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Utilization of Heavy Metal Pollution Indices to Appraise Surface Water Quality According to WHO Standards

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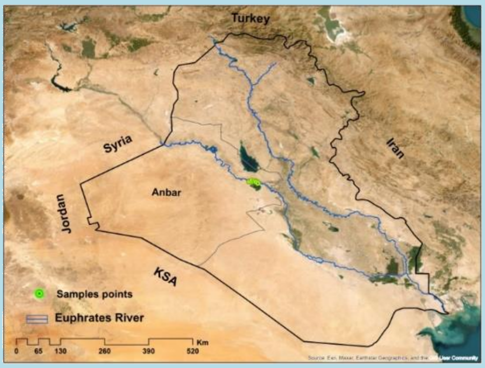
Abstract: This article concentrated on appraising the water quality of the Euphrates River in the city of Ramadi, Anbar Province western Iraq from the Ramadi Dam to the AL-Khalidiyah Bridge. Seven heavy metals: (Mn, Cu, Fe, Zn, Cr, Cd, and Pb) and ten positions were selected to assess the presence and concentration of these heavy metals in this part of the river. These heavy metals can be a risk and cause cancers due to they do not decompose and can accumulate in body organisms. The samples were analyzed using an atomic absorption spectrophotometer. Three indicators were utilized to appraise water quality: the Heavy Metal Evaluation Index, Contamination Degree, and Heavy Metal Pollution Index. The average concentrations of Mn, Cu, Fe, Zn, Cr, Cd, and Pb in the river water samples were found to be 15.87, 53.16, 152.1, 55.5, 10.41, 0.37, and 0.36 µg/L, respectively. The findings discovered that the concentrations of heavy metals in the samples are below the acceptable limits based on the World Health Organization (WHO). The average values of the indicators (HMPI, HMEI, and CD) were 49.106, 1.716, and -5.282 respectively, which are all below the acceptable limits established set by the World Health Organization. Based on these findings, the water quality of the Euphrates River in the study region is categorized as low pollution. Statistical analysis of heavy metals represented by Pearson correlation displays that the sources of the low pollution levels in the study region consequence of various human activities. Although heavy metal pollution in the Euphrates River in the study region is low, the river water cannot be pumped directly into residential units. This is due to the river water contains other pollutants, such as turbidity and suspended solids, and may also contain pathogens, including bacteria and viruses. Therefore, it must be treated at the water treatment plant before it can be used for drinking.



Keywords: Euphrates River; Pollution, Heavy Metals, water quality, HMPI, HMEI, CD.

Introduction

The contamination of river water can badly affect its physical and chemical characteristics, which can have a risky impression on the life of the society living nearby and utilizing this water for different drives. Regular observation of river water is essential to assess pollution levels and recognize the factors causing pollution. Such studies can play a considerable role in raising the realization among the people about the declining quality of river water and how it affects its diverse utilizations [1]. Presently heavy metal contamination of drinking water is one of the biggest environmental challenges, and some of them can create adverse effects on human health when their levels exceed the permissible limit in drinking water [2]. Heavy metals are extremely venomous and can significantly influence the environment and anthropological health [3]. The main sources of heavy metals in aquatic environments are human activity or natural sources [4]. Heavy metals are naturally found in the soil through geological weathering processes like leakage, bearing, and chemical weathering of minerals [5]. The main human sources of heavy metal pollution are partially treated pollutants, industrial wastes, and heavy metals from different industries such as medical manufacture and the haphazard use of heavy metal-containing chemicals and fertilizer in agricultural regions [6-7]. Municipal solid waste can introduce significant amounts of heavy metals into aquatic environments through coatings, inks, pesticides, and personal care products. [8]. Heavy metals are widely recognized for their toxic and cancerous impacts on biological organisms. [9]. Some heavy metals, like zinc and copper, are essential for life processes in organisms. However, many other metals, such as lead and cadmium, have no recognized physiological impacts [10-11]. Rivers, lakes, wells, and springs supply drinking water to Iraq. These sources are exposed to various kinds of pollutants, such as industrial, agricultural, and sewer wastes, which are challenging to monitor, control, and appraise [12]. Heavy metal pollution is a major worldwide concern. Approximately 20 metals are categorized as venomous. The release of heavy metals without proper treatment and management presents a serious threat to general health, leading to issues such as growth issues, tumors, tissue damage, neurological harm, and, in critical cases, death. [13]. Water quality indices are significant instruments to appraise water quality. There are numerous methods for discovering water quality data and representing appropriate outcomes, such as creating a list of all water quality parameters and this list may be difficult to understand for a people. To speech this issue, water quality indicators were proposed. [14]. Water quality indexes combine data from many water quality parameters into a lone number that evaluates the sustainability of the environment. This number catalogs the quality of water into diverse classes, ranging from excellent to very low. It is simply understandable for political decision-makers, non-technical water managers, and the general people. [15]. Sahab et al. submitted a study that appraised the groundwater quality for

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irrigation in the Al-Wafaa district in the western region of Iraq by analyzing eighteen water specimens combined from eighteen wells Dispersed in the research region. pH, EC, Total Dissolved Solid (TDS), main cations, and anions (Na+, K+, Ca2+, Mg2+, Cl-, HCO3-1 -, NO3-1) were monitored. The chief cations were utilized for calculating the sodium adsorption ratio (SAR) and the percent sodium (%Na). In addition. United States salinity laboratory diagrams were engaged to appraise the appropriateness of the groundwater quality for watering. The finding designates that the samples are not suitable for irrigation [16]. Khan et al. used the heavy metal pollution index to determine the Gomti River's contamination level. The findings revealed that the mean heavy metal pollution indices value is greater than 100, indicating an imminent risk of pollution, due to 30% of the location having an index value below the high pollution level, while 60% had an index value greater than 100, indicating an extreme contamination state. [17].

Several researchers have studied heavy metal concentrations, distribution, and pollution in water, sediments, aquatic organisms, and vegetation of the Euphrates River in Iraq.

Jazza et al. Studied the water quality treated that is delivered to residential regions for drinkable purposes in Misan province, southern Iraq by application of the indexes related to heavy metal concentration. Ten samples were collected from ten positions. Eight heavy metals were selected: Cobalt, Cadmium, Lithium, Iron, Nickel, Chromium, Lead, and Zinc, and were measured. The Heavy Metal Pollution Index (HPI) was calculated to appraise the total quality of drinking water for human use. The results indicated that the concentrations of heavy metals at all the selected positions were below the acceptable limits based on the Iraq specification. The value of HPI depending on the average concentration was found to be 2.49246 which is significantly below the dangerous pollution index value of 100. According to these findings, drinking water can be used as safe water for human utilization. [18]. Salah et al. employed the Heavy Metal Pollution Index (HMPI) and Metal Index (MI) to appraise the water quality of the Euphrates River in Amiriyah Fallujah, Iraq. The Heavy Pollution Index (HPI) data revealed that the water was severely contaminated with cadmium, chrome, and lead. Depending on metal index (MI) data, the water is gravely endangered by metal contamination and unfit for drinking and watering. [19]. Al-Khuzaie et al. The study inspects the influence of untreated wastewater on the Euphrates River in the province of Al-Diwaniyah, southern Iraq, revealing severe pollution due to the unregulated discharge of sewage and industrial effluents. 40 water samples were collected from the study region. Heavy metal concentrations as well as physical and chemical properties were measured. The study utilized the Heavy Metal Pollution Index (HPI) to appraise water quality and utilized the Inverse Distance Weighting (IDW) tool to forecast HPI values and their spatial distribution. The study highlighted the extreme contamination levels in the Euphrates River, transcending Iraqi specification thresholds for nickel, iron, and cadmium concentrations. [20]. The purpose of the present research is to evaluate the heavy metal concentrations in water inside the Euphrates River, which runs from the Ramadi Dam to the AL-Khalidiyah Bridge in the Governorate of Anbar. Contamination indices related to heavy metals, specifically (HMPI, HMEI, and CD) were applied for assessment.

Methodology

Study region description

The Euphrates River is one of the two primary rivers in Iraq. It originates in Turkey, runs through Syria, and enters Iraq along the western border. The river travels a distance of approximately 2,700 kilometers before emptying into the Arabian Gulf. The river water is utilized for agriculture, drinking, pleasure, and angling. The river accomplishes its ultimate flow in the April and May months due to the melting of snow in the mountainous areas from which the river originates [21,22]. Ramadi is the administrative center of Al-Anbar province, located 110 kilometers northwest of Baghdad. Ramadi city is at Latitude 33°25'11" N, Longitude: 43°18'45" E [23]. The city of Ramadi is a relatively developed area with several minor enterprises and a population of over 270,000 people [24]. The Euphrates River runs through the Anbar governorate shown in (Figure 1). It provides water to several major and minor cities in the governorate of Anbar including AL-Qaeem, Haditha, Rawa, Ana, Heet, Ramadi, and Fallujah [25]. The river is the primary supply of drink purpose and supports industry and crops irrigation. It also acts as an embouchure for water and waste treatment [26, 27].

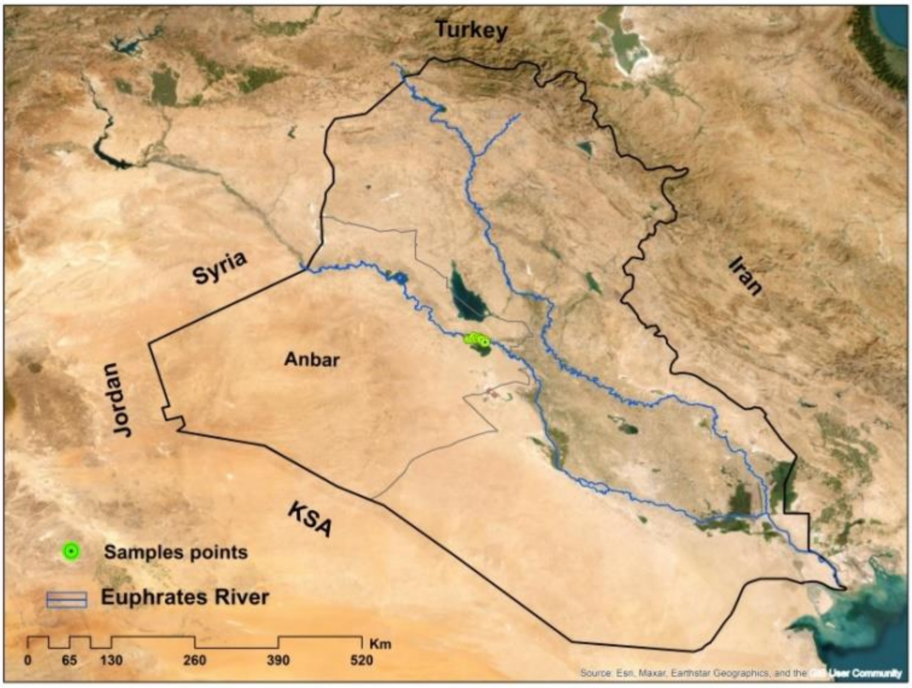

Figure (1): The map indicates to the study region.

Sampling Collection

The water samples were taken from ten positions along the Euphrates River from the Ramadi Dam to the AL-Khalidiyah Bridge in Anbar province once a month, as shown in Figure 2.

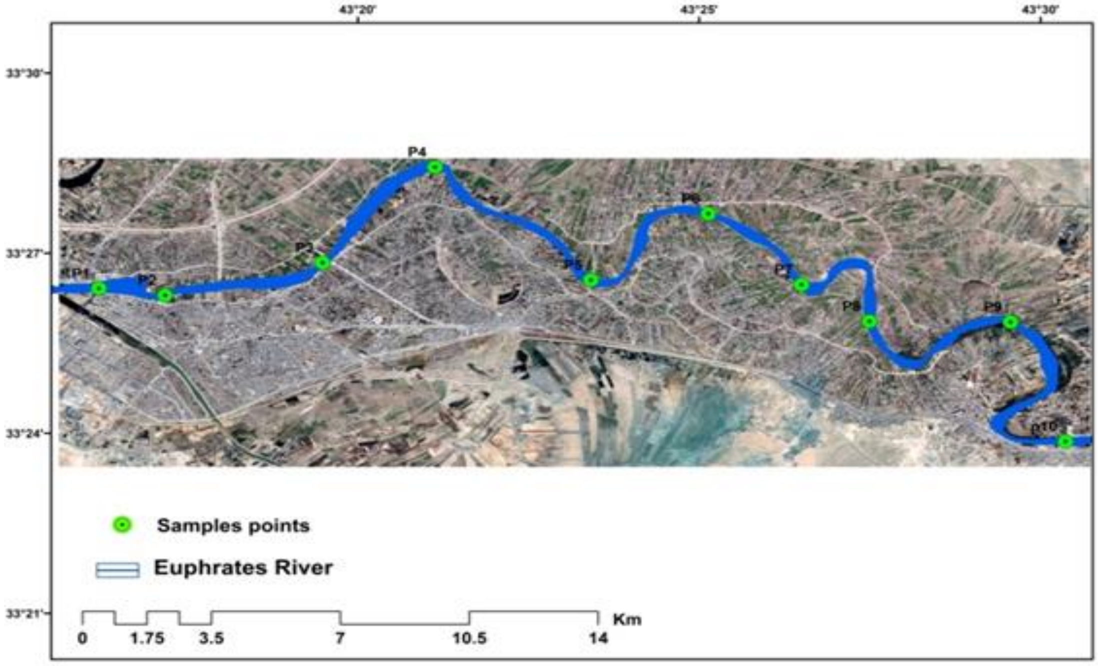

Figure (2): Location of the points.

The samples were collected from 30 cm below the river surface, and the coordinates of the positions were determined using (GPS) and notarized in (Table 1). The samples were deposited in clean polyethylene bottles with a 1000 mL capacity and kept in ice containers. Three samples were collected from each position: the left bank, the right bank, and the center point of the river. These samples were mixed to produce one sample representative for each position. The concentration of heavy metals (Mn, Cu, Fe, Zn, Cr, Cd, and Pb) in water samples was measured as shown (Figure 3.) by flame atomic absorption spectrometry (AA500) in the quality control department, Central Laboratory for drinking water tests based on the Standard Method for Examination of Water and Wastewater. [28].

Table (1): The coordinates of the study section.

Position	The region	The coordinates
P1	Ramadi Dam Region	N 33˚ 44 02.51 E 43˚ 27 01.07
P2	Albo-Alwan Region	N 33˚ 43 83.51 E 43˚ 28 62.69
P3	Al-Soofia Region	N 33˚ 44 73.93 E 43˚ 32 47.11
P4	Al bo-Mehl Region	N 33˚ 47 39.16 E 43˚ 35 21.74
P5	Al- Maomun Bridge Region	N 33˚ 44 25.75 E 43˚ 39 02.46
P6	Gweeba Region	N 33˚ 46 09.94 E 43˚ 41 89.36
P7	Elwibed Region	N 33˚ 44 13.22 E 43˚ 44 16.77
P8	Eastern Ehseba Region	N 33˚ 43 10.95 E 43˚ 45 82.66
P9	Al-Madeq Region	N 33˚ 43 09.21 E 43˚ 49 27.31
P10	AL-Khalidiyah Bridge Region	N 33˚ 39 77.41 E 43˚ 50 61.41

Figure (3): Sampling analyses using flame atomic absorption spectrometry.

Pollution indicators related to heavy metals

Heavy metal pollution Index (HMPI): The heavy metal pollution index (HMPI) is an appraisal method that demonstrates the compound impact of individual heavy metals on overall water [29]. HPI is developed in two steps. The first step involves establishing a rating scale for each selected parameter and assigning weightage, while the second step focuses on selecting the pollution parameter that the index will be based on. The rating system is assessed by making values inversely proportional to guidelines which are taken from WHO as shown in Table 2. The heavy metal pollution index (HAMPI) was calculated as:

$$\mathbf{HMPI} = \frac{\sum_{i=1}^{n} Wi * Qi}{\sum_{i=1}^{n} Wi} \quad (1)$$

$$\mathbf{Qi} = \sum_{i=1}^{n} \frac{Mi-Ii}{Si-Ii} \times 100 \quad (2)$$

Where, Qi: is sub-index of ith heavy metals, Wi: is unit weight of ith heavy metals, n: is the number of heavy metals which equals 7 (Mn, Cu, Fe, Zn, Cr, Cd, and Pb) for this article, Mi: is measured concentration of ith heavy metals, Ii: is ideal value of ith heavy metals, Si: is a criterion according to WHO guidelines of ith heavy metals.

Quality of water is classified based on HMPI into three categories: low risk (less than 100), criterion risk (equal to 100), and high hazard (greater than 100). If the HMPI exceeds 100, drinking water is unsafe [30]. The calculations were based on the guidelines provided by the World Health Organization (WHO) [31]. The essential parameters of heavy metals to calculate water quality indices are shown in Table 2.

Table (2): Applied parameters for calculation of water quality index (according to WHO guidelines). [31].

Heavy metals HMs	Symbol	Guidelines (ppb)	Weightage Wi=1/guideline	Highest Permissible in (ppb) Ii	Permissible Standard in (ppb) Si	Maximum admissible concentration in(ppb) MAC
Manganese	Mn	50	0.02	500	100	50
Copper	Cu	1000	0.001	2000	1000	1000
Iron	Fe	300	0.003	200	300	200
Zinc	Zn	5000	0.0002	3000	5000	5000
Chrome	Cr	50	0.02	50	1	50
Cadmium	Cd	3	0.3	3	5	3
Lead	Pb	1.5	0.70	10	100	1.5

Heavy metal evaluation Index (HMEI): The heavy metal evaluation index (HMEI): is a method used to appraise the water qualities, specifically focusing on heavy metals in drinkable water: [32]. It is computed using the following equation:

$$\text{HMEI} = \sum_{i=1}^{n} \frac{Mi}{MAC} \quad (3)$$

Where, Mi: is measured concentration of ith heavy metals, MAC: Maximum admissible concentration in (ppb).

Water qualities classified based upon HMEI are: <10 for low pollutions, (10-20) for moderate pollutions and > 20 is high pollutions

Contamination degree (CD): The term CD refers to the combined negative impact of heavy metals on surface water [33]. CD signifies the total concentration factors. The contamination degree must be determined for each specimen that surpasses the typical value. The CD indicator is calculated using the equations 4 and 5 as follows:

$$\mathbf{CD} = \sum_{i=1}^{n} \text{CFi} \quad (4)$$

$$\mathbf{CF_i} = \frac{Mi}{MAC} - 1 \quad (5)$$

Where, CD: is contamination degree, CFi: is contamination factor, Mi: is measured concentration of ith heavy metals, MAC: Maximum admissible concentration in (ppb).

The levels of contamination between locations are divided into three categories based on CD value: low pollution (CD less than 1), medium pollution (CD great than 1), and severe pollution (CD great than 3) [34].

Result and Discussion

Concentration of heavy metals

(Table 3) displays statistical extractions (minimum, maximum, and mean) and reveals the heavy metal levels in the specimens of water collected from the study location. The mean concentrations of studied metals in the water samples are as follows: Fe+2 > Zn+2 > Cu+2 > Mn+2 > Cr+3 > Cd >Pb+2. The concentrations of Mn, Cu, Fe, Zn, Cr, Cd, and Pb are listed in (Figures. 4, 5, 6, 7, 8, 9 and 10) respectively. The mean concentrations of (Mn, Cu, Fe, Zn, Cr, Cd, and Pb) are 15.87, 53.16, 152.1, 55.5, 10.41, 0.37, and 0.36, respectively, and are all below the World Health Organization (WHO) standard levels for drinking water. The Euphrates River in the study region was considered below pollution. The obtained results in this study were compared with previous studies conducted on rivers worldwide (Table 4) to evaluate the heavy metals. The findings of the comparison suggest that the heavy metal concentration of the Euphrates River in the study area is much lower than the concentrations of the mentioned rivers. Based on the findings, the Euphrates River is less polluted than many rivers worldwide due to different human activities and unique geological and hydrological conditions.

Table (3): Heavy metals (ppb) and water quality indexes WQIs (according to WHO guidelines).

Position	Heavy metals (ppb)						
	Mn	Cu	Fe	Zn	Cr	Cd	Pb
P1	20.39	80.33	188	60	7.51	0.58	0.72
P2	10.54	91.13	192	49	22.00	0.76	0.25
P3	14.65	34.00	125	66	5.66	0.18	0.36
P4	12.31	41.73	121	37	11.63	0.26	0.12
P5	27.76	59.52	243	45	13.41	0.21	0.38
P6	14.91	24.75	65	63	10.01	0.31	0.09
P7	9.85	35.05	175	79	8.47	0.39	0.52
P8	12.19	49.12	112	34	6.13	0.41	0.09
P9	12.99	41.01	184	38	13.00	0.45	0.15
P10	23.11	75.00	116	84	6.27	0.18	0.95
Min	9.85	24.75	65	34	5.66	0.18	0.09
Max	27.76	91.13	243	84	22.00	0.76	0.95
Average	15.87	53.16	152.1	55.5	10.41	0.37	0.36
Guide Line (ppb)	50	1000	300	5000	20	3	1.5

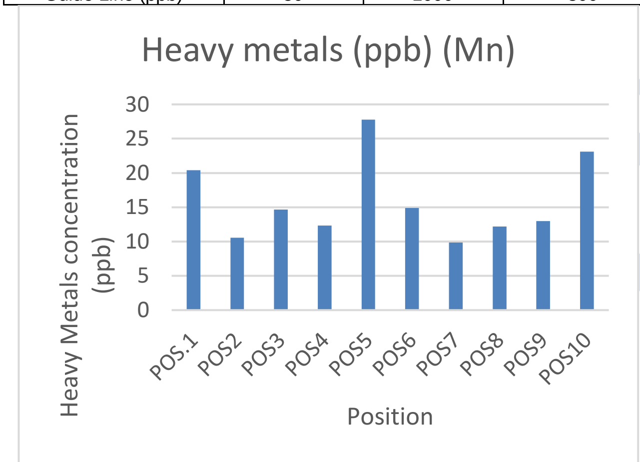

Figure (4): Manganese concentration in the study area

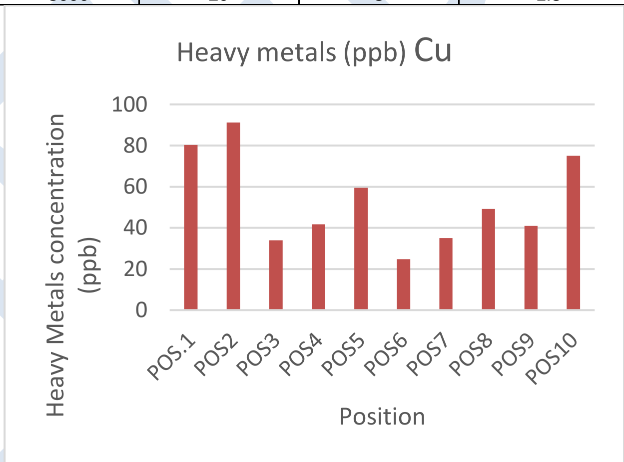

Figure (5): Copper concentration in the study area

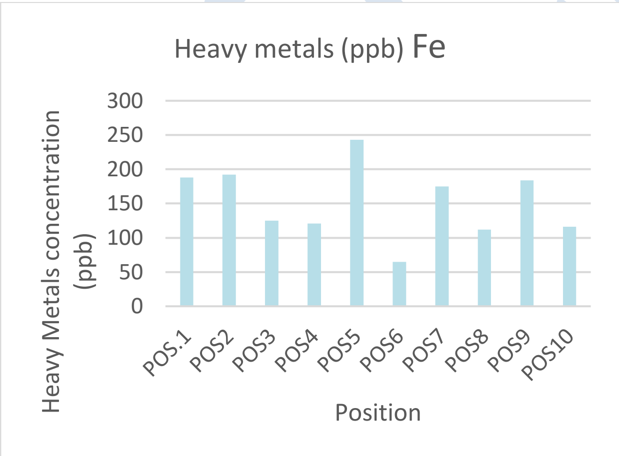

Figure (6): Iron concentration in the study area.

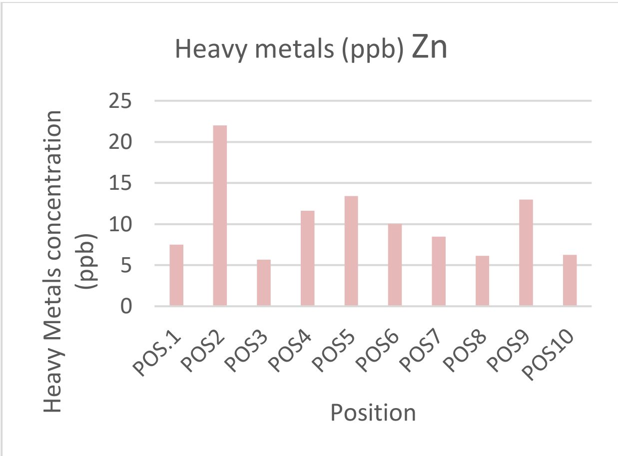

Figure (7): Copper concentration in the study area.

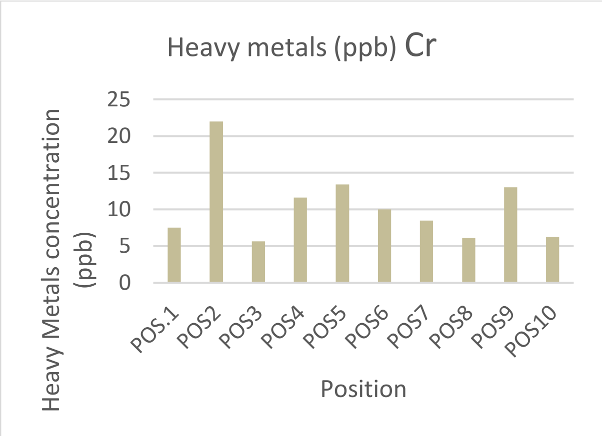

Figure (8): Chrome concentration in the study area.

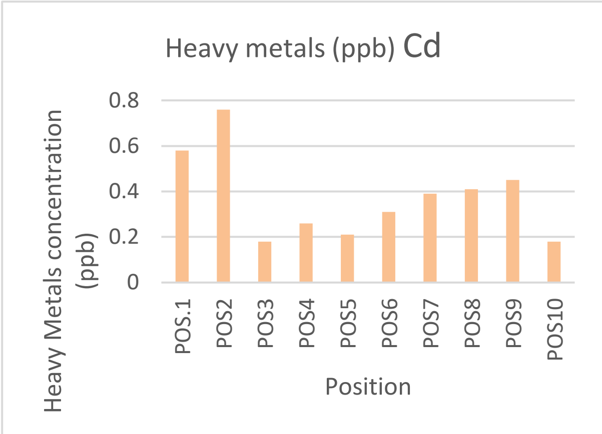

Figure (9): Cadmium concentration in the study area.

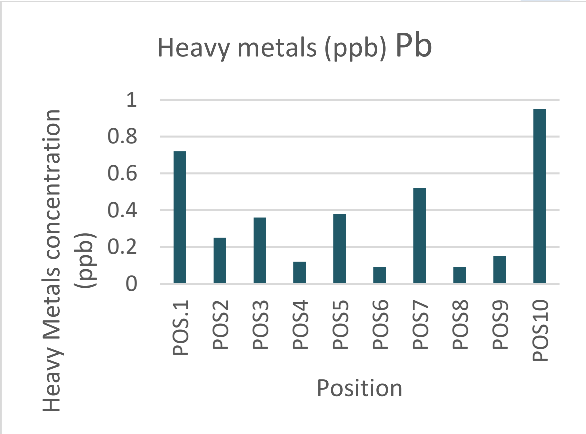

Figure (10): Lead concentration in the study area.

Table (4): Comparison of average heavy metals concentrations (ppb) in the water of different worldwide rivers with the Euphrates River water in the study area.

Region	Mn	Cu	Fe	Zn	Cr	Cd	Pb	References
Euphrates River, Ramadi City, Anbar Province, Iraq.	15.87	53.16	152.1	55.5	10.41	0.37	0.36	Current Study
Yuxi River, China	-	16	-	134	-	1	25	[35]
Ganga River, India	26	10	80	60	124	5	120	[11]
Nile, Egypt	-	-	-	-	-	4.5	180	[36]
Major River, Argentine	22	3.1	172	22	-	0	1.7	[37]
Yamuna River, India	-	75	126.7	1516.7	26.7	-	15.3	[38]
Khoshk River, Iran	250	30	-	1700	190	30	70	[39]
Diyala River,Iraq	231.3	120.4	676.6	2951.5	152.8	33.4	787.5	[40]

Heavy Metals Pollution Water Indices

The values of (HMPI) shown in (Table 5) and (Fig. 11) ranged from 43.12 to 52.18 with an average value of 49.106. The results suggested that the (HMPI) values in all positions are less than the guideline WHO pollution value of 100. The values of (HMEI) shown in (Table 5) and (Fig. 12) ranged from 1.024 to 2.430 with an average value of 1.716. The findings indicated that the (HMEI) values in all positions are much below the recommended (WHO) pollution value of 10. The values of (CD) shown in (Table 5) and (Fig. 13) ranged from -5.975 to -4.569 with an average value of -5.282. The results indicate that the (CD) values in all positions are significantly below the commend WHO pollution value of 1. According to the result of heavy metals pollution indexes (HMPI, HMEI, and CD) lower than the recommended (WHO) the quality of Euphrates water is low contamination.

Table (5): Heavy Metals Pollution Water Indexes.

POS	Qi-Mn	Qi-Cu	Qi-Fe	Qi-Zn	Qi-Cr	Qi-Cd	Qi-Pb	ΣWi × Qi	HMPI	HMPI classification	HMEI	HMEI classification	CD
P1	119.90	191.96	12	98	86.71	121	10.31	47.88	45.87	Low pollution	2.263	Low pollution	-4.736
P2	122.36	190.88	8	147.55	57.14	112	10.83	45.01	43.12	Low pollution	2.131	Low pollution	-4.868
P3	121.34	196.6	75	146.7	90.49	141	10.7	54.48	52.18	Low pollution	1.378	Low pollution	-5.621
P4	122	195.83	79	148.15	78.31	137	10.98	53.26	51.02	Low pollution	1.299	Low pollution	-5.700
P5	118.06	194.05	43	148	75	140	10.69	53.71	51.45	Low pollution	2.430	Low pollution	-4.569
P6	121.27	197.52	135	146.85	82	135	11	52.91	50.67	Low pollution	1.024	Low pollution	-5.975
P7	122.55	196.50	25	146.05	84.75	131	10.5	51.12	48.96	Low pollution	1.768	Low pollution	-5.231
P8	122	195	88	148.3	89.53	129.5	11	51.27	49.11	Low pollution	1.178	Low pollution	-5.821
P9	121.75	195.89	16	148	75.15	127.5	10.94	50.11	48.00	Low pollution	1.738	Low pollution	-5.261
P10	119.2	192.5	84	146	89.24	141	100.5	53.96	51.68	Low pollution	1.952	Low pollution	-5.047
Min	118.06	190.88	8	98	57.14	112	10.31	45.01	43.12	Low pollution	1.024	Low pollution	-5.975
Max	122.55	197.52	135	148.3	90.49	141	100.5	54.48	52.18	Low pollution	2.430	Low pollution	-4.569
Average	121.04	194.67	56.5	142.36	80.83	131.5	19.74	51.37	49.11	Low pollution	1.716	Low pollution	-5.282

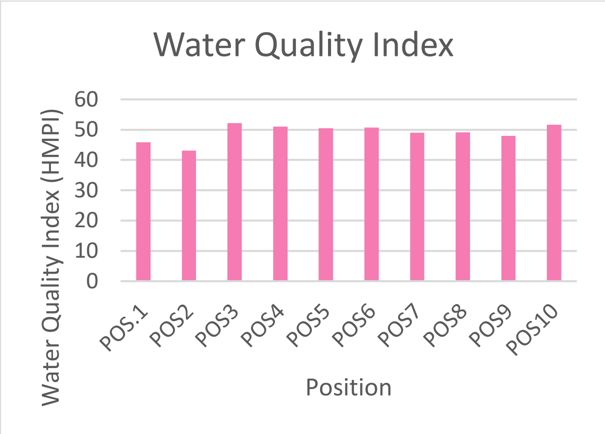

Figure (11): HMPI in the study area.

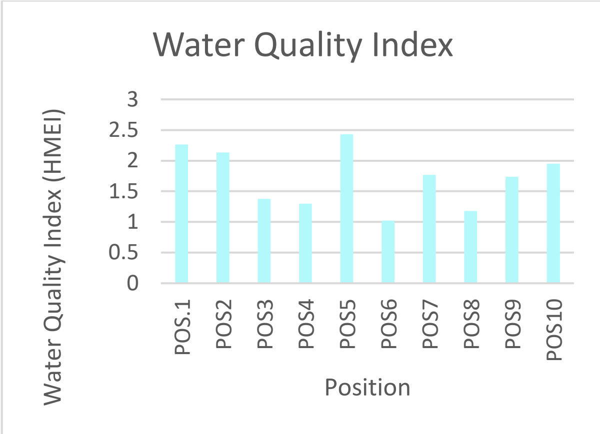

Figure (12): HMEI in the study area.

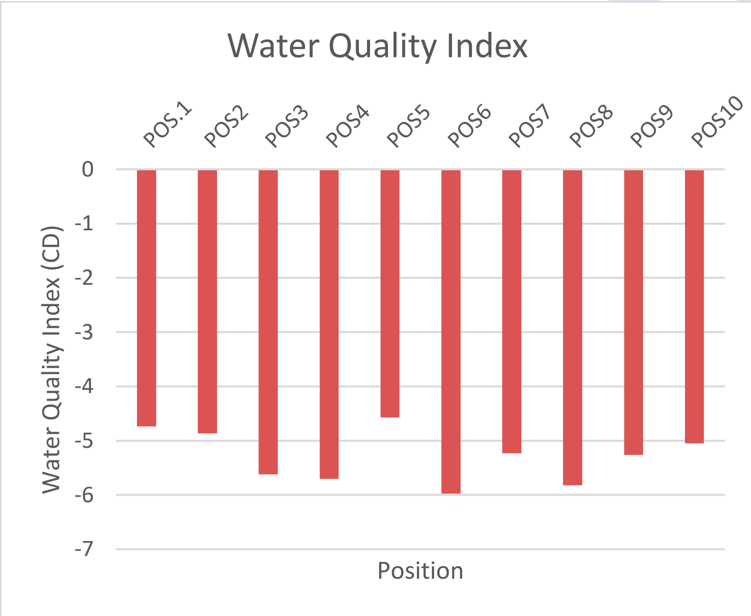

Figure (13): CD in the study area.

Statistical analyses of heavy metals

Correlation analysis effectively discovers the relationships between multiple variables, helping to understand the impacting factors and sources of chemical components [41]. The association between heavy metals can supply vital insights into their sources and pathways [42, 43, 44]. The Pearson correlation coefficient matrix between 7 heavy metals is registered in Table 6. Typically, a correlation coefficient larger than 0.7 indicates a strong relationship between two parameters, while values ranging from 0.5 to 0.7 suggest a moderate relationship. Based on (Table 6.) a strong positive correlation between Zn and Pb has been found (r = 0.746) indicating anthropogenic sources of these heavy metals. Moderate correlations were found between Mn and Pb (r = 0.546), Cu and Cd (r = 0.541), Cu and Pb (r = 0.508), and Cr and Cd (0,596). Fe displayed poor correlation with the other metals suggesting that Fe is from different sources than other metals.

Table (6): Pearson correlation matrix.

Element	Mn	Cu	Fe	Zn	Cr	Cd	Pb
Mn	1						
Cu	0.339	1					
Fe	0.326	0.472	1				
Zn	0.181	0.029	-0.191	1			
Cr	-0.179	0.400	0.475	-0.395	1		
Cd	-0.422	0.541	0.344	-0.252	0.596	1	
Pb	0.546	0.508	0.202	0.746	-0.352	-0.131	1

Conclusions and Recommendations

The section of the Euphrates River from the Ramadi Dam to the Khalidiya Bridge is very important as it serves as the chief provider of drinkable water for the city of Ramadi, the center of Anbar province, and one of its largest cities. To know if the water in this section contains heavy metals, samples were collected from the study area and analyzed using an atomic absorption spectrophotometer to measure seven heavy elements: (Mn, Cu, Fe, Zn, Cr, Cd, and Pb). The finding indicated that the concentrations of heavy metals at all positions were below the limits recommended by the (WHO). Three indicators were used to evaluate the suitability of the river water for drinking purposes. The results indicated that the values of the indicators are lower than the limits recommended by the (WHO), and therefore the Euphrates River water in this section is low in pollution. Statistical analysis of heavy metals indicates that the sources of the low contamination in the study area originate from miscellaneous anthropogenic. This research recommends conducting studies in the other sections of the Euphrates River to assess the quality of water for drinking. This investigation promotes further studies to assess the organic contaminants in the Euphrates River. The research suggests conducting a study to assess the lethal dose level for heavy metals and their influence on living organisms. The study commended the importance of continuous monitoring of water quality and measuring the concentrations of heavy elements in aquatic organisms and plants, as well as in industrial and agricultural waste. This research commended the importance of maintaining water quality, even if it has low contamination levels and does not use the water directly from the river. Rather, it passes through multiple treatment stages to ensure purification before being distributed to the city.

Disclosure Statement

- Ethics approval and consent to participate: Not applicable
- Consent for publication: Not applicable
- Availability of data and materials: The raw data required to reproduce these findings are available in the body and illustrations of this manuscript
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NOMENCLATURE

HMPI	Heavy Metals Pollution Index
HMEI	Heavy Metals Evaluation Index
CD	Contamination degree.
WHO	World health organization

PLI	pollution load index.
Igeo	geo-accumulation index.
EF	The enrichment factor EF.
%Na	The Percent Sodium
SAR	Sodium Adsorption Ratio
POS	Position.