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Molluscan assemblage as pollution indicators in Al-Khobar coastal plain, Arabian Gulf, Saudi Arabia

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ABSTRACT

To assess the anthropogenic sources of pollution along Al-Khobar coastal area, Saudi Arabian Gulf, bivalve and gastropod shells were collected from 15 sites for Al, Sr, Ni, Fe, Hg, Zn, Cr, Se, Co, Cd, Cu, As, Mn and Pb analyses using Inductively Coupled Plasma Mass Spectrometer. The molluscan assemblage was composed of shallow sandy bottom in-fauna, and hard rocky shore epi-fauna. Results indicated a decrease in the frequency of the molluscan assemblage and an increase in the abundance of some taxa and the average values of some heavy metals in the gastropods and bivalve shells in comparison with those in worldwide seas and gulfs. Correlation analyses and principal component analysis classified metals in the studied molluscans into two groups. The abundance and frequency of the molluscan assemblage along Al-Khobar coastline may be attributed to their mode of life, tidal currents, and pollutants from desalination process, oil exploration, transportation, and industry and sewage discharges.

1. Introduction

Coastal areas are exposed to a wide range of anthropogenic effects resulting from landfilling, oil spills, desalination plants, fishing boats, solid rubbish, sewage, and other human activities. Sewage discharges are among the most common anthropogenic impacts on rocky shores, resulting in enrichment of organic nutrient and trace elements from industrialized or urbanized areas (Crowe et al., 2000; Cabral de Oliveira, 2013). Therefore, the analysis of trace elements is an essential task to assess the potential environmental and human health risk associated with sewage discharges (Maceda-Veiga et al., 2013). Using remote sensing technology, Loughland et al. (2012) observed changes from a relatively pristine to a highly developed coastal zone because of economic growth expansion along the coastal areas of the Arabian Gulf.

Many studies have been conducted to assess the coastal areas along the Saudi Arabian Gulf using heavy metal analyses in coastal sediments and seawater samples (e.g., El-Sorogy et al., 2016a, 2018; Alharbi and El-Sorogy, 2017; Alharbi et al., 2017; Al-Kahtany et al., 2018; Alharbi and El-Sorogy, 2019). These studies revealed higher enrichment factors in many heavy metals such as Sr, Cr, Zn, Cu, V, Hg, Mo, and Se, indicating anthropogenic pollutants from oil spills, desalination plants, industrial and sewage effluents, particularly from Al-Jubail industrial city.

The distribution of organisms in the intertidal zone is influenced by several physical and biological variables (Murray et al., 2006). Owing to the rapid industrial development at the Arabian Gulf coast, and being a shallow and semi-enclosed basin, the impact of intensive anthropogenic activities on its coastal environment may be amplified, and become the source of pollution to marine organisms (Pourang et al., 2005). Benthic invertebrates are used to assess the status of marine ecosystems worldwide. They have been proved to respond to several types of anthropogenic impacts, from physical disturbances to chemical contamination and nutrient enrichment (Teixeira et al., 2010; Cabral de Oliveira, 2013; El-Sorogy et al., 2013, 2016a, b; El-Sorogy and Youssef, 2015; Youssef et al., 2015). The main purpose of this study is to document the molluscan assemblage along the Al-Khobar coastline in the Saudi Arabian Gulf, and to use this assemblage as pollution indicators to assess the rate of pollution along the studied coast.

2. Material and methods

The Al-Khobar City is located in the eastern province of Saudi Arabia (Fig. 1). The Al-Khobar coastline is classified into sandy-dominated, biogenic-dominated and artificial and natural rocky shores (Figs. 2 and 3). Gastropod and bivalve shells were collected from the intertidal zone of 15 localities along the studied coast (Fig. 1). For

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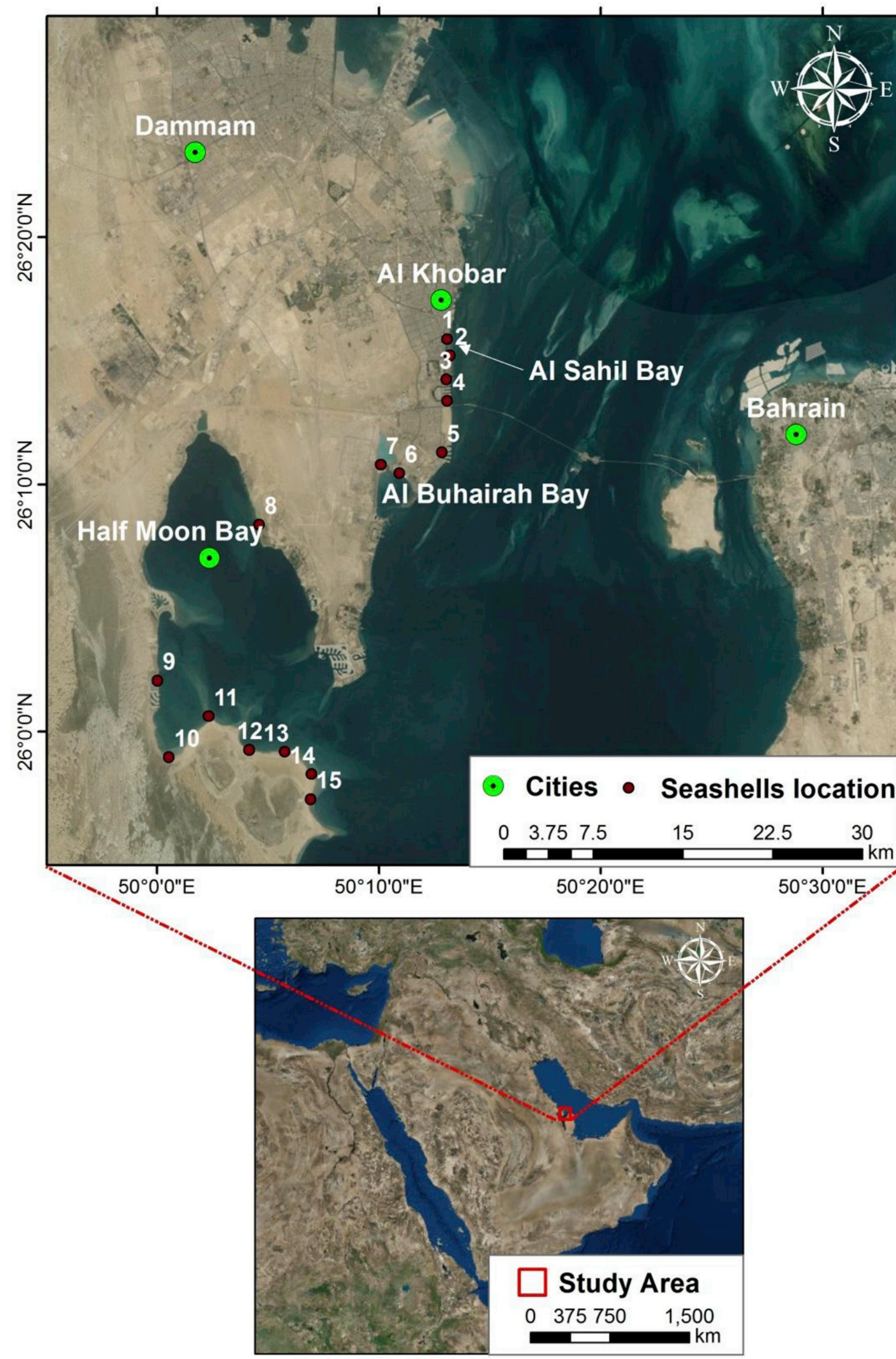

Fig. 1. Location map of the Al-Khobar coastal plan.

Fig. 2. A, Artificial rocky shore inhabited by *Planaxis sulcafus* and other cemented gastropods (locality 3). B, Sandy dominated shore with bivalve accumulation, mostly veneriids (locality 4). C, Sandy dominated shore with gastropods accumulation, mostly cerithids (locality 4).

heavy metal analysis, 15 *Lunella coronata* (Gmelin, 1791) and *Barbatia parva* (Sowerby, 1833) were selected to determine As, Fe, Al, V, Zn, Cr, Co, Cd, Hg, Pb, Ni, Sr, Mn and Cu levels using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS): NexION 300D (PerkinElmer, USA). The collected molluscs were cleaned and identified using previous literatures and monographs. Pearson's correlation coefficients were calculated using SPSS program and principal component analyses (PCA) were performed to establish the relationship between metals in the studied samples. The materials were deposited in the Museum of the Geology Department, College of Science, King Saud University (MGD-CSc-KSU-1-85).

3. Results

3.1. Taxonomic composition and distribution of the assemblage

Table 1 shows the identified gastropods and bivalves, their distribution, modes of life, and preferable substrates throughout the studied coastline. A total of 29 gastropod species were identified, belonging to 23 genera and 17 families. The highest abundance of gastropods was recorded in the Cerithiidae (*Cerithium caeruleum, C. adansonii, Clypeomorus persicus*), Potamididae (*Potamides conicus*), Trochidae (*Calliostoma fragum, Trochus erithreus, Mondonta nebulosi, Clanculus pharaonius*) and Turbinidae (*Lunella coronata*) families. The abundance of the other families and their related genera and species, ranging from low to moderate abundances were recorded in the remaining localities. Gastropods of family Trochidae were the most diverse (4 species) followed by those of Cerithiidae, Cypraeidae and Muricidae (3 species for each).

In addition, 40 bivalve species were identified, belonging to 32 genera and 16 families. The highest abundance of bivalves was recorded in the Veneridae (*Bassina calophylla, Circe intermedia, Circenita callipyga, Amiantis umbonella, Gafrarium pectinatum, Callista florida,*

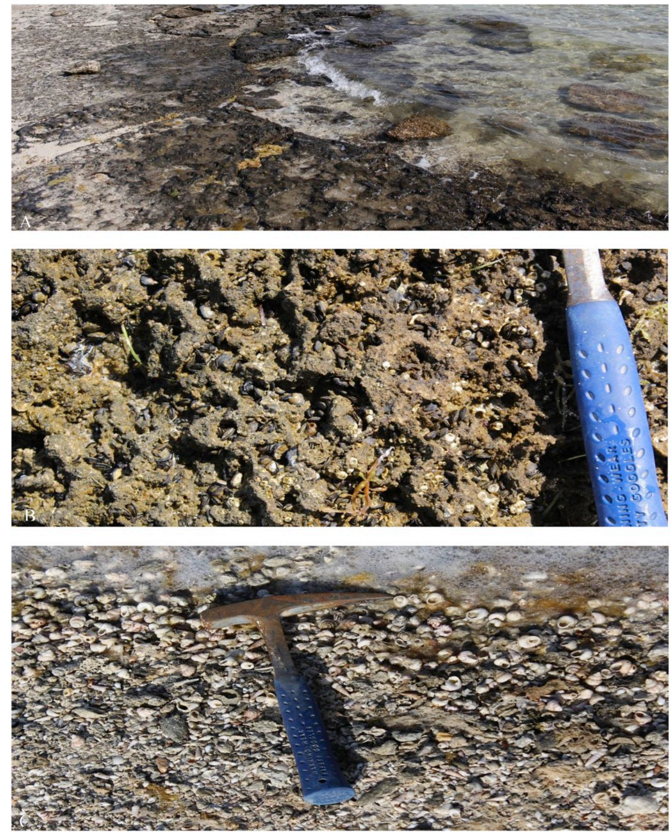

Fig. 3. A, Natural rocky shoe made up of consolidated sands (locality 11). B, Living bivalves, mostly mytillids cemented by byssus, infilling grooves in natural rocky shore (locality 11). C, Accumulation of gastropods, mostly naticids and neriniids on natural rocky shores (locality 12).

Dosinia tumida, Marcia flammea), Arcidae (*Arca avellana, Barbatia. parva, B. setigera, Anadara antiquata*), Pteriidae (*Pinctada nigra, P. margaritifera, P. radiata*), and Lucinidae (*Ctena diavergens, Divalinga arabica, Anodontia edentula*). The other families and their related genera and species, ranging from low to moderate abundances, were recorded in the remaining localities. The Veneridae family was the most diverse one (8 species) followed by Arcidae (4 species). Glycymerididae, Pteriidae, Lucinidae and Cardiidae were represented by 3 species.

3.2. Concentration of metals in seashells

Table 2 shows the Fe, V, Ni, Zn, Cr, Co, Cd, Cu, Pb, As, Hg, Sr, Mn and Al in *Lunella coronata* and *Barbatia parva*. Fig. 4 shows the spatial distribution of these heavy metals in the two selected species throughout the studied localities. Fe was the most abundant heavy metal (average 1966.38 μg/L) followed by Sr (1372.75 μg/L), As (89.96 μg/L), Al (89.75 μg/L), Ni (25.11 μg/L), V (19.86 μg/L), Zn (4.79 μg/L), Mn (3.67 μg/L), Cu (3.49 μg/g), Cr (2.00 μg/L), Pb (1.41 μg/g), Co (1.26 μg/L), Hg (0.90 μg/L), and Cd (0.27 μg/L).

The highest value of Cu (5.1 μg/g) was recorded at locality 14 in *L. coronata* and the lowest (1.6 μg/g) at locality 13 in *B. parva*. Table 3 shows that the average values of Cu were lower than those recorded off the coasts of Indonesia and Malaysia (Amin et al., 2006), the Red Sea coast (Madkour, 2005), and the Arabian Gulf (de Mora et al., 2004). It was higher than the values recorded in Tarut Island, Arabian Gulf (El-Sorogy and Youssef, 2015), the south-east coast of India (Ponnusamy et al., 2014), North Adriatic Sea (Martincié et al., 1984), and Nile branch of Egypt (Lotfy, 2006). The highest values of Pb (1.81 ìg/g) was recorded at localities 10 and 14 in *L. coronata* and the lowest one (0.98 μg/g) at locality 7 in *B. parva*. The average value of Pb was lower

Table 1
The identified molluscan assemblage and its modes of life and distribution throughout the studied coastline.

Family	Species	Substrate		Life mode		Studied localities														
		Hard	Soft	Epi-faunal	In-faunal	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gastropoda																				
Fissurellidae	*Diodora funiculata*	x		x				x	x							x	x	x		
	D. rueppellii	x		x				x	x							x	x	x		
Trochidae	*Calliostoma fragum*	x			x			x	x							x	x	x		
	Trochus erithreus	x		x				x	x							x	x	x		
	Mondonta nebulosa	x		x				x	x							x	x	x		
	Clanculus pharaonius	x			x			x	x							x	x	x		
Turbinidae	*Lunella coronata*	x		x				x	x							x	x	x		
Neritidae	*Nerita albicilla*	x		x				x	x							x	x	x		
Planaxidae	*Planaxis sulcatus*	x		x				x	x							x	x	x		
Cerithiidae	*Cerithium caeruleum*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	C. adansonii		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Clypeomorus persicus		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Potamididae	*Potamides conicus*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Turritellidae	*Turritella cochlea*		x		x	x				x				x						
Naticidae	*Natica cernica*		x		x	x				x				x						
Cypraeidae	*Cypraea annulus*	x		x				x								x		x		
	C. kieneri	x		x				x								x		x		
	C. macandrewi	x		x				x								x		x		
Muricidae	*Hexaplex kuesterianus*	x		x				x								x		x		
	Cronia konkanensis		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Thais tissoti		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Nassariidae	*Nassarius persicus*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	N. fredericì		x		x		x							x						
Olividae	*Ancilla castanea*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Mitridae	*Mitra subruppeli*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Conidae	*Conus boschorum*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	C. milesi		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Bullidae	*Bulla ampulla*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Siphonariidae	*Siphonarìa belcheri*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Bivalvia																				
Arcidae	*Arca avellana*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Barbatia parva		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	B. setigera		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Anadara antiquata		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Glycymerididae	*Glycymeris arabica*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	G. livida		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	G. pectunculus		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Mytiloidea	*Brachidontes variabilis*	x		x				x								x		x		
	Madiolus barbatus	x		x				x								x		x		
Pteriidae	*Pinctada nigra*	x		x				x								x		x		
	P. margaritifera	x		x				x								x		x		
	P. radiata	x		x				x								x		x		
Ostreidae	*Alectryonella plicatula*	x		x																
Plicatulidae	*Plicatula australis*	x		x				x								x		x		
Pectinidae	*Chlamys livida*	x		x																
Spondylidae	*Spondylus marisrubri*	x		x				x								x		x		
	S. hystrix	x		x				x								x		x		
Lucinidae	*Ctena diavergens*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Divalinga arabica		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Anodontia edentula		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Carditoidea	*Beguina gubernaculum*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Cardites bicolor		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Chamidae	*Chama asperella*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Ch. reflexa		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Cardiidae	*Vepricardium exochum*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Acrosterigma assimile		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	A. lacunosa		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Mactridae	*Mactra lilacea*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	M. rochebrunei		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Psamobiidae	*Asaphis violascens*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Hiatula mirbahensis		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Trapezidae	*Trapezium sublaevigatum*		x		x	x	x		x	x	x	x	x	x	x		x		x	x
Veneridae	*Bassina calophylla*		x		x	x	x	x				x								
	Circe intermedia		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Circenita callipyga		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Amiantis umbonella		x		x	x	x													
	Gafrarium pectinatum		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Callista florida		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Dosinia tumida		x		x	x	x		x	x	x	x	x	x	x		x		x	x
	Marcia flammea		x		x	x	x		x	x	x	x	x	x	x		x		x	x

Table 2
Heavy metal concentrations (μg/g) in *Lunella coronata* (L) and *Barbatia parva* (B) in the study area (n = 11).

S. N.	Species	Al	As	Sr	Ni	Cd	Co	Cr	Cu	Fe	Mn	Hg	Pb	V	Zn
1	L	80	73.4	922	24.8	0.18	1.24	1.6	2.8	1866	3.9	0.8	1.23	18.1	7.5
	B	102	110.2	1668	26.3	0.42	1.41	2.4	4.2	2100	4.6	0.9	1.65	25.2	7.8
2	L	75	62.3	1005	22.1	0.15	1.11	1.4	2.9	1756	3.2	0.6	1.16	16.8	6.8
	B	101	107.3	1800	26	0.38	1.38	2.6	5	2122	5	1.1	1.45	22	5
3	L	78	67.1	988	23.2	0.16	1.21	1.5	3.3	1822	3.6	0.7	1.35	17.2	7.2
	B	98	112.2	1722	27.3	0.42	1.4	2.6	4.8	2222	4.8	1.2	1.62	16.8	5.6
4	L	82	75.5	1042	23.1	0.11	0.98	1.2	2.6	1635	2.6	0.7	1.25	19.2	3.6
	B	96	109.6	1689	26.7	0.35	1.52	3	4.3	1988	4.3	1.3	1.72	16.7	4.6
5	L	75	72.4	986	20.6	0.16	1.1	1.4	2.1	1852	2.1	0.7	1.36	25.3	3.2
	B	102	99.7	1812	29	0.4	1.45	2.8	4	2205	4	1	1.32	13.9	3.8
6	L	72	77.5	1005	22.6	0.13	0.98	1.3	1.9	1808	2.9	0.6	1.24	23.3	2.4
	B	106	111.2	1772	28.5	0.44	1.36	2.6	4.6	2155	4.6	0.9	1.57	24.6	7.5
7	L	66	71.6	966	21	0.09	0.84	1.2	2.4	1769	1.8	0.7	0.98	17.4	3.4
	B	110	108.8	1804	27.9	0.48	1.42	1	4.6	1912	4.6	1.1	1.28	10.8	6.5
8	L	82	70.4	1046	21.8	0.16	1.2	2.8	2.2	2010	3.2	0.9	1.44	21	2.9
	B	108	112.3	1788	30	0.38	1.44	3.2	4.1	2188	4.8	1.2	1.55	16.7	3.4
9	L	77	76.6	1002	23.2	0.11	0.96	1.3	2.9	1744	2.9	0.6	1.3	20.2	4.1
	B	98	106.6	1698	27.7	0.48	1.39	2.9	4.4	2000	4.4	1	1.22	23.4	3.2
10	L	72	72.8	1014	21.7	0.16	1.12	1	2	1806	2	1.2	1.57	25	4.2
	B	100	104.4	1805	28.9	0.39	1.46	2.6	4.3	2210	4.3	0.6	1.81	17.3	3
11	L	78	74.9	973	22.5	0.18	0.86	1.2	3	1888	3	0.9	1.26	29	5
	B	104	109.3	1718	30.1	0.32	1.42	2.7	4.8	2154	4.4	1	1.39	10.5	3.3
12	L	82	70	1012	23.4	0.1	1.16	1.4	3.1	1876	3.1	0.7	1.48	24.4	3.9
	B	112	104.8	1798	28	0.42	1.38	2.5	4.6	2236	4	1.1	1.57	18.6	3.4
13	L	72	73.9	975	20.8	0.12	1.22	1.1	1.6	2008	1.6	0.8	1.42	19	5.2
	B	98	108	1666	27.4	0.44	1.81	2.8	4.4	1912	4.2	1.2	1.39	15.5	4.5
14	L	76	75.8	1008	22.8	0.11	1.1	1.2	2.9	1766	2.7	0.8	1.28	24	3.9
	B	108	105.9	1784	26.2	0.33	1.4	2.6	5.1	2100	4.8	0.9	1.81	22.3	7.2
15	L	80	70.6	966	24	0.12	1	1.4	2	1932	2.7	0.7	1.4	18.2	4.3
	B	104	109.1	1760	25.1	0.42	1.32	2.4	4	2011	5.9	1	1.34	23.5	6.8
Min.		66	62.3	922	20.6	0.09	0.84	1	1.6	1635	1.6	0.6	0.98	10.5	2.4
Max.		112	112.3	1812	30.1	0.48	1.81	3.2	5.1	2236	5.9	1.3	1.81	29	7.8
Average		89.75	89.96	1372.75	25.11	0.27	1.26	2.00	3.49	1966.38	3.67	0.90	1.41	19.86	4.79

than those recorded from the coasts of Indonesia and Malaysia (Amin et al., 2006), the Arabian Gulf (de Mora et al., 2004), Shatt Al-Arab River (Al-Jaberi, 2014) and the Red Sea coast (Madkour, 2005; El-Sorogy et al., 2013). It was higher than the values recorded from the Mediterranean Sea, Egypt (El-Sorogy and Attiah, 2015), coasts of India (Kesavan et al., 2013; Ponnusamy et al., 2014) and Tarut Island, Arabian Gulf (El-Sorogy and Youssef, 2015).

The highest value of Zn (7.8 μg/g) was recorded at locality 1 in the

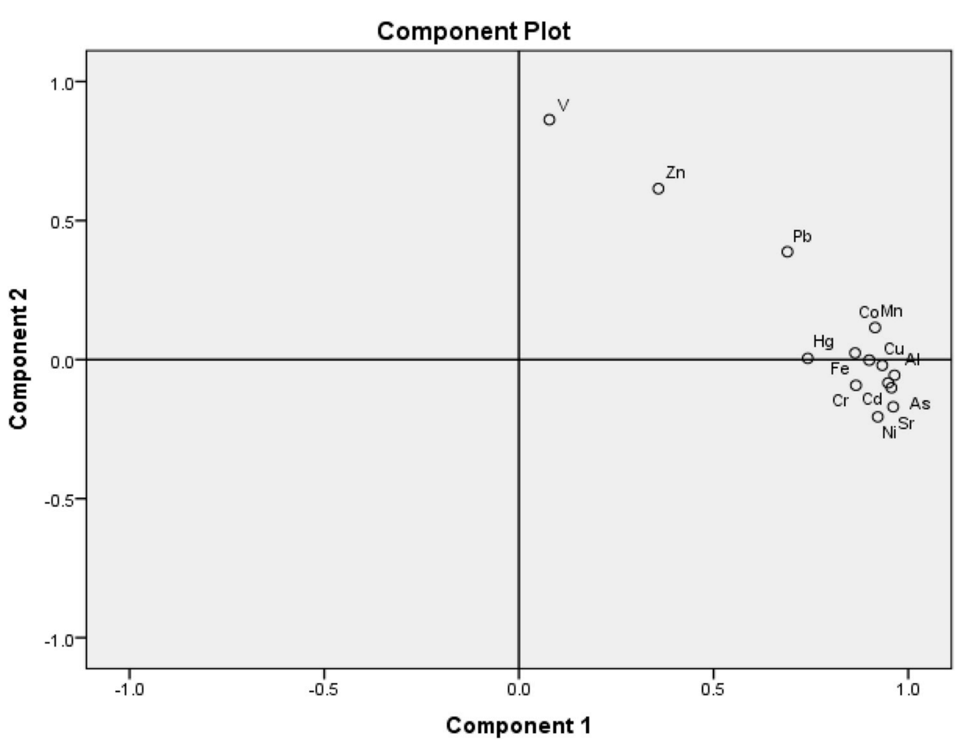

Fig. 4. Factor analysis and concentration of metals in two component plots.

Table 3
Comparison between heavy metals in the studied molluscs and other worldwide ones.

Locality	Cu	Zn	Pb	Cd	As	Co	Cr	Hg	V	Ni	Sr	References
Present study	3.49	4.79	1.41	0.27	89.96	1.26	2.00	0.90	19.86	25.11	1372.75	
Arabian Gulf, Saudi Arabia	5.46	9.05	1.44	0.16	26.25	1.31	4.86	0.76				El-Sorogy et al. (2016a)
Mediterranean Sea, Egypt		1.694	0.426		0.759		0.133			1.92	5860	El-Sorogy and Attiah (2015)
Indonesia and Malaysia	5.90	3.74	44.43	4.14	-	-	-			20.73		Amin et al. (2006)
Tarut Island, Arabian Gulf	0.247	0.231	0.205	0.004	4.263	0.185	0.103	0.052				El-Sorogy and Youssef (2015)
India	0.10–0.84	0.29–3.64	0.03–0.08	0.002–0.09	-	0.003–0.07	-					Kesavan et al. (2013)
South coast of Portugal	-	5.5	-	-	-	-	-					Cravo et al. (2002)
Shatt Al-Arab River	271.5	117	19.2	-	-	9.3	10.7			12	1671.6	Al-Jaberi (2014)
Arabian Gulf and Gulf of Oman	3.13–276	69.1–1830	0.089–3.92	1.17–19.9	11.1–156	0.12–12.9	0.01–3.76	0.009–0.32	0.27–7.30			de Mora et al. (2004)
Red Sea coast	12.4–81.4	11.4–32.6	12.3–44.7	1.32–1.82	-	-	-					Madkour (2005)
Belledune Harbor	0.10–1.30	-	0.19–1.00	0.3–49.1	-	-	-					Bourgoin (1990)
South east coast of India	0.13–0.36	0.95–3.63	0.18–0.36	0.014–0.038	-	-	0.09–0.15					Ponnusamy et al. (2014)
Pondicherry, India	0.21–0.98	0.57–0.79	-	0.13–0.24	-	-	-					Kaviarasan et al. (2012)
North Adriatic Sea	4.40	1.7	1.17	0.040	-	-	-					Martincié et al. (1984)
Northwest Spain	0.1–1.3	3.0–7.6	0.19–1.3	0.04–0.22	-	-	-					Pérez-López et al. (2003)
Nile branch, Egypt	0.12–7.71	0.94–4.94	0.12–3.05	0.01–0.078	0.16–1.33	0.012–0,10	0.01–0.56			0.019–1.04	0.16–6.9	Lotfy (2006)
Red Sea coast	0.81	2.13	94.17		1.56							El-Sorogy et al. (2013)

gastropod *L. coronata* and the lowest (2.4 μg/g) at locality 6 in the bivalve *B. parva* (Table 2). Average values of Zn were lower than the ones recorded from the south coast of Portugal (Cravo et al., 2002), Shatt Al-Arab River (Al-Jaberi, 2014), the Red Sea coast (Madkour, 2005), and Arabian Gulf (de Mora et al., 2004). It was higher than the levels recorded from the Mediterranean Sea, Egypt (El-Sorogy and Attiah, 2015), coasts of Indonesia and Malaysia (Amin et al., 2006), Tarut Island, Arabian Gulf (El-Sorogy and Youssef, 2015), south east coast of India (Ponnusamy et al., 2014; Kaviarasan et al., 2012) and North Adriatic Sea (Martincié et al., 1984). The highest level of Cd (0.48 μg/g) was found at locality 9 in *L. coronata* while the lowest (0.09 μg/g) was recorded at locality 7 in *B. parva* (Table 2). The average value of Cd was lower than those recorded from coasts of Indonesia and Malaysia (Amin et al., 2006), Arabian Gulf and Gulf of Oman (de Mora et al., 2004), the Red Sea coast (Madkour, 2005) and Belledune Harbor (Bourgoin, 1990). It was higher than the values recorded from the coasts of India (Kesavan et al., 2013; Ponnusamy et al., 2014; Kaviarasan et al., 2012), Tarut Island, Arabian Gulf (El-Sorogy and Youssef, 2015) and Nile branch of Egypt (Lotfy, 2006).

The highest concentration of As (112.3 μg/g) was recorded at locality 8 in *L. coronata* and the lowest (62.3 μg/g) at locality 2 in *B. parva* (Table 2). Average value of As was higher than those recorded from the Arabian Gulf and Gulf of Oman (de Mora et al., 2004), Tarut Island, Arabian Gulf (El-Sorogy and Youssef, 2015), Nile branch, Egypt (Lotfy, 2006) and Mediterranean Sea, Egypt (El-Sorogy and Attiah, 2015). Co values ranged from 0.84 μg/g in *B. parva* to 1.81 μg/g in *L. coronata* in locality 7. Average value was higher than those recorded from the coasts of India (Kesavan et al., 2013), the Arabian Gulf (El-Sorogy and Youssef, 2015) and Nile Delta (Lotfy, 2006). It was lower than the one recorded from Shatt Al-Arab River (Al-Jaberi, 2014). Values of Cr ranged from 1 μg/g in localities 7 and 10 in *B. parva* to 3.2 μg/g in *L. coronata* in locality 8. Average value was higher than those recorded from the Mediterranean Sea coast (El-Sorogy and Attiah, 2015), the Arabian Gulf (El-Sorogy and Youssef, 2015) coasts of India (Ponnusamy et al., 2014) and Nile Delta (Lotfy, 2006). It was lower than those recorded from Shatt Al-Arab River (Al-Jaberi, 2014).

4. Discussion

The identified molluscs were epifaunal inhabited hard rocky shores, and the infaunal ones inhabited shallow sandy bottoms (Table 1). *Lunella coronata* (Gmelin, 1791) and *B. parva* (Sowerby, 1833) were chosen for heavy metal analysis due to their abundance, benthic sessile modes of life, occurrence throughout the 15 studied localities, and their modes of feeding (filter feeders), so they have the potential to accumulate pollutants present in the seawater or within the sediments. The highest heavy metal concentrations were found in *Barbatia parva* (Sowerby, 1833) in all the studied localities. Similarly, in their study along the Saudi Arabian Gulf, El-Sorogy and Youssef (2015) founded that *B. parva* was a good accumulator of Cu, Zn, Pb, Cd, Se, B, Hg, Mo, and Hg, while *L. coronata* was a good accumulator of Fe, Mn, and Co. The differences in heavy metal uptake between the two studied molluscs may explain the differences in their incorporation of elements within the crystal lattice of the carbonates composing their skeletons or their modes of life (Cravo et al., 2002).

The most abundant living cerithiid and planaxid gastropods were recorded on the natural and artificial rocky shores (e.g., localities 3, 11, 13). These gastropods are adapted to many stresses at these biotopes (e.g. increasing air exposure, anthropogenic impacts originating both from land and sea, and the differences in the wave action and topography of the shore). The environmental conditions favor their survival as hardgrounds are stable, well oxygenated, and high in energy with a good food supply for the suspension feeders that form a great proportion of their fauna (Wilson and Palmer, 1992; Crowe et al., 2000). These hardground shores are co-inhabited by barnacles, worm tubes, and gastropods (Fig. 2). In other localities, rocky shores comprise oysters and mussels, which cling to boulders and rocks via byssus threads or firm cemented with large areas of attachment to resist buffeting by

Table 4
Principal component loadings and explained variances for the two components with a Varimax normalized rotation.

Component Matrix		
Metals	PC1	PC2
Al	**.964**	-.056
As	**.957**	-.101
Sr	**.961**	-.170
Ni	**.922**	-.206
Cd	**.948**	-.084
Co	**.900**	-.002
Cr	**.866**	-.092
Cu	**.933**	-.021
Fe	**.863**	.024
Hg	**.742**	.004
Mn	**.915**	.115
Pb	**.690**	.388
V	.078	**.863**
Zn	.358	**.615**
Variance %	69.224	9.911
Cumulative %	69.224	79.135

Extraction Method: Principal Component Analysis.

currents and may be wedged into holes or ensconced in tunnels (Fig. 3). The high abundance of venerid bivalves was recorded on sandy biotopes as in localities 1, 4, 8, 13, and 15. The sandy shores are the habitat of burrowing bivalves and gastropods. They are often littered with the shells of sand-burrowing naticids, or moon snails, and the dismembered valves of tellins and other sand-burrowing bivalves. The accumulation of the abundant death cerithiid shells on the sandy shores of localities 4 and 12 was attributed to drift from nearby rocky shores by storms and tidal currents.

Molluscan assemblage showed decline in diversity in contrast to somewhat earlier studies, which were conducted on the Arabian Gulf (e.g. Biggs, 1969; Ahmed, 1975; Bosch and Bosch, 1982, 1989; Beu, 1986; Bosch et al., 1995). Similarly, Littler and Murray (1975) found a decrease in species richness and total cover as a result of sewage effects on a rocky intertidal community. Sewage discharges led to decrease in or the absence of sensitive bivalves, and, consequently, increased other species due to the lack of competition for food and space. Furthermore, sewage discharges lead to increasing the ephemeral green algae cover and the abundance and diversity of tolerant species in the polluted areas (López-Gappa et al., 1990).

Fe > Sr > As > Al > Ni > V > Zn > Mn > Cu > Cr > Pb > Co > Hg > Cd was the order of the average metal levels in the studied shells. Principal component analyses (PCA) indicated two principal components (Table 4). The first component contained a high positive loading of Al, As, Sr, Ni, Cd, Co, Cr, Cu, Fe, Hg, Mn, and Pb

Fig. 5. Examples of anthropogenic sources of pollutants along Al-Khobar coastline. A, Al-Khobar desalination station. B, Landfilling due to new constructions, fishing boats and the King Fahd causeway. C, Solid wastes and landfilling on the coastline.

(0.964, 0.957, 0.961, 0.922, 0.948, 0.900, 0.866, 0.933, 0.863, 0.742, 0.915, and 0.690 respectively) which explained 69.22% of the total variance. The second component showed a positive loading for V and Z (0.863 and 0.615, respectively) and accounted for 9.911% of the total variance. Results of PCA were supported with the correlation matrix (Table 5), which showed positive correlations between Al and As, Sr, Ni, Cd, Co, Cr, Cu, Fe, Hg, Mn, and Pb ($r = 0.92$, $r = 0.96$, $r = 0.90$, $r = 0.92$, $r = 0.79$, $r = 0.75$, $r = 0.91$, $r = 0.78$, $r = 0.60$, $r = 0.88$ and $r = 0.54$, respectively) indicating similar sources for these elements. In contrast, negative correlations were observed between each of V and Zn and most of aforementioned metals. The component plot indicated that the concentration of all studied metals, except each of V, Zn, and Pb occurred in one zone (Fig. 4), which is consistent with the previous results.

The average values of some heavy metals in the studied molluscs were higher than those recorded in the Mediterranean Sea and certain Indian coasts (Pb, Zn, and Cr). The highest concentrations of heavy

Table 5
Correlation matrix among studied metals.

	Al	As	Sr	Ni	Cd	Co	Cr	Cu	Fe	Hg	Mn	Pb	V	Zn
Al	1.00													
As	**0.92**	1.00												
Sr	**0.96**	**0.97**	1.00											
Ni	**0.90**	**0.88**	**0.89**	1.00										
Cd	**0.92**	**0.94**	**0.95**	**0.85**	1.00									
Co	**0.79**	**0.80**	**0.82**	**0.78**	**0.83**	1.00								
Cr	**0.75**	**0.77**	**0.79**	**0.75**	**0.74**	**0.77**	1.00							
Cu	**0.91**	**0.89**	**0.91**	**0.86**	**0.87**	**0.76**	**0.72**	1.00						
Fe	**0.78**	**0.76**	**0.80**	**0.76**	**0.74**	0.67	**0.78**	0.68	1.00					
Hg	0.60	0.68	0.64	0.54	0.66	0.66	0.56	0.56	0.50	1.00				
Mn	**0.88**	**0.84**	**0.85**	**0.80**	**0.85**	**0.72**	**0.74**	**0.88**	0.65	0.51	1.00			
Pb	0.54	0.52	0.53	0.45	0.43	0.55	0.53	0.47	0.64	0.37	0.42	1.00		
V	−0.30	−0.25	−0.31	−0.46	−0.25	−0.41	−0.20	−0.29	−0.20	−0.20	−0.20	0.07	1.00	
Zn	0.21	0.15	0.14	0.07	0.23	0.19	−0.04	0.28	0.05	0.06	0.39	0.14	0.05	1.00

metals found in molluscan shells, coastal sediments and seawater samples were recorded in localities within Al Sahil, Al Buhairah, and the Half Moon bays. This may be due to anthropogenic sources resulting from the rejected water from desalination plants of Al-Khobar, landfilling due to new constructions, industrial and sewage discharges and oil leakages from transportation and exploration (Fig. 5). Results of this study are consisted with those studies which were conducted in the Al-Khobar area, including coastal sediments (Alharbi and El-Sorogy, 2017) and seawater samples (Alharbi et al., 2017). These studies found severe enrichment factors in Sr, Cr, Zn, Cu, V, Hg, Mo, and Se, and increases in the average values of Zn, Fe, Mn, Cu, As, and Cr, particularly within the bays.

5. Conclusions

The study of the gastropod and bivalve assemblages from 15 localities along the Al-Khobar coastal plain, and selection of representative molluscan shells for heavy metal analyses revealed the following:

1- -The identification of 29 and 40 gastropod and bivalve species, respectively. The identified molluscan assemblage consisted of epifaunal and infaunal taxa which inhabited hard rocky shores and shallow sandy bottoms, respectively. The most abundant cerithiid and planaxid gastropods occurred in the natural and artificial rocky shores, while the most abundant venerid bivalves were found in the sandy biotopes.
2- -*Barbatia parva* (Sowerby, 1833) had the higher concentration of heavy metals in all the studied localities, than *Lunella coronata* (Gmelin, 1791). The highest average values were recorded particularly within Al Sahil, Al Buhairah, and Half Moon bays and nearby the sources of anthropogenic pollutants, such as the desalination plant of Al-Khobar, landfilling due to new constructions and sewage disposal.
3- -Molluscan assemblage had a lower diversity in this study than in somewhat earlier studies conducted along the Arabian Gulf coastline. Moreover, average concentration of heavy metals in the studied molluscs were higher than those recorded in molluscs from other seas, such as the Mediterranean Sea, Adriatic Sea, coasts along the Indian Ocean and Nile branch.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafrearsci.2019.103564.

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