www.trjfas.org
ISSN 1303-2712
*Turkish Journal of Fisheries and Aquatic Sciences 15: 923-930 (2015)* DOI: 10.4194/1303-2712-v15_4_16

# Indicator Based Ecological Health Analysis Using Chlorophyll and Sea Surface Temperature Along with Fish Catch Data off Mumbai Coast

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Received 11 August 2015
Accepted 31 December 2015

**Abstract**

The dense population of the metropolis Mumbai, exerts a lot of stress on the overall ecosystem including coastal zones. Authors have attempted to study the coastal ecosystem health using long term chlorophyll-a and Sea Surface temperature (SST) trends from 2003-2012. Remotely sensed data has been used for this study because of its proven advantages. MODIS data has been used to estimate the chlorophyll-a and SST trends. Fish catch data is plotted and its correlation using Pearson Correlation technique is used for Chlorophyll and SST data around Mumbai.

The study area was divided into zones based on the variations observed during field visits in the ambient water conditions; these zones are 0-15 km, 15-30 km and 0-30 km zones. In the 0-15 km zone, Pearson correlation coefficient for chlorophyll-a with fish catch data was found to be 0.06 whereas for the 15-30 km zone it was found to be comparatively higher at 0.46. But in the 0-30 km zone the correlation coefficient of chlorophyll-a with fish catch was found to be 0.4. SST correlation with fish catch was found to be highest in the 0-15 km range at 0.47.

*Keywords*: Remote sensing, fish catch, chlorophyll, suspended particulate matter, sea-surface temperature, MODIS, SeaWiFS.

## Introduction

Chlorophyll pigment concentration has been used by researchers as an index of phytoplankton biomass whereas Sea Surface Temperature (SST) explains the ocean environment suitable for productivity. Both of these parameters can be measured from remote sensing and can help in explaining the oceanic environment and availability of food resource in an ecosystem for fishery resources exploration (Solanki *et al*., 2001). Coastal zones are highly productive and very accessible to human population (Beatley *et al*., 2002). Mostly in the developing countries, high population growth has been linked to environmental degradation as the local inhabitants attempt to improve their resource base and economic level through environmental over-exploitation (Commoner, 1991). Degradation of the coastal ecosystem has been attributed to the growing population in these major coastal cities of which soil and water are most affected due to the anthropogenic behavior.

Marine ecosystems are constantly changing and are affected by the surrounding environment, which varies spatially and temporally. Changes in the sea water temperature can be linked to alterations in circulation patterns of the ocean, which affects the direction and speed of the winds. These winds, in turn, are responsible for driving the ocean currents and mix the nutrient rich deep column water with the surface waters which affect the abundance and the distribution of the planktons (Vivekanandan and Jeyabaskaran, 2010). Changes in temperature of water, ocean currents and other ocean conditions caused due to global climate change, is expected to affect the productivity of marine fisheries. Food security could be affected due to changes in the geographic distribution of available fish, as marine fisheries are important food source. (Cheung *et al*., 2009)

These changes alter the species composition and will also result in changing of the structure and function for the ecosystem. The changes in species abundance happen in a period of a few years to decades. Longer time duration sometimes also result in changes in the net primary productivity. Many tropical fish stocks are already facing the extremes of temperature and some may face extinction while others may change their location moving toward colder latitudes (Perry *et al*., 2005). Studies have revealed, that in response to climate change, marine fishes and invertebrates tend to shift their distributions

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toward higher latitudes and deeper waters which affects the relative abundance of species as some habitats become less appropriate for them (Cheung *et al.*, 2009).

Photosynthesis is the process in which the energy from sunlight is utilized to generate chemical energy. The key biochemical component responsible for photosynthesis is chlorophyll present in green plant cells. Chlorophyll is present within the living cells of algae and other phytoplanktons that are found in water column in various forms (YSI, 2013). Phytoplanktons are the primary food source of many small pelagic species (Zainuddin, 2004), including fish. The two environmental parameters mostly used in investigations about relationships between the fish abundance and environmental changes are Chl-a concentration which is an indicator of phytoplankton biomass and sea surface temperature (SST) (Diankha, 2013). Since chlorophyll and SST are important parameters for the marine environment, continuous monitoring of these parameters is required to understand the dynamics of the coastal ecosystem.

Monitoring the water quality for understanding the changes in the marine ecosystem, spatially and temporally, has been a challenge. To overcome the challenges, remote sensing techniques have been extensively used which are particularly advantageous to assess the marine environment, where water mass characteristics may vary rapidly and field exercises can be expensive. The synoptic view provided by remote sensing has been considered essential for understanding and monitoring of the water conditions (Howden, 1995).

In the recent past, several studies have been conducted to study the correlation between fish-catch, SST and chlorophyll as mentioned here. Studies correlating SST and chlorophyll-a along with the seasonal variability of *Ethmalosa fimbriata* abundance off Senegal Coastal Waters has been investigated for the years 1999-2009 by Diankha (2013). Pearson correlation has been used for this study. Other study by Pörtner (2010) highlights how changes in environmental conditions influence the spatial distributions of marine fishes and shifts in distributions will result in species gains and losses and changes in fish capture. As suggested by Sumaila *et al.* (2011), ocean warming may also be linked to the increase in abundance of lobsters in deep waters compared to shallow waters in Western Australia. Study conducted by Kizhakudan *et al*., (2014) tries to relate the fish catch directly to the SST using Pearson correlation. This study was conducted for Tamil Nadu, India for a period of 105 years (1906 -2010). Kizhakudan’s work also highlights that very few studies have been conducted for Indian sub-continent on the impact of changes in SST on fish production.

As per Space Applications Center Ahmedabad, India, (2012), approximately 40% of the Indian population dwells within 100 km of its coastline. Majority of the metros in India, like Mumbai, Chennai and Kolkata are coastal cities. Unprecedented increase in human activities in Mumbai and its suburbs has increased the stress on the surrounding marine environment (Sawant *et al*., 2006). It is understood from the literature that there exist a need to study the correlation between chlorophyll and SST with respect to fish catch and this study tries to find that correlation in and around Mumbai. This is achieved by using statistical methods explained in the paper.This study uses satellite based remotely sensed data to calculate SST and chlorophyll-a for a period of ten years (2003 – 2012).

### Study Area

Mumbai lies on the western coast of Maharashtra, Indiafalling within 19° 8' N, 72° 40' E and 18° 48' N, 72° 58' E latitude-longitude coordinates. Climate of Mumbai is predominantly hot and humid. Average recorded ambient air temperature in this region varies from 25 to 42 degree Celsius, (Ranger *et al*., 2011) whereas relative humidity ranges from 54.5% to 85.5% (MPCB, 2005). Mumbai receives rains due to south-west monsoon during the months of June to September. Average annual rainfall in this are aranges between 1500 – 2000 mm. (Gupta, 2005; Ranger *et al*., 2011).

Fishing has been carried out in the coastal belt of Maharashtra and there are many fisher-folk communities dependent on this profession. Increase in fish catch can improve the lifestyle of these fisher folk to a certain extent. Maharashtra is one of the major fish producing states which ranks 4$^{th}$ in India with an average annual marine fish landings of 360,000 Ton during 2001-2010 (Ramchandran *et al*., 2013). Fish catch for Mumbai district according to the data received from the fisheries department of India was found to be ~1.5 lac tonnes for the year 2012 (Department of Fisheries, 2013). Algal bloom has been reported in the west coast of India during the monsoon months and during the February – May period (De Silva *et al*., 2012).

## Materials and Methods

MODIS sensor data and SeaWiFS data have been used for this analysis. Data of monsoon months (June-September) has not been considered for the trend generation as the remotely sensed images had maximum cloud-cover and are unusable. Fish catch data used here has been collected from the Department of Fisheries, Govt. of India. This study aims to find a correlation of Chlorophyll-a with fish catch data and SST with fish catch data.

Reconnaissance surveys and initial analysis of satellite data showed a distinct water front in the ambient waters of the study area. To identify this water front, random satellite images were sampled. Visual interpretation of the visible bands revealed that there exists a front in the ambient water at around

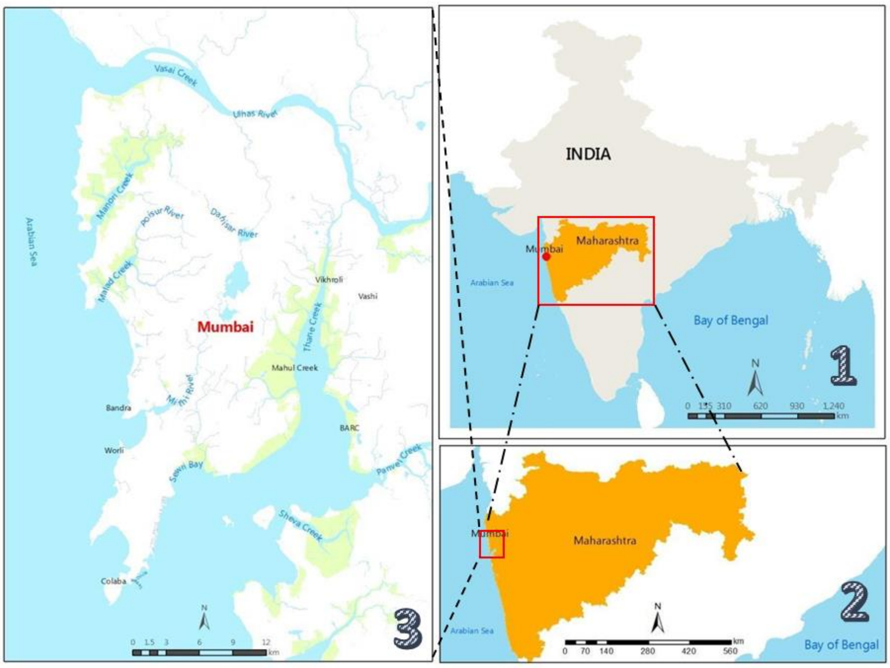


**Figure 1.** Study area (Mumbai coast), (1) India showing Maharashtra state, (2) Maharashtra showing Mumbai, (3) Mumbai.

15km from shoreline. There exists a thermal front at about 30 km from the shoreline as per the study carried out by Azmi *et al*. (2013). Based on these observations two separate zones were demarcated in the study area i.e. 0-15km zone and 15-30km zone.

The study area was divided into two zones, viz.,

1. Near coast zone comprising of area between 0 and 15 km from the coast
2. Far coast zone comprising of area between 15 and 30 km from the coast

A cumulative zone which was studied to observe the difference in the correlations for 0-30 km from the shoreline.

SST and Chlorophyll-a parameters have been calculated using SST algorithm proposed by Minnett (1990) and Chlor_a3 algorithm proposed by Carder *et al*. (1999) respectively. Yearly average for both have been calculated. Fish catch data is plotted against chlorophyll-a and SST and correlation coefficients are calculated. The flow chart depicting the methodology is as shown in Figure 2.Details of the algorithm used for chlorophyll and SST are given below.

### Chlorophyll-a Algorithm (Chlor_a3)

Chlor_a3 algorithm has been found suitable for chlorophyll estimation (Darecki and Stramski, 2004) in Mumbai region (Bhattacharya *et al*., 2010) and is applied to the dataset of duration 2003 to 2012, excluding the monsoon month (June to September). Monthly spatial average for chlorophyll data is calculated for the same duration. The empirical formula for the Chlor_a3 Algorithm given by Carder *et al*.(1999) is given below

Empirical formula (mg/m$^3$):

$$C=10\^{}(a0+a1\times R+a2\times R^2)$$

Where
Band ratio R = log(Rrs488 / Rrs551)
Coefficients: [a0 = 0.289, a1 = -3.2, a2 = 1.2]

### SST Algorithm

SST Algorithm proposed by (Brown *et al*., 1999) was found suitable for the Mumbai region based on study conducted by Azmi *et al*., 2013. Calculation of SST was done in the following manner. First the brightness temperature was calculated from the spectral emissive radiance data using the standard formula for Newton-Boltzmann as given in equation 1.

$$L= 2 * h * c2 * \lambda -5 / [e(h * c / k*\lambda*T) - 1] \quad [1]$$

Where,

$L$ = Radiance (Watts/m$^2$/ steradian/ m)
$h$ = Planck's constant (joule second)
$c$ = speed of light in vacuum (m/s)
$k$ = Boltzmann gas constant (joules/ Kelvin)
$\lambda$ = band or detector center wavelength (m)
$T$ = temperature (Kelvin)

SST was derived from this brightness temperature data. This temperature obtained is the skin temperature ranging from 5-10 micrometer depth of the sea (Brown *et al*., 1999). The algorithm followed for SST calculation is MODIS-SST ECMWF (European Centre for Medium-Range Weather Forecasts) based model, which has been preferred to the radiosonde-based model which has a similar structure but different coefficients are used.

The algorithm is as given below:

MODIS _SST = c1 + c2 * T31 + c3 * T3132 + c4 * (sec(θ) -1) * T3132

Where,

T31: is the band 31 brightness temperature (BT)

T3132: is (Band32 - Band31) BT difference

θ: is the satellite zenith angle

This buffering has been done, based on in-situ observations, so that the coastal waters and the deeper waters can be dealt separately as the water quality is different in these areas. The correlations were calculated separately for these zones. After calculating the SST, it was averaged for a 5 km area and then the monthly average SST was calculated.

### Pearson Product-Moment Correlation Coefficient

The Pearson product-moment correlation coefficient is a statistical measurement of the correlation (linear association) between two sets of values. The Pearson product-moment correlation coefficient (Lane *et al*., 2008) for two sets of values, x and y, is given by the equation (2):

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad (2)$$

where x and y are the sample means of the two arrays of values.

If the value of r is close to +1, this indicates a strong positive correlation, and if r is close to -1, this indicates a strong negative correlation. Pearson correlation has been used in this study as it was suitable for current dataset. Fish catch is considered to be the dependent variable whereas chlorophyll-a and SST are considered as independent variable.

## Results and Discussions

The decadal trends of the ocean color parameters like Chlorophyll-a and SST have been determined. The trends for the study area have been generated from MODIS daily images from October 2003 till May 2012 depending on data availability. Daily images have been used to generate monthly mean and standard deviation images. The graphs (Figure 3, Figure 5) show the trend of near coast, far coast and complete study area of all values of chlorophyll and SST from October to May and the fish catch data in metric tons. As the fish catch data was not available seasonally, chlorophyll and SST data was also

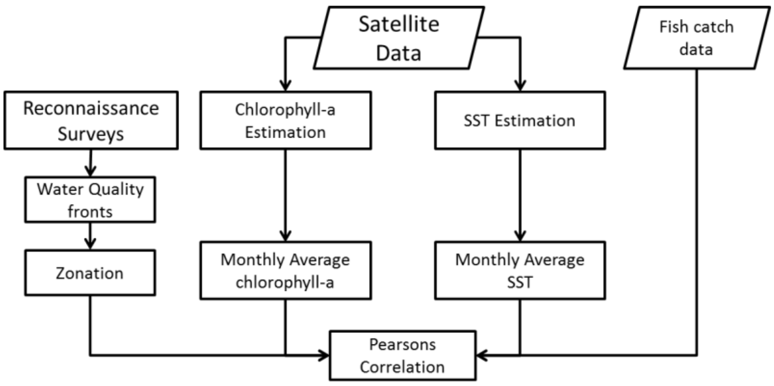


**Figure 2.** Flowchart of the methodology followed for the study.

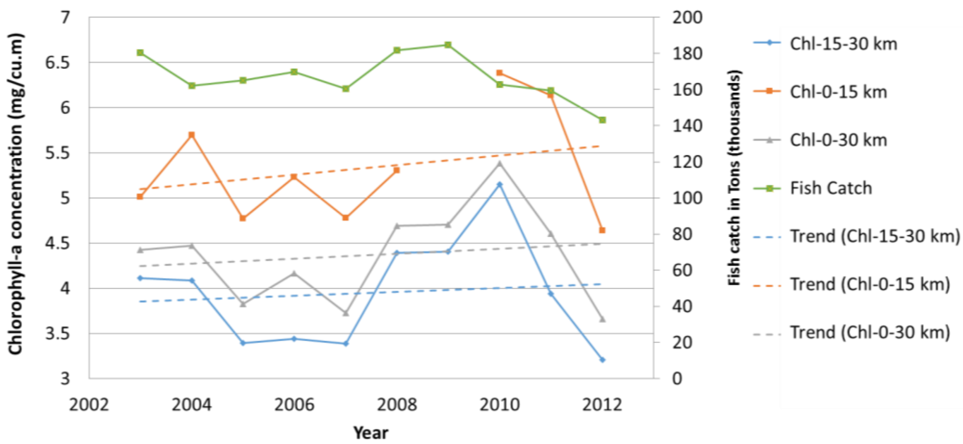


**Figure 3.** Graph showing chlorophyll-a conc. (mg/m$^3$) and fish catch (thousand metric tons).

categorized accordingly.

**Chlorophyll-a**

Chlorophyll-a dataset are plotted for a period of 10 years starting from 2003 till 2012. The chlorophyll trend shown in the Figure 3 depicts the zonal values of chlorophyll-a and the corresponding fish catch data for that year. Chl-0-15 km is the coastal zone of 0-15 km, Chl-15-30 km is the deep sea zone of 15-30 km and Chl-0-30 km is the 0-30 km zone. Fish catch data is shown in the secondary axis of the graph.

It can be seen from Figure 3 that the coastal values are higher when compared to the deep sea and the overall 0-30 km zone. All the chlorophyll values are seen to be increasing for the year 2008 to 2010 after which there has been a decline in chlorophyll-a concentration.

The correlation between chlorophyll-a and fish catch for the coastal zone is lower compared to the remaining two zones as seen from Table 1. This could be because of the sediment load carried in Mumbai region by the storm water drains. During monsoon there is a lot of sediment load that is carried along with other nutrients into the sea.

Figure 4 shows higher spread of chlorophyll-a. Chlorophyll-a concentration data ranged from 0.3-3.9 mg/m$^3$. Sediment load carried during the monsoon along with the nutrient can be a reason for this increase. The areal spread of chlorophyll-a is seen to be increased in the southern portion of the study area as depicted in the image. This is because of the Ulhas River and Mahul, Thane creeks flowing in this area. These water bodies can be attributed in contributing to the sediment load from the terrigenous sources. In the mid portion of the study area, the spread is reduced as there are no significant water bodies that contribute to the ocean.

**Sea Surface Temperature**

Factors such as SST are expected to affect either directly or indirectly, the distribution of marine species, including those that are targeted by fisheries. Sea Surface Temperature has been calculated from the brightness temperature data using MODIS dataset. This is the sea surface skin temperature ranging from 5-10 micrometer depth (Brown and Minnett, 1999). MODIS-SST ECMWF (European Centre for Medium-Range Weather Forecasts) based model is the algorithm implemented for SST calculation.

The graph in Figure 5 shows the SST values in the near, far and cumulative zones from the coast overlaid with fish catch data. The graphs shows the SST data plotted from 2003 to 2012. SST-0-15 km is the coastal zone of 0-15 km, SST-15-30 km is the deep sea zone of 15-30 km and SST-0-30 is the 0-30 km zone. Fish catch data is shown in the secondary axis of the graph. It can be seen from the graph that the ideal temperature for fishes is between 27.9 to 28.2° C. It can be inferred that, in this temperature range the fish catch has increased. Increase of temperature above 28.2 and decrease in temperature below 27°C has resulted in decline in fish catch.

Table 2 shows the correlation of SST with Fish catch data. The correlations show that SST is highly correlated to fish catch in the 0-15 km stretch whereas the correlation is lower away from coast and lowest in the cumulative zone.

Chlorophyll-a is found to be highly correlated with fish catch in the zone away from the coast, while, around the near coast zone there seems to be little or no correlation between these two parameters. Reason for this decline could be attributed to the interference of high suspended particulate matter concentrations in these waters (high sediment load coming from the land) affecting the accurate estimation of chlorophyll from satellite data. Increased sediments can hinder the estimation of chlorophyll (Han, 1994). Overall, in the 30 km stretch chlorophyll is better correlated as compared to SST.

Figure 6 shows December 2004 SST image for the study area. Points 1 and 2 marked on the map are the hotspot locations that have been marked from the SST data. These areas have warm masses of water in the Thane creek and Mahul creek that lie on the eastern Mumbai. This could be due to the discharge from industries located in the North/North-east of Mumbai region (MCGM, 2005). The observations of Azmi *et al*. (2013) from the SST images clearly suggest anthropogenic interferences by sources of thermal pollution. The distance from the coast is found to have an inverse correlation with the variation in SST. SST variation is found to decrease with increase in the distance from the coast, which implies that maximum possible variation in SST is near the coast; whereas away from the coastline, the waters are found to be very stable. During December, the area near Vashi Creek was found to be less warm as compared to the waters 5 km off the coast. Overall temperature has been found to be increasing within the short span of 7 years (2004–2010) in the coastal waters, which excludes the year 2006, which was a La Niña year.

## Conclusions

There are several conclusions that can be drawn from this study with regards to Chlorophyll-a, SST and fish catch. For the chlorophyll-a parameter, it has been observed that fish catch shows a better correlation in deep sea clear waters as compared to the near shore turbid waters. Chlorophyll has increased during 2008 and 2009 which is also reflected by the increase in fish catch during the same period. Chlorophyll and fish catch has declined for the period of 2010 - 2012.

Currently, it is not easy to quantify the fish catch fluctuations with in-depth analysis of phenology and fish species distribution due to data constraints. A

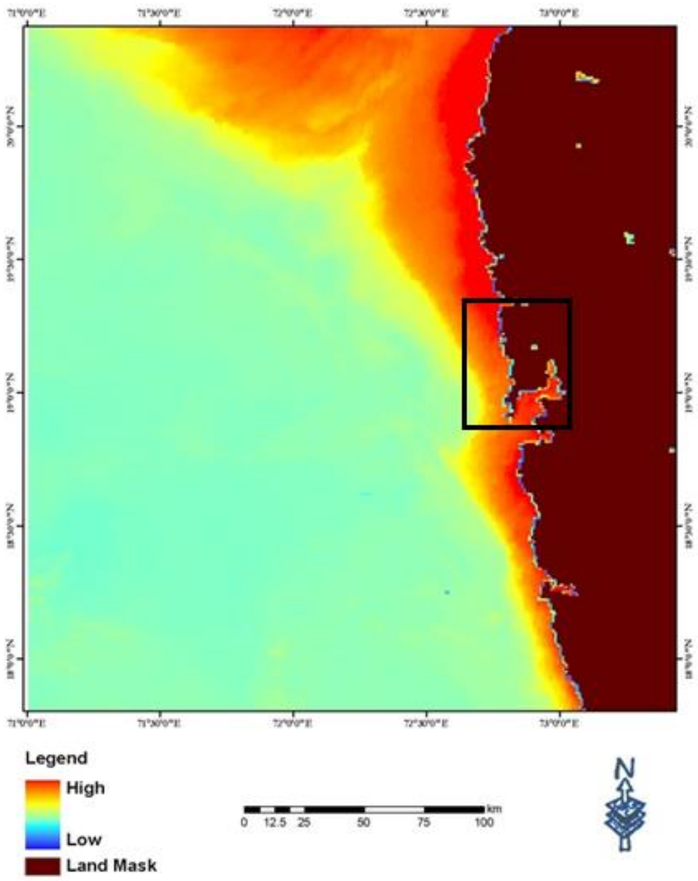


**Figure 4.** Chlorophyll-a concentration for the year 2003 using Chlor_a3 algorithm.

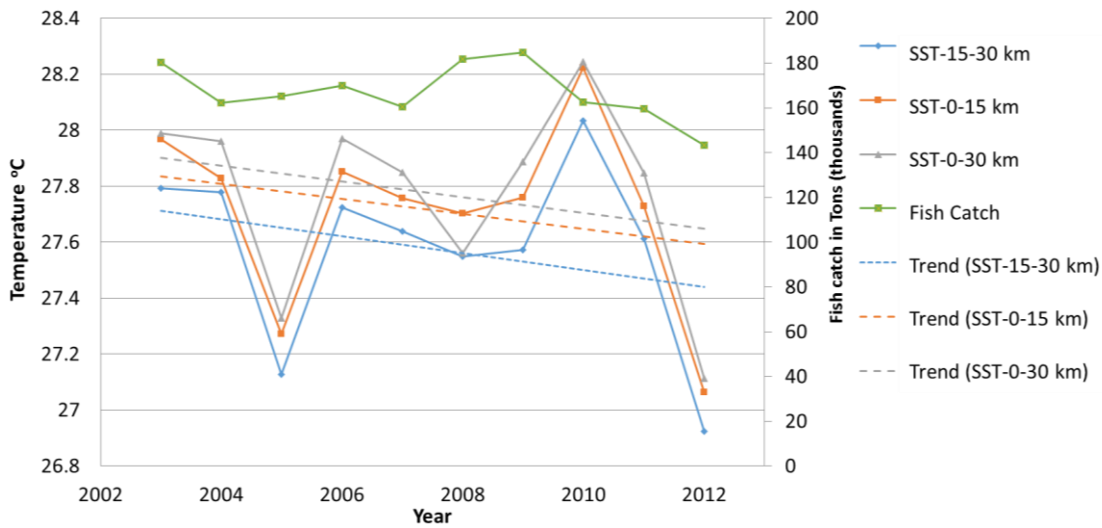


**Figure 5.** Graph showing Sea Surface Temperature and its average value with fish catch data.

**Table 1.** Pearson's Correlation coefficients

| Distance from Coast (km) | Chl-a vs Fish Catch |
|---|---|
| 0-15 | 0.065258 |
| 15-30 | 0.460036 |
| 0-30 | 0.431066 |

**Table 2.** Pearson's Correlation coefficients

| Distance from Coast (km) | SST vs Fish catch |
|---|---|
| 0-15 | 0.470359 |
| 15-30 | 0.420842 |
| 0-30 | 0.383855 |

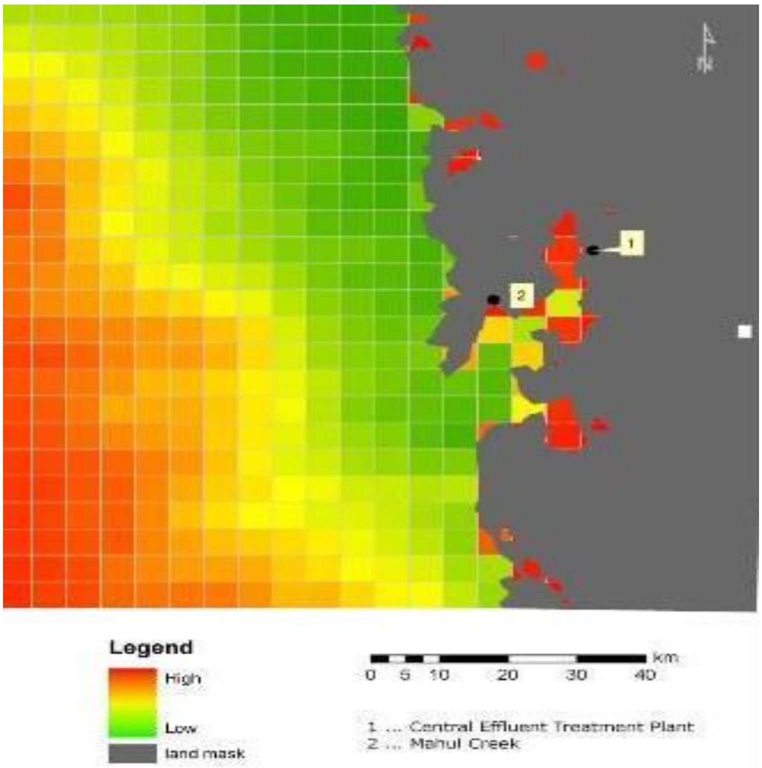


**Figure 6.** December 2004 SST image.

report by MoEF (2010) stated that time-series analysis on fish stock biomass of different species does not exist along the Indian coast. Based on the correlation coefficients it can be concluded that around the near shore areas, SST is a better indicator of fish yield as compared to chlorophyll-a. The condition for fish breeding is more suitable in clear waters within a certain ambient temperature range. Around the 15-30 km clear water stretch, fish catch has a good correlation with both chlorophyll-a and SST. Correlation coefficients also point that chlorophyll-a and SST can be used as parameters for further modeling of fish production in this area with threshold on SPM concentration. Station-wise fish catch data if available can be used for zonal correlations.

As pointed out in the discussion, it is evident from the previous studies (MCGM, 2005, Azmi *et al.*, 2013), that there is discharge in the ocean from the industries located in the North/North-east regions of Mumbai, which are affecting the water quality and this phenomena may affect the fish catch. Detailed data pertaining to exact fish catch location (boat location) along with species wise distribution can make the correlations better representative of the ground truth in the study area, which can lead to significant improvement in species-wise predictions.

## Acknowledgments

Authors would like to thank the Dept. of Fisheries, Govt. of Maharashtra, India for fishery data; NASA for data support and IIT Bombay for infrastructure. The MODIS Terra data is courtesy of the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/data_access)

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