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ORIGINAL PAPER

Status of trace metals in surface seawater of Sharm Al-Kharrar lagoon, Saudi Arabia

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Abstract
To assess the environmental quality of Sharm Al-Kharrar lagoon, Red Sea coast, Saudi Arabia, forty-five water samples were collected for nickel (Ni), zinc (Zn), arsenic (As), copper (Cu), lead (Pb), cobalt (Co), chromium (Cr), and cadmium (Cd) analysis using an inductively coupled plasma-mass spectrometer. Ni was the most abundant heavy metal (5.76 μg/L), followed by Zn (4.19 μg/L), As (2.07 μg/L), Cu (1.24 μg/L), Pb (0.28 μg/L), Co (0.26 μg/L), Cr (0.26 μg/L), and Cd (0.06 μg/L). Seawater analysis indicated higher average values of the heavy metals Pb, Zn, Ni, Cu, and As in comparison with the average oceanic concentration and those values recorded from Arabian Gulf, Gulf of Aqaba, Red Sea, and Mediterranean Sea. The higher average values of metals in seawater may be attributed to atmospheric input or anthropogenic sources, like electric power and water supply plants, Aramco company refinery, and Aramco residential area, which distributed along the lagoon.

Keywords Contamination · Surface water · Al-Kharrar lagoon · Saudi Arabia

Introduction

The coastal areas suffer from increasing the levels of heavy metals in the marine environment due to the rapid development of industrialization and urbanization (Shriadah et al. 2004). The high concentrations of some metals in seawater are indicative of either the anthropogenic sources or natural sources (e.g., Al-Taani et al. 2014; El-Sorogy et al. 2016, 2018, 2020; Zhang et al. 2018).

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The Saudi Red Sea coast represents about 1840 km of the Red Sea's eastern coast. Numerous coastal lagoons are present along the Saudi coastal stretch, and some are known as Sharms (Rasul 2015). The origins of these lagoons have been discussed by many authors (e.g., Rabaa 1988; Head 1987; Braithwaite 1987; Brown et al. 1989). The Sharm Al-Kharrar lagoon is a small inlet located north of Jeddah and was called in some previous studies as Rabigh Lagoon. The lagoon is characterized by shallow depths (2–11 m), low tidal currents, soft sediments, and high turbidity, an environment rich for many foraminiferal species, and considered a biologically productive area. The lagoon received a variety of discharges from urban, commercial, and industrial activities due to increasing human activities and development (El Sayed 2002; Al-Farawati 2010; Youssef and El-Sorogy 2016). Also, the lagoon annually receives fine fluvial sediments from Wadi Rabigh (Ghandour and Haredy 2019).

Assessment of contamination in aquatic ecosystems along the Saudi Red Sea coast has become a priority in recent years. Among other contaminants, heavy metals (HMs) have received particular attention as they help in assessing the early impacts of anthropogenic activities on the marine ecosystems. Some metals are potentially toxic (Diagomanlin et al. 2004; Zheng et al. 2008; Batayneh 2010). Assessment of the heavy metal contamination in the coastal sediments in Saudi coasts receive attention of many authors (e.g. Youssef and El-Sorogy 2016; Al-

Dubai et al. 2017; Touliabah and Elbassat 2017; Hariri and Abu-Zied 2018).

Few studies have subjected to heavy metal levels in seawater along the Arabian Gulf (e.g., Alharbi et al. 2017; Alharbi and El-Sorogy 2019). Two studies only deal with the HM levels in the seawater in Saudi Red Sea (Al-Farawati et al. 2011; El-Sorogy and Youssef 2021). The Saudi coast in the last few years is subjected to intensive industrial and tourism activities. Therefore, the present study is an attempt to use seawater analyses to assess the current status and spatial distribution of HMs in Sharm Al-Kharrar lagoon.

Materials and methods

The Sharm Al-Kharrar lagoon is located between latitudes 22° 45′ and 23° 00′ N and longitudes 39° 00′ and 38° 45′ E, northwest of Rabigh City, Red Sea coast (Fig. 1). It is connected to the Red Sea through a narrow channel located at the northwestern side. Mangroves are common on the lagoon islands. The tidal range at the lagoon is very low, approximately 20 to 30 cm. Sediment is mainly composed of mud, sandy mud, and gravelly sand of biogenic origin. The floor of the lagoon is covered by seagrass; some coral reefs are recorded. The authors report that many of fishing boats active the whole day. The nearshore margins of the lagoon consist of siliciclastic sediments discharged from nearby wadies. The waves, marine currents, Aeolian action, and tidal currents are affected the lagoon. The lagoon is influenced by northerly currents and waves controlling the movement of both water and sediments to the adjacent tidal flat (Ghandour and Haredy 2019).

Surface water samples were collected from forty-five stations using a small motorboat; the samples were collected in June 2020. The samples were collected pre-acidified polyethylene containers, kept in an icebox, and transported to a laboratory. Pb, Cd, Zn, Ni, Co, Cr, Cu, and As were analyzed using an inductively coupled plasma-mass spectrometer (ICP-MS). The calibration curves of the 6 elements, Cr, Cd, Cu, Pb, Co, and Ni, were obtained using the blank and three working standards 0, 50, 100, and 200 μg/L (Panreac, 766333. 1208) and for As and Zn elements using the blank and three working standards 0, 50, 100, and 200 μg/L (Aristar grade, BDH laboratory supplies, England for the heavy metals). Calibration curves showed an excellent linearity for all elements.

Univariate statistical analyses were conducted using SPSS (ver. 23, IBM Corp., Armonk, NY, USA). Correlation coefficient analysis was used to create a correlation matrix between metal concentrations. Univariate statistical analyses were conducted using hierarchical clustering between groups (Ward's

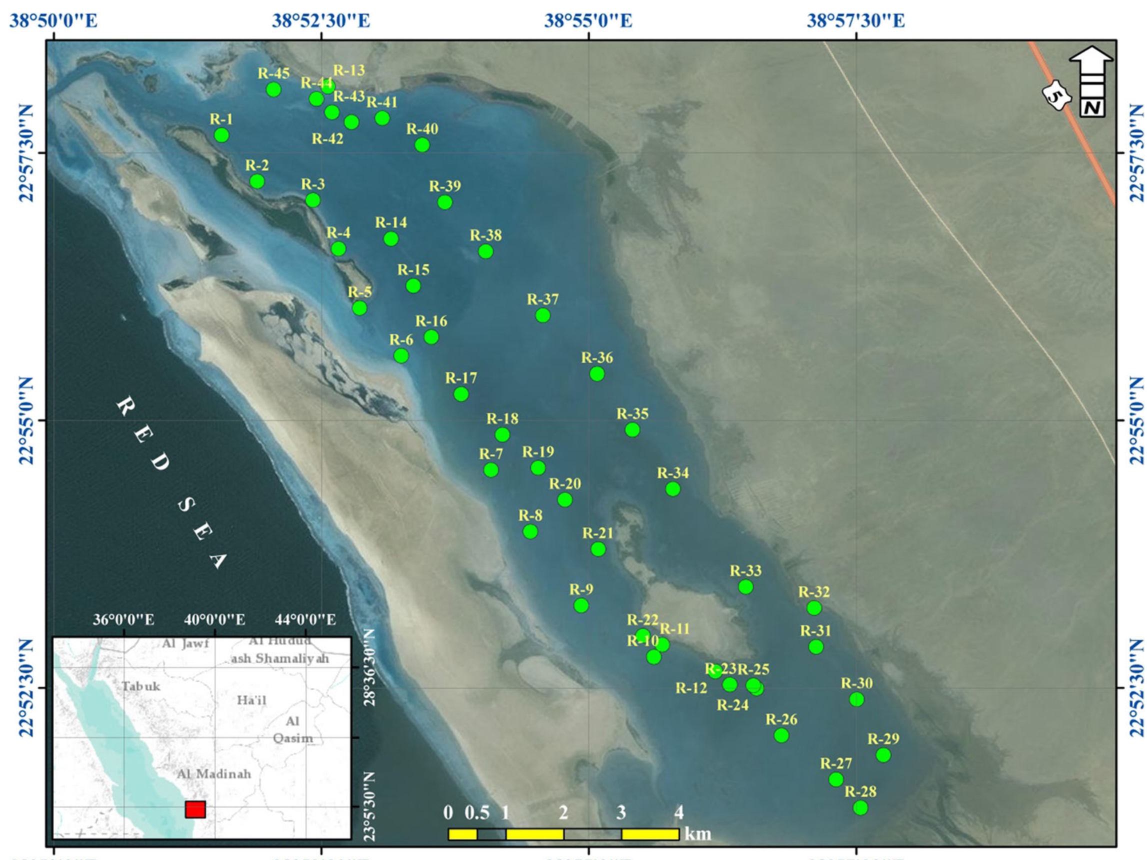

Fig. 1 Location map and sampling locations in the Sharm Al-Kharrar lagoon

method) to determine Euclidean distances. Principal component analysis (PCA) was applied to identify possible the sources of the metals in the studied sediments.

Results and discussion

Table 1 shows the results of heavy metal content along Sharm Al-Kharrar lagoon. The average levels were in the following order: Ni>Zn>As>Cu>Pb>Co>Cr>Cd. Nickel was the most abundant metals (average 5.76 μg/L), followed by zinc (4.19 μg/L), arsenic (2.07 μg/L), copper (1.24 μg/L), lead (0.28 μg/L), cobalt (0.27 μg/L), chromium (0.26 μg/L), and cadmium (0.06 μg/L). The concentration of the heavy metals in the studied lagoon is shown in Fig. 2. Distribution pattern of HMs exhibited fluctuated values within the studied sites (Fig. 3).

Table 2 illustrates a comparison between our metal levels and those recorded from many neighboring and worldwide water masses. Average concentration of lead is less than the ones recorded from north Atlantic and Pacific, Oman Sea and Tarut Island, Arabian Gulf, Red Sea-Gulf of Aqaba (Donat and Bruland 1995; Bazzi 2014; El-Sorogy et al. 2016; El-Sorogy and Youssef 2021) and higher than those recorded from Sharm Al-Khobar and Bahrain (Arabian Gulf), average oceanic concentration, Red Sea and Gulf of Aqaba (Alharbi et al. 2017; Al-Sayed et al.1994; Broecker and Peng 1982; Al-Taani et al. 2014). Average value of cadmium is less than those involved in Table 2, except those recorded from Gulf of Aqaba and Tarut Island. Also, chromium value is less those involved in Table 2, except those from the Red and Mediterranean seas. The distribution pattern of Cr showed high levels at the central sites of the lagoon, with decreasing levels towards the sides.

The average value of nickel is higher than those average values recorded in different areas summarized in Table 2, except that recorded in Oman Sea. Average concentration of zinc is less than the ones recorded from Al-Khobar (Arabian Gulf), Oman Sea, and the Red Sea and higher than those recorded from north Atlantic and Pacific, Bahrain, average oceanic concentration, Mediterranean Sea, and Gulf of Aqaba. The spatial distribution of Zn in surface seawater showed a decreasing pattern southwards. Average value of cobalt is less than those recorded from north Atlantic and Pacific, Al-Khobar, and Tarut Island and higher than those recorded from Al-Khafji (Arabian Gulf), Gulf of Aqaba, and the Red Sea.

The average concentration of copper is less than the ones recorded from Al-Khobar, Tarut Island and Al-Khafji (Arabian Gulf), Oman Sea, and Gulf of Aqaba, and higher than those recorded from north Atlantic and Pacific, average oceanic concentration, Bahrain, and the Red Sea coast. Cu levels were elevated in the southern and northern ends of the lagoon, with an apparent decrease towards the central part.

Table 1 Heavy metal concentrations (μg/L) in surface water from the locations studied in the Sharm Al-Kharrar lagoon

S. N	Pb	Zn	Cu	Ni	Co	Cd	Cr	As
1	0.2	5.7	1.5	6.3	0.3	0.05	0.2	1.9
2	0.2	4.5	1.1	6	0.4	0.08	0.3	2.2
3	0.2	5.6	1.4	5.6	0.2	0.06	0.2	2.4
4	0.1	4.6	1.7	5.4	0.3	0.07	0.3	1.7
5	0.2	3.8	1.1	4.8	0.1	0.1	0.2	1.9
6	0.4	2.5	1.3	5.5	0.3	0.06	0.4	2.3
7	0.2	3.4	1	5.4	0.4	0.06	0.2	2
8	0.4	3.2	1.2	6.2	0.3	0.05	0.3	2.4
9	0.1	2	1.1	6	0.2	0.05	0.3	1.8
10	0.2	3.3	1.5	5.3	0.3	0.04	0.2	2.2
11	0.2	3.4	1.2	6	0.3	0.08	0.2	2.1
12	0.3	4.5	1.2	5.5	0.2	0.09	0.3	2.4
13	0.4	6.2	1.3	6.2	0.2	0.08	0.2	2
14	0.3	5.8	1.2	5.8	0.3	0.07	0.2	1.8
15	0.3	4.4	1.2	5.4	0.4	0.05	0.3	2.3
16	0.2	5.2	1.1	5.2	0.2	0.04	0.2	2.5
17	0.4	5.2	1.2	6	0.3	0.06	0.3	1.9
18	0.1	3.6	1.1	5.6	0.1	0.05	0.4	1.7
19	0.2	3.2	1.2	5.2	0.3	0.06	0.4	2
20	0.2	2.4	1.3	6.4	0.2	0.07	0.3	1.9
21	0.4	6	1.1	6.4	0.4	0.1	0.2	1.8
22	0.1	2.9	1	5.9	0.3	0.06	0.3	2.2
23	0.2	4.1	1.2	4.1	0.2	0.05	0.2	2.1
24	0.3	4.2	1.1	4.2	0.3	0.06	0.2	2.4
25	0.3	3.1	1.2	6.1	0.2	0.06	0.3	2
26	0.4	3.9	1	5.9	0.2	0.05	0.2	1.8
27	0.4	6.2	1.7	6.2	0.4	0.04	0.3	2
28	0.3	5.8	1.2	6	0.2	0.08	0.1	2.4
29	0.4	4	1.3	5.4	0.3	0.09	0.3	1.7
30	0.4	5.2	1.2	6	0.1	0.08	0.2	1.9
31	0.3	4	1.2	6.7	0.3	0.07	0.4	2.3
32	0.2	4.6	1.1	5.8	0.2	0.05	0.3	2.6
33	0.4	3.2	1.2	6.2	0.4	0.04	0.2	2
34	0.3	2.4	1.1	5.3	0.3	0.06	0.3	2.4
35	0.1	3.4	1.2	6.2	0.2	0.05	0.3	2.3
36	0.2	6.4	1.2	6.4	0.3	0.07	0.3	2
37	0.3	3.4	1.2	6	0.3	0.05	0.2	1.9
38	0.3	5.6	1.3	6.1	0.3	0.07	0.3	2
39	0.3	3.7	1.6	4.7	0.2	0.05	0.3	1.7
40	0.4	4.5	1.2	5.4	0.3	0.04	0.2	2.3
41	0.4	4.6	1.5	5.6	0.3	0.06	0.3	2.5
42	0.3	3.2	1.3	6.2	0.2	0.05	0.3	1.9
43	0.4	2.4	1.6	6.4	0.3	0.06	0.3	1.7
44	0.4	3.4	1.2	5.9	0.3	0.06	0.2	2
45	0.3	6	1.2	6.4	0.3	0.09	0.2	1.9
Average	0.28	4.19	1.24	5.76	0.27	0.06	0.26	2.07

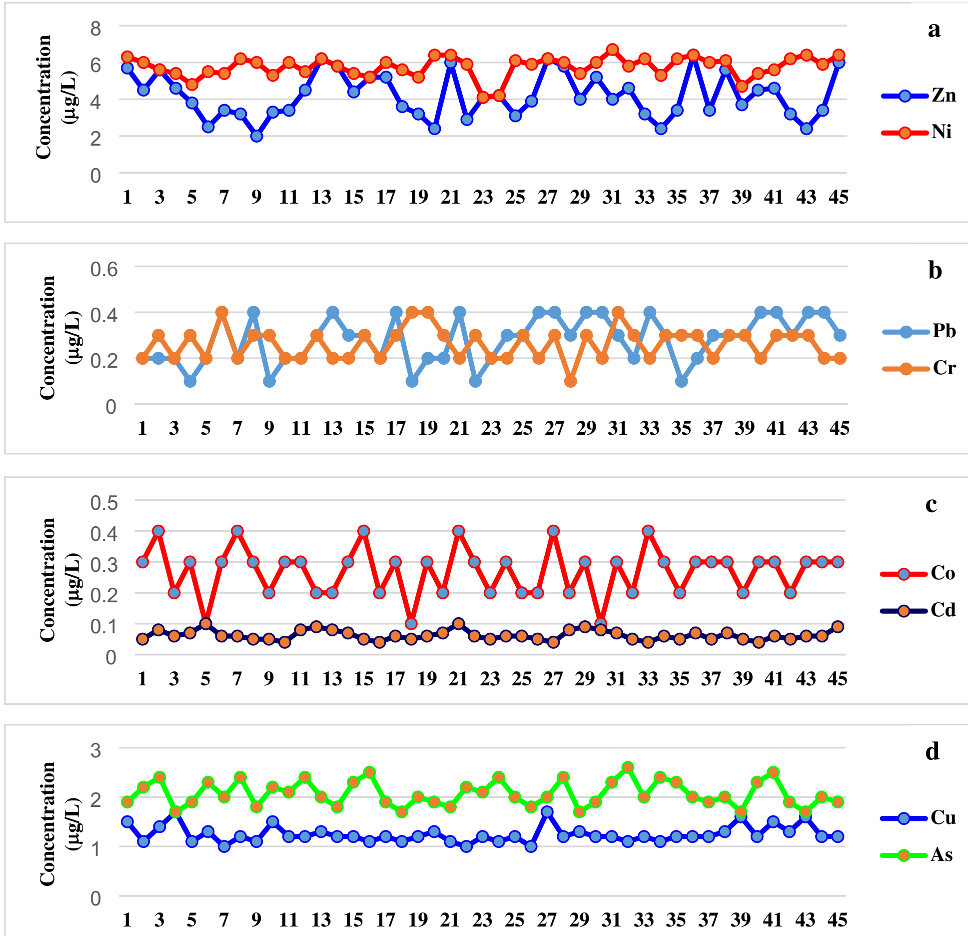

Fig. 2 Concentrations of heavy metals in 45 seawater samples from the Al-Kharrar lagoon: **a** Zn and Ni, **b** Pb and Cr, **c** Co and Cd, and **d** Cu and As

Arsenic value is less than those recorded from north Atlantic and Pacific, Al-Khobar, and Tarut Island and higher than those recorded from Al-Khafji (Arabian Gulf), Gulf of Aqaba, and the Red and Mediterranean seas (Table 2).

The present study is also confirmed with the more recent study on spatial distribution and metal contamination of the coastal sediments of the same study area (Youssef and El-Sorogy 2016; Hariri and Abou-Zeid 2018). The high enrichment factor values for Pb, As, Cu, Cr, Co, and Zn (> 2) indicate their anthropogenic sources, whereas the remaining elements were of natural origins consistent with their low enrichment levels.

Biologically, Al-Kharrar lagoon is a mesotrophic ecosystem; the most dominant group of zooplankton was Copepoda, followed by Protista and Rotifera. Chlorophyll also has the same pattern with the standing crops of the phytoplankton (Touliabah and Elbassat 2017). The lagoon is also having the mangrove *Avicennia marina*, macro-algae, seagrasses (*Halophila stipulacea* and *Cymodocea rotundata*), and algal mats (*Cyanobacteria*) which dominate the intertidal and supratidal areas of the lagoon, tolerating extremely high salinity and high-temperature conditions; corals were observed alive at the southern part of the lagoon (Al-Dubai et al. 2017).

HCA analyses was used, and the resulted dendrogram is illustrated (Fig. 4) for the concentrations of the 8 elements in the 45 seawater samples. The elements are classified into three different groups. The first includes four elements (Co, Cr, Pb, and Cd), the second includes Cu and As, while the third one includes Zn and Ni. The dendrogram of the studied 45 samples is illustrated in Fig. 5; the studied samples are divided into three main groups: Group A includes 12 samples (1, 3, 13, 14, 17, 21, 27, 28, 30, 36, 38, 45); group B constitutes 12 samples (2, 4, 5, 12, 15, 16, 23, 24, 32, 39, 40, 41); and group C contains 21 samples (6, 7, 8, 9, 10, 11, 18, 19, 20, 22, 25, 26, 29, 31, 33, 34, 35, 37, 42, 43, 44).

These results are supported by Pearson's correlation coefficient (Table 3). Negative correlations were observed between As and each of Pb, Cu, Ni, Cd, and Cr. Also, negative correlations are recorded between Cr and each of Cd, Zn, and Cd. Table 4 illustrates the component matrix, from which four principal ones are extracted. These components account for 68.29% of the total variance. The first component accounts 21.80% and shows a high positive loading of Zn and Pb (0.715 and 0.599 respectively). The second component explains 17.99% and contains positive loading for Cr and Cu (0.607 and 0.0588 respectively). The third component factor

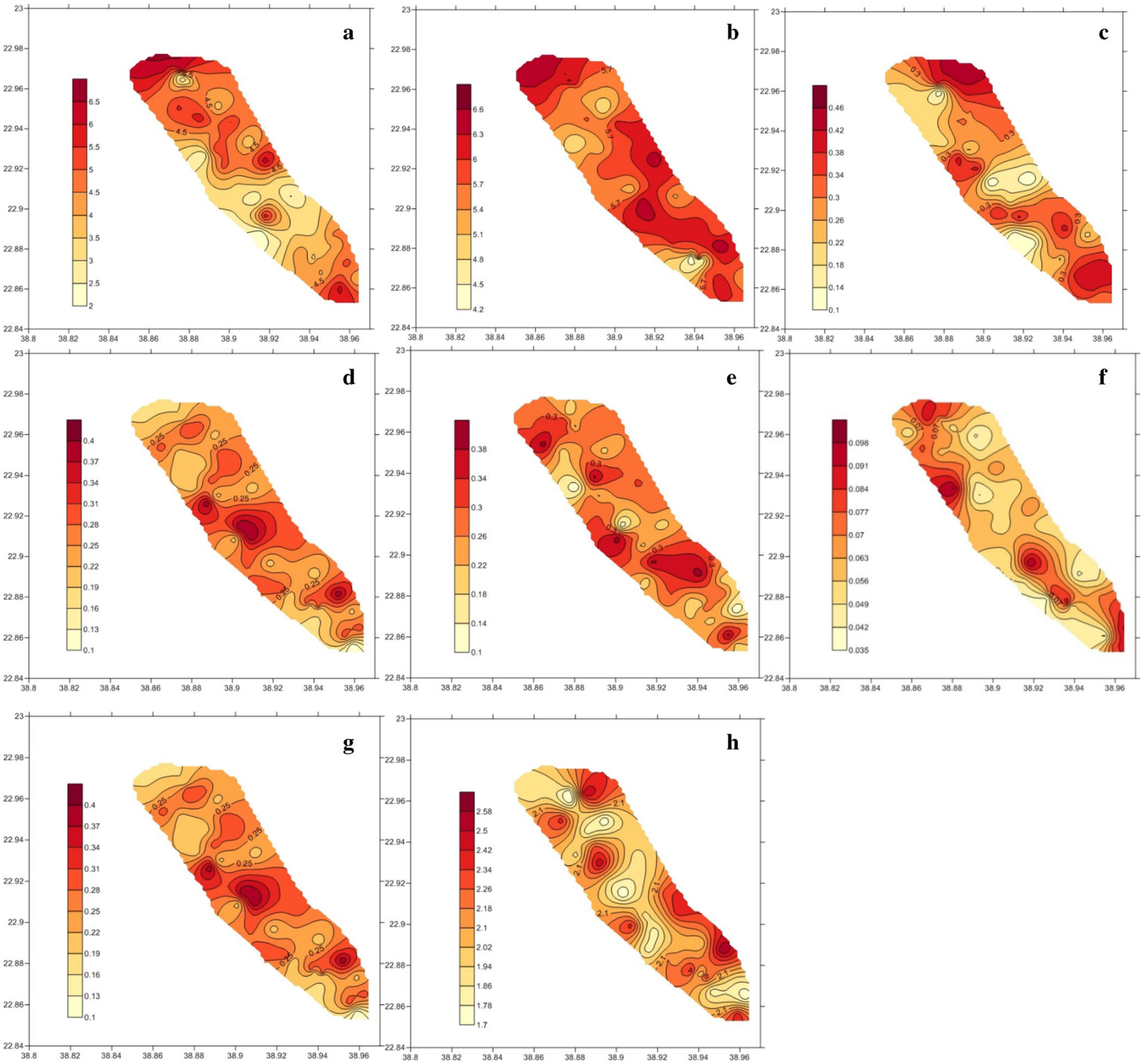

Fig. 3 Spatial distribution patterns: **a** Pb, **b** Cr, **c** Zn, **d** Ni, **e** Cu, **f** As, **g** Co, and **h** Cd elements in 45 seawater samples from the Al-Kharrar lagoon

accounts 15.51% and shows positive loading for As (0.722). Each group of elements possibly originates from similar sources. A varimax method with the Kaiser normalization led to distribute HMs in two groups, corresponding to the results from the principal component analysis (Fig. 6).

The concentrations of heavy metals in coastal waters are known to be higher than those from open waters (Boyle et al. 1985; Vann Geen et al. 1991). River inputs and runoff are considered important factors that cause high concentrations of trace metals in coastal areas (Venkatramanan et al. 2014). The influences of these factors on the coastal waters of the Red Sea are negligible, as there are no permanent rivers in Saudi Arabia. In the arid regions, runoff can play a role in providing trace metals to the coastal waters via wadies (Sabina et al. 2005). This factor is linked to the occasional rains that are very rare in this area.

More than 50% of the heavy metals to the open waters of the northwest Mediterranean come from Atmospheric input (Guieu et al. 1997; Martin et al. 1989). Higher concentrations of crustal-derived elements in Red Sea aerosols than those from the eastern Mediterranean and the Arabian Sea (Orif 2007) were recorded. On the other hand, more impact of atmospheric input on the coastal waters of Saudi Arabia was recorded, since a plain surface to the east bordered the coastal areas. The dust contributes to the load of trace metals and the aerosols during dust storms; the HMs find their way to the sediments and contribute to the concentrations of metals in the overlaying waters.

Table 2 Comparison of measured metals concentrations (µg/L) in seawater from the study area and neighboring and worldwide water masses

Location	Reference	Pb*	Zn*	Cu*	Ni*	Co*	Cd*	Cr*	As*
Rabigh Lagoon, Red Sea	Present study	0.1	5.7	1.4	0.3	0.3	4.2	1.2	2.1
Average oceanic concentration	Broecker and Peng 1982	0.001	0.4	0.12	-	-	0.07	0.33	-
North Atlantic	Millero 1996	0.019	-	-	-	-	0.005	-	-
North Atlantic	Donat and Bruland 1995	125	0.15	1.15	-	159	5.5	3.5	20
North Pacific		32	0.15	0.9	-	27	5.5	3	20
Mediterranean	Tanker and Statham 1996	-	0.17	-	-	-	-	-	-
Oman Sea	Bazzi 2014	2.22	11.7	2.77	10.9	-	0.13	15.51	-
Bahrain, Arabian Gulf	AL-Sayed et al. 1994	0.16	0.84	0.20	0.31	-	0.11	-	-
Gulf of Aqaba	Shriadah et al. 2004	0.32	0.24	0.14	0.22	0.17	0.57	-	-
Red sea		0.03	5.5	0.97	0.76	0.03	0.06	0.18	1.29
Gulf of Aqaba	Al-Taani et al. 2014	0.20	3.32	6.18	-	0.24	0.03	0.96	0.82
Tarut Island	El-Sorogy et al. 2016	0.48	0.97	2.65	-	2.06	0.03	12.95	11.13
Rosetta coast	El-Sorogy and Attiah 2015	0.006	0.013	-	-	-	-	0.004	0.30
Al-Khobar, Arabian Gulf	Alharbi et al. 2017	0.04	16.21	5.24	4.36	0.36	0.11	1.38	2.41
Al-Khafji, Arabian Gulf	Alharbi and El-Sorogy 2019	0.28	1.53	2.44	4.40	0.23	0.07	0.70	1.74
Red Sea-Gulf of Aqaba	El-Sorogy and Youssef 2021	1.31	5.5	2.34	2.45	0.31	0.05	0.26	2.43

*The average concentration in µg/L

One of the expected sources of metals concentrations in the lagoon is diffusion from anthropogenic activities. The Rabigh area is attractive for many industrial activities: petroleum refineries, the Aramco oil company, the Petro Rabigh Company, the Rabigh industrial port, the Rabigh cable factory, and a desalination plant. The waste effluent of the industries is discharged into the sea, either treated or partially treated (Youssef and El-Sorogy 2016).

The coastal areas of the Red Sea are undergoing rapid construction activities that are often associated with intensive dredging and reclamation. The coastal and marine environment in the Red Sea is the target for most of the major housing, tourism, and economic developments. Dredging and reclamation processes are typically associated with elevated levels of heavy metals that are mobilized during these activities (Guerra et al. 2009; Hedge et al. 2009). These contaminants can enter important food web components, including fish and shellfish. Sewage discharges are the major source of pollution in the coastal areas of the Red Sea (El Sayed 2002; Al-Farawati 2010). Petroleum refinery wastewater is composed of, among other chemicals, heavy metals like Cr, Fe, Ni, Cu, Se, and Zn (Wake 2005). Environmental evaluation helps to develop an effective coastal management plan and strategies to better manage coastal activities. This is of particular importance, as the Red Sea coastal area is important in terms of marine waterways, fishing, tourism, and various commercial activities.

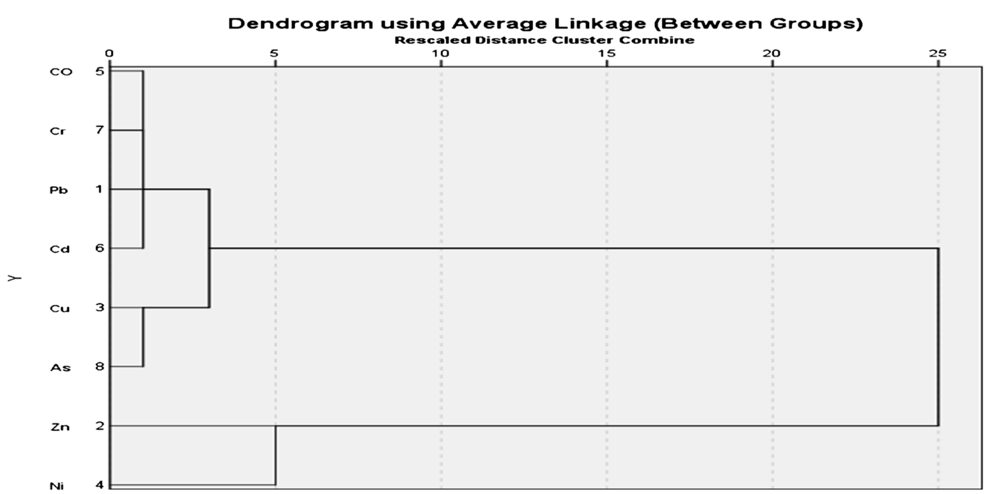

Fig. 4 Dendrogram for hierarchal clusters analyses of 8 metals in surface seawater samples collected from Sharm Al-Kharrar lagoon

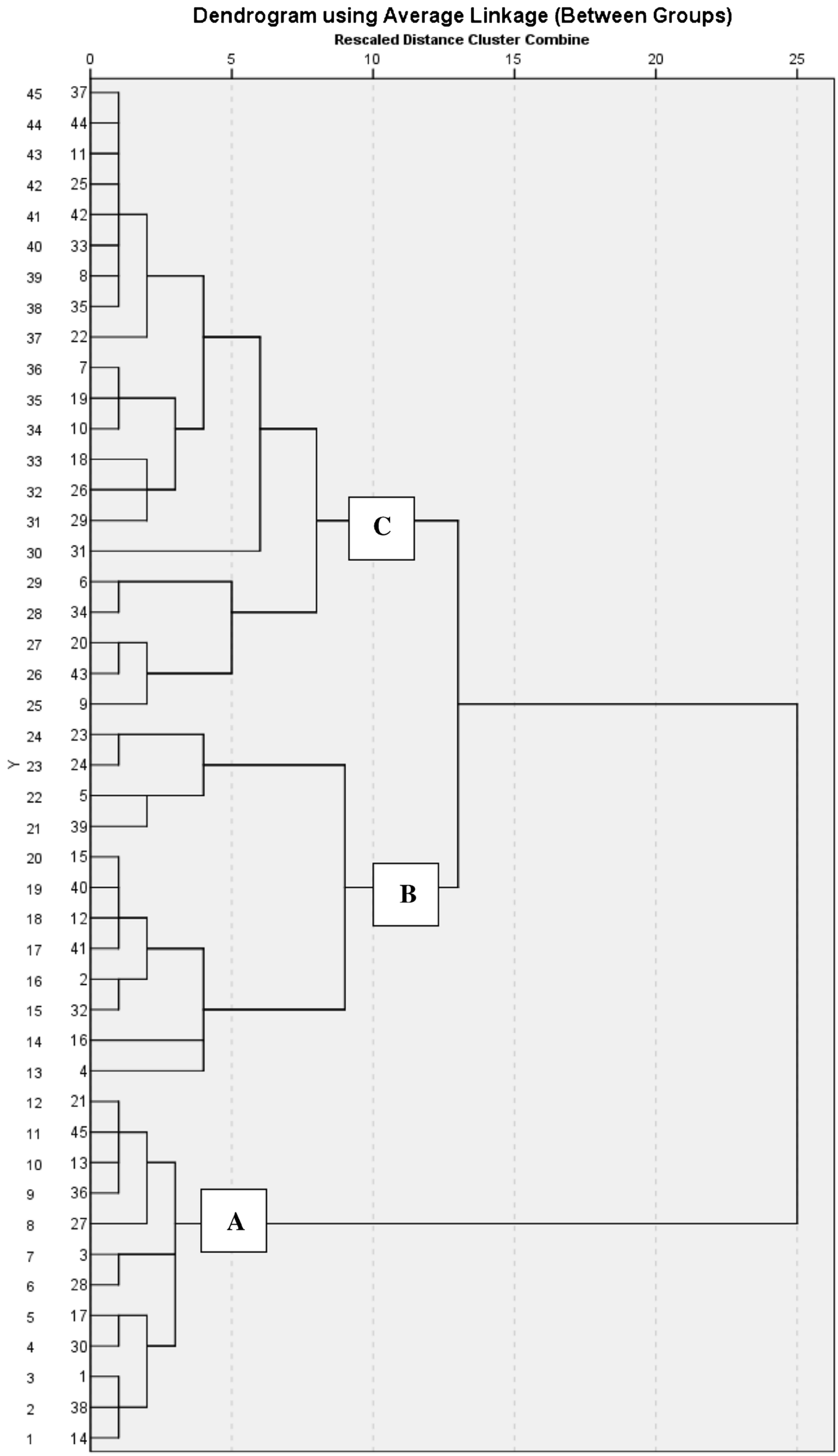

Fig. 5 Dendrogram for hierarchal clusters analyses of 45 samples in surface seawater samples collected from Sharm Al-Kharrar lagoon

Table 3 Correlation matrix among analyzed metals

	Pb	Zn	Cu	Ni	CO	Cd	Cr	As
Pb	1.000							
Zn	0.180	1.000						
Cu	0.143	0.150	1.000					
Ni	0.176	0.150	0.048	1.000				
CO	0.260	0.084	0.120	0.180	1.000			
Cd	0.086	0.300	− 0.162	0.137	− 0.081	1.000		
Cr	− 0.144	− 0.368	0.126	0.109	0.030	− 0.121	1.000	
As	− 0.023	0.039	− 0.218	− 0.174	0.056	− 0.192	− 0.025	1.000

Table 4 Principal component loadings and explained variance for the five components with varimax normalized rotation

	Component			
	1	2	3	4
Zn	0.715	− 0.312	0.117	− 0.216
Pb	0.599	0.215	0.310	0.068
Cr	− 0.415	0.607	− 0.256	0.283
As	− 0.246	− 0.270	0.722	0.261
Cd	0.483	− 0.409	− 0.496	0.251
Co	0.355	0.460	0.476	0.288
Cu	0.243	0.588	− 0.010	− 0.669
Ni	0.473	0.361	− 0.265	0.496
Percent of variance	21.80	17.99	15.51	12.99
Cumulative percent	21.80	39.80	55.30	68.29

Extraction method: principal component analysis

a. Four components extracted

Conclusion

The average levels of HMs in 45 seawater samples from Sharm Al-Kharrar lagoon were in the following order: Ni>Zn>As>Cu>Pb>Co>Cr>Cd. Most of the HMs fluctuated in their distribution pattern without obvious trend. The average values of Pb, Zn, Ni, Cu, and As were mostly higher than those recorded from the average oceanic concentration, Arabian Gulf, Gulf of Aqaba, Red Sea, Mediterranean Sea, and North Atlantic and the Pacific. The possible industrial sources along the Rabigh coast were Arabian cement factory, electric power plant, water supply plant, Aramco company refinery, and Aramco residential area.

This study provides baseline information on the anthropogenic impacts of environmental pollution. Hence, it could be useful for the management and sustainable development of the studied localities. This data can serve as a guideline for future researchers and environmental managers to identify future anthropogenic impacts at the study area with respect to the

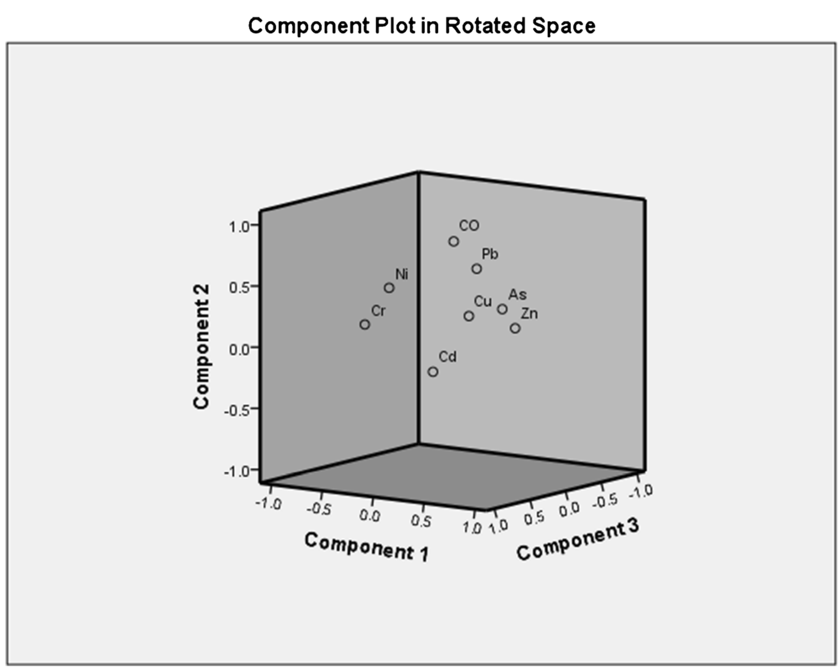

Fig. 6 Two component plots using the varimax method with the Kaiser normalization

studied metals and better assess the need for remediation by monitoring for changes from the existing levels.

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Declarations

Conflict of interest The author(s) declare that they have no competing interests.

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