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Baseline

Elucidation of seasonal variations of physicochemical and biological parameters with statistical analysis methods in Puducherry coastal waters

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ABSTRACT

The present investigation aimed to study the effect of monsoonal and anthropogenic influences on the water quality parameters of Puducherry coastal waters. Surface water sampling was performed at three fixed stations in four distinct seasons during 2011. Physical water quality parameters such as salinity and TSM showed strong seasonal and spatial variability. Evaporation and monsoonal runoff seem to be the major controlling forces for these parameters in the coastal waters. Seasonal distribution of the parameters showed a random pattern for nitrate and a well-defined pattern for silicate. Chl-*a* was minimum during monsoon when high TSM was encountered in the system. Moreover, factors that regulated the phytoplankton biomass varied with seasons. Moreover, TSM was strongly correlated with silicate. The relationship between Chl-*a* and nutrients were more consistent throughout the year, and much weaker correlations were noticed between Chl-*a* and TSM. Cluster analysis depicted the existence of a marked seasonal heterogeneity.

Coastal marine ecosystems are the most ecologically and economically productive regions on the planet, providing more than US$10 trillion in annual resources or ~40% of the global ecosystem goods and services (Costanza et al., 1997). Approximately 40% of the world population lives within 100 km of a coastline, subjecting these regions to a multitude of anthropogenic stressors including intense nutrient loading (de Jonge et al., 2002; Valiela, 2006). The coastal water quality, which is affected by both natural and anthropogenic influences (Jarvie et al., 1998), and particularly the near shore waters and estuaries, exhibits considerable variation depending upon the regional environmental setup such as rainfall, quantum of fresh water inflow, tidal incursion, and biological activities (Satpathy et al., 2011).

The phytoplankton are a crucial source of food for a diverse range of large and more familiar aquatic organisms such as invertebrates, fin and shell fish, and whales (Onyema et al., 2007). Growth and abundance of phytoplankton are primarily regulated by the combination of both biotic and abiotic interactions in coastal ecosystems (Dayala et al., 2014); this ultimately regulates the food web and biodiversity. Wastewater discharges are the major sources of organic and inorganic pollutants (including nutrients) in the coastal water ecosystems (Specchiulli et al., 2010). In addition to nutrients, physical properties such as salinity (McLusky, 1971), turbidity, and light availability (Cloern, 1987) also play major roles in the regulation of phytoplankton growth and their distribution in coastal waters. Moreover, top-down control by zooplankton can constrain phytoplankton concentrations within certain levels (Reid et al., 1990).

Because coastal water quality changes with time and space, continuous monitoring of water quality is necessary for the effective management of coastal water (Wu et al., 2010). There seems to be a great difficulty in analyzing the quality of water depending on the robust and sophisticated data sets provided by the monitoring programs, and therefore, some reduction methods are generally opted to make the data sets significant and easily accessible. In such cases, multivariate statistical analyses, such as factor analysis and cluster analysis (CA), have been effectively used to evaluate the temporal and spatial characteristics of coastal water and river water quality (Vega et al., 1998; Simeonov et al., 2003; Simeonov et al., 2004; Singh et al., 2004; Panda et al., 2006; Shirodkar et al., 2009; Wu et al., 2010). In the present study, multivariate analyses, i.e. CA and correlation analysis, were used to elucidate seasonal variations of physical, chemical and biological parameters in Puducherry coastal waters. The statistical approach gave an idea of the inter-relationship between various parameters that control the water quality. It also provides an insight into not only factors that chiefly affect the phytoplankton biomass but also those that are affected by variations in phytoplankton biomass.

Considering the influence of physical parameters on the productiv-

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ity potential of coastal waters, numerous studies have been made along the east coast of India to evaluate their seasonal and spatial behavior (Jayaraman, 1951, 1954; Sankaranarayanan and Reddy, 1968; Naqvi et al., 1978; Rajendran et al., 1980; Panigrahy et al., 1984; Sasmal et al., 1986; Choudhary and Panigrahy, 1991). Paramasivam and Kannan (2005) reported that factors related to water quality such as temperature, pH, salinity, dissolved oxygen, total organic carbon, and nutrients are particularly important for determining the biota and ecosystem functions in coastal waters. Information on general hydrography and biology from Puducherry coastal waters are available (Ananthan, 1995; Satheeshkumar and Khan, 2009, 2012). Moreover, earlier studies have been conducted along the Puducherry coast, particularly on mangrove-adjacent areas (Saravanan, 2005), river-adjacent areas (Vijayakumar et al., 2012, 2014), and sediment metal-related works (Ananthan et al., 2005; Solai et al., 2010). However, there is a paucity of information on the spatial and seasonal distributions of physicochemical and biological parameters that determine water quality and how they are influenced by external factors such as rainfall in the Puducherry coast. The present study aimed to evaluate the climatic influence (monsoonal runoff) and effects of physical, chemical, and biological variables on phytoplankton biomass (in terms of chlorophyll-*a* [Chl-*a*]) in the coastal waters of Puducherry located in the southeast coast of India.

The present study area is located in the Puducherry region, which is the largest among the four isolated domains of the union territory of Puducherry and is located on the east coast of India (Nathan et al., 2012). The Puducherry coast is surrounded by the Bay of Bengal on the east and by Tamil Nadu state on the other three sides. Stations were selected at the Puducherry coast, covering a distance of 5 km from shore (Fig. 1). The study area experiences a tropical subhumid type of climate with an annual mean temperature of 25 °C and average annual precipitation of 1200 mm (Solai et al., 2010). This region is an agriculture area, and around 56% of the land is used for crop production (Nathan et al., 2012). Puducherry has a population of 7,35,000 and generates wastewater of about 45,000 Kilo Liter per Day (KLD). The entire wastewater is discharged into the sea through backwaters and creeks in an untreated form. Puducherry has six major industries that manufacture paper, alcoholic beverages, chemicals, and pharmaceuticals. The total treated wastewater discharged from industries is about 7000 KLD (http://www.icmam.gov.in/comaps/pon.pdf).

For the present study, three stations were selected in Puducherry coastal waters from three different zones, namely (i) shore (0.5 km), (ii) inshore (2 km), and (iii) offshore (5 km) (Fig. 1), covering a 5-km distance from shore. The temporal sampling was conducted quarterly during 2011 for seasonal analysis such as postmonsoon (March 24th), summer (June 17th), premonsoon (September 23rd), and monsoon (December 14th).

Field data such as temperature, salinity, dissolved oxygen (DO), and pH were measured in the forenoon. Surface water temperatures were measured using a mercury thermometer. Salinity was estimated using a handheld refractometer (Atago, Japan), and pH was measured using a digital pH meter. Transparency in the water column was measured with the help of secchi disc. For the analysis of nutrients, surface water samples were collected in clean polyethylene bottles, kept in an ice box, and transported immediately to the laboratory. The water samples were analyzed for ammonia, dissolved inorganic phosphate, nitrate, nitrite, and reactive silicate by adopting the standard methods described by Grasshoff et al. (1999). Water samples for Chl-*a* determination were filtered through Whatman GF/F (47 mm) glass fiber filters, and pigment extraction was performed using 90% acetone. Chl-*a* pigment concentrations were measured by using UV–visible spectrophotometer (Strickland and Parsons, 1972). DO and biological oxygen demand (BOD) were estimated by the modified Winkler's method (Strickland and Parsons, 1972) and are expressed as mg/L. For total suspended matter (TSM) estimation, about 150 mL of water samples were filtered through pre-weighed 0.22 μm polycarbonate filters (Millipore), dried at 40 °C, and reweighed. The difference between the two weights was taken as the TSM content (mg/L). Mesozooplankton samples were collected by horizontally towing a bongo net with 200 μm mesh. The volume of water filtered by the net was measured using a calibrated flow meter (Hydrobios, USA) mounted at the mouth of the net. Mesozooplankton biomass was estimated by the standard displacement volume method (Harris et al., 2000), and the biomass was expressed in milli liter per cubic meter (mL/m^3).

Multivariate analysis included CA and correlation analysis on the present water quality data to understand the inter-relationships between different variables. Seasonal associations of nutrients (silicate), TSM, DO, phytoplankton biomass, and zooplankton biomass were examined by hierarchical CA using the Euclidean distance similarity index as an estimate of similarity among seasons using the software Primer 5.2.8. The clusters are divided by their unique characteristics, and often, it helps to interpret the data (Vega et al., 1998). The correlation coefficient (Spearman) among physicochemical and biological parameters was computed. Data were analyzed using the statistical software Statistica 8.0. Spearman rank-order correlation, which gives an idea of the inter-relation between various water quality parameters, was considered to be not significant when the value of the probability of significance (p) was > 0.05. Grapher (version 3) was used for the graphical representation of the data.

Rainfall is an important cyclic phenomenon in tropical countries and brings vital changes in the hydrological characteristics of coastal marine environments (Satheeshkumar and Khan, 2012). In India, the rainfall is largely influenced by two monsoons: (1) the southwest monsoon on the west coast and northern and northeastern India and (2) the northeast monsoon on the southeast coast (Paramasivam and Kannan, 2005). The average rainfall is about 149.31 mm/year and is prolonged from April to December. Major rainfall occurs during October to December (northeast monsoon), while a weak spell of southwest monsoon brings rain during June to September (http://knoema.com/icrqbyg/monthly-rainfall-data-district-wise-for-2004-2013) (Fig. 2). According to reports on the Tamil Nadu coastal region, the quality and distribution of rainfall is crucial in determining the condition of the coastal waters (Satpathy et al., 2011; Muthulakshmi et al., 2012).

The spatial and seasonal variations of water quality parameters (Fig. 2; Fig. 3 and Fig. 4) with their mean and standard deviation along the Puducherry coast are summarized in Table 1. Most of the parameters showed greater seasonal variability than spatial variability.

The maximum surface water temperature (28.5 °C) was recorded during the summer season (Table 1). Hydrographical parameters such as salinity, transparency, and TSM have shown significant spatial and seasonal variability in Puducherry coastal waters (Fig. 2 & Table 1). These variations can be attributed to the typical features of the tropical regions, e.g., intense cloud cover and reduced effect of solar radiations. Salinity was higher during summer (33.8 ± 1.1 PSU) than during other seasons, which may be because of the higher degree of evaporation in the study area (Fig. 2). The lowest salinity was found during the monsoon period (32.4 ± 0.1 PSU) due to heavy rainfall at the coast. A similar trend in the salinity values was also observed from various parts in the southeast coast of India (Seenivasan, 1998; Palanichamy and Rajendran, 2000; Sulochana and Muniyandi, 2005; Prabu et al., 2008; Damotharan et al., 2010). Spatially, salinity values were lower toward the shore and gradually increased toward offshore. Turbidity measures the presence of material in water that affects the transparency or light scattering of the water (Gadhia et al., 2012). A higher TSM value was recorded during monsoon (65.4 ± 20.4 mg/L) and a low value during postmonsoon (21.7 ± 4.4 mg/L) (Fig. 2). During the monsoon season, silt, clay, and other suspended particles contribute to the turbidity values, while during other seasons, settlement of silt and clay result low turbidity (Manikannan et al., 2011). Bathusha and Saseetharan (2007), Garg et al. (2006), Prasad and Patil (2008), Saravanakumar et al. (2008), and Upadhyay et al. (2010) have also reported high turbidity