

Role of physical processes in the distribution of chlorophyll *a* in the northwest Bay of Bengal during pre- and post-monsoon seasons

Chlorophyll *a* (Chl *a*) concentration is one of the indicators of phytoplankton biomass in the ocean and is responsible for photosynthesis. Distribution of Chl *a* in the EEZ (Exclusive Economic Zone) of India during different seasons was reported earlier¹. Chlorophyll bloom off Sri Lanka during the SW monsoon season due to coastal upwelling driven by monsoon winds and intensification of phytoplankton bloom due to cyclones in the Bay of Bengal during the NE monsoon season were reported^{2,3}. Chlorophyll data in the coastal waters of the east coast of India are sparse. Recently, several studies^{4–6} reported satellite-derived chlorophyll concentration in the Arabian Sea and the Bay of Bengal. In the present study, *in situ* and satellite estimates of Chl *a* off Andhra–Orissa coast during pre- and post-monsoon seasons for the year 2000 are presented and discussed in relation to physical processes.

The weekly composite data of Chl *a* from TERRA-MODIS sensor were obtained from GSFC (Goddard Space Flight Center), NASA, USA and processed to estimate satellite-derived chl *a* according to the details given elsewhere⁷. Satellite images of Chl *a* for the periods 4–15 and 21–28 March 2000 (pre-monsoon), and 5–12 and 13–19 October 2000 (post-monsoon) in the northwest Bay of Bengal (15–22°N; 80–87°E) are shown in Figure 1. *In situ* surface Chl *a* in the coastal waters off six stations (Puri, Gopalpur, Bheemunipatnam, Visakhapatnam, Kakinada and Gauthami Godavari) during pre- and post-monsoon seasons of 2000 were estimated.

High patches of Chl *a* (>10 mg/m³) were noticed off north Orissa coast (18–20°N; 84–86°E). A consistent decrease in chlorophyll from the coast to the offshore is clearly seen. The contour of 2 mg/m³ (blue) runs almost parallel to the coast (Figure 1 *a*). At the end of March (21–28 March), the spreading of high concentrations is clearly seen in the northern side due to the freshwater from Dhamra, Mahanadi and Rushikulya and East India Coastal Current (EICC)⁸ which might have shifted the blue contour line (2 mg/m³) to the offshore from an earlier period (Figure 1 *b*). During October (Figure 1 *c*) maximum values of

6 mg/m³ are noticed off Dhamra and south of Godavari due to the respective river discharges. The concentrations are very low off Visakhapatnam and equal to

offshore values due to the existing sinking process supported by the EICC which develops during October and intensifies, then flows equatorward all along the

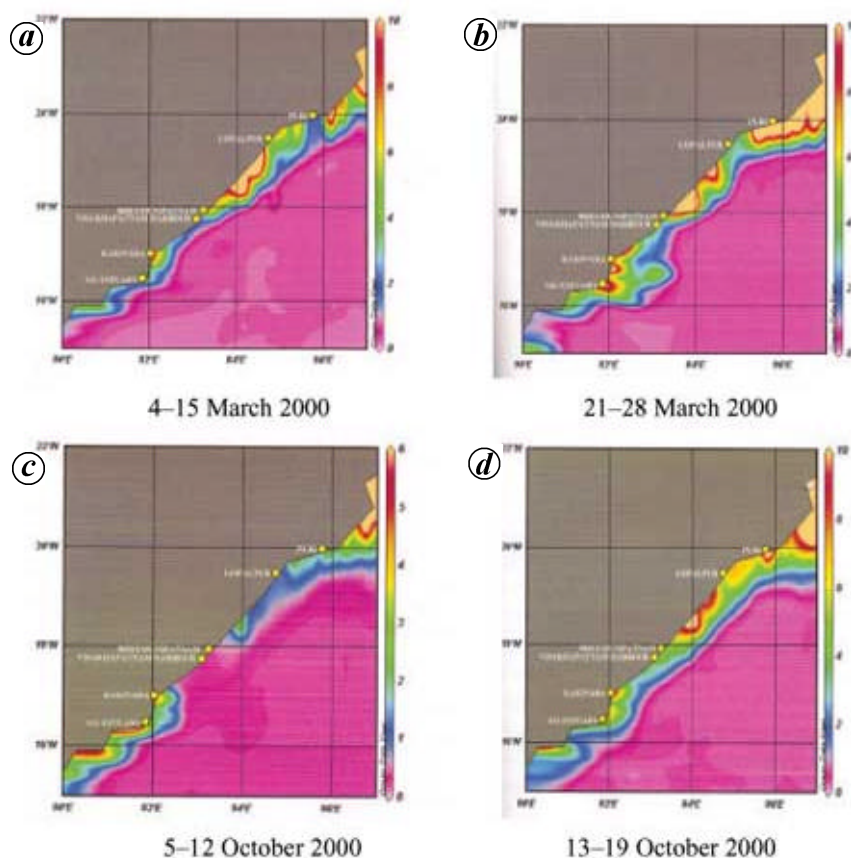


Figure 1. Distribution of Chl *a* (mg m⁻³) in northwest Bay of Bengal during pre-monsoon (*a*, *b*) and post-monsoon (*c*, *d*) seasons.

Table 1. Comparison of *in situ* and satellite estimations of Chl *a* (mg/m³) during pre-monsoon (I) and post-monsoon (II) seasons

Transect	Season	Chl <i>a</i>	
		<i>In situ</i>	Satellite
Puri	I	1.92	1.62
	II	1.13	17.3
Gopalpur	I	2.07	14.84
	II	4.67	8.09
Bheemunipatnam	I	2.98	12.14
	II	1.62	0.52
Visakhapatnam	I	2.18	2.32
	II	1.55	0.17
Kakinada	I	1.09	2.81
	II	1.34	0.74
Gauthami Godavari estuary	I	0.82	2.50
	II	1.37	4.94

coast. In general, there was enhancement of Chl *a* concentration by middle of October (Figure 1d) with a maximum (>8 mg/m³) off Gopalpur–Visakhapatnam coast which could be due to the influx of waters from the adjacent Rushikulya estuary and Chilka Lake. The high concentrations observed during post-monsoon season compared to pre-monsoon may be due to combined effect of biological productivity and anthropogenic inputs, in addition to the physical processes.

A comparison between the *in situ* estimations and satellite-derived values of Chl *a* for pre-monsoon (I) and post-monsoon seasons (II) for the year 2000 are presented in Table 1. Average values at the surface (from the coast to 12 km) are shown. There is reasonable agreement between the *in situ* and satellite estimations of Chl *a* off Puri, Visakhapatnam and Kakinada while the errors are large off Gopalpur, Bheemunipatnam and Gauthami Godavari during the pre-monsoon season. The error is maximum off Puri

during post-monsoon season. Satellite estimates are lower than the *in situ* values off Bheemunipatnam, Visakhapatnam and Kakinada during post-monsoon season. Hence it is inferred that there is a need to improve and develop site-specific algorithms for different coastal waters off the east coast of India.

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Need for earthquake-resistant design of harbour structures in India in view of their performance during the 2004 Sumatra earthquake

Harbours and jetties are lifeline structures as they provide a cost-effective method for transporting large quantities of goods and raw materials into and out of a region. These are important structures especially in islands like the Andaman and Nicobar (A&N), where the main mode of transportation is the sea, since these are a set of 572 islands separated by channels and creeks. These structures also play a significant role in the transportation system in terms of evacuation of people before or after natural disasters, e.g. earthquakes and tsunamis. Further, these are useful to supply relief materials after the natural disaster when other transportation systems fail to deliver. Similar roles were accomplished by some of the less damaged ports and jetties in the A&N Islands after 26 December 2004, when the great Sumatra earthquake of magnitude M_w 9.1 caused a devastating tsunami in the Indian Ocean. Some damaged, unserviceable offshore and foreshore harbour structures, north of Port Blair (capital of A&N Islands,

India), caused total disruption of sea transport that caused a delay in the supply of relief work in the earthquake and tsunami-affected areas¹. This underlines the need to design these structures so that they can withstand earthquakes.

According to the Indian seismic hazard zone map², the entire A&N Islands lie in the most severe seismic zone, i.e. zone V, where the expected intensity of shaking is IX or greater on the MSK intensity scale. However, in the case of the 2004 Sumatra earthquake, it was observed that the intensity of shaking in the Andaman Islands, located about 1000 km northwest from the epicentre (03.295°N 95.982°E according to USGS) was between VI and VII. Performance of the structures could have been better than what was observed if these were designed and detailed properly. In India, currently there is no code for earthquake-resistant design of such structures. The existing earthquake-resistant design codes i.e. IS 1893 (ref. 2) and IS 13920 (ref. 3) are intended for building

systems and are not sufficient for harbour structures which behave differently than buildings and bridges.

Based on the reconnaissance study conducted by the authors immediately after the earthquake, damages to harbour structures located north of Port Blair are described here along with their possible causes and remedies. Jetties at Rangat Bay and Mayabandar Harbours in the Middle Andaman Islands, and at Diglipur and Gandhinagar in the North Andaman Islands were severely affected, while Kalighat Jetty in North Andaman and Uttara Jetty in Middle Andaman sustained only minor damages (Figure 1). Berthing jetty and a portion of the approach jetty at Sagar Dweep totally collapsed during this earthquake and the jetty was not operational for post-earthquake relief operation (Figure 2).

The most common damages of jetties resulted from the pounding at the construction joint of two portions of the jetties supported by piles. Pounding can occur between two adjoining structures due to