

ASSESSMENT OF COASTAL WATER QUALITY ALONG SOUTH WEST COAST OF INDIA USING MULTILE REGRESSION ANALYSIS ON SATELLITE DATA

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ABSTRACT

The coastal waters being the ultimate receiver of all the wastes, shows a declining trend in its quality. It is of immense importance to know the extent of pollution for its monitoring and management. Measurement of dissolved oxygen (DO), biological oxygen demand (BOD), pH and fecal coliform (FC) are vital in water quality monitoring and assessment studies. Usually these parameters are determined by analysing water samples collected from various locations. Since this is tedious and expensive, it is limited to small scales. In this paper, an effort has been made to quickly assess the quality of coastal waters of Kerala directly from the satellite imagery by estimating National Sanitation Federation Water Quality Index (NSFWQI) along with DO, BOD, pH and FC. Multiple linear regression is used to develop statistically significant models using Sea Surface Temperature (SST) and Remote Sensing Reflectance (R_{rs}) from Moderate Resolution Imaging Spectroradiometer (MODIS) and in-situ data available on DO, BOD, pH and FC. The models when validated showed good correlation between in situ values and predicted values with r values ranging from 0.73 ($p=0.001$) for DO to 0.89 for NSFWQI ($p=0.018$). Spatial maps are generated showing the distribution of these parameters along the coast. The parameters in the study are checked to see if they are in compliance with the standards. The study gives models to estimate the daily distribution of these parameters along the coast using MODIS data. Thus, appropriate control measures could be adopted to limit the effect on susceptible rural population.

Keywords: Water Quality, Moderate Resolution Imaging Spectroradiometer, Remote Sensing Reflectance, National Sanitation Federation Water Quality Index.

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Introduction

The activities on land are the major contributors of pollutants in the oceans. Over 80 per cent of marine pollution, comes from oil spill, fertiliser, sewage and garbage disposal, toxic chemicals, and ballast water from ships (Vikas and Dwarkish, 2015). Marine creatures and plants are affected by toxic substances from dumped materials (Caroline, 1996). The consumption of affected fishes can cause health issues to human beings. Moreover, fishes being one of the crucial parts of aquatic food chains show a declining trend in its production (Islam and Tanaka, 2004). This affects the livelihoods of the rural fishing community.

A huge amount of effluents are being disposed daily into the rivers of the State from the cities, towns and industries. These pollutants finally reach the coastal waters through the estuaries (Chattopadhyay and Franke, 2006). The conventional method of water quality monitoring involves the collection of samples from various locations and its analysis. Though this method may

give accurate results, it can only be employed for small scales as it is expensive and time-consuming. A solution for the above problem is the usage of satellite remote sensing. Sometimes the temporal and spatial resolution of sensors might be inadequate. So, a combination of both these methods might be effective in tackling the problem. This study aims to estimate DO, BOD, FC, pH and NSFQI using MODIS sensor data and thereby quickly ascertaining the water quality along the coastline of Kerala.

Study Area

Kerala is situated along the south western coast of India, between 8°17'30" and 12°47'40" north latitudes and 74°27'47" E and 77°37'12" E longitudes. Kerala with an area of 38,863 km² has got a coast 580 km in length, while its width varies from 35 to 120 km. The State is thickly populated with 33.3 million inhabitants resulting in a population density of 860, while the national average of population is 382. Two-thirds of Kerala's population lives in rural areas.



Figure 1: Location Map of Kerala

Methodology

Water Quality Monitoring Data: A programme by Government of India, known as Coastal Ocean Monitoring and Prediction System (COMAPS) collects data on various parameters of coastal

water from 0-10 km sector of the coast. Among the data, the values of parameters namely DO, BOD, pH and FC from year 2002-2010 have been chosen for the study. Ground points used in this study are presented in Figure 2.



Figure 2: Study Area with the Sampling Locations

Satellite Imagery and Data Processing: The cloud-free images of MODIS sensor of AQUA and TERRA have been used in the study. The water quality data of 10 major coastal centres of Kerala during 2000 to 2010 have been acquired from COMAPS data. Field monitoring data for 135 days have been thus collected. The satellite imagery on the corresponding sampling dates was also collected for the study. The sampling points were overlaid on the images to see if those are cloud-free. The process has been repeated for the

imagery of 135 days for the different sampling points. 69 cloud-free data points were obtained for DO, pH and BOD during 2002-2010 whereas 26 were obtained for FC. The cloud-free images were not obtained in the year 2000 and 2001. The reflectance at the cloud-free points wave lengths 412 nm, 443 nm, 469 nm, 488 nm, 531 nm, 541 nm, 555 nm, 645 nm, 667 nm and 678 nm along with SST were acquired.

Calculation of NSFQI: The National Sanitation Federation Water Quality Index is one among

widely used water quality index. The modified BOD and FC as critical parameters with weight NSFQI for Indian conditions consider DO, pH, (Wi) 0.31, 0.22, 0.19 and 0.28, respectively.

Table 1: Sub-index Equations for NSFQI (CPCB, 1986)

Water Quality Parameter	Range Applicable	Equation
Per cent Saturation DO	0-40%	IDO=0.18+0.66*(% Saturation DO)
	40-100%	IDO=-13.5+1.17*(% Saturation DO)
	100-140%	IDO=163.34-0.62*(% Saturation DO)
BOD	0-10	IBOD= 96.67-7*(BOD)
	10-30	IBOD= 38.9-1.23*(BOD)
	>30	IBOD=2
Ph	2-5	IpH= 16.1+7.35*(pH)
	5-7.3	IpH= -142.67+33.5*(pH)
	7.3-10	IpH= 316.96-29.85*(pH)
	10-12	IpH= 96.17-8.0*(pH)
	<2,>12	IpH=0
FC (counts/100ml)	1-103	IFC = 97.2-26.6*log(FC)
	103-105	IFC = 42.33 -7.75*log(FC)
	>105	IFC=0

$$NSFWQI = \sum_{i=1}^p W_i I_i \tag{1}$$

Table 1 shows the equations for determining the sub-index of the water quality parameters used for surface waters. Table 2 suggests the description for water quality based on NSFQI.

Table 2: Description of Water Quality Based on NSFQI (CPCB, 2001)

S. No.	NSFWQI	Description
1	63-100	Good to excellent
2	50-63	Medium to good
3	38-50	Medium to bad
4	<38	Bad to very bad

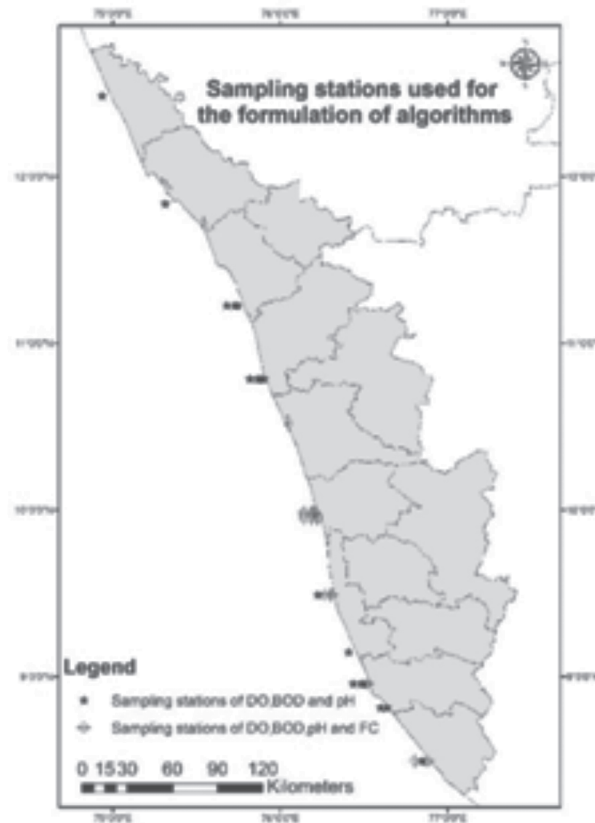


Figure 3: Location of Sampling Stations Used for the Formulation of Algorithm

Development of Multiple Linear Regression Models: The reflectance values of bands, band ratios along with SST values obtained from MODIS are used as independent variables to develop regression models. The values of DO, BOD, pH, FC and NSFQI were used as the dependent variables. The models with maximum correlation coefficient and which are significant at 95 per cent confidence level are selected as the final ones. Among the 69 datasets available for DO, pH and BOD, 51 were used for the formulation of algorithm and the rest for validation. In case of

FC and NSFQI, among the 26 data, 20 were used for making the model and the rest for validation of the predictive model. Figure 3 shows the sampling locations used for formulation of algorithm.

Validation of Predictive Model: The SST, remote sensing reflectance values of bands and band ratios corresponding to date of validation dataset are used for the calculation of parameters using the equations developed. These values obtained are compared to the actual field values obtained. The correlation coefficient (r) of the

estimated values and the actual values are calculated and the model giving maximum r value is selected as the final one. Figure 4 shows the location of sampling points used for the validation of algorithms.



Figure 4: Location of Sampling Points Used for the Validation of Algorithm

Preparation of Spatial Maps: The spatial maps were developed from the MODIS imagery on a relatively cloud-free day. Using the reflectance values obtained from MODIS and the algorithms developed, choropleth maps are obtained showing the variation of values of the parameter along the coast.

Results and Discussion

Values of NSFQI: The values of DO, BOD, pH, and FC for sampling sites in the Indian coast are

used to calculate NSFQI using equation 1 and the equations of Table 1. The field value of DO, BOD, pH, FC and the estimate values of NSFQI are given in Table 3.

Development and Validation of Algorithm:

In the case of FC and NSFQI, the algorithms developed using 20 sets of data with r values of 0.59 and 0.61, respectively with p value less than 0.03 were selected as the final ones. The algorithms of FC and NSFQI are validated with

6 sets of data to give r values of 0.78 and 0.94, respectively. The algorithms for pH, DO and BOD were developed using 51 sets of in-situ values. These algorithms gave correlation coefficients (r) of 0.50, 0.66 and 0.70 at the time of development with p less than 0.02. The algorithms thus developed were validated using 18 sets of data to give r values of 0.79, 0.94 and

0.73 for pH, BOD and DO with p less than 0.001.

NSFWQI

The values of NSFWQI used for formulation of algorithm are given in Table 3.

$$NSFWQI = 74.247 - 0.503 * SST + 0.674 * R_{rs} \frac{5.55}{4.43} \quad (2)$$

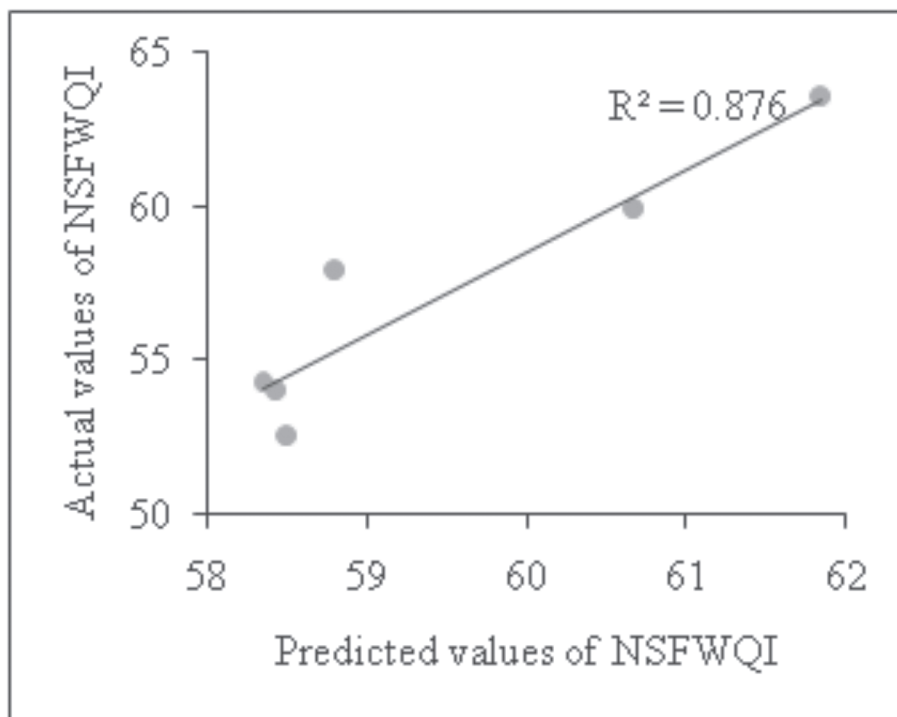


Figure 5: Graph Showing Predicted Values of NSFWQI Using Equation (6) Against the Actual Values

Table 4 shows the actual values of NSFWQI calculated using equation 1 from the field data and predicted values of NSFWQI calculated using equation 2. The predicted value of NSFWQI using

Equation (2) had strong correlation with its actual values. Figure 5 shows the scatter plot of actual values of NSFWQI and that which is predicted by equation 2.

Table 3: NSFQI Calculated from field Values for Formulation of Algorithm

Sampling Area	Station coordinates		Date of Sampling	OXY SAT (%)	BOD (mg/L)	pH	FC (CFU/100 ml)	NSFWQI
	Latitude (N)	Longitude (E)						
Kochi	09°57'05"	76°13'30"	29-04-2010	69.7	2.28	8.14	86000	53.8
Kochi	09°59'15"	76°12'24"	29-04-2010	77.32	2.79	8.07	36000	57.2
Kochi	09°57'05"	76°11'18"	29-04-2010	67.47	2.32	8.12	1480	52.5
Kochi	09°58'10"	76°11'18"	29-04-2010	72.51	2.18	7.96	180000	55.6
Kochi	09°59'15"	76°11'18"	29-04-2010	71.05	2.06	8.09	148000	54.4
Kochi	09°58'10"	76°08'33"	29-04-2010	81.44	2.82	7.96	16000	60.1
Kochi	09°59'15"	76°08'33"	29-04-2010	81.96	2.96	7.98	21000	59.7
Kochi	09°58'10"	76°11'18"	12-12-2010	92.84	1.59	8.16	15000	64.6
Kochi	09°59'15"	76°11'18"	12-12-2010	95.6	1.62	8.18	9000	66
Kochi	09°57'05"	76°11'18"	12-12-2010	89.21	1.26	8.11	34000	63.3
Kochi	09°59'15"	76°08;33"	12-12-2010	89.48	1.3	8.17	24000	63.3
Kochi	09°57'05"	76°08'33"	12-12-2010	78.84	1.72	8.16	48000	58.3
Veli	08°29'39"	76°53'15"	01-01-2006	59.18	0.42	6.22	6000	53.2
Veli	08°29'39"	76°52'10"	05-10-2008	79.19	2.94	7.68	8000	61.7
Veli	08°29'39"	76°48'20"	05-10-2008	79.19	2.94	7.68	3000	62.6
Veli	08°29'39"	76°53'15"	10-02-2005	53.24	1.18	4.2	1500	47.2
Veli	08°29'39"	76°52'10"	10-02-2005	66.12	0.92	7.25	500	66.1
Neendakara	08°57'29"	76°31'13"	14-09-2002	64.28	1.5	8.18	4000	55.5
Allepy	09°29'28"	76°18'20"	7-10-2008	74.98	0.92	7.7	23000	61.7
Allepy	09°29'28"	76°16'17"	7-10-2008	80.42	0.94	7.76	9000	64.1

Table 4: Actual and Predicted Values of NSFQI

Sampling Area	Station coordinates		Date of Sampling	FC		NSFWQI	
	Latitude	Longitude		Actual	Predicted	Actual	Predicted
Kochi	09°58'10"	76°12'24"	29-04-2010	240	659	57.9	58.7
Kochi	09°57'05"	76°08'33"	29-04-2010	400	674	54	58.5
Veli	08°29'39"	76°52'10"	01-01-2006	220	174	54.2	58.3
Veli	08°29'39"	76°51'04"	05-10-2008	30	187	59.9	60.6
Neendakara	08°57'29"	76°29'05"	14-08-2002	30	225	52.5	58.5
Allepy	09°29'28"	76°17'17"	07-10-2008	130	266	63.5	60.7

Fecal Coliform: In equation 3, value of fecal coliform increases with the surface temperature. This is in agreement with the fact that FC optimum growth happens at high temperature (Walsh et al., 2008).

$$FC = -3452.91 + 125.428 * SST + 4.725 * R_{rs} \left(\frac{44.3}{41.2} \right) \quad (3)$$

The scatter plot of actual and predicted values of FC with a coefficient of correlation of 0.78 and coefficient of determination of 0.605 is given in Figure 6.

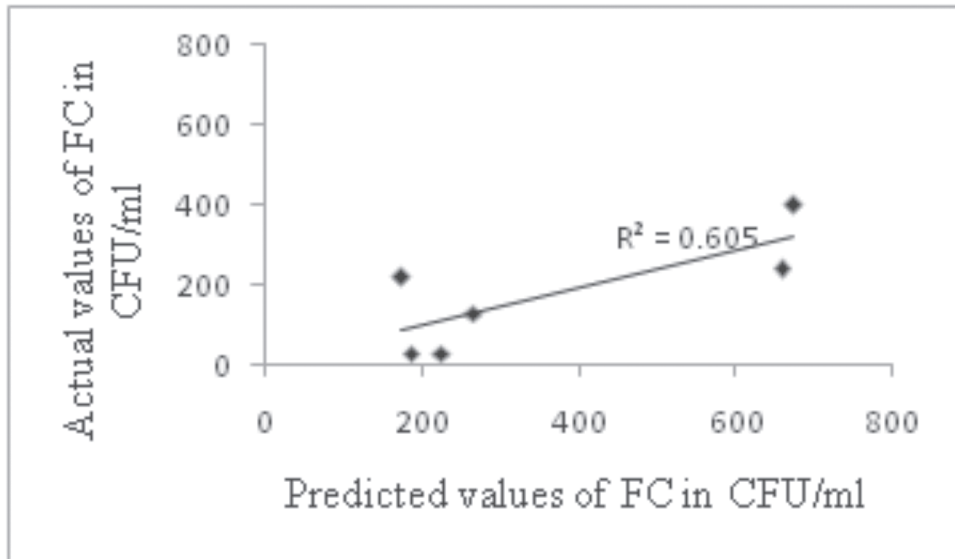


Figure 6: Graph Showing Predicted Values of FC Using Equation (3) Against Actual Values

Dissolved Oxygen: The equation (4) has sea surface temperature and chlorophyll band ratio considered, which influence dissolved oxygen in water. Figure 7 shows the plot between actual and predicted values of DO with an r=0.7.

$$DO = 6.601 - 0.074 * SST - 0.02 * R_{rs} \left(\frac{488}{443} \right) + 0.121 * R_{rs} \left(\frac{678}{555} \right) + 69.369 * R_{rs} (555) + 0.053 * R_{rs} \left(\frac{443}{555} \right) \quad (4)$$

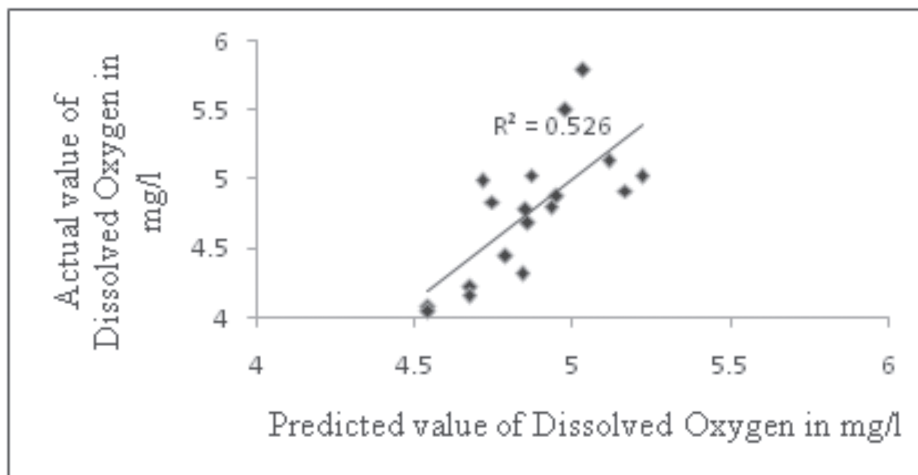


Figure 7: Graph Showing Predicted Values of Dissolved Oxygen Using Equation (2) Against Actual Values

pH

$$pH = 8.154 + 68.628 * R_{rs} \left(\frac{488}{443} \right) - 0.086 * R_{rs} \left(\frac{488}{443} \right) - 0.349 * R_{rs} \left(\frac{443}{488} \right) - 73.061 * R_{rs} (678) + 0.132 * R_{rs} \left(\frac{678}{443} \right) \quad (5)$$

The above equation shows that the variation pH increases with the reflectance in band 488 and it decreases with reflectance in band 678. This is in agreement with the finding (Sheela et al., 2013) that pH is related to reflectance of both green and red bands. Figure 8 shows the plot of actual values of pH against its predicted values.

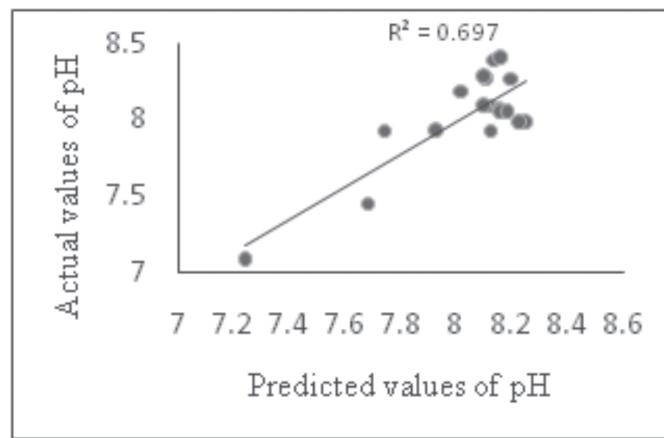


Figure 8: Graph Showing Predicted Values of pH Using Equation (3) Against Actual Values

Biochemical Oxygen Demand: $BODV = 5.194 + 0.241 * SST - 58.77 * R_{rs} (488) - 0.139 * R_{rs} \left(\frac{488}{555} \right) \quad (6)$

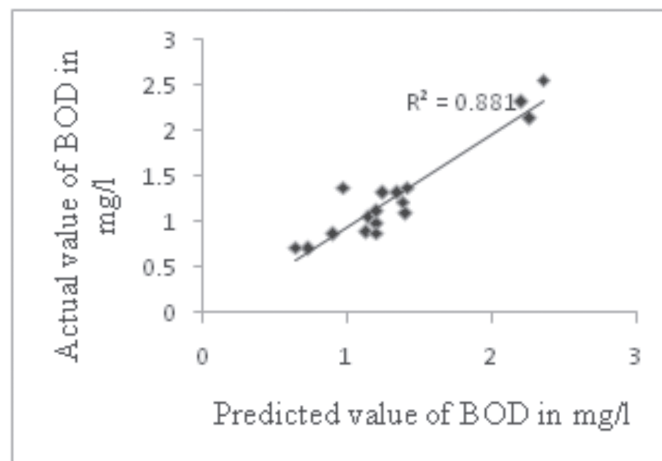


Figure 9: Graph Showing Predicted Values of BOD Using Equation (4) Against Actual Values

In the equation, the value of BOD decreases with the reflectance values in the band 488 and with the ratio of reflectance values in the bands of 488 and 555. This is in agreement with the equation derived (Sheela et al., 2013). In the algorithm, BOD value increases with sea surface temperature. Figure 9 shows the plot of actual values of BOD against predicted ones.

Spatial Maps Showing the Distribution of DO, BOD, pH, FC and NSFQI: The distribution of DO, BOD, pH, FC and NSFQI along the coast of Kerala on a relatively cloud-free day (3 January 2016) applying the algorithms developed on MODIS sensor are shown in Figures 10, 11, 12, 13 and 14, respectively.

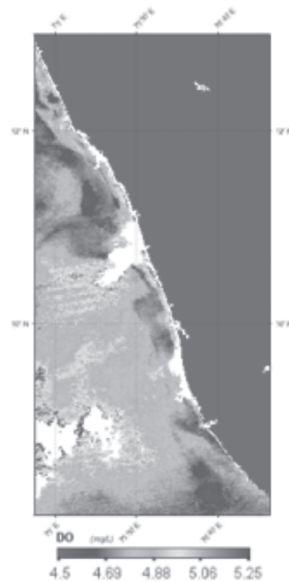


Figure 10: Map Showing the Variation DO Along the Kerala Coast

Dissolved Oxygen

Figure 10 shows the variation of dissolved oxygen in the sea near Kerala coast. The dissolved oxygen level in majority of region is less than 5.25 mg/l. This indicates that hypoxic condition exists in the entire coastal waters. The dissolved oxygen level is less than the limiting standard of 5mg/l for SW-1 prescribed by the CPCB.

Biochemical Oxygen Demand: Figure 12 shows the varying trend of BOD along the coast. BOD values vary from 0.2 to 1.6mg/l. It shows the greater values of BOD near the shore than offshore indicating waste disposal into coastal waters leading to increased organic content in water. The BOD values are more in the southern and northern portion indicating discharge of waste water.

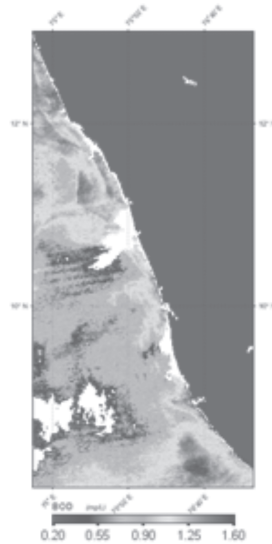


Figure 11: Map Showing the Variation BOD Along the Kerala Coast

pH

In the study area, higher values of pH exist on the coast than offshore. pH varies from 7.8 to 8.3. The pH values lie within the standard of 6.5

to 8.5. pH values are higher along the coast. This is in agreement with the finding of (Jamshidi and Baker, 2011) that higher pH values are due to the greater contribution of the riverine water.

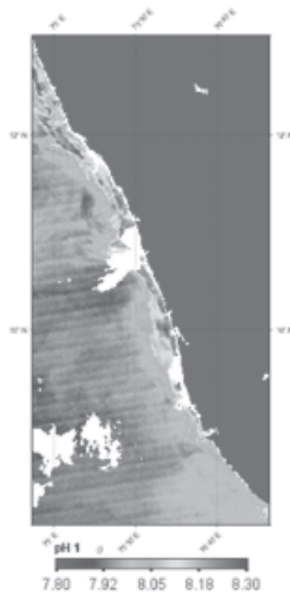


Figure 12: Map Showing the Variation pH Along the Kerala Coast

Fecal Coliform

Figure 13 shows the variation of fecal coliform along the coast. The values of FC varied from 0 to 500 MPN/100ml. Higher values can be observed along the coast. FC values are higher than the standard of 100mg/l prescribed for SW-2 (bathing) by CPCB. The values of FC are more

on the southern coast indicating fecal pollution of coastal waters. The entry of sewage into the sea through the Akkulam Lake, Karamana River of the Thiruvananthapuram city may be the reason for the high level of fecal coliforms in the southern portion of the study area.

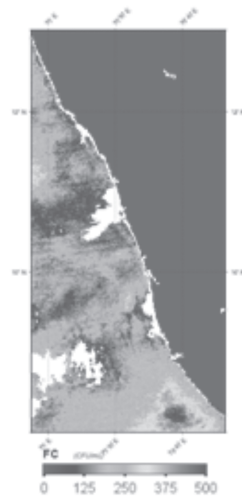


Figure 13: Map Showing the Variation FC Along the Kerala Coast

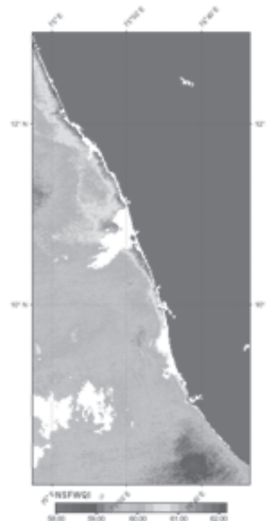


Figure 14: Map Showing the Variation NSFQI Along the Kerala Coast

National Sanitation Federation Water Quality Index (NSFWQI): Figure 14 shows the variation of NSFWQI along the sea. NSFWQI values vary from 60-60.5 along the coast. This indicates that comparatively lower quality water exists in the sea coast. The NSFWQI values suggest that water is of medium to good quality. The general trend implies improved water quality moving away from the shore.

Conclusion

The present study gives models to quickly estimate the water quality along the entire coast of Kerala using multiple linear regression by estimating the water quality index. Significant correlations were observed between optically inactive parameters (DO, BOD, pH and FC) dealt in the study and remote sensing reflectance. The dissimilar response of these parameters to statistical analysis for the development of prediction algorithm lead to unique equations.

These algorithms are validated for their useful future application.

The application of these algorithms to develop spatial map showing the distribution of NSFWQI on 03-01-2016 suggests that the overall water quality falls in the category of medium to good. The spatial maps of DO, BOD, pH and FC show anthropogenic impact on their distribution. DO and FC values falls above the prescribed CPCB standards. The rise in organic matter and faecal coliform and reduction in dissolved oxygen can be observed near the coast.

Huge coastal pollution affects the marine organisms namely fishes on which the rural fishing community depend on for their daily living (Bhuyan and Islam, 2016). The models developed may help in effective daily monitoring and prediction of marine water quality of Kerala, thus helping in resolving the problem in rural coastal communities which are the most vulnerable group of coastal pollution.

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