



Water quality and impacting factors on heavy metals levels in Shatt Al-Arab River, Basra, Iraq

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Received: 20 November 2018 / Accepted: 31 March 2020 / Published online: 13 April 2020
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Abstract

The aim of this study was to evaluate the water quality of Shatt Al-Arab River (SAR) and investigate the influences on the variations of heavy metals levels. The surface water and bed sediments samples at four stations have been collected (4 months) during 2017–2018, and seven heavy metals (Ni^{2+} , Cr^{3+} , Pb^{2+} , As^{3+} , Hg^{2+} , U^{4+} and Cd^{2+}), as well as 11 parameters including total dissolved solids, the concentration of hydrogen ions, dissolved oxygen, nitrate, chlorides, turbidity, total hardness, electrical conductivity and alkalinity were investigated. The results indicated that the water quality in the SAR depend on the combined effects of natural and anthropogenic factors. The variation of water quality of SAR influenced by the chemical ions inflow from the Tigris River and the marine salt from Arabian Gulf. The highest value of TDS was in S4 it reached to 42,844 mg/l. The results showed that most of the ions increase their concentration by more than 200%, especially in summer season at Fao area due to the effect of the seawater intrusions. In comparison to the sediments, low concentrations and a uniform distribution of most metals were observed in the river water. The river sediments were polluted with heavy metals, while pollution levels in the water were still within permissible limits for drinking, irrigation and aquatic life. These findings indicated that the major sources of river contamination with heavy metals were the atmospheric deposit of gaseous emissions from oil production and electric generators and the surface runoff from agricultural areas after rainfall. Additionally, the tide greatly controls the distribution heavy metals in the river.

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

Introduction

The water quality subject considered new is scientific in the hydrological studies. Therefore, the governments and international institutions began to interest this subject, especially in the early of 21th century as a result of the growing crisis of water scarcity and diversity of the water uses under climate change has affected the world in general and our region in particular (Al-Tememi et al. 2015; Al-Asadi et al. 2019). The major ions concentration magnitude changes according seasons in ascertain area. To study the characterization of any stream, we need to fixed and determine the water quality of the anions and cations concentration to specific the validity of streams, as well as to understand the behavior and the variation of water quality parameters and stream flow. This variation in water quality of the SAR is influenced by the chemical ions inflow from its main tributaries and the marine salt from Arabian Gulf (Moyel et al. 2015; Abdullah 2016a, b; Al-Asadi 2016). As well as, it's affected by many

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factors which is formed by the different substances in the surface water due to the different activities in the stream catchment area, especially the random activities, the water quality seasonally and spatially affected by all these factors combined (Al-Asadi et al. 2019).

Therefore, the expected decline of fresh water discharge in the SAR will severely affect the water quality as a result of the Gulf's seawater intrusion into the river especially in the last two years. The study of water quality gives a clear vision of the validity of the water river for different uses (Al-Asadi 2017).

Despite the fact that rivers estuaries are major regions for rapid economic development, the growth of human activities and the increases water resources utilization. Therefore, the freshwater flow of many rivers into the sea have been declining (Xu et al. 2019). The SAR 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. Heavy metals 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). In the present study, the term 'heavy metals' is used to refer to metals that are neither beneficial nor essential to living organisms, irrespective of their atomic weight and density. 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^{2+}), Chromium (Cr^{3+}), Lead (Pb^{2+}), Arsenic (As^{3+}), Mercury (Hg^{2+}), Uranium (U^{4+}) and Cadmium (Cd^{2+}) are often considered to be environmental contaminants.

Different and various pollutants including heavy 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 2014; 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 heavy 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. 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).

There are very few studies investigating heavy metals. Such previous studies, including Abaychi and Douabul (1985), Abdullah (2013) 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 heavy elements and their sources in the SAR are very limited. Additionally, the examination of water quality can constitute a challenge. In order to fill this gap, the levels of heavy metals in the river and the factors affecting their variation must be measured.

The present study aimed to investigate of hydrochemical variations of SAR for the chemical parameters among selected stations and determine the concentration of seven heavy metals Ni^{2+} , Cr^{3+} , Pb^{2+} , As^{3+} , Hg^{2+} , U^{4+} and Cd^{2+} in the surface water and river bed sediments along the SAR. Demonstration the possible spatial and temporal variations of metals at the selected Stations and seasons. In addition investigate the main factors affecting these deposits of heavy metals; and evaluate the suitability of the river water and bed sediments for different uses by comparing the levels of heavy metals with international guidelines.

Description of the study area

The Shatt Al-Arab River SAR is located in the southern Iraq within the Basra province, between $29^{\circ} 45' - 31^{\circ} 15' \text{ N}$ and $47^{\circ} 10' - 48^{\circ} 45' \text{ E}$. 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 Basra City. From Qurna, the SAR flows downstream for the total area 200 km to join the Arabian Gulf (Fig. 1). The Tigris, Euphrates, Karkheh and Karun Rivers are the major tributaries of the SAR. The hydrological system of the river has rapidly changed due to the decrease of the freshwater discharge from $25.67 \text{ km}^3/\text{year}$ from 1994 to 1995 to around $1.39 \text{ km}^3/\text{year}$ 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 SAR is affected by the tidal phenomenon of the Arabian Gulf, which has a semidiurnal

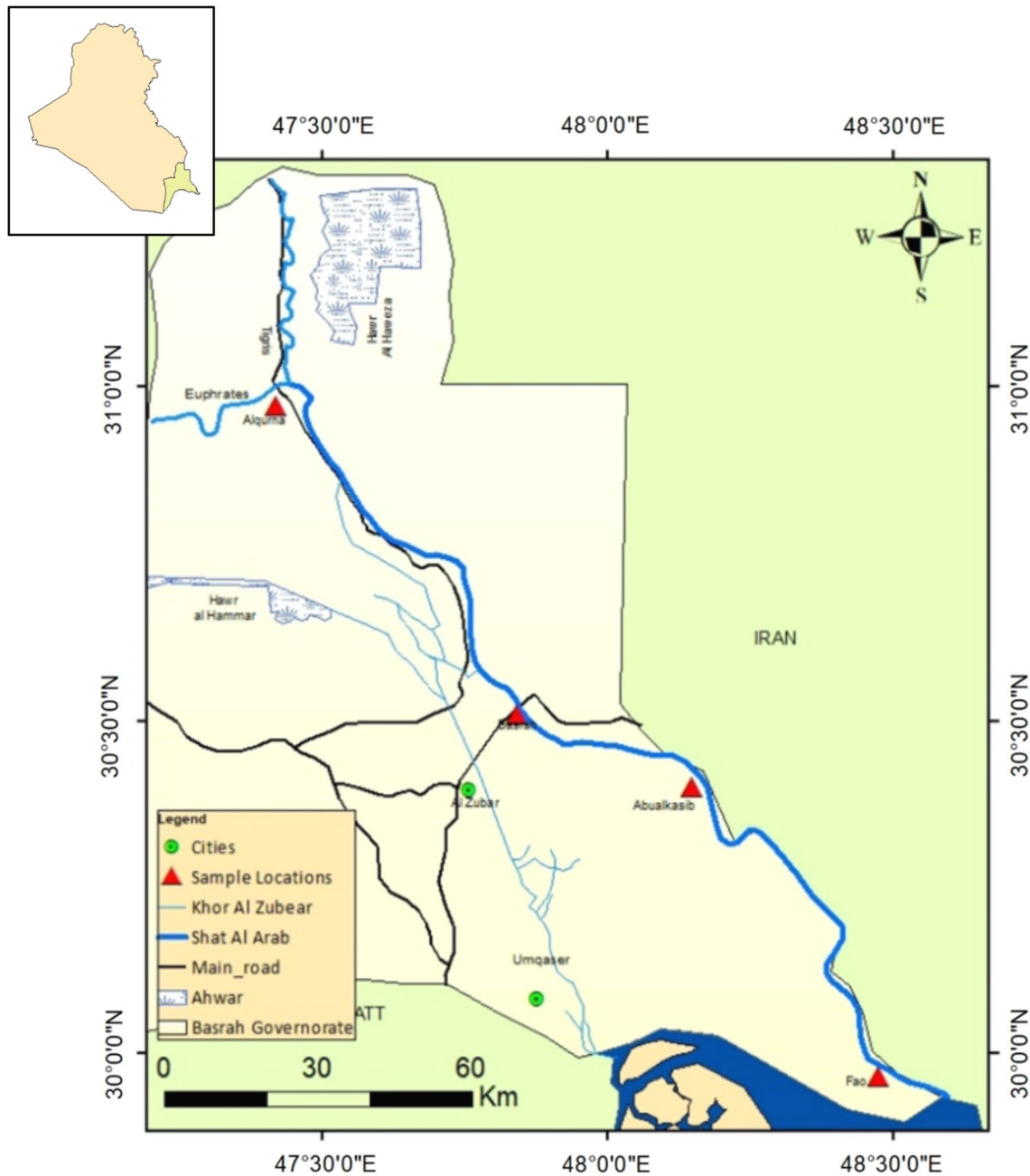


Fig. 1 Map of the SAR and sampling stations

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 2016a, b). 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 to May) is about 100 mm (ESCWA 2013), with the main rainfall occurring during January and February.

Materials and methods

Sample collection and preparation

Sample stations were selected to represent four different conditions (Table 1; Fig. 1). Station 1 was considered to be a control because of its relatively clean water. In station 2 and 3, domestic sewage discharge and agricultural activities

Table 1 Geographic locations of sampling stations at SAR

Sampling site	Site name	Longitude	Latitude
S1	Qurna	47°30'13"	30°54'10"
S2	Basrah	47°49'15"	30°30'36"
S3	Abulkasib	48°01'31"	30°27'42"
S4	Fao	48°28'03"	29°59'19"

are possible sources of pollution respectively. In contrast, the impact of marine water is more prevalent in station 4. Samples of surface water and bed sediments were collected from the middle stream of the SAR. Additionally, 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 were made during the dry season (July) in 2017 and the wet season (February) in 2018. The samples were analysed using standard procedures (APHA 1998). Field measurements in each of the selected Stations were made for 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 two to five days of collection) to be analyzed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), Agilent, USA, Model 7700.

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.

Results and discussion

Physicochemical parameters of the water and sediments

The results of the physical and chemical properties measured in the water and bed samples of the SAR are reported

in Tables 2 and 3 and Fig. 2. The water temperatures in the river exhibited minor variations among the stations, with a low CV value of (1.695), due to differences in sampling times. Generally, the lowest value of water temperature (19 °C) was recorded in the winter at S4 and the highest (32 °C) in summer at S3. The pH values in the water had a distribution similar to those of temperature, in which the spatial variation was relatively uniform at all the four stations. However, the southern part of the river, i.e., the Fao station had slightly higher pH values than those of the other stations. The mean pH values ranged from 7.86 at station 1 to 8.07 at S4. Thus, the river water at the four sampling stations creates a slightly alkaline environment.

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 S 1, and increased at S 4 from 0.51 to 0.62 m/s in the flood and on ebb respectively. The bed texture of the SAR 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.

Electrical conductivity (EC) and total dissolved solid (TDS)

The pattern of EC values clearly increased from north to south along the SAR, 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 S 1 and 4 respectively Fig. 2.

Total dissolved solid are expression of water salinity, which is reflect the validity of the river and assess its quality. Salinity in the (SAR) is high and can be considered highly-salinity Rivers. Salinity comes from various sources, including the salts coming from the Tigris and the Euphrates, as well as by the Karun River and the impact of the Gulf's sea water intrusion, which extends over variable distances from the downstream area. (Hussain et al. 1991). Figure 3 shows the variation in salinity through the study area. The minimum value was in 916 mg/l in S1 while the highest value of salinity was 42,844 mg/l in S4 in summer season respectively, generally, the increase in TDS magnitude is found in S4 because of its proximity to the Gulf sea water. As well as, (SAR) suffering in the last two years from scarcity of water discharges, which it lead to influence by interning the Gulf sea water to the river in first stage, in addition to the highly evaporation rates in river catchment area and increase the different activities on the river basin, all that leads to decoration in water quality of the river.

Table 2 Physicochemical parameters of SAR water and sediments

Stations	Season	EC (dS/m)	pH	Temp. (°C)	Water Velocity m/s	Particle size (%)		
						Clay	Silt	Sand
S1	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
S2	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
S3	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
S4	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
S D		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

Table 3 Conductivity (dS/m) and pH values and concentrations of heavy 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	Summer	12.7	7.92	<10	<5	<5	<5	<1	<1	<1
Khorah rive	Winter	21.2	7.72	28.8	<5	<5	7.9	<1	<1	<1
Abulkasib	Summer	9.78	7.91	<10	<5	<5	<5	<1	<1	<1
Abu Mgera canal	Winter	17.3	6.97	26.3	<5	<5	<5	<1	<1	<1

Dissolved oxygen (DO)

Adequate dissolved oxygen is necessary for good water quality. Oxygen is a necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1–2 mg/l for a few hours can result in large fish kills. The dissolved oxygen in SAR ranged between 6.3 the minimum rate in autumn in S4 and 12.9 as maximum rate in winter in S1 at the north of SAR as shown in Fig. 3.

Major cations and inions

The cations in surface water represents by Ca²⁺, Mg²⁺, Na⁺, and K⁺, Fig. 3 illustrate the variation in concentration between the seasons and stations, generally the highest values of cations recorded in S4 in Fao location through the seasons (Table 4). Where the concentration of elements increased by 200 percent in S4 compared to other stations except in Winter where all cations concentrations are reduced. The concentration of Ca²⁺ ion ranges from 78 mg/l in S1 in the Summer to 780 mg/l in S4 in the Summer with 100% increase than other stations Fig. 3. The concentration of Mg²⁺ ion ranges from 51 mg/l in S1 in the Summer to

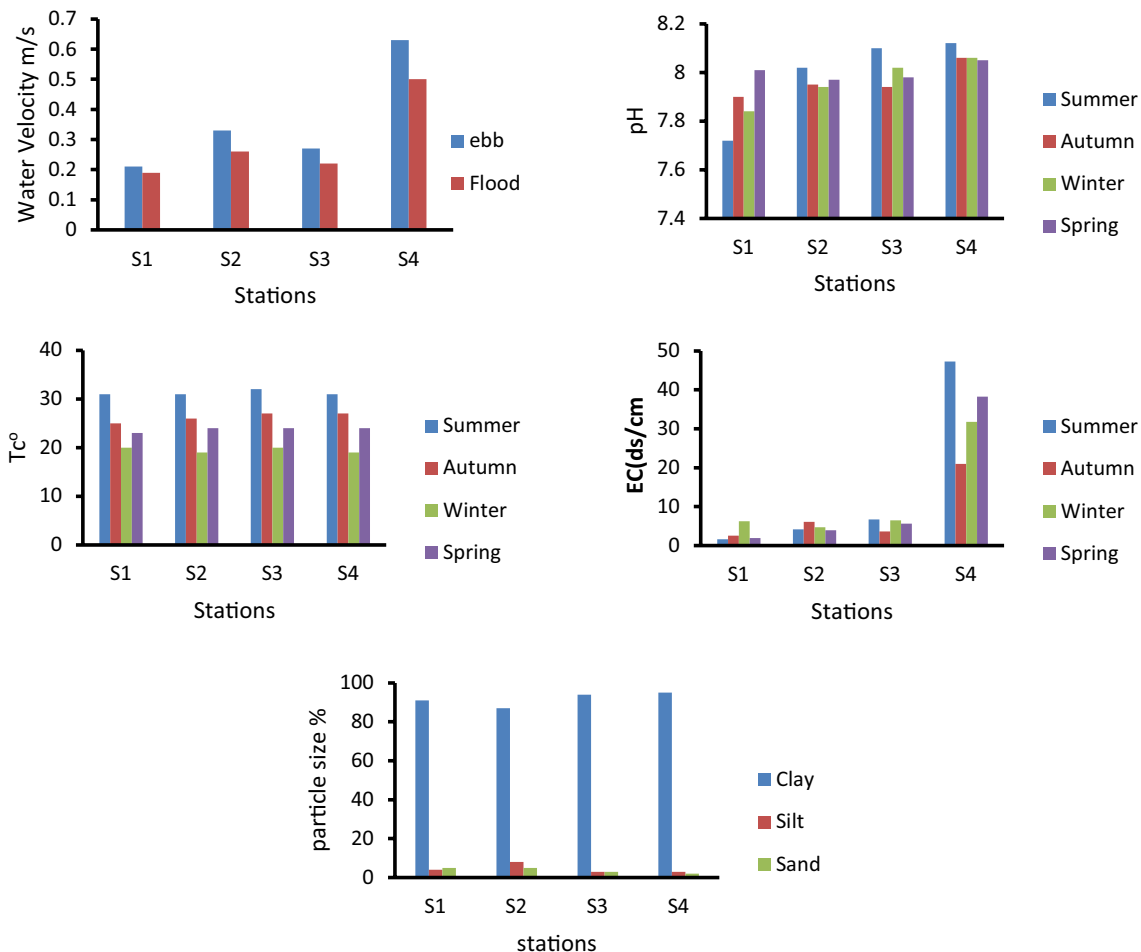


Fig. 2 The values of EC, pH, temperature, water velocity and particle size at four SAR stations

1504 mg/l in S4 in the Summer with 10 times increase than other locations Fig. 3, the concentration of both Na^+ and K^+ ranged from 160, 4.6 mg/l in S1 in Summer to 16,000, 430 mg/l in S4 in summer respectively, The increase is more than ten times the measured concentration in other station, so the high recorded concentration in S4 is due to the proximity of the S4 to the Gulf sea waters.

The measured ions in study area are PO_4^{2-} , Na^+ , SO_4^{2-} and Cl^- , Fig. 3 illustrate the variation in concentration between the seasons and stations. The concentration of PO_4^{2-} and NO_3^- increase in the upstream in S1 in Qurna location may be due to the relative increase of agricultural activities in the area. The concentration of PO_4^{2-} ion ranged from 0.22 mg/l in S3 to 0.97 mg/l in S1, while the concentration of NO_3^- ion ranged from 2.18 mg/l in S2 to 4.05 mg/l in S1 in different seasons as shown in Fig. 3. SO_4^{2-} and Cl^- they have the same behavior as their concentration increases at the end of the river in station S4 the Fao area because their a proximity to Gulf seawater, the SO_4^{2-} concentration ranged from 140 mg/l in S1 to 1600 mg/l in S4

also the Cl^- concentration ranged from 225 mg/l in S1 to 22,325 mg/l in S4, in Summer season as shown in Fig. 3. The drastic increase of the chloride concentration can be an indicator to the marine water is the dominant factor on the water quality in the river.

Heavy metals concentrations in the water

The concentrations of dissolved heavy metals in river water are summarized in Table 5 and Fig. 4. In this study, six heavy metals Cr^{3+} , Pb^{2+} , As^{3+} , Hg^{2+} , U^{4+} and Cd^{2+} detected in the river water are characterized by low concentrations, ranging between < 1 and < 5 $\mu\text{g/l}$ during four seasons at each of the selected stations. The low concentrations of these metals in the river water maybe 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 SAR. These levels may be indicators of the limited effect of anthropogenic activities on the heavy metals. Such

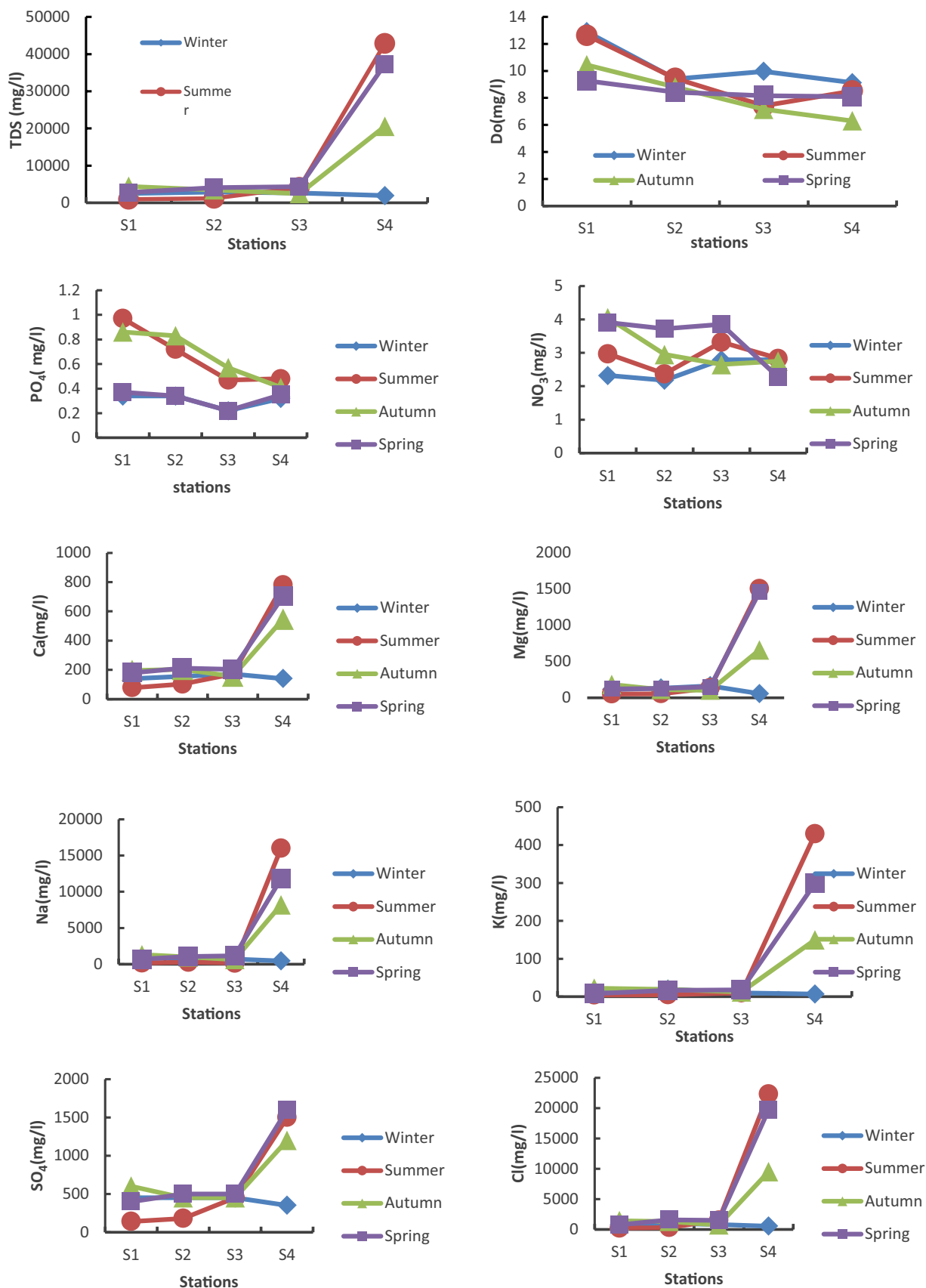


Fig. 3 Distribution of major element levels (mg/l) in SAR water at four stations

Table 4 Chemical parameters of SAR water and sediments

Station	Season	DO	PO ₄	NO ₃	Ca	Mg	K	Na	SO ₄	CL	TDS
S1	Winter	12.9	0.34	2.32	140	113	12.8	760	450	841	2514
	Summer	12.63	0.97	2.97	78	51	4.6	160	140	225	916
	Autumn	10.45	0.86	4.05	195	183	22.5	1300	600	1425	4406
	Spring	9.27	0.37	3.91	179	122	8.2	690	400	768	2738
S2	Winter	9.41	0.34	2.18	156	132	20	910	450	998	2852
	Summer	9.45	0.72	2.37	103	55	5.3	280	180	323	1150
	Autumn	8.81	0.83	2.95	203	113	19.4	1000	450	1321	3460
	Spring	8.42	0.34	3.72	211	127	16.5	1050	500	1577	4066
S3	Winter	9.96	0.22	2.79	172	165	10	700	450	793	2636
	Summer	7.42	0.47	3.32	172	136	10.1	140	450	1520	4120
	Autumn	7.16	0.57	2.65	156	103	12.5	650	450	732	2450
	Spring	8.17	0.22	3.85	203	150	17.9	1160	500	1511	4336
S4	Winter	9.13	0.32	2.79	140	56	7	450	350	546	1912
	Summer	8.51	0.48	2.83	780	1504	430	16,000	1500	22,325	42,844
	Autumn	6.3	0.41	2.75	546	658	150	8200	1200	9500	20,552
	Spring	8.1	0.35	2.27	702	1457	300	11,800	1600	19,680	37,264

Table 5 Concentrations of heavy metals ($\mu\text{g/l}$) in SAR water

Stations	Season	Metals						
		Ni	Cr	Pb	As	Hg	U	Cd
S1	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
S2	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
S3	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
S4	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

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 heavy metals. The influence of the sewage disposal on the levels of heavy metals in the river water may be limited, because concentrations of heavy 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 SAR. Additionally, the chemistry of seawater in the Arabian Gulf contains lower levels of heavy

metals, varying between 0 and 0.78 $\mu\text{g/l}$ (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 physico-chemical 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 heavy metals in the river water were spatially and temporally uniform, with the exception

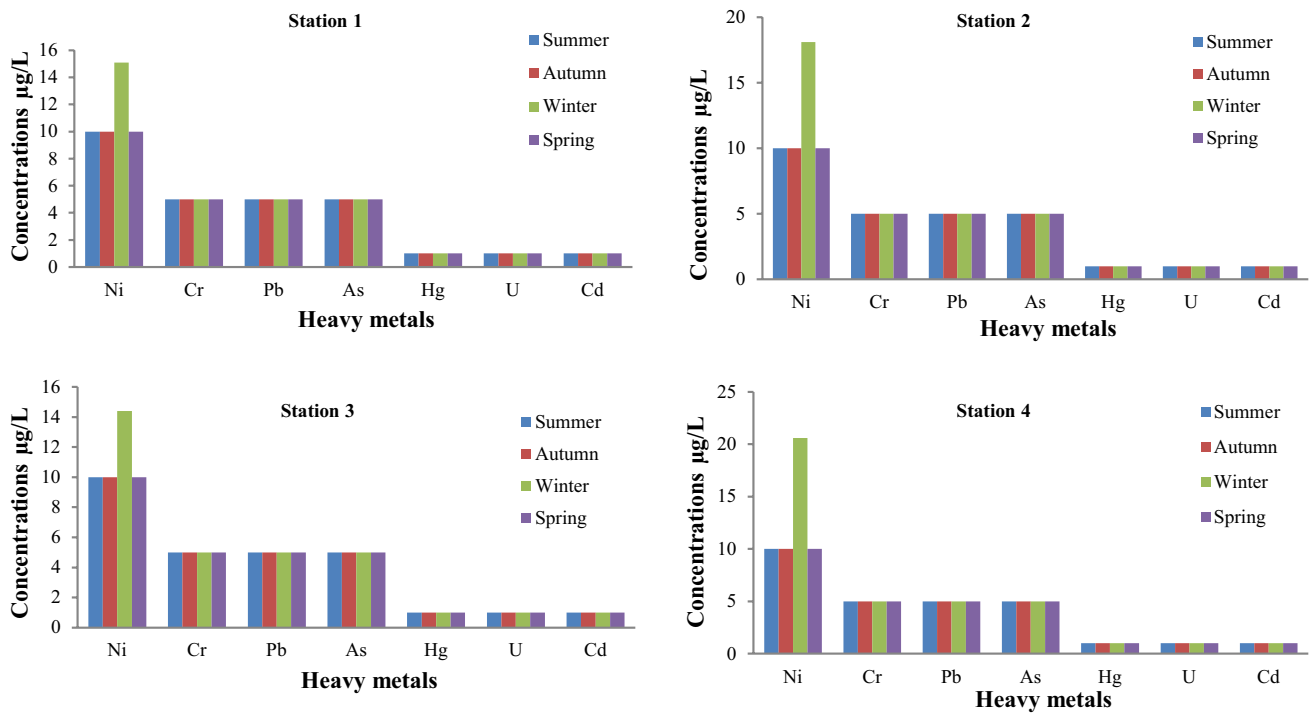


Fig. 4 Distribution of heavy metals levels (µg/l) in SAR water at four stations

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 to 20.6 µg/l. This situation is most likely due to the high deposition of 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 heavy metals in Shatt Al-Arab water are in the order of Ni > Cr; Pb; As > Hg; U; Cd in all sampling locations.

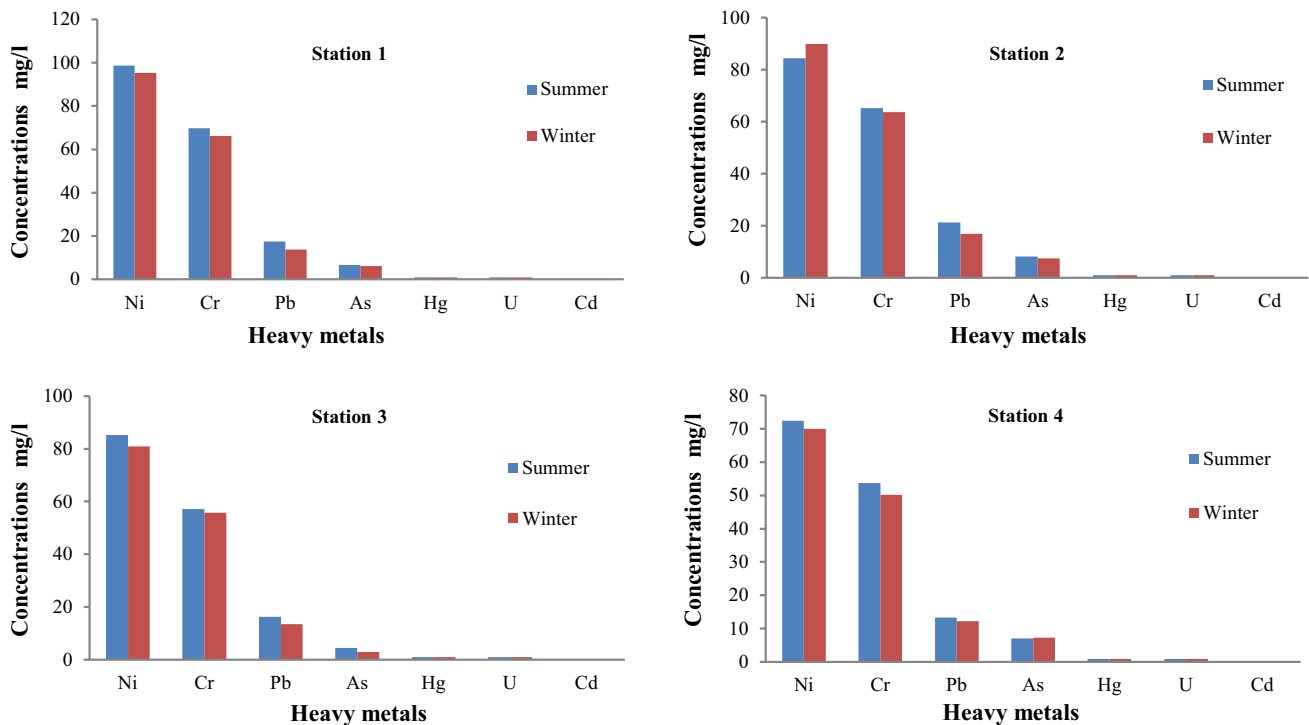
The present levels of heavy metals in the river water were significantly lower than those reported by Moyel et al. (2015) and Al-Hejuje et al. (2017) as in the Table 5. But these findings (except for nickel) come in line with the findings of Abaychi and Douabul (1985) and Abdullah (2013) (Table 6). Based on the present observation, the concentrations of heavy metals indicate that the river water at various sampling stations 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 6).

Table 6 Comparison of the observed concentrations of heavy metals (µg/l) in SAR water with previous studies and international standard values

Heavy 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 7 Concentrations of heavy metals (mg/l) in sediments of SAR

Stations	Season	Metals							
		Ni	Cr	Pb	As	Hg	U	Cd	
S1	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	
S2	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	
S3	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	
S4	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. 5** Distribution of heavy metals levels (mg/l) in sediments at four SAR stations

Content of heavy metals in sediments

Table 7 and Fig. 5 present a summary of the heavy metals and give the coefficient of variation statistical parameters (CV) found in the sediments of the four sampling stations of the SAR. The concentrations of the all heavy 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 higher at the four sediment stations 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 station (96.9 and 68.0 mg/l respectively), while the Basra station had slightly higher levels of Pb (19.1 mg/l) and As (7.8 mg/l). Fao is the station 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 Station (3.6 mg/l). Overall, the distribution of most metal concentrations in the sediments shows a decrease at the Fao Station. 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 heavy metals in the sediments. Therefore, the marine water of Arabian Gulf is often responsible for the spatial variations of heavy metals levels found in sediment samples.

Elevated level of Cr (66.2 to 69.7 mg/l) in the sediment at the Qurna Station 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 SAR 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 heavy than hexavalent Cr (VI) (Tchounwou et al. 2012). The mean values of Pb in the sediments varied between 12.7 to 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 Station, which is subject to receive a large amount of tailings and effluents from thermal power plants.

The four metals Ni²⁺, Cr³⁺, Pb²⁺ and As³⁺ measured in the river sediments showed insignificant temporal variations. Generally, their concentrations were higher in summer than in winter at four Stations. 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 Hg²⁺, U⁴⁺ and Cd²⁺ 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 Stations. Therefore, the sources of Hg²⁺, U⁴⁺ and Cd²⁺ in the river were not entirely clear. The average concentrations of Ni²⁺ in the sediment samples at each of the four Stations was the highest, ranging from 71.2 to 96.9 mg/l, in comparison to the other metals studied. Cd had the lowest value of <0.1 mg/l. Hence, the heavy metals present at the different locations in descending order were Ni > Cr > Pb > As > Hg, U > Cd in all sampling locations.

The study of heavy metals in sediments shows that their concentrations are lower than they were in the previous studies conducted by Al-Tawash et al. (2013) and Al-Jaberi et al. (2016) (Table 8). But these levels were higher than the concentrations reported by Abaychi and Douabul (1985) (Table 8). Sediment quality guidelines of CCME (2001) are used to evaluate the possible heaviness of the river sediments. The results prove that the concentrations of heavy metals exceed the permissible limits, causing adverse effects on the aquatic life in the SAR (Table 8).

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 heavy metals in the sediments

Table 8 Comparison of the observed concentrations of heavy metals (mg/l) in sediments of SAR with Canadian guidelines and other studies

Heavy 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 9 Pearson correlation coefficient matrix for heavy metals in sediments of SAR

	Ni	Cr	Pb	As	EC (dS/m)	pH	Temp. (°C)	Velocity (m/s)	Clay	Silt	Sand
<i>Summer (n = 26)</i>											
Ni	1										
Cr	0.881	1									
Pb	0.475	0.719	1								
As	-0.124	0.351	0.430	1							
EC (dS/m)	-0.839	-0.771	-0.770	0.151	1						
pH	-0.892	-0.885	-0.312	-0.176	0.547	1					
Temp. (°C)	0.003	-0.388	-0.176	-0.918	-0.253	0.396	1				
Velocity (m/s)	-0.908	-0.748	-0.609	0.302	0.973*	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*	0.743	0.343	-0.792	-0.868	-0.365	-0.763	-0.898	0.695	1
<i>Winter (n = 26)</i>											
Ni	1										
Cr	0.993*	1									
Pb	0.608	0.657	1								
As	0.009	0.122	0.282	1							
EC (dS/m)	-0.851	-0.810	-0.661	0.392	1						
pH	-0.949	-0.951*	-0.409	-0.154	0.654	1					
Temp. (°C)	0.428	0.323	-0.288	-0.783	-0.527	-0.416	1				
Velocity (m/s)	-0.859	-0.800	-0.462	0.493	0.967*	0.713	-0.715	1			
Clay	-0.553	-0.615	-0.991*	-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*	1	
Sand	0.861	0.893	0.926	0.215	-0.808	-0.718	0.000	-0.685	-0.898	0.775	1

2-tailed test of significance is used

*Correlation is significant at the 0.05 level

showed that both Cr and EC were positively correlated to sand and water velocity respectively (Table 9). However, in winter season, Ni and EC were positively correlated to sand and water velocity respectively. In contrast, Cr, Pb and Clay were negatively correlated to pH, clay and silt respectively (Table 9). This suggests that different physicochemical parameters influence the concentrations of some heavy metals in the sediments and water. The insignificant relationship between all heavy metals suggests different sources of input (human or natural) for these metals in the river sediment (Bastami et al. 2012).

Additionally, Fig. 6 shows a significant linear correlation between electrical conductivity, pH, water velocity and sand with Nickel ($r^2=0.75, 0.84, 0.81$ and 0.81 respectively) and Chromium ($r^2=0.63, 0.83, 0.60$ and 0.95 respectively) in the SAR. This indicated that human activities inputs were probably the major contribution for accumulation in sediments of SAR (Gao and Chen 2012). Water temperatures did not result in any strong correlation to the metals levels, except for As ($r^2=0.93$). As well as the Hg, U, and Cd did not show any significant correlation with the selected parameters (Table 10 and Fig. 6).

Conclusions

The current study revealed that the concentrations of major elements and heavy metals (Ni, Cr, Pb, As, Hg, U and Cd) in the water of the SAR were low and uniform, except for Ni during the winter. Bed sediments exhibited a higher content of heavy metals than the river water. These levels indicate that the accumulation of heavy metals in the river bed was more extensive than the processes of solubility and mobility. The concentrations of Ni, Cr, Pb and As in the sediments was 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 heavy 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 a limited effect on heavy metals deposits because the concentrations of heavy metals in domestic sewage were low. A severe

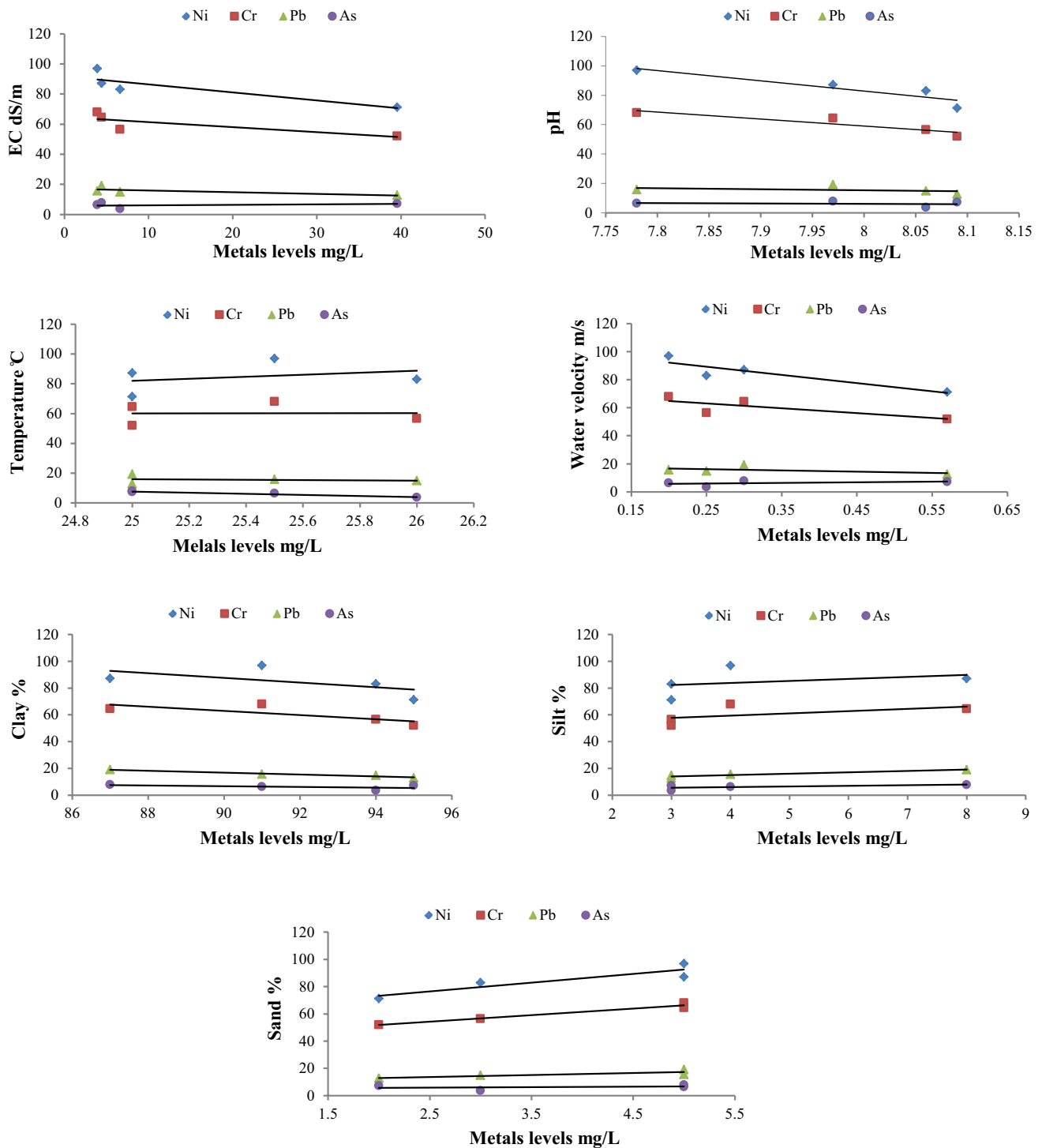


Fig. 6 Linear correlation coefficient (R^2) of the selected physicochemical properties with Ni, Cr, Pb and As concentrations in SAR sediments

decline in the freshwater flow of the SAR contributed to the relatively higher levels of some heavy metals upstream. Seawater intrusion affected the levels of heavy 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 severe decline in their levels. The water environment of the river has not been significantly contaminated by heavy metals, as their concentrations were found to be within a safe limit. However, uncontrolled urban development in the

Table 10 Correlation coefficients (R^2) for of selected physicochemical parameters versus levels of heavy metals in sediments

Heavy 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	–	–	–	–	–	–	–

region is likely to increase the level of water pollution in the future. The SAR 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.

Acknowledgements The authors thankful to the Environmental agency. The authors are also pleased to thank the reviewers for their thoughtful, constructive and useful comments, which greatly improved the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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