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Seasonal Variability and Behavior of Hydrographic and Nutrient Parameters in the Estuarine Waters of Gauthami Godavari, East Coast of India

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Abstract: *Monitoringofriver waters arean important in now a days because of increasing industrialization, urbanization and anthropogenic actives from river banks. The industrial effluents, domestic sewage, agricultural wastesand aquacultural wastes are being discharged into the river waters and finally reaching into coastal waters that causing degradation of water quality. The present study was carried out to determine the water quality in terms of seasonal variability and behavior of physicochemical and nutrients parameters for a period of one year during 2013 in the estuarine waters of Gauthami Godavari along its longitudinal stretch at seven station from the head of the estuary to mouth of the estuary. The temperature valuesin the estuarine waters, varied from 25.60 to 31.80 ^{O}C, pH values in the in the range of 7.20 to 8.3, salinity ranged from 0.23 to 31.83 psu, dissolved oxygen values ranged from 2.36 to 6.82 mg.l^{-1}. The dissolved nitrite concentrationsvaried from 0.04 to 1.98 µM, nitrate concentrations varied from 0.48 to 17.20 µM, ammonia concentrations varied from 1.72 to 6.6 µM, phosphate concentrations varied from 0.11 to 3.41 µM, and silicate concentrations ranged from 6.56 to 165.94 µM. Hydrographical parameters(temperature, pH, salinity, dissolved oxygen) indicated distinct spatial and seasonal variations. Nutrients (nitrite, nitrate, ammonia, phosphate, silicate) in general, exhibited a decreasing trend from riverine to estuarine region indicating that dominant occurrenceof river water. This was also supported by the relatively higher levels in September (monsoon) when compared with March (pre-monsoon) and December (post-monsoon).*

Keywords*: Godavari estuary, physicochemical parameters, nutrients behavior, seasonal variations.*

I. Introduction

Estuaries constitute a major interface between land and the oceans and have been regarded as one of the most important aquatic systems. Distribution of chemical constituents in estuarine environment is controlled by physical, chemical, geological and biological processes since they govern the fate and net fluvial transport of weathered materials from continents to the oceans. Studies on the distribution and behavior of hydrographic and dissolved constituents such as nutrients in estuarine regions are therefore important for assessing riverine inputs into the oceans.. Some physio-chemical studies such as temperature, salinity and current distributions, diurnal variations of salinity, temperature and some nutrients behavior and their seasonal variationsin Godavari estuaries have been reported (Rama Sarma, 1970; Reddy and RangaRao, 1983; Sarinet al., 1985;Ranga Rao et al., 1988; Ramanaet al., 1989;Sarmaet al., 1993; Padmavathi andSatyanarayana, 1999;Sarma et al., 2009, 2010). However, no systemic studies have been carried out so far on the distribution and behavior of hydrography, nutrient parameters in the estuarine waters of GauthamiGodavari along its longitudinal stench. In view of this, the author has thereforebeen undertaken adetailed study ofthe behavior and seasonal distribution ofthese parameters for a period of one year during 2013.

II. Materials and Methods

The Gauthami-Godavari River estuary is the largest estuary in the central east coast of India. The estuary is a drowned river mouth type of estuary (16º41'-16º56'N, 81º.45'-82º21'E) and covers an area of 330 km^2 in the state of Andhra Pradesh. Godavari is one of the largest rivers in India, after Ganga and Brahmputra and covers 3.1 x 10^5 km^2 and opened to the Bay of Bengal on the east coast of India. The river originates at an altitude of about 1600 m near Nasik in the Western Ghats and travels about 1480 km eastwards across the peninsular India and drains into the Bay of Bengal. During its course, it divides into two major distributaries, one flowing towards the east called Gauthami-Godavari estuary and the other flowing towards the south termed as Vasista-Godavari estuary. The basin climate is generally dry with an average rainfall of 1512 mm y^{-1} and more than 85% of the annual rain fall received in the catchment during summer monsoon (Rao, 1975). The river discharge in to the Gouthami estuary, downstream of Rajahmundry, is regulated by a century old Dam at Dowleswaram, The river discharge is high during June-September (Indian summer monsoon) and low during October to December and then river discharge is almost negligible. The present study was undertaken in the

Gauthami-Godavari, which is the major branch of Godavari River. The average range of tides is about 2-2.5 m and current speed is 10-80 m,s^{-1} at the estuarine location.

Seven sampling stations are fixed along the stretch of GauthamiGodavari estuary, starting from head of the estuary (Kotipalle, St.1,Dangeru, St.2, Yanam St.3, VrudhaGauthami, St.4, Balusuthippa, St.5, Mangroove area, St.6) to the mouth of the estuary (Bhiravapalem, St.7) is sown in Fig. 1.

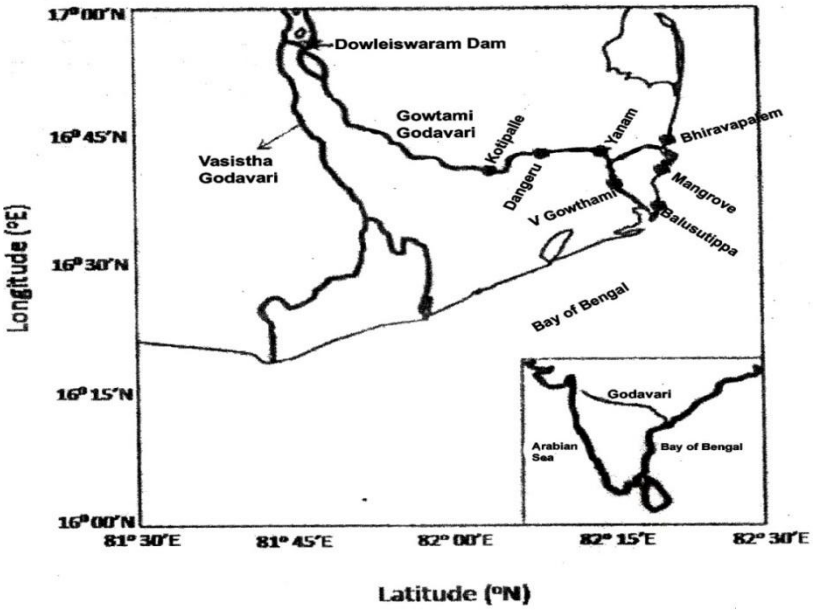

Fig.1. Station locations in the Godavari estuary

Water samples were collected seasonally over a period of one year, starting from pre-monsoon (March), onset of monsoon (June), monsoon (September) and post-monsoon (December).The average depth of the water column in the study area varied from 5 to 12 m. A hired mechanized boat used to collect water samples. The water samples were collected from surface and near bottom with the help of Niskin water sampler.

During the sampling time surface and bottom temperature was recorded immediately with a precision thermometer, Dissolved oxygen was fixed with Winkler A and B reagents on the boat itself. After completion of sampling, water samples were filtered through glass fiber filter papers (GF/F of 0.45 µm), the filtered water samples are used to analyze pH, salinity, and nutrients like nitrite, nitrate, ammonia, phosphate, and silicate following standard spectrophotometric procedures (Grashoff,1983) within 6 hours of the sample collection. The precisions of the nitrite, nitrate, ammonia, phosphate, and silicate were ±0.02, ±0.02, ±0.01, and ±0.02 µM respectively. Particulate matter was collected on GF/C filter papers in each station, was extracted with 90% acetone and used them for estimation of Chlorophyll-a on spectrophotometrically (Parsons 1984) with a precision of ±4.3%. A simple correlation analysis was made taking all the data to know the interrelationships among the analyzed parameters.

III. Results and Discussions

The statistical data on the hydrographic andnutrient parameters in the study area are given in Table 1. Annual average concentrations of hydrography and nutrients at eachindividual stations are shown in Fig. 2 for hydrography and Fig.3 for nutrients.

Table 1. Statistical data on the hydrography and nutrient parameters in estuarine Waters of Gauthami Godavari during 2013

Parameter	Surface				Bottom			
	Min.	Max.	Mean	S.D (±)	Min.	Max.	Mean	S.D (±)
Temp. (° C)	26.50	31.80	29.62	2.01	25.60	31.40	28.84	2.14
pH	7.20	8.20	7.71	0.27	7.43	8.30	7.94	0.21
Salinity (psu)	0.23	31.83	15.43	11.91	4.63	34.26	19.77	10.13
D.O. (mg/L)	4.23	6.82	5.53	0.76	2.36	5.12	3.93	0.77
Chl.a (mg/m^3)	3.45	11.25	6.65	2.18	2.52	6.25	4.30	0.89
Nitrite (µM)	0.11	0.98	0.70	0.57	0.04	0.74	0.27	0.19
Nitrate (µM)	1.01	17.20	6.89	4.22	0.48	11.25	3.99	2.62
Ammonia (µM)	2.12	6.62	3.75	1.22	1.72	4.95	2.84	0.79

Phosphate (µM)	0.29	3.41	1.09	0.97	0.11	2.25	0.82	0.48
Silicate (µM)	12.24	165.94	77.36	48.30	6.56	97.77	52.16	28.21

Temperature:

The station-wise summery statistics of temperature in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average variations of temperature in both surface and bottom waters at individual stations are shown in Fig. 1. The temperature values in the surface waters of the Guthami Godavari were in the range of 26.50 to 31.80 ^{O}C with an average of 29.62^{O}C, where as in the bottom waters, the temperature ranged from 25.60 to 31.40 ^{O}C with an average of 28.84 ^{O}C. The surface as well as bottom water temperatures are high during pre-monsoon and onset of monsoon seasons and low during post-monsoon season in all the stations. The higher temperature observed during pre and onset of monsoon season due to summer heating of the surface waters and the lower temperature noticed during post-monsoon season is due to winter cooling. Similar seasonal variations of temperature were reported earlier in the Godavari estuarine waters (Sai Sastry and Chandra Mohan, 1990; Rao et al., 1988; Reddy and Ranga Rao, 1994; Padmavathi and Satyanarayana, 1999). Similar seasonal variations of temperature were also reported in the estuaries of India and elsewhere, are Mandovi estuary (Varma et al., 1975); Vellar estuary (Chandran and Ramamoorthi, 1984); Mahanadi estuary (Upadhyay, 1988) Bahuda estuary (Mishra et al., 1993); Rushikulya estuary (Gouda and Panigrahy, 1993); Great Quse estuary, England (Rndellet al., 1997); in a tropical estuary of Costa Rica (Kress et al., 2002); in the northeastern Pacific estuary (Sigleo and Frick (2007); Pichavaram mangrove waters (Senthilkumaret al., 2008); Kaduviyar estuary, southeast coast of India (Perumalet al., 2009); Ennore estuary (Rajkumaret al., 2011); estuaries of Khambhat (Deshkaret al., 2012); estuaries of Kodungallur-Azhikode, Kerala, India (Jachandranet al., 2012); Cochin backwaters (Robin et al., 2012); Zuari estuary, India (Sunitaet al., 2013), in Parangipettai coastal waters and Vellar estuary, southeast coast of India (Santhosh Kumar and Ashok Prabhu, 2014), and in Narmada estuary (DeshkarSonalet al., 2014). In general, the surface water temperature was always higher than that of bottom waters. The gradient in temperature between surface and bottom was less during premonsoon ($\bar{x}$ = 0.51°C) and onset of monsoon (0.71°C) due to intense tidal mixing, and is high during monsoon ($\bar{x}$ =1.11°C) due to partial mixing in the estuary, as the flooding of estuary and the entire estuary is filled with fresh water when the river discharge and direct precipitation is maximum during this season.

pH:

The station-wise summery statistics of pH values in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average variations of pH in both surface and bottom waters at individual stations are shown in Fig. 2. The pH values in the surface waters of the Gauthami Godavari were in the range of 7.20 to 8.20 with an average of 7.71, where as in the bottom waters, the pH ranged from 7.43 to 8.30 with an average of 7.94. In general, higher pH values were observed at the mouth of the estuary (Bhairavapalem) due to the dominance of seawater and the lower pH values were observed at the head of the estuary (Kotipalle) due to the dominance of river water. The pH values showed an increasing trend from surface to bottom at all stations may be attributed to the bottom intrusion of seawater in all stations and seasons. The surface to bottom gradient of pH is more during monsoon ($\bar{x}$ = 0.35) due to flooding of fresh water in to the estuary and less during pre-monsoon ($\bar{x}$ = 0.12), due to intense tidal mixing. The fluctuations in pH values during different seasons of the year can be attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of estuarine waters by freshwater influx and decomposition of organic materials (Karuppasamy and Perumal, 2000; Rajasegar, 2003).The surface as well as bottom water temperatures are high during pre-monsoon and onset of monsoon seasons and low during post-monsoon season in all the stations. The higher pH values were observed during pre and onset of monsoon season due to summer heating of the surface waters and the lower pH values were observed during monsoon season is due to influx of fresh water in the estuary and slight increase in post-monsonsoon season. Such a seasonal variations in pH values have also been reported from the Vellar estuary Chandran and Ramamoorthi, 1984), Mahanadi estuary (Upadhyay, 1988), Rushikulya estuary (Gouda and Panigrahy, 1993), Pichavaram mangrove area (Prabhuet al., 2009) and Kaduviyar estuary (Perumalet al., 2009).

Salinity:

Salinity plays a dominant role in influencing chemical constituents in water and sediment and its distribution strongly depends on sea water intrusion through mouth and on influx from the river water into the estuary. Salinity of estuarine waters has been considered as an index of the estuarine mixing processes and tidal effects. The station-wise summery statistics of salinity values in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average variations of salinity in surface and bottom waters at individual stations are shown in Fig. 1. The salinity values in the Gauthami estuary, ranged from 0.23

to 31.83 psu with an average of 15.43 psu in surface waters and 4.63 to 34.26 psu with an average of 10.13 psu in the bottom waters. The salinity showed a decreasing trend from pre-monsoon to monsoon followed by a slight increase in post-monsoon season at all stations. The difference in salinity gradient between surface and bottom varied from 2.43 to 3.00 psu during pre-monsoon, 2.50 to 4.10 psu during onset of monsoon, from 4.40 to 10.4 psu during monsoon and from 2.6 to 3.48 psu during post-monsoon season. Thus, the salinity distribution suggests slight stratification during monsoon and well mixed conditions during pre and post-monsoon seasons prevailed in the estuary (Reddy and Ranga Rao (1994), Padmavathi and Satyanarayana (1999), Narasimha Rao (2001) and Sarmaet al., (2009). Similar seasonal variations of salinity were also reported in the estuaries of India and elsewhere, are Mandovi estuary (Varma et al., 1975); Vellar estuary (Chandran and Ramamoorthi, 1984); Mahanadi estuary (Upadhyay, 1988) Bahuda estuary (Mishra et al., 1993); Rushikulya estuary (Gouda and Panigrahy, 1993); Great Quse estuary, England (Rndellet al., 1997); in a tropical estuary of Costa Rica (Kress et al., 2002); in the northeastern Pacific estuary (Sigleo and Frick (2007); Pichavaram mangrove waters (Senthilkumaret al., 2008); Kaduviyar estuary, southeast coast of India (Perumalet al., 2009); Ennore estuary (Rajkumaret al., 2011); estuaries of Khambhat (Deshkaret al., 2012); estuaries of Kodungallur-Azhikode, Kerala, India (Jachandranet al., 2012); Cochin backwaters (Robin et al., 2012); Zuari estuary, India (Sunitaet al., 2013), in Parangipettai coastal waters and Vellar estuary, southeast coast of India (Santhosh Kumar and Ashok Prabhu, 2014), and in Narmada estuary (DeshkarSonalet al., 2014).

Dissolved Oxygen:

The station-wise summery statistics of dissolved oxygen values in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average variations of dissolved oxygen values both in surface and bottom waters at individual stations are shown in Fig. 1. The dissolved oxygen values in the estuarine waters of Gauthami Godavari ranged from 4.23 to 6.82 $mg.l^{-1}$ with an average of 5.33 $mg.l^{-1}$ in surface waters and from 2.36 to 5.12$mg.dm^{-3}$ with an average of 3.93 $mg.l^{-1}$ in the bottom waters. Higher values of D.O. were observed during pre and post-monsoon seasons due to higher photosynthetic activity and lower values were observed during monsoon due to oxidation of organic matter. More organic waste is entering into the estuarine waters during this season along with huge fresh water runoff. Similar distribution of oxygen was also reported in these waters by Padmavathi and Satyanarayana (1999), Sarmaet al., (2009). Similar seasonal variations of dissolved oxygen were also reported in the estuaries of India, are in Mandovi estuary (Varma et al., 1975); in Vellar estuary (Chandran and Ramamoorthi, 1984); in Mahanadi estuary (Upadhyay, 1988), in Bahuda estuary (Mishra et al., 1993); in Rushikulya estuary (Gouda and Panigrahy, 1993); in Pichavaram mangrove waters (Senthilkumaret al., 2008); in the waters of Kaduviyar estuary, southeast coast of India (Perumalet al., 2009); in Ennore estuary (Rajkumaret al., 2011); in estuaries of Khambhat (Deshkaret al., 2012); in the estuaries of Kodungallur-Azhikode, Kerala, India (Jachandranet al., 2012); in Cochin backwaters (Robin et al., 2012); in Zuari estuary, India (Sunitaet al., 2013), in Parangipettai coastal waters and Vellar estuary, southeast coast of India (Santhosh Kumar and Ashok Prabhu, 2014), and in Narmada estuary (DeshkarSonalet al., 2014). In general, the surface water dissolved oxygen was always higher than that of bottom waters.

Seasonal variation of dissolved oxygen both at surface and bottom in the estuarine waters exhibited a distinct trend namely (i) decreasing in its concentrations from riverine (head) to mouth (marine) of the estuary, and (ii) decrease in its concentration from surface to bottom in all seasons. The former is due to greater solubility of oxygen in fresh-water region when compared to estuarine and coastal waters, and latter is due to utilization of oxygen in the oxidation of organic matter.

Chlorophyll-a:

The station-wise summery statistics of chlorophyll-a values in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average variations of salinity in surface and bottom waters at individual stations are shown in Fig. 1. The chlorophyll-a values in the surface waters of Gauthami estuary, ranged from 3.45 to 11.25 $mg.m^3$ with an average of 6.55 $mg.m^3$and in the bottom waters, varied from 2.52 to 6.25 $mg.m^3$ with an average of 4.30$mg.m^3$ .Higher values of Chlorophyll-a were observed during onset of monsoon and post-monsoon season. This may be attributed mainly due to the favorable conditions prevailed in the estuarine waters like salinity, temperature, nutrients and light intensity during these periods. Lower values were observed during monsoon season which may be due to high turbulence of flood water and also decrease in isolation during this period. Similar seasonal variations of chlorophyll-a were also observed in the estuarine systems of Goa (Bhargava, 1973; Bhargava and Dwivedi, 1974;Bhargava and Dwivedi, 1976) in the estuarine waters of Auranga and Ambika (Desai et al., 1984). Higher values of chlorophyll-awerealways observed in the surface waters than that of bottom waters. A longitudinal decrease of chlorophyll-avalues was observed in all seasonal, as salinity increases, the values of chlorophyll-awere decreasing towards mouth of the estuary. Similar distributionof chlorophyll-avalues were also reported in these waters (Padmavathi and Satyanarayana, 1999; Sarmaet al., 2009).

Nutrients

Nitrogen Species

Dissolved Nitrite, Nitrate and Ammonia:

The station-wise summery statistics of nitrogen species concentrations in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average variations of nitrogen species in both surface and bottom waters at individual stations are shown in Fig. 2. The dissolved nitrite concentrations in the surface waters Gauthami estuary varied from 0.11 to 1.98 µM with an average of 0.70 µM, where as in the bottom waters, its concentrations varied from 0.04 to 0.74 µM with an average of 0.27 µM. The dissolved nitrate concentrations in the surface waters varied from1.01 to 17.20 µM with an average of 6.89 µM where as in the bottom waters, its concentration varied from 0.48 to 11.25 µM with an average of 3.99 µM. The dissolved ammonia concentrations in the surface waters varied from 2.12 to 6.62 µM with an average of 3.75 µM, where as in the bottom waters, its concentrations varied from 1.72 to 4.95 µM with an average of 2.84 µM. Among the three, nitrate concentrations are higher than that of ammonia and nitrite concentrations. Seasonally, higher concentrations of all these nutrients were observed during monsoon season and lower concentration were observed during pre-monsoon season. Higher concentrations of these during monsoon season due to the discharge of more industrial effluents, domestic sewage, agricultural effluents and aquaculturalwastes into the estuarine waters along with huge runoff of freshwater. Lower concentrations were observed during pre-monsoon season (March) due to the low inputs of these effluents and also by the utilization of phytoplankton are more during this season. Similar seasonal variations of nitrite and nitrate were reported in the estuarine waters and elsewhere, river mouths of Zauri (De Sousa, 1977), estuarine systems of Mandovi and Zuari (De Sousa et al., 1981b), estuarine waters of Mahanadi (Upadhyay, 1988), in the Periyar estuary (Salara Devi et al., 1991), in the estuarine waters of Rushikulya (Gouda and Panigrahy, 1995), in the waters of Gulf of Nicoya, Costa Rica, a tropical estuary (Kress et al., 2005), in the waters of Pichavaram mangroves (Prabuet al., 2008; Senthilkumaret al., 2008)) and the waters of Kaduviyar estuary (Perumalet al., 2009). in the estuarine waters of Ennore, Tamil Nadu, India (Rajkumaret al., 2011), in the estuarine waters of Kodungallur-Azhikode, Kerala, India (Jayachandranet al., 2012), in the waters of urbanized tropical estuary, Cochin (Robin et al., 2012).

Phosphate:

The station-wise summery statistics of phosphate concentrations in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average concentrations of phosphate in both surface and bottom waters at individual stations are shown in Fig. 2.The dissolved phosphate concentrations in the surface waters varied from 0.29 to 3.41 µM with an average of 1.09 µM where as in thebottom waters, its concentrations varied from 0.11 to 2.25 µM with an average of 0.82 µM.Higher concentrations of phosphate observed in surface waters of all stations in the estuary. St. 1 recorded highest concentrations of phosphate in October in the surface waters. This could be attributed to the influence of the influx of industrial effluents and land drainage at this station. Seasonally higher concentrations of phosphate were observed during monsoon than those of pre-monsoon and post-monsoon season. The maximum concentrations of phosphate in the estuarine waters during monsoon season due to the release of industrial effluents, agricultural effluents from thebanks of the river. Similar seasonal variations were also observed in the estuarine complex of Cochin (Pai and Reddy, 1981), off Malpe, south Kanara in the near shore region of Thal, Maharashtra (Varshneyet al., 1983), in Cochin backwaters (Sankaranarayana and Qasim ,1969), in Mandovi and Zuari estuaries (Dehadrai, 1970; De Sousa et al., 1981), in Bahuda estuary (Mishra et al., 1983), in Rushikulya estuary (Gouda and Panigrahy, 1995), in Mahanadi estuary (Upadhyay, 1988, Das et al., 1997), in the waters of Vellar estuary (Rajasegar, 2003), in waters of Pichavaram mangrove estuary (Senthilkumaret al., 2002, 2008), in Cochin estuary (Gupta et al., 2009) and in Kaduviyar estuary (Perumalet al., 2009).A pronounced horizontal gradient (downward) existed in the concentrations of phosphate from Sts. 1 to St.7.

Silicate:

The station-wise summery statistics of silicate concentrations in the estuarine waters of the Gautami Godavari during the study period were given in Table 1. The annual average concentrations of silicate in both surface and bottom waters at individual stations are shown in Fig. 2.The dissolved silicate concentrations in the surface waters of Gauthami Godavari varied from 12.24 to 165.94 µM with an average of 77.36 µM, where as in the bottom waters, its concentrations varied from 6.56 to 97.77 µM with an average of 52.16 µM. Higher concentrations of silicate were observed during monsoon season is a common occurrence in the estuarine and coastal waters (Purushothaman and Venugopalan, 1972; Joseph,1974). It is well known that land-born runoff is the chief source for silicate while its removal byphytoplankton and adsorption onto suspended sediments are the main processes operative in the marine environment (Beinet al., 1958; Liss and Spencer, 1970). Low silicate concentrations were observed during premonsoonseason.Gradual seaward decrease coupled with higher monsoonal concentrations indicate that intrusion of silicate into the estuary mainly takes place through surface

runoff, which is an agreement with earlier observations made in Cochin estuary (Sankaranarayanan and Qasim, 1969; Anirudhan and Nambisan, 1990;), Mondovi and Zuari estuaries (De'Sousaet al., 1981), Vellar estuary (Purushothaman and Venugopalan, 1972; Chandran and Ramamoorthi,1984; Kannan and Krishnamurthy,1985;) and Mahanadi estuary (Upadhaya, 1988). Lower silicate concentrations with the occurrence of diatom blooms during premonsoon season suggest that biological utilization acts as an important factor associated with removal of silicate from the water. Similar instances of silicate removal occurrence with occurrence of diatom blooms have been reported from Vellar estuary (Chandran, 1985) Cochin back waters (Sankaranarayanan and Qasim, 1969) and in the lower reaches of the present study. The non-conservative behavior of silicate was observed in the present study which is a commonly encountered in many other estuaries. In general, surface concentrations of silicate were higher than those of bottom waters. Relatively high values of silicate (165.94 µM) were observed in the surface waters of St.1, which drastically fell in the direction of St.7 (12.24 µM)

Relatively higher values of all nutrients were observed during monsoon season and lower concentrations were observed during pre-monsoon season, higher values during monsoon season due to the inputs of high river runoff along with agricultural, domestic sewage, aqua cultural waste and industrial effluents, where as lower concentrations of all nutrientswere observed during pre-monsoon season, due to negligible influx of the river runoff and their utilization by phytoplankton.

Inter-correlations of hydrography and nutrients parameters:

The correlation coefficients have been computed among hydrography and nutrient parameters to understand inter-relationships in the estuarine waters of Gauthami Godavari is given in Table 2.

Table 2 Inter-relations among salinity, nutrients, Chlorophyll-a in the Estuarine waters of Gauthami Godavari during 2013

Parameter	Temp	pH	Salinity	D.O	NO_2	NO_3	NH_3	PO_4	SiO_4
Temp									
pH	0.50							**N = 56**	
Salinity	0.47	0.82						**P = <0.001**	
D.O.	-0.26	-0.76	-0.76						
NO_2	-0.35	-0.91	-0.75	0.73					
NO_3	-0.54	-0.95	-0.87	0.79	0.89				
NH_3	-0.40	-0.96	-0.84	0.78	0.95	0.94			
PO_4	-0.42	-0.86	-0.75	0.65	0.82	0.90	0.91		
SiO_4	-0.42	-0.86	-0.95	0.80	0.84	0.92	0.91	0.82	
Chl-a	0.10	-0.41	-0.33	0.54	0.29	0.38	0.39	0.33	0.39

Significant inverse correlations ($p = < 0.001$) were observed between salinity and nutrients in the estuarine waters of Gauthami Godavari indicating that distribution of these parameters is believed to be primarily govern by land runoff along with industrial effluents, domestic sewage, agricultural runoff and aquacultural wastes which releasing into the river waters during monsoon season. The nutrient concentrations in the estuarine waters behaved non-conservatively. Similar observations have also been reported by several workers in different estuarine and coastal environments of India.Significant positive correlations were observed between pH and salinity indicates that pH of the estuarine waters 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 due to mixing and dilution of river water when it meets to the estuarine and coastal waters. Moderate positive correlations were observed between chlorophyll-aand dissolved oxygen, indicating that most of the dissolved oxygen produced in the estuarine waters through phytoplanktonic photosynthesis. Significant positive correlations were observed within the nutrients attributing their common sources of occurrence in the estuarine waters.

Nutrient index

Nutrient index (I) values are calculated using the equation of Karydset 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 and values <3 indicate oligotrophic waters. Nutrient Indies were calculated for nitrate, ammonia and phosphate in the surface waters for all 7 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 3.

Table 3 Nutrient index (I) values in the estuarine waters of Gauthami Godavari during 2013

St. No.	Nitrate	Ammonia	Phosphate
1	3.01	3.14	3.05
2	3.00	3.11	3.08
3	2.78	2.52	2.38
4	2.21	2.41	2.25
5	2.22	2.34	2.14
6	2.02	2.21	2.11
7	2.01	2.11	2.01

From the above table it is evident that the estuarine waters are in oligotrophic nature as the nutrient index (I) valuesnot exceed 5. This can be attributed to the less discharge of domestic sewage and industrial effluents are not rich in organic matter into the estuarine waters. Nutrient index (I) shows an increasing trend with increase of nutrient concentrations in the estuarine stations thus offering a measure of degree of eutrophication at different stations. At stations 1-2 influenced by sewage outfall and discharge of industrial effluents containing organic matter recorded higher values (I>3) for all the nutrients. On the other hand the nutrient index relatively lower values in the stations 6and 7 waters indicating mesotrophic conditions. It is interesting to note that the values exhibits a decreasing tend from head of the estuary to mouth of the estuarine waters. This is due to dispersion and dilution of nutrients from head to mouth of estuarine waters due to dilution and dispersion of these nutrients from the coastal waters of Bay of Bengal.

IV. Conclusions

From the findings of the present study, it is known that the estuarine waters of Gauthami Godavari are not polluted. Further increase of the nutrient concentrations poses a serious threat to the aquatic organisms and especially water quality of the estuary. The results would form a useful tool for the eradication of pollution.

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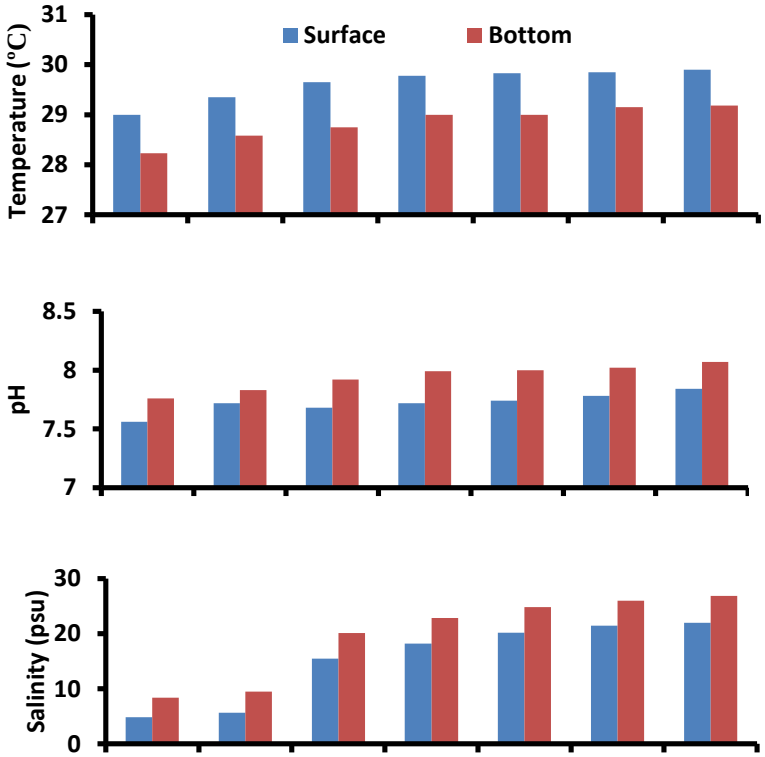


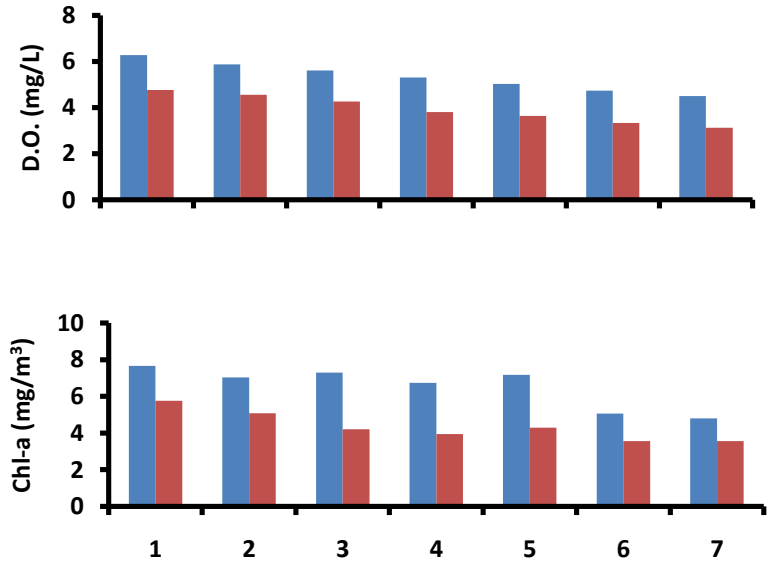
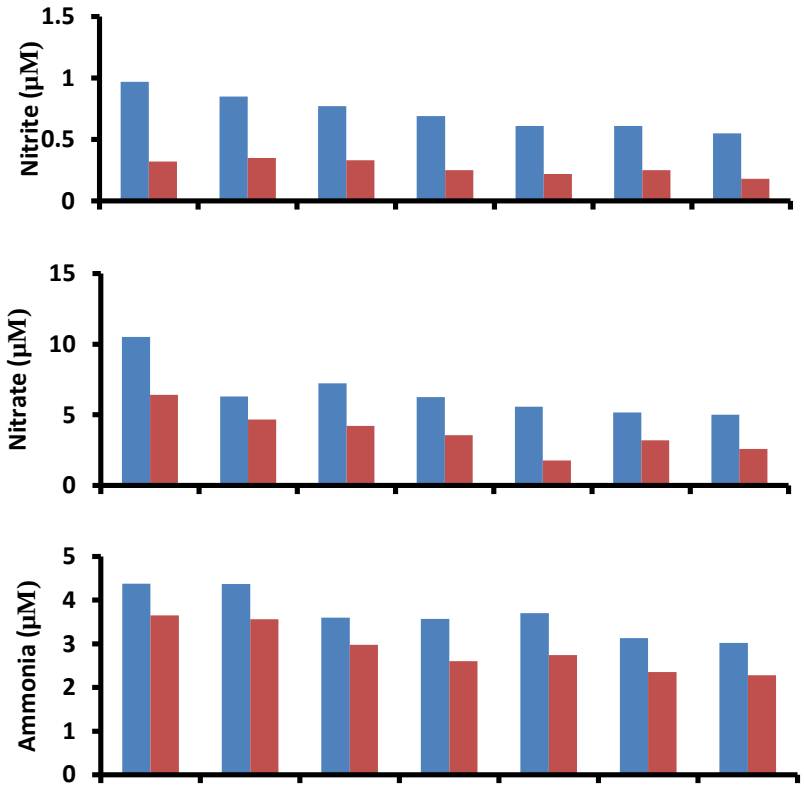


Fig. 2. Station wise (annual mean) distribution of hydrographical Parameters in the estuarine waters of Gauthami-Godavari During2013.



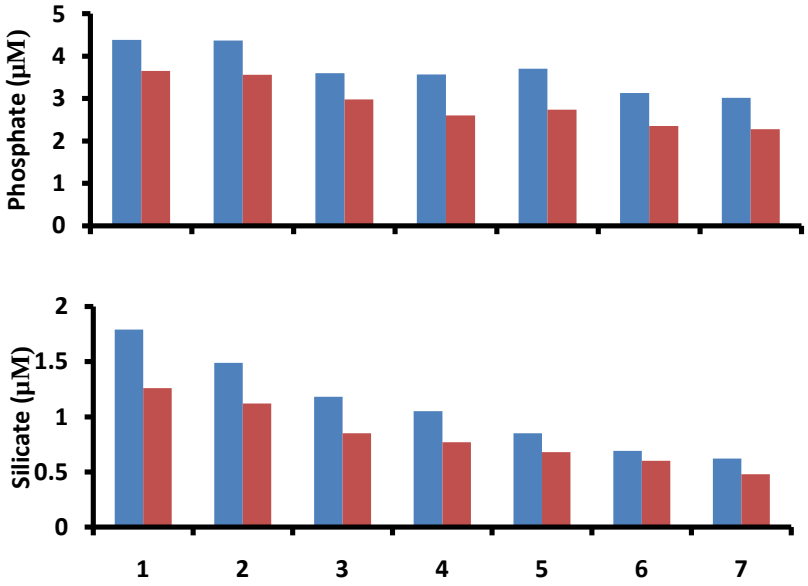


Fig. 3. Station wise (annual mean) distribution of nutrient Parametersin the estuarine waters of Gauthami-Godavari During 2013.

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