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Assessment of bioaccumulation potential of mangroves along the coast of Maharashtra, India using statistical indices

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Mangroves are a group of plants growing in estuarine region. These species survive well in saline environment with some adaptations in them. The members of family Avicenniaceae and Sonneratiaceae are of accumulating in nature and may bio-accumulate the pollutants from sediments and water. In order to improve the comprehensive understanding of heavy metal tolerance, the sediments and plant material (leaves) of mangroves were analyzed for heavy metals concentration from different creeks and estuaries of Maharashtra coast using atomic absorption spectrophotometer. The mangrove sediments were analyzed for indices such as enrichment factor, pollution load index, geo-accumulation index etc. to understand the level of pollutants. The bioaccumulation factor was also estimated to understand the bioaccumulation potential mangrove species i.e. *Avicennia marina* and *Sonneratia apetala*. The former species is commonly known as pollution tolerate, while the latter is pioneer in mangrove succession. The objectives of the study were to understand the potential of *S. apetala* in phytoremediation of heavy metals from both sediments and waste water. The mangrove sites like Kandalwada and Uran are on the borderline of pollution and needs proper protection and management.

[**Keywords:** *Avicennia*, Bioaccumulation, Heavy metal, Maharashtra, Mangroves, *Sonneratia*]

Introduction

Mangroves are the important coastal barrier and act as a boundary between the sea and the land. This group of plants sustain well in saline environment. The mangroves bear salt accumulation, salt exclusion and salt excretion mechanism which helps them to avoid heavy loads of salt through a combination of these mechanisms[1]. A separate filtration mechanism and some advanced adaptations in the root system help them to survive in saline conditions.

Although the mangroves grow in tidal environment and have the ability to sustain saline environment, now a days they are exposed to adverse environmental conditions because of human interference. The uncontrolled urbanization and industrial establishments in the coastal region exerts elevated pressure on this vegetation. The human encroachment, sewage disposal, industrial discharge, transportation, dredging and shipping etc. continuously load pollutants in the mangrove ecosystem. Moreover, addition of heavy metals from the urban, recreational and industrial development has posed a threat on mangrove ecosystems[2].

Heavy metals found naturally in the earth's crust and their composition varies among different localities[3,4] and helps in governing various biochemical processes and physiological functions in living organisms at low concentrations. The increasing concentration of heavy metals in plants have adverse effect on various metabolic processes and is directly proportional to the concentration of metals in the surrounding environment like water, sediments and period of exposure[5].

Bioaccumulation of heavy metals in mangrove species is one of the indicators for monitoring the coastal heavy metals pollution[6] and the mangroves contributes to remediation by redistributing pollutants between the land and sea[7]. Mangroves sediments usually exceed heavy metal concentration and such high concentrations leads to bioaccumulation in animal and plant species within mangrove environment[8,9]. These heavy metals cannot be degraded easily and therefore stay accumulated into the plant tissues. It is generally considered that the different mangroves species have metal accumulation abilities and can tolerate heavy metal pollution at relatively higher rate[10].

On this background, the species i.e. *Sonneratia apetala* Buch. Ham. and *Avicennia marina* (Forsk) Virrh were analyzed for heavy metal concentration.

Materials and Methods

Study sites

The soil samples and plant material i.e. leaves of *S. apetala* and *A. marina* were collected from different localities like Uran (18.87, 72.94), Mithaghar (18.27,73.04), Usadi, Vashi-Pen, Kaleshri, Revdanda, Kural, Revas, Vashi-Haveli, Nidi and Kandalwada, Maharashtra (Plate 1). The collected soil and plant samples were dried, crushed, sieved and used for heavy metal analysis.

Determination of heavy metal concentration

The dried soil and plant samples were analyzed for different heavy metals such as Cadmium, Cobalt, Lead, Zinc, Copper, and Iron usingAtomic Absorption Spectrophotometer (Thermo Scientific, AA 203, Waltham, MA USA)[11].

Indices

The indices, namely contamination factor, enrichment factor, pollution load index, and geo-accumulation index were used to assess the metal pollution in intertidal mangrove sediments, and to assess the bioaccumulation potential.

Contamination factor

The contamination factor (CF) is an indicator of contamination through toxic substances. It is expressed as concentration of metal with respect to the background value (natural content of metal in the soil) of that metal in the sediments[12].

CF = metal concentration in sediment/ background value of metal.

Enrichment factor

Enrichment Factor (EF) is used to assess the presence and intensity of anthropogenic contaminant deposition on surface soil and is calculated by the normalization of one metal concentration with respect to the concentration of a reference element. A reference element (e.g. Fe) characterized by absence of vertical mobility and degradation phenomena and is stable in the soil. The EF is calculated using following equation[17]:

$$EFs = (C_x/Fe)_{sample} / (C_x/Fe)_{shale}$$

Where, (C_x/Fe) and (C_x/Fe) are sample and average shale values,

Pollution load index

The pollution load index (PLI) is the concentration factor of each heavy metal with respect to the background values of that metal in the sediment[13].

$$PLI = (CF1 \times CF2 \times CF3 \times \ldots\ldots \times CF_n)^{1/n}$$

Where, n = number of metals and CF = contamination factors.

Geoaccumulation index

Geoaccumulation index (I_{geo}) is calculated suing flowing equation[15].

$$I_{geo} = \log_2 (C_n/1.5_{Bn})$$

Where, C_n is the concentration of the element n in the sediment sample and B_n is geochemical background value of the element n of average shale.

Bioaccumulation factor

Bioaccumulation factor is defined as the ratio between C_{biota}/C_{soil}, where C_{biota} and C_{soil} are the total metal concentration in plant and soil, respectively[15].

Results and Discussion

The concentration of heavy metals in the soil varies significantly with the sites (Table 1). The sediments of Kandalwada were found to be rich in Cd, Co and Pb. While the Zn and Cu content was higher in Vashi-Haveli sediments. All the heavy metals were ranged between 0.25-0.9, 16.8-30.25, 8.5-161, 0.78-9.1, 1.13-17.45 and 8.95-33.5 for Cd, Co, Pb, Zn, Cu and Fe, respectively. The order of concentration for these metals is observed as Pb >Fe >Co >Cu >Zn >Cd. In the sediments of Dongzhai harbor (Hainan Island, China) the order of metal accumulation was reported as Zn >Pb >Cu >As >Cd[16]. The potential source of lead include industrial processes, food, drinking water as well as domestic sources, but the currently examined site does not have any domestic discharges as it is away from the main stream[4]. The mean concentration of heavy metal such as Cu, Pb, Zn, Cd, Cr, Hg and As were 15 ± 9, 24 ± 9, 58 ± 37, 0.2 ± 0.1, 30 ± 20, 0.08 ± 0.04 and 10 ± 4 g g^{-1} in mangrove sediments was reported earlier[3]. The lead has more positive correlation with cadmium (Table 2) and Zn is negatively correlated with other heavy metals. Coefficient of determination (Table 3) interpreted as proportion of variance and ranges from 0 to 1.0 indicate the dependent variation cannot be predicted from the independent variable and 1 indicates its prediction.

Pollution indices

Contamination factor

The range for contamination factor (CF) varies from less than 1 to more than 6. The CF for the

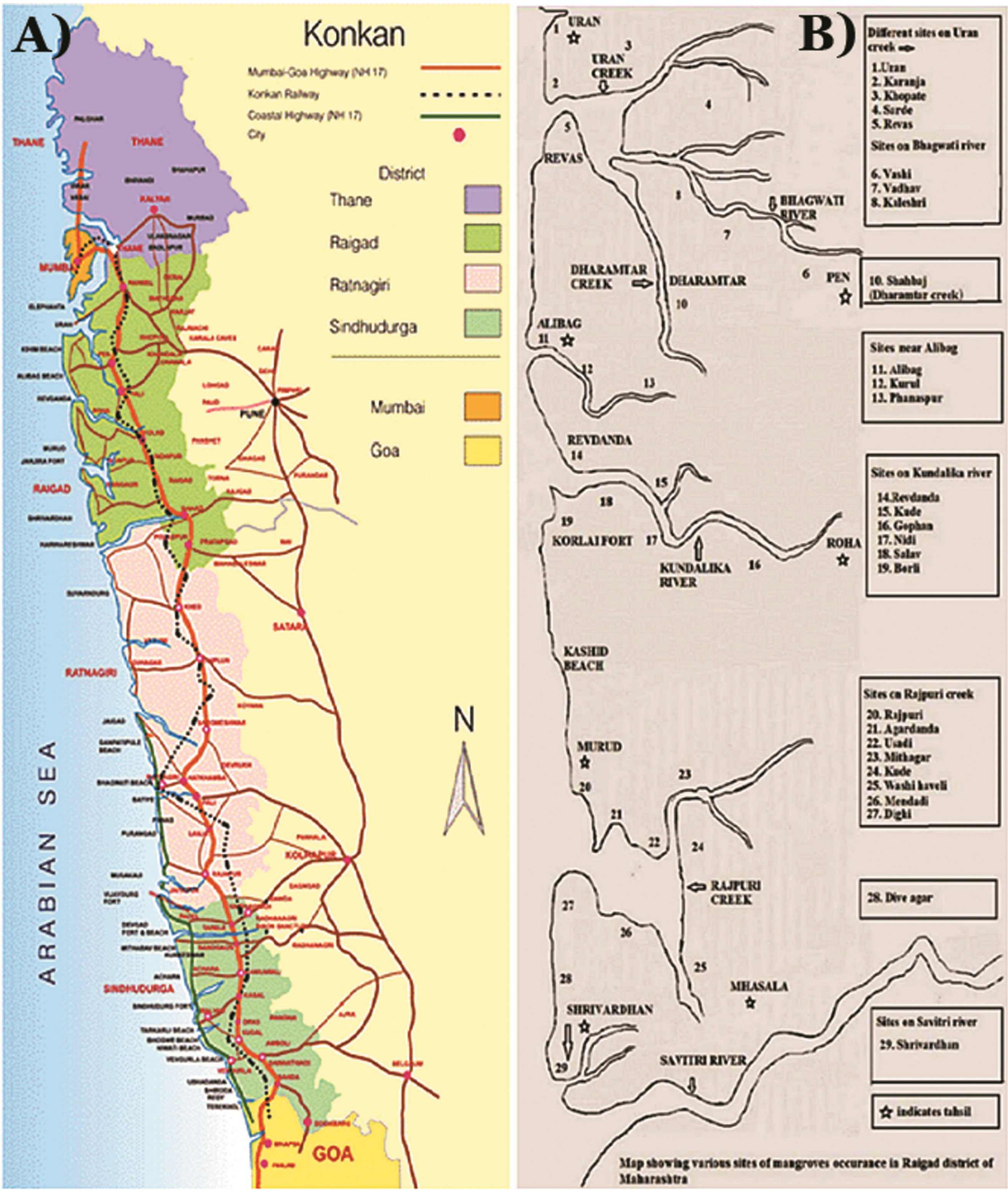

Plate 1 — A) Map of coastal region of Maharashtra and B) Map of Raigad District of Maharashtra

studied heavy metals range from 0.833-3, 0.88-1.59, 0.425-8.05, 0 .008-0.095, 0.025-0.387, 0.189-0.709 for Cd, Co, Pb, Zn, Cu and Fe respectively, indicating low to moderate level of contamination in the sediments

(Table 4). The concentration of lead at Kandalwada is alarming. Similar observations were reported in Sg, Puloh mangrove estuary of Malaysia indicating very high concentration of Pb and Cd is above baseline value and mangrove sites are medium to moderately contaminate with Cd. The high Pb CFs could be result of scavenging and agricultural runoff[17-19].

Enrichment Factor

Enrichment factor is a convenient measure of geochemical trends and used as a tool to differentiate between anthropogenic and natural occurring metal in the sediments[20-22]. Fe is used as a normalizer because it is the fourth major element of earth crust, and has little or no adverse environmental concerns[22]. The enrichment factor classified as EF <1 indicate no enrichment, 1-3 indicate minor enrichment, 3-5 moderate enrichment, 5-10 moderate to severe, 10-25 severe enrichment, 25-50 very severe and more than 50 indicates extremely sever enrichment[17]. The result (Table 5) of present work ranged between 0.024-11.342, indicating site and metal specific enrichment for Zn and Cu, the factor is less than 1, and Cd, Co and Pb it is moderate to severe except, the lead at Kandalwada indicating severe enrichment. The values of EF are more than 1 for Pb, Zn and Cu[20] and metal enrichment is site specific[17].

Table 1 — Concentration of heavy metals in various study sites

Site	Cadmium	Cobalt	Lead	Zinc	Copper	Iron
Uran	NA	NA	NA	4.15	2.45	11.4
Revas	0.43	21.7	14.75	1.93	9.34	26.37
Usadi	0.46	20.95	19.4	6.67	10.03	30.95
Vashi-Haveli	0.25	26.8	8.5	9.1	17.45	32.35
Vashi-Pen	0.37	23.6	17.1	1.6	1.13	27.8
Revdanda	0.35	19.7	9.75	1.42	14.18	22.25
Nidi	0.43	21	17.85	1.33	3.75	15.38
Kurul	0.33	16.8	11	3.33	4.58	24.53
Mithaghar	0.34	24.25	9.8	2.03	8.16	32.15
Kaleshri	0.37	22.5	13.85	0.78	4.5	8.95
Kandalwada	0.9	30.25	161	1.65	10.04	33.5
Mean	0.423	22.755	28.3	2.984	8.316	25.423
Min	0.25	16.8	8.5	0.78	1.13	8.95
Max	0.9	30.25	161	9.1	17.45	33.5
Average shale*	0.3	19	20	95	45	47.2
STDEV	0.211	7.736	45.189	2.609	5.070	8.703
CV (%)	49.88	33.99	159.67	87.43	60.96	34.23

*Turekian and Wedepohl (1961)

Pollution load index

The pollution load index (PLI) is the estimated geometric mean of relative concentration factor of selected heavy metal of a seemingly polluted site. For assessing the extent of pollution at a site for a selected number of metals, the PLI are used as integrated tool[23]. The PLI value equal to 1 suggests absence of pollution, where PLI >1 suggests the site is polluted[24]. The range of PLI as PLI = 0 indicates background concentration, 0-1 unpolluted, 1-2 moderately to unpolluted, 2-3 moderately polluted, 3-4 moderately to highly polluted, 4-5 highly polluted and >5 very highly polluted[25]. In the present work, the range of PLI is 0.082 to 0.684, the highest PLI at Kandalwada and lowest at Uran (Table 6). The PLI values range from 0.08 to 0.17[ref. 20], 0.25-0.72[ref. 15] and 0.122 to 2.898[ref. 19] similar to our results at different study sites.

Geo- accumulation Index

Geo accumulation index determines the sediment contamination by organic and inorganic substances by

Table 2 — Correlation coefficient of different heavy metals

	Cadmium	Cobalt	Lead	Zinc	Copper	Iron
Cadmium	1	0.74258468	0.867336	-0.30304	0.191185	0.47177
Cobalt		1	0.479074	-0.05614	0.443719	0.6187
Lead			1	-0.20464	0.136075	0.381307
Zinc				1	0.515246	0.369695
Copper					1	0.538748
Iron						1

Table 3 — Coefficient of determination of different heavy metals

	Cadmium	Cobalt	Lead	Zinc	Copper	Iron
Cadmium	1	0.752272	0.091833	0.036552	0.222567	0.752272
Cobalt		1	0.229512	0.003152	0.196887	0.38279
Lead			1	0.041878	0.018516	0.145395
Zinc				1	0.265478	0.136674
Copper					1	0.290249
Iron						1

Table 4 — Contamination factor

Site	Cadmium	Cobalt	Lead	Zinc	Copper	Iron
Uran	-	-	-	0.043	0.054	0.241
Revas	1.433	1.14	0.737	0.020	0.207	0.558
Usadi	1.533	1.1	0.97	0.070	0.222	0.655
Vashi-Haveli	0.833	1.41	0.425	0.095	0.387	0.685
Vashi-Pen	1.233	1.24	0.855	0.016	0.025	0.588
Revdanda	1.166	1.04	0.487	0.014	0.315	0.471
Nidi	1.433	1.11	0.892	0.014	0.083	0.325
Kurul	1.1	0.88	0.55	0.035	0.101	0.519
Mithaghar	1.133	1.28	0.49	0.021	0.181	0.681
Kaleshri	1.233	1.18	0.692	0.008	0.1	0.189
Kandalwada	3	1.59	8.05	0.017	0.223	0.709

Table 5 — Enrichment Factor

Site	Cadmium	Cobalt	Lead	Zinc	Copper
Uran	-	-	-	0.180	0.225
Revas	2.565	2.044	1.320	0.036	0.371
Usadi	2.338	1.681	1.479	0.107	0.339
Vashi-Haveli	1.215	2.058	0.620	0.139	0.565
Vashi-Pen	2.094	2.108	1.451	0.028	0.042
Revdanda	2.474	2.199	1.034	0.031	0.668
Nidi	4.398	3.391	2.739	0.042	0.255
Kurul	2.116	1.701	1.058	0.067	0.195
Mithaghar	1.663	1.873	0.719	0.031	0.266
Kaleshri	6.504	6.245	3.652	0.043	0.527
Kandalwada	4.226	2.243	11.342	0.024	0.314

Table 6 — Pollution load index

Site	PLI
Uran	0.082
Revas	0.375
Usadi	0.505
Vashi-Haveli	0.482
Vashi-Pen	0.259
Revdanda	0.327
Nidi	0.284
Kurul	0.314
Mithaghar	0.350
Kaleshri	0.231
Kandalwada	0.684

comparing present metal concentration with preindustrial levels. Geo-accumulaton index (I_{geo}) is classified as I_{geo}<0 unpolluted, 0-1 unpolluted to moderately polluted, 1-2 moderately polluted, 2-3 moderately polluted to strongly polluted, 3-4 strongly polluted, 4-5 strongly polluted to extremely polluted, I_{geo} >5 extremely polluted[25]. In the present work it was observed that the highest value for lead at Kandalwada and lowest at Vashi-Haveli (Table 7). The surface sediment of Sg. Poluh mangrove estuary, Malaysia is moderately polluted by Cd and Pb,

Table 7 — Geo-accumulation index

Site	Cadmium	Cobalt	Lead	Zinc	Copper	Iron
Uran	-	-	-	-5.101	-4.784	-2.634
Revas	-0.065	-0.393	-1.024	-6.206	-2.853	-1.424
Usadi	0.031	-0.444	-0.628	-4.417	-2.750	-1.193
Vashi-Haveli	-0.848	-0.088	-1.819	-3.968	-1.951	-1.129
Vashi-Pen	-0.282	-0.272	-0.810	-6.476	-5.900	-1.348
Revdanda	-0.362	-0.532	-1.621	-6.648	-2.251	-1.669
Nidi	-0.065	-0.440	-0.749	-6.743	-4.169	-2.202
Kurul	-0.447	-0.762	-1.447	-5.419	-3.881	-1.529
Mithaghar	-0.404	-0.232	-1.614	-6.133	-3.048	-1.138
Kaleshri	-0.282	-0.341	-1.115	-7.513	-3.906	-2.983
Kandalwada	1	0.085	2.424	-6.432	-2.749	-1.079

Table 8 — Nemerow Pollution index (Pn)

Site	Pn
Uran	0.420
Revas	1.024
Usadi	1.070
Vashi-Haveli	1.011
Vashi-Pen	0.974
Revdanda	0.934
Nidi	1.010
Kurul	0.902
Mithaghar	0.977
Kaleshri	0.948
Kandalwada	2.270

moderately to strongly polluted by Zn[17]. In our result, the Kandalwada is moderately polluted with Cd and Co and strongly polluted by lead. The mangrove ecosystem of Ghana is unpolluted by Cd, Pb and Zn[19] but our results shows that the sediment is moderately polluted by Cd and Co, and strongly polluted by Pb.

Nemerow Pollution Index (Pn)

Nemerow Pollution Index used to know the status of the surface soil by heavy metals and to assess the quality of soil environment[27,28]. The range of Nemerow pollution index (Pn) is Pn <0.7: no pollution, 0.7-1: pollution warning line, 1-2: low-level of pollution, 2-3: moderate level of pollution and Pn >3: is high level of pollution[16]. The result of present work (Table 8) shows that Mithaghar, Vashi-pen, Kaleshri, Revdanda, Kural are on warning line, low-level occurs at Revas, Vashi Haveli and Nidi whereas Kandalwada is moderately polluted.

Bioaccumulation factor

Environmental pollutants, metals are non-biodegradable and they can undergo biomagnifications in living tissue[29]. Bioaccumulation factor (BAF) or bio concentration factor (BCF) is defined as a ratio of metal concentration in plant shoot

Table 9 — Bioaccumulation factor for different concentration of heavy metal in *A. marina* andn *S. apetala*

Site	Species	Cadmium	Cobalt	Lead	Zinc	Copper	Iron
Uran	*A. marina*	-	-	-	6.120	4.897	69.035
	S. apetala	-	-	-	6.602	5.918	11.666
Revas	*A. marina*	1.860	0.188	0.203	7.979	1.0171	11.376
	S. apetala	-	-	-	-	-	-
Usadi	*A. marina*	1.739	0.234	0.257	2.098	1.096	51.114
	S. apetala	-	-	-	-	-	-
Vashi-Haveli	*A. marina*	-	-	-	-	-	-
	S. apetala	1.400	0.182	2.941	2.417	0.401	11.282
Vashi-Pen	*A. marina*	-	-	-	-	-	-
	S. apetala	1.162	0.360	1.549	17.187	8.407	12.877
Revdanda	*A. marina*	0.971	0.030	3.333	20.070	1.692	40.134
	S. apetala	0.800	0.568	3.261	15.492	0.528	20.943

to extractable concentration of metal in the soil. It is the progressive increase in the amount of metal in a living plant because the rate of intake exceeds the plant's ability to remove substance from the body[30]. The uptake of metals from the soil depends on different factors such as their soluble content, soil pH, plant growth stages, types of species, etc[31,32].

Bioaccumulation factor studied for *A. marina* and *S. apetala* from the sites of their occurrence (Table 9), it is observed that *A. marina* is important bio-accumulator of Iron. The largest value recorded at Uran followed by Usadi and Revdanda. The values for Cd, Pb and Zn are more or less similar for the both the species at Revdanda and Uran, while more accumulation of cobalt in *S. apetala* is notable, indicating its accumulation potential.

Conclusion

Some of the sites especially Kandalwada and Uran are on the border line of pollution. Kandalwada is in the interior and comparatively protected site, but even then the pollution level is alarming for some of the metals while the port activities in Uran have raised tremendous pressure. Eco-restoration of the species like *S. apetala* and *A. marina* will be helpful for phytoremediation of these pollutants from mangrove habitat and being a pioneer species, *S. apetala* may become important alternative for the mangrove conservation program.

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Conflict of Interest

The authors whose names are listed have NO conflict of interest in the subject matter or materials discussed in this manuscript.

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