Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24600

168 (2019) 165–174
November

Assessment of heavy metal pollution in the Great Al-Mussaib irrigation channel

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Received 27 January 2019; Accepted 19 June 2019

ABSTRACT

The Great Al-Mussaib channel (GMC), in Babylon province, Iraq, has been selected as a case study to measure the concentration of nine heavy metals (Pb, Ni, Zn, Fe, Cd, Cr, Cu, Mn and Co) in both water and sediments of the GMC. The channel is used as a raw water source for two cities, which reveals the importance of the current study. Where, any heavy metals pollution could cause significant health problems for the population of these cities. The obtained results revealed that the concentrations of the studied heavy metals in the water of the GMC were less than the pollution levels and followed the order: Pb < Ni < Cu < Cr < Mn < Zn < Fe. It is noteworthy to highlight that the concentrations of Co and Cd were below the detectable limits. Additionally, the results obtained from the analyses of the studied sediment samples showed, according to the values of pollution load index and geo-accumulation index (I_{geo}), that the concentrations of studied metals were less than the pollution levels (except for a few cases) and followed the order: Cd < Co < Cu < Pb < Ni < Cr < Zn < Mn < Fe.

Keywords: Great Al-Mussaib irrigation channel; Heavy metals; Sediments; Pollution load index; Geo-accumulation index

1. Introduction

Although there are different kinds of environmental pollution such as air, soil, water, thermal and noise pollution [1–5], water pollution is one of the major challenges to the global environment due to several reasons, such as the limited quantity of fresh water on this planet [6,7]. In addition, the rapid increase in global population that increases the quantity of discharged wastewater and urban drainage into the sources of fresh water [6,8]. The literature highlights a wide range of organic and inorganic water pollutants [9–13]. However, heavy metals are the most environmentally problematic pollutants due to their high toxicity and their ability to accumulate in the aquatic system [14,15]. In addition, heavy metals are not biologically degradable, thus they accumulate in plants and aquatic organisms to a very high level that can severely damage the aquatic life [16–18]. Moreover, heavy metals cause many diseases for mankind, such as congenital malformations, kidney damage or spontaneous abortion, and decreases levels of intelligence [19].

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Therefore, the negative impacts, treatment and occurrence of heavy metals in water and wastewater have been extensively investigated [20,21]. For instance, Wang et al. [22] investigated the concentration of eight heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) in sediments of the Yangtze River, China. The outcomes of this study indicated that the concentrations of the studied heavy metals in the collected samples were higher than their concentrations in the surrounding soil, which indicates metal pollution. Ahmad et al. [23] carried out a study to assess the spatial and temporal distribution of Pb, Cd, Ni, Cu and Cr in water and sediments of the Buriganga River. Their study revealed that this river could be categorised as a heavy metal polluted river. A risk assessment of heavy metals in the Mahanadi basin, India, was carried out by Sundaray et al. [24] to assess the environmental risks of Cd, Co, Mn, Cu, Zn, Ni and Pb. The obtained results indicated a high environmental risk of Cd, Ni, Co and Pb. Similar studies have been carried out in Iraq to assess the metal pollution in the sediments and water of some of the country's rivers. For example, Al-Juboury [25] studied the concentration of Cr, Cu, Ni, Pb and Zn in the sediments of the Tigris River and some of its tributaries and found that the concentrations of these metals were more than the allowable limits. Rabee et al. [26] investigated the concentration of Mn, Ni, Pb, Cu and Cd in the sediments of the Tigris River inside the region of Baghdad. The outcomes of this investigation indicated that the collected samples were slightly polluted with Pb and Cd. Salman and Hussain [27] studied the metal pollution in water and sediments of the Euphrates River; the authors found high concentrations of Pb, Ni, Mn, Co, Cu and Fe in sediment in comparison with water. Abdullah [28] stated that the concentrations of Fe, Zn, Cu, Cd, Pb and Ni in the Shatt Al-Arab River are below the pollution level. Similar study was carried out to assess the heavy metal pollution in the Danube [29]. This study focused on the concentrations of six heavy metals (Cu, Cr, Ni, Zn, Pb and Cd). It has been found that the concentration of both Cu and Ni in sediments could cause harmful biological effects, while the concentration of the rest of the studied metals was within the permissible limit.

According to the literature, most of the previous studies in Iraq focused on rivers [26,30,31]. Therefore, the current investigation has been carried out to assess the metal pollution in a channel (GMC) used for irrigation, municipal water supply and agricultural drainage.

2. Objectives

The current work has been mainly devoted to investigate the concentration of heavy metals in the GMC channel. The specific objectives of the current project are follows:

- To measure the concentration of Pb, Ni, Zn, Fe, Cd, Cr, Cu, Mn and Co in the water of Great Al-Mussaib channel (GMC).
- To quantify the concentration of Pb, Ni, Zn, Fe, Cd, Cr, Cu, Mn and Co in the sediment of GMC.
- Application of pollution indicators (pollution load index [PLI] and geo-accumulation index [I_{geo}]) to assess the metal pollution level in water and sediment of the GMC.
- To conduct a statistical analysis to study the explanatory variables those are closely related to the concentration of sediments.

3. Description of the study area

The Great Al-Mussaib channel (GMC), which is a branch of the Euphrates River, lies to the northeast of the Babylon Province. It has an approximate length of 50 km, maximum discharge of 40 m^3/s, average flow depth of 2.50 m and average top width of 25 m, and it occupies an area of 900 km^2. This channel was officially opened in 1957, and it is considered to be one of the major strategic agricultural projects in Iraq [32,33]. Main winter crops in the area of the Great Al-Mussaib channel are wheat, barley, alfalfa, clover and vegetables. While in summer, the farmers focus on corn, clover, cotton, sunflower, sesame and different vegetables [34].

The GMC represents the main source of raw water for many cities and villages in Iraq. At the same time, GMC receives agricultural wastewater from a network of drainage channels in Babylon city [33]. In addition, GMC receives large quantity of domestic and industrial wastewater, especially at the city of Jballa (the final 7 km segment of the studied area) [32,33]. It is noteworthy to highlight that the agricultural wastewater represents the main source of pollution for GMC. The annual rainfall rate in the project area is 150 mm in winter, while evaporation rate is 13 mm/d in summer and 5 mm/d in winter. Recently, the salinity in soil surrounding the GMC, which is classified as sedimentary, has noticeably increased, which in turn increases pollution of the GMC [35].

4. Materials and methods

The studied segment of the GMC and the locations of the monitoring stations are shown in Fig. 1.

4.1. Study sites and sampling period

Five study stations, S1, S2, S3, S4 and S5, were distributed along the studied segment of the GMC, Fig. 1. S1, S2, S3, S4 and S5 were located at distances of 1, 10, 20, 35 and 42 km (from the beginning of the channel), respectively. The sampling process covered a 5-month period starting at the beginning of March 2017 and ending at the end of August 2017. This period has been chosen as it is the intensive farming season in the middle of Iraq, which in turn decreases the water level in the GMC to its minimum level, and consequently results in the maximum pollution level.

4.2. Water flow rate

The water flow rate (discharge) of the GMC was measured in-situ using a current meter (type: WaterMark, model: 6200FD) which measures the velocity of water in the channel. The flow rate (discharge) measurement method was based on dividing the total width of the channel, at each station, into equal segments. The average depth of each segment was measured, and then it was used to calculate the area of the segment (by multiplying the average depth by the width of the segment). The velocity of water

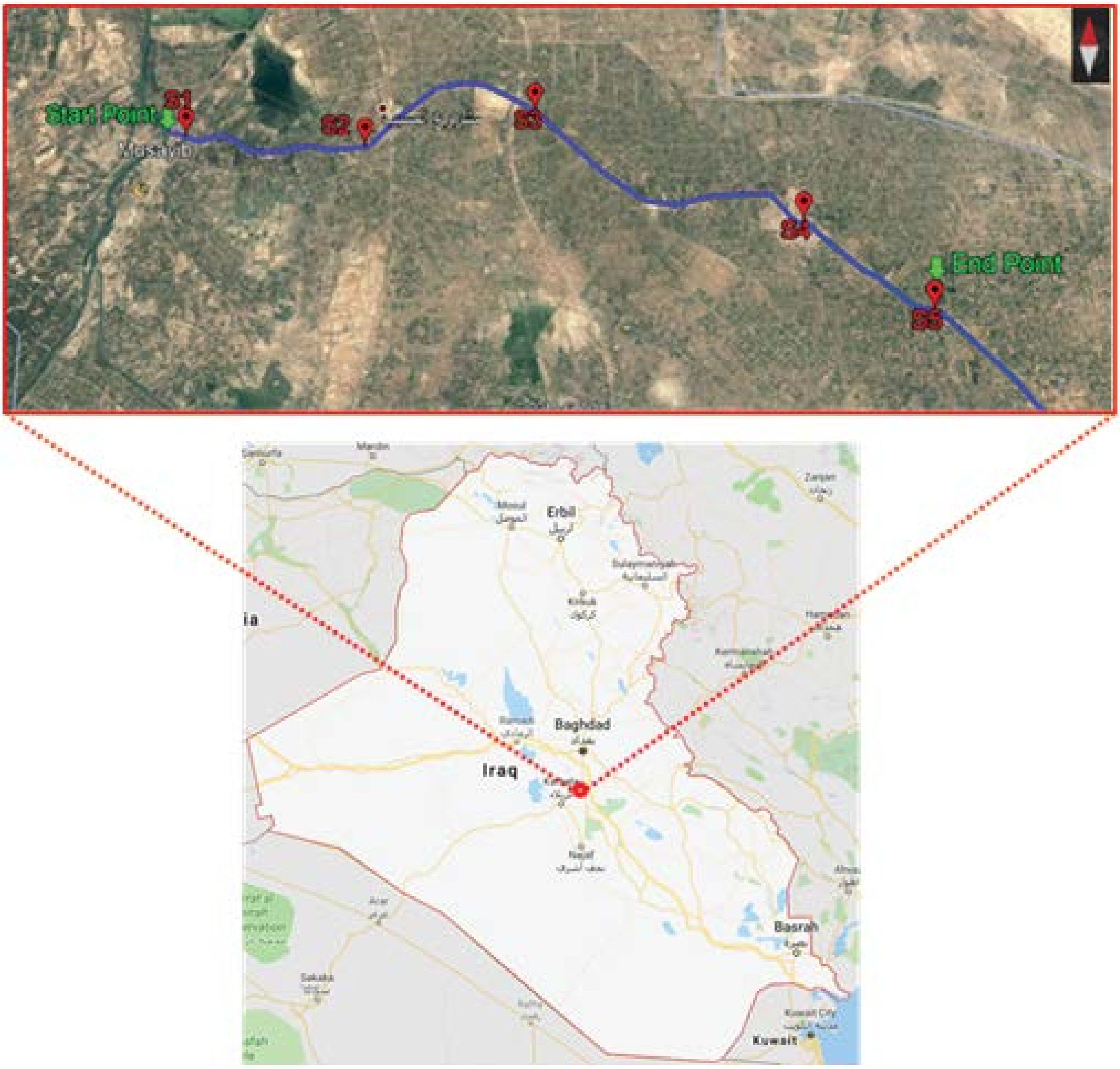

Fig. 1. Studied segment and locations of the monitoring stations along GMC.

was measured at each single segment. The discharge at each segment was calculated by multiplying velocity of water by segment area [36]. The total discharge at each station equals the summation of discharges of these segments.

4.3. Concentration of sediments

In order to determine the concentration of sediments, the total width of the channel, at each station, was divided into equal segments. Two water samples were collected from each segment at different depths, then the concentration of the sediments was measured according to Omran et al. [36]. The sediment concentration rate was calculated by dividing average sediment concentration by the cross-sectional area of each segment. The total sediment concentration rate, at each station, equals the algebraic summation of the sediment concentration rates of all the segments. More details about sampling methods and equipment have been mentioned by Edwards et al. [37], and Diplas and Fripp [38].

4.4. Particle size distribution analysis

Particle size distribution analysis was carried out by taking a sample of soil from the centre of the channel cross-section at each station. The collected samples were placed in polyethylene bags, numbered according to the studying location, and transferred to the laboratory. Laboratory analysis was carried out according to the standard procedures [36].

4.5. Chemical analysis

4.5.1. Chemical analysis of water samples

Water samples were collected at a depth of 35 cm, which is recommended in the literature [39], from three different points across the section of the channel at each studying station (left bank, centre of the channel and right bank). The three collected samples were mixed together (for each station) in a plastic container, marked with the number of the station and sampling time and date, and transferred immediately to the laboratory. Water analysis covered key physical and chemical parameters, which are water temperature, pH and concentration of Pb, Ni, Zn, Fe, Cd, Cr, Cu, Mn and Co.

The temperature and pH of the collected samples were measured in-situ using a portable handheld meter (type: Hanna meter, Model: HI 98130), while the determination of the concentration of heavy metals was initiated by acidifying the collected samples, to a pH of 2, using nitric acid. Then, the acidified samples were transferred into a 250-mL thermal beaker and heated, using a hotplate model Isotemp RT AVCD, up to 130°C. The heated samples were left at room temperature to cool down to 20°C ± 1°C, and then filtered using 0.45 μm Whatman filters [40]. The collected filtrate was then tested for the concentration of heavy metals using an atomic absorption spectrophotometer (AAS) device.

4.5.2. Chemical analysis of sediment samples

All sediment samples were collected at a depth of 50 cm below the bottom of the channel. Three samples were collected, using an auger tube, from different points across the section of the channel at each studying station (left bank, centre of the channel, and right bank). The collected samples were placed in polyethylene bags, numbered according to the studying location, and transferred to the laboratory.

The chemical analysis was initiated by drying the collected samples at 105°C for 48 h; then the dry samples were ground and sieved in a 106-micron sieve. The digestion process was carried out using the microwave assisted digestion technique, detailed by Sandroni et al. [41], to avoid any risk of external contamination. The digested samples were left at room temperature to cool down to 20°C ± 1°C, and then filtered using 0.45 μm Whatman filters. The collected filtrate was then made up to 50 ml and tested for the concentration of heavy metals using an AAS device [41,42].

4.6. Sediment pollution indices

Two pollution indices, PLI and geo-accumulation index (I_{geo}), have been applied in the current investigation to assess the pollution of the sediments samples collected from the GMC. These indices were chosen due to their good accuracy and reliability [43]. Due to the lack of data about the background values of the studied heavy metals in the GMC area, the background level of the studied heavy metals has been adopted from previous studies (under similar conditions and far from the impact of human and industrial activities) [20,22].

4.6.1. Pollution load index

The PLI was calculated using the following formula [44]:

$$\mathrm{PLI} = \left(\mathrm{CF1} \times \mathrm{CF2} \times \mathrm{CF3} \times \ldots\ldots\ldots\ \mathrm{CF}n\right)^{1/n} \tag{1}$$

where n is the number of heavy metals and CF is the contamination factor, which is calculated as follows:

$$\mathrm{CF} = \frac{C_{\mathrm{metals}}}{C_{\mathrm{background}}} \tag{2}$$

where C_{metals} and $C_{\mathrm{background}}$ represent the measured concentration of the heavy metal in sediment sample and in background sample, respectively. It is noteworthy to highlight that PLI values were assessed according to the categories reported by Tomlinson et al. [45] and Hakanson [46].

4.6.2. Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) was calculated by using the following proposed method [47]:

$$I_{\mathrm{geo}} = \log_2\left(\frac{C_{\mathrm{metals}}}{1.5\,C_{\mathrm{background}}}\right) \tag{3}$$

The total geo-accumulation index (I_{tot}) is the summation of I_{geo} of all heavy metals considered for the station [48].

4.7. Method summary

In summary, to achieve the planned objectives of the current study, five study stations, S1, S2, S3, S4 and S5, were distributed, along the studied segment of GMC, at distances of 1, 10, 20, 35 and 42 km, respectively. The area of the channel, at each station, was calculated by dividing its width into equal segments (same width), and the average depth of each segment was calculated. The area of each segment has been obtained by multiplying its width by its averaged depth. While the velocity of water at these segments was in-situ measured using a current meter (type: WaterMark, model: 6200FD). The measured velocity was used to calculate the flow rate multiplying the obtained velocity of water by the area of each segment. The total flow rate, at each station, is the algebraic summation of the flow rates of the segments. The collected samples were subjected into a series of chemical and physical tests, which are:

- Concentration of sediments.
- Particle size distribution
- Concentration of heavy metals (Pb, Ni, Zn, Fe, Cd, Cr, Cu, Mn and Co)

Finally, both PLI and geo-accumulation index (I_{geo}) were calculated for the collected samples.

4.8. Statistical analysis

A stepwise multiple regression has been performed to study the explanatory variables that are highly correlated with sediment concentration. The general regression equation is [49–51] as follows:

$$Y = a_0 + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_nX_n + e \quad (4)$$

where Y = dependent variable, sediment concentration (ppm); a_0 = intercept with the Y-axis; b_1, b_2, b_3,… …, b_n = partial regression coefficients; X_1, X_2, X_3,… …, X_n = independent variables; e = error term (residuals) which must be NID (0,1).

SPSS 20 software package has been used to perform the stepwise multiple regression analysis and its relevant statistical tests.

In order to perform the statistical analysis, the studied heavy metals were coded as follows: Pb = X_1, Ni = X_2, Zn = X_3, Fe = X_4, Cd = X_5, Cr = X_6, Cu = X_7, Mn = X_8, Co = X_9, distance downstream = X_{10}, d_{35} = X_{11}, d_{50} = X_{12}, d_{65} = X_{13}, and Y = sediment concentration.

5. Results and discussion

5.1. Concentration of sediments in the GMC

The obtained results indicated that the sediment concentration in the GMC channel ranges from 165 mg/L at the first parts of the channel to 211 mg/L downstream (Table 1). This increase, about 28%, in sediment concentration at the downstream parts of the channel could be attributed to two main reasons: first, because a significant amount of water will be used for irrigation and water supply for the cities, which in turn significantly decreases the flow rate from 64.87 m^2 upstream to 36.54 m^2 downstream. Second, due to the influence of the domestic and agricultural wastewater discharged into the channel from the neighbouring cities and farms [32,33].

5.2. Particle size distribution analysis

Table 2 describes the different specifications of sediments analysed at the five study sites (S1, S2, S3, S4 and S5).

The obtained results indicated that the soil of the GMC is silty sand with very little clay. The relative density of the bottom soil of the GMC ranges between 2.70 and 2.72. Additionally, it has been found that the bottom soil of the channel is more rough upstream (d_{35} = 0.060, d_{50} = 0.092, d_{65} = 0.188 mm) in comparison with soil downstream (d_{35} = 0.024, d_{50} = 0.055, d_{65} = 0.092 mm), and it is more homogeneous downstream than it is upstream.

It can be seen from Table 3 that the silt quantity increased by 60% downstream of the channel, which could be attributed to the decrease in water discharge at the downstream which results in deposition of the suspended load.

5.3. Concentration of heavy metals in water of the GMC

The outcomes of the current investigation showed that the concentrations of the studied heavy metals in the water of the GMC were within the allowable limits, Table 3, and followed the order: Pb < Ni < Cu < Cr < Mn < Zn < Fe, while the concentrations of both Cd and Co were below the detectable limits. Generally, the obtained results indicated the concentrations of the studied metals at downstream stations, especially at stations S4 and S5, were greater than the concentrations at the upstream stations. This increase could be attributed to the fact that these two stations were located

Table 1
Locations and specifications of sampling stations

Site No.	Distance from upstream of the channel (km)	Bottom width of flow section (m)	Average depth of flow section (m)	Area of flow section (m^2)	Hydraulic radius of flow section (m)	Average velocity of flow section (m/s)	Slope of water surface (cm/km)	Roughness factor (manning coefficient)	Discharge (m^3/sec)
S1	1	19.47	2.90	64.87	2.34	0.804	13	0.025	52.16
S2	10	19.36	2.66	58.57	2.18	0.767	13	0.025	44.92
S3	20	19.30	2.40	52.08	1.99	0.746	14	0.025	38.85
S4	35	18.90	1.83	37.94	1.58	0.689	15	0.024	26.14
S5	42	18.50	1.80	36.54	1.55	0.681	15	0.024	24.88

Table 2
Specifications of sediment of GMC

Site No.	Distance from upstream of channel (km)	Sediment concentration (ppm)	Field discharge of sediment load (m^3/s)	Diameter of soil particles (mm)			Specific gravity of soil
				d_{35}	d_{50}	d_{65}	
S1	1	165	3.16×10^{-3}	0.060	0.092	0.188	2.72
S2	10	172	2.85×10^{-3}	0.056	0.088	0.179	2.71
S3	20	185	2.66×10^{-3}	0.050	0.083	0.154	2.70
S4	35	201	1.95×10^{-3}	0.028	0.060	0.095	2.70
S5	42	211	1.94×10^{-3}	0.024	0.055	0.092	2.70

Table 3
Values of heavy metal concentration (mg/L) in water of the GMC

Site No.	Pb	Ni	Zn	Fe	Cd	Cr	Cu	Mn	Co
S1	0.014	0.019	0.382	0.092	Nil	0.074	0.031	0.081	Nil
0.014	0.019	0.092	0.382	Nil	0.074	0.031	0.081	Nil	Nil
0.029	0.024	0.114	0.691	0.002	0.096	0.072	0.094	0.016	Nil
0.039	0.046	0.281	0.851	0.004	0.104	0.118	0.106	0.025	Nil
0.062	0.065	0.306	1.082	0.007	0.116	0.158	0.126	0.037	Nil
0.058	0.066	0.334	1.460	0.008	0.119	0.186	0.151	0.039	Nil
0.04	0.044	0.225	0.893	0.004	0.102	0.113	0.112	0.023	Nil
0.02	0.022	0.127	0.408	0.003	0.018	0.063	0.027	0.016	0.05
5.0	0.20	2.0	5.0	0.01	0.10	0.20	0.20	0.05	

close to the discharge points for domestic and industrial wastewater as the latter usually contain high concentrations of heavy metals [52,53].

According to the standard limitations of the World Health Organisation (WHO) for irrigation water, the measured concentrations of the studied heavy metals were below the toxicity levels, except for a very small increase in the concentration of Cr (Table 3). Therefore, the water of the GMC may be classified as non-polluted with heavy metals according to the standard specifications of irrigation water.

5.4. Concentration of heavy metals in sediments of the GMC

Table 4 lists the concentrations of the studied heavy metals in the sediment samples collected from the GMC. It can be clearly seen from Table 4 that the Fe concentration was the highest one (about 2,182.66 mg/kg), followed by Mn at a concentration of 256.37 mg/kg, while the lowest concentration was of Cd at 0.45 mg/kg. Generally, the measured concentrations of these metals followed the order: Cd < Co < Cu < Pb < Ni < Cr < Zn < Mn < Fe. It is noteworthy to mention that the order of pollutants (magnitudes of the studied heavy metals) could be attributed to the chemical composition of both the soil of the studied area and the anthropogenic sources [54].

Additionally, the obtained results indicated that the concentrations of the studied heavy metals in the river flowing through the GMC are within the allowable limits, except for Ni, Fe, Cr and Mn, which exceeded the standard limits of the WHO and USEPA (United States Environmental Protection Agency) [42,55,56] (Table 5).

By comparing the results from Tables 4 and 5, it can be noticed that increase in the concentrations of these three heavy metals was in the downstream stations, especially S4 and S5. This increase could be attributed, as mentioned before, to the fact that these two stations were located close to the discharge points for domestic and industrial wastewater, which usually contain concentrations of heavy metals and other pollutants [52]. Consequently, the concentrations of heavy metals were increased at the downstream stations.

5.5. Evaluation of sediment pollution with heavy metals

Fig. 2 shows the calculated values of PLI for the studied heavy metals in sediments of the GMC. The highest value of PLI was at station 5, followed by station 4, while the lowest value was detected at station 1. Generally, the PLI values are higher downstream due to the influence of domestic and agricultural wastewater. The values of PLI range from 0.32 to 0.87, which confirms that the sediments are not polluted with heavy metals [45].

The obtained results from the PLI highly agreed with the results of the geo-accumulation index (I_{geo}) shown in Fig. 3. According to Muller [57], the calculated I_{geo} values confirm the absence of metal pollution in the sediments of the GMC, except for a few minor points downstream.

In conclusion, according to the results obtained from the calculated concentrations of the studied heavy metals in both sediments and water of the GMC and the results of the pollution indices, there is no metal pollution in the GMC, except for a few minor cases. Results of the current study are comparable with the results obtained by Bazrafshan et al.

Table 4
Concentrations (mg/kg) of heavy metals in sediments of GMC

Site No.	Pb	Ni	Zn	Fe	Cd	Cr	Cu	Mn	Co
S1	11.35	26.84	23.4	1,605.36	0.11	30.49	11.43	181.72	7.48
S2	18.86	33.9	48.86	1,871.29	0.31	36.36	15.4	235.41	8.53
S3	20.45	45.16	64.65	2,090.85	0.49	48.25	18.46	262.71	10.06
S4	25.46	58.34	80.08	2,485.32	0.61	58.36	22.62	291.42	14.97
S5	31.56	69.13	91.93	2,860.46	0.74	71.91	27.85	310.57	16.61
Average	21.54	46.67	61.78	2,182.66	0.45	49.07	19.15	256.37	11.53

Table 5
A comparison between heavy metal concentrations (mg/kg) in the GMC and the limitations of both WHO and USEPA

Heavy metal	Mean value	Standard deviation	WHO limitations	USEPA limitations
Pb	21.54	7.55	–	40
Ni	46.67	17.32	20	16
Zn	61.78	26.88	123	110
Fe	2,182.65	497.41	–	30
Cd	0.45	0.25	6	0.6
Cr	49.07	16.70	25	25
Cu	19.15	6.36	25	16
Mn	256.36	50.54	–	30
Co	11.53	5.06	–	–

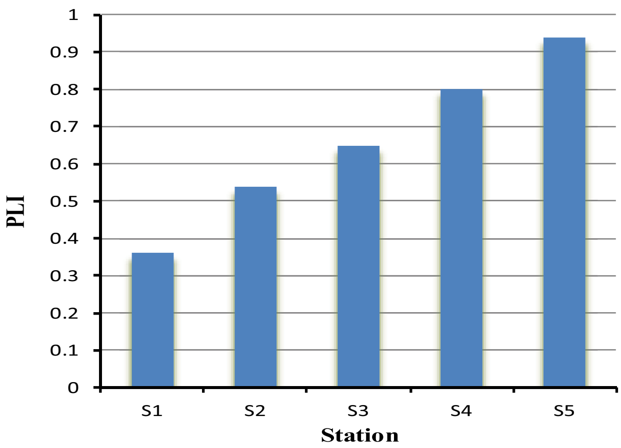

Fig. 2. PLI values for the studied heavy metals in the sediments of the GMC.

[58] in their study applied on surface water and sediments of Chah Nimeh water reservoir in Sistan and Baluchestan province, Iran. However, Mirzabeygi et al. [59] found that the concentration of chromium and cadmium in wells water, in Sistan and Baluchestan province/ Iran, were above acceptable risk levels.

Additionally, for comparison purposes, Table 6 shows the concentration of some pollutants in the sediments of different rivers in Iraq [26,30,31].

To avoid any unwanted increase in the concentration of heavy metals in both water and sediments of GMC, it is recommended to use proper wastewater treatment methods for the discharged domestic, industrial, and agricultural wastewater. For instance, electrocoagulation treatment method (EC) could be used to treat these types of wastewaters due to its high efficiency in the removal of heavy metals [18,60], and it produces small quantity of sludge (solid waste), the latter requires complicated and expensive handling and treatment processes [61,62]. Additionally, due to the recent development in the sensing technology [63,64], smart monitoring stations could be used to monitor and control the concentration of heavy metals in the discharged wastewater to GMC.

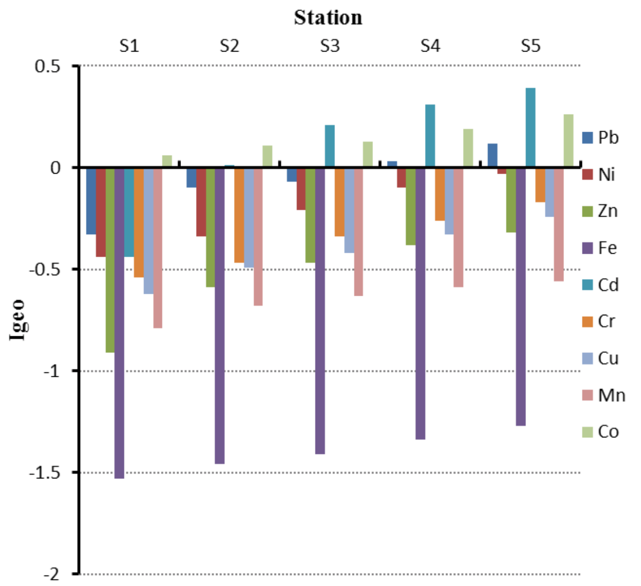

Fig. 3. Values of geo-accumulation index for the heavy metals in sediments of the GMC.

6. Statistical analysis

The stepwise multiple regression technique (Eq. (4)) has been applied to the obtained data shown in Tables 2 and 4, which produced the following model:

$$Y = 134.909 + 1.112X_2 + e \quad (5)$$

This model can predict the sediment concentration (Y) in terms of Ni (X_2) concentration (mg/kg).

In terms of reliability of the developed regression model, it has an F-ratio of 1,754.713 and a statistical significance (α) of 0.000, which confirms the significance of the

Table 6
Concentrations of some heavy metals (mg/kg) in the sediments of different rivers in Iraq

River location/date of test	Pb	Ni	Zn	Fe	Cd	Cr	Cu	Mn	Co
Tigris/1993	17–30	105–125	8–47	–	0.10–1.70	–	17–28	451–565	–
Tigris/2008	7–90	6–30	–	–	0.30–130	–	5–55	166–426	–
Euphrates/1998	19.50	182.91	91.16	–	3.60	119.4	45.25	–	48.6
Euphrates/2008	39.10	29.10	–	–	0.730	–	46.60	302.75	–

Table 7
Correlation coefficients matrix for the studied sediment samples

Control variables		Correlations	Cr sludge	Ni sludge	Sediment concentration (ppm)
None[a]	Cr sludge	Correlation	1.000	0.997	0.994
		Significance (2-tailed)	–	0	0.001
		df	0	3	3
	Ni sludge	Correlation	0.997	1.000	0.999
		Significance (2-tailed)	0	–	0.000
		df	3	0	3
	Sediment concentration (ppm)	Correlation	0.994	0.999	1.000
		Significance (2-tailed)	0.001	0	–
		df	3	3	0
Sediment concentration (ppm)	Cr sludge	Correlation	1.000	0.901	
		Significance (2-tailed)	–	0.099	
		df	0	2	
	Ni sludge	Correlation	0.901	1.000	
		Significance (2-tailed)	0.099	–	
		df	2	0	

[a]Cells contain zero-order (Pearson) correlations.

model. Additionally, this developed model has a coefficient of determination (R^2) of 0.998, which indicates a good reliability. Table 7 lists the results of the correlation matrix for the independent variables (Ni and Cr) with the highest correlation with (Y). It can be concluded that (Ni and Cr) were highly correlated to the sediment concentration with a clear high correlation between them, but in terms of step wise multiple regression (Ni) was the dominant explanatory variable.

7. Conclusions

The current study has been devoted to investigate the variation in the concentration of nine heavy metals along 42 km of the GMC (in water and sediments). Although the obtained results indicated that neither water nor sediments of the GMC are currently polluted with heavy metals, the negative influence of the domestic and agricultural wastewater on the water and sediments of GMC were very clear, especially at downstream stations. The results obtained from water and sediment analysis and the application of the pollution indices showed that the highest concentrations of the studied metals were at the last two downstream stations. Thus, the outcomes of the current study indicate a worsening scenario that requires action to reverse the increasing metal pollution trend in the sediments and water of the GMC.

To avoid additional increase in the concentrations of metal pollution in the GMC, different strategies and technologies could be applied, such as installing monitoring stations near the wastewater discharge points, and increasing the public's environmental awareness.

Acknowledgements

The authors thank the directorates of the Water Resources and Environmental Protection Agency in Babylon province, Iraq, for helping in overcoming the obstacles and providing some of the facilities and data required for the research.

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