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Time series monitoring of water quality and microalgal diversity in a tropical bay under intense anthropogenic interference (SW coast of the Bay of Bengal, India)

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ABSTRACT

In recent decades, material fluxes to coastal waters from various land based anthropogenic activities have significantly been enhanced around the globe which can considerably impact the coastal water quality and ecosystem health. Hence, there is a critical need to understand the links between anthropogenic activities in watersheds and its health. Kakinada Bay is situated at the SW part of the Bay of Bengal, near to the second largest mangrove cover in India with several fertilizer industries along its bank and could be highly vulnerable to different types of pollutants. However, virtually, no data is available so far reporting its physicochemical status and microalgal diversity at this bay. In order to fill this gap, we conducted three time series observations at a fixed station during January, December and June 2012, at this bay measuring more than 15 physical, chemical and biological parameters in every 3 h over a period of 36 h in both surface (0 m) and subsurface (4.5 m) waters. Our results clearly depict a strong seasonality between three sampling months; however, any abnormal values of nutrients, biological oxygen demand or dissolved oxygen level was not observed. A *Skeletonema costatum* bloom was observed in December which was probably influenced by low saline, high turbid and high Si input through the river discharge. Otherwise, smaller diatoms like *Thalassiosira decipiens*, *Thalassiothrix frauenfeldii*, and *Thalassionema nitzschioides* dominated the bay. It is likely that the material loading can be high at the point sources due to intense anthropogenic activities, however, gets diluted with biological, chemical and physical processes in the offshore waters.

1. Introduction

In recent decades, anthropogenic activities in and around coastal areas are increasing in an alarming rate and are indeed detrimental for aquatic ecosystems (Diaz and Rosenberg, 2008). Various amounts and types of material (organic/inorganic, dissolved/particulate) input into the coastal systems from land based anthropogenic activities have significantly been enhanced around the globe due principally to the production of food and energy to support the overgrowing population. This may often lead to "eutrophication" or enrichment of nutrients in the coastal waters (Seitzinger et al., 2010). Excess anthropogenic nutrient (nitrogen, phosphate and silicate in particular) inputs to the coastal areas have been increased to the magnitude of many folds over the last three to four decades (Conley, 2000; Conley et al., 2009). Enhancement in inorganic nitrogen input to the coastal waters can lead to increased phytoplankton biomass, changes in species composition, the possible proliferation of harmful algae and even hypoxia (Officer and Ryther, 1980; Smayda, 1990). This has resulted in the changes in structure and function of coastal ecosystems especially of shallow coastal areas where phytoplankton blooms were correlated with fluctuations in the river discharge pattern, nutrient dynamics and light availability, water column stratification and grazing pressure by zooplankton (Seitzinger et al., 2010). Thus coastal marine environmental health is an issue of major concern all over the world (Elmgren and Larsson, 2001; Rabalais and Nixon, 2002; Smith et al., 1999) and hence, there is a critical need to understand the links between anthropogenic activities in watersheds, nutrient inputs to the coastal systems, and its health.

However, phytoplankton shows immediate response to alterations in environmental conditions (Reynolds, 1984; Stolte et al., 1994) and hence has been considered as an excellent bio-indicator to assess natural and seasonal changes in the coastal ecosystems (Harris, 1986, Rimet and Bouchez, 2012). Compared to the open ocean, coastal areas show a wide array of changes in both physicochemical parameters and in phytoplankton assemblages (Cloern, 1996; Carter et al., 2005). Smith (2006) combined and analyzed a data set from 92 coastal zone ecosystems from all over the globe and revealed that Chl*a* (indicator of phytoplankton biomass) was always correlated with total nitrogen and phosphorus loading into the system. Usually, diatoms dominate the phytoplankton community in the coastal areas due to the presence of sufficient silicate; however, other groups like green algae and dinoflagellates and others can also be present depending on the environmental

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conditions (Leterme et al., 2006). Coastal phytoplankton contributes to a significant part of global carbon production and hence any alternation in the coastal systems may lead to change in the global carbon cycle. Moreover, the prey–predator relationship in the food chain and commercial fish population are tightly linked to the type and size of phytoplankton that dominate a particular ecosystem. Thus far, any modification in these patterns may significantly alter the entire food chain and finally the fish population, which has direct socioeconomic impact and this has already been observed globally.

Organic carbon concentration (both terrestrial sources and in situ phytoplankton production) can largely control several physical, biological and chemical characters of the water bodies (Kirk, 1994) including oxygen consumption by heterotrophic microbial activities leading to a hypoxic condition and high biological oxygen demand (BOD). The BOD test is one commonly used method to quantify the consumption of oxygen in the water column from the decay of organic matter and nitrification of ammonia (Sullivan et al., 2010). BOD has been widely used as an indicator for the amount of organic pollutants in most aquatic systems, especially a good indicator for biodegradable organic compounds (Hur and Kong, 2008). Thus BOD can be used as a proxy for organic carbon loading in aquatic ecosystems (APHA, 2005) and a close coupling has been observed between DOC loading and BOD concentrations in different aquatic systems (Reader et al., 2014). Worldwide, there are numerous cases reporting increasing BOD concentrations either due to increasing organic carbon pollution or due to extensive algal blooms induced by eutrophication in the coastal waters.

With increasing population worldwide, the usage of petroleum (provides 40% of world's energy) and its contaminants has been increased several times in coastal environments (Tahir et al., 1997; Saramun and Wattayakorn, 2000; Wattayakorn, 2012) and can have severe damaging effects on its biota (Mackay and Hodgkinson, 1996; Hylland, 2006; Venkatachalapathy et al., 2012). PHCs are the primary constituents of oil, gasoline, diesel, and a variety of solvents and some are highly toxic (aromatic hydrocarbons, poly-nuclear aromatic hydrocarbons, gasoline additives and combustion emissions from fuels). Pollution of the coastal and marine areas by PHCs occurs mainly through land based discharges, marine operations and atmospheric and natural inputs (Laws, 2000). A significant part of PHCs can come from land runoff, urban drainage, municipal waste, oil tanker operation, shipping, boating, atmospheric deposition and docking activities from urban areas. A PHC is a viscous mixture of thousands of organic compounds mainly consisting carbon and hydrogen. In general, they are long chain hydrophobic organic compounds and are highly insoluble, hence persistent in the water column. Possible fates of hydrocarbons released into the environment include volatilization, photo-oxidation, chemical oxidation, bioaccumulation, and adsorption on soil particles, leaching, and microbial degradation (Cerniglia, 1992; Harayama et al., 1999). Increasing input of PHCs in coastal waters can adversely impact phytoplankton communities and can also enhance BOD values during the aerobic degradation process. There are plenty of examples showing the acute toxicity of PHCs on phytoplankton communities in tropical waters both in experimental exposure (Mahoney and Haskin, 1980; Nayar et al., 2005; Parab et al., 2008) as well as during natural oil spill events (Jaiswar et al., 2013). Hence, PHC contamination in coastal waters is a growing concern globally (Mackay and Hodgkinson, 1996) and essential to be monitored for those areas that are vulnerable to oil pollution.

Although, nutrient input to coastal waters is increasing globally, the South Asian countries were found to be the highest contributor of inorganic nitrogen and phosphorus input into the coastal waters (Seitzinger et al., 2010). India is one of the fastest growing countries in the world with the second largest population and hence the coastal waters of India could be extremely vulnerable to anthropogenically induced eutrophication. The coastal waters of the Bay of Bengal are highly dynamic with low surface salinity due to the immense freshwater inputs through excessive precipitation over evaporation and river discharge (McCreary et al., 1993). Thus, this large freshwater influx causes considerable seasonal variability with varying sediment loads and nutrient inputs to the nearby coastal waters. The present study was carried out in the coastal waters of Kakinada Bay, southeast coast of India, offering an opportunity to analyze the effects of local hydrology and other allochthonous activities on phytoplankton community structure during three different times of the year. Although the hydrography of this region was well reported, there was little or no attention paid towards monitoring the temporal and seasonal variability among phytoplankton communities with respect to the environmental alterations induced by river discharge and urban and industrial runoff from nearby areas. However, a lag in extensive observations along the southwest coast of India in general and from the Kakinada Bay waters in particular has motivated us to carry out the present investigation.

2. Study area

Kakinada Bay, situated in the southwestern part of the Bay of Bengal, is a shallow marginal bay and a part of the Kakinada–Godavari estuarine area (16°41′–16°53′ N and 82°14′–82°21′ E). One of the branches of the river Godavari, called Goutami–Godavari meets the Bay of Bengal at the south of this point. On its southern part a mangrove swamp, Coringa mangrove, India's second largest mangrove system is situated and a natural sand bar runs from the mangrove area towards the northern side almost 11 km along the coast. This area is under heavy anthropogenic activities due to extensive agricultural practices, proximity of several fertilizer industries, aquaculture farms, port activities and contiguity of the Kakinada city. Kakinada is part of the proposed Special Economic Zone called 'Petroleum, Chemical and Petrochemical Investment Region' (PCPIR) and it is also nicknamed as 'Fertilizer City' because of several fertilizer industries in close vicinity. Many channels and creeks from the Coringa mangrove system are connected to this bay and deliver significant amounts of organic and inorganic materials into the bay along with huge amounts of city sewage through the Kakinada canal. In view of the importance and scarcity of reports from this coastal bay (Fig. 1), time series observations were carried out to monitor the physicochemical parameters and phytoplankton bloom dynamics over the 36 h time scale in the months of January (Jan), June and December (Dec) in 2012 at this bay. Almost 15 parameters including salinity, water temperature, pH, total alkalinity, dissolved oxygen (DO), biological oxygen demand (BOD), dissolved inorganic phosphate (DIP), dissolved inorganic silicate (Si) and dissolved inorganic nitrogen (DIN), petroleum hydrocarbon (PHC) and phytoplankton community structure over the 36 h time period (in every 3 h) were measured.

3. Materials and methods

3.1. Physicochemical parameters

Water samples were collected from both surface and subsurface (average depth: 4.3 m) using a pre-cleaned 5 L Niskin water sampler for the estimation of chemical and biological parameters. Salinity was measured by using a portable Conductivity–Temperature–Depth profiler (CTD; SBE-19 plus, Sea Bird Electronics, USA) at the bay location, Kakinada. For nutrient analysis 500 mL of water samples was collected in acid cleaned plastic containers (from Tarsion, India) and was preserved with mercuric chloride in order to restrict the consumption/release of inorganic nutrients ($NO_3 + NO_2$, NO_2^-, NH_4^+, PO_4^{-3} and SiO_4^-) and kept closed till analysis. Dissolved inorganic nutrients were analyzed following standard spectrophotometric methods (Grasshoff et al., 1999). Samples for pH and alkalinity measurement were collected in pre-acid cleaned glass bottles and samples were filled without any head space and were also fixed with mercuric chloride solution. Bottles were tightly closed to avoid any change. pH and total alkalinity were analyzed using a 794 Basic Titrino from Metrohm, following Dickson et al. (2003).