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Baseline

Seawater quality conditions of the south Andaman Sea (Bay of Bengal, Indian Ocean) in lustrum during 2010s decade

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ABSTRACT

Andaman and Nicobar islands is one of the major tourism hubs of the World. Most travelers visit these islands for historical attractions, beaches, snorkeling, scuba diving, coral reefs, adventure and recreation. Port Blair is the capital and sole entry/exit point of these islands. The coasts of Port Blair Bay (PBB) and Wandoor Creek (WC) are largely populated due to its services offered to different public/private sectors and for the economic significance. Nevertheless, the global recognition of these islands relies on its healthy ecosystem. Effective management of beaches, bays and their environmental services requires knowledge of coastal water quality. This study assesses the datasets of twenty seawater quality parameters of PBB and WC generated during five years (2011–2015) at eight sites. Multivariate statistical techniques were used for (i) analysis and interpretation of water quality parameters (ii) identification of pollution factors/sources and (iii) understanding spatio-temporal variations valuable for coastal water quality management.

Coastal bays are prone to a number of environmental factors that reflect the interactions between the land and ocean. These ecosystems are subject to anthropogenic activities, natural and oceanic variations (Dong et al., 2010). Human activities have already negatively influenced water quality and aquatic ecosystem functions and have created greater pressure on the ecosystem, resulting in a decline of water quality, biodiversity, loss of critical habitats and an overall decrease in the quality of life of local inhabitants (Herrera-Silveira and Morales-Ojeda, 2009). In the Port Blair Bay (PBB) and Wandoor Creek (WC) of the Andaman and Nicobar (A and N) islands, amongst the diverse human activities found in the coastal zone, fishing, shipping, harbour works, recreation, adventure sports and beach tourism are some of the most important activities, given its economic significance. These activities influence the seawater quality in one way or the other. In addition, the land-based activities also affect the water quality that has detrimental results on the services offered by several small bays in the PBB (Jha et al., 2015). Port Blair is the capital city of the A and N islands and Wandoor is a small village situated along the west coast of south Andaman. They represent as major tourism attractions of the islands. Hence, the critical responsibility of maintaining the ecosystem health is directly related to its global significance and recognition, besides its economic importance of these areas. The PBB is the most important and intensively used area compared to all other areas populated in the A and N Islands. The population growth is considered as a driving force of many area management problems and the rapid increase of population have caused the large-scale exploitation of the coastal resources and marine environmental disturbances (De Sherbinin et al., 2007). Besides these factors, the likely cause for coastal water pollution at PBB and WC could be the release of untreated municipal sewage release from urban areas into the coastal environment. Previous studies have shown a significant increase of fecal coliforms in PBB (Dheenan et al., 2016), which may be linked to possible consequence of domestic sewage release (Kelsey et al., 2004). Further, maximum counts of *Enterococcus* species are reported in PBB throughout the year especially in Phoenix Bay and Junglighat Bay (Meena et al., 2015). Domestic waste release into the bay ultimately reduces the quality of seawater and

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increase the bacterial load (Dunn et al., 2012). In addition, the land based discharge from on-shore built-up coverage and agricultural runoff has been identified as a major cause of seawater pollution of the PBB (Jha et al., 2015). Many marine ecosystems worldwide are affected by eutrophication and hypoxia (Osterman et al., 2009; Fuksi et al., 2018). One of such example is represented by the PBB. The blooming of diatom species such as *Chaetoceros curvisetus* Cleve, 1889 is a common phenomenon in the Junglighat Bay and Haddo Harbour of the PBB (Sahu et al., 2014; Begum et al., 2015), which could be perhaps due to addition of iron (Klaas et al., 2001; DiTullio et al., 1993; Rose et al., 2009) released either from the land run-off or leaching through the harbour related activities, where many old and new ships are anchored.

Monitoring of physico-chemical parameters is necessary for ecosystem conservation because the divergence of given ranges of these parameters may affect the marine organisms such as hindrance of growth, mortality and an overall reduction in ecosystem services (Koch et al., 2007; Wild et al., 2011). It is therefore essential to prevent and control marine water pollution and to implement regular monitoring programs, which help us to understand the temporal and spatial variations in marine water quality and diagnose the present condition of coastal water quality condition (Simeonov et al., 2003, 2004; Pati et al., 2014). Seawater quality monitoring programs have generated huge datasets describing the variation of spatial and temporal patterns for water quality condition. The large and complicated datasets of seawater quality parameters are often difficult to investigate meaningfully and require data reduction methods to simplify the data structure to extract useful and interpretable information that could explicate the spatial and temporal variation patterns of water quality. In recent years, multivariate statistical analysis, such as cluster analysis (CA), cross-correlation analysis (CCA), principal component analysis/factor analysis (PCA/FA) and discriminant analysis (DA) have been effectively employed by many researchers (Zhou et al., 2007; Martinez-Ortega et al., 2009; Wu et al., 2010; Akbal et al., 2011; Huang et al., 2011; Tosic et al., 2013; Gupta et al., 2013; Pati et al., 2014; Wu et al., 2015; Fang et al., 2015) to evaluate the temporal and spatial characteristics of coastal water quality. In this study, a large dataset obtained during the five year (2011–2015) long-term and continuous monitoring program consisting of 20 seawater quality parameters at eight different sites was subjected to a comprehensively coupled multivariate statistical techniques such as CA, CCA, PCA/FA and DA to extract information on (i) the similarities or dissimilarities between sampling sites, (ii) identification of water quality variables responsible for spatial and temporal variations in seawater quality, (iii) the hidden factors explaining database structure, and (iv) the influence of possible sources (natural and anthropogenic) on the seawater quality parameters of PBB and WC of the south Andaman Sea.

PBB is situated in the south eastern part of the south Andaman island surrounded by Port Blair city with its 30 km^2 area. The PBB has many smaller bays namely Flat Bay (FB), Minnie Bay (MB), Junglighat Bay (JB), Haddo Harbour (HH), Phoenix Bay (PB), Aberdeen Bay (AB) and it begins at the Open Sea (OS) nearby Ross island. Wandoor Creek (WC) is located on the west coast of the south Andaman island between Wandoor and Alexandra island. Wandoor is commonly known as the gateway to the Mahatma Gandhi Marine National park comprising of 15 islets, rich in mangroves, corals and tropical forest. The A and N islands receive heavy rainfall (approximately 3035 mm/year) during eight months of the year (Indian Meteorological Department (IMD), Port Blair). For this study, surface seawater samples were collected from FB, MB, JB, HH, PB, AB, OS and WC (Fig. 1). The point of sample collection at each bay or creek was positioned approximately or within 1 to 2 km from the coastline. The datasets of eight water quality monitoring stations comprising of 20 water quality parameters were monitored seasonally i.e., pre-monsoon (P-M) (Mar-May), south-west monsoon (SW-M) (June–September), north-east monsoon (NE-M) (October–December) and non-monsoon (N-M) (January–February), including both the dry (January–May) and rainy seasons (June–December) over five years (2011–2015). The seawater quality parameters, their codes and units are summarized in Table 1. T_{sw} and *pH* were measured in situ using mercury filled Celsius thermometer with an accuracy of 0.1 °C. (Brannan, Cleator Moor, UK) and *pH* meter (Thermo Orion 420 A plus, Waltham, Massachusetts, USA). *TRANS* was measured from Secchi disc depth. *DO* was analyzed by Winkler's method (Grasshoff et al., 1999) and *SAL* was estimated by Mohr-Knudson Argentometric titration method described in Strickland and Parsons (1977). *TSS* was determined by filtering 1 L of seawater through pre-dried and pre-weighed 0.45 μm pore-size filter paper (Merck Millipore Ltd., Delhi, India). Filtered samples were used to analyze nutrients such *NO_2-N*, *NO_3-N*, *NH_3-N*, *IP* and *SiO_4*. Unfiltered samples were used to determine *TN* and *TP*. The concentration of nutrients in seawater was measured on a lambda-25-UV/Visible spectrophotometer with an accuracy of 0.004 μM/L and MDL between 0.004 μM/L and 100 μM/L (Perkin Elmer, Waltham, Massachusetts, USA) (Grasshoff et al., 1999). The data quality was checked by careful standardization, procedural blank measurements and duplicate samples. *ZOO* samples were identified and counted in a Sedgewick-Rafter plankton counting chamber under zoom stereo microscope (Nikon SMZ800, Tokyo, Japan) and phase contrast microscope (Nikon Eclipse Ni-U, Tokyo, Japan) (Kasturirangan, 1963; Santhanam and Srinivasan, 1994). *PHY* was identified and counted under zoom stereo microscope (Nikon SMZ800, Tokyo, Japan) and phase contrast microscope (Nikon Eclipse Ni-U, Tokyo, Japan) (Utermöhl, 1931; Santhanam et al., 1987). *Chl-a* and *PHE* concentrations were measured on lambda-25-UV/Visible spectrophotometer with an accuracy of 0.004 μM/L and MDL between 0.004 μM/L and 100 μM/L (Perkin Elmer, Waltham, Massachusetts, USA) (USEPA, 2002a). For enumeration and isolation of health indicator bacteria, membrane filtration method of United States Environmental Protection Agency (USEPA, 2002b) and Central Pollution Control Board, India was applied. Further, biochemical and sugar fermentation tests were done to identify *EC* and *EF* (Holt et al., 1994). *TVC* was estimated using Zobell Marine Agar by spread plate method. The results were expressed as colony forming units (CFU)/100 mL for each water sample.

The seawater quality dataset of PBB and WC were subjected to four multivariate techniques namely, CA, CCA, PCA/FA and DA. DA was applied to raw data, whereas CA, CCA and PCA/FA were applied to experimental data, standardized through z-scale transformation to avoid misclassifications arising from the different orders of magnitude of both numerical values and variance of the parameters analyzed. The statistical computations were made using SPSS Statistics software (version 23.0). CA is an unsupervised pattern detection method that partitions all cases into smaller groups or clusters of relatively similar cases that are dissimilar to other groups (Gupta et al., 2013). The methods employed for clustering and distance measure plays a vital role in final assembling of variables. Amongst several clustering methods hierarchical agglomerative clustering analysis (HACA) was found to be the best method, which follows linear clustering approach (Ahmad et al., 2013). This method is distinct from all other methods, as it uses ANOVA (analysis of variance) approach to evaluate the distances between clusters that are formed at each step and reduce the error of two clusters created in every step. HACA is based on similarity between two clusters, it can be expressed as:

$$S_{ij} = 1 - \left(\frac{d_{ij}}{d_{max}}\right)$$

where, d_{ij} is the distance between the two clusters and d_{max} is the maximum d_{ij}, respectively. The final output of HACA was presented in the form of a tree diagram called dendrogram. Dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity, with a dramatic reduction in dimensionality of the original data (Gupta et al., 2013). In dendrogram, the horizontal lines indicate the links between the clusters or variables