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Original article

Benthic foraminifera as bioindicators of anthropogenic pollution in the Red Sea Coast, Saudi Arabia

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ABSTRACT

The concentrations of Fe, Mn, Cu, Ni, Zn, Pb, Cr, Co, and Cd were measured in the tests of two foraminiferal species (*Sorites orbibulus* and *Peneroplis planatus*) using ICP-MS to assess the marine contamination. Iron was the most abundant metal (3294 µg/g), followed by Mn (133 µg/g), Cu (34.7 µg/g), Zn (28.3 µg/g), Cr (25 µg/g), Ni (18.9 µg/g), Pb (12.2 µg/g), Co (9.5 µg/g), and Cd (0.85 µg/g). The values enrichment factor, geo-accumulation index, and contamination factor show that the foraminiferal shells are enriched in (Cd, Cu, Pb) posing an ecological risk. Iron shows highest concentration amongst the heavy metals recorded in the study shells, however, shows low concentration in comparison with surrounding areas of Red Sea coast in Saudi Arabia and Egypt. Other heavy metals show higher concentrations than those recorded in Egypt and Saudi Arabia. The elevated heavy metal concentrations in the foraminiferal tests may be attributed to the industrial and urban activities along Yanbu coast.

1. Introduction

The heavy metal incorporation into foraminiferal tests is a good tool for environmental applications, and facilitates monitoring of anthropogenic footprints on the environmental systems (Schmidt et al., 2021). Many attempts used foraminiferal tests to assess the heavy metal contamination in polluted coastal environments (Frontalini and Coccioni, 2008; Frontalini, 2012; Al-Kahtany et al., 2015; Youssef, 2015; Price et al., 2019; AlKahtany et al., 2015; Al-Kahtanya et al., 2020; Sagar et al., 2021; Oron et al., 2021; Barik et al., 2022; Piwoni-Piórewicz et al., 2022). Large benthic foraminifera in the shallow shelf areas have algal symbionts (Hallock, 1999). Large benthic foraminifera are used also as bio-indicators of environmental conditions in many reef settings (Hallock et al., 2003; Gebhardt et al., 2013; Sagar et al., 2021).

The coastal area rapidly changed with the transformation of Saudi Arabia into modern industrial country (Badr et al., 2009). Many studies use sediments and water samples to analyze and monitor the ecosystem of the Red Sea coast's coastal zones (e.g. El-Sorogy et al., 2020; Youssef and El-Sorogy, 2016; Kahal et al., 2020; Youssef et al., 2020; El Zokm et al., 2020).

Few studies have examined the Red Sea's environmental contamination in Saudi Arabia using geochemical analysis of benthic foraminiferal tests for heavy metal levels (e.g. Youssef, 2015; Youssef et al., 2021). The aim of this study is to use the foraminiferal shell as bioindicators for the natural and anthropogenic inputs affect coastal areas along the Red Sea coast in Yanbu.

2. Materials and methods

The study area lies along the Yanbu coastline, Saudi Arabia, between 23° 40́ 33́ N – 38° 29′ 11″ E and 24° 15′ 52″ N – 37° 43′ 03″ E (Fig. 1). The samples were collected from the subtidal zone of the Yanbu coastline (Fig. 1). The grain size analysis shows that the main component of the most samples are silt and sand (El-Sorogy et al., 2021).

Rose Bengal solution (5 g of Rose Bengal in 1 L of ethanol) is used to stain the samples in the field. The standard preparation technique of foraminifera is used; sediment was stored for 15 days before washing with tap water over a 0.625-mm mesh to remove fine silt and clay. The residues were examined under stereo zoom microscope after drying; the selected foraminiferal species were

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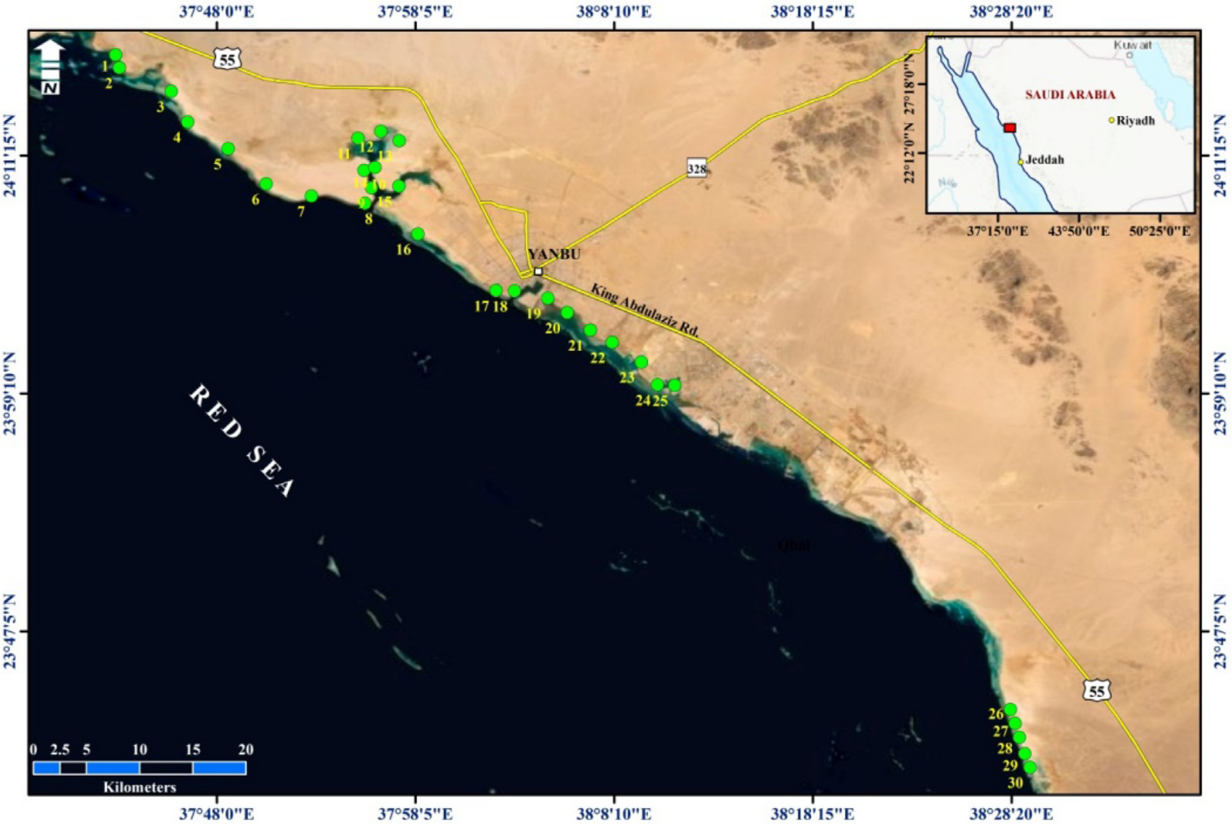

Fig. 1. Location map for the Study Area and Sampling Stations (El-Sorogy et al., 2021).

picked. The taxonomic classification of Hottinger et al. (1993) was used in the identification.

We picked the living tests of *S. orbiculus*, *P. planatus* from 14 samples as follows (1, 3, 4, 5, 7, 8, 13, 14, 15, 17, 18, 19, 20, and 30). We picked ≤0.2 g of each studied species and analyzed them for Iron, manganese, copper, zinc, chromium, nickel, lead, cobalt, and cadmium. The samples were analyzed with ICP-MS (Inuctive Coupled Plasma-Mass Spectrometer, Thermo Fisher scientific, Instrument) in central laboratory college of science (CLCS) King Saud University, Riyadh, KSA. Each sample was analyzed in three replicates. Digestions of samples were performed on Topwave Analytik Jena microwave digestion system using ultra-pure Nitric acid (HNO3, 63 %), Hydrogen Fluoride (40 %) and Hydrochloric acid (HCl, 36 %). About 0.1 gm sample was put into the DAP 60 digestion vessels of 60 ml capacity. Add 6 ml Hydrochloric acid, 2 ml nitric acid and 2 ml Hydrochloric acid then shake the mixture carefully. A blank without the sample was also carried out through the complete procedure. 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 method) to determine Euclidean distances. Principal component analysis (PCA) was applied to identify possible the sources of the metals in the studied sediments.

3. Results

The most abundant heavy-metal (Table 1 and Figs. 2, 3) was Fe (3294 μg/g), Mn (133 μg/g), followed by Cu (34.7 μg/g), Zn (28.3 μg/g), Cr (25 μg/g), Ni (18.9 μg/g), Pb (12.2 μg/g), Co (9.51 μg/g), and Cd (0.85 μg/g). The HM concentrations in sediments of the studied samples show the same trend (El-Sorogy et al., 2021).

The average concentration of Fe (Table 1; Fig. 2) was lower than the average value recorded in the shells of *S. orbiculus, P. planatus* from Sharma (Youssef et al., 2021), also lower than the average values recorded in Jeddah (Youssef, 2015), While the recorded values higher than those reported at Egyptian Red Sea coast (e.g. Youssef et al., 2017). *S. orbiculus* shows the highest concentration of Mn (195 μg/g), where *P. planatus* shows the lowest value (104 μg/g) in samples 4 and 5 respectively (Table 1; Fig. 2). Mn shows higher concentration than was recorded in Jeddah and Egyptian Coast (e.g. Madkour and Ali, 2009; Youssef, 2015). El-Sorogy et al. (2021) reported 192 μg/g of Mn in the sediments, may be due to terrestrial influx by wadies and aeolian deposition (Bantan et al., 2020), or human activities. The Cu bioaccumulation in foraminifera record average value 34.7 μg/g, where the highest value (45.5 μg/g) was recorded in in sample 4 and the lowest value (28.7 μg/g) was recorded in in *S. orbiculus* sample 20 (Table 1; Fig. 2). The comparison between our average Cu levels and those in other sites was shown in Table 3), where it is higher than south Saudi coast (Youssef, 2015) and lower than northern Saudi coast and Egyptian coast (e.g. Mansour et al., 2005; Youssef et al., 2021). The average concentration of Zn in foraminiferal tests in Yanbu Coast is 28.3 μg/g. The highest value (37.2 μg/g) was recorded in *S. orbiculus* in sample 4 where the lowest value (20.8 μg/g) was reported in *P. planatus* in sample 7 (Table 1; Fig. 2). Sediments show 80.4 μg/g average concentration of Zn (El-Sorogy, et al., 2021). Zinc remains in the marine environment for long time after precipitate with calcium carbonate (Rothenstein et al., 2012).

Cr concentration record highest value in *S. orbiculus* (37.2 μg/g) of sample 4, while the lowest (20.7 μg/g) was in *P. planatus* in

Table 1
Concentrations of heavy metals in the living foraminifera tests of the sediment samples investigated.

S. No	Species	Lat.	Long.	Fe	Mn	Cu	Zn	Cr	Ni	Pb	Co	Cd
Y-1	*S. orbiculus*	24° 15′ 52″	37° 43′ 03″	3000	150	34.8	30.8	21	18	11.9	9.8	1.1
	P. planatus			3010	165	35.2	31.1	21.6	17.6	11.3	10.2	1
Y-3	*S. orbiculus*	24° 14′ 31″	37° 45′ 41″	3205	165	37.2	29.5	23.9	17.6	11.5	10	1
	P. planatus			3003	170	36.8	31	24.1	17	12.5	10.2	0.9
Y-4	*S. orbiculus*	24° 12′ 58″	37° 46′ 31″	3817	195	45.5	37.2	37.2	20.8	9.2	11.4	0.9
	P. planatus			3750	193	44.8	36.8	35.5	20.6	9.8	12	0.7
Y-5	*S. orbiculus*	24° 11′ 36″	37° 48′ 34″	2080	105	32.8	23.6	26.6	21.3	13	7.2	0.7
	P. planatus			2003	104	31.3	24	25.2	20.1	12.9	8	1.2
Y-7	*S. orbiculus*	24° 09′ 12″	37° 52′ 48″	2550	109	32.3	21.4	26.3	19.5	14.1	7.9	0.9
	P. planatus			1483	107	34.8	20.8	25.5	20.1	13.8	8	0.5
Y-8	*S. orbiculus*	24° 08′ 50″	37° 55′ 31″	3995	129	37.3	33.6	21.1	21	13.2	11.2	0.6
	P. planatus			4013	127	36.8	32.4	20.8	20.2	12.8	11	0.6
Y-13	*S. orbiculus*	24° 12′ 01″	37° 57′ 15″	4150	125	33.9	31.9	25.3	18	12.1	9.9	0.9
	P. planatus			4061	127	32	33	24.5	18.8	11.8	10.2	0.8
Y-14	*S. orbiculus*	24° 10′ 39″	37° 56′ 01″	3497	131	35.8	31.2	25.8	18.2	12.4	8.6	0.6
	P. planatus			3605	135	36.3	31	26.2	18	12	8.3	0.9
Y-15	*S. orbiculus*	24° 09′ 42″	37° 57′ 14″	2807	135	33	31.2	22.8	16.7	13.2	9.4	0.8
	P. planatus			4101	137	31.7	29.8	23	16.5	13	9	0.7
Y-17	*S. orbiculus*	24° 04′ 24″	38° 02′ 10″	4001	133	36.4	29.2	24.5	17.6	11.8	9.6	0.8
	P. planatus			3975	131	36	28.8	24	17.4	11.5	9.2	0.6
Y-18	*S. orbiculus*	24° 04′ 23″	38° 03′ 06″	3550	111	34	24.2	29	20.2	11.6	11.6	0.9
	P. planatus			3597	109	33.4	22.9	30.1	20	10.2	11.2	1
Y-19	*S. orbiculus*	24° 04′ 01″	38° 04′ 48″	2805	110	32	31	23	17.5	11.8	9	1.3
	P. planatus			3580	108	29	20.9	21.2	18.5	12	8.5	1
Y-20	*S. orbiculus*	24° 03′ 17″	38° 05′ 47″	3970	135	28.7	24	25.3	16.5	11.7	10	1.2
	P. planatus			4000	131	33.7	25	21.1	21	13	7.8	0.8
Y-30	*S. orbiculus*	23° 40′ 33″	38° 29′ 11″	2560	125	31.5	21.3	24.2	19.6	14.1	8	0.7
	P. planatus			2075	127	33.3	24	20.7	21.3	13	9.2	0.6
Average				3294	133	34.7	28.3	25	18.9	12.2	9.51	0.85
Maximum				4150	195	45.5	37.2	37.2	21.3	14.1	12	1.3
Minimum				1483	104	28.7	20.8	20.7	16.5	9.2	7.2	0.5

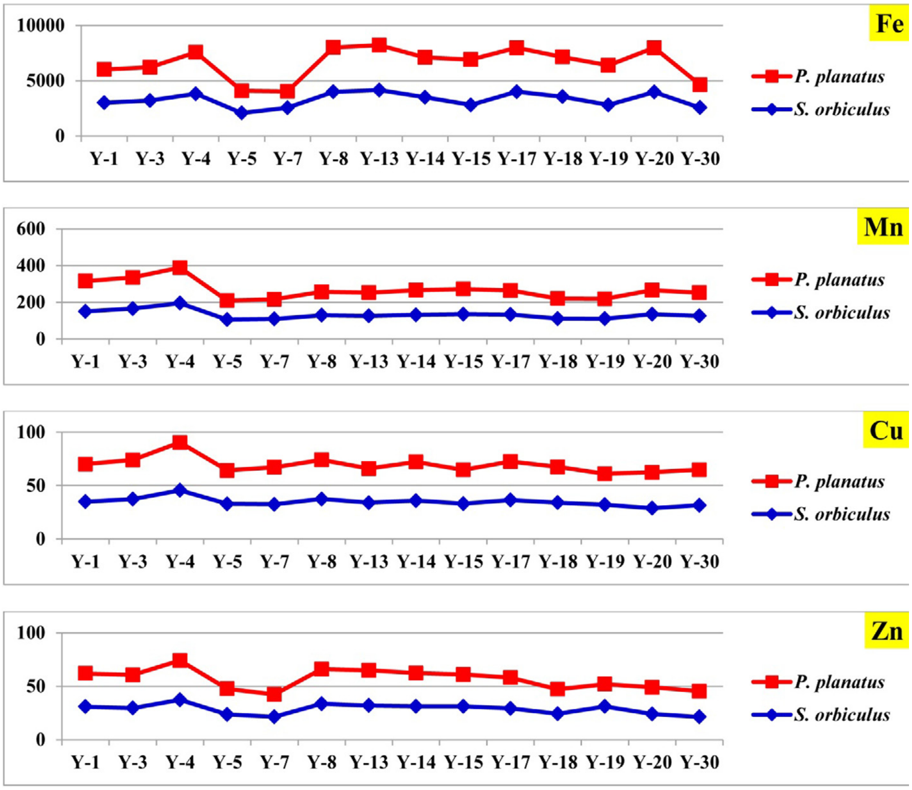

Fig. 2. Heavy-metal concentrations of foraminiferal tests of the study coastal area; Fe, Mn, Cu, and Zn.

sample 30 (Table 1; Fig. 3). The comparison of the average concentration of Cr with the different areas along Red Sea coast (e.g. Youssef, 2015; Youssef et al., 2021) indicate low average value, while it nearly around the background concentration in uncontaminated sediment (Oana, 2006). The average concentration of Ni in the shells is 18.9 μg/g and the values range from 16.5 μg/g to

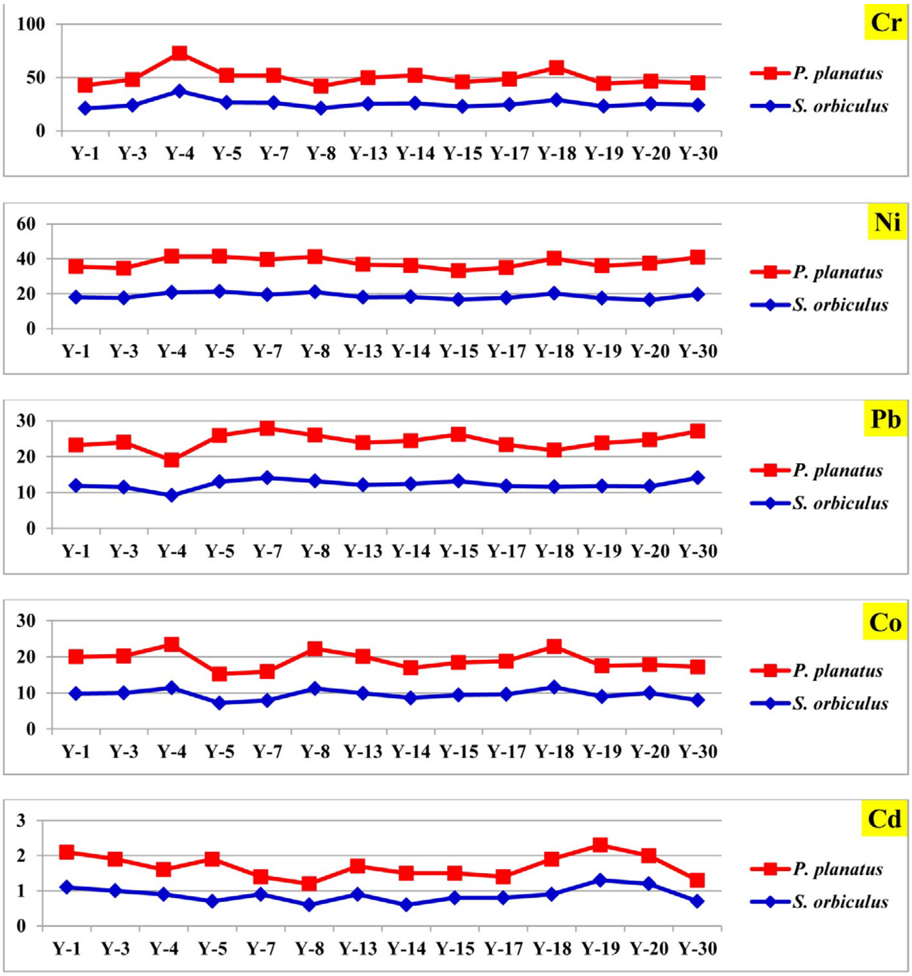

Fig. 3. Heavy-metal concentrations of foraminiferal tests of the study coastal area; Cr, Ni, Pb, Co, and Cd.

21.3 μg/g in *S. orbiculus* in samples 20 and 5 respectively (Table 1; Fig. 3). High average value of Ni was recorded comparing to that recorded on the Egyptian and Saudi coast (Table 2). The average value of Ni concentrations in sediments was 23.5 μg/g (El-Sorogy et al., 2021). Anthropogenic and industrial discharge may be the possible sources for Ni, however De Carlo and Spencer (1995) suggest little importance for anthropogenic contribution for Ni to sediment. The concentration of Pb ranges from 9.2 μg/g in *S. orbiculus* of sample 4 to 14.1 μg/g in sample 30 (Table 1; Fig. 3). In comparison with the Pb concentration with other areas, it is significantly lower than the reported values from Egyptian coast, and higher than those recorded from Jeddah (Table 2). Industrial origin of lead is the probable source (Abu-Zied et al., 2013; Youssef, 2015). The lowest value of Co (7.2 μg/g) was recorded in *S. orbiculus* of sample 5, the highest value (12 μg/g) was recorded in *P. planatus* in sample 4 (Table 1; Fig. 3). The concentration of Cd was relatively low. The lowest value (0.5 μg/g) is recorded in *P. planatus* in samples 7, while the highest value (1.3 μg/g) is recorded in *S. orbiculus* of sample 19 (Table 1; Fig. 3). The average concentration of Cd is 0.85 μg/g. In comparison with the surrounding areas low average value was reported (Table 2). Cd concentration shows 0.89 μg/g average value in sediments samples.

4. Discussion

The shells exhibit enrichment in certain elements with ecological risk values for EF, Igeo, and CF (Table 3). For the calculation of different indicators please see supplementary table. Cd record the highest average value of EF (>10), indicating possible source of

Table 2
The Yanbu coast's mean heavy-metal concentrations were compared to those in other nearby regions using foraminiferal shells.

Location	*Fe*	*Mn*	*Cu*	*Ni*	*Zn*	*Pb*	*Cr*	*Co*	*Cd*	References
Yanbu, Red Sea	3294	133	34.7	28.3	25	18.9	12.2	9.51	0.85	Present study
Sharma-Maqnah, Red Sea	3367	142	30.4	13.9	24.1	6.95	20.9	4.6	0.8	Youssef el al., 2021
Red Sea Coast, Egypt	901.2	–	5.4	19.9	13.8	9.4	8.6	2.5	0.3	El-Kahawy et al., 2020
Red Sea Coast, Egypt	2098	124.1	7.3	11.5	11.1	6.7	–	2.6	0.7	Youssef et al., 2017
South Jeddah, Saudi Arabia	7182	27.6	8.7	23.3	14.9	22.9	38.5	–	0.09	Youssef, 2015
Salman Bay, Saudi Arabia	7698	14.3	8.2	24.2	13.3	10.8	36.24	–	0.1	
Coastal lagoons, Red Sea, Egypt	1115.3	35.02	17.5	28.2	18.2	23.9	–	–	1.5	Madkour and Ali, 2009
Red Sea coast, Egypt	760	43.3	46.9	33.9	22	28.5	–	–	1.6	Mansour et al., 2005

Table 3
Minimum, maximum, and average values of single element pollution indices for the investigated HMs; EF, Igeo, CF.

Metals	Species	EF		Igeo	CF					
		Min	Max	Aver	Min	Max	Aver	Min	Max	Aver
Fe	*S. marginalis*	–	–	–	−5.09	−4.09	−4.46	0.04	0.09	0.07
	P. planatus	–	–	–	−5.58	−4.11	−4.48	0.03	0.09	0.07
Mn	*S. marginalis*	1.67	2.86	2.30	−3.60	−2.71	−3.28	0.12	0.23	0.16
	P. planatus	1.68	4.01	2.41	−3.62	−2.72	−3.28	0.12	0.23	0.16
Cu	*S. marginalis*	7.58	16.54	11.44	−1.23	−0.57	−0.97	0.64	1.01	0.77
	P. planatus	8.11	24.61	12.04	−1.22	−0.59	−0.97	0.64	1.00	0.77
Zn	*S. marginalis*	3.00	5.64	4.42	−0.87	−0.32	−0.59	0.22	0.39	0.30
	P. planatus	2.90	6.97	4.46	−0.90	−0.33	−0.62	0.22	0.39	0.29
Cr	*S. marginalis*	2.77	6.71	4.21	−0.89	−0.32	−0.71	0.23	0.41	0.28
	P. planatus	2.72	9.02	4.27	−0.90	−0.36	−0.74	0.23	0.39	0.27
Ni	*S. marginalis*	2.88	7.11	4.15	−1.13	−0.87	−1.00	0.24	0.31	0.28
	P. planatus	2.79	9.41	4.46	−1.13	−0.87	−0.99	0.24	0.31	0.28
Pb	*S. marginalis*	5.69	14.75	9.29	−0.49	−0.06	−0.21	0.46	0.71	0.61
	P. planatus	6.17	21.96	9.69	−0.43	−0.08	−0.22	0.49	0.69	0.61
Co	*S. marginalis*	5.93	8.60	7.35	−1.98	−1.30	−1.59	0.38	0.61	0.50
	P. planatus	4.84	13.40	7.69	−1.87	−1.25	−1.60	0.41	0.63	0.50
Cd	*S. marginalis*	23.63	72.92	44.06	0.98	1.75	1.34	2.00	4.33	2.95
	P. planatus	23.52	94.26	41.80	0.80	1.67	1.25	1.67	4.00	2.69

pollutants from urban, industrial activities and tourism projects in the coast. The average values for Cu and Pb were >5; and for Zn, Cr, and Co they were >2, indicating natural origins. Cd had the highest degree of enrichment (EF = 44 and 41 in *S.orbiculus* and *P. planatus* respectively. The lowest reported value of EF is for Mn < 2 indicate no enrichment to minor enrichment (Youssef et al., 2020). The average CF value for Cd indicated a moderate contamination (CF = 2.95 and 2.69 at *S. orbiculus* and *P. planatus*, respectively). The average CF value for the rest of the heavy metals indicated low contamination factor. The average Igeo value of Cd (Igeo = 1.34 and 1.25 in *S. orbiculus* and *P. planatus* respectively) indicated that the shells were moderately polluted, where are unpolluted for the rest of heavy metals. Q mode HCA subdivided the studied heavy metals into two different clusters (Fig. 4). The first cluster contains Fe, while the second cluster includes the rest of the recorded heavy metals. The Pearson's correlation shows high positive correlations between certain element pairs, for example: Fe-Zn (r = 512), Fe-Co (r = 0.523), Mn-Cu (r = 0.763), Mn-Zn (r = 0.706), and Mn-Co (r = 0.533). Cu-Zn (r = 0.696), Cu-Cr (r = 0. 036), and Cu-Co (r = 0.554). Zn-Co (r = 0.584). In contrast, there are negative correlations between Fe-Pb and Ni (r = − 0.466, −0.248), Pb-Cr, Co (−0.637, −0.674). See (Table 4) for detailed correlations between the studied heavy metals. The correlations of Zn and Co with Fe suggest that those metals were strongly associated with the Fe oxy-hydroxides phase, and they have a common source (Reitermajer et al., 2011). The positive correlation of Cu, Zn, and Co with Mn is a good proxy for terrigenous material (El-Sorogy et al., 2021). The extraction method of the principal component analysis (PCA) subdivided the variables into three components, accounting 45.37 %, 18.81 %, and 13.29 % of the total variance, respectively (Table 5). The first component presents significant positive loading for Fe, Mn, Cu, Zn, Cr, and Co (0.562, 0.823,

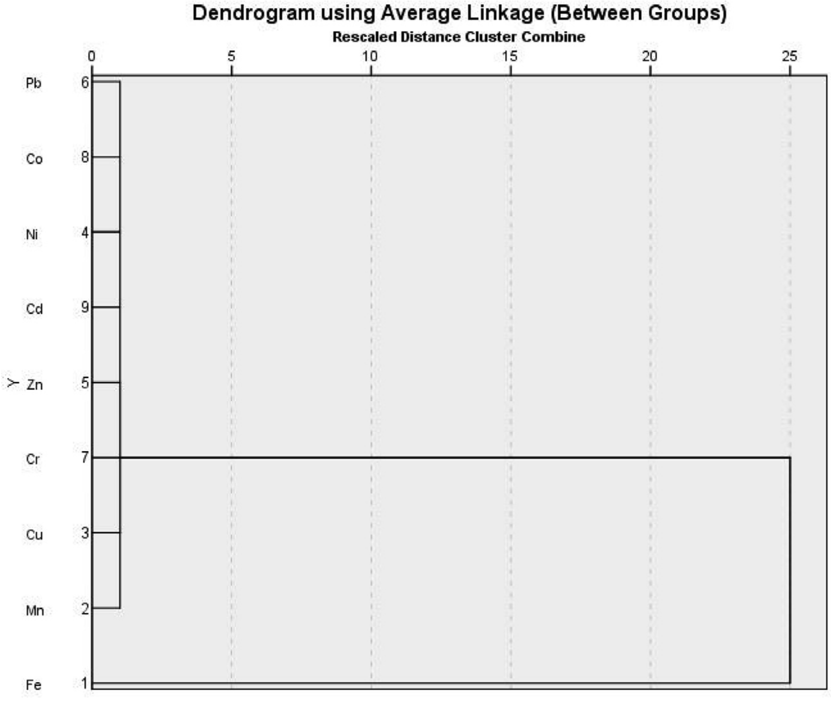

Fig. 4. Dendrogram of 9 metals in bottom sediment samples taken from the North Red Sea coast using hierarchal cluster analysis.

Table 4
Correlation coefficients (r) of heavy metals of marine sediment samples from Yanbu area; A) in whole samples, B) in *S. marginalis*, in C) *P. planatus*.

	Fe	Mn	Cu	Ni	Zn	Pb	Cr	Co	Cd
Fe	1								
Mn	0.307	1							
Cu	0.231	**0.763****	1						
Ni	−0.248	−0.150	0.274	1					
Zn	**0.512****	**0.706****	**0.696****	−0.186	1				
Pb	−0.466*	−0.575**	−0.564**	0.042	−0.502**	1			
Cr	0.103	0.392*	**0.603****	0.288	0.237	−0.637**	1		
Co	**0.523****	**0.533****	**0.554****	0.042	**0.584****	−0.674**	0.391*	1	
Cd	−0.012	−0.005	−0.293	−0.359	−0.061	−0.320	0.028	0.044	1

Table 5
Extraction method: Principal component analysis; highly positive loadings are in bold.

	Component		
	1	2	3
Fe	**0.562**	−0.398	−0.323
Mn	**0.823**	−0.040	−0.134
Cu	**0.846**	0.415	−0.102
Ni	−0.001	**0.855**	0.201
Zn	**0.808**	−0.148	−0.372
Pb	−0.830	0.167	−0.403
Cr	**0.624**	0.362	**0.530**
Co	**0.803**	−0.073	0.014
Cd	0.004	−0.665	**0.664**
% of Variance	45.371	18.810	13.287
Cumulative %	45.371	64.181	77.468

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

0.846, 0.808, 0.624, 0.803, respectively). The second component presents positive loading for Ni (0.855). The third component presents high positive loading for Cr and Cd (0.530 and 0.664). The moderately severe enriched HMs (Fe, Mn, Cu, Cr, and Co) with positive loading in the first component may have significant anthropogenic origins connected to urbanization, industrial, and agricultural activities (El-Sorogy et al., 2021). Agricultural activities marked by Cd content (Kelepertzis, 2014; Kahal et al., 2020). A varimax method with Kaiser Normalization was used to explain these components. Corresponding to the results from the PCA the HMs in the component plot was distributed into three groups, (Fig. 5).

5. Conclusion

The concentrations of heavy metals (HM) Fe, Mn, Cu, Ni, Zn, Pb, Cr, Co, and Cd were measured in the two most common species of benthic foraminifera *S. orbibulus* and *P. planatus*. The analyses of HMs in the shells of *S. orbiculus* and *P. planatus* of 14 surface coastal sediments from Yanbu coastline, Saudi Arabia indicated the following concentrations of heavy metals: Fe (3294) > Mn (133) > Cu (34.7) > Zn (28.3) > Cr (25) > Ni (18.9) > Pb (12.2) > Co (9.51) > Cd (0.85). Among the heavy metals detected in the study area, the foraminiferal tests reveal the highest concentration of Iron. The concentrations of heavy metals in Yanbu are higher than in other regions along the Red Sea coast in Saudi Arabia and Egypt. The HM concentrations along the Yanbu Coast could be attributable to natural sources or anthropogenic resources from industrial and urban activities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

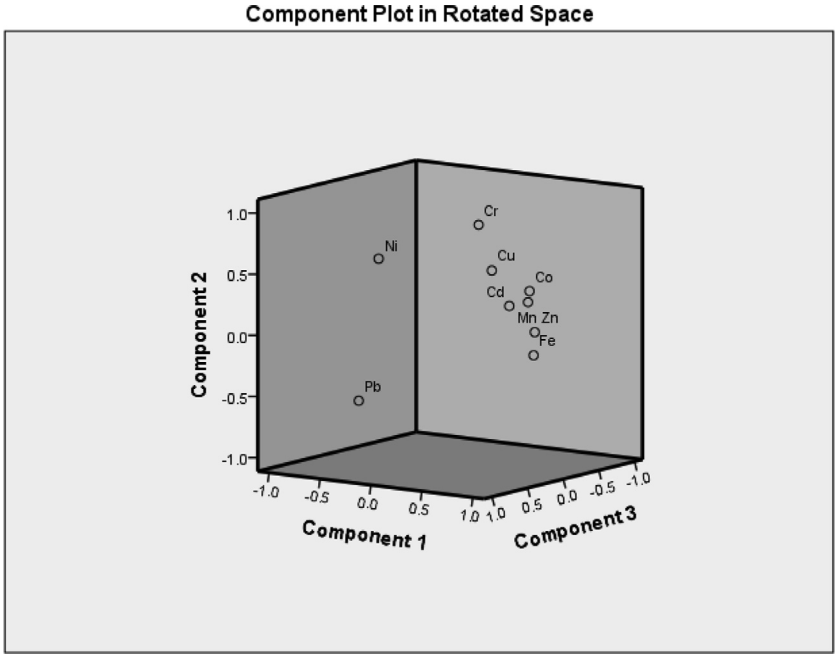

Fig. 5. Three component plots using the varimax method with Kaiser Normalization.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jksus.2022.102383.

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