Assessment of pollution load of coastal mudflats along the western bank of Gulf of Khambhat with special reference to microbial community structure as bioindicator

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INTRODUCTION

The interfaces between the land and the water are called coastal regions, and they are home to significant ecosystems and infrastructure. Around 40% of mankind lives within 100 km of coastal areas (Xiong *et al.*, 2023). Coastal regions (including estuaries and deltas) are extremely complex settings with different hydrodynamic and bio-geomorphological contexts, as well as significant socioeconomic and ecological issues. These systems are among the most impacted by human influence as a result of urbanization and port operations, as well as industrial and tourism activities. Climate change has a direct influence on sea level, storm surge frequency and severity, and the recurrence of coastal river floods (Laignel *et al.*, 2023). India has a coastline that stretches for over 8000 km, with nine coastal states, 60 districts, and two main island groupings where fishing provides a living for many Indian populations (Senapati & Gupta, 2014). India, being a developing country, is rapidly industrializing and expanding economically. As a result, the country is dealing with climate change and pollution of the marine environment, posing health risks to marine biota and humans. Out of the nine coastal states in India, Gujarat possesses the longest coastline (about one-fifth of the country's total length), with 49 ports and businesses that support people's livelihoods including the automotive, energy, chemical, and pharmaceutical sectors (MM&FICCI, 2019; Rabari *et al.*, 2022).

Coastal water contains more marine species than open ocean water. Water characteristic in coastal areas is an important component of marine life and its surroundings (Gray, 1997; Zenati *et al.*, 2023). Humans have a substantial detrimental influence on coastal and estuarine ecosystems across the world due to pollution and habitat loss. More than 80% of the sources of marine pollution are industrial, agricultural, and urban activities (Priya *et al.*, 2023). Among the contaminants most typically found in these places are nutrients, plastic debris, metals, and persistent organic pollutants which come from both point and nonpoint sources. The ecological effects of coastal pollution include habitat and biodiversity loss, as well as changes in environmental functions and processes, which result in increased sensitivity to disturbances and a decline in ecosystem services. Aside from all of these consequences, pollution in coastal areas creates public health issues as well as significant economic losses (Bessa *et al.*, 2018; Kanchana *et al.*, 2023; Qian *et al.*, 2015; Sathish *et al.*, 2023).

Sustainable Development Goals (SDG) 14 (Life below water) is one of the UN's worldwide SDGs aimed at reducing marine pollution and its possible harmful consequences,

as well as conserving marine and coastal regions and ecosystems, and is significantly interconnected with and linked to other SDGs (Xiong *et al.*, 2023). Coastal water evaluation and monitoring is a critical and high-priority component of environmental policy (Patel *et al.*, 2022). However, in recent years, much focus has been dedicated to studying the impact of anthropogenic activity on physico-chemical characteristics and dissolved heavy metals of the coastal waters around India to determine marine water properties and productivity (Athira *et al.*, 2022; Hardikar *et al.*, 2017; Kumkar *et al.*, 2023; Naik *et al.*, 2020; Pasumpon *et al.*, 2023; Patra *et al.*, 2023; Pattanaik *et al.*, 2019; Sahoo & Swain, 2023; Vase *et al.*, 2018).

Since aquatic sediments have a direct and indirect impact on other important and non-essential data of those environments due to their interactions, both positively and negatively influencing one another, the study of their physico-chemical properties primarily aims to complement any research conducted in water bodies. Soil salinity, pH, phosphorus, nitrogen, and sulphur have an impact on the biodiversity of the region and the existence or absence of certain living things. Chemical components and elements are also quite important in this. Heavy metals can have a high or low concentration; even necessary heavy metals can become poisonous and fatal (Abuzahrah *et al.*, 2023).

Understanding and supervising human activities in this environment requires comprehensive scientific evaluation and monitoring procedures due to its vulnerability to many types of pollution (Förstner & Wittmann, 1981). As a result of direct transit from pollution sources or precipitation from seawater, marine sediments serve as both a reservoir and a repository for metals. These sediments operate as dynamic metal sinks, impacting metal distribution and cycling within the marine ecosystem (Wang *et al.*, 2018). Several pathways for heavy metal entry into the environment exist such as natural weathering processes in metal-rich rocks and anthropogenic activities including sewage discharge, shipping, industrial operations, mining, tourism, painting, and the use of renewable boats etc., (Nour & El-Sorogy, 2017). Many studies have been conducted to detect heavy metal contamination in coastal sediments (Halawani *et al.*, 2022; Lei *et al.*, 2023; Mookan *et al.*, 2023; Zhuang & Zhou, 2021). Contaminated sediments may serve as sources of heavy metal discharge into the water column (Zhong *et al.*, 2006) and due to their intrinsic toxicity, endurance, and resistance to breakdown processes, they impose a serious hazard as pollutants (Idris *et al.*, 2007).

The marine environment covers approximately 70% of the earth's surface and contains vast biological diversity which accounts for more than 90% of the whole biosphere and offers

a great source of novel compounds (Aneiros & Garateix, 2004). The marine environment is a prolific resource for the isolation of less exploited microorganisms and represents a largely untapped source for the isolation of new microorganisms (Bredholt *et al.*, 2008). Thus, marine ecosystems and coastal regions are particularly promising because of the rightly adapted species in the harsh environment. Bacteria from marine environments grow in extreme environmental conditions such as high pressure, low temperature, high salinity, and depletion of micronutrients (Valli *et al.*, 2012).

Hence, the exploration of marine microorganisms from the marine environment has led to the discovery of hundreds of microbes with biologically active compounds and versatile properties like bioremediation, biodegradation, and bioleaching. Marine microorganisms have become a significant source of novel microbial products exhibiting antibacterial, anticancer, anti-viral, anti-coagulant, anti-inflammatory, antioxidant, and cardioprotective properties Varied types of halophilic and halotolerant microbes have been isolated from a broad range of aquatic environment (Jensen *et al.*, 2005). Species-specific variability regions of 16S rRNA gene sequence analysis are the most supportive for the classification of phylogenetic uniqueness in conformity to the phenotypic profiles for the identification of microbes (Xiang *et al.*, 2008)

Metals like copper, iron, manganese, and zinc are essential for life processes whereas others like cadmium, lead, nickel, and mercury have no physiological function but often result in harmful disorders at higher concentrations (Lenin *et al.*, 2014). Many heavy metals are even non-degradable and hence once released into the environment remain in circulation. Heavy metals containing industrial effluents lead to health hazards to plants, animals, aquatic life, and humans thus increasing pressures on the flora and fauna (Balasubramanian, 2012). Lead and cadmium which are major contaminants found in the environment are extremely poisonous to humans, animals, plants, and microbes which can damage cell membranes, alter functions of enzymes, and damage the structure of DNA. Microbes have evolved mechanisms such as active efflux or sequestration with proteins or insoluble compounds through which they may resist, detoxify, or metabolize these heavy metals. It is important to note that bioremediation technologies based on microbes are economically viable, cost-effective, and environmentally friendly (Rahman & Singh, 2019; Tchounwou *et al.*, 2012).

Hence, by considering the scope of marine bacteria and the less exploited nature of marine microorganisms, the present study has been taken up to isolate and characterize bacteria

from polluted marine coastal sediments along with physico-chemical environmental assessment of the coastal zone.

AIM

To study the Assessment of pollution load of coastal mudflats along the western bank of Gulf of Khambhat: microbial community structure as bioindicator.

OBJECTIVES

1. Physico-chemical and heavy metal analysis of coastal surface water.
2. Physico-chemical and heavy metal analysis of coastal surface sediment.
3. Microbial diversity of coastal surface sediment.

STUDY AREA

The study area lies in the western coast of the Gulf of Khambhat, Gujarat along the west coast of India in the Arabian Sea. Bhavnagar is a coastal district in Gujarat, located at 21.7645^{o}N 72.1519^{o}E. The Gulf of Khambhat has an average elevation of 8 m above mean sea level (MSL). The Gulf is 130 km in length, 70 km in width, and has an average depth of 30 m (Misra & Balaji, 2015). The establishment of a large number of diamond-cutting-polishing facilities, agro-based, salt-marine chemicals, cotton textile, woollen, silk, artificial thread-based, chemical, mineral-based, plastics, shipbuilding, and ship-breaking companies has taken place in the Bhavnagar district (MSME-GOI, 2010-11).

Energy, petrochemical, agrochemical, metal–mining, auto components, textile, pharmaceutical, effluent treatment, and port industries were located on the outskirts of the research region (MM&FICCI, 2019; Rai, 2020). On the Bhavnagar coast, Alang and Sosiya have the world's biggest ship-breaking yard, which actively dismantles decommissioned ships along the shore; the Ghogha coast has ferry services as well as relatively small ship maintenance businesses. Tourism has an impact on Mithivridi, Kuda, and the Gopanth coast, and Sartanpar is a fish landing hub. Fishing and sand extraction activities can be witnessed at all sampling locations. Figure 1 shows the location map of the study site and Table 1 represents coordinates and onsite observation of study sites.

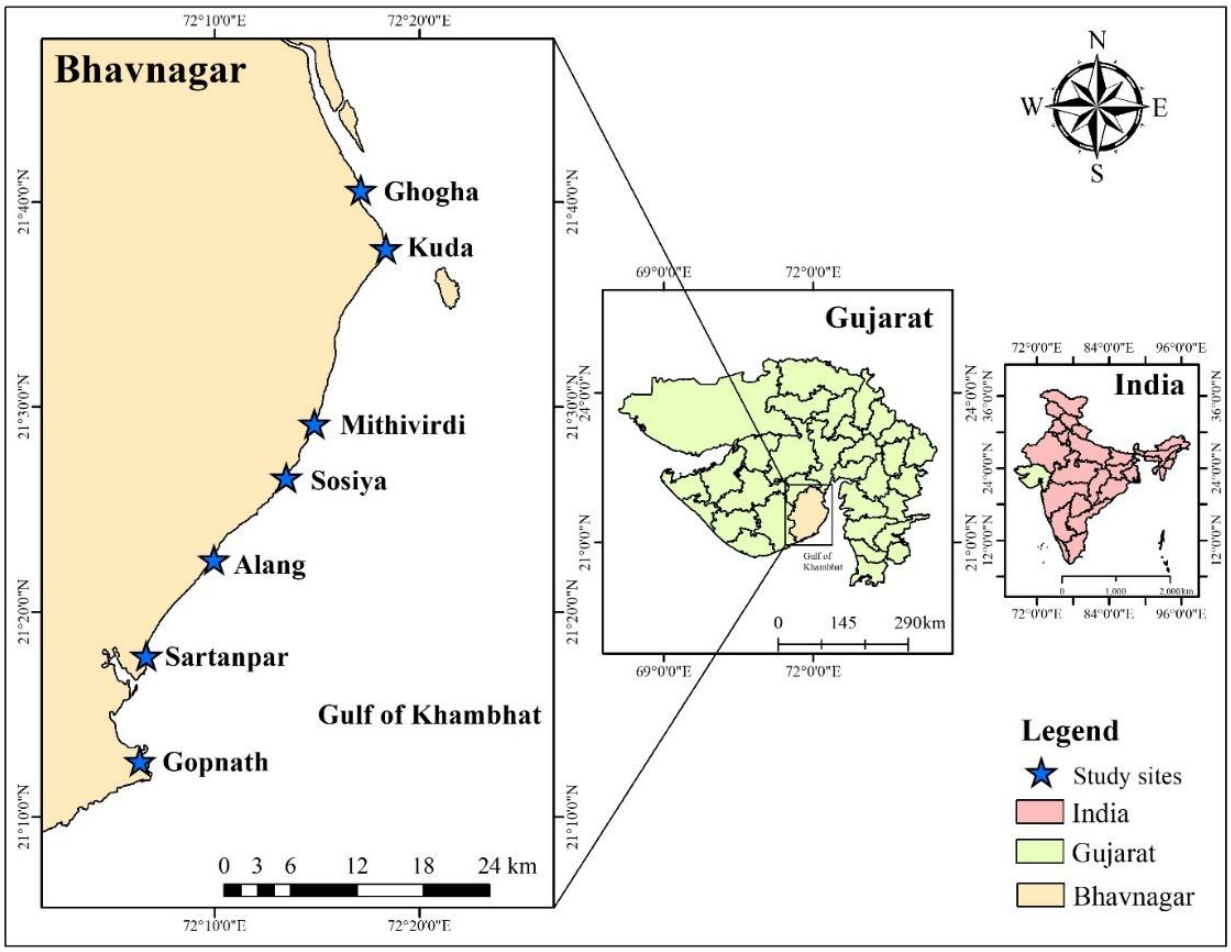

Figure 1 Geographical distribution of the sampling sites in the Bhavnagar coastal region, Gulf of Khambhat

Table 1 Geographical location of sampling sites and on-site observation

Site	Name	Latitude	Longitude	On-site observation
S1	Ghogha	21°40'36.0"N	72°17'07.1"E	A muddy shore with ferry service, ship painting-welding, and sand extraction can be seen at the site.
S2	Kuda	21°37'44.7"N	72°18'21.1"E	A sandy shore has tourism, sand extraction and fishing activity.
S3	Mithivirdi	21°29'11.6"N	72°14'51.2"E	Sandy shore has tourism, sand extraction, shrimp farming, fishing
S4	Sosiya	21°26'34.0"N	72°13'29.2"E	Rocky, muddy nature of the shore having shipbreaking, tourism, and sand extraction activity can be seen at the site.
S5	Alang	21°22'34.0"N	72°09'58.3"E	Rocky with muddy nature of shore having shipbreaking, tourism, and sand extraction.
S6	Sartanpar	21°17'52.6"N	72°06'39.3"E	A muddy shore with having Fish landing center and sand extraction activities.
S7	Gopnath	21°12'44.3"N	72°06'20.5"E	Rocky with muddy shore which has tourism, fishing and domestic waste

MATERIALS AND METHODS

1. Physico-chemical and heavy metal analysis of coastal surface water

A total of 63 coastal water samples (21 samples × 3 seasons) were collected during low tide 250m apart for hydrochemistry and dissolved heavy metal evaluation of the Bhavnagar coast, Gulf of Khambhat. The study examines the influence of various industries during different seasons i.e., pre-monsoon, monsoon, and post-monsoon. The coastal water samples were collected in triplicates from all the sampling locations. Coastal surface water's temperature, pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), total hardness (TH), calcium hardness (Ca^{+2}), chloride (Cl^{-}), salinity, dissolved oxygen (DO), 5^{th}–day biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total phosphorous (TP), total sulphur (TS) were done according to standard methods (APHA, 2012; Grasshoff *et al.*, 1999). For the determination of dissolved heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) the method from APHA (2012) was used. The heavy metal analysis was carried out using Atomic Absorption Spectroscopy (PerkinElmer PinAAcle-500 AAS).

2. Physico-chemical and heavy metal analysis of coastal surface sediment

A total of 63 sediment samples (21 samples × 3 seasons) were collected to assess the physico-chemical parameters and presence of heavy metals along the Bhavnagar coast, Gulf of Khambhat. The sediment sampling was done in three seasons, i.e., pre-monsoon, monsoon, and post-monsoon. Composite sampling was done where sediment was collected from four corners and one from the center of the quadrat from low intertidal, mid intertidal a high intertidal area. Each sample had a minimum of 200g sediments and immediately after collection; they were transferred into pre-cleaned plastic zipper bags. Physico-chemical properties of coastal sediments such as pH, organic matter (OM), total available phosphate (TAP), total sulphur (TS), and available nitrogen were done using standard method (Shao *et al.*, 2020). For the analysis of heavy metals, the acid digestion modified method was used (Baird *et al.*, 1999). Atomic Absorption Spectroscopy (PerkinElmer PinAAcle-500 AAS) was used to determine the concentration of metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) in the sample.

3. Microbial diversity of coastal surface sediment

Quantitative estimation of the viable bacteria was done by serial tube dilution method, plating, and colony count. The bacteria were isolated by spread plate method on Zobell Marine

Agar, incubated at 37°C for 24 h to obtain colonies. The individual colonies were picked based on their macroscopic characteristics such as size, shape, surface appearance, texture, and colour. These colonies were subjected to repeated streaking on Zobell Marine Agar plates/slants. The obtained marine bacterial isolates were stored at 4°C for further studies (Bergey, 1994; Sinimol *et al.*, 2015). Colony and cell morphology based on their colour, shape, margin, elevation, surface, and arrangement of bacteria were studied (Bergey, 1994). The standard Gram staining procedure was followed for the morphological characterization of isolates (Bartholomew & Mittwer, 1952; Bergey, 1994).

For taxonomic identification, different biochemical tests were performed for the isolates to check their metabolic activities by following standard protocols (Bergey, 1994). The DNA of the isolates was extracted using a standard Phenol/Chloroform Separation protocol (Wright *et al.*, 2017). The 16S rRNA gene sequence of the isolates was used to carry out BLAST with the database of NCBI Genbank. Based on the maximum identity score, the first ten sequences were selected and aligned using the multiple alignment software program Clustal W. Distance matrix was generated, and the phylogenetic tree was constructed using MEGA 7 (Mandragutti *et al.*, 2021).

RESULTS

1. Physico-chemical and heavy metal analysis of coastal surface water

All of the physico–chemical characteristics demonstrated distinct seasonal trends, which are typical of the tropical marine environment. The temperature fluctuated from 27°C – 33°C among all the studied sites. The seasonal variations in the average temperature of coastal water were 33.3 ± 0.5 ^{o}C, 29.24 ± 0.4 ^{o}C, and 27.7 ± 0.3 ^{o}C during pre–monsoon, monsoon, and post–monsoon, respectively. The pH of water is a key component in determining its feasibility for aquatic life. The pH among all the stations ranged from 8.04 – 8.74. It was discovered that seasonal variation was not significant as the average value of pH found were 8.58 ± 0.04, 8.38 ± 0.17, and 8.29 ± 0.15 for pre–monsoon, monsoon, and post–monsoon, respectively. TSS levels were discovered to be in the range of 1813 – 2950 mg/L from all the study sites. The average TSS of the coastal water samples varied from 2528.0 ± 130.5 mg/L, 2250.8 ± 178.2 mg/L, and 2294.1 ± 379.1 mg/L during pre–monsoon, monsoon, and post–monsoon, respectively. TDS levels ranged from 18000 to 45000 mg/L across all research stations. The average TDS results were found to be 41460.4 ± 2957.9 mg/L, 30002.0 ± 3856.8 mg/L, and 29207.5 ± 4852.7 mg/L at pre–monsoon, monsoon, and post–monsoon, respectively.

The measurements of electrical conductivity varied between 26000 – 64000 µS/cm. The average electrical conductivity readings along the Bhavnagar coast ranged from 59229.2 ± 4225.6 µS/cm, 42860.0 ± 5510.8 µS/cm, and 41725 ± 6932.5 µS/cm during pre–monsoon, monsoon, and post–monsoon, respectively. The hardness levels fluctuated from 3800 – 7100 mg/L at all the sampling locations. The average total hardness level of 6697.3 ± 353.9 mg/L, 4231.0 ± 261.5 mg/L, and 5851.8 ± 857.4 mg/L was reported for pre–monsoon, monsoon, and post–monsoon, respectively. The calcium concentration ranged from 677 mg/L to 1185 mg/L. average calcium content of 1062.7 ± 69.4 mg/L, 752.7 ± 60.1 mg/L, and 917.69 ± 92.7 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. The chloride levels measured in this study varied from 11913 to 21625 mg/L among all the stations. The average chloride levels were 20692.2 ± 765.7 mg/L, 13150.3 ± 697.8 mg/L, and 18591.4 ± 276.3 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. The average salinity levels were 37.3 ± 1.3 ppt, 23.7 ± 1.2 ppt, and 33.59 ± 0.4 ppt during pre–monsoon, monsoon, and post–monsoon, respectively.

DO varied from 4.39 – 6.76 mg/L for all the seven locations. The average DO seasonal variation was not significant as the average value of DO were 5.9 ± 0.4 mg/L, 5.8 ± 0.5 mg/L, and 5.4 ± 0.7 mg/Ls for pre–monsoon, monsoon, and post–monsoon, respectively. BOD levels ranged from 1.18 mg/L to 5.89 mg/L across all locations investigated. The average value of BOD was 3.9 ± 0.8 mg/L, 4.2 ± 0.7 mg/L, and 3.0 ± 1.4 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. The chemical oxygen demand (COD) varied significantly between 745.44 – 1782.04 mg/L for all the sites. The average value of COD were 1616.3 ± 118.0 mg/L, 977.9 ± 189.4 mg/L, and 1426.1 ± 207.6 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively.

The average concentration of dissolved heavy metal in coastal surface water among all the sites ranked in the following order Lead (Pb) > chromium (Cr) > Nickle (Ni) > cobalt (Co) > Fe > cadmium (Cd) > Manganese (Mn) > Copper (Cu) > Zine (Zn). Lead (Pb) concentration among sampling sites, ranged between 0.34 – 0.66 mg/L. The average concentration of Pb was 0.54 ± 0.03 mg/L, 0.46 ± 0.09 mg/L, and 0.41 ± 0.14 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. Cr concentration in water ranged between 0.09 – 0.86 mg/L which was higher than the acceptable limits at all the sites. The average concentration of Cr was 0.72 ± 0.12 mg/L, 0.25 ± 0.03 mg/L, and 0.12 ± 0.02 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. Nickle (Ni) levels in the water at all sites ranged from 0.14 – 0.39 mg/L. The average concentration of Ni was 0.35 ± 0.02 mg/L, 0.19 ± 0.03 mg/L, and 0.25 ± 0.03

mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. The cobalt (Co) concentration in coastal water was noted to be 0.011 – 0.275 mg/L among the study sites. Co average concentration were 0.25 ± 0.02 mg/L, 0.17 ± 0.02 mg/L and 0.07 ± 0.07 mg/L for pre–monsoon, monsoon and post–monsoon, respectively. Cadmium (Cd) in the range of 0.026 to 0.090 mg/L in water which is higher than the acceptable limits at all the studied sites. Average Cd concentrations were 0.05 ± 0.004 mg/L, 0.03 ± 0.004 mg/L, and 0.08 ± 0.006 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. Copper (Cu) ranged from 0.02 – 0.05 mg/L. Cu average concentrations were 0.04 ± 0.003 mg/L, 0.04 ± 0.006 mg/L, and 0.02 ± 0.002 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. The range of these micronutrients during the study varied as follows 0.01 – 0.11 mg/L for Zn; 0.01 – 0.09 mg/L for Mn; and 0.06 – 0.29 mg/L for Fe among all the researched sites, respectively. Zn average concentrations were 0.04 ± 0.03 mg/L, 0.02 ± 0.01 mg/L, and 0.02 ± 0.01 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. Mn average concentrations were 0.08 ± 0.01 mg/L, 0.04 ± 0.004 mg/L, and 0.024 ± 0.009 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively. Fe average concentrations were 0.25 ± 0.03 mg/L, 0.11 ± 0.02 mg/L, and 0.07 ± 0.002 mg/L for pre–monsoon, monsoon, and post–monsoon, respectively.

2. Physico-chemical and heavy metal analysis of coastal surface sediments

The pH ranged from 8.5 – 9.5. The average value of pH was 9.4 ± 0.11, 8.8 ± 0.20, and 9.1 ± 0.12 for pre–monsoon, monsoon, and post–monsoon, respectively. The total available phosphorus (TAP) ranged from 125.6 – 279.1 mg/kg. The average value of TAP was 246.1 ± 29.41 mg/kg, 179.7 ± 40.62 mg/kg, and 194.3 ± 13.65 for pre–monsoon, monsoon, and post–monsoon, respectively. The sulphate ranged from 146.2 – 219 mg/kg. The average value of sulphate was 204.1 ± 17.11 mg/kg, 152 ± 5.54 mg/kg, and 175.9 ± 9.92 for pre–monsoon, monsoon, and post–monsoon, respectively. The available nitrogen ranged from 100.3 – 181.8 mg/kg. The average value available nitrogen was 171.4 ± 7.4 mg/kg, 108.6 ± 7.4 mg/kg, and 194.3 ± 137.8 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average organic matter (OM) ranged from 0.10 % - 4.13 %. The average value of TOC was 3.12 ± 0.68 %, 0.93 ± 0.50 %, and 0.87 ± 0.56 % for pre–monsoon, monsoon, and post–monsoon, respectively.

The studied heavy metals displayed the following trend with average concentration (mg/kg) Fe (561.4) > Mn (58.9) > Cr (42) > Zn (12.5) > Pb (8.2) > Ni (7) > Cu (5.2) > Co (2.7) > Cd (0.3). The following elements concentrations were found in the coastal sediments of

Bhavnagar: Cu ranged between 0.7 - 12.7 mg/kg; Cr ranged between 10.6 - 98.4 mg/kg; Co ranged between 1.3 - 8.4 mg/kg; Cd ranged 0.1 - 0.8 mg/kg; Fe ranged 364 - 696 mg/kg; Mn ranged 21.8 - 120 mg/kg; Ni ranged 1.3 - 14.7 mg/kg; Pb ranged 2.1 - 13.5 mg/kg; Zn ranged 2.7 - 42.7 mg/kg. The average value of Ni was 11.09 ± 2.1 mg/kg, 4.8 ± 1.8 mg/kg, and 4.98 ± 1.5 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Cu was 6.81 ± 3.34 mg/kg, 4.81 ± 2.55 mg/kg, and 4.1 ± 1.65 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Mn was 71.81 ± 21.05 mg/kg, 59.47 ± 16.25 mg/kg, and 46.14 ± 15.83 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Cr was 65.97 ± 17.7 mg/kg, 27.07 ± 9.98 mg/kg, and 33.01 ± 5.95 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Pb was 9.04 ± 1.65 mg/kg, 7.18 ± 2.6 mg/kg, and 8.45 ± 0.63 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Zn was 15.6 ± 10.8 mg/kg, 14.71 ± 10.3 mg/kg, and 7.2 ± 4.93 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Co was 2.82 ± 0.8 mg/kg, 3.2 ± 1.4 mg/kg, and 2.23 ± 0.63 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Cd was 0.16 ± 0.07 mg/kg, 0.44 ± 0.16 mg/kg, and 0.19 ± 0.04 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. The average value of Fe was 670.6 ± 20.1 mg/kg, 622.08 ± 30.58 mg/kg, and 391.55 ± 12.05 mg/kg for pre–monsoon, monsoon, and post–monsoon, respectively. Previous studies also suggest that heavy metal contamination could arise from shipbreaking activity in shipbreaking areas and nearby areas (Ali *et al.*, 2022; Hasan *et al.*, 2023). Significant geographical and temporal variation in coastal heavy metal concentrations and physico-chemical parameters was discovered in the study, indicating a possible impact on the marine ecosystem.

3. Microbial diversity of coastal sediment

The overall isolate counts were 1420 for pre-monsoon, 1117 for monsoon, and 1204 for post-monsoon from 10^{-9} dilution of 1g sediment, respectively. Out of these, 47 individual isolates were selected for the further analysis based on their macroscopic characteristics such as size, shape, surface appearance, texture, and colour. Shape of isolated colonies varied from small to large. Smooth, mucoid, rough surface with convex elevation with yellow, orange and white pigmentation was observed on Zobell Marine agar plate. 47 isolates were proceeded for the biochemical characterization. The indole test showed negative test for all the 47 colonies, it is performed to determine the ability of the organism to convert tryptophan into indole. Methyl Red and Voges-Proskauer (MR-VP) tests are commonly used in conjunction with the

indole and citrate tests. MR-VP test is used to determine which fermentation pathway is used to utilize glucose. All the isolated colonies showed negative test for MR-VP test. The citrate test screens a bacterial isolate for the ability to utilize citrate as its carbon and energy source. Out of 47, six isolates showed positive test citrate utilization. Out of 47 isolates, 28 isolates showed positive test for the urea hydrolysis. This test is used to identify bacteria capable of hydrolyzing urea using the enzyme urease. All the isolates showed positive test for ammonia production. All the isolates showed Gamma hydrolysis for hemolysis test. Hemolysis tests the ability of an organism to produce hemolysins, the enzymes that damage/lyse red blood cells present in agar. Based on these parameters different isolated bacterial species confirmed and such species were tested for barcoding and phylogenetic for the better confirmation.

OUTCOME

Land-based anthropogenic inputs have a considerable impact on parameters like temperature, DO, BOD, COD, Cl, and dissolved heavy metals including Ni, Cu, Mn, Cr in coastal water. The study showed spatial-temporal variation of physico-chemical and heavy metal concentration in both the coastal water and sediment. This variation appeared to be noticeable and could be harmful to present marine environment. In comparison to the monsoon season, the dry season (pre–monsoon & post–monsoon), exhibited higher amounts of physico-chemical parameters and dissolved heavy metals in the coastal water and coastal sediments. Anthropogenic activities increase during the dry season, which causes a larger build–up of heavy metals in water and sediments. However, the dilute impact of freshwater incursion during the wet season leads to a lower amount of concentration of heavy metal and physicochemical parameters during the monsoon season. The microbial study under examination which will give proper idea about microbial diversity with reference to the present pollution status.

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PUBLICATIONS

- ✓ **Gosai, H. G., & Mankodi, P. (2023). Metal Contamination Status in Sediment along the Western Belt of Gulf of Khambhat, Gujarat, India. In *Animal Agriculture Modern Practices and Issues* (Vol. 1, pp. 33-56). Excel India Publishers.**
- ✓ Yadav, M., Gosai, H. G., Singh, G., Singh, A., Singh, A. K., Singh, R. P., & Jadeja, R. N. (2023). Major Impact of Global Climate Change in Atmospheric, Hydrospheric and Lithospheric Context. In P. Singh, B. Ao, & A. Yadav (Eds.), *Global Climate Change and Environmental Refugees: Nature, Framework and Legality* (pp. 35-55). Springer International Publishing. https://doi.org/10.1007/978-3-031-24833-7_3
- ✓ Gosai, H. G., & Narolkar, S. (2022). Isolation, Characterization and Optimization of Bioflocculant Producing Bacteria from the Aquaculture Ponds. *Journal of Emerging Technologies And Innovative Research (JETIR)*, *9*(1), a434–a442.

Oral and Poster presentation

- ✓ **Oral** presentation in **National** level conference 'Biological Tools for Sustainable Environment' organized by VNSGU, Surat on 25th March, 2023.
- ✓ **Poster** presentation in **International** level conference 'Path and Prospects in Applied Bioscience' organized by VNSGU, Surat on 30-31st July, 2022.
- ✓ **Oral** presentation at Present Day Biology 2021 **National** level conference on 10-11th December organized by St. Xavier's College Ahmedabad, Gujarat.

Training program

- ✓ Participated in a Hands-on training program on "Molecular Techniques to Monitor and Investigate Antimicrobial Resistance (AMR)" conducted under the GCRF-STARS program from 15-24th September 2021 at Anand Agricultural University, Anand, Gujarat collaboration with Royal Veterinary College, London, Uk and Gujrat Biotechnology Research Centre (GBRC), Gandhinagar, Gujarat.
- ✓ Attended BNHS, Mumbai crash course "Introduction to Marine Biology" from 9th May 2021 to 20th June 2021 organized by BHNS, India.

Webinar

- ✓ Attended webinar on "Enhance Communication Skills for Environmental and Sustainable development" on 27th & 28th February 2021 organized by Society for Environment & Sustainable Development, New Delhi, India.

- ✓ Attended Two days of International workshop on "Changing Paradigm of Geo Science, Bio Science & Eco Science" organized by IIARI in collaboration with DERO from 4th-5th March 2021.
- ✓ Attended Webinar Training on "QGIS Beginner Course" on 6th March 2021 organized by TGIS.
- ✓ Attended the online course on "Geoinformatics for Disaster Management" from 5th-16th April 2021 organized by the Indian Space Research Organization.
- ✓ Attended Webinar on "Earth ka Arth" on 22nd April 2021 organized by Department of Environmental Studies, The Maharaja Sayajiroa University of Baroda, Vadodara.
- ✓ Attended Webinar on "Avifaunal and Coral Diversity of Gujarat" on 4th May 2021 Organized by the Department of Zoology at Ashok & Rita Patel Institute of Integrated Study & Research In Biotechnology And Allied Science (ARIBAS) jointly organized with Association of Zoologists (AOZ) on 4th May 2021.
- ✓ Attended "One Day Virtual Workshop on PCR, UV-VIS Spectrophotometer and HPLC" on 17th May 2021 organized by Ashok & Rita Patel Institute of Integrated Study & Research in Biotechnology and Allied Science (ARIBAS).
- ✓ Attended Webinar on "World Endangered Species Day" on 21st May 2021 organized by Department of Environmental Studies, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara.
- ✓ Attended Webinar on World Ocean Day with a theme of "Marine Ecosystem: conservation and Challenges" jointly organized by Shri R. R. Lalan college and Association of Zoologists on 8th June 2021.
- ✓ Attended Webinar on "World Nature Conservation Day" Organized by Department of Zoology, Biomedical Technology, Human Genetics, and Wildlife Biology & Conservation, University School of Sciences, Gujarat University, Ahmedabad, Gujarat, India 28th July 2021, Wednesday In Association With AOZ Association of Zoologists and National Green Corps.
- ✓ Attended International Webinar on "Research Article Writing" on 23-24 July 2021 organized by PODAR GROUP OF INSTITUTION.
- ✓ Attended the online course on "Molecular Techniques to Monitor and Investigate Antimicrobial Resistance (AMR)" course on 28th June 2021 to 6th August 2021 jointly organized by BBSRC, RVC University of London, Anand Agriculture University (AAU), and GBRC.
- ✓ Attended AWSAR (Augmenting Writing Skills for Articulating Research) Webinar on "Popular Science Writing" on 3rd September 2021 organized by the Department of Science and Technology (DST), Government of India, and Vigyan Prasar (VP) in Collaboration with Agharkar Research Institute, Pune.
- ✓ Attended webinar on "Fantastic animals and How to identify them" on 1st September organized by Association of Zoologists.

- ✓ Attended Webinar on "Green Consumer Day" on 28th September organized by Akhil Bhartiya Grahak Panchayat, Gujarat, India in association with Department of Zoology, Biomedical Technology, Human Genetics, and Wildlife Biology & Conservation, University School of Science, Gujarat University, Ahmedabad, Gujarat, India, and National Green Corps.
- ✓ Attended webinar on "Citation and Reference Management" organized by the Association of Zoologists on 9th September.
- ✓ Attended webinar named "*Advances in Marine Conservation & Research*" organized by CAMPA-Dugong Project Wildlife Institute of India on 1st October.
- ✓ Attended webinar named "*Conservation of Dugong and their Habitats in Gulf of Kutch, Gujarat*" held on 24th October.
- ✓ Attended ICC Sustainability Conclave 2021 Clean India – Green India on 2-3rd December.
- ✓ Attended Online Workshop on "Building Sustainable Campus" on 17th-18th Dec 2021 organized by TERI School of Advanced Studies.
- ✓ Attended "Present Day Biology 2021" National Conference on 10th-11th December organized by St. Xavier's College Ahmedabad, Gujarat.
- ✓ Attended the GSBTM, DST, GoG sponsored *"International Conference on Emerging Trends in Biological Sciences (ICETBS 2022)*" on 9th-11th January organized by P. D. Patel Institute of Applied Sciences, Charotar University of Science and Technology, Changa.
- ✓ Attended International Science Symposium on "Recent Trends In Science And Technology" on 22nd-23rd January 2022 organized by Christ College, Rajkot, Saurashtra University.

Research student
Hardik Giri Gosai

Research Guide
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