Assessment of surface water quality during different tides and an anthropogenic impact on coastal water at Gulf of Kachchh, West Coast of India

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Abstract

The port-based activity is often associated with industrial growth in the hinterland and similar phenomenon is reported from the Gulf of Kachchh, India. The establishment of industrial clusters close to the coastline is a matter of concern as the release of effluents which influenced the marine ecosystem. The present paper tries to evaluate the variation in the water quality during the high tide and low tide in relation with the anthropogenic or natural influence in Gulf of Kachchh. The tidal variation is important as it reflects the influence of the land-based activity on the coastal waters. To prove this logic a series of stations were taken along the coastal water and statistical analysis *viz.*, Pearson correlation, Box plot, Hierarchical Cluster Analysis (HCA) and Factor Analysis (PCA/FA) were conducted. Pearson correlation and Box plot represents visual impact of parameter variations in respected tides. The chemometric analysis i.e. HCA and PCA/FA clearly indicates an anthropogenic impact on coastal water. Surface water temperature 32.1–34.1°C, pH 7.9–8.7, EC 6.3–9.9 mS/cm, salinity 36.0–52.0 ppt, DO 2.43–6.91, BOD 1.63–4.49 mgO_2/L, TSS 1.88–6.98 g/L and turbidity 3–32 NTU. Similarly nutrient concentrations in the gulf of Kachchh were phosphates 0.10–1.54 mg/L, total nitrogen 0.38–0.63 mg/L and sulphate 23.66–37.35 mg/L. The results of HCA revealed that major anthropogenic and domestic impact were found at various stations during low tide. The PCA/FA supported the HCA and justify most of variation in coastal ecosystem were mainly attributed due to the land based activities and sewage outfall points. Overall, the study reveals that water quality parameters like pH, salinity, dissolved solid, oxygen, turbidity, sulphate and nutrients are impacted by the anthropogenic activities and tidal influence. The findings of the paper will be useful for developing effective management strategies for policy maker or stakeholders operational in the coastal area.

Introduction

Water is the most essential element for the sustainability of life on earth and the establishment of human civilization near to water sources is a witness (Noori et al. 2010; Jonah et al. 2015; Sachaniya et al. 2020). In our Earth, ocean is the largest reservoir of water harnessing 97% of the total water body (Gosai et al. 2018a,b). The tides in the ocean are governed with the wind flow and the lunar movements that ultimately control the largest reservoir and coastal ecosystem. Therefore, marine ecosystem is a largest ecosystem on the earth and covers great potential of various habitats such as mangrove, coral reefs, sandy beaches, mudflats and others. If we saw socioeconomic development of humans and coastline, that was majorly dependent on various habitats or their end products. Therefore, more attention has been given to water research and an impact of anthropogenic activity on coastal waters and dependent biota (Pejman et al. 2009; Velsamy et al. 2013; Panseriya et al. 2019; Sachaniya et al. 2019). Furthermore, excessive nutrient load led to eutrophication and impact on mangrove forest, coral reef, marine animals, microbes, seaweed and other coastal biotic communities (Fallah et al. 2016; Gosai et al. 2018b). Additionally, natural aspects that cover tidal flow, sediment transport with tidal current, rain flow and seasonal changes also able to change microhabitat of coastal environment (Panseriya et al. 2021). The shift in the abiotic components influence the biotic component (productivity and fishing yield etc.) and finally at the ecological food web on larger scale (Praveena and Aris 2013; Sankpal et al. 2015).

In coastal environment, tide is a primary source of energy and regulates various coastal processes (Bokuniewicz and Gordon 1980). Tides also regulate biogeochemistry at spatial scale such as circulation cycle, tidal flooding, discharge, re-suspension, exchange flow and many more (Geyer et al. 2000; Bianchi 2013). Additionally, tidal regime plays a pivotal role in control of phytoplankton biomass and nutrient input into estuaries. Various sources such as agriculture, urban, rural, wastewater and industrial discharge enter into coastal environment which are responsible for phytoplankton growth promoting nutrients. An event such as eutrophication, harmful algal blooms and water quality deterioration occurs mostly due to over enrichment of nutrients in coastal areas (Rabalais and Turner 2001). A variation in biochemical characteristics of coastal ecosystem complicates further developmental events. Hence, to understand the biogeochemical characteristic and physical processes which control chemistry and biology of coastal ecosystem is crucial for the evaluation of complex environmental issues such as biodiversity, climate change, pollution and deforestation.

Various authors have summarized abiotic components i.e. nutrients and other water quality parameters such as dissolved solids, oxygen demand, turbidity, salinity etc. which could impact on coastal water quality and dependent habitat (Tien et al. 2017; Rybak and Gąbka 2018; Semprucci et al. 2019; Lalegerie et al. 2020). Similar trends have been evaluated by its spatial behavior of abiotic components in coastal water for Gulf of Kachchh (Kunte et al. 2003; Vethamony et al. 2007; Saravanakumar et al. 2008; Bhadja and Kundu 2012; Devi et al. 2014; Gosai et al. 2018a,b; Panseriya et al. 2020,2021; Maurya and Kumari 2021). Bhadja and Kundu 2012; Devi et al. 2014; Gosai et al. 2018; Panseriya et al. 2021 revealed that various industrial activities, mining activities, geographic location, seasonal change, strong agricultural and domestic activities are major factors contributing towards vulnerability of water pollution in the Gulf. These factors influenced abiotic parameters which control overall marine ecosystem during high and low tide. At the International level similar studies have been reported from other parts such as east coast of Terengganu, Malaysia (Juahir et al. 2018), Queensland, Australia (Mill et al. 2006), and Sundarban mangroves, Bangladesh (Shil et al. 2014). In India, various researcher concluded that the major factors were influenced differently during low and high tide at Port Blair Bay, South Andaman (Sahu et al. 2013), Mahanadi Estuary, East Coast of India (Das et al. 1997; Baliarsingh et al. 2021), Gangetic Delta Region, West Bengal (Mitra et al. 2011), Mulki estuary, Southwest coast of India (Vijayakumar et al. 2000) and Bay of Bengal, India (Sourav et al. 2015). In contrast, there is no evidence of similar studies reported in west coast of India especially in gulf of Kachchh, where there is presence of rich mangrove, biodiversity and coral ecosystem.

Therefore, there is a limited knowledge on variability of hydro-biological parameters over tidal cycle in the Gulf of Kachchh. On this backdrop, the present study was carried out with an aim to understand the variability of different abiotic parameters in response to tidal cycle and land based anthropogenic pressure.

Materials And Methods

Study area, sampling strategy and sample collection

Study area

The study area lies in the southern coast of Gulf of Kachchh, Gujarat along the west coast of India in the Arabian Sea. The area comprises of industrial cluster that includes oil refineries and fertiliser plants, mining area, major and minor jetties or ports covering an area of ~150 km^2 from 22° 28′ N 69° 04′ E to 22° 56′ N 70° 04′ E illustrated in Fig. 1. The geomorphology of gulf system has complex setup of shoals, channels, inlets, creeks, islands and no major river flows into it (Kunte et al. 2003). The tidal current in Gulf of Kachchh is measured at Navlakhi, shows maximum tidal height of 7.2 m and tidal current measured during spring season is 1.5-2.0 m/s (Babu et al. 2005). This unique predominant tidal driven characteristic demarcated GoK as highly energetic gulf and bottom topographic shoaling generates high tidal flux. The coastline is dotted with industries cluster such as fertilizer, oil refinery, cement plant and thermal power plants, interspersed with ports, jetties and presence of precious Marine National Park (MNP). The effluents are released into the coastal area and previous studies indicated impact on MNP and National Sanctuary (Kunte et al. 2003; Babu at al. 2005; Vethamony and Babu 2010). The Gulf coastline has presence of natural and anthropogenic activity overlooking and influencing each other finally impacting the ecosystem at larger scale. The health of the ecosystem with the overriding climate change prospects shift from degenerate state to degrade state with little time for recovery (Bogan et al. 2015). Hence, it becomes enviable to conserve and maintain the precious natural resources.

Sampling strategy and sample collection

A total of seven monitoring stations were considered for evaluating the coastal water quality. The sampling points included: S1-Okha port, S2-Pindara, S3-Salaya, S4-Dhani Beyt, S5-Narara, S6-Sikka and S7-Rozi Beyt as shown in Table 1 and sampling was conducted between summer-premonsoon, 2016. The sampling strategy was designed to cover a wide range of study area so as to have representation of entire GoK stretching about 150 Km. The study examines precisely the influence of various industries during different tidal interval on coastal water located along the GoK. The samples were collected in triplicates at each station from the intertidal zone. A minimum distance of 500 m was maintained between each sampling point. Each sample from the corresponding station comprised of 3 pooled samples, collected at a distance of 250m each during low tide (LT) and high tide (HT). Therefore, comprehensively a total of 9 samples were collected from the each sampling station during each of the tide. Samples were kept in an ice container till transported to laboratory and then stored at -20 °C for further analysis.

Sample analysis

Water quality parameters comprised of 12 variables i.e. temperature (Temp), pH, electrical conductivity (EC), salinity, total suspended solids (TSS), total solids (TS), turbidity (Turb), dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD), total nitrogen (TN), total phosphate (TP), and sulphate. Temperature, pH, EC, Salinity and Turbidity were estimated with the help of Electrometric and Nephelometric method, whereas, TSS and TS were estimated by Gravimetric method (APHA 1995). DO and BOD were estimated by Winkler's method whereas, nutrient parameters such as TN, TP, and sulpahte using spectrophotometer (Grasshoff et al. 1999; COMAPS 2012). The methods used for sampling and analysis were the standard methods as given in APHA (1995), Grasshoff et al. (1999), and COMAPS (2012).

Statistical analysis

Statistical analysis such as correlation analysis, mean value data transformation and chemometric analysis using software SPSSv20 by using of water quality parameters of high tide and low tide.

Pearson's correlation analysis

Correlation coefficient (r) was used for statistical relationship between two variables to check significance of the models. It was considered to be more significant when the probability of significance (p) was less than 0.05 ($p<0.05$). Generally, correlation coefficient was followed by Ward's method which gave one and two tailed *p* values (Satheeshkumar and Khan 2012; Panseriya et al. 2022).

Data treatment

Chemometric (multivariate statistical) methods require normal distribution of variables. The normality of the distribution of each variable was checked by analyzing kurtosis and skewness statistical tests before and after (log transformed data of original dataset) multivariable statistical analysis. The kurtosis and skewness statistical tests indicate that log transformed data were more suitable for normal distribution of dataset. In case of HCA and PCA/FA, all log-transformed variables were also z-scale standardized (the mean and variance were set to 0 and 1, respectively) to minimize the effects of different units and variance of variables for rendering the data dimensionless (Huang et al. 2011).

Hierarchical cluster analysis (HCA)

The sampling stations were located within ~150 km stretch and therefore HCA was used for qualitative identification of water quality contamination. The mean concentrations of each parameter were used for the similarities of the water quality along the various sampling stations in HCA analysis. The analysis was carried out using squared Euclidian distance by Ward's method (Panseriya et al. 2020; 2021).

Principal component analysis/ Factor analysis (PCA/FA)

Generally, PCA/FA is used to extract variables from large datasets to investigate effect of key variables. PCA analysis explains variance in observed data using a compact structure of orthogonal variables known as principal components (PC) (Pekey et al. 2004). Before conducting PCA, the Kaiser–Meyer–Olkin (KMO) test was performed to examine the validation for the PCA. Once Kaiser's VARIMAX rotation is performed, factor loadings remain orthogonal and are no longer directed toward maximum explained variance, and the scores are not orthogonal (Pere´-Trepat et al. 2006). Using PCA along with FA, the unobservable, latent pollution sources could be identified (Helena et al. 2000).

Result And Discussion

The results of physico-chemical characteristics of water quality parameters are summarized for high and low tide in Table 2 and the description for different parameters is elaborated.

Hydrobiology of coastal water during tidal influences

Surface water temperature in all the stations fluctuated between 32.1°C - 34.1°C during both of the tides. The temperature difference between HT and LT was marginal and ranged from 32.7°C (S6) to 34.1°C (S3) during HT, while it was between 32.1°C (S1) to 34.1°C (S5) during LT. Only the S1 site showed the fluctuations in the surface water temperature to the tune of 1.06°C between both the tides attributed to site geographic location *viz*., in the mouth of the Gulf (Shetye, 1999; Kumar et al., 2015). The absence of fluctuation in the tidal temperature is because of sampling close to the open sea coastline at Arabian sea.

The pH of the water governs the chemical state of the water. In the present study, the pH of the coastal water was recorded in a range of 8.0 to 8.7 during the HT while, 7.9 to 8.4 during the LT. The observed pH results were similar to the previous studies in the GoK (Devi et al., 2014; EIA & EMP, 2015). The electric conductivity (EC) of water is dependent on the presence of total dissolved solids. The present study, EC values ranged from 6.3 mS/cm (S2) to 9.5 mS/cm (S7) during the HT, whereas 6.5 mS/cm (S4) to 9.9 mS/cm (S7) during the LT. The influence of tides on conductivity was highly observed at S6 and S7, during both tides the conductivity was recorded maximum (>9 mS/cm) throughout the study area. These two stations are located at inner gulf where the arid climatic conditions and high temperature regime is prevalent that influence the water quality.

The water salinity during the high and low tide showed negligible variations. The salinity values ranged from 36.0 ppt (S1) to 52.0 ppt (S4) during HT and 37.0 ppt (S1) to 51.0 ppt (S4) during LT. The high evapo-transpiration rate along with an absence of inflow of freshwater into the marine system has accounted for higher salinity in the Gulf. Other authors have reported similar results from the GoK (Saravanakumar et al., 2008; Devi et al, 2014; EIA & EMP, 2015). The presence of high salinity at S4 indicates the release of brine from the salt pans located in the coastal region of the sampling site.

There was no significant difference in the DO values between the HT and LT in major stations except S1 and S6. These both stations S1 and S6 have highest oxygen fluctuations ~2.03 mgO_2/L due to high tidal flux (Kunte et al, 2005). The study area S1 lies in the open sea and is under the higher influence of high tide which brings in oxygenated rich water from the sea. On the other hand, S6 lies at inner gulf where the biggest industrial cluster is established and various towns developed for the workers. The major source in the S6 was these industrial effluents and domestic input near shoreline has resulted in low DO during the LT. Similar results also investigated by various researchers and conclude that the lower DO conditions in the coastal areas were mainly due to the anthropogenic influence or industrial activities (Vijayakumar et al., 2000; Bhadja and Kundu, 2012; Devi et al, 2014). The BOD values were 1.63 mgO_2/L (S2) to 3.28 mgO_2/L (S7) during the high tide whereas, 1.65 mgO_2/L (S3) to 4.49 mgO_2/L (S5) during low tide indicated the highly dilution effect in the Gulf.

The TSS results revealed that all the stations had higher suspended solids during HT (2.24-6.98 g/L) as compared to LT (1.88-3.53 g/L). The sampling was conducted during the onset of monsoon due to the highly active currents. Among that, there is heavy churning of the sea bottom bringing the sediments into the water suspension. The long-shore currents are active bringing in Indus sediments into the GoK and finally exiting from the mouth of the Gulf at Okha (Nair et al., 1982). The observation revealed that the presence of high TSS at S6 and S7 (6.89-6.98 g/L) as compared to other stations (2.42-2.68 g/L) supports the earlier fact that sediment travels from east to west in the southern coastline of the GoK (Shetye, 1999; Vethamony and Babu, 2010).

Turbidity in study sites was recorded from 3 NTU (S3) to 21 NTU (S2) during HT and from 4 NTU (S5&S6) to 32 NTU (S2) during LT. Similar results were previously reported by various researchers (Shetye, 1999; Rasheed and Balchand, 2001; Sinha et al., 2010; Masood et al, 2015). Spatial distribution showed that S2 and S3 have higher turbidity during LT attributed to geographic location and bay-like conditions. The presence of low turbidity at S5 located in the central part of the Gulf that incidentally represents Marine National Park (MNP) justifies the occurrence of corals and various marine biota at the site (Panseriya et al. 2021).

The nutrient level in terms of total phosphates was comparatively fluctuating throughout the studied area. The total phosphates levels were higher during the HT (0.10 mg/L to 1.54 mg/L) as compared to the LT (0.17 mg/L to 0.65 mg/L). Earlier Saravanakumar et al., 2008 and Srilatha et al., 2013 obtained similar results in the GoK. Total nitrogen in the present study ranged from 0.38 mg/L to 0.63 mg/L during both tides. A similar results were also reported previously at many locations from GoK (ICZM, 2013), indicative of no major input in nitrogen load. Sulphate values varied from 23.66 mg/L to 37.35 mg/L during both tides. A comparison of sulphate values among different stations showed higher concentration at S6. The presence of heavy transportation of coal and cement industry nearby accounted for the presence of higher sulphate at S6. Therefore total sulfate and chlorine ratio of the present study was higher than the standard seawater sulphate : chlorine ratio of 1.18. The sulphate : chloride of HT and LT were 1.34 and 1.36, respectively. Moreover, the results indicate higher sulphate concentration could be attributed due to land-based activities especially anthropogenic sources at the coastline during summer and pre-monsoon seasons (Stromberg and Cumpston, 2014).

Distribution of physico-chemical water quality during tidal variation

The box plot or box and whisker plot is summarized and interpreted in tabular data and provides a visual impact of the location and shape of a primary distribution. The circles and asterisks are also called the outliers and far outliers which indicates a change in a variable between the stations. The box plot results of physico-chemical parameter illustrated in Fig. 2, which explain long whiskers at the top of the box (e.g. pH and EC box plot) and indicate primary distribution has been scattered towards high concentration. The pH, TSS and TS in the box plot showed a visual difference between the low tide and high tide values (Fig. 2). The circles and asterisk were prominent for turbidity and sulphates indicative of a difference in the values between the stations. Turbidity represents a quantum of suspended solids present in the water as explained in the previous section, whereas the TS differed between two tides attributed to current movements. A similar observation was confirmed from the box plot method. There are coal transportation jetties close to S1 and S7, which accounted for high sulphate levels in the water column. The box plot justifies this observation and relates the influence of anthropogenic activity on the water quality during the low and high tides.

Pearson's correlation analysis

The correlation analysis indicates nutrients were significantly correlated during LT as compared to HT (Table 3). This could be due to the discharges of anthropogenic activities from industries or domestic waste bringing in high nutrients.

The Pearson's correlation analysis of HT (Table 3) highlighted that surface water temperature correlates with TS ($p<0.05$). As the temperature raises the dissolution of minerals ions in the water column increases, therefore a positive correlation was observed. DO and BOD showed a positive correlation ($p<0.05$), the source of DO is because of churning and oxygen mixing during the upwelling process of high tide. However, the presence of inorganic waste from the industrial outfall points has contributed to high BOD in the GoK samples. The results from Table 3 indicated high physico-chemical parameter load during LT by industrial or anthropogenic pressure. This indicates that there was low flushing of waste out of the Gulf and the presence of waste by industrial clusters will result in high nutrient concentration in the Gulf in coming years disrupting the coastal and marine ecosystem process. In the longer run, the mangroves and corals are likely to be affected by the release of industrial and domestic sewage or anthropogenic impact.

Spatio-temporal variability in coastal water quality: Hierarchical cluster analysis (HCA)

The result obtained by HCA based on physico-chemical parameters classified similar groups of dendrogram into two statistically significant clusters. The HCA of the current study express tidal characteristics of coastal water quality viz., nutrients, pH, temperature, conductivity, turbidity, TSS, DO and BOD. The clusters obtained for both the tides were highly distinct from each other, largely due to differences in the contaminant load prevalent during the respective tide (Fig. 3).

During HT, HCA results indicate the distribution of all the stations in two clusters, clusterI and cluster II. ClusterI have similar water quality and contains S4, S6 and S2 study zone. However, the sources of pollution differ in all these stations. The S4 receives concentrated brine discharged from salt pans, while industrial clusters and effluent discharge points represent S6. The S2 is a geographical bay, where the tidal current played a significant role. The clusterI results indicated salinity sulphate, TSS, and turbidity were key parameters that influenced the water quality. The ClusterII results were includes the water quality of S3, S5, S7 and S1. The S3 receives water from the open sea and enters into estuarine of the study area which increase salinity, and DO. The S5 zone recognized as MNP which sustains corals, marine creatures and mangroves forest. The reported higher concentration of DO is important for the aquatic life such as bacteria, fish, invertebrates, and plants. The BOD possibly received from the effluent discharge points located close by to the S5. The S7 has well-developed industrialization, fishing, transportation of coal and cement, etc. along with outlets of industrial effluents which influenced the water quality. The S1 is located at the mouth of the gulf which opens in the Arabian Sea, therefore dilution effect is very high as described in previous studies by Shetye, 1999; Bhadja and Kundu, 2012.

During LT, the HCA result generated two clusters, i.e. clusterI and clusterII. ClusterI includes S2 and S4 with similar water qualities. In which S2 is a bay condition wherein the water column contained a mixture of nutrients and litter detritus that increased the phosphate, nitrogen, and turbidity of coastal water. The field observation suggests S4 had salt pans which influenced the DO, salinity, and sulphate. ClusterII includes stations S5, S6, S7, S1 and S3. The water quality parameters such as salinity and EC observed variation in the stations S5, S6 and S7. Stations S5 and S6 were located in the inner gulf in the study area. The results indicated that domestic waste influenced S5 coastal water quality, whereas S6 is an industrial zone but most of the industrial effluents were disposed into the deep-sea through pipelines while discharges of domestic waste were near the coastline. In contrast, S7 has both contaminants from the domestic waste of Jamnagar city and industrial waste from the surrounding land area. In other stations, S1 was located at the mouth of the open sea and S3 received waste from domestic discharges, fishing activity, transport and boat construction activities. The key impacted parameters were EC, salinity and DO during the low tide.

The overall analysis indicates industrial pressure was on the coastal area of the Gulf of Kachchh. The present study points out that during the high tide, the effluents that are discharged into the sea return back with the water column towards the coastline. Further, land-based domestic and industrial activity contributes to deteriorating water quality during low tide.

Principle indicators evaluation during different tide by factor analysis

The results of factor analysis were separately applied to the water quality data set of high and low tide. Factor analysis includes eigenvalues, factor loading, variable loading, total and cumulative variance and represented in Table 4. The results of the eigenvalue and scree plot were used for significant factors, whereas the factor loadings were sorted as strong, moderate and weak according to the absolute loading values of >0.75, 0.75-0.5 and 0.5-0.3 respectively (Liu et al., 2003; Panseriya et al., 2021). Chemometric or factor loadings were illustrated in Fig. 4.

A chemometric analysis produced four significant factors with >1 eigenvalue that explained the total variance (93.75%) of the high tide dataset. The factor 1 (PC1) indicates 29.10% of total variance which includes strong positive loading of total nitrogen, total phosphate and turbidity, Hence, PC1 comprises of a common source of nutrients due to natural tidal activity and also included with outfall of industrial waste from the deep sea. The second (PC2) explains 24.79% of total variance which includes strong positive loading of salinity, pH, and sulphate. PC2 suggests the combined effect of natural and anthropogenic activities. The PC3 explains 21.60% of total variance with strong positive loading of DO and BOD and strong negative loading of total solids. The PC3 indicates the natural scenario of the Gulf of Kachchh and is indicative of the biological activities during the summer season. During summer high evaporation rate and low inflow of water from the existing streams have ultimately affected TS and TSS. The last PC4 explains 18.26% of total variance with strong positive loading of EC and TSS.

Similarly, Factor analysis of the low tide data set produced three significant factors that explained 80.22% of the total variance of the data set. In FA, PC1 explains 28.87% of total variance which includes strong positive loading of salinity, temperature, sulphate, and TS with moderate negative loading of pH. The PC1 indicates the loadings were due to the receding water effect on the substratum, which re-suspends the bottom sediments and degrades mangrove stands. The high level of suspended solids in low tide is purely due to re-suspension of bottom and coastal eroded sediment by tidal effect. Moreover, positive loading of salinity is mainly due to brine water from salt industries near Okha, Pindara, Dhani, Sikka and Rozy (Fig. 2). The PC2 explains that 27.44% of total variance with strong positive loading of phosphate, nitrogen and turbidity, as well moderate negative loading of DO. The positive loading of nutrients and negative loading of DO clearly shows the main source of contaminant load from land-based activities, sewage disposal or other anthropogenic activities. The third PC3 explains that 23.91% of total variance which include strong positive loading of DO, BOD and EC. The components explained anthropogenic and biological activities. Due to organic matter, microbial activities were increased which increases BOD and all these hydrolysis processes for degradation of acidic material cause a decrease in pH value (Singh et al., 2004).

Conclusions

The present work is a first comprehensive study for Gulf of Kachchh to identify tidal and spatial pattern of physico-chemical parameters using correlation analysis, box plot method, hierarchical cluster analysis and factor analysis. Tidal influence, industrial impact along with domestic waste on the water quality was assessed in this study. The results revealed that the coastal waters is highly affected with the land based industrial development and release of effluents during the low tide. The geographical location in the Gulf of Kachchh played a major role in presence of pollution load and influenced with the tidal activity. The Pearson correlation and box plot revealed that the concentration of parameters in a reasonable boundary. The hierarchical cluster analysis grouped the sites as natural and anthropogenic input which showed similarities between sites during the tides. The major impacted parameters were oxygen, BOD, salinity, turbidity, total nitrogen and phosphate by industrial impact or tidal variation. The results concluded that anthropogenic impact is almost same at S4 and S2 during both the tidal variation of high and low tide, whereas anthropogenic impact was relevant at S6 during high tide. Factor analysis identified natural and anthropogenic impact such as land run-off, organic and sewage outfall. The factor analysis concluded that the major source of nutrients and other major parameters were from land run off, industrial outfall in to the sea and port based activity. Overall, the study area showed enhanced contamination load during low tide attributed to land based anthropogenic influence, which could be detrimental to marine biodiversity in long run. Thus, this study can be used as a foot print to develop policies and strategies for remediation of Gulf of Kachchh, west coast of India.

Declarations

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Author contributions

Haresh Z Panseriya: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Software; Validation; Visualization; Writing - original draft, review & editing. **Haren B Gosai:** Writing - review & editing. **Deepa J Gavali and Bharti P Dave:** Funding acquisition; Project administration; Resources; Supervision; Writing - review & editing.

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Conflict of Interest

All authors declare that we do not have any conflict of interest for above entitled manuscript.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

Data Availability and Materials Statements

Authors can confirm that all relevant data are included in the article. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Tables

Table 1: Study sites of southern region at Gulf of Kachchh

Station No.	Site	Location	Site description
S1	Okha	22° 28.139'N, 69° 4.662'E	Open sea with domestic and industrial water outlet, coal transportation
S2	Pindara	22˚ 15.952'N, 69° 15.144'E	A muddy shore with Geographic Bay condition
S3	Salaya	22˚ 19.163'N, 69° 36.151'E	Fishing and ship recycling activities
S4	Dhani	22˚ 18.303'N, 69° 35.153'E	Mainly Salt pan area
S5	Narara	22˚ 27.464'N, 69° 43.517'E	Marine protected area with industrial outfall in deep sea
S6	Sikka	22˚ 26.054'N, 69° 49.725'E	Various chemical and cement industries, fishing business
S7	Rozi	22˚ 33.575'N, 70° 02.469'E	Coal transportation, domestic waste

Table 2: Mean value of Physico-chemical characteristic of high tide (HT) and low tide (LT) at Gulf of Kachchh

Parameters	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	S4	S5	S6	S7
	High tide (HT)							Low tide (LT)						
Salinity (ppt)	36.00	45.00	43.00	52.00	44.00	38.00	39.00	37.00	40.00	44.00	51.00	38.00	37.00	39.00
Temp (°C)	33.60	33.20	34.10	32.9	33.6	32.70	33.50	32.10	33	33.70	33.8	34.00	32.70	33.00
pH	8.24	8.18	8.06	8.79	8.70	8.20	8.22	8.40	8.2	7.90	8.20	8.30	8.30	8.20
EC (mS/cm)	7.10	6.30	7.50	7.00	7.30	9.10	9.50	7.20	7.2	6.90	6.50	8.80	9.20	9.90
DO (mgO_2/L)	4.06	2.43	5.69	4.87	5.28	4.06	6.09	6.09	3.65	4.47	4.47	6.91	6.09	6.09
BOD (mg O_2/L)	2.45	1.63	2.47	2.46	3.27	1.65	3.28	2.47	2.05	1.65	2.06	4.49	3.28	3.28
TP (mg/L)	0.19	1.54	0.21	0.10	0.16	0.13	0.19	0.19	0.35	0.65	0.17	0.21	0.17	0.18
Sulphate(mg/L)	23.60	34.90	32.60	37.30	32.80	29.60	30.90	27.40	30.1	32.10	36.0	29.60	30.10	29.60
TN (mg/L)	0.38	0.78	0.49	0.51	0.58	0.40	0.48	0.39	0.63	0.60	0.45	0.43	0.43	0.41
TSS (g/L)	2.24	5.03	2.67	2.68	2.55	6.98	6.89	2.18	3.04	2.79	2.58	1.88	2.98	3.53
TS (g/L)	52.30	68.60	62.50	75.80	64.30	81.50	61.40	50.70	57.1	59.4	72.70	55.10	53.70	55.80
Turbidity(NTU)	7.00	21.00	4.00	3.00	4.00	6.00	12.00	8.00	32.00	12.00	5.00	4.00	4.00	7.00

Table 3: Correlation between Physicochemical parameters along the study sites during High tide (HT) and Low tide (LT)

Tides	Parameters	Salinity	DO	BOD	Temp	TP	Sulfates	TN	TSS	TS	Turb
	Salinity	1									
	DO	-.013	1								
	BOD	-.001	**.811***	1							
	Temp	-.203	.459	.516	1						
	TP	.208	-.748	-.507	-.148	1					
High Tide (HT)	**Sulfates**	**.910****	.017	-.040	-.228	.333	1				
	TN	.516	-.480	-.197	-.004	**.866***	.638	1			
	TSS	.538	-.215	-.489	-.750	.016	.605	.110	1		
	TS	.420	-.219	-.507	**-.800***	.062	.555	.102	**.977****	1	
	Turb	-.103	-.609	-.356	-.113	**.912****	.087	.687	-.201	-.083	1
	Salinity	1									
	DO	-.602	1								
	BOD	-.558	**.859***	1							
	Temp	.582	-.148	.125	1						
Low Tide (LT)	**TP**	.000	-.743	-.468	-.053	1					
	Sulfates	**.953****	-.527	-.410	.656	-.067	1				
	TN	.257	**-.824***	-.605	.272	**.842***	.230	1			
	TSS	**.974****	-.513	-.394	.637	-.044	**.966****	.163	1		
	TS	**.976****	-.540	-.416	.620	-.022	**.973****	.183	**.997****	1	
	Turb	-.032	-.733	-.488	-.132	**.996****	-.112	**.813***	-.083	-.059	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Table 4: Varimax rotated factor loadings and communality of physico-chemical parameters during High tide and Low tide.

Variables	High tide					Low tide			
	PC1	PC2	PC3	PC4	Communality	PC1	PC2	PC3	Communality
Salinity	.063	.926	-.073	-.287	.949	.768	-.023	-.619	.974
DO	-.607	.162	.690	.338	.986	-.254	-.695	.642	.960
BOD	-.398	.182	.810	.078	.854	-.046	-.428	.872	.946
Temp	.079	-.256	.880	-.256	.911	.957	.101	.225	.977
pH	-.442	.709	-.075	-.324	.809	-.569	-.512	.171	.615
EC	-.381	-.240	.064	.888	.996	-.236	-.272	.809	.785
TP	.967	.065	-.197	-.136	.997	.270	.665	-.166	.542
Sulfate	.247	.944	-.045	.065	.958	.836	-.049	-.466	.918
TN	.832	.497	.022	-.156	.964	.238	.934	-.197	.968
TSS	.250	-.135	-.298	.901	.981	-.104	.324	-.041	.118
TS	-.086	.509	-.729	.373	.937	.796	-.071	-.511	.900
Turb	.925	-.115	-.092	.176	.908	-.198	.924	-.178	.924
Eigenvalues	3.49	2.97	2.59	2.19		3.46	3.29	2.87	
Variance%	29.10	24.79	21.60	18.26		28.87	27.44	23.91	
Cumulative%	29.10	53.89	75.49	93.75		28.87	56.31	80.22	

Figures

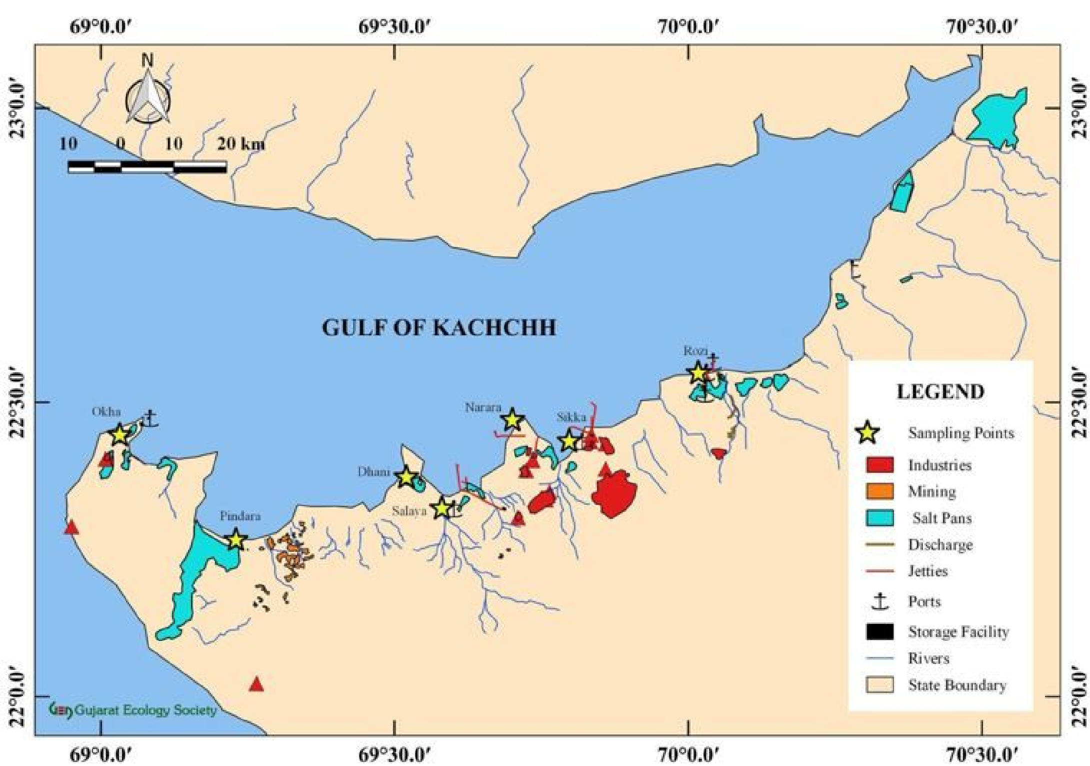

Figure 1

Geographic study area and sampling sites at Gulf of Kachchh (GOK)

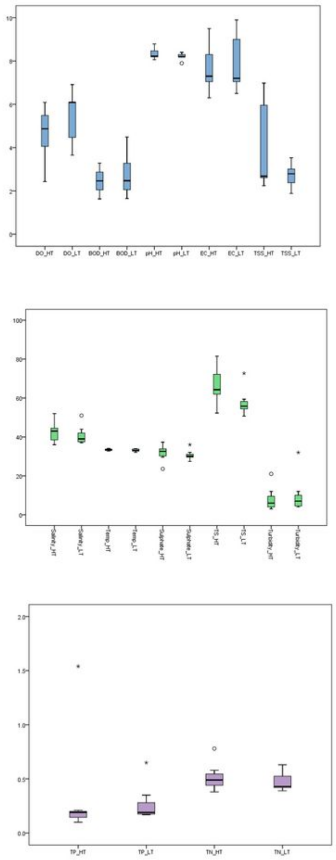

Figure 2

Tidal variations-box plot for selected parameters for two tides (LT: Low tide, HT: High tide) (DO: Dissolved oxygen, BOD: Biological oxygen demand, EC: Conductivity, TSS: Total Suspended Solid, TS: Total Solid, TN: Total Nitrogen, TP: Total Phosphorus). In each box plot, the central point represents the median, the box gives the interval between the 25% and 75% percentiles, and the whisker indicates the range.

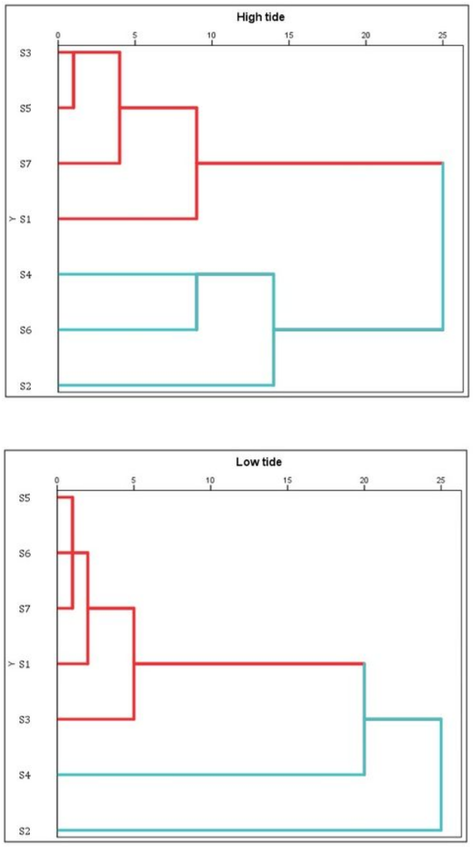

Figure 3

Dendrogram based on Ward’s clustering method showing spatial clustering between the studied sites (High tide and Low tide)

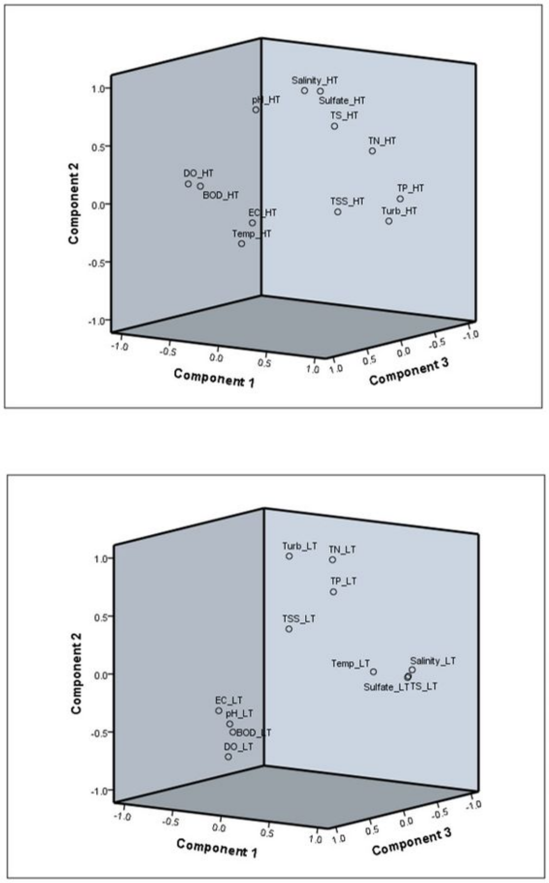

Figure 4

Factor loading of high tide (HT) and low tide (LT) of Gulf of Kachchh