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Hydrographical studies in the nearshore waters of Keni and Belekeri, Ankola, Uttara Kannada district, Southwest coast of India

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Abstract
Hydrographical study is an important pre-requisite in nearshore waters as it is very susceptible to natural and manmade influence. In this paper, attempt has been made to study the spatial and temporal variations in hydrographical properties of the nearshore waters of Keni and Belekeri, Ankola, Uttara Kannada district, Southwest coast of India during the period from October 2020 to September 2021. The air and water temperatures ranged from 25.5 to 33.5 °C and 26.0 to 34.5 °C respectively, pH varied from 8.0 to 8.6, salinity fluctuated from 16 to 34PSU, dissolved oxygen ranged from 4.88 to 8.54 mg/l, ammonia-nitrogen varied from 0.63 to 32.52 µg-at./l, concentrations of nutrients, viz., nitrite-nitrogen and nitrate-nitrogen ranged from 0.06 to 8.13 µg-at./l and 0.13 to 15.67 µg-at./l respectively, phosphate-phosphorus and silicate-silicon varied from 0.29 to 3.53 µg-at./l and 2.44 to 72.71 µg-at./l respectively were recorded. The higher values of temperature, pH and salinity were recorded during pre-monsoon season. In contrast, an increase in dissolved oxygen, ammonia, nitrite, nitrate, phosphate and silicate were observed during monsoon season. Dissolved oxygen, ammonia and silicate showed significant positive correlations with each other, nitrite showed a significant positive correlation with nitrate and salinity showed significant negative correlations with dissolved oxygen, ammonia and silicate. The hydrographical parameters showed significant spatial and temporal variations.The present baseline information is useful for the further ecological monitoring and assessment along the coastal beaches.

Keywords: Water quality, nearshore, Keni and Belekeri, Southwest coast

Introduction
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 (Clarke, 1996) [11]. 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 (Shruthi *et al.*, 2022) [46].

Beaches, the most dynamic coastal landform on earth, show dynamic changes over different timescales such as diurnal, tidal, monthly, and seasonal changes. These changes can be constructive or destructive. The long-term studies on beaches help in understanding and planning for any coastal management programs (Sagar *et al.*, 2020). Karnataka is one of India's maritime states and is located along the Arabian Sea on the southwest coast of India. Karnataka has a coastline of around 320 km spans three coastal districts namely Uttara Kannada, Udupi and Dakshina Kannada. Keni beach is situated on the open coast about 4 Km of Ankola town in Uttara Kannada district of Karnataka. The Keni stream, a tributary of river Gangavali and the Keni creek is formed by the tributaries of Gangavali estuary and opens into Arabian Sea on the Southwest coast of India. The estuarine environment of Keni creek is characterized by constant churning of freshwater from the river Gangavali with marine water, which may be challenged by modifications in water quality (Chandrakant Lingadhal *et al*., 2020) [9]. Belekeri Beach is located 8 km north of Ankola and 15 km South of Karwar, in Uttara Kannada District of Karnataka. The tidal inlets and the river mouths are located on littoral transport shore lines; they are often in a natural equilibrium with respect to bypassing of the littoral drift, which normally occurs on a shallow bar across the inlet. The area is characterized by sandy beaches and coastal plain. Survey showed that the coastal dunes, which play a key role in preventing erosion, have been dug up for creating fields by the local farmers, thereby making the sea coast more prone to sea erosion (EMPRI, 2007) [14].

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. Coastal waters are considered to be the pillar and essential of marine life. The study of hydrographical properties of coastal environments is important, because the variations in the instantly influence on the floral and faunal production. The variations affect the species diversity, pattern of diversity, breeding, survival and other activities. To maintain optimum level of water quality parameters is better for the species survival and healthy ecosystem. Good quality of water resources depends on a large number of hydrographical parameters, the magnitude and source of any pollution load; and to assess that, monitoring of these parameters is essential. However, there is a paucity of information in relation to hydrographical properties in the nearshore waters of Keni and Belekeri. Hence the present work was undertaken to study the spatio-temporal variations in hydrographical properties in the nearshore waters of Keni and Belekeri, Ankola, Uttara Kannada District, Southwest coast of India.

Materials and Methods

Study area

The Keni beach (Latitude 14^{0}39’46”N and Longitude 74^{0}16’42”E) and Belekeri beach (Latitude 14^{0}42’16.2”N and Longitude 74^{0}15’48.7”E) are situated on the open coast about 4 Km and 8 Km respectively of Ankola town in Uttara Kannada district of Karnataka on the Southwest coast of India. A total of six stations were selected, three stations were located in the nearshore waters of Keni and designated as S1, S2, S3 (Fig.1), whereas other three stations were located in the nearshore waters of Belekeri and designated as S4, S5, S6 (Fig.2). The sampling stations were fixed by the global position system (GPS). The quantum of rainfall received in the study area was collected from Karnataka State Drought Monitoring Cell (KSDMC), Department of Agriculture, Ankola, Government of Karnataka.

Water sample collection and analysis

The surface water samples were collected at monthly interval in the nearshore waters of Keni and Belekeri for a period of one year from October 2020 to September 2021 to assess the various hydrographical parameters. The atmospheric and surface water temperatures were recorded at the sampling site using standard mercury centigrade thermometer, pH was measured using pocket pH meter (Hanna), whereas the analyses of salinity and dissolved oxygen were done in the laboratory as per the standard methods (APHA, 2017) [5]. For analysis of dissolved oxygen, water samples were collected by glass bottles of 125 ml capacity and fixed on the field using Winkler’s reagents. For the estimation of Ammonia-Nitrogen (NH_3-N),water samples were collected in amber coloured glass bottles(125 ml capacity) and were pretreated in the field itself following the phenol-hypochlorite method (Strickland and Parsons, 1972).For the analysis of nutrients, surface water samples were collected in clean polythene bottles and kept immediately in an icebox and transported to the laboratory. The water samples were filtered and analysed for Nitrite-Nitrogen (NO_2-N), Nitrate-Nitrogen (NO_3-N), Phosphate-Phosphorous (PO_4-P) and Silicate-Silicon (SiO_3-Si) by adopting standard procedure (Strickland and Parsons, 1972). The absorbance for different parameters was measured using UV-VIS spectrophotometer.

Statistical analysis

The simple correlation was determined between various hydrographical parameters such as water temperature, pH, salinity, dissolved oxygen, ammonia and nutrients.

Fig 1: Map showing the Keni beach and location of sampling stations (S1, S2 and S3).

Fig 2: Map showing the Belekeri beach and location of sampling stations (S4, S5 and S6).

Results and Discussion

The study of hydrographic properties of nearshore waters is important as it is more prone to natural and anthropogenic activities and the variations in the instantly influence on the floral and faunal production. In the present study, monthly variations in hydrographical parameters such as Surface Water Temperature, pH, Salinity, Dissolved Oxygen, Ammonia-Nitrogen, Nitrite-Nitrogen, Nitrate-Nitrogen, Phosphate-Phosphorus and Silicate-Silicon were recorded. Seasonal comparisons were made as post-monsoon (October-January), pre-monsoon (February-May) and monsoon (June-September). Monthly rainfall data during the study period were given in Table 1 and data on the seasonal mean values of hydrographical parameters were given in Table 2. Correlation coefficients between various hydrographical parameters from station S1 to station S6 were given in Table 3.

Table 1: Monthly rainfall data for the period from October 2020 to September 2021 at Keni and Belekeri, Ankola

Months	No. of rainy days	Rainfall (mm)
October 2020	9	229.88
November	2	16.65
December	1	9.95
January 2021	4	25.30
February	3	27.27
March	1	12.75
April	9	35.86
May	14	332.95
June	26	892.24
July	29	1125.07
August	25	394.50
September	22	765.41
Total	145	3867.83

Table 2: Seasonal mean values of various hydrograghical parameters at selected staions of Keni and Belekeri nearshore waters.

Seasons	Place	Stations	Air Temp. (°C)	Water Temp. (°C)	pH	Salinity (PSU)	Dissolved Oxygen (mg/l)	Ammonia –Nitrogen (µg-at/l)	Nitrite-Nitrogen (µg-at/l)	Nitrate-Nitrogen (µg-at/l)	Phosphate – Phosphorus (µg-at/l)	Silicate-Silicon (µg-at/l)
Pre-monsoon	Keni	S1	32.3	32.6	8.38	30.75	6.31	3.99	0.64	1.81	0.97	11.02
		S2	32.0	32.6	8.45	30.75	6.72	4.96	0.35	1.43	0.91	10.76
		S3	31.9	32.8	8.38	31.00	6.82	3.51	0.28	1.72	0.68	13.22
	Belekeri	S4	31.0	31.6	8.40	31.25	7.22	4.44	0.45	1.85	1.03	14.23
		S5	30.8	31.8	8.35	31.25	7.02	5.16	0.46	1.62	0.96	13.65
		S6	30.8	31.6	8.35	31.25	7.12	5.21	0.83	2.22	1.14	15.05
Monsoon	Keni	S1	28.1	29.4	8.30	23.25	7.63	8.18	0.44	1.85	1.78	48.47
		S2	27.9	29.3	8.30	23.00	7.84	9.35	0.94	3.11	1.81	54.59
		S3	28.4	29.3	8.40	23.00	7.53	8.01	1.42	3.36	1.69	55.37
	Belekeri	S4	28.8	29.3	8.35	23.50	7.94	15.91	2.32	5.28	2.26	53.26
		S5	28.8	29.3	8.33	23.75	7.44	13.55	0.68	3.06	2.46	49.83
		S6	28.6	29.0	8.30	24.00	8.04	18.11	0.96	2.52	2.14	51.43
Post-Monsoon	Keni	S1	30.3	30.5	8.20	30.50	6.11	4.69	1.45	3.15	1.48	10.87
		S2	30.1	30.4	8.15	30.50	6.31	4.23	0.68	1.47	1.30	10.78
		S3	30.1	30.3	8.30	30.80	6.11	5.15	1.29	4.61	1.41	13.94
	Belekeri	S4	30.1	30.3	8.20	31.30	6.72	5.32	0.90	3.38	1.49	9.86
		S5	30.4	30.4	8.20	31.30	6.51	5.26	1.17	2.76	1.27	11.57
		S6	29.8	30.3	8.20	31.50	6.41	4.50	1.26	2.69	1.33	10.44

Table 3: Significant correlation coefficient between different parameters at selected stations of near shore waters of Keni and Belekeri, Ankola

Parameters	Air Temperature	Water Temperature	pH	Salinity	Dissolved Oxygen	Ammonia-Nitrogen	Nitrite-Nitrogen
Air Temperature		0.863**(S1) 0.774**(S2) 0.905**(S3) 0.701*(S4) 0.763**(S5) 0.795**(S6)					
Dissolved Oxygen				-0.600*(S1) -0.703**(S2) -0.662*(S3) -0.648*(S5) -0.688*(S6)			
Ammonia-Nitrogen				-0.600*(S1) -0.523**(S2) -0.630*(S3) -0.610*(S4) -0.620*(S5) -0.655*(S6)	0.698*(S1) 0.703**(S2) 0.578*(S4) 0.788**(S6)		
Nitrite- Nitrogen					-0.604*(S1)	-0.577*(S1)	
Nitrate - Nitrogen							0.974**(S1) 0.841**(S3) 0.950**(S4) 0.906**(S5)
Phosphate-Phosphorus		-0.493*(S2) -0.742**(S4)	-0.444*(S2)				0.654*(S4)

Silicate - Silicon	-0.605*(S1) -0.488*(S2)			-0.868**(S1) -0.876**(S2) -0.643*(S3) -0.883**(S4) -0.901**(S5) -0.868**(S6)	0.827**(S1) 0.822**(S2) 0.685*(S3) 0.609*(S4) 0.734**(S5) 0.822**(S6)	0.705*(S1) 0.717*(S2) 0. 617*(S3) 0.806**(S4) 0.815**(S5) 0.845**(S6)	

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Meteorological parameters
Rainfall
Rainfall is the most important cyclic phenomenon in tropical countries as it brings important changes in the hydrographical characteristics of the marine 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 (Perumal, 1993) [27]. The total annual rainfall recorded during the study period was 3867.83 mm from September 2020 to October 2021 (Source: Karnataka State Drought Monitoring Cell (KSDMC), Department of Agriculture, Ankola, Government of Karnataka.). Maximum rainfall was recorded during monsoon season in the months of July (1125.07 mm), June (892.24 mm) and September (765.41 mm). The patterns of rain fall along west coast of India revealed that the bulk of precipitation was received during South-west monsoon season followed by post-monsoon and pre-monsoon seasons. Similar rain fall patterns were reported in south-west coast made by Chethan (2012) [10], Madhavi (2014) [23], Chandrakant Lingadhal *et al*. (2020) [9] and Shruthi *et al.* (2022) [46].

Air temperature
Air temperature during the sampling of different seasons was found to vary from 25.5 to 33.5 °C. Air temperature was recorded more or less similar in all the stations and differs during seasons (Fig.3).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. Lowest temperature recorded during south west monsoon period may be attributed to the monsoon wind and precipitation and soon after monsoon the temperature increased gradually due to the increase in solar radiation and change in wind condition, thus, highest temperatures were observed during pre-monsoon (April) and lowest values during monsoon (August) seasons. Similar observations were made by Raveesha (2007) [35], Saravanakumar *et al.* (2008) [40], Ganapathi Naik (2012) [16], Madhavi (2014) [23], Thasneem *et al.* (2018) [54] and Shruthi *et al.* (2022) [46] in the Southwest coast of India.

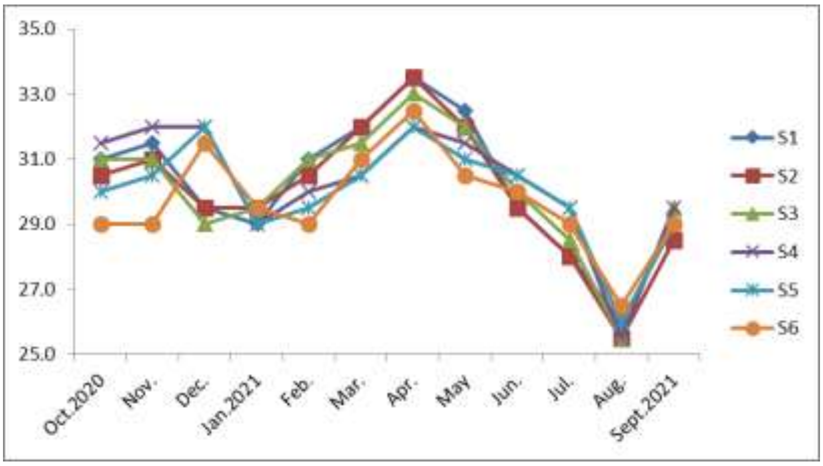

Fig 3: Monthly variations in Air Temperature (°C) of nearshore waters of Keni and Belekeri, Ankola.

Hydrographical parameters
Water temperature
It is well known that water temperature influences the nearshore organisms directly by effecting on their physiological parameters and indirectly through change in the hydrographical properties of nearshore water. It influences the chemical processes such as dissolution-precipitation, adsorption-desorption, oxidation-reduction and physiology of biotic community in the nearshore habitat. Therefore, water temperature becomes an important factor in the environmental studies. Water temperature during the sampling of different seasons was found to vary from 26.0 to 34.5 °C. Water temperature was recorded more or less similar in all the stations and differs during seasons (Fig.4). Temporally the maximum water temperature was recorded during pre-monsoon and minimum during monsoon season. The highest temperature recorded during pre-monsoon has been influenced by the high intensity of solar radiation coupled with evaporation. The minimum temperature recorded during the monsoon could be attributed to the rainfall caused by the south-west monsoon (Muruganantham *et al*., 2012) [25]. Similar findings were also recorded by Manikannan *et al.* (2011) [24], Behera *et al.* (2014) [8], Ravichelvan *et al.* (2015) [36], Vasanthi & Sukumaran (2017) [55], Shruthi *et al.* (2020) [45] and Chandrakant Lingadhal *et al*. (2020) [9]. Water temperature showed a significant positive correlation with air temperature. Generally water temperature correspond with air temperature indicating that the samples collected from shallow zones has a direct relevance with air temperature, shallow water reacts quickly with changes in atmospheric temperature (Rajkumar *et al.*, 2011) [33].

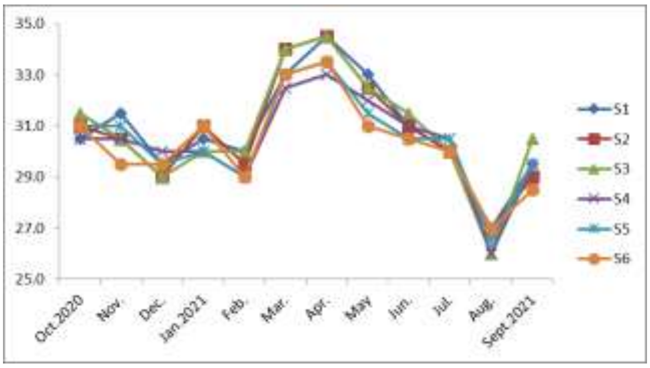

Fig 4: Monthly variations in Water Temperature (°C) of nearshore waters of Keni and Belekeri, Ankola.

pH

The effect of pH on the chemical and biological properties of liquids makes its determination very important. It is one of the most important parameter in water chemistry. The pH concentration gets changed with time due to the changes in temperature, salinity and biological activity (Balasubramanian and Kannan, 2005) [7]. The variation of hydrogen ion concentration (pH) during the study period is presented in Fig.5.The pH for the water samples varied from 8.0 to 8.6.The pH was recorded more or less similar in all the stations and differs during seasons. During the monsoon and post-monsoon seasons water pH was lower compared to pre-monsoon season. The observed pH maxima during pre-monsoon could be attributed to the high rate of evaporation under high temperature conditions. The observed monsoon and post-monsoon minima can be ascribed to rainfall, resultant freshwater mixing. The pH remains alkaline throughout the study period at all stations registering a minimum during monsoon season may be attributed to the influence of fresh water influx, dilution of sea water, low temperature and organic matter decomposition (Saravana kumar *et al.*, 2008) [40]. Several investigators Shanthanagouda (2001) [42], Tripathi (2002) [53], Swetha (2009) [52], Chethan (2012) [10], Madhavi (2014) [23] and Shruthi (2015) [43] while working on the hydrography of Nethravati-Gurupur estuarine and coastal waters of Mangalore, have reported lower values of pH during monsoon and post-monsoon seasons.

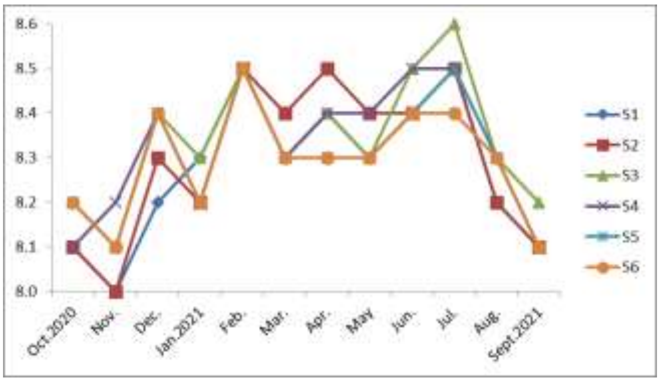

Fig 5: Monthly variations in pH of nearshore waters of Keni and Belekeri, Ankola.

Salinity

Salinity is a dynamic indicator of the nature of the exchange system. Salinity is one of the important factors which profoundly influence the abundance and distribution of the animals in estuarine environment and inshore waters. Salinity levels in coastal water vary because of river inputs, tidal and oceanic currents and influx of ground water, variable evaporation rates and freshwater runoff with rainfall. Surface water salinity in the present study was fluctuated from 16 to 34PSU. The salinity was recorded more or less similar in all the stations and differs during seasons (Fig.6). In the present study, considering the seasonal trend, the maximum salinity of water was observed in the month of February (pre-monsoon), whereas the minimum salinity was observed in the month of September (monsoon) at all the sampling stations. It is well known that salinity is determined by the factors like precipitation, run-off, evaporation and the degree of dilution caused by the mixing of sea and river water. In the present study also the salinity showed an increasing trend from monsoon to pre-monsoon season. Similar trend in the salinity values were also observed from various parts in southwest coast of India (Sridhar *et al.*, 2006, Saravanakumar *et al.*, 2008, Kadam and Tiwari, 2011, Muruganantham *et al.*, 2012, Sushanth *et al.*, 2014, Chandrakant Lingadhal *et al.*, 2020 and Shruthi *et al.*, 2022) [47, 40, 18, 25, 50, 9 46]. Salinity showed a significant negative correlations with dissolved oxygen, ammonia-nitrogen and silicate-silicon.

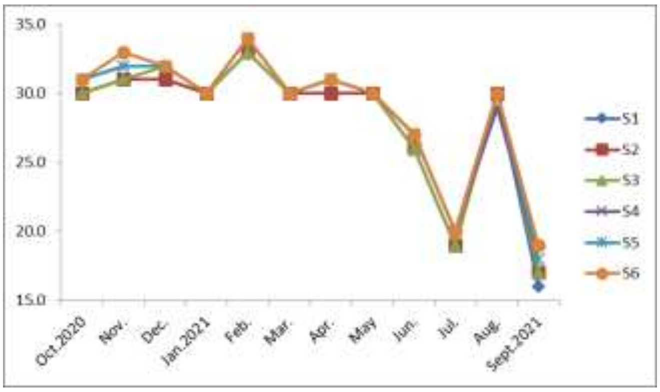

Fig 6: Monthly variations in Salinity (PSU) of nearshore waters of Keni and Belekeri, Ankola.

Dissolved oxygen (DO)

Dissolved oxygen is an important parameter of water and its concentration in water is an indicator of prevailing water quality and ability of water body to support a well-balanced aquatic life. Two main sources of dissolved oxygen are diffusion of oxygen from the air and photosynthetic activity. Oxygen is considered to be the major limiting factor in water bodies with high concentration of organic materials (Amadi *et al.*, 2010) [1]. Dissolved oxygen in the present study varied between 4.88 and 8.55 mg/l. The lower DO concentration was recorded in the month of January (post-monsoon) at Keni beach (S1) while higher concentration was recorded in the month of July (monsoon) at Belekeri beach(S4, S5 and S6). There was a well oxygenated water condition observed during monsoon followed by pre-monsoon and post-monsoon seasons (Fig.7).Seasonal variation in dissolved oxygen is due to freshwater flow and terrigenous impact of sediments (Kumar *et al.*, 2009) [22]. Maximum was due to cumulative effects of higher wind velocity, increased turbulence coupled with heavy rainfall and minimum was due to high biological activity besides low solubility of oxygen under high temperature and salinity conditions. However, in intertidal waters the resultant freshwater mixing through run-off also might have resulted in high dissolved oxygen content. The results obtained in the present study are almost similar to Tripathi (2002) [53], Saravana kumar *et al*. (2008) [40], Rajeshwari (2009) [32], Arumugam and Sugirtha (2014) [6], Shruthi *et al.* (2020) [45] and Chandrakant Lingadhal *et al.* (2020) [9] in the southwest coast of India. Dissolved oxygen showed significant positive correlations with ammonia-nitrogen and silicate-silicon and negative correlation with salinity. It is well known that the temperature and salinity affect the dissolution of oxygen in seawater (Saravanakumar *et al.*, 2008) [40].

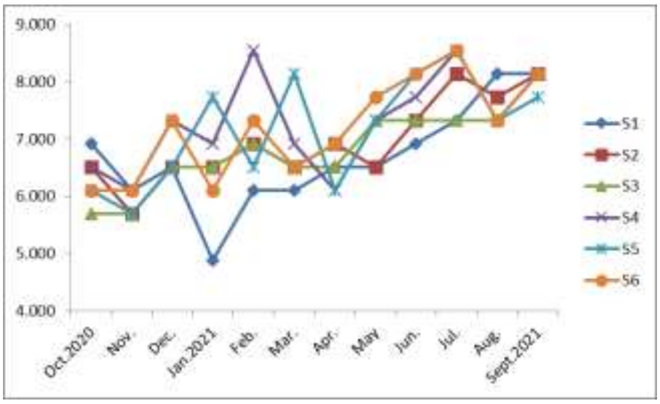

Fig 7: Monthly variations in Dissolved Oxygen (mg/l) of nearshore waters of Keni and Belekeri, Ankola.

Nutrients

The distribution of nutrients is mainly based on season, tidal conditions and freshwater influx from land source (Saravanakumar *et al.*, 2008) [40]. Distribution of nutrients determines the fertility of potential water mass. Nitrogen being a major nutrient element plays an important role in determining the fertility status of an aquatic ecosystem. As organic matter decomposes, nitrogen gets liberated as ammonia in the soil. Nitrifying bacteria converts ammonia to nitrate. The nitrate form is very soluble and is taken up by plants by absorption or used by microorganisms. Aquatic plants require certain micronutrient elements for their healthy growth and multiplication. It bears a fundamental relationship to all protein synthesis and often played an important role in controlling primary production. The seasonal variations of abiotic and biotic processes affect the nutrient cycle of different coastal environments.

Ammonia-Nitrogen (NH_3-N)

Ammonia is the nitrogenous end product of the bacterial decomposition of organic matter. Total ammonia in water includes both ionized (NH_4^+) and un-ionized (NH_3) forms. Ammonium (NH_4^+) may be more readily bio-available for plant growth than nitrate. Ammonia (NH_3) is the most important nitrogen source for phytoplankton growth. In the present investigation, the ammonia-nitrogen (NH_3-N) was ranged from a minimum of 0.63 µg-at./l in the month of January at Belekeri station (S4) to maximum of 32.52 µg-at./l in the month of July at Belekeri station (S6), with a variation of 31.89 µg-at./l. The monthly variations of ammonia-nitrogen concentrations were observed maximum during June to July and the minimum during January to April (Fig.8). Seasonally lower concentrations recorded during pre-monsoon and post-monsoon seasons. The observed low ammonia-nitrogen values during the study period could be due to the uptake by phytoplankton which might have influenced the dissociation of total ammonia, thereby resulting in its low level. The observed high values during monsoon might be due to influx of nutrient laden terrestrial and river run-off. Our findings are in accordance with the reports of Amrutha (2010) [2], Anitha and Sugirtha (2013) [3], Srilatha *et al.* (2013) [48], Dattatreya *et al.* (2018) [13], Narshivudu *et al*. (2018) [26] and Chandrakant Lingadhal *et al*. (2020) [9]. Ammonia-Nitrogen showed significant positive correlations with dissolved oxygen and silicate-silicon and negative correlation with salinity.

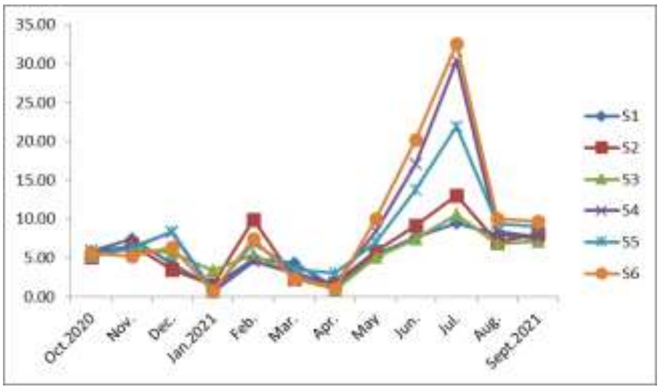

Fig 8: Monthly variations in Ammonia-Nitrogen (µg-at/l) of nearshore waters of Keni and Belekeri, Ankola.

Nitrite-Nitrogen (NO_2-N)

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 ammonium form by de-nitrification processes. During the present investigation, the Nitrite-Nitrogen (NO_2-N) content was ranged between 0.06 µg-at./l and 8.13 µg-at./l, with a variation of 8.07 µg-at./l. Seasonally higher concentration recorded during monsoon and lower during pre-monsoon (Fig.9). The minimum values were observed in the month of March (pre-monsoon) at Belekeri station (S5) and maximum observed in the month of August (monsoon) at Belekeri station (S4). The higher values at Belekeri station (S4) which receives freshwater runoff during the monsoon season, could be due to the oxidation of ammonia, reduction of nitrate and also due to the formation as intermediate compound during the decomposition of autochthonous and allochthonous organic matter (that entered into these waters through land run-off during monsoon season). The higher concentration of nitrite-nitrogen 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 present in the environment (Govindasamy *et al.*, 2000) [17]. Low values of nitrite observed during the summer may be due to the lesser amount of freshwater inflow and higher salinity. According to Rajasegar (2003) [30], the reduction of nitrite content may be attributed to low river discharge during pre-monsoon resulting in extreme stagnations and also by the use of nitrite by phytoplankton. Similarly maximum value in monsoon and minimum value in pre-monsoon season (summer) was also recorded by Rajeshwari (2009) [32], Damotharan *et al.* (2010) [12], Manikannan *et al.* (2011) [24], Arumugam and Sugirtha (2014) [6], Dattatreya *et al.* (2018) [13]. Narshivudu *et al*. (2018) [26] and Chandrakant Lingadhal *et al*. (2020) [9]. 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 (Ravaniah *et al.*, 2010) [34]. In the present study, nitrite-nitrogen showed a significant positive correlation with nitrate-nitrogen.

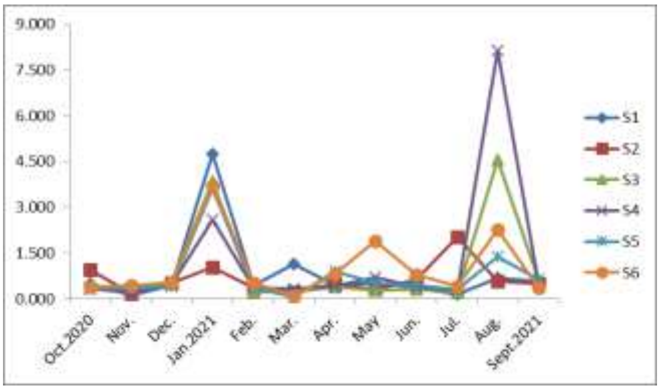

Fig 9: Monthly variations in Nitrite-Nitrogen (µg-at/l) of nearshore waters of Keni and Belekeri, Ankola.

Nitrate-Nitrogen (NO_3-N)

Nitrates are the most oxidized forms of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter. Generally, nitrate is considered as limiting nutrient for primary production in case of seawater. The data collected on the fluctuation of Nitrate-Nitrogen concentration at selected stations during the study period shown that the concentration ranged between 0.13 µg-at./l and 15.67 µg-at./l. The minimum value was observed in the month of March (pre-monsoon) at Belekeri station (S5) and maximum observed in the month of August (monsoon) at Belekeri station (S4). The seasonal variations of nitrate values were recorded maximum during monsoon and post-monsoon seasons and minimum during pre-monsoon season (Fig.10). The recording highest nitrate values during monsoon season may be mainly due to the organic materials receiving from the rivulets during rainfall. High nitrate during monsoon season could be due to freshwater influx and increased organic matter input to the system (Santhanam and Perumal, 2003) [27]. The increasing nitrate levels are due to fresh water inflow, litter fall decomposition and terrestrial run-off during the monsoon season. Another possible way of nitrates entry is through oxidation of ammonia form of nitrogen to nitrite and then consequently to nitrate (Rajasegar, 2003) [30]. The low values records during summer/pre-monsoon period may be due to its utilization by phytoplankton as evidenced by high photosynthetic activity (Govindasamy *et al.*, 2000) [17]. Similar observations were also documented by Prabhu *et al.* (2008) [28], Damotharan *et al.* (2010) [12], Manikannan *et al.* (2011) [24], Arumugam and Sugirtha (2014) [6] and Dattatreya *et al*. (2018) [13]. According to Ravaniah *et al.* (2010) [34], the peak value of nitrate during the monsoon season may be attributed to the influence of seasonal rainfall and low value during summer season might be due to the lesser amount of freshwater inflow and high salinity. In the present study, nitrate-nitrogen showed a significant positive correlation with nitrite. Relative values are higher than the corresponding values of Nitrite.

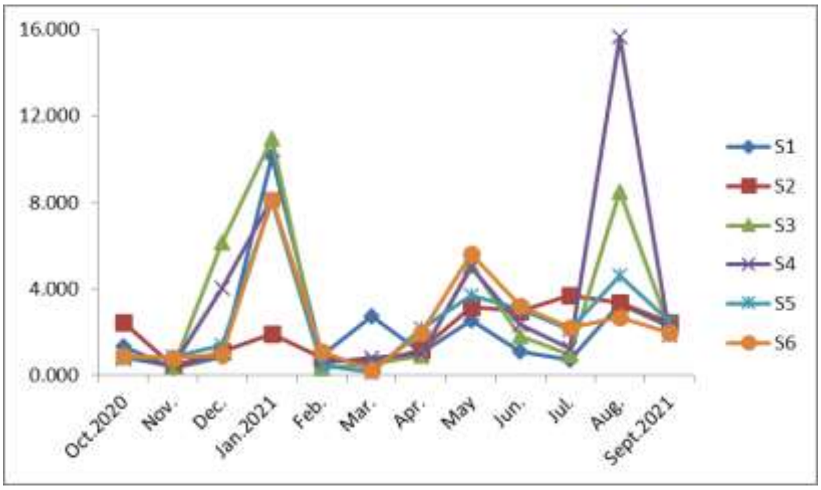

Fig 10: Monthly variations in Nitrate-Nitrogen (µg-at/l) of nearshore waters of Keni and Belekeri, Ankola.

Phosphate-Phosphorus (PO_4-P)

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 (Karl, 2000) [19]. The limiting nutrient concentrations vary with season, location and phytoplankton community structure (Fisher *et al.*, 1992) [15] and phosphate is one of the important organic nutrients that can limit the phytoplankton population in tropical waters. The phosphates are essential for the growth of organisms and a nutrient that limits the primary productivity of the water body. Phosphate-phosphorus content in the present study ranged between 0.29 µg-at./l and 3.53 µg-at./l. The minimum value was recorded in the month of March (pre-monsoon) at Keni station (S3) while maximum observed in the month of August (monsoon) at Belekeri station (S4). The phosphate concentrations in the study area fluctuated between the stations as well as the seasons (Fig.11). Seasonally monsoon season recorded higher phosphate-phosphorus concentration than the post and pre-monsoon seasons. The peak values of phosphate observed during the monsoon may be attributes to the influence of seasonal rainfall, land runoff and discharge of sewage wastes from the rivulets. The result of low phosphates value during summer/pre-monsoon may be attributed to the limited flow of freshwater, high salinity and utilization of phosphate by phytoplankton (Senthil kumar *et al.*, 2002) [41]. Similarly maximum value in monsoon and minimum value in post-monsoon/pre-monsoon seasons were also recorded by Katti *et al*. (2002) [21], Rajashekar (2010) [31], Sahu *et al*. (2012) [38], Shruthi and Rajashekhar (2013) [44], Madhavi (2014) [23], Narshivudu *et al*. (2018) [26] and Chandrakant Lingadhal *et al*. (2020) [9]. Phosphate concentration in coastal waters depend upon its concentration in the freshwater that mixed with the seawater within the sea-land interaction zone, phytoplankton uptake, addition through localized upwelling and replenishment as a result of microbial decomposition of organic matters.

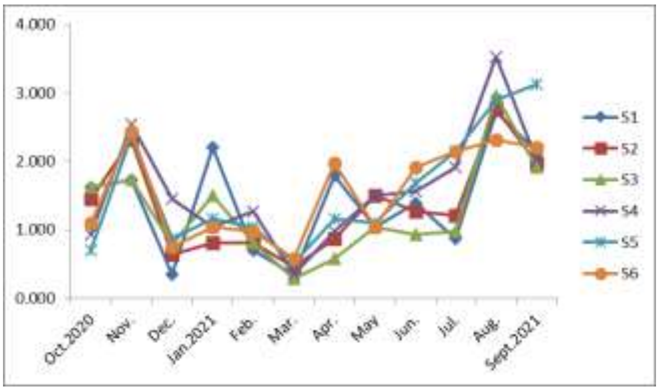

Fig 11: Monthly variations in Phosphate-Phosphorus (µg-at/l) of nearshore waters of Keni and Belekeri, Ankola.

Silicate-Silicon (SiO_3-Si)

Diatoms growth mainly depends on silicate availability in addition to nitrate and phosphate. In the coastal waters, diatoms utilize the dissolved silicate from the external and internal inputs. External inputs include silicate coming from land *via* rivers, ground water or the atmosphere and from the open ocean through advection of surface waters and upwelling and internal inputs of dissolved silicate through recycling in the water column, at the sediment-water interface and deeper in the sediments (Annadurai *et al.*, 2012) [4]. The silicate-silicon content ranged from 2.44 µg-at./l to 72.71 µg-at./l with an overall variation of 70.27 µg-at./l. The present investigation revealed that the higher silicate concentration recorded in the month of July at Belekeri station (S4), while relatively lower concentration was recorded in the month of April at Keni station (S2). The silicate-silicon concentrations in the study area varied between the stations as well as the seasons (Fig.12). The seasonal variations of silicate-silicon concentrations were observed higher during monsoon and the minimum during post-monsoon and summer/pre-monsoon seasons. The peak value of silicate-silicon observed in the Belekeri station S4 was mainly due to heavy inflow of freshwater from rivulets 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. Similar observations were also made by Katti *et al*. (2001) [20], Sridhar *et al*. (2006) [47], Raveesha (2007) [35], Damotharan *et al*. (2010) [12], Sushanth and Rajashekhar (2012) [51], Muruganantham *et al*. (2012) [25], Madhavi (2014) [23], Narshivudu *et al*. (2018) [26] and Shruthi *et al*. (2020) [45]. According to Purushothaman and Venugopal (1972) [29], 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. Silicate-Silicon showed significant positive correlations with dissolved oxygen and ammonia-nitrogen and negative correlation with salinity. Salinity plays an important role in the regeneration of biogenic silica. Hence, it has been revealed that the silicate values decreased as salinity increased and vice versa.

Hydrographical properties in the nearshore waters of Keni and Belekeri appears to be varied temporally and seasonally. The higher values of temperature, pH and salinity were recorded during pre-monsoon season. In contrast, an increase in dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus and silicate-silicon were observed during monsoon season. Among all the sampling stations, Belekeri station (S4) recorded the higher values of nutrients during monsoon season which receives freshwater runoff and monsoonal rains brought into the study area nutrients as land run off.

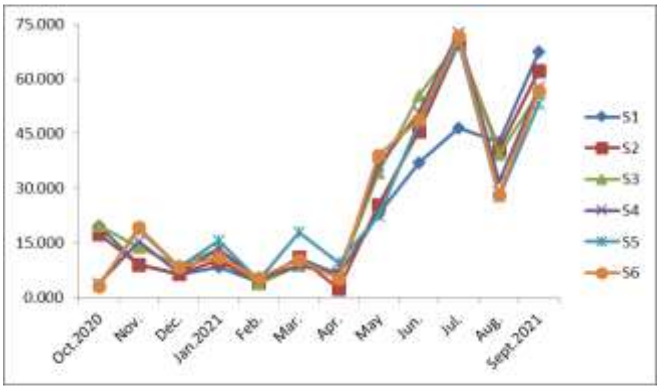

Fig 12: Monthly variations in Silicate-Silicon (µg-at/l) of nearshore waters of Keni and Belekeri, Ankola.

Conclusion

The hydrographical parameters in the nearshore waters of Keni and Belekeri showed clear seasonal patterns. Freshwater discharges through the river and rivulets include additions of nitrate, phosphate and silicate to the nearshore water mainly during the monsoon season has been observed in the sampling stations. The knowledge of nutrients, related to their sources, availability and the utilization levels gives us the information about the productivity potential and health of the coastal ecosystem. The study revealed that all the selected stations are in a good state of health as they reflected water quality is in normal condition. The present study provides a good outline on the prevailing condition of the nearshore waters and baseline information for better management and conservation of Keni and Belekeri inshore waters.

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