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Spatiotemporal Variation of Heavy Metals and Pollution Indices in Groundwater Around Al-Diwaniyah Open Dump

Fatin F. Aziz[1*], Entessar Kareem Hussain[1]

[1] Department of Civil Engineering, Collage of Engineering, University of Al-Qadisiyah, Al Diwaniyah, Qadisiyyah Province, Iraq

* Corresponding author's e-mail: eng.civ21.post10@qu.edu.iq

ABSTRACT

Potential environmental hazards associated with heavy metals have been reported at Al-diwaniyah open dump in Iraq. Therefore, the levels of heavy metals and their spatial and temporal variability have been studied, in addition to pollution indices (HPI, HEI, Cd) to achieve environmental management and sustainability. Concentrations of seven heavy metals in groundwater wells at various distances around dumpsite were analyzed for the period 2022–2023 using atomic absorption spectrophotometer. Results revealed that heavy metals levels in samples examined decreased with the distance from the dumpsite W1>W2>W3 and it followed this pattern: Cd <Ni <Cr <Pb<Cu < Fe < Zn, with average concentrations in dry and rainy seasons were Zn (0.641,0.305), Fe (0.199,0.375), Cu (0.208,0.068), Pb (0.035,0.117), Cr (0.031,0.073), Ni (0.106,0.055), Cd (0.023,0.0095). On one hand, seasonal variation showed that 57.14% of heavy metals were raising in the dry season, and on the other, pollution indices showed that the groundwater taken from the W1 site was heavily polluted and unfit for consumption, while the other two sites were in low pollution category, which showed little impact of waste dumps on groundwater in these sites. Analysis results indicated that groundwater is appropriate for drinking purposes compared to the permissible limits of WHO/IQS, apart from those taken from site W1. All wells also provide water suitable for irrigation purposes based on the guidelines of the Food and Agriculture Organization (FAO). The Statistical analysis demonstrated a strong correlation between some heavy metals, in addition to the influence of sampling sites on heavy metal levels. It is recommended to expand this study to include additional regions in order to provide more environmental monitoring for groundwater and examine its potential human health risks in the study region, construct an engineering landfill equipped with leachate collector system, moreover, systematic treatment of heavy metals concentrations should be carried out regularly.

Keywords: open dumpsite, heavy metal, contamination, groundwater, solid waste, pollution indices

INTRODUCTION

Anthropogenic activities and processes tend to generate massive amounts of waste, ranging from biodegradable and non-biodegradable materials to extremely hazardous materials. The United Nations Environment Programmer (UNEP) is concerned about the rapid increase in waste produced in third-world countries. Due to its lack of technical advancements and infrastructure, waste landfilling and its treatment pose significant challenges in these nations (Essien et al., 2022). Furthermore, open dumps are utilized as the most prevalent municipal solid waste (MSW) disposal method, and in recent decades, their environmental implications have gained considerable concern (Abd El-Salam & Abu-Zuid, 2015; Mishra et al., 2019). According to studies, open dumps continue to be the most prevalent cause of water and environmental contamination (Divya et al., 2020; Laskar et al., 2022). Which significantly influenced the physical and chemical characteristics in addition to the concentration of heavy metals (HMs) in groundwater (Udofia & Udiba, 2016).

The filtration of river water and the leakage of pollutants through the soil into groundwater is considered one of the primary causes of water pollution at solid waste disposal sites (Alao et al., 2022). HMs are often discovered in leachate generated from hazardous waste landfills and solid waste dumps (Hussein et al., 2021; Deng et al., 2018). Consequently, identifying and characterizing the ecotoxicological profile of heavy metals in the environment impacted by landfill leachate and the associated health risks presented by municipal dumpsites is of paramount importance.

HMs have persistence, toxicity, and bioaccumulation features in the environment (Kazemi Moghaddam et al., 2022). Therefore, its presence in water at certain levels may make it suitable or unsuitable for consumption. Among many heavy metal types, some are poisonous, including lead, cadmium, and chromium, which are also categorized as hazardous by ATSDR (2012). The USEPA (2005) claims that a variety of factors, including pH, alkalinity, clay silicate, and exchangeable carbonate fractions, affect the sorption of heavy metals. In previous studies, Folorunsho et al. (2022) revealed that most of the trace metals in leachate samples of dumpsites in Okene Metropolis, Nigeria, were at a high level compared to the groundwater samples, with some of trace metals exceeding WHO permissible limit. Alghamdi et al. (2021) also reported higher concentrations of NO3, Cd, As, Fe, Cr, Ni, Mo, and Pb in groundwater samples from Al-Madinah Al-Monawara landfills. A study conducted by Omorogieva and Tonjoh (2020) within the Benin Formation Aquifer (BFA) reported an anomaly in the concentration of toxic heavy metals like Pb, Cr, Cd, and others.

Unwarranted subjection to water containing heavy metals composes a human health concern (Jafarzadeh et al., 2022). Therefore, identifying, quantifying, and evaluating the environmental toxicological profiles of heavy metals in groundwater affected by leaching from landfills and the associated health risks posed by municipal waste dumps, and evaluating the groundwater quality concerning heavy metals, becomes significantly critical. That requires knowledge of water quality indices (Mgbenu and Egbueri, 2019). The most widely used indexical methods in groundwater studies are heavy metal pollution indices (HPIs). Several heavy metal pollution indices have been proffered to evaluate the level of heavy metal contamination (Chaturvedi et al., 2019; Elumalai et al., 2017; Zhuang et al., 2018). However, the degree of contamination (Cd), heavy metal evaluation index (HEI), and heavy metal pollution index (HPI) have been more frequently used to study heavy metal pollution.

Quite a few researches have been carried out to evaluate the concentration of heavy metal content in groundwater in many parts of the world. But there is truly little research conducted in Iraq, especially around this study area (Diwaniya landfill), related to indexing heavy metal pollution. Consequently, this study was undertaken to (i) establish toxic metal concentrations in groundwater collected from hand-dug wells around Al-Diwaniyah municipal waste dumpsite and their relation to seasonal and spatial variations. (ii) assess the extent of heavy metals contamination using pollution indices. moreover, statistical analysis was also used to confirm the correlation between the obtained results and (iii) assess the groundwater quality in accordance with heavy metal levels to accomplish goals of sustainable development and compare their concentrations with the permissible limitations of WHO (2022) and IQS (2014) for domestic use; furthermore, compare with FAO (1985) limitations for agricultural use.

MATERIAL AND METHODS

Describing the study area

The survey area is located at the intersection of latitude 31° north and longitude 45° east (Diwaniyah-Basra) within the geographical coordinates of (32°00'08.9"N 45°03'18.5"E) southeast of Al-Diwaniyah city in Al-Qadisiyah Governorate, Iraq (Fig. 1). This open dump didn't employ engineering standards and is not equipped with a leachate drainage channel. The site has been in operation for more than 25 years with an area of 13 Hectare. It serves Al-Diwaniyah district with a population of 534,000 capita at 2019 census. Topographically, the study area is characterized by its low slope generally which trends approximately from the northwest towards the south and southeast direction. Climatologically, the study area has a desert climate with high temperature, low rainfall, and low relative humidity.

Field and analytical procedures

For the stated purpose of this study, three groundwater samples from hand-dug wells at variance distances from the dumpsite as shown

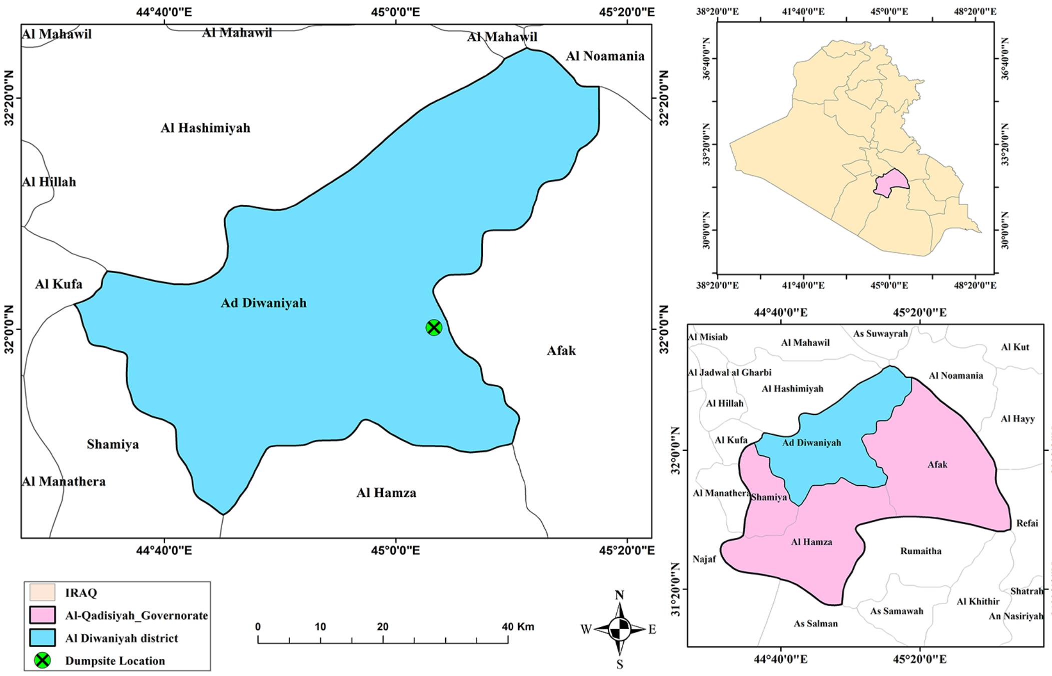

Fig. 1. Geographical map of study area showing Al-Diwaniyah District and studied dumpsite

in Table 1 were collected periodically during the period of August 2022-March 2023 to represent the impacted Groundwater with heavy metals using sterile 1-liter plastic bottles, respectively from each site. Each sampling site was identified using Google Earth software (Fig. 2). Before transfer to the laboratory, the samples of groundwater were stocked in glass bottles, marked, and stored at 4˚C in coolers filled with ice cubes prior to analysis. The required standard quality control and quality confidence proceedings were accurately followed during sample collecting, keeping, and the elemental analysis was completed within 48 hours of the sample being collected in accordance with standard methods for the examination of water and wastewater (APHA, 2019).

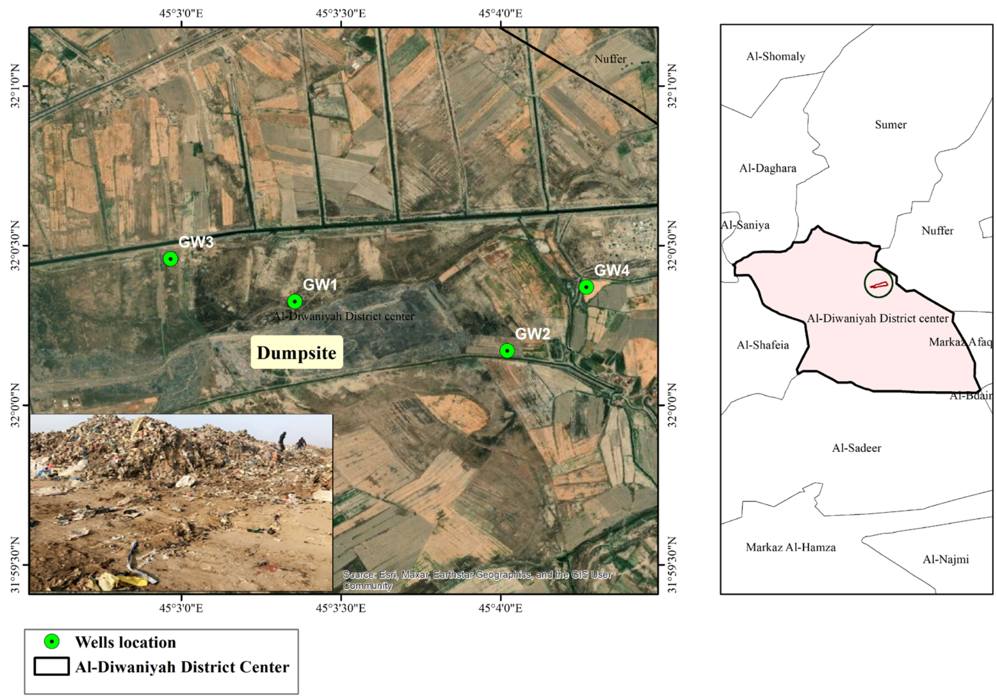

Fig. 2. Location of the dumpsite and wells distribution in the study area

Table 1. Groundwater monitoring wells details

Well sample	Coordinate		Distance from dumpsite (m)
	Latitude (N)	Longitude (E)	
W 1	32°00'19.5"	45°03'21.3"	100
W 2	32°00'27.5"	45°02'58.0"	500
W 3	32°00'22.2"	45°04'16.1"	750

Analysis of groundwater and leachates

Atomic Absorption Spectrophotometer (Model AA-7000, Company SHlMADZU) was used to determine the concentration of each heavy metal directly at its respective wavelength. cadmium (228.9 ηm), nickel (232 ηm), chromium (357.9 ηm), lead (217 ηm), copper (324.8 ηm), iron (245.3 ηm), and zinc (213.9 ηm) by the flame atomic absorption method. All methods used for data analysis in this research were in accordance with those presented by the American Public Health Association (APHA 2019). Samples were analysed at the U-Science Laboratory in Al-Diwaniyah District, Al-Qadisiyah Governorate, Iraq.

Assessment of water contamination

Heavy metals pollution index (HPI)

The HPI reflects the overall quality of water with regard to heavy metals and evaluates whether they are suitable for human consumption (Rizwan et al. 2011) and based on the weighted arithmetic quality mean method (Hassouna et al. 2019) HPI can be calculated as follows:

$$PI = \frac{\sum_{i=1}^{n}(Qi \times Wi)}{\sum_{i=1}^{n} Wi} \quad (1)$$

$$Wi = {}^{k}/_{S} \quad (2)$$

where: Qi – ith parameter sub-index, Wi – ith parameter's unit weight, n – the number of considered parameters.

The sub index (Qi) of the parameter is.

$$Qi = \frac{Vi}{Si} * 100 \quad (3)$$

where: Vi – the measured metal value for the ith parameter, Si – the standard value.

In general, potable water with an HPI value less than 100 is considered safe for consumption. (Balakrishnan and Ramu 2016). The present research utilized allowable value by WHO for drinking water standards.

Heavy metal evaluation index (HMEI)

Computation of HEI was carried out through the following equation (Boateng et al. 2015):

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

where: H_c – the concentration of each element as measured (mg/L), $Hmac$ – the permissible maximum concentration (MAC) (mg/L) of the ith parameter.

The heavy metal evaluation index (HEI) classifies pollution into three levels: low (20), middle (20–40), and high (> 40).

Contamination degree (Cd)

Cd displays the relative contamination of various heavy metals independently. This index is computed with the following formula: (Backman et al. 1998).

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

$$C_{fi} = \frac{CAi}{CNi} - 1 \quad (6)$$

where: C_{fi} – the Contamination Factor for metal i, Cai – the concentration of each metal as measured i, CNi – the permissible maximum concentration of heavy metal globally. According to the extent of pollution, the water was categorized into three levels: low (10), medium (10–20), and high (> 20).

Statistical analysis

SPSS software (v. 22) was used to implement the statistical analysis for Laboratory result data to:

1. The interrelationships between the studied heavy metals were determined by calculating the Pearson correlation matrix at 95% confidence level and its values of the correlation coefficients always lie between −1 and 1 (Bhuiyan et al. 2016).
2. Level of significance was identified through p-values using the one-way ANOVA test which demonstrates if there is statistically significant correlation between dependent variables (heavy

metals) and independent variables (site of observation wells) and level of risk possibility of 1 % and 5 % were considered in the process of defining the statistical significance of results.
3. Post hok Scheffe test was utilized to define the significance of the difference between the groups of wells sites (Pantelic et al. 2012).
4. In addition, descriptive statistics such as arithmetic mean, maximum, minimum, box plots, and standard deviation were used to study the groundwater quality characteristics.

RESULTS AND DISCUSSION

Quality characteristics of groundwater

Table 4 summarized the results of heavy metals concentration in groundwater during dry and rainy seasons. The heavy metals concentration of groundwater samples examined in the study region increases by ranking of Cd < Ni < Cr < Pb < Cu < Fe < Zn.

Among the investigated heavy metals, the highest concentration was recorded for zinc (Zn) 0.921 mg/L with a gradual decrease in its level during the observation period, as it ranged during the dry season from 0.262 to 0.961 mg/L, with an average value of 0.641 mg/L. Then, it decreased in the rainy season to range from 0.101 to 0.542 mg/L, with an average value of 0.305 mg/L (Table 2). The higher and lower levels of zinc were concentrated in samples W1 and W3, respectively Fig. 3. Zinc is an essential mineral for optimal human development and growth. The allowable limit for zinc according to WHO/IQS is 3 mg/L while it was 2 mg/L for irrigation water standards issued by FAO (1985). Zinc concentration has fallen below this limit, therefore is suitable for human consumption and irrigation. From ANOVA test it appeared significant difference, at the level $p < 0.01$ ($F = 6.78$, $p = 0.0063$) for zinc as shown in Table 3. Whereas no statistically significant differences were identified for zinc between the sites of the wells through Scheffe's post hoc test, except the difference between sites (W1/W2). Sanga et al. (2022) reported that Zn concentrations fluctuated between 1.60±0.85 to 18.40±1.05 mg/L in groundwater around Iringa dumpsite, which was greater than those reported in this study. In addition, Sankoh et al. (2023) found similar results of Zn values ranging from below detected limit to 0.92 in groundwater samples around Granvillebrook and Kingtom dumpsites. This release of excess zinc concentrations into groundwater may be due to the intrusion of zinc leachates from the combined disposal of solid waste containing zinc minerals.

Seasonal variation of samples taken periodically indicated the concentration of iron (Fe) in groundwater during the wet season was the highest. The average concentration of iron in rainy season for W1, W2, and W3 were (0.772), (0.258), and (0.096) mg/L, respectively, and in the dry season were (0.407), (0.14), and (0.049) mg/L, respectively (Table 2). Both rainy and dry seasons reported the lowest and highest iron concentration at W3 and W1, sequentially as shown in Fig. 1. All samples were within WHO/IQS limitations of drinking water, except for W1, which is significantly higher than the standard requirement of 0.3 mg/L. likewise, Fe values of all wells fall below FAO limits (5 mg/L) for irrigation water. This result contradicts Aduojo et al.'s (2023) findings who observed Iron concentrations between 3.82 and 5.41 mg/L in groundwater surrounding the Solous lll dumpsite in Lagos, Nigeria. However, this conforms to Sanga et al., (2022) who reported that all groundwater samples had mean concentrations of Fe ranging from 0.34±0.01 to 0.50±0.04 mg/L. Regarding the statistical analysis, ANOVA test showed significant differences ($F = 28.03$, $P = 0.000$) for Fe in observation wells (Table 3). The results of Scheffe post-hok test confirm that there are statistically significant differences between site 1 and other two investigated sites of wells regarding values of Fe ($F' > 7.11$). On the other, no statistically significant differences exist between sites 2 and 3. Extra quantities of Fe in leachates and its further emission into underlying groundwater may be evidence of dumping of iron and steel scraps wastes in the dumpsite. Moreover, this clearly suggests that groundwater quality in well (W1) may have been influenced by landfill leachates.

As can be seen in Table 1, variations of copper were significant at level ($p < 0.05$) ($F = 4.62$, $p = 0.023$). According to Scheffe test, there are no statistical differences between copper concentrations measured in shallow groundwater except between W1/W3 there was a slight statistical difference. The copper results registered in dry season were generally higher than in rainy season, as it ranged from 0.006 to 0.202 mg/L in the wet season and 0.008 to 0.641 mg/L in the dry season. W3 and W1 revealed the lowest and highest value in the wet and dry seasons (Fig. 3).

Table 2. Average seasonal concentration of heavy metals in groundwater of Al-Diwaniyah dumpsite and Criteria of water quality according to IQS, WHO, and FAO

Heavy metal	Season	W1	W2	W3	IQS Standards (MPL)	WHO Drinking water (MPL)	FAO Standards (MPL)
Cadmium	Dry	0.051	0.0164	0.002	0.003	0.003	0.01
	Wet	0.0237	0.0037	0.001			
Chromium	Dry	0.084	0.0072	BDL	0.05	0.05	0.1
	Wet	0.19	0.0277	BDL			
Copper	Dry	0.508	0.0967	0.0193	1.0	2.0	0.2
	Wet	0.101	0.063	0.039			
Iron	Dry	0.407	0.140	0.05	0.3	0.3	5.0
	Wet	0.772	0.258	0.096			
Nickel	Dry	0.165	0.109	0.042	0.02	0.07	0.2
	Wet	0.098	0.039	0.027			
Lead	Dry	0.092	0.014	BDL	0.01	0.01	2.0
	Wet	0.306	0.044	BDL			
Zinc	Dry	0.901	0.673	0.35	3.0	3.0	2.0
	Wet	0.412	0.362	0.14			

Note: * all concentrations are given in (mg/L).

During the mentioned seasons, copper recorded concentrations considerably below the permissible limits of WHO/IQS (2 mg/L) and (1 mg/L) respectively. In addition, copper in groundwater samples was acceptable for irrigation except for W1 in wet season according to FAO confirmed limit of 0.2 mg/L. Relatively, Elevated copper levels in groundwater samples close to dumpsites primarily arise from the disposal of scrap metals, discarded medications, and batteries (Rana et al. 2018). These findings contradict those stated by Osuagwu et al. (2023) and Sanga et al. (2022), but similar to the results of Aduojo et al. (2023).

The analysis data of observation wells revealed that lead during arid season was lower than rainy season which ranged from ND to 0.1141 mg/L in the dry season and ND to 0.373 mg/L in the wet season (Table 2). lead was not detected at site W3, Whereas the highest concentration was at W1 in the wet season. The lead concentrations in groundwater at all sites exceeded the WHO/IQS admissible limits (0.01 mg/L) except W3. Consequently, water consumption poses a significant hazard. In contrast, all samples had Pb concentrations well below the FAO (1985) maximum acceptable limit of 2 mg/L for irrigation water. Sanga et al. (2022) detected lead in groundwater samples at a similar level to that reported in this study. Also, groundwater analysis by Osuagwu et al (2023) recorded Lead levels (0.001–0.125) around Osisioma Open Dumpsite in Aba, Abia State, Nigeria less than in the present study. Significant differences (F= 18.92, P= 0.000) can be observed in lead values measured. This is confirmed with post hok test as a significant difference was observed between (W1/W2), and (W1/W3), Except between (W2/W3) as shown in Table 3. Lead contamination of groundwater in the study area may be caused by indiscriminately discarded Pb-containing solid waste, such as paint containers, colored plastics, and Pb-based batteries.

The rainy season recorded an increased chromium concentration than the dry season. In the rainy season, chromium concentration in groundwater varied from undetectable to 0.324 mg/L, whereas in the dry season, varied from undetectable to 0.098 mg/L. As illustrated by Table 2 the mean chromium concentrations for both dry and wet seasons for all samples were W1 (0.084, 0.191) mg/L, W 2 (0.0072, 0.028) mg/L, and W 3 was below detection level, respectively. W2 and W3 recorded the lowest concentration in all seasons, whereas W1 recorded the highest concentration, consecutively (Fig. 3). chromium concentrations were within WHO/IQS allowable levels of 0.05 mg/L except for W1. Moreover, they are below the maximum allowable limit (0.1 mg/L) by FAO required for irrigation except W1 in wet season. This result was higher than those recorded by Aduojo et al. (2023) in groundwater surrounding the Solous lll dump site, Nigeria. However, this result is similar to that recorded by

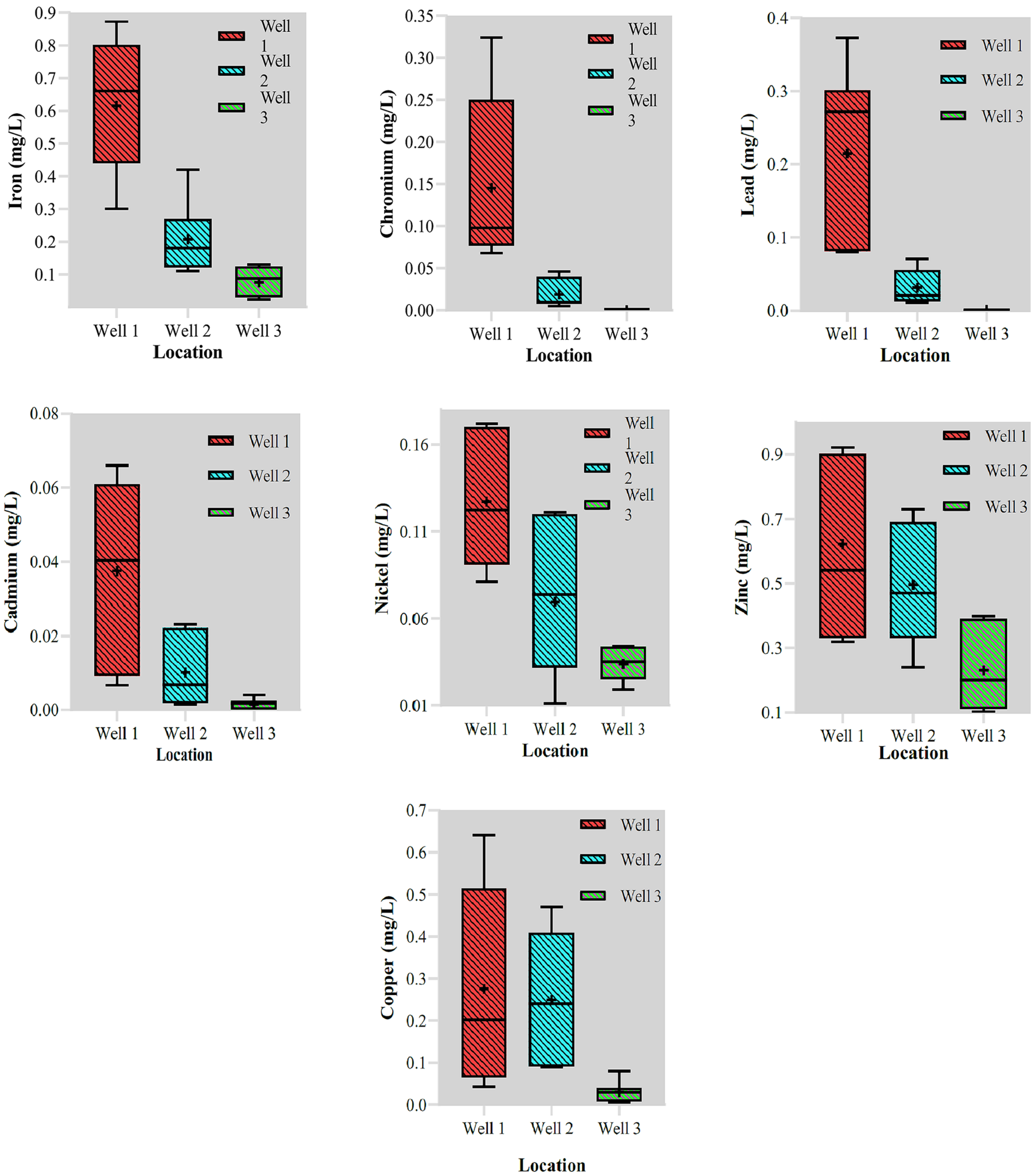

Fig. 3. Multiple box and whisker plots of heavy metal concentrations in observation wells

Aliyu et al. (2023) in Groundwater in Nasarawa Metropolis, Nigeria. Table 3 shows that Cr variations are significant at level $p < 0.01$ ($F = 12.64$, $p = 0.000$), Based on the Scheffe test, only, there are significant statistical differences between sample W1 and other samples.

The arid season had increasing nickel concentration in water compared to the rainy season. Nickel concentrations range were (0.019 to 0.1222 mg/L), and (0.0401 to 0.172 mg/L) during the rainy and dry seasons respectively. W1 and W3 registered the highest and lowest nickel concentrations in both seasons as shown in Fig. 3. Ni in the dumps is a result of the indiscriminate disposal of Ni-containing waste materials, such as Ni-Cd batteries, ceramics, Ni-coloured products, and Ni-plated materials. Only W2 in all seasons and W3 samples in wet season were below WHO (2022) permissible limits. In contrast, Ni concentrations were not in line with the IQS (2009)

Table 3. Statistical results for the concentrations of groundwater samples around the dump

Heavy metal	Iron	Chromium	Lead	Nickel	Cadmium	Zinc	Copper
Min	0.03	0	0	0.019	0	0.101	0.006
Max	0.873	0.3242	0.373	0.172	0.066	0.921	0.641
Mean	0.3	0.055	0.082	0.076	0.0163	0.45	0.185
Std. dev.	0.271	0.086	0.118	0.051	0.021	0.255	0.193
ANOVA analysis among location of samples around dumpsite							
F–value	28.032	12.646	18.922	13.69	12.127	6.782	4.628
P–value	0.000**	0.00037**	0.000**	0.00024**	0.00046**	0.0063**	0.023*
P–value Inference	Sig. diff.	Sig. diff.	Sig. diff.	Sig. diff.	Sig. diff.	Sig. diff.	Sig. diff.
Scheffe post hok test (F’)							
W1–W2	29.45	16.18	23.66	10.25	12.86	1.35	0.09
W1–W3	51.57	21.40	32.42	26.89	22.24	13.02	7.70
W2–W3	3.08	0.36	0.69	3.94	1.28	5.98	6.09

Note: *, and ** value significant at 0.05 and 0.01 level, F’crit. = 7.11.

guideline limit of 0.02 mg/L and FAO (1985) irrigation standards in all samples, hence unsuitable for consumption. The statistically significant difference at $p < 0.01$ was found by ANOVA test for Ni at all wells ($F = 13.69$, $p = 0.000$). As well significant difference was noticed between the well located closer to dumpsite and other remaining two wells ($F' > 7.1$) by test of Scheffe post-hok. On other hand, there are no statistically significant differences between wells 2 and 3($F' < 7.1$). Sanga et al. (2022) also found similar findings in Ni concentrations ranging from <0.01 mg/L to 0.20±0.03 mg/L. In contrast, Saheed et al. (2020) revealed Ni concentrations lower than those of this study, in groundwater nearby municipal dumpsites in Ibadan Metropolis, Nigeria.

Further findings show that the content of Cadmium increased in the dry season compared to the rainy season. The Cadmium in the wet season ranged from below detectable level to 0.042 mg/L, with an average of 0.0095 mg/L, whereas the dry season ranged from 0.0018 to 0.066 mg/L with an average of 0.023 mg/L (Table 1). The sites W3 and W1 revealed the lowest and highest value of Cadmium in the wet and dry seasons respectively (Fig. 3). The Cadmium measured in all sites was below the WHO/IQS allowable limitations (0.003 mg/L) except for W3. However, only W2 values through the wet season and W3 values were below the permitted level (0.01 mg/L) set by FAO’s criteria for irrigation water. A big difference was observed for Cadmium at $p < 0.01$ ($F = 12.127$, $p = 0.000$) by ANOVA test. Scheffe test illustrated a Statistically significant difference between station W1 and stations W2, and W3 for Cd concentration. Nevertheless, there is no difference between W2/W3 wells. Cadmium levels of groundwater samples in the study of Boateng et al. (2019) were found like as results of the current study, although higher than those published by Sanga et al. (2022).

Pollution indices

Heavy metal pollution indices were calculated for each analyzed groundwater sample using international standards (Edet and Offiong 2002) and the average concentrations of heavy metals observed through the rainy and drier seasons. This enables us to evaluate the water quality at each sampling location, which can be used to compare the index of every specimen. Table 4 and Fig. 4 display the result of the HPI, HEI, and Cd at groundwater sample locations throughout the studied seasons. One of the widest indicators used for assessing water quality is the Heavy metal pollution index as it demonstrates how individual minerals combined impact the water quality (Reza and Singh, 2010).

The range and mean HPI during the dry season were 64.8–1385 and 630.3, whereas, during the wet season, they were 35.4–1186.3 and 470.8. From the HPI results, it has appeared that all water samples except sample W3 that were taken from the monitoring wells were significantly higher than the critical value set by (Balakrishnan and Ramu 2016), after which the degree of water pollution is unacceptable. In a state the proper actions are not taken to lessen the concentration of heavy metals in the region, these levels

Table 4. Heavy metal pollution indices at each observation well for dry and rainy seasons

Sites	HPI		HEI		Cd	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
W1	1385	1186.3	38.27	50.1	31.27	43.1
W2	441	190.7	13.28	9.23	6.276	2.234
W3	64.8	35.4	3.1	2.094	-3.901	-4.906
Mean	630.3	470.8	18.22	20.475	11.215	13.475
SD	680.1	624.47	17.3	25	18.1	25.9

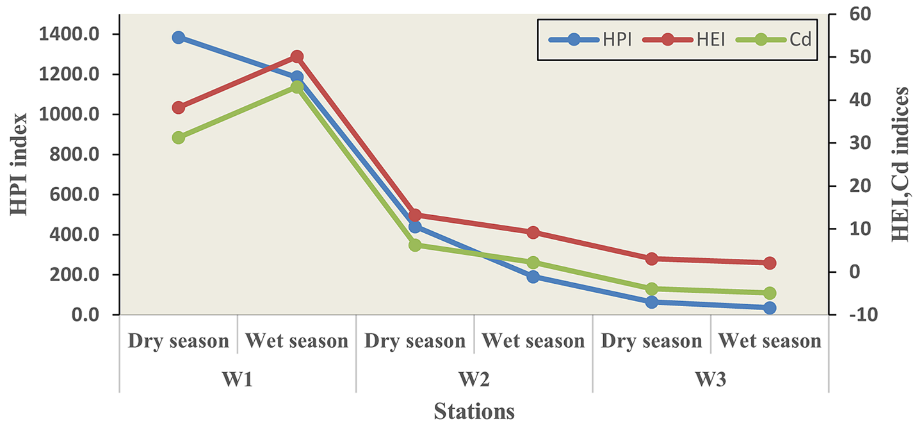

Fig. 4. Graphical representation of HEI, HPI and Cd values

may rise in the future. The variation of HPI and its increase during the rainy season indicated the impact of water supplies on water quality in the region. Also, higher levels of Cd and Pb detected at locations of observation wells may account for the observed increases in HPI there. Since the units weight (Wi) given to other metals (Cr, Fe, Cu, Ni, and Zn) were very low, these metals did not contribute much to the evaluation of HPI of the groundwater around the dump, but Cd and Pb gave high weight units and have a significant contribution. The HPI findings in this study are consistent with those of Wagh et al. (2018) from Nashik, India, but contrary to the finding of Podlasek et al. (2021) who observed underground water HPI levels of below 100 around landfills in Poland and Czech Republic.

The heavy metal evaluation index was used for a better understanding of the pollution indices (Edet and Offiong 2002). Based on HEI average values shown in Table 4 for each sampling site which varied from 3.1 to 38.27 during dry season and from 2.094 to 50.1 during wet season, samples were classified as low heavy metals level for all samples (HEI < 20) except sample W1was lies in high-level pollution (HEI >40) according to (Edet and Offiong, 2002) classification.

Sankoh et al. (2023), Amano et al. (2021), and Boateng et al. (2019) reported similar trends in HEI levels in groundwater vicinity of dumpsites. However, The HEI values obtained in this study are higher than that observed by Podlasek et al. (2021) in groundwater at Landfill sites in Poland and the Czech Republic.

Regarding the contamination index (Cd), the rainy season revealed the highest value (43.1) and lowest value (-4.9) in samples taken at site W1 and site W3 respectively. Based on Cd results and their average values (11.215 in the dry season and 13.475 in the rainy season), the studied groundwater was found to be low pollution (Cd < 10) according to the classifications of (Backman et al., 1998; Edet and Offiong, 2002) except samples taken from W1 which was high pollution. Sankoh et al. (2023) showed a similar trend of Cd levels in groundwater vicinity of the Granvillebrook and Kingtom dumpsites, Freetown, Sierra Leone.

In contrast, seasonal variance showed that chosen pollution indices fluctuated at different locations. In some instances, the values of indices were higher during the dry season; this may have been caused by dilution, temperature, and evaporation factors, whereas heavy metal-laden leachate percolating underground from a dumpsite

Table 5. Pearson's correlation coefficient between heavy metals in groundwater samples

Element	Fe	Cr	Pb	Ni	Cd	Zn	Cu
Fe	1						
Cr	0.873	1					
pb	0.962	0.87	1				
Ni	0.089	0.06	0.058	1			
Cd	0.127	-0.04	0.06	0.893	1		
Zn	-0.31	-0.29	-0.352	0.897	0.825	1	
Cu	-0.204	-0.211	-0.265	0.93	0.854	0.983	1

may account for the higher indices results during the wet season.

Correlational analysis

The interrelationships of the heavy metals in the groundwater of the Al- Diwaniyah dumpsite was studied using Pearson's correlation matrixes. Generally, significant positive correlations between pairs of heavy metals suggest that the heavy metals are from the same origin, whereas weak or negative correlations indicate that they are of distinct origins (Rezaei et al., 2019). Table 5 shows the Pearson's correlation matrix results between heavy metals in groundwater of all three study regions.

Pearson's correlation results of groundwater revealed that Cu is statistically correlated with most heavy metals as it showed a positive strong correlation with Ni (0.93), Cd (0.854), and Zn (0.983). Also, a good correlation was observed between (Zn-Ni), (Zn-Cd), (Cr-Fe), (Pb-Fe), and (Pb-Cr) which implied that the increase in one heavy metal would be offset by a noticeable increase in other metal. On the contrary, Ni, Cd, Zn, and Cu were (poor)weakly correlated to Fe, Cr, and Pb, and most of them negatively showed an indirect relationship between the variables.

CONCLUSIONS

There is dearth of information on the pollution status of groundwater around the illegal open dumpsite of Al-Diwaniyah, Therefore, groundwater around dumpsite have been studied to elucidate the the degree of heavy metal contamination and if it is suitable to human consumption using relevant heavy metal pollution indices. According to seasonal variation, the concentration of Fe, Cu, Ni, and Cd in dry season were found higher than other heavy metals in the observation wells. to contrast, Zn, Pb, and Cr having concentrations high in wet season. Whereas spatial variation revealed sampling site W1 adjacent to dumpsite was more contaminated than other sampling sites with investigated metals, mainly lead, cadmium, and nickel which indicates Improvement of groundwater quality is directly proportional to the distance from the pollution source. Most of the sites recorded concentrations for Fe Cr Cu Zn conform to the IQS/WHO requirements. In contrast, Pb Ni Cd concentrations at all sites exceeded the IQS/WHO permissible limits. However, all concentrations of samples were in line with FAO (1985) for irrigation water except for Nickel. Illustrated from Heavy metals pollution indices that groundwater taken from W1 site is heavily polluted and unfit for consumption, while the other two sites were within the low polluted category that showed a negligible effect of dumpsite and anthropogenic activities on the groundwater. As for the statistical analysis it was evidenced significant differences for most heavy metals in observation wells at 99% confidence level, also confirm that there are statistically significant differences between most investigated sites (F' > 7.11). On the other, Pearson's correlation analysis demonstrated the existence of an association between Cu and most heavy metals, Also, a good correlation was observed between (Zn and Ni, Cd), (Cr and Fe) (Pb and Fe, Cr). Perhaps due to originating from the same source. On the contrary, Ni, Cd, Zn, and Cu were (poor) weakly correlated to Fe, Cr, and Pb, and most of them negatively that showed an indirect relationship between the variables. It is clear from the foregoing that the migration of leachate from the base of the dump has a significant impact on the groundwater in the region, wherefore it is recommended to constantly monitor the groundwater near the dump and manage it to avoid the movement of leachate that will pollute the groundwater bodies. Therefore, existing illegal dumps should be disposed of, non-biodegradable and toxic wastes should be segregated and treated in particular along with application of environmentally friendly treatment to recover polluted dumps.

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