SPATIAL AND TEMPERATURE CHANGES OF SEA SURFACE PHYTOPLANKTON PIGMENT CONCENTRATION OVER GULF OF MANNER, INDIA

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ABSTRACT

Marine chlorophyll plays aprimary role in conserving the marine ecosystems which are essential for the marine food web. Understanding the variation of Chl-a (or Phytoplankton) over the aquatic systems is necessary for various applications like predicting the potential fishing zone. Advancement in the remote sensing with multispectral sensors, image processing techniques and tested remote sensing models together provide a powerful tool to analyse and monitor the ocean parameters. Ocean colour remote sensing is a simple and easiest tool which is used for the quantifying the chlorophyll. In this study, we analyse the spatial and temporal variation of chlorophyll pattern in the marine surface for the Gulf of Manner of Indian coastal waters. The Chl-a concentrations were estimated from the standard chlorophyll algorithm. Moderate resolution imaging spectroradiometer (MODIS) satellite data were effectively used to quantify the spatial and temporal changes of surface chlorophyll. The outcome of this analysis contributes to deliver an advance tool to analyse the long-term changes in phytoplankton pigment concentration in coastal and open ocean.

Keywords: chlorophyll, MODIS, remote sensing, Indian Coastal Waters.

AIMS AND BACKGROUND

Coastal waters cover a small portion of seawater on the Earth which plays a significant role for social, ecological, and economic perspective, by providing high quantity of fish yield through primary production [1] . Primary productivity mainly refers as the development of organic matter by chlorophyll or phytoplankton. Phytoplankton needs a collection of chemicals, and those with the potential to be scarce in surface waters are typically identified as nutrients. This enriched phytoplankton acts as marine food webs and is also responsible for Earth's climate change by converting the CO_2 to biomas [10]. The growth of the phytoplankton shows variation in quantity with respect to regional and latitudes in the oceans [11]. The growth patterns are mainly affected by local environmental conditions and are also

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due to other processes such as sunlight, water column properties and nutrient resources. This spatial variation affects the carbon fluxes and results in other mismatches in marine ecosystem leading to consequences for fisheries [12]. This is the reason for representing the potential fishing zones as closely correlated with the phytoplankton life cycle [13].

Deviations of bio-physical processes in reaction with ecological changes in the sea surface layer are the major cause of seasonal variation of chlorophyll pigment concentrations [14]. The seasonal phytoplankton bloom can be characterised by phenological metrics of different phases of its lifecycle. The phenological metrics of phytoplankton include the initiation stage, termination stage, peak stage, period of growth and magnitude of the concentration [6]. These phenological metrics are highly suitable for coastal areas or case-2 water. It is also dependent on other environmental parameters such as seabed, and wind stress. Spatial variability of phytoplankton in coastal areas depends highly on the river plumes [18]. These factors are not much involved in the phytoplankton growth in the deep or open ocean water which is case-1 water.

The continuous field measurements of seawater constituents for understanding the variation of Chl (or phytoplankton) were difficult. Offshore continuous measurement systems using buoys were also difficult to capture the spatial pattern trend of Chl concentration initiated by coastal currents, river runoffs and bathymetry [7]. To overcome this problem, remote sensing linked with *in situ* measurements provides the potential solution for understanding the spatial changes of Chl [8]. After undergoing the atmospheric correction, the water leaving radiance (L_w) or remote sensing reflectance (R_{rs}) is the only component available in the satellite datas [15]. For the ocean colour remote sensing, R_{rs} is the primary parameter used to retrieve the seawater constituents such asphytoplankton or chlorophyll (*Chl*). Also, various scientists have developed models for the retrieval of *Chl* from R_{rs}, which were tested globally, regionally and seasonally. The ratios of different bands of R_{rs} were known as band-ratio method and were used to retrieve the *Chl* concentration . Another method expressed in the polynomial equation based on two different bands was used for the retrieval of *Chl* from R_{rs} . Similary, three band algorithms were also developed in previous studies using visible bands [19] and bands . Using the *in-situ* dataset measured from different case-1 (open ocean) and case-2 (coastal and inland) waters, the chlorophyll algorithm has developed and provides the chlorophyll with algal bloom index which is known as ABI-Chl [20]. Several existing Chl models gives the provision to the ocean colour remote sensing which provides the spatial and time series trends for understanding the changes of phytoplankton biomass. The phytoplankton biomass is the major indicator for understanding the significance of ecosystem functioning [21].

Globally, several research works have been reported for the estimation of Chl through ocean colour remote sensing . Using this background, the primary objective of this study was to investigate the variation of chlorophyll over the coastal waters of off Point calimere.

EXPERIMENTAL

SATELLITE OCEAN COLOUR DATASET

The ocean colour data used in this report were obtained USING the Moderate resolution imaging spectroradiometer (MODIS) for the Point Calimere location in the southeast coast of India. MODIS have two satellites one for Terra application and another one for Aqua application. The optical system of MODIS includes four refractive objective assemblies based on two-mirror off-axis afocal telescope which covers four spectral regionS such as visible, near-infrared, short-wave infrared and long-wave infrared. It is a 12-bit radiometric sensor with 36 spectral bands ranging in wavelength from 400 to 14400nm. Time taken for both Aqua and Terra sensor to cover the entire Earth surface is approximately every 1-2 days.

STUDY AREA

The Gulf of Mannar is a shallow water region located in the south eastern part of Tamilnadu of India which has an inlet from the Indian Ocean. This shallow marine park includes 21 coral small islands with high diversity of coastal and marine habitats. The gulf is almost 160 km long and 275 km wide with the availability of pearl bank in the seabed. It receives the Thamirabarani river water from India and the Aruvi river water from Sri Lanka. The ocean physical effects such as sea surface temperature, acidification, sea-level changes and tsunami were also much impacted in this region. These impacts directly affect the growth of phytoplankton along with the changes of biological and chemical conditions of the water column. The biological and physical conditions of this region are entirely controlled by the environmental changes which affect in favour or destroy the habitats including coral reefs and mangroves in seabed.

In this work, we observed a Chl-a concentration occurred in the Point calimere and Gulf of Manner during the 2016 and 2019 with time series analysis. Three regions of interest (ROI) were considered for the analysis of time series. They are spotted in the red box in Fig. 1. ROI-1 (centred Lat 9.384, Lon 79.167) is the shallow water zone located near in the GOM. ROI-2 (centred Lat 10.017, Lon 79.33) is the coastal water location with highly dominated with Chl-a and this area located exactly in east of GOM and west of PC location. ROI-3 (centred Lat 10.077, Lon 80.057) is the off-shore waters of Bay of Bengal located towards east PC location.

Fig. 1. Geographic location of the study area - map with regions of interest (ROIs) used for the analysis (Image source: USGS)

METHODOLOGY

MODIS instrument has 36 spectral bands which is used for the observation of land, ocean and clouds.

Level-1 data processing. The raw data received from the MODIS sensor undergo preprocessing steps and provides L1A data. This L1A data were processed using the SeaDAS software which was developed by NASA. The four processing steps were involved in the L1A data processing. First step generates the file which provides the latitude and longitude for each pixels of the MODIS image. Second step is generation of L1B file from L1A file. Third step of the processing is to be in online which downloads the ancillary data for the level-2 data processing [23]. The final fourth step is origination of L2 File from L1B to with the support of L1B, GEO and ancillary files. The L2gen option in the SeaDAS will process this L1A data and utilise the land and cloud bands for the aquatic application.

Atmospheric correction model. The satellite captured images required an atmospheric correction algorithm for the removal for atmospheric signals for the retrieval of sea surface geophysical products such as water leaving radiance, remote sensing reflectance, chlorophyll-a concentration, suspended sediment concentration, etc. The key factor of this atmospheric

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correction is the removal of aerosol radiance from the total measured radiance obtained from the top of the atmosphere (L_{TOA}). Several researchers worked on different atmospheric correction algorithms for the removal of aerosol radiance. In this work, the atmospheric correction procedure developed by Ocean Biology Processing Group from NASA was used for the accurate retrieval for water leaving radiance and remote sensing reflectance. The major assumption of this algorithm is that the remote sensing reflectance at NIR band is considered as zero which is also known as black pixel assumption [24]. This assumption considers the magnitude of the L_{TOA} at the NIR bands is considered as aerosol radiance (L_a). Using aerosol models, the magnitudes are used to estimate the L_a at visible bands. Subsequently, the R_{rs} values were estimated for the visible bands. For coastal waters, the R_{rs} (NIR) is not equal to zero, which leads to consider that the iteration technique provides the *Chl-a* and b_{bp} (NIR). This provides a way to reconstruct the R_{rs} (NIR) in the iteration which removes the accurate estimation of L_a and better reconstruction of visible band values.

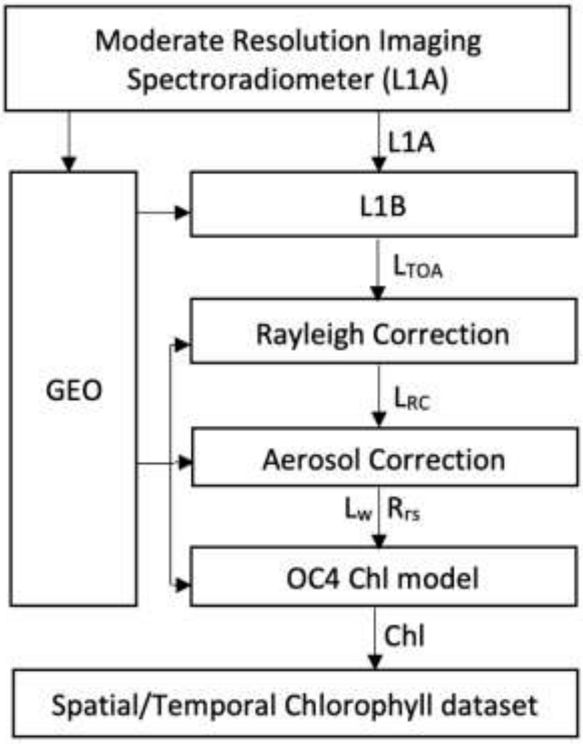

Fig. 2. Schematic block diagram of the methodology for the estimation of chlorophyll concentration from MODIS Aqua L1A data

OC3 Chlorophyll algorithm. This subsection explains the algorithm for the chlorophyll extraction from the MODIS remote sensing reflectance R_{rs} data. Several models have been developed for the estimation of Chl from R_{rs}. OC3 algorithm is one of the models which provides Chl with high accuracy [25]. OC3 model avoids the switching method for the Chl estimation which removes the gap between the intermediate range of R_{rs} data. OC3 model was developed based on the maximum band ratio method using a single 4th order polynomial equation which is defined as follows:

$$Chl = 10^{X} \quad (\text{mg m}^{-3}) \quad (1)$$

where X is the polynomial equation which is expressed as:

$$X = a_0 + a_1 R + a_2 R^2 + a_3 R^3 + a_4 R^4 \quad (2)$$

$$R = \log_{10}\left(\frac{R_{rs}(443) > R_{rs}(488)}{R_{rs}(551)}\right) \quad (3)$$

The coefficients of the polynomial equations are: a_0 = 0.2424; a_1 = -2.7423; a_2 = 1.8017; a_3 = 0.0015; and a_4 = -1.228; which are mainly derived for MODIS sensor [26]. Here, R_{is} is the blue-green maximum band ratio which considers three bands information for Chl estimation which intend to represent the OC model as OC3. The numerator in equation (3) explains that the ratio of R_{rs} magnitude at 443 and 551 will be mainly used for the clear and moderately clear water. The other ratio of R_{rs} magnitude at 488 and 551 were used for the Chl dominated water and turbid waters.

RESULTS AND DISCUSSION

SPATIOTEMPORAL ANALYSIS

In this section, we analysed the spatiotemporal variation of Chl-a concentration occuring over the region of Gulf of Manner and point calimere, India using MODIS Aqua images. This analysis explains the annual non-seasonal changes in Chl-a concentration for the year of 2016. Figure 3 represents the single day MODIS images of each month during 2016.

The quantitative investigation of the MODIS images for single day per month for the year in 2016 shows the interesting pattern of Chl-a concentration for each month. Throughout this year, the presence of Chl-a was continuously distributed in the constant range from January to December with concentration in between 18-20 mg m^{-3} in the region between the Point calimere (PC) and Gulf of Manner (GOM) shown in Fig. 3. The maximum sea surface concentration of Chl-a was observed during the summer in the month of May, June and July.

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Furthermore, the Chl-a concentration was extended its distribution to the offshore in the coast of Bay of Bengal from May to October. The minimum Chl-a values can be seen during the summer in the month of February, March and December.

The Chl-a distribution over the offshore of PC is very small in January and similar pattern was observed during February, March and April. Eventually, the Chl-a pattern was shows high concentration of Chl-a during the month of May, which may be due to high productivity during the summer. Again, during the month of June it shows very less distribution. Later in July, Chl-a pattern shows moving from coastal zone to offshore which indicates the high Chl-a values over the off-shore in Bay of Bengal. The Chl-a concentration were very high in offshore during August, September and October. High Chl-a concentration can be observed during the month of August. Later, the concentration was gradually reduced from November and December. The distribution of lowest Chl-a concentration was found in offshore over the coast of Bay of Bengal during November and gradually increases until the month of April.

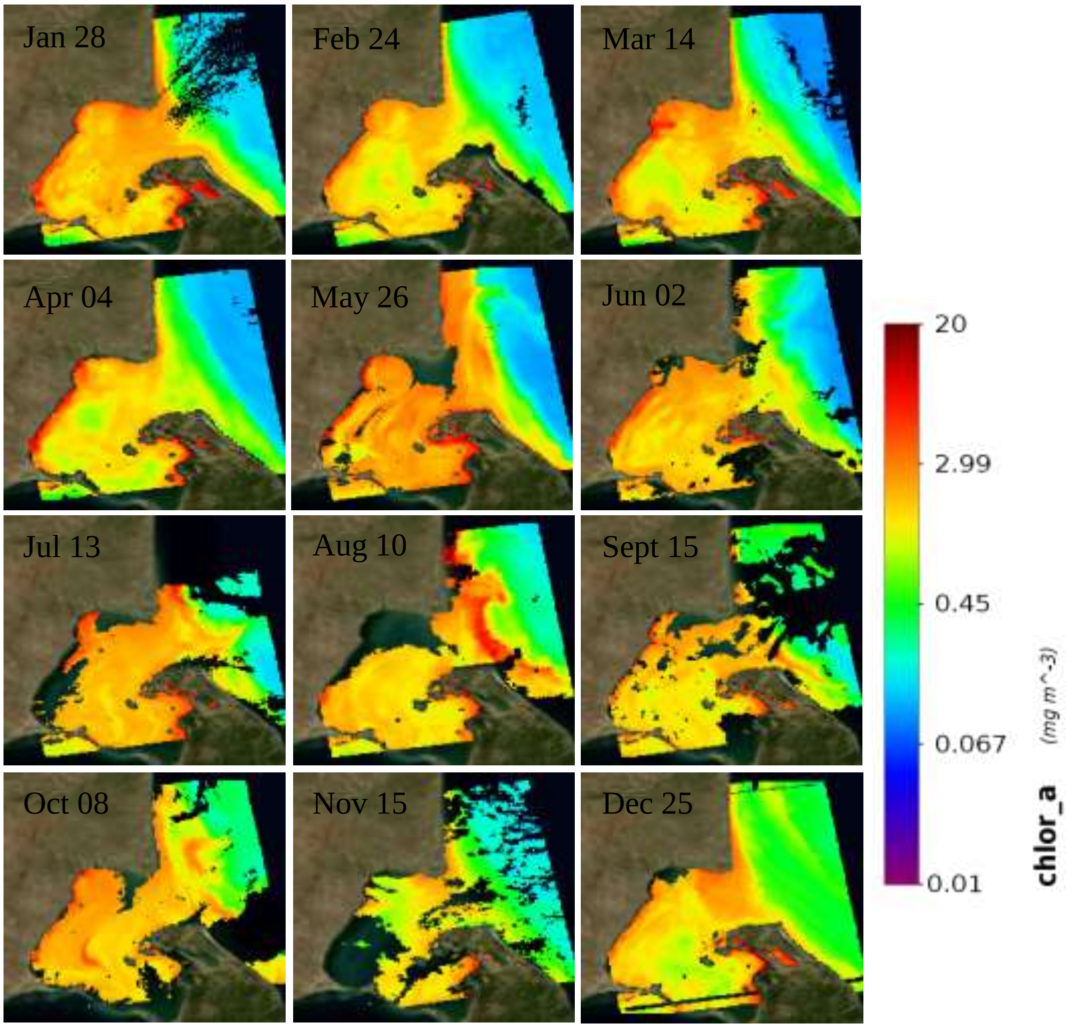

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Fig. 3. Spatiotemporal analysis based on single day Chl-a (maximum upto 20 mg mg^{-3}) from MODIS images centred over the Point calimereand Gulf of Manner, India for the each month from January to Decemberof the year 2016 (MODIS captured month and date were displayed in each images)

SPATIAL ANALYSIS

Using MODIS Aqua images, we analysed the six-month composite spatial distribution of Chl-a concentration occuring over the location of Gulf of Manner and point calimere, India. Figure 4 shows the six-month composite Chl-a image processed from MODIS Aqua images for two duration from 1st January 2019 to 30th June 2019 (left) and 1st July 2019 to 31st December 2019 (right). The results represent the bi-annual non-seasonal changes of Chl-a concentration for the year of 2019. Observations from the Fig. 4 describe that there three common things happen all over the year irrespective of the seasonal changes. First observation explains that only small concentrations of the Chl-a were observed in the south western part of Gulf of Manner, which may be due to the flow of currents over this region. Second analysis shows that the Chl-a values highly dominated (up to 20 mg m^{-3}) in the region between the Gulf of Manner and Point Calimere. Third observation reveals that the Chl-a values are predominantly small in the offshore of the Point Calimere (in Bay of Bengal), which is in the north east of Point Calimere. Although the concentration of Chl-a patterns obtained from both images are almost close to each other, 90% of the pixels in Fig. 4a shows high Chl-a values. Already, we have seen that during August the phytoplankton pigments move to the offshore. This shows that during the northeast monsoon the presence of the phytoplankton population in between GOM and PC is less compared with the other monsoon such as southwest.

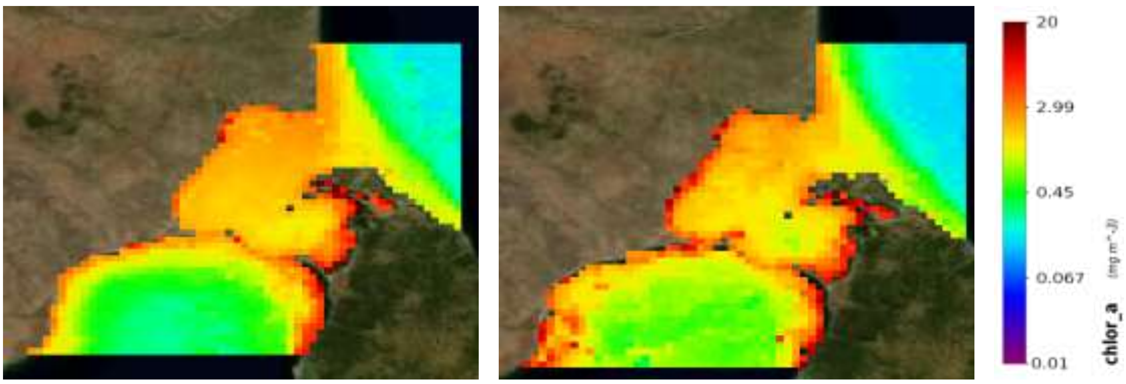

Fig. 4. Merged 6 month composite MODIS processed Chl-a image from 1st January, 2019 to 30th June, 2019 - a and 1st July, 2019 to 31st December 2019 over the study area in between the Gulf of Manner and Point Calimere, India - b

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TEMPORAL ANALYSIS

The time series analysis for the Chl-a variability was discussed in this section for three regions of interest (ROI-1, 2, and 3). ROI-1 is the location found very close to the GOM (Fig. 5). ROI-2 is the region in between the PC and GOM location. The ROI-3 is the zone located in the offshore of PC. The locations of all ROIs are indicated in Fig. 1. For each ROI, data from single day image per month were taken for the analysis from the year of 2016.

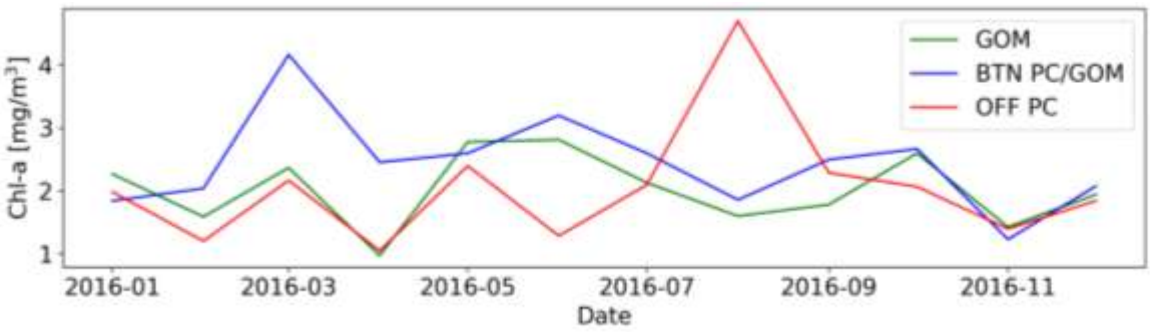

Fig. 5. Time series of monthly Chl-a concentration from the year 2016 for three ROIs: Gulf of Manner (GOM) – 1; between Point Calimere and Gulf of Manner (BTN PC/GOM) – 2, and off-Point Calimere, India (OFF PC) - 3

ROI-1 is the shallow water zone located near in the GOM. The concentration of Chl-a is maximum during the month of May and minimum during April. The ROI-1 water looks very green and dominated with bloom name called Noctiluca scintillans. Meanwhile, ROI-2 is dominated with Chl-a which is the coastal water location exactly in between GOM and PC. As we have seen already, the peak Chl-a values were observed during the month of March and minimum Chl-a values were seen during November. Similarly, ROI-3 is offshore of PC and Chl-a concentration are very small in this region. The Chl-a values are almost small when compared with the ROI-2. Note that during October the Chl-a from ROI-2 is decreasing and ROI-3 is increasing. This clearly explains the evidence of mixing occurring heavily due to the tides and currents during the northeast monsoon. This shows the Chl-a variability pattern in the offshore of PC.

CONCLUSIONS

Extreme Chl-a dominated waters have been identified in the Gulf of Manner, India. In this research work, MODIS level-1 data have been used to obtain the chlorophyll images with the OC3 algorithm after the atmospheric correction procedure. The analysis based on annual Chl-a data for a single day from each month of year 2016 were reported. Also, the six-month composite Chl-a images were processed and identified the spatial quantitative changes of Chl-a. Finally, we also analysed the time series analysis for three location which helps to understand the magnitude changes of Chl-a. The observations clearly revealthe concentration have been highly predominant in gulf of manner in the region between the PC and GOM.

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