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GIS based spatial distribution of environmental parameters at selected locations along the coastline of the country

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Present study presents the spatial distribution of chemical elements, such as, dissolved oxygen and nitrate at Ennore and Puri using the data collected under the COMAPS programme to elucidate the extent of spatial variation of chemical elements seasonally. Transect based spatial data of these parameters collected at 0, 2 and 5 km distance in the sea was interpolated using the spatial analyst module of GIS and the interpolated area was ranged from 97-917 sq km. Data revealed the extent of spatial distribution of low oxygenated water in Ennore and Puri. From the spatial data collected at Chilika, it could be found that nitrate concentrations in the range of 0.01-2 µmol/l provided substantial Chlorophyll concentration of more than 4 mg/m^3. Similar result was obtained for coastal waters of Ennore. Further, increase of nitrate levels did not lead to higher productivity. This implies that the nitrate uptake saturation levels could happen even at 2 µmol/l. From the results obtained, the spatial data has been found to be useful in determining zones of safe use of seawater and to understand the extent of relationship between the relatable parameters.

[**Keywords:** GIS, Spatial relationship, Nitrate, Chlorophyll]

Introduction

The seas around Indian coastline of 7500 km is facing continuous threat from anthropogenic activities due to increased utilization of coastal space for human settlement, industrial growth and related developmental activities. Mega cities such as Mumbai and Chennai and few highly populated cities and towns such as Surat, Mangalore, Kochi, Trivandrum, Tuticorin, Pondicherry, Vishakapatnam, Puri are located along the coast. Besides, a number of rivers form estuaries along the coast and on the banks of rivers/estuaries mega city like Kolkata and several towns are situated. Effluents generated from human settlements and industries reach the sea both directly and indirectly through the rivers. It has been estimated that about 19000 MLD of untreated sewage and 700 million KL per year of industrial wastes, mostly of untreated in nature, reach the sea. Due to such large inputs, the quality of seawater along certain stretches has either deteriorated severely or started facing deterioration recently.

A long-term programme for monitoring levels of marine pollutants namely, Coastal Ocean Monitoring and Prediction System (COMAPS) has been operational since 1990. The data collected under the programme has helped in determining status of health of coastal waters at 76 locations along with trends of variation of chemical elements in the sea. The data that are collected at fixed sampling locations from 0-5 km in the sea indicate concentration of these environmental parameters at that location in terms of distance from the coast and the depth. Information on spatial distribution of chemical elements, especially, the pollutants will help to understand the extent of distribution of the concentration levels along the coast and also offshore. Such information is necessary to plan for drawl of seawater for desalination, aquaculture and to determine safe fishing zones. The present paper has studied the spatial distribution of chemical elements such as dissolved oxygen, nitrate and Chlorophyll-*a* at Ennore, Puri, and Chilika lagoon for different seasons. The study locations are provided in Fig. 1. Further, an attempt has been made to understand the relationship between nutrients and chlorophyll *a* using the overlay analysis of GIS.

Materials and Methods

The data on dissolved oxygen, nitrate and Chlorophyll-*a* collected under the COMAPS programme at, Ennore by CAS in Marine Biology,

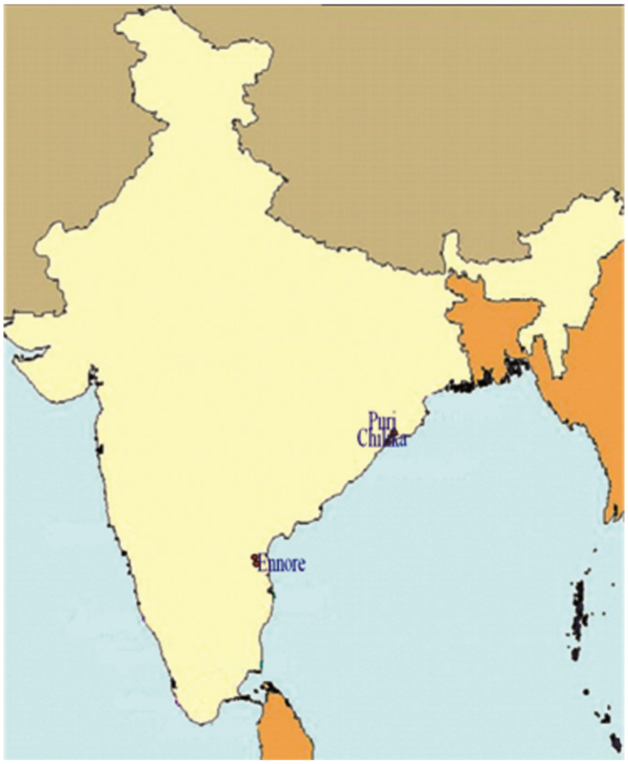

Fig. 1—Map showing study locations.

Annamalai University, Puri by Institute of Minerals and Material Technology and Chilika lagoon by ICMAM PD and Andhra University were used for spatial analysis. The data collected from 1990 to 2003 (with gaps in-between) at 0, 1, 2 and 5 km transects were used for all the above sites except for Chilika lake. For Chilika lagoon, the data collected at 36 locations during the 2005 were used. Estimation of all the above parameters was carried out using the method described by Grasshoff[1].

The data were subjected to spatial analysis using the Spatial Analyst module of ArcGIS 9.2. The data at different points were interpolated adopting the Kriging method which resulted in a more reasonable output compared to the other methods such as IDW and nearest neighbour. In case of coastal waters, interpolation area was fixed as 2 km on either side of the transects and also about 500 m beyond the outermost offshore station depending on the location. In case of the Chilika lagoon, interpolation was carried out for the entire lake due to higher data density. The spatial data of each parameter was classified into various ranges of concentrations and categorized as low, moderate, normal and high. For example, for Chlorophyll-*a* was classified into the following ranges and categories: 0.01-1 mg/m^3 - low; 1-3 mg/m^3 - moderate; 3-4 mg/m^3 - Normal and > 4 mg/m^3 - High. These ranges vary with respect to parameters and also among coastal locations. The classifications were based on the frequency of occurrence of concentrations of above said parameters over a long period of time. Long-term data on the parameters chosen for spatial distribution are available for several locations under the COMAPS programme of Ministry of Earth Sciences.

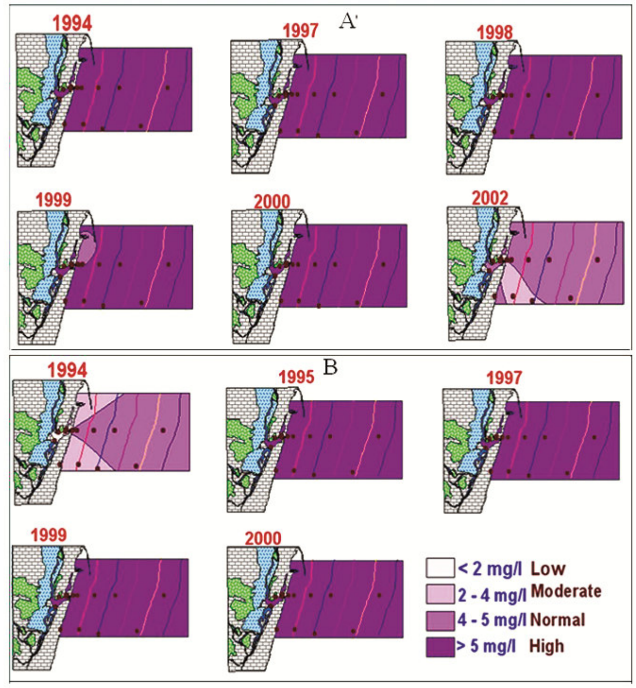

Fig. 2—Spatial distribution of dissolved oxygen during summer (A) and pre-monsoon (B).

Results and Discussion

Ennore

The coastal waters of Ennore near Chennai receive industrial effluents through Ennore creek, untreated sewage through Buckingham canal connected to the creek and also from a marine outfall located south of the creek. GIS applications facilitated estimation of extent of area of distribution and the distance up to which the above parameters present in the near shore waters. The data collected in the transects were interpolated to the near shore area and the interpolated area was 97 sq.km. (Fig. 2). The pre-monsoon data of 1994 showed normal dissolved oxygen of 4-5 mg/l especially offshore, covering an area of 77 sq.km (Fig. 2). However, low oxygenated water (2-4 mg/l) prevailed on either side of the creek as a narrow band covering an area of 20 sq.km (Fig. 2). The summer

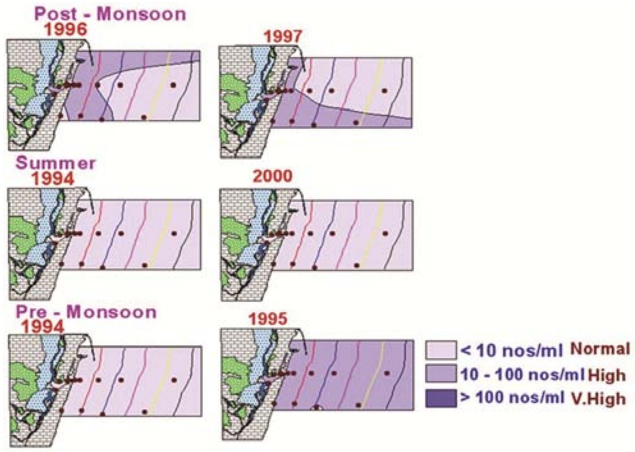

Fig. 3—Spatial distribution of *Streptococcus feacalis.*

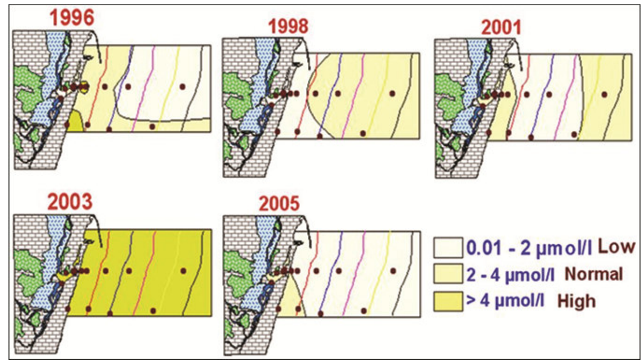

Fig. 4—Spatial distribution of nitrate in post-monsoon.

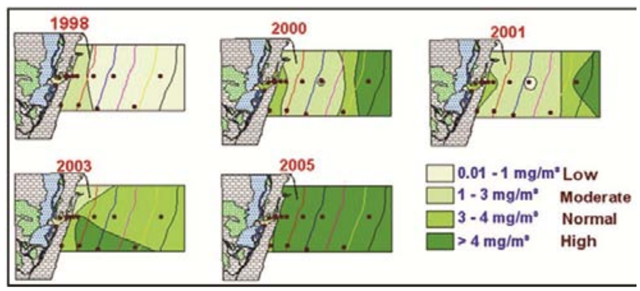

Fig. 5—Spatial distribution of chlorophyll-*a* in post-monsoon.

data of 1994-2000 showed well mixed concentrations of DO up to a distance of 10 km with a few exceptions. Interestingly, during 2002 (summer) a plume with a low DO concentration of 2-4 mg/l could be detected revealing strong water flow from the creek to the coastal waters. This indicates that occasionally large scale flow of waste waters containing low DO prevail at this location (Fig. 2). The area of distribution was estimated to be 10sq.km. The spatial distribution of *S. feacalis* did show distinct plume like characteristics for certain months. For example, in the post-monsoon month of 1996 and 1997, well defined high concentration of *S. feacalis* prevailed in an area of 41 and 35 sq km respectively (Fig. 3). Both the years, plumes could be detected up to 2-10 km distance in the near shore area in a horse shoe shape (Fig. 3).

Nitrate is present in seawater and is an indicator of sewage contamination especially when it exceeds 4 µmol/l. Similar to DO, nitrate did indicate plume like pattern especially in post-monsoon of 1996 measuring to an area of 39sq.km. During 2001 and 2005, the concentration range of 2-4 µmol/l showed a distribution area of 11 and 8 sq.km respectively (Fig. 4). The spatial distributions of DO and *S. feacalis*, indicate extent of influence of creek water that normally carries land based effluents.

While, DO and *S. feacalis* do indicate influence of sewage, however, the nitrate except during 2003 did not indicate any correlation. Probably, the concentration of nitrate is regulated more by the phytoplankton uptake. However, the Chlorophyll-*a* showed wide range of concentration with distinct distribution patterns with often low to moderate area of spatial distribution around the creek similar to the DO (Fig. 5). Distribution of values above 4 mg/m^3 was dominant in the 2005 (Fig. 5). In the area of nearshore immediate to the creek, moderate concentration of 2-4 mg/l spread over an area ranging from 8 to 24 sq.km was predominant which might be due to influence of low oxygenated water in this area apart from other regulating factors such as grazing by zooplankton. Even though the spatial data on above parameters varied year to year in terms of classes, it could be reasonably concluded that presence of low oxygenated and *S .feacalis* indicate contamination of nearshore waters on either of the creek up to 2 km. Therefore, water from these areas should be avoided for mariculture and desalination purposes.

GIS offers unique facility of overlay analysis, which is normally used in detection of changes in resources, land cover etc., between the required years. In the present study the overlay analysis has been used to understand the correlation between two dependent parameters. Nitrate being one of the essential nutrients for phytoplankton growth, it is felt that by using the overlay analysis, whether the spatial distribution of Chlorophyll-*a* (an indicator of phytoplankton biomass) levels are linear to the spatial levels of nitrate. Based on the long-term data on the frequency of occurrence of nitrate concentrations, spatial nitrate concentrations were divided into three classes namely 0.01-2 µmol/l (low), 2-4 µmol/l (Normal) and > 4 µmol/l (High). Similarly the Chlorophyll-*a* levels were divided into 0.01-1 mg/m^3 (low), 1-3 mg/m^3 moderate, 3-4 mg/m^3 (Normal) and > 4 mg/m^3 (High). The spatial classes of Chlorophyll-*a* were overlaid on nitrate classes. The results obtained in terms of Chlorophyll-*a* spatial area over three classes of nitrate are shown in Table 1.

The data in Table 1 indicates that high levels of biomass in terms of chlorophyll prevails even at concentrations below 2µmol/l revealing that nitrate is not a limiting factor for phytoplankton growth in the coastal waters of Ennore.

Puri

The sampling locations along the Puri coast was fixed off the waste water distribution canal which carries mostly untreated sewage arising from the Pilgrim town of Puri. Puri also depicted a similar pattern as that of Ennore with sewage plume showing considerable influence on spatial distribution of dissolved oxygen but only for the year 1993. The plume area was spread over 57 sq km of the total 193 sq km of the nearshore area and located off the disposal canal with low oxygenated water along the northern side of the coastal waters (Fig. 6). Similar scenario was also found in the case of Chlorophyll-*a*. As the sewage was treated in the aeration ponds after 1993 before disposed into the sea, no such low DO plumes were observed during the subsequent years. While the nitrate levels showed varied patterns with most of the area around the mouth of canal showing spread of higher values, Chlorophyll-*a* showed distinct band of plume with low spread area around mouth of the canal especially in the summer months of 2003 and 2005 and the monsoon month of 1993 (Fig. 7). Such a distribution pattern revealed that the method used to treat the sewage was effective to improve only the DO levels in the sea and not effective for reducing nitrate. From the above, it is clear that data on spatial distribution of primary parameters like DO and nitrate has been useful in understanding the effectiveness of a particular method adopted for treatment of wastes like domestic sewage.

Table 1— Spatial overlay results of chlorophyll-*a* over nitrate in Ennore

Nitrate Concentration	Chlorophyll-*a* spatial area (sq.km) Low	Moderate	Normal	High
0.01-2 µmol/l	6	81	43	279
2-4 µmol/l	79	40	31	119
>4 µmol/l	-	42	127	124

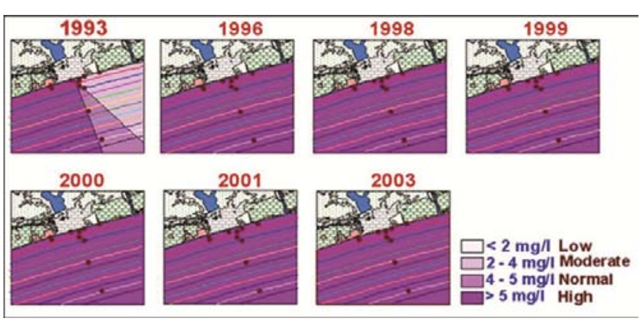

Fig. 6—Spatial distribution of dissolved oxygen in monsoon in Puri.

Chilika

Chilika lagoon, a brackish water body having a water spread area of about 900 sq km is considerably influenced by freshwater from the rivers of northern side. The tidal inflow from the Bay of Bengal varies considerably year to year depending on the depth and width of the mouth. Due to heavy siltation, the seawater flow into the lagoon is weaker during dry months of January to May. During the wet months, it is dominated by freshwater flow. As a result of varied tidal flow of about 1.2 to 2.3 m at its mouth, considerable influence of tide is noted in the central region and along the dredged canals up to the north. Apart from the tidal currents, wind stress is also found to influence mixing in the lagoon.

Based on salinity features, the lagoon has been divided into south, central and north region. The southern side has moderate freshwater and seawater flow, exhibits moderate to normal salinity conditions.

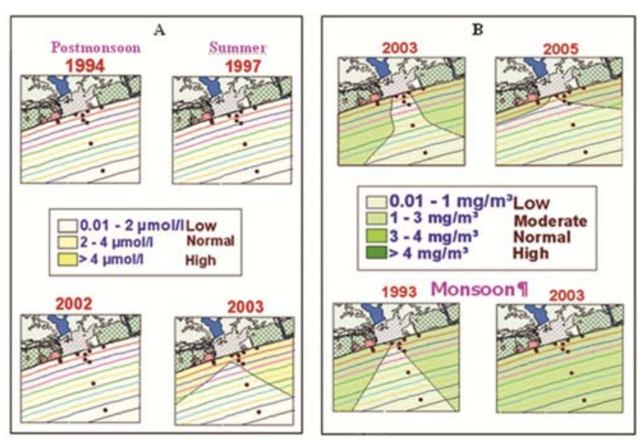

Fig. 7—Spatial distribution of nitrate (A) in post monsoon and Chlorophyll-*a* (B) in summer and monsoon in Puri.

The central region is influenced by seawater as well freshwater and as a result it shows brackishwater conditions. The northern side is dominated by freshwater during most part of the year and the extreme north is occupied by aquatic weeds (Fig. 8).

Spatial distribution of nitrate and chlorophyll was studied to understand the relationship between these parameters, especially to determine at what levels of nitrate, the chlorophyll concentration increases to reach the level of eutrophication, if any. It is well established that in brackishwater and seawater systems, nitrate is one of the preferred nutrients that leads to enhanced production, at times resulting in eutrophication. The data on nitrate and chlorophyll-*a* collected at 36 locations during 2005 were spatially interpolated and spatial data of nitrate and Chlorophyll-*a* for the year 2005 are given in Figs. (9 & 10). The nitrate concentrations were categorized into the classes of low (0.1-2 µmol/l), normal (2-4 µmol/l l), high (4-8 µmol/l) and very high (>8 µmol/l). Similarly, Chlorophyll-*a* concentrations were categorized into the classes of Low (0.01-4 mg/m^3), normal (4-8 mg/m^3), High (8-12 mg/m^3), Very high (12-20 mg/m^3) and Excess (> 20 mg/m^3). As the central part of the lagoon was dynamic and show brackishwater conditions, an attempt has been made to correlate the spatial data of nitrate with that of Chlorophyll-*a* to assimilate the influence of production. Spatial data of 8 stations in the central part of the lagoon of Chlorophyll-*a* and nitrate are given in Table 2. All classes of Chlorophyll-*a* were overlaid on each of four classes of nitrate using the overlay analysis of GIS to understand the existence of linear relationship between these two parameters. The results obtained from the overlay analysis have been given in Table 3. Out of the data, the total of spatial values from each of the class as presented in Table 4, were analysed to see how the various classes of Chlorophyll-*a* fared against the classes of nitrate.

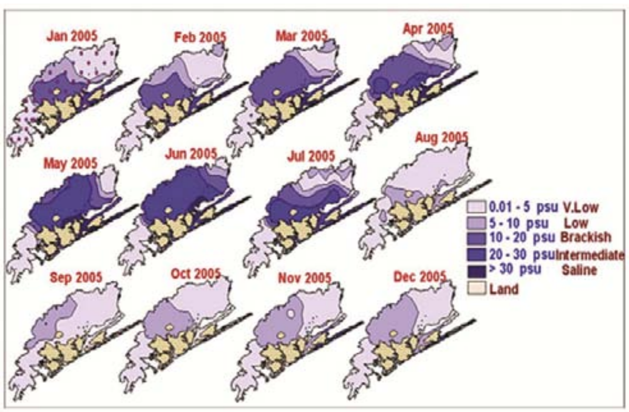

Fig. 8—Spatial distribution of salinity in Chilika Lake.

From the data in Table 4 it is clear that even low concentrations of nitrate can lead to substantial Chlorophyll-*a* compared to the concentrations above 2 µmol/l and the areas of high nitrate levels did not show corresponding increase in Chlorophyll-*a*. This explains that nitrate uptake saturation is achieved within 2 µmol/l itself in the Chilika lagoon. Similar kind of observation especially a parabolic relationship between nitrate uptake and phytoplankton was reported in earlier studies. Enrichment experiments conducted using natural mixed species of phytoplankton in tropical Pacific showed a parabolic relationship between nitrate and phytoplankton fluorescence[2]. Similar hyperbolic relationship between nitrate and phytoplankton growth was observed in cultures of diatom *S. costatum*[3]. Experiments with *S. costatum* and *Thalassiosira weissflogii* also indicated that classical saturation kinetics were observed in the lower range nitrate concentration of 1-40 µM [4].

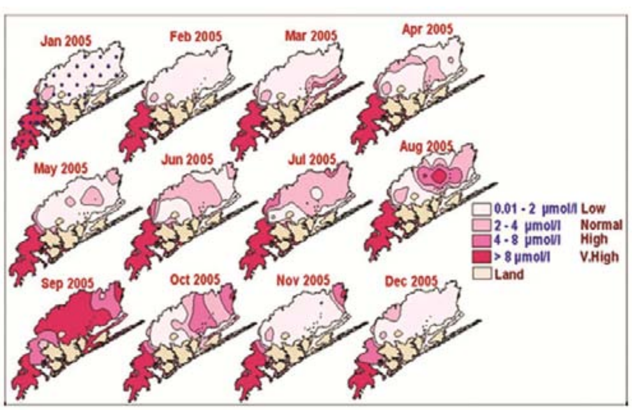

Fig. 9—Spatial distribution of nitrate in Chilika Lake

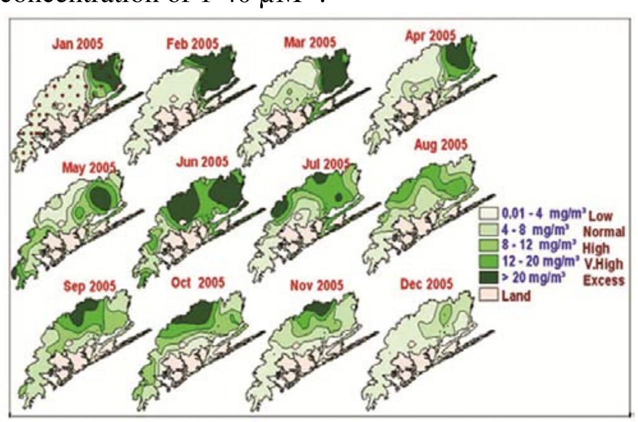

Fig. 10—Spatial distribution of chlorophyll-*a* in Chilika Lake.

Table 2—Spatial distribution of nitrate and Chlorophyll-*a* at central part of lagoon in the year 2005

	Nitrate (sq.km)				Chlorophyll-*a* mg/m^3 (sq.km)				
Month	Low	Normal	High	Very High	Low	Normal	High	V.High	Excess
January	414	17	18	82	443	48	42	48	40
February	462	25	15	101	362	38	20	27	123
March	306	74	58	91	229	191	27	38	57
April	331	157	16	87	308	152	34	42	9
May	374	85	17	88	124	214	123	48	64
June	204	223	20	157	51	63	85	197	204
July	157	298	36	120	92	121	105	209	65
August	238	75	101	132	60	226	142	157	-
September	0	13	142	499	54	198	140	115	66
October	201	175	143	110	138	102	154	94	98
November	482	23	19	102	248	171	103	57	43
December	409	58	79	0	444	118	31	-	-
Total	**3578**	**1223**	**664**	**1569**	**2553**	**1642**	**1006**	**1032**	**769**

Table 3—Spatial area of Chlorophyll-*a* classes against different spatial classes of nitrate in Chilika Lake

	Chlorophyll-*a* when nitrate >8 µmol/l					Chlorophyll-*a* when nitrate 4-8 µmol/l				
Month	Low	Normal	High	V. High	Excess	Low	Normal	High	V. High	Excess
Jan						18				
Feb						15				
Mar		13				2	10	2	6	42
April	10	6				16				
May	0	5	2				4	10		
June	33	19				3	12	4	3	
July	9	39	2	1	1	5	2	4	5	23
Aug	1	35	23	14			35	32	40	
Sep.	54	120	109	97	66		111	21	18	
Oct						31	38	37	23	30
Nov						35				
Dec						81				
Total	**107**	**237**	**136**	**112**	**67**	**206**	**313**	**110**	**95**	**95**

	Chlorophyll-*a* when nitrate 2-4 µmol/l					Chlorophyll-*a* when nitrate 0.01-2 µmol/l				
Month	Low	Normal	High	V. High	Excess	Low	Normal	High	V. High	Excess
Jan	14	2	1	-	-	305	45	42	47	4
Feb	20	1	2	3	-	254	38	18	23	134
Mar	11	34	4	25	-	149	139	22	8	-
April	74	37	18	21	-	151	115	14	15	-
May	7	18	14	11	-	117	145	65	30	30
June	-	13	25	114	74	11	26	34	62	71
July	11	52	62	100	36	33	28	40	52	4
Aug	1	33	19	27	-	7	119	39	75	-
Sep.	-	6	7	-	-	-	-	-	-	-
Oct	54	23	19	12	35	50	29	34	56	33
Nov	22	-	-	-	-	132	167	103	57	43
Dec	58	-	-	-	-	304	47	-	-	-
Total	**272**	**219**	**171**	**313**	**145**	**1513**	**898**	**411**	**425**	**319**

Table 4—Total spatial area of Chlorophyll classes over various nitrate classes

Nitrate Classes	Chlorophyll-*a* classes (sq.km)				
	Low	Normal	High	V. High	Excess
0.01-2 µmol/l	1513	898	411	425	319
2-4 µmol/l	272	219	171	313	145
4-8 µmol/l	206	313	110	95	95
>8 µmol/l	107	237	136	117	67

Month	Chlorophyll-*a* when nitrate >8 µmol/l					Chlorophyll-a when nitrate 4-8 µmol/l				
	Low	Normal	High	V. High	Excess	Low	Normal	High	V. High	Excess
Jan	-	-	-	-	-	18	-	-	-	-
Feb	-	-	-	-	-	15	-	-	-	-
Mar	-	13	-	-	-	2	10	2	6	42
April	10	6	-	-	-	16	-	-	-	-
May	-	5	2	-	-	-	4	10	-	-
June	33	19	-	-	-	3	12	4	3	-
July	9	39	2	1	1	5	2	4	5	23
Aug	1	35	23	14	-	-	35	32	40	-
Sep.	54	120	109	97	66	-	111	21	18	-
Oct	-	-	-	-	-	31	38	37	23	30
Nov	-	-	-	-	-	35	-	-	-	-
Dec	-	-	-	-	-	81	-	-	-	-
Total	**107**	**237**	**136**	**112**	**67**	**206**	**313**	**110**	**95**	**95**

Conclusion

The use of spatial data derived from the point data has been found to be useful in determining the extent of quantitative spatial distribution of chemical elements in the coastal waters. The pattern of spatial distribution of DO, nitrate and pathogenic bacteria indicated the possible impact of sources like sewage and influence of physical parameters like coastal currents on the zonal spatial distribution of these parameters. The increase of concentration of dissolved oxygen off Puri after 1993 clearly revealed the effectiveness of treatment method used. But the presence of high concentration of nitrate and bacteria in seawater revealed limited application of treatment method and its effectiveness only to improve the DO. Therefore, the data on quantitative spatial distribution of parameters like nitrate can reveal the effectiveness of waste treatment methods. Further, information on spread area of seawater with high bacteria and low DO can be used to avoid zones for drawl of seawater for desalination, mariculture and other human related use. The overlay analysis of GIS proved to be an excellent tool to study the relationship between vital nutrient like nitrate and phytoplankton biomass in terms of Chlorophyll-*a*. An exercise done using this tool to study the effect of nitrate on phytoplankton biomass in terms of chlorophyll-*a* revealed that even at concentrations below 2 µmol/l, high levels of chlorophyll could be achieved indicating that the nitrate is not a limiting nutrient in coastal waters of Ennore and lagoon waters of Chilika. Even though, the existence of such a relationship can be demonstrated using the location specific point data, the level of confidence increases when a GIS based spatial data is used, as it explicitly indicates the extent of quantitative spatial distribution of concentrations and also facilitates better understanding of existence of correlations between the parameters.

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References

1 Grasshof Klaus, Kremling K & Ehrhardt, *Methods of seawater analysis*, *(Publ. Wiley-VCH)* 1999, pp. 632.

2 Thomas, W.H., Effect of Ammonium and nitrate concentration on chlorophyll increases in natural tropical Pacific phytoplankton populations, *Limnol. Oceanogr.*, 15(3) (1970) 386-394.

3 Liv, Skoglund. & Arne, Jensen., Studies on N-limited growth of diatoms in dialysis culture, *J. Exp. Mar. Biol. Ecol.*, 21(2) (1976) 169-178.

4 Collos, Y., Siddiqi, M.Y., Wang, M.Y., Glass, A.D.M. & Harrison, P.J., Nitrate uptake kinetics by two maine diatoms using the radioactive trace ^{13}N, *J. Exp. Mar. Biol. Ecol.*, 163(2) (1992) 251-260.