Seasonal variation in trace metal concentrations in water and the bioaccumulation factor in phytoplankton along the Cochin backwaters in Kerala, India

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Abstract

The study attempts to evaluate seasonal variation in different metals (Fe, Ni, Zn, Cu, Cr, Mn, Cd, and Pb) in water and bioaccumulation factors in phytoplankton from the Cochin backwaters. The trace metal concentrations in surface water of the Cochin backwaters were found to be in the following order: Fe > Zn > Pb > Ni > Mn > Cr > Cu > Cd. The concentration of trace metals in phytoplankton was found to be in the order of Fe > Zn >Mn> Cu > Ni > Cr >Pb> Cd. Significant variations (p value <0.05) in metal concentrations were observed in water and phytoplankton during the study period. Heavy river runoff during the monsoon and post-monsoon seasons, combined with the influx of industrial effluents, agricultural and domestic waste, and environmental parameters, act as a favourable factor for trace metal accumulation in phytoplankton in the Cochin backwaters. This work is highly significant and useful for biomonitoring studies as well as essential to focus current status of metal toxicity in Cochin backwater.

Keywords: Trace metals, Bioconcenteration factor, Phytoplankton, Cochin backwaters, India

Introduction

Trace metals are well-known for their pollutant nature due to their toxicity, persistence in the environment, and bioaccumulative characteristics (Donat and Bruland, 1995). Trace metal availability in aquatic environments shapes biogeochemical processes which influence the growth-related metabolic functions of phytoplankton communities (Huntsman and Sunda, 1981; Sunda and Huntsman, 1998). Besides, trace metal contents in phytoplankton reflect biochemical demands as well as environmental availability, which control the distribution of metals in aquatic systems (Twining and Baines, 2013). Being primary producers, phytoplankton in most aquatic habitats concentrate metals so effectively that they are able to transfer metals to higher trophic levels in aquatic food webs (Subramanyam and Kumari, 1990; Sunda, 1991). Phytoplanktons have the capability of accumulating trace metals in their bodies much higher than the level present in water (Knauer and Martin, 1973; Morel et al., 1991). As potentialities vary on a geographical scale, the results obtained in the present study will certify them as pollution indicators and bioaccumulation factors can be used as a potential tool for monitoring particular metal concentrations in backwaters, which ultimately leads to enabling protocols for industrial policies in respective regions.

Materials and methods

Study area

Cochin backwaters is situated along the southwest coast of India and it extend from Cochin to Alappuzha (9° 40.12' N and 10° 10.48'N and 76° 09.52' E and 76° 23.57'E) which forms part of the Vembanad - Kol wetland Lake system; one of the 'Ramsar Sites' (No.1214) in Kerala. The backwater situated longitudinally parallel to the west coast of Arabian Sea. Five perennial rivers: Meenachil, Manimala, Achankoil, Pambaand Muvattupuzha rivers flow into Vembanad Lake at different locations and heavy water discharge occurs during monsoon season. The freshwater from these rivers flush out into the Arabian Sea at Cochin bar mouth region regularly. The Cochin estuary is monsoonal influenced ecosystem as it under the profound influence of southwest monsoon (Revichandran et al., 2012). A human made hydraulic barrage at Thanneermukkom (Thanneermukkom bund) regulates free flow of river discharge during non monsoon season. Hence, the backwater system is important from the point of view on biodiversity, fishery resources and economy. Five sampling stations were selected using Global positioning system based on specific geographic features, anthropogenic activities, and inflow of pollutant from different sources (Figure 1).

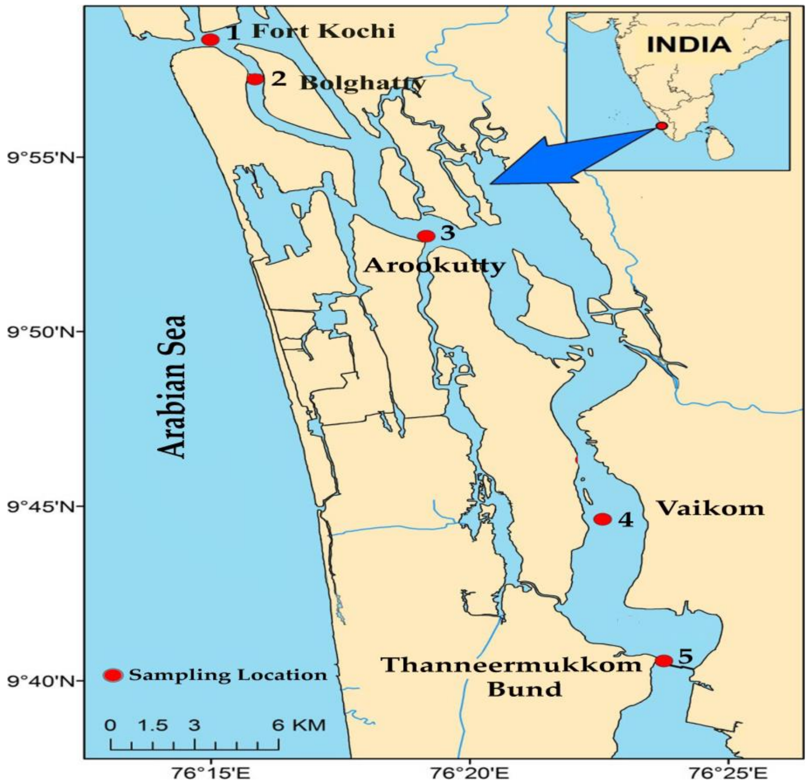

Figure 1. Station locations

Sample Collection

Samples were collected bimonthly from five stations during pre-monsoon (February-May) monsoon (June-September) and post-monsoon (October- January) for a period of two years from March 2017 to January 2019. Water samples for the analysis of environmental parameters were collected as per standard protocol (Strickland and Parsons, 1972; APHA, 2012).

Water temperature was determined by a standard degree centigrade mercury thermometer, pH by electrometric method (Eutech PH 700 meter), and electrical conductivity by water analyser (Systronics 371) APHA (2012). Total dissolved solids (TDS) was measured electrometrically using the water analyser (Systronics-Model no.371). Salinity was measured with a standard Refractrometer (Model- MCP0-100). The total alkalinity and total hardness of water was determined by the titrimetric method. Winkler method was used for the estimation of dissolved oxygen (APHA, 2012). Nutrients (nitrite, nitrate, phosphate and silicate) were estimated spectrophotometrically (Shimadzu, UV-160A) using standard methods (Strickland and Parsons, 1972, Grasshoff et al., 1999. The concentrations of trace metals such as Fe, Ni, Zn, Cu, Cr, Mn, Cd and Pb in water samples were analysed using an Atomic Absorption Spectrophotometer (AAS) as per methodology provided by Grasshoff et al., 1983.

Phytoplankton samples were collected using standard plankton net with a mesh size of 20 µm through horizontal trawls from surface waters for qualitative studies as well as metal analysis. Subsamples were transferred to a 250 ml container, preserved with 2-5% Formaldehyde and Lugol's iodine solution, and transported to the laboratory for identification of phytoplankton species. The species identification was carried out with the aid of standard published references (Gopinathan, 1971; Tomas, 1997; Subramaniyan, 1946).

Prior to metal analysis, samples were washed thoroughly using milli Q water to remove any non-planktonic particulates, adsorbed metals and metalloid ions. Each sample was later examined under binocular microscope (Olympus, New York, USA) to remove non-planktonic residues like small leaves, stalks, shells, and impure materials. Water samples containing phytoplankton was filtered through pre-weighed filter papers. Filter papers along with filtrate were dried to calculate the dry weight of phytoplankton. A constant weight of filtrate was digested for 3 hours at 80 ºC with 3 ml nitric acid and 1 ml perchloric acid mixture until the solution turned colourless. The concentration of trace metals in phytoplankton was determined with Atomic Absorption Spectrophotometer (Perkin Elmer India Pvt. Ltd; model: PinAAcle 900 H). The calculations of the selected metals in plankton were evaluated using the equation,

$$\text{Concentration of metal in the sample} = \frac{\text{AAS reading} \times \text{Volume of sample} \times \text{dilution factor}}{\text{Dry weigh of the sample taken}}$$

Bioconcenteration factor (BCF) was used to evaluate bioaccumulation of trace metals in phytoplankton (USEPA, 1991). It can be calculated by BCF = C org / C w

Where, C org is the concentration of metal element in organism, C w is the concentration of metal element in surrounding medium.

All analysis was done in duplicate to avoid statistical error, and mean values were used to present the data. Analysis of variations (two-way) was performed to determine any significance in concentration of metals in phytoplankton on spatial or temporal basis. A Pearson correlation coefficient analysis was carried out on the obtained bioaccumulation factor data of phytoplankton with environmental variables.

Results

Physico-chemical parameters

The surface water temperature in Cochin backwaters fluctuated between 26ºC to 30ºC. The pH value ranged between 6.4 and 8.2 with mean value 7.34 ± 0.42. Maximum pH value (7.39 ± 0.28) was observed during monsoon and minimum (7.27± 0.38) during post-monsoon. The observed salinity in the backwater was 16.75 ± 10.63 ppt. Salinity showed wide variations from 0.2 ppt to 34.1 ppt in surface water. The dissolved oxygen ranged between 2.05 to 7.8 mg/L during the study period. Electrical conductivity in Cochin backwaters varied between 0.19 mS/cm to 48.14 mS/cm. TDS value was low (0.08 ppm) during post-monsoon and high (33.2 ppm) during monsoon in Cochin backwaters. When compared to pre-monsoon (71.88± 26.96mg/L) and monsoon season (35.03 ± 12.03 mg/L), relatively high alkalinity was observed during post-monsoon (80.04 ± 25.61 mg/L). Total hardness showed a maximum value of 4631± 1940.3 mg/L during pre-monsoon and minimum value during monsoon (496.82 ± 350.35 mg/L). Concentration of nutrients such as nitrite, nitrate, phosphate and silicate were high during monsoon followed by pre-monsoon and post monsoon (Table 1). The phosphate, nitrite, nitrate and silicate concentration in

Cochin backwater was 2.33 ± 1.11 µmol/L, 0.96 ± 0.69 µmol/L, 12.34 ± 15.43 µmol/L, 59.1 ± 66 µmol/L respectively. Seasonal variations of physico-chemical parameters in surface waters were observed with peak value during monsoon and lowest during pre-monsoon (Table 1).

Table 1 Seasonal variation of physico-chemical parameters (Mean ± SD) in the Cochin backwaters.

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Parameters	PRM			MON			POM		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature (ºC)	28.2	30.0	29.34 ± 0.6	26.0	28.9	27.53 ± 0.9	27.7	29.9	29.04 ± 0.7
pH	6.4	8.2	7.35 ± 0.6	6.9	7.9	7.39 ± 0.3	6.69	7.90	7.27 ± 0.4
Salinity (ppt)	14.3	34.1	24.8 ± 7.8	0.2	13	5.11 ± 4.03	7.9	32.4	20.35 ± 7.1
DO (mg/L)	2.1	6.1	4.36 ± 1.0	4.9	7.8	7.08 ± 0.9	2.9	7.6	5.8 ± 1.5
EC (mS/cm)	19.5	48.1	33.1 ± 10.6	0.19	10.5	4.55 ± 3.6	4.1	46.2	25.53 ± 11.9
TDS (ppm)	11.5	33.2	19.9 ± 6.7	0.08	6.9	2.98 ± 2.4	2.1	28.0	15.18 ± 7.6
Alkalinity (mg/L)	35.0	110.0	71.88 ± 26.9	16.0	52.8	35.03 ± 12.0	34.4	135.0	80.04 ± 25.6
Hardness (mg/L)	2000.0	6954.0	4631 ± 1940	20.0	1840.0	496.82 ± 350.4	790.0	6500.0	3462.00 ± 1898.2
Phosphate (µmol/L)	0.49	3.90	1.66 ± 1.0	0.80	4.9	2.8 ± 1.1	1.0	4.5	2.54 ± 0.9
Nitrite (µmol/L)	0.08	1.8	0.96 ± 0.6	0.02	3.1	1.31 ± 0.9	0.20	1.30	0.61 ± 0.3
Nitrate (µmol/L)	4.7	8.5	4.67 ± 2.7	4.5	23.3	12.07 ± 7.1	1.4	12.0	7.31 ± 3.5
Silicate (µmol/L)	12.2	50.1	29.56 ± 11.2	34.5	106.0	73.36 ± 21.5	34.9	90.0	52.84 ± 14.7

Dissolved trace metals in water

The metal concentrations in surface water of Cochin backwaters were in the rank of order Fe> Zn >Pb> Ni>Mn> Cr > Cu >Cd. The mean value for concentration of dissolved trace metals in surface waters of Cochin backwaters were recorded in the order, Fe (0.63 ± 0.28 ppm), Zn (0.18 ± 0.08 ppm), Pb (0.044 ± 0.03 ppm), Ni (0.041 ± 0.02 ppm), Mn (0.037 ± 0.01ppm), Cr (0.03 ± 0.01 ppm), Cu (0.025 ± 0.01ppm) and Cd (0.007 ± 0.004 ppm). Seasonal variation of dissolved trace metals were also observed in the Cochin backwaters (Table 2).

Table 2 Seasonal variation of dissolved trace metals (ppm) in surface waters

Trace metals	PRM	MON	POM
Ferrous	0.77 ± 0.30	0.49 ± 0.18	0.63 ± 0.29
Nickel	0.03 ± 0.02	0.03 ± 0.02	0.06 ± 0.02
Zinc	0.21 ± 0.11	0.15 ± 0.06	0.17 ± 0.08
Copper	0.022 ± 0.01	0.019 ± 0.13	0.025 ± 0.01
Chromium	0.04 ± 0.02	0.016 ± 0.01	0.037 ± 0.02
Manganese	0.05 ± 0.02	0.03 ± 0.02	0.04 ± 0.01
Cadmium	0.008 ± 0.006	0.003 ± 0.002	0.010 ± 0.002
Lead	0.039 ± 0.02	0.038 ± 0.02	0.054 ± 0.02

PRM – Pre-monsoon, MON – Monsoon, POM – Post monsoon

Trace metals in Phytoplankton

Mean value for Fe concentrations observed in phytoplankton is high among the all metals. The observed values during pre-monsoon, monsoon and post-monsoon seasons were 6683.53 ± 1428.57 ppm, 11287.14 ± 2836.53 ppm, and 11226.52 ± 3832.09 ppm, respectively. The mean concentration of trace metals bioaccumulated in phytoplankton was in the decreasing order of magnitude: Fe > Zn >Mn> Cu > Ni > Cr >Pb> Cd (Table 3). The ranking of different metals in phytoplankton showed that iron is much more efficiently bio-accumulated than any other metal which is followed closely by Zn whereas cadmium is least bioaccumualted. ANOVA revealed significant seasonal variations were observed Fe, Ni, Zn, Cr, Mn, and Pb concentration in phytoplankton at $p<0.05$ level (Table 4).

Table 3 Seasonal variation of trace metals in phytoplankton (Mean value ± Sdv in ppm)

Trace metals	PRM	MON	POM
Ferrous	6683.53 ± 1428.6	11287.14 ± 2836.5	11226.52 ± 3832.1
Nickel	32.85 ± 11.5	50.90 ± 14.9	36.09 ± 12.5
Zinc	268.01 ± 83.4	413.67 ± 47.4	364.17 ± 57.5
Copper	46.99 ± 11.1	52.67 ± 14.9	49.37 ± 19.1
Chromium	30.36 ± 11.4	44.98 ± 9.2	43.61 ± 10.4
Manganese	71.11 ± 17.8	128.10 ± 47.1	100.48 ± 48.7
Cadmium	0.55 ± 0.4	0.74 ± 0.3	0.79 ± 0.3
Lead	7.29 ± 5.9	19.76 ± 10.2	14.79 ± 13.2

PRM – Pre-monsoon, MON – Monsoon, POM – Post monsoon

Table 4 ANOVA on metal concentrations in phytoplankton of the Cochin Backwaters.

Metals in phytoplankton	Source of variations	F value	*p* value
P-Ferrous	Seasons	11.46	0.004
P-Nickel	Seasons	16.92	0.001
P-Zinc	Seasons	18.39	0.001
P-Copper	Seasons	0.762	0.498

P-Chromium	Seasons	6.107	0.025
P-Manganese	Seasons	14.40	0.002
P-Cadmium	Seasons	1.127	0.371
P-Lead	Seasons	4.593	0.047

Bioconcentration factors (BCF) of trace metals in phytoplankton.

The mean bioconcentration factors (BCF) of trace metals in phytoplankton follows a decreasing rank of order: Fe (15424.58) >Mn (2687.38) > Cu (1957.32) > Zn (1948.15) > Cr (1278.10) > Ni (985.92) >Pb (319.91) > Cd (97.96). The high BCF observed indicate that phytoplankton has high potential to uptake trace metals. The order concerning metal content in phytoplankton and bioaccumulation factors varies for metals like Zn, Mn, Cu, Ni, and Cr which might be related to complex hydrochemical conditions and or the composition of phytoplankton in the study area. Seasonal variations of BCF were ranked high during monsoon than in pre-monsoon and post-monsoon. BCFs of metals, Fe, Zn, Cr, Cd, Pb and Mn metals in phytoplankton was high during post-monsoon than pre-monsoon and reverse the pattern in Ni and Cu (Figure 2).

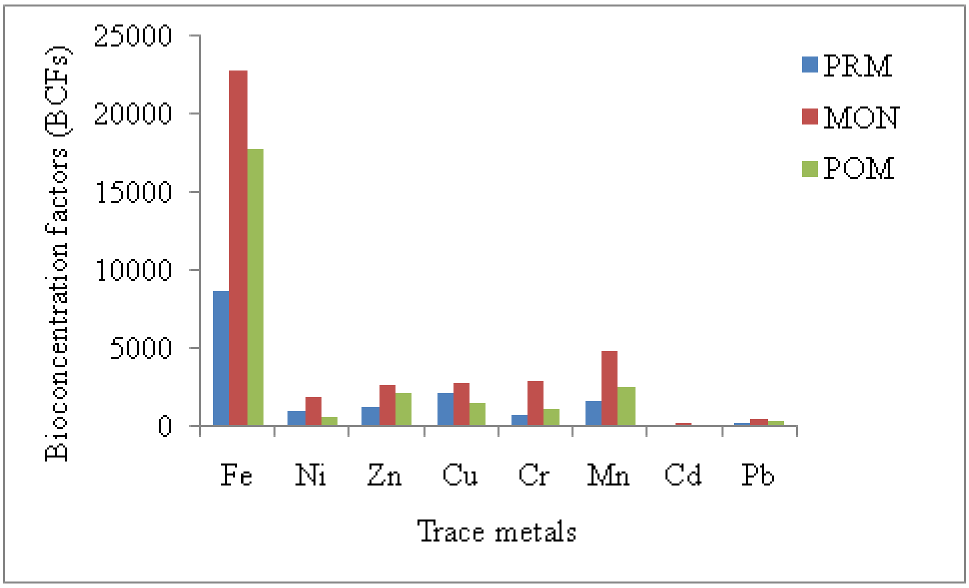

Figure 2. Temporal variation on bioconcenteration factors of metals in phytoplankton at Cochin backwaters.

Discussion

Anthropological activities form major cause of pollution that affects water quality. The degree of pollution is explained by variation in physico-chemical parameters of water bodies and its effects on survival of plankton community (Duran et al., 2007). The rate of biological, chemical, and physical processes as well as the distribution and health of the aquatic species, are influenced by the water temperature (Roessig et al., 2004). It is an important factor in aquatic life, especially for primary producers as it adjusts diffusion of gases in water and subsequently influences photosynthesis. The maximum temperature was monitored during pre-monsoon (29.34ºC) and the minimum during monsoon (27.53ºC) in the Cochin backwater. Longer photoperiod, high evaporation rate, dry wind and bright sunshine are associated with the summer season, which is a reason for high water temperature during pre-monsoon (Mathivanan and Rajaram, 2014). The pH concentration was high during monsoon due to an increase in chemical load through river discharge and minimum in post-monsoon. Minimal salinity was recorded during monsoon and increased slowly during post-monsoon and attained maximum during pre-monsoon. The increased salinity in pre-monsoon and post-monsoon might be due to tidal influx as well as evaporation rate of surface water that directly or indirectly influence metal concentration in water. Dissolved oxygen levels are comparatively high during monsoon season than post-monsoon and pre-monsoon which attributed to the large quantity of freshwater influx into Cochin backwaters. The decreasing trend in EC values during post-monsoon and further decreased drastically may be attributed to evaporation of ions coupled with steady mineralization of organic matter in water. The high values were observed during pre-monsoon and post-monsoon than monsoon in this backwater system. The high amount of dissolved or suspended total solids in the water adversely affects the water quality and is unsuitable for drinking and irrigational purposes (Sujatha et al., 2009). The high hardness value was observed during pre-monsoon and the low during monsoon season, where fresh water is more prevalent. High phosphate content was observed in surface waters during monsoon. Anila et al. (2007) have also observed high phosphate concentration during monsoon in Adimalathura estuary and reported that it may be due to rainfall and river runoff. George et al., (2019) have also made a similar observation, where the monsoon period showed high phosphate concentration (>3 µmol/L) and explained that during monsoon, freshwater discharges through the river influence the region. However, during pre-monsoon, high phosphate concentration (>2 µmol/L) in lower estuary correspond to high saline waters imply that it is derived from internal recycling or re-suspension of sediments. Nitrite was found to be high during monsoon and decreased slowly from post-monsoon onwards. This elevated concentration of nitrite during monsoon is not only from river discharges, but also through increased domestic and industrial activities (Jyothibabu et al., 2006). An elevated level of silicate concentration in the Cochin backwater was found in surface water indicating that freshwater runoff is the principal source of silicate input (Shivaprasad et al., 2013).Seasonal variations were also apparent with high concentrations recorded during monsoon followed by post-monsoon. During monsoon, all stations showed a similar pattern of increase and could be attributed due to the heavy flux of freshwater flow from river discharge.

Industrial discharges also form major source of metal contamination in Cochin backwaters. The Central Pollution Control Board has detected the Cochin industrial region (Eloor-Edayar) as most hazardous waste-contaminated sites in India (CPCB, 2015). Cochin estuary is facing gross pollution problems because the system receives approximately 0. 104× 10^6 m^3d^{-1} of untreated industrial and 0.26× $10^3m^3d^{-1}$ of domestic wastes on daily basis (Balachandran et al., 2005). The type of industries include fertilizer, pesticides, radioactivity mineral processing, chemicals and allied industries, petroleum refining and heavy metal processing as well as fish processing units.

The present study reveal that Fe is the most abundant and Cd the least content in surface waters in Cochin backwaters irrespective of season. The temporal trends showed low concentrations during monsoon and high concentrations during non-monsoon season. Similar observations have been reported from Cochin estuarine water bodies (Nair et al., 1990; Anju et al., 2011) and may be attributed to the concentration of these metals in the stagnant water due to slow freshwater flow during non-monsoon.

The phytoplankton community represents species under Bacillariophyceae (diatoms), Chlorophyceae (green algae), Dinophyceae and Cyanophyceae (blue-green algae). In Cochin backwaters, diatoms form the predominant group among phytoplankton throughout the year. The order of metal concentration in phytoplankton ((Zn > Cu >Pb> Cd) observed during the present study is quite agreeable with reports from the Lake Manzala, Egypt (Bahnasawy et al., 2011) and Uppanar, Vellar and Kaduviar estuaries of the southeast coast of India (Senthilnathan and Balasubramanian, 1994). Metal accumulation in phytoplankton in different seasons was ranked in the following decreasing order: monsoon > post-monsoon > pre-monsoon. High concentrations of metals were accumulated in phytoplankton during monsoon than post-monsoon or pre-monsoon periods. For instance, Fe, Zn, Ni, Cu, Cr, Mn, Cd, and Pb concentration noted in phytoplankton showed 1.7, 1.5, 1.4, 1.1, 1.5, 1.8, 1.3 and 2.7 respective times enrichment during monsoon when compared to pre-monsoon. The high enrichment of metals in phytoplankton is hypothesized to be increased bioavailability of metals in the Cochin estuary owing to reduced formation of metal organochloro-complexes in low salinity waters during the monsoon and post-monsoon periods than the pre-monsoon period (Wright, 1995; Verslycke et al., 2003; Renjith et al., 2016; Jayasooryan et al., 2021). Phytoplankton often forms diet for many primary consumers, which are remarkably contributed to transfer trace metals to higher trophic levels. High concentration of all metals was reported in earlier works as in zooplankton like Mysids and Copepods during monsoon season (Biju and Rejomon 2020; Bettina et al. 2022).

In this study, all metals in phytoplankton showed a significant negative correlation with temperature (Table 4). Gupta and Rastogi (2008) reported lower adsorption of Cd by *Oedogonium* sp. at high temperatures. The strong negative correlation between metal content in phytoplankton and temperature suggest that an increase in metal uptake is favourable for phytoplankton while decreasing water temperature. The negative relationship between metal concentrations in phytoplankton and salinity implies that the freshwater waters derived through river runoff play a major role in the trace metal uptake in phytoplankton of the Cochin estuary. The analysis revealed strong positive correlation with pH. Influence of pH on uptake of Cd and Zn also reported as increase in Cd and Zn accumulation in *Desmodesmus pleiomorphus*, when pH was increased (Monteiro et al. 2009, 2010). The strong positive correlation exists between the metal content in phytoplankton and dissolved oxygen (Table 5). It indicates strong association of metals in phytoplankton with increasing oxygen saturation in water. The strong correlations were also noted between trace metals present in phytoplankton and major nutrients like nitrate, nitrite, phosphate and silicate which indicate that phytoplankton require major nutrients for their growth and metabolic activities. Wang and Dei (2001) has reported influence of major nutrients (nitrite, phosphate, silicate) on the accumulation of Cadmium, Selenium and Zinc in marine phytoplankton. The nutrient addition significantly influenced the metal uptake rate and cell growth rate in the phytoplankton. It is assumed that large amount of trace metals, in the form of fine-grained suspended particulate matter, reached estuary from various sources as river runoff and tides may undergo precipitation/flocculation in the estuarine salinity gradients which are quite favourable for biogeochemical uptake by phytoplankton through absorption/or adsorption phenomena (Ouseph, 1992; Senthilnathan and Balasubramanian, 1994; Sunda and Huntsman, 2000). The heavy river runoff during monsoon and post-monsoon led to decreased salinity considerably which in turn increased the bioavailability of metals by favouring a high absorption/or adsorption of metals on phytoplankton cell surface. This probably led to a high metal enrichment in phytoplankton during monsoon and post-monsoon periods (Gonzalez-Davila, 1995).

Table 5 Correlation analysis of metal concentration in phytoplankton with environmental variables ($p<0.05$)

	Metal concentration in phytoplankton							
Parameters	Ferrous	Nickel	Zinc	Copper	Chromium	Manganese	Cadmium	Lead
Temperature	-0.60	-0.86	-0.59	-0.54	-0.60	-0.70	-0.41	-0.75
pH	0.43**	0.39	0.20	0.51**	0.41**	0.19	0.57**	0.52**
DO	0.21	0.48**	0.52**	-0.03	0.45**	0.68**	0.26	0.43**
Salinity	-0.11	-0.38	-0.39	0.06	-0.21	-0.61	0.12	-0.07
Alkalinity	0.16	-0.20	-0.20	0.23	0.02	-0.40	0.29	0.08
Hardness	-0.01	-0.30	-0.30	0.14	-0.10	-0.50	0.25	0.02

The BCF is used as tool to assess the capacity of aquatic organisms to accumulate chemicals from their environment. The BCF is considered to be significant when it exceeds 100 or more (USEPA, 1991). In the present study, observed value of BCF for selected trace metals in phytoplankton were higher than 100 except for Cd (Figure 2). High values indicate the elevated capacity of phytoplankton to enrich trace metals through different mechanisms directly from the surrounding water (Katarzyna et al., 2005).

Conclusion

The present study revealed seasonal variation of dissolved trace metals both in water and phytoplankton of Cochin backwaters. Trace metal accumulation in phytoplankton during different seasons showed rank in the following decreasing order: monsoon > post-monsoon > pre-monsoon. Significant variation was observed in the distribution of dissolved metals in water and phytoplankton ($p<0.05$). Physico-chemical parameters act as an influent factor for trace metal accumulation in phytoplankton. The concentration of trace metals accumulated in phytoplankton in the present study was many times higher than the dissolved levels of trace metals in Cochin backwaters, which reflects the capacity of phytoplankton to accumulate trace metals and reveals its ability in biomonitoring studies. This will help to improve mitigation measures for environmental policy makers in aquatic habitats.

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