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Research Article

A multivariate approach for comparative study of water and sediment at Juhu Koliwada and Haji Ali

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The Juhu Koliwada and Haji Ali are coastal locations situated in the suburbs of Mumbai and South Mumbai, Maharashtra, respectively. They are among the attraction points for tourists and are known for their marine diversity. The present study aims to investigate the physicochemical parameters of water and sediment of the rocky intertidal zone during low tides. A monthly sampling was conducted from April 2023 to July 2023, encompassing two distinct seasonal periods: pre-monsoon (April–May) and monsoon (June–July). Seasonal variations in seawater temperature, pH, TDS, salinity, turbidity, COD, electrical conductivity, PO_4-P, and NO_3-N were prominent. High standard deviation from the mean in physicochemical data indicates the presence of temporal and spatial variations caused by polluting sources. Principal Component (PC) 1 shows 62.87 % variance, with strong positive loadings of electrical conductivity (0.994), COD (0.973), water temperature (0.983), TDS (0.968), specific gravity (0.887), salinity (0.888), PO_4-P (0.794), turbidity (0.792), and total alkalinity (0.788). In comparison, PC 2 explains 22.98 % of the total variance and indicates a strong positive loading for DO (0.997), pH (0.976), and a moderate positive loading for NO_3-N (0.541). On the other hand, PC 3 accounts for 14.15 % of the variance and shows a strong positive loading for BOD (0.977) in the water. The magnitude of effluent discharge, rainfall, and other anthropogenic activities throughout the season affects the levels of phosphate, nitrate, and organic carbon in the sediment. Urban runoff, household greywater discharge, the non-organised sector, and unregulated tourism are among the anthropogenic factors that require urgent consideration for the continuous assessment of the coastline of Mumbai. This study provides baseline data to identify the physicochemical variables and their driving factors. A comparative study of similar marine ecosystems is essential for long-term conservation planning, as it demands the making of pollution control strategies and policy decisions to implement and improve environmental conservation and management.

[**Keywords**: Anthropogenic, Coastline, Intertidal, Marine pollution, Physicochemical parameters]

Introduction

India is one of the 12 mega-biodiverse countries and hosts 25 hotspots for the world's most threatened eco-regions. Among Asian countries, India has a unique biotic and abiotic environment with its enormous mangroves, backwaters, salt marshes, rocky beaches, sandy stretches, and coral reefs[1]. It has a diverse marine ecosystem, including numerous endemic species[2].

Water is one of the most important and abundant components in the environment. All living species on the planet require water to survive and thrive[3]. Mumbai is a coastal city with many residents who depend on the sea for their livelihoods and production, and rely heavily on it for trash disposal[4]. While the sea plays an important role in the well-being of coastal communities, it is constantly degraded by sewage and effluent expulsions from cities and industrial areas, causing critical ecological damage.

Several studies conducted in the coastal environments of India revealed that Mumbai and Gujarat on the west coast, as well as Pondicherry on the east coast, had damaged coastal habitats as a result of discharges from industry and households[5-7]. Diminished coastal resources, public health concerns, and loss of biodiversity have emerged as consequences of careless discharges of partially treated or untreated waste into receiving water bodies, without regard for their assimilative potential. Tidal currents dilute effluent in coastal environments; however, this natural process is insufficient to counteract the increasing anthropogenic pressure[8,9]. The implementation of waste management policies and guidelines amid rising industrialisation and urbanisation has become a major concern[10]. Because of the consequences for human health and aquatic ecosystems, including a diverse range of marine species, marine water quality has become a major area of concern[11].

The properties of the marine ecosystem are determined by nutrient content, biomass availability, pollutant sources, as well as the physical and chemical characteristics[12,13]. Water pollutants and physicochemical characteristics such as pH, temperature, salinity, DO, and BOD have significant impacts on aquatic life[14]. Oceanographic processes influence sediment characteristics, including origin, beach morphology, hydrodynamic conditions, and hydraulic sorting of sands[15].

High-quality soils support natural ecosystems and enhance air and water quality. Soil physicochemical properties play a key role in preventing deterioration. Soil quality is influenced by pH, phosphate, nitrate, and organic matter levels, all of which are closely linked to productivity[16].

Juhu Koliwada and Haji Ali are tourist attractions and are highly prone to anthropogenic activities. The intertidal zone of Juhu Koliwada comprises rocky and sandy beaches, whereas Haji Ali is characterised by extensive basaltic rocky formations interspersed with sandy patches[17]. Both locations have a single point source of effluent discharge, making the physicochemical parameters of the water and sediment highly variable. pH, temperature, salinity, turbidity, phosphate, nitrate, and organic matter are important abiotic factors that can significantly impact biodiversity living in the ecosystem.

Hence, regular and systematic monitoring of these parameters is required to assess ecosystem health and ensure the conservation of marine diversity. The current study aims to provide insight into the physicochemical conditions of the study sites, thereby contributing to the development of a sustainable approach for conserving these ecologically sensitive marine habitats.

Materials and Methods

Study area and research design

A comparative study of water and sediment physicochemical parameters was conducted at Juhu Koliwada (19°05'01.7" N; 72°49'27.5" E) and Haji Ali (18°58'58.3" N; 72°48'32.1" E), located in the Mumbai suburban and South Mumbai, Maharashtra, respectively (Fig. 1). Both study sites have identified a point source for the effluent discharge. Additionally, the ongoing Coastal Road Project is a major developmental activity contributing to environmental stress in the region. In addition to liquid effluent, various solid wastes such as plastics, thermocol, and religious offerings are frequently introduced into the coastal environment, exacerbating pollution levels. The study was conducted between April 2023 and July 2023 and categorised into two distinct seasonal periods: pre-monsoon (April–May) and monsoon (June–July). For the sediment collection, nine points were marked using a mobile phone GPS with Google Maps. Water and sediment samples were collected during the lowest tide of each month. The water

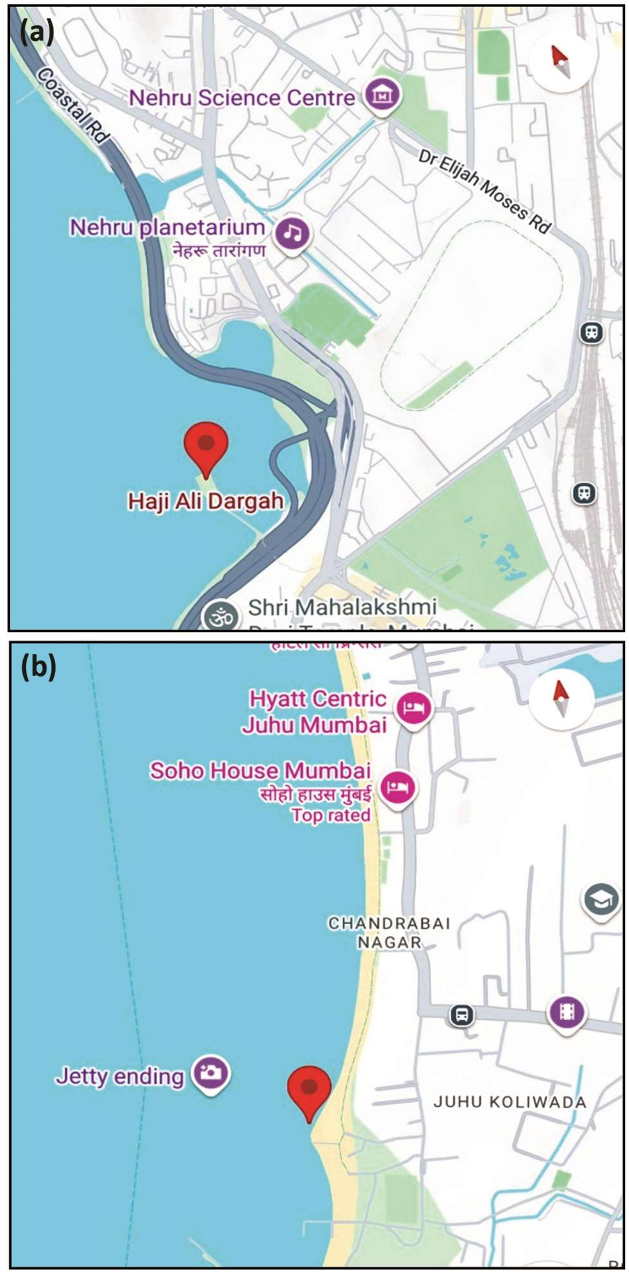

Fig. 1 — (a) Study area Haji Ali (18°58'58.3" N; 72°48'32.1" E); and (b) Juhu Koliwada (19°05'01.7" N; 72°49'27.5" E) (Image from Google maps)

sample was collected during low tide from two points along the seafront, maintaining a minimum distance of 100 m. Samples were collected in clean, pre-washed 1-litre polyethylene bottles. Eight samples per study site were collected. The sample name and date of collection were labelled on the bottle. Sediment samples were collected using a spatula into the pre-labelled zip-lock bags.

Sample analysis and data analysis

The collected water samples were brought to the laboratory for analysis of physical and chemical parameters. Analytical grade chemicals were used to prepare reagents and standard solutions. Estimation of the water sample for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) was done by the Winkler's Azide modification method, and samples were fixed immediately on the study sites after collection to minimise the error. The instruments were calibrated according to the guidelines and the Standard Operating Procedures (SOPs) in the manufacturer's manual. Water pH and temperature were measured on-site using a pocket pH meter (Equiptronics: EQ-612) and a mercury thermometer, respectively. Water salinity was measured with a refractometer (Erma: ERS-10), Electrical Conductivity (EC) with a conductivity meter (Equiptronics: EQ-662), turbidity with a turbidity meter (Equiptronics: EQ-812), and Total Dissolved Solids (TDS) with a TDS meter (Equiptronics: EQ-682). Water total alkalinity was measured by acid titration. Organic matter (Walkley-Black method), PO_4-P (Ascorbic acid method) and NO_3-N (Phenol-disulphonic acid method) were analysed by following standard methods by APHA, 2022[ref. 18] and Trivedy & Goel[19]. Bar diagrams and tables were made using Microsoft Excel. Principal Component Analysis (PCA) and Pearson's correlation were carried out with PAST software (Version 4.03). The study area map was obtained from Google Maps (Google LLC) for illustrative purposes.

Results

The physicochemical parameters of water at Juhu Koliwada and Haji Ali are summarised in Table 1. The present study revealed significant seasonal variations in various parameters, including water temperature, pH, TDS, salinity, turbidity, COD, electrical conductivity, PO_4-P, and NO_3-N, between the pre-monsoon and monsoon. Water temperature across both sites ranged from 27.33±0.58 °C to 32.53±0.93 °C, with the highest value recorded at Haji Ali during the pre-monsoon condition. Seasonally, there was a minimal variation in the mean pH across the study sites. A noticeable decline in TDS, EC, and salinity was observed during the monsoon at both the study sites. The pre-monsoon conditions exhibited slightly higher total alkalinity. In both seasons, the DO level remained low at Juhu Koliwada, falling below the standard limit guidelines established by the Central Pollution Control Board (CPCB, 1998)[20] for class SW II water. An elevated concentration of phosphate in water was observed before the monsoon season but declined during the monsoon period. However, nitrate in water showed an inverse trend, reaching its highest levels during the monsoon season at both study locations. The elevated phosphate levels, along with lower DO than at Haji Ali, suggest that Juhu Koliwada experiences greater

Table 1 — Water physicochemical parameters measured during the study period (April to July 2023)

Season	Pre-monsoon		Monsoon	
Location	Juhu	Haji Ali	Juhu	Haji Ali
Air temperature (°C)	34.13±0.75	33.73±1.1	27.67±1.15	28.5±1.73
Water temperature (°C)	31.23±1.63	32.53±0.93	27.33±0.58	28.00±1.15
pH	7.39±0.42	7.98±0.67	7.41±0.59	7.94±0.27
TDS (ppt)	39.38±1.75	36.56±12.21	26.66±12.75	29.98±13.42
Salinity (ppt)	29.67±3.5	30.67±4.27	22.67±15.1	27.5±13.6
Electrical conductivity (mS/cm)	49.53±4.14	51.9±2.23	33.47±15.25	37.60±15.86
Turbidity (NTU)	29.89±22.27	26.78±20.23	19.89±13.02	8.50±7.06
Alkalinity (mg/L)	120±17.32	130±26.46	115.56±26.94	117.50±17.08
DO (mL/L)	3.50±3.93	6.45±0.96	3.83±2.0	7.30±0.93
BOD (mL/L)	0.83±0.37	0.34±0.19	0.51±0.18	0.90±0.39
COD (mg/L)	69.44±7.68	61.44±7.00	30.11±26.86	40.25±33.61
PO_4-P (mg/L)	1.597±0.236	0.669±0.043	0.175±0.258	0.282±0.490
NO_3-N (mg/L)	0.076±0.037	0.049±0.023	0.130±0.146	0.339±0.518

organic and inorganic pollution in the pre-monsoon period. The minimum and maximum level of COD was recorded during monsoon (30.11±26.86 mg/L) and pre-monsoon (69.44±7.68 mg/L) at Juhu Koliwada. This could be attributed to the dilution of discharged effluents during the monsoon.

The sediment phosphate content during the pre-monsoon period is quite comparable across the study locations; however, in the monsoon, there is an increase at Haji Ali (0.468±0.230 mg/L) and a fall at Juhu Koliwada (0.230±0.136 mg/L) (Fig. 2). During the monsoon, nitrate concentration increased at both sites (Fig. 3). In monsoon season, level of nitrate (0.983±0.624 mg/L) in the sediment was highest at Haji Ali. The percentage of organic matter shows a small decline during the monsoon compared with pre-monsoon conditions, suggesting that sediment is being washed away due to surface runoff and rainfall associated with the monsoon (Fig. 4).

A comparison of phosphate concentrations in water and sediment (Fig. 2) revealed higher levels in water during the pre-monsoon season at both study sites. However, during the monsoon, phosphate concentration in sediment surpassed that in the water column. In contrast, nitrate concentrations (Fig. 3) in both water and sediment increased during the monsoon compared to the pre-monsoon.

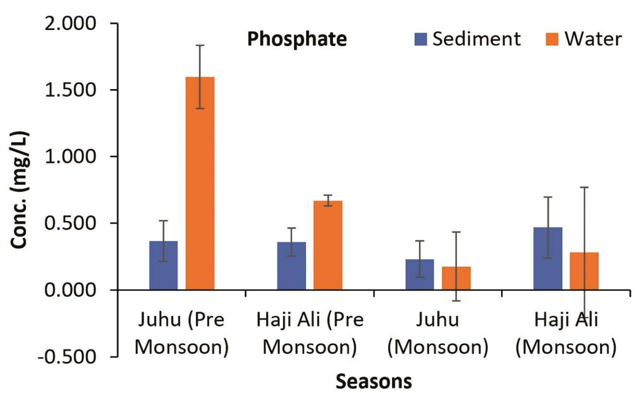

Fig. 2 — Level of phosphate in water and sediment

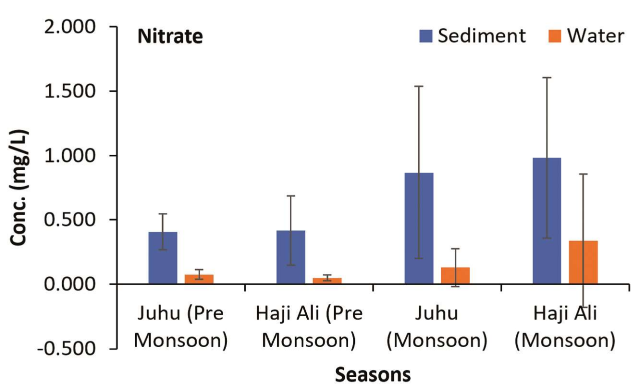

Fig. 3 — Level of nitrate in water and sediment

PCA assists in visualising the correlation between different water quality parameters. Parameters with strong loadings on the same principal component are likely interconnected, suggesting shared sources or influences. PCA finds a group and a set of variables with similar properties. Loading points greater than 0.7 (or ≤ 0.7 for negative correlation) represent a strong positive contribution of the variables to the principal component. The PCA biplot visualises the seasonal variation of water physicochemical parameters of the study sites into three components, indicating a notable difference between pre-monsoon and monsoon data. Principal Component 1 (PC 1) explains the maximum variability of 62.87 %, Principal Component 2 (PC 2) explains the second largest variability of 22.98 %, and Principal Component 3 (PC 3) explains 14.15 % variability. Figure 5 represents a PCA biplot of PC 1 and PC 2.

PC 1 shows a strong positive loading of air temperature (0.997), electrical conductivity (0.994), water temperature (0.983), COD (0.973), TDS (0.968), salinity (0.888), specific gravity (0.887), PO_4-P (0.794), turbidity (0.792), and alkalinity (0.788). PC 2 indicates strong positive loadings for DO (0.997) and pH (0.976), and a moderate positive loading for NO_3-N (0.541). PC 3 shows a strong positive loading for BOD (0.977).

Correlation coefficient data shows the strength of a linear relationship between variables (Fig. 6). Air temperature and water temperature show a positive relationship, which indicates that atmospheric temperature strongly affects the water temperature. There is typically a strong, linear relationship between salinity and Total Dissolved Solids (TDS), as both factors directly affect the capacity of water to carry

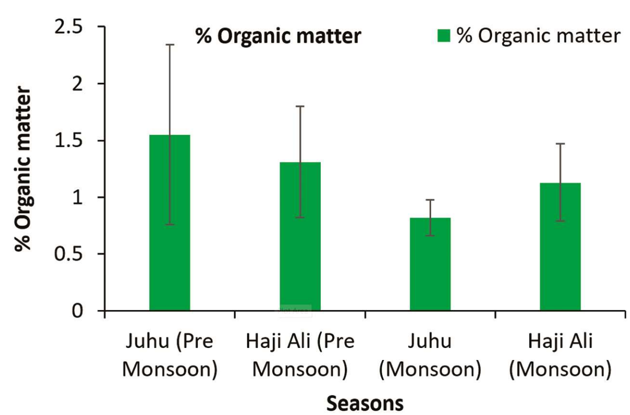

Fig. 4 — Level of %organic matter in sediment

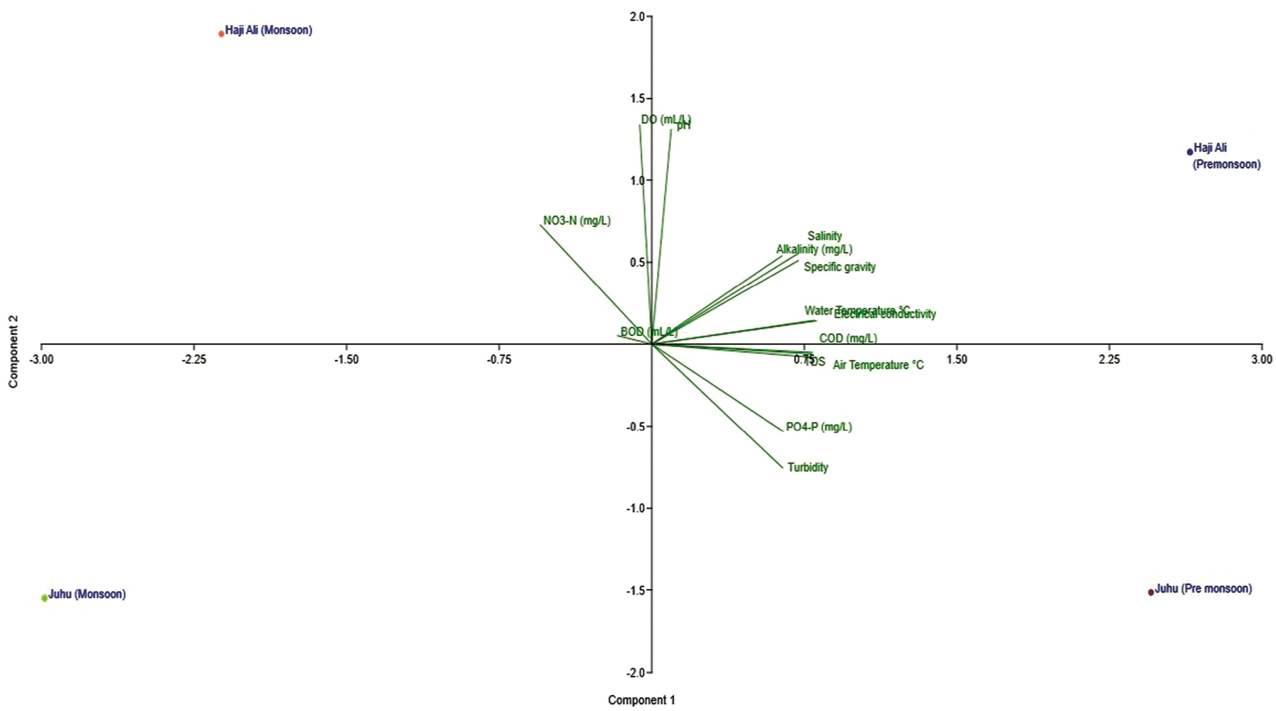

Fig. 5 — PCA correlation biplot of water physicochemical parameters

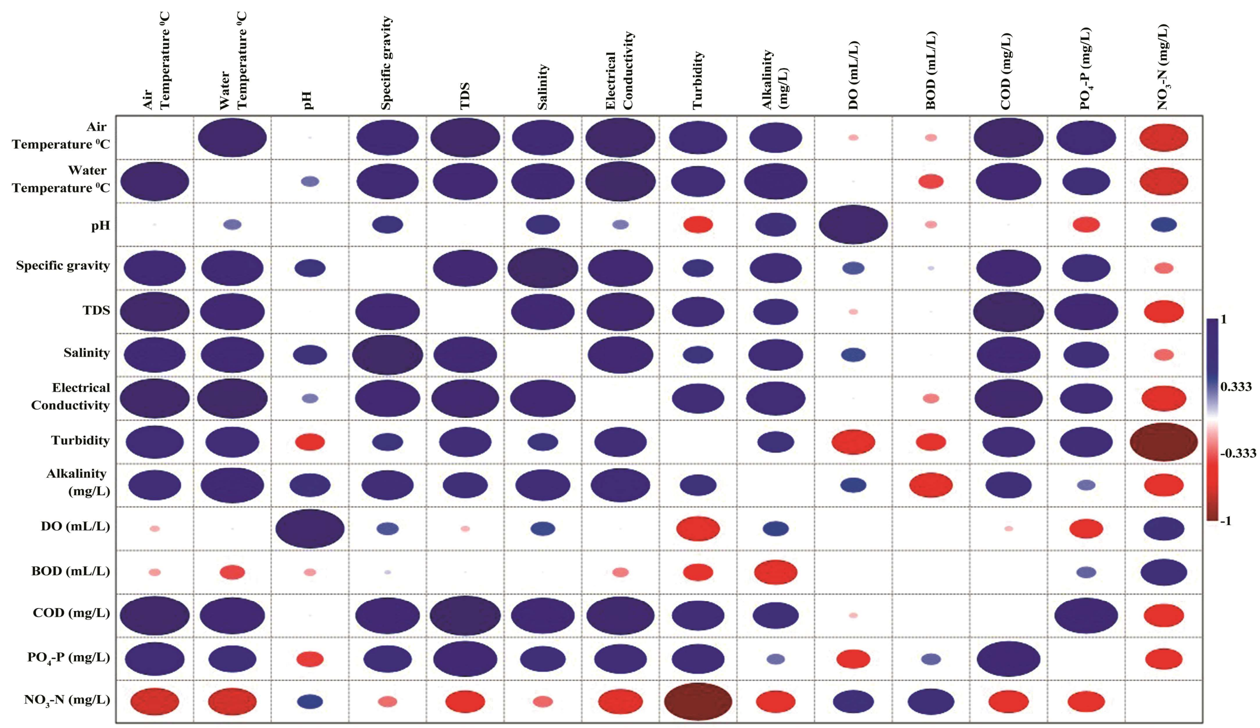

Fig. 6 — Pearson's correlation of water physicochemical parameters

electricity. BOD and COD quantify organic contamination and show a positive correlation; BOD counts biodegradable organic matter, and COD counts both biodegradable and non-biodegradable organic materials. Turbidity reflects the presence of suspended particles and shows a negative correlation with DO and nitrate, whereas a positive correlation with temperature and phosphate. Total alkalinity is positively correlated with salinity and water temperature. The buffering ability of water, which is impacted by dissolved salts and carbonates, is measured by alkalinity. pH shows a highly strong positive correlation with DO.

Discussion

The physicochemical water parameters of Juhu Koliwada and Haji Ali displayed seasonal and geographical fluctuations. Although little variation in pH was observed during the study, pH can considerably influence several facets of water quality, including dissolved oxygen, turbidity, the physiological processes in living organisms, and the availability of nutrients[21].

Alkalinity helps maintain a stable pH by providing a buffering effect and preventing abrupt changes in pH levels. Fluctuations in alkalinity can signal pollution, as both industrial and household wastewater can alter alkalinity by adding substances that affect the buffering ability[13].

Salinity in marine water is one of the key factors that affect organisms, such as plankton abundance and distribution. Salinity also depends on the amount of rainfall and the degree of freshwater influx[12,22,23]. EC and TDS are parameters that indicate salinity levels, making them quite beneficial for studying freshwater intrusion. The values of EC and TDS are correlated[24].

A low level of dissolved oxygen of 3.50±3.93 mg/L (pre-monsoon) and 3.83±2.0 mg/L (monsoon) was observed at Juhu Koliwada. A similar study by Ponkshe[12] reported a low DO level of 3.35 mg/L from the Mumbai coast. A decreased DO level acts as a limiting factor for aquatic organisms and suggests a load of organic pollutants[4].

PCA showed elevated levels of organic pollution indicator parameters, such as BOD and COD, which might be attributed to effluent discharge and runoff. Even though there are organic and inorganic pollutants in the water, the level is below the permissible limit set by the Ministry of Environment, Forest and Climate Change[25]. The levels of nitrate and phosphate were also affected by effluent and runoff at both sites. Water and soil data showed high nutrient load, suggesting the presence of organic and inorganic pollutants in both seasons (Figs. 2 & 3).

An analysis comparing water and sediment data revealed that phosphate levels were more concentrated in water than in the sediment during the pre-monsoon. The likely cause of the reduction in phosphate levels in water during the monsoon is primarily rainfall and the dilution of effluent. The study by Sekar *et al*.[23] in the coastal waters of Thoothukudi, affected by effluent discharge, reports similar results for inorganic phosphate. Untreated or inadequately managed sewage and industrial discharges also add substantial nutrient levels to aquatic ecosystems. An overabundance of nutrients fosters eutrophication[13].

Throughout the season, nitrate levels in the sediment were consistently higher than those in the water samples. There was no major difference in nitrate levels across seasons in both the sediment and water at the study locations. Usually, nitrate, together with phosphate, is essential for marine organisms[12]. The increased nitrate levels observed during the monsoon can be influenced by enhanced phytoplankton excretion, ammonia oxidation, nitrate reduction, nitrogen recycling, and bacterial decomposition of planktonic detritus in the environment. In addition, these elevated values can be attributed to denitrification processes and chemical exchange via air-sea interactions[21].

Conclusion

There is temporal and spatial variation in Juhu Koliwada and Haji Ali across seasons, exhibiting distinct profiles and suggesting the effects of different anthropogenic activities and natural environmental conditions. Hali Ali exhibits better water quality, likely due to better mixing of marine water than the Juhu Koliwada site. The high levels of phosphate and nitrate are indicative of effluent and organic pollutant interference in the physicochemical parameters of water. The phosphate and nitrate contaminants can lead to algal blooms. Both study sites have been affected by point-source effluent discharge, altering water quality in terms of the magnitude and nature of pollutants. Water parameter data suggest that Juhu Koliwada is more polluted than Haji Ali. Although most parameters- such as pH, BOD, and turbidity fall within the permissible/acceptable limits set by the CPCB. Elevated levels of phosphate and organic carbon suggest a moderate degree of pollution. Therefore, continuous monitoring of water quality at these locations is essential. Effluents from point sources must be treated effectively before being released into the marine environment. These can be achieved by implementing current pollution control measures and guidelines to protect the marine ecosystem. Since these are tourist attractions, there must be awareness programs about beach cleanliness and educational outreach among school and college students about the importance of the marine ecosystem.

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Conflict of Interest

The authors declare that they have no competing interests.

Ethical Statement

This manuscript is authors' original work and has not been published elsewhere. Furthermore, this manuscript is not under consideration for publication elsewhere.

Author Contributions

SG: Water and sediment samples collection and laboratory testing of the same, and writing- original draft of the manuscript ; and PD: Supervision and reviewing of the manuscript.

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