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ANALYZING THE RISK OF HEAVY METAL POLLUTION IN WASTEWATER FROM THE OPEN DRAINAGE SYSTEM IN RAJSHAHI CITY, BANGLADESH

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ABSTRACT

This study evaluates heavy metal concentrations in drainage wastewater from 12 locations in Rajshahi City, assessing risks to aquatic ecosystems and public health using di-acid digestion method and atomic absorption spectrophotometry. The mean levels of heavy metals were Zn > Mn > Pb > Cr > Cu > Cd. Pb, Cr, and Cd levels exceeded the permissible limits set by the USEPA (0.006, 0.05, and 0.01 mg/L, respectively) and WHO (0.01, 0.05, and 0.003 mg/L, respectively), indicating significant contamination risks. Cu, Zn, and Mn levels, remained within permissible thresholds. All samples showed high metal concentrations with metal index values above 1. Notably, 75% of sites had HPI values over 100, 75% of the samples exhibited DC values over 3, 50% of the samples showed EWQI readings exceeding 0.3. The findings highlight the urgent need for improved wastewater treatment and sustainable water management practices to mitigate health and environmental risks.

Keywords: *Contamination; Heavy Metals; Pollution Index; Risk Assessment; Wastewater; Water Quality.*

1. INTRODUCTION

A necessary component of existence for humans is water, and water quality should be maintained for every human being and also for aquatic systems. Although heavy metal concentrations in water are normally modest, human intervention has caused them to rise over time. A city's drainage system is essential to maintaining environmental safety and leading a healthy urban life. A drainage system malfunction is quite concerning since it immediately affects public health and cleanliness. The drainage system in a neighborhood is not functional because of poor planning. Regrettably, among developing nations, drainage planning is the most overlooked component of the management and planning of cities. The quantities of heavy metals in wastewater have drawn a lot of interest recently as a means of identifying any that may be harmful to human health. If this wastewater gets mixed with the river water, then it will easily contaminate the water ecosystem, which will eventually affect human hygiene and life cycle.

Heavy metal-contaminated wastewater is also harmful for eco- system and human health via contaminated drinking water, the food chain, or direct contact or ingestion (Fliesbach *et al*., 1994; Shahriar *et al*., 2022; Shahriar *et al*., 2024a). Over the past few years, the buildup of heavy metals in water bodies has drawn international attention. These metals have the potential to build up to extremely dangerous proportions and have a detrimental effect on aquatic life without giving any outward symptoms. The problem has been made worse by the growing population, urbanization, industry, and agricultural methods (Giguère *et al*., 2004; Shahriar *et al*., 2024b). A lot of discussion has also centered on the removal of metal ions from wastewater due to their toxicity, nonbiodegradable nature, and relationship with health risks for all living things (Akther *et al*., 2022; ElSayed, 2018). Metal poisoning in humans has been associated with numerous health problems. Lead (Pb) affects neurological development, kidney function, and blood pressure, while cadmium (Cd) causes kidney damage, osteoporosis, and is carcinogenic. Chromium (Cr), particularly Cr (VI), is highly toxic, causing cancer and skin irritation. Copper (Cu) can lead to gastrointestinal issues, liver damage, and neurological disorders. Zinc (Zn), though essential in small amounts, can impair immunity and iron absorption when excessive. Manganese (Mn) exposure affects cognitive and neurological health, resembling Parkinson's disease (Akther *et al*., 2016; Haidar *et al*., 2023; Mollah *et al*., 2022).

Nowadays, Rajshahi City of Bangladesh is contaminated due to construction work, small industrialization, etc. Many industries can be found in Rajshahi City, such as manufacturing of paint and coatings, small-scale metal and craft industries, recycling of electronic trash, paint and coating manufacturing, tanneries and leather processing, automobile repair, battery production, maintenance, and recycling, and textile and apparel

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manufacturing. Herbicides, insecticides, and fertilizers used in agricultural production can cause heavy metals to leak into the soil and water (Shahriar *et al*., 2024c,d). In Rajshahi City, the maximum drainage system is connected with the Padma River, and contamination takes place in river water, and pollution occurs in the aquatic ecosystem.

Water from the Padma River is used for different purposes such as bathing, irrigation, navigation, fisheries, and recreation. Water is crucial for effective crop production, highlighting the essential role of irrigation in ensuring food safety and security. In Rajshahi City, irrigation water is primarily sourced from the groundwater, surface water, and the Padma River (Shahriar *et al*., 2023a). However, the existence of heavy metals in this water poses a serious threat to health as crops may absorb these metals and subsequently enter the food chain, directly affecting human health (Shariar *et al*., 2014). On the other hand, its drainage infrastructure is widely known, particularly in the communities surrounding it. The majority of this city's areas lack an organized system, and the majority of homes carelessly dump their trash into the city's existing drains (Haldar & Chakraborty 2011). This region's uneven drainage patterns create hazardous circumstances for the free passage of both liquid and solid waste and have a negative influence on the ecosystem (Islam & Islam, 2021).

This study aims to assess the concentrations of these heavy metals (Cu, Zn, Cd, Pb, Cr, and Mn) in the collected wastewater samples from open drainage channels across Rajshahi City. These heavy metals were chosen for their environmental and health relevance, as well as their common occurrence in urban and industrial effluents. The water supply of Rajshahi primarily relies on the Padma River. Various drains connect to the river, discharging both treated and untreated wastewater. This increases the possibility of contaminated water getting into the distribution network or irrigated land. By quantifying these pollutants, the research seeks to evaluate the potential risks posed to human populations, agricultural crops and livestock exposed through direct or indirect contact with polluted water. Such an assessment is crucial for devising effective mitigation strategies and promoting sustainable urban water management practices in rapidly developing cities like Rajshahi. By focusing on Rajshahi City as a case study, this research contributes to a deeper understanding of urban water pollution dynamics in similar developing regions. It underscores the urgent need for enhanced wastewater treatment infrastructure, improved waste management practices, and stringent environmental regulations to safeguard both human health and ecosystem integrity in metropolitan settings.

2. MATERIALS AND METHODS

2.1 Study Area

Bangladesh is a South Asian nation that is in the northwest of the Indian subcontinent, above the Bay of Bengal. Its coordinates are 20°34' to 26°38' N, longitude 88°01' to latitude 92°41' E. In Bangladesh, Rajshahi is a prominent urban, commercial, and educational hub and an established metropolis. Rajshahi is located in the Barind Tract, 23 meters (75 feet) above sea level, and at 24°22′26″N 88°36′04″E. The Padma River, which flows through the city's southern edge and has alluvial plains nearby, is where the city is situated. Paba Upazila, a district-level subdivision, forms its borders on the east, north, and west (Shahriar *et al*., 2023b). To provide drinking water for city dwellers, Rajshahi's Water Supply and Sewerage Authority (WASA) apply a traditional water purification system, distributing it through a pipeline network. Coagulation, flocculation, sedimentation, filtering, and chlorine disinfection are steps in the treatment operation. The water supply for irrigation and other domestic uses in Rajshahi primarily relies on the Padma River. Various drains connect to the river, discharging both treated and untreated wastewaters, thereby raising the possibility that irrigated land or the distribution infrastructure may be affected by contaminated water. Consequently, the sampling sites were chosen randomly.

Drainage wastewater samples were randomly collected from open drainage system in November 2023 to December 2023. The present study collected drainage wastewater samples randomly from four different location those are connected with Padma River which shown in the Figure 1 and tabulated in Table 1.

2.2 Sample Collection and Preservation

Drainage wastewater samples were collected from various distances around 12 points from different sides of Fultola, Talaimari, Padma Garden and Alupotti areas. Samples of water were kept in plastic containers.

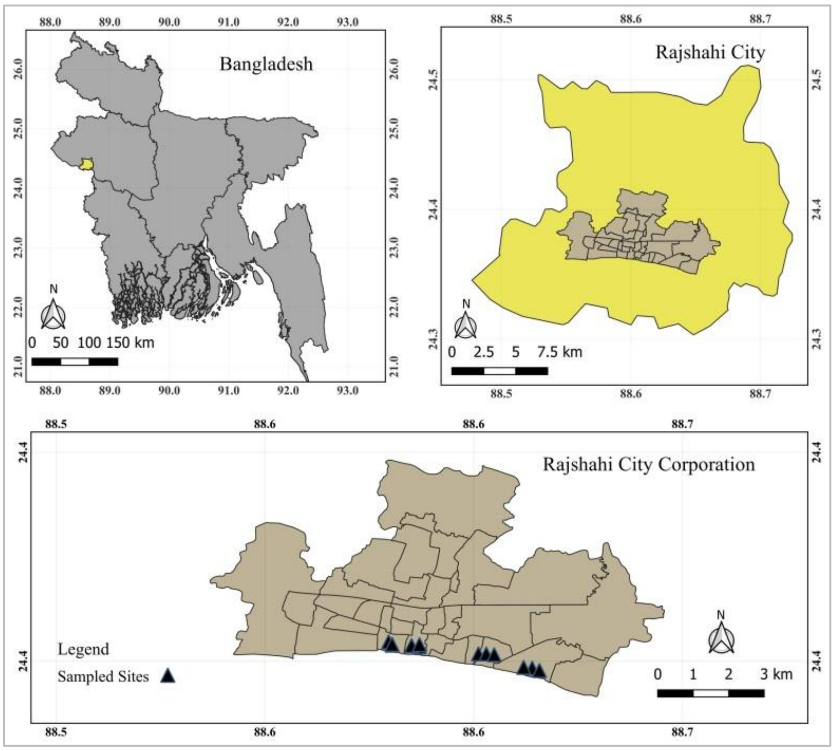

Figure 1: Location of the research area.

The collected samples were carefully stored. For metal analysis, samples were preserved in a 500ml plastic bottle. Diluted nitric acid was used to rinse the plastic bottles after they were properly cleaned, then with deionized (DI) water before use. Nitric acid concentrate was used to acidify a part of all the water samples that were collected (2 mL acid per liter of sample) at the time of collection to minimize fungus growth and metals adhering to the walls of the containers. Then samples were employed for metal analysis. The containers were labeled with the date, sample number and location information during sampling. The wastewater samples identification number are presented in Table 1.

Table 1: Drainage wastewater samples collection location

Sample ID No.	Location
W_1	Fultola (24°21’24.8"N 88°37’56.9"E)
W_2	Fultola (24°21’24.4"N 88°37’55.0"E)
W_3	Fultola(24°21’26.0"N 88°37’54.3"E)
W_4	Padma-garden(24°21’42.6"N 88°35’56.8"E)
W_5	Padma-garden(24°21’43.2"N 88°35’55.6"E)
W_6	Padma-garden(24°21’42.2"N 88°35’56.0"E)
W_7	Talaimari (24°21’35.4"N 88°37’15.6"E)
W_8	Talaimari (24°21’36.5"N 88°37’16.8"E)
W_9	Talaimari (24°21’35.8"N 88°37’14.6"E)
W_{10}	Alupotti(24°21'41.0"N 88°36'14.8"E)
W_{11}	Alupotti (24°21'41.8"N 88°36'14.2"E)
W_{12}	Alupotti (24°21'40.4"N 88°36'13.4"E)

2.3 Sample Digestion

In a beaker, 50 mL of wastewater sample was taken for acid digestion. Then 5 mL nitric acid (69%) was added in it. The total volume was heated avoiding boiling to about 20 mL. Following a room temperature cooling period, it was filtered away. The filtered sample put together with flask washing and was increased to 10 mL with DI water. The volume was then diluted in a volumetric flask with DI water to 100 mL (Shahriar *et al*., 2023a).

2.4 Analysis of Elements

At BCSIR, Dhaka, an atomic absorption spectrophotometer (Model No. AA-6300, Shimadzu) was used to quantify the concentrations of Zn, Cu, Cd, Cr, Pb, and Mn in the filtrate of digested wastewater samples. The instrument had a special metal lamp installed in it. Drift blanks and manually made standard solutions of the appropriate heavy metals were used to calibrate the device. All of the metals' standard stock solutions, containing 1000 parts per million (ppm), were acquired from Kanto Chemical Co. Inc. in Tokyo, Japan. To calibrate the device, these liquids were diluted to the appropriate concentrations. Table 2 lists the Shimadzu AA-6300 AAS's operational parameters and LOD.

Table 2: Operating Conditions and LOD of Shimadzu AA-6300 AAS

Element	Wavelength (nm)	Slit width (nm)	Lamp Current (mA)	Atomizer	LOD (mg/kg)
Pb	283.3	0.7	5.0	Flame	0.25
Cr	357.9	0.7	5.0	Flame	0.25
Cd	228.8	0.7	4.0	Flame	0.25
Cu	324.8	0.7	3.0	Flame	0.25
Zn	213.9	0.7	4.0	Flame	0.25
Mn	279.5	0.7	5.0	Flame	0.25

2.5 Data Analysis

The Statistical Package for Social Sciences (SPSS) for Windows (Version 20) was used to do the analysis, with a 0.1% significant level. The mean and standard deviation (SD) for the various measurements in the wastewater samples were calculated as part of the descriptive statistics.

2.6 Water Quality Assessment

The Environmental Conservation Rules (ECR) of Bangladesh (ECR, 1997) were used as a guide to compare the metal contents in the samples with the national guidelines for wastewater. Additionally, the heavy metal concentrations were compared to various reference levels, including the USEPA wastewater regulations and the WHO. To assess water quality, the metal index (MI), heavy metal pollution index (HPI), heavy metals evaluation index (HEI), degree of contamination (DC) and environmental water quality index (EWQI) were studied in this research.

2.6.1 Metal Index (MI)

Many indices are used in the assessment of water quality in order to determine the extent of pollution and any hazards related to heavy metals. The MI is one often used index. As a measure of water quality, the metal index (MI) compares the amounts of different metals to their respective maximum acceptable concentrations (MAC) values to determine the combined degree of pollution. Lower water quality is indicated by higher metal contents relative to their MAC values. MI is computed using Equation (Eq.) 1 below (Badeenezhad *et al*., 2023):

$$MI = \sum_{i=1}^{n} \frac{C_i}{MAC_i} \quad (1)$$

Where, C_i represents individual metal concentration and MAC_i stands as the maximum allowable concentration of individual metal. Compliance with safety regulations is stated when the MI is below 1. On the other hand, MI greater than 1 indicates that there may be health hazards associated with the water and that it should not be used for drinking or other purposes due to high metal concentrations (Mawari *et al*., 2022).

2.6.2 Heavy Metal Pollution Index (HPI)

Assessing the level of heavy metal pollution in water sources is made possible in a significant way by the HPI. It offers a thorough analysis of the existence and effects of certain heavy metals on the quality of water. Each heavy metal is given a weighting factor according to its toxicity and possible health hazards in order to calculate the HPI. These weighting factors, which represent the relative importance of every metal in contributing to the total pollution and its potentially harmful effects on human health and the surroundings, are established by rigorous scientific study and regulatory criteria. Usually, the HPI is computed using Eq. 2 (Badeenezhad *et al*., 2023; Reza & Singh, 2010).

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

The weighting factor (W_i) in the provided equation is allocated for every metal according to its toxicity and possible health hazards. The W_i for various metals are as follows: Cu = 0.001, Zn = 0.0002, Cd = 0.3, Cr = 0.02, Pb = 0.7, and Mn = 0.0002 (Badeenezhad *et al*., 2023). The ith parameter's sub-index value is represented by the Q_i, and the total number of parameters taken into consideration is shown by n. Equation 3 is used to calculate the Q_i for every parameter. (Badeenezhad *et al*., 2023; Hartiningsih *et al*., 2024):

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \times 100 \quad (3)$$

Where, M_i is the i-th sample's assessed metal concentration, The ideal concentration for the i-th parameter is denoted by I_i, which is, successively, 0.01, 0.05, 0.003, 2, 3, and 0 mg/L for Pb, Cr, Cd, Cu, Zn, and Mn. (Badeenezhad *et al*., 2023), S_i is the maximum or standard value that can be used for drinking water for the i-th parameter, taken from (ECR, 1997). Pb, Cr, Cd, Cu, Zn, and Mn have S_i levels of 0.05 mg/L, 0.05 mg/L, 0.005 mg/L, 1 mg/L, 5 mg/l and 0.1 mg/l respectively, for drinking water. (ECR, 1997). Indicating the numerical difference between these two integers, the symbol (−) does not account for the algebraic sign. (Badeenezhad *et al*., 2023). If the HPI value is less than 100, it means that there are no heavy metals in the water; if it is greater than 100, there may be heavy metal pollution. The HPI indicates the threshold for harmful contamination when it hits 100 (Baskaran & Abraham, 2022).

2.6.3 Heavy Metals Evaluation Index (HEI)

A statistical approach for determining the concentrations of heavy metals in water samples is the HEI. It is computed by summing the ratios of observed concentration (H_c) to every factor's maximum allowable concentration (H_{max}). The H_c is given in micrograms (μg) per liter (L) or (μg/l), while the upper limit value set for every particular heavy metal is indicated by the maximum allowable concentration (H_{max}). The HEI is computed using Eq. 4 (Badeenezhad *et al*., 2023).

$$HEI = \sum_{i=1}^{n} \frac{H_c}{H_{max}} \quad (4)$$

Where, H_c represents the i-th parameter's observed amount in μg/L, and H_{max} denotes, for the i-th parameter, the maximum allowable concentration in μg/L. For drinking water, the H_{max} values are 50, 50, 5, 1000, 5000, and 100 μg/L for Pb, Cr, Cd, Cu, Zn, and Mn, respectively (ECR, 1997). A heavy metal pollution level is considered low if the HEI value is less than 40, and intermediate contamination is suggested if the value ranges from 40 to 80. High levels of heavy metal pollution are indicated by HEI values exceeding 80, which pose serious hazards to the quality of water and perhaps human health (Badeenezhad *et al*., 2023).

Measured concentrations are compared to allowable limits in the HEI, which offers a clear evaluation as compared to the HPI. On the other hand, HPI provides a more intricate assessment by taking into account the relative toxicity of every element using predetermined weighting factors. While HPI provides a more comprehensive examination of pollution, taking into account differences in metal toxicity, HEI streamlines the assessment of regulatory compliance. Conversely, the MI is a useful tool for determining which metals offer the most health hazards since it assesses contamination severity directly. However, it may not always detect metals that are present at low enough concentrations to be dangerous. The regulatory environment and the specific assessment objectives will determine which of HEI and MI to use (Badeenezhad *et al*., 2023).

2.6.4 Degree of Contamination (DC)

The DC index is another tool that may be used to evaluate the level of heavy metal contamination in water samples. Several water quality metrics that are deemed detrimental for household use and would therefore have an impact on humans are compiled with the objective to determine the degree of contamination. For every examined sample of water, the DC value is computed independently by adding up the contamination factors of all the constituents that surpass the highest allowable value. It is computed using Eq. 5 and 6 (Low *et al*., 2016; Munkhsuld *et al*., 2024).

$$DC = \sum_{i=1}^{n} C_{fi} \quad (5)$$

$$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1 \quad (6)$$

Where, C_{fi} stands for the contamination factor of the i-th parameter, C_{Ai} represents the analytical value of the i-th parameter, and the maximum allowed level of the i-th component is denoted by C_{Ni}. It is supposed that the C_{Ni} and the H_{max} of the HEI are the same. Analytical readings that are less than the maximum allowable concentration value are not taken into account in the computation (Munkhsuld *et al*., 2024).

In general, lesser DC readings signify a lesser level of contamination, whereas higher DC values often suggest a higher level of contamination. The DC values obtained can be used to categorize water samples into three categories of pollution: low (DC < 1), medium (DC = 1-3), and high (DC > 3). These groups aid in determining the possible risks connected to the reported amounts by offering more information about the degree of contamination by heavy metal in the water samples (Badeenezhad *et al*., 2023).

2.6.5 Environmental Water Quality Index (EWQI)

Ali *et al*. (2017) presented the EWQI assessment, a new indicator. To estimate the EWQI, The first computation of the heavy metal toxicity index (HMTI) included multiplying the total score allocated by the Agency for Toxic Substances and Disease Registry's Toxicological Profiles of the Priority List of Hazardous Substances, by the contents of each heavy metal measured in this study (ATSDR, 2019). This is given below in Eq. 7.

$$HMTI = \sum_{i=1}^{n} C_{HM} \times TS_{HM} \quad (7)$$

Where, TS_{HM} stands for total score of a single heavy metal according to the guidelines of ATSDR (2019), with the following scores: Cr = 893, Pb = 1531, Mn = 797, Cu = 805, Cd = 1318, and Zn = 913. C_{HM} denotes the measured concentration of the corresponding heavy metal. Afterwards, the EWQI is determined using Eq. 8 (Zakir *et al*., 2020).

$$EWQI = \frac{HPI}{HMTI} \quad (8)$$

The EWQI readings fall into three categories: good quality (less than 0.2), medium quality (between 0.2 and 0.3), and lower quality (greater than 0.3). Higher levels are correlated with lower water quality (Sharmin *et al*., 2020).

3. RESULTS AND DISCUSSION

The levels of specific heavy metal concentrations (Cd, Cr, Pb, Mn, Zn, and Cu) in drainage wastewater samples from Rajshahi City were determined in this study. The suggested thresholds for the heavy metals under study as per the United States Environmental Protection Agency (USEPA), World Health Organization (WHO), Bangladesh (ECR and Department of Environment), the World Bank, and China (the National Standard of China and CMH) have been taken from and documented in the literature (Table 6).

Table 6: Recommended limits of studied heavy metals in drinking water, and wastewater as set by the WHO, USEPA, Bangladesh, China, and World Bank

Organization /Country	Variable Examined	Recommended limits for the studied heavy metals (ppm)						Reference
		Pb	Cr	Cd	Cu	Zn	Mn	
WHO	Drinking water	0.01	0.1 h	0.005	1.5	5	0.4	(Kinuthia *et al*., 2020); (WHO, 2011); (WHO, 2017)
	Wastewater (effluents)	0.01	0.05 h	0.003	NG	3	NG	(Kinuthia *et al*., 2020); (Aneyo et al., 2016)
USEPA	Drinking Water	0.05	0.1 t	0.005	1.3	5	0.0 5	(Kinuthia *et al*., 2020); (USEPA, 1992, 2023); (EPDA, 2020)
	Wastewater (effluents)	0.006	0.05 h	0.01	3	5	10	(Kinuthia *et al*., 2020); (EPDA, 2020)
Environmental Conservation Rules (ECR), Bangladesh	Drinking water	0.05	0.05 t 0.05 h	0.005	1	5	0.1	(ECR, 1997)
	Inland Surface Water	0.1	0.5 t 0.1 h	0.50	0.5	5	5	(ECR, 1997)
	Public Sewerage system	1.0	1.0 t 1.0 h	0.05	3.0	10	5	(ECR, 1997)
China (Chinese Ministry of Health; and The National Standards)	Drinking water	0.01	0.05 h	0.005	1.0	1.0	0.1	(CMH, 2006)
	Wastewater (effluents)	1.0	0.5 h	0.03	NG	NG	NG	(Kinuthia *et al*., 2020)
World Bank	Wastewater (effluents)	0.1	0.5 t	0.1	0.5	NG	NG	(Kinuthia *et al*., 2020; World Bank, 2007)

Note: NG stands for Not Given; t = as total Cr; h = as hexavalent Cr; ppm implies mg/kg or mg/L.

3.1 Level of Heavy Metals in Wastewater

Lead: The samples gathered had Pb values ranging from 0.0272 mg/L to 0.3376 mg/L. Sample W5 from Padma Garden contained the maximum value, 0.3376 mg/L, while the lowest concentrations of 0.0272 mg/L were found in samples W_7 and W_{11} from Talaimari and Alupotti, respectively. The results indicated that the large drains located at Padma Garden are burdened with substantial amounts of garbage from city residents and market waste (including batteries, metal plating, paint additives, etc.), as well as vegetable waste. These factors contribute to the higher concentration of metals at the study site. According to the ECR of Bangladesh, the recommended limit for Pb in wastewater (public sewerage system) is 1.00 mg/L (ECR, 1997). In contrast, recommended limits have been established by the USEPA and the WHO, respectively, at 0.006 and 0.01 mg/L. (Table 6). All samples in this study had Pb concentrations lower than the suggested upper limit set by the ECR of Bangladesh. However, all samples exceeded the recommended level set by the WHO and the USEPA. This suggests that untreated drainage wastewater can contaminate crop production with heavy metals and the food chain if proper wastewater management practices are not implemented. Uddin & Alam (2023) investigated the health risks associated with elevated heavy metal concentrations at the textile industry's wastewater discharge locations in Bangladesh's Tongi, Dhaleshwari and Shitalakkhya which receive effluents from wastewater treatment plants. They identified Pb concentrations ranging between 0.08 and 0.12 mg/L.

Table 7: Metal concentration (mg/L) in drainage wastewater samples

Sample Id No.	**Pb**	**Cr (total)**	**Cd**	**Cu**	**Zn**	**Mn**
W_1	0.244±0.0008*	0.078±0.0012*	0.008±0.0004*	0.115±0.0008*	0.131±0.0008*	0.519±0.0004*
W_2	BDL	0.021±0.0014*	0.003±0.0002*	0.227±0.0032*	0.121±0.0008*	0.295±0.0016*
W_3	0.143±0.0004*	BDL	BDL	0.099±0.0008*	0.03±0.0014*	0.485±0.0004*
W_4	0.205±0.0006*	BDL	0.005±0.0006*	0.123±0.0008*	0.011±0.0008*	0.701±0.0004*
W_5	0.337±0.0010*	0.134±0.0006*	0.010±0.0008*	0.123±0.001*	0.0012±0.0004*	0.381±0.0004*
W_6	0.244±0.0008*	0.150±0.0010*	0.014±0.0004*	0.060±0.0004*	0.083±0.0008*	0.760±0.0092*
W_7	0.027±0.0004*	0.064±0.0006*	0.016±0.0008*	0.080±0.0008*	0.243±0.0008*	0.130±0.0006*
W_8	BDL	0.121±0.0006*	0.012±0.0006*	0.076±0.0006*	0.038±0.00018*	0.462±0.0004*
W_9	0.104±0.0002*	0.136±0.0007*	BDL	0.072±0.0012*	0.029±0.001*	0.124±0.0006*
W_{10}	0.050±0.0004*	BDL	BDL	0.115±0.0006*	0.016±0.0004*	0.106±0.0012*
W_{11}	0.027±0.0008*	0.150±0.0006*	0.006±0.0004*	0.082±0.0006*	0.026±0.0016*	0.280±0.0012*
W_{12}	0.127±0.0002*	0.193±0.0004*	0.014±0.0006*	0.092±0.0002*	0.012±0.0006*	0.096±0.0022*
Max	0.337	0.150	0.016	0.227	0.243	0.760
Min	0.027	0.021	0.003	0.060	0.011	0.096
Avg.	0.152	0.116	0.0097	0.106	0.062	0.362
SD	0.105	0.052	0.0043	0.0440	1.390	0.229
%RSD	69.26	45.16	44.44	41.42	60.78	63.21
RL^a	1.00^a	1.00 (as total or hexavalent)	0.05	3.00	10.00	5.00
RL^b	0.006	0.05 (as hexavalent)	0.01	3.00	5.00	10.00

Note: Max = maximum, Min = minimum, Avg. = average, SD = standard deviation, %RSD = relative standard deviation. RL^a = recommended limits for wastewater (public sewerage system) set by (ECR, 1997), RL^b = recommended limits for wastewater (effluents) set by USEPA (EPDA, 2020; Kinuthia et al., 2020). Values expressed as means ± SD of the analysis of one independent sample analyzed in triplicate (n=3). *p value at < 0.001 was used to indicate significant differences.

Conversely, (Rafiquel *et al*., 2016) assessed contamination levels in the Kushtia industrial region of Bangladesh and found that Pb concentrations were within the standard limits set by the ECR. Hasan *et al*. (2020) conducted a detailed assessment of eleven heavy metals in effluent discharged from a CETP (central effluent treatment plant) into the Dhaleshwari River, Bangladesh. They identified significant heavy metal contamination, including Pb, and concluded that there is insufficient or ineffective operation of the CETP. Studies have shown that Pb levels in major Bangladeshi rivers are exceeding the recommended limits for irrigation water, as reported by (Islam *et al*., 2018). Researches from various parts of the world have reported diverse levels of Pb contamination in wastewater. For instance, Otieno *et al*. (2022) in Kenya measured Pb concentrations in factory wastewater varying between 0.318 and 0.326 mg/L, exceeding the standards set by the WHO and the USEPA (Table 6). Similarly, Mulugeta & Tibebe (2019) in Ethiopia identified maximum Pb levels in textile industry effluents reaching 0.85 mg/L, surpassing WHO and USEPA permissible limits. Conversely, Khan et al. (2023) conducted a study in effluents from the Hayatabad Industrial Estate, Peshawar, reporting mean Pb contents of 0.046 to 0.096 mg/L in industrial wastewater, consistently exceeding the WHO and the USEPA standards. Additionally, Kinuthia *et al.* (2020) studied Pb levels at eight sites in Kenya, finding an average concentration of 0.01362 mg/L, which exceeded WHO and USEPA recommended limits for Pb in wastewater. Furthermore, Bakare & Adeyinka, (2022) observed Pb concentrations in effluent samples spanning from 0.295 to 0.303 mg/L. These concentrations also surpassed the recommended values set by the USEPA and the WHO for Pb in wastewater. Moreover, Dagne (2020) found Pb concentrations between 1.98 to 3.11 mg/L in the Eastern Industrial Zone, Central Ethiopia, which were higher than the recommended limits. Conversely, Hailu & Nibret (2023) studied Pb levels in the Oromia region, Ethiopia, falling between 0.001 to 0.006 mg/L, which were within the acceptable ranges. These findings highlight the global variability in Pb contamination levels in industrial wastewater and underscore the dire need for stringent regulatory measures and effective wastewater treatment techniques to mitigate environmental and health risks. The concentrations of selected heavy metals (Cd, Cr, Pb, Mn, Zn, and Cu) in drainage wastewater are detailed in Tables 7.

Chromium: The total Cr content in the analyzed wastewater samples varied between 0.021 and 0.1936 mg/L. The maximum level (0.193 mg/L) was observed in sample W_{12} from Alupotti, while the lowest concentration (0.0212 mg/L) was found in sample W_2 from Fultola. The recommended limits for Cr in wastewater (effluents) are 1.0 mg/L (total or hexavalent) according to the ECR, and 0.05 mg/L (hexavalent) according to both the WHO and USEPA (Table 6). In this study, all samples were within the ECR recommended limit, but 66.67% went beyond WHO and USEPA guidelines. Therefore, the studied wastewater may contribute to Cr contamination in river water, irrigation water, and the food chain if proper treatment or management is not implemented before discharge. Uddin & Alam, (2023) examined Cr levels in Bangladesh's Dhaleshwari, Tongi and Shitalakkhya rivers, which consume wastewater treatment plant effluents. They found Cr concentrations in the Dhaleshwari River exceeding the standard limit (Table 6), with levels ranging from 9.29 to 12.03 mg/L and an average of 10.514 mg/L. Corresponding Cr values were observed in the Dhaleshwari River by Hasan *et al*., (2020). The high Cr concentrations are attributed to untreated wastewater discharged from nearby tanneries, which increased significantly after the tanneries were relocated in Savar from Old Dhaka, near the Dhaleshwari River. Considering the widespread usage of Cr sulfate salts in the leather manufacturing process, Cr contamination is prevalent in the leather sector (Uddin & Alam, 2023). Rafiquel *et al*. (2016) investigated the pollution of wastewater in Bangladesh's industrial Kushtia area and found Cr concentrations below the detection limit of their equipment. Various studies have reported Cr levels in major Bangladeshi rivers exceeding the recommended limits for irrigation water (Islam *et al*., 2018). Worldwide, similar investigations have been carried out. Hailu & Nibret (2023) found Cr levels varying from 0.001 to 0.045 mg/L in wastewater in Oromia Regional State, Ethiopia, which are within the recommended limits (Table 6). Similarly, Kinuthia *et al.* (2020) reported Cr values between 0.0007 and 0.0507 mg/L in wastewater from open drainage channels in Nairobi, Kenya. Kaur *et al*. (2021) found Cr levels between 0.05 and 0.06 mg/L in discharge from Ludhiana, Punjab, India. High Cr concentrations at wastewater discharge points are a global issue, not limited to Bangladesh. Cr levels in wastewater samples in Durban, South Africa, were found to range from 0.119 to 128 mg/L by Bakare & Adeyinka, (2022). Edori & Friday (2018) reported Cr levels in effluent discharge sites into the New Calabar River in Port Harcourt, Nigeria with a mean of 1.78 mg/L. Dagne (2020) found Cr levels varying between 0.20 and 1.04 mg/L in wastewater around the Eastern Industrial Zone in Central Ethiopia. Khan *et al.* (2023) found a maximum Cr concentration of 0.541 mg/L in effluents from the Hayatabad Industrial Estate, Peshawar. Dan'azumi & Bichi (2010) obseved mean Cr concentrations of 2.297 mg/L during dry season and 1.634 mg/L during wet season in industrial effluent discharge into the Challawa River, Kano, Nigeria. The results of all these studies exceeded the recommended limits for Cr in wastewater (Table 6).

Cadmium: The Cd concentration of the wastewater samples that were analyzed was between 0.0032 to 0.0156 mg/L. The maximum amount found in sample W_7 which indicated the location Talaimari and lowest concentration found in W_2 which indicated the location Fultola. The recommended level of Cd for Public

Sewerage system set by the WHO, USEPA and ECR are 0.003, 0.01 and 0.05 mg/L respectively. According to this investigation, 66.67% of the samples exceeded the recommended level set by the WHO, whereas 33.33% cross the USEPA guidelines. All the studied samples found within the recommended limit set by the ECR. Few are below detection limit of machine. These findings revealed that studied sample may contribute in Cd contamination in food chain if proper treatment in not taken before discharge in the river. This result can be compared with other researches of Bangladesh and worldwide. A study found Cd in effluents from wastewater treatment plants in between 0.014–0.018 mg/L which surpasses the upper range of the WHO and USEPA standard (Uddin & Alam, 2023). Rafiquel *et al.* (2016) investigated the amount of Cd in wastewater in Bangladesh's Kushtia industrial zone and found below detection limit of machine. Hasan *et al.* (2020) found Cd cancentration within the recommended limit in effluent discharged from a CETP into the Dhaleshwari River, Bangladesh. Several studies have consistently found varying levels of Cd in river waters across Bangladesh (Islam *et al.*, 2018). The Hayatabad Industrial Estate in Peshawar has effluents with a highest level of Cd which is 0.077 mg/L, according to Khan *et al.* (2023). Bakare & Adeyinka (2022) found that effluent samples in Durban, South Africa, had Cd values ranging from 0.179–0.761 mg/L. The effluent from Ludhiana, Punjab, India, had Cd values between 0.001 to 0.004 mg/L, according to (Kaur *et al.*, 2021). Kinuthia *et al.* (2020) discovered that the quantities of cadmium in wastewater collected from open drainage channels in Nairobi, Kenya, range from 0.00308 to 0.00812 mg/L. The New Calabar River in Port Harcourt, Nigeria, has Cd levels at its effluent discharge sites, according to an article from Edori & Friday (2018), with a mean range of the levels was 0.03 – 0.28 mg L. Dagne (2020) discovered that wastewater in Central Ethiopia's Eastern Industrial Zone contains Cd values varying from 0.04 to 0.08 mg/L. All of these studies' findings were higher than the WHO's established limits for Cr in wastewater (Table 6).

Copper: The concentration of Cu in wastewater samples varied between 0.06 and 0.1158 mg/L. The highest levels were found in samples W_{10} and W_1, from Alupotti and Fultola respectively, while the lowest concentration was found in sample W_6 from Padma Garden. While the WHO has not specified a limit, the USEPA and the Environmental Conservation Rules (ECR) of Bangladesh recommend a limit of 3.00 mg/L for Cu in wastewater effluents (Table 6). This study found that all the samples contained Cu concentrations well below the permissible limits, indicating that the wastewater is safe for discharge into river streams. Similar results have been observed in other research. Uddin & Alam (2023) examined heavy metal concentrations in the wastewater treatment plant effluent of Tongi, Dhaleshwari and Shitalakkhya. They reported an average Cu concentration of 0.114 mg/L, which is below the ECR and USEPA limits. Another study by Rafiquel *et al*. (2016) found Cu concentrations varying from 1.33 to 1.58 mg/L in wastewater from the Kushtia industrial region of Bangladesh. Hasan *et al*. (2020) stated a maximum Cu level of 0.01 mg/L in effluents discharged into the Dhaleshwari River, Bangladesh from a central effluent treatment plant. Both studies reported Cu levels below the recommended limits (Table 6). Research from various parts of the world has shown diverse levels of Cu contamination in wastewater. Dagne (2020) found mean Cu concentrations varying from 0.30 to 0.99 mg/L in the Eastern Industrial Zone, Central Ethiopia. Hailu & Nibret (2023) studied Cu levels in the Oromia region, Ethiopia, and found concentrations spanning from 0.001 to 0.200 mg/L. Kaur *et al*. (2021) reported Cu levels between 0.02 and 0.03 mg/L in effluents from Ludhiana, Punjab, India. Cu values in effluent discharge points into the New Calabar River, Port Harcourt, Nigeria, ranged from 0.035 to 1.22 mg/L, according to (Edori & Friday, 2018). Dan'azumi & Bichi (2010) found mean Cu concentrations of 0.727 mg/L in the wet season and 1.290 mg/L in the dry season in industrial effluent discharge into the Challawa River, Kano, Nigeria. All these studies reported Cu concentrations within the recommended limits (Table 6). Overall, the Cu concentrations in wastewater found in this study do not exceed the recommended limits and may be considered safe for discharge into river streams.

Zinc: The Zn concentration in the studied wastewater samples varies from 0.0012 to 0.2438 mg/L. The maximum amount was found in sample W_7 from Talaimari, while the lowest was found in sample W_5 from Padma Garden. The WHO, USEPA, and ECR of Bangladesh have suggested limits of 3 mg/L, 5 mg/L, and 10 mg/L, respectively, for zinc in wastewater effluents (Table 6). All the samples in this study contained Zn concentrations well below these permissible limits, indicating that the selected samples are safe from Zn toxicity and can be discharged into river streams without posing a risk. This finding aligns with other research conducted in Bangladesh and worldwide. (Uddin & Alam, 2023) reported the level of zinc in wastewater treatment plant effluents that discharge into the Tongi, Shitalakkhya, and Dhaleshwari rivers ranged from 0.97 to 1.02 mg/L. (Hasan *et al*., 2020) found Zn concentrations spanning from 0.01 to 0.18 mg/L in wastes dumped into Bangladesh's Dhaleshwari River from a central effluent treatment plant. Similarly, (Sarker *et al*., 2015) reported Zn level ranging from 0.20 to 1.00 mg/L in wastewater from textile and garment industries in the Bhaluka industrial area, Mymensingh, Bangladesh. All these studies reported Zn levels within the recommended limits. Globally, (Khan *et al*., 2023) found Zn concentrations in effluents from the Hayatabad Industrial Estate in Peshawar varied between 0.003 and 1.904 mg/L. (Bakare & Adeyinka, 2022) reported Zn values ranging from 0.133 to 0.341 mg/L in effluent samples from Durban, South Africa. (Kaur *et al*., 2021) found the amount of Zn ranging from 0.02 to 0.13 mg/L in effluent from Ludhiana, Punjab, India. Zn concentrations in wastewater from the Eastern Industrial Zone of Central Ethiopia ranged from 0.07 to 0.21 mg/L, according to (Dagne, 2020). Additionally, Dan'azumi & Bichi (2010) reported mean Zn concentrations of 2.230 mg/L in the wet season and 2.986 mg/L in the dry season in industrial effluents discharged into the Challawa River, Kano, Nigeria. All these studies reported Zn concentrations below the established limits for Zn in wastewater (Table 6). Overall, the results indicate that the effluent samples have negligible levels of zinc contamination, which is unlikely to cause further contamination in the receiving surface waters.

Manganese: The investigated wastewater samples had Mn concentrations spanning 0.0960 to 0.7604 mg/L. The maximum concentration was found in sample W_6 from Padma Garden, while the lowest was in sample W_{12} from Alupotti. The recommended limits for Mn in wastewater are 10.0 mg/L according to the USEPA and 5.0 mg/L in accordance with Bangladesh's ECR, though the WHO does not specify a limit (Table 6). All samples in this study were below these permissible limits, suggesting that the wastewater is safe for discharge into river streams and is not a significant source of Mn contamination. Similar results have been reported in other studies. (Uddin & Alam, 2023) found Mn values varying from 0.015 to 0.108 mg/L in effluents from wastewater treatment plants discharging into the Tongi, Shitalakkhya, and Dhaleshwari rivers of Bangladesh, all within the recommended limits. Mn concentrations were found by (Rafiquel *et al.*, 2016) to be between 0.68 and 0.72 mg/L in wastewater from the Kushtia industrial region of Bangladesh, while (Akter *et al.*, 2010) found Mn concentrations between 0.0305 and 3.558 mg/L in Sirajganj, Bangladesh's Belkuchi industrial effluents. All these concentrations were below permissible limits (Table 6). Internationally, research has shown varied Mn levels in wastewater. Hailu & Nibret (2023) observed that the range of Mn levels was 0.013 to 0.045 mg/L in the Oromia region, Ethiopia. Dan'azumi & Bichi (2010) found mean Mn concentrations in the dry season, 2.054 mg/L and in the rainy season, 2.013 mg/L in industrial effluents discharged into the Challawa River, Kano, Nigeria. Mulugeta & Tibebe (2019) identified Mn levels in textile industry effluents spanning from 0.25 to 0.37 mg/L in Ethiopia. All these studies reported Mn concentrations within the recommended limits (Table 6). Thus, Mn levels in wastewater are generally within permissible limits and do not indicate significant contamination.

3.3 Water Quality Assessment

Table 9 presents the MI, HPI, and HEI of the studied drainage wastewater samples. The MI evaluates metal concentrations in relation to their MAC values to determine the extent of contamination directly. This technique works especially well for locating metals that greatly beyond regulatory limits. The study revealed that all samples have MI values greater than 1, indicating elevated metal concentrations. Consequently, these wastewater samples require treatment to reduce metal contamination before being discharged into secondary water bodies.

Table 9: The MI, HPI, and HEI of studied drainage wastewater samples

Sample Id No.	MI	HPI							HEI
		Pb	Cr	Cd	Cu	Zn	Mn	Overall HPI	
W_1	13.371	335.326	0	61.415	-0.154	0.023	8.499	405.109	13.371
W_2	4.221	BDL	0	0	-0.145	0.023	4.831	4.709	4.221
W_3	7.815	190.591	0	BDL	-0.155	0.024	7.943	198.395	7.815
W_4	12.235	279.438	0	24.566	-0.153	0.024	11.481	315.355	12.235
W_5	15.353	468.596	0	85.981	-0.154	0.025	6.239	560.688	15.353
W_6	18.357	335.325	0	135.113	-0.159	0.024	12.447	482.751	18.357
W_7	6.449	24.361	0	159.679	-0.157	0.023	2.129	186.035	6.449
W_8	18.702	BDL	0	110.547	-0.158	0.016	7.566	117.980	18.702
W_9	6.118	134.703	0	BDL	-0.154	0.024	2.031	136.601	6.118
W_{10}	2.178	57.321	0	BDL	-0.154	0.024	1.736	58.927	2.178
W_{11}	7.627	24.361	0	36.849	-0.157	0.024	4.586	65.663	7.627
W_{12}	10.254	181.993	0	135.113	-0.156	0.024	1.572	304.216	10.254

The HPI provides a thorough evaluation by accounting for metal toxicity using preset weighting factors that are based on substantial scientific research and legal requirements. This approach takes into account the relative toxicity of each metal to produce a more sophisticated assessment of contamination. Findings indicated that 75.0% of the sample sites are contaminated with heavy metals, as the overall HPI exceeds 100. The individual HPI identifies the specific metals responsible for the elevated overall HPI (Table 9). The HEI values for all wastewater samples were lower than 40, indicating a low contamination level with heavy metals. Although the MI is quite good at identifying metals that greatly exceed permitted levels, the HPI offers a more comprehensive assessment. This makes HPI accurate in capable of correctly identifying metals with different degrees of toxicity and how they contribute to pollution in general (Badeenezhad *et al.*, 2023; Goher *et al.*, 2014).

Table 10 presents the DC in wastewater sample, which spans from 0.06 to 18.46. Based on the DC values, sample W_{10} is categorized as low-level contamination (DC < 1), whereas samples W_2 and W_7 are categorized as medium-level contamination (DC = 1-3), and 75% of the samples are classified as high-level contamination (DC > 3). According to Badeenezhad *et al*. (2023) water contamination levels vary in regions, with high, medium, and low levels observed in 25%, 7.5%, and 67.5% of regions during the wet season and 40%, 2% and 55% during dry season. In the study of (Mahfooz *et al*., 2020), the degree of contamination was much higher than the maximum contamination level (≥ 3) in industrial effluent (33.85) and sewage effluent (14.05). Table 10 also displays the computed HMTI and EWQI values. The values of HMTI varied between 268.215 and 1079.583. Both the HPI and HMTI indices are integrated in the EWQI computation. The computed EWQI values ranged from 0.008 to 0.743. Higher EWQI values indicate poorer water quality. With a few exceptions, the EWQI readings from this study exhibited patterns that were nearly identical to those of other water quality metrics. Table 10 makes clear that 50% of the sample is over 0.3, 25% of the sample is between 0.2 and 0.3, and 25% is below 0.2. This shows that the majority of the sample had lower-quality water. These results show a good enough correlation with the study by Sharmin *et al*. (2020), in which 76% of the samples had EWQI values greater than 0.2. The EWQI values in surface and groundwater samples were determined by Zakir *et al*. (2020) and ranged from 0.04 to 3.54 with a mean value of 0.43.

Table 10: The DC, HMTI and EWQI of studied drainage wastewater samples

Sample Id No.	DC	HMTI	EWQI
W_1	18.46	1079.583	0.375
W_2	1.95	551.03	0.008
W_3	5.71	712.563	0.278
W_4	9.11	988.2	0.319
W_5	11.23	1052.5566	0.533
W_6	14.28	650.045	0.743
W_7	2.78	509.446	0.365
W_8	6.44	594.645	0.198
W_9	3.04	463.937	0.294
W_{10}	0.06	268.215	0.219
W_{11}	4	496.103	0.132
W_{12}	6.2	546.767	0.556

This study's findings reveal substantial heavy metal contamination in wastewater, threatening public health and the environment. These findings highlight the necessity of including water quality monitoring into urban planning frameworks. Local authorities could utilize these findings to enforce more stringent restrictions for industrial and home wastewater management. Furthermore, the data provided can inform the development of targeted initiatives, including the enhancement of drainage systems and the prioritization of high-risk locations for remediation. By tackling these concerns, governments can alleviate the detrimental impacts of wastewater contamination on human and ecological systems.

4. CONCLUSIONS

This study revealed significant heavy metal contamination in wastewater samples from Rajshahi City's open drainage channels. The Padma River, the primary water source, receives both treated and untreated wastewater, influencing the random selection of sampling sites. Cr, Zn, Cu, Pb, Mn and Cd had average concentrations of 0.116, 0.0616, 0.106, 0.152, 0.362 and 0.0097 mg/L, respectively, in wastewater. Mean Cr, Pb, and Cd contents in wastewater were higher than USEPA and WHO limits, whereas Cu, Zn and Mn levels were within permissible limits. Notably, some sites showed undetectable amounts of Cd, Pb, and Cr. The HPI and MI results revealed significant contamination, with Cd being a major contributor to the elevated HPI values, although HEI values indicated low contamination levels with heavy metals. DC values showed that 75% of the samples were highly contaminated, while EWQI results further confirmed degraded water quality in half of the samples. The presence of domestic cattle scavenging from the channels suggests potential human exposure pathways. Identified pollution sources include household, market, and roadside waste. Although Rajshahi is not a major industrial city, ongoing pollution could worsen the Padma River's ecological condition. An appropriate management plan, improved sewage treatment, and sufficient dilution flow are essential to mitigate metal contamination. Continuous monitoring, public education on health hazards, and further research on heavy metal bioaccumulation in the river's aquatic life are recommended to address these environmental challenges effectively.

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