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ORIGINAL ARTICLE

Factors Affecting the Levels of Toxic Metals in the Shatt Al-Arab River, Southern Iraq

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Abstract
During the last two decades, the changes in the economic setting of the Basra province and the hydrological system of the Shatt Al-Arab River have led to significant shifts in the sources and levels of contaminants in the river. Therefore, the levels of toxic metals (Ni, Cr, Pb, As, Hg, U, and Cd) in the surface water and bed sediments at four sites have been measured to investigate the natural and anthropogenic influences that have led to these shifts. In comparison with the sediments, low concentrations and a uniform distribution of most metals were observed in the river water. The results show that the river sediments were polluted with toxic metals, while pollution levels in the water are still within permissible limits for drinking, irrigation, and aquatic life. These findings indicated that the major sources of river contamination with toxic metals are the atmospheric deposit of gaseous emissions from oil production and electric generators and the surface runoff from agricultural areas after rainfall. In addition, the tide greatly controls the distribution toxic metals in the river. In addition, the physicochemical properties of the water and sediments play an important role in the metal accumulation, while the effect of agricultural, industrial, and domestic sewage is limited. However, the water quality in the Shatt Al-Arab River reflects the combined effects of natural and anthropogenic factors.

Keywords Heavy metals · Pollution · Sediments · Sewage · Shatt Al-Arab River · Water quality

1 Introduction

The concentrations of heavy metals are found to be (less than 1 mg/L) in natural water, and they are a widespread concern due to their adverse risks to humans, animals, plants, and the entire ecosystem (Khan and Ghouri 2011; Das et al. 2014). Toxic metals may also be called heavy metals, irrespective of their atomic weight and density (Kamunda et al. 2016). In the present study, the term 'toxic metals' is used to refer to metals that are neither beneficial nor essential to living organisms. Instead, they have damaging effects on organisms even in low levels. There are 59 elements classified as heavy metals, but some of these exhibit extreme toxicity and hazardous effects (Nand et al. 2012). Namely, Nickel (Ni), Chromium (Cr), Lead (Pb), Arsenic (As), Mercury (Hg), Uranium (U), and Cadmium (Cd) are often considered to be environmental contaminants.

Different and various pollutants including toxic metals often find their way into the aquatic environment of rivers; most metals in the water are solid and remain insoluble for a long time (Pendias and Pendias 2001). They tend to accumulate on the river bed, where sediments have the ability to absorb and concentrate dissolved metals into their particles (Malik and Maurya 2015; Edokpayi et al. 2016). Therefore, river-bed sediments are important reservoirs for heavy metals, they can be used as indicators of the contamination level in the water environment, and they can also assist in tracing contaminating sources. Deposits of toxic metals in river water and its sediments are caused by several sources including natural ones such as the chemical weathering of rocks, soil erosion, and atmospheric depositions.

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However, the highest levels of heavy metals result from the untreated effluents of the industrial, and agricultural chemical waste and domestic sewage (He et al. 2005; Singh et al. 2011; Tchounwou et al. 2012). Iraq is located in these areas, where water resources face many threats and a lot of damages, especially in the second half of the last century, where the drying of large parts of the marshes which represented half of water body as well as shrinking water resources of lakes and rivers because of construction of dams on the rivers (outside and inside Iraq) and also the irrigation projects which led to a large proportion of the rural population suffers from scarcity of drinking water (Ghalib and Sogut 2014; Ghalib 2017; Al-Ibrahimi and Ghalib 2018).

The Shatt Al-Arab River is the most important source of water for the province of Basra. The freshwater in the river has been extensively degraded during the last two decades, due to the fact that the river and its lateral branches have become repositories for contaminants from diverse sources. Thus, monitoring the pollution levels in the river is crucial for human health in the area. The water quality and the aquatic environment of the Shatt Al-Arab River have been studied extensively. However, there are very few studies investigating toxic metals. Such previous studies, including Abaychi and Douabul (1985), Moyel et al. (2015) and Al-Hejuje et al. (2017), have provided an appropriate understanding of the spatial variation of the metals levels in the river water and its sediments; however, some important metals and influential factors have not being examined. The available data on toxic elements and their sources in the Shatt Al-Arab River are very limited. In addition, the examination of water quality can constitute a challenge. To fill this gap, the levels of toxic metals in the river and the factors affecting their variation must be measured.

The objectives of this paper are: (1) to determine the concentration of seven toxic metals Ni, Cr, Pb, As, Hg, U, and Cd in the surface water and river-bed sediments along the Shatt Al-Arab River; (2) to illustrate possible spatial and temporal variations of metals at the selected sites and seasons; (3) to investigate the main factors affecting these deposits of toxic metals; and (4) to evaluate the suitability of the river water and bed sediments for different uses by comparing the levels of toxic metals with international guidelines.

2 Materials and Methods

2.1 Description of the Study Area

The Shatt Al-Arab River is located in the southern Iraq within the Basra province, between 29°45′ and 31°15′N and 47°10′–48°45′E. The river under investigation is formed by the confluence of the Tigris and Euphrates Rivers at the town of Qurna, which is 65 km north of the city of Basra. From Qurna, the Shatt Al-Arab River flows downstream for 200 km to join the Arabian Gulf (Fig. 1). The Tigris, Euphrates, Karkheh, and Karun Rivers are the major tributaries of the Shatt Al-Arab River. The hydrological system of the river has rapidly changed due to the decrease of the freshwater discharge from 25.67 km^3/year from 1994 to 1995 to around 1.39 km^3/year from 2011 to 2015 (Al-Asadi et al. 2015). This drastic decrease is the result of hydraulic control structures in the river basin. Currently, the river depends mainly on the freshwater flow from the Tigris River (Al-Asadi 2017; Al-Tememi et al. 2015).

The water flow in the Shatt Al-Arab River is affected by the tidal phenomenon of the Arabian Gulf, which has a semidiurnal pattern, with the tidal range varying from about 1 m at Basra to around 3 m at Fao (Al-Ramadhan and Pastour 1987). The length of the seawater intrusion from the Arabian Gulf into the river may reach 92 km (Abdullah 2016). The climate of the river region is hot and dry, with monthly temperature means ranging from 9 to 41 °C, in January and July, respectively. The mean annual rainfall (October–May) is about 100 mm (ESCWA 2013), with the main rainfall occurring during January and February.

For the last two decades (1998–2017), the Shatt Al-Arab River region has seen significant changes in terms of economic activity and population growth. Crude oil production in the province of Basra grew by 2.2 million barrels per day, rising from 0.7 million in 1998 to almost 2.9 million in 2017 (Ministry of Oil 2017). In contrast, agricultural area has decreased in favor of residential constructions. In 1997, the irrigated areas were about 11.55 thousand hectares, but this decreased to around 1.96 thousand hectares in 2017 (Ministry of Agriculture 2017). Currently, many factories have stopped operating, probably due to the lack of industrial-sector planning after 2003. Between the 1998 census and the 2017 estimates, the regions along the Shatt Al-Arab River grew in population from 1.17 to 1.96 million people, this representing almost 66% the total population in Basra province (Ministry of Planning 2017). The increase in population caused growth in electricity generation through two thermal power plants located north of the city of Basra and through a rise in the number of vehicles.

2.2 Sample collection and preparation

Sample sites were selected to represent four different conditions (Table 1; Fig. 1). Site I was considered to be a control because of its relatively clean water. In sites II and III, domestic sewage discharge and agricultural activities are possible sources of pollution, respectively. In contrast, the impact of marine water is more prevalent in site IV. Samples of surface water and bed sediments were collected from the middle stream of the Shatt

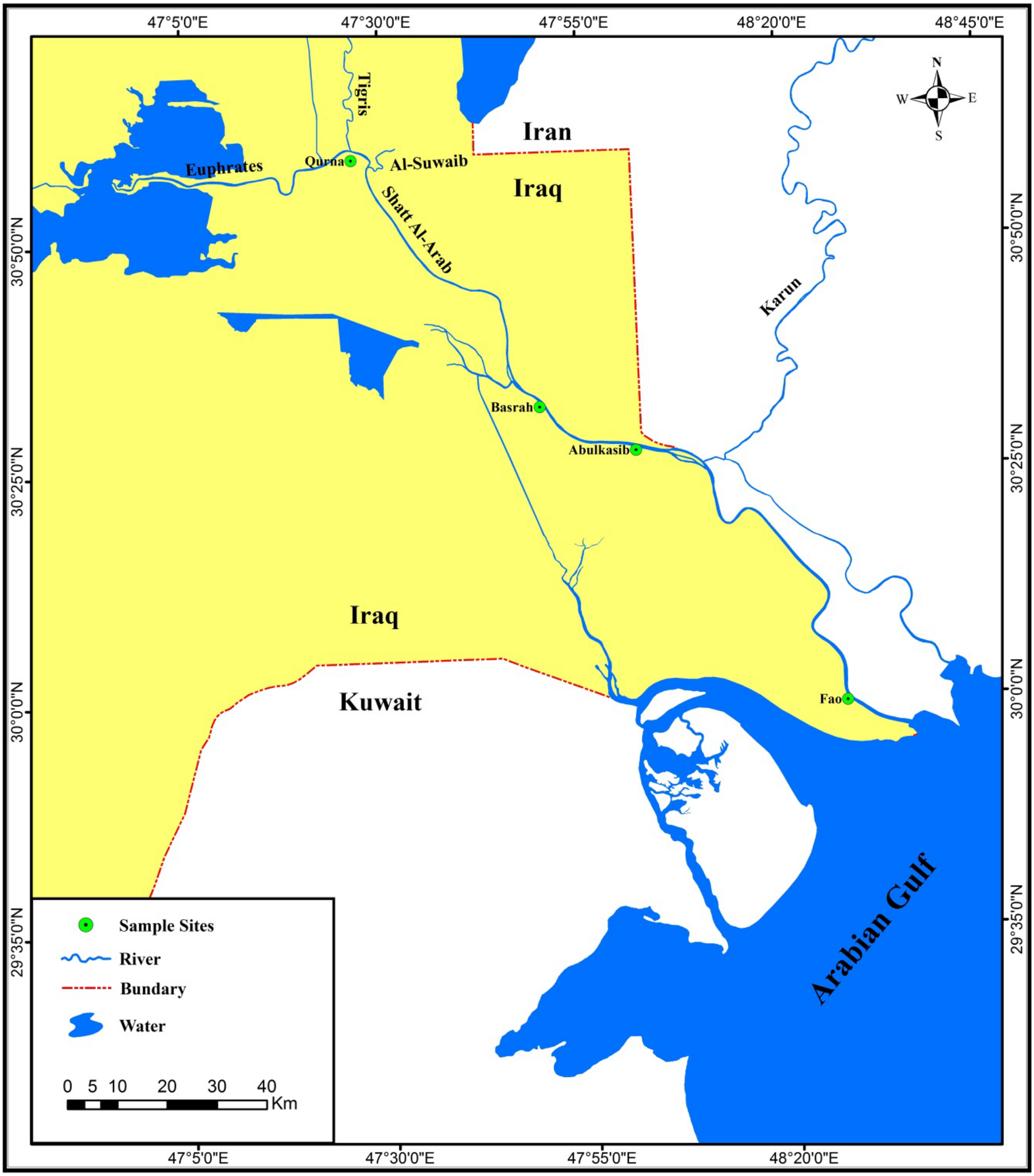

Fig. 1 Map of the Shatt Al-Arab River and sampling sites

Al-Arab River. In addition, two samples of wastewater were collected from urban and agricultural areas, whose waste flows directly into the river. Water Samplings were carried out during July (summer), November (autumn) in 2017 and February (winter), April (spring) in 2018. While the samplings of sediments and wastewater were made during the dry season (July) in 2017 and the wet season (February) in 2018. The samples were analyzed using standard procedures (APHA 1998). Field measurements in each of the selected sites were made for

Table 1 Geographic locations of sampling sites at Shatt Al-Arab River

Sampling site	Site name	Longitude	Latitude
I	Qurna	47°30′13″	30°54′10″
II	Basrah	47°49′15″	30°30′36″
III	Abulkasib	48°01′31″	30°27′42″
IV	Fao	48°28′03″	29°59′19″

electrical conductivity (EC), pH and water temperature by the means of a Horiba U-10 device, and the velocity of the water current was measured by the current-meter model CM2. One-liter surface water samples were collected in clean bottles and acidified with nitric acid (0.5%), and half-kilogram sediment samples were collected using a Van Veen Grab and placed in plastic bags. All samples were stored at 10–15 °C, and then sent to the central laboratory at the Amirkabir University of Technology in Iran (within 2–5 days of collection) to be analyzed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), Agilent, USA, Model 7700.

2.3 Statistical Analysis

Data were statistically analyzed using the statistical package, SPSS 24.0 (SPSS, USA). The means and standard deviations (SD) and the coefficient of variation (CV) of the metal concentrations in sediments were calculated. A Pearson's bivariate correlation was used to evaluate the inter-element relationship in sediments. Other calculations were performed by Microsoft Excel 2016.

3 Results and Discussion

3.1 Physicochemical Parameters of the Water and Sediments

The results of the physical and chemical properties measured in the water and bed samples of the Shatt Al-Arab River are reported in Table 2 and Fig. 2. The water temperatures in the river exhibited minor variations among the sites, with a low CV value of (1.695), due to differences in sampling times. In general, the lowest value of water temperature (19 °C) was recorded in the winter at site IV and the highest (32 °C) in summer at site III. The pH values in the water had a distribution similar to those of temperature, in which

Table 2 Physicochemical parameters of Shatt Al-Arab River water and sediments

Sites	Season	EC (dS/m)	pH	Temp. (°C)	Water velocity (m/s)	Particle size (%)		
						Clay	Silt	Sand
I	Summer	1.59	7.72	31.00	0.17–0.24 (0.21)	90	4	6
	Autumn	2.55	7.90	25.00				
	Winter	6.25	7.84	20.00	0.13–0.25 (0.19)	92	4	4
	Spring	1.94	8.01	23.00				
	Mean	3.08	7.86	24.75	0.15–0.25 (0.20)	91	4	5
II	Summer	4.14	8.02	31.00	0.27–0.39 (0.33)	88	7	5
	Autumn	6.06	7.95	26.00				
	Winter	4.72	7.94	19.00	0.21–0.31 (0.26)	86	9	5
	Spring	3.96	7.97	24.00				
	Mean	4.72	7.97	25.00	0.24–0.35 (0.30)	87	8	5
III	Summer	6.71	8.10	32.00	0.25–0.29 (0.27)	95	2	3
	Autumn	3.64	7.94	27.00				
	Winter	6.50	8.02	20.00	0.19–0.25 (0.22)	93	4	3
	Spring	5.66	7.98	24.00				
	Mean	5.62	8.01	25.75	0.22–0.27 (0.25)	94	3	3
IV	Summer	47.30	8.12	31.00	0.57–0.69 (0.63)	96	2	2
	Autumn	20.96	8.06	27.00				
	Winter	31.80	8.06	19.00	0.45–0.55 (0.50)	94	4	2
	Spring	38.28	8.05	24.00				
	Mean	34.58	8.07	25.25	0.51–0.62 (0.57)	95	3	2
Total average		12.00	7.977	25.187	0.330	91.75	4.500	3.75
SD		15.090	0.088	0.426	0.165	3.594	2.380	1.50
CV		125.750	1.108	1.695	50.038	3.917	52.899	40.00

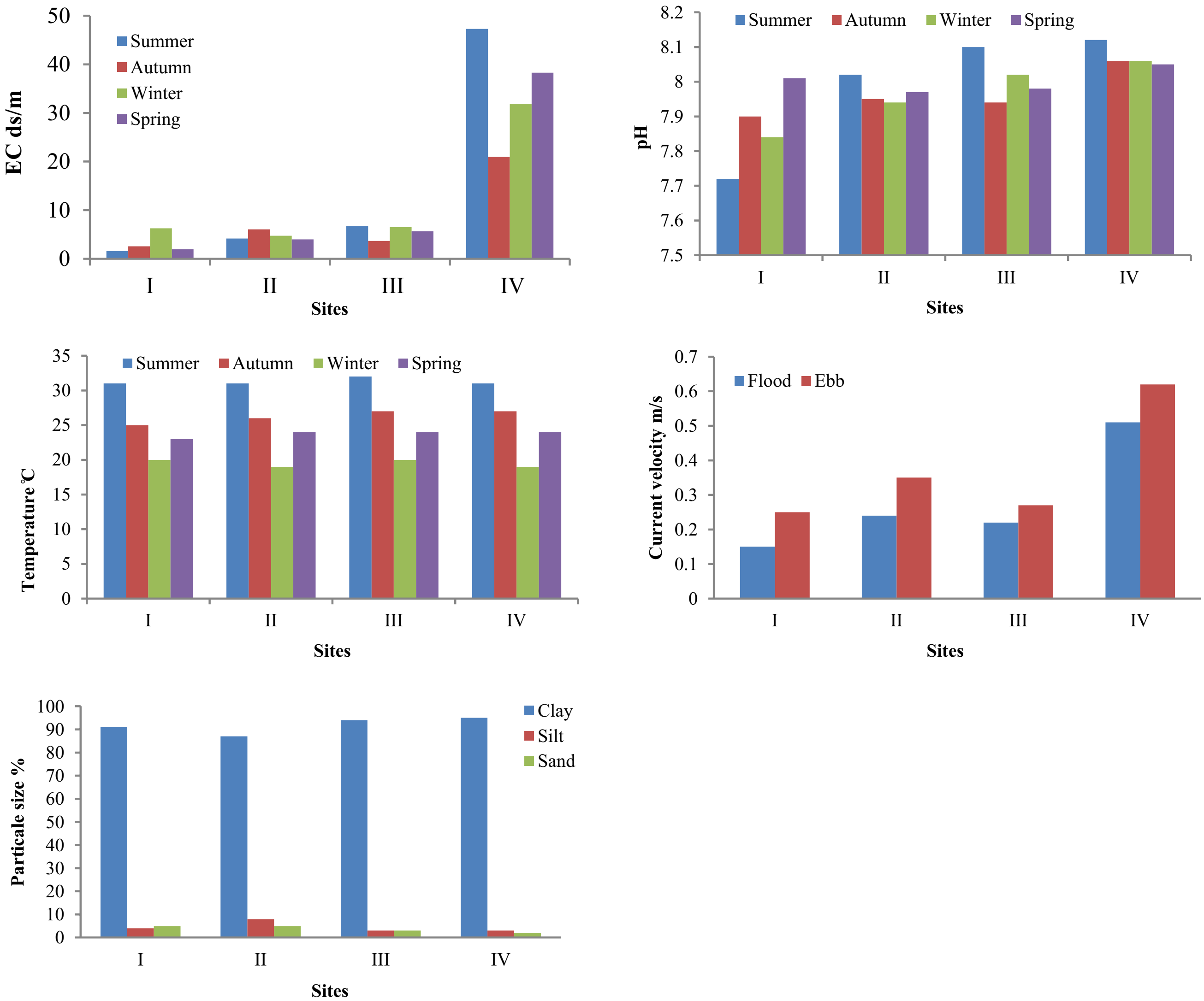

Fig. 2 Values of EC, pH, temperature, water velocity, and particle size at four Shatt Al-Arab River sites

the spatial variation was relatively uniform at all the four sites. However, the southern part of the river, i.e., the Fao site had slightly higher pH values than those of the other sites. The mean pH values ranged from 7.86 at site I to 8.07 at site IV. Thus, the river water at the four sampling sites creates a slightly alkaline environment. The pattern of electrical conductivity (EC) values clearly increased from north to south along the Shatt Al-Arab River, where the high CV value is 125.750, due to the increased seawater flow from Arabian Gulf. The average levels of EC range from 3.08 to 34.58 dS/m at sites I and IV, respectively.

The velocity of the river water varies as a result of the sequence of the tide as the river approaches the gulf. The mean values of the current velocity ranged between 0.15 m/s in the flood and 0.25 m/s during the ebb at site I, and increased at site IV from 0.51 to 0.62 m/s in the flood and on ebb, respectively. The bed texture of the Shatt Al-Arab River mainly consists of fine-grained sediments with clay and silt constituting about 95% of the total particles of bottom sediments. In general, particle size becomes finer towards the Estuary.

3.2 Concentrations of Toxic Metals in Wastewater

Toxic metals levels in domestic sewage and drainage water were low, ranging from <1 to <28.8 µg/L (see Table 3). These low levels of heavy metals indicate that the amount of chemicals used in homes and farms was limited. Most metal levels in the wastewater were spatially and temporally uniform during the summer and winter seasons with the exception of Ni and As, whose levels in sewage increased during the winter to 28.8 and 7.9 µg/L, respectively.

Table 3 Conductivity (dS/m) and pH values and concentrations of toxic metals (μg/L) in water of Khorah and Abu Mgera irrigation canal

Area	Season	EC	pH	Metals						
				Ni	Cr	Pb	As	Hg	Cd	U
Basra city Khorah rive	Summer	12.7	7.92	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Winter	21.2	7.72	28.8	< 5	< 5	7.9	< 1	< 1	< 1
Abulkasib Abu Mgera canal	Summer	9.78	7.91	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Winter	17.3	6.97	26.3	< 5	< 5	< 5	< 1	< 1	< 1

3.3 Toxic Metal Concentrations in the Water

The concentrations of dissolved toxic metals in river water are summarized in Table 4 and Fig. 3. In this study, six toxic metals Cr, Pb, As, Hg, U, and Cd detected in the river water are characterized by low concentrations, ranging between < 1 and < 5 μg/L during four seasons at each of the selected sites. The low concentrations of these metals in the river water may be due to their low solubility in the water in addition to their being heavy metals that are associated with suspended colloids via the adsorption process (Mimba et al. 2017). This is probably due to the alkaline environment of the Shatt Al-Arab River. These levels may be indicators of the limited effect of anthropogenic activities on the heavy metals. Such observation may be attributed to the fact that most factories stopped operating during the study period, in addition to the diminishing area irrigated with drainage water that has low levels of toxic metals. The influence of the sewage disposal on the levels of heavy metals in the river water may be limited, because concentrations of toxic metals in domestic sewage were low. Moreover, the Ashar and Khandek Rivers were closed for cleaning and rehabilitation during the study period. These two rivers (in addition to the Rabat and Khorah Rivers) are the main channels for the flow of untreated wastewater into the Shatt Al-Arab River. In addition, the chemistry of seawater in the Arabian Gulf contains lower levels of toxic metals, varying between 0 and 0.78 μg/L (Fowler et al. 1984; Manavi 2013). Therefore, the tide decreases the levels of heavy metals in the river through the mixing and dilution processes as a result of the changing flow direction of currents of the gulf during the ebb and flood.

Although there are relative variations in the physicochemical parameters of the surface water, composition of sediments, environmental conditions as a result of the domination of freshwater upstream and seawater downstream and sources and levels of contaminants by anthropogenic actions, the concentrations of toxic metals in the river water were spatially and temporally uniform, with the exception of Ni in the winter. This finding could be attributed to the significantly low concentrations of examined elements, as the technique employed was unable to detect the potential differences among trace concentrations of metals.

The levels of Ni were significantly higher in the winter at all sampling points, within a range of 14.4–20.6 μg/L. This situation is most likely due to the high deposition of

Table 4 Concentrations of toxic metals (μg/L) in Shatt Al-Arab River water

Sites	Season	Metals						
		Ni	Cr	Pb	As	Hg	U	Cd
I	Summer	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Autumn	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Winter	15.1	< 5	< 5	< 5	< 1	< 1	< 1
	Spring	< 10	< 5	< 5	< 5	< 1	< 1	< 1
II	Summer	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Autumn	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Winter	18.1	< 5	< 5	< 5	< 1	< 1	< 1
	Spring	< 10	< 5	< 5	< 5	< 1	< 1	< 1
III	Summer	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Autumn	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Winter	14.4	< 5	< 5	< 5	< 1	< 1	< 1
	Spring	< 10	< 5	< 5	< 5	< 1	< 1	< 1
IV	Summer	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Autumn	< 10	< 5	< 5	< 5	< 1	< 1	< 1
	Winter	20.6	< 5	< 5	< 5	< 1	< 1	< 1
	Spring	< 10	< 5	< 5	< 5	< 1	< 1	< 1

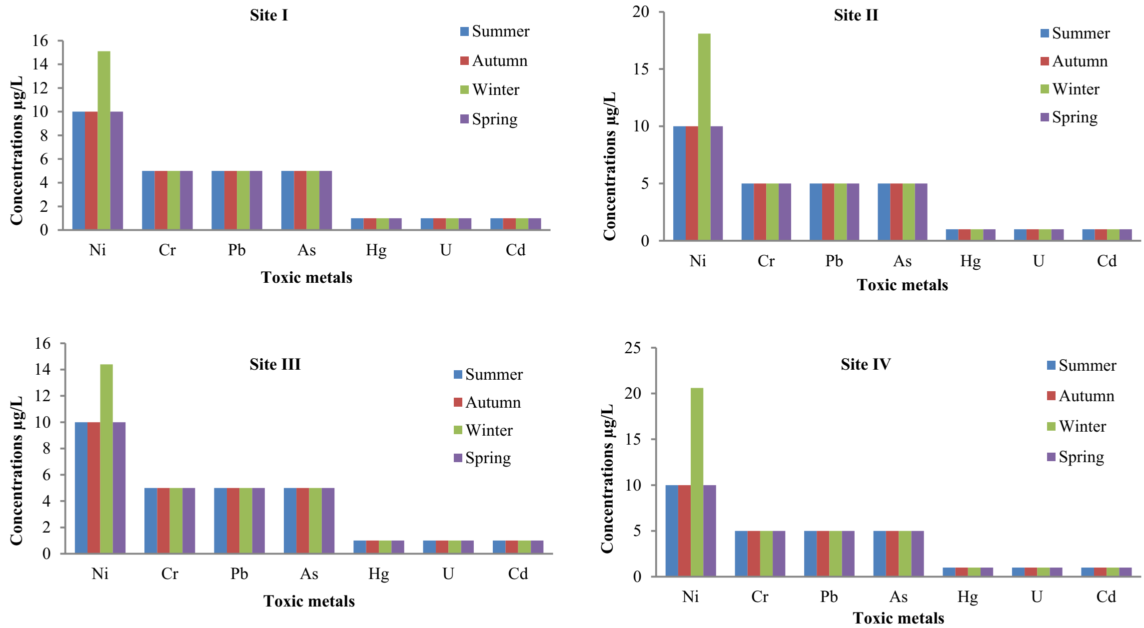

Fig. 3 Distribution of toxic metals levels (µg/L) in Shatt Al-Arab River water at four sites

atmospheric oil pollutants during the rainfall period. Furthermore, the runoff from the roads and agricultural areas near the river during rainstorms can contribute to the substantial amount of nickel deposited in the river. Fossil fuel combustion is a major source of Ni (90%). Nickel itself is one of the most traceable metals resulting from oil pollution, second only to vanadium (Pacyna and Pacyna 2001). The results demonstrated that the distribution pattern of toxic metals in Shatt Al-Arab water is in the order of Ni > Cr; Pb; As > Hg; U; Cd in all sampling locations.

The present levels of toxic metals in the river water were significantly lower than those reported by Moyel et al. (2015) and Al- Hejuje et al. (2017), as shown in Table 5. However, these findings (except for nickel) come in line with the findings of Abaychi and Douabul (1985) and Abdullah (2013) (Table 5). Based on the present observation, the concentrations of toxic metals indicate that the river water at various sampling sites is still within the permissible levels, suitable for drinking (WHO 2006), irrigation (Ayers and Westcot 1994), and aquatic life (Schneider 1971; Shanbehzadeh et al. 2014) (Table 5).

3.4 Content of Toxic Metals in Sediments

Table 6 and Fig. 4 present a summary of the toxic metals and give the coefficient of variation statistical parameters (CV) found in the sediments of the four sampling sites of the Shatt Al-Arab River. The concentrations of the all toxic metals in the bed sediments ranged from < 0.1 to 98.6 mg/L. In case of sediments, the levels of studied metals are significantly

Table 5 Comparison of the observed concentrations of toxic metals (µg/L) in Shatt Al-Arab water with previous studies and international standard values

Toxic metals	Present study	Other studies (average)				International standard		
		Abaychi and Douabul (1985)	Abdullah (2013)	Moyel et al. (2015)	Al-Hejuje et al. (2017)	Drinking	Irrigation	Aquatic
Ni	20.6	3.40	4.4	80.68	9.51	20	200	150
Cr	< 5	–	–	–	–	50	100	50
Pb	< 5	0.30	0.2	1828.43	43.67	10	500	100
As	< 5	–	–	–	–	10	100	1000
Hg	< 1	–	–	–	–	6	–	–
U	< 1	–	–	–	–	–	–	–
Cd	< 1	0.26	0.2	40.13	3.01	3	10	50

Table 6 Concentrations of toxic metals (mg/L) in sediments of Shatt Al-Arab River

Sites	Season	Metals						
		Ni	Cr	Pb	As	Hg	U	Cd
I	Summer	98.6	69.7	17.5	6.7	< 1	< 1	< 0.1
	Winter	95.3	66.2	13.7	6.1	< 1	< 1	< 0.1
	Mean	96.9	68.0	15.6	6.4	< 1	< 1	< 0.1
II	Summer	84.4	65.2	21.3	8.2	< 1	< 1	< 0.1
	Winter	89.8	63.6	16.9	7.4	< 1	< 1	< 0.1
	Mean	87.1	64.4	19.1	7.8	< 1	< 1	< 0.1
III	Summer	85.2	57.2	16.2	4.4	< 1	< 1	< 0.1
	Winter	80.9	55.8	13.4	2.9	< 1	< 1	< 0.1
	Mean	83.0	56.5	14.8	3.6	< 1	< 1	< 0.1
IV	Summer	72.4	53.7	13.3	7.1	< 1	< 1	< 0.1
	Winter	70.0	50.2	12.2	7.3	< 1	< 1	< 0.1
	Mean	71.2	51.95	12.7	7.2	< 1	< 1	< 0.1
Total average		84.55	60.213	15.55	6.25	< 1	< 1	< 0.1
SD		10.640	7.308	2.664	1.857	0	0	0
CV		12.585	12.137	17.132	29.719	0	0	0

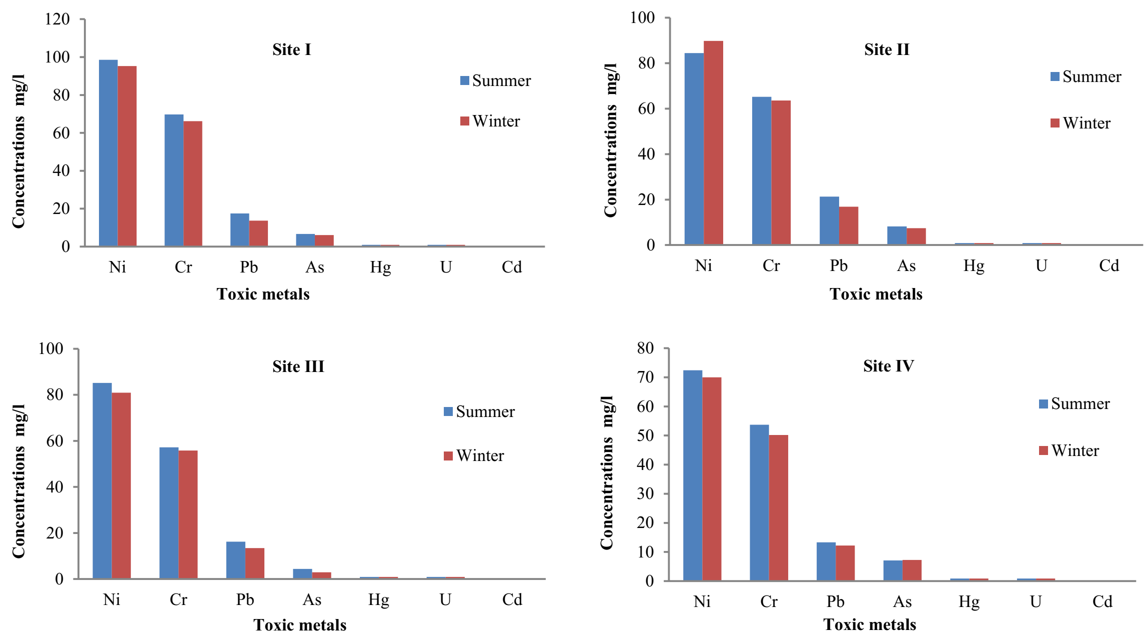

Fig. 4 Distribution of toxic metals levels (mg/L) in sediments at four Shatt Al-Arab River sites

higher at the four sediment sites than those of the river water. These levels may indicate an excessive accumulation of heavy metals in bed sediments because of many complex factors associated with the flow characteristics of the water in the river and the physicochemical properties of the recharging sources.

There are geographical differences among the metal levels in the sediment, which caused the CV value to vary between 12.137 and 29.719 for four metals (Ni, Cr, Pb, and As). Hence, the highest average Ni and Cr concentrations were found at the Qurna site (96.9 and 68.0 mg/L, respectively), while the Basra site had slightly higher levels of Pb (19.1 mg/L) and As (7.8 mg/L). Fao is the site with the lowest levels of Ni, Pb, and Cr (71.2, 51.95, and 12.7 mg/L, respectively). The minimum level of As was found at the Abulkasib site (3.6 mg/L). Overall, the distribution of most metal concentrations in the sediments shows a decrease at the Fao site. This may be due to several reasons, such as the intrusion of marine waters as well as the water turbulence and the erosion of the river bed created by the relatively high current velocity; all of which reduced the accumulation of toxic metals in the sediments. Therefore, the marine water of Arabian Gulf is often responsible for the spatial variations of toxic metals levels found in sediment samples.

Elevated level of Cr (66.2–69.7 mg/L) in the sediment at the Qurna site may be caused by polluting oil deposits, blacksmithing, the corrosion of the oil pipelines and/or floating bridges. The level of Cr in the water is significantly smaller than that in the sediments. This result proves that the chromium found in the Shatt Al-Arab River is insoluble and tends to be adsorbed by particles and accumulate in bed sediments. Thus, the chromium is in the trivalent Cr(III) form, which is much less toxic than hexavalent Cr(VI) (Tchounwou et al. 2012). The mean values of Pb in the sediments varied between 12.7 and 19.1 mg/L. The availability of Pb in the sediments is affected by the gaseous emissions of oil production activities, as well as vehicles and electric generators. Relatively high concentrations of As (16.9–21.3 mg/L) were found in bed sediments at the Basra site, which is subject to receive a large amount of tailings and effluents from thermal power plants.

The four metals Ni, Cr, Pb, and As measured in the river sediments showed insignificant temporal variations. In general, their concentrations were higher in summer than in winter at four sites. The high concentrations of metals during the summer may be due to the rise in electrical conductivity and pH values, which accelerates the adsorption process and the accumulation of the metal ions in the water.

The levels of Hg, U, and Cd in the sediments were significantly low, ranging from <0.1 to <1 mg/L. They have a distribution similar to that of the river water with invariable levels across all four sites. Therefore, the sources of Hg, U, and Cd in the river were not entirely clear. The average concentrations of Ni in the sediment samples at each of the four sites were the highest, ranging from 71.2 to 96.9 mg/L, in comparison with the other metals studied. Cd had the lowest value of <0.1 mg/L. Hence, the toxic metals present at the different locations in descending order were Ni > Cr > Pb > As > Hg, U > Cd.

The study of toxic metals in sediments shows that their concentrations are lower than that they were in the previous studies conducted by Al-Tawash et al. (2013) and Al-Jaberi et al. (2016) (Table 7). However, these levels were higher than the concentrations reported by Abaychi and Douabul (1985) (Table 7). Sediment quality guidelines of CCME (2001) are used to evaluate the possible toxicity of the river sediments. The results prove that the concentrations of toxic metals exceed the permissible limits, causing adverse effects on the aquatic life in the Shatt Al-Arab River (Table 7).

3.5 Pearson Correlation Coefficients with Physicochemical Characteristics

Statistical analyses were performed to elucidate the associations among heavy metals in sediment and to identify the important factors involved in controlling the transport and distribution of metal contaminants (Islam et al. 2015), e.g., Pearson's correlation. Pearson's correlation (PC) matrix for analyzed sediment parameters was calculated to see if some of the parameters interrelated with each other and the results are presented in Table 8. During summer, the Pearson correlation analysis between water physicochemical parameters and toxic metals in the sediments showed that both Cr and EC were positively correlated with sand and water velocity, respectively (Table 8). However, in winter season, Ni and EC were positively correlated with sand and water velocity, respectively. In contrast, Cr, Pb, and Clay were negatively correlated with pH, clay, and silt, respectively (Table 8). This suggests that different physicochemical parameters influence the concentrations of some toxic metals in the sediments and water. The insignificant relationship between all toxic metals suggests different sources of input (human or natural) for these metals in the river sediment (Bastami et al. 2012).

In addition, Fig. 5 shows a significant linear correlation between electrical conductivity, pH, water velocity, and sand with nickel ($r = 0.74$, 0.84, 0.81, and 0.81, respectively) and chromium ($r = 0.63$, 0.83, 0.60 and 0.95, respectively) in the Shatt Al-Arab River. This indicated that

Table 7 Comparison of the observed concentrations of toxic metals (mg/L) in sediments of Shatt Al-Arab River with Canadian guidelines and other studies

Toxic metals	Present study	Other studies (average)			Guidelines for aquatic
		Abaychi and Douabul (1985)	Al-Tawash et al. (2013)	Al-Jaberi et al. (2016)	
Ni	96.9	42	145	107	–
Pb	19.1	12.2	20.5	14.4	35
Cr	64.4	–	142	330	37.3
As	7.8	–	6.5	–	5.9
Hg	< 1	–	–	–	0.17
U	< 1	–	0.7	–	–
Cd	< 0.1	0.15	–	–	0.6

Table 8 Pearson correlation coefficient matrix for toxic metals in sediments of Shatt Al-Arab River

	Ni	Cr	Pb	As	EC	pH	Temp.	Velocity	Clay	Silt	Sand
Summer ($n=26$)											
Ni	1										
Cr	0.881	1									
Pb	0.475	0.719	1								
As	−0.124	0.351	0.430	1							
EC	−0.839	−0.771	−0.770	0.151	1						
pH	−0.892	−0.885	−0.312	−0.176	0.547	1					
Temp.	0.003	−0.388	−0.176	−0.918	−0.253	0.396	1				
Velocity	−0.908	−0.748	−0.609	0.302	0.973[a]	0.626	−0.322	1			
Clay	−0.602	−0.889	−0.922	−0.605	0.695	0.592	0.475	0.569	1		
Silt	0.305	0.680	0.934	0.724	−0.525	−0.297	−0.494	−0.340	−0.941	1	
Sand	0.880	0.999[a]	0.743	0.343	−0.792	−0.868	−0.365	−0.763	−0.898	0.695	1
Winter ($n=26$)											
Ni	1										
Cr	0.993[a]	1									
Pb	0.608	0.657	1								
As	0.009	0.122	0.282	1							
EC	−0.851	−0.810	−0.661	0.392	1						
pH	−0.949	−0.951[a]	−0.409	−0.154	0.654	1					
Temp.	0.428	0.323	−0.288	−0.783	−0.527	−0.416	1				
Velocity	−0.859	−0.800	−0.462	0.493	0.967[a]	0.713	−0.715	1			
Clay	−0.553	−0.615	−0.991[a]	−0.403	0.561	0.377	0.402	0.353	1		
Silt	0.350	0.424	0.946	0.468	−0.389	−0.172	−0.577	−0.153	−0.974[a]	1	
Sand	0.861	0.893	0.926	0.215	−0.808	−0.718	0.000	−0.685	−0.898	0.775	1

Two-tailed test of significance is used

[a]Correlation is significant at the 0.05 level

human activities inputs were probably the major contribution for accumulation in sediments of Shatt Al-Arab River (Gao and Chen 2012). Water temperatures did not result in any strong correlation to the metals levels, except for As ($r=0.93$). As well as the Hg, U, and Cd did not show any significant correlation with the selected parameters (Table 9 and Fig. 5).

4 Conclusions

The current study revealed that the concentrations of Ni, Cr, Pb, As, Hg, U, and Cd in the water of the Shatt Al-Arab River were low and uniform, except for Ni during the winter. Bed sediments exhibited a higher content of toxic metals than the river water. These levels indicate that the accumulation of heavy metals in the river bed is more extensive than the processes of solubility and mobility. The concentrations of Ni, Cr, Pb, and As in the sediments were high. Regarding Hg, U, and Cd, their concentrations have no environmental concern. The water quality in the river reflects the combined effects of natural and human factors. As such, the rapid development of oil production and electric power plants and the increased number of vehicles in the area led to a higher level of toxic metals in the river-bed sediments, while the closure of most factories in the region and the shrinking of the irrigated area have reduced the concentrations of dissolved metals in the water. Despite the rapid population growth, the sewage disposal has had a limited effect on toxic metals deposits, because the concentrations of toxic metals in domestic sewage were low. A severe decline in the freshwater flow of the Shatt Al-Arab River contributed to the relatively higher levels of some toxic metals upstream. Seawater intrusion affected the levels of toxic metals in the water and sediments to a significant extent. It has been noted that the physicochemical properties of the water and the sediment also play an important role in the adsorption and accumulation of metal ions in the river. However, the sources of Hg, U, and Cd were not entirely clear due to a

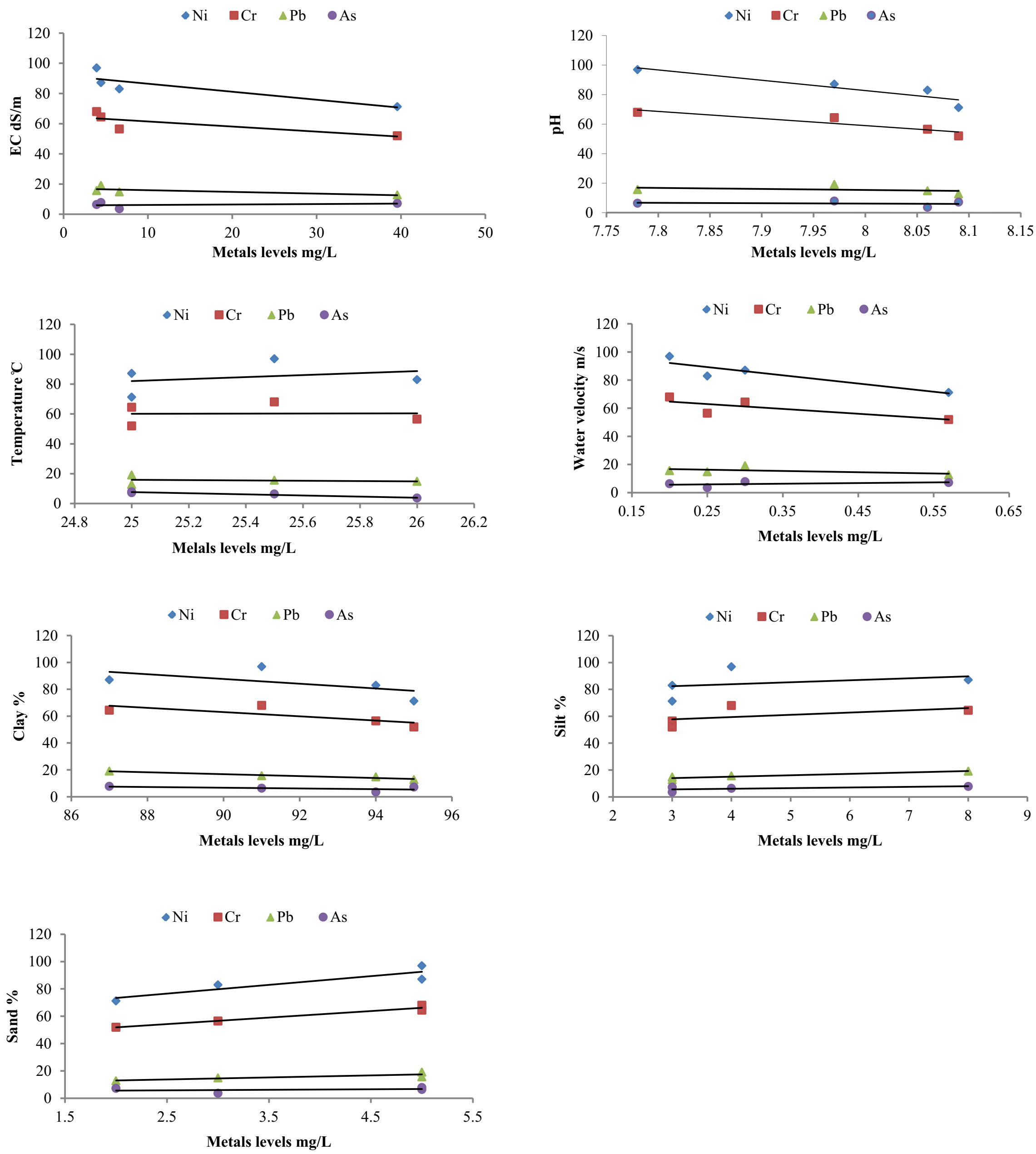

Fig. 5 Linear correlation coefficient (R^2) of the selected physicochemical properties with Ni, Cr, Pb, and As concentrations in Shatt Al-Arab River sediments

severe decline in their levels. The water environment of the river has not been significantly contaminated by toxic metals, as their concentrations were found to be within a safe limit. However, uncontrolled urban development in the region is likely to increase the level of water pollution in the future. The Shatt Al-Arab River has a complex hydrological system, because the quantity and quality of its water are affected by various factors. Hence, more monitoring is required to detect a wider spectrum of river contaminants.

Table 9 Correlation coefficients (*r*) for of selected physicochemical parameters versus levels of toxic metals in sediments

Toxic metals	Parameters						
	EC	pH	Temp.	Water velocity	Particle size		
					Clay	Silt	Sand
Ni	0.7491	0.8411	0.0916	0.8162	0.3539	0.1091	0.8121
Cr	0.6334	0.8395	0.0003	0.6085	0.5981	0.3029	0.9594
Pb	0.5403	0.1410	0.0359	0.3119	0.2671	0.8754	0.7028
As	0.0812	0.0387	0.9318	0.1652	0.9402	0.3547	0.0859
Hg	–	–	–	–	–	–	–
U	–	–	–	–	–	–	–
Cd	–	–	–	–	–	–	–

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