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Behavior of Nutrients and Assessment of Eutrophication in the Visakhapatnam Harbor Waters, Central East Coast of India

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Abstract: *Rapid urbanization due to industrialization of Visakhapatnam, more amounts of domestic sewage and industrial effluents are entering into harbor waters. The impact of nutrient pollution and assessment of nutrient pollution on the quality of waters in the Visakhapatnam harbor has been studied over a period of one year at five stations. The enrichment of nutrients in these waters enhanced the eutrophication. The construction of outer harbor retards the tidal flushings resulting in a greater stagnation of inner harbor waters. The distribution pattern of these nutrients indicates the flow of pollutant rich waters at surface towards the sea during the study period. The extent of nutrient eutrophication in the harbor waters has been quantitatively calculated using nutrient index (I). The index values for all nutrients in the harbor waters (I>5) proved the extent of eutrophication in harbor waters. Further the nutrient index values decreased from inner harbor to outer harbor waters indicating mesotrophic conditions at outer harbor waters. This is attributed to the discharge of domestic sewage and industrial effluents containing organic matter into the inner harbor and their subsequent dispersion into the outer harbor and to coastal waters of Bay of Bengal.*
Keywords*: Nutrients behavior, eutrophication, Visakhapatnam harbor waters.*

I. INTRODUCTION

The combined domestic and industrial effluents discharge into Visakhapatnam harbor deteriorates its water quality. Pollution studies in the Visakhapatnam harbor waters have been reported (1-7). However, it appears that no systematic study has been carried out to assess the nutrient pollution in the harbor waters. Although eutrophication has been a recognized problem in freshwater environment, it has not attracted much attention in marine environment. It may be triggered off by a variety natural causes which results in organic enrichment of water bodies, but generally becomes wide spread phenomenon only under anthropogenic influences. Disposal of biological wastes containing nutrients can cause eutrophication of harbor and coastal waters, this is a major concern to environmental scientists and resource managers (7). Detection and measurement of eutrophication through estimation of biological indicators such as phytoplankton productivity, species composition diversity have been reported earlier (8,9). However, they require elaborate data collection and processing. Other simpler methods available to assess the water quality include nutrient-salinity relationships for evaluating the dilution and transportation of sewage effluents (2, 3) and N : P atomic ratios (8) for defining eutrophication conditions in the marine environment. Since none of the above methods could explain the eutrophication in quantitative terms, Karydis et al (8) formulated a simpler method based on the calculation of nutrient index designed to be specific for each nutrient to evaluate eutrophication levels in the marine environment influenced by domestic sewage. The present communication deals with the quantitative assessment of nutrient eutrophication levels in the harbor waters based on this method and also individual distribution of nutrients along with behavior and variations of hydrographic parameters in the harbor waters.

II. MATERIAL AND METHODS

The Visakhapatnam harbor is a natural harbor and also is one of the leading major ports of India. It is located on the central east coast of India at a latitude of 17º 42’ 00” North and longitude of 83º23’ 00” East. The harbor has divided into two regions, namely outer harbor, inner harbor. The outer harbor with a water spread of 200 hectares has 6 berths and the inner harbor, inter connected by a narrow entrance channel. The inner harbor stretches into three directions with northern, northwestern, and western arms which all units at the turning basin. One of the city’s main drainage system the ‘southern lighter channel’, also opens into turning basin. A freshwater stream from the monsoon-fed reservoir ‘Mehadrigedda’ empties into the north-western arm at its tail end turning the inner harbor waters brackish during monsoon season. The stream also acts a major polluting body as it carries several effluents (though treated) from various large, medium and small industries, such as Hindustan Petroleum Corporation Ltd., Coromandal Fertilizers Ltd., Hindustan Zinc Ltd., and Visakha Dairy. Hence a pollution gradient exists in the region from inner harbor to the outer harbor (7, 16, 17). The harbor waters receive domestic sewage from the city (3×10^3 m^3 day^{-1}) and industrial effluents (6×10^5 m^3 day^{-1}) from the neighboring industries.

Monthly surface and bottom water samples were collected for a period of one year at five stations in the harbor waters during the year 2012 - 13 is shown in Fig.1. Surface waters are collected with a clean plastic bucket and bottom waters are collected with Niskin bottom water sampler, they were immediately filtered through Glass Fiber GF/F filter papers. The filtered waters are used for the determination of salinity, nitrite, nitrate, ammonia, phosphate and reactive silicate were ±0.02, ±0.02, ±0.01 and ±0.02 µM respectively. Dissolved oxygen is determined by the Winkler's modified method (19). pH is measured using an Elico pH meter with glass and calomel electrodes.

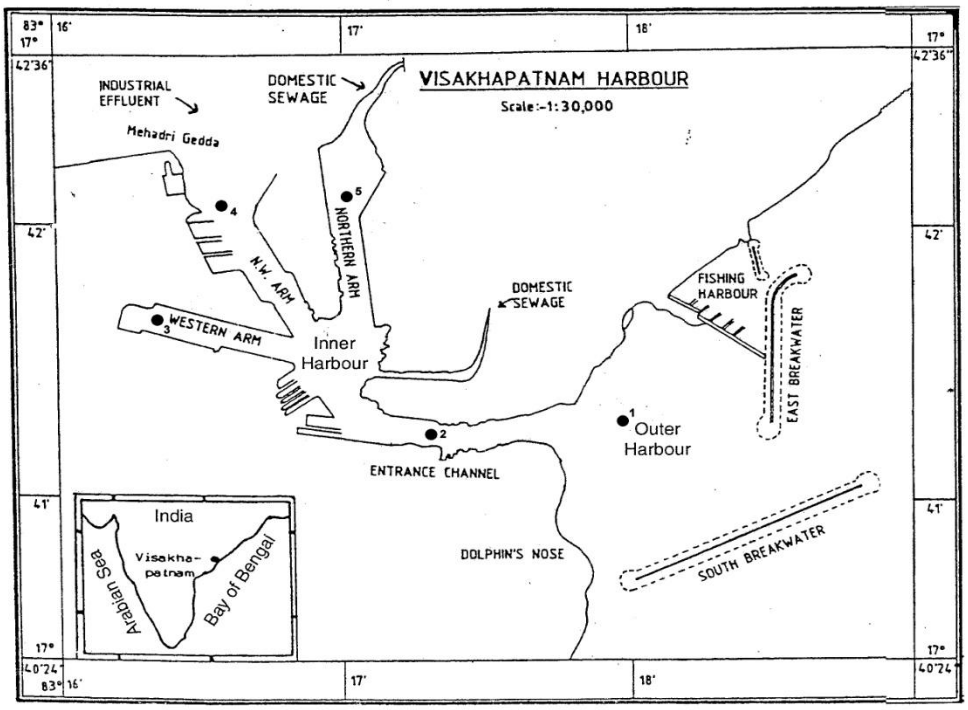


Fig. 1. Station locations at Visakhapatnam harbor waters

III. RESULTS AND DISCUSSIONS

Statistical data on hydrography and nutrient parameters in the harbor waters during the study period are given in Table 1. Annual average concentrations of hydrography and nutrients at individual stations are shown in Fig. 2 and 3 are discussed below.

Table 1
Statistical data on the hydrography and nutrient parameters in the Visakhapatnam harbor waters during 2012 - 13

Parameter	Surface				Bottom			
	Min.	**Max.**	**Mean**	**S.D (±)**	**Min.**	**Max.**	**Mean**	**S.D (±)**
Temp. (^{O}C)	28.00	32.00	30.39	1.06	27.00	30.80	29.14	0.91
pH	6.03	8.03	7.30	0.51	7.04	8.09	7.72	0.24
Salinity (psu)	19.24	34.39	20.18	3.26	26.94	35.64	32.11	2.28
D.O. (mg/L)	4.79	15.70	8.68	2.46	3.51	7.89	5.87	0.77
Chl-a (mg/m^3)	10.00	245.50	57.43	44.35	3.50	42.32	13.17	8.23
Nitrite (µM)	1.39	64.40	18.86	15.24	0.37	51.50	9.67	9.74
Nitrite (µM)	4.83	106.00	32.07	25.47	3.28	47.00	15.62	12.48
Ammonia (µM)	12.00	100.90	44.20	23.10	2.98	57.42	23.33	11.98
Phosphate (µM)	22.80	279.00	72.62	49.07	8.32	119.23	39.83	23.83
Silicate (µM)	10.80	100.23	42.93	23.54	2.56	60.63	19.43	11.49

Temperature : Temperature values are in the range of 28.0 to 32.0ºC with an average of 30.39ºC in the surface waters, where as in the bottom waters, temperature values varied from 27.0 to 30.8ºC with an average of 29.14ºC. The maximum temperature recorded during May 2012, while the minimum during January 2013. The surface as well as bottom temperature started to increase from March 2012 onwards and reached maximum in May 2012 at all stations, the increased trend continued up to July 2012. Follow the maximum, the temperature showed a decreasing trend up to January 2013 at all stations. The distribution of temperature essentially reflected climatic conditions of the area. Seasonally, maximum temperature noticed in pre-monsoon followed by post-monsoon and then monsoon. Similar distribution of temperature in the harbor and coastal waters of Visakhapatnam are reported earlier (20, 21).

pH : The pH values are in the range of 6.03 to 8.03 with an average of 8.03 in the surface waters, where as in the bottom waters, pH values varied from 7.04 to 8.09 with an average of 7.72. The pH values increased from March to July (pre-monsoon) when marine conditions prevailed increasingly in the harbor waters. It showed a decreasing trend from August to November (monsoon) when a large influx of freshwater occurred into the harbor. The surface pH values were always lower than those of bottom due to intrusion of high saline water into bottom. At St. 4, the pH values were lowest among all stations due to the discharge of (acidic) effluents from a fertilizer complex (Coramandal Fertilizer Limited) and a Zinc Smelter (Hindustan Zinc Limited) in the upper reaches of this station. At St. 5 also, the values were low due to the discharge of city's domestic sewage. Similar variations of pH were reported earlier in these waters (6, 8), and in the river Par and its abatement where industrial effluents were dominant (22),

Salinity : The salinity values in the harbor waters, varied in the range of 19.24 to 34.39 (psu) with an average of, 30.18 (psu) in the surface waters where as in the bottom waters, salinity varied from 26.94 to 35.64 (psu) with an average of 32.11 (psu). Maximum values of salinity are observed in May in the bottom water of St. 1, while minimum value of salinity was observed in October (monsoon season) in the surface waters of St. 4. From the monthly distribution of salinities, the following pattern of its distribution could be noticed in the harbor waters. A period of relatively high salinity observed from March to June 2012 and a period intermediate values of salinity observed from December 2012 to February 2013. Similar trend of salinities in the harbor and costal waters are reported earlier (6, 20, 21).

Dissolved oxygen : The dissolved oxygen values varied in the range of 3.79 to 15.70 mg/L with an average of 8.68 mg/L in the surface waters where as in the bottom waters, dissolved oxygen content varied from 3.51 to 7.89 mg/L. The surface waters are supersaturated with dissolved oxygen because of formation several planktonic blooms already reported in these waters (4). Higher concentrations of dissolved oxygen were observed during post-monsoon and pre-monsoon seasons due to the existing meteorological conditions are favorable for the growth of planktonic blooms (23). Low concentrations of D.O were observed during monsoon season due to the adverse conditions for the bloom formation, and the monsoonal runoff which carries the organic wastes into the harbor waters and oxygen is utilized for the degradation of organic matter. During the study period low oxygen concentrations were observed in the bottom waters at stations 3 to 5 are attributed to the oxidation of organic matter.

Nutrients

Nitrogen species : Abnormally high concentrations of nitrite, nitrate and ammonia are observed in the harbor waters. The maximum concentrations of these nutrients are at station 2 - 5. Nitrite concentrations ranged from 1.39 to 64.40 µM with an average of 18.86 µM in the surface waters, where as in the bottom waters, nitrite concentrations ranged from 0.37 to 51.50 µM with an average of 9.67 µM. Nitrate concentrations in the surface waters, ranged from 4.83 to 106 µM with an average of 32.07 µM, where as in the bottom waters, its concentrations ranged from 2.28 to 47 µM with an average of 15.62 µM. Ammonia concentrations in the surface waters ranged from 12.00 to 100.90 µM with an average of 44.20 µM, where as in the bottom waters, its concentrations varied from 2.98 to 57.42 µM with an average of 23.33 µM. Among the three nitrogen species, ammonia is the major constituent in the harbor waters.

The maximum concentrations of these nutrients are observed at Sts. 3 - 5 when compared to St. 1. Nutrient enrichment through pollution was reported from other marine environments (24, 25). The enrichment of nutrients enhances the eutrophication and stimulates the algal growth. The seasonal variation in all the nitrogen constitutes shows similar trend at all stations. Seasonally, higher concentrations of these nutrients were observed during monsoon season due to the discharge of more industrial effluents and domestic sewage into the harbor waters, followed by post and pre-monsoon seasons. Higher concentrations of nitrogen species in surface waters may be the reasons for plankton peaks as reported earlier (26, 27).

Phosphate : Phosphate concentrations ranged from 22.80 to 279.00 µM with an average of 72.62 µM in the surface waters, where as in the bottom waters its concentration varied from 8.32 to 119.23 µM with an average of 39.66 µM. Higher concentrations of phosphate observed in surface waters of all stations in the harbor. St. 4 recorded highest concentrations of phosphate (279 µM) in October in the surface waters. This could be attributed to the influence of influx of industrial effluents and land drainage in this station. Seasonally, higher concentrations of phosphate were observed during monsoon than those of pre-monsoon and post-monsoon seasons. The maximum concentrations of phosphate in the harbor waters during monsoon season due to the release of industrial effluents from the Coromandel Fertilizer Limited and spillage during loading / unloading of fertilizer. Similar seasonal variations were also observed in the estuarine complex of Cochin (28), off Malpe, South Kanara in the near shore region of Thal, Maharashtra (29). A pronounced horizontal gradient (downward) existed in the concentrations of phosphate from Sts. 3 - 5 to St. 1.

Silicate : Silicate concentrations ranged from 10.80 to 109.23 µM with an average of 42.93 µM in the surface waters, where as in the bottom waters its concentration varied from 2.56 to 60.63 µM with an average of 19.43 µM. Higher concentrations of silicates were observed during August to October (Monsoon) and lower concentrations were observed during March to May (Pre-monsoon season). High concentrations of silicate in monsoon season is a common occurrence in the coastal and harbor waters (30, 31). It is well known fact that land-born runoff is the chief source for silicate while its removal utilization by phytoplankton and adsorption into the suspended sediments are in the main processes operative in the marine environment (32, 33). With high concentration of silicate in the harbor waters an intense growth of diatoms like *Skeletonema costaum* and *Cyclotella meneghenina* occurs. Major peaks in diatoms production were reported earlier during October to November when the concentrations of silicate also were observed to be maximum (6, 34). Relatively low concentrations of silicate were observed during pre and post-monsoon season may be either to its supply being less (from runoff) or to its biological utilization into both processes operating simultaneously. In general, surface concentrations of silicate were higher than those of bottom waters. Relatively, high values of silicate (100.23 µM) were observed in the surface waters of St. 4, which drastically fell in the direction of St. 1.

Chlorophyll-a : Phosphate concentrations ranged from 10.00 to 245.50 $mg.m^3$ with an average of 57.43 $mg.m^3$ in the surface waters, where as in the bottom waters its concentration varied from 3.50 to 42.32 $mg.m^3$ with an average of 13.17 $mg.m^3$. Highest concentrations of Chlorophyll-a were observed in January & February and lowest values were observed during July to September. Higher values of chlorophyll-a were observed during pre and post-monsoon season which may be attributed to the favorable conditions of nutrient supply, light intensity and temperature in the ambient waters that led to maxima in primary production. Lower concentrations of chl-a were observed during monsoon season, may be attributed to the unfavorable conditions like high turbidity, low light, low salinity and low pH. Chl-a values were relatively higher at St. 4 (245.5 $mg.m^3$) in the surface waters, when compared to other stations due to the continous supply of ammonia and phosphate to this station from the industrial effluents of Coramandel Fertilizer industry.

Inter-correlations of hydrography and nutrients parameters

The correlation coefficients have been computed among hydrography and nutrient parameters to understand inter-relationships in the harbor waters is given in Table 3.

Table 3
Correlation between hydrography and nutrient parameters in the Visakhapatnam harbor waters during 2012-13

	Temp.	pH	Salinity	D.O.	NO_2	NO_3	NH_4	PO_4	SiO_4
pH	-0.23								
Salinity	0.04	0.76					N =120		
D.O.	0.31	-0.16	-0.09				P<0.0001		
NO_2	0.33	-0.82	-0.69	-0.03					
NO_3	0.25	-0.89	-0.80	-0.01	0.91				
NH_4	0.33	-0.84	-0.73	0.15	0.88	0.88			
PO_4	0.33	-0.84	-0.73	0.15	0.88	0.88	0.98		
SiO_4	0.40	-0.85	-0.68	0.29	0.85	0.85	0.92	0.92	
Chl-a	0.39	-0.25	-0.17	0.82	0.18	0.15	0.36	0.36	0.50

Significant inverse correlations ($p = < 0.001$) were observed between salinity and nutrients in the harbor waters indicating that distribution of these parameters is believed to be primary govern by land runoff along with industrial effluents and domestic sewage. Similar observations have been reported by several workers in different coastal environments of India. Significant positive correlations were observed between pH and salinity indicates that pH increases with increase of salinity. Significant negative correlations were observed between salinity, pH and nutrients may be attributed that the nutrient concentrations are decreased with increasing pH and salinity. Significant positive correlations were observed between chlorophyll-a and dissolved oxygen, indicating that most of the dissolved oxygen produced in the harbor waters through phytoplanktonic photosynthesis. Significant positive correlations were observed within the nutrients attributing their common sources of occurrence in the harbor waters. Chlorophyll-a moderately correlated (positive) with ammonia, phosphate and silicate attributing that these waters are eutrophic in nature.

Nutrient Index

Nutrient index (I) values are calculated using the equation of Karyds *et al* (1983)

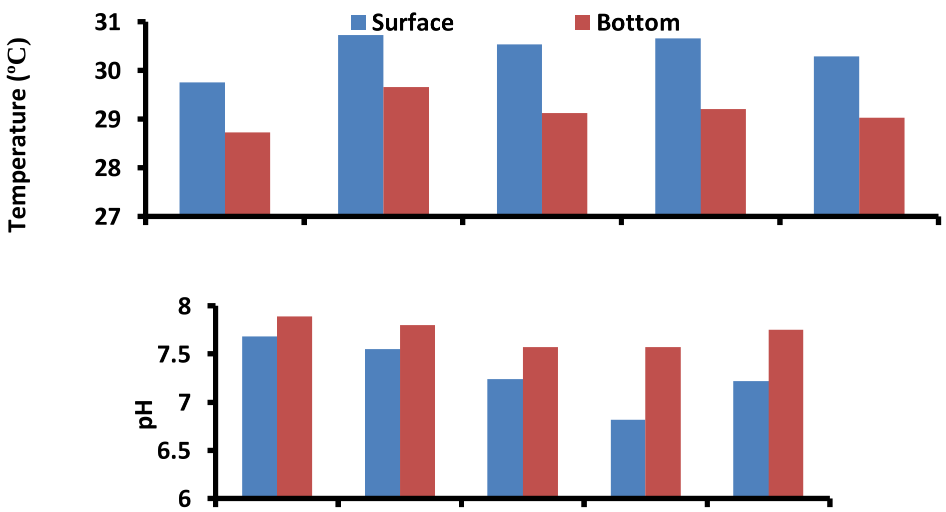
$$I = \frac{C}{C - \log x} = \log A$$

Where C is the log of total loadings (annual) of given nutrient in an area (X_{ij}), x is the total (annual) concentration of nutrient at a certain station (X_i) and A is the number of stations. According to the method, the index values of > 5 indicate eutrophic, values ranging between 3 and 5 mesotrophic values < 3 indicate oligotrophic waters. Nutrient indices were calculated for nitrate, ammonia and phosphate in the surface waters for all 5 stations since their effect on eutrophication is more pronounced at surface waters, the index values at individual stations for different nutrients are given in Table 2.

Table 2
Data on the nutrient index (I) in the Visakhapatnam harbor waters during 2012-13

St. No.	Nitrate	Ammonia	Phosphate
1	4.01	4.14	4.25
2	5.24	5.51	5.08
3	5.78	6.22	7.38
4	7.21	7.61	8.25
5	6.22	6.54	6.84

From the above table it is evident that the harbor waters are eutrophic as the nutrient index (I) values at Sts. 2 - 5 exceed 5. This can be attributed to the discharge of domestic sewage and industrial effluents rich in organic matter into the harbor waters. Existence of eutrophication in the Visakhapatnam harbor waters was reported earlier based on abnormally high concentrations of nutrients, poor transparency of high BOD. High plankton standing stock and chlorophyll concentrations accompanied by low species diversity in the harbor as against normal conditions in the open sea was attributed to severe eutrophication (8, 35). Nutrient Index (I) shows an increasing trend with increase of nutrient concentrations in the harbor stations thus offering a measure of degree of eutrophication at different stations. Inner harbor (Sts. 3 - 5) influenced by sewage outfall and discharge of industrial effluents containing organic matter recorded higher values (1>5) for all the nutrients. On the other hand the nutrient index relatively lower values in the outer harbor waters indicating mesotrophic conditions. It is interesting to note that the value exhibits a decreasing trend from inner harbor to outer harbor waters. This is due to dispersion and dilution of nutrients from inner harbor to outer harbor as it is evident from the decreasing trend of nutrient concentrations. It can therefore be concluded that the eutrophication is more in the inner harbor waters than to outer harbor waters due to dilution and dispersion of these nutrients from the coastal waters of Bay of Bengal.



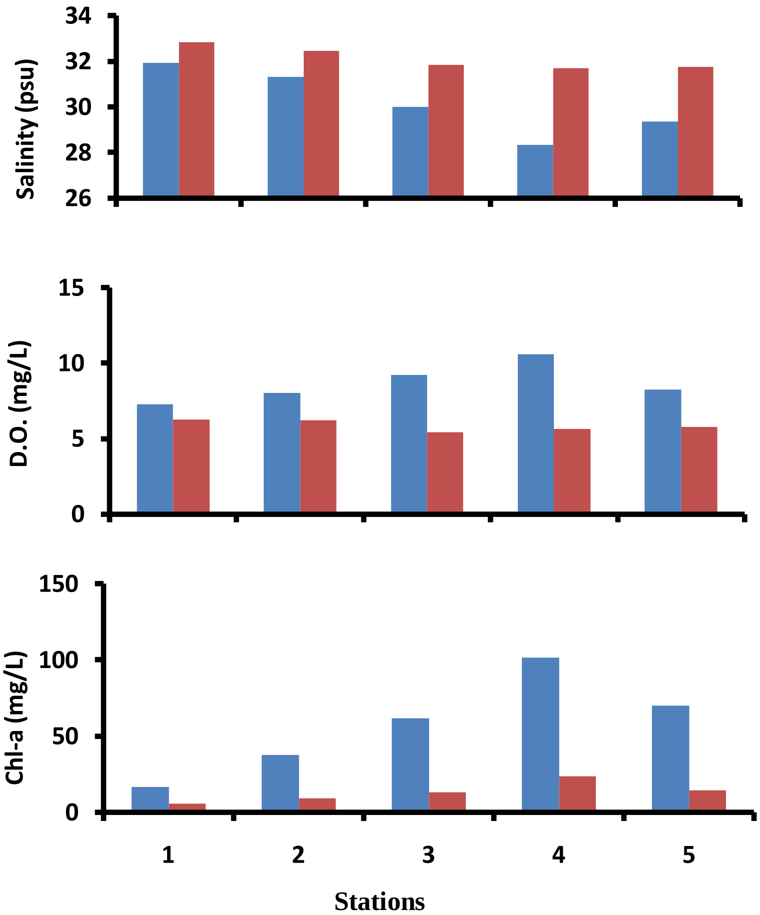
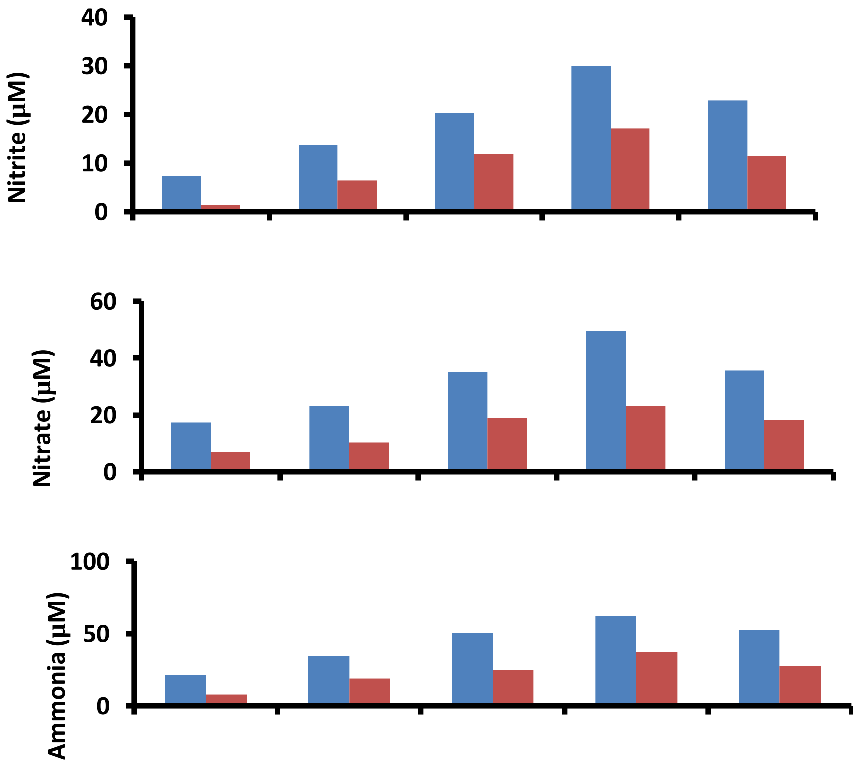


Fig. 2. Station-wise (annual mean) variations of hydrographic parameters in the Visakhapatnam harbor waters during 2012-13



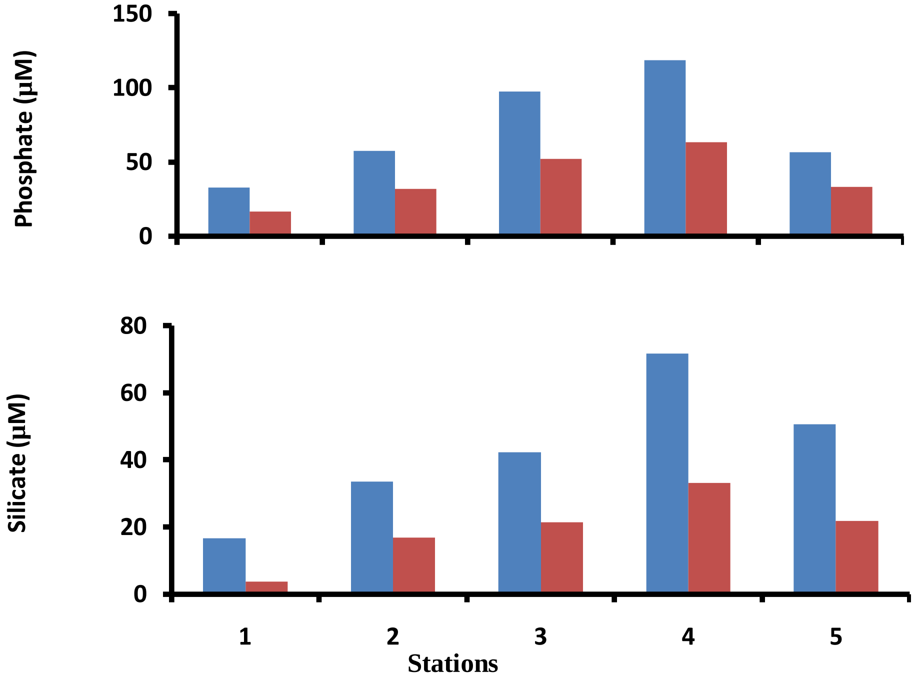


Fig. 3. Station-wise (annual mean) distribution of nutrients parameters in the Visakhapatnam harbor waters during 2012-13

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