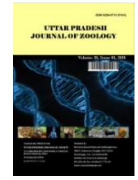
UTTAR PRADESH JOURNAL OF ZOOLOGY

42(6): 53-63, 2021
ISSN: 0256-971X (P)



APPRAISAL OF CLAM BED SEDIMENT QUALITY IN TWO LAKES, A DEEP AND A SHALLOW

M. AMPILI[1*] AND S. K. SHINY[2]

[1]Department of Zoology, N.S.S. Hindu College, Changanacherry, Affiliated to Mahatma Gandhi University, Kottayam, Kerala, India.
[2]S. N. College Chengannur, Affiliated to University of Kerala, India.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between both authors. Author MA designed the study, managed the analyses of the study, performed the statistical analyses, and wrote the manuscript. Author SKS guided the study and corrected the manuscript. Both authors read and approved the final manuscript.

Article Information

Editor(s):
(1) Dr. Angelo Mark P. Walag, University of Science and Technology of Southern Philippines, Philippines.
Reviewers:
(1) Emmanuel Kennedy da Costa Teixeira, Federal University of São João del-Rei, Brazil.
(2) N. Onwuachi-Iheagwara, Delta state university, Nigeria.

Received: 20 January 2021
Accepted: 25 March 2021
Published: 30 March 2021

Original Research Article

ABSTRACT

The study was carried out to assess the sediment parameters of two Lakes, a deep and a shallow, influencing the macrobenthos. A precise knowledge of the substratum is a prerequisite to manage the stock, culture and fishery of the clams. The sediment samples collected from the sampling sites of two Lakes were air dried and used for the analysis of soil parameters *viz.,* soil texture, electrical conductivity, organic carbon, phosphorus, potassium and sediment pH. Sediment texture was analysed following pipette analysis. The sand-silt-clay distribution was determined using shepard-Ternary-Plot. Sediment pH measured using 1:1 soil water paste in Digital pH meter, electrical conductivity was determined by electrometric method using a digital electrical conductivity meter, soil organic carbon was analysed following Walkley-Black method, soil phosphorus estimated following sodium bicarbonate method and Flame photometric method employed for potassium estimation. In all the three seasons, deep Lake exhibited sandy loam sediment texture whereas the upper reaches of shallow Lake exhibited loamy sand texture throughout and its lower reaches depicted sandy loam texture in pre-monsoon and sandy clay loam texture in other two seasons. The sediment composition delineated similar trends in the two Lake. The mean values of various sediment parameters from deep Lake and shallow Lake were recorded. Sediment pH(6.34 ± 1.23 and 6.56 ± 1.25, (t(286)=- 1.462,*P*= .07)), electrical conductivity (5.48 ± 3.79 mS cm-1 and 8.03 ± 4.49 mS cm-1, (t(286) = -5.195, *P*= .0001)), organic carbon(0.57 ± 0.50 % and 0.61 ± 0.41%, (t(286) = -0.634, *P*= .26)), phosphorus (1.14 ± 0.36 mg g-1 and 1.59 ± 1.09 mg g-1, (t(286) = -5.943, *P*= .0001)) and sediment potassium (1.93 ± 1.09 mg g-1and 2.21 ± 0.99 mg g-1, (t (286) = - 2.275, *P*= .01)) respectively. Both the estuarine sediments were fertile with ample amounts of nutrients and microbial activity. The results of the present study endorsed that both the Lakes are ecologically stable.

**Corresponding author: Email: ampilirajeev@gmail.com;*

Keywords: Lake; macrobenthos; sediment profile; sediment nutrients; estuarine; electrical conductivity; organic carbon.

1. INTRODUCTION

Estuarine sediment and water are characterized by specific and complex physical, chemical and microbiological properties. These properties depend on and interact with each other and collectively contribute a unique environment to the organism. In an aquatic ecosystem, sediment acts as the storage reservoir of nutrients. The replenishment of these nutrients in times of need and their consequent removal greatly helps in the biological cycle of the system [1]. Such an exchange of nutrients depends upon the characteristics of the sediment and hydrographic features of the estuary.

The extent of biological activity and indirectly the fertility of the water and also the pollution status of the ecosystem are indicated by the sediment. Organisms exert a profound effect upon sediments in which they live [2]. The main factors that influence the composition of the benthic communities are the substrate particles, sedimentation rate, amount of organic matter, and upwelling currents. In the coastal zones, variations of salinity, temperature, and dissolved oxygen in the water-sediment interface are also important. The most important factors influencing the occurrence and distribution of estuarine invertebrates are shore level, salinity and sediment texture [3]. The nutrient economy of an aquatic ecosystem is mainly governed by the sediment and their interaction with water which in turn determines the productivity and the distribution of macrobenthic organisms. The physico- chemical character of sediment regulates the type of food, feeding and other life activities of benthic forms to a great extent [4].

An understanding of the soil characteristics is a prerequisite for the assessment of the distribution of the macrobenthos especially the clams in the estuary. In the habitat, bivalve species maximises their fitness and survival potential by setting a specific sediment type within the sedimentary system. The apparent preference of benthic species for certain sediment may be due to active or passive post settlement dispersal. To delineate the abundance and distribution of benthic organisms, it is essential to have a comprehensive knowledge on the substratum in which the organisms live.

Several researchers associated spatial heterogeneity of macrobenthos along the estuarine gradient in relation to salinity and sediment composition [5-7]. Sediment is a very important component of a water body as it influences the type of organisms living there [8]. The sediment characteristics like soil pH, organic carbon, phosphorus, potassium along with sediment texture affect the distribution and dynamics of the clams. The replenishment of the nutrients depends on the characteristics of the sediment and the hydrographic features of the estuary [9]. Even though the sediment may not form the active habitat selection criterion [10], it gives a measure of the correlated variables that can influence habitat selection [11]. Sediment type can be indirectly correlated to food availability [12,13]. The sediment acts as an indicator of the biological activity, fertility and pollution status of the ecosystem [14].

Several studies showed the influence of physico-chemical parameters of sediment and overlying water on the vertical distribution of the bivalves [15-22]. Benthic species occur in greater densities at particular sediment grain size, hence, sediment-animal relationships are considered as shortcuts for examining habitat suitability [23-25]. The burrowing bivalves are affected more by the sediment factors than the hydrographic factors. Hence, this study was carried out to identify the parameters such as pH, sediment texture, organic carbon and the nutrients present in the sediment of clam beds. A compendious knowledge of the habitat is a prerequisite for the management of stock and culture practices.

2. MATERIALS AND METHODS

2.1 Sediment Sampling

The random sediment samples were collected from a depth of 20 cm at each sampling point using a Petersen grab dredge. Six sampling sites were fixed from bar-mouth to upper reaches, four samples were collected from each site for two years. Bivalves were separated from sediment samples using 5mm mesh sieve. The soil samples were air dried and used for the analysis of soil parameters.

2.2 Parameters of Sediment Quality

2.2.1 Sediment texture

Sediment texture was analysed following pipette analysis [26]. The sand-silt-clay distribution was determined using Shepard – Ternary- Plot [27].

2.2.2 Sediment pH

1:1 soil-water paste was used for pH determination. Digital pH meter was used for pH measurement.

2.2.3 Electrical conductivity

The electrical conductivity of a soil sample was determined by electrometric method using a digital electrical conductivity meter. A 1:1 soil-water extract was prepared by mixing 20 grams of soil with 20 ml distilled water in a 50 ml shaking bottle. Filtered and electrical conductivity was measured using conductivity meter.

2.2.4 Organic carbon

Soil organic carbon was analysed following Walkley-Black method [28]. 0.5 grams of soil was taken in a 500 ml Erlenmeyer flask, added 10 ml potassium dichromate and 20 ml concentrated sulphuric acid and mixed rapidly and thoroughly for one minute. The mixture was allowed to stand for 20 minutes in a fume cupboard. Diluted with 250 ml distilled water, added10 ml phosphoric acid and allowed to cool. Using O-phenanthroline as indicator titrated with 0.4 N ferrous-ammonium-sulfate. Colour change sharply to green indicates the end point. A blank titration was carried out without soil. The carbon content of the soil was calculated and expressed in percentage.

2.2.5 Phosphorus

Soil phosphorus was estimated following sodium bicarbonate method [29]. 2.5 g of air dried soil was weighed into 150 ml Erlenmeyer flask, 50 ml of Olsen's reagent (0.5 M $NaHCO_3$ Solution, pH8.5) and one teaspoonful of activate charcoal were added. The flasks were shaken for 30 minutes on the electrical shaker and contents filtered immediately through Whatman filter paper (No. 41). 5 ml of the filtrate was pipetted out into 25 ml of volumetric flask and was neutralized with 1:4 H_2SO_4 using paranitrophenol as indicator. The volume was made up by adding distilled water. Colour developed when few crystals of stannous oxalate were added. The solution was shaken well and intensity of blue colour was read in photoelectric calorimeter within 10 minutes at wavelength of 730 to 840 µm. A blank was run without soil. A calibration graph of absorbance against phosphorus concentration was plotted and phosphorus content of the sediment was determined.

2.2.6 Potassium

Flame photometric method was used for the estimation of potassium in the sample soil. Five grams of air-dried sample was taken in 150 ml Erlenmeyer flask and 25 ml of 1 N ammonium acetate was added to the flask. The contents were shaken for 5 minutes on a mechanical shaker and filtered immediately through a dry filter paper (Whatman No.1). The filtrate was collected in a beaker. 5 ml of filtrate was diluted to 25 ml with distilled water. Atomized the above diluted extract to flame photometer and the reading was noted at 768 µm. A curve was prepared by running a series of standards and found out the quantity of potassium contained in the sediment. A blank is aspirated to zero the instrument.

The results were subjected to statistical analyses such as correlation, Analysis of variance (ANOVA), Duncan's Multiple Range Test (DMRT) and Principal Component Analysis (PCA). Student's t-test was employed to analyse the differences in sediment variables between two estuaries.

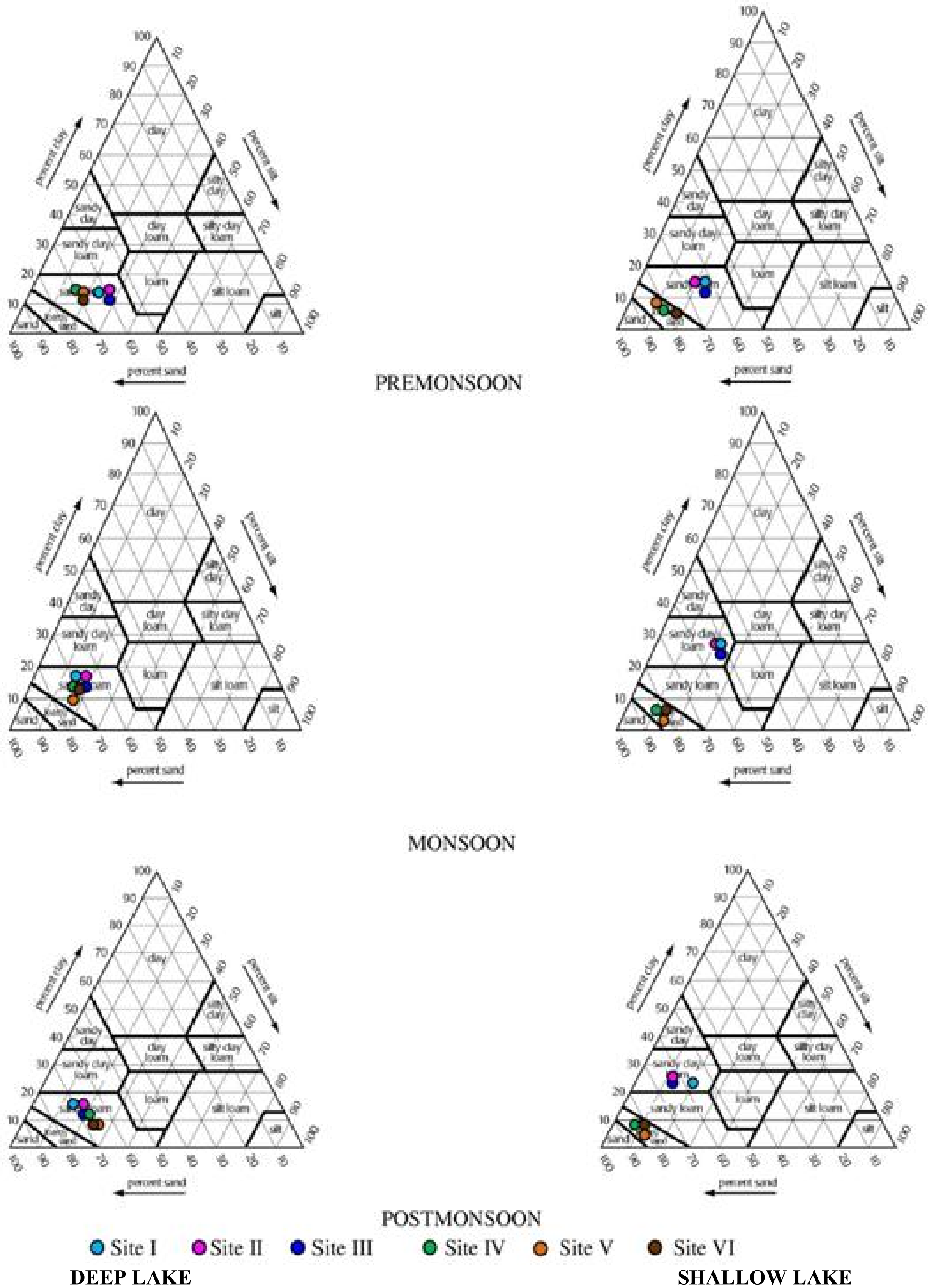
3. RESULTS

Sediment texture: Comparison of two Lake systems.

Differences in percentage of sediment composition in the clam beds of deep Lake and shallow Lake are delineated in (Table 1). No significant differences in the percentages of sediment composition between two estuaries were noticed during the present study. Shepard-Ternary-Plot depicting the sand-silt-clay distribution in the sediment of deep Lake system (AE) and shallow Lake system (KE) is presented in (Fig. 1). In all the three seasons, sediment of sites in deep Lake exhibited sandy loam texture. In shallow Lake loamy sand texture was exhibited by sites of the upper reaches in all the three seasons and sites of lower reaches depicted sandy loam texture in the pre-monsoon and sandy clay loam texture in other two seasons.

Table 1. Variation in mean values of sediment textural composition (%) in Deep Lake (AE) and Shallow Lake (KE) during the study period

Variables	Location	Mean	SD	Mean difference	t - value	df	*P* - value
Sand (%)	AE	68.58	9.92	-1.21	-0.82	286	.206
	KE	69.79	14.73				
Silt (%)	AE	16.47	8.66	0.39	0.40	286	.344
	KE	16.08	8.03				
Clay (%)	AE	14.94	5.65	0.81	0.92	286	.179
	KE	14.13	8.99				



Sites I-III Lower reaches of Lake system
Sites IV-VI Upper reaches of Lake system

Fig. 1. Shepard-Ternary-Plot depicting the sand-silt-clay distribution in the sediment

Sediment variables: Comparison of two Lake systems.

Variations in the mean values of the sediment variables *viz.*, pH, electrical conductivity, organic carbon, phosphorus, potassium in the deep Lake and shallow Lake during the study period are presented in (Fig. 2). The mean values of sediment pH recorded from the deep Lake and shallow Lake were 6.34 ± 1.23 and 6.56 ± 1.25 respectively. The statistical analysis showed that the differences in mean values of sediment pH between the Lakes were not significant (t(286)=- 1.462,*P*= .07). The mean value of sediment electrical conductivity recorded from the deep Lake and shallow Lake were 5.48 ± 3.79 mS cm-1 and 8.03 ± 4.49 mS cm-1 respectively. It was observed that the mean values of electrical conductivity of deep Lake had significant variation when compared to the mean value of shallow Lake (t(286) = -5.195, *P*= .0001). The mean values of organic carbon recorded in the deep Lake and shallow Lake were 0.57 ± 0.50 % and 0.61 ± 0.41% respectively. The variations in mean values between the estuaries were not significant (t(286) = -0.634, *P*= .26). The mean value of phosphorus recorded from the deep Lake was 1.14 ± 0.36 mg g-1 and that of shallow Lake was 1.59 ± 1.09 mg g-1. The mean values of nutrient phosphorus of deep Lake had significant statistical difference when compared to the mean value of shallow Lake (t(286) = -5.943, *P*= .0001). The mean value of sediment potassium recorded from the deep Lake was 1.93 ± 1.09 mg g-1and that of shallow Lake was 2.21 ± 0.99 mg g-1. It was observed that the mean values of sediment potassium of deep Lake had statistically significant variation when compared to the mean value of shallow Lake (t (286) = - 2.275, *P*= .011).

4. DISCUSSION

Sediments constitute a major controlling factor in the ecology of estuaries. Sediments may accumulate contaminants in concentrations higher than those observed in the water column, producing negative effects to the benthic biota and to the organisms that feed on the benthos or on the sediment. According to [8] the sediment is a very important component of water body as it influences the type of organisms living there. The morphology, feeding and dominance patterns of benthic species are a function of the substratum type [30]. In addition, the ecological relationships among the benthos are pivoted on the characteristics of the estuarine sediments. Since sediment indicates the extent of biological activity and indirectly the quality of the overlying water, and the distribution of benthic organisms, an extensive knowledge on the sediment physico-chemical

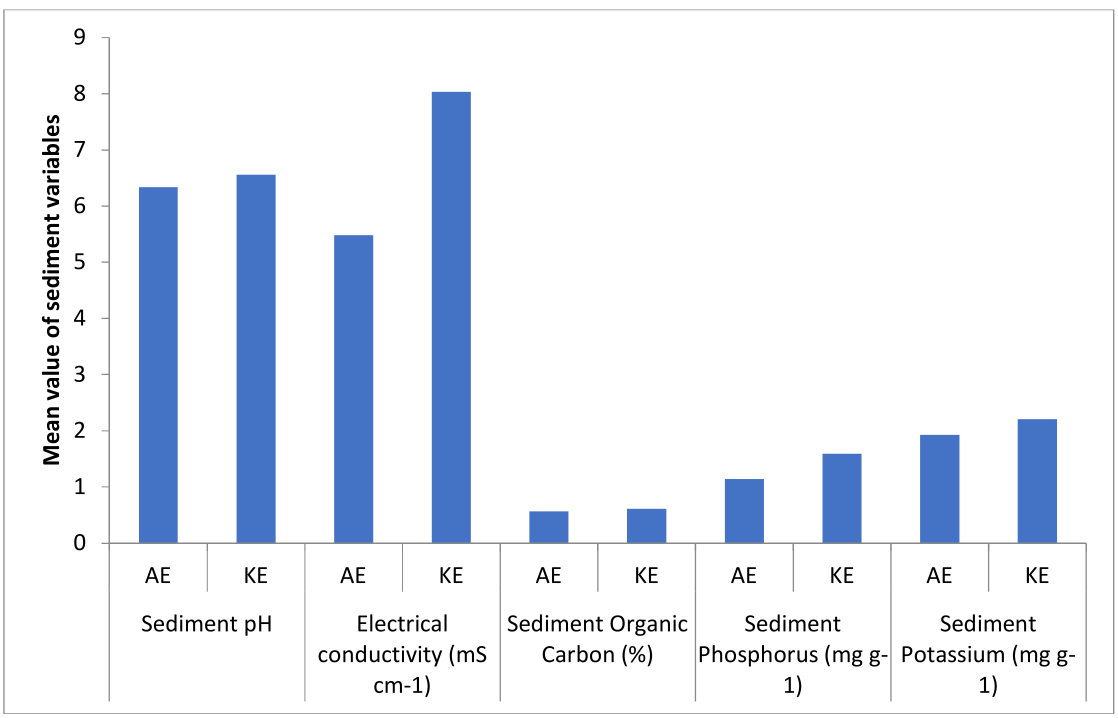


Fig. 2. Variation in mean values of sediment variables in Deep Lake (AE) and Shallow Lake (KE) during the study period

characteristic is highly essential to delineate the abundance and distribution of clams in the estuary. Textural characteristics of estuarine sediments are strongly influenced by several factors, including source area composition of adjacent lands, climate, length and energy of sediment transport, redox conditions in the depositional environments [31,32].

The sediment distribution in estuaries and near shore regions depends to a large extent on the source and texture of the sediment supplied and topographic features of the concerned area [33]. The sediment within the estuary is usually quite different from the adjacent sea and river. The textural characteristics of sediments play a significant role in the distribution and concentration of carbon, nitrogen and phosphorus, both in the sediment and overlying water column.

In the present study, sediment contained larger fractions of sand than silt and clay in both the estuaries studied, irrespective of the seasons. Similar results were reported by [34] from Adayar, Cooum and Ennore backwaters and [35] from Vellar estuary. High sand fraction in the Ashtamudi sediment was reported earlier by [36] and in Kayamkulam Lake by [37]. Higher percentage of sand than other finer particles in the sediment during the monsoon could be ascribed to the flushing of fine materials from estuarine region to the sea. The different combinations of sediment observed are mainly due to the transport of sediment from one place to another. The perusal of data on the sediment texture in the present study revealed that the most predominant fractions are sand followed by silt and clay in both the estuaries.

pH of the sediment is known to control biogenic and abiogenic reactions and has a direct influence on the sediment nutrient status as well as the conditions of overlying water. The vertical concentration gradient of ions in water, which controls the benthic communities, is closely related to pH [38]. In the present study, the sediment pH remained predominantly acidic throughout the study period. The soil pH showed higher values during the pre-monsoon and lower values during the monsoon in both the estuaries. Similar observation was reported by [39] from Ashtamudi Lake and [34] from Adayar estuary. All the observed sites of deep Lake exhibited an acidic pH throughout the study period whereas the sites near the bar mouth of the shallow Lake was alkaline in the pre-monsoon and during the remaining season they also exhibited an acidic pH. The drastic physico -chemical conditions brought in by the monsoon might have caused severe damages to the clam beds of the estuary especially in the bar mouth region. The decomposition of these dead clams may be a cause for the reduction of the sediment pH.

Researchers such as [40,41,36] noted the sediment pH of Ashtamudi Lake as 3.4 to 6.1 and 4.9 to 6.7 and 2.9 to 7.3 respectively. Lowering of pH may be due to exposure of relatively higher acidic subsurface basin soil as a consequence of monsoon turbulence and bottom currents [42] or the increasing organic pollution in the estuary [43].

Electrical conductivity (EC) expresses ion contents of solution. Conductivity gives a clear idea of the soluble salts present in the soil, as it is the measure of current carrying capacity. Soil electrical conductivity is a measurement that correlates with properties of soil *viz.*, texture, cation exchange capacity, organic matter level, salinity and sub soil characteristics. The electrical conductivity is a good indication of the amount of nutrients available in the sediment. Higher electrical conductivity values indicate higher amount of nutrients in the sediment. A good soil electrical conductivity will be between 0.2 mS cm-1 and 1.2 mS cm-1. Any soil below 0.2 mS cm-1 indicates that there are not enough nutrients available or the soil is sterile with little microbial activity. An electrical conductivity above 1.2 mS cm-1 indicates much high salts or increased salinity. Electrical conductivity increases as microbes are releasing more nutrients from soil. Thus electrical conductivity provides a very rapid means of obtaining a good estimate of total dissolved solid concentration and salinity. As salinity increases electrical conductivity also increases [44].

Electrical conductivity values were higher in the post-monsoon and pre-monsoon periods than the monsoon period in both the estuaries in the present study. The lowering of electrical conductivity during monsoon may be due to dilution of soil water by rain water. [45] opined that the decrease in salinity in the monsoon may be due to the leaching of salt ions as a result of precipitation. In both the study areas, electrical conductivity values were higher in the sites near the bar mouth than the upper reaches of the estuary. This might be due to the intrusion of saline water from the sea. According to [46] low electrical conductivity values of soil is an indication of less soil contamination since the presence of organic matter and other pollutants increases soil resistivity.

Organic carbon content in the sediment is derived from the primary production within the water body and also terrigenous run off [47]. The organic carbon provides the main energy source for heterotrophic organisms in the aquatic sediments [48]. An understanding of the organic carbon distribution and its impacts on other physico-chemical and biological parameters is a pre requisite for nutrient input and biological transformation of major and minor element of the system. While studying the vertical and horizontal distribution pattern of organic carbon in the mangrove sediment of Cochin, [49] reported that the organic carbon concentration increased as particle size of sediment decreased. He was of the opinion that the total organic carbon content in the sediment has a major role in keeping the fertility of the soil and thereby flourishing the biota. According to [50] the sediment organic content, instead of showing a general pattern, varied from station to station depending on the nature of soil texture and hydrological condition. Increased organic carbon is associated with clay and silt sediments and high rate of sedimentation. An abundant supply of organic matter in water column and low oxygen content of water immediately above the bottom sediments would favour high organic carbon content in the bottom sediment [51].

In the present study, in shallow Lake, lower and higher values of organic carbon were observed in the monsoon and pre-monsoon respectively. During these seasons, the sites near the bar mouth recorded relatively low percentage of organic carbon. This might be due to constant flushing activity of tides along with the impact of waves, which remove the finer fraction of the sediment from the fringing area. Further, the sediment was mainly composed of sand brought in by incessant flow of fresh water during monsoon [52]. While the lower values of the upper reaches of deep Lake can be attributed to the coarse sand particles of the sites. In the present study, the high organic carbon content during post monsoon can be ascribed to the fine nature of the sediment (clayey and silty sediment) and high rate of sedimentation [53] and decomposition of organic matter in the area as opined by [54]. The increase in the organic carbon in the post-monsoon, recorded in the present study, may be due to heavy mortality of clams in the area due to the impact of monsoon. [55,56] were of the same opinion that the high nutrient loads in non-monsoon might be due to the decomposition of organic matter trapped in mud. The fluctuations of the organic carbon in the deep Lake may be attributed to various reasons like temperature variations, nature of vegetation, rate of accumulation of dead and decaying plant and animal matter, topography, soil texture and water depth. [37] also observed similar conditions in Kayamkulam Lake, a shallow Lake and they opined that the variations in organic carbon in the estuary may be due to variations in the sediment texture. [57] in Vellar estuary observed that low values of organic carbon were associated with sandy sediment. This finding is in agreement with the present study too. Highly significant negative correlation was observed between organic carbon and sand particles in deep Lake.

In shallow Lake lower values of organic carbon was obtained in the sites of upper reaches where sand particles predominated. Distribution of total organic carbon closely followed the distribution of sediment type viz., sediment low in clay content was low in organic carbon and as the clay content increased, the total organic carbon also increased [58,59]. [60] reported a maximum organic carbon value in Kollam region of Ashtamudi estuary. A relatively low percentage of organic carbon was delineated by [36] in lower reaches of Ashtamudi Lake. Similar trends were reflected in present study too in deep Lake.

Phosphorus is one of the crucial nutrients having a strong bearing on the physical, chemical and biological processes operating in the aquatic environments. The increased loading of phosphorus can damage the functioning of the system as it leads to eutrophication. The increase in phosphorus in the coastal and estuarine sediments has earlier been reported by [61]. The particle size exerts a control in phosphorus distribution in sediments. Phosphorus adsorption increases with decreasing grain size [62], and as a result smaller sediment particles such as silt show more phosphorus content. The dominant role in the adsorption of phosphorus by estuarine silts in sediment is also reported by [63]. The capacity of sediment to retain or release phosphorus is one of the important factors, which influence the concentration of phosphorus in the overlying water. Detritus is the main source of phosphorus in the sediment. Phosphorus bounded by the shells of clams is released into the sediment due to the death of clams. The lower value of phosphorus in the monsoon was attributed to the leaching of phosphorus to the overlying water [64].

In the present study, phosphorus content was lowest during pre-monsoon and its concentration increased in monsoon and reached maximum in post monsoon. Same trend was exhibited by both the estuaries for phosphorus concentration. But the variations in phosphorus content between the two estuaries were significant. There was significant variation in phosphorus content between sites in deep Lake. The sediment with fine grain size of lower reaches showed more phosphorus content than the upper stretches with large grain size. The increase in phosphorus content may be due to rain fall and land run off [65,66]. The findings of the present study were affirmed by these earlier research findings. The increased phosphorus content in monsoon and post-monsoon might be due to the effect of south west monsoon and north east monsoon respectively. The increased phosphorus content may be due to the dead organic matter settling in the sediment and the decreased values may be due to the removal of top layer of sediment by flood and sand deposition. Further, it was evidenced by the positive correlation between organic carbon and phosphorus in both the estuaries. [67] observed similar phosphorus level in Ashtamudi estuary. Studies of [68] have reported high phosphorus concentration in mud collected from Vembanad Lake during north east monsoon. Higher phosphorus content was observed by [69] in sediment of Vellar estuary during monsoon and lower during late summer. High phosphorus in clayey-silt type sediments in Mandovi estuary was reported by [70].

Potassium is a dietary requirement of all organisms. It is highly essential for many physiological functions. Potassium from dead flora and fauna is often bound to clay minerals in sediment, before it dissolves in water. Potassium recorded lowest values in both the estuaries in post monsoon. Towards the pre-monsoon the values of potassium gradually increased in both the estuaries. During the monsoon the potassium values decreased in the deep Lake. But in the shallow Lake the maximum value of potassium was recorded in the monsoon in all sites. The lower values of monsoon may be due to dilution of estuarine water by rain water. Higher values of pre-monsoon may be due to decay of vegetation, liberating potassium. Observation of [71] on the distributions of potassium in Ashtamudi Lake underpins the findings of the present study.

5. CONCLUSION

Estuarine ecosystems are highly productive systems that are subject to seasonal and daily fluctuations in a variety of physico-chemical parameters. Sediment, together with the overlying water determines the ecology of the estuary, of this sediment being the prime factor since the physico-chemical properties of the overlying water is greatly influenced by the soil. In both the estuaries studied, viz. deep Lake and shallow Lake, sediment contained large fraction of sand than silt and clay. The differed combinations of sand observed are mainly due to the transport of sediment from one place to another under the influence of monsoon.

In both the Lakes, the sediment pH remained predominantly acidic throughout the study period. The soil electrical conductivity showed that both estuarine sediments were fertile with ample amounts of nutrients and microbial activity. In both the estuaries, the organic carbon values were low owing to the predominance of sand in the substratum. The nutrient economy of the aquatic ecosystem was known to be governed by the sediment nutrient level. On comparing the sediment nutrient profiles of the two Lakes, it was evinced that the shallow Lake was rich in nutrients than the deep Lake. From the results of the present study, it can be concluded that both the Lakes are ecologically stable. Some paradoxical results obtained from the shallow Lake might be due to the shallowness of the estuary, when compared to the deep Lake.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Gupta BP, Krishnan KK, Joseph KG, Muralidhar M, Ali, S., Gopal C. Soil and water characterestics and growth of Penaeus monodon fed with formulated feed in experimental tanks. Indian Journal of Fisheries. 2001;48(4):345-351.
2. Sanders HL. Benthic studies in Buzzards Bay. Animal-sediment relationships. Limnology and Oceanography. 1958;3:245-258.
3. Green J. The Biology of Estuarine Animals. Sidgwick and Jackson, London. 1968;401.
4. Ramachandra UT, Gupta RC, Katti RJ. Macrobenthos and sediment characterestics of Mulki estuary, West coast of India. Indian Journal of Marine Sciences. 1984;13:109-112.
5. Mannino A, Montagna PA. Small-scale spatial variation in macrobenthic community structure. Estuaries. 1997;20:159-173.
6. Ysebaert T, Meire P, Coosen J, Essink K. Zonation of intertidal macrobenthos in the estuaries of Schelde and Ems. Aquatic Ecology. 1998;32:53-71.
7. Stolyarov AP. Some features of the macrobenthos community structure in estuary ecosystems (Kandalaksha Bay, the White Sea). Biology Bullettin Reviews. 2013;3(6):505-521.
8. Ouyang Y, Zhang JE, Ou LT. Temporal and spatial distribution of total organic carbon in an estuary river. Journal of Environmental Quality. 2006;35:93-10.
9. Pomeroy LR, Smith EE, Grant CM. The exchange of phosphate between estuarine waters and sediments. Limnology and Oceanography. 1965;10:167-172.
10. Huxham M, Richards M. Can postlarval bivalves select sediment type during settlement? A field test with *Macoma balthica* (L.) and *Cerastoderma edule* (L.). Journal of Experimental Marine Biology and Ecology. 2003;288:279-293.
11. Snelgrove PVR, Butman CA. Animal-sediment relationships revisited: Cause versus effect. Oceanography and Marine Biology-An Annual Review. 1994;32(1):111-177.

12. Levinton JS. Ecology of deposit-feeding animals in marine sediment. Quarterly Review of Biology. 1987;62:235-259.
13. Underwood GJC, Kromkamp J. Primary production by phytoplankton and microphytobenthos in estuaries. Advances in Ecological Reaserch. 1999;29:93-153.
14. Alagarswamy R. Organic carbon in the sediments of Mandovi estuary, Goa. Indian Journal of Marine Science. 1991;20: 221-222.
15. Rajasekar KT, Peramal P, Santhanam P. Phytoplankton diversity in the Coleroon estuary, Southeast coast of India. Journal of the Marine Biological Association of India. 2005;47:127-132.
16. Sridhar R, Thangaradjou T, Kumar SS, Kannan L. Water quality and phytoplankton characteristics in the Palk Bay, South east coast of India. Journal of Environmental Biology. 2006;27:561-566.
17. Anilakumary KS, Azis APK, Natarajan P. Water quality of the Adimalathma estuary, South west coast of India. Journal of the Marine Biological Association of India. 2007;49:1-6.
18. Raja P, Amarnath AM, Elangovan R, Palanivel M. Evaluation of physical and chemical parameters of River Kaveri, Tiruchirappalli, Tamil Nadu, India. Journal of Environmental Biology. 2008;29(5):765-768.
19. Pradhan UK, Shirodkar PV, Shahu BK. Physico-chemical characteristics of the coastal water off Devi estuary, Orissa and evaluation of its seasonal changes using chemometric techniques. Current Science. 2009;96(9):1203-1209.
20. Srivastava N, Harit G, Srivastava R. A study of physico-chemical characteristics of Lakes around Jaipur, India. Journal of Environmental Biology. 2009;30(5):889-894.
21. Damotharan P, Perumal NV, Perumal P. Seasonal variation of physico-chemical characteristics of Point Calimere coastal waters (South east coast of India). Middle-East Journal of Science Research. 2010;6(4):333-339.
22. Prasanna MB, Ranjan PC. Physicochemical properties of water collected from Dhamra Estuary, International Journal Environmental Science. 2010;1(2):95-100.
23. Wolff WJ. Estuarine benthos. In: Ecosystems o f the World, Estuaries and Enclosed Seas. Ketchum BH. (Ed.). Amsterdam, Elsevier, 1983;26:337-374.
24. Thrush SF, Hewitt JE, Norkko A, Nichollas PE, Funnell GA, et al. Habitat change in estuaries: predicting broad–scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progressive Series, 2003;263: 101-112.
25. Ellis J, Ysebaert T, Hume T, Norkko A, Bult T, Herman P, et al. Predicting macrofaunal species distributions in estuarine gradients using logistic regression and classification systems. Marine Ecology Progressive Series. 2006;316:69-83.
26. Krumbein WC, Pettijohn FJ. Manual of Sedimentary Petrography Appleton Century Crofts, New York. 1938;25:521–537.
27. Shepard FP. Nomenclature based on sand-silt-clay ratios: Journal of Sediment Petrology. 1954;24:151.
28. Walkley A, Black IA. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Science. 1934;63:251-263.
29. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U. S. Department of Agriculture Circular. 1954;939.
30. Kennish MJ. Ecology of Estuaries: Physical and Chemical Aspects. Boca Raton, USA: CRC Press. 1986;391.
31. Bhatia MR, Cook KAW. Trace element characteristics of Graywackes and tectonicsetting discrimination of sedimentary basins. Contribution of Mineralogy and Petrology. 1986;92:181–193.
32. Fralick PW, Kronberg BI. Geochemical discrimination of clastic sedimentary rock sources. Sedimentary Geology. 1997;113: 111–124.
33. Sesamal SK, Sahu BK, Panigrahy RC. Texture and composition of sediments of Hooghly estuary and near shore environment. Indian Journal of Marine Sciences. 1986;15: 201-202.
34. Selvam V, Mohan R, Ramasubramanian R, Azariah JA. Plant communities and soil properties of three mangrove stands of Madras coast. Indian Journal of Marine Sciences. 1991;20:67-69.
35. Rajasegar M, Srinivasan M, Ajmal Khan S. Distribution of sediment nutrients of Vellar estuary in relation to shrimp farming.Indian Journal of Marine Science. 2002;31(2):153-156.
36. Soumya W, Radhakrishnan T, Radhakrishnan S. Sediment characteristics along the Ashtamudi Estuarine System. International Journal of Biological Technology. 2011; 2(3):11-16.

37. Srinivas R, Sajan K. Significance of textural analysis in the sediments of Kayamkulam Lake, Southwest coast of India. Indian Journal of Marine Sciences. 2010;39(1):92-99.
38. Banerjea SM. Water quality and Soil condition of fish ponds in some state of India in relation to fish production. Indian Journal of Fisheries. 1967;14:115-144.
39. Devendran K, Maya K, Natarajan P. Studies on microbial ecology of South West Coast of India. Proceedings of National Seminar on Estuarine Management, Trivandrum. 1987;425-432.
40. Bhadran G. Heavy metal pollution in ashtamudi estuarine system. PhD. Thesis, University of Kerala, India; 1997.
41. Vishnu SR. Comparative Study of the Hydrology of Clean and Polluted Regions of Ashtamudi Lake Adjoining Kollam Bus Station. M. Phil. Dissertation, University of Kerala, India; 2005.
42. Unnithan VK, Nandan BS, Vava CK. Ecology and fisheries investigation in Vembanad Lake. CIFRI Publication, Barrackpore. 2001; 15-23.
43. Remani KN, Venugopal P, Saraladevi K, Unnithan RV. Organic matter in sediments from Cochin backwaters. Indian Journal of Marine Sciences.1981;10:44-48.
44. Richards LA. Diagnosis and improvement of saline and alkali Soils, U. S. Department of Agriculture Handbook, Washington D. C., USA. 1954;60:160.
45. Chandrasekar KR, Sandhyarani S. Salinity induced chemical changes in Crotalaria striata DC. Plants. Indian Journal of Plant Physiology. 1996;1:44–48.
46. Asadi SS, Azeem S, Prasad AVS, Anji RM. Analysis and mapping of soil quality in Khandaleru catchment area using remote sensing and GIS. Current Science. 2008; 95(3):391-396.
47. Likens GE. Nutrients and eutrophication. Special symposium American Society of Limnology and Oceanography, Allen Press, Lawrence. 1972;1:328.
48. Hakanson L, Jansson M. Lake Sedimentology. Springer Verlags, Berlin. 1983;316.
49. SunilKumar R. Distribution of organic carbon in the sediment of Cochin Mangroves, South west coast of India. Indian Journal of Marine Sciences. 1996;25:56-61.
50. Santhosh S. Hydrogeochemistry of Paravur-Kappil backwaters with special reference on phytoplankton. PhD. Thesis. Department of Environmental Sciences. University of Kerala; 2002.
51. Sverdrup V, Johnson MW, Fleming RH. The oceans, their physics, chemistry and general biology. Prentice Hall, New York. 1942;1087.
52. Bragadeeswaran S, Rajasegar M, Srinivasan M, Knakarajan U. Sediment texture and nutrients of Arasalar estuary, Karaikkal, Southeast coast of India. Journal of Environmental Biology. 2007;28:237-240.
53. Reghunath R, Murthy STR. Carbonate and organic matter studies of the shelf of Kasargod, west coast of India. Indian Journal of Marine Sciences. 1996;25:355-357.
54. Ramanathan AL. Sediment characteristics of the Pichavaram mangrove environment, Southeast coast of India. Indian Journal of Marine Sciences. 1997;26:319-322.
55. Babu NK, Omana PK, Mohan M. Water and sediment quality of Ashtamudi estuary, a Ramsar site, Southwest coast of India-a statistical appraisal. Environment Monitoring Assessment. 2010;165:307-319.
56. Singh KP, Malik A, Sinha S. Water quality assessment and apportionment of pollution sources of Gomti River (India) using multivariate statistical techniques-a case study. Analytica Chimica Acta. 2005;538:355–374.
    DOI: 10.1016/j.aca.2005.02.006
57. Shanmukhappa H. Organic matter and C:N:P in sediments of Porto Novo. Proceedings of National Seminar on Estuarine Mangroves. Trivandrum. 1987;128-133.
58. Gray JS. The ecology of marine sediments. An introduction to the structure and function add the shallow sublittoral benthos. Cambridge University Press, Cambridge, UK. 1981;185.
59. Reddy VHR, Hariharan V. Distribution of nutrients in the sediments of the Netravathi-Gurupur estuary, Mangalore. Indian Journal of Fisheries. 1986;33:123-126.
60. Thomas G. Comparative Studies on the Ecobiology of Three Mangrove Communities along the Backwater Systems of Kerala. Ph.D Thesis, University of Kerala, India; 1995.
61. Sankaranarayanan VN, Panampunnayil S. Studies on organic carbon, Nitrogen and phosphorous in sediment of Cochin backwater. Indian Journal of Marine Sciences. 1979;8:27-30.
62. Aston SR, Hewitt CN. Phosphorus and carbon distribution in a polluted coastal environment. Estuarine and Coastal Marine Science. 1977;5:243-254.
63. Jitts HR. The absorption of phosphate of estuarine bottom deposits. Australian Journal of Marine and Freshwater Research. 1959;10: 7–21.

64. Nasnolkar CM, Shirodhar PV, Singbal SYS. Studies on the organic carbon, nitrogen and Phosphorous in the sediment of Mandovi estuary, Goa. Indian Journal of Marine Science. 1996;2:120-144.
65. Callender E, Hammond DE. Nutrient exchange across the sediment-water interface in the Potomac River estuary. Estuarine, Coastal and Shelf Science. 1982;15:395-413.
66. Fox LE, Sager SL, Wofsy SC. Factors controlling the concentrations of soluble phosphorus in the Mississippi Estuary. Limnology and Oceanography. 1985;30:826-832.
67. Nair NB, Arunachalam M, Abdul Azis PK, Krishnakumar K, Dharmaraj K. Ecology of Indian estuaries. Part 1: Physiochemical features water and sediment nutrients of Ashtamudi estuary. Indian Journal of Marine Sciences. 1983;12:143-150.
68. Murthy PSN, Veerayya M. Studies on the sediments in Vembanad Lake, Kerala State: Part I, Distribution of Organic Matter. Indian Journal of Marine Sciences. 1972;1:45-48.
69. Sivakumar V, Thangaraj GS, Chandran R, Ramamoorthi K. Seasonal variations in carbon, nitrogen and phosphorus in sediments of the Vellar estuary. Mahasagar National Institute of Oceanography. 1983;16: 175-181.
70. Rajagopal MD, Reddy CVG. Phosphorus Retention Capacity of Sediments in Mandovi Estuary (Goa). Indian Journal of Marine Sciences. 1984;13:1-4.
71. Nair NB, Abdul Azis PK, Arunachalam M, Dharmaraj K, Krishnakumar K. Ecology of Indian estuaries: Ecology and distribution of benthic macrofauna in the Ashtamudi estuary, Kerala, Mahasagar. 1984;17:89-101.