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Reduced river discharge intensifies phytoplankton bloom in Godavari estuary, India

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ABSTRACT

Changes in river discharge alter material load and the consequent estuarine and coastal biogeochemical process. Evidence for biogeochemical response to variable rainfall over catchment area or changes in river discharges due to dam regulations is sparse. Inter-annual variability in monsoon rainfall and the consequent river discharges, either dam regulated or otherwise, in India are the best suited to test the influence of altered discharges on estuarine biogeochemistry. Our experiments in Godavari river estuary over three years revealed that a decrease in precipitation over the Indian subcontinent from 2007 to 2009 resulted in the lowering of mean annual discharge from 748.63 $m^3 s^{-1}$ in 2007 to 218.40 $m^3 s^{-1}$ in 2009. The reduced water discharge, during the peak discharge period, slowed the flushing of the estuary from 1.2 days to 6.3 days, respectively. The consequent increase in stability of water column and reduced suspended material load gave rise to intense phytoplankton blooms (Chl *a* 18 $\mu g\ l^{-1}$ in 2007 to 28 $\mu g\ l^{-1}$ in 2009). Resilience towards the unwanted phytoplankton bloom and overall health of the Indian estuaries is thus tuned by the variability in monsoon rainfall and dam regulated discharge.

1. Introduction

The health of estuaries and coastal oceans and their resilience towards extreme phytoplankton bloom varies considerably in different parts of the world (Clarke et al., 2006; Garnier et al., 2010; Seitzinger et al., 2010). Most estuaries in the United States and European Union are moderate to highly eutrophic (Bricker et al., 2008; Ferreira et al., 2007; Scavia and Bricker, 2006). In the estuaries of those regions it has been observed that fresh water discharge during the spring freshets enhances the nutrient load from the drainage basin and intensify the phytoplankton bloom (Admiraal et al., 1990; Van Bennekom and Salomons, 1981). However, the evidence of unnatural phytoplankton bloom has not been found in the estuaries of high discharge rivers such as Amazon with the highest discharge of 209000 $m^3 s^{-1}$ and other major rivers such as, Congo, Brahmaputra, Ganges etc., where average discharge exceeds 20000 $m^3 s^{-1}$ (Selman et al., 2008).

Indian subcontinent houses some of the worlds' largest estuaries at the mouth of mighty rivers such as the Ganges, Godavari, Krishna, Narmada etc. which are largely fed by Indian Summer Monsoon (ISM) rainfall (July-September). Most of these rivers are dammed at several locations along their course for crop irrigation and domestic as well as industrial consumptive usages. Availability of fresh water in the downstream rivers and estuaries are thus regulated by dam authorities who allow excess water to flow down by lifting the sluice gate when water holding capacity of dam reservoirs surpass. During the monsoon period huge volume of fresh water is discharged from the dam reservoir (at times greater than the entire volume of estuary) that flushes entire estuary less than a day (Vijith et al., 2009). In contrast, enhanced stratification sets in during the lean discharge period with longer flushing time. Alluvial plains along the Indian rivers and the coasts are rich cultivable land and application of fertilizers, such as urea, di-ammonium phosphate and potash (nitrogen-phosphorus-potassium), in agricultural fields is quite high; ~24.34 kg $hectare^{-1}$ (Indian Agricultural department, http://indiastat.com/agriculture/2/stats.aspx). Cultivation of paddy, which is the major crop in India, is done during the ISM period when the rainfall is plentiful throughout the alluvial plain. Excess of the fertilizers that are applied in the field during this time is washed by the rainfall and ultimately make their entry in different water bodies including estuaries. Fresh water discharge into the monsoonal estuaries also peaks during the same time period making them prone towards intense and large scale phytoplankton bloom. Biogeochemical aspects of Indian estuaries have been mostly studied concerning nutrient dynamics (Mukhopadhyay et al., 2006; Sarma et al., 2010), inorganic and organic carbon biogeochemistry and trace gases(Bouillon et al., 2003; Bouillon et al., 2000; Sarma et al., 2009; Sarma et al., 2011), behaviour of different elements (Sarma et al., 1993) and heavy metals (Somayajulu et al., 1993).Virtually no systematic studies have been undertaken so far in these estuaries focussing on spatial and-temporal variability of phytoplankton biomass. Likewise our understanding

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about the response of this sensitive ecosystem towards excessive nutrient load from the agricultural field is nil.

To address this knowledge gap, three year (2007–2009) extensive daily time series observation was carried out in the Godavari river estuary, a major river of Indian subcontinent, to examine how inter-annual variability in the monsoon driven rainfall and consequent discharge pattern regulates phytoplankton biomass.

Sarma et al. (2009) reported that Godavari estuary is net heterotrophic where water column respiration far exceeds over the mean photic zone productivity. As a result, a large portion of the carbon demand in Godavari estuary is met from the terrestrial organic carbon input. Resulting high heterotrophic activity, mostly triggered by the bacterial respiration makes Godavari as one of the highest CO_2 emitter estuaries in the world (Sarma et al., 2011). River discharge was identified as the major source of nutrients in Godavari estuary by Sarma et al.(2010).They observed that significant amount of nutrients (>80 μM of dissolved inorganic nitrogen (DIN) and >12 μM of dissolved inorganic phosphate (DIP)) were associated with peak discharge. However, during that time phytoplankton biomass remained low (<2 mg m^{-3}) due to severe light limitation.

Present study focuses on the inter annual (2007–2009) variability of phytoplankton biomass in Godavari estuary with a major objective of finding the mechanistic link between the phytoplankton bloom and monsoon driven river discharge. Major emphasis has been given on year 2009 which was a drought-hit year with lowest recorded rainfall in last two decades.

2. Study region

Godavari is the largest among the Indian Peninsular rivers which are mostly rain fed and non- perennial (www.india.gov.in.knowindia_rivers.php). It originates in the western ghats and flows towards south east before opening into the Bay of Bengal, east coast of India. It contributes ~5% (Rao, 1975) of the riverine inputs into the Bay of Bengal. Its Deltaic plain is extensively cultivated and the fertilizer usage (~49.34 kg hectare^{-1}) is almost double to that of the national average. The river is dammed at four locations in upstream and one of the dams (Dowleiswaram), that regulates fresh water flow into the estuary, is situated at approximately 60 km upstream of the mouth. The river bifurcates into two distributaries, Gouthami and Vasishta after emerging from the Dowlaiswaram dam. Our daily time series station was located at Gouthami branch as it carries the majority (~70%) of flow. Lower 40 km stretch of Gouthami Godavari constitutes the estuary until where tidal effect is observed. Tide is semidiurnal in nature with the amplitude of 1.5 m and average current speed of 1–2 m s^{-1}. The average water column depth of the estuary is 7 m.

3. Material and methods

Daily observations were carried out at Yanam, situated in the middle of the Gautami branch of the Godavari estuary (Fig. 1) since September 2007 at fixed time (11:00 h). The time was fixed to avoid the associated diurnal changes in biogeochemical properties while comparing the daily data. Temperature, salinity and depth were measured using respective sensors attached to a CTD system (SBE 19 plus, Sea-Bird Electronics, USA). The precisions of temperature and salinity were found to be 0.001 °C and 0.004, respectively. Salinity values obtained from conductivity sensor of the CTD, particularly during peak monsoon period, were routinely checked against the results of Autosal (8400b) and argentimetric titrations as CTD sensors are less precise at low salinity ranges (accuracy between the two was found to be 0.02 RSD).

Flushing time (T_{fR}) is defined as the time required to renew existing volume (V_e) of water in an estuary at a volumetric flow rate of (Q) through the estuary due to river run off alone (Vijith et al., 2009) i.e.

$$T_{fR} = V_e/Q \qquad (1)$$

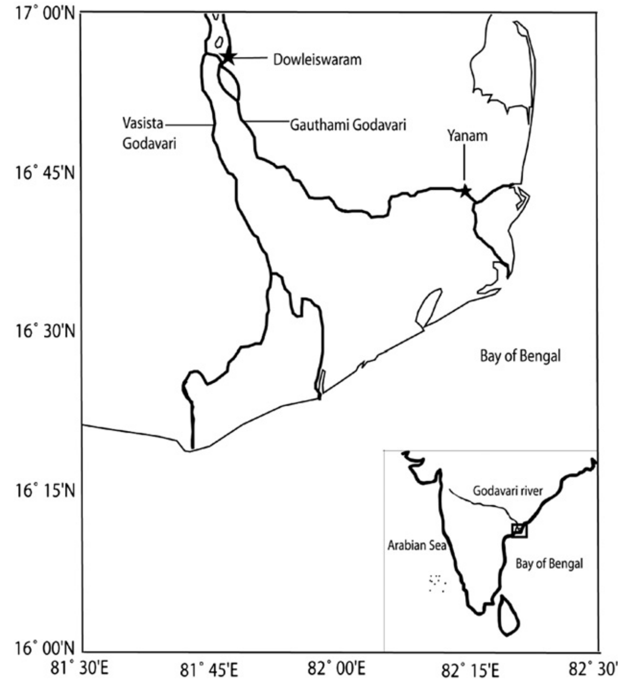

Fig. 1. Map showing the study area and locations of daily sampling station (Yanam) and dam (Dowleiswaram). In set shows the entire course of the river Godavari along Indian sub continent.

Tide- driven flushing time (T_{fT}) during dry/zero discharge period was calculated by tidal prism method following (Dyer, 1991; Monsen et al., 2002).

$$T_{fT} = VeT/(1-b)P \qquad (2)$$

where, T is tidal period, P is the tidal prism and b is the return flow factor (Monsen et al., 2002).According to Vijith et al. (2009), b was assumed to be 0.5.A tide gauge was installed at Yanam which continuously logged data at 1 minute interval.

Daily discharge data, for Gautami Godavari, were obtained from the irrigation department of Dowleiswaram dam authorities. Nutrients for dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP) and dissolved inorganic silicate (DSi) samples were collected in 50 ml polyethylene containers which were filled up to the brim. To stop the biological uptake of nutrients a few drops of saturated mercuric chloride solution was added into the bottles before they were air tightened by means of sticky plaster. Nutrient bottles were frozen in −20 °C freezer until they were analyzed using autoanalyzer as per the standard method (Grasshoff et al., 1992). The precisions of the DIN, DIP and DSi were ±0.02, 0.02 and 0.01 μmol l^{-1}, respectively. About 150 to 500 ml of a water sample was filtered, through preweighed 0.22 μm polycarbonate filters (Millipore), dried at 40° C and reweighed to quantify suspended particulate matter (SPM, g l^{-1}). Another 150 ml of water sample was filtered through GF/F filter (Whatman) and Chlorophyll-a (henceforth, Chl-*a*) on the filter was extracted with N,N, Dimethyl Formamide (DMF) at 4 °C in dark for 24 h and was measured spectrofluorometrically (Cary Eclipse-Fluorescence Spectrophotometer, Varian Instruments, USA) following Suzuki and Ishimaru (1990). The analytical precision for Chl-*a* analysis was ±4%. About 300–500 ml of samples were also filtered through GF/F filter and pigments in the filter were extracted into 90% acetone and measured using High Performance Liquid Chromatography (LC 1200 series, Agilent Technologies, USA). Method proposed by Van Heukelem and Thomas (2001) was adopted for pigment analysis during the study. Variation in diatom population in the present study was monitored using their class specific marker