International Journal of Medical Toxicology & Legal Medicine Volume 27, No. 4S, 2024
e-ISSN: 0974-4614
p-ISSN: 0972-0448
https://doi.org/10.47059/ijmtlm/V27I4S/067

Evaluation of Heavy Metal Levels and Water Quality Index of Al-Diwaniyah River

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Received: 10.09.2024 Revised: 18.10.2024 Accepted: 24.11.2024

ABSTRACT
The growing global concern for heavy metal contamination highlights its significant threat to both human health and the environment. The Al-Diwaniyah River, a crucial freshwater source for a large population in Iraq, has been increasingly polluted due to rapid urbanization and industrial activities over recent decades. Compounding the issue, the unstable economic situation in Iraq has led to inadequate monitoring of the river's water quality in many critical areas. This study aimed to address this gap by conducting a thorough analysis of heavy metal concentrations (Pb, Cd, Zn, Fe, Cu) and the overall water quality of the Al-Diwaniyah River. Four strategically selected sampling sites were chosen based on their proximity to agricultural, urban, and industrial activities along the riverbank. Samples of both water and sediment were collected during summer 2023 and winter 2024. Heavy metal concentrations were determined using atomic absorption spectroscopy, while physical and chemical properties were assessed using a water analysis kit. The results reveal a higher concentration of heavy metals during the summer months compared to winter, with site 4, located near rubber and textile factories, showing the highest levels of contamination. Conversely, site 1 had the lowest heavy metal concentration. The water quality index (WQI) mirrored these findings, with site 4 exhibiting the poorest water quality (WQI of 767-1374), and site 2 showing better quality (WQI of 343-494). The overall WQI for the river was found to be 840 in summer and 384 in winter, indicating that the river is heavily polluted. Consequently, the water from the Al-Diwaniyah River is unsuitable for drinking without extensive treatment.

Keywords: Al-Diwaniyah River; heavy metals; water quality index, surface water, river sediment

1. INTRODUCTION

The quality of water is a significant problem for humanity, as it is the essential resource for survival (Kozicki & Baiyasi, 2019). In recent decades, water resources have been increasingly polluted by hazardous chemical substances as a result of the expanding human presence near rivers (du Plessis, 2019). Heavy metals are a significant type of pollutants that pose a global problem due to their ability to stay in soils and water for extended periods [3, 4]. This persistence leads to an increase in geo-ecological risks and disrupts normal biogeochemical cycles. Human activities, such as agriculture, mining, industrial processes, and urbanization, result in the production and discharge of significant quantities of heavy metals into water bodies [5, 6]. These metals accumulate in sediments and become increasingly concentrated as they are passed throughout the food chain, a process known as biomagnification.

Heavy metals present a substantial environmental hazard worldwide. Marine fish possess the capacity to acquire hazardous metals not just from the water and sediment around them, but also from the food they consume (Agbugui & Abe G O, 2022). A recent study found that canned sardines sourced from Brazil had an average lead (Pb) level of 2.15 mg/kg (Leite et al., 2022). In a similar vein, a separate study carried out in the south-western region of Nigeria discovered that European pilchard contained an average concentration of 0.19 mg/kg of cadmium (Cd) (Olusola & Ademola Festus, 2015). Leung et al. (Leung et al., 2014) found that tilapia supplied from the Pearl River Delta in China had an average lead (Pb) level of 8.62 mg/kg. These studies collectively suggest that marine fish may be contaminated by heavy metals. Prolonged and excessive contact with heavy metals and metalloid elements has widely recognized harmful effects on human health [11, 12, 13]. Cadmium (Cd), commonly present as inorganic compounds with a +2 oxidation state, has the ability to pass through different biological membranes and cause neurological diseases, carcinogenic consequences, and skeletal weakening and deformities (Nawrot et al., 2010). Extended exposure to mercury (Hg) has a detrimental impact on the pituitary gland and liver, affecting the functionality of the immune system [15, 16]. Lead (Pb) has been associated with neurological disorders, hematological impacts, kidney failure, high blood pressure, and cancer [17-20]. Hence, it is justifiable to suggest that the ingestion of marine fish polluted with heavy metals has potential health hazards.

Global concerns over heavy metal contamination are widespread due to the detrimental effects they have to humans, animals, plants, and the whole ecosystem [21, 22]. Heavy metals are prevalent environmental contaminants due to their poisonous, persistent, and non-biodegradable nature. In light of these issues, a multitude of research has concentrated on the issue of water scarcity and the decline in favorable water quality [23, 24]. Most of the heavy metals present in rivers' aquatic environment are in solid form and persist as insoluble substances for an extended period (Reza & Singh, 2010). As a result, these metals tend to accumulate on the river bed, where sediments possess the capacity to absorb metals into their particles. Sediment quality is recognized as a significant indicator or geo-marker of water pollution (Al-Asadi & Al-Kafari, 2022). Specifically, there are times when the levels of heavy metals in water fall below the detectable thresholds. Nevertheless, these metals are not permanently attached to the particles of benthic sediments as they are redistributed throughout the sediments and water column due to fluctuations in environmental circumstances (Haynes & Zhou, 2022). Contaminated bed sediments can serve as secondary non-point sources of heavy metals, releasing them into the water column and causing substantial harm to the aquatic system (Ismukhanova et al., 2022).

Due to the prevailing arid desert climate, the Al-Diwaniyah River serves as the primary freshwater source for the Al-Qadisiyah province (Walli et al., 2018). It is utilized for a range of reasons, such as home water supply, agriculture, and industrial applications. In addition to the river water, there is an influx of untreated wastewater due to numerous human activities. Therefore, it is necessary to monitor and evaluate the pollution levels in the river water and its sediments in order to effectively regulate the introduction of contaminants into the river. By doing so, it will help reduce the presence of dangerous concentrations and prevent them from reaching toxic levels. Only a limited number of researches have examined the presence of heavy metals in the Al-Diwaniyah River (Al Asadi et al., 2023). Nevertheless, certain crucial metals have still to be scrutinized. Consequently, there is a severe lack of data on heavy metals in the river, making it difficult to assess water quality. In order to address this study deficiency, it is imperative to quantify the levels of heavy metals in the River ecosystem in order to identify their various origins.

Due to Iraq's abundance of petroleum resources, the growth of petroleum production, construction of electric power plants, and rise in vehicle usage has led to the buildup of heavy metals in river sediments [30, 31]. A research investigation carried out in Nasiriyah, a city situated to the south of Baghdad, has revealed the existence of specific toxic elements (Copper, Cadmium, Nickel, and Lead) in both the river and the drinking water (Al-ameer et al., 2020). The study also emphasized the significant risk of elevated levels of lead (Pb) in all water samples, as well as a minor concern over the presence of nickel and cadmium (Al-ameer et al., 2020). In addition, a study examining the levels of heavy metals in the Shatt Al-Arab River in southern Iraq revealed that there were no notable connections between the concentrations of heavy metals and variations in seasons (Al-Asadi et al., 2020). The Euphrates River in Iraq is extensively researched for its high levels of heavy metal toxicity in freshwater and river fishes (Hasham & Ramal, 2022). Therefore, Fallujah and Al-hiti (Fallujah & Al-hiti, 2015) conducted a study to analyze the amounts of soluble heavy metals in several locations along the Euphrates River, specifically in Al-Hindia, Al-Kifl, Kufa, and Al-Mussaib Channel. The results unveiled different levels of concentration and a distinct sequence of heavy metals in each site. The Euphrates waterways stations revealed an ascending sequence of heavy metal concentrations, with Cd being the highest, followed by Co, Ni, Pb, and Fe (Fallujah & Al-hiti, 2015). In the Al-Mussaib Channel, the heavy metal concentrations were found to decrease in the following order: lead (Pb) < nickel (Ni) < copper (Cu) < chromium (Cr) < manganese (Mn) < zinc (Zn) (Fallujah & Al-hiti, 2015). This implies that the levels of heavy metals vary not just among different locations along the Euphrates River, but also in terms of the specific types of heavy metals found.

These studies suggest that the presence of high levels of heavy metals in the water channels of the majority of Iraqi rivers is caused by human activities, both residential and industrial, in the surrounding areas. Hence, the primary objectives of this study are as follows: (1) determine the concentration of five heavy metals in water of Al-Diwaniyah River at summer and winter season (2) determine the concentration of five heavy metals in surface sediments of Al-Diwaniyah River at summer and winter season, and (3) determine the water quality index (WQI) of Al-Diwaniyah River at summer and winter season.

2. MATERIALS AND METHODS

2.1 Selecting Sampling Sites

The Al-Diwaniyah River lies in central Iraq, between 31° 30′–32° 14′ N and 44° 42′–45° 16′ E, within the boundaries of the Al-Qadisiyah governorate (Al-Asadi & Al-Kafari, 2022). The River flows through four major administrative divisions in the Al-Qadisiyah governorate: Al-Saniyah sub-district, Al-Sader sub-district, Al-

Hamza district, and the central Al-Qadisiyah governorate (Al-Diwaniyah) (Al-Asadi & Al-Kafari, 2022). It is around 121 kilometres long. The river also flows into the governorate of Al-Muthanna. The width of the river varies from 45 to 50 metres and widens further to about 70 metres in certain places. The depth of the river ranges from 2 to 4 metres. The path of the river is divided into a number of channels; there are six main streams and nineteen smaller channels. The main sources of water feeding the Al-Diwaniyah River are precipitation and snowmelt in the Euphrates River headwaters in Syria and Turkey, which account for 98% of the river's running water. The amount that Iraq contributes to the River's overall water flow drops to about 2%. Between 2010 and 2020, the river water discharge rate will be about 50 m^3/s (Al-Asadi & Al-Kafari, 2022; Al Asadi et al., 2023). The river course area is situated in a desert climate zone, which is distinguished by summertime highs and droughts, and wintertime mild heat and precipitation. The primary source of fresh water for the 696,701 people living in the Al-Qadisiyah governorate—or 51.24% of the governorate's total population of 1,359,642—is the Al-Diwaniyah River (Al-taher, 2024). But because there is only one water source in the study area, the people of central Al-Diwaniyah receive the most water and rely entirely on it for all of their daily needs. Because the river water spreads along the river, it is also utilized for agriculture. The projected area of vast agricultural land is 33,859 hectares (Al-taher, 2024). The study region has an electric power plant and a few enterprises, including dairy, textile, and rubber. Wastes from industry, agriculture, and homes are all dumped untreated into the river.

North of the city, close to the Diwaniyah water treatment facility, was where Station 1 was situated. This location is crucial since it provides the majority of the local population's drinking water. Because the site is bordered by agricultural area, researchers chose it specifically to assess the water's potability. There is reason for concern regarding the risk of heavy metal poisoning of the water supply due to pesticides, fertilizers, and agricultural runoff because of the close proximity to agricultural areas. Station 2, which is located in Abd Al Rasool and is a component of residential zones designated for the delivery of drinking water, was the next place we visited. Here, we assessed how human occupancy affects the pollution caused by heavy metals. Residential areas are often associated with human activities including car traffic, industrial pollution, and home waste disposal that could lead to environmental contamination. Scientists collected water samples from this station in order to assess the effects of human activities on the levels of heavy metals in the environment and any potential health risks. The selection of Station 3, located near Rivers Elementary School on Al Naher Street, exposes the existence of heavy metal contamination in areas designated for educational purposes. Educational institutions can be hubs of activity, much like residential neighborhoods, but with different sources and patterns of pollution. Nearby educational institutions and children give rise to concerns regarding potential heavy metal exposure, which could have detrimental effects on health, particularly for vulnerable populations. This station was included in the sample plan because researchers sought to assess the potential risks that heavy metal contamination might have to the health and safety of employees, teachers, and students. Lastly, Station 4 at the Diwaniyah Rubber Factories serves as an illustration of an industrial area where the main economic activity is manufacturing. Industrial zones are known sources of heavy metal contamination due to the pollutants released from waste disposal practices, production processes, and industrial effluents. This station was selected by researchers to investigate how industrial activities impact environmental heavy metal pollution levels and potential impacts on ecosystems and human health. The study area and sampling stations are shown in the following Figure 1.

Sampling Stations	GPS Location
Station 1	N = 31°96'27.5": E = 44°94'81.6"
Station 2	N = 32°00'42"; E = 44°53'54"
Station 3	N = 31°59'21"; E = 44°54'45"
Station 4	N = 31°37'35"; E = 44°56'41"

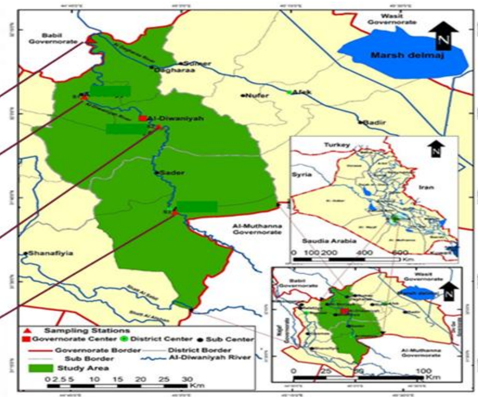

Figure 1: Study area and sampling site coordinates of Al-Diwaniyah River.

2.2 Chemicals

The chemicals included Nitric Acid (HNO_3) with a purity of 65% (w/w), supplied by Merck, Germany, and Hydrochloric Acid (HCl) with a purity of 37% (w/w), also from Merck, Germany. Additionally, Hydrogen Peroxide (H_2O_2) with a purity of 30% (w/w) was used, sourced from Sigma-Aldrich, USA. For the preparation of standard solutions, Multi-element Standard Solution (1000 mg/L) from PerkinElmer, USA, was employed.

The study also used Deionized Water produced by a Milli-Q system from Millipore, USA, to ensure the accuracy and reliability of the results.

2.3 Preparation of Standard Solution

Working standards were created for lead (Pb), iron (Fe), copper (Cu), zinc (Zn), and cadmium (Cd). Stock standard solutions of 1000 ppm (parts per million) of each element in 2 N nitric acid were used to create these working standards. The elements' concentrations were measured and calibrated using an atomic absorption spectrophotometer. The least squares method was used to construct calibration curves for each individual element based on linear correlation. When calculating the concentrations of the different elements, a blank reading was also considered and any necessary modifications were made.

2.4 Water Sample Collection and Digestion

In both the summer and winter seasons, water samples were taken at four Al Diwaniyah River sampling stations. It is common for the mercury to rise above 40°C (104°F), particularly in the southern and central regions. Occasionally, temperatures can even exceed 48°C (118.4°F) in the peak summer months of July and August, the sample collection for the summer season was taken place weekly from 18th of July to 28th of August, 2023; while the samples for the winter season were collected weekly from 12th of December, 2023, to 20th of January, 2024. Water samples were collected from a uniform depth of 7m. To prevent soil and waste from the riverbed from contaminating the sample, samples were taken at least 1m above the riverbed at each depth. One-liter polyethylene bottles were used to gather water samples from four different places. All sample bottles were cleaned with detergents and rinsed with deionized water before being used. Before gathering the samples, the bottles were washed three times with water from the appropriate lake during the sampling period. The collected samples were kept in an icebox until they were taken to the laboratory for further processing in order to preserve sample integrity.

In the beginning of water digestion process, a marker was used to mark a beaker with a volume of roughly 20 milliliters. The United States Environmental Protection Agency (USEPA, 2021) 3005 Methods was followed in the digestion of a 50 mL piece of well-mixed water samples in a covered beaker with a watch glass on top. One milliliter of concentrated (69–72%) HNO_3 and two milliliters of concentrated (30%) HCl was added to the water sample during the digesting process. After that, the beaker was heated to 90°C on a hot plate until the solution boils and heating was stopped when the fumes cleared. The beaker was then removed from the heat source and allowed to reach room temperature. A 100 mL volumetric flask was used to hold each digested water sample after it has been filtered via filter paper. Two milliliters of nitric acid were added to the flask to produce a transparent solution after deionized water had been added up to the mark according to Gebremedhin (2015) and Gerenfes et al. (2019). Shimadzu AA-7000 atomic absorption spectrometer (AAS) (made in Japan)was used to measure the content of heavy metals using the final solution. By interpolating or extrapolating the calibration curve that will be prepared for known concentrations of various heavy metals, the recorded absorbance from the AAS was used to determine the concentration of heavy metals.

2.5 Sediment Sample Collection and Digestion

From each sampling sites, sediments samples were collected from river bed surface, 25 cm at the water depth of 10 m. The sample collection for the summer season was taken place weekly from 18th of July to 28th of August, 2023; while the samples for the winter season were collected weekly from 12th of December, 2023, to 20th of January, 2024. Finally, the samples were placed in sampling beg with the station number. Each sample was weighed between 0.5 and 1 kg.

After collecting and labeling samples from several sampling sites, they were dried in an oven at 130°C and then pulverized into powder. A 5:1:1 solution of tri-acid was made using 70% nitric acid, 70% sulfuric acid, and 65% perchloric acid. Subsequently, 1 gram of each dried and powdered soil sample was placed in a beaker, followed by the addition of 15 milliliters of the tri-acid solution. The mixture was kept at a constant temperature of 80°C until the reaction was completed and a clear solution was obtained. At this temperature, all heavy metals in the soil sample would interact with the tri-acid solution. The solution was then cooled to room temperature and filtered. The strained solution was thinned to 50 mL with deionized water, following the method of Parvez et al. (2023) and Zhang & Wang (2020). This ultimate solution was utilized to detect the concentration of heavy metals using Shimadzu AA-7000 atomic absorption spectrometer (AAS) (made in Japan). The absorbance data obtained from the AAS was utilized to determine the concentration of heavy metals by analyzing a calibration curve created using known concentrations of various heavy metals.

2.6 Calibration of AAS

Calibration curves were created in order to ascertain the heavy metal contents in the sample solutions (Fig. 2). For every metal, intermediate standard solutions containing a concentration of 100 mg/L were created. The stock standard solutions that contained 1000 mg/L of Cd, Pb, Cu, Zn, and Fe were used to create these intermediate solutions. Using an extraction solution, the intermediate solution was serially diluted to provide working standards for each metal solution. The working standards were successively inhaled into the atomic absorption spectrometer in accordance with the instructions in the instrument operation handbook for increased sensitivity, and their absorbance values will be noted. Plotting absorbance versus concentrations (mg/L) using several data points from the various metal standard solutions allowed calibration curves to be created. Direct readings of the metal concentrations were then taken when the sample solutions were sucked into the AAS device right after calibration using the reference solutions.

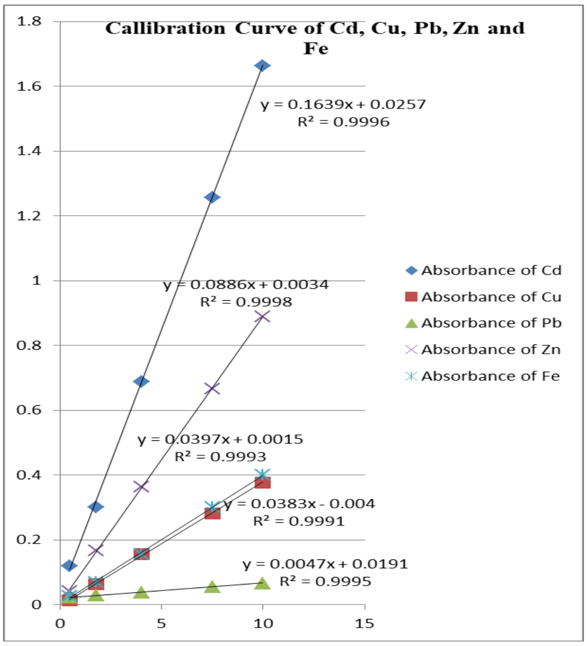

Figure 2: Calibration Curve of Cd, Cu, Pb, Zn and Fe.

2.7 Physiochemical Analysis of Water

Using Globe Technics water analysis kit model 191 E (from India), physico-chemical parameters such as pH, turbidity, electrical conductivity (EC), total suspended solids (TSS), and total dissolved solids (TDS) were assessed. The kit's multiprobes were all calibrated simultaneously using the same guidelines and practices. The standard potassium chloride solutions of 0.005, 0.05, and 0.5 M were used to calibrate electrical conductivity. pH was measured between pH -4 and pH -9.2 using a standard buffer solution. Using Hydrazine Sulphate and Hexamethylene Tetramine, a standard solution of 400 N.T.U. was used to calibrate turbidity. By passing 50 millilitres of water through Whatman 41 filter paper, the total suspended solids (TSS) in the sample was determined. 50 cc of the sample was buffered at pH 8–10 (NH_4Cl and NH_4OH) and titrated against standard EDTA using Erichrome Black T as an indicator in order to determine the hardness of the sample. Biological Oxygen Demand (BOD) was determined by monitoring the oxygen content decrease during three days of incubation at 270 degrees Celsius. By oxidizing the sample with an excess of acidified potassium dichromate solution and titrating the excess dichromate against a standard ferrous ammonium sulphate solution using ferrion indicator, Chemical Oxygen Demand (COD) was ascertained.

2.8 Assessment of Water Quality Index (WQI)

In order to calculate the water quality index, 13 parameters were selected, based on the data available. These parameters include the pH value, Orthophosphate (PO_4^{3-}), Nitrate (NO_3^-), Cadmium (Cd), Copper (Cu), Zinc (Zn), Iron (Fe), Lead (Pb), Total Hardness (TH), Sulphate (SO_4^{2-}), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and Electrical Conductivity (EC). The weights of the chemical variables according to their relative influence on water quality for drinking purposes are required for computing the WQI (Al Asadi et al., 2023; Tiwari et al., 2015). The assigned weights are used to calculate the relative weights according to equation 1 as listed in Table 1 (Al Asadi et al., 2023; Tiwari et al., 2015; WHO, 2017). (Equation 1)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad 1$$

Where w_i and W_i are the weight and relative weight factors of the i^{th} variable, respectively and n is the number of tested variables.

The ratio of variable concentration in water samples (C_i) to the standard of the variable (S_i) assigned as quality rating index (Q_i) of i^{th} variable (Eldaw et al., 2020) and computed according to Equation (2):

$$Q_i = \frac{C_i}{S_i} \times 100 \qquad 2$$

The sub-index of each variable (SIi) is computed by multiplying of quality rating index (qi) by the relative weight (Wi) of each variable as given in Equation (3):

$$SI_i = Q_i \times S_i \qquad 3$$

The summation of SIi of all variables represents the value of WQI as in Equation (4):

$$WQI = \sum_{i=1}^{n} SI_i \qquad 4$$

where, and n is number of the parameters considered.

Table 1 was used to classify the WQI of the Al Diwaniyah, where the water was classified under six classes, ranging from excellent water quality to highly polluted water.

Table 1: Standards, weights (w_i) and percentage weights (Wi) of WQI variables (Al Asadi et al., 2023; Tiwari et al., 2015; WHO, 2017).

Variables	**WHO Standards**	**Weight (wi)**	**Percent Weight (Wi)**
Pb	0.05	5	0.1163
Cd	0.01	5	0.1163
Zn	0.02	2	0.0465
Fe	1	1	0.0233
Cu	0.05	3	0.0698
pH	8.2	4	0.093
EC	1000	5	0.1163
TH	500	4	0.093
TDS	1000	3	0.0698
TSS	60	1	0.0233
SO_4	200	4	0.093
PO_4	0.5	1	0.0233
NO_3	50	5	0.1163
	Total	43	1.000

Table 2: Water quality classification based on WQI value (Tiwari et al., 2015)

Value of WQI	Water Quality
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
300-400	Polluted
>400	Very polluted

3 RESULTS AND DISCUSSION

3.1 Heavy Metal Concentration in Surface Water

The following Table 3 represents the heavy metal concentration of water at different sampling station in both summer and winter season. From the data, it is evident that S4 has the highest concentration of HMs, followed by S3 as the second highest concentration site for HMs. The concentration of heavy metals decreased during winter season at every sampling site. This is due to the fact that low temperatures can affect the solubility of heavy metals in water(Jaishankar et al., 2014). These heavy metals exhibit decreased solubility and therefore precipitate from the water column with decreasing temperature. As a result, the water's concentration of dissolved metals decreases. Moreover, it was also observed that among the five heavy metals that were analyzed in the study, Pb has the highest concentration (average 1.21 ppm at summer), followed by Fe (average 0.747

ppm at summer). The order of the HMs concentration in water during summer: Pb > Fe > Cu > Zn > Cd. The order of the HMs concentration in water during winter: Cu > Fe > Zn > Pb > Cd.

The low concentrations of heavy metals at sampling site 1 and 2 can be attributed to the limitation of human and industrial activities in the study area. Industrial activity of the textile and the rubber factories tend to increase the concentration of heavy metals in sampling site 4. The heavy metals in the river water tend to adsorb to the suspended particles leading to precipitation in the river bed; due to that, they have low solubility. Moreover, river water alkalinity decreases heavy metals' solubility and increases the adsorption process (Ahmed et al., 2020; Al-Asadi et al., 2020). The relatively high concentration of Pb (0.7059- 2.5721 ppm) in the river water, especially in sampling site 4. Textile factory dumps untreated pollutants directly into the river, so they are considered possible sources of the metal(Ahmed et al., 2020; Hou et al., 2019). Despite the strong adsorption of the Pb on the sediment particles (Al-Asadi et al., 2019), their high levels in Al-Diwaniyah River may indicate that it was more than most of the other heavy metals and exceeded the WHO and Iraqi standards (0.01 mg/L) during the summer. The water current and discharge velocity play an important role in the variation of heavy metal concentrations. The increase of discharges contributes to a dilution of metal levels, while an increase in current velocity leads to water column turbulence(Mukherjee et al., 2021). It contributes to increase the heavy metal contents in water due to the mixing process with the bottom sediments (WHO, 2017). Heavy metals dissolved in the river water are characterized by a non-uniform random variation during the whole year, with a spatial variation of their levels tending to increase in Al-Diwaniyah station. The reason can be attributed to the relative increase in anthropogenic activities and the presence of textile and rubber factories in Al-Diwaniyah.

Table 3: Heavy metal concentration (in ppm) of water from Al-Diwaniyah River at different sampling station in both summer and winter season (2023-2024).

	Summer					**Winter**				
Site	Pb	Cd	Zn	Fe	Cu	Pb	Cd	Zn	Fe	Cu
S1	0.436 ± 0.33	ND	0.437 ± 0.31	0.5809 ± 0.25	0.6879 ± 0.33	0.12 ± 0.09	ND	0.247 ± 0.17	0.366 ± 0.17	0.556 ± 0.26
S2	0.567 ± 0.11	ND	0.403 ± 0.15	0.2479 ± 0.26	0.5102 ± 0.34	0.156 ± 0.03	ND	0.229 ± 0.09	0.156 ± 0.17	0.413 ± 0.27
S3	1.261 ± 0.31	0.168 ± 0.04	0.795 ± 0.07	0.6073 ± 0.24	0.6709 ± 0.31	0.346 ± 0.08	0.124 ± 0.03	0.45 ± 0.04	0.382 ± 0.15	0.543 ± 0.25
S4	2.572 ± 0.79	0.23 ± 0.09	0.727 ± 0.19	1.5502 ± 0.25	1.063 ± 0.19	0.705 ± 0.22	0.17 ± 0.07	0.412 ± 0.11	1.244 ± 0.09	0.859 ± 0.15

ND = Not Detected

3.2 Heavy Metal Concentration in River Sediment

The following Table 4 represents the concentration of heavy metals in Al-Diwaniyah River sediment at summer and winter. S4 has the highest concentration of HMs, followed by S3 as the second highest concentration site for HMs, except Cd, which exhibit maximum concentration at S3, followed by S4. The Concentration of HMs increased during winter season at every sampling site. This is due to the fact that low temperatures can affect the solubility of heavy metals in water. Moreover, winter conditions such as low temperatures and reduced biological activity can influence the redox (oxidation-reduction) conditions in river sediments. Under anaerobic (low oxygen) conditions prevalent in winter, certain heavy metals may become more mobile and soluble, leading to their release from sediments into the water column. Additionally, the formation of ice cover on rivers can create localized anoxic (no oxygen) conditions, promoting the release of dissolved heavy metals from sediments. It was also observed that among the five heavy metals that were analyzed in the study, Fe has the highest concentration (average 16035.29 ppm at winter), followed by Pb (average 108.15 ppm at winter). The order of the HMs concentration in river sediments at Summer: Fe > Pb > Zn > Cu > Cd. The order of the HMs concentration in water at Winter: Fe > Pb > Zn > Cu > Cd.

Table 4: Heavy metal concentration (in ppm) of sediment from Al-Diwaniyah River at different sampling station in both summer and winter season (2023-2024).

	Summer					**Winter**				
Site	**Pb**	**Cd**	**Zn**	**Fe**	**Cu**	**Pb**	**Cd**	**Zn**	**Fe**	**Cu**
S1	79.38 ±	0.22 ± 0.1	57.11 ± 8.39	12823.05 ± 1940.1	33.54 ± 3.12	91.51 ± 13.84	0.23 ± 0.1	62.46 ± 9.18	14280.62 ± 2160.6	38.18 ± 3.55

	12.01									
S2	86.72 ± 4.08	0.24 ± 0.1	59.04 ± 6.3	12657.27 ± 1847.9	42.68 ± 2.98	99.98 ± 4.7	0.25 ± 0.11	64.57 ± 6.89	14096.0 ± 2058	48.58 ± 3.39
S3	99.05 ± 4.5	0.55 ± 0.25	66.92 ± 6.22	15415.4 ± 587.41	48.73 ± 8.04	114.19 ± 5.18	0.58 ± 0.26	73.19 ± 6.8	17167.64 ± 654.18	55.47 ± 9.15
S4	110.08 ± 6.38	0.26 ± 0.18	68.19 ± 7.51	16698.75 ± 1117.6	57.8 ± 9.67	126.91 ± 7.35	0.28 ± 0.19	74.58 ± 8.22	18596.86 ± 1244.6	65.8 ± 11

3.3 Physical and Chemical Properties of Water

The above Table 5 represents the physical properties of water at different sampling station in both summer and winter season. From the table it is evident that, water in S4 has the highest value of electrical conductivity, while the highest value of pH, TDS, TSS and NTU was observed at S1, S3, S1 and S3, respectively throughout the year around. The increase in the values of physical properties at winter can be attributed to several factors such as decreased dilution, limited sunlight, human activities and snowmelt and ice formation. For instance, the process of snowmelt and ice formation can result in the release of dissolved ions and suspended particles into the water, leading to an elevation in electrical conductivity, TDS, TSS, and turbidity levels. Aquatic plants and algae have a decrease in the rate of photosynthesis due to limited sunshine. Consequently, their ability to absorb dissolved nutrients like phosphates and nitrates is reduced. while, the presence of greater nutrient concentrations in the water might lead to elevated levels of TDS(Ahmed et al., 2022; Al-Asadi & Al-Kafari, 2022; Ismukhanova et al., 2022). In addition, heightened human activity in metropolitan areas and agricultural regions during winter can transport pollutants such sediment, fertilizers, and chemicals into rivers, resulting in elevated levels of TDS, TSS, and turbidity.

On the other hand, Table 6 represents the chemical properties of water at different sampling station in both summer and winter season. From the table it is evident that: water in S4 has the highest value of Total Hardness, while the highest value of COD, BOD, NO_3^-, PO_4^{3-} and SO_4^{2-} was observed at S2, S2, S4, S1 and S2, respectively throughout the year around. The increase in the values of chemical properties at winter can be attributed to several factors. For instance, in agricultural areas, winter may coincide with periods of increased fertilizer application, particularly for crops like winter wheat(Walli et al., 2018). The runoff from agricultural fields can contain high concentrations of nitrogen (from fertilizers) and phosphorus (from animal manure and fertilizers), leading to elevated levels of NO_3^- and PO_4^{3-} in the water. Moreover, cold temperatures during winter can slow down microbial activity and decomposition processes in water bodies, leading to the accumulation of organic matter and nutrients over time(Li et al., 2018). This accumulation can result in higher BOD levels as organic material decomposes more slowly in colder water, consuming oxygen during the process

Table 5: Physical properties of sediment from Al-Diwaniyah River at different sampling station in both summer and winter season (2023-2024).

	Summer					**Winter**				
Site	**EC (dS/m)**	**pH**	**TDS (mg/L)**	**TSS (mg/L)**	**NTU**	**EC (dS/m)**	**pH**	**TDS (mg/L)**	**TSS (mg/L)**	**NTU**
S1	1.767 ± 0.06	7.673 ± 0.16	1136.67 ± 20.55	3568.67 ± 95.06	6 ± 0.41	2.78 ± 0.09	7.87 ± 0.16	1199.3 ± 21.79	3683 ± 98.14	6.43 ± 0.45
S2	2.01 ± 0.08	7.37 ± 0.19	1355 ± 36.38	2888.33 ± 756.56	10.83 ± 3.47	3.17 ± 0.13	7.56 ± 0.19	1429.7 ± 38.42	2981 ± 780.98	11.6 ± 3.72
S3	1.92 ± 0.39	7.6 ± 0.23	1244.33 ± 182.67	2995 ± 1066.3	14.67 ± 11.95	3.03 ± 0.62	7.79 ± 0.23	1313.33 ± 192.7	3091 ± 1100.2	15.7 ± 12.82
S4	2.187 ± 0.21	7.313 ± 0.13	1397.33 ± 158.53	2663 ± 1183.6	19.17 ± 9.08	3.45 ± 0.34	7.5 ± 0.14	1474.7 ± 167.03	2748.33 ± 1221.4	20.5 ± 9.74

Table 6: Physical properties of sediment from Al-Diwaniyah River at different sampling station in both summer and winter season (2023-2024).

	Summer						**Winter**					
Site	**Total Hardness (mg.L)**	**COD (mg/L)**	**BOD (mg/L)**	**NO3 (mg/L)**	**PO4 (mg/L)**	**SO4 (mg/L)**	**Total Hardness (mg.L)**	**COD (mg/L)**	**BOD (mg/L)**	**NO3 (mg/L)**	**PO4 (mg/L)**	**SO4 (mg/L)**
S1	572.1 ±	57.5 ±	2.77 ±	4.79 ±	6.48 ±	541.43	604.27 ±	67.9 ±	3.07 ±	5.41 ±	4.42 ±	576.78

	38.25	10.45	0.76	1.62	0.57	± 90.06	40.42	12.33	0.84	1.83	0.39	± 95.95
S2	588.77 ± 56.33	83.23 ± 8.71	4.57 ± 0.45	15.67 ± 5.75	5.27 ± 2.79	579.4 ± 155.68	621.87 ± 59.51	98.3 ± 10.3	5.1 ± 0.5	17.7 ± 6.49	3.59 ± 1.9	617.2 ± 165.81
S3	652.9 ± 125.81	66.03 ± 4.02	3.5 ± 0.08	14.66 ± 7.09	6.34 ± 0.98	476.4 ± 173.09	689.63 ± 132.09	78 ± 4.74	3.9 ± 0.08	16.56 ± 8.01	4.32 ± 0.67	507.47 ± 184.38
S4	716.33 ± 101.14	65.9 ± 30.93	4.03 ± 1.39	21.24 ± 11.44	5.42 ± 0.75	481.43 ± 389.31	756.63 ± 106.81	77.83 ± 36.54	4.53 ± 1.55	23.98 ± 12.92	3.7 ± 0.51	512.83 ± 414.69

3.4 Water Quality Index (WQI) of Al-Diwaniyah River

The following Figure 4 represents the water quality index (WQI) of the sampling stations of Al-Diwaniyah River in summer and winter season.

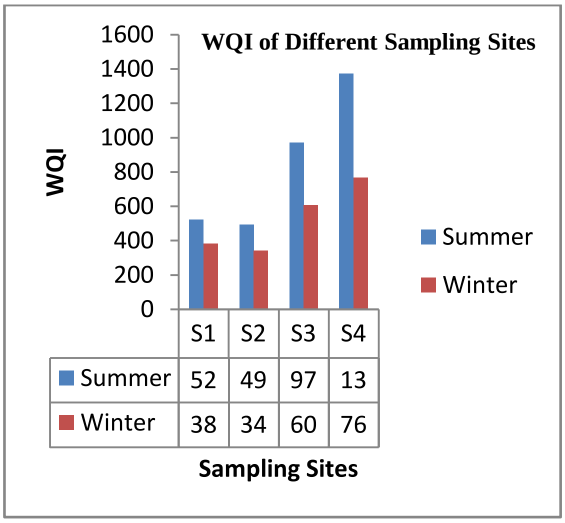

Figure 3: Water Quality Index (WQI) of Al-Diwaniyah River.

From the data, it is evident that, during the summer season, all of the sampling stations are much polluted, since calculated WQI values for all sampling sites are greater than 400, indicating poor quality. During, both summer and winter, the highest pollution was observed at sampling site 4 (WQI = 1374 A and 767 at summer and winter, respectively) since it is located in the proximity of industries such as rubber factories and cannery factories. The third sampling site has the second highest pollution with WQI value 970 and 604 at summer and winter, respectively, since this site is located at the center of the city. On the other hand, sampling site 1 and 2, have lower pollution level comparatively. These two stations outside the urban area and thereby less pollution level. Though, calculated WQI values of the river sampling sites indicate that the river water is not drinkable without heavy treatment both at winter and summer. However, river water at sampling site 1 and 2 is comparatively less polluted than summer. The lower pollution of river water during could be attributed to reduced water flow and lower precipitation during the winter. Moreover, lower temperature during winter season could potentially reduce the activity of decomposers and other organisms that break down organic matter in the river(Raj & Maiti, 2020). These phenomena are somewhat responsible for the variation in the water quality of Al-Diwaniyah River.

4 CONCLUSION

This study conducted an in-depth investigation of the heavy metal pollution as well as physical and chemical properties of Al-Diwaniyah River water in summer and winter season. To conduct the study four sites were chosen based on agricultural, urban and factory activities. The concentration of the selected heavy metals (Pb, Cd, Zn, Fe and Cu) as well as the physical and chemical properties of water was compared with the WHO standards and WQI was evaluated accordingly. The findings of the study indicates that Pb, Cd, Zn and Cu concentration is above the WHO standard level, indicating higher pollution in the river water. Similar to the water, sediments of Al-Diwaniyah river is also highly polluted with heavy metals. However, the findings also indicated that heavy metal concentration is significantly lower during the winter than the summer season. The increasing order of heavy metals concentration at summer is Pb > Fe > Cu > Zn > Cd and at winter is Cu > Fe > Zn > Pb > Cd. The investigation into the WQI of the river water at summer and winter indicated that the river water is not suitable for drinking without rigorous treatment. The sampling station 4 has the poorest water quality with a WQI value 767-1374 throughout the year, due to the presence of rubber and textile factory activities. Therefore, in order to save the river and its aquatic organisms, it is necessary to take necessary steps to conduct continuous monitoring according to the clean environmental roles to prevent the rising pollution levels in the future. Moreover, the anthropogenic wastes along the river banks must be verified periodically to assess the pollution state.

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