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Eutrophication Potential Modelling Using Geographical Information System and Fuzzy Logic

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Abstract - This paper attempts to model the eutrophication potential of the Mumbai coastal waters during winter season using Geographical Information System and Fuzzy Logic. The study gives insight to the environmental impact of the system due to excessive growth of algae in different trophic areas. These areas are part of Arabian Sea with huge primary production that aids in the economic development of the country. The study uses in-situ methods to determine the primary factors that are responsible for eutrophication and determine Chlorophyll concentration changes during the pre-winter and post-winter period thus analyze the natural phenomena of seasonal upwelling. In-situ methods will be used to measure the quality attributes of the ocean water, with the help of chemical laboratory. Empirical relationship is to be derived between Chl-a concentration and other primary factors that aid in algal growth. Potential modelling will be done with the help of Geographic Information System (ArcGIS) and Fuzzy Logic (Matlab). Different weightages are given to the predictor maps based on the data analysis and maps are overlaid based on the weightages, generating areas that have high Chl-a potential. Fuzzy logic comprises of two methods; Mamdani Fuzzy Inference System and Sugeno Fuzzy Inference System. Mamdani uses conceptual model to generate fuzzy inference and Sugeno uses empirical relationship developed between data regarding eutrophication and other primary factors. The models are tested for each of these regions with the help of in-situ Chl-a data, and their behavior is analyzed. The study also emphasizes on changes in trophic levels before and after the phenomena of seasonal upwelling in Arabian Sea.

Keywords: Eutrophication, Index Overlay, Mamdani, Sugeno Fuzzy Inference System, Upwelling

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1.0 INTRODUCTION:

Every pollution in the planet ends up in a single destination, the ocean, contamination of coastal marine waters are of higher degree than of any other natural resource. The chemical waste and the nutrients supplied by natural phenomenon of upwelling, especially the Nitrogen and Phosphorous compounds, accelerate the flora growth and lead to eutrophication. Eutrophication is a natural process characterizing excessive algal growth due to nutrient supply to the water bodies. Based on the concentration of chlorophyll concentrations the water bodies are termed as eutrophic, mesotrophic and oligotrophic.

Nitrogen compounds such as Nitrate (NO_3), Nitrite (NO_2) and phosphorous compounds such as phosphates (PO_4), both in dissolved and suspended form are the major nutrients that cause marine pollution (Nixon, 1995). An increase in the temperature up to a certain threshold value will result in increased phytoplankton growth rates. As the algal growth increases the DO concentration (Dissolved Oxygen) reduces and based on that we term the coastal pollution as mesotrophic: DO greater than 7ppm, eutrophic: DO falls between 5 to 7ppm, hypereutrophic: DO less than 4ppm (Kitsiou and Karydis, 2001). Euphotic depth is the depth of water at which rate of plant or algal respiration exactly balances the rate of photosynthesis and is an indicator of eutrophication (Tyler, 1968).

The best way to determine the algae population density is to measure the Chlorophyll-a concentration. Predictor maps, those are likely to be good predictors of the chlorophyll concentration, with different weightages are the building blocks of potential modelling. The classes of each reclassified maps can also be given various weightages based on the effect on the output. The assignment of weights can either be carried out using statistical criteria, using an actual study region to estimate the spatial relationships between predictor maps and the response map, or the weights can be estimated on the basis of expert opinion. In contrast with traditional logic theory, where binary sets have two-valued logic: true or false, fuzzy logic variables will have a truth value that ranges in degree between 0 and 1 (Bonham-Carter, 2002). In this study, we determine the eutrophication potential of the study area with a station based modelling approach using GIS and Fuzzy Inference System in Mumbai coastal area for the period of December 2011 to April 2012.

2.0 STUDY AREA:

The coastal waters off the shore of Mumbai are part of a very-resource rich stretch of the Arabian Sea with bi-annual productivity blooms. The study area lies on the western coast of India, comprising of the coastal and offshore waters off the coast of Mumbai, roughly falling between the latitude-longitude coordinates: 19°04′23′′N, 72°58′41′′E and 18°53′17′′N, 72°46′57′′E. The study area is divided into

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eighteen different stations to collect the in-situ data. For the station based approach, the parameters collected in each station at a given time are assumed to be homogeneous throughout the station and resembles the attributes of the station. The stations are Bandra Outfall (a), Bandra Outfall (b), Mahim Bay, Worli Outfall (a), Worli Outfall (b), Haji Ali Point (a), Haji Ali Point (b), Back Bay, Southern Point (a), Southern Point (b), Collaba Outfall, Gateway of India, Mumbai Port 1(a), Mumbai Port 1(b), Mumbai Port 2, Trombay Jetty, Thane Creek (a), Thane Creek (b).

3.0 MATERIALS AND METHODS:

The in-situ data consists of analytical measures of various concentrations of nutrients, Euphotic Depth, Sea Surface Temperature, pH, Dissolved Oxygen (primary factors) and Chl-a concentrations (output). The water samples collected from various stations are analyzed in the Coastal and Marine lab. The factors are used as inputs for various potential modelling techniques. Various tests used to determine the primary factors are explained in **Table 1**.

For approaching potential modelling there are two types of potential models called data-driven and knowledge-driven. In data-driven modelling, the various input maps are combined using models such as logistic regression, weights of evidence or neural network analysis. Knowledge-driven models include the use of expert opinion or data acquired from literature surveys, fuzzy logic, etc. In this study we will be using basic knowledge driven approaches like Index overlay method and Fuzzy Logic.

A. Index Overlay Method

To create a predictor map for Index overlay, the in-situ data collected from each station has to be converted to shape files. Convert the data into shape files and then convert them into raster maps. The Index overlay method support only integer raster. Hence floating raster is converted to integer raster through reclassification. Each class in a reclassified map can be given different scores based on how they affect the potential. In applying Index overlay approach to the mapping of eutrophication, subject knowledge and expert opinion is required.

Each map is multiplied by its weight factor, summed over all the maps being combined and normalized by the sum of the weights. The result is a value ranging between 0 and 1, which can be classified into intervals appropriate for mapping, At any location, the output score, S,

$$S = \Sigma W_i \text{ class } (MAP_i) / \Sigma W_i$$

(Eq.1.1)

Where $\mathbf{W_i}$ is the weight of the i-th map, and **class** $\mathbf{(MAP_i)}$ is either 1 for presence or 0 for absence of the condition.

For eutrophication potential modelling nutrients get the highest weightages. Nitrates and phosphates are the driving factor and the most important factor of eutrophication. As the amount of nitrates and phosphates increases to a large extent water changes from eutrophic to hypereutrophic (Karydis *et al.*, 1983). Due to this reason the nitrates and phosphates get weightages of 2 out of 10. The nitrites are also a factor that aids in eutrophication as in higher pH nitrites tends to convert to nitrates and hence gets a weight of 1. The euphotic depth is the best indicator of eutrophication and suspended pollutants in the sea water (Tyler, 1968). Due to this reason the euphotic depth is a primary indicator and hence will have a weightage of 1.5 out of 10. The optimum temperature for phytoplankton growth is 24-26^{0}c in the tropics. The growth of phytoplankton reduces slightly when there is a deviation of temperature from optimal value in both the directions. As temperature is not as important as nutrients it gets a weightage of 1. The dissolved oxygen should be above 10 ppm to consider the marine water as not polluted (Ignatiades *et al.*, 1992). Hence low DO is an indicator of eutrophication and gets a value of 1. The reduction in pH in shallow coastal waters increases the growth of phytoplankton. As pH of coastal water reduces, more algal growth is assured and gets a weightage of 1.5. The attribute tables for predictor maps are explained in **Table 2**.

B. Potential Modelling Using Fuzzy Logic

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. *Mamdani-type inference*, expects the output membership functions to be fuzzy sets and Sugeno-type inference expects output membership function to be linear (Bonham-Carter, 2002). For eutrophication modelling five input membership functions are selected and one output membership function. The inputs are Nitrates, Phosphates, Euphotic depth, pH and SST. The output is eutrophic potential. Each inputs and output is divided further into low, average and high based on the concentrations. Steps for both types of fuzzy inference modelling are explained below. (Mathworks R2012a Documentation, 2012).

Step 1: *Fuzzify Input-* The selection of membership function is subjective. The membership functions selected for eutrophication modelling are Gaussian and triangular. Gaussian function are used when Smooth and concise notation is required and 67% of values fall in between the range of mean + or – standard deviation. Gaussian functions were assigned to Nitrates, Phosphates, Temperature, and Output. pH and euphotic depth were associated with triangular function.

Step 2: *Apply Fuzzy Operator-* The logical operators that we used for our analysis are Fuzzy AND. For AND operator output map is controlled by smallest fuzzy membership value. Hence it is pessimistic in nature. 15 out of 35 rules applied for eutrophication potential modelling are described on **Table 3**.

Step 3: *Apply Implication Method-* The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Eutrophication modelling was done by minimum implication function for a pessimistic approach and to get the areas which are highly suitable.

Step 4: *Aggregate All Outputs-* Decisions are based on testing of all the rules in a FIS. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Three methods are used. They are max (maximum), probor (probabilistic OR), sum (simply the sum of each rule's output set). Potential modelling prefers max operator as it gives the output for the larger area of the curve and when defuzzified it averages the output.

Step 5: *Defuzzify*- The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. The most popular defuzzification method is the centroid calculation, which returns the center of area under the curve and eutrophication potential modelling uses the same method for defuzzification.

The steps of implementing Sugeno fuzzy systems are similar to Mamdani systems except the output is linear. For Sugeno method, output membership function has to be derived from an existing data. Hence a database was created from MPCB report on “Monitoring of Coastal Marine and Estuarine Ecology of Maharashtra- Phase 1” (2009). The inputs are Nitrates, Phosphates, Euphotic depth, pH and temperature for the month of March, 2008. The output is average Chlorophyll concentration for the same month. The data were collected for 31 different stations. They are classified into low, average and high chlorophyll concentration. **Table 4** contains the database of primary factors obtained from the MPCB report.

The linear relationship that exists between independent variables and one depended variable are

$Y= a1X1 + a2X2 + a3X3 + a4X4 + a5X5 + constant$ (Eq.1.2)

Y is chlorophyll concentration and X1, X2, X3, X4, X5 are Nitrates, Phosphates, Euphotic depth, pH and temperature for the month of March. The five parameters and the output are subjected to multiple regression analysis with least square fit and hence determined. The linear coefficients of the primary factors for the Sugeno method are explained in **Table 5**.

4.0 RESULTS AND DISCUSSION:

Three methods are used to determine the eutrophication potential model. They are Index overlay potential modelling, Fuzzy Inference Systems which include Mamdani and Sugeno type fuzzy inference systems. The results are detailed below.

A. Index Overlay Potential Modelling Results

The shape files of the primary factors are converted to raster map using inverse distance weighing method. The raster predictor maps formed for the analysis are Nitrate, Nitrite, Phosphate, Dissolved oxygen, Temperature, pH, Euphotic Depth map. Specifying a lower power in IDW such as 2 will give more influence to the points that are farther away. **Figure 1(a), 1(b), 1(c), 1(d), 1(e), 1(f), 1(g)** are the Nitrate, Nitrite, Phosphate, DO, SST, Euphotic depth, pH predictor maps respectively. **Figure 2** represents the potential map using Index overlay.

Using index overlay method the potential of each area is determined. Stations such as Thane creek (a) and (b) and Haji Ali point (a) and (b) have high eutrophic potential. A small

For the analysis and validation of results the in-situ chlorophyll concentrations are estimated for the month of December, January and April. The Chl-a is calculated for each station and for the exact geographic co-ordinates. In the month of December a small part of one station, Thane creek was

portion of Back Bay also has high eutrophic potential and can turn eutrophic when there are plenty of nutrients available during the upwelling. The Gate way of India station, a small part of Worli and Bandra outfall area has the least potential mainly due to low nutrient available and high pH which restricts the growth of plants. Other twelve stations have average potential and can turn eutrophic in the coming months if optimum conditions prevail for a longer time.

B. Fuzzy Logic Based Potential Modelling Results

Using Mamdani method eutrophication potential of Thane creek is 7.3/10 which is the highest output as the best and optimum conditions for the growth of phytoplankton exists there. Similarly the potential for each station are determined by this method. When Sugeno method was adopted there is a significant decrease in potential of many places and certain places have improved their potential comparatively from potential of Mamdani method. This is because the output is based data from the month of March, 2008. A threshold value of 3 is applied to the output to separate high and low potential. Thane Creek, Mumbai port, Back Bay and Haji Ali point have higher potential. The highest potential is for Haji Ali point with 3.3/10. The eutrophication potential of various stations determined by Mamdani and Sugeno method is shown in **Table 6**. **Figure 3** and **Figure 4** represents the potential map generated by Mamdani and Sugeno method respectively.

Output of the three methods had many things in common. Eutrophication potential was highest for Thane creek and second highest for Haji Ali point. In all the three potential model analysis Thane creek and Haji Ali point has high potential. This is because there are very high concentration of nitrates and phosphates in this area. (375, 390) for Haji Ali Point and (360, 423) in Thane creek. The pH falls in optimum range (7.3-7.5) in these two areas for plant growth. Thane creek has low Euphotic depth (1.5 m) compared to Euphotic depth of Haji Ali point (1.7 m) but the Sea surface temperature is optimum of 25^0c for Haji Ali point compared to high temperatures of Thane creek.

5.0 ANALYSIS OF RESULTS:

All the three results can be subjected to further analysis. The areas of higher potential are intersected to determine the areas with very high potential and certain of getting eutrophic after the upwelling. The raster maps are converted back to shape files and are intersected to generate the final potential map. The highest eutrophication potential is for Thane Creek (a) and (b) and Haji Ali point (a) and (b). These stations risk the situation of eutrophication. Stations such as Southern point, Collaba outfall, Gateway of India has lowest potential and hence should be safe from eutrophication and its adverse effects. All other stations have average potential and hence are uncertain about the condition of the coastal water quality in the month of April, 2012.

having high Chl-a concentration to be termed as eutrophic. In the month of April 2012 six stations were found to be eutrophic according to the definition with a Chl-a concentration above 10 mg/m^3. The stations are Thane Creek (a), Thane Creek (b), Back Bay, Haji Ali point (a), Haji Ali point (b) and a part of Mumbai port 1 (a) and(b). Hence by the analysis of potential modelling we are able to detect 4 out of actual 6 stations and an area of 70% of the actual area that turned eutrophic in later month of April. The stations we predicted exactly are Thane Creek (a) and (b) and Haji Ali point (a) and (b). Thane Creek has the highest Chl-a concentration in April with 15.2 mg/m^3. **Figure 5** and **Figure 6** represents the overall potential map and Chl-a distribution map for month of April.

The Mamdani method is best when there is no availability of previous data. It uses the logical reasoning and expert opinion for modelling. As the previous year's data is not used, it has its own limitations. The predictive time period for eutrophication will be less for Mamdani method. Eutrophication potential of next two months can be predicted almost accurately by this method. Here Mamdani was able to predict 80% of the area which turned eutrophic in the month of February. For Sugeno the data of previous year, i.e., March 2008 data was used. Hence our models will be able to predict the eutrophication potential for the month of April based on the data of March. Sugeno was able to predict 90% of eutrophic area for the month of April, hence more accurate than other methods.

6.0 CONCLUSION:

The eutrophication potential modelling helps in determining the areas that are susceptible to eutrophication. The primary factors such as Nitrites, Nitrites, Phosphates, Sea Surface Temperature, Dissolved Oxygen, Euphotic Depth and pH are having high influences on the phenomenon of eutrophication. Index overlay is a weighted overlay based potential model used in GIS for modelling the potential and is very flexible. It is suitable for potential modelling where there is less knowledge about previous data collected. Fuzzy inference is the process of formulating the map from a given input to an output using fuzzy logic. Mamdani-type inference, expects the output membership functions to be fuzzy sets. This method is suitable when no previous data regarding the phenomenon is available and is very flexible. The membership functions, rules, operators are decided by the modeler himself. But it has limitations in time period prior to prediction. It will be more accurate for a prediction period of 1-2 months, for eutrophication potential. Sugeno-type inference, expects the output membership functions to be linear. Among the methods Sugeno-type inference systems is best suited for eutrophication modelling in this project. It was able to predict more than 90% areas that will turn into eutrophic in the month of April using the data collected in December.

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Table 1: Methods used to determine the Primary Factors of Eutrophication

PRIMARY FACTOR	METHOD	SOURCE
Nitrate-Nitrogen	Absorbance using Spectrometer	APHA, 1998
Nitrite-Nitrogen	Absorbance using Spectrometer	APHA, 1998
Phosphate-Phosphorous	Absorbance using Spectrometer	APHA, 1998
Dissolved Oxygen	Winkler's method	Strickland and Parsons, 1968
Euphotic Depth	Secchi Disc Method	Suresh *et al.*, 2006
Sea Surface Temperature	Electronic Thermometer	

Table 2: Attribute tables for predictor maps used for eutrophication potential modelling

Predictor Maps	Class	Score	Legend	Weightage of map
Nitrates	1	2	240 - 270 (µg/lit)	**2**
	2	2	270 - 300 (µg/lit)	
	3	3	300 - 330 (µg/lit)	
	4	5	> 330 (µg/lit)	
Phosphates	1	2	245 - 280 (µg/lit)	**2**
	2	2	280 - 315 (µg/lit)	
	3	2	315 - 350 (µg/lit)	
	4	3	350 - 385 (µg/lit)	
	5	4	> 385 (µg/lit)	
Nitrites	1	1	74 - 90 (µg/lit)	**1**
	2	2	90 - 105 (µg/lit)	
	3	2	105 - 120 (µg/lit)	
	4	3	120 - 135 (µg/lit)	
	5	3	> 135 (µg/lit)	
pH	1	5	7.30 - 7.40	**1.5**
	2	5	7.40 - 7.50	
	3	4	7.50 - 7.6	
	4	4	7.6 - 7.8	
	5	3	> 7.8	
Euphotic Depth	1	5	1.5 - 1.7 m	**1.5**
	2	4	1.7 - 1.9 m	
	3	3	1.9- 2.1 m	
	4	2	2.1 -2.3 m	
	5	2	> 2.3 m	
Dissolved Oxygen	1	5	6.2 - 6.8 mg/lit	**1**
	2	5	6.8 - 7.0 mg/lit	
	3	4	7.0 - 7.2 mg/lit	
	4	4	7.2 - 7.4 mg/lit	
	5	4	> 7.4 mg/lit	
Surface Temperature	1	5	24.5 - 25 c	**1**
	2	5	25 - 26 c	
	3	4	26 - 27 c	
	4	4	27 - 28 c	
	5	4	> 28 c	

Table 3: Rules applied for eutrophication potential modelling

IF	Nitrates	Phosphates	SST	Eu. Depth	pH	POTENTIAL
IF	HIGH-AND	HIGH-AND	AVERAGE-AND	LOW-AND	AVERAGE	HIGH
IF	LOW-AND	LOW-AND	AVERAGE-AND	LOW-AND	AVERAGE	LOW
IF	HIGH-AND	LOW-AND	AVERAGE-AND	AVERAGE-AND	AVERAGE	AVERAGE
IF	HIGH-AND	LOW-AND	HIGH-AND	HIGH-AND	AVERAGE	LOW
IF	LOW-AND	HIGH-AND	AVERAGE-AND	AVERAGE-AND	AVERAGE	AVERAGE
IF	LOW-AND	HIGH-AND	HIGH-AND	HIGH-AND	AVERAGE	LOW
IF	LOW-AND	LOW-AND	AVERAGE-AND	LOW-AND	AVERAGE	LOW
IF	LOW-AND	LOW-AND	HIGH-AND	HIGH-AND	HIGH	LOW
IF	LOW-AND	LOW-AND	LOW-AND	LOW-AND	LOW	LOW
IF	HIGH-AND	HIGH-AND	AVERAGE-AND	LOW-AND	AVERAGE	HIGH
IF	HIGH-AND	LOW-AND	AVERAGE-AND	LOW-AND	AVERAGE	HIGH
IF	HIGH-AND	LOW-AND	HIGH-AND	LOW-AND	AVERAGE	AVERAGE
IF	HIGH-AND	LOW-AND	AVERAGE-AND	AVERAGE-AND	AVERAGE	HIGH
IF	HIGH-AND	HIGH-AND	AVERAGE-AND	HIGH-AND	AVERAGE	HIGH
IF	LOW-AND	LOW-AND	LOW-AND	HIGH-AND	HIGH	LOW

Table 4: Database created from data, March 2008

Low Chl						
Station	Nitrate (µg/l)	Phosphates (µg/l)	SST	Eu. Depth	pH	Chl-a (µg/l)
Dahanu coastal	911.4588	275.442	27.6	4	8	0.5
Dahanu middle creek	706.8456	465.402	30	2.5	8	2.2
Bassien creek coastal	1915.9236	332.43	23	3	7.8	1.9
Manori lower creek	1302.084	930.804	24.4	2.3	7.9	2.6
Manori upper creek	520.8336	1681.146	25.3	2.3	7.3	2.6
Versova lower creek	403.026	66.486	30.5	2.1	8	3.6
Versova upper creek	266.6172	1728.636	26	2.1	7.5	3.7
Thane creek	706.1036	586.166	25.6	2.2	7.7	3.1
Kundalika coastal	452.6292	332.43	27.7	1.8	8	3.9
Kundalika lower	824.6532	455.904	26.2	1.8	7.5	3.8
Average Chl						
Station	Nitrate (µg/l)	Phosphates (µg/l)	SST	Eu. Depth	pH	Chl-a (µg/l)
Tarapur upper	700	200	30.5	1.4	8.1	5.5
Bassien creek lower	690	210	30	1.4	8.1	5.4
Bassien creek middle	720	220	25.7	1.3	7.4	5.7
Mahim lower creek	533	427	24.2	1.8	8.1	4
Mahim upper creek	614	387	24.6	1.7	7.6	4.2
Bandra	620	400	24.7	1.7	7.5	4.3
Thane creek	843	824	25.3	1.6	7.8	4.8
Thane creek upper	750	579	24	1.6	7.4	4.5
Amba estuary lower	558	294	23.2	1.5	7.5	4.9
Amba estuary middle	651	247	22.4	1.5	7.4	4.9
High Chl						
Station	Nitrate (µg/l)	Phosphates (µg/l)	SST	Eu. Depth	pH	Chl-a (µg/l)
Tarapur coastal	787	104	28.1	1	7.7	7.8
Tarapur middle	1438	47	29.4	0.6	8.2	11.7
Bassien creek upper	1463	579	26	0.7	7.2	10.5
Worli	539	256	24.9	1.1	8.1	7.1
Thane creek lower	2269	855	24.1	1.2	7.4	6.8
Patalganga estuary lower	1048	218	31.8	0.8	7.6	9.6
Patalganga estuary middle	1178	133	30.5	0.8	7	9.7
Thane creek coastal	4843	1824	25.3	0.6	7.8	12.8
Thane creek middle	4706	1586	25.6	0.6	7.7	13.1
Patalganga estuary lower	1463	579	26	0.7	7.2	10.5
Patalganga estuary middle	1178	133	30.5	0.8	7	9.7
Patalganga estuary upper	1048	222	31	0.8	7.5	9.8

Table 5: Linear coefficients of primary factors

	a1	**a2**	**a3**	**a4**	**a5**	**constant**
Low Chl-a	-0.00083	-0.00044	-0.13388	-1.41833	0.095759	9.997959
Medium Chl-a	-0.00054	0.000276	0.064488	-3.28044	-0.14407	9.682613
High Chl-a	0.000674	-0.00078	-0.03378	-8.60666	0.30358	14.74688

Table 6: Eutrophication potential of stations determined by Mamdani and Sugeno method

STATIONS	Potential (Mamdani)	Potential (Sugeno)
Bandra Outfall	4.7	2.7
Mahim Bay	1.2	2.9
Worli Outfall	6.6	3
Haji Ali Point	7.2	3.3
Back Bay	6.4	2.9
Southern Point	4.2	2.3
Collaba Outfall	1.5	2.5
Gateway of India	3.6	2.8
Mumbai Port 1	5.8	3.0
Mumbai Port 2	3.5	3.0
Trombay Jetty	0.88	2.9
Thane Creek	7.3	3.25

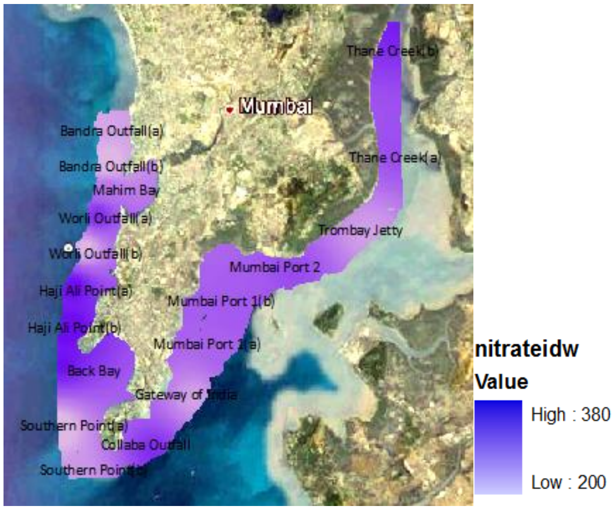


Fig 1(a) – Nitrate Potential Map

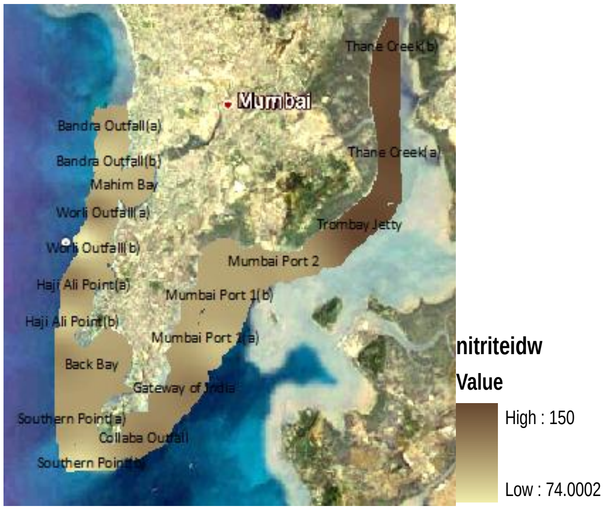
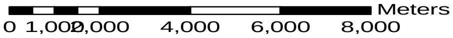


Fig 1(b) – Nitrite Potential Map



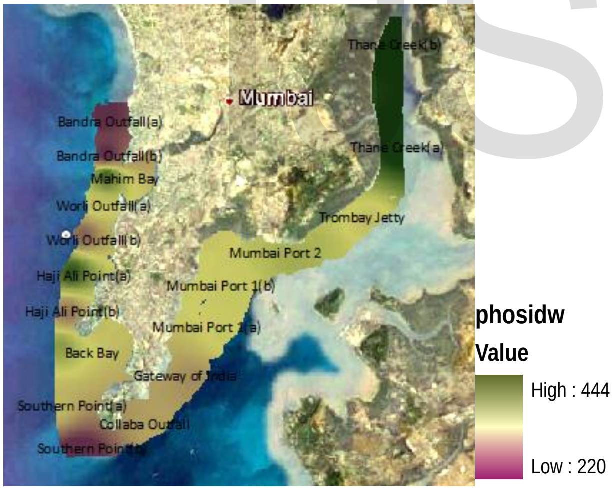


Fig 1(c) - Phosphate Potential Map

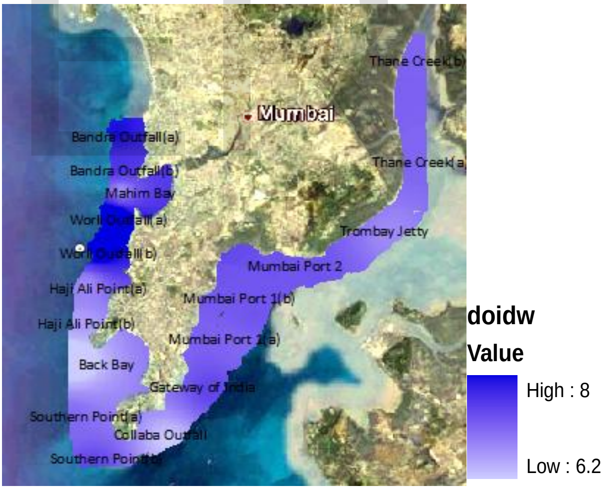


Fig 1(d) – Dissolved Oxygen Potential Map

Fig 1(e) - SST Potential Map

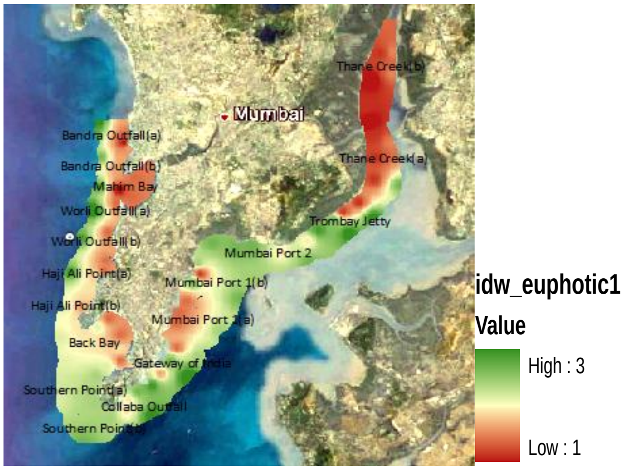
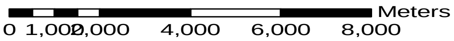


Fig 1(f) – Euphotic Depth Potential Map



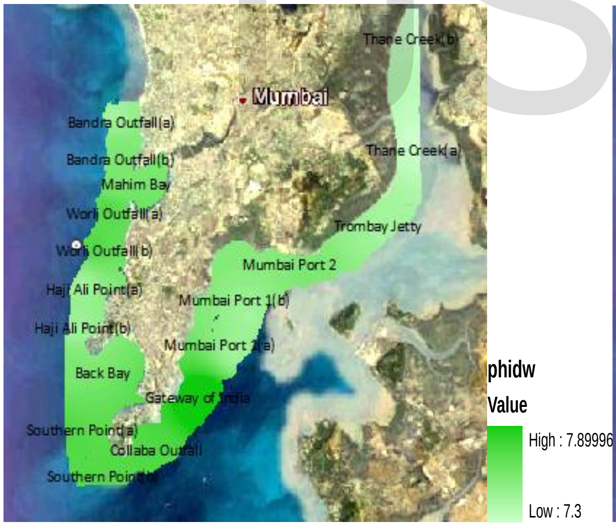


Fig 1(g) – pH Potential Map

Fig 2 –Potential (Index Overlay)

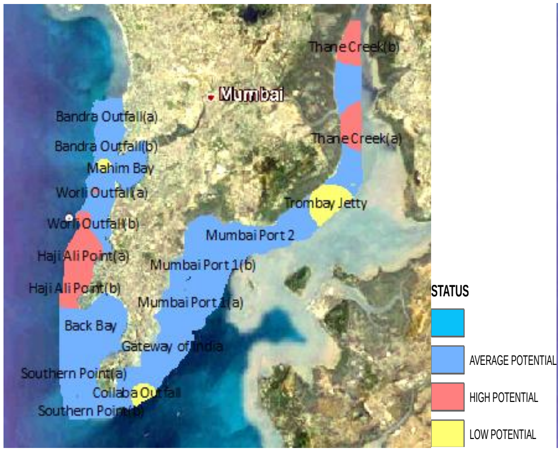


Fig 3 –Potential (Mamdani FIS)

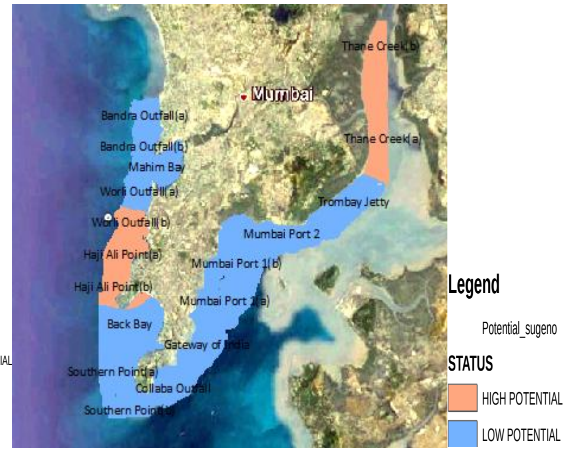


Fig 4 –Potential (Sugeno FIS)

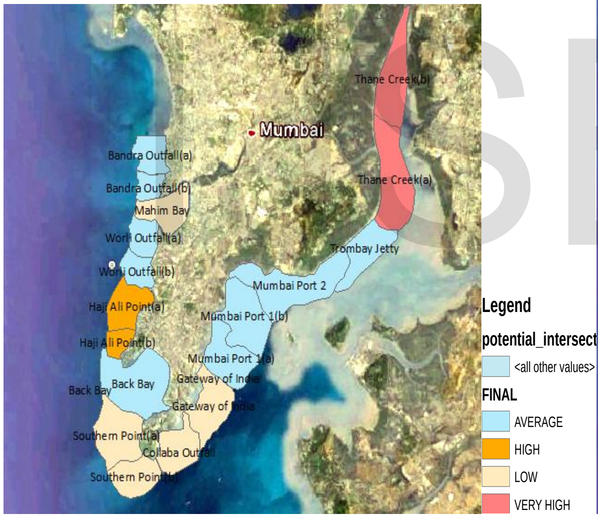


Fig 5 – Overall Eutrophication Potential

Fig 6 – Chl-a Concentration (April month)

Mr. Arjun Gopakumar