Research Article

Ecological risk assessment of heavy metal contamination in mangrove forest sediment of Gulf of Khambhat region, West Coast of India

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Abstract
Mangrove forests are in severe threat from heavy metals pollution stimulated by the several human activities connected with hasty industrialization and urbanization. Heavy metals contamination of mangrove ecosystems has caused serious concern worldwide. The objective of the present research is to identify the heavy metal pollution in the mangrove forest sediments of the Gulf of Khambhat, Gujarat, India. The samples were collected from the 12 selected sites of the GoK and investigated for Pb, Cu, Cd, Cr, Ni, As, Co, Mn, Zn, and Hg using Inductively Coupled Plasma Mass Spectrometry. The abundance of heavy metals concentration in the sediment were found in the decreasing order of Mn > Zn > Cr > Ni > Cu > Pb > As > Co > Hg > Cd with average concentration of 669.07, 84.02, 48.19, 34.66, 11.64, 7.14, 2.79, 0.25, 0.12, 0.09 mg/kg respectively. The contamination status of each metal in the sediment of GoK was assessed by various pollution indices and assesses their prospective ecological risk to the environment. The pollution indexes confirmed that Zn and Hg moderately contaminated the surface sediment of GoK due to anthropogenic activities. The concentration of the significant metals described in this study would be helpful as a reference point for assessment in future sediment quality research.

Keywords Heavy metals · Sediments · Eco-toxicological · Contamination assessments · Pollution indices · Ecological risk · Mangrove forest

1 Introduction

The Gulf of Khambhat, west coast of India, is the leading ecosystem of marine areas. The pollution of the marine environment is known to increase due to coastal developmental activities viz. industries, ports, jetties, mining, and other human activities have become a worldwide problem. The coastal zone receives waste generated by several points and non-point sources, especially sewerage, industrial effluents, solid waste, sediment, petroleum hydrocarbons, agricultural chemicals runoff, fertilizers, and pesticides. The marine sediments are one of the leading reservoirs for the heavy metals in coastal areas. Heavy metal contamination in the coastal water and sediments has expanded in recent years due to its possible impacts on the biosphere [1–3]. Heavy metal in the soil is an important indicator for monitoring the environmental quality of any ecosystem. Heavy metals are supposed to most severe toxic contaminants in the environment attributable to their harmfulness, tenacity, non-biodegradable, and bioaccumulation issues [4–7]. Mangroves forest are environmentally significant constituents of the coastal ecosystems and currently under severe threat worldwide [8]. Heavy metal contamination in mangrove forests is a genuine problem, which has been comprehensively studied around the globe [9, 10]. Marine sediments are a reservoir of heavy metals and are conveyed straight from the source of contamination from seawater [11, 12].

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The mangrove sediments are contaminated with heavy metals in different ways such as effluents disposal, terrestrial or surface runoff, chemicals instigating from diverse human-induced activities, industrial activities, farming activities, and atmospherically deposition [13–16]. Mostly heavy metals are discharged into coastal water and estuaries at several sites due to mining practices, industrial and port activities. Together with significant metals, many pollutants are toxic to aquatic organisms and turn out lethal or sub-lethal adverse effects on biota. Mangrove forest sediments favoring the retention of water-borne trace metals because they are anaerobic and reduce in nature, as well as being rich in organic matter and sulphide [17, 18]. Salinity, freshwater discharge, flow rates, and geomorphological arrangement are important factors that affect the heavy metals concentration within the sediments among gulfs [19].

Many research studies have been performed worldwide on diverse traits of toxic elements with their dispersal, toxicity, insistent nature, bioaccumulation ability, and possible eco-toxicological hazards to evaluate the anthropogenic influences in various marine ecosystems [20–23]. The environmental strain can be observed through the ecological risk linked to concentrations of different toxic elements within sediments and contamination degree [24–26].

Sediments play a significant role within the surface assimilation of dissolved heavy metals, controlling the concentration of metals in several aquatic ecosystems, behaviors of metals, sedimentation, and re-suspension determining the pollution patterns of coastal ecosystems. Sediment quality assessment tools are useful in identifying sediment quality conditions in which adverse biological effects are more likely to occur. Several sediment quality assessment tools were used to assess the quality of sediments such as the geo-accumulation index, enrichment factor, contamination factor, degree of contamination, and pollution load index [27, 28].

The present research study was conducted to inspect the heavy metals contamination in the mangrove forest sediments of the Gulf of Khambhat, Gujarat, India, through different sediment quality assessment tools and to explore the pollution nature of sediment using multivariate and cluster exploration.

2 Materials and methods

2.1 Study area

The Gulf of Khambhat region (formerly known as the Gulf of Cambay), Gujarat, India is located at the latitude of 21° 00′ N–22° 18′ N and longitude of 72° 15′ E and 72° 45′ E (Fig. 1) covering about 3120 km^2 and an elevation of 8 m (26 feet) above mean sea level (MSL). The gulf is 130 km in length, 70 km in width, and has a depth of 30 m [29]. Spread over 1, 85,365 ha, this wetland is identified as Intertidal mudflats, creeks, salt pans, salt marsh, and mangroves, etc. The Gulf of Khambhat, covering 400 km long coastline forms about one-fourth of the total coastline of the state. The Gulf of Khambhat receives treated and untreated wastewater from the industries in the region. The Cross-section width between the site BGS and BDS is 27 km; the distance between the BDS and SDB is around 60 km, and the distance between site SDB and site NPE is 19 km. The details of sampling sites are given below (Table 1).

2.2 Sample collection and analytical procedures

The surface sediment samples were collected at a depth of 0–20 cm through a sampler from four different sites {three subsamples of sediment from each site ($n = 12$)} of the inter-tidal regions of the mangrove forest, GoK, India during monsoon season, immediately transferred to airtight containers. The sediment samples were desiccated in a hot air oven at 110 °C for 24 h, ground in a mortar, and then passed through a 2 mm plastic sieve. Well-mixed 2 g soil samples were treated with 10 mL of freshly prepared aqua regia ($HNO_3 + 3HCl$) on a sand bath for 2 h. After the samples were completely dried, the samples were dissolved in 10 mL of 2% HNO_3, filtered via Whatman filter paper No 541, and then diluted to 50 mL with miliq water [30]. The acid digested sediment samples were transferred into acid-washed plastic bottles and analyzed for lead, copper, cadmium, chromium, nickel, cobalt, manganese, and zinc using an inductively coupled plasma mass spectrometry (ICP-MS). The sediment samples were prepared as per the method suggested by Mohammed et al. [31] to analyze the volatile elements such as arsenic and mercury. The sediment samples were predigested at 24–26 °C for 24 h. Again, the samples were digested on a hot plate at 60–150 °C using 65% HNO_3, 37% HCl and 30% H_2O_2-ACS grade (Sigma-Aldrich, USA). After the digestion process, the samples were cooled and filtered using Whatman filter paper No. 541. The final volume was made up to 50 mL with distilled water and stored in acid-washed plastic bottles at 4 °C until analysis.

2.3 Estimation of heavy metal contamination indicators

The heavy metals contamination indicators such as geo-accumulation index (Igeo), enrichment factor (EF), contamination factor (CF), degree of contamination (CD), and pollution load index (PLI) were estimated for

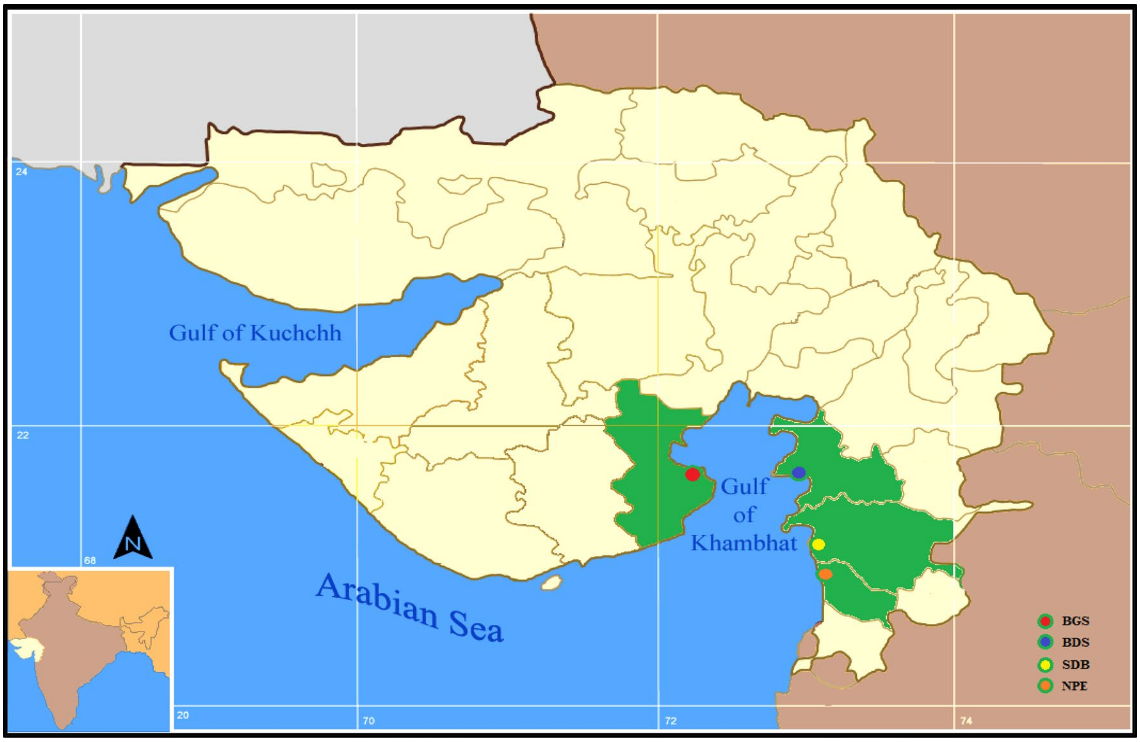

Fig. 1 The map presenting the sampling sites of the Gulf of Khambhat region, Gujarat, India

Table 1 Locations of sediment samples collection

Location	Sampling points	Latitude	Longitude
Bhavnagar (BGS)	BGS1	21° 40′ 21.7″ N	72° 17′ 07.1″ E
	BGS2	21° 40′ 14.0″ N	72° 17′ 07.1″ E
	BGS3	21° 40′ 04.9″ N	72° 17′ 08.4″ E
Bharuch (BDS)	BDS1	21° 71′ 38.6″ N	72° 52′ 66.6″ E
	BDS2	21° 71′ 62.6″ N	72° 52′ 74.4″ E
	BDS2	21° 71′ 94.5″ N	72° 52′ 80.3″ E
Surat (SDB)	SDB1	21° 04′ 43.7″ N	72° 42′ 34.0″ E
	SDB2	21° 04′ 41.1″ N	72° 42′ 43.9″ E
	SDB3	21° 04′ 37.4″ N	72° 42′ 53.2″ E
Navsari (NPE)	NPE1	20° 55′ 24.0″ N	72° 47′ 12.6″ E
	NPE2	20° 55′ 22.4″ N	72° 47′ 22.0″ E
	NPE3	20° 55′ 21.4″ N	72° 47′ 20.1″ E

evaluating the heavy metals contamination in the sediment. Average concentrations or background values utilized in the various equations for Igeo, EF, CF, and PLI were taken from Turekian and Wedepohl [32] were used for the present study because the background levels of some of the trace metals vary generally depending upon the locations.

2.4 Determination of geoaccumulation index (Igeo)

Possible heavy metals enrichment in sediment was evaluated in terms of the geo-accumulation index. The Igeo values indicates the status of metals pollution in core sediments. The Igeo was calculated to measure the metal contamination in sediments [33] by Eq. (1):

$$\mathrm{Igeo} = \log_2\left[\mathrm{Cn}/(1.5 \times \mathrm{Bn})\right] \tag{1}$$

where Cn is analyzed concentration of metal (n) in the sediment, Bn is the background value of metal (n), and factor 1.5 is taken to reduce the effect of potential deviations in the background concentration that might be accredited to lithological differences in the sediments [34]. According to this method, the heavy metal pollution in the sediments was divided into seven classes of Geoaccumulation Index (Table 2).

2.5 Determination of enrichment factor (EF)

The enrichment factor was used to measure the contamination degree and also the probable human-induced influences in the sediments of the Gulf of Khambhat region, Gujarat. The metal concentrations within the sediments were standardized to the textural character of the

Table 2 Heavy metal contamination categories based on the geo-accumulation index (Igeo)

Class	Metal pollution status	Igeo values
0	Uncontaminated	Igeo ≤ 0
1	Uncontaminated to Moderately contaminated	0 < Igeo < 1
2	Moderately contaminated	1 < Igeo < 2
3	Moderately to Severely contaminated	2 < Igeo < 3
4	Strongly contaminated	3 < Igeo < 4
5	Strongly to Enormously contaminated	4 < Igeo < 5
6	Enormously contaminated	5 > Igeo

Table 3 Categories of heavy metal contamination based on contamination factor and contamination degree

Class	CF values	CD values	Sediment quality
1	CF < 1	CD < 6	Low Contamination
2	1 ≤ CF < 3	6 ≤ CD < 12	Moderate Contamination
3	3 ≤ CF < 6	12 ≤ CD < 24	Considerable Contamination
4	CF ≥ 6	CD ≥ 24	Excessive Contamination

sediments using EF. The EF is a relatively easy tool to analyze the enrichment degree and relating the pollution of various ecological media [35]. Manganese (Mn), which is the principal component of coastal sediments was used to normalize the metals in the sediments. Heavy metal contamination classes based on enrichment factor (EF), no enrichment if the EF < 1, minor enrichment if EF = 1–3, moderate enrichment if EF = 3–5, and extremely severe enrichment if EF > 5 [36].

In the current study, Mn was used as a conservative tracer to distinguish between natural and human-induced constituents. The enrichment factors calculation can be performed using Eq. (2) as suggested by Zoller et al. [37].

$$EF = \frac{[M/Mn]\ \text{Sample}}{[M/Mn]\ \text{Background}} \quad (2)$$

where $[M/Mn]_{Sample}$ is the proportion of metal concentration to the concentrations of Mn in the sample, $[M/Mn]_{Background}$ is the proportion of background concentration of metal and background concentration of Mn.

2.6 Determination of contamination factors, contamination degree, and pollution load index (PLI)

The pollution load assessment of the sediments to heavy metals using contamination factor (CF) and contamination degree (CD) has delivered four grades of sediments based on CF and CD values respectively [38, 39] (Table 3).

The pollution load index delivers a proportional means to evaluate the eminence of a study site as indicated by Tomlinson et al. [40]. A value of PLI < 1 indicates unpolluted whereas PLI > 1 recommends the presence of pollutants of the sites [41]. CF, CD, and PLI were calculated using the following Eqs. 3, 4 and 5 respectively:

$$CF = C_{metal}/C_{background} \quad (3)$$

$$CD = \sum_{i=1}^{n} Cf^{i} \quad (4)$$

$$PLI = {}^{n}\sqrt{(CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)} \quad (5)$$

where C_{metal} = concentration of analyzed metal, $C_{background}$ = background value of analyzed metal, and n = number of metals.

2.7 Statistical analysis

The pollution indices (Igeo, CF, CD, EF, and PLI) were used to measure the degree of metals pollution in sediment. The correlation coefficient between heavy metals was used to establish the association between two variables. The principal component factors (PCFs) was used to observe relationship among the variables and to classify the key components regulating the geochemistry of significant metals in the sediments of the Gulf of Khambhat. All the statistical analysis were performed using the IBM SPSS statistics software package (version 20).

3 Results and discussion

3.1 Heavy metal concentrations in sediments

The mean concentrations and distributions of 10 trace metals were detected in the mangrove forest sediments of four selected study sites. The sampling sites displayed a flexible range of metals concentration mainly due to the impact of various ecological parameters, numerous sources of pollution, and land-use patterns. The findings indicated the highest mean concentration of Mn in the sediments, trailed by the subsequent trend Zn > Cr > Ni > Cu > Pb > As > Co > Hg > Cd. The distribution of different heavy metals in the sediment along the coastline of the Gulf of Khambhat, Gujarat are presented in Table 4. The observed concentrations of different metals showed that the majority of the heavy metals were found below the geochemical background value of average shale, whereas mercury (Hg) was found above the geochemical background value of average shale.

Table 4 Level of heavy metals concentration in mangrove forest sediments from Gulf of Khambhat region, Gujarat

Location	Sampling points	Metal concentration (mg/kg dry weight)									
		Pb	Cu	Cd	Cr	Mn	Ni	Zn	As	Co	Hg
Bhavnagar (BGS)	BGS1	6.833	9.369	0.066	45.421	630.77	32.15	76.383	2.835	0.125	0.078
	BGS2	6.856	9.372	0.068	45.508	630.82	32.21	76.428	2.842	0.128	0.082
	BGS3	6.902	9.285	0.072	45.488	630.52	32.17	76.352	2.46	0.13	0.075
Bharuch (BDS)	BDS1	7.378	12.035	0.084	49.921	700.058	36.066	85.783	2.978	0.326	0.053
	BDS2	7.362	12.041	0.087	49.932	700.152	36.072	85.792	2.982	0.328	0.062
	BDS3	7.385	12.038	0.085	49.938	700.095	36.077	85.788	2.985	0.332	0.058
Surat (SDB)	SDB1	6.014	11.89	0.064	39.962	587.701	32.032	85.379	2.621	0.284	0.039
	SDB2	6.018	11.95	0.066	39.985	587.705	32.035	85.382	2.629	0.288	0.042
	SDB3	6.02	11.93	0.069	39.955	587.709	32.039	85.388	2.632	0.29	0.043
Navsari (NPE)	NPE1	8.275	13.256	0.122	57.373	757.543	38.328	88.525	2.872	0.236	0.299
	NPE2	8.285	13.259	0.125	57.402	757.555	38.342	88.53	2.864	0.239	0.295
	NPE3	8.288	13.266	0.127	57.385	757.562	38.339	88.532	2.879	0.241	0.298
	Min.	6.014	9.369	0.066	39.955	587.701	32.032	76.352	2.46	0.125	0.039
	Max.	8.288	13.266	0.127	57.420	757.562	38.342	88.532	2.985	0.332	0.299
	Average	7.135	11.641	0.086	48.189	669.016	34.655	84.022	2.798	0.246	0.119
	SD	0.858	1.491	0.024	6.659	67.859	2.791	4.774	0.171	0.079	0.109
	ASV[a]	20	45	0.3	90	850	68	95	13	19	0.08
	SQG[b]	21	28	1	8.1	30	20.9	68	6	–	0.1
	SQG, ERM[c]	218	270	9.6	370	–	51.6	410	70	–	0.71
	SQG, ERL[c]	46.7	34	1.2	81	–	20.9	150	8.2	–	0.15
	SQG, PEL[c]	112	108	4.21	160	–	42.8	271	41.6	–	0.7
	SQG, TEL[c]	30.24	18.7	0.68	52.3	–	15.9	124	7.24	–	0.13
	PL[d]	47.82	49.98	0.65	76	–	23.77	140.48	11.29	–	0.23

Min Minimum, *Max* maximum, *SD* standard deviation, *ASV* average shale values, *SQG* sediment quality guidelines, *ERM* effect range median, *ERL* effect range low, *PEL* probable effect level, *TEL* threshold effect level, *PL* permissible limit

[a]Turekian and Wedepohl [32]

[b]USEPA (1999)

[c]Buchman (2008)

[d]USEPA (2004)

The heavy metal concentrations were found in commercially important fish and crustacean species within the Gulf of Khambhat can represent the earlier as well as the present contamination status [42]. Numerous biogeochemical processes and anthropogenic factors play a crucial part in fluctuating the heavy metals concentration in the mangrove forest sediments [19].

The important sources of metals in the marine ecosystem includes various human-induced impacts like disposal of industrial effluents and domestic wastes [43–45]. The selected region has come across huge industrial development such as plastic, pharmaceuticals, textiles, paper, and pesticides. Additionally, the region also gets enormous sewage from the adjacent urban area [46]. The vehicular emission, open dumping of solid waste, burning of waste have also caused steady deposition and accretion of toxic metals in the marine ecosystem [47, 48].

Kehrig et al. [49] described that the Jequia mangrove forest in Brazil was extremely contaminated from different toxic metals by the man-made sources adjoining the gulf. Similarly, Ramanathan et al. [50] also revealed that the distribution of heavy metals were found beneath the levels in contaminated and uncontaminated creeks and mangroves forest sediments in the Pichavaram mangrove forest, India.

The comparative analysis of the heavy metal levels in the four selected locations, BGS (Bhavnagar), BDS (Bharuch), SDB (Surat), and NPE (Navsari) showed that Pb, Cu, Cd, Cr, Ni, Mn, Zn, and Hg levels at NPE site are higher than those detected at BGS, BDS, and SDB sites. However, As and Co recorded higher concentrations at the BDS than those detected at the three other sites.

3.2 Correlation analysis

The coefficient of correlation matrix of heavy metals contained by the sediments of Gulf of khambhat region are presented in Table 5. The correlation analysis specified that Ni is strongly correlated with Mn (r = 0.97), Cr (r = 94), Cd (r = 0.94), Pb (r = 0.93), Cu (r = 0.75), Zn (r = 0.70), Hg (r = 0.78) at the 0.01 level (2-tailed) and As (r = 0.68) at the 0.05 level (2-tailed). Hg is strongly correlated with Pb (r = 0.84), Cd (r = 0.94), Cr (r = 0.86), Mn (r = 0.80), Ni (r = 0.78) and no correlation with Co & Pb at the 0.05 level. Pb is intensely correlated with Cr (r = 0.99), Cd (r = 0.92), Mn (r = 0.98), Ni (r = 0.93) and Hg (r = 0.84) at the 0.01 level (2-tailed). Cu is intensely correlated with Cd (r = 0.72), Zn (r = 0.99), Ni (r = 0.75), Co (r = 0.71) at the 0.1 level (2-tailed) and Mn (r = 0.59), Hg (r = 0.56) at the 0.05 level (2-tailed). The highly significant positive correlations between soil heavy metals indicated the possibility of comparable source input which are maybe natural or anthropogenic [51].

3.3 Analysis of principal component factor

Principal component analysis can deliver an informal approach to discuss the correlated data sets [52]. PCA was executed for 10 selected metals, two principal components are extracted covering 89.52% of the cumulative variance (Table 6). The loading of the variables on the two principal components showed that Pb, Cd, Cr, Mn, Ni, and Hg were the dominant variables on the PC1 (.986, .932, .986, .954, .891, and .906 respectively); whereas Cu, Zn and Co (.849, .901, and .968 respectively) were the dominant variables on the PC2 (Fig. 2). PC1 was primarily influenced by an anthropogenic influence from industrial processes, surface overflow, and disposal of waste materials, while PC2, in the main influenced by the natural earth science background. Nour [53] also reported similar findings for principal component factors at the southern coast of the Sinai Peninsula on the Gulf of Aqaba and revealed that heavy metals such as cadmium, iron, lead, copper, zinc, manganese, cobalt, and nickel might be resulting from human-induced activities. Zhou et al. [54] specified that heavy metals are naturally present in sediment posture minerals of oceanic geological deposits besides anthropogenic amelioration.

Table 6 Varimax rotated component matrix for two principal component factors (PCFs)

Variables	PCF1	PCF2	Communalities
Pb	0.986	–	0.979
Cu	0.454	0.849	0.927
Cd	0.932	–	0.952
Cr	0.986	–	0.990
Mn	0.954	–	0.969
Ni	0.891	0.441	0.988
Zn	0.369	0.901	0.948
As	0.560	0.334	0.425
Co	–	0.968	0.951
Hg	0.906	–	0.822
Eigenvalue	6.008	2.944	–
% of variance	60.077	29.438	–
% of cumulative variance	60.077	89.515	–

3.4 Assessment of heavy metals contamination

The heavy metal contamination of the selected sites was evaluated using various pollution indices such as geo-accumulation index (Fig. 3), enrichment factor (Fig. 4), contamination factor (Table 7), degree of contamination (Table 7), and pollution load index (Table 7).

Table 5 Pearson correlation coefficient matrix among significant metals within the sediments of Gulf of Khambhat region, Gujarat

	Pb	Cu	Cd	Cr	Mn	Ni	Zn	As	Co	Hg
Pb	1									
Cu	0.482	1								
Cd	0.92**	0.72**	1							
Cr	0.99**	0.53	0.94**	1						
Mn	0.98**	0.59*	0.93**	0.99**	1					
Ni	0.93**	0.75**	0.94**	0.94**	0.97**	1				
Zn	0.40	0.99**	0.65*	0.46	0.53	0.70**	1			
As	0.62*	0.37	0.46	0.62*	0.69**	0.68*	0.36	1		
Co	− 0.01	0.71**	0.13	0.030	0.15	0.34	0.78**	0.35	1	
Hg	0.84**	0.56*	0.94**	0.86**	0.80**	0.78**	0.47	0.27	− 0.15	1

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

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

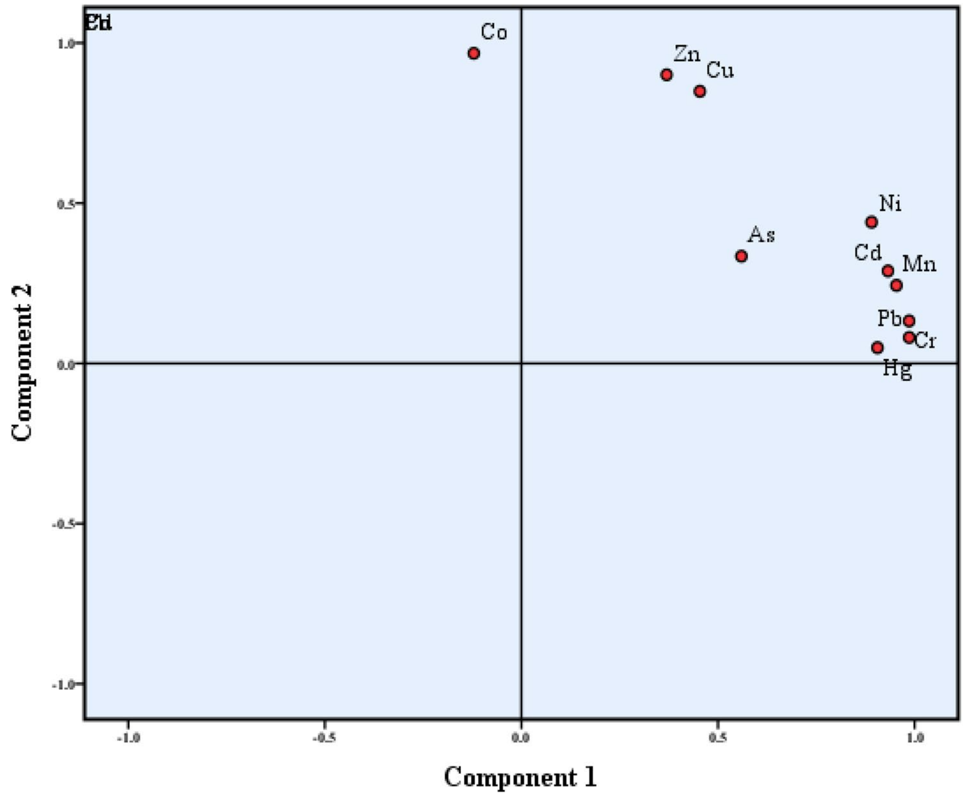

Fig. 2 Rotated space component plot

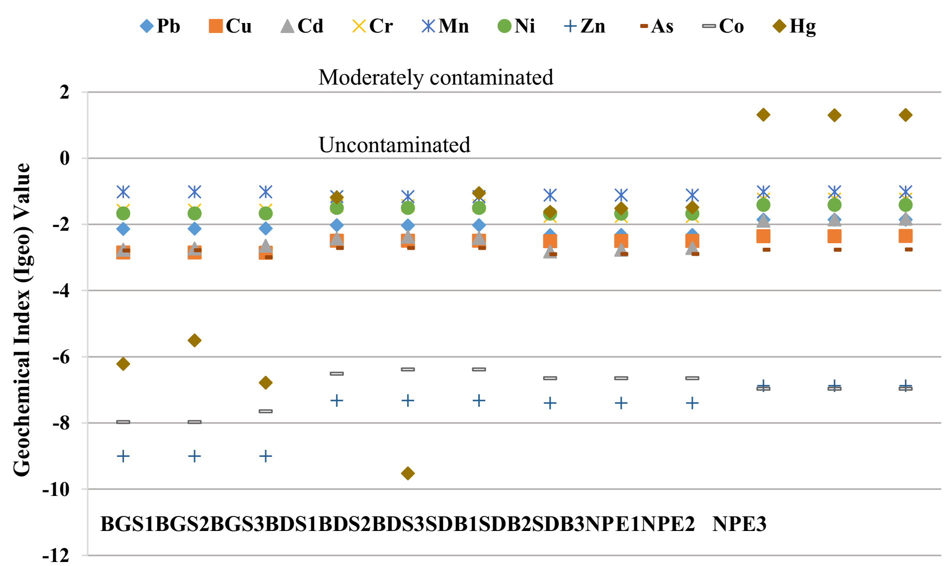

Fig. 3 Geo-accumulation Index of various metals in surface sediments of Gulf of Khambhat

3.4.1 Geoaccumulation index

The geoaccumulation index for Gulf of Khambhat, shows that all the selected metals (Pb, Cu, Cd, Cr, Ni, As, Co, Mn, and Zn) fall under class 0 of Muller's grade scale (Fig. 3), whereas mercury (Hg) was placed moderate (Igeo, class = 2) for sediments at NPE sites. High accumulation of Hg at NPE sites shows anthropogenic influences.

Karbassi et al. [55] described that geo-accumulation values can be applied efficiently to determine sediment quality. The observed Igeo values in the present study recommend that the sediments of the Gulf of Khambhat are uncontaminated. The occurrence of different metals in sediment might be due to the combination of increased particulate material with comparatively unpolluted sediments [56].

Fig. 4 Enrichment factors of various metals in surface sediments of the Gulf of Khambhat

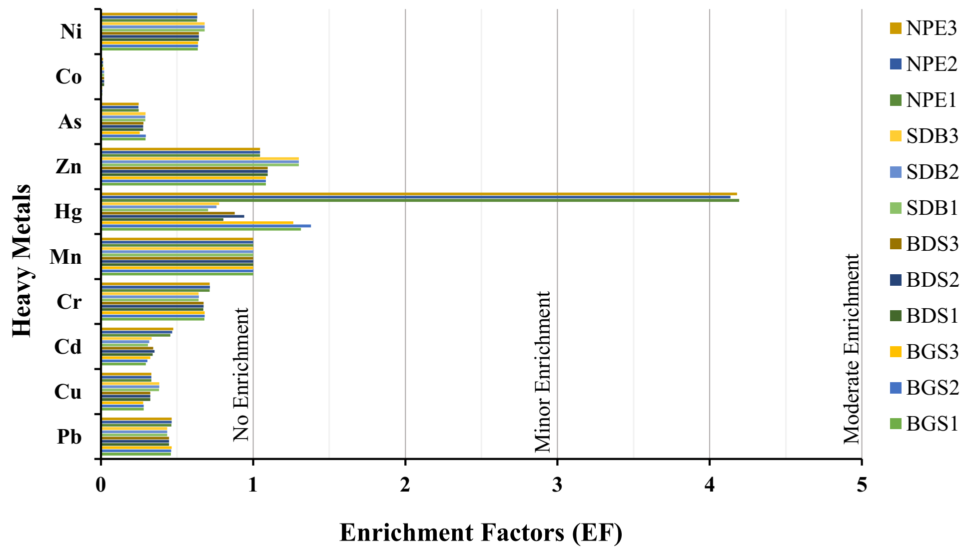

Table 7 Contamination factor (CF), Contamination degree (CD), and Pollution Load Index (PLI) for sediments

Sites	Contamination factor [a](Cf)											
	Pb	Cu	Cd	Cr	Mn	Ni	Zn	As	Co	Hg	[b](CD)	PLI
BGS	0.343	0.208	0.229	0.505	0.742	0.473	0.804	0.209	0.007	0.979	4.499	0.283
BDS	0.369	0.268	0.284	0.555	0.824	0.530	0.903	0.229	0.017	0.721	4.700	0.333
SDB	0.301	0.265	0.221	0.444	0.691	0.471	0.899	0.202	0.015	0.517	4.026	0.285
NPE	0.414	0.295	0.416	0.638	0.891	0.564	0.932	0.221	0.013	3.717	8.099	0.418
Average	0.357	0.259	0.288	0.535	0.787	0.510	0.884	0.215	0.013	1.483	5.331	0.340

[a](Cf) is the contamination factor

[b](Cd)is the contamination degree

3.4.2 Enrichment factor (EF)

The enrichment factor values of sediments at the various sampling points are demonstrated in Fig. 4. The EF values of lead (Pb) ranged 0.435–0.465; copper (Cu) 0.278–0.384; cadmium (Cd) 0.296–0.475; chromium (Cr) 0.642–0.716; nickel (Ni) 0.632–0.681; arsenic (As) 0.247–0.295; cobalt (Co) 0.009–0.022; zinc (Zn) 1.046–1.300; mercury (Hg) 0.705–4.194 in the sediment of the study area. The findings indicated that mercury (Hg) was resulting from various anthropogenic sources at the NPE site because enrichment factor values were observed more than 1.5 according to Zhang and Liu [57]. The potential sources of contaminants are tourist activities, boat painting, plastic wastes, and gasoline combustion. Moreover, waste-water might be one of the most significant causes of various metals like cadmium, lead, and cobalt [53].

3.4.3 Contamination factor (CF), degree of contamination (CD), and pollution load index (PLI)

The spatial distribution of contamination factors for heavy metals (Pb, Cu, Cd, Cr, Mn, Ni, Zn, As, Co, and Hg) in selected sites were demonstrated in Table 7. Concerning heavy metal pollution, the contamination factors and contamination degree values of the study sites indicated that each metal is causing low contamination except mercury (Hg), which is considerably contaminated NPE site with CF-3.717, and CD-8.099. The PLI was calculated for every sampling site using Pb, Cu, Cd, Cr, Mn, Ni, Zn, As, Co, and Hg (Table 7). The mean PLI values specified that the sediments of the study area are uncontaminated with heavy metals as PLI values ranged from 0.283 to 0.418 (PLI < 1). The configuration for greatly to the slightest polluted sites was NPE > BDS > SDB > BGS.

4 Conclusion

Heavy metal contamination along the Gulf of Khambhat coastal region was investigated by analyzing the concentrations of different metals in the sediments at twelve sampling points. The conclusions of the present research shown the presence of Cu, Cd, Pb, Cr, Ni, As, Co, Zn, Mn, and Hg in the sediments of the Gulf of Khambhat. The pollution assessment approaches enabled us to define the significant contents of heavy metals in the selected region of the Gulf of Khambhat. The contamination was described by the multivariate and statistical approaches, including correlation analysis, principal component factors (PCFs) analysis. The examination of CFs, PLIs, and Igeo recognized these metals as the major contaminants in the sediments of the selected study area. Several pollution indices such as EF, Igeo, CF, and PLI designated that the sediments are facing adequate pollution and an insignificant level of ecological risk, however mercury (Hg) was found beyond the permissible limit. The concentrations of the studied metals in sediments were lesser than the resultant ASV at all of the sampling points showing that adversative effects do not arise often for all locations excluding NPE sampling points by mercury. The Hg concentrations in the sediments were significantly higher than the geochemical background value of average shale representing that the industrial activity may have increased the heavy metal concentrations in these sediments. The higher concentration of Hg in the sediments usually reaches the coastal waters from industrial establishments in the region which require either Hg as raw material or as a catalyst such as plastic industries, chlorine, and alkali plants. The findings of contamination factors and degree of contamination indicate that Hg concentration needs to be monitored to avoid potential pollution risk in the future. The increasing sediment pollution from a different point and non-point sources can impact the elemental profiling of the adjoining biotic community.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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