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Assessment of Water Quality Parameters in Mangrove Ecosystems Along Kerala Coast: A Statistical Approach

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ABSTRACT: Water samples were collected from five selected mangrove ecosystems along Kerala coast, North of Cochin, on seasonal basis and analysed for various hydrographic parameters. To explain spatio-temporal variations and the processes controlling their distribution, ANOVA (two factor without replication), correlation and principal component analysis were carried out. Concentration of total nitrogen varied from 10.26 to 188.38 µM and total phosphorous from 1.53 to 22.88 µM, with comparatively higher concentration in monsoon season which could be attributed by land run off. Chlorophyll pigments recorded significant seasonal variation ranging from ND to 40.86 µg/L (chlorophyll a), ND to 6.00 µg/L (Chlorophyll b) and ND to 13.80 µg/L (Chlorophyll c). Both monsoon and post monsoon seasons recorded higher concentration of pheophytin compared to Chlorophyll a and the maximum concentration of chlorophyll was observed during pre monsoon. Station 2 (Pappinissery) exhibited elevated concentration of nutrients (especially NH_4^+) and lower DO content which pointed towards the reducing environment by anthropogenic stress. Factor analysis revealed six components which explained 92.77% of the total variance. It also described the processes like diagenesis, sediment remineralisation, anthropogenic activities, tidal and river influx which make the ecosystem highly complex.

Key words: Mangrove, Northern Kerala coast, Water quality, Nutrients, Major ions, Chlorophyll

INTRODUCTION

Anthropogenic activities have remarkably influenced the quality of ecosystems in aquatic environments (Jiang *et al.*, 2011; Pei *et al.*, 2011; Jing and Zhiyuan, 2011; Hallare *et al.*, 2011; Siddiqui, 2011; Feng *et al.*, 2012; Clemente *et al.*, 2012; Kiteresi *et al.*, 2012). Mangroves dominate majority of the world's tropical and subtropical coastline, forming 15 million hectares of forests worldwide, which provide habitat for rich biodiversity, ranging from bacteria, fungi and algae through to invertebrates, birds and mammals (FAO, 2004). The high productivity in mangrove ecosystems is often attributed to greater litter degradation rates and efficient recycling of nutrients, which are supplied by both autochthonous litter and allochthonous inputs from natural and anthropogenic sources (Lee, 1990; Kazungu *et al*., 1993; Bouillon *et al*., 2002). The stability of the mangrove is influenced by salinity, soil type and chemistry, nutrient content and dynamics, physiological tolerance, predation and competition at local level (Smith *et al*., 2003). Besides the environmental stress factors, habitat destruction through human encroachment has been the primary cause of mangrove loss.

Despite the fact that nutrients in the tropical marine ecosystems are generally low (Qasim & Wafar, 1990), mangrove ecosystems are considered to be the most productive and complex ecosystems (Naskar & Mandal, 1999) with the ambience being rich in organic production and nutrients (Manson *et al*., 2005). Primary production by microalgae can also contribute to the complexity of the temporal and spatial variation of dissolved compounds (Harrison *et al*., 1997; Trott & Alongi, 1999). The nutrients such as inorganic phosphorus, nitrogen, potassium, and organic carbon are provided to adjacent coastal and marine, as well as terrestrial ecosystems through active and passive transport (Odum, 2000; Gonneea *et al*., 2004).Changes in proportions of dissolved nutrients in mangrove

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water are primarily caused by supply from agricultural seepage, aquaculture effluents, human settlements, etc., and leads to changes in nutrient stoichiometric ratios (Si:N, N:P and Si:P), significantly impacting the coastal food web dynamics (Moncheva *et al*., 2001; Zhao *et al*., 2005).

Total area of mangroves in India is about 4461 km^2, constituting 0.41% of countries geographical area (Jagtap *et al*., 2002). Mangrove vegetation in Kerala is now confined largely to river mouths and tidal creeks and there has been no significant mangrove cover south of Cochin in Kerala coast (Kurien, *et al*., 1994; FSI, 2003). Inland and coastal wetlands around Cochin have been lost over years due to reclamation, conversion to industrial use, dumping of solid waste, discharge of untreated sewage from municipal waste, effluents from industries and encroachment for construction. A recent study by Radhakrishnan *et al*., 2006 pointed out mangrove vegetation in four northern districts of Kerala - Kasargod, Kannur, Kozhikode and Malappuram - is approximately 3,500 hectare, which represents about 83 percent of mangrove cover in the State.

The conservation, management and sustainable development of the mangroves depend on the maintenance of hydrogeochemical characteristics of the system. Most of the research works on hydrochemical aspects of mangrove ecosystems are limited to central part of Kerala and studies on northern Kerala coast has not been reported so far. The present study is a preliminary attempt to reveal ecological health and status of mangrove ecosystems along northern Kerala Coast for management strategy and conservation. Objective of the study is to evaluate the spatial and temporal variation of general hydrographical parameters along with chlorophyll pigments for water samples collected from the selected mangrove ecosystems, employing statistical methods.

MATERIALS & METHODS

Water samples were taken from five mangrove ecosystems located at Kannur and Calicut districts of northern Kerala on west coast of India. The sampling locations are depicted in Fig. 1. Station 1 (Thalassery), is the mangrove ecosystem found in the vicinity of Arabian Sea, is fringed with dense growth of *Rhizophora spp.* and *Avicennia officinalis*, *Acanthus illcifolius*, *Excoecaria agallocha*, *Aegiceros corniculatum* and *Thespesia populnea* with isolated column of old trees of *Sonneratia sp.* and *Kandelia candel*. Station 2 (Pappinissery) is formed on the banks of Valapattanam estuary (area of about 20 hectare) by covering a distance of 4-5 km from the coastline. Major mangrove species found at this site includes: *Avicennia, Rhizophora, Kandelia and Acanthus* with isolated growths of *Aegiceras corniculatum* and creeper *Derris trifoliata*. Station 3 (Pazhayangadi) is situated at a distance about 3-4 km from coastline was found to be almost free from human activities. Major species found at this station include: *Avicennia marina, Avicennia officinalis, Aegiceras corniculatium and Rhizophora mucronata*. Station 4 (Kunjimangalam) is situated in the estuarine environment formed by Pullamcode puzha and Kunjimangalam river which is located at 2 km away from coastline with an area of around 18 hectares. The major species occurred in this region include: *Avicennia, Acanthus ilicifolius, Rhizophora mucronata, Rhizophora apiculata, Kandelia candel, Clerodendron inerme, Aegiceros corniculatium* and *Excoecaria agallocha*. Station 5 (Kadalundi) is situated on the banks of Kadalundi river which joins the Arabian Sea through a permanent bar mouth. Mangroves cover an area of 10 hectare which includes *Rhizophora mucronata, Excoecaria agallocha, Aegiceros corniculatum,* and *Acanthus ilicifolius Avicennia officinalis* etc. (CMFRI, 2002).

There are three seasonal conditions prevailing in Kerala viz. monsoon (June-September), post monsoon (October-January) and pre monsoon (February-May). Sampling was carried out during October 2009, May 2010 and August 2010 representing three seasons. Water samples were collected using a clean plastic bucket, transferred to clean plastic bottles and transported to the laboratory on ice and stored in a deep freezer (-20°C) till analysis. Samples were collected in triplicate from each station and average value for each parameter was reported. pH of water samples was measured in situ and salinity was estimated by Mohr-Knudsen method (Muller, 1999). Modified Winkler method was used for the estimation of dissolved Oxygen (Hansen, 1999). Alkalinity of the water samples were estimated by the method of Koroleff (Anderson *et al*., 1999). Nutrients (nitrite, nitrate, phosphate, silicate,) were estimated spectophotometrically using standard methods (Grasshoff, 1999). The total nitrogen and total phosphorous content were measured after alkaline persulphate oxidation (Hansen & Koroleff, 1999). The major elements like sodium, potassium, lithium were analyzed using flame photometer, calcium and magnesium were determined using EDTA titration, iron was analyzed using phenanthroline method and nephelometric method was employed for sulphate determination (APHA, 1995). Chlorophyll pigments and pheophytin in water samples were filtered through 0.45 µm glass fiber filter paper, extracted using 90% acetone and measured spectrophotometrically (APHA, 1999).

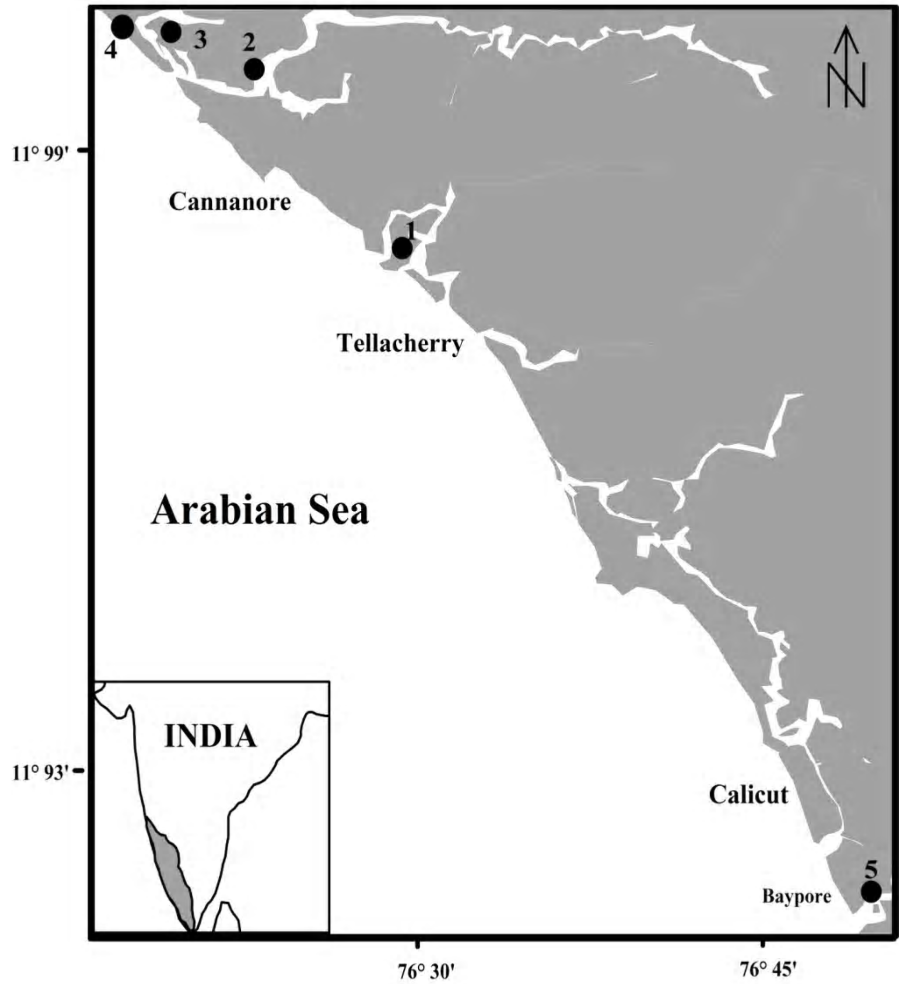
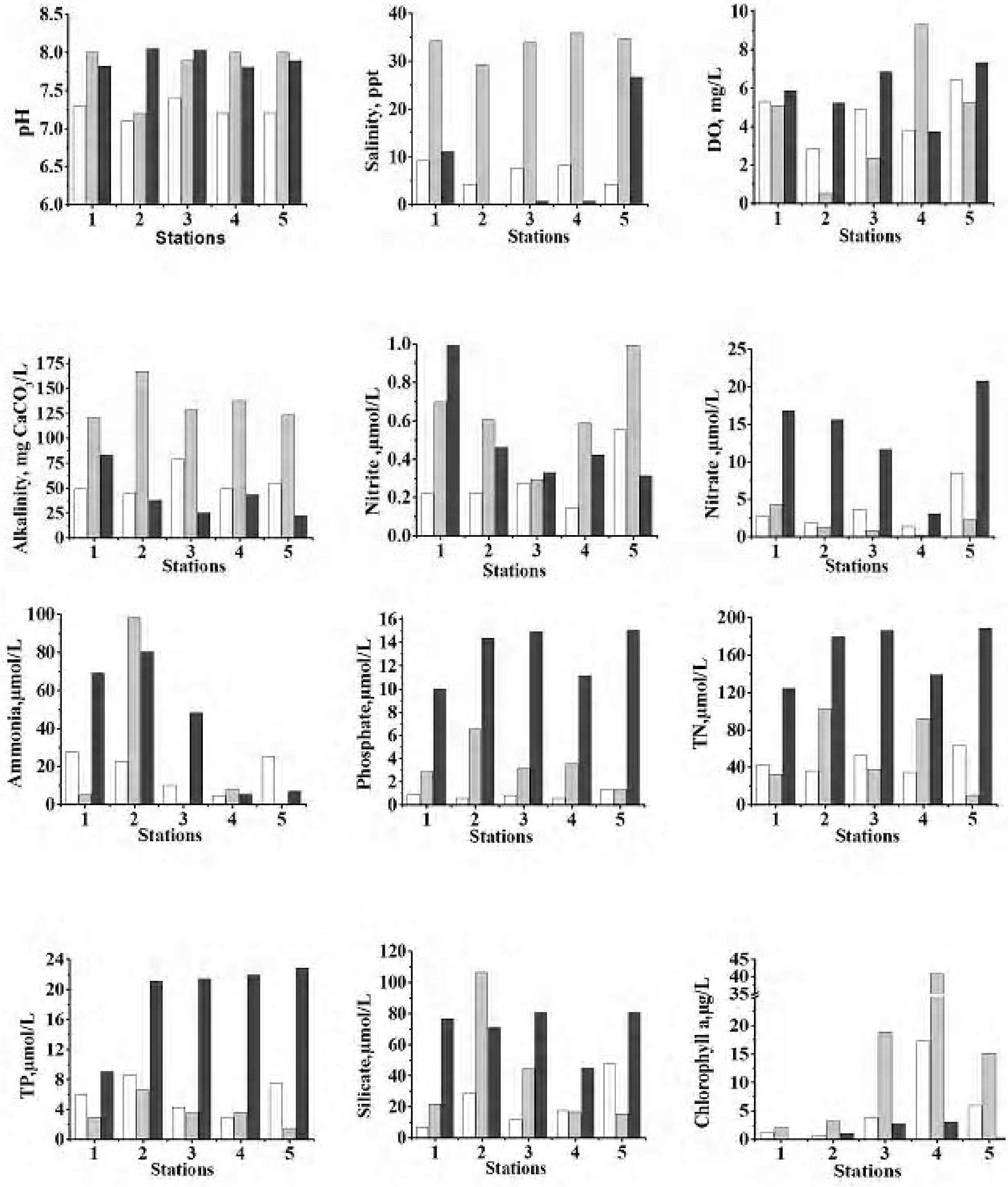


Fig. 1. Map showing location of sampling stations

Analysis of variance (ANOVA) was employed to evaluate the temporal and spatial variation in concentration of the analysed parameters. The effect of natural and anthropogenic flux was evaluated using factor analysis by applying Varimax rotation.

RESULTS & DISCUSSION

The seasonal and spatial variations of the analysed parameters are depicted in Fig. 2. pH displayed significant seasonal variation (P< 0.01) and comparatively lower values were detected during post monsoon with its minimum was recorded at station 2. In post monsoon, pH varied from 7.10 and 7.40 (avg.7.24±0.11), in pre monsoon 7.20 to 8 (avg.7.82±0.35), and in monsoon it varied from 7.81 to 8.05 (avg.7.92±0.11). A profound seasonal variation (P<0.01) was noticed for salinity ranging from 4.26 to 9.25 ppt (avg.6.73±2.32 ppt; post monsoon), 29.31 to 35.97 psu (avg.33.65±2.54 ppt; pre monsoon) and 0.24 to 26.64 psu (avg.7.89±11.44 ppt; monsoon). Dissolved Oxygen (DO) showed variation in concentration from 2.86 to 6.41 mg/L (avg.4.66±1.37 mg/L), 0.51 to 9.34 mg/L (avg.4.52±3.34 mg/L) and 3.76 to 7.35 mg/L (avg.5.82±1.42 mg/L) during post monsoon, pre monsoon and monsoon seasons respectively. Alkalinity displayed significant seasonal variation (P <0.01), exhibiting higher values during pre monsoon and lower values during monsoon. It varied from 44.55 to 79.20 mg$CaCO_3$/L during post monsoon (avg.55.44±13.44 mg$CaCO_3$/L), 121.25 to 167.33 mg $CaCO_3$/L (avg.135.8±18.78 mg $CaCO_3$/L) and 22.31 to 83.42 mg$CaCO_3$/L (avg.42.49±24.51 mg$CaCO_3$/L), pre monsoon and monsoon seasons respectively. Nitrite concentration ranged from 0.15 to 0.55 µM (avg.0.28±0.16 µM; post- monsoon), 0.29 to 0.99 µM (avg.0.63±0.25 µM; pre monsoon) and 0.31 to 0.99 µM (avg.0.50±0.28 µM; monsoon) with a minimum of 0.15 µM from station 4 during post monsoon. Nitrate displayed a significant seasonal variation (P<0.01) and it recorded variation in concentration from 1.37 to 8.43µM (avg.3.63±2.82 µM; post monsoon), 0.29 to 4.33 µM (avg.1.82±1.59µM; pre monsoon) and 3.14 to 20.79



☐ Post monsoon ■ Post monsoon ■ Monsoon

Fig. 2. Variation of water quality parameters in mangrove ecosystems

µM (avg.13.62±6.70 µM; monsoon). Ammonia content varied from 4.73 to 27.95 µM during post monsoon (avg.18.20 ± 10.13 µM), ND to 98.09 µM (avg.22.38±42.45 µM) and 5.52 to 80.36 µM (avg.42.15±34.67 µM), pre monsoon and monsoon seasons respectively. Inorganic phosphate showed significant seasonal variations and its concentration varied from 0.59 to 1.37µM (avg.0.86±0.32µM) during post monsoon season, 1.32 to 6.56µM (avg.3.49±1.91µM) during pre monsoon and 9.98 to 15.07 µM (avg.13.09±2.37µM) during monsoon season. Significant seasonal variation was exhibited by silicate ($P<0.05$) and its content ranged from 7.33 to 47.79 µM (avg.22.72 ±16.10 µM; post monsoon), 15.55 to 106.60µM (avg.41.08±38.48 µM; pre monsoon) and 44.98 to 80.76 µM (avg.70.9±15.02 µM; monsoon). Concentration of total nitrogen (TN) was found to vary from 34.55 to 63.69 µM (avg.46.17± 12.20 µM; post monsoon), 10.26 to 102.78 µM (avg.55.19±40.1 µM; pre monsoon) and 124.78 to 188.38 µM (avg.163.68±29.67µM; monsoon). A significant seasonal variation was observed for TN ($P<0.01$), with its minimum content reported during pre monsoon and maximum during monsoon (station 5). Total phosphorous (TP) content ranged from 2.96 to 8.61 µM (avg.5.87±2.30 µM), 1.53 to 6.65 µM (avg.3.67±1.87 µM), and 10.04 to 22.88 µM (avg.19.29±5.77 µM) during post monsoon, pre monsoon and monsoon seasons respectively. TP also displayed highly significant seasonal variation ($P<0.01$) with its maximum concentration recorded during monsoon and the minimum during pre monsoon.

Significant seasonal variation for chlorophyll pigments were observed from ANOVA ($P <0.05$). Chlorophyll a (chl a) recorded variation in concentration from 0.77 to 17.29 µg/L (avg. 5.82 ±6.75µg/L; post monsoon), 2.18 to 40.86µg/L (avg.16.07±15.66; µg/L; pre monsoon) ND to 3.09 µg/L (avg.1.47±1.41 µg/L; monsoon). The samples collected during pre monsoon recorded comparatively higher chl a content (station 4) whereas lower concentration was reported during monsoon. Concentration of chlorophyll b (chl b) varied from ND to1.61 µg/L (avg.0.45 ±0.66 µg/L), 1.12 and 6.00 µg/L (avg.3.04±1.89 µg/L) and ND to 1.71 µg/L (avg.0.96±0.89 µg/L) during post monsoon, pre monsoon and monsoon seasons respectively. Comparatively higher chl b content was recorded at station 5 (pre monsoon). Chlorophyll c (chl c) ranged from ND to 4.34 µg/L (avg.1.58±1.73 µg/L), from 1.70 to 13.80 µg/L (avg.6.50±4.67µg/L) and ND to 2.44 µg/L (avg.0.67±1.06 µg/L) during post monsoon season, pre monsoon and monsoon seasons respectively. All stations recorded higher pheophytin content during post monsoon season with a maximum at station 4 (31.01 µg/L). It varied from 4.01 to 31.01 µg/L (avg.17. 96±12.84µg/L; post monsoon), 1.01 to 22.27µg/L (avg.8.68±8.56µg/L; pre monsoon) and ND to 23.20 µg/L (avg.5.59±9.94 µg/L; monsoon).

Among the major elements studied, calcium content found to vary from 21.78 to 172.51 mg/L (avg. 85.99±58.74 mg/L) during post monsoon, 148.37 to 453.13 mg/L (avg. 266.38 ± 126.81 mg/L) during pre monsoon and 8.02 to 108.27 mg/L (avg. 30.45 ±43.31 mg/L) during monsoon. Concentration of magnesium ranged from 65.44 to 540.23 mg/L (avg.260.23±175.99 mg/L; post monsoon), 616.65 to 1362.8 mg/L (avg.1017.77±284.73 mg/L; pre monsoon) and 8.63 to 621.09 mg/L (avg.141.39 ±268.36 mg/L; monsoon season). The sodium content in water samples varied from 434 to 2523 mg/L (avg.1249±777mg/L) during post monsoon, 4000 to 7400 mg/L (avg. 5700±1245mg/L) during pre monsoon and 50 to 2600 mg/L (avg.626±1105.23 mg/L) during monsoon seasons. Concentration of potassium ranged from 18 to 105 mg/L (avg.56.22±31.9 mg/L), 160 to 320 mg/L (avg. 228.57±68.78 mg/L) and 3.3 to 130 mg/L (avg.31.34±55.21 mg/L) during post- monsoon, pre monsoon and monsoon seasons respectively. The sample from station 3 recorded higher concentration for sodium and potassium during pre monsoon. Lithium content varied from 0.2 to 1.0 mg/L during post monsoon season, 1.6 to 3.2 mg/L during pre monsoon and ND to 1.4 mg/L during monsoon.

The sulphate content varied from 235.24 to1086.5 mg/L (avg.594.93±359.75 mg/L; post monsoon), 1700 to 4166.67 mg/L (avg.3104.76 ±1057.09 mg/L; pre monsoon) and 12 to 966.67 (avg.224.4 ±415.41 mg/L; monsoon). The maximum concentration of sulphate was observed at station 4 during pre monsoon and the minimum was recorded at station 2 during monsoon. The iron content ranged from 0.089 to 0.85 mg/L (avg.0.31±0.31 mg/L), 0.078 to 0.624 mg/L (avg.0.31±0.25 mg/L) and 0.04 to 1.43 mg/L (avg.0.43 ±0.58 mg/L) during post monsoon, pre monsoon and monsoon season respectively.

Salinity exhibited minimum value during monsoon season due to fresh water runoff. The maximum was reported from station 4 which might be due to the land locked nature of the sampling site. Compared to other stations, stations 1 and 5 are situated in the close proximity of Arabian Sea and therefore prominent tidal activity can alter salinity of these systems. In aquatic systems, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter, re-aeration (Granier *et al*., 2000), and physicochemical properties of water (Aston, 1980).The organic pollution by domestic sewage at station 2 resulted in the depletion of dissolved oxygen. The dissolved oxygen super saturation (132 %) was observed at station 4 (pre monsoon) could be resulted by the photosynthesis by phytoplankton, confirmed by the higher chlorophyll content. Limited tidal rhythm and flushing also contributed to the dissolved oxygen super saturation. Dissolved gas super saturation (DGS) can be produced in rivers and lakes which have high densities of plankton, aquatic plants, and algae (White *et al.*, 1991).

Nitrate exhibited higher concentration during monsoon (station 5) and lower content during pre monsoon (station 4). According to Solanki *et al*., 2010, the proportion of different forms of nitrogen in any water body is determined by the balance between assimilation, mineralization, nitrification, denitrification and nitrogen fixation. Station 2 received large quantity of domestic garbage, poultry waste resulting to the reducing environment and recorded elevated concentration of nutrients (especially NH_4^+) and low DO. At stations 2 and 3, burrowing crabs produce sediment micro pores which are reducing in nature resulting in the build up of ammonium, by the process of anaerobic ammonification (Smith *et al*., 1991).

Comparatively higher content of phosphate was recorded during monsoon and lower content during post monsoon season. During the monsoon, nitrate and phosphate level in water increases considerably due to land drainage and anthropogenic input. Faecal contamination and excreta of birds enhanced the higher level of phosphate in these mangrove ecosystems. The lower content observed during post monsoon and summer seasons might be due to decreased runoff, adsorption to sediments, and utilization by phytoplankton (Ramakrishnan *et al*., 1999). Phosphate was found to be positively correlated with pH (Table 1), which may be due to the release of phosphorous from iron and aluminium oxides by ligand exchange reactions (Boers, 1991) under favourable conditions. Water samples from station 1 during post monsoon recorded a minimum silicate content of 7.33 µM and sample from station 2 during pre monsoon showed higher value of 106.60 µM. Weathering process and land run-off mainly contribute to silicate concentration of these mangrove ecosystems.

The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphate (DIN: DIP) ranged from 10.63 to 42.60 (avg.25.70±12.71; post monsoon), 0.62 to 15.25 (avg.5.75 ±5.90; pre monsoon) and 0.82 to 8.73 (avg.4.43±3.29; monsoon). Maximum value for this ratio was estimated at station 2 during post monsoon and the minimum at station 3 during pre monsoon. All stations were found to be nitrogen depleted during pre monsoon and monsoon which might be due to the slow regeneration of NO_3^- compared to PO_4^{3-}.

Total nitrogen to total phosphorus (TN: TP) ratio in the study region varied from 4.27 to 12.39 (avg.8.79±3.33; post monsoon), 6.70 to 25.06 (14.40±7.01; pre monsoon) and 6.33 to 12.42 (8.84±2.22; monsoon). Samples collected during pre monsoon exhibited maximum value for TN: TP ratio and the minimum recorded during monsoon. At stations 3 and 4, major portion of the total nitrogen was in organic form, because naturally occurring organic nitrogen from decaying plant remains are slowly converted to NH_4^+ state by biological degradation (Valentina & Joseph, 2005). Sewage from excreta being richer in nutrients seemed to enhance the eutrophication problem in the study region. Uptake by trees and benthic microorganisms and sorption into the sediment matrix can considerably reduce nutrient concentrations in pore-water which can make the mangrove forest to an effective sink for nutrients (Alongi, 1996). From the interrelationships between nutrients (Table.1), it could be inferred that they were originated from the same source.

Chlorophyll displayed highly significant seasonal variation ($P<0.01$) with higher concentration during pre monsoon. Chlorophyll is considered as the most reliable index of phytoplankton biomass. Also, chl a to pheophytin ratio provides the first hand information on the physiological status of phytoplankton. This ratio ranged from 0.15 to 0.56 (average 0.28±0.16; post monsoon), 1.63 to 2.14 (average 1.88±0.19; pre monsoon) and ND to 1.54 (average 0.77±0.0.76; monsoon). Higher concentration of pheophytin compared to chl a during post monsoon and monsoon seasons indicated the presence of more detritus matter in these environments, which could be attributed to decomposition of organic matter, from the sediment and community structure, harbouring in the surrounding water (Tripathy *et al.*, 2005). In pre monsoon season, the reverse trend was observed due to the growth of phytoplankton in the high light intensity and low turbulent waters of mangrove ecosystems. Absence of correlation between chlorophyll pigments and nutrients indicated that nutrients have no significant role on primary production. The presence chl b revealed the contribution of green algae to the productivity of mangrove ecosystems. Chl b to chl a and chl c to chl a ratios are <1 suggesting the possibility of healthy phytoplankton populations in lower light intensity and low turbulent areas (Takahashi & Nakamoti, 1972).

The high correlations obtained between salinity and cation concentrations pointed towards the same origin of investigated elements by intrusion of Sea water. At stations 2, 3 and 4 seasonal patterns of measured parameters were modulated by precipitation, evaporation and temperature and at stations 1 and 5 along with these factors, tidal influx of Sea water also

Table 1. Correlation matrix for the estimated parameters (n=15)

Parameters	pH	salinity	DO	Alkalinity	NO_2^-	NO_3^-	Ammonia	PO_4^{3-}	SiO_4^{2-}	TN	TP	C_a	C_b	C_c	pheophytin	DIN	Mg	Ca	Na	K	Li	So_4^{2-}	Fe
pH	1																						
Salinity	0.35	1																					
DO	0.36	0.01	1																				
Alkalinity	0.09	0.79**	-0.29	1																			
NO_2^-	0.41	0.41	0.18	0.51	1																		
NO_3^-	0.37	-0.28	0.42	-0.53*	0.15	1																	
Ammonia	-0.10	-0.28	-0.24	0.06	0.23	0.36	1																
PO_4^{3-}	0.56*	-0.24	0.17	-0.40	0.06	0.77**	0.44	1															
SiO_4^{2-}	0.14	-0.12	-0.15	-0.05	0.16	0.60**	0.73**	0.76**	1														
TN	0.42	-0.33	0.27	-0.45	-0.04	0.75**	0.48	0.96**	0.74**	1													
TP	0.34	-0.50	0.17	-0.67**	-0.20	0.70**	0.29	0.91**	0.60**	0.91**	1												
Ca	0.21	0.54*	0.29	0.48	0.07	-0.49	-0.40	-0.35	-0.40	-0.29	-0.47	1											
Cb	0.44	0.53*	0.11	0.55*	0.53*	-0.33	-0.14	-0.12	-0.12	-0.20	-0.26	0.56*	1										
Cc	0.28	0.64**	0.25	0.62**	0.22	-0.48	-0.28	-0.31	-0.29	-0.28	-0.48	0.96**	0.72**	1									
Pheophytin	-0.25	-0.18	0.34	-0.09	-0.33	-0.30	-0.31	-0.35	-0.34	-0.21	-0.29	0.49	0.06	0.41	1								
DIN	-0.02	-0.30	-0.14	-0.04	0.25	0.52*	0.98**	0.55*	0.79**	0.58*	0.40	-0.46	-0.19	-0.35	-0.34	1							
Mg	0.06	0.79**	-0.29	0.92**	0.42	-0.48	0.11	-0.36	-0.03	-0.41	-0.64**	0.39	0.33	0.50	-0.23	0.01	1						
Ca	-0.02	0.64**	-0.54*	0.78**	0.14	-0.53*	-0.03	-0.41	-0.03	-0.49	-0.58*	0.35	0.37	0.43	-0.18	-0.13	0.74**	1					
Na	0.15	0.84**	-0.32	0.92**	0.34	-0.52*	-0.04	-0.38	-0.09	-0.47	-0.65**	0.48	0.44	0.57*	-0.17	-0.14	0.94**	0.88**	1				
K	0.09	0.77**	-0.43	0.90**	0.33	-0.49	0.03	-0.37	-0.01	-0.46	-0.63**	0.37	0.38	0.47	-0.23	-0.06	0.91**	0.93**	0.98**	1			
Li	0.09	0.77**	-0.45	0.90**	0.40	-0.43	0.12	-0.31	0.08	-0.41	-0.58*	0.32	0.44	0.45	-0.30	0.03	0.91**	0.91**	0.96**	0.98**	1		
So_4^{2-}	0.35	0.87**	0.08	0.81**	0.53*	-0.49	-0.32	-0.44	-0.38	-0.52*	-0.68**	0.68**	0.69**	0.78**	0.00	-0.38	0.78**	0.57*	0.81**	0.72**	0.71**	1	
Fe	0.27	-0.25	0.06	-0.18	-0.14	0.04	0.00	0.20	0.07	0.17	0.19	-0.09	0.23	0.02	0.40	0.01	-0.33	-0.07	-0.21	-0.18	-0.21	-0.16	1

*Correlation is significant at 0.05 level

**Correlation is significant at 0.01 level

Table 2. Factor loadings for the analysed parameters

	Component					
	1	**2**	**3**	**4**	**5**	**6**
pH	0.21	0.71	-0.18	0.04	0.51	0.24
Salinity	0.83	0.09	-0.28	0.15	0.28	-0.16
DO	-0.42	0.27	-0.16	0.55	0.51	-0.18
Alkalinity	0.90	-0.24	0.06	0.15	0.20	0.02
Nitrite	0.33	-0.02	0.21	-0.08	0.86	-0.01
Nitrate	-0.45	0.57	0.38	-0.19	0.31	-0.18
Ammonia	0.04	0.05	0.96	-0.15	0.02	0.01
Phosphate	-0.22	0.87	0.40	-0.15	0.06	0.07
Silicate	0.08	0.52	0.76	-0.18	-0.08	0.02
TN	-0.32	0.82	0.46	0.01	-0.02	0.00
TP	-0.50	0.78	0.24	-0.23	-0.12	0.07
C_a	0.43	0.00	-0.34	0.80	0.05	-0.01
C_b	0.47	0.06	-0.18	0.29	0.47	0.47
C_c	0.55	0.00	-0.24	0.75	0.16	0.12
Pheophytin	-0.28	-0.31	-0.12	0.78	-0.19	0.28
DIN	-0.04	0.15	0.95	-0.17	0.09	-0.03
DON	-0.36	0.90	-0.09	0.13	-0.09	0.01
DOP	-0.73	0.34	-0.11	-0.26	-0.34	0.04
Mg	0.90	-0.21	0.08	0.07	0.13	-0.20
Ca	0.90	-0.20	-0.06	-0.09	-0.19	0.14
Na	0.97	-0.16	-0.07	0.07	0.07	-0.05
K	0.97	-0.19	0.01	-0.04	0.01	-0.01
Li	0.97	-0.16	0.09	-0.08	0.06	-0.01
Sulphate	0.74	-0.15	-0.34	0.29	0.45	-0.01
Iron	-0.19	0.11	0.04	0.10	-0.02	0.91

Rotated Component Matrix, Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization

had a profound influence. The observed negative correlations of calcium with DO suggest the uptake of calcium by primary producers (Cohen *et al*., 1999). Sodium, potassium, lithium, calcium and sulphate contents varied seasonally while concentration of magnesium displayed both seasonal and spatial variation and iron exhibited a significant spatial variation only.

The effect of natural and anthropogenic flux was evaluated using factor analysis with Varimax rotation. A total of 92.77% of variance was explained by all the six factors. The first factor contributed 35.63% of the total variance (Table 2), and depicted strong positive loadings on all major elements, alkalinity, salinity and moderate loading on sulphate. It suggested the fact that intrusion of Sea water was the major parameter controlling the distribution of major elements. This factor showed negative loadings on nitrate TP and DOP with positive loadings on chlorophyll a, b and c. The variables in the second factor were characterised by strong positive loadings on phosphate, silicate, total nitrogen and DON, moderate loading on total phosphate and pH, accounting for 18.15 % of the total variance. It also displayed a positive loading on nitrate. Release of phosphate from sediment during alkaline condition can be confirmed with this factor loading. This factor pointed towards the sediment remineralisation and digenetic processes occurring in the mangrove ecosystem.

Third factor contributed 14.24 % of the total variance exhibiting high positive loadings on ammonia and DIN, moderate loading on silicate, phosphate and total nitrogen. Faecal materials along with other anthropogenic and sewage wastes entering the mangrove ecosystem by land run off contributed towards this factor loading.

Fourth factor reflected 10.53 % of the total variance which had a loading on DO and strong loadings on chl a, chl c and pheophytin. This factor pointed towards the fact that primary production had a control over the DO concentration in the study area. Fifth and sixth factors accounted for 8.73% and 5.50% of the total variance respectively. Variables in component 5 consist of nitrite (strong), pH, DO, chlorophyll b and sulphate while that in component 6 consisted of iron (strong) and chl b. The effect of dissolved oxygen on nitrification and sulphate reduction can be predicted in the ecosystem. This factor can also provide information about effect of pH on nitrification rates.

CONCLUSION

All the mangrove ecosystems in the study region were found to be nitrogen depleted during pre monsoon and monsoon which may be due to the slow regeneration of NO_3 compared to PO_4^{3-}. Internal loading of phosphorous was evident from the correlation and factor analysis; hence phosphorous was not a limiting nutrient in the present investigation. Compared to other seasons, pre monsoon was characterised by higher chlorophyll content. From factor and correlation analysis it was evident that nutrients has no control over primary production. High turbulent water restricted the light attenuation resulting in lower primary production in post monsoon and monsoon season. The dissolved oxygen super saturation (132 %) was noticed at Kunjimangalam during pre monsoon which might be due to higher rate of photosynthesis and limited flushing. All major elements showed positive correlation with salinity indicating saline water influx from adjacent estuarine system. Factor analysis can also explain the processes like diagenesis, river influx and anthropogenic stress in the study region.

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