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Hydrographical studies along the coastal waters off Mangalore and Padubidri, southwest coast of India

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Abstract
In this paper, attempt has been made to study the spatial and temporal variations of hydrographical parameters in the coastal waters off Mangalore and Padubidri, Southwest coast of India from September 2014 to May 2015. The air and water temperature ranged from 24.1 to 28.9^{0}C and 25.7 to 32.3^{0}C respectively, light extinction coefficient varied from 0.31 to 1.48m, total suspended solids ranged between 32 and 164mg/l, pH varied from 7.36 to 8.49, salinity fluctuated from 15 to 35PSU, dissolved oxygen ranged from 4.08 to 7.76mg/l. Concentrations of nutrients, viz. ammonia, nitrite and nitrate ranged from 0.78 to 20.32µg-at NH_3-N/l, 0.06 to 11.70µg-at NO_2-N/l and 0.08 to 39.77µg-at NO_3-N/l respectively, phosphate and silicate varied from 0.10 to 2.80µg-at PO_4-P/l and 8.35 to 52.35µg-at SiO_3-Si/l respectively were recorded. The higher values of temperature, pH, ammonia and salinity were recorded during pre-monsoon season, nitrite and nitrate higher values were observed during post-monsoon season. In contrast, an increase in dissolved oxygen and silicate were observed during monsoon season. The studies revealed that the hydrographical parameters in the coastal waters off Mangalore and Padubidri exhibited considerable seasonal and spatial variations and are greatly affected by the monsoon system for southwest monsoon.

Keywords: hydrographic variables, seasonal variations, Mangalore and padubidri coast

1. Introduction

Coastal waters are the interface between land and ocean which found along continental margins. Coastal margins that are influenced by major rivers are an important source of dissolved and particulate material to the ocean and to global biogeochemical fluxes. Coastal ecosystems are more productive and dynamic because it receives considerable amounts of freshwater, nutrients, dissolved and particulate organic matter, sediment, contaminants and pollutants from the industries and other human activities [5]. In recent years, coastal areas have been assuming greater importance, owing to their increasing human population, urbanization and accelerated developmental activities. The quality of water is getting vastly deteriorated due to unscientific waste disposal and improper waste management and careless towards protecting the environment. Good quality of coastal water is an important part of keeping our coasts healthy for the future. Increased anthropogenic activities in and around water bodies damage the aquatic systems and ultimately the physico-chemical properties of water. The pollution of coastal water affects the marine organisms, which are at the vicinity of the coast. The Mangalore coast is extensively exposed to sewage and anthropogenic pollutants compared to Padubidri coast. Either directly or indirectly, the effluents of the industries, chemical factories, municipal and sewage wastes, refineries, fertilizer and iron ore companies, which are situated nearby, pump their toxic load to the rivers or the sea and finally everything enters the sea water. The Mangalore coast is situated at the western part of the Indian peninsula stretching to about 22Kms of coastal district of Dakshina Kannada, Karnataka. Coastal waters off Mangalore Provide for a multi-species fishery and the area is known as one of the largest upwelling systems in the world.

Hydrography is an important requisite in coastal waters as it is very susceptible to natural and manmade influence. Prevalence of favourable hydrographical conditions is a prerequisite for optimum primary and secondary productions on which depends the fish production. Spatial and temporal variations in hydrographical parameters have impact on diversity of planktonic organisms and thereby it gives indication about the coastal water quality. Several researchers are engaged in the monitoring of coastal waters off Mangalore and Padubidri to understand the various physico-chemical processes governing the biological production [10, 23, 9, 24, 4, 15, 12, 7]. Hydrological study of physico-chemical parameters are of utmost importance, as it is having lot of influence on the composition, density and relative abundance of planktonic communities which are finally going to decide the fate of productivity of coastal waters. Hence the present work was undertaken to study the hydrographical parameters in the coastal waters off Mangalore and Padubidri, Southwest coast of India.

2. Materials and Methods

2.1 Study area

A total of six stations were selected in the coastal waters with an average depth of 8m (Fig.1). Out of six stations selected, five stations were located in coastal waters off Mangalore and designated as S1, S2, S3, S4, S5 whereas one station was located along the coastal waters off Padubidri and designated as S6. The first station (S1) was selected adjacent to the bar mouth region of Nethravathi and Gurupur estuary (12°50'766"N and

74°48'576"E) which greatly receives freshwater from river, land nutrients, municipality and domestic sewage, decayed plant and animal matter, pesticides from agriculture activities and suspended matter from dredging activities. Second station (S2) was selected in the Thannirbhavi region (12°54'468"N and 74°47'853"E) which receives fertilizers from industries, waste water from fish meal plants and dredging activities are also going on in this area. Third station (S3) was selected in the Chitrapur region (12°57'338"N and 74°47'085"E) which receives oil and fertilizers from industries. Fourth station (S4) was selected along the coastal waters of Surathkal (13°00'535"N and 74°46'179"E) which is away from fresh water and receives pollutants from smaller industries. Fifth station (S5) was selected in the coastal waters of Mulki region (13°03'997"N and 74°43'438"E) which has a fresh water influx from Shambhavi River. Sixth station (S6) was selected along the coastal waters off Padubidri region (13°08'149"N and 74°44'336"E) which greatly receives warm water and other effluents from the industries and this station is completely away from freshwater influx.

2.2 Water sample collection and analysis

The water samples were collected at monthly interval for a period of nine months from September 2014 to May 2015 for analysis of different hydrographical parameters. Atmospheric and surface water temperature was recorded using standard thermometer. The pH and transparency (light extinction coefficient) was measured using pH meter (EUTECH, pH 700) and Secchi disc, respectively. The salinity, total suspended solids, dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorous and silicate-silicon concentrations of the sample were estimated following standard methods [30]. The simple correlation matrix was applied to find out the significant relation between different hydrographical parameters.

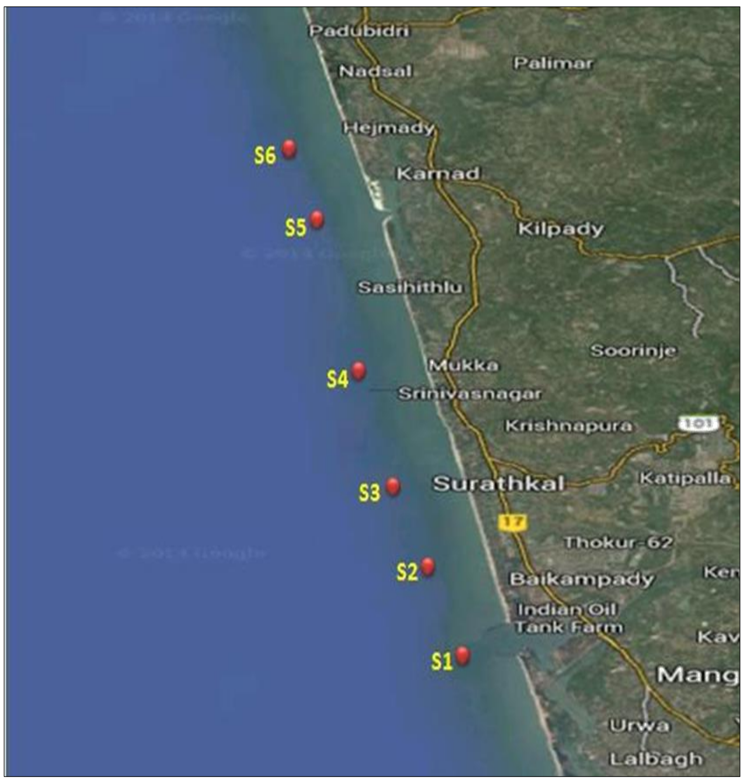

Fig 1: Map showing the location of sampling stations

3. Results and Discussion

Monthly variations in meteorological and hydrographical parameters were presented in Figures 2 to 14. Seasonal comparisons were made as pre-monsoon (February-May), monsoon (September-October) and post-monsoon (November-January) and data on the range and seasonal mean of various hydrographical parameters were given in Tables 1 and 2. Correlation coefficients (significant at 99% and 95%) between different hydrographical parameters were given in Table 3.

Table 1: Range and mean of hydrographical parameters at coastal waters off Mangalore and Padubidri

Parameters	Station 1			Station 2			Station 3			Station 4			Station 5			Station 6		
	Min.	Max.	Mean ±SE	Min.	Max.	Mean ±SE	Min.	Max.	Mean ±SE	Min.	Max.	Mean ± SE	Min.	Max.	Mean ±SE	Min.	Max.	Mean ±SE
Air temperature (^{0}C)	24.1	28.5	26.5 ±0.40	24.2	28.4	26.5 ±0.39	24.3	28.7	26.7 ±0.41	24.4	28.5	26.7 ±0.39	24.5	28.6	26.9 ±0.36	24.6	28.9	27.1 ±0.38
Water temperature (^{0}C)	26.1	31.1	28.7	25.8	31.5	29.0	26.5	31.6	29.2	27.0	31.5	29.2	25.7	31.7	29.3	26.8	32.3	29.6

			±0.42			±0.46			±0.43			±0.42			±0.51			±0.47
Light Extinction Coefficient (m)	0.46	1.48	0.86 ±0.10	0.50	1.06	0.76 ±0.06	0.44	1.24	0.74 ±0.09	0.31	1.30	0.72 ±0.11	0.42	1.22	0.75 ±0.09	0.35	1.21	0.65 ±0.09
Total Suspended Solids (mg/l)	36	164	86 ±10.86	56	92	78 ±3.80	48	132	85 ±7.10	32	84	72 ±5.09	44	100	76 ±5.25	60	104	82 ±4.84
pH	7.36	8.38	8.04 ±0.12	7.83	8.39	8.21 ±0.05	7.87	8.45	8.25 ±0.06	7.91	8.49	8.30 ±0.05	7.68	8.45	8.27 ±0.07	8.02	8.45	8.29 ±0.04
Salinity (PSU)	15.00	33.75	25.70 ±2.06	28.75	33.13	31.11 ±0.46	29.38	34.38	31.81 ±0.47	30.00	34.38	31.95 ±0.43	28.13	34.69	31.70 ±0.60	30.63	35.00	32.31 ±0.46
Dissolved oxygen (mg/l)	4.08	6.11	5.48 ±0.21	4.48	7.34	6.11 ±0.24	4.89	7.74	6.07 ±0.24	4.48	7.76	6.21 ±0.26	4.89	7.34	6.16 ±0.27	4.48	7.34	5.98 ±0.25
Ammonia (µg-at NH_3-N/l)	0.95	16.08	6.73 ±1.22	1.12	20.32	7.30 ±1.63	0.95	16.34	8.18 ±1.56	0.78	19.97	7.50 ±1.76	2.51	15.82	8.10 ±1.66	2.85	9.34	5.97 ±0.70
Nitrite (µg-at NO_2-N/l)	0.06	11.70	2.30 ±1.07	0.13	3.57	1.09 ±0.30	0.13	2.96	0.67 ±0.27	0.13	2.67	0.89 ±0.22	0.17	0.88	0.39 ±0.06	0.09	1.49	0.58 ±0.14
Nitrate (µg-at NO_3-N/l)	0.81	39.77	8.25 ±3.54	1.13	22.03	5.79 ±1.88	0.32	7.13	3.06 ±0.71	0.32	9.64	2.43 ±0.83	0.08	12.07	3.74 ±1.04	0.57	7.61	2.85 ±0.63
Phosphate (µg-at PO_4-P/l)	0.12	1.35	0.61 ±0.11	0.25	1.45	0.77 ±0.11	0.10	2.80	1.10 ±0.28	0.35	2.10	0.93 ±0.16	0.13	2.00	0.84 ±0.17	0.12	1.20	0.72 ±0.10
Silicate (µg-at SiO_3-Si/l)	19.87	52.35	34.60 ±2.96	18.39	43.07	30.98 ±2.58	13.19	44.26	28.25 ±3.18	15.25	43.79	29.65 ±2.76	11.23	39.20	26.07 ±2.99	8.35	19.08	14.31 ±0.98

Table 2: Seasonal mean values of hydrographical parameters at coastal waters off Mangalore and Padubidri

Seasons	Stations	Air temp. (^{0}C)	Water temp. (^{0}C)	Light Extinction Coefficient (m)	Total Suspended Solids (mg/l)	pH	Salinity (PSU)	Dissolved oxygen (mg/l)	Ammonia (µg-at NH_3-N/l)	Nitrite (µg-at NO_2-N/l)	Nitrate (µg-at NO_3-N/l)	Phosphate (µg-at PO_4-P/l)	Silicate (µg-at SiO_3-Si/l)
Pre-monsoon	1	27.1	29.6	0.70	87	8.27	31.10	5.00	9.10	0.54	3.02	0.66	25.83
	2	27.1	30.1	0.84	79	8.31	32.66	5.81	9.90	0.59	2.78	0.81	23.59
	3	27.3	30.1	0.82	96	8.33	33.13	5.91	9.77	0.55	1.84	1.21	22.56
	4	27.3	30.2	0.79	78	8.40	33.13	5.91	11.84	0.41	1.42	0.91	21.04
	5	27.4	30.3	0.86	71	8.35	33.52	6.01	10.65	0.44	1.24	0.91	17.64
	6	27.5	30.5	0.72	76	8.33	33.63	5.91	7.85	0.33	1.34	0.69	11.46
Monsoon	1	26.8	27.4	1.18	58	7.64	16.25	5.71	3.68	1.14	5.27	0.83	48.44
	2	26.8	27.4	0.54	86	7.97	29.07	6.52	1.99	0.74	3.00	0.93	40.08
	3	27.0	27.8	0.48	92	8.07	30.01	6.73	2.68	0.22	1.58	0.80	38.59
	4	27.1	28.3	0.50	58	8.07	31.25	6.74	1.34	0.68	1.13	1.03	38.66
	5	27.0	28.0	0.43	100	7.96	29.07	6.32	2.90	0.28	3.89	0.78	37.85
	6	27.0	28.8	0.37	90	8.09	31.26	6.12	3.16	0.36	2.43	0.95	16.80
Post-monsoon	1	25.5	28.4	0.87	103	8.02	24.79	5.98	5.62	5.43	17.23	0.39	37.07
	2	25.5	28.7	0.80	72	8.24	30.42	6.25	7.38	2.00	11.66	0.60	34.76
	3	25.7	28.8	0.82	65	8.28	31.25	5.84	9.71	1.13	5.67	1.14	28.93
	4	25.8	28.6	0.76	73	8.34	30.84	6.25	5.82	1.67	4.64	0.90	35.13
	5	26.4	28.9	0.81	65	8.36	31.04	6.25	8.15	0.38	6.99	0.79	29.46
	6	26.6	29.1	0.75	85	8.37	31.25	5.98	5.33	1.06	5.16	0.62	16.47

Table 3: Correlation coefficients (significant at 99% and 95%) between different hydrographical parameters

Parameters	AT	WT	LEC	pH	DO	NO_2	NO_3	SiO_3
LEC	-.740* (S4) -.728* (S6)	-.821**(S1)						
pH		.723* (S3) .709* (S4) .727* (S5)						
DO		-.815**(S2) -.724* (S3) -.832**(S4) -.764* (S5)						
NH_3			.749* (S5)					
NO_2	-.711* (S4)	-.666* (S4)	.780* (S3)					
NO_3						.975**(S1) .968**(S2) .915**(S4)		
Sal		.669* (S2) .678* (S4)		.710* (S2)		-.689* (S4)		.891**(S1)

		.710* (S5)						
TSS				.738* (S4)	.671* (S6)	-.746* (S2)	-.728* (S2) -.719* (S3)	
**.Correlation is significant at the 0.01 level (2-tailed).								
*.Correlation is significant at the 0.05 level (2-tailed).								

AT-Air temperature, WT-Water temperature, LEC-Light Extinction Coefficient, DO-Dissolved Oxygen, NH_3-Ammonia, NO_2-Nitrite, NO_3-Nitrate, SiO_3-Silicate, Sal-Salinity, TSS-Total Suspended Solids

3.1 Meteorological parameters

Rainfall

Rainfall is the most important cyclic phenomenon in tropical countries as it brings important changes in the hydrographical characteristics of the coastal and estuarine environments. The rainfall in India is largely influenced by two monsoons viz., southwest monsoon on the west coast, northern and north-eastern India and by the northeast monsoon on the southeast coast [18]. During the study period the total rainfall received was 767.5mm from September 2014 to May 2015. Minimum was observed in the months of January (4.0mm) and December (11.00mm) and no rainfall was observed during the months of February and March (Fig.2). Maximum rainfall was observed in the months of September (291.20mm) and October (255.00mm) and these monsoonal rains brought in to the study areas lot of nutrients as land run off. This evident in the present study recorded high values of nutrients. Muruganantham *et al* [16] reported that monsoonal rains brings terrigenous matter and abundant nutrients to the coastal waters through land runoff and brought wide spatial and temporal variations in physico-chemical parameters in South-east coast.

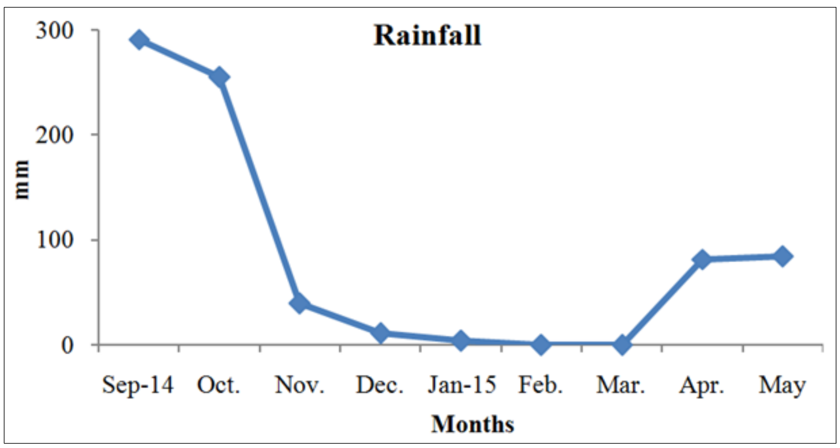

Fig 2: Monthly variations in rainfall (mm) in the study area during September 2014 to May 2015

Air temperature

Air temperature was subjected to considerable variation through space and time. Air temperature in the present study was fluctuated between 24.1 and 28.9°C with a variation of 4.8°C (Fig.3). Air temperature was recorded more or less similar in all the stations and differs during seasons. The lower temperature (24.1°C) prevailed during the month of January and hottest temperature (28.9°C) during the month of April. The pre-monsoon season showed continuous increase in temperatures which decreases during monsoons, increases slightly during the post-monsoon season and again decreases during the winter. As observed by several workers like Vijaya Kumar and Vijaya Kumara [34], Arumugam and Sugirtha [2], Naseema *et al* [17] and Thasneem *et al* [32] in the southwest coast of India, the present work also showed summer peaks and monsoonal troughs in air and water temperature.

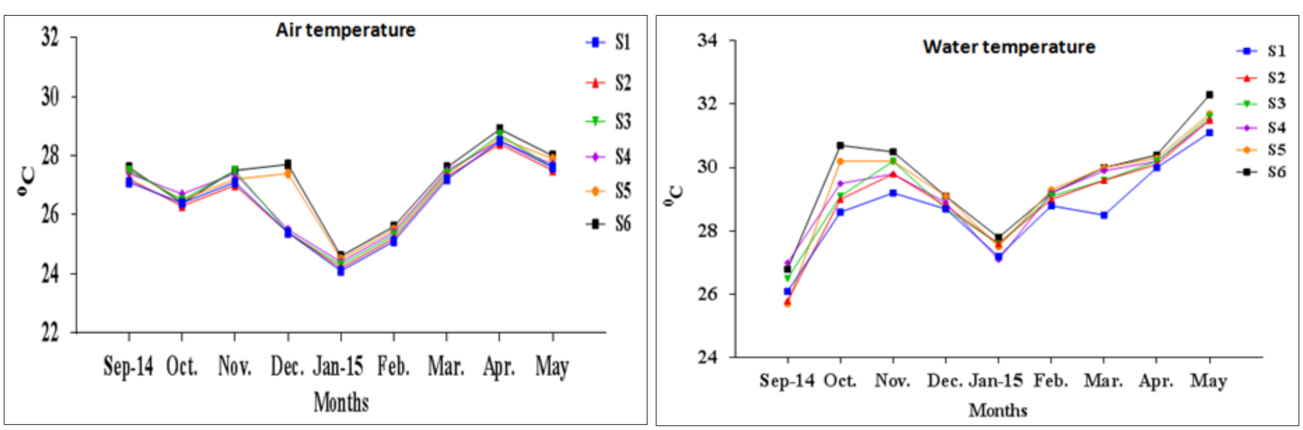

Fig 3, 4: Monthly variations in Air Temperature (^{0}C) and Water Temperature (^{0}C)

3.2 Hydrographical parameters

Water temperature

The temperature variation is one of the important factors in the coastal ecosystem, which may influence the hydrographical characteristics and also influence the distribution and abundance of flora and fauna [28]. Water temperature during the sampling of different seasons was found to vary from 25.7 to 32.3^{0}C with a variation of 6.6^{0}C (Fig.4). The water temperature in the study area fluctuated between the stations as well as the seasons. The maximum temperature (32.3ºC) was observed in the month of May at station S6 and minimum temperature (25.7ºC) observed in the month of September at station S5. The surface water temperature showed the maximum in station S6 throughout the study period. This could be due to inflow of warm water from the industry and high solar radiation. The minimum surface water temperature observed in the station S5 was due to fresh water influx, cooling and flow from adjoining neritic waters as opined by Govindasamy *et al* [6]. Water temperature varied with the seasons as lowest in monsoon months and highest during pre-monsoon/summer. Saravana Kumar [26] revealed that the increased temperature in the summer season could be because of high solar radiation and evaporation of surface waters. The minimum temperature recorded during the monsoon could be attributed to the rainfall caused by the south-west monsoon [16]. Water temperature showed a significant positive correlation with pH (S3, S4, S5) and salinity (S2, S4, S5) while significant negative correlation with dissolved oxygen (S2, S3, S4, S5), light extinction coefficient (S1) and nitrite (S4).

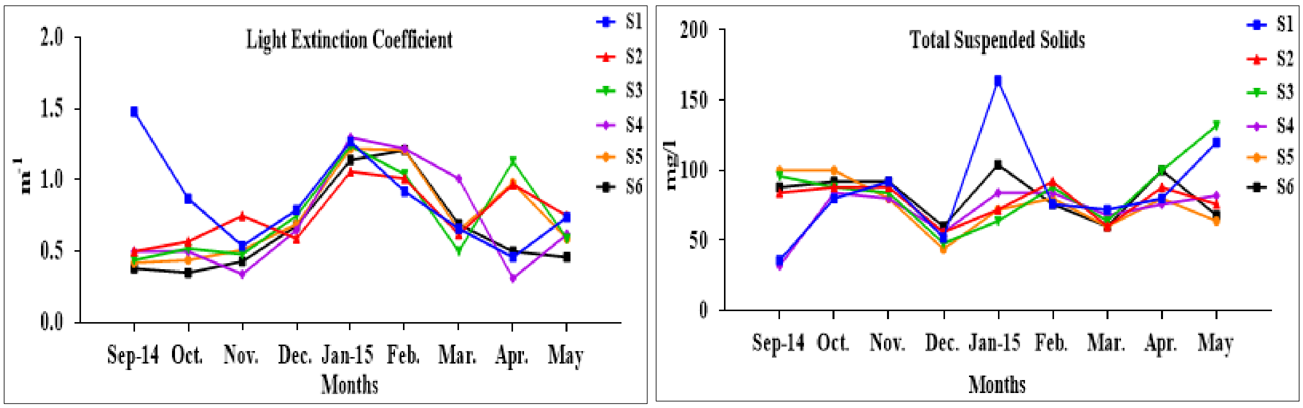

Fig 5, 6: Monthly variations in Light Extinction Coefficient (m) and Total Suspended Solids (mg/l)

Light extinction coefficient (LEC)

Light penetration through the water column is controlled by the amount and kinds of materials that are dissolved and suspended in the water. These materials mainly cause turbid water. Turbidity is mainly caused by land runoff during monsoon season, which alters the quality of water thereby it affects photosynthetic activity of phytoplankton. The recorded value of light extinction coefficient was varied from 0.31 to 1.48m^{-1} with a variation of 1.17m^{-1}. The light extinction coefficient in the study area varied between the stations as well as the seasons. The maximum LEC (1.48m^{-1}) was noticed in the month of September (monsoon) in station S1 and minimum (0.31m^{-1}) was noticed in the month of April (pre-monsoon/summer) in station S4 (Fig.5). Higher LEC value indicates the lower light penetration. The higher LEC found in the station S1 was mainly due to land runoff during monsoon season and freshwater discharge from the Nethravathi River. The monsoonal maximum of LEC could be attributed to the turbid nature of the coastal waters caused by the land runoff [25]. Sridhar *et al* [29] reported the maximum LEC during post-monsoon season was mainly due to wave action, tides, wind agitation and freshwater discharges which stir up the bottom. The lower LEC observed in the station S4 could be due to clear water condition and no runoff from any river nearer to the station. Madhavi [12] observed low value of LEC in summer was corroborated high solar insolation, clear water condition and low runoff.

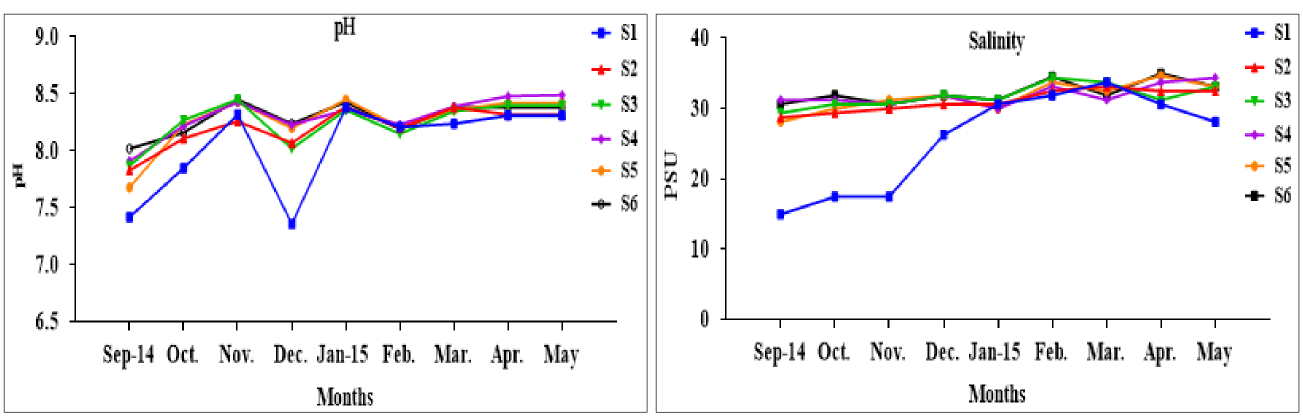

Fig 7, 8: Monthly variations in pH and Salinity (PSU) of water

Total suspended solids (TSS)

Suspended solids are the organic and inorganic matter that are suspended or carried by the water. This includes a wide variety of material such as silt, decaying plant and animal matter, industrial wastes and domestic sewage. These particulate matters play an important role in the primary production. The total suspended solids in the present study ranged between 32 to 164mg/l with a variation of 132mg/l. TSS in the study area varied between the stations as well as the seasons. The maximum (164mg/l) was observed during the month of January at station S1 and minimum (32mg/l) in the month of September at station S4 (Fig.6). The high value of TSS in station S1 may be due to dredging activities in Nethravathi River and estuary and also decayed plant and animal matters carried by the estuary. The low TSS value recorded in station S4 might be due to lack of river runoff and no dredging activities in this area. Suspended solids mainly affect the penetration of light. The suspended particulate matter concentration between 10 and 100mg/l is expected to suppress phytoplankton growth to certain extent [13].

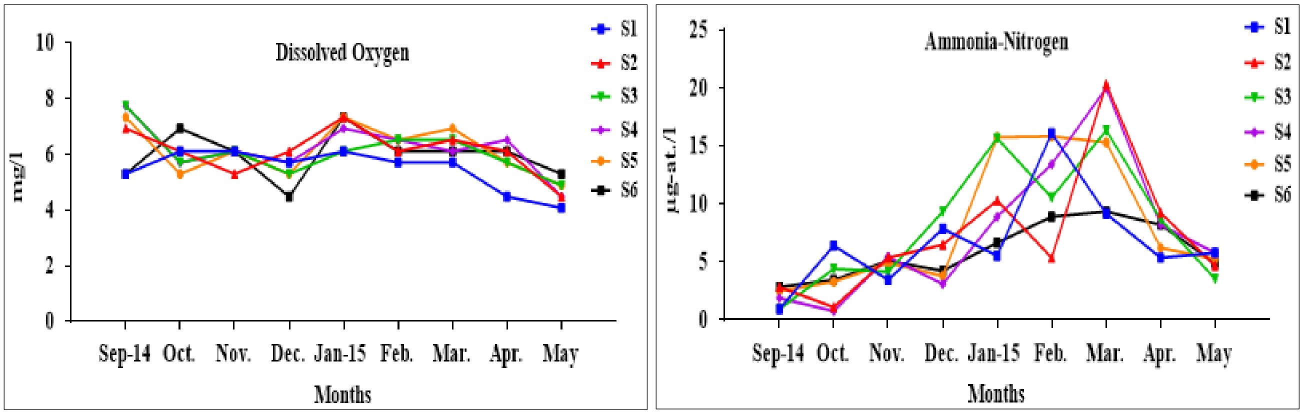

Fig 9, 10: Monthly variations in Dissolved Oxygen (mg/l) and Ammonia-Nitrogen (µg-at/l) concentration of water

PH

In coastal waters pH is highly variable on a wide range of time and space scales. Like dissolved oxygen, temperature, nutrients and salinity, pH are said to be indicators of water quality. The pH for the water samples varied from 7.36 to 8.49 during the study period. Living organisms, especially aquatic life, function best in a pH range of 6.0 to 9.0. The pH remained alkaline throughout the study period in all the stations. The pH concentrations in the study area varied between the stations as well as the seasons. The maximum value of pH (8.49) was found in the month of May at station S4 and minimum (7.36) was found in the month of December at station S1 with a variation of 1.13 (Fig.7). The maximum pH was observed during pre-monsoon season and minimum was recorded during monsoon season. The peak pH value recorded at station S4 might be due to the less or no freshwater influx to this area and this could also be attributed due to higher temperature and evaporation rate. Madhavi [12] observed maximum pH during pre-monsoon due to high rate of evaporation under high temperature conditions. Whereas the lower pH value recorded in station S1 might be due to influence of freshwater influx, dilution of saline water, reduction of salinity and temperature. The pH showed a significant positive correlation with temperature (S3, S4, S5), salinity (S2) and total suspended solids (S4). Babu *et al* [3] recorded the maximum pH during summer and post-monsoon and minimum during monsoon season and further noticed positive correlation of pH with temperature and salinity.

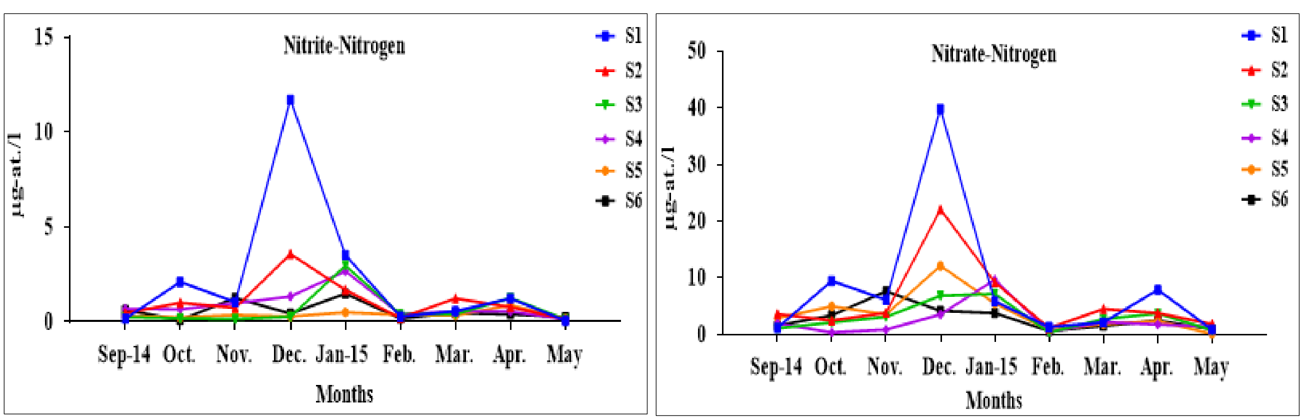

Fig 11, 12: Monthly variations in Nitrite-Nitrogen (µg-at/l) and Nitrate-Nitrogen (µg-at/l) concentration of water

Salinity

The salinity acts as a limiting factor in the distribution of living organisms and its variation caused by dilution and evaporation which is most likely to influence the fauna in the coastal ecosystem [14]. The salinity distribution within coastal water ways reflects the relative influx of fresh water supplied by rivers. Surface water salinity in the present study was fluctuated from 15 to 35PSU with a wide variation of 20PSU. The salinity values in the study area fluctuated between the stations as well as the seasons. The maximum salinity (35PSU) was recorded during the month of April at station S6 and minimum (15PSU) was recorded during the month of September at station S1 (Fig.8). The maximum salinity was recorded during pre-monsoon/summer season and the minimum was observed during monsoon season. The higher salinity value may be attributed to the higher degree of evaporation in the study area and the minimum salinity found in station S1 was mainly due to the influence of rainfall and influx of freshwater from the river. Salinity showed a significant positive correlation with temperature (S2, S4, S5), pH (S2) and silicate (S1), while significant negative correlation with nitrite (S4). Vengadesh *et al* [33] revealed that salinity is influenced by the higher temperature which is evident from the obtained significant positive correlation with temperature and they recorded the high salinity during summer season and low during the monsoon season.

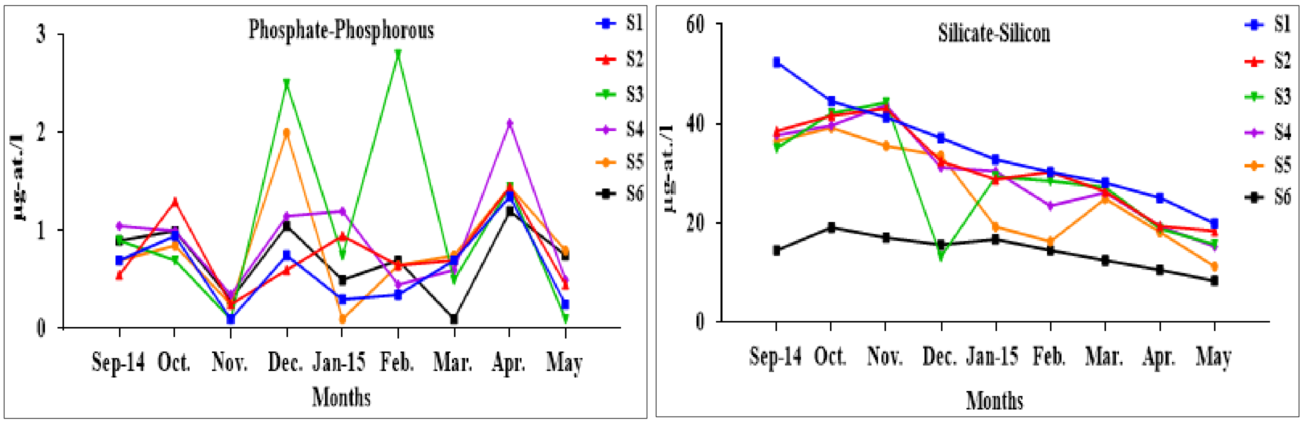

Fig 13, 14: Monthly variations in Phosphate-Phosphorous (µg-at/l) and Silicate-Silicon (µg-at/l) concentration of water

Dissolved oxygen

Dissolved oxygen is the most important indicator of the health of a water body and its capacity to support a balanced aquatic ecosystem of plants and animals. Oxygen is considered to be the major limiting factor in water bodies with high concentration of organic materials [1]. Dissolved oxygen in the present study at different stations varied between 4.08 and 7.76mg/l with a variation of 3.68mg/l. The maximum DO (7.76mg/l) was recorded in the month of September at station S4 and minimum (4.08mg/l) was recorded in the month of May at station S1 (Fig.9). The DO values in the study area differed between the stations as well as the seasons. The peak value of DO noted in station S4 was due to inflow of oxygen rich fresh water through the rainfall and higher wind velocity. The low value of DO noted in station S1 could be due to high temperature and salinity which prevent the dissolution of oxygen. Maximum dissolved oxygen was recorded during monsoon and post-monsoon seasons and minimum dissolved oxygen values were recorded during pre-monsoon. The high values of DO during monsoon and post-monsoon periods could be attributed to the input of DO-rich freshwater [21]. In the present study, season-wise observation of dissolved oxygen showed an inverse trend to temperature and salinity. Several studies have reported that the greater solubility of oxygen especially during the monsoon season might be due to low temperature and low salinity values [20]. This is well explained by the significant negative correlation of dissolved oxygen with temperature (S2, S3, S4, S5).

Nutrients

In coastal ecosystems nutrients are considered as the most Important parameters that influence growth, reproduction and metabolic activities of biotic components. Coastal water receives nutrients from various inputs *viz.*, terrestrial runoff, estuary, effluent discharge etc. The distribution of nutrients is mainly based on season, tidal conditions and freshwater influx from land source [26]. Distribution of nutrients determines the fertility of potential water mass. The seasonal variations of abiotic and biotic processes affect the nutrient cycle of different coastal environments.

Ammonia-Nitrogen

In coastal waters, ammonia present in the form of ammonia salts. Ammonia is the most important nitrogen source for phytoplankton growth. It may be more readily bio-available for plant growth [11]. Among all the nitrogenous nutrients, ammonia salt is considered to be the most preferred form of marine plants. Ammonia–nitrogen concentration in the present study at different station was ranged from 0.78 to 20.32µg-at NH_3-N/l with a wide variation of 19.54µg-at NH_3-N/l. The NH_3 concentrations in the study area varied between the stations as well as the seasons. The maximum value of ammonia–nitrogen (20.32µg-at NH_3-N/l) was observed during the month of March at station S2 and minimum (0.78µg-at NH_3-N/l) was observed during the month of October at station S4 (Fig.10). The peak value of ammonia-nitrogen recorded in the station S2 may be due to direct runoff of ammoniacal fertilizers from industry and also due to decomposition of phytoplankton. The lower value of ammonia-nitrogen was observed in station S4 could be due to the uptake by phytoplankton, which might have influenced the dissociation of total ammonia, thereby resulting in its low level. The seasonal variations of ammonia concentrations were observed maximum during January to March (summer) and the minimum during September to October (monsoon). Babu *et al* [3] observed higher concentration of ammonia-nitrogen during summer season might be due to the death and subsequent decomposition of phytoplankton and also excretion of ammonia by planktonic organisms. Swati *et al* [31] recorded higher concentration of ammonia during summer season was could be to direct discharge of drainage from industrial waste, fertilizer runoff, municipality sewage and domestic sewage.

Nitrite-Nitrogen

Nitrite-nitrogen has been considered to be a very unstable component among the three nitrogenous nutrient and being an intermediately stage in the nitrogen cycle. Nitrite gets converted to either nitrate state by nitrification or changes to ammonia or ammonia form by denitrification process [27]. The nitrite values during the study period ranged from 0.06 to11.70µg-at NO_2-N/l with a huge difference of 11.64µg-at NO_2-N/l. The NO_2 concentrations in the study area fluctuated between the stations as well as the seasons. The maximum concentration of nitrite-nitrogen (11.7µg-at NO_2-N/l) was recorded during the month of December at station S1 and minimum (0.06µg-at NO_2-N/l) was recorded during the month of May at station S1 (Fig.11). The peak values recorded in station S1 was mainly due to decomposition of organic matter which transported from river through domestic sewage during monsoon season and also due to oxidation of ammonia and reduction of nitrate. The lower value was found in station S1 was due to less freshwater input, higher salinity, higher pH and also uptake by phytoplankton. The seasonal variations of nitrite values were recorded maximum during post-monsoon and minimum during monsoon/pre-monsoon (summer) seasons. The higher concentration of nitrite and seasonal variation may also be attributes to the variation in phytoplankton excretion, oxidation of ammonia form of nitrogen to nitrite, reduction of nitrate and bacterial decomposition of planktonic detritus [6]. Low values of nitrite observed during the summer may be due to the lesser amount of freshwater inflow and higher salinity. Inorganic nitrite concentration was found to be lower than nitrate probably due to its very stable nature and it perhaps gets immediately converted to ammonia or nitrate and evaporated and its seasonal distributions was similar that of nitrate [22]. This evident in the present study showed significant positive correlation of nitrite with nitrate (S1, S2, S4).

Nitrate-Nitrogen

Nitrates are the most oxidized forms of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter. Nitrate is present at higher concentration than that of nitrite and ammonia. Generally, nitrate is considered as limiting nutrient for primary production in case of seawater. The nitrate values during the study period varied from 0.08 to 39.77µg-at NO_3-N/l with a highest variation of 39.69µg-at NO_3-N/l. The nitrate concentrations in the study area changed between the stations as well as the seasons. The maximum concentration of nitrate-nitrogen (39.69µg-at NO_3-N/l) was recorded during the month of December at station S1 and minimum (0.08µg-at NO_3-N/l) was recorded during the month of May at station S5 (Fig.12). The maximum value of nitrate-nitrogen in the station S1 was mainly due to river runoff, domestic sewage, decayed plant and animal materials from nearer estuary and also due to nitrification process. The minimum value of nitrate-nitrogen in the station S5 was mainly due to utilization by phytoplankton, low runoff of nitrate poor water from river. The seasonal variations of nitrate values were recorded maximum during post-monsoon and minimum during monsoon/pre-monsoon (summer) seasons. Nitrate showed spatial and temporal variations due to quick assimilation by phytoplankton and enhancement by surface runoff. Another possible way of nitrates entry is through oxidation of ammonia form of nitrogen to nitrite and then consequently to nitrate [21]. The low values records during summer/pre-monsoon period may be due to its utilization by phytoplankton as evidenced by high photosynthetic activity [6] and low value during summer season might be due to the lesser amount of freshwater inflow and high salinity.

Phosphate-Phosphorous

Phosphorus is an essential element in life processes including photosynthesis, metabolism, building of cell walls and energy transfer and intimately associated with organisms in aquatic systems [8]. Phosphate-phosphorus content in the present study ranged between 0.10 and 2.80µg-at PO_4-P/l with a difference of 2.70µg-at PO_4-P/l. The maximum phosphate-phosphorus (2.80µg-at PO_4-P/l) was noticed in the month of February in station S3 and minimum (0.10µg-at PO_4-P/l) was noticed in the month of May in station S3 (Fig.13). The peak value of phosphate observed in station S3 (February) could be due to fertilizers from industries and release of total phosphorous from bottom mud into the water column by turbulence and mixing. The minimum values were found in the station S3 (May) was due to limited flow of freshwater, high salinity and utilization of phosphate by phytoplankton. The variation of phosphates may be due to the various processes like adsorption and desorption of phosphates and buffering action of sediment under varying environmental conditions [21]. Phosphate concentration in coastal waters depend upon its concentration in the freshwater that mixed with the seawater with in the sea-land interaction zone, phytoplankton uptake, addition through localized upwelling and replenishment as a result of microbial decomposition of organic matters.

Silicate-Silicon

Coastal waters receive silicate from land *via* rivers, ground water or the atmosphere and from the open ocean through advection of surface waters and upwelling and recycling in the water column, at the sediment-water interface and deeper in the sediments. Silicate concentration in the present study varied ranged from 8.35 to 52.35µg-at SiO_3-Si/l with an overall variation of 44.00µg-at SiO_3-Si/l. The silicate concentrations in the study area varied between the stations as well as the seasons. The seasonal variations of silicate concentrations were observed higher during monsoon/post-monsoon and the minimum during summer/pre-monsoon seasons. The maximum silicate-silicon concentration (52.35µg-at SiO_3-Si/l) was recorded during the month of September in station S1 and minimum concentration (8.35µg-at SiO_3-Si/l) was recorded during the month of May in station S6 (Fig.14). The peak value of silicate observed in the station S1 was mainly due to heavy inflow of freshwater from river which carry silicate leached out from the rocks and also due to removal of silicate from the sediment during monsoon season, which might have been exchanged with overlying water. The low value of silicate observed in station S6 throughout the study period could be due to uptake of silicate from planktonic diatoms, it greatly reduced the water column reservoir of dissolved silicate and some related processes like absorption and co-precipitation of soluble silicon might also affects the distribution of dissolved silicate in the coastal waters. Similar observations were also made by Sridhar [29], Muruganantham *et al* [16] and Madhavi [12]. According to Purushothaman and Venugopal [19], the spatio-temporal variation of silica in coastal water is influenced by several factors, more importantly the proportional physical mixing of sea water with freshwater, adsorption of reactive silicate onto sedimentary particles, chemical interaction with clay minerals, co-precipitation with humic compounds and biological removal by phytoplankton, especially by diatoms and silicoflagellates.

4. Conclusion

The present study shows that hydrographical characteristics in the coastal waters off Mangalore and Padubidri are greatly affected by the monsoon system that prevails from May to October, for southwest monsoon. The study agree well with hydrographical parameters in the Mangalore coastal waters particularly in bar mouth region of Nethravathi and Gurupur estuary (station S1) found increase in nutrients from domestic and sewage waters discharged into adjacent rivers causing deterioration of water quality. The knowledge of nutrients, related to their sources, availability and the utilization levels gives us the information about the health of the coastal ecosystem. A further continuous monitoring of hydrographical parameters could provide useful information in understanding such eco-sensitive zones.

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6. References

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