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Assessment of Heavy Metal Concentration in Seawater and Sediments from Selected Areas of Ratnagiri Coast [Maharashtra, India]

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ABSTRACT

Heavy metal contamination in marine ecosystems has emerged as a major environmental concern due to their persistence, toxicity, non-biodegradable nature and strong tendency for bioaccumulation and bio magnification in aquatic food webs. Coastal regions are particularly vulnerable to heavy metal pollution because they receive inputs from various resources like terrestrial runoff and industrial discharge. Once introduced into the aquatic system, heavy metals are distributed among the dissolved phase, suspended particles and bottom sediments, with sediments acting as both a sink and secondary source of metal contamination. The present study investigates the distribution and seasonal variations of selected heavy metals in seawater, sediments and organic matter along the Ratnagiri coast of Konkan region in Maharashtra state. Ratnagiri is an important coastal region characterized by intense fishing activities, tourism development and the pressure of increasing anthropogenic establishments. Industrial effluents, agricultural runoff, domestic wastewater, port activities and natural weathering of lateritic soils are the prime contributors to the release of heavy metals into the coastal marine ecosystems. Samples of seawater, sediment and organic matter were collected from multiple locations along the Ratnagiri coastline at seasonally. Further, they were subjected for the heavy metal analysis by using various analytical methods for different metals. The results indicated measurable concentrations of heavy metals in all environmental matrices studied. Zinc showed relatively higher concentrations compared to other metals, whereas the detection of mercury at one sampling site is of particular concern due to its high toxicity and potential for bioaccumulation in marine organisms. Seasonal variations in metal concentrations were also observed. It indicated the influence of hydrological conditions, sediment dynamics and anthropogenic inputs. As a result, the present study highlights that coastal sediments act as reservoir of heavy metals and may release them back into the water column under changing physicochemical conditions. The presence of heavy metals in coastal ecosystems possess potential ecological risks and may affect fishery resources as well as human health through the seafood consumption, continuous monitoring and effective Management strategies are therefore essential to control heavy metal pollution in the Ratnagiri coastal region.

Keywords: Heavy metals, Coastal pollution, Ratnagiri coast, Marine ecosystem.

Introduction

Coastal ecosystems provide essential ecosystem services such as fisheries, nutrient cycling, and shoreline protection, yet face increasing pressures from anthropogenic pollution including heavy metals. Heavy metals such as mercury (Hg), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn) are persistent, toxic pollutants that accumulate in marine organisms through bioaccumulation and biomagnification, posing risks to ecosystem health and human consumers [5, 6].These metals enter coastal waters via industrial effluents, agricultural runoff, urban wastewater, and port activities, where they partition across seawater, suspended particles, and sediments [11,15]. Sediments serve as both sinks and secondary sources of contamination, releasing metals under changing environmental conditions [21, 24].

In marine surroundings, heavy essence does in colorful physicochemical forms and are distributed among different environmental chambers including the dissolved phase in seawater, suspended patches, and nethermost sediments. The partitioning of essence among these chambers is controlled by several environmental factors similar as pH, saltness, redox eventuality, organic matter content, and hydrodynamic conditions [18, 20]. Essence may live as free ions, inorganic complexes, or adsorbed onto particulate matter in the water column. Suspended patches, including complexion minerals and organic debris, play a pivotal part in transporting essence through submarine systems. Ultimately, these patches settle and deposit on the seabed, leading to the accumulation of essence in littoral sediments. Sediments thus serve as an important Gomorrah for heavy essence in submarine surroundings [21,22]. Due to their high face area and reactive mineral factors, fine- granulated sediments similar as complexion and ground have a strong capacity to adsorb and retain essence ions. Processes similar as adsorption, rush, and complexation with organic matter grease the long- term storehouse of essence within deposition matrices. Over time, sediments can accumulate significant attention of heavy essence, frequently exceeding those set up in the overlying water column [23,24]. Environmental parameters including deposition flyspeck size, organic auto-bon content, and microbial exertion impact the speciation, mobility, and bioavailability of essence within sediments. Accordingly, sediments act not only as a depository but also as a implicit secondary source of heavy essence impurity when environmental conditions change, leading to the remobilization of preliminarily deposited essence.

The ecological counteraccusations of heavy essence impurity in littoral surroundings are substantial. Numerous heavy essence parade high toxin indeed at fairly low concentrations, affecting a wide range of marine organisms including phytoplankton, oceanographic pets, fish, and marine mammals [25,27]. Essence similar as cadmium and mercury are particularly dangerous due to their strong affinity for natural apkins and their capability to intrude with metabolic and enzymatic processes. Dragged exposure to elevated essence attention can beget physiological stress, reproductive impairment, growth inhibition, and mortality in submarine organisms. Likewise, heavy essence can accumulate in organisms through bioaccumulation and latterly suffer bio magnification along submarine food chains. As a result, bloodsuckers enwrapping advanced trophic situations may accumulate significantly advanced attention of poisonous essence compared to organisms at lower trophic situations. This miracle poses serious pitfalls to ecosystem health as well as to mortal populations that calculate on seafood as a primary source of protein [28, 30]. Coastal sediments play a particularly important part in the transfer of heavy essence to oceanographic organisms [31,33]. Numerous oceanographic species similar as polychaetes, mollusks, and crustaceans live in close contact with sediments and ingest deposition patches as part of their feeding geste. Accordingly, these organisms are largely vulnerable to heavy essence exposure and frequently serve as bioindicators of environmental impurity. Changes in deposition chemistry may impact the bioavailability of essence and determine the extent to which they can enter the marine food web. Habitual exposure to defiled sediments can alter oceanographic community structures, reduce biodiversity, and disrupt ecological processes similar as nutrient cycling and deposition bioturbation.

India's 7,500 km coastline supports millions through fisheries and tourism, but rapid industrialization and urbanization have elevated heavy metal levels in coastal waters and sediments [34,36]. Studies from Maharashtra, Gujarat, Tamil Nadu, and Kerala report significant contamination linked to port operations, petrochemical industries, and urban development [37,40]. The Ratnagiri coast along the Konkan region of Maharashtra, characterized by high monsoon rainfall (2,500–3,500 mm annually), lateritic soils, and growing tourism and fishing activities, remains underexplored despite its ecological and economic importance. Because of its toxicity, persistence, and lack of biodegradability, heavy metal pollution in marine settings has become a major worldwide environmental concern.

Three main compartments make up the distribution of heavy metals in marine systems: dissolved phase in bottom sediments, suspended particles, and seawater. Physicochemical factors like pH, salinity, redox potential, organic matter content, and hydrodynamic circumstances control how metals are distributed across different phases (Zhao et al., 2013; Suresh et al., 2015). Heavy metals are transported and eventually deposited in sediments by suspended particles. As a result, in marine ecosystems, sediments are the last sink for heavy metals (Li et al., 2018).

In the dynamics of heavy metals, sediments have two roles. On the one hand, they serve as reservoirs, gradually accumulating metals through complexation with organic matter, precipitation, and adsorption. However, they are able to act as secondary sources of contamination as the environment shifts and previously bonded metals become remobilized (Birch, 2017; Ostner, 2011). Because of their wide surface area and increased organic content, fine-grained sediments especially clay and silt have a higher adsorption capacity, which makes them essential for regulating the bioavailability of metals.

High concentrations of heavy metals have been found in coastal sediments all around the world, according to numerous studies. For example, Gao and Chen (2013) found that industrial discharge significantly contaminated surface sediments, whereas Wang et al. (2016) highlighted the dangers to the environment posed by heavy metal buildup in marine sediments. According to Reddy et al. (2004) and Veerasingam et al. (2015), research conducted in coastal areas of India, such as the Bay of Bengal and Arabian Sea, have revealed rising levels of heavy metal pollution associated with fast industrialization and urbanization.

Heavy metals have significant biological effects in maritime habitats. Metals like cadmium and mercury can be extremely hazardous to marine life, even at low amounts. These metals cause physiological stress, growth suppression, reproductive failure, and mortality by interfering with enzymatic and metabolic processes (Rainbow, 2007; Wang et al., 2018). Additionally, heavy metals have a great propensity for bioaccumulation and biomagnification, which raises their concentrations at higher trophic levels. This presents significant threats to human health through seafood intake as well as marine biodiversity (Singh et al., 2018). Because of their intimate relationship to sediments, benthic organisms such as mollusks, crustaceans, and polychaetes—are especially susceptible to heavy metal exposure.

According to Zhang et al. (2017), these organisms frequently act as bioindicators of environmental pollution. The bioavailability and absorption of metals can be greatly impacted by changes in sediment chemistry, which might have an impact on the composition and functionality of benthic communities. Reduced biodiversity and disturbance of ecological processes like nitrogen cycling can result from long-term exposure to polluted sediments.

RESEARCH GAP

Even though a lot of study has been done on heavy metal contamination in marine habitats both internationally and in India, there are still a number of important gaps, especially when it comes to the Ratnagiri coast:

1. **Deficiency in Integrated Multi-Matrix Analysis:**
The majority of research focuses on sediments or seawater separately. Integrated studies that examine heavy metals in seawater, sediments, and organic matter at the same time to comprehend their linkages and transmission mechanisms are scarce.

2. **Limited Temporal and Seasonal Information:**
Insufficient research has been done on the seasonal dynamics of heavy metal distribution in the Ratnagiri region, particularly under monsoonal impact. There is also a dearth of long-term monitoring data.

3. **Insufficient Research on Source Apportionment:**
Few studies have used sophisticated statistical or geochemical indicators to statistically differentiate between anthropogenic and natural (lithogenic) sources of heavy metals.

4. **Inadequate Ecological and Human Health Risk Evaluation:**
Comprehensive ecological risk assessments and human health risk evaluations through seafood eating are still few, despite the availability of concentration data.

5. **Underrepresentation of New Analytical Methods:**
The precision of understanding metal bioavailability is limited since advanced techniques like ICP-MS for ultra-trace detection and speciation investigations are not widely used in regional studies.

6. **Ratnagiri Coast Is Not Given Enough Attention:**
Despite growing developmental demands, the Ratnagiri coast has received less investigation than other coastal locations in India.

Conclusion of the Literature Review:

Sediments serve as large reservoirs and potential secondary sources of heavy metal contamination, which is a serious environmental concern in coastal ecosystems, according to the body of available knowledge. For areas like Ratnagiri, localized and thorough research is crucial, even while national and international studies offer a solid theoretical and empirical basis. In addition to improving scientific knowledge, filling in the identified research gaps will aid in the development of effective environmental management and public health and marine ecosystem protection policies.

MATERIALS AND METHODOLOGY

Study Area:

The present investigation was conducted along the Ratnagiri coast of Maharashtra, situated on the western shoreline of India along the Arabian Sea [34,37]. The coastal region is characterized by sandy beaches, rocky outcrops, and estuarine environments. The area is influenced by anthropogenic activities such as fisheries, tourism, and small-scale coastal settlements.

Five representative sampling locations were selected to assess spatial variation in heavy metal concentration. The geographic coordinates of the study sites are presented in Table

Table 1: Sampling Locations with Geographic Coordinates

Site Name	Latitude (°N)	Longitude (°E)
Ganpatipule	17.1448	73.2733
Aare-Ware	16.9895	73.2962
Sakhartar	16.9230	73.3035
Bhatye	16.9890	73.3120
Ganeshgule	16.8795	73.3112

A detailed sampling map was prepared using GIS software to depict the spatial distribution of the selected stations along the Ratnagiri coastline. Geographic coordinates were recorded using a handheld GPS device. The map includes coastal features and nearby anthropogenic influences, enabling better interpretation of pollution sources.

Seasonal Sampling:

Sampling was carried out during three distinct seasons to evaluate temporal variation:

- Pre-monsoon (March–May)
- Monsoon (June–September)
- Post-monsoon (October–February)

Seasonal changes influence metal concentration through runoff, dilution, sediment transport, and biological activity [31,41].

Sample Collection

Seawater Samples: Seawater samples were collected at a depth of approximately 0.5 m using pre-cleaned polyethylene bottles. Samples were acidified with concentrated nitric acid to maintain pH below 2 and stored at 4°C until analysis [42,43].

Sediment Samples

Surface sediment samples (0–5 cm) were collected using a stainless-steel grab sampler. Samples were air-dried, homogenized, and sieved through a 63 µm mesh [44,45].

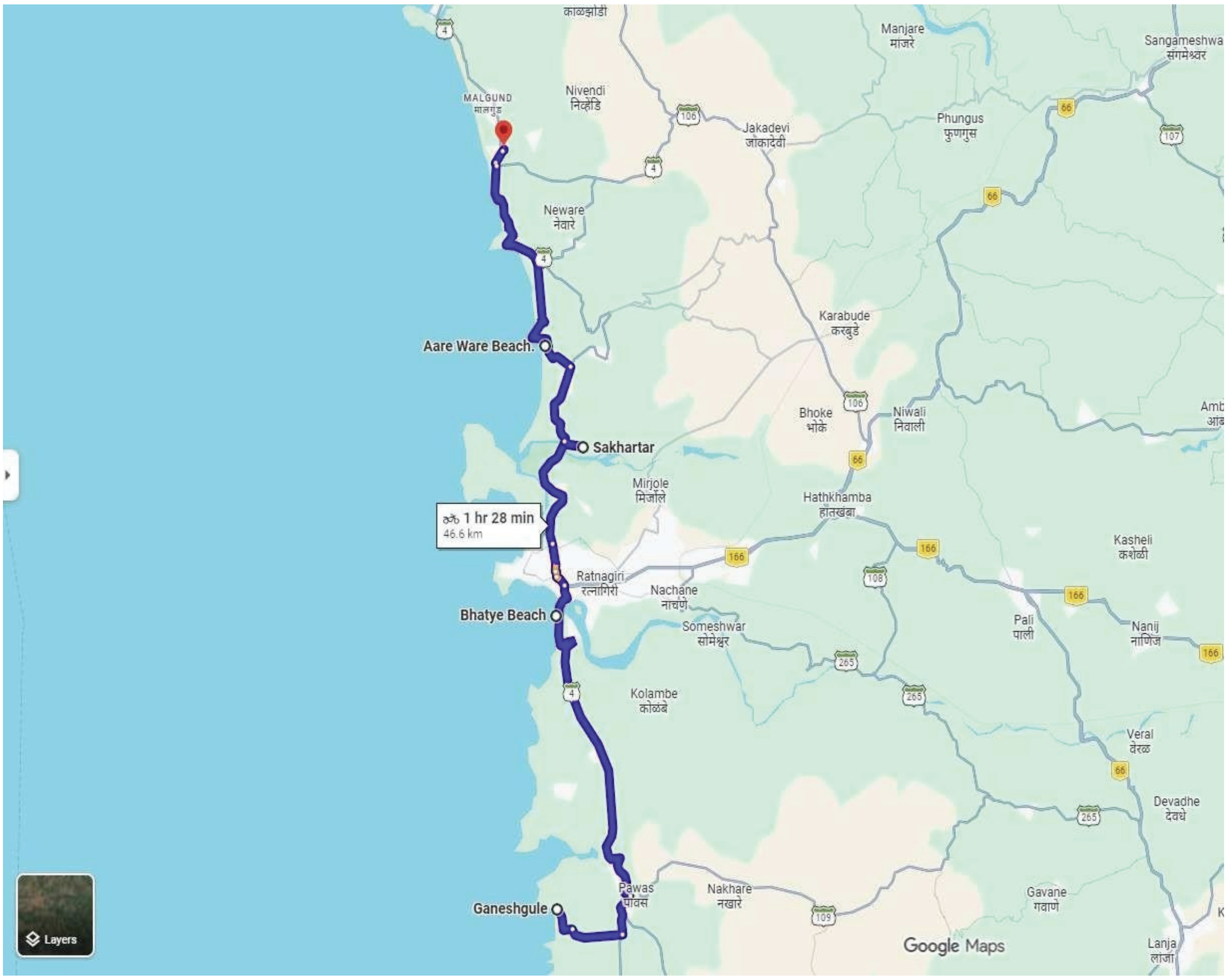

Figure 1: Sampling Location Map:

Sample Preparation

Seawater Samples were filtered using Whatman No. 42 filter paper and subjected to acid digestion where required.

Sediment

Approximately 1 g of dried sediment was digested using nitric acid (HNO3) and perchloric acid (HClO4) until a clear solution was obtained. The digest was filtered and diluted with deionized water.

Heavy Metal Analysis

Atomic Absorption Spectroscopy (AAS)

Seawater and sediment samples were analyzed for the following heavy metals:

- Mercury (Hg)
- Copper (Cu)
- Zinc (Zn)
- Cadmium (Cd)
- Chromium (Cr)
- Lead (Pb)

Calibration standards and blanks were used to ensure analytical accuracy [47].

Permissible Limits of Heavy Metals:

Table 2: WHO/FAO Limits for Water

Metal	Water (mg/L)
Hg	0.001
Cu	2.0
Zn	3.0
Cd	0.003
Cr	0.05
Pb	0.01

Table 3: Sediment Quality Guidelines

Metal	TEL (mg/kg)	PEL (mg/kg)
Hg	0.13	0.70
Cu	18.7	108
Zn	124	271
Cd	0.7	4.2
Cr	52.3	160
Pb	30.2	112

- TEL = Threshold Effect Level (no adverse biological effects expected)
- PEL = Probable Effect Level (adverse effects likely to occur)

Quality Assurance and Quality Control

- All glassware was acid-washed prior to use
- Blanks and duplicate samples were analyzed
- Standard reference materials ensured accuracy
- Calibration curves maintained with R2 > 0.99

Statistical Analysis

Data analysis was performed using MS Excel and SPSS. The following statistical tools were applied:

- Mean and standard deviation
- Analysis of variance (ANOVA)
- Correlation analysis

RESULT AND DISCUSSION:

I. **Table No. 4: Heavy metals concentration (mg/kg) in sediment samples at selected sites**

Sites/Metals	Zn	Cu	Cr	Hg	Pb	Cd
S1 Ganpatipule	38	45	216	21	BDL	BDL
S2 Aare-Ware	17	12	67	14	BDL	BDL
S3 Sakhartar	309	373	155	11	BDL	BDL
S4 Bhatye	118	195	250	29	BDL	BDL
S5 Ganeshgule	13	13	72	18	BDL	BDL

Table No. 5: Heavy metals concentration (mg/L) in water samples at selected sites

Sites/Metals	Zn	Hg	Pb	Cd	Cr	Cu
MW-01 Ganpatipule	0.08	0.008	BDL	BDL	BDL	BDL
MW-02 Aare-Ware	0.15	0.007	BDL	BDL	BDL	BDL
MW-03 Sakhartar	0.14	0.007	BDL	BDL	BDL	BDL
MW-04 Bhatye	1.47	BDL	BDL	BDL	BDL	BDL
MW-05 Ganeshgule	0.07	BDL	BDL	BDL	BDL	BDL

Table No. 4 shows heavy metal concentration (mg/kg) in sediment samples at selected sites along Ratnagiri coast. According to analysis results, the values of metal concentration ranges were observed as follows:

- Zn: 13 – 309 mg/kg
- Cu: 12 – 373 mg/kg
- Cr: 67 – 250 mg/kg
- Hg: 11 – 29 mg/kg
- Pb: BDL
- Cd: BDL

Heavy metal concentrations in sediment samples were found in the decreasing order: (Cu > Zn > Cr > Hg > Pb ≈ Cd) The highest concentration of copper (373 mg/kg) and zinc (309 mg/kg) was observed at Sakhartar site, indicating strong anthropogenic input, possibly due to fishing activi- ties, antifouling paints and localized coastal discharge. Chromium concentrations were relatively high at Bhatye (250 mg/kg), which may be attributed to natural lithogenic sources such as lateritic soil erosion prevalent along Konkan coast. Mercury concentrations were found comparatively elevated at Bhatye (29 mg/kg), suggesting accumulation in fine-grained organic-rich sediments.

Lead and cadmium were below detection limits in all sediment samples, indicating negligible industrial contamination from these metals in the study region. Table No. 5 shows heavy metal concentration (mg/L) in seawater samples at selected sites. According to analysis results, the values of the metal concentration ranges were observed as:

- Zn: 0.07 – 1.47 mg/L
- Hg: BDL – 0.008 mg/L
- Pb: BDL

- Cd: BDL
- Cr: BDL

Heavy metal concentrations in water samples were found in decreasing order: (Zn > Hg > Cu ≈ Pb ≈ Cd ≈ Cr) Zinc showed comparatively higher concentration in all water samples, with maximum value at Bhatye (1.47 mg/L), which is significantly higher than normal seawater back- ground levels, indicating localized contamination. Mercury was detected only at few stations (0.007–0.008 mg/L), suggesting trace-level contamination possibly from anthropogenic sources such as fuel combustion, marine traffic and runoff. Other metals such as Pb, Cd, Cu and Cr were below detection limits, indicating relatively unpolluted marine water conditions.

The present study reveals that heavy metals are more concentrated in sediments than in water, which supports earlier studies stating that sediments act as a sink for heavy metals due to adsorption, precipitation and complexation processes.

I. CONCLUSION:

Present study reveals that Ratnagiri coastal region shows moderate heavy metal contamination with spatial variation among different sites. The seawater quality is relatively good, as most toxic metals such as Pb, Cd, Cu and Cr were found below detection limits. However, elevated levels of zinc and trace presence of mercury indicate initial signs of marine pollution.

Sediment samples showed significantly higher concentrations of metals, particularly copper, zinc, chromium and mercury, indicating long-term accumulation and possible ecological risk. The sites such as Sakhartar and Bhatye were identified as pollution hotspots due to higher metal concentrations. The study clearly indicates that Ratnagiri coastal environment is approaching threshold levels of metal contamination and may become polluted in future if proper management strategies are not implemented. Heavy metals accumulated in sediments may enter the food chain through benthic organisms, posing potential risk to marine life and human health. Therefore, proper monitoring, regulation of anthropogenic activities, and environmental management strategies are necessary to control further contamination.

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