Multivariate and Statistical Evaluation of Coastal Water Quality and Seasonal Variation in the Physicochemical Properties of Gulf of Khambhat Region, Gujarat, India

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Abstract Coastal basins are the world's largest ultimate natural system for productivity and more than 40% of the world's population prefers to live on the coastline. Thus, the coastal region is of great economic and nutritional importance. The current research study investigates the seasonal deviations in coastal water quality at four different locations along the Gulf of Khambhat, Gujarat, India, for three consecutive seasons (pre-monsoon, monsoon, and post-monsoon). The coastal water samples were collected and analyzed for the water quality in the prescribed study area. As a result, sea surface temperature, salinity, pH, EC, alkalinity, turbidity, salinity, total suspended particles, dissolved oxygen, biological oxygen demand, chemical oxygen demand, chloride, sulfate, and nutrients such as nitrate, nitrite, phosphate, and total organic carbon were investigated at Gulf of Khambhat Region. The samples were collected from four different locations (Ghogha, Dumas, Dahej, and Purna). The multivariate statistical analysis indicates that oxygen, dissolved solids, salinity, nutrients, the natural, and anthropogenic conditions are the major factor that affects water quality. The water quality index was calculated to evaluate the seasonal water quality of GoK. The results revealed that the quality of water was moderate in pre-monsoon, monsoon, and post-monsoon. The findings suggest that anthropogenic disturbances and the development of a variety of activities with increased point and non-point stormwater runoff are pumped directly into the coastal areas which damaged water quality. Therefore, the outcomes of physicochemical research of water quality indicators may be a useful tool for government leaders trying to ensure GoK's long-term sustainability.

Keywords Gulf of Khambhat · Water quality index · Principal component analysis · Correlation coefficient

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1 Introduction

The deterioration of coastal water quality due to the discharge of domestic and agricultural wastes into the

sea has affected coastal leafage and fauna. Water quality is determined by the physicochemical properties of the water and is depend on the environment (Tanjung et al., 2019). For humans, the marine ecosystem is one of the most significant ecological and economically productive corridors of the abysms, as well as a precious niche for living biota (Panseriya et al., 2019). Coastal water quality can be affected by the various anthropogenic factors (Hamid et al., 2019) as well as due to enormous amounts of environmental pollutants being introduced into coastal areas (Tornero & Hanke, 2016; Wu et al., 2016). Likewise, original environmental changes analogous as a downfall, brackish input, tidal incursion, natural activities, and so on can impact water quality (Herbert et al., 2015; Ramesh Kumar et al., 2019a, 2019b).

Despite its significance to humans, water is the world's most deficiently managed resource, particularly in developing countries, and is under severe trouble as a result of a variety of anthropogenic applications (Ustaoğlu & Islam, 2020). The profusion of various types of pollutants such as heavy substances and nutrient enrichments from anthropogenic activities like marine jilting, dredging, artificial backwoods, ceaseless external, agricultural waste, domestic discharges, and atmospheric activities has come to a global apprehension in modern eras (Bristy et al., 2021; Raknuzzaman et al., 2016).

The Gulf of Khambhat, along with India's west coast, is the most important marine ecosystem (Singh, 2020). The pollution of the marine terrain has come to a global problem as a result of coastal developmental efforts such as industrialization, harbors, jetties, mining, and other mortal action. Sewage, synthetic backwoods, solid waste, oil, hydrocarbons, agricultural runoff, and pesticides are among the wastes that reach the coastal zone from point and non-point sources. Various anthropogenic stresses, including eutrophication, and other consequences affect marine water (Panseriya et al., 2021). Heavy substances, organic pollutants, radioactive elements, chemicals, and other nutrients are responsible for about 80% of the pollution load in the deep ocean (Landrigan et al., 2020). Nutrient over-enrichment occurs as a result of extensive use, reluctant processes, soil acidification, and groundwater contamination which damage the marine ecosystems. As a result, enforcing effective operations to avoid and regulate water quality changes instigated by natural and manmade activities is critical. Due to constant fluctuations in littoral ecological situations

and spatial-seasonal trends, a water quality study is a difficult task to complete. Systematic monitoring is essential to extract critical ecological indicators of surface water by assessing physicochemical and biological parameters (Grzywna & Bronowicka-Mielniczuk, 2020; Shi et al., 2016). The flow of organic and inorganic substances through gutters, upwelling processes, perpendicular mixing of water, and anthropogenic sources like husbandry, monoculture, fishing, energy consumption, and water discharge may affect the water quality (Drira et al., 2017; Tjahjono et al., 2017).

The main objective of this research work was to assess the current condition of the Gulf of Khambhat region. The downstream flow of many rivers such as Sabarmati, Tapi, Mahi, and Narmada is restricted due to large- and medium-sized dam constructions. These rivers no longer convey freshwater into the Gulf of Khambhat instead, they are transporting industrial and domestic wastewater which is also chemically polluted as a result of people's consumption of detergent and soap. Therefore, the present research study was performed to determine the current status of hydrographic parameters of coastal water in the Gulf of Khambhat, Gujarat, India, by exploring the quality of coastal water using multivariate and statistical analysis such as correlation and principal component analysis as well as water quality index. This information would be valuable for a deeper understanding of the ecological monitoring of the selected coastal area.

2 Materials and Analytical Methods

2.1 Study Area

The Gulf of Khambhat region is located between the latitude of 21°00′N–22°18′N and longitude of 72°15′E –72°45′E (Fig. 1) covering about 3120 sq. km and an average elevation of 8 m above mean sea level. The gulf is 130 km in length, 70 km in width, and has an average depth of 30 m (Misra & Balaji, 2015). It is characterized by several inlets and creeks formed by the confluence of rivers. Spread over 185,365 ha, this wetland is identified as extensive intertidal mud flats, scattered sandy beaches, salt pans, salt marsh, creeks, estuaries, mangroves, etc. The tidal range at the Gulf of Khambhat is known to be one of the largest along the Indian coastline
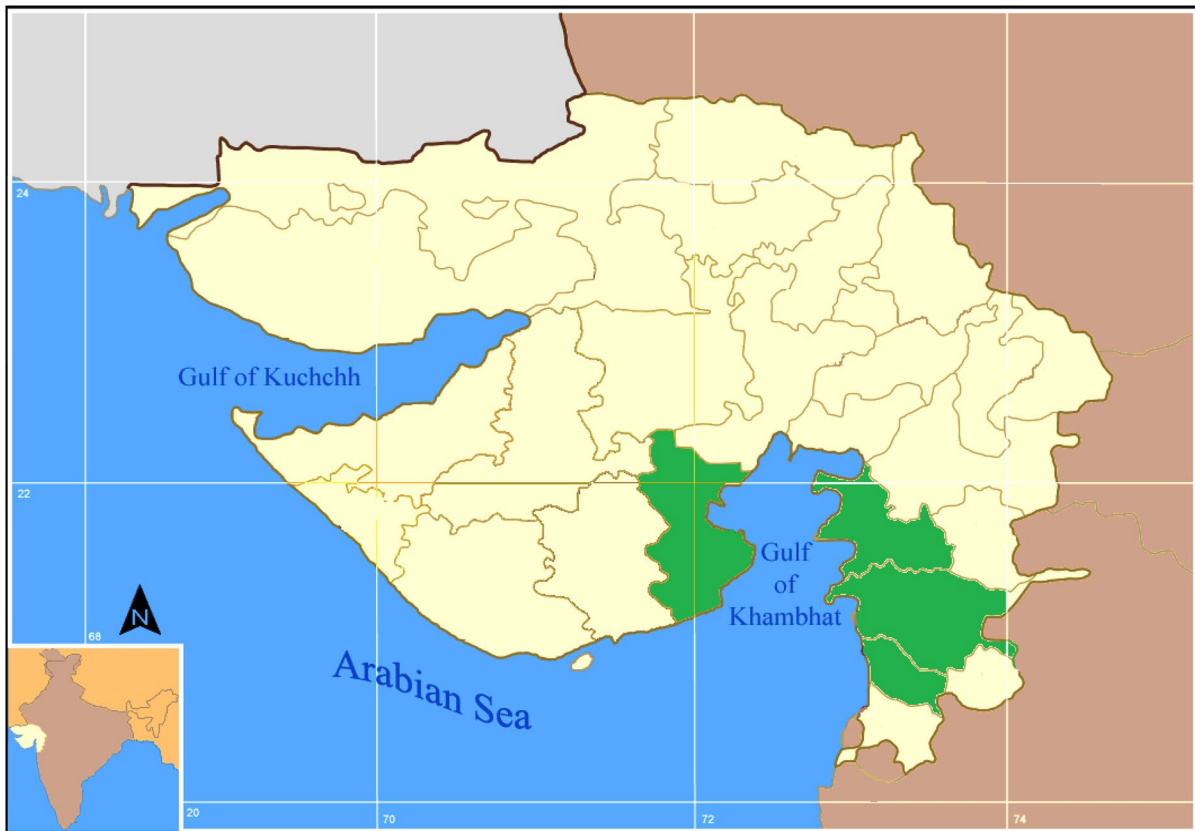
Fig. 1 Geographical location of the study area

(Kumar and Ramakrishnan, 2015). The tidal amplitude is also very high which sometimes exceeds 10 m in the Gulf of Khambhat and varies between 3 and 8 m in the Gulf of Kachchh.

2.1.1 Climatic Conditions of the Region

The coast of the Gulf of Khambhat has a very dynamic climate and environmental conditions. The Gulf of Khambhat region is located in a semi-arid zone, with a hot bio-climate, a very high average annual temperature variation of about 12 °C, and annual rainfall of 900 mm. Annual rainfall averaged 570 mm in Bhavnagar, 705 mm in Bharuch, 1355 mm in Surat, and 1772 mm in Navsari between 1985 and 2014 (Indian Meteorological Department). The temperature in the gulf is extreme, the lowest being about 10 °C during January and the highest of about 43 °C during May. The relative humidity ranges between 65 and 86%

thus offering semi-arid to sub-humid climatic conditions. The Gulf of Khambhat has a typical dry tropical monsoon climate, with three seasons running 4 months each: pre-monsoon (February–May), monsoon (June–September), and post-monsoon (October–December). The soil conditions in this region are mostly brackish, sandy, and saline to hyper-saline in nature, whereas the soil is mostly blackish in color and muddy-clayey-silty intertidal in mangrove habitats.

2.1.2 Selection of Study Sites

A preliminary survey for identifying coastal mangrove sites in Gujarat was conducted. The different sites of the coastal mangrove ecosystem had been identified. In this research study, four coastal mangrove sites, i.e., Bhavnagar, Surat, Bharuch, and Navsari district of Gujarat were identified as study sites.

2.1.3 Importance of Study Sites

Due to the drainage of 16 major and minor rivers, the Gulf of Khambhat is a unique coastal marine habitat in the tropical belt with a significant continental influence. This gulf area is highly diverse in nature and an important ecologically sensitive area. The Shetrunji, Sabarmati, Mahi, Narmada, Tapi, Damanganga, Par, Purna, Aurunga, Ambica, and Mindhola are the major rivers that form estuaries around the Gulf of Khambhat. Dahej and Ghogha are important ports since histories mark their presence in the Gulf of Khambhat. Bharuch, Navsari, and Surat are industrial belts and come under the economic zone of Gujarat. In recent decades, the Gulf of Khambhat region has experienced considerable industrial growth. Besides that, many industrial zones, such as GIDC, SEZ, and ZSI, emerged in Ankleshwar, Bharuch, Surat, Dahej, Valsad, Vapi, and Daman. However, environmental issues have come about as a result of this industrial expansion. The Gulf of Khambhat gets wastewater from the industrial area, which is either treated or untreated. On the Gujarat Coast, pollution from industrial wastewater discharge is a big problem. Anthropogenic and coastal erosion are both serious problems in South Gujarat, according to this current research study.

2.1.4 Study Sites

The study sites are demonstrated in Fig. 2, which is comprised of four districts along Gujarat's coastline, and Table 1 shows the study sites in detail. The description of the sites is mentioned below:

Ghogha Coast: Bhavnagar Bhavnagar district is situated in southern Gujarat and lies between 21°76′ N latitude and 72°15′ E longitude and covers about 170 km of coastline. The total district area is 11,155 sq. km. The average rainfall of is 548 mm. Shetrunji is the most important river in the region that flows towards the Southeast and meets the Arabian Sea. The composition of vegetation in the Ghogha coastal area is an evergreen natural forest. The mangroves species such as *Avecennia marina* and *Prosopis juliflora* are dominant in the region. One of the largest areas of intertidal mudflats (300 km) is located immediately to the north of Ghogha, near Bhavnagar.

Dumas Beach: Surat Surat district is located at 21°00′N to 21°23′N (latitude) and 72°38′E to 74°23′E (longitude) with an area of 7451.00 sq. km. The main river Tapi originates in the Satpuda mountain ranges and meets the Arabian Sea in the west. Kim, Mindhola, Purna, and Ambika are the other rivers that originate in the east and flow west. There are several petroleum industries including Essar, Shell, Kribhco, Larson and Turbo, NTPC, ONGC, GAIL, and other industries making it one of the fastest-growing cities in India. Dumas Beach (latitude 21°40′N, longitude 72°40′E) is an urban beach on the Arabian Sea located 21 km southwest of Surat city, near the riverine mouth of Tapi, where the river enters into the sea. The mangrove vegetation at Dumas coastal area exhibits flourishing growth with *Avicennia marina* and *Sonneratia apetala* as dominant species. The most abundant and dominant flora species associated with mangroves were *Prosopis juliflora*, *Suaeda maritime*, *Salvadora persica*, *Sesuvium portulacastrum*, etc.

Dahej Coast: Bharuch Bharuch district is also one of the coastal districts located along the Narmada River. Narmada River originates from the Amarkantak plateau of the Satpura Ranges in Rewa and travels through Madhya Pradesh, Maharashtra, and Gujarat before entering the Arabian Sea near Bharuch in the Gulf of Khambhat. The Narmada, Kim, Kaveri, and Dhadhar rivers run through the Bharuch district and all of these rivers meet the Arabian Sea in the west. Dahej falls in Vaghra taluka of Bharuch district. It lies between 21°43′N and 72°31′E and is situated in the Dhadhar river estuary. In this study site, the dominant mangrove flora species are *Avecennia marina* and *Prosopis juliflora*.

Purna Estuaries: Navsari The Navsari district is located in Gujarat's southernmost region Gulf of Khambhat and lies between 20.07° and 21.00°N latitudes and 72.43° to 73.00°E longitudes. The district covers a total area of 2657.56 sq. km, with an average rainfall of 1782 mm. Ambika, Purna, Kaveri, and Midhola are the major rivers that flow from the east and enter the Arabian Sea in the west. The Purna River spreads into a large estuary (21′55′N, 72′45′E). The composition of vegetation in Purna estuaries is highly diverse. The main mangrove species are *A. marina*, *A. ilicifolius*, *B. cylindrica*, *C. tagal*, and
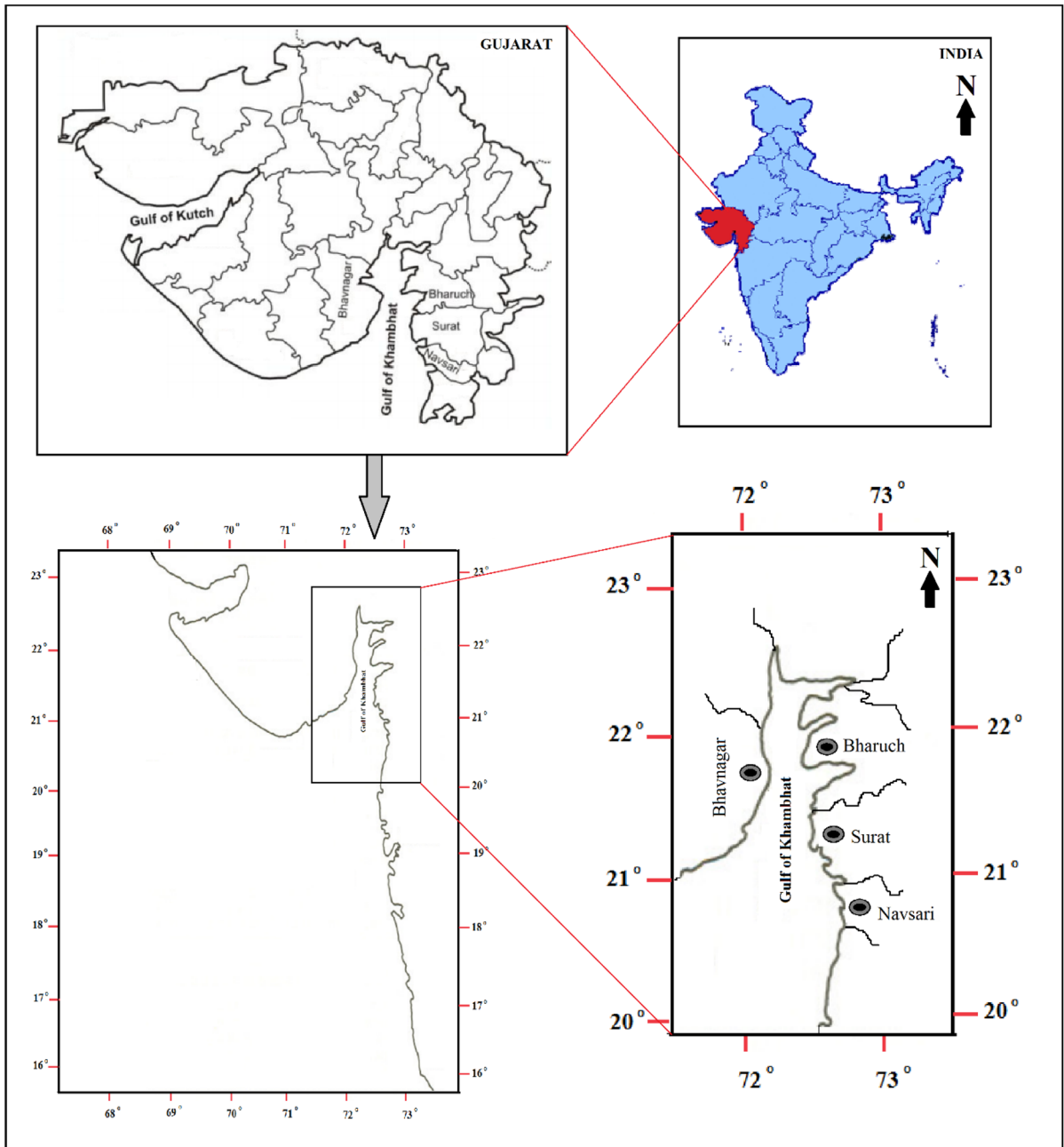
Fig. 2 Location map of the study area and selected study sites

Sonneratia apetala, and the dominant flora species associated with mangroves are *Prosopis juliflora*, *Suaeda maritime*, *Salvadora persica*, and *Sesuvium portulacastrum*.

2.2 Collection of Samples and Analysis

Four representative coastal water samples were collected from the Gulf of Khambhat region during the

Table 1 Details of the study areas in the Gulf of Khambhat, Gujarat

Sites	Location	Geographical coordinates	Dominant mangrove vegetation
Bhavnagar	Ghogha Coast	21°40′N, 72°17′E	*Avecennia marina*
Bharuch	Dahej Coast	21°71′N, 72°52′E	*Avecennia marina*
Surat	Dumas Beach	21°40′N, 72°42′E	*Avecennia marina and Sonneratia apetala*
Navsari	Purna estuaries	20°55′N, 72°47′E	*Avecennia marina*, *Bruguiera cylindrical*, *Ceriops tagal*, and *Sonneratia apetala*

pre-monsoon, monsoon, and post-monsoon seasons (Fig. 2). The water samples were collected in 1 L pre-washed high-density polyethylene bottles with a narrow mouth, and the systematic sampling was done according to the BIS, 1987. The water samples were kept iced until it is brought to the laboratory for analysis. A total of 19 water quality parameters were investigated, i.e., temperature, pH, electrical conductivity (EC), turbidity, salinity, total dissolved solids (TDS), alkalinity, chloride (Cl^-), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO_3-N), nitrite (NO_2-N), ammoniacal nitrogen (NH_3-N), sulfate (SO_4^{2-}), phosphate (PO_4^{2-}), total carbon (TC), inorganic carbon (IC), and total organic carbon (TOC). pH, EC, temperature, and salinity are evaluated by the electrometric technique. The turbidity was analyzed by the nephelometric method. Argentometric titration was used to analyze the chloride, whereas TDS was estimated by the gravimetric method in the water sample. DO and 5 days BOD were assessed by Winkler's method while COD was analyzed by the open reflux method. Nutrient parameters such as NO_3-N, NO_2-N, PO_4^{2-}, and SO_4^{2-} were estimated by the spectrophotometer method (Model: 2060+, Analytical). Total organic carbon was investigated using a TOC analyzer (model no.: Multi N/C 3100, Analytikjena). Analysis of coastal water samples was done as per standard methods described in APHA, 1998. All reagents of analytical grade were used for analysis purposes.

2.3 Multivariate and Statistical analysis

2.3.1 Pearson Correlation Coefficient

The correlational coefficient matrix is the most common measure of dependence between two water parameters. It is an indicator that shows how one variable affects another (Howladar et al., 2014; Kumar et al., 2017, 2020). The correlation coefficient (*r*) is a number that ranges from −1 to 1. When *r* approaches −1, the correlation is said to be negatively correlated. When the value of r is around +1, the association is reflected as positively correlated. The points are thought to grow less correlated and eventually uncorrelated as the value of r tends to zero (Howladar et al., 2014). The Pearson correlation coefficient is calculated as follows:

$$rxy = \frac{\sum_{i=1}^{n}(xi - \bar{x})(yi - \bar{y})}{\sqrt{\sum_{i=1}^{n}(xi - \bar{x})2}\sqrt{\sum_{i=1}^{n}(yi - \bar{y})2}} \tag{1}$$

where *x* and *y* are two different water parameters, *I* and *j* are sample numbers, *n* is the total number of data points, and *x* and *y* are the two-parameter means.

2.3.2 Principal Component Analysis (PCA)

Assessing the state of the coastline water quality, finding the influencing variables of water quality, and enhancing the water quality of the coastal basin's environment are a difficult and time-consuming task (Baba et al., 2020; Singh et al., 2020). PCA was used on the GoK to get a holistic perspective of all the elements in the system (Gorgoglione et al., 2019; Rajesh Kumar et al., 2019a, 2019b). The PCA was used to determine the primary variable that influences the geochemistry of the Gulf of Khambhat and to explain the relationship between the variables.

2.3.3 Water Quality Index (WQI)

WQI is the most essential measure for assessing the water quality of GoK's coastal water in a single unit. The WQI for GoK was calculated using physiochemical parameters such as pH, DO, Cl^-, PO_4^{2-}, and

NO$_3$-N. It is calculated as follows Q_i value and weight factor W_i (Jha et al., 2015):

$$WQI = \sum WiQi \qquad (2)$$

where Q_i is the water quality of an individual parameter and W_i denotes the comparative significance of that parameter to the complete water quality (Al-Mutairi et al., 2015).

3 Results and Discussion

The physicochemical parameters of coastal water were evaluated at four coastal mangrove sites in the Gulf of Khambhat, Gujarat: Ghogha Coast (Bhavnagar), Dahej Coast (Bharuch), Dumas Beach (Surat), and Purna estuaries (Navsari). Seasonal variations in physicochemical parameters and nutrients of coastal water, as well as four sampling locations in the Gulf of Khambhat, Gujarat, India, are shown in Tables 2, 3, and 4.

3.1 Physicochemical Characteristics of Coastal Water

The physicochemical properties of coastal water in marine environments are very important. Variations in the physicochemical parameters influence the species diversity, reproduction, growth, survival, and other activities of flora and fauna (Sarkar et al., 2020). The optimum value of water quality parameters should be maintained for a healthy coastal ecosystem and species survival (Bhateria & Jain, 2016). The quality of water depends on the physicochemical factors; therefore, analyzing and monitoring these parameters are very much essential (Rahman et al., 2021).

The authors have thoroughly investigated the water quality of the Sundarbans, the world's biggest mangrove forest ecosystem (Rahman et al., 2013). Satyanarayana and Krishna (2017) studied the water quality of the mangrove ecosystem (Coringa Wildlife Sanctuary) in East Godavari, Andhra Pradesh, for 2 years (January 2015 to December 2016), and

Table 2 Physicochemical characteristics of coastal water samples collected during the pre-monsoon season

Parameters	Study sites (mean ± SD)				Range	Average
	Ghogha coast (Bhavnagar)	Dahej Coast (Bharuch)	Dumas Beach (Surat)	Purna estuaries (Navsari)		
Temperature (°C)	28.52 ± 0.08	30.74 ± 0.73	26.40 ± 0.29	31.58 ± 0.13	26.40–31.58	29.31
pH	8.57 ± 0.07	7.97 ± 0.21	7.74 ± 0.29	8.22 ± 0.28	7.74–8.57	8.13
EC (mS/cm)	51.34 ± 0.51	39.74 ± 1.40	40.20 ± 0.47	36.98 ± 0.23	36.98–51.34	42.07
Turbidity (NTU)	45.78 ± 2.44	151.40 ± 26.26	96.27 ± 12.01	141.40 ± 9.04	45.78–151.40	108.71
Salinity (ppt)	33.42 ± 0.18	26.70 ± 1.13	25.48 ± 0.40	23.36 ± 0.15	23.36–33.42	27.24
TDS (g/l)	30.84 ± 0.40	28.68 ± 2.54	25.36 ± 0.96	22.62 ± 0.22	22.62–30.84	26.88
Alkalinity (mg/l)	62.20 ± 5.26	126.80 ± 27.70	138.00 ± 20.78	110.20 ± 12.09	62.20–138.00	109.30
Chloride (g/l)	21.79 ± 2.39	28.26 ± 3.52	10.60 ± 2.22	10.91 ± 1.17	10.60–28.26	17.89
DO (mg/l)	8.04 ± 0.35	5.63 ± 0.35	3.29 ± 0.32	4.93 ± 0.74	3.29–8.04	5.47
BOD (mg/l)	12.21 ± 3.13	12.93 ± 2.10	3.11 ± 0.78	11.49 ± 4.22	3.11–12.93	9.94
COD (mg/l)	156.40 ± 82.20	317.20 ± 89.01	354.40 ± 106.67	261.20 ± 41.12	156.40–354.40	272.30
NO$_3$ − N (mg/l)	10.03 ± 1.23	10.99 ± 2.71	9.15 ± 0.94	6.69 ± 1.23	6.69–10.99	9.22
NO$_2$ − N (mg/l)	1.37 ± 0.32	2.65 ± 1.17	1.46 ± 0.34	0.90 ± 0.37	0.90–2.65	1.60
NH$_3$ − N (mg/l)	0.19 ± 0.16	0.14 ± 0.08	0.73 ± 0.37	1.37 ± 0.27	0.14–1.37	0.61
SO4^{2-} (mg/l)	121.96 ± 12.76	170.48 ± 24.41	146.28 ± 5.97	141.40 ± 8.69	170.48–146.28	145.03
Phosphate (mg/l)	0.47 ± 0.32	0.53 ± 0.31	0.81 ± 0.35	0.58 ± 0.18	0.47–0.81	0.60
TC (mg/l)	23.98 ± 6.32	82.60 ± 10.14	82.34 ± 1.38	41.02 ± 0.47	23.98–82.60	57.49
IC (mg/l)	17.99 ± 4.49	72.08 ± 8.75	77.21 ± 0.66	37.69 ± 0.49	17.99–77.21	51.24
TOC (mg/l)	5.99 ± 1.91	10.52 ± 2.23	5.13 ± 1.46	3.33 ± 0.11	3.33–10.52	6.24

*Mean ± SD: mean of values from the five locations.

Table 3 Physicochemical characteristics of coastal water samples collected during the monsoon season

Parameters	Study sites (mean ± SD)				Range	Average
	Ghogha Coast (Bhavnagar)	Dahej Coast (Bharuch)	Dumas Beach (Surat)	Purna estuaries (Navsari)		
Temperature (°C)	29.30 ± 0.73	29.42 ± 0.33	30.12 ± 0.36	29.66 ± 0.46	29.66–30.12	29.63
pH	8.00 ± 0.23	7.95 ± 0.20	7.87 ± 0.14	7.59 ± 0.25	7.59–8.00	7.85
EC (mS/cm)	37.18 ± 1.13	39.64 ± 0.76	38.80 ± 1.15	35.88 ± 0.55	35.88–39.64	37.88
Turbidity (NTU)	121.26 ± 38.38	147.60 ± 7.02	79.46 ± 25.45	117.14 ± 16.47	79.46–147.60	116.37
Salinity (ppt)	24.40 ± 2.09	23.22 ± 0.38	24.32 ± 0.64	22.60 ± 0.53	22.60–24.40	23.64
TDS (g/l)	22.94 ± 1.03	24.94 ± 1.11	24.42 ± 1.15	22.36 ± 0.76	22.36–24.94	23.67
Alkalinity (mg/l)	72.80 ± 8.44	112.80 ± 18.79	136.20 ± 5.50	94.20 ± 14.75	72.80–136.20	104.00
Chloride (g/l)	17.86 ± 0.84	24.96 ± 1.00	6.80 ± 0.63	8.75 ± 1.01	6.80–24.96	14.59
DO (mg/l)	3.87 ± 0.29	4.42 ± 0.44	4.40 ± 0.16	3.91 ± 0.36	3.87–4.42	4.15
BOD (mg/l)	5.62 ± 1.08	10.17 ± 3.00	8.62 ± 2.60	5.39 ± 1.80	5.39–10.17	7.45
COD (mg/l)	53.60 ± 7.40	107.60 ± 25.86	102.40 ± 20.27	93.80 ± 24.72	53.60–107.60	89.35
NO_3-N (mg/l)	12.10 ± 1.28	13.43 ± 3.58	12.70 ± 1.74	9.09 ± 1.68	9.09–13.43	11.83
NO_2-N (mg/l)	1.70 ± 0.40	2.05 ± 0.33	1.79 ± 0.18	1.89 ± 0.49	1.70–2.05	1.86
NH_3-N (mg/l)	0.42 ± 0.39	0.22 ± 0.28	1.15 ± 0.21	2.07 ± 0.28	0.22–2.07	0.97
$SO4^{2-}$ (mg/l)	103.06 ± 11.65	424.52 ± 137.44	103.80 ± 7.06	97.0 ± 13.63	97.0–424.52	182.10
Phosphate (mg/l)	1.14 ± 0.41	1.06 ± 0.18	0.31 ± 0.21	1.59 ± 0.48	0.31–1.59	1.03
TC (mg/l)	29.62 ± 5.50	45.86 ± 4.70	37.11 ± 2.08	35.25 ± 1.53	29.62–45.86	36.96
IC (mg/l)	24.69 ± 5.13	38.30 ± 4.61	32.02 ± 1.80	28.34 ± 1.08	24.69–38.30	30.84
TOC (mg/l)	4.92 ± 0.89	7.56 ± 1.60	5.09 ± 0.77	6.92 ± 0.89	4.92–7.56	6.12

found the parameters like temperature, pH, salinity, DO, ammonia, alkalinity, nitrite, hardness, calcium, and magnesium are varied between 26 and 33.8 °C, 7.15 and 8.5, 0 and 24 ppm, 4 and 7.8 ppm, 0.05 and 1.2 ppm, 80 and 340 ppm, 0.01 and 1 ppm, 110 and 3500 ppm, 80 and 250 ppm, and 180 and 450 ppm respectively.

In the present research study, the average values of pH, temperature, DO, BOD, and nitrite are found below the permissible limits throughout the study period as recommended by EPA. The physicochemical characteristics of coastal water samples of four different sites in the Gulf of Khambhat showed seasonal as well as spatial variations.

3.1.1 Water Temperature

Temperature influences the growth of flora and fauna in aquatic habitats and is the most essential component in controlling the rate of chemical reactions. In coastal and estuarine water systems, it has an impact on physical, chemical, and biological

processes (Bhateria & Jain, 2016; Nievola et al., 2017). The temperature of the coastal surface water ranged from 26.40 to 31.58 °C, with less fluctuation between the four sites on average over the study period. This suggested that the research area's seasonal variance was due to its unique climatic nature. The observed temperature variance might be accredited to the mixing of fresh water and the varying intensity of water currents. Our findings were found to be following Martin et al. (2008), who described a temperature range of 28–32 °C during the pre-monsoon season for the Cochin Estuary in south India. George et al. (2012) observed a wide range of temperatures for estuary water in the Gulf of Khambhat, India, ranging from 22 to 33.2 °C. During the monsoon season, the Dahej Coast and Purna estuaries had the lowest average water temperature. The surface water temperature is affected by factors such as latitude, altitude, seasons, air circulation, evaporation, insolation, flow, depth, freshwater mixing, solar radiation intensity, and water currents (Cronin et al., 2019).

Table 4 Physicochemical characteristics of coastal water samples collected during post-monsoon season

Parameters	Study sites (mean ± SD)				Range	Average
	Ghogha Coast (Bhavnagar)	Dahej Coast (Bharuch)	Dumas Beach (Surat)	Purna estuaries (Navsari)		
Temperature (°C)	29.34 ± 0.62	30.46 ± 1.06	30.58 ± 0.60	30.58 ± 0.55	29.34–30.58	30.24
pH	8.04 ± 0.19	7.88 ± 0.35	7.71 ± 0.33	8.09 ± 0.20	7.71–8.09	7.93
EC (mS/cm)	37.72 ± 2.19	38.63 ± 1.95	39.12 ± 1.03	35.96 ± 2.51	35.96–39.12	37.86
Turbidity (NTU)	72.52 ± 21.83	131.60 ± 14.67	79.76 ± 20.89	133.00 ± 8.15	72.52–133.00	104.22
Salinity (ppt)	30.14 ± 1.36	26.94 ± 2.12	15.42 ± 3.61	20.50 ± 1.99	15.42–30.14	23.25
TDS (g/l)	24.38 ± 1.82	22.97 ± 1.87	24.00 ± 1.07	21.65 ± 1.56	21.65–24.38	23.25
Alkalinity (mg/l)	75.80 ± 8.98	88.80 ± 13.66	130.60 ± 7.92	102.00 ± 13.66	75.80–130.60	99.30
Chloride (g/l)	18.89 ± 1.02	26.21 ± 1.03	10.81 ± 0.70	9.30 ± 0.27	9.30–26.21	16.30
DO (mg/l)	5.49 ± 1.30	6.25 ± 1.02	7.23 ± 0.56	6.62 ± 1.02	5.49–7.23	6.40
BOD (mg/l)	8.86 ± 5.36	10.41 ± 3.94	15.25 ± 3.57	12.21 ± 1.17	8.86–15.25	11.68
COD (mg/l)	71.20 ± 12.93	57.60 ± 8.02	92.20 ± 28.71	78.20 ± 14.43	57.60–92.20	74.80
NO_3^- N (mg/l)	14.58 ± 1.68	14.15 ± 0.61	10.46 ± 1.34	10.49 ± 1.44	10.46–14.58	12.42
NO_2 − N (mg/l)	1.91 ± 0.33	2.56 ± 0.36	1.83 ± 0.31	2.54 ± 0.52	1.83–2.56	2.21
NH_3 − N (mg/l)	0.82 ± 0.53	0.42 ± 0.23	1.52 ± 0.42	1.80 ± 0.53	0.42–1.80	1.14
$SO4^{2-}$ (mg/l)	99.26 ± 17.14	207.94 ± 8.44	105.82 ± 11.80	97.0 ± 14.06	97.0–207.94	127.51
Phosphate (mg/l)	1.00 ± 0.29	1.36 ± 0.68	2.09 ± 0.13	1.34 ± 0.33	1.00–2.09	1.45
TC (mg/l)	33.16 ± 4.25	42.19 ± 3.10	38.02 ± 1.76	33.45 ± 1.56	33.16–42.19	36.71
IC (mg/l)	25.84 ± 4.62	35.50 ± 4.14	32.27 ± 1.81	28.41 ± 1.82	25.84–35.50	30.51
TOC (mg/l)	7.33 ± 0.50	6.68 ± 1.25	5.75 ± 1.04	5.04 ± 0.53	5.04–7.33	6.20

*Mean ± SD: mean of values from the five locations.

3.1.2 pH

In this study, there were minor differences in the average pH values of study locations over three seasons. The pH values in the coastal water samples ranged from 7.59 to 8.57, indicating alkaline nature, which is a common aspect of the coastal marine environment. Similarly, the pH range of 6.9 to 8.6 was reported by George et al. (2012) and Jangala et al. (2013) for estuary and coastal water along the Gujarat coast. The pH ranges from 7.8 to 8.3 in the estuarine area (Millero, 1986), which could be related to the seawater buffering capacity. Satpathy et al. (2010) found a pH range of 7.7–8.3 in the waters of India's Kalpakkam coast. In this study, the pH value did not show much geographical variation like temperature. Organic matter decomposition, carbon dioxide (CO_2) consumption by photosynthesis through bicarbonate degradation, dilution of seawater with freshwater inflow, temperature, and salinity decrease are all factors that cause pH changes in different seasons or locations (Balakrishnan et al., 2017; Palanivel et al., 2019; Pederson et al., 2021; Sarathy et al., 2022).

3.1.3 Electrical Conductivity (EC)

The EC of water is a measure of the mineral content, which is made up of anions and cations. The EC of water is greatly influenced by changes in total dissolved solids (TDS) and salinity (Maliki et al., 2020). During the three seasons, the EC of coastal water samples ranged from 35.88 to 51.34 mS/cm, with a significant positive connection with TDS and salinity. The EC value fluctuation could be related to the mixing of freshwater and seawater. The high EC value could be related to increased anthropogenic pollution during the pre-monsoon period (Clifford et al., 2021; Sharma et al., 2021). The electrical conductivity ranged from 26.65 to 52.0 mS/cm in the mangrove ecosystems of the Pondicherry Coast (Satheeshkumar & Khan, 2012).

3.1.4 Turbidity

Turbidity is influenced by suspended particulate matter including sand, silt, clay, organic matter, inorganic compound, plankton, and other microscopic organisms (Grobbelaar, 2009). During the same season (pre-monsoon), turbidity was found to be high on the Dahej Coast and low on the Ghogha coast, showing that the differences were spatial rather than seasonal. Freshwater carrying suspended particles, discharge of industrial effluents from various non-point sources, and tidal action may all contribute to the wide variance in turbidity values recorded at four study locations and in different seasons. The turbidity value varied between 45.78 and 157.40 NTU. Gadhia et al. (2012) found that turbidity values in the Tapi Estuary, Gujarat, ranged from 54 to 152 NTU, with a peak during the pre-monsoon season, which supported the findings of the present study, as most of the locations had higher values in the pre-monsoon season.

3.1.5 Salinity

During the study period, average water salinity differed significantly, ranging from 15.42 to 33.42 ppt. For particular areas and seasons, the salinity value of coastal water exhibits significant fluctuations. The shallowness of the water, tidal patterns, low rainfall, high evaporation, and high aridity of the region, as well as the neritic water effect, all contribute to coastal water salinity (Geng et al., 2016). During the pre-monsoon season, more salinity was seen, but during the monsoon and post-monsoon seasons, decreased salinity was observed. During the monsoon season, high rainfall results in an inflow of freshwater from the land, resulting in moderately reduced salinity. A previous research study conducted by Gadhia et al. (2012) on Tapi estuary, Gujarat, demonstrated high salinity in the pre-monsoon season and low salinity during the monsoon and post-monsoon seasons. Salinity variations in brackish water habitats such as mangroves, estuaries, and backwaters are primarily influenced by freshwater inflow from land runoff, which is influenced by rainfall and tidal variations, as previously reported by Srinivasan and Natesan (2013) in the Gulf of Kachchh; Saravanakumar et al. (2008) in the creek waters of Kachchh mangrove and Mayalagu et al. (2009) in the mangrove forest at

Pichavaram and similar results were also perceived in the present study.

3.1.6 Total Dissolved Solids (TDS)

The average TDS values were observed high in the pre-monsoon seasons than in monsoon and post-monsoon, varied between 21.65 and 30.84 g/l. More or fewer variations may be due to the tidal activity. The high TDS value (> 30 g/l) was also observed at Veraval and Diu, South Saurashtra coastline (Bhadja and Vaghela, 2013). The TDS range 39.03 to 44.82 g/l in seawater was found on the Gujarat Coast (Bhadja & Kundu, 2011). The high TDS in the coastal water samples might be perceived due to the direct influence of seawater.

3.1.7 Alkalinity

The alkalinity of the coastal water samples was recorded between 62.20 to 138 mg/l. The highest and minimum values in the pre-monsoon season suggested that the fluctuations were spatial rather than seasonal. The higher values of alkalinity may be due to the presence of excess free CO_2 (Bozorg-Haddad et al., 2021). Jangala et al. (2013) found that alkalinity values fluctuated between 72.27 to 197.21 mg/l at Mahi estuary, Gujarat, and remained comparatively high during the non-monsoonal season. Rahman et al. (2013) perceived a similar sort of alkalinity (100–150 mg/l) in the Sundarbans mangrove forest's water. The alkalinity is affected by pollutant load fluctuations. However, industrial discharges, low rainfall, excessive evaporation, and seawater intrusion may all contribute to the progressive increase in alkalinity during the winter and summer seasons (Moore & Joye, 2021). Due to adequate river discharge, alkalinity values for all stations stay constant during the wet season (Dey et al., 2021; Pramanik et al., 2020; Shil et al., 2019).

3.1.8 Dissolved Oxygen (DO)

DO levels are generally high in coastal and estuarine waters. The photosynthetic process or the cumulative effect of heavy rainfall combined with increasing wind speed and the resulting freshwater influx could explain the relatively high concentration of DO in coastal water (Comfort et al., 2019; Hammer et al.,

2019). A low level of DO could be attributed to the coastal water's lower agitation and turbulence or the organic matter decomposition process's microbial demand for oxygen (Arnott et al., 2021). The solubility of oxygen is also influenced by the salinity and temperature of the water. Through the pre-monsoon season, the spatial variation in the DO was from 3.29 (Dumas Coast) to 8.04 mg/l (Ghogha Coast). Kumar et al., (2010) reported a similar range of DO concentration (1.68 to 9.55 mg/l) in estuarine water in the Gulf of Cambay, India. When compared to the other two seasons, the average monsoon DO value was lower. This reflects the geographical nature of variation rather than seasonal change.

3.1.9 Biochemical Oxygen Demand (BOD)

BOD fluctuated from 3.11 to 15.25 mg/l for all four locations, with the minimum and maximum mean values for Dumas Beach site being 3.11 ± 0.78 mg/l during the pre-monsoon season and 15.25 ± 3.57 mg/l during the post-monsoon season, respectively. The BOD values were within the recommended value of Indian coastal water quality standards for swimming and aquatic life (30 mg/l or less). The BOD values were also observed within the standard value at the port and harbor region (Gupta et al., 2005); Mahi estuary (Jangala et al., 2013); Gulf of Kachchh (Gopal et al., 2014); and Bhavnagar coast (Parekh & Gadhvi, 2015).

3.1.10 Chemical Oxygen Demand (COD)

COD concentrations varied significantly from 53.60 to 354.40 mg/l. For all sites, the highest COD value was detected during the pre-monsoon season, followed by the post-monsoon and monsoon seasons. During the pre-monsoon season, COD levels at Dumas Beach and the Dahej Coast site were found to be higher than the Indian coastal water quality guidelines for swimming and aquatic life (250 mg/l or less). Jangala et al. (2013) reported a high amount of COD during the pre-monsoon period at J-point of Mahi Estuary, Gujarat. The presence of high COD could be ascribed to the release of industrial and domestic effluents from nearby locations (Aniyikaiye et al., 2019; Yaseen & Scholz, 2019). The COD value declined significantly after the pre-monsoon season, possibly due to increased freshwater influx and strong

river runoff during monsoonal floods (Jargal et al., 2021).

3.1.11 Nitrogen (NO₃-N, NO₂-N, and NH₃-N) Concentration

NO_3-N, NO_2-N, and NH_3-N concentrations were found to be low in the pre-monsoon season but increased through the monsoon season compared to the post-monsoon season in the current study. Rainfall, residential waste, and fertilizers from the nearby agricultural area could all have contributed. According to George et al. (2012) through the monsoon season, additional nitrogenous compounds and phosphate complexes have come into the coastal waters through freshwater inflow by rivers and rivulets. The increasing nitrate level was caused by the breakdown of mangrove leaves and terrestrial runoff during the monsoon season (Sanyal et al., 2020). Higher salinity may have contributed to the low nitrite levels recorded during the study period. The oxidation of ammonia (NH_3-N) to nitrite (NO_2-N) and then to nitrate (NO_3) nitrogen may be the cause of high nitrate concentrations reported at all places during all seasons (Norton & Stark, 2011). Most of the study sites show a similar trend with similar seasonal changes in NO_3-N, NO_2-N, and NH_3-N concentration in water.

3.1.12 Phosphate-Phosphorus (PO₄-P)

Phosphate concentrations in estuarine and coastal water are influenced by the amount of freshwater combined with seawater in the intertidal zone, microbial decomposition of organic materials, and phytoplankton consumption (Davies & Ugwumba, 2013). In the present study, phosphate was ranging from 0.31 to 2.09 mg/l at all four sites. Malik et al. (2012) reported phosphate concentration range between 0.6 and 4.2 mg/l in South Gujarat Rivers, and Dubey and Ujjania (2013) demonstrated phosphate concentration ranging between 0.10 and 0.73 mg/l in Tapi estuaries water. The lower concentration of phosphate could be due to the absorption of phosphorous from water by phytoplankton (Bunce et al., 2018). Generally, nitrogen and dissolved inorganic phosphorus concentrations have relatively low stocks in estuarine waters of the mangrove ecosystem (Lomas et al., 2014; Reis et al., 2017). Martiny et al. (2019) also described that the surface waters have the lowest phosphate

concentration observed anywhere in the ocean. Phosphate-phosphorus content was found to be high in coastal water samples, which could be accredited to the impact of industrial effluents (Kateb et al., 2018). Ajithamol et al. (2016) observed similar conditions in the Manakudy Estuary on India's South West Coast. The increase in phosphate levels may be related to the intrusion of upwelling seawater into the creek (Chen et al., 2021; Schulz et al., 2019).

3.1.13 Sulfate

The sulfate concentration in all coastal water samples at the four study sites was observed between 97.0 and 424.52 mg/l. Kuttimani et al. (2017) similarly observed sulfate concentrations ranging between 40.5 and 408 mg/l in the Nagapattinam coastal area of Tamil Nadu, India. Rahman et al. (2013) also described the sulfate concentrations ranging from 9.02 to 968.3 mg/l in the water samples of the Sundarbans. Increased sulfate levels in coastal mangrove waters could be caused by degraded organic matter mixing with seawater flows and oxidation of buried biogenic materials (Cao et al., 2021; Santos et al., 2021). The high value of sulfate during the pre-monsoon season might be due to the decomposition of sulfide-bearing minerals and sulfate-rich effluents from husk retting grounds, whereas the low value in the monsoon season might be due to dilution caused by rainfall and freshwater inflow (Sunil Kumar, 2018). Its concentration tends to rise due to the discharge of industrial and domestic sewage. The largest runoff from the river and neighboring farming regions (e.g., fertilizers and wastewater), eroded soils, and aquaculture operations may be responsible for the highest amounts of sulfate (Sherafati & Satpathy, 2011).

3.1.14 Total Organic Carbon (TOC) Content

Due to the presence of terrestrial detritus and mangrove litters in the suspended matter, the surface water of the mangrove ecosystem often has a high organic carbon content (G. Chen et al., 2017; Kida & Fujitake, 2020). Total organic carbon (TOC) levels ranged from 3.33 to 10.52 mg/l at the sampling locations. Similarly, Kumar et al. (2010)

described TOC concentrations ranging from 8.78 to 39.09 mg/l in surface water of the Tapi Estuary, Gulf of Cambay, India (Figs. 3, 4, and 5).

*Mean ± SD: mean of values from the five locations.

4 Multivariate and Statistical Analysis

4.1 Correlation Among Water Quality Parameters

The correlation coefficients were calculated between physicochemical characteristics of coastal water through different seasons to distinguish the interdependence of variables. Tables 5, 6, and 7 show the correlation matrices for different seasons of all four study sites of the Gulf of Khambhat. In pre-monsoon season, salinity shows the strong positive correlation with EC ($r = 0.977$, $P < 0.01$), TDS ($r = 0.818$, $P < 0.01$), and dissolved oxygen ($r = 0.811$, $P < 0.01$). Turbidity and chloride show the significant positive correlation with temperature ($r = 0.647$, $P < 0.01$) and TDS ($r = 0.754$, $P < 0.01$) respectively. Dissolved oxygen also the significant positive correlation with pH ($r = 0.750$, $P < 0.01$), EC ($r = 0.769$, $P < 0.01$), and TDS ($r = 0.687$, $P < 0.01$). BOD shows the significantly positive correlation with temperature ($r = 0.682$, $P < 0.01$) and DO ($r = 0.707$, $P < 0.01$). Nitrite and TOC shows positive correlation with nitrate ($r = 0.776$, $P < 0.01$) and $Cl-$ ($r = 0.769$, $P < 0.01$) respectively.

In monsoon season, the positive correlation was observed between TDS and EC ($r = 0.649$, $P < 0.01$), DO and TDS ($r = 0.796$, $P < 0.01$), chloride and turbidity ($r = 0.653$, $P < 0.01$), COD and alkalinity ($r = 0.742$, $P < 0.01$), and between sulfate and chloride ($r = 0.757$, $P < 0.01$). However, TOC shows significant positive correlation only with turbidity ($r = 0.447$, $P < 0.05$).

During post-monsoon season, data shows that the highest positive correlation was observed between BOD and DO ($r = 0.856$, $P < 0.01$), nitrites and turbidity ($r = 0.764$, $P < 0.01$), nitrates and chloride ($r = 0.756$, $P < 0.01$), nitrates and salinity ($r = 0.753$, $P < 0.01$), and between DO and temperature ($r = 0.602$, $P < 0.01$)

Fig. 3 Seasonal variation of coastal water parameters **A** temperature, **B** pH, **C** EC, **D** turbidity, **E** salinity, and **F** TDS at study sites
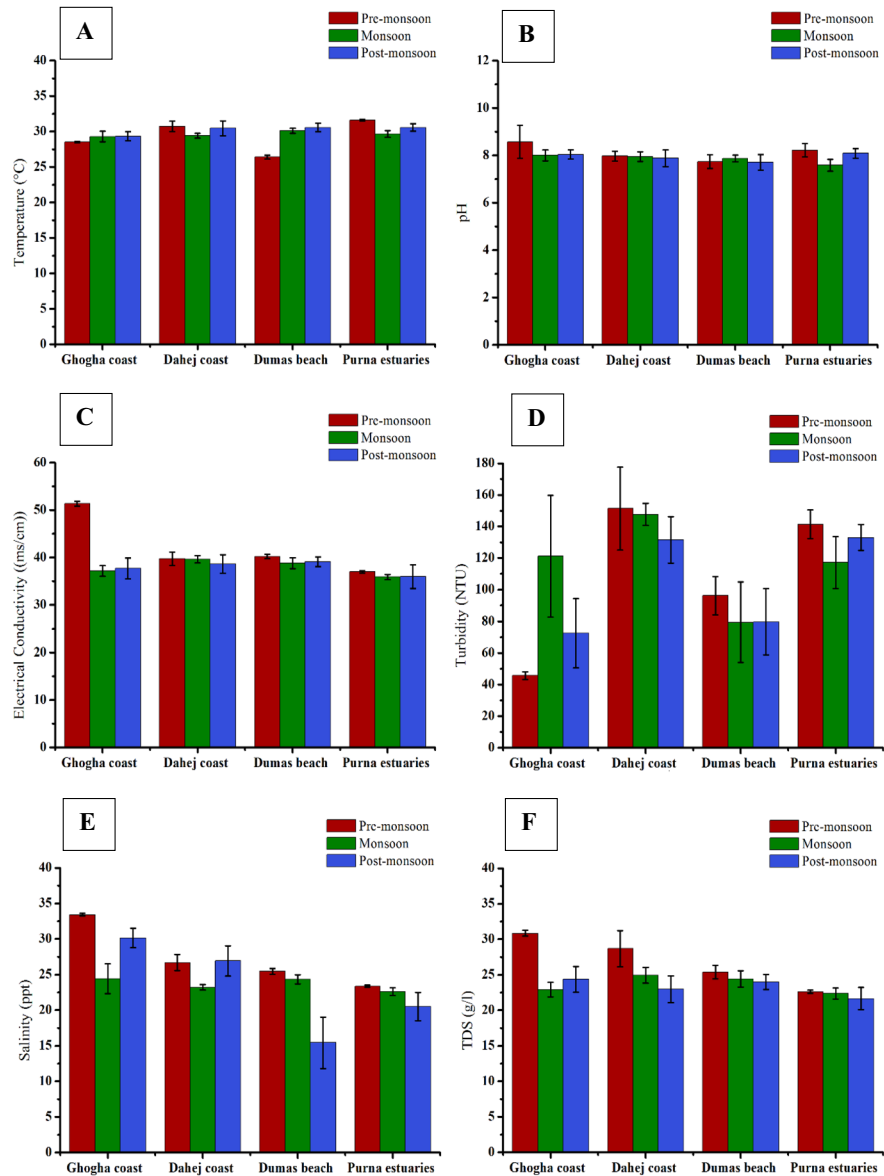

4.2 Principal Component Analysis

The principal component analysis provides an easy approach to deliberate the linked data sets (Kumar & Fulekar, 2019; Singh et al., 2020). Two principal components spanning 81.89% of the cumulative variance in pre-monsoon, 79.30% in monsoon, and 75.33% in post-monsoon were retrieved using PCA for 18 selected parameters (temperature, pH, electrical conductivity, turbidity, salinity, total dissolved solids, alkalinity, chloride, dissolved oxygen, biological oxygen demand, chemical oxygen demand,

nitrate, nitrite, sulfate, phosphate, total carbon, inorganic carbon, total organic carbon).

According to principal component analysis for pre-monsoon studies, PC1 has a total variability of 52.07% while PC2 has a total variability of 29.82% represented in Fig. 6a. The sampling location Ghogha is showing a negative correlation at PC1 and PC2 while Dahej is presenting positive correlation at PC1 and PC2. The sampling sites Dumas and Purna are exhibiting a positive correlation at PC1 and a negative correlation at PC2. The various physicochemical and demand parameters were carried out during

Fig. 4 Seasonal variation of coastal water parameters **G** alkalinity, **H** chloride, **I** DO, **J** BOD, **K** COD, **L** NO_3-N at study sites
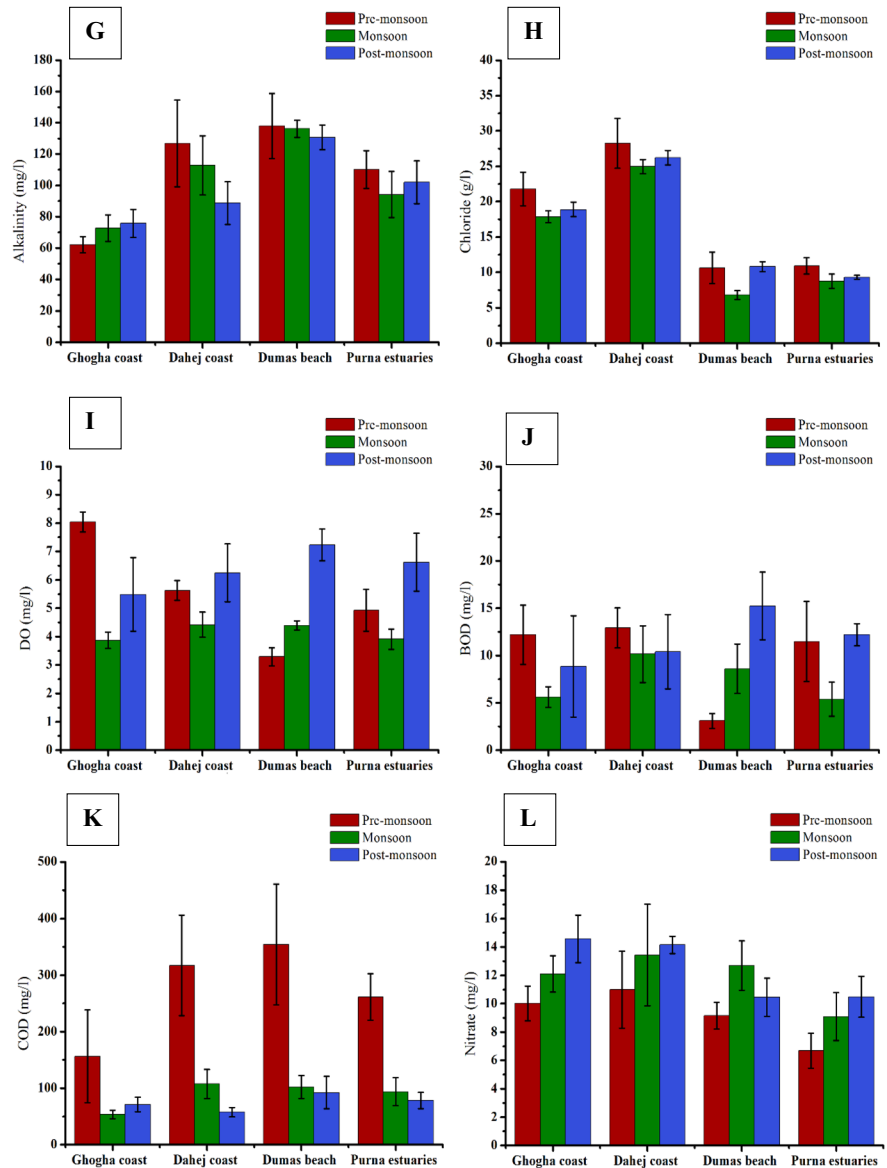

pre-monsoon studies where pH, EC, salinity, and DO were found to be prevailing at Ghogha. pH was found to be negative correlation at PC1 and PC2, while N-NO$_3$, temperature, chloride, TDS, BOD, salinity, EC, and DO were showing a positive correlation at PC1 due to soil weathering of nutrients, surface runoff, and contribution of anthropogenic nutrients (Mohammed et al., 2020), and negative at PC2. N-NO$_2$, SO$_4$, TC, IC, turbidity, COD, and alkalinity were demonstrating a positive correlation at PC1 and PC2. The PO$_4^{2-}$ was found to be dominant at Dumas which was observed as negative at PC1 and positive

at PC2. The Ghogha was found in the 1st quadrant while Dahej in the 2nd and Purna and Dumas were in the 4th quadrant in PCA.

According to principal component analysis for monsoon studies, PC1 has a total variability of 50.78% while PC2 has a total variability of 28.52% represented in Fig. 6b. The sampling location Ghogha is showing a negative correlation at PC1 and PC2 while Dahej is revealing a positive correlation at PC1 and PC2. The sampling location Dumas and Purna shows positive correlation with PC1 and negative correlation with PC2. During the monsoon season,

Fig. 5 Seasonal variation
of coastal water parameters
M NO$_2$-N, **N** NH$_3$-N, **O**
SO4^{2-}, **P** PO$_4$-P, **Q** TC, and
R TOC at study sites
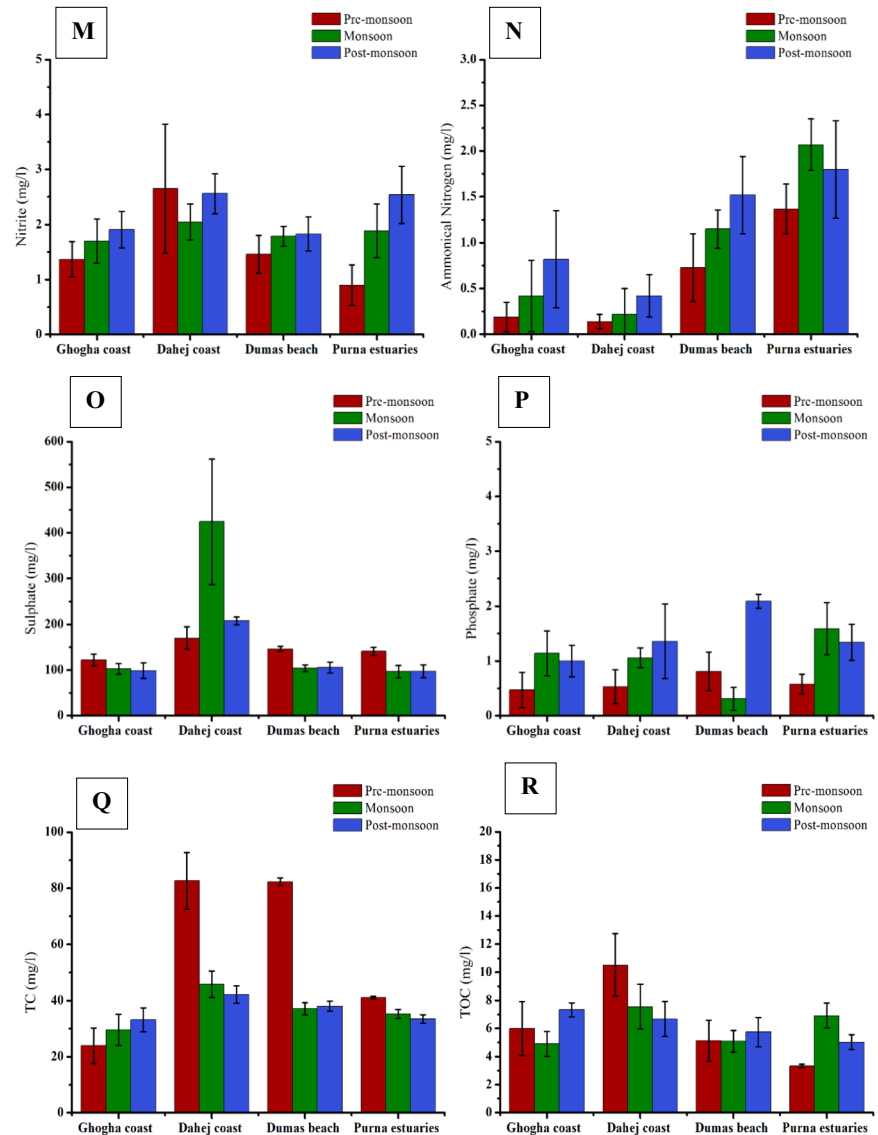
some physicochemical and demand parameters like
TOC, Cl$^-$, NO$_2$-N, SO$_4$$^{2-}$, TC, IC, and COD were
showing a strong positive correlation with PC1 and
PC2 and dominant in the Dahej location. PC2 and
PC1 exhibited positive turbidity loadings but negative
salinity loadings. This development may be attributed
to land-based and marine activities such as the trans-
portation of cement, fertilizer, coal, chemicals, met-
als, and other materials. Furthermore, the turbidity of
coastal water has increased as a result of the inflow
of domestic waste (Miyittah et al., 2020). The BOD,
TDS, DO, NO$_3$-N, alkalinity, pH, and temperature
were found dominant at Dumas which was observed

to be negative at PC1 and positive at PC2. Salinity
showed negative correlation with PC1 and PC2 at the
Ghogha sampling sites and PO$_4$$^{2-}$ shows positive cor-
relation with PC1 and negative correlation with PC2
at the Purna sampling location.

According to principal component analysis for
post-monsoon studies, PC1 has a total variability of
47.97% while PC2 has a total variability of 27.36%
represented in Fig. 6c. The sampling sites Dumas
and Purna were indicating positive correlation with
PC1 and negative correlation with PC2. The sam-
pling location Ghogha expressed negative correlation
with PC1 and PC2 and sampling site Dahej displayed

Table 5 Pearson correlation coefficient matrix between various coastal water quality parameters of study sites during pre-monsoon season

	pH	Temp	EC	Turb	Sal	TDS	Alk	Cl⁻	DO	BOD	COD	NO₃-N	NO₂-N	NH₃-N	SO₄²⁻	PO₄-P	TOC
pH	1																
Temp	0.264	1															
EC	0.598^{**}	-0.371	1														
Turb	-0.411	0.647^{**}	-0.856^{**}	1													
Sal	0.570^{**}	-0.289	0.977^{**}	-0.751^{**}	1												
TDS	0.266	-0.194	0.724^{**}	-0.456^{*}	0.818^{**}	1											
Alk	-0.661^{**}	-0.078	-0.694^{**}	0.599^{**}	-0.660^{**}	-0.537^{*}	1										
Cl⁻	0.127	0.260	0.332	0.063	0.486^{*}	0.754^{**}	-0.202	1									
DO	0.750^{**}	0.237	0.769^{**}	-0.428	0.811^{**}	0.687^{**}	-0.763^{**}	0.573^{**}	1								
BOD	0.520^{*}	0.682^{**}	0.170	0.179	0.251	0.301	-0.407	0.512^{*}	0.707^{**}	1							
COD	-0.718^{**}	-0.139	-0.553^{*}	0.414	-0.549^{*}	-0.299	0.580^{**}	-0.156	-0.587^{**}	-0.271	1						
NO₃-N	0.073	-0.272	0.347	-0.240	0.383	0.532^{*}	-0.013	0.529^{*}	0.248	0.057	0.068	1					
NO₂-N	-0.238	-0.011	-0.035	0.134	0.046	0.338	0.146	0.563^{**}	0.005	0.055	0.284	0.776^{**}	1				
NH₃-N	-0.067	0.225	-0.576^{**}	0.303	-0.666^{**}	-0.788^{**}	0.172	-0.761^{**}	-0.511^{*}	-0.227	0.122	-0.683^{**}	-0.477^{*}	1			
SO₄²⁻	-0.492^{*}	0.196	-0.503^{*}	0.613^{**}	-0.429	-0.209	0.682^{**}	0.253	-0.335	0.052	0.670^{**}	0.308	0.593^{**}	-0.107	1		
PO₄-P	-0.256	-0.258	-0.178	0.118	-0.181	-0.223	0.588^{**}	-0.292	-0.370	-0.451^{*}	0.046	-0.029	-0.197	0.135	0.138	1	
TOC	-0.123	0.155	0.082	0.280	0.229	0.470^{*}	0.201	0.769^{**}	0.212	0.334	0.173	0.366	0.425	-0.658^{**}	0.482^{*}	-0.167	1

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

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

$N=20$.

Table 6 Pearson correlation coefficient matrix between various coastal water quality parameters of study sites during monsoon season

	pH	Temp	EC	Turb	Sal	TDS	Alk	Cl⁻	DO	BOD	COD	NO₃-N	NO₂-N	NH₃-N	SO₄²⁻	PO₄-P	TOC
pH	1																
Temp	−0.161	1															
EC	0.521*	0.125	1														
Turb	−0.078	−0.278	−0.129	1													
Sal	0.073	0.153	0.119	0.086	1												
TDS	0.408	0.226	0.649**	−0.035	0.022	1											
Alk	0.200	0.425	0.520*	−0.307	0.084	0.469*	1										
Cl⁻	0.404	−0.433	0.431	0.653**	−0.028	0.291	−0.270	1									
DO	0.174	0.300	0.506*	−0.122	0.119	0.796**	0.556*	0.104	1								
BOD	0.161	0.312	0.503*	0.202	0.123	0.423	0.531*	0.329	0.594**	1							
COD	0.154	0.315	0.323	−0.026	−0.141	0.445*	0.742**	−0.096	0.448*	0.367	1						
NO₃-N	0.165	−0.076	0.547*	−0.027	0.237	0.336	0.074	0.394	0.367	0.486*	−0.157	1					
NO₂-N	0.021	0.139	0.060	0.229	−0.356	0.175	−0.024	0.224	0.116	0.229	0.155	0.247	1				
NH₃-N	−0.487*	0.310	−0.504*	−0.406	−0.339	−0.418	0.066	−0.752**	−0.138	−0.277	0.141	−0.449*	0.057	1			
SO₄²⁻	0.299	−0.179	0.618**	0.493*	−0.199	0.368	0.180	0.757**	0.194	0.531*	0.380	0.370	0.356	−0.476*	1		
PO₄-P	−0.197	−0.448*	−0.481*	0.363	−0.392	−0.384	−0.493*	0.173	−0.237	−0.338	−0.086	−0.270	0.007	0.215	0.016	1	
TOC	−0.303	−0.231	−0.001	0.447*	−0.328	0.238	0.017	0.318	0.340	0.058	0.204	−0.101	0.230	0.050	0.323	0.322	1

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

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

$N = 20$.

Table 7 Pearson correlation coefficient matrix between various coastal water quality parameters of study sites during post-monsoon season

	pH	Temp	EC	Turb	Sal	TDS	Alk	Cl⁻	DO	BOD	COD	NO₃-N	NO₂-N	NH₃-N	SO₄²⁻	PO₄-P	TOC
pH	1																
Temp	−0.288	1															
EC	−0.192	0.054	1														
Turb	0.143	0.326	−0.297	1													
Sal	0.322	−0.349	−0.085	0.029	1												
TDS	−0.322	−0.109	0.286	−0.394	0.151	1											
Alk	−0.320	0.293	0.301	−0.173	−0.798**	0.002	1										
Cl⁻	−0.043	−0.159	0.265	0.143	0.700**	0.195	−0.576**	1									
DO	−0.128	0.602**	0.480*	−0.085	−0.524*	−0.080	0.508*	−0.319	1								
BOD	−0.042	0.526*	0.440	−0.122	−0.518*	−0.203	0.483*	−0.389	0.856**	1							
COD	0.064	0.305	0.273	−0.172	−0.417	0.093	0.466*	−0.524*	0.431	0.403	1						
NO₃-N	0.090	−0.333	0.199	−0.124	0.755**	0.206	−0.629**	0.756**	−0.408	−0.488*	−0.477*	1					
NO₂-N	0.189	0.268	−0.457*	0.764**	0.146	−0.358	−0.310	0.198	−0.248	−0.224	−0.332	−0.055	1				
NH₃-N	0.044	0.199	−0.369	−0.011	−0.564**	−0.317	0.531*	−0.799**	0.079	0.094	0.565**	−0.607**	−0.116	1			
SO₄²⁻	−0.066	0.100	0.226	0.452*	0.336	−0.009	−0.174	0.803**	−0.097	−0.207	−0.443	0.387	0.412	−0.593**	1		
PO₄-P	−0.215	0.437	0.404	−0.123	−0.614**	0.061	0.730**	−0.321	0.516*	0.598**	0.377	−0.351	−0.256	0.306	−0.065	1	
TOC	−0.234	−0.139	0.055	−0.326	0.577**	0.400	−0.465*	0.572**	−0.299	−0.286	−0.372	0.620**	−0.014	−0.538*	0.179	−0.331	1

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

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

$N = 20$.

Fig. 6 Principle component for **a** pre-monsoon, **b** monsoon, and **c** post-monsoon
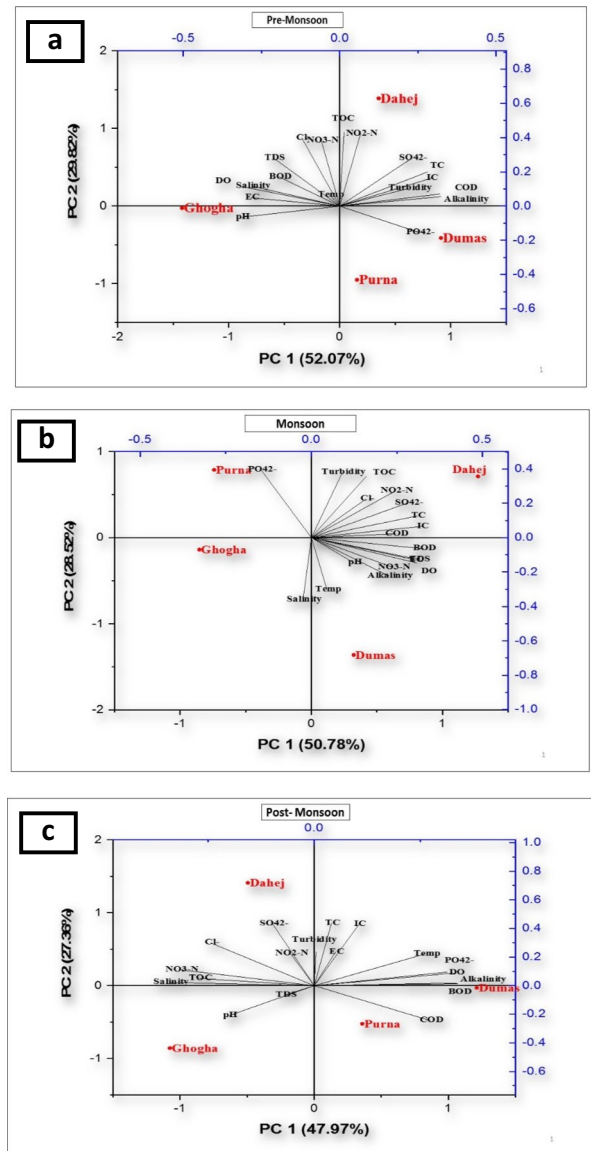
positive correlation with PC1 and negative correlation with PC2. In the post-monsoon season, some physicochemical and demand parameters such as TC, EC, IC, temperature, PO_4^{2-}, DO, and alkalinity were showing a strong positive correlation with PC1 and PC2. The BOD and COD were dominant at Purna which was observed to be negative at PC1 and positive at PC2. pH and TDS indicated negative correlation with PC1 and PC2 at Ghogha sampling sites and NO_2-N, SO_4^{2-}, Cl^-, NO_3-N, TOC, and salinity showed positive correlation with PC1 due to soil weathering of nutrients, surface runoff, and

contribution of anthropogenic nutrients (Mohammed et al., 2020) and negative correlation with PC2 at Purna sampling location.

4.3 Water Quality Evaluation Using WQI

Analyzing total water quality by looking at several criteria, especially different standards for different applications, is a tough process. The health of the marine ecosystem can be evaluated by the surface water quality index (Chen et al., 2019). Water quality signifies a healthy ecosystem and opens up several

economic and social developments. Poor water quality causes a variety of diseases as well as the extinction of living organisms on the other hand (Chu & Karr, 2017). WQI integrates data from several common water quality parameters to explain water quality in a specific area and time (Akhtar et al., 2021; Uddin et al., 2021). This study classified surface water quality into five groups centered on its eminence and influence on the biological structure. If the water quality index is 25, it denotes that the quality of water is extremely bad, WQI ranging between 26 and 50 is considered as bad, WQI fluctuating between 51 and 70 is reflected as moderate, WQI reaching between 71 and 90 is deliberated as good, and if the WQI is ranging between 91 and 100; then, it is considered very good (Jha et al., 2015). The weight of each parameter was calculated to evaluate the WQI and the results are demonstrated in Table 8.

Surface water in GoK is categorized into two categories according to the WQI of the current study

(Fig. 7). Due to the inflow of pollutants from land-based activity, the seasonal scenario implies that pre-monsoon will fall into the moderate to bad categories. Dumas and Purna had spatio-seasonal patterns in seasonal water quality fluctuations that differed across contamination and non-contamination zones. Water quality improved during the post-monsoon season, for example, some GoK stations with bad water quality during pre-monsoon improved to moderate (Dumas and Purna) during post-monsoon. The dilution caused by the monsoon freshwater flow could be responsible too. Due to surface runoff from the catchment area, the WQI is moderate in the monsoon season.

The water quality at GoK was moderate, according to the WQI results. The water quality was moderate with a WQI of 70 at all four stations. The high amounts of nutrients in the water column are due to the occurrence of a large industrial cluster in this area, as well as discharges of untreated and treated pollutants.

Table 8 Relative weight of physicochemical parameters

Parameters	Units	Weight (w_i)	Relative weight (W_i)
pH	-	3	0.111
DO	mg/l	7	0.259
Cl-	mg/l	6	0.222
TP	mg/l	6	0.222
NO_3-N	mg/l	5	0.185
			$\sum W_i = 1$

5 Conclusion

The current study provided significant information about the GoK marine biota for a better understanding of water quality. The goal of this study was to describe variations in physicochemical properties and nutrients in the Gulf of Khambhat during the course of the year. There is seasonal variation along the GoK due to the dilution of pollutants during the monsoon.

Fig. 7 Water quality index along Gulf of Khambhat Region

PCA indicates that NO_2-N, SO_4^{2-}, turbidity, NO_3-N, TOC, COD, alkalinity, and DO are the major parameters that influenced the water quality in GoK. The influence of the prime parameter was monitored during all the seasons which indicated the pollution load near the coastline from natural and manmade sources. The water quality index is the most essential sign to exploring coastal water. The total water quality index is moderate (51–70) in pre-monsoon, monsoon, and post-monsoon according to seasonal change. As a result, WQI data revealed that rainfall and freshwater mixing played a significant influence in reducing pollution along the coast. The input of numerous pollutants from seasonal impacts, and industrial and domestic waste, affects the Gulf of Khambhat marine biota and hydro-geochemical cycle. The statistics of this study could be used to develop effective management approaches for better coastal conservation and future monitoring programs.

Author Contribution   J. K. S. conceived, designed and performed the experiments. P. K. and S. V. analyzed and interpreted the data, original draft preparation, and revised the manuscript.

Data Availability   The datasets generated during the current study are available from the corresponding author on reasonable request**.**

Declarations

Ethics Approval and Consent to Participate   Not applicable.

Consent for Publication   Not applicable.

Competing Interests   The authors declare no competing interests.

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