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Nutrient dynamics of northern Bay of Bengal (nBoB)—Emphasizing the role of tides

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ABSTRACT

The variability of nutrient concentrations (dissolved inorganic nitrogen, DIN; dissolved inorganic phosphorus, DIP; and dissolved inorganic silicate, DSi) along with salinity, total suspended matter (TSM), chlorophyll-*a* (chl-*a*) and dissolved oxygen (DO) were investigated in the shallow continental shelf waters of the northern Bay of Bengal. The sampling was conducted during the high tide and low tide conditions (day time) of the spring and neap phases throughout two annual cycles (February, 2013 to January, 2015). All analyses were carried out to evaluate the hypothesis—tidal processes principally regulate the nutrient variability in short-term scale. Results portrayed that DIN, DIP and DSi concentrations varied significantly between spring and neap phases as well as between high and low tides ($p < 0.05$). Short-term spring–neap and high tide-low tide contrast was most prominent in pre-monsoon and post-monsoon season. Considering the entire dataset, DIN, DSi and DIP concentrations were 8.83 ± 3.45 mg l^{-1}, 8.43 ± 3.32 mg l^{-1} and 0.61 ± 0.36 mg l^{-1} during the spring phase and 9.79 ± 3.61 mg l^{-1}, 9.24 ± 3.19 mg l^{-1} and 0.73 ± 0.41 mg l^{-1} during the neap phase respectively. TSM exhibited strongest positive correlation with DIN and DSi ($R^2 = 0.9$) followed by a strong negative correlation with salinity ($R^2 = 0.7$), however, DIP showed a moderate correlation with both salinity and TSM. Salinity and TSM being a proxy of tidal variability, significant correlation between these two parameters and nutrient concentrations enabled the proposed hypothesis to be accepted. Moreover, this region exhibited low abundance of chl-*a* ($\sim$0.1 to 3.5 mgm^{-3} throughout the study period) though nutrient values were quite high, as this region was phosphate limited in the post-monsoon, and for the rest of the year it was light limited.

1. Introduction

Whenever two completely different natural waters (freshwater and seawater) unite they generate a unique surroundings—estuaries are one such distinctive ecosystems where freshwater from river mixes with steadily intruding seawater. Considering the volume, these regions are relatively small; however, they have a major contribution to global primary productivity (Alheit, 2009). This type of transition region between land and open marine system experiences high fluxes of freshwater bringing dissolved nutrients and organic matter from adjoining rivers, resulting in relatively high primary productivity (Laane et al., 2005). Owing to this enhanced productivity, these areas generally serve as breeding grounds for marine organisms, nursery for juveniles and a potential fishery habitat. The degree of estuarine inputs of freshwater, dissolved nutrients, organic material and sediments to the coastal ocean is principally regulated by the changes in the quantum of freshwater discharge, rainfall pattern and tidal cycle (Schubel and Pritchard, 1986; Balls, 1994), the estuarine types (Webb and

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Walling, 1985) and the associated biogeochemical dynamics of the estuary (Billen et al., 1985; Froelich, 1988).

Inorganic nitrogen (nitrate + nitrite), phosphorus (phosphate) and silica (reactive silicate) are the key dissolved nutrients that generally regulate the phytoplankton growth in natural waters. Previous studies revealed that nitrogen-limitation is a widespread phenomenon in tropical coastal waters of Indian Ocean (Ram et al., 2003; Gupta et al., 2009; Mukhopadhyay et al., 2006). However, seasonal phosphate-limitation has also been found in several estuaries as well (Gle et al., 2008; Xu et al., 2008).

Indian subcontinent is known for a wide distribution of perennial and rain-fed rivers, out of which many rivers drain into the Bay of Bengal and the Arabian Sea. Several studies were conducted in many Indian Estuaries namely Hugli Estuary (Mukhopadhyay et al., 2006), Godavari Estuary (Sarma et al., 2010; Bouillon et al., 2003), Cochin Estuary (Martin et al., 2008) and Mandovi–Zuari estuarine system (Ram et al., 2003). Most of these studies aimed to understand the seasonal changes in nutrients and organic carbon cycles vis-a-vis the estuarine freshwater discharge. The prime emphasis of these studies was given to characterize the effect of monsoonal discharge on the overall nutrient dynamics and biological productivity of the respective study areas. However, the conventional approach of monitoring the seasonal or annual variability of nutrients and associated biogeochemical parameters with respect to river discharge and rainfall pattern is not supposed to yield all the adequate information to evaluate and properly address all the controlling factors of nutrient cycles in an estuary due to the inherent complexity of the processes that significantly vary in time with various other phenomena. One such important phenomenon is the tide induced short-term variability of nutrients (Cabrita et al., 1999; Yin and Harrison, 2000). The nutrient dynamics cannot be properly characterized unless the dramatic temporal changes in environmental conditions due to the alternating replacement of overlying water with sea and river waters is taken into account (Sakamaki et al., 2006) especially in meso-macro tidal estuaries. The seasonal variability of nutrient concentrations was frequently studied with respect to variations in physical and chemical factors (e.g. water quality, temperature, sediment condition etc.). Most of these studies tried to emphasize upon the response of microphytobenthos to changes in illumination (i.e. photosynthetic potential in the euphotic depth) while delineating the short-term diurnal nutrient variation (Kuwae et al., 1998; Sundback et al., 2000). However, in estuaries the water column chemistry, especially the solute concentrations may be largely defined by the relative contribution of seawater and freshwater (Sakamaki et al., 2006). Thus apart from the conventional seasonal monitoring adopted in various studies, it is also extremely crucial to examine the short-term changes in nutrients during different tidal conditions for sufficiently longer periods, e.g. throughout one or two complete years to understand the sources and cycling of nutrients particularly in a tide influenced tropical coastal waters.

The present study was carried out in the coastal waters of the northernmost end of the northern Bay of Bengal off the Hugli Estuary. Mukhopadhyay et al. (2006) portrayed the nutrient fluxes within the Hugli Estuary and emphasized on the effect of monsoonal discharge towards the annual load of nutrients flowing from the estuary towards the northern Bay of Bengal. However, few studies have been conducted in this estuary while considering the transition to shallow continental shelf waters and at the same time considering nutrient variation as a function of tidal conditions (Das et al., 2015; Mitra et al., 2011). Das et al. (2015) described the nutrients variability in the same study area under different tidal conditions during winter seasons only, while (Mitra et al., 2011) studied in the lower Gangetic Delta Region. A comprehensive study in this region with respect to the role of tides throughout all the seasons is still to be reported. Hence the present endeavor was framed to study the nutrient dynamics along with selected physico-chemical parameters [i.e. salinity, dissolved oxygen (DO), total suspended matter (TSM) and chlorophyll-*a* (chl-*a*)] during the peak high tide and low tide conditions (day-time) of all the spring tide and neap tide phases throughout two complete annual cycles (February, 2013 to January, 2015). The principal objective of the present study was to examine the impact of tidal fluctuation on nutrient concentrations. The secondary objectives were to study and analyze the (i) intra- and inter-seasonal variability of nutrient concentration and other physico-chemical parameters, (ii) vertical and horizontal nutrient variability and (iii) interrelationships among the nutrient and physico-chemical parameters under different tidal conditions. The sampling strategy and accordingly the principal objective were postulated to test the only hypothesis of the present study that the tidal cycle significantly regulates the nutrient concentrations in the present study region.

2. Materials and methods

2.1. Study area

Bay of Bengal (BoB) is known to be the largest bay of the world in terms of areal cover. Major perennial rivers like Ganges, Brahmaputra and Meghna (GBM) ultimately drain into the northern part of BoB (nBoB). The present study was carried out in the shallow continental shelf waters off the Hugli Estuary to offshore transition zone situated in the nBoB (Fig. 1). The Hugli Estuary happens to be a tributary of River Ganges and acts as one of the main arteries of the GBM delta flowing through India and finally ends in the nBoB. There are several other localized river distributaries like Muriganga, Saptamukhi, Thakuran, Matla, Gosaba and Bidya. This estuary is known to be a 'well-mixed' estuary which experiences a semidiurnal tide of meso-macrotidal nature (2.5–7 m) and the mean current velocities vary between 117 and 108 cm s^{-1} during low and high tide, respectively (De et al., 2011). This region is characterized by a very shallow bathymetry of <24 m even up to distances of 60 km away from the shoreline (Akhand et al., 2013). Rainfall in this region (almost 70%–80% of the annual total) mainly takes place during the south-west monsoon (Mukhopadhyay et al., 2006) leading to peak Hugli River discharge (∼16,600 million m^3) during August–September whereas in the non-monsoon lean phase the average discharge remains around 4300 million m^3 per month (Rudra, 2014).

The present monitoring was performed in two fixed stations, one situated near the shore [17 km away from the shoreline—hereafter referred to as Station A (Lat. 21°27′30″N; Long. 88°18′30″E)] and the second one situated towards the offshore [56 km away from the shoreline—hereafter referred to as Station B (Lat. 21°06′30″N; Long. 88°16′30″E)]. The distance of the sampling stations has been estimated from the Frasuregunje Fishing Harbour (Lat. 21°34′46″N; Long. 88°15′05″E) in the state of West Bengal, India. Station A is situated very close to the mouth of Hugli Estuary, whereas, Station B is far away from it. The influence of Hugli discharge should be more in the Station A compared to Station B. In order to understand the difference between near shore and off shore water, we have deliberately selected these two sampling stations at the distances from shore indicated above.

2.2. Sampling strategy

Fishing trawlers were hired from the Frasuregunje Fishing Harbour to carry out the entire sampling process throughout the two annual cycles of study. Surface water samples were collected with the help of a pre-rinsed and cleaned Tarson bottles made of