

Environmental status of some beaches in Daman and south Gujarat, India

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Abstract

Beaches are the prime choice of amusement, hence determining its quality is significant to public health. The existing status of water and sediment quality of four beaches along the north-west coast of India is evaluated at high and low tide (for three weeks) during the pre-monsoon season. Water samples were measured for hydrography, nutrients, petroleum hydrocarbons (PHc) and fecal coliform (FC). Sediments were analyzed for heavy metals, PHc and FC. Results indicated, higher concentrations of ammonia (28.7 $\mu\text{mol/l}$) and phosphate (57.3 $\mu\text{mol/l}$) in the waters of Tadgam beach owing to the proximity of industrial discharge. Metals such as Fe, Al, Mn, Cr, Zn, Cu, Ni, Co, and Hg were found to be above Lowest Effective Range (LER) as compared to Cr and Fe, those exceed Severe Effective Range (SER). Elevated levels of FC in both water and sediment in all the studied beaches indicated microbial contamination relative to anthropogenic activities.

Keywords: Fecal coliform; Metals; Nutrients; Sediment; Water; West coast of India.

Introduction

At present, the coastal regions are deteriorating at a great pace due to pollution caused by industrial outlets and domestic sewage¹. Most of the human habitat and industrialization take place beside water bodies due to the comfort of waste discharge and easy utilization of water. Developmental activities due to population rise also play a critical role in accelerating disturbance in coastal environments. India is a tropical country having the majority of its borders fronted by water, with the total coastline accounting about 7516 km, having population along with coastal districts of 171 million (iomenvis.nic.in). The west coast of India is relatively crowded with two major industrial states (Gujarat and Maharashtra). There are approximately 99 recreational beaches along the west coast of India. Having majority of coastal towns, most of the population is diverted to beaches for recreational purposes. Taking this into consideration it is of prime importance to understand sources and physical processes that accelerate beach contaminants thereby decreasing the aesthetic beauty of beaches. Additionally, monitoring microbiological contamination is also a necessity as it is associated with numerous health risks and enteric illness while the presence of the same also indicates confluence of untreated sewage water with beach water²⁹. As India is developing economically at a faster pace, it is indicative that there will be significant growth in tourism infrastructure. Clean beaches are therefore valuable nodes for recreational users which in turn promotes the economic status of the country. Thus, to enhance tourist attraction, it is vital to prevent environmental degradation of beaches. Present study is an attempt to monitor the Physico-chemical and microbiological aspects that affect beaches in certain ways and may have a negative impact on tourism activity.

Macro pollutants such as manmade debris enhance chemical and biological factors and affect negatively², which harms the intrinsic value of beaches. As per the study was undertaken by South Asia Co-operative Environment Programme (SACEP, 2018), three major sources of marine litter were noted at Indian beaches accounting to plastic, waste generated by tourists and sewage-related debris. Thus, to enhance the aesthetic beauty of the beach and attract tourism, marine debris must be taken care of, as the majority of them are non-biodegradable and persists in the environment for a long time. Taking the globe into consideration, many of the beaches are routinely groomed to remove sea-grass, algae, and litter for enhancing serenity and tourist health, the same should be implemented in the beaches under study recognizing the growth in beach activity³.

Keeping in mind, tourism and economic status of Daman, along the north-west coast of India, it is vital to maintain the beach quality of this coastal land and the available data can also be made useful for further management decisions in improving the coastal ecosystem. The present study was designed to study the quality of beaches in Daman and neighboring two beaches viz. Tithal Beach and Tadgam beaches along the Gujarat coast. The ever-increasing population and industrial growth negatively affect marine biodiversity and finally threatens aquatic life thereby indirectly affecting humans⁴. The proposed study can be regarded as pilot study for snapshot observation of tourism important beaches at west coast of India to determine the pollution status as many articles reported degradation of coastal environment along the west coast of India⁵⁻⁶. Also, two rivers Damanganga and Kolak can be considered as a source of pollution as they migrate through the industrial towns housing Textile, paper, and pulp, chemical-based, Rubber, Plastic and Mineral based industries. Around 23 large scale and few small-medium scale industries are located in Daman and nearby areas (dcmsme.gov.in). The study conducted on Damanganga in the year 1979 reported the discharge of wastewater around $3.9 \times 10^3 \text{ m}^3 \text{ day}^{-1}$ from industrial sites located at Vapi ($20^\circ 20' 32.57'' \text{ N}$, $72^\circ 54' 35.24'' \text{ E}$) and Silvassa ($20^\circ 17' 38.74'' \text{ N}$, $72^\circ 58' 55.71'' \text{ E}$).

Materials and methods

Study area

Water and sediments were collected from four beaches Jampore and Devka located in the Union territory of Daman and Tithal and Tadgam located in southern Gujarat. The study was carried out in three consecutive weeks of March and April, 2018. During each sampling, two samples were collected from all beaches, representing ebb and flood period. Water and sediment samples from areas close to visible effluent discharge site such as pipeline located in the vicinity of Tadgam Beach (TGD) were also collected. A total of 54 water samples and 27 sediment samples were collected throughout the study period. The entire stretch of the study covering all the four beaches along the west coast of India accounts for ~50 km frontier of the Arabian Sea (Figure 1). Two major rivers named Daman Ganga ($20^\circ 24' 44.33'' \text{ N}$, $72^\circ 49' 58.87'' \text{ E}$), originates from Sahyadri hills (length 131 km) and Kolak River ($20^\circ 27' 58.59'' \text{ N}$, $72^\circ 51' 26.45'' \text{ E}$), originates from Saputara mountain range (length 50 km) drains in Arabian Sea along this stretch.

The studied beaches can be described as Tadgam, Gujarat which is next to the village Tadgam with inhabitants 2541 and 513 houses (Census, 2011). Jampore beach which is flat while the rivulet flow which joins the beach at its southern tip. Devka beach which has long coastline with the rocky formation which can be seen during low tide condition. Tithal beach which is located near the industrial town Valsad, Gujarat.

Analytical methodology

Surface water samples at each station were collected in a pre-cleaned polypropylene bottle. Samples for dissolved oxygen (DO) were collected in a glass bottle, fixed immediately with Winkler's solutions and thereby oxidized using hydrochloric acid (50% v/v). The liberated iodine was titrated using standard sodium thiosulphate (0.01N Na₂SO₃) solution⁷. Samples for nutrients were analyzed by colorimetry method using an Autoanalyzer (Model: Skalar San plus system). The relative error of nutrient analyses (nitrate, nitrite, ammonia, and phosphate) measured repetitively (at least 20 times) as well as relative to international seawater standard (OSIL, UK) was <5%. PHc in water samples were extracted using n-Hexane evaporated and measured using a Spectro fluorophotometer (Model: Shimadzu RF 5301: emission wavelength 360 nm; excitation wavelength: 310 nm)⁸. Water samples for the microbiological study were taken in a pre-sterilized bottle then after serial dilutions, it was analyzed using the spread plate technique for FC using media mFC agar⁹.

Sediments at each station were collected in polyethylene bags for the determination of metals, PHc, and microbiological parameters. For the PHc analysis, briefly 100g wet sediment was treated with potassium hydroxide (KOH) and methanol (CH₃OH) in a hot water bath (80-85°C), filtered and extracted using n-hexane. The aliquoted was then passed through an Al₂O₃ filled glass column along with n-hexane and methylene chloride (CH₂Cl). The residual solution was collected then evaporated and diluted with n-hexane before measuring in a Spectro fluorophotometer¹⁰. Briefly, 1 g sediment was used for FC counts in 100 ml phosphate buffer saline as a medium, from which 0.1 ml was taken for analysis on mFC agar plate. Powdered and homogenized sediment samples were used for metal analysis. The sediment samples were digested using concentrated hydrofluoric (HF), perchloric (HClO₄), hydrochloric (HCl) and nitric (HNO₃) acid mixture¹¹. All the chemicals and acids used were of supra-pure grade (Merck, Germany). After digestion, samples were diluted to constant volume with Milli-Q water and

metal analysis was performed immediately on the resultant digest using ICP-OES (Optima 7300DV, Perkin Elmer) for Fe, Mn, Cr, Co, Ni, Cu, and Zn. For Hg analysis sediments were digested with aqua Regia followed by oxidization with KMnO_4 . The oxidized samples were decolorized with hydroxyl ammonium chloride and further reduced using alkaline sodium borohydride. Analysis of Hg was carried out using cold vapor generation technique on Flow Injection Mercury System (FIMS-400, Perkin Elmer) coupled with an amalgamation system for on-line pre-concentration. To authenticate the results, CRM MESS-3 and PACS-2 were also analyzed along with each set of analyses (NRCC, Canada). The precision/accuracy was better than $\pm 5\%$ for all metals. Grain-size (Texture) of sediment was segregated in terms of contents of clay ($< 4 \mu\text{m}$), silt ($4\text{--}63 \mu\text{m}$) and sand ($> 63 \mu\text{m}$) using wet-sieving method. Dried sediments were added with Sodium hexametaphosphate $[(\text{NaPO}_3)_6]$ then passed through 63 microns sieve for sand. The supernatant solutions were separated based on density, dried and weighed for clay and silt content. The entire procedure has a measurement error of 3-5 % in this study.

Results and Discussion

Water

During study period (March and April, 2018), the measured atmospheric temperature was in the range of 24.5°C to 36°C and the water temperature was in the range of 25.5°C to 35°C throughout the study. pH values obtained were within the range of 7.7 to 8.6, which were within the permissible limits prescribed by the Central Pollution Control Board (CPCB) under class SW II for recreational waters. Salinity values were in the range of 26.0 to 36.3 practical salinity units (PSU). The lowest value was obtained at Tadgam in the vicinity of discharge point (Tadgam DP) during low tide conditions, indicated combined effect of freshwater influx from associated creek effluent discharge. Changes in the chemical status of the beach can occur naturally or anthropogenically. Mainly in the recreational beaches, water is affected by anthropogenic factors which include discharges, public waste, improper solid waste management, infrastructure development, etc. The beach water was seen much aerated in most of the location while the low DO values ($<4 \text{ mg/l}$) were observed at Tadgam effluent discharge point (DP) during low tide indicating consumption of DO during oxidation of organic matter associated with industrial effluent¹². Along the rest of the beaches, average DO values were observed $>5.5 \text{ mg/l}$, which indicated better coastal water conditions. Three locations JP-2 in phase II and TG and DP in

phase I and II showed D.O < 5.0 mg/l, which is below normal condition¹³. However, the conditions were seen recovered in the final phase of monitoring. The recovery was observed due to lower prevalence of organic matter (OM) which consumes DO during diagenetic reactions. Total suspended solids measured were higher, which decrease the visibility and light penetration in seawater. The concentration of TSS in nearly 50% of the samples was > 500 mg/l. The higher TSS values attributed to the presence of higher silt and clay in the sediment from the beaches. Unclear water may be due to wave action that generates turbulence especially during pre-monsoon, which resuspends silt varying from (12.1-94.8%) and (0.1- 25.8%) clay in bottom sediment thereby increasing the turbidity in water¹⁴. This indicates much of the beaches were enriched with finer grain-size thus escalating resuspension of TSS.

Nutrients such as forms of nitrogen and phosphorus are essential for the survival of phytoplankton, while the excess of them can cause algal blooms¹⁵, which depletes dissolved oxygen levels in the water. The anthropogenic sources of these nutrients are from industrial discharges, sewage and fertilizer drain from agricultural land in nearshore environments¹⁶. The levels of $\text{PO}_4^{3-}\text{-P}$ were in the range of 0.6 $\mu\text{mol/l}$ to 57.3 $\mu\text{mol/l}$ during this study. $\text{NO}_2^-\text{-N}$, an intermediate state between oxidation of $\text{NH}_4^+\text{-N}$ and reduction of $\text{NO}_3^-\text{-N}$ and is thermodynamically unstable its concentration remains <1 $\mu\text{mol/l}$ in coastal Sea¹⁷. Its concentration was a maximum of 4 $\mu\text{mol/l}$ at Tithal beach during low tide. The higher values obtained in this study may be related to the discharge of domestic and industrial effluent contributing to the accumulation of $\text{NO}_2^-\text{-N}$ in this water before its oxidation to $\text{NO}_3^-\text{-N}$ ¹⁸. $\text{NO}_3^-\text{-N}$ is an important form of inorganic nitrogen as its presence contributes generally over 60 % of total inorganic nitrogen, was in the range of 3.7- 15.1 $\mu\text{mol/l}$ in this study. As per EPA, excess of $\text{NO}_3^-\text{-N}$ in seawater can cause hypoxic conditions making the environment toxic for aquatic life¹⁹. The interrelationship between $\text{NO}_2^-\text{-N}$ and $\text{NO}_3^-\text{-N}$ was always positive irrespective of the tide in all the beaches. However, a moderately weak correlation was seen in the interrelationship between $\text{NO}_2^-\text{-N}$ and $\text{NO}_3^-\text{-N}$ at Tithal beach (0.57-0.43) along with Jampore during L.T (0.38). Broadly, the values of $\text{PO}_4^{3-}\text{-P}$ were in the range of 1.54- 6.95 $\mu\text{mol/l}$, with a mean value of 4.4 $\mu\text{mol/l}$. and the values of $\text{NO}_3^-\text{-N}$ was in the range of 0.2- 2.3 $\mu\text{mol/l}$ with mean 1.07 $\mu\text{mol/l}$. The range of $\text{PO}_4^{3-}\text{-P}$ and $\text{NO}_3^-\text{-N}$ obtained during this study was higher as compared to previously reported results²⁰. $\text{NH}_4^+\text{-N}$ is a widespread pollutant found in beach waters, its concentration beyond the certain permissible limit is said to be harmful to aquatic life²¹. The permissible limit

0.2 mg/l \approx 11.7 μ mol/l indicates toxic water for aquatic species²¹ comparing with these limits, the NH_4^+ -N values at Tadgam DP were higher (12.8 μ mol/l and 28.7 μ mol/l in I and II phases respectively). The high concentration obtained may be the result of the decomposition of organic matter discharged in the form of sewage or partially treated effluent. Other possible reasons could be the generation of ammonia due to the dissimilation of NO_3^- -N and/or from proteins, amino acids and urea, which are the prime ingredient of fertilizers²². Another possibility of comparatively higher values may also due to the impact of the discharge of partially treated effluent and sewage²³ that is discharged into Daman ganga and Kolak river, which finally opens to the Arabian Sea giving rise to enhancement of nutrients in the beach²⁴. Variation in nutrients observed during high and low tide conditions, due to the effect of wave-driven currents²⁵ are presented in (Table 1). Owing to reduce the concentrations of some nutrients it should be considered that wastewater and industrial discharges should be made into 20 m water depth²⁶. This will influence the diffusion and dispersion of pollutants and reduce its impact on coastal water.

Petroleum hydrocarbons (PHc) in water arises due to anthropogenic sources such as oil spillage, leakages in fishing trawlers or boats or discharge of petroleum product in water. Many studies confirmed the deposition of tar ball along the west coast of India during pre-monsoon, which resulted due to leakage of oils in offshore oil fields and oil spillages by container ships²⁷. PHc values were found to be in the range of 6.0- 7.0 μ g/l for all the beaches excluding Tadgam DP point which revealed the average value of 15.2 μ g/l and higher than that obtained at other stations indicating petroleum-based discharge of effluents.

Microbiological Aspects

During the three-phase study of beaches the concentration of FC was in the order of Jampore > Devka > Tithal > Tadgam with highest FC pollution at Jampore and lowest at Tithal. Respective values obtained were in the range of 3-25, 4-5, 2-4, 0-5 CFU/ml which exceeded CPCB limit of 1 CFU/ ml showing a severe threat to tourists. It is estimated that around 120 million cases of gastrointestinal illness and 50 million cases of respiratory diseases are reported due to recreational activities in sewage polluted beaches²⁸. Fecal indicator bacteria like *Escherichia coli* and *Enterococci* are widely used indicator bacteria and their presence is an indication of other pathogenic bacteria that are often excreted in feces. Accidental swallowing of

such contaminated water during recreational activities leads to illness like gastroenteritis, acute respiratory disease and eye, ear and skin infections²⁵. Considering such serious impacts of microbials, treated waste water must be discharged into sea. Study performed at Mumbai; west coast of India also revealed recreational beaches polluted due to increase in domestic sewage discharge considering FC as indicator²⁹.

Hierarchical Cluster Analysis

The hierarchical clustering or dendrograms indicate the variation in dissimilarity between the stations³⁰. The vertical line referred to as Y-axis indicates the name of stations while horizontal i.e. X-axis indicates distances or dissimilarity points. Stations having little or no dissimilarity are placed closed to each other like in case of DK 1-DK 2, JP 1-JP 2, TG 1-TG 2 have nearly similar properties in context to nutrients at low tide, while DP at Tadgam shows highest dissimilarity factor showing higher values as compared to all other stations plotted. High distance traveled by DP indicates the highest effluent and sewage discharge activities that are evident from Tadgam discharge point. Due to higher values of $\text{NH}_4^+\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ obtained at Devka the distance traveled by them shows increased nutrient pollution during hightide conditions owing to the confluence of Damanganga River and Kolak River. However, DP shows recovered conditions during high tide, which might be due to the effect of dilution.

Sediment

Chemical Aspects

Apart from bathing and water sport at beaches, the majority of tourists spend their time basking, playing or walking naked feet which contacts beach sediment. Contaminated sediment has a probability of containing toxic materials that may affect human health or environment³¹. Hence it becomes important to monitor the beach sediment and its quality to make sure it is harmless for recreational use. For determining sediment quality PHc and metals were analyzed. While the probable source of PHc is known, adsorption of metals in sediment is from industrial and domestic discharges in seawater³², which can be transported to the inland beach due to the action of a wave. A higher concentration of PHc restricts the growth of an aquatic organism, gives objectionable smell or flavor to fishes thus decreasing their economic value³³. PHc was in a range of 0.1- 0.6 $\mu\text{g/g}$ (wet sediment) with mean value of 0.25 $\mu\text{g/g}$ at all beaches, except at

Tadgam DP where it was higher (1.93 $\mu\text{g/g}$). The obtained values of PHc were lower as compared to other areas of the Indian coast^{34,35}.

Anthropogenic factors responsible for metal pollution in sediments mainly involve untreated domestic and industrial wastewater release, which after precipitation gets attached to suspended matter³⁶. The grain size revealed that the beaches of Jampore and Devka highly dominated with silt (83-91%) with lower concentration of sand (2-17%) and clay (0-26%). In the case of Tadgam and Tithal comparatively low concentration of clay (1-21%), while distribution of sand and silt was (20- 94%) and (44-94%) respectively. Thus, the concentration of metals in sediment was seen to be on the higher side due to domination of finer grain size (silt and clay), which adsorbs metal due to their smaller grain size and larger surface area⁴⁸ (Table 2). Comparing with study conducted along the west coast of India before and after the commissioning of Bombay Disposal Sewage Project (BDSP), along the coastline of the present study, revealed lower concentrations of Cr, Ni, Cu, Zn than that in the present study³⁷. Concentrations of Cr and Zn were higher at Tadgam and Tithal. The concentration of Cr (138-224 $\mu\text{g/g}$) exceeded SEL indicating chromium contamination in all the beach sediment³⁸. While study performed by CSIR-NIO, 2012 along the coast of Daman indicated values in the range ($\mu\text{g/g}$) of 95-223, 801-1053, 23-32, 50-58, 79-111, 85-108 for Cr, Mn, Co, Ni, Cu, and Zn respectively indicating a slight change of metal concentration as compared to our study. The contaminated sediment in some beaches might be the cause of certain anthropogenic factors like coastal construction, industrial discharges and tourist activities which causes metal input³⁹.

Microbiological Aspects

The sediment usually has higher counts of bacteria as they remain protected from deactivation by sunlight, nutrient scarcity²⁵. The reports of tourists' illness due to contact with contaminated sands are well published however there are no standards to implement for sediment quality. While sediment at Tadgam showed an absence of FC they were detected only once at Tithal indicating the non-point source of pollution. Considering the sediment of Devka, FC was intensely contaminated as compared to Jampore. Values obtained for Jampore and Devka were 100- 200 and 100- 300 CFU/g respectively. However, awareness must be made against the possible consequences. As treatment for the illness caused by contaminated water with high FC is getting difficult, beach management program should be implemented promoting beach closing

which is followed by developed countries. The same should be practiced in India too as it is also advised by WHO⁴¹ under guidelines for safe recreational water environments, 2003. As compared FC contaminated water, it is clearly evident that FC has less capability to bind sediment.

Conclusion

Four prime beaches along the west coast of India were studied on account of contamination. Result of study highlights excess anthropogenic load, especially in Tadgam beach. FC is found higher than the permissible limit indicating contamination by microbial communities. Sedimentary metal compositions were above LEL and lower than SEL except for Cr and Fe, indicating anthropogenic pollution due to release of industrial effluents and sewage. Hence, any water must be treated well before its release. The impact of contaminants can be significantly lowered when remedial measures are taken at the source of pollution considering safety of recreational users.

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Conflict of Interest

Respective authors of the Manuscript declare that there is no conflict of interest.

Author contribution

AR and UKP made the fund acquisition and initiated the study. SL prepared and conceptualized the final draft of manuscript. Sampling and analysis along the beaches were done by SL, UPB, AG, LK for chemical aspects of sediment and water. Microbial study was done by ABF. The manuscript was reviewed by all the authors.

References

1. Gupta I., Dhage S., & Kumar R., Study of variations in water quality of Mumbai coast through multivariate analysis techniques, *Indian J Mar Sci*, 38 (2) (2009) 170-177.
2. Moore Charles James, Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. *Environ. Res.* 108 (2) (2008) 131-139.
3. Schlacher, Thomas A., Serena Lucrezi, Rod M. Connolly, Charles H. Peterson, Ben L. Gilby, *et al.*, Human threats to sandy beaches: A meta-analysis of ghost crabs illustrates global anthropogenic impacts. *Estuar. Coast. Shelf Sci.* 169 (2016) 56-73.
4. Vignesh Sivanandham, Hans-Uwe Dahms, Kunnampuram Varghese Emmanuel, Murugaiah Santhosh Gokul, Krishnan Muthukumar, *et al.*, Physicochemical parameters aid microbial community? A case study from marine recreational beaches, Southern India. *Environ. Monit. Assess.* 186(3) (2014) pp. 1875-1887.
5. Zingde M. D., & Govindan K, Health status of the coastal waters of Mumbai and regions around. *Indian J Mar Sci* (2000) 119-132.
6. Zingde M. D., & Desai B. N, Pollution status of estuaries of Gujarat-an overview. Goa: National Inst of Oceanography, *Indian J Mar Sci* (1987) 245-267.
7. Grasshoff K., Kremling K., & Ehrhardt M. eds. *Methods of seawater analysis*. John Wiley & Sons; (2009) Jul 30.
8. IOC-UNESCO, Manual for monitoring oil and dissolved dispersed petroleum hydrocarbons in marine waters and on beaches. *Manual and Guides No. 13*, (1984)
9. Federation W.E. and American Public Health Association, Standard methods for the examination of water and wastewater. American Public Health Association (APHA): Washington, DC, USA. 2005.
10. IOC-UNESCO, The determination of petroleum hydrocarbons in sediments. *Manuals and Guides No.11*, (1982) 38.
11. Loring D. H., & Rantala R. T. Manual for the geochemical analyses of marine sediments and suspended particulate matter. *Earth Sci. Rev.* 32 (4) (1992), 235-283.
12. Gupta Vinod Kumar, Imran Ali, Tawfik A. Saleh, Arunima Nayak, Shilpi Agarwal. Chemical treatment technologies for waste-water recycling—an overview. *RSC Adv.* 2(16) (2012), 6380-6388.
13. Ramana V., L. M. Rao, and C. Manjulatha, Physico-Chemical Parameters of Coastal Waters of Visakhapatnam, East Coast of India, *Asian J. Exp. Sci* 29, no. 1&2 (2015), 7-10.
14. Nixon Scott W, Physical energy inputs and the comparative ecology of lake and marine ecosystems, *Limnol. Oceanogr.*, 4(2) (1988), 1005-1025.

15. Purwono A.R., Hibbaan M. & Budihardjo, M.A., Ammonia-nitrogen (NH₃-N) and Ammonium-nitrogen (NH₄⁺-N) equilibrium on the process of removing nitrogen by using tubular plastic media. *J Mater. Environ. Sci.*, (8) (2017), 4915-4922.
16. Shirodkar P. V., A. Mesquita, U. K. Pradhan, X. N. Verlekar, M. T. Babu, *et al.*, Factors controlling physico-chemical characteristics in the coastal waters off Mangalore—a multivariate approach, *Environ. Res.* 109(3) (2009), 245-257.
17. Ram Anirudh, Jiyalal Ram M. Jaiswar, M. A. Rokade, S. Bharti, C. Vishwasrao, *et al.*, Nutrients, hypoxia and mass fishkill events in Tapi Estuary, India, *Estuar. Coast. Shelf Sci.*, 148 (2014), 48-58.
18. Razumov V. A., & Tyutyunova F. I., Nitrite contamination of the Moskva River: causes and effects, *Water Resour.*, 28(3) (2001), 324-334.
19. Boman B. J., Wilson P. C., & Ontermma E. A., Understanding water quality parameters for citrus irrigation and drainage systems, *Univ. of Florida IFAS Extension, Circ.* (2002) pp. 1406.
20. Zingde M. D., Narvekar P. V., Sarma R. V., & Desai B. N., Water quality of the river Damanganga (Gujarat), *Indian J Mar Sci* (1980), 94-99.
21. Randall D. J., & Tsui T. K. N., Ammonia toxicity in fish, *Mar. Pollut. Bull.*, 45(1-12) (2002), 17-23.
22. Jones J. G., Simon, B. M., & Horsley, R. W., Microbiological sources of ammonia in freshwater lake sediments, *Microbiology*, 128(12) (1982), 2823-2831.
23. Pereira-Filho J., Schettini, C. A. F., Rörig, L., & Siegle, E., Intratidal variation and net transport of dissolved inorganic nutrients, POC and chlorophyll a in the Camboriú River estuary, Brazil, *Estuar. Coast. Shelf Sci.*, 53(2) (2001), 249-257.
24. Nirgude N. T., Shukla S., & Venkatachalam A., Physico-chemical analysis of some industrial effluents from Vapi industrial area, Gujarat, India, *Rasayan J. Chem*, 6(1) (2013), 68-72.
25. Lee C. M., Lin T. Y., Lin C. C., Kohbodi, G. A., Bhatt A., *et al.*, A. Persistence of fecal indicator bacteria in Santa Monica Bay beach sediments, *Water Res.*, 40(14) (2006), 2593-2602.
26. Beder S., Engineering Sydney's sewerage pollution: Public relations assisted technology, *Curr Aff Bull*, 66 (1989), 27-31
27. Chapman H., Purnell K., Law R. J., & Kirby M. F., The use of chemical dispersants to combat oil spills at sea: A review of practice and research needs in Europe, *Mar. Pollut. Bull.*, 54(7) (2007), 827-838.

28. Dwight R. H., Fernandez L. M., Baker D. B., Semenza J. C., & Olson B. H., Estimating the economic burden from illnesses associated with recreational coastal water pollution—a case study in Orange County, California, *J. Environ. Manage.*, 76(2) (2005), 95-103.
29. Maloo A., Fulke A. B., Khade K., Sharma A., & Sukumaran S., Virulence gene and antibiogram profile as markers of pathogenic *Escherichia coli* in tropical beaches of North West India: Implications for water quality and human health, *Estuar. Coast. Shelf Sci.*, 208 (2018), 118-130.
30. D.L. Massart, L. Kaufman, The interpretation of analytical chemical data by the use of cluster analysis, *Wiley-Interscience, New York* (1983), 179-208.
31. Buruaem L. M., Hortellani M. A., Sarkis J. E., Costa-Lotufo L. V., & Abessa D. M. Contamination of port zone sediments by metals from Large Marine Ecosystems of Brazil, *Mar. Pollut. Bull.*, 64(3) (2012), 479-488.
32. Adamo P., Arienzo M., Imperato M., Naimo D., Nardi G., *et al.*, Distribution and partition of heavy metals in surface and sub-surface sediments of Naples city port, *Chemosphere*, 61(6) (2005), 800-809.
33. Daniel I. E., & Nna P. J. Total Petroleum Hydrocarbon Concentration in Surface Water of Cross River Estuary, Niger Delta, Nigeria, *Asian J. Environ. Ecol*, 1(2) (2016), 1-7.
34. Veerasingam S., Raja P., Venkatachalapathy R., Mohan R., & Sutharsan P., Distribution of petroleum hydrocarbon concentrations in coastal sediments along Tamilnadu coast, India, *Carpath. J. Earth Environ. Sci.*, 5(2) (2010), 5-8.
35. Gupta R. Sen, S. P. Fondekar, and R. Alagarsamy., State of oil pollution in the northern Arabian Sea after the 1991 Gulf oil spill, *Mar. Pollut. Bull.*, 27 (1993) 85-91.
36. Majithiya D., Yadav A., & Ram A., Behaviour of trace metals in the anoxic environment of Veraval harbour, India, *Mar. Pollut. Bull.*, 129(2) (2018), 645-654.
37. Dhage S. S., Chandorkar A. A., Kumar R., Srivastava A., & Gupta I., Marine water quality assessment at Mumbai West Coast, *Environ. Int.*, 32(2) (2006), 149-158.
38. United States Environmental Protection Agency (USEPA). The role of screening-level risk assessments and refining contaminants of concern in Baseline ecological risk assessments, (2001) pp. 9345.
39. Alharbi T., & El-Sorogy A., Assessment of metal contamination in coastal sediments of Al-Khobar area, Arabian Gulf, Saudi Arabia, *J. Afr. Earth Sci.*, 129 (2017), 458-468.
40. Jayasiri H. B., Vennila A., & Purushothaman C. S., Spatial and temporal variability of metals in inter-tidal beach sediment of Mumbai, India, *Environ. Monit. Assess.*, 186(2) (2014), 1101-1111.

41. Boehm A. B., Keymer D. P., & Shellenbarger G. G., An analytical model of enterococci inactivation, grazing, and transport in the surf zone of a marine beach, *Water Res.*, 39(15) (2005), 3565-3578.
42. Santhiya G., Lakshumanan C., Jonathan M. P., Roy P. D., Navarrete-Lopez, *et al.*, Metal enrichment in beach sediments from Chennai Metropolis, SE coast of India, *Mar. Pollut. Bull.*, 62(11) (2011), 2537-2542.
43. Vetrimurugan E., Shruti V. C., Jonathan M. P., Roy P. D., Kunene N. W., & Villegas L. E., Metal concentration in the tourist beaches of South Durban: An industrial hub of South Africa, *Mar. Pollut. Bull.*, 117(1-2) (2017), 538-546.
44. iomervis.nic.in
45. dcmsme.gov.in

Legends to Figures:

Fig. 1 Location of the studied beaches of Daman and Gujarat, north-west coast of India.

Fig. 2 Distribution of DO (mg/l) and Nutrients ($\mu\text{mol/l}$) during three phases, phase-1 (P-1), phase-2 (P-2) and phase-3 (P-3) of studies at stations 1 and 2 during High tide and Low tide conditions along the beaches Tadgam (TG), Jampore (JP), Devka (DK) and Tithal (TL).

Fig.3 Dendrogram showing similarity among status based on DO (mg/l) and Nutrients ($\mu\text{mol/l}$) during different tidal conditions along the studied beaches.

Tables:

		DO (mg/l)		NO ₃ ⁻ -N (μmol/l)		NO ₂ ⁻ -N μmol/l)		NH ₄ ⁺ -N (μmol/l)		PO ₄ ³⁻ -P (μmol/l)	
		Low tide	High tide	Low tide	High tide	Low tide	High tide	Low tide	High tide	Low tide	High tide
Tadgam	Range	3.3-7.8	5.9-6.9	3.7-15.6	5.5-15.1	0.3-1.4	0.3-1.3	0.5-28.7	5.5-15.7	1.0-57.3	2.0-4.6
	Sd	1.56	0.32	3.29	3.04	0.34	0.39	8.75	3.04	17.08	0.96
Jampore	Range	6.2-8.5	3.6-7.2	5.8-9.1	8.8-13.8	0.2-0.5	0.2-1.2	1.1-7.7	8.8-13.8	1.4-4.7	1.0-4.8
	Sd	0.79	2.5	1.26	1.82	0.13	0.44	2.33	1.82	1.17	1.35
Devka	Range	4.9-8.2	5.9-6.9	11.3-14.8	12.1-15.1	0.8-2.0	0.8-1.2	1.1-7.6	12.1-15.1	0.6-5.1	1.0-7.3
	Sd	1.07	0.45	1.33	0.9	0.45	0.13	2.14	0.9	1.6	2.26
Tithal	Range	6.5-7.2	4.9-7.5	5.9-14.7	5.4-14.1	0.1-4.0	N.D-1.0	0.6-5.8	5.4-14.1	1.8-8.4	1.6-5.8
	Sd	0.31	1.47	3.44	3.41	1.37	0.33	1.71	3.41	2.38	1.68

Table 1. Ranges of DO and nutrients recorded in the water in the vicinity of different studied beaches.

Table 2. Comparison of sediment quality between present studies and other studied tourist beaches across the world.

Beaches	Al (%)	Cr (µg/g)	Mn (µg/g)	Fe (%)	Co (µg/g)	Ni (µg/g)	Cu (µg/g)	Zn (µg/g)	Hg (µg/g)	Study
Tadgam	4.3-6.8	169-285	924-1330	7.5-10.5	42-66	55-64	46-87	76-112	N.D-0.01	Present study
Mean	5.2	224	1085	9	53	60	61	91	0.07	
Jampore	3.7-7.3	137-211	985-1755	7.9-9.3	40-70	46-54	40-88	63-96	N.D-0.14	Present study
Mean	4.8	148	1058	7	44	43	59	74	0.06	
Devka	6.2-7.7	136-181	1070-1235	8.7-9.7	38-49	53-56	79-96	99-118	0.07-0.09	Present study
Mean	6.1	138	960	8	38	46	77	93	0.07	
Tithal	5.6-7.5	146-295	1142-1535	9.3-14.4	44-91	53-63	98-123	107-184	N.D-0.14	Present study
Mean	5.5	164	1097	9	52	49	90	111	0.07	
Mumbai⁴⁰	...	40- 527	328-793	1.2-8.8	63-125	45-94	15-48	28-83	...	(40)
Pre-commission³⁷	...	151-189	...	...	...	57- 98	72- 99	73- 91	...	(37)
Post- commission³⁷	...	64-171	...	...	...	28- 90	72- 96	74- 103	...	(37)
Chennai (avg.), India⁴²	...	14.1	46.84	44.2	5.05	9.17	4.05	9.89	...	(42)
Al-Khobar coast, Saudi Arabia³⁹	...	51.03	113.97	...	4.75	75.1	182.97	52.68	0.8	(39)
South Darban, S.A⁴³	...	223-352	605-1039	...	45-52	93-118	28-42	31-57	1-2	(43)
LEL³⁸	...	26	460	2	...	16	16	120	...	(38)
SEL³⁸	...	110	1100	...	...	75	110	820	...	(38)

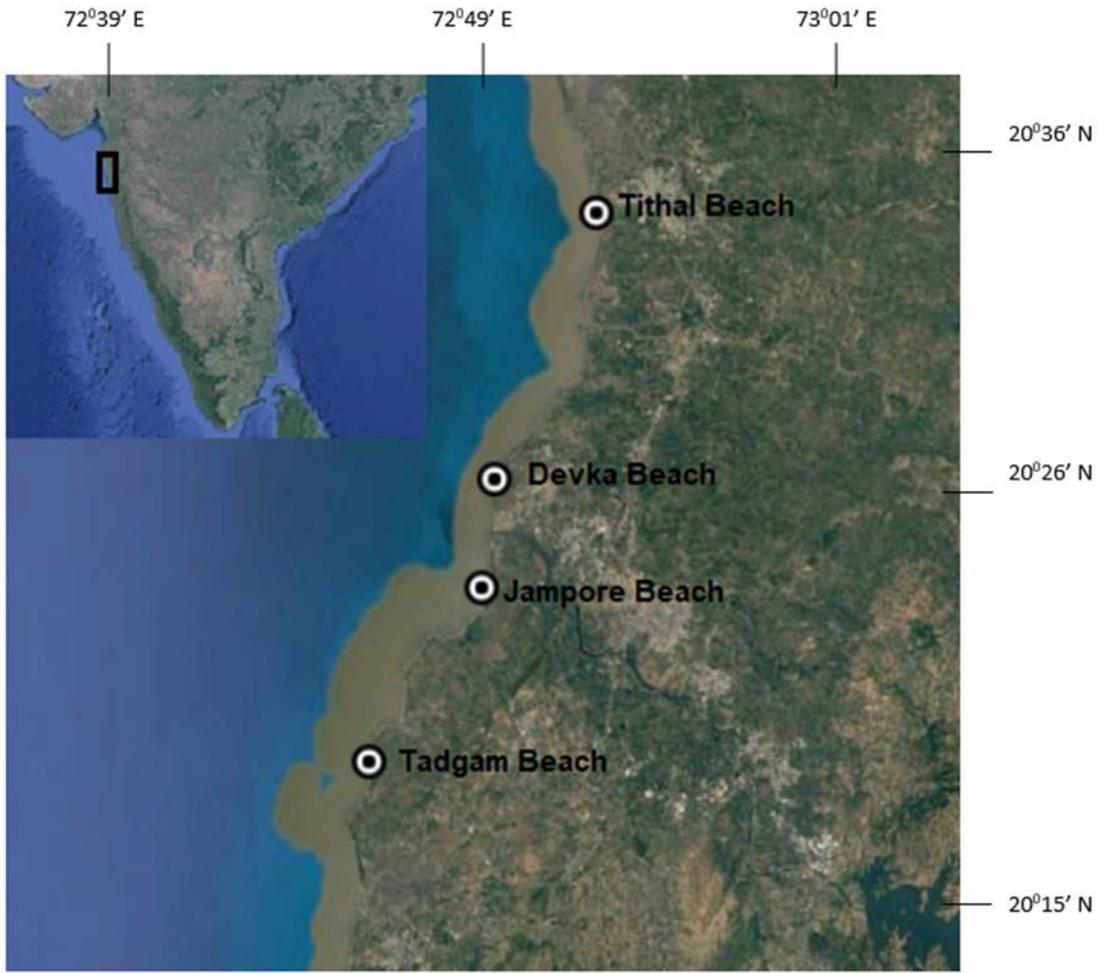


Figure 1.

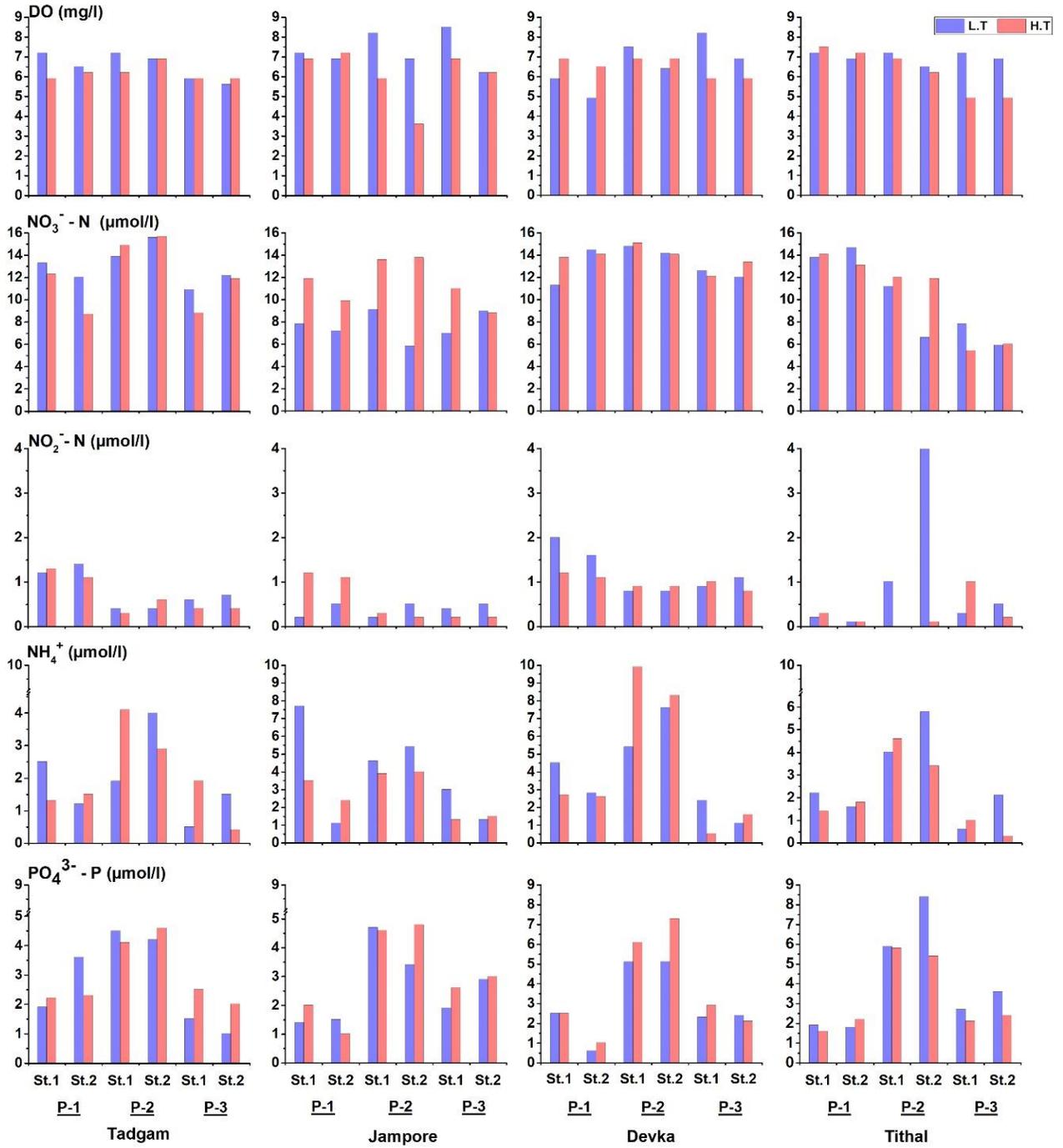


Figure 2.

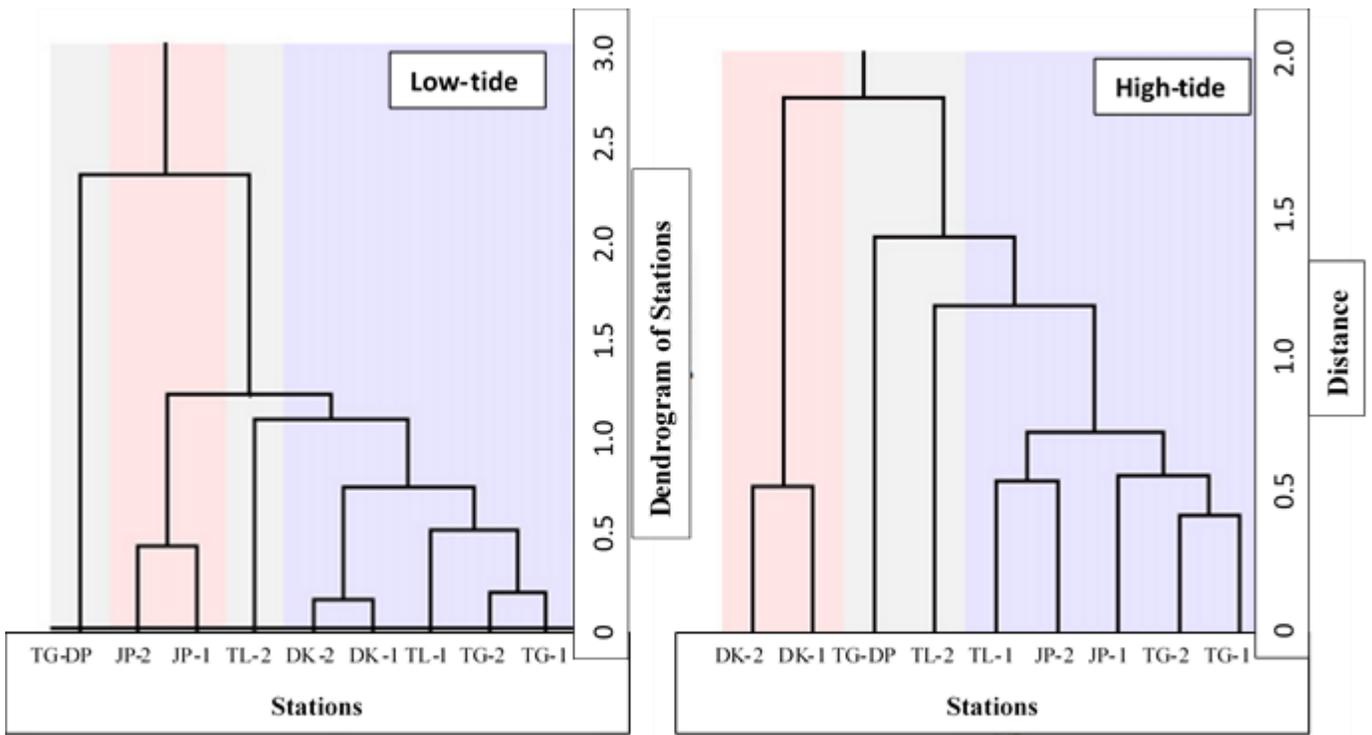


Figure 3.