

Sodium is significant cation occurring naturally in waters. The major source of Na in natural waters is due to weathering of various rocks such as igneous rocks. Practically all Na compounds such as Na salts are highly water soluble and tend to remain in aqueous solution because unlike Ca and Mg there are no precipitating reactions to reduce its concentrations (Ramesh and Anbu, 1996; Tripathi and Govil, 2001; Goel, 2006). In generally, concentration of Na in natural water is mostly lower than Ca and Mg but many industrial wastes and domestic sewage are rich in Na and increase its concentration in natural waters after disposal (Tripathi and Govil, 2001; Goel, 2006). Potassium occurs in various minerals, from which it may be dissolved through weathering processes. It is not an integral part of any major plant component but it does play a key role in a vast array of physiological processes vital to plant growth, from protein synthesis to maintenance of plant water balance. Potassium is a macronutrient that is present in high concentrations in soils but is not bioavailable since it is bound to other compounds. Generally, wastewater contains low potassium concentrations insufficient to cover the plant's theoretical demand, and use of wastewater in agriculture does not normally cause negative environmental impacts (Mikkelsen and Camberato, 1995).

In the present study, sodium and potassium in wastewater at all the sampling spots varied from 9.62 to 28.64 and 2.01 to 7.60 mg/L; 10.62 to 27.65 and 2.45 to 8.25 mg/L; and 9.62 to 28.64 and 2.26 to 7.24 mg/L in January, February and March, respectively. The average sodium and potassium results were 21.54 and 2.96 mg/L, 21.36 and 3.61 mg/L, and 21.54 and 4.28 mg/L in aforementioned months, respectively. Both maximum and minimum values of sodium were found to be in March at Spot-4: Ali Club and Spot-5: Nobopolli in the study area. The highest potassium value was observed in February at Spot-10: Mirardanga, whereas the lowest value was in January at Spot-1: No.2 Kasamnagor. The reasons behind these variations were like due to the background concentrations in supplied water containing dissolved salts.

3.1.9 Nitrate ions (NO_3^-)

Nitrate as nitrogen is a necessary primary macronutrient for plants that stimulates plant growth and is usually added as a fertilizer but can also be found in wastewater as nitrate, ammonia, organic nitrogen or nitrite (Pescod, 1992). The most important factor for plants is the total amount of nitrogen (N) regardless of whether it is in the form of nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N) or organic-nitrogen (Org-N). The concentration of nitrogen required varies according to the crop with more sensitive crops being affected by nitrogen concentrations above 5 mg/l, whilst most other crops are relatively unaffected until nitrogen exceeds 30 mg/l (Bai *et al.*, 2010).

The results of NO_3^- in wastewater at all the observation stations ranged from 0.37 to 4.18 (average of 1.11), 0.44 to 7.25 (average of 1.34) and 0.47 to 6.55 (average of 1.37) mg/L in January, February and March, respectively. The maximum and minimum values were found to be in February at Spot-6: Karimnagor and January at Spot-8: Sasanghat Boyra, respectively. It is also found that the mean monthly nitrate concentrations increased gradually from January to the following months.

3.1.10 Sulfate ions (SO_4^{2-})

Sulfates occur in natural waters at concentration up to 50 mg/l. Concentration of 1000 mg/l can be found in water having contact with certain geological formations e. g. gypsum reserves, water from pyrite quarries. Sulfur is required in the synthesis of proteins and is released in their degradation. Rain water has quite high concentration of sulfates particularly in areas with high atmospheric pollution. In humid region, sulfate is readily leached from the zone of weathering by infiltration-waters and surface run-off (Kotaiah and Swamy, 1994). The values of sulfate in wastewater varied from 13.64 to 77.73, 12.35 to 60.12 and 13.25 to 54.32 mg/L in January, February and March, respectively. The average concentrations were 36.15, 33.68 and 29.19 mg/L in the study months, respectively. The highest value was found to be in January at Spot-9: Andhairghat whereas the lowest was in February at Spot-8: Sasanghat Boyra.

3.1.11 Phosphate ions (PO_4^{2-})

Phosphorus is also a primary macronutrient that is essential to the growth of plants and other biological organisms but quantities can be excessive and if the concentrations in water are too high noxious algal blooms can occur. Phosphates are classified as orthophosphates, poly-phosphates and organic phosphates. Municipal waste waters may contain between 4 and 16 mg/l of phosphorus (Asano *et al.*, 2003). The phosphate contents in wastewater at all the stations ranged from 0.89 to 37, 0.63 to 34.29 and 1.14 to 40.58 mg/L in January, February and March, respectively. The highest concentrations were found in March at Spot-6: Karimnagor whereas the lowest was found to be in February at Spot-3: Iskon Sasanghat. The monthly average concentration decreased first from January (5.81 mg/L) to February (5.45 mg/L) and then increased to 6.25 mg/L in March.

4. DISCUSSION ON RESULTS

4.1 Suitability of Wastewater for Reuse in Agriculture

As expected, high temperatures in wastewater were recorded during the warm month (March) at the study area. The sequence of temperature rises were found to be as January<February<March. These may be attributed to both the meteorological conditions and the geographical relief of the KCC area. Thermal increase can also be caused by the removal of trees and vegetation that shade and cool the city area. It is well established that the ranges of water temperature significantly affect the changes in physicochemical parameters. Elevated temperature increases the solubility of certain chemicals and generally decreases the solubility of gases especially the amount of dissolved oxygen. High temperature, during the warm period/month, can result in intensive evaporation and low water flow, which many times leads to the accumulation of organic matter, responsible for oxygen depletion in the water (Justic *et al.*, 1997).

The nearly neutral to slight acidic pH values were found in all the observation spots during the study period. The lowest pH value was found to be in February whereas the highest value was found in March, which might be due to the outstanding concentration of bicarbonate in wastewater. Seasonal variation of the pH values did not show great differences. The observed values were within the range to permit reuse in agriculture (Table 4 in Appendix-A). The average monthly DO concentration decreased gradually from January to March, which might be due to the increasing trend in temperature from colder month (January) to the following warmer months (February and march) in the study area. During the warm period DO showed lower values. In high temperatures all wastewater elements are in the state of maximum oxidation (C as CO_2, HCO_3 as CO_3, N as NO_3, S as SO_4, etc.). Oxygen is reduced first, but when its concentration falls below a certain point, nitrates or nitrites are used as oxidants (Capblancq, 1989). The values of DO were found to be below the standard recommended for irrigation by Bangladesh Environment Conservation Rules (ECR) 1997. pH variations and DO levels, in turn, regulate most of the biochemical and chemical reactions affecting water composition.

Conductivity and hardness give information about the concentration of dissolved salts. The conductivity value increased first from January to February and finally decreased in the subsequent month. The variations in TDS results at all the observation spots during the study period are found to be same as the aforementioned variations in EC results. These might be due to the variable mixing of ion producing electrolytes in wastewater from the background concentrations present in supplied salts dominated water in the Khulna City, the dilution caused by direct runoff (atmospheric precipitation) and by wastewaters from less solute laden drains, the higher evaporation in summer, etc. Some observed values of EC and TDS exceeded the Bangladesh irrigation water quality standard recommended by ECR 1997. It is also found that the values of EC and TDS restrict moderately to reuse wastewater in agriculture (Ayers and Westcot, 1994).

Chloride is the dominant anion following bicarbonate, sulfate, phosphate and nitrate in wastewater of KCC area. These anions were found to be significant in concentrations in Gollamari (Spot-2), Iskon Sasanghat (Spot-3), Nobopolli (Spot-5), Karimnagor (Spot-6), Andhairghat (Spot-9) and Mirardanga (Spot-10) areas. The value of chloride in wastewater at Mirardanga area (Spot-10) exceeded the Bangladesh irrigation water quality standard, whereas nitrate contents were found to be within the standard. The concentrations of bicarbonate and phosphate also exceeded the safe limits for irrigation. Calcium was found to be the dominant cation following magnesium, sodium and potassium in wastewater generated in KCC area during the dry season. Calcium was prevalent in Mirardanga area (Spot-10) whereas magnesium in Iskon Sasanghat area (Spot-3), sodium in Ali Club area (Spot-4) and phosphorus in same area as the calcium. Almost all the cations were found to be exceeded the water quality standard recommended by FAO. It is seen from the discussion that the wastewater, generated in KCC area, is not totally safe for reuse in agriculture in terms of values of EC, some anions and cations.

4.2 Management System of Wastewater in KCC Area

Survey of a large number of households in Khulna city shows that about 60 percent of the households have no planned drainage facilities in and round their premises while only 40 percent have some sort of drainage facilities. The existing drains in KCC area are discharging into the nearby khals, rivers, low-lying areas and beels. There is no underground storm water drainage system in Khulna City. Concrete box culverts are being used for road crossing only. The existing drainage facilities in the fringe and sub-urban areas are inadequate and unsatisfactory.

5. CONCLUSIONS

The wastewater, generated in KCC area, possesses elevated concentrations of anions and cations during the dry season. This domestic effluent dominated wastewater flow through the numerous concrete and earthen drains which finally dispose of to the nearby water bodies, i.e. the Mayur River, Rupsha River, etc. without treatment. As the quality of wastewater is not fully satisfactory, there are valid probabilities for occurring pollution problems in river waters, becoming alarming situation in health and sanitation sectors, deteriorating environmental conditions, etc. However, the Mayur River, located at western fringe of Khulna City, have already become a dumping ground for untreated wastewater coming from municipal area of Khulna. The wastewater, generated in KCC area, is not totally safe for reuse in agriculture at peri-urban Khulna City in terms of some physico-chemical characteristics during the dry season. Nutrients are clearly present in wastewater, and especially sulfate is high in content following the phosphate and nitrate. These nutrients can be beneficial for agricultural use, but the quantities need to be known before they are applied in the field. Some sorts of treatment should be done prior to discharge to the nearby canal, rivers, etc. and to application of wastewater in cultivable land if similar characteristics were found in the subsequent dry season.

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APPENDIX-A:

Results of the Physico-Chemical Characteristics of Wastewater

Table 1: Physico-Chemical Characteristics of Wastewater in January, 2011.

Parameters	**Sampling Spots**									
	1	2	3	4	5	6	7	8	9	10
Temperature (°C)	18.3	19.2	18	18.5	18	15.5	16	17	16.2	18
DO (mg/l)	0.9	0.6	1	0.9	0.8	1.4	1.3	0.9	1.3	0.9
pH	6.73	6.67	6.79	6.75	6.86	6.32	6.78	6.79	6.82	6.66
EC (dS/m)	1.54	1.55	1.54	1.49	2.17	1.55	1.9	1.57	1.51	2.42
TDS (mg/L)	876	1009	1081	842	1274	945	1162	1023	976	1403
CO_3^{2-}(mg/L)	0	0	0	0	0	0	0	0	0	0
HCO_3^- (mg/L)	323.3	335.5	378.2	329.4	335.5	335.9	317.2	341.6	311.6	324.5
Cl^- (mg/L)	150.66	283.6	132.93	186.11	434.26	336.77	443.12	283.125	265.87	646.96
Ca^{2+} (mg/L)	16	30	18	16	26	22	32	16	22	38
Mg^{2+} (mg/L)	10.8	19.2	34.4	25.2	24	19.2	22.8	15.6	22.8	31.2
NO_3^- (mg/L)	0.721	0.9131	0.657795	0.94505	0.8972	0.46655	0.53035	0.37085	1.439	4.1829
Na^+ (mg/L)	20.83	21.85	18.45	24.9	19.47	24.22	9.62	28.64	20.83	26.6
K^+ (mg/L)	2.014	2.6485	2.5216	2.3947	2.7754	2.1409	2.7754	2.3947	7.5976	2.34
PO_4^{2-} (mg/L)	1.1724	1.1599	1.3554	1.4594	1.189	37.23	5.2492	7.038	1.32216	0.8885
SO_4^{2-} (mg/L)	38.2	19.7575	33.1	36.925	17.335	52.225	13.6375	21.63758	77.725	50.95

Table 2: Physico-Chemical Characteristics of Wastewater in February, 2011.

Parameters	**Sampling Spots**									
	1	2	3	4	5	6	7	8	9	10
Temperature (°C)	19	21	20	19.2	19.5	20	21	20	20	19.6
DO (mg/l)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
pH	6.85	6.72	6.8	6.63	6.7	6.7	6.78	6.82	6.73	6.67
EC (dS/m)	1.52	1.54	1.47	1.52	2.82	1.52	1.51	2.21	1.82	1.68
TDS (mg/L)	835	989	833	858	1313	880	925	1286	1099	1024
CO_3^{2-}(mg/L)	0	0	0	0	0	0	0	0	0	0
HCO_3^- (mg/L)	322.258	253.154	335.264	365.254	378.258	317.25	274.65	312.58	345.258	322.12
Cl^- (mg/L)	158.23	280.36	140.65	189.325	433.25	138.14	225.32	265.45	254.36	525.21
Ca^{2+} (mg/L)	36.3	26.23	14.5	13.23	19.25	18.45	22.91	10.91	17.23	31.25
Mg^{2+} (mg/L)	29.2	26.23	14.5	13.23	19.25	18.45	22.91	10.8	17.23	31.25
NO_3^- (mg/L)	0.4665	0.8972	0.4391	0.657985	0.72125	7.25	0.91312	0.9456	0.53037	0.5873
Na^+ (mg/L)	19.12	17.95	23.32	26.17	19.47	22.56	10.62	27.65	19.38	27.33
K^+ (mg/L)	3.012	2.556	2.9512	2.45	3.123	3.256	2.963	3.01	4.569	8.254
PO_4^{2-} (mg/L)	1.14	1.189	0.6278	1.172	1.3554	1.1599	34.286	5.2492	7.038	1.3221
SO_4^{2-} (mg/L)	30.12	25.32	24.3	37.36	30.23	46.325	25.32	12.354	45.36	60.12

Table 3: Physico-Chemical Characteristics of Wastewater in March, 2011.

Parameters	**Sampling Spots**									
	1	2	3	4	5	6	7	8	9	10
Temperature (°C)	25.6	26	27	25.8	26	26.6	27.2	26	27	27.8
DO (mg/l)	0.3	0.3	0.5	0.6	0.3	0.7	0.5	0.8	0.4	0.5
pH	6.89	6.35	6.47	6.68	6.45	6.73	6.57	6.71	6.82	6.39
EC (dS/m)	1.64	1.5	1.4	1.56	1.66	1.53	1.56	1.56	2.06	1.75
TDS (mg/L)	905	862	733	770	944	862	889	1140	985	993
CO_3^{2-}(mg/L)	0	0	0	0	0	0	0	0	0	0
HCO_3^- (mg/L)	307.2	385.23	345.58	335.25	298.32	341.25	325.36	269.32	335.235	362.34
Cl^- (mg/L)	283.3	167.25	158.32	198.23	389.23	365.21	421.365	269.32	501.21	597.23
Ca^{2+} (mg/L)	18.45	33.25	17.58	12.36	27.08	16.9	19.3	23.78	32.85	30.91
Mg^{2+} (mg/L)	12.58	22.12	14.6	11.16	19.5	13.5	18.01	14.259	20.457	25.47
NO_3^- (mg/L)	0.587	0.466	0.8972	1.4391	6.5452	0.5303	0.721	0.9131	0.6579	0.9456
Na^+ (mg/L)	24.9	26.6	20.836	28.641	9.6225	19.472	18.452	21.851	20.831	24.223
K^+ (mg/L)	2.365	3.564	2.312	4.235	6.3325	7.235	5.6123	3.254	2.256	5.621
PO_4^{2-} (mg/L)	1.3221	1.1412	7.038	1.54	5.2492	40.58	1.189	1.3554	1.8992	1.1725
SO_4^{2-} (mg/L)	25.3	38.4	30.45	32.22	13.25	17.58	19.85	21.3254	54.321	39.25

Table 4: Maximum, Minimum and Average Values of the Physico-Chemical Characteristics of Wastewater with Standard

Parameters	**January, 2011**			**February, 2011**			**March 2011**			**Standards for Irrigation**		
	Max	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Bangladesh**	**WHO**	**FAO**
Temperature (°C)	19.2	15.5	17.47	21	19	19.93	27.8	25.6	26.5	NA	NA	NA
DO (mg/l)	1.4	0.6	1	0.7	0.7	0.7	0.8	0.3	0.49	≥ 5.0	NA	NA
pH	6.86	6.32	6.717	6.85	6.63	6.74	6.89	6.35	6.606	6.0-8.5	6.5-8.5	6.0-8.5
EC (dS/m)	2.42	1.49	1.724	2.82	1.47	1.761	2.06	1.4	1.622	2.25	1.2	0-3
TDS (mg/L)	1403	842	1059.1	1313	833	1004.2	1140	733	908.3	1000	2100	0-2000
CO_3^{2-}(mg/L)	0	0	0	0	0	0	0	0	0	NA	NA	0-3
HCO_3^- (mg/L)	378.2	311.6	333.27	378.258	253.154	322.6046	385.23	269.32	330.5085	NA	58.4	0-610
Cl^- (mg/L)	646.96	132.93	316.3405	525.21	138.14	261.0295	597.23	158.32	335.0665	600	600	0-1050
Ca^{2+} (mg/L)	38	16	23.6	36.3	10.91	21.026	33.25	12.36	23.246	75	15	0-400
Mg^{2+} (mg/L)	34.4	10.8	22.52	31.25	10.8	20.305	25.47	11.16	17.1656	30-35	4.1	0-60
NO_3^- (mg/L)	4.1829	0.37085	1.11238	7.25	0.4391	1.340843	6.5452	0.466	1.37024	10	10	0-620
Na^+ (mg/L)	28.64	9.62	21.541	27.65	10.62	21.357	28.641	9.6225	21.54285	1000	6.3	0-920
K^+ (mg/L)	7.5976	2.014	2.96028	8.254	2.45	3.61442	7.235	2.256	4.27868	12	2.3	0-78
PO_4^{2-} (mg/L)	37.23	0.8885	5.806396	34.286	0.6278	5.45394	40.58	1.1412	6.24866	6	NA	0-62
SO_4^{2-} (mg/L)	77.725	13.6375	36.14926	60.12	12.354	33.6809	54.321	13.25	29.19464	400	NA	0-960