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Preliminary Assessment of Oceanic Chlorophyll Concentration using MODIS-Aqua Ocean Color Satellite Data

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ABSTRACT

Ocean chlorophyll concentration is a crucial element in marine biology. The concentration is determined by the ocean current, nutrient levels, and temperature. Satellites like MODIS-Aqua, MODIS-Terra, Ocean sat, and VIIRS-SNPP is commonly used to measure ocean chlorophyll. This study examines the change in chlorophyll concentration from 2014 to 2019 globally and in India. A seasonal shift in India's fishing potential was also studied in 2018. The study used MODIS-Aqua satellite Level 3 Ocean Colour data from NASA Ocean Colour. The data from the Giovanni portal is retrieved to analyse the monthly and seasonal mean chlorophyll concentrations globally and in India. Calculating zoning numbers revealed possible fishing spots. The results of the temporal study show that August (0.35 mg/m3) and September (0.34 mg/m3) have the highest average concentration of chlorophyll in the World. In India, the same months have the highest average concentrations of 0.80 mg/m3 and 0.73 mg/m3, respectively. Gujarat and West Bengal offer the best fishing possibilities all year. An extensive analysis can help define daily fishing potential based on chlorophyll, SST, and winds.

Introduction:

Phytoplankton is tiny plant-like organisms that live in water (NASA, n.d., 1998). Because phytoplankton can photosynthesise its food, it is the principal constituent of the marine ecosystem to feed other marine organisms (Kotta &Kitsiou, 2019). The pigment chlorophyll found in phytoplankton gives greenish hues to satellite images of the ocean (Nababan et al., 2016). Factors including ocean circulation, sea surface temperature, and fertiliser concentration influence chlorophyll concentration (Marrari et al., 2006).

Satellites can measure chlorophyll content (Salyuk&Stepochkin, 2015). Many satellites are employed for ocean remote sensing and colour data extraction using reflectance (Schwarz et al., 2010). Ocean colour radiometry is the study of the spectral composition of visible light reflected from the ocean surface (Curtis Mobley, 1994; Jeremy Werdell& McClain, 2019).

The main goal of satellite ocean colour analysis is to examine spectrum reflectance to quantify chlorophyll concentration (Jeremy Werdell& McClain, 2019). Finding chlorophyll concentration helps understand ocean dynamics and locate fishing zones for better fisheries management (Zamir et al., 2015).

Ocean remote sensing is one of the most intriguing fields. This study aimed to learn what ocean colour is and how data on ocean colour might help determine ocean chlorophyll content (Loisel et al., 2017). Because chlorophyll is an essential component of marine biology, knowing its temporal and spatial extent helps identify fishing zones (Shen et al., 2008). This study

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uses Moderate Resolution Imaging Spectrometer (Modis)Aqua sensor data for the ocean colour product chlorophyll. Modis-Aqua has been harnessed for ocean remote sensing since 2002 and delivers good results (Kahru et al., 2012). This study examines the temporal fluctuation of mean monthly and seasonal chlorophyll concentrations in Modis-Aqua over six years (2014-2019). This research also examines how fishing potentiality changes with each season in India in 2018.

National Aeronautics and Space Administration (NASA) launched its first oceanographic satellite, Seasat, in 1978. (R. P. Singh & Chaturvedi, 2010). Even while ocean remote sensing has advanced significantly since then, it still lags terrestrial and aerial remote sensing. Many satellites with ocean monitoring sensors have been launched over time to study the oceans' biological and physical elements (Joy et al., 1990). Currently, the Modis-Aqua satellite is the most widely used ocean remote sensing sensor.

The two significant factors in marine biology are chlorophyll and Sea Surface Temperature (SST) (Wynne et al., 2005). These two factors are inversely connected. Therefore, an increase in chlorophyll concentration implies a drop in SST. Linear regression was used to identify recent shifting trends (Feng & Zhu, 2012). The approach uses the Mods-Aqua dataset from 2002-2009. The time series trend results reveal that worldwide chlorophyll increased from 2002-2009 while the sea surface temperature decreased (Yadav et al., 2019).

It is expected that satellite sensors can have data gaps. This can be due to an ambient effect or a sensor issue (Kumar et al., 2018). Local linear regression was applied to fill up data gaps in chlorophyll remote sensing (Umbert et al., 2020). Modis-Aqua data products onchlorophyll (Chl-a) and SST employed this approach. Chl-a and SST synergised to boost chl-a's spatial extent (George et al., 2013). Finally, cross-validation was done between satellite obtained data and filled gaps fused chl-a data (Pinkerton et al., 2005).

The majority of ocean-related work has been done in Europe and America. Only a few studies have been done on Indian coasts. An Arabian Sea study used Modis-Aqua data to determine annual changes of chlorophyll-a (Zamir et al., 2015). The study presented a temporal analysis of chl-a and revealed that chlorophyll concentration changes with each month. The SST was also lower in the months with increased chl-a content (Feng & Zhu, 2012).

The worldwide chlorophyll content varies greatly. Each latitude, ocean, and even shore has its own. Shallow continental shelf zones had higher chlorophyll concentrations than open oceans (Dasgupta et al., 2009). Despite receiving monsoon and trade winds, the Bay of Bengal has reduced chlorophyll concentration (Belkin & O'Reilly, 2009). Ocean currents and surface winds both play an impact on the ocean's chlorophyll concentration. Ocean currents can both positively and negatively affect phytoplankton development (Narayanan et al., 2013). Ocean currents help transfer vital nutrients for phytoplankton growth. Fish reproduce in areas where both cold and warm currents meet because phytoplankton is abundant due to ocean water's upwelling (Amol et al., 2019). Only warm currents are detrimental to phytoplankton growth (S. Singh, 2012).

India, a pioneer in space science, has its ocean color sensor, which was aboard IRS-P4. Ocean Color Monitor (OCM) was introduced in IRS P4 in 1999. (Dey & Singh, 2003). The higher spatial resolution makes quantitative chlorophyll evaluation ideal (Chauhan et al., 2002). The OCM result corresponded well with the in-situ data after atmospheric correction, proving the sensor's effectiveness (Dey & Singh, 2003).

Compared to Modis-Aqua, IRS-P4 is better at estimating chlorophyll (R. P. Singh & Chaturvedi, 2010). The deltaic parts of the Indian Coast have higher chl-a content than other places (R. P. Singh & Chaturvedi, 2010). The Arabian Sea (NE) and Bay of Bengal (Southern) continental shelf regions' chlorophyll fluctuation was studied extensively using the IRS P4 Ocean Colour Monitor (Dey & Singh, 2003).

The Arabian Sea and the Bay of Bengal have different chlorophyll concentrations. The Bay of Bengal has a lower Chl-a concentration due to less vertical mixing and poorer nutrient content than the Arabian Sea (Dey & Singh, 2003). Another factor is that the Bay of Bengal has more open water, whereas the Arabian Sea has more chlorophyll-rich Gulf areas (Dey & Singh, 2003). The Bay of Bengal and the Arabian Sea are very stable and show slight fluctuation in the works.

The most significant research gap in ocean chlorophyll studies is that long-term effects are rarely studied. The other gap is in chlorophyll application. Since chlorophyll is one of the primary elements in identifying fishing zones, not many users recognise it. The proper use of chlorophyll in fishing areas will benefit both fishermen and the government.

This study aims to examine and understand how ocean chlorophyll varies globally in spatial and temporal scales. The goals are to detect the temporal change of chlorophyll concentration of the World and Indian coasts Seasonal prospective fishing zones on the Indian and Pacific coasts.

2.0 Materials and Methods

2.1 Dataset

Table 1 details the type of data used, the file format in which it was stored, the source of the data, and the period for which it was used in this study.

Indian National Centre for Ocean Information Services (INCOIS) and Indian Space Research Organization (ISRO) derived fishing zones into 11 sectors. In addition to converting the raster data to Geo-Tiff, the shapefiles were reprojected to the projected coordinate system. The zonal statistic was derived from identifying possible fishing zones based on chlorophyll content. This tool is used in both Food and Agriculture Organization (FAO) and INCOIS Potential Fishing Zones (PFZs). This study utilises ArcMap's zonal statistics toolset.

Table 1: Dataset used for analysing chlorophyll-a concentration pattern

Dataset*	Type	Source	Period	Resolution
Modis-Aqua Level 3 Chl-a	NetCDF	NASA Ocean Color (https://oceancolor.gsfc.nasa.gov/)	2014 – 2019	4 km
FAO Fishing zone of World	Shapefile	Fishery Division of Food and Agriculture Organisation (http://www.fao.org/home/en/)	2018	-
Potential fishing zone of India	Shapefile	INCOIS (https://incois.gov.in/)	2019	-

**All datasets used the WGS 1984 geographic coordinate system.*

2.2 Methodology

ArcGIS Desktop was used to analyse the data in this work. Data for Modis-Aqua Level 3 Chl-a Concentration were obtained from the Giovanni web portal (https://giovanni.gsfc.nasa.gov/) and extracted monthly and seasonal time series graphs for the world and India. Giovanni is a graphical user interface-based programme for displaying and analysing geophysical parameters. Modis-Aqua Level 3 chl-a concentration raster data for India in 2018 and composite mission data for the rest of the world were retrieved from the NASA Ocean Color website at a resolution of 4 km.

For each zone defined by zonal shapefile data, in this case, FAO and PFZ shapefiles, a statistic is computed using values from raster data, in this case, chlorophyll concentration raster data. After computing zonal statistics for each zone in the input zone dataset, a table is created based on the user-specified input statistic, in this instance, mean statistics. Following the facts, Seasonal Fishing Potential Zone Maps of India and World Fishing Potential Zone Maps were created.

An overview of methods followed in the study is given in figure 1.

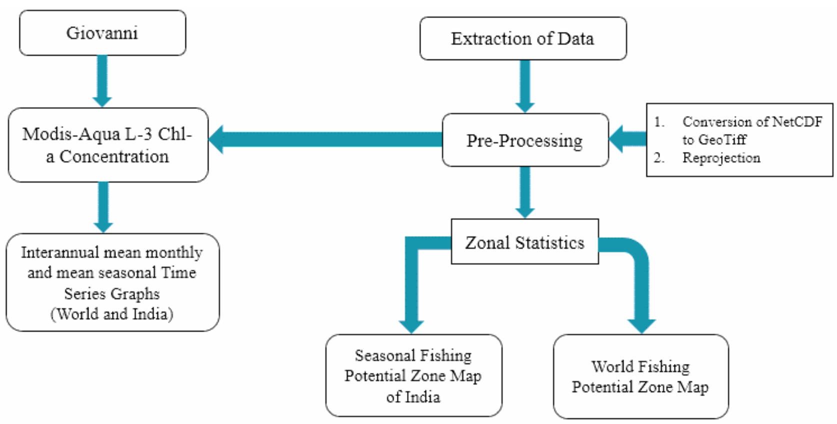

Fig. 1: Flowchart depicting the overview of methods used in the study

3.0 Results and Discussion

3.1 Temporal variation of the Chl-a of the World

Ocean chlorophyll content varies between oceans and months. Each month has a different level of concentration.

Figure 2 depicts an inter-annual time-series graph. The graph shows that December and January have a lower concentration of chlorophyll. In the last six years (2014-2019), the concentration level has been lower in these two months (Dec-Jan) than in the other months. The month of December had the lowest chlorophyll concentration of 0.244 mg/m3 in 2014 and the maximum chlorophyll concentration of 0.278 mg/m3 in 2019. In contrast, January had the lowest reading of 0.243 mg/m3 in 2015 and the highest reading of 0.271 mg/m3 in 2019. As shown in the figure, the months of May and August have relatively high chlorophyll concentrations, occupying the peak position in the curve. August had the highest level of 0.386 mg/m3 in 2019, while May had the lowest of 0.377 mg/m3 in the same year. May, June, July, August, and September have the highest chlorophyll levels, while November, December, January, February, and March have the lowest. The months of April and October are in the transition zone between months with the highest chlorophyll content and months with the lowest chlorophyll content.

Like the change in chlorophyll concentration that occurs monthly, the variation occurs seasonally as well. Spring, summer, autumn, and winter are the four seasons that are observed throughout the year.

Figure 3 depicts the interannual time series of chlorophyll's average seasonal fluctuation. The picture clearly shows that the summer season- June, July and August (JJA) has the highest overall concentration level of chlorophyll. This season had the highest concentration in each of the previous six years. Winter – December, January and February (DJF) have the lowest chlorophyll concentration throughout this time. It is now clear that as the amount of solar radiation received increases in the summer, the growth of phytoplankton increases, as does the degree of concentration. In the winter, though, the situation is precisely the opposite.

Concerning fig. 2, the months with the highest chlorophyll concentrations are June, July, and August, which form the summer season. Similarly, the months of December, January, and February in the preceding table had the lowest concentration, as these months fall during the winter season. That is why, in fig. 3, the winter season is depicted at the bottom.

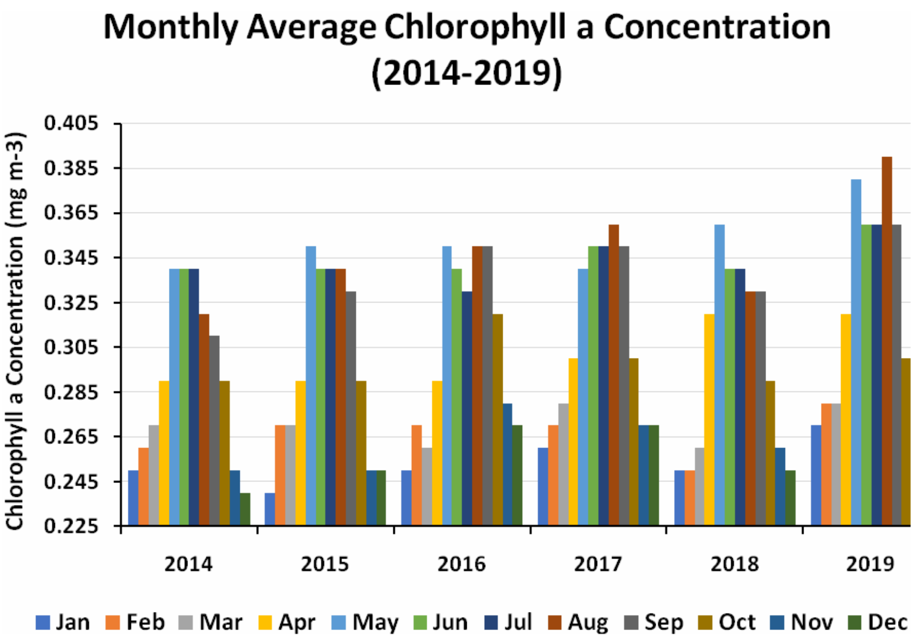

Fig. 2: Mean monthly chlorophyll concentration of the World (2014-2019)

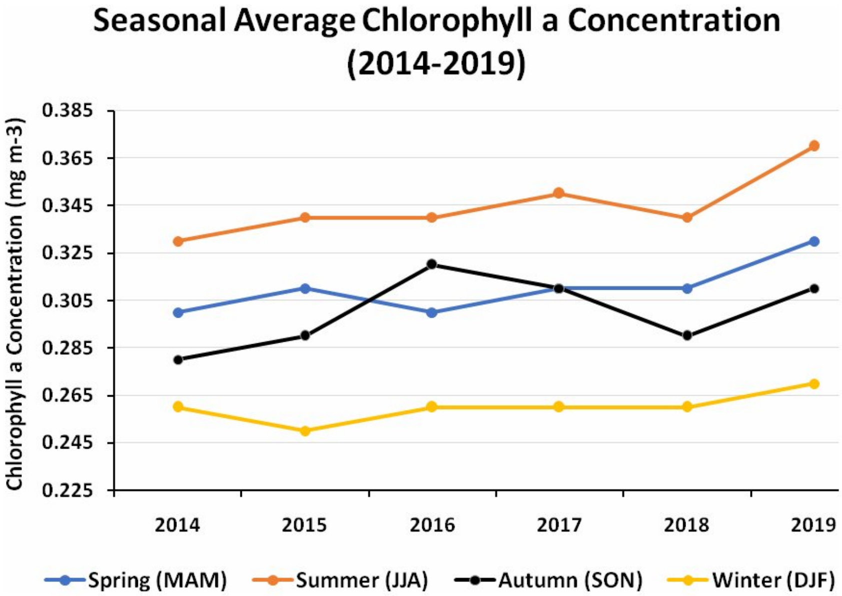

Fig. 3: Mean seasonal chlorophyll concentration of the World (2014-2019)

3.2 FAO Fishing Potential Zones based on Chl-a Concentration

Chlorophyll is an essential component for the identification of fishing zones. Two other components also help in the identification of zones, such as SST and wind. In this study, only chlorophyll is used,and the areas it created of higher and lower fish found are based on the chlorophyll data indeed states that chlorophyll is a significant component.

The chlorophyll content of the World is depicted in fig. 4 using MODIS-Aqua Mission Composite data. Figure 4 shows that the Northern Hemisphere has a higher concentration of chlorophyll than the Southern Hemisphere.

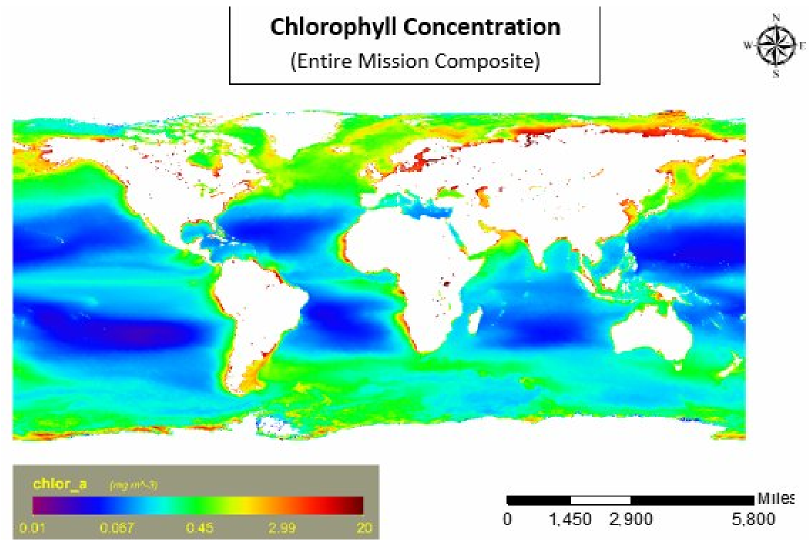

Fig. 4: Composite chlorophyll concentration of the World (2002-2020): NASA Ocean Color (https://oceancolor.gsfc.nasa.gov/l3/)

The zonal statistics are calculated using the fig. 4 and merged with the FAO world fishing zone shapefile to determine the highest and lowest fish occurrence zones in the FAO world fishing zone. There were 19 fishing zones in the World, and these four zones were classified into four groups based on chlorophyll content. The zones have been divided into four groups based on their mean chlorophyll concentrations: low, medium, high, and extremely high. The colour peach represents the very high fishing area, including Arctic Sea-Zone 18 (2.80 mg/m3) and Atlantic Northeast-Zone 27 (2.05 mg/m3). Indian Ocean Eastern (Zone 57), Pacific Southwest (Zone 81), Indian Ocean, Antarctic and Southern (Zone 58), Atlantic, Antarctic (Zone 48), and Pacific Eastern Central (Zone 48) are the lowest Zones, which are represented by a light violet colour (Zone 77).

In fig. 5, it can be seen that locations with a confluence of warm and cold currents, such as zone 27, have a high chlorophyll concentration. In contrast, areas with no confluence of currents have a low chlorophyll concentration. This indicates that ocean currents impact chlorophyll concentration because they transport critical nutrients for phytoplankton growth. Zones with many phytoplankton, such as 18, 21, and 37, have a lot of fishing potential. Newfoundland, which is in zone 21, has the most potential and supply of seafood.

3.3 Temporal variation of the Chl-a of India

In India, as in the rest of the World, the temporal variation of chlorophyll content is as comprehensive. Compared to other months, March, April, and May have lower average chlorophyll concentrations.

Figure 6 of the Interannual Time Series graph of different months in India is shown in fig. 6. The graph clearly shows that July, August, and September have significantly higher chlorophyll concentrations than the other months. In both 2018 and 2019, August had the highest average chlorophyll concentration of 1.48 and 1.02 mg/m3, respectively. May has the lowest concentration of any of the other months, and this is across six years. May's lowest reading was 0.24 mg/m3 in 2015, while the highest was 0.34 mg/m3 in 2016. It is clear from the graph that not every month of the year is the same. In 2015, the line graph of September revealed an average value of 0.46 mg/m3. However, in 2016, the graph flew up to 1.41 mg/m3 average value, making September the highest concentration month of the year. However, it has been steadily diminishing in recent years. This is why predicting future concentration levels is extremely difficult.

Unlike the global seasonal concentration, which does not vary significantly, India's seasonal concentration

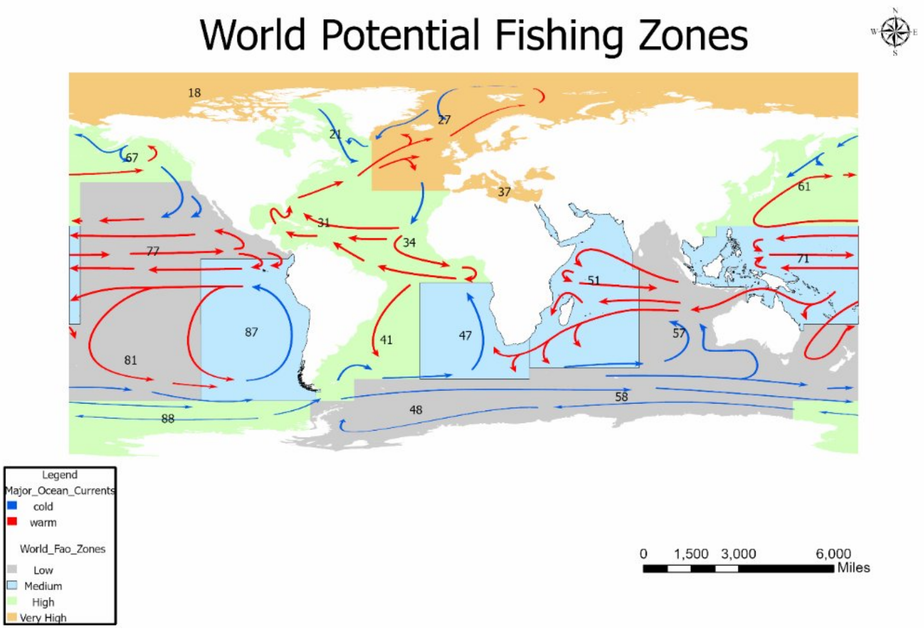

Fig. 5: World fishing potential zonesand ocean currents (extracted from ArcGIS Online Living Atlas using ArcGIS desktop) of 2020.

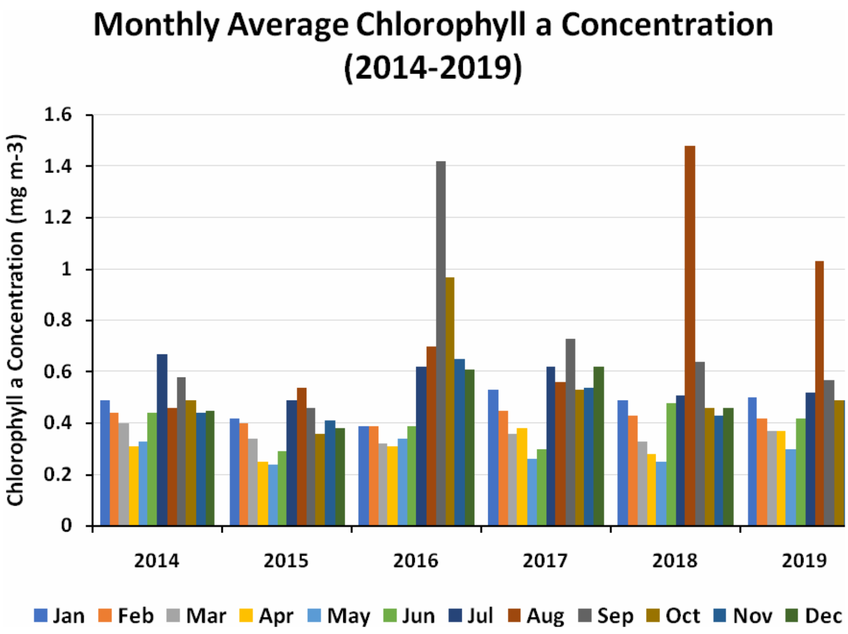

Fig. 6: Mean monthly chlorophyll concentration of Indian Coast (2014-2019)

varies significantly. Only the spring season has maintained its position at the bottom, while the other three compete for the highest concentration.

Spring includes March, April, and May, with the lowest chlorophyll concentration, as shown in fig. 7. As can be seen from the previous graph, all three months had the lowest concentration. Summer and autumn have the highest concentration. Summer in 2018 had the highest value of 0.82 mg/m3, whereas spring in 2016 had the highest value of 1.01 mg/m3. We can

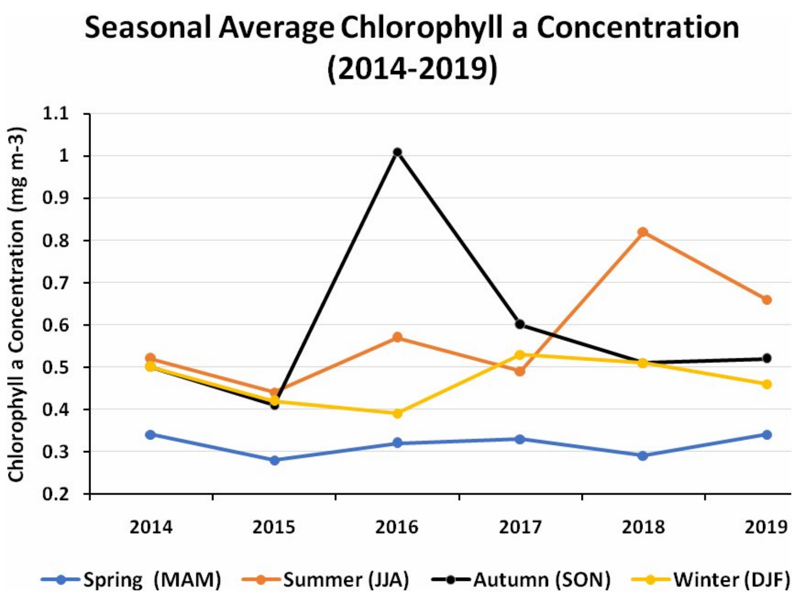

Fig. 7: Mean seasonal chlorophyll concentration of Indian Coast (2014-2019)

see from the preceding graph that August and September have the highest average monthly concentrations, which explains why the summer and spring seasons are influenced mainly by these two monthsand have the most significant concentrations.

3.4 INCOIS PFZ based on Chl-a Concentration

The Indian fishing zones have been classified into 11 zones based on coastal states by INCOIS. Each zone has a varied fish potential, primarily determined by the chlorophyll content in that zone or region. More specifically, each zone has a different level of phytoplankton, which changes daily, monthly, seasonally, and yearly. The varying fishing potential capacity of each zone based on the mean chlorophyll has been shown in this study using seasonal chlorophyll data from 2018.

The graph of mean seasonal chlorophyll concentration of probable fishing zones dedicated by the INCOIS is shown in fig. 8. The graph demonstrates that the concentration of chlorophyll is highest in the summer and lowest in the autumn. Kerala has the highest chlorophyll concentration in the summer, followed by South Tamil Nadu. In West Bengal and Gujarat zones, the average chlorophyll content remains relatively constant throughout the year. Kerala's zone has a lot of chlorophyll variation. As can be seen from the graph, each zone has a different fishing capacity during each season.

The ocean colour map of chlorophyll content during the spring season is shown in fig. 9a. In this season, the effect of chlorophyll is shallow, as seen by the map. The PFZ map for the spring season was created using a zonal statistic based on this map. Figure 10a depicts 11 possible fishing zones based on chlorophyll data from the 2018 spring season. The zones are separated into four categories (Very High, High, Medium, and Low). Because of the high chlorophyll concentration, it is easy to see that West Bengal (1.97 mg/m3) and Gujarat (1.97 mg/m3) have the best fishing potential. During this spring season, the other zones are mostly ranging from medium to low.

The ocean color in fig. 9b may be seen to have a lot of green and reddish areas. In comparison to the Bay of Bengal, the Arabian Sea has a higher chlorophyll concentration. This shows that the concentration of chlorophyll is highest in the summer. The higher and lower fishing grounds have been identified using this zonal statistic. The states of West Bengal (2.80 mg/m3), Gujarat (2.96 mg/m3), Kerala (3.97 mg/m3), and South Tamil Nadu (3.07 mg/m3) have more significantfishing potential than the other zones, as shown in fig. 10b. The colour red is used to represent

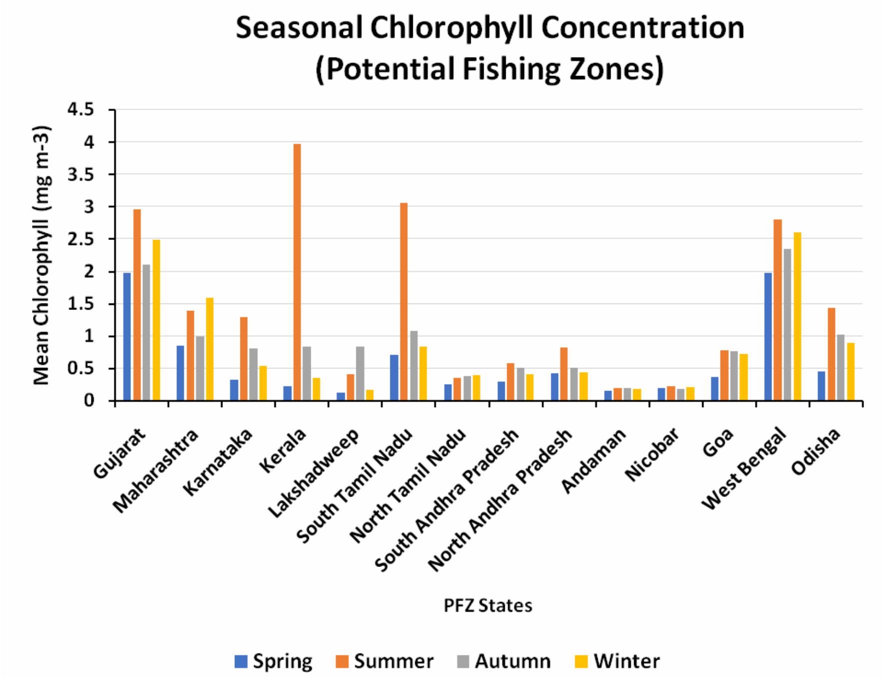

Fig. 8: Mean seasonal chlorophyll concentration of the fishing zones in Indian Coast (2018)

these zones. During this month, only the zones of Andaman, Nicobar, Lakshadweep, and North Tamil Nadu have lesser fishing potential than the other zones.

The chlorophyll content during the Autumn season is depicted in fig. 9c. The greenish colour is equally distributed, indicating that the chlorophyll concentration is stable. The majority of the fishing zones vary from medium to high fishing potential, as shown in fig. 10c. This is the only season in which there are no low-fishing-potential zones along the Indian Coast. Five of the 11 zones are classified as high, while three are classified as medium. Because of the availability of chlorophyll, the fishing potentiality of the Arabian Sea zones is higher than that of the Bay of Bengal zones once again.

The chlorophyll concentration throughout the winter season is depicted in fig. 9d. Near West Bengal, Gujarat, and the Palk Strait, the majority of the greenish and reddish patches can be found. Figure 10d shows that eight of the eleven fishing zones have limited fishing potential. This season, as in previous seasons, West Bengal and Gujarat have the best fishing opportunities. Fishing potential is moderate in the zones of Odisha (0.89 mg/m3), Goa (0.72 mg/m3), Karnataka (0.54 mg/m3), and South Tamil Nadu (0.84 mg/m3).

4.0 Conclusion

Chlorophyll is a crucial component of ocean biology. Based on chlorophyll, one can speculate how much of that area or portion of the ocean has fishing potential. As is well known, chlorophyll determines phytoplankton, indicating if a region or a portion is rich in fish.

Based on Ocean Colour Mapping, this project was primarily used to determine the temporal change of chlorophyll content. This research established that the concentration of chlorophyll varies throughout time, both within months and seasons. This research was conducted on a global scale as well as in India. August and September exhibited a higher chlorophyll concentration than the other months of the year in the mean monthly temporal variation of both the World and India. The sole variation between World and Indian chlorophyll concentrations has been observed: in the World, the lowest chlorophyll concentration is found in December and January, whereas in India, the lowest chlorophyll concentration is found in March, April, and May.

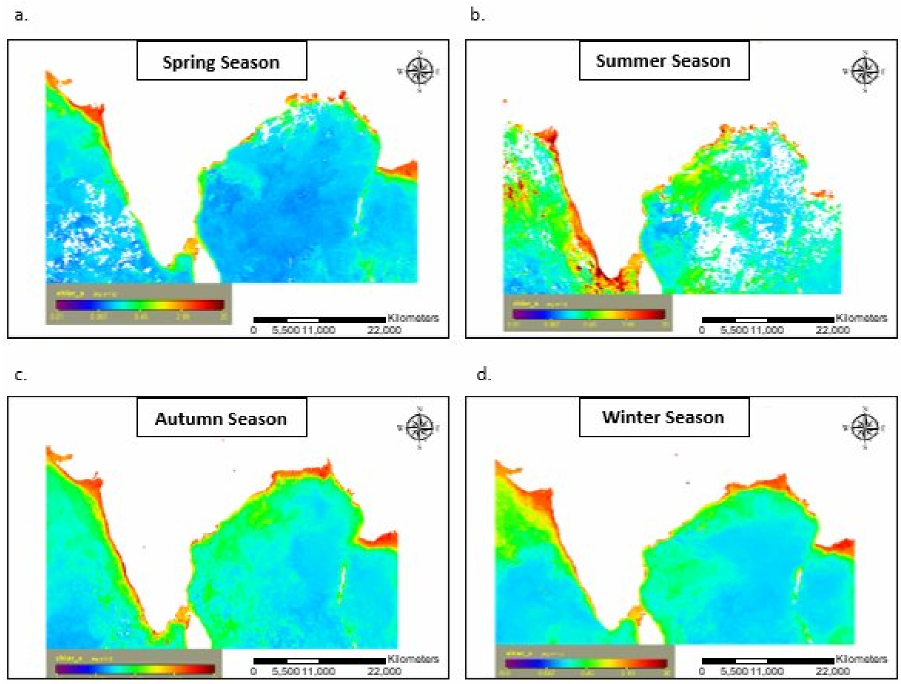

Fig. 9: Ocean colour map showing chlorophyll concentration of Indian Coast: a. spring season, b. summer season c. autumn season, and d. winter season NASA Ocean Color (https://oceancolor.gsfc.nasa.gov/l3/)

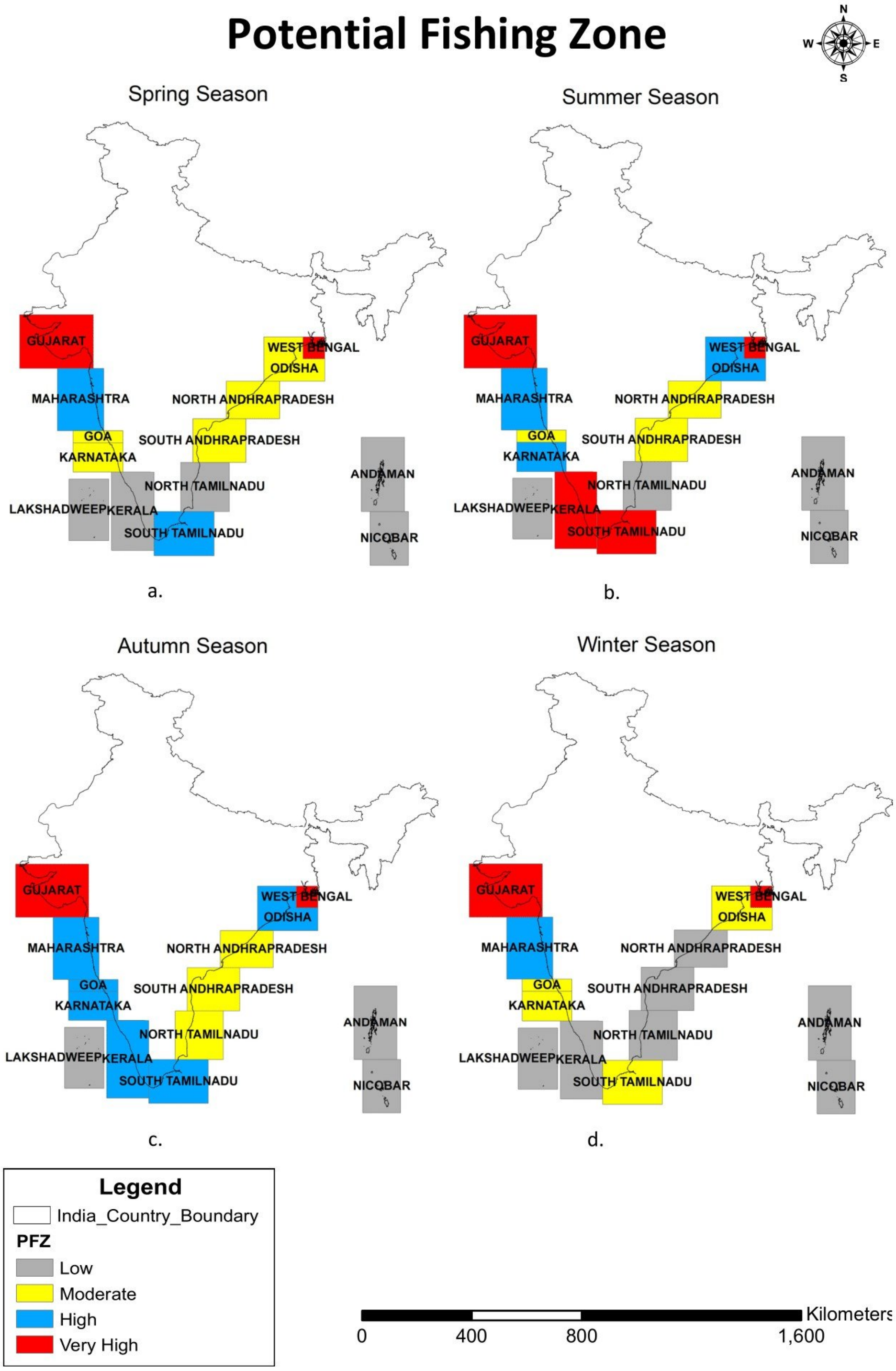

Figure 10: The map showing fishing potentiality zones of Indian Coast:
a. spring season, b. summer season, c. autumn season, and d. winter season

Because monthly chlorophyll concentrations vary, seasonal chlorophyll concentrations must vary as well. A temporal analysis was conducted for both the World and India to determine the change in mean seasonal chlorophyll concentrations. In the instance of global seasonal concentration, the graph was straightforward to understand, with the highest concentration occurring during the summer and the lowest during the winter. However, the summer and autumn seasons compete for the highest concentration in India, while the spring season has the lowest concentration.

The project's second phase involved determining potential fishing zones based on chlorophyll concentration. The governments of the World and India have previously identified fishing zones, but the question was which zone had the best fishing potential compared to the others. INCOIS separated Indian coastal region into 11 fishing zone, whereas the FAO defined 19 fishing zones from the world. Composite data was utilised to determine fishing potentials in the instance of the World MODIS-Aqua project. To distinguish amongst the zones, a unique colour combination was used. Peach denoted a high level of fishing potential, whereas light violet denoted a lower level of fishing potential. The overlaying of the ocean current shapefile over the fishing potential zones helped us understand that places where warm and cold currents meet are areas with abundant phytoplankton, implying more significant fishing potential. The theory existed, and this map demonstrated it to be correct. Another notion circulating was that tropical waters had lower chlorophyll concentrations than temperate and polar oceans. The potential fishing map proved that the theory was correct, with polar oceanic areas having more significant concentrations and tropical areas having lower concentrations.

MODIS-Aqua seasonal chlorophyll data from 2018 were used to create Indian fishing potential zones. The fishing potential of each zone changes with each season, according to this study. West Bengal, Gujarat, Lakshadweep, Andaman, and Nicobar were the only zones that did not alter the seasons. West Bengal and Gujarat had higher fishing potential in all seasons, while Lakshadweep, Andaman, and Nicobar had lower fishing potential. According to earlier studies, the Arabian Sea has a higher chlorophyll content than the Bay of Bengal. This aspect was also demonstrated by this fishing potential zone, as the maps show that the prevalence of lower fishing potential zones based on chlorophyll data is substantially higher in the Bay of Bengal than in the Arabian Sea. West Bengal and Gujarat have higher chlorophyll-a concentrations than other zones, which increases their fishing potential. This is due to shallow and stable water currents and mangrove forests, which makes the ground suitable for fish breeding.

The study has limitations in that it focuses exclusively on chlorophyll content rather than on other critical characteristics (e.g., SST). Although this type of study is highly dependent on in-situ data, access to those data is not always possible, which is why the study could not be validated using in-situ data.

This study demonstrates a strong case for future research. Other characteristics such as SST and wind speed, in addition to chlorophyll, will be able to provide more detailed findings. Numerous coastal countries engage in marine fishing, so an extensive evaluation of possible fishing zones based on chlorophyll content will benefit them significantly. Estimating chlorophyll changes daily can assist in identifying places with chlorophyll irregularity due to climate change and natural hazards such as cyclones.

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