Trace Metals Content in Annually-Banded Scleractinian Coral '*Porites Lobata*' Across the Northern Persian Gulf

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Abstract

Concentration of trace metals in skeleton growth bands of dominant scleractinian coral '*Porites lobata*' were investigated in Kharg and Hebourabi islands across the northern Persian Gulf. The highest average concentration of elements were as Sr> Mg> Zn> Ba> Cu> U> Ni> Mn> Cr> Co> Pb> V> Cd in Kharg Island respectively and as Sr> Mg> Ba> Cu> U> Ni> Zn> Mn> Cr> Co> V> Pb> Cd in Hendourabi Island. Except for Cr, the concentrations of other trace metals in Kharg Island were higher than those of Hendourabi Island. The coefficient of variation percentage (CV%) for Cr, Mn, Zn, Ba and Pb in Kharg Island and for Cu and Ba in Hendourabi Island was more than 50%. Results of PCA analyses revealed that the trace metals Kharg Island was defined by three principal components including the first component (Mn, V, Pb, Zn, Ni and half of Mg, Cr and Co) corresponding to the past regional military conflicts and oil pollution, second component (Sr, U and Mg) corresponding to SST changes, and the third component (Cr and Co) corresponding to other factors. Results of PCA analyses revealed that trace metals in Hendourabi Island was defined by two principal components including first component (Co, Ni, Cr, Mn and half of Ba) corresponding to annual precipitation changes and the second component (U, Zn and Ba) corresponding to coastal constructions.

Introduction

Coastal regions are some of the most sensitive and yet severely impacted environments in both industrial and developing nations. Extensive efforts are underway to monitor coral ecosystems in regions with rapid physical and chemical changes affecting the land-sea margin. Corals may function as an indicators of pollution level in seawater (David 2003; Chen et al. 2010) because they concentrate trace metals in their growth bands that may reflect the chemical variations in the ambient environment (Prouty et al. 2013; Tanaka et al. 2013; Song et al. 2014). According to a metal-Ca-exchange interact, metal ions are accumulated in the coral skeletons during the formation of CaCO₃ (Ramos et al. 2004; Chen et al. 2010). Trace metals such as Cu, Cr, Fe, Mn, Ni, Zn, V, and Pb have been used to explore the historical metal pollution originating from anthropogenic and or terrestrial sources such as industrial activities, sewage pollution (David 2003; Al-Rousan et al. 2007; Edinger et al. 2008; Chen et al. 2010), and dredging (Esslemont et al. 2004; Nguyen et al. 2013; Li et al. 2017). Massive scleractinian corals, such as *Porites*, are considered as the important archives of historical climate data. This is because *Porites* genera are widely distributed, are sensitive to environmental changes and their annual growth bands may function as recorders of changes in seawater properties including nutrient levels, and other pollutants entering the marine environment (David 2003; Ramos et al. 2004; Al-Rousan et al. 2007; Forouzan et al. 2014; Zamani et al. 2020).

The Persian Gulf is a semi-enclosed sea located in the subtropical northwest of the Indian Ocean and is surrounded by arid landmasses. The coral reefs in this sea are especially in danger of degradation and destruction because of thermal stress, maritime transport pollution, limited water circulation, and increasing toxic pollutants driven from inland and offshore oil and gas industries. Superimposed on natural threats, coastal development will continue in this sea with increased rates of landfill and dredging causing more stress to the nearshore reefs. Large quantities of industrial and domestic wastewater enter this sea despite high standards for wastewater treatment existing in some parts of the region (Sheppard et al. 2010). Industrial effluents originate from manufacturing industries that produce fertilizers, plastics, chemicals, petrochemicals, and minerals (Gevao et al. 2006) that may continually enter the chemicals such as hydrocarbons and trace metals into the Gulf. Trace element pollution in aquatic sediments has been reported by many researchers in the Persian Gulf (Dehghan Chenari and Lak 2014; Ranjbar et al. 2017, 2018). Generally, concentration of the trace metals have a upward trend from the east to the west part of the Persian Gulf suggesting its external input at these locations. Exploitation and exploration of the crude oil are important source of pollutants in the Persian Gulf adversely impacting the coral reefs in this gulf (Ranjbar et al. 2017, 2018). The aim of this study was to investigate temporal variation of candidate trace metals in the aquatic environment of two islands across the northern Persian Gulf by examining long-term variation of trace metal in the growth bands of massive coral *Porites lobata*. The present study also aimed to provide baseline information on the environmental conditions of the coral reefs in the Persian Gulf that suffer from anthropogenic inputs of contaminants.

Materials And Methods

Study area

The core samples of *Porites lobata* were collected in 2016 from two distinctly apart islands (Kharg and Hendourabi islands) located across the northern Persian Gulf (Fig. 1). Kharg Island (29°15'N, 50°18'E) is located in north-west of the Gulf and due to being an oil terminal, the sea water and sediment of this island are likely contaminated by oil compounds. Hendourabi Island (26°40'N, 53°38'E) as nonresidential and wildlife refuge is located at a distance of 325 km from Bandar Abbas mainland in the middle north of the Gulf. Thus, the corals in Hendourabi Island are not exposed to any direct pollution.

Sampling and processing

The cores from living *P.lobata* corals were taken using a pneumatic drill powered by scuba tank. The cores were planed (Suharsono and Cahyarini 2012; Song et al. 2014) and X-rayed (Helmle et al. 2002; Bolouki Kourandeh et al. 2018). The annual bands were defined by a pair of adjacent high-density and low-density coral sections (Kearney 2011).

About 10-15 mg of coral powder samples taken from each annual growth band were dissolved with 7N nitric acid in ultraclean PFA beakers. The homogenized solution was split, with about 1.5mg of dissolved coral and was transferred to a PFA vial, spiked with ⁶Li, ⁶¹Ni, Rh, In, Re, ²³⁵U internal standards and reached a total volume of 4.5 ml by adding 2% HNO₃. The solution was shaken for well mixing and became ready for ICP-MS analysis at the Radiogenic Isotope Facility, the University of Queensland, Australia.

Using ICP-MS procedure, the trace elements were measured following the protocol by Eggins and modified by the Radiogenic Isotope Laboratory (Eggins et al., 1997, Kamber et al., 2003, Lawrence et al., 2006). Samples were analysed on a Thermal X series 2 equipped with an ESI SC-4 DX FAST autosampler. A screen was used and the operating conditions were optimised for the highest sensitivity with low oxides rate (<2% CeO/Ce) and low doubly charged ion rate (<3%, Ce⁺⁺/Ce) with four repeats of 131 sweeps at one point with dwell times of 5-15ms for each analysis. Isobar and polyatomic interferences were corrected using the formation rates measured with pure single element REE and Ba after each experiment. Apart from BaO⁺ interference on Eu, all other oxide interference, especially on REE were corrected. USGS W2a was used as reference standard and crossed checked with BIR-1, BHVO-2 and JCP-1. Instrument drift mass bias were corrected with internal standards and external monitors.

Data analysis

The normality of concentration data for each trace metal was tested using Shapiro-Wilk test. The results showed that concentration data for Cd, Sr and Mg were normally distributed, but not for remaining metals. Therefore, the difference in concentrations of Cd, Sr and Mg between Hendourabi and Kharg islands within the period of 2000 - 2015 were tested using independent student t-test. The difference in concentration of other trace elements (i.e., Cr, Mn, Ni, Cu, Zn, Ba, Pb, U, Fe, Co, V, Ca) between Hendourabi and Kharg islands within the period of 2000-2015 were tested using Mann-Whitney U test. Spearman correlation test was used to investigate the relationships between pairwise trace elements in each island. SPSS v19 was used for statistical analyses.

The coefficient of variation (CV%) was used as a measure to explore the variability of annual values on trace metals concentrations over time (inter-annual variability) irrespective of differences in their means (Helmle et al. 2011). The non-metric Multidimensional Scaling (nMDS) analysis test based on Euclidean distance was employed to represent the position of studied islands based on the concentration of trace metals in their coral samples. Further, nMDS plot was depicted to reveal the grouping of trace metal concentrations across the years in each island. A Principal Component Analysis (PCA) was employed, to classify the samples according to the concentrations of trace metals. A PCA can take annual coral samples properties and express them in terms of a smaller data dimensional space. PCA identifies potential sources of the trace metals and explains their properties. As necessary precondition in PCA analysis, Anti-image, Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) for all variables must be more than 0.5. Therefore, Cu and Ba in Kharg Island and Mn, Sr, V, Pb and Cu in Hendurabi Island were eliminated. Varimax rotation method was used to express the trace metals data in the rotation space, and this made the Principal Components from the original datasets more interpretable. The statistical analyses were performed with SPSS v19 and Primer v6.0 (Plymouth Routines in Multivariate Ecological Research, Plymouth Marine Laboratory, Plymouth, UK) (Clarke and Gorley 2006).

Results

The mean (±SD), min, max and CV% for trace metals within the period of 1985 to 2015 for Kharg Island and within the period of 2000 to 2016 for Hendourabi Island are presented in Table 1. Variation in concentrations of trace metals in coral samples for Kharg and Hendourabi Islands are presented in Fig. 2. Order the concentration of metals were as Sr> Mg> Zn> Ba> Cu> U> Ni> Mn> Cr> Co> Pb> V> Cd and as Sr> Mg> Ba> Cu> U> Ni> Zn> Mn> Cr> Co> V> Pb> Cd for Kharg and Hendourabi islands, respectively. The CVs for Cr, Mn, Zn, Ba and Pb in Kharg Island and Cu and Ba in Hendourabi Island were more than 50%. The CV for Mg, Sr, U, Ca and Ni in Kharg Island and for Mg, Sr, U, Ni, Ca and Co in Hendourabi Island were lower than 10%.

Table 1: Mean, ±SD (ppb), min, max and CV% for trace metals within the period of 1985 to 2015 for Kharg Island and within the period of 2000 to 2016 for Hendourabi Island

	Cr ×10 ³	Mn ×10 ³	Ni ×10 ³	Cu ×10 ³	Zn ×10 ³	Cd	Ba ×10 ³	Pb ×10 ³	Sr ×10 ⁶	U ×10 ³	Co ×10 ³	Mg ×10 ⁶	V ×10 ³
Kharg Island													
Mean	0.46	1.28	2.68	4.15	21.86	6.66	8.06	0.25	8.05	3.00	0.26	1.00	0.12
SD	0.26	0.84	0.16	1.48	15.69	2.27	10.59	0.16	0.17	0.16	0.07	0.05	0.05
Min	0.07	0.58	2.48	1.55	6.85	1.37	5.17	0.13	7.78	2.69	0.21	0.91	0.08
Year	1988	1988	1993	1994	1988	2003	2015	1988	1990	1993	1993	1988	1988
Max	0.99	4.16	3.17	9.38	94.93	12.33	67.85	1.00	8.34	3.29	0.60	1.10	0.32
Year	2004	2010	2015	1984	1998	1984	2003	1984	2015	2015	2010	1995	1998
CV%	56.78	65.49	6.01	35.7	71.75	34.14	131.38	61.07	2.08	5.46	27.24	4.71	40.6
Hendourabi Island													
Mean	0.61	0.82	2.53	5.46	1.54	6.84	10.00	0.07	7.78	2.93	0.20	0.95	0.08
SD	0.27	0.28	0.08	3.42	0.65	3.30	17.92	0.01	0.13	0.20	0.01	0.04	0.01
Min	0.05	0.45	2.41	1.23	0.87	2.71	3.97	0.05	7.52	2.38	0.18	0.89	0.06
Year	2013	2016	2016	2003	2007	2016	2016	2009	2012	2012	2001	2003	2014
Max	0.90	1.53	2.70	11.41	3.38	14.20	79.43	0.10	8.01	3.21	0.20	1.02	0.10
Year	2001	2006	2011	2015	2002	2006	2006	2006	2015	2016	2011	2010	2006
CV%	43.56	34.18	3.28	62.75	42.24	48.21	179.17	17.63	1.69	6.67	2.93	4.12	14.39

The nMDS plot based on Euclidean distance measure revealed that concentration of trace metals in coral samples collected from Kharg and Hendurabi islands formed separate groups for each corresponding island (Fig3).

The results of Independent Student t-test and Mann-Whitney U test revealed significant differences in concentrations of Cr, Mn, Ni, Zn, Ba, Pb, Co, V, Ca, Sr, and Mg and non-significant difference in concentrations of Cd, Cu and U between Hendourabi and Kharg islands within the period of 2000-2015 (Table2). Except for Cr, other trace metals in Kharg Island had a higher level than that of Hendourabi Island. Yet, the concentration of Cu and U were higher in Hendourabi Island with no significant difference between two islands.

Table 2. Summary results for testing the differences in the concentrations of trace metals in coral samples collected from Kharg and Hendourabi islands.

	Trace elements	Mean (ppb)		<i>t</i> value / Mann–Whitney U	P value
		Kharg	Hendourabi		
Independent Student t-test	Cd	6.66	6.84	0.22	0.83
	Sr (×10⁶)	8.05	7.78	5.76	0.00
	Mg (×10⁶)	1.00	0.95	3.5	0.00
Mann-Whitney U test	Cr (×10³)	0.46	0.61	-2	0.05
	Mn (×10³)	1.28	0.82	-2.4	0.02
	Ni (×10³)	2.68	2.53	-3.74	0.00
	Cu (×10³)	4.15	5.46	-0.72	0.47
	Zn (×10³)	21.86	1.54	-5.77	0.00
	Ba (×10³)	8.06	10.00	-2.02	0.04
	Pb (×10³)	0.25	0.07	-5.77	0.00
	U (×10³)	3.00	2.93	-0.7	0.48
	Co (×10³)	0.26	0.20	-5.77	0.00
	V (×10³)	0.12	0.08	-5.01	0.00

Results of nMDS test based on Euclidean distance measure showed that concentration of trace metals in Kharg Island corresponding to different years could be categorized into three clear groups including (1) year 1998, (2) years 1992 and 1993, and (3) remaining years (Fig. 4).

Using Spearman rank correlation, the geochemical behaviors of trace metals in coral skeleton of the studied areas were explored (Table 3). In Kharg Island, concentrations of Mn, Pb, Co, V, Ni and Zn showed strong significant pairwise correlations, particularly for Mn and Pb ($r = 0.74$, $P = 0.001$), Mn and Co ($r = 0.72$, $P = 0.001$), Mn and V ($r = 0.71$, $P = 0.001$), Mn and Ni ($r = 0.69$, $P = 0.001$), Co and Ni ($r = 0.89$, $P = 0.001$), Co and Pb ($r = 0.7$, $P = 0.001$). Sr, U and Mg showed significant strong pairwise correlations, including positive correlation between U and Sr ($r = 0.85$, $P = 0.001$) and negative correlation between U and Mg ($r = -0.71$, $P = 0.001$).

In Hendourabi Island, significant strong correlations were found between Co, Cr and Ni, particularly between Co and Ni ($r = 0.71$, $P = 0.001$). Likewise, there was a significant negative correlation between Cu and Ba ($r = -0.81$, $P = 0.001$). A strong significant correlation ($r = 0.78$, $P = 0.001$) was detected between Sr and U in Hendourabi Island. By contrast, Mn did not show significant correlation with Ni. Co had significant negative correlation with Cr ($r = -0.71$, $P = 0.001$).

Table 3. Results of Spearman correlation coefficients testing the pairwise relationship among trace metals in *Porites lobata* in Kharg and Hendourabi islands.

	Cr	Mn	Ni	Cu	Zn	Cd	Ba	Pb	Sr	U	Co	Mg	V
Kharg Island													
Cr	1												
Mn	0.44**	1											
Ni	0.28	0.69**	1										
Cu	-0.05	-0.45**	-0.2	1									
Zn	0.37*	0.56**	0.25	-0.44**	1								
Cd	-0.15	0.02	0.17	0.09	-0.06	1							
Ba	0.42*	0.6**	0.01	-0.39*	0.62**	0.02	1						
Pb	0.41*	0.74**	0.65**	-0.22	0.65**	0.02	0.5**	1					
Sr	0.29	0.36*	0.63**	-0.1	0.44**	0.14	0.03	0.51**	1				
U	0.19	0.13	0.45**	-0.06	0.39*	0.27	0.01	0.33	0.85**	1			
Co	0.35*	0.72**	0.89**	-0.09	0.31	0.07	0.11	0.70**	0.62**	0.37*	1		
Mg	-0.05	0.36*	0.01	-0.2	-0.01	-0.15	0.34*	0.11	-0.57**	-0.71**	0.04	1	
V	0.2	0.71**	0.65**	-0.6**	0.48**	0.17	0.51**	0.61**	0.43*	0.39*	0.57**	0.21	1
Hendourabi Island													
Cr	1												
Mn	-0.28	1											
Ni	-0.61**	0.37	1										
Cu	-0.31	-0.23	0.16	1									
Zn	0.21	0.04	0.29	-0.3	1								
Cd	0.12	0.50*	-0.11	-0.2	0.18	1							
Ba	0.33	0.33	-0.21	-0.81**	0.10	0.41	1						
Pb	0.21	0.6*	0.08	-0.18	0.00	0.58*	0.26	1					
Sr	-0.15	-0.14	0.31	0.52*	-0.1	-0.16	-0.56*	-0.1	1				
U	0.13	0.00	-0.12	0.38	-0.23	0.15	-0.3	0.22	0.78**	1			
Co	-0.71**	0.50*	0.71**	0.45	0.04	0.21	-0.38	0.09	0.34	0.01	1		
Mg	-0.34	0.22	0.23	0.2	-0.02	-0.23	-0.2	0.00	-0.22	-0.25	0.25	1	
V	0.19	0.67**	0.00	-0.52*	-0.08	0.24	0.63**	0.48*	-0.25	0.03	-0.10	0.2	1

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

To clearly identify temporal behavior characteristics of the trace metals, Varimax rotation was used in the PCA analysis, and the 3-D plot for trace elements produced from PCA were presented in Fig. 5.

For Kharg Island, the rotated PC1 with an eigenvalue of 4.94 accounted for 49.45% of the variation. The rotated PC1 which explained Mn, V, Pb, Zn, Ni and half of Mg, Cr and Co did correspond to peaks of these elements arising in period of 1988 and 1992-1993 in which subsamples scores on PC1 were higher. There were high concentrations of six elements within these two periods (Fig. 6). The PC2 with an eigenvalue of 2.53 correlated highly with Sr, U and Mg. The PC3 with an eigenvalue of 1.00 explained Cr and Co. The high scores on PC3 occurred in 1993 (Fig. 7).

For Hendourabi Island, the rotated PC1 with an eigenvalue of 3.66 accounted for 52.35% of the variation. The rotated PC1 explained Co, Ni, Cr, Mn and half of Ba. The PC2 with an eigenvalue of 1.50, accounted for 21.38% of the variation and correlated with U, Zn and Ba. The peaks of scores for PC1 and PC2 were aroused in 2016 (Fig. 8).

Discussion

Concentrations of trace metals in coral samples of the studied areas in the northern Persian Gulf revealed that some abnormally high values of these elements occurred during some periods. The concentration trend of most trace metals in coral samples in this study was identical to those in reef sediments (Ranjbar et al. 2017) across the Persian Gulf. Yet, V and Cu concentrations in coral samples in this study were lower and higher, respectively, than those in reef sediments (Ranjbar et al. 2017) suggesting different absorption behaviors for these trace metals in corals and reef sediment.

Except Ba and Cr, concentrations of all trace metals in Kharg Island were higher than those for Hendourabi Island suggesting that exploitation and exploration activities of the crude oil may be an important source of these metals in Kharg Island. However, there was no significant difference in the amount of Cd, Cu and U in coral skeletons between two islands.

According to earlier studies, trace metals (e.g., Cr, Pb, Zn, Mn) in corals may be driven from anthropogenic activities and costal development (Livingston and Thompson 1971; Al-Rousan et al. 2007). Among the evaluated trace metals, Zn and Pb concentrations were noticeable with maximum records for Kharg Island suggesting that the marine biota have been severely affected by human activities (Ranjbar et al. 2017).

The high CV% values for Cr, Mn, Zn, Ba and Pb elements in Kharg Island, and for Cu and Ba elements in Hendourabi Island indicated that these elements have skewed distributions in coral skeletons, which result from high-level outlier, occurred for these elements. On the other hand, CV% for Mg, Sr, U and Ni in Kharg and Hendourabi islands showed approximately normal distribution corresponding to the changes of their percentile concentrations.

Mean concentrations of Cr, Mn, Pb, V and Co in coral samples in the present study were lower than those in samples from elsewhere in the world (Table 4). Cr in the Persian Gulf showed the same levels as reported in Yongxing Island (China) (Song et al. 2014), Gulf of Mannar (India) (Krishnakumar et al. 2015) and Lakshadweep Archipelago (India) (Anu et al. 2007). Rate of Mn in the Persian Gulf showed the same levels as reported in Marinduque Island (Philippines) (David 2003) and in Yongxing and Xiaodonghai islands (China) (Song et al. 2014). Levels of Mn in Kharg Island varied over different time periodes with high values in 1982 (3.67 ppm) and 1988 (4.16 ppm). Concentrations of Pb in coral samples from Hendourabi Island was lower than those reported from elsewhere in the world. Yet concentrations of Pb in coral samples from Kharg Island showed the same levels as reported in Pioneer and Nelly Gulf (Australia) (Esslemont 2000), Yongxing Island (China) (Song et al. 2014), and Gulf of Mannar (India), (Krishnakumar et al. 2015). In the present study high level of Pb was recorded in 1988 (1 ppm).

Concentrations of V and Co in coral samples in the present study was lower than reported from elsewhere in the world (Table 4), Rate of V in coral samples in the present study was as same as that recorded in Nha Trang Bay in Vietnam (Nguyen et al. 2013). In the present study, highest rate of V was recorded in 1988 (0.32 ppm).

In the present study, Zn concentration in Hendourabi Island was lower than those reported from elsewhere in the world including Ulan (Philippines) (David 2003), and Lakshadweep Archipelago (India) (Anu et al., 2007). But in Kharg Island, Zn was higher than those reported from elsewhere in the world (e.g., Pioneer Bay, Australia), (Esslemont 2000). In the present study, highest level of Zn was recorded in 1988 (94.93 ppm).

Cu and Ni seem to be moderate pollutants in corals from the Persian Gulf. For example, Cu in coral samples collected from Nelly Bay (Australia) and Nha Trang Bay (Vietnam) study (Esslemont 2000; Nguyen et al. 2013) had a same level of Cu recorded in the present study. Ni in the present study had a rate similar to those recorded from Gulf of Mannar and Lakshadweep Archipelago (India) (Anu et al. 2007; Krishnakumar et al. 2015). In the present study, high rates of Ni were recorded in 1982, 1988 and 1993 (3.17 ppm). High levels of Mn, V, Pb, Zn, Ni and Cr were recorded in 1988 in Kharg Island. The high rates of these elements have been reported in oil polluted areas (Fu et al. 2014; Ahmad Dasuki et al. 2015).

Cd, Ba, Sr, U, Sr and Mg had a relatively high mean values in corals of the present study in comparison to those recorded elsewhere in the world (Table 4). Cd rate in corals at the present study fell in the range reported from Tuticorin Coast (India) (Jayaraju et al. 2009). The mean values for Ba were very high in 2015 in Kharg Island and in 2016 in Hendourabi Island, but in general Ba values were low. Concentrations of Sr, U and Mg in Kharg Island were relatively higher than that of Hendourabi Island, displaying normal distributions in coral samples from Hendourabi Island.

Table 4. Concentration (ppm) of trace metals in different *Porites* corals in the present study and those reported from elsewhere in the world.

	Cr	Mn	Ni	Cu	Zn	Cd	Ba	Pb	Sr	U	Co	Mg	V	Ref
Befor 1965 (Jordan)		2.46		4.70	5.40	2.35		41.51						Al-Rousan <i>et al.</i> 2007
After 1965 (Jordan)		8.22		5.36	5.52	5.15		47.91						Al-Rousan <i>et al.</i> 2007
Fossil coral (Jordan)		2.89		3.83	5.06	3.60		43.14						Al-Rousan <i>et al.</i> 2007
Gulf of Aqaba (Jordan)		0.35		3.88	7.32	4.19		38.1						Al-Rousan <i>et al.</i> 2007
Tuticorin Coast (India)	5.23	8.53	72.2	10.65	2.51	7.21		28.3			6.89			Jayaraju <i>et al.</i> 2009
Dafangji Island (China)	1.08	4.27	9.54	11.7	16.9	0.097		1.62			0.9			Peng <i>et al.</i> 2006
Caganhao (Philippines)		0.8		0.7	1									David 2003
Ulan (Philippines)		1		3.1	1.8									David 2003
Ihatub (Philippines)		0.8		0.9	2									David 2003
Bajo Caiman (Venezuela)	1.95			12.52	9.12			1.04					0.26	Bastidas and García 1999
Punta Brava (Venezuela)	0.8			16.33	10.67			0.21					0.31	Bastidas and García 1999
Red Sea (Polluted Area)		6.67	0.15	0.83	9.28	0.06		51	1600			417	7.58	Hanna and Muir 1990
Red Sea (unPolluted Area)		5.60	0.11	0.77	3.38	0.04		44	1200			140	5.92	Hanna and Muir 1990
Gulf of Mannar (India)	0.26	2.02	2.48	3.46	4.47	0.45		1.07						Krishnakumar <i>et al.</i> 2015
Nha Trang Bay (Vietnam)		2.90		5.53		0.01		0.24					0.07	Nguyen <i>et al.</i> 2013
Pioneer Bay (Australia)	44		31	1.6	23	>0.09		>0.24						Esslemont 2000
Nelly Bay (Australia)	21		10	5.5	37	>0.09		0.19						Esslemont 2000
Lakshadweep Archipelago(Arabian Sea)	4.33	2.74	11.1	0.49	2.62	2.13		24.18			7.30			Anu <i>et al.</i> 2007
Lakshadweep Archipelago (Arabian Sea)	0.82	0.32	2.07	1.02	1.29	0.27		0.71			0.79			Anu <i>et al.</i> 2007
Xiaodonghai, Hainan Island (China)	3.12	0.88	6.04	3.20	3.43	0.002	6.15	11.32	6700	2.47				Song <i>et al.</i> 2014
Yongxing Island (China)	0.30	0.64	6.26	1.27	2.65	0.002	4.66	0.36	6600	2.27				Song <i>et al.</i> 2014
Kharg Island (Iran)	0.46	1.28	2.68	4.15	21.86	0.006	8.06	0.25	8050	3	0.26	1000	0.12	This study
Hendourabi Island (Iran)	0.61	0.82	2.53	5.46	1.54	0.006	10	0.07	7780	2.93	0.2	950	0.08	This study

Concentrations of Mn, Pb, Co, V, Ni and Zn, in Kharg Island and concentrations of Co, Cr and Ni in Hendourabi Island showed strong significant correlations, suggesting that they had the same geochemical behaviors or sources. By contrast, in Hendourabi Island Mn had significant correlation with V but it did not show significant correlation with Ni, Pb and Co as observed in the samples from Kharg Island. On the other hand, Co revealed significant negative correlation with Cr in contrast to that of Kharg Island. This indicates some unusual events or source impact geochemical behavior for Cr. Cu showed a significant correlation with Ba in Hendourabi Island.

Sr and U revealed a strong significant correlation in Kharg and Hendourabi Islands. Mg also showed significant strong pairwise correlations with Sr and U in Kharg Island. Previous studies suggest that these elements are likely impacted by seawater temperature (Mitsuguchi et al. 1996; Wei et al. 2000).

Cd in Kharg Island, and Zn and Mg in Hendourabi Island did not show significant correlations with other metals suggesting that their contamination sources and characteristics may be different.

In Kharg Island, the PCA analysis explaining Mn, V, Pb, Zn, Ni and half of Mg, Cr and Co did correspond to peaks of these elements arising in periods of 1988 and 1992 - 1993 in which subsamples scores on PC1 were higher. There were high concentrations of six elements within these two periods. The concentrations of Zn, Cd, Ni, V, Mn and Pb may be high in oil polluted areas (Fu et al. 2014; Ahmad Dasuki et al. 2015). Military activities or war could have an impact on the environment. For example shipwreck during the Persian Gulf war have caused extensive marine pollution (Sanderson et al. 2010; Sato 2010) during which two wars occurred (i.e., Iran - Iraq war, 1980-1988, the Iraq and Kuwait Gulf war (1990-1991). During the first war, as named as tanker war, the oil terminal and oil tankers at Kharg Island were attacked in early 1984 and 1988. The regional conflicts have been considered as source for trace metal contamination in the ocean as recorded in the coral (Wang et al. 2011).

During the Gulf war (1990 – 1991), the largest marine pollution event occurred in the Persian Gulf that an estimated 10.8 million barrels of oil were spilled from tankers and oil terminals and also oil fallout from the smoke plumes of the over 600 oil-well blow-outs and fires in near the coastal areas of Kuwait (Reynolds 1993; Tawfiq and Olsen 1993). It is likely that Kharg's distance from Kuwait and regional counter clockwise water circulation pattern may have led to the effects of this pollution within the time period of 1992-1993 on Kharg Island. Therefore, the PC1 in figure 6 could be related to the military activities and wars.

The PC2 correlated highly with Sr, U and Mg. As reported in previous studies, geochemical behavior of Sr, U and Mg in corals are impacted by SST, and these elements could be indicators of change in SST (Wei et al. 2000; Eakin and Grottol, 2006). Therefore it can be concluded that in Kharg Island, PC2 may explain the impact of SST variation. The PC3 corresponded to Cr and Co showed that these metals were impacted by other factors.

In Hendourabi Island, the PC1 correlated highly with Mn, Cr, Co, Ni and half of Ba. Although the concentration of most trace metals have been detected in oil polluted areas (Ahmad Dasuki et al. 2015), Ba could be a signal of land use, river or flood inputs (Lewis et al. 2007; Prouty et al. 2010), Hendourabi Island as a wildlife refuge has not been exposed to any direct pollution. Yet, the results of this study revealed mean level of trace elements (except Ba) in Hendourabi Island coral lower than other locations worldwide. Hendourabi Island has not any river input, so it may be inferred to precipitation. Precipitation between 2000 - 2016 in Lavan Island as the closest island to Hendourabi Island (25 km) may has led to increment of trace metals in corals from the Hendourabi Island that might be driven from land runoff and precipitation through the sea. PC1 may represent the effect of precipitation and runoff between 2000 - 2015. Mn, Cr, Co, Ni and Ba in Hendourabi Island may be due to the terrestrial inputs. Harbor construction in Hendourabi Island in 2016, may be a source of trace metals as explained in PC2.

In Hendourabi Island, the PC2 correlated with Ba, Zn and U. rate of Ba was very high in 2016, that may be due to a large-scale infrastructure constructions including harbor and airport construction. Thus, the higher scores of PC2 suggest contamination by Ba that may be driven from infrastructure development (Prouty et al. 2010).

Conclusion

Coral reef experienced increased manmade pressure that have been presented in the form of elevated concentrations of trace metals in their skeleton. The elevated concentrations of trace metals in coral skeletons may be reliable indicators for environmental change. In conclusion, except for Cr, other trace metals in coral skeleton from Kharg Island had higher levels than that in Hendourabi Island suggesting that corals in Kharg Island seems to be more polluted than in Hendourabi Island. The coral reefs in Kharg Island have experienced significant impact driven by regional conflicts and oil pollution as indicated in the geochemical behaviors of Mn, V, Pb, Zn, Ni, Mg, Cr and Co. Yet, the rates of Sr, U and Mg in coral skeletons are likely been affected by the changes in SST. In the case of Hendourabi Island, local activities such as harbor construction are likely the main factors for geochemical behaviors of Ba, Zn and U. The high concentrations for Mn, Cr, Co, Ni and Ba in Hendourabi Island are likely associated with terrestrial inputs.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by M Bolouki Kourandeh, SM.B Nabavi, M.R Shokri, K Ghanemi, and Y Feng. The first draft of the manuscript was written by M Bolouki Kourandeh and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Map of study area and sampling locations. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Variation in concentration (ppb) of trace metals in coral samples of Kharg Island within period of 1982 – 2015 (Left) and within period of 2000-2016 in Hendourabi Island (Right).

Figure 3

Results of nMDS plot obtained from Euclidean distance measure representing the concentration of trace metals in coral samples collected from Kharg and Hendurabi islands.

Figure 4

Results of nMDS test obtained from Euclidean distance demonstrating the concentration of trace metals in coral samples collected from Kharg Island (left) and Hendourabi Island (right) during different years.

Figure 5

Loading 3-D plot for trace elements produced from PCA, (a) Kharg Island with three principal components and (b) Hendourabi Island with two principal components with Varimax rotation solution.

Figure 6

Principal score1 for Kharg Island based on the principal components with Varimax rotation solution.

Figure 7

Principal scores 2 (left) and 3 (right) for Kharg Island based on the principal components with Varimax rotation solution

Figure 8

Principal scores 1 (left) and 2 (right) for Hendourabi Island based on the principal components with Varimax rotation solution