STUDY ON THE CHARACTERISTICS OF DRAINAGE LIQUID WASTES AND DIPOSITED DRINAGE SOLIDS OF RAJSHAHI CITY

Md. Niamul Bari*[1], Md. Zahanggir Alam[2], Anupam Chowdhury[3], Jahidul Islam[4], Md. Mahfuz Alam[4], Murshida munni[4], Shakibul Hasan[4], Md. Shahorian[4], Md. Kaysar Ahmed Limon[4]

[1]*Professor, Rajshahi University of Engineering & Technology, Bangladesh, e-mail:* niamulbari@gmail.com
[2]*Associate Professor, Rajshahi University of Engineering & Technology, Bangladesh, e-mail: zahangir02@gmail.com*
[3]*Associate Professor, Rajshahi University of Engineering & Technology, Bangladesh, e-mail: anupam.19ce@gmail.com*
[4]*Undergrade student, Rajshahi University of Engineering & Technology, Bangladesh*

***Corresponding Author**

ABSTRACT

Urban environmental management and public health depend greatly on an understanding of drainage water quality. The surface drainage system in Rjshahi city receives sanitary wastewater, storm water and solids from roadsides as well as household solid wastes. In this aspect, the characterisitics of the drainage wastewater might be different from other part of the world having sewerage system. The main focus of the study to determine the characteristics of drainage wastewater as well as the deposited drainage solids. The physical, chemical, and biological characteristics of the drainage wastewater and physica properties of the deposited drainage solidswere determined. A number of physical, chemical, and biological factors were assessed, including pH, temperature, electric conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), DO, BOD, COD, flow rate, and total coliform (TC), fecal coliform (FC), E. coli and for solid it includes particle size, moisture content, dry density, volatile organic content. The results show that the concentrations of EC, TSS, DO, COD, BOD, TC, FC and E.coliform are 1387.5±62.92 µs/cm to 1500±40.83 µs/cm, 150 ± 57.735 mg/l to 350 ± 129.099 mg/l, 1.6 ± 1.211 mg/l to 2.4 ± 1.674 mg/l, 40.5 ± 12.39 mg/l to 270 ± 9.83 mg/l, 110 ± 48.4 mg/l to 150 ± 98.6 mg/l, 800 ± 141.421 cfu/100 ml to 1150 ± 129.099 cfu/100 ml, 550 ± 129.099 cfu/100 ml to 800 ± 81.650 cfu/100 ml, and 350 ± 57.735 cfu/100 ml to 425 ± 150 cfu/100 ml, respectively at different locations that make it "unfit" for effluent release without adequate treatment. This study reveals the drainage system in Rajshahi city is carrying mainly wastewater coming from sanitary facilities of the households. Moreover, the roadside sand, grit etc enter in the drainage system that reduces the wastewater carrying capacity.

Keywords: *Urban drainage, wastewater, deposited solids, characteristic, potential hazard*

1. INTRODUCTION

Municipal wastewater refers to household sewage or the combination of domestic sewage from businesses and institutions, and storm water runoff that enter the sewer system. It has a wide range of pollutants due to the mixing of wastewater from the aforementioned sources (Mridha, 2011). The surface drainage system in the non-sewered countries in the world like Bangladesh is practically serving as an open sewerage system by receiving the sanitary sewage and faecal matter from onsite sanitation facilities (Sultana, et al., 2023; Bari, et al., 2018; Bari, et al., 2012).

Rajshahi is one of the metropolitan cities situated in the north-western region of Bangladesh. There is no sewerage system in this city and most of the sanitation facilities are constructed without soak pit to receive the septic tank effluent. The city dwellers connected their septic tank directly to the surface drains (Bari, 2017). As a consequence, the urban drainage system receives sanitary sewage (sullage and black-water) and storm runoff as well. Unfortunately, much of the Rajshahi city's sewage is released into the environment untreated. It extremely causes the public health problems as well as contaminates the surface water bodies, groundwater resources and surrounding environment.

Moreover, about 0.85 million people are living in Rajshahi city of 96.72 sq km area (WaterAid, 2018). This huge population daily produces about 420 tons of municipal wastes of which a little portion is collected and disposed of in wastes dumping site (Das, et al., 2021). The remaining portion is going to open land, water bodies and surface drains (Ahmed, et al., 2019) through illegal disposal by the city dwellers. It is more expensive to collect and dispose of waste when solid waste is dumped in an open area without being treated (Islam and Islam, 2021). These situations extremely aggravated the quality drainage water as well as rapidly reduced the drainage capacity by solid deposition at the bottom of the drainage system.

A few studies have been carried out to determine the characteristics of the wastewater receiving by the surface drains in the Rajshahi. It is essential to know the present conditions of drainage wastewater and the situation of drainage system of the study area. Therefore, the aim of this study was to determine the physical, chemical and biological characteristics of wastewater and to evaluate the characteristics with comparison to the guideline provided by the Bangladesh Environmental Conservation Rule (BECR 2023). The study also aims to know the wastewater flow characteristics and characteristics of deposited solids in the drainage system.

2. STUDY AREA AND SAMPLE COLLECTION ROUTE

Rajshahi, the center of Rajshahi division is located at North-western part of Bangladesh. Rajshahi city corporation (RCC) is located in between 24o20' and 24o24' north latitudes and in between 88o32' and 88o40' east longitudes. The topography of this metropolitan area is flat. Approximate road length is 186.64 km and drain length is 192.18 km. Dwellers of RCC area usually consume water for domestic, commercial, and industrial purposes and public sector. The wastewater effluents, generated in RCC area, flow through the numerous concrete and semi concrete drain which finally dispose of to the nearby water bodies.

The first sampling point is at the starting point of a minor drain at Northernmor (24.365835N, 88.622608E) and the last sampling point is at near the City hut (24.405638N, 88.593011E) which is the junction point of all other primary drains via Montessori School (24.3666857N, 88.6200578E), Baliapukur (24.3701991N, 88.6207448E), Vodra (24.375024N, 88.6216577E), Shalbagan (24.383033N, 88.607708E), Postal academy (24.397262N, 88.606791E) and Amchattar (24.4087893N, 88.6085474E). There were eight sampling points selected considering the type and size of the drains (Figure 1).

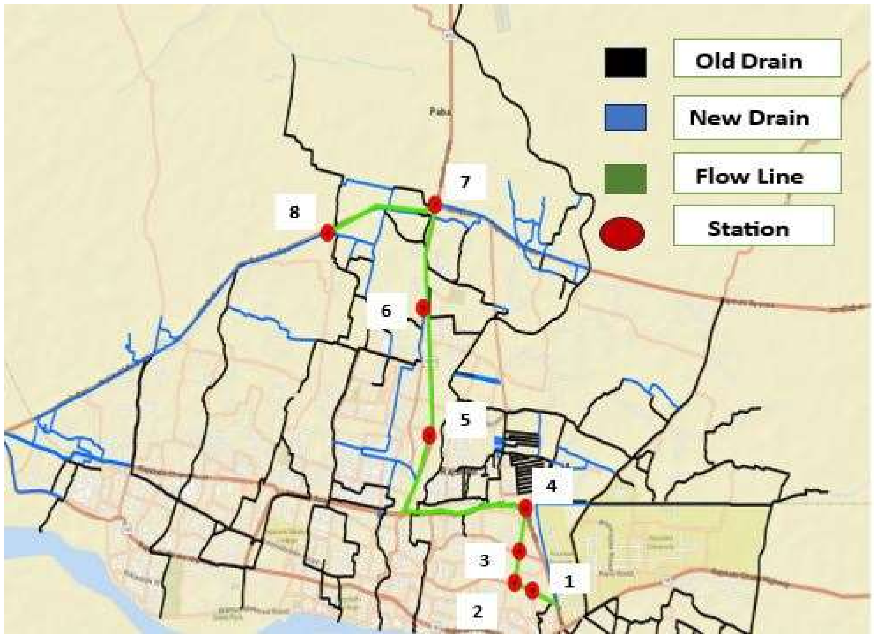

Figure 1: Drainage network and sampling points

3. METHODOLOGY

To ascertain the characteristics of municipal wastewater, thorough study has been carried out from the starting point of a drain to the last point of the community before disposal during April to October, 2023 which covers dry and wet seasons. The methodology of the study is elaborated in the following sections.

3.1 Sample Collection and Field Study

The representative wastewater and deposited solid samples from designated eight distinct collection points of drains were collected in the months of April, June, September, and October considering before monsoon and during monsoon. The collected samples were transported to the laboratory in ice box and experiment started immediately. The dimensions (width and depth) of drain at each point and depth of flowing wastewater and depth of deposited solids were measured. The flow velocity was also determined at every location to obtain the discharge of wastewater. The dissolved oxygen (DO), electrical conductivity (EC), temperature and pH were measured at site and experiment for BOD was started at site to avoid any biological change. Other experiments were conducted in the laboratory.

3.2 Experimental Procedure

3.2.1 Laboratory experiment for wastewater

The laboratory experiments of drainage wastewater were conducted for total dissolved solids (TDS) (ASTM D5907), total suspended solids (TSS) (ASTM D5907), biochemical oxygen demand (BOD) (APHA 5210), chemical oxygen demand (COD) (APHA 5220), total coliforms (TC) (APHA 9222D), faecal coliforms (FC) (APHA 9132), and Escherichia coli (E. coli) (USEPA 8367). These parameters were analyzed in the laboratory following the procedure outlined in the Standard Methods (ASTM, APHA, USEPA) and guidelines provided by the American Public Health Association (APHA) and United State Environmental Protection Agency (USEPA).

3.2.2 Laboratory experiment for deposited Solids

The moisture contents of the deposited solids were determined after removal of excess water by gravity following standard test method (ASTM D2216-19). The volatile organic compound was determined by ASTM E2686-09R21, and particle size distribution was conducted by following ASTM D6913 method using sieve analysis.

4. RESULTS AND DISCUSSIONS

The experimental results on physical (TDS, TSS, Temperature and flow rate), chemical (pH, EC, DO and COD) and biological (BOD, TC, FC and EC) parameters as well as deposited solids are discussed in the following sections in comparison with Environmental Protection Act (EPA) and Bangladesh Environmental Conservation Rule (BECR).

4.1 Physical Characteristics

Total dissolved solid (TDS) refers to the combined concentration of all inorganic and organic substances dissolved in wastewater while TSS is the portion of total solids in suspended condition. It contains a variety of things that are dissolved in water, including minerals, salts, ions, metals, and organic molecules. Several variables, such as the geographic location, climate, season, and particular drainage system, can have a considerable impact on the average temperature of municipal drainage water. The results are presented in Figure 2.

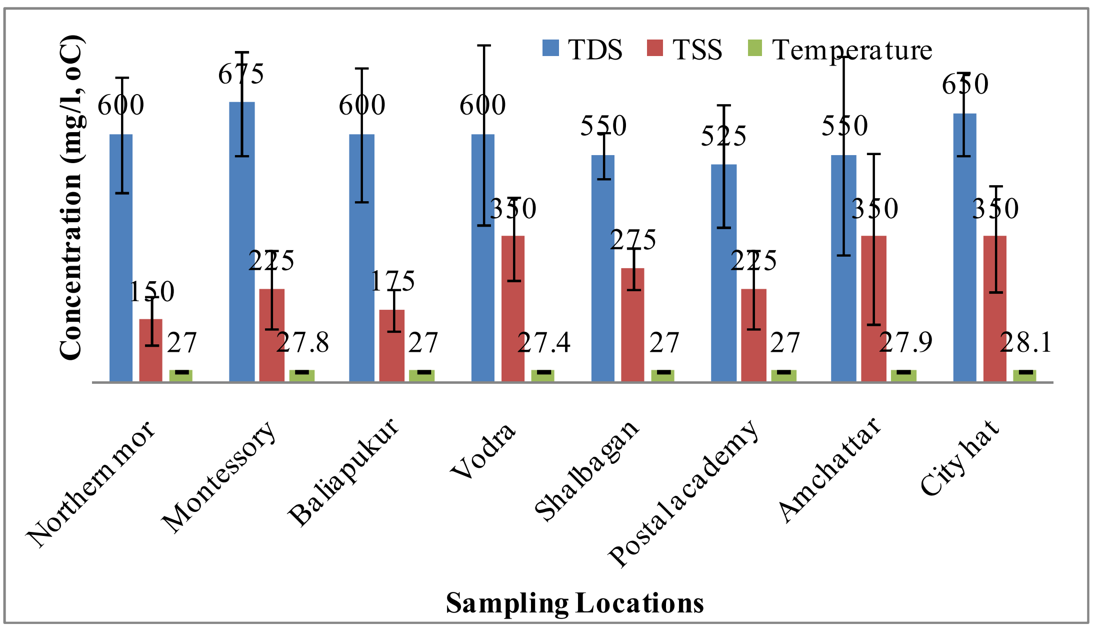

Figure 2: Concentration of TDS (mg/l) and TSS (mg/l) as well as temperature (ºC) of drainage wastewater

The TDS from starting point to the farthest point varies from 525 ± 150 mg/l to 675 ± 125.831 mg/l with an average of about 600 mg/l and TSS varies from 150 ± 57.735 mg/l to 350 ± 129.099 mg/l with an average of about 260 mg/l. There are no definite trends of variation of TDS and TSS which might be due to the distributed source of wastewater feeding and addition of indefinite types of pollutant along the course of drainage system. However, the TDS in the drainage system in Rajshahi city is much less than the standard according to EPA (1500 mg/l) and BECR (2100 mg/l) while TSS is higher or equal to EPA standard (50 mg/l) and BECR standard (150 mg/l). The researcher found that the TDS in Khulna city varies from 908.3 mg/l to 1059.1 mg/l (Mridha, 2011) which is much higher than the TDS of Rajshahi city. There is no significant variation in the average temperature at different locations. The temperature varies within 27 ± 1.826 °C to 28.1 ± 2.250 °C. It is observed from Figure 2 that the TDS and TSS are not following similar trend. This unusual pattern might be due to the continuous feeding of wastewater along the length of drains and entering of different solids from surrounding the drains.

Drainage systems are often built to accommodate peak flow rates, which can be significantly higher than the normal flow rate, during periods of intense rainfall. The average flow rate values of eight different locations are shown in Figure 3.

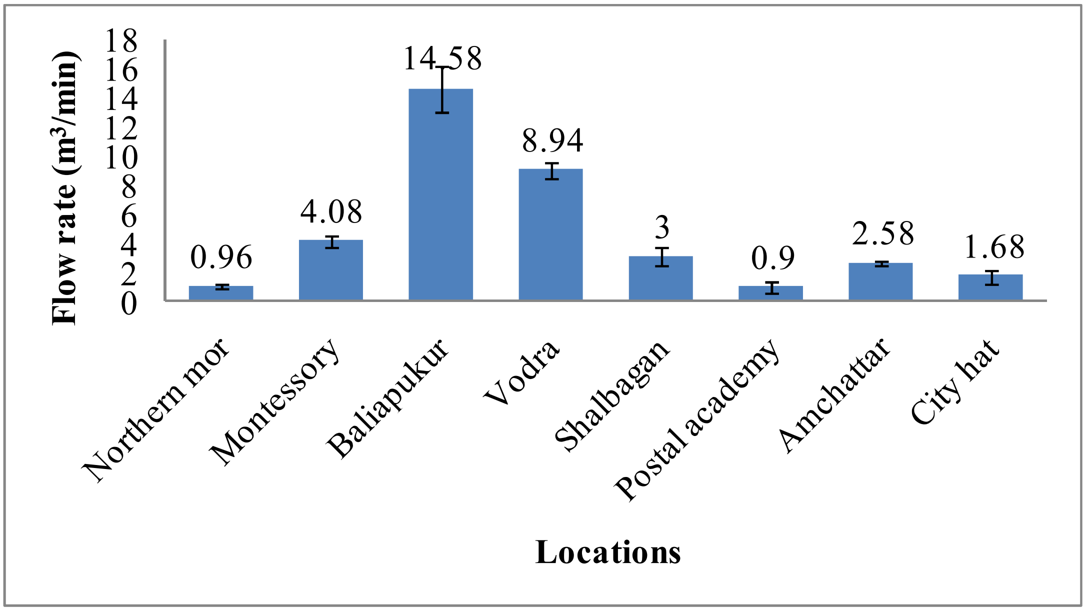

Figure 3: Variation of average drainage water flow rate at different locations

The average value at Northernmor, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar and Cityhat were 0.96 ± 0.15 m^3/s, 4.08 ± 0.42 ^{m3}/s, 14.58 ± 1.56 ^{m3}/s, 8.94 ± 0.54 m^3/s, 3 ± 0.62 m^3/s, 0.9 ± 0.39 m^3/s, 2.58 ± 0.18 m^3/s, 1.68 ± 0.48 m^3/s, respectively. The Figure 3 shows that the highest average flow rate at Baliapukur and the lowest at postal Academy. This study has been carried out to understand the any deviation in expected flow condition. From the results it is clearly observed that the flow of wastewater in the drainage system is not flowing uniformly. This non-uniform flow rate is due the distributed feeding of wastewater into the drains from households along the course of drains and blockage of drains in different places due to the solid deposition in the drains. The flow rate of wastewater in the drains is supposed to increase gradually due to gradual feeding. However, practically it was not happen in the drainage system due to blockage by solid deposition.

4.2 Chemical Characteristics

The measurement of electric conductivity (EC) is used to assess the level of ion concentration in water. The quantity of ions is influenced by several factors, including the surroundings, water velocity, and sources of water. The chemical characteristics of drainage wastewater at different locations are shown in Figure 4.

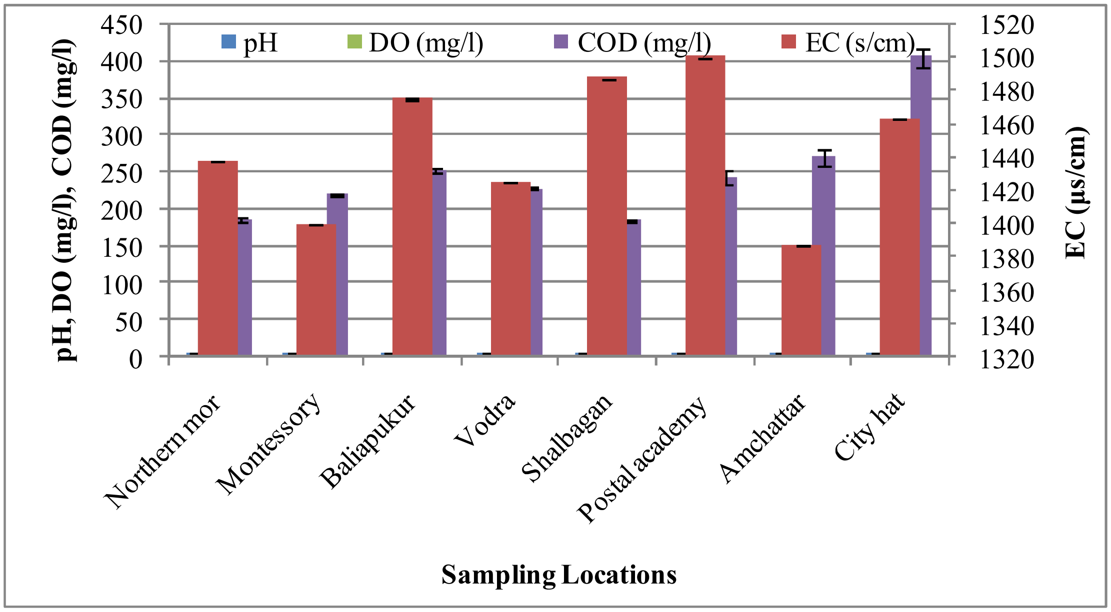

Figure 4: Variation of chemical parameters in eight different locations

The average value of electric conductivity is varying from 1387.5±62.92 µs/cm at Amchattar to 1500±40.83 µs/cm at Postal academy. The presented results clearly show that the EC is fluctuating within a short range. However, the obtained ECs of drainage wastewater are much higher than EPA and ECR guidelines which indicate the wastewater is highly mineralized. It might be due to distributed feeding sources of wastewater along the course of drainage in Rajshahi City which is being mixed unevenly with ion-producing electrolytes. The EC of wastewater in Khulna municipal area was ranging from 1622 µs/cm to 1761 µs/cm (Mridha, 2011).

The pH scale is an important tool for assessing the purity of drinking water. The health of aquatic ecosystems, such as streams, rivers, and lakes, can be impacted by pH. The average pH value at Northernmor, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar and Cityhat were 6.6 ± 0.058, 6.4 ± 0.129, 6.4 ± 0.265, 6.50 ± 0.216, 6.4 ± 0.216, 6.3 ± 0.082, 6.5 ± 0.082, 6.4 ± 0.082, respectively. According to EPA regulations and BECR recommendations, the pH range for acceptable effluent water quality standard is 6 to 9. The average drainage wastewater pH in Khulna city was found to be from 6.6 to 6.7 in the study of Mridha (2011). Therefore, pH levels of the drainage wastewater in Rajshahi city remain within the permitted range in accordance with EPA regulations and BECR guidelines.

Dissolved oxygen (DO) is a measure of how much oxygen is dissolved in the water. It is crucial for the survival of aquatic species including fish, invertebrates, and microbes and is a key indicator of the health of aquatic ecosystems. To effectively remove contaminants and safeguard the environment, wastewater treatment operations must be monitored and controlled for dissolved oxygen levels. Wastewater contains organic and inorganic substances that can consume oxygen as they decompose. The average DO values at different locations are varying from 1.6 ± 1.211 mg/L to 2.4 ± 1.674 mg/L. Mridha (2011) found the average DO was ranging from 0.49 mg/L to 1 mg/L of wastewater in Khulna municipal area (Figure 4).

Chemical Oxygen Demand (COD) is an important indicator for estimating the concentration of organic and inorganic pollutants or toxins in water. It helps operators in figuring out the best treatment setups, chemical doses, and aeration rates needed to bring the COD down to manageable levels in wastewater treatment process. The average values of COD at Northern mor, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar and Cityhat were 185 ± 3.42 mg/L, 220 ± 2.16 mg/L, 253 ± 2.63 mg/lL, 228 ± 1.26 mg/l, 185 ± 1.29 mg/l, 243 ± 9.29 mg/l, 270 ± 9.83 mg/l, 40.5 ± 12.39

mg/l, respectively. In the observation of Dey and Islam (2015), from a wastewater characterization in Bangladesh, the average COD value in Gazipur was ranging from 41 mg/L to 140 mg/L. The allowable limits for COD, prescribed by BECR and EPA are 200 mg/L and 250 mg/L respectively.

4.3 Biological Characteristics

The BOD and coliforms were determined in the drainage wastewater to determine the biological characteristics. The biological characteristics are shown in Figure 5. The BOD is the quantity of dissolved oxygen (DO) consumed by bacteria and other microorganisms during the aerobic breakdown of organic materials in wastewater. BOD is commonly measured in wastewater treatment plants to evaluate the efficacy of the treatment procedures and adherence to environmental requirements. High BOD content in wastewater may have a negative impact on natural water bodies. Microbial breakdown of organic materials may cause oxygen deprivation (hypoxia), impair aquatic life, and even result in fish kills and ecological imbalances.

The average BOD at different locations is 110 ± 75.8 mg/l, 110 ± 67.9 mgl, 130 ± 116.3 mg/l, 120 ± 82.3 mg/l, 110 ± 48.4 mg/l, 130 ± 89.4 mg/l, 140 ± 105.5 mg/l, 150 ± 98.6 mg/l. The BOD at every location fluctuates in wide ranges. The lowest average BOD was found at Northern mor, Montessory, and Shalbagan whereas the highest average BOD value was found at Cityhat which might be caused by the presence of organic matter brought about by the influx of waste from industry, livestock, and homes that has high concentrations of organic pollutants. Karmoker et al. (2018) found the average BOD value ranging from 16 mg/l to 71 mg/l of wastewater from Jhenaidah municipality area of Bangladesh. The permissible BOD limit of dischargeable water according to both EPA and BECR is 30 mg/l.

Total coliform is a group of bacteria that is frequently used as an indicator for both the presence of faecal and non-faecal contamination in water sources and the quality of the water itself. In order to evaluate the security of drinking water, recreational water, and water used for various purposes, monitoring and maintaining total coliform levels in water is a common practice. Season, weather, and other environmental factors may influence total coliform levels. Total coliform (TC) in eight different locations are 850 ± 238.048 cfu/100ml, 800 ± 141.421 cfu/100ml, 950 ± 208.167 cfu/100ml, 1050 ± 208.167 cfu/100ml, 900 ± 216.025 cfu/100ml, 900 ± 81.650 cfu/100ml, 900 ± 216.025 cfu/100ml, 1150 ± 129.099 cfu/100ml. The lowest average TC was found at Montessory whereas the highest average TC was found at Cityhat.

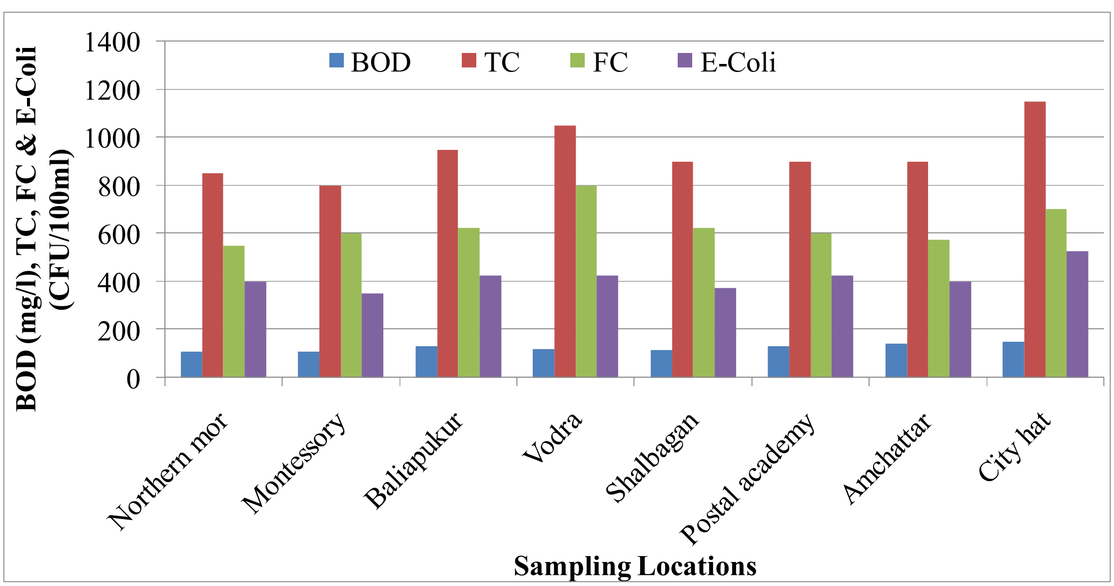

Figure 5: Biological characteristics of drainage wastewater in Rajshahi city

Fecal coliform bacteria are a sub-group of total coliform bacteria which appear in great quantities in the intestines of people and animals and used as indicator of fecal contamination. Monitoring fecal coliform levels in water is very important for evaluating the security and quality of water for various applications, particularly for identifying any potential pathogens connected to faecal matter. The level of coliform varies with season, weather conditions, and other environmental factors. Fecal Coliform (FC) in eight different locations is found to be of 550 ± 129.099 cfu/100ml, 600 ± 141.421 cfu/100ml, 625 ± 150 cfu/100ml, 800 ± 81.650 cfu/100ml, 625 ± 150 cfu/100ml, 600 ± 141.421 cfu/100ml, 575 ± 95.743 cfu/100ml, 700 ± 115.470 cfu/100ml.

E. coliform is a sub-group of the fecal coliform group and prevalent in both human and warm-blooded animal intestines. But certain strains might really make us sick. The observed E. coliform in eight different locations is 400 ± 81.650 cfu/100ml, 350 ± 57.735 cfu/100ml, 425 ± 150 cfu/100ml, 425 ± 95.743 cfu/100ml, 375 ± 50 cfu/100ml, 425 ± 95.743 cfu/100ml, 400 ± 81.650 cfu/100ml, 525 ± 50 cfu/100ml. The lowest average E. coliform was found at Montessory whereas the highest average E. coliform was found at Cityhat which might be caused by contamination by fecal matter, indicating potential sewage or animal waste.

4.4 Solid Waste Deposition in Drainage System

Solid deposition in the drainage system reduces the discharge capacity. The solids deposited at the bed of drain come from roadside dirt, sand, household solid wastes, etc. The average depth of solids deposition, its moisture content, dry density, organic content, and particle size were determined to characterize the drainage deposited solids. The deposited solid depth in a drain can vary significantly based on the type of drainage system, the size of the drainage area, the local climate, and the frequency of maintenance. The average Solid depth values of eight different locations are shown in Figure 6.

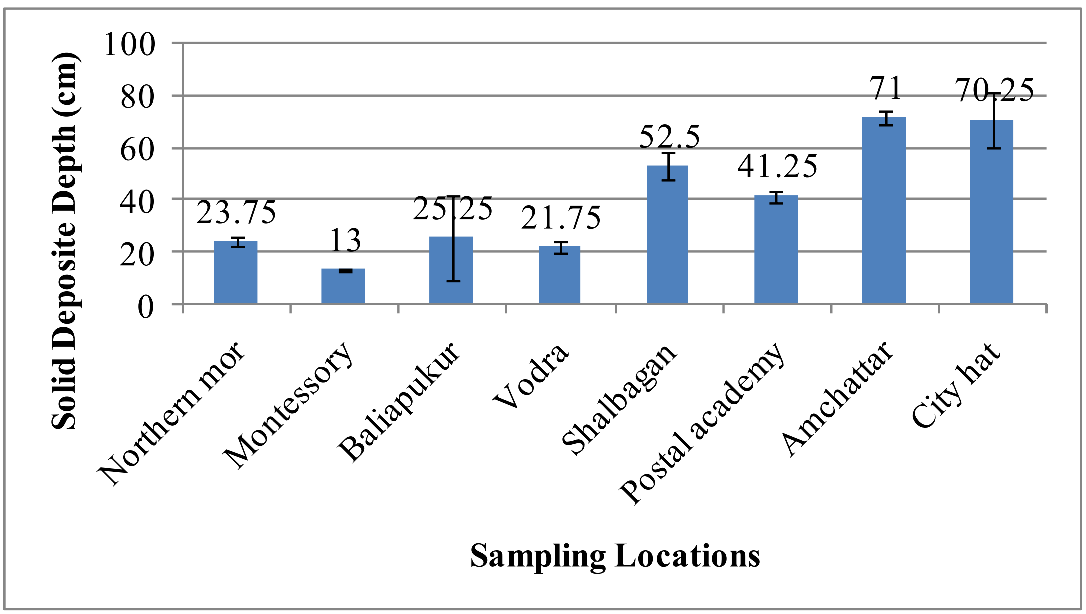

Figure 6: Variation of average drainage solid depth in eight different locations

The average depth of deposited solids varies from 13 ± 0.8 cm to 71 ± 2.6 cm. The highest solid depth observed at Amchattar followed by city hat point. The depth and width of drains from Northernmor, to Cityhat are different. The size of the drains is gradually increased towards the downstream. Therefore, the deposited volumes of solids are also varying, and larger volume is at the Amchattar as well as Cityhat.

The particle size of deposited solids in the drainage in important to know for the understanding about the nature of the solids and its possible application. The particle size distributions of the deposited solid at eight different locations are shown in Figure 7.

The effective sizes of deposited solids at Northernmor, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar, and Cityhat are of 0.167 mm, 0.167 mm, 0.085 mm, 0.164 mm, 0.166 mm, 0.086 mm, 0.087 mm, and 0.082 mm, respectively. Furthermore, the uniformity coefficient values (Cu) of deposited solids for the same locations are found to be of 1.68, 1.78, 1.75, 1.74, 1.80, 1.76, 1.73 and 1.71, respectively. According to the MIT soil classification it is found from the particle size distribution curves that all the deposited solids are sand which particle sizes are within 0.06 mm to 2 mm. Furthermore, 100% particles of deposited solids at Northernmor, Montessory, Vodra and Shalbagan are greater than 0.1 mm and about 70% particles are greater than 0.2 mm. From this analysis it could be mentioned that the deposited solids are mostly coming from roadside sand and grit. Therefore, the entrance of solids in the drainage could be possible to prevent by introducing sand trap and raising the sides of the drains.

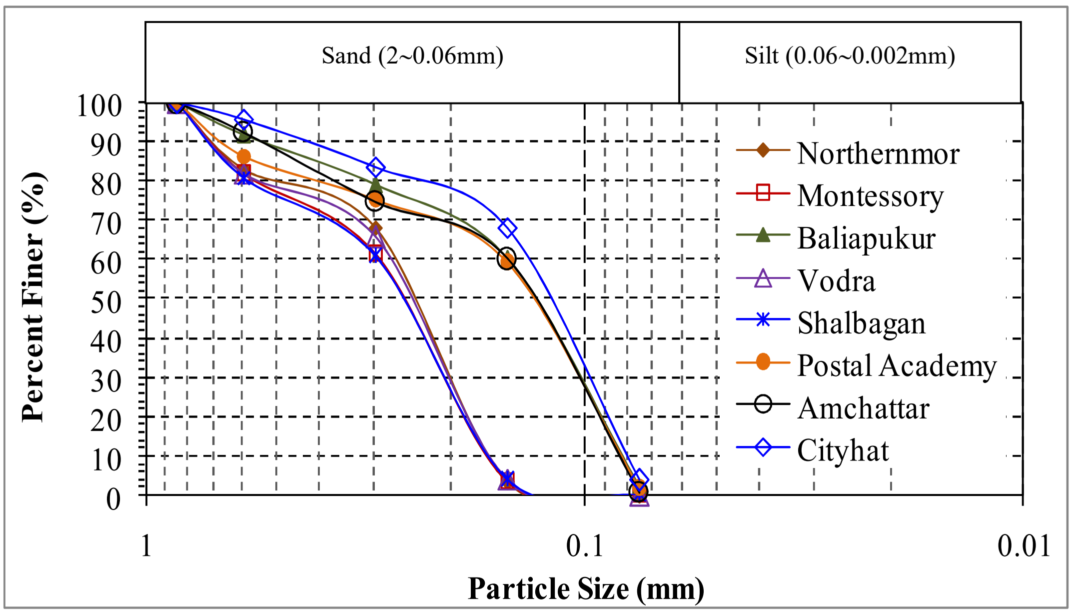

Figure 7: Particle size distribution of deposited solids in drainage system

From different properties of solid waste moisture content, dry density and volatile organic content were also determined in this study and the results are presented in Table 1.

Table 1: Physical propertise of drainage deposited solids

Locations	Moisture content (%)	Dry density (gm/cm^3)	VOC (%)
Northern mor	66.67	0.200	21.43
Montessory	77.14	0.192	22.73
Baliapulur	71.23	0.195	17.81
Vodra	64.00	0.209	17.33
Shalbagan	68.92	0.202	17.57
Postal Academy	82.09	0.180	11.94
Amchattor	82.35	0.186	11.76
Cityhat	75.71	0.190	15.71

The moisture content analysis revealed varying levels across the studied locations, Northern, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar, and Cityhat exhibiting percentages of 66.67%, 77.14%, 71.23%, 64%, 68.92%, 82.09%, 82.35%, and 75.71%, respectively.

Among these, the highest moisture content was observed in Amchattar at 82.35%, while the lowest was recorded in Vodra at 64%.

The yielded values of dry density observed at Northern, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar, and Cityhat are of 0.2 gm/cm³, 0.192 gm/cm³, 0.195 gm/cm³, 0.209 gm/cm³, 0.202 gm/cm³, 0.180 gm/cm³, 0.186 gm/cm³, and 0.190 gm/cm³, respectively. The dry densities among these areas are almost uniform and around 0.20 gm/cm³. The volatile organic content analysis in the investigated locations, comprising Northern, Montessory, Baliapukur, Vodra, Shalbagan, Postal Academy, Amchattar, and Cityhat, revealed percentages of 21.43%, 22.73%, 17.81%, 17.33%, 17.57%, 11.94%, 11.76%, and 15.71%, respectively. Notably, the highest volatile content was observed at Montessory, recorded at 22.73%, while the lowest was recorded at Amchattar, at 11.76%.

5. CONCLUSIONS

The physical, chemical, and biological characteristics of drainage wastewater in Rajshahi city fluctuate along the tertiary, secondary and primary drains. However, concentrations of total suspended solids, electrical conductivity, BOD, COD, TC, FC, and E-coliform are higher than the standard value according to EPA and BECR (2023) recommendations. On the other hand, the temperature, pH levels, and TDS limit are within the acceptable range. As a result, owing to exceeding the permissible range, this wastewater requires necessary treatment for safe disposal. The wastewater flow rate is also fluctuating along the course of drainage system from 0.9 to 14.6 m3/min. The alarming issue is the feeding of sand and deposition in the drain with the thickness of 13 cm to 71 cm. It is a matter of concern that the faecal contamination is very high probably due to the connection of septic tank with municipal drains. The findings of the study revealed that the drainage system in Rajshahi city is carrying mainly wastewater coming from sanitary facilities of the households and roadside sand, grit etc enter in the drainage system that reduces the wastewater carrying capacity.

REFERENCES

Ahmed, T., Ahmed, R. & amul Bari, M.N. (2019). "Monitoring of Solid Waste Disposal by Urban Slum Dweller in Rajshahi City and its Impact on the River Water Quality". Proceedings of the WasteSafe 2019 – 6th International Conference on Solid Waste Management in South Asian Countries, 23-24 February 2019, Khulna, Bangladesh.

APHA 5210. Standard Test Methods for Determining Biochemical Oxygen Deman.

APHA 5220. Standard Test Methods for Determining Chemical Oxygen Deman.

APHA 9132. Standard Test Methods for Determining Total Coliform: Membrane-Filter Technique

APHA 9222D. Standard Test Methods for Determining Faecal Coliform: Membrane-Filter Technique

ASTM D2216-19. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

ASTM D5907. Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Non filterable Matter (Total Suspended Solids) in Water.

ASTM E2686-09R21. Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis

ASTM D6913. Standard Test Methods for Particle-Size Distribution (Gradation) of Soils using Sieve Analysis.

Bari, M.N. (2017). "Study on Existing Faecal Sludge Management Situation in Rajshahi City". Proceedings of the WasteSafe 2017 – 5th International Conference on Solid Waste Management in South Asian Countries, 25-27 February 2017, Khulna, Bangladesh.

Bari, M.N., Ali, S., Basak, S., Khatun, F. & Rasel, H.M. (2012). "Characterization of Septic Tank Sludge for Using As Potential Substrate for Bio-Products". 1st International Conference on Advances in Civil Engineering 2012 (ICACE 2012), 12–14 December 2012, Chittagong University of Engineering & Technology, CUET, Chittagong, Bangladesh. ID: AEE 007.

Bari, M.N., Bushra, A. & Zaman, J. (2018). "Management of faecal sludge by Rajshahi City Corporation". Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6).

Islam, S. M., & Islam, A. M. (2021). "Assessment of efficacy of drainage system in Rajshahi City Corporation, Bangladesh". Advances in Environmental Research-an International Journal, 10(2), 105–116.

Mridha, U.K. (2011). Wastewater Characteristics of Khulna Municipal Area in Bangladesh.

Pronob Das, P., Islam, M.S. & Huda, N. (2021). "Feasibility analysis of municipal solid waste (MSW) for energy production in Rajshahi City Corporation". *AIP Conf. Proc.* 2121, 120004 (2019). https://doi.org/10.1063/1.5115941

Sultana, M.S., Waine, T., Bari, M.N. & Tyrrel, S. (2023). "Towards a new spatial representation of faecal sources and pathways in unsewered urban catchments using open-source data". Journal of Water, Sanitation and Hygiene for Development, Vol 13 No 4, 289-300. doi: 10.2166/washdev.2023.227

USEPA 8367. Standard Test Methods for Determining E-Coliform: Membrane Filtration Method Method

WaterAid 2018 SFD Lite Report of Rajshahi City Corporation Bangladesh.