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Original Article

Inter-Annual Variation of Hydrological Parameters in the Northern Indian Ocean using Modis Data

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Abstract *- Using MODIS data, the present study analyzed spatial distributions and annual variability of Bio-Geochemical concentrations from 2011 to 2020 in the Northern Indian Ocean. The study observed significant variations in the parameters such as PAR (Photosynthetically Active Radiation), SST (Sea Surface Temperature), and Chlorophyll. The Annual composite images of MODIS-Aqua derived Chlorophyll & SST, PAR & POC were retrieved from 2011 to 2020, covering the northern part of the Indian Ocean. And the same study revealed increased solar radiation and a clear atmosphere during the study period. The minimum and maximum values for these parameters are derived by SEADAS 7.5.3.*

Keywords *- Chlorophyll, Particulate organic carbon, Photosynthetically active radiation and Sea surface temperature, MODIS.*

1. Introduction

The ocean plays a profound role in climate change because the gradual changes in the ocean climate change at the inter-annual, decadal, and longer timescales may extend its impacts on the regular patterns of oceans *(Trenberth and Hurrel, 1994; Ault et al., 2009)* and it loads important concern to biogeochemistry on the same. Among all the biogeochemistry processes, four parameters have been considered- chlorophyll, PAR, POC, and SST. All the natural processes are done under the source of sunlight. The significant component for the primary production in both the terrestrial and marine kingdoms is chlorophyll. The evolution of the world is possibly provoked by the chlorophyll pigments, which utilize solar radiation as chemical energy through photosynthesis *(Callot, 1991; Scheer, 1991)*. The carbon cycle in oceans is influenced by particulate organic carbon (POC), which can be conjoined with other processes, including the re-suspension of sediments and the biological pump. The concentration of POC can be traced using a well-validated algorithm with a minimum number of negative phases *(Evers-king et al., 2017)*. Many studies are available on determining POC concentration in the Atlantic and Pacific oceans *(Roman Kevich, 1984; Gordon and Cranford, 1985; Yoro et al., 1997)*, and specifically, there are some studies done in the Bay of Bengal and Indian Ocean *(Radhakrishnan et al., 1978; Bhattathiri et al., 1980; Bhosle et al., 1998; Nandhakumar et al., 1987)*. The correlation between Partial Organic Carbon and Chlorophyll in Gdansk Deep is statistically significant *(Maciejewska and Pempkowiak, 2014, 2015)*. The POC in the bottom can be pumped up by three times due to high wind speed, which initiates re-suspension (Hung et al., 2000). The uneven SST fluctuations can change the ocean thermodynamics and air-sea interaction. The observation of the fluctuation will be useful in monitoring large-scale global events such as El-Niño and climate change. The influence of seawater temperature (SWT) changes can be observed in weather, climate, fisheries, and the linear observations lead to an important forecast of daily weather systems, including tropical cyclones. Spatio-temporal patterns can monitor the near-surface and surface phytoplankton concentration and sediment dynamics from satellite ocean color monitoring datasets which can be elaborated in the study of carbon cycles, biogeochemical cycles, primary productivity, and fisheries *(Sarangi et al., 2008a & b). Jyothibabu et al., 2018)* studied the photosynthetically available radiation (PAR) levels present in the Bay of Bengal at significant fluctuations in the phytoplankton. *Devasena et al., 2014* investigated changes due to climate and seasonal variability of chlorophyll and primary production in the north Indian Ocean. Higher PAR helps promote plant growth and monitoring, and also air pollution affects PAR by filtering out the amount of sunlight that can reach plants. (There are no concluding remarks as to why you have chosen this study in the first place).

2. Materials and Methods

The data of chlorophyll-*a* (CHL-a), sea surface temperature (SST), particulate organic carbon (POC), and Photosynthetically Active Radiation (PAR) were acquired from NASA MODIS AQUA through the website ***(modis.gsfc.nasa.gov)*** from 2011 through 2020. The MODIS is capable of viewing in the Visible and infrared wavebands; thus, almost all the images have cloud cover at various extents. The monthly composite data of chlorophyll, SST, PAR, & POC parameters were acquired to interpret the annual variability. The calendar year has been converted into four seasons for the interpretation purpose, i.e., (1) post-monsoon (January - March), (2) summer (April- June), (3) pre-monsoon (July – September), (4) monsoon (October - December) and the images were plotted for the respective month. All the satellite data were processed using SEADAS 7.5.3 software. SEADAS is a comprehensive software package for the processing, display, analysis, and quality control of ocean color data, and it applies to many satellite-based earth science data analyses. SEADAS can evaluate ocean, land, and atmospheric data and produce true color imagery. It can perform an area crop of the geometric bound of the file, where the area crop is done in either pixel space (or) in geographic coordinate space (or) in geographic space. In the present investigation, the area cropping was done by subsetting the image under the space of geographic coordinates.

Geographic region crop performs an area crop in geographic coordinate, and the bounded region is over the Arabian Sea and Bay of Bengal. The bounded region is divided into 5 subset images by using the coordinates of each individual of the subset image. They are (1) the entire Arabian sea and Bay of Bengal (AS & BOB), (2) North Arabian Sea (NAS), (3) South Arabian sea (SAS), (4) North Bay of Bengal (BOB) (5) South Bay of Bengal(SBOB). From these 5 subset images, yearly Mean, Minimum and Maximum values were taken. Microsoft excel 2007 was used to plot the graphs to illustrate the mean variation from the data acquired.

3. Results and Discussion

3.1. Annual variability of chlorophyll

The Chlorophyll concentration has been analyzed in the place of phytoplankton biomass from 2011 to 2020.

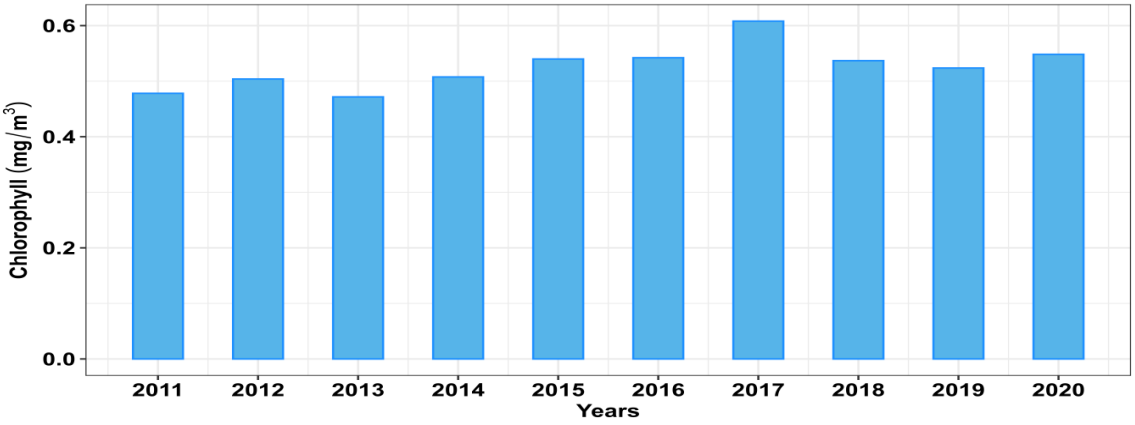
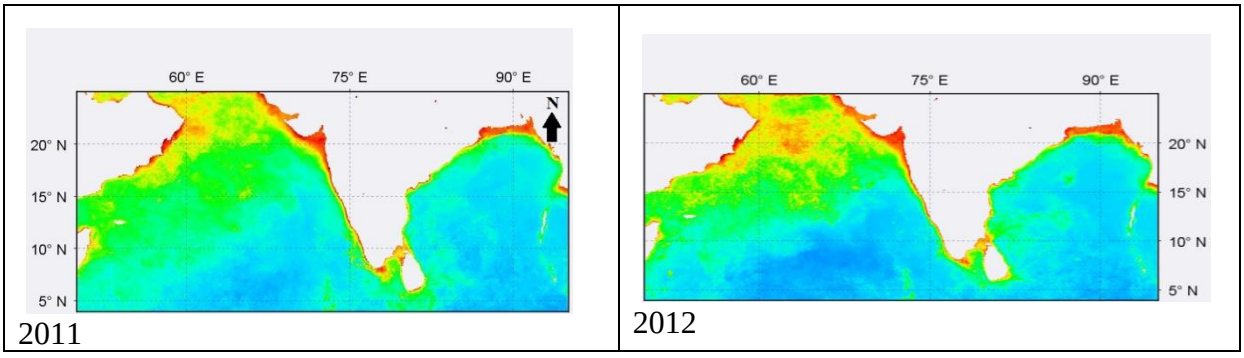


Fig. 1 Annual variation of basin averaged MODIS-AQUA derived chlorophyll in the NIO.



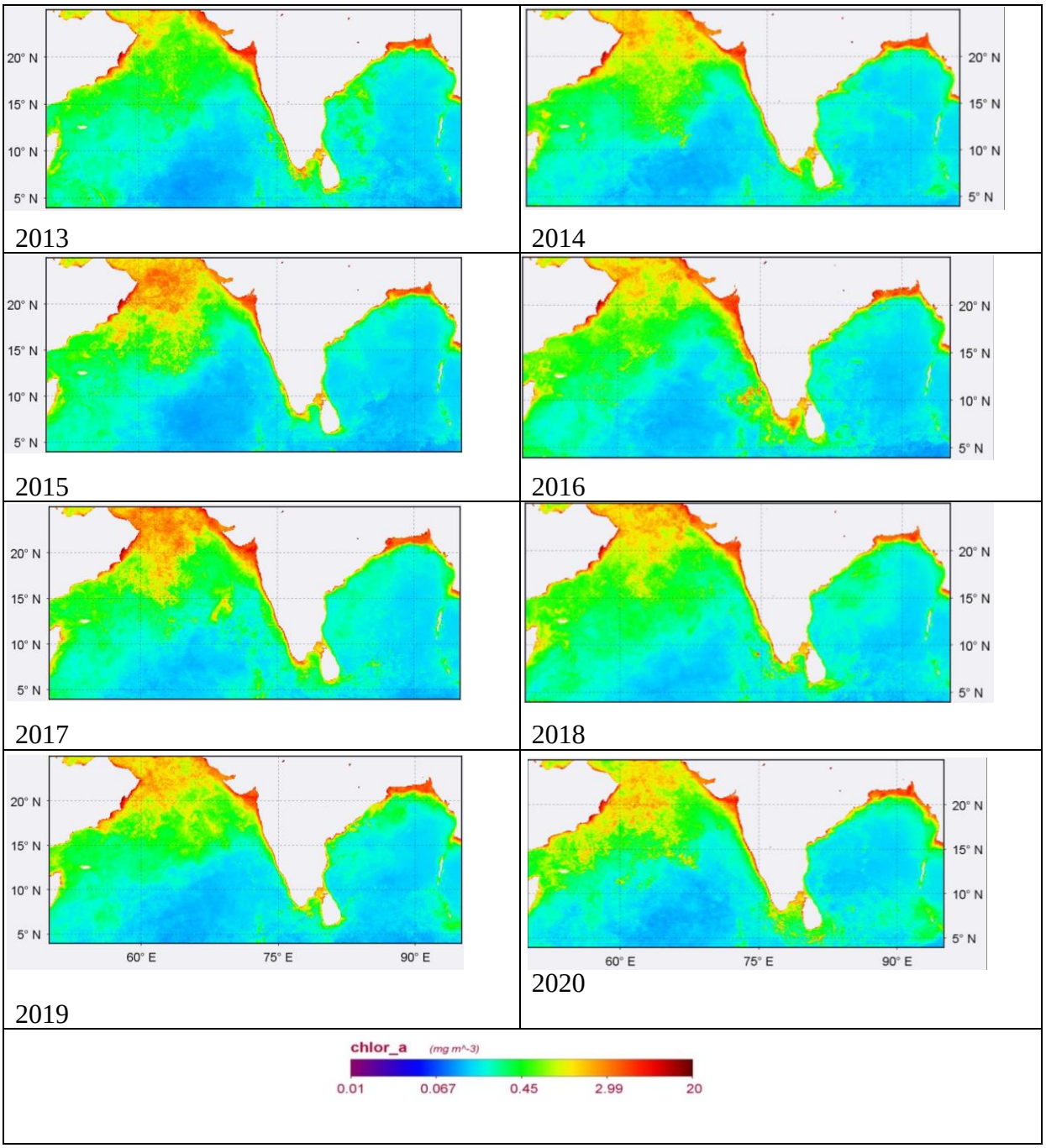


Fig. 2 MODIS retrieved annual composites of chl –*a* from the year 2011 to 2020

The overall high mean value of chlorophyll registered at 0.6081mg/m^3 in 2017.

The Low mean value of chlorophyll was registered in 2013, and the same year was also evident for heavy rainfall.

3.2. Annual variability of POC

POC annual variability in the Northern Indian Ocean was studied from the data acquired as annual composite images of MODIS from 2011 to 2020.

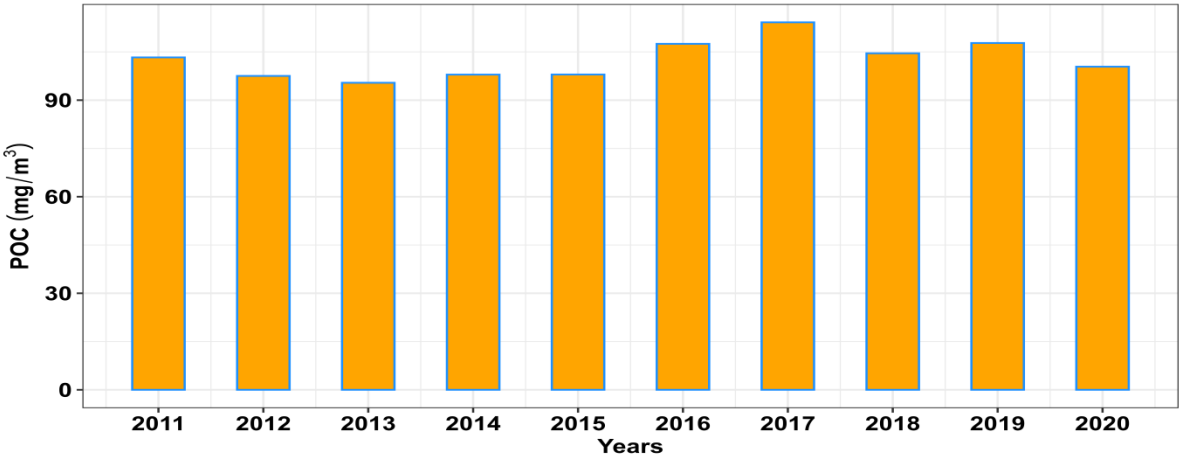
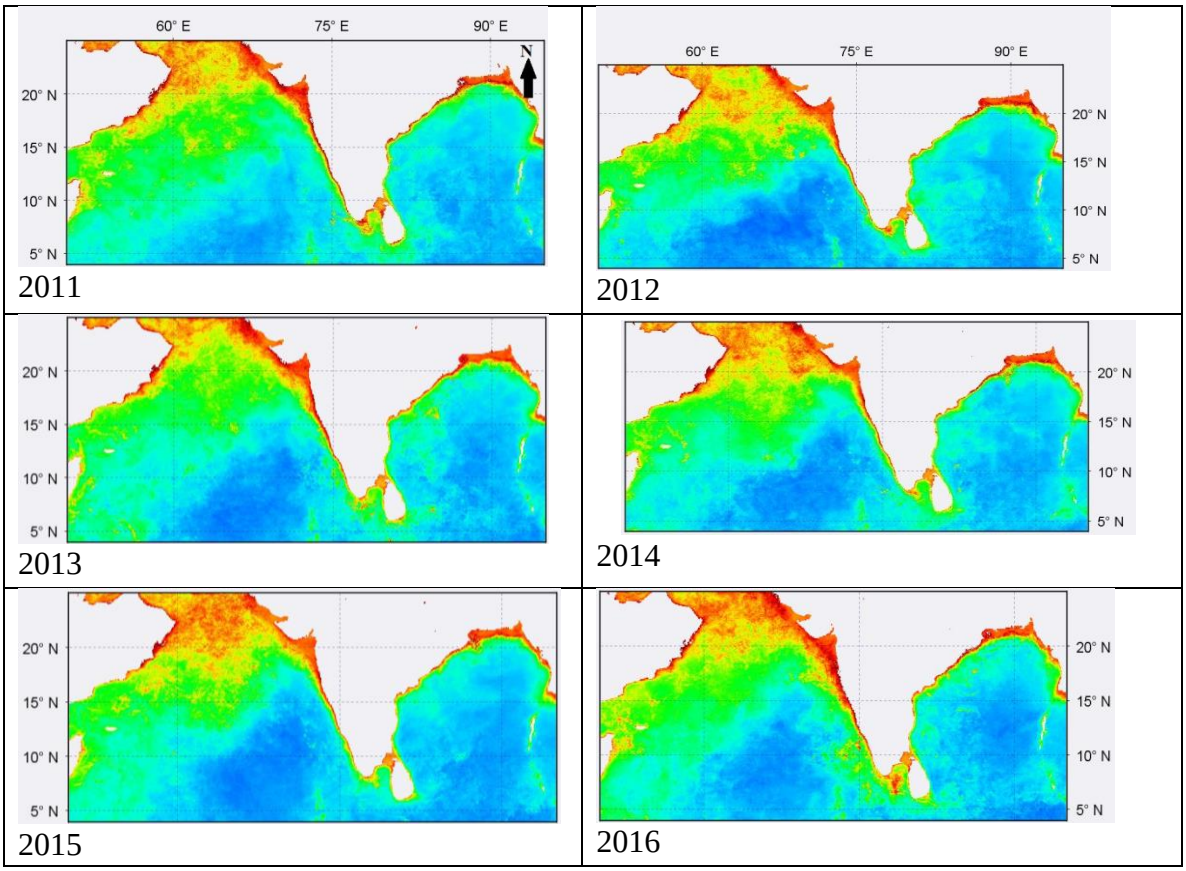


Fig. 3 Annual variation of basin averaged MODIS-AQUA derived POC in the NIO

The overall high mean value of POC was 114.1817 mg/m^3 in 2017, whereas the low mean value of POC was registered in 2013.



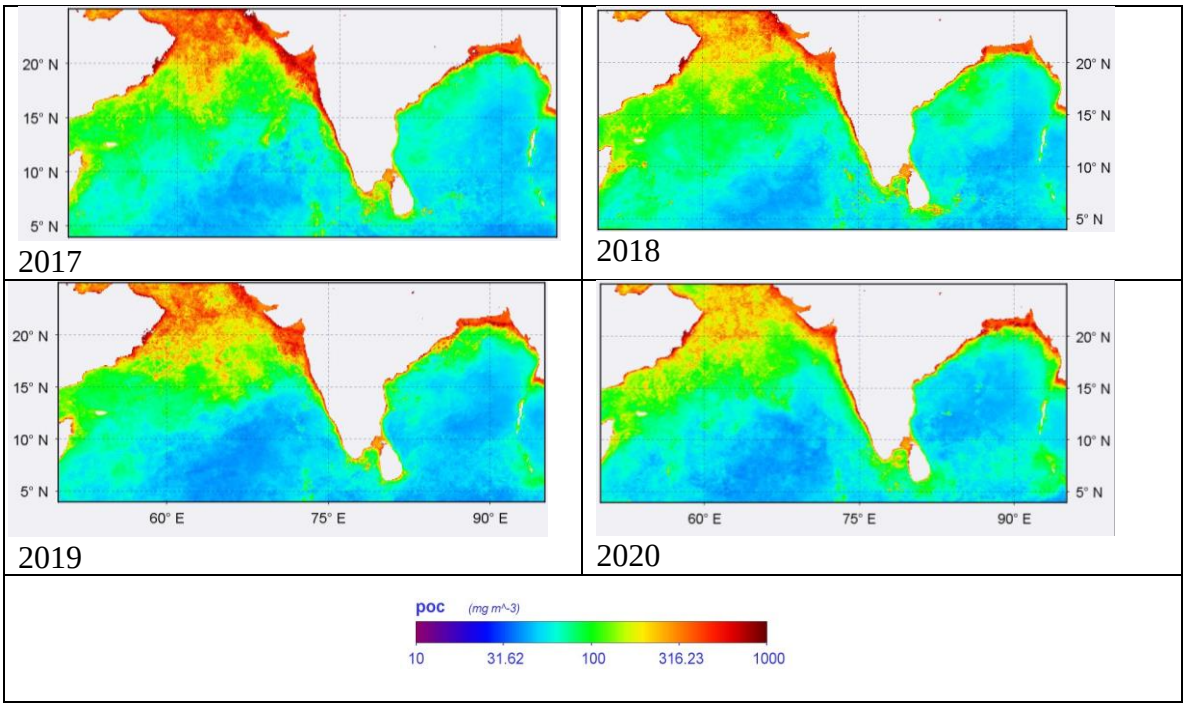


Fig. 4 MODIS retrieved annual composites of POC from 2011 to 2020

3.3. Annual variability of par

Annual variability of PAR in the NIO was studied from the annual composite images of MODIS from 2011to2020.

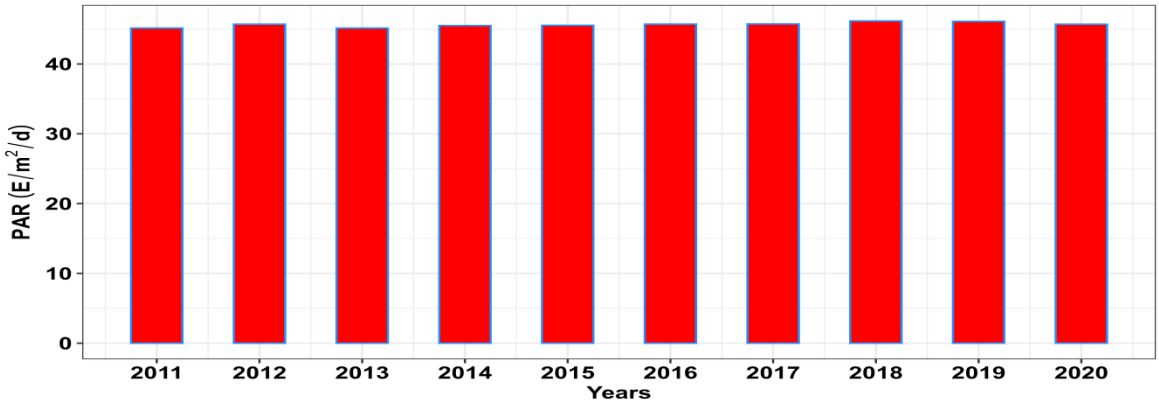


Fig. 5 Annual variation of basin averaged MODIS-AQUA derived PAR in the NIO.

The overall high mean value of PAR observed was 46.1653 E/m^2/day in 2018, whereas the less mean value of PAR observed was 45.1411 E/m^2/d in 2013.

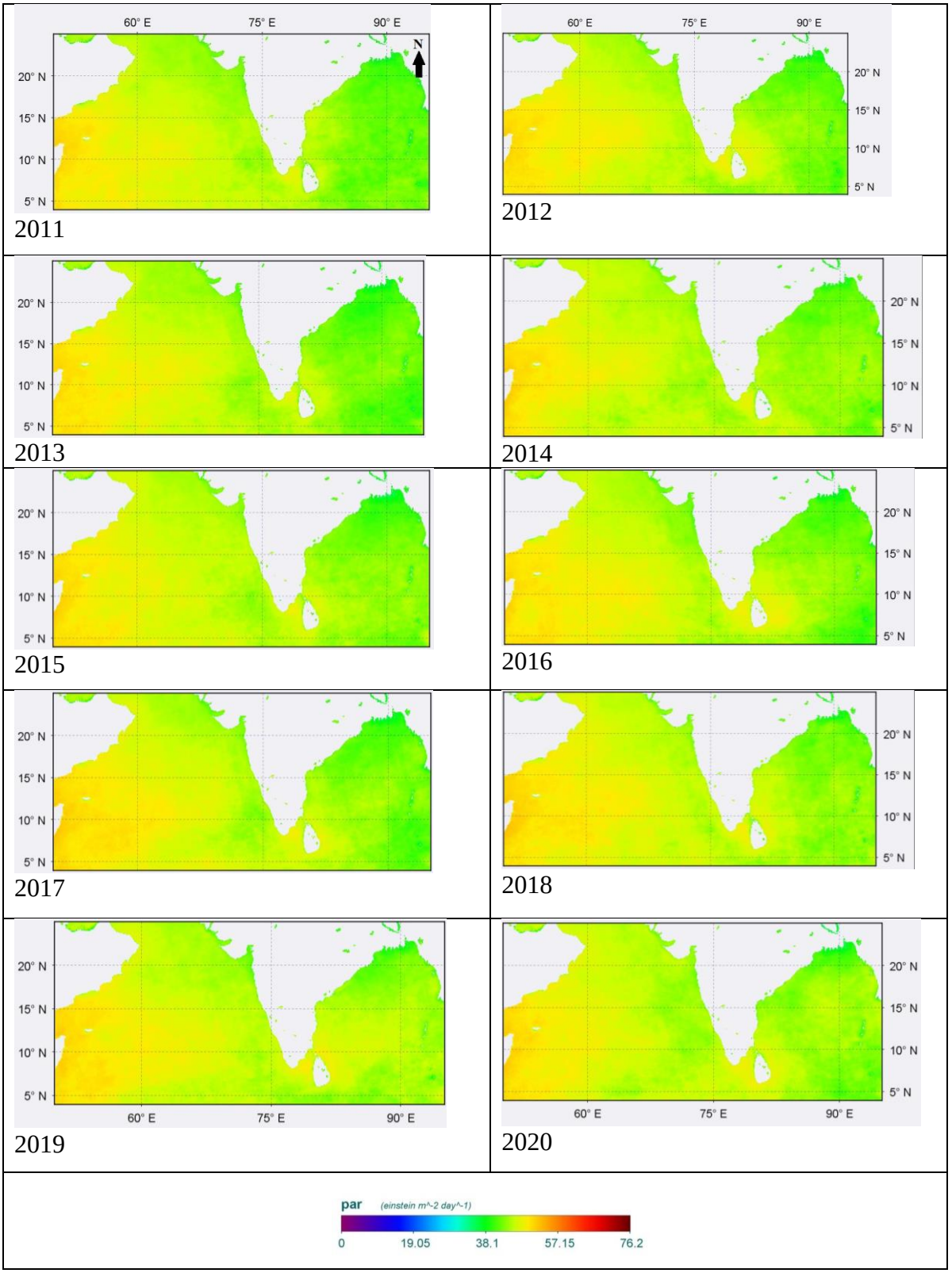


Fig. 6 MODIS retrieved monthly composites of PAR from the year of 2011 to 2020

3.4. Annual variability of SST

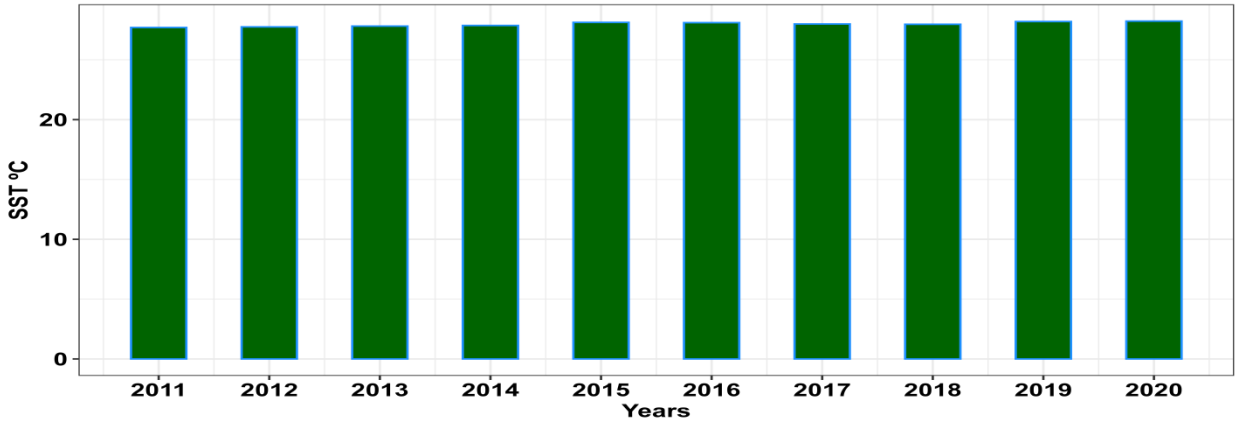
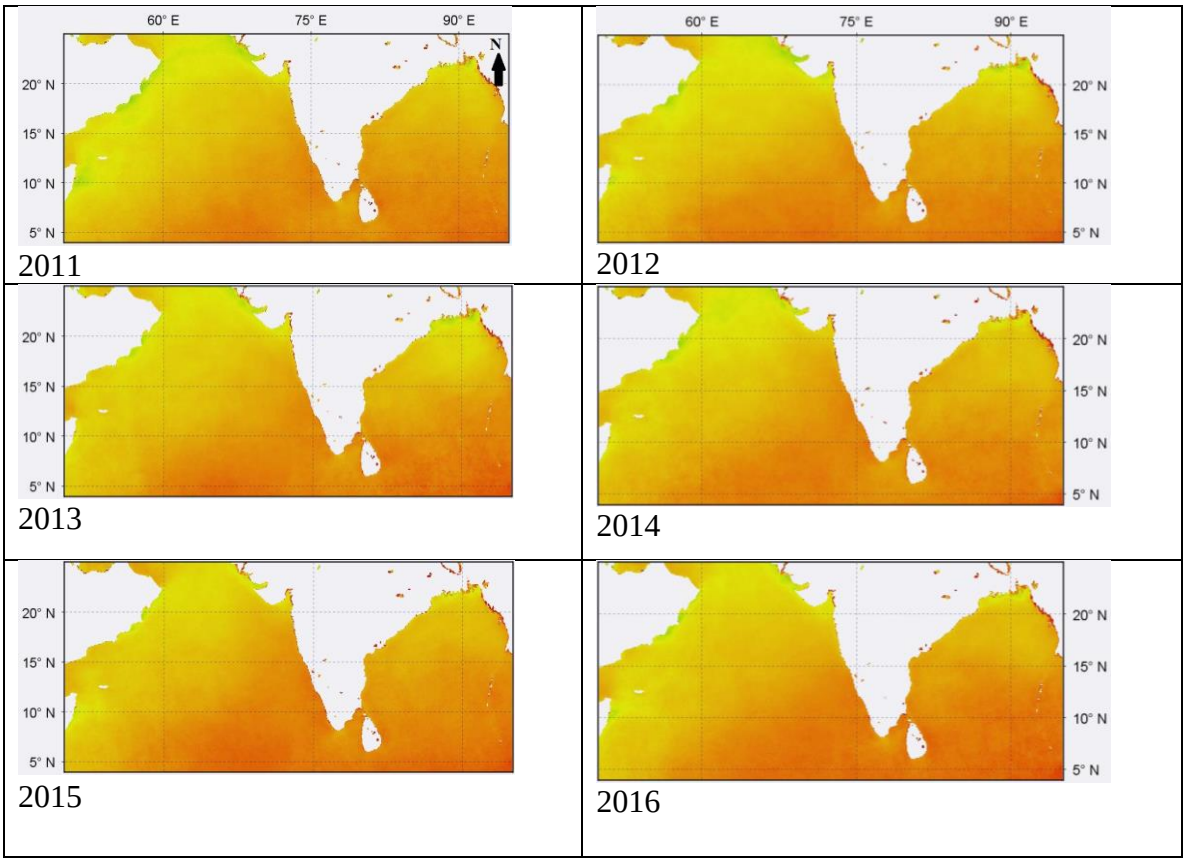


Fig. 7 Annual variation of basin averaged MODIS-AQUA derived SST in the NIO

The maximum mean value of SST was observed to be 28.2ºC in 2020, while the least mean value was noted in 2013.



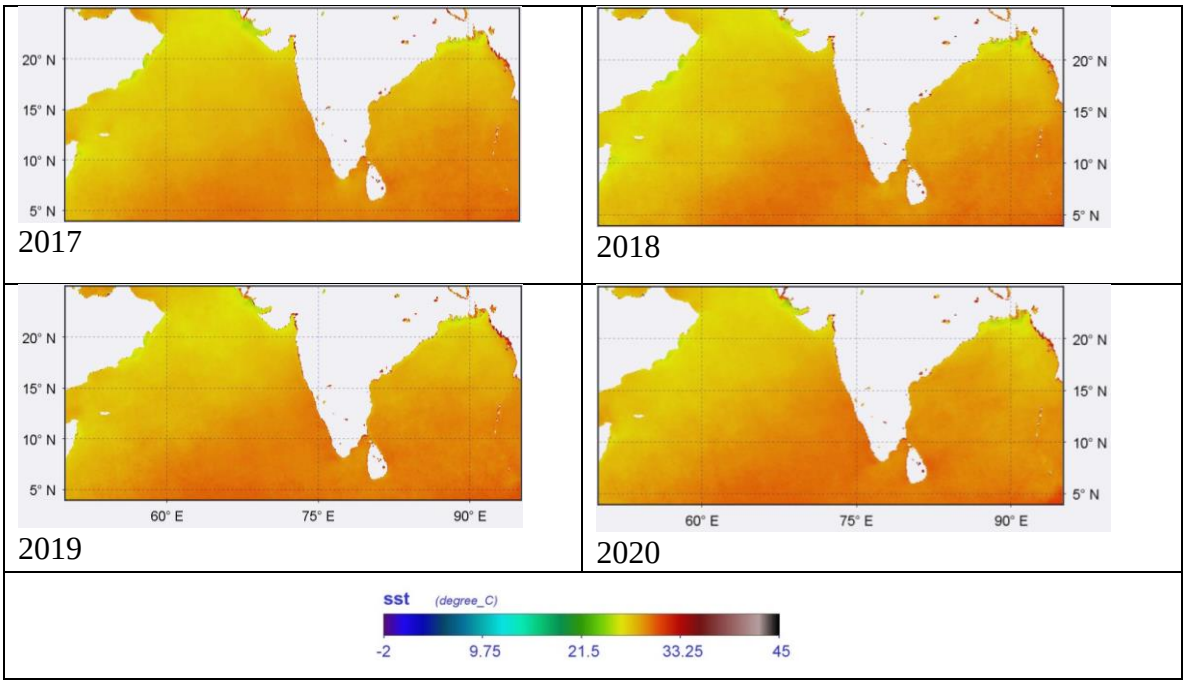


Fig. 8 MODIS retrieved annual composites of SST from the year of 2011 to 2020

The substantial mean values in the chlorophyll concentration were observed in 2020 along the entire Bay of Bengal and the Arabian Sea. Increased rainfall and pollution-free atmosphere act as the causative agents for upwelling and mixture of water. Upwelling promotes a high concentration of nutrients & primary productivity. The lowest value was recorded in 2015 and the entire Northern Indian. And the elevated chlorophyll concentration is a reason for the southern riverine discharge which enhances the high nutrient supply (Yoder,2000; *Kumar et al., 2007*).

In the northern Indian ocean, 2018 represents the year of more rainfall compared to other years. Biological and physical processes such as primary production, advection, vertical mixing, and upwelling of oceans govern the distribution of POC concentration in a spatial manner (*Stramska, 2014)*. In summer, the POC concentration is typically low because of certain significant features, including the source of nutrients, regions of convergence, and downwelling of surface water masses; thus, generating primary production is low (*West berry et al. 2008)*. The higher value of PAR was registered in 2018 along with SAS, and the increased rainfall was observed in the same year during the monsoon. Higher PAR-taking by phytoplankton through chlorophyll may cause an increased concentration of Net Primary Productions (NPP). The lower value of PAR was registered in 2011and. The results of PAR also correlate with the study of (*Mithun et al., 2008*), which has the highest value of PAR in March –April, followed by a secondary peak in August- September. The highest mean SST concentration was observed in 2015 along the entire Northern Indian Ocean due to flawless solar insolation, irradiance, and cloud-free atmosphere. The minimum SST was registered during the winter monsoon of 2011, and the maximum temperature was observed during spring inter-monsoon in 2020. The significant peak of net heat flux while spring inter-monsoon results in the observed warmest SST (*Narvekar and Kumar., 2006*).

4. Conclusion

The Indian peninsula is covered by the basins that possess unique characteristics elaborated by various biogeochemical processes, including eddies, cyclones, and coastal currents, which influence large coastal circulations, riverine discharge, and the monsoonal reversal winds. The basins' characteristics help attain a significant impact on primary and biomass production (Shanthi et al., 2016). Compared to other oceans, the north Indian Ocean is observed with prevailed upwelling induced by strong wind patterns, and the process results in the increased concentration of chlorophyll in monsoon. The increased primary productivity in the northern Indian Ocean can be a reason for the observed sizeable load of POC concentration. During the summer monsoon, SST was less compared to spring inter-monsoon. The amplification of the southwest monsoon by reduced SST makes the majority of the Bay of Bengal an upwelling zone. The parameters are widely influenced by external physical characterizations of the ocean and are the cause for representing the basins around the Indian peninsula as much more productive and balanced.

5. Conflicts of Interest

We declare that there is no conflict of interest regarding the publication of this paper.

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