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CHLOROPHYLL CHANGES TRACKING USING SENTINEL-2A/B OVER THE GULF OF MANNER, INDIA

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Abstract:

Understanding the variability of Chlorophyll (Chl) concentration through aquatic remote sensing over the coastal waters are very difficult through spatial low resolution sensor images. The Sentinel-2A/B from European Space Agency is specifically designed with spatially high resolution satellite images (30/10m) which can be easily adaptable for monitoring the variability of Chl over the coastal waters. In this study, satellite derived dataset from high resolution satellite images of sentinel-2A/B were used to understand the spatio-temporal patterns of Chl in the Gulf of Manner. The standard Chl model based on the OC algorithm were used to estimate the Chl from remote sensing reflectance (R_{rs}).The study area is located in Gulf of Mannar, India where the coastal waters are dominated with the Chlorophyll which are to be monitored using the Sentinel-2A/B images. Results obtained from the images able to track the Chl variability in coastal waters. The spatio-temporal patterns observed from the Sentinel-2A/B images can be effectively useful for understanding the changes of Chl over the Coastal waters.

*Keywords:*Sentinel-2A/B, Aquatic Remote Sensing, Chlorophyll, Remote Sensing Reflectance, Gulf of Manner

1. Introduction

Importance of chlorophyll in ocean and coastal water is providing food for the living organism and also for making the oxygen in our atmosphere that help to breathe every second. Chlorophyll is responsible for the green color of many plants and algae(Platt & Sathyendranath, 2008; Sathyendranath et al., 2005). Plants are perceived as green because chlorophyll absorbs mainly the blue and red wavelength, reflected by plant structures like cell walls. Ocean chlorophyll concentrations are microscopic, floating, plant like organism that live in ocean ad coastal water. The primary pollutant of the ocean, phytoplankton forms the base of the marine food web converting solar energy into organic matter. Climate change activities have significantly affected ocean and coastal water. Chlorophyll level vary with nutrient levels, environmentally conditions and also seasonally(Andreo et al., 2016; Yang et al., 2020; Zhang et al., 2017).The amount of chlorophyll varies with change in season as growing conditions like temperature, precipitation and sunlight also change. Normally, maximum amount of chlorophyll is recorded in summer season followed by spring season and least amount is recorded in autumn season because of low temperature and short day conditions in this season(Shanmugam, 2011). These varying environment condition in different season of this region can leads to variations in growth responses of algae flora of the ocean(Yoon et al., 2019). The variability of chlorophyll during winter, pre-monsoon and post-monsoon over the study region is interconnected.

Remote sensing plays a major role in collecting the aquatic products from coastal and ocean water. Data product derived from Sentinel-2A/B observations describes features of the terrain, ocean and the atmosphere that can be used for studies of processes and trends on local to global scale(Pahlevan et al., 2018). Aquatic color products are produced by the ocean color data processing system and distributed to the science and applications community. Improvement in ocean color remote sensing with availability of better sensor resolutions over the year has resulted in efficient chlorophyll retrieval. Currently active sensors with medium spatial resolutions, Multi Spectral Imager (MSI) on board sential-2A/B have promoted for estimating various water quality parameters in recent times(Balasubramanian et al., 2020). MSI provides data very near to the coast, with spatial resolution of 10m and a 5 day revisit period. Both the sentinel missions provide good quality high resolution data in the form of levels 1B, 1C and2A. Several studies have been conducted to assess the variability and inter-compare the performance of this sensor, estimating chlorophyll in the dynamic and highly turbid waters of the open and coastal waters.

Several studies were conducted for understanding the variations of Chl over the coastal water. Dey & Singh, 2003 shows variations of chlorophyll concentration has been presented over the north-eastern Arabian Sea and the southern Bay of Bengal using Ocean Color Monitor (OCM) data onboard Indian Remote Sensing Series Polar satellite (IRS-P4).Latha et al., 2014processed OCM-2 data of OCEANSAT-2 Satellitewith the available global ocean color algorithms for analysis of chlorophyll-a concentrations.in the Kakinada and Vanam coast, Bay of Bengal onboard a coastal vessel. Chen et al., 2013 evaluated the three-band algorithm in determining chlorophyll-a in eutrophic coastal waters, and to improve the model using improved three-band algorithm.Reddy et al., 2011 undergone the Bio optical measurements off Visakhapatnam Coastal Waters East Coast of India along Bay of Bengal and provides the algorithm for the estimation of the chlorophyll concentration in the case 2 waters of the Visakhapatnam Coastal Water. Chauhan et al (2014) worked on the quantitative analysis of chlorophyll concentration and their distribution in the coastal water of kalpakkam using OCEANSAT-2 ocean color monitor (OCM-2) with in-situ chlorophyll concentration. Chen et al (2019) collected in-situ data from the Bohai, Yellow and East china seas were used to assess the performance of HY-1C in retrieving chlorophyll-a concentration in the coastal waters. Their results showed that two algorithms based on blue-green band ratios performed well and the broadband channels of the HY-1C CZI can retrieve chlorophyll-a concentration in turbid waters.Wandong et al (2009) presents chlorophyll-a retrieval algorithm for coastal water based on in-situ hyper spectral data. The water quality parameters in the Yantai's coastal region were obtained. This assessment shows that a good linear relationship between the chlorophyll-a concentration and simulated of MERIS and of MODIS. Yoon et al., 2019 shows to validated results of the Geostationary Ocean Color Imager derived chlorophyll-a estimates for Jinhae Bay obtained by two global open ocean algorithms and four regional algorithms for Korean coastal water.Alexander et al (2010) reports a comprehensive study on the algorithms for the estimation of chlorophyll-a concentration in the coastal waters. In this work, they tested the two and three band algorithms with bands that matched the spectral channels of MERIS.Regina et al (2017) to evaluated the performance of several approaches

based on multispectral data to estimate chlorophyll-a in a productive tropical estuarine-lagoon system, using in situ measurements of remote sensing reflectance. Several studies used this MSI sensor as a computing tool for accurately mapping chlorophyll concentration along the coastal water.

Measuring chlorophyll in the surface water is an indication of how much primary production is occurring in the surface of water. The Gulf of Mannar chlorophyll concentrations are higher during the northeast monsoon. That is, cold water generally has higher chlorophyll concentrations than warm water because it contains nutrients that have recently come up from the deep ocean(Balasubramanian & Shanmugam, 2015; Balasubramanian et al., 2013). In places where ocean currents cause upwelling, sea surface temperatures are often cooler than nearby waters and chlorophyll concentrations are higher. The vertical distribution of temperature and dissolved oxygen at different depth zones in the shelf waters along the southwest coast of India up to the western proximity of the Gulf of Mannar coastal upwelling signatures in terms of the surfacing of cold and low-oxygenated deep water. The most striking feature here in the present context is the spatial extent of the cold and low oxygenated water in the three depth zone.Being a tropical region, the Gulf of Mannar has a warm climate with less change in sea surface temperature over seasons(Tholkapiyan, 2012). When surface waters are cold, it is easier for deeper water to rise to the surface, bringing nutrients to sunlight areas where phytoplankton can use them. Even though a large number of studies are available on the faunal diversity in the Gulf of Mannar, convincing explanation on its oceanographic causes is completely absent. Since the Gulf of Mannar is an extension of the South-eastern Arabian Sea, differentiating the features of the Gulf of Mannar from the SEAS has great importance. This feature is also consistent in the vertical sections of temperature and dissolved oxygen in ROMS, showing that the coastal upwelling prevails only up to the southern Indian tip and does not extend into the Gulf of Mannar.

The main objective of this study was to explore the primary productivity by understanding the spatial variation of chlorophyll concentration through medium spatial resolution satellite images over the Gulf of Manner. The next section explain the details of the study area with satellite dataset and method of estimating the chlorophyll concentration from remote sensing reflectance. The section-3 describes the results of the study organised with the details of spatial distribution of chlorophyll concentration from Sentinel-2A/B images. Final Section explains the conclusion of this article.

2. Data and methods

2.1. Study Area

The study area Vedaranyam is located in Gulf of Mannar is the first Indian Marine Biosphere Reserve in India. In this study, we analyse the Vedaranyam coastal water which is in the north entrance of the Gulf of Manner. The stations used for the analysis are shown in Table.1. Fig. 1. The schematic spatial map shows the study area named as Vedaranyam (Latitude: 10.24 N; Longitude: 79.88 E) which is located in the south-eastern part of India in Gulf of Manner (Left side). The right side image shows the closed or extended view map of

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Vedaranyam coastal waters. The Gulf of Mannar is relatively deep and extends 190 Km along the Indian coastline. It lies between the west coast of Sri Lanka and the south-eastern tip India, in the Coromandel Coast region. The Gulf of Mannar has astonishingly rich and diverse fauna compared to the adjacent regions, and the Kurusadai Island, one of the 21 small islands situated close to the Indian coastline in the Gulf of Mannar. The Gulf of Mannar region is enriched with productive habitat such as coral reefs, sea grasses, mangroves and sandy beaches. Gulf of Mannar water has high transparency, aerated and sandy seafloor conducive for the growth of diverse corals and many sensitive fauna. Even though Gulf of Mannar is one of the biologically rich areas, it has been exploited heavily over the past year. More than 4223 species of flora and fauna have been identified in the Gulf of Mannar area.

Table 1. Locations of the study area in the Vedaranyam coastal waters

Stations	Latitude (N)	Longitude (E)
St-1	79.89	10.33
St-2	79.88	10.28
St-3	79.83	10.26
St-4	79.77	10.25

Fig. 1. The schematic spatial mapshows the study area named as Vedaranyam (Latitude: 10.24 N; Longitude: 79.88 E) which is located in the south-eastern part of India in Gulf of Manner (Left side). The right side image shows the closed or extended view map of Vedaranyam coastal waters.

2.2. Satellite Data

Sentinel 2 data can be used as a computing tool for accurately mapping chlorophyll concentration along the coastal water. The data is of a high quality, as sentinel-2 carries an innovative wide swath high resolution multispectral imager (MSI) with 13 spectral bands, thus permitting for unprecedented perspective on our ocean. It can measure subtle changes in ocean color, and can use the amount of green light reflected from the ocean's surface to generate maps of global chlorophyll concentration. The present work aims to characterize patterns of seasonal variability of Chlorophyll in the Gulf of Mannar usingSentinel-2 (A/B) sensors. Coastal water quality parameters monitoring and analysis has been developed

significantly over recent years as a result of the development of sentinel 2 satellite sensor(Pahlevan et al., 2017; Pahlevan et al., 2018). The Sentinel-2 (A/B) captured images were processed and atmospheric corrections were carried out using the ACOLITE software(Vanhellemont, 2019).This work estimate chlorophyll concentration in the Vedaranyam coastal waters of Gulf of Mannar using Sentinel-2 (A/B) satellite sensors with good spatial resolutions for ocean applications and to assess the variability and inter-compare the performance of the sensors. Sentinel-2 (A/B) sensor estimates the chlorophyll-a in the dynamic and highly turbid water in the study area.

2.3. Standard OC Algorithm for Chl:

Chlorophyll-a concentration is an index for estimating primary productivity and biomass in coastal water, and it is an important indicator of Eutrophication.In optical remote sensing, there are several algorithms were existing for the retrieval of chlorophyll from remote sensing reflectance. The detailed review of some selected bio-optical algorithms was discussed for the retrieval chlorophyll concentration. Ocean Color (OC) Algorithm is the band-ratio based bio-optical algorithms to retrieve the chlorophyll-a concentration from remote sensing reflectance developed by O'Reilly & Werdell, 2019. The study suggests that the minimal error in chlorophyll retrievals due to the CDOM absorption in case-1 waters. The model shows limitation in coastal waters due to presence of other sea water constituents. The model performance was improved in the revised OC version.6 is in O'Reilly et al. (2019). The fourth order polynomial expression for the chlorophyll retrieval algorithm is as follows,

$$log_{10}(CHL) = a_0 + a_1 Ratio + a_2 Ratio^2 + a_3 Ratio^3 + a_4 Ratio^4 \quad (1)$$

blue and green bands were used for the estimation of intermediate Ratio values. The Ratio is logarithm ratio of remote sensing reflectance at blue and green band.Here, the coefficients a_0 = 1.22914, a_1=−4.99423, a_2=5.64706, a_3=−3.53426, and a_4 = 0.69266. This OC algorithm using two bands were used in this study for the estimation of Chl from captured R_{rs} from MSI images.

3. Results and discussion

This results and discussion section presents the detailed analysis of spatio-temporal variation of Chl concentration for understanding the water types and its variation over the Vedaranyam coastal waters over the Gulf of Manner. Here, the presented results were obtained from the Sentinel-2A/B satellite images. In the first part of this section explains the spectral distribution of remote sensing reflectance. The later part explains the spatial distribution of Chl.

3.1. Spectral variation of Rrs:

Fig. 2.shows the spectral distribution of remote sensing reflectance obtained from the sentinel-2A/B images after processing with atmospheric correction through the ACOLITE platform. The data were collected from four different station mentioned in table-1. The magnitude of Rrs were plotted against wavelengths (442, 492, 559, and 665 nm) for the Sentinel-2A/B specific bands for the four stations (St1-St4) is shown in fig.2. Each stations

have four Rrs spectra obtained from different images over different years from 2017 (Blue), 2018 (Red), 2019 (Grey) and 2020 (Orange). The Rrs spectrum captured from the Sentinel-2A/B data exhibited with a dynamic range of Rrs variability with the spectral shape and magnitude over the coastal waters.

The spectrum corresponding to blue color were collected from coastal water stations of Vedaranyam during 2017. The Rrs spectral values increases with increasing wavelength from 442 to 559nm. After reaching the primary peak at 559 nm, the values need to decrease at 665 nm for the normal coastal moderately turbid waters. But here the magnitude increase which represent special feature of highly dominated with sediment concentration. This indicates that the spectral data from sediment dominated can be easily captured by Sentinel-2A/B sensor at Vedaranyam coastal waters.

During 2018, the spectral shape of Rrs shows that the magnitude of Chl concentration were increases with increasing the wavelength from 442 to 559 nm. After reaching the primary peak at 559 nm, the Rrs magnitude decreases at 665nm. This shows the features are closely related to the moderately turbid waters with dominated Chl concentration in the coastal waters. Similar type of spectral features were observed other spectra captured during the year of 2019 and 2020. This spectral analysis describes that this regional waters is occupied with diverse water types with the mixed properties of water quality parameters such as Chl and sediment concentration.

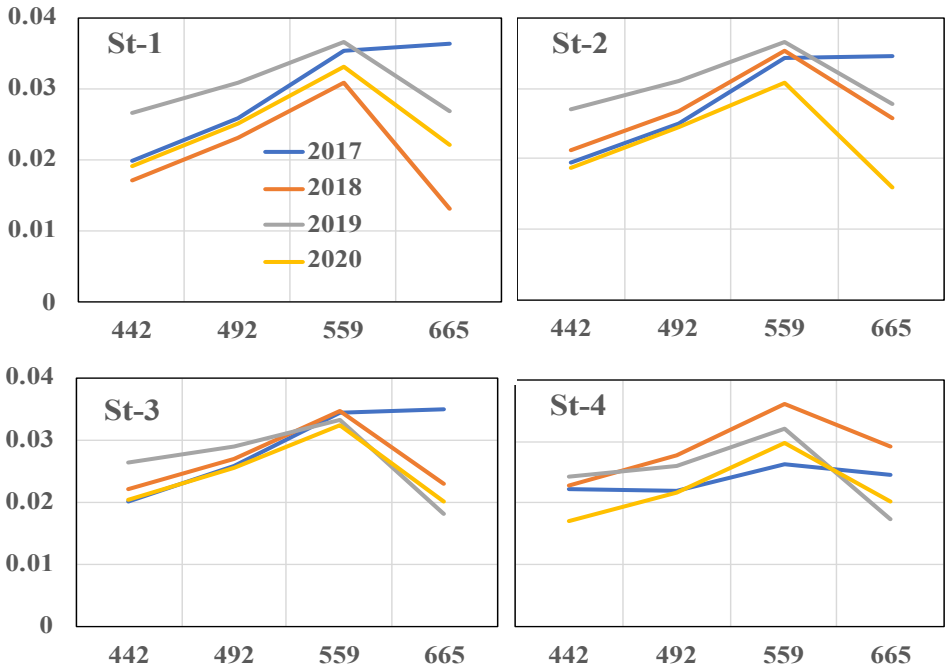

Fig. 2. Comparison of spectral plots of remote sensing reflectance (R_{rs}) obtained from Sentinel-2A/B for four different images from 2017-2020 different stations for different in the Vedaranyam coastal waters over the Gulf of Manner.

3.2. Spatial variation of Chl:

In this section, the spatio temporal analysis of Chl using the MSI images were analysed and explained for the Vedaranyam coastal waters over the gulf ofManner. The Chl images captured from four different years on 2017 (12th December from S2B), 2018 (17th November

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from S2B), 2019 (31st January from S2A), and 2020 (26th December from S2B) of Sentinel-2A/B were shown in fig.3. All these MSI images were processed through the default atmospheric procedure followed by ACOLITE software. The vicinity of cloud and land were flagged out from the final processed images. Finally, the Chl concentration were estimated using the OC algorithm from the remote sensing reflectance of MSI images. Fig. 3 shows the spatio-temporal variation of Chl from MSI images in the Vedaranyam coast, Gulf of Manner, Tamilnadu, India.The MSI image from 2017 (Fig.3) shows that the water is less chlorophyll concentration over the coastal waters. As per the analysis in section 3.1, the water highly dominated with suspended sediment concentration, subsequently the concentration of chlorophyll were supressed in those water types. The features of the inland water region also captured in the images, but not in clear due to the cloud. In 2018, MSI image are 100% cloud free images near the coast and the vicinity of the inland waters are clearly shown. Here, the spatial pattern of Chl concentration were clearly shown with range of Chl values from 2.4~9.5 mg/m^3.

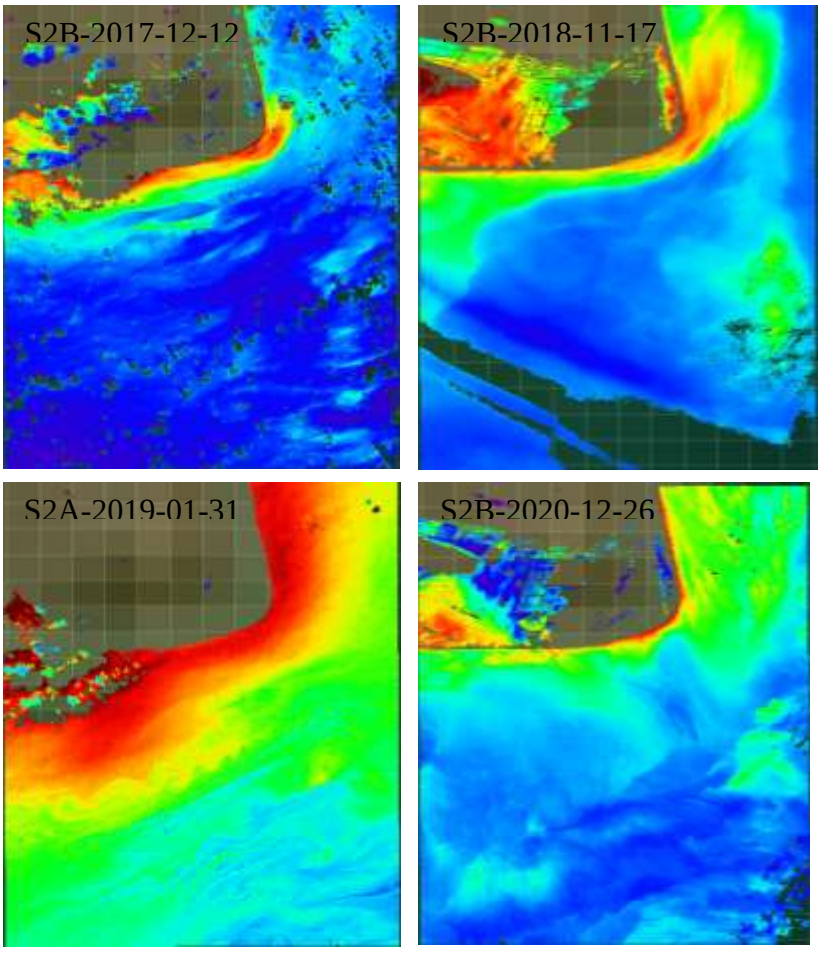

Fig. 3.Spatial distribution of Sentinel-2A/B satellite derived Chl product estimated from the standard OC model in Vedaranyam coastal waters over the Gulf of Manner, South-eastern part of India

High concentration of Chl were observed in the spatial images of MSI (from Sentinel-2A) captured during the year of 2019 (Fig.3) over the coastal waters. This dynamic range of Chl

shows clearly the upwelling features in the coastal waters and values of Chl are very high as 6.78~15.45 mg/m^3. Due to the domination cloud over the inland regions, the inland aquatic zones were masked in 2019 MSI image. High quality cloud free image were captured (from Sentinel-2B) in 2020 is used for the spatio-temporal analysis of Chl concentration. Here the inland waters are clearly indicated with range of Chl values maximum 8.3 mg/m^3. Similarly, the range of Chl are 3.3 as minimum and 6.7 as maximum values over the coastal waters. This spatiotemporal analysis clearly shows the variation of Chl were low during the November and early December. Also, the concentration of Chl wereobserved as very high during the late December and January. This analysis also shows the consistency of the Chl retrievals from both sensor of Sentinel-2A and Sentinel-2B.

4. Conclusions

The present work aims to characterize patterns of seasonal variability of Chlorophyll in the Vedaranyam region over the Gulf of Mannar using MSI sensor from Sentinel-2A/B satellites. The regional patterns of Chl for the different years in the Vedaranyam are analysed using aquatic remote sensing.The ratio of Rrs of the coastal waters at green and blue bands were used to estimate the Chl concentration which is based on the standard OC2 algorithm. The spectral pattern of Rrs were analysed and results that this region is covered with diverse water types. Then the OC2 algorithm are applied to the Sentinel-2A/B images for understanding the spatio temporal distribution of Chl over the coastal waters from 2017-2020. High Chl concentration over the coastal waters of Vedaranyam can be easily estimated using the Sentinel-2A/B images. The cloud cover and adjacency effect are the major limitations of this spatio-temporal analysis over the coastal waters using Sentinel-2A/B images. This study confirms that the consistency of Sentinel-2A/B sensors and these images can much usefulfor monitoring the changes in water quality parameters in coastal waters for various seasons for understanding the eutrophication process and highly useful for the remote sensing community.

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