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ORIGINAL ARTICLE

# Sediment distribution pattern and environmental implications of physico-chemical characteristics of the Akkulam-Veli Lake, South India

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**Abstract**

This study reports the spatial distributions of diatom assemblages and potential relationships between diatom diversity and environmental variables (C/N ratio, $CaCO_3$%, clay mineralogy) using multivariate analyses in surface sediments of the Akkulam-Veli Lake. Surface sediment samples were collected at 19 sites throughout the lake to analyse diatom distribution, TOC, N, $CaCO_3$%, clay mineralogy and sediment texture. The results suggest that the clay fraction is predominant in the eastern flank, whereas sand fraction is more in the western flank. TOC% and $CaCO_3$% in the lake floor sediments are attributed to high organic activity within the lake and contributions from the vegetation around the lake margins. The results suggest that N is being added to the lake from secondary sources from catchment area leading to eutrophication of the lake. Further, clay mineralogy of the sediment samples reveals that kaolinite mineralogy dominates in clay fractions. Diatom studies show rich diversity of freshwater, marine and brackish diatoms and abundance of pollution-reflecting species such as *Cyclotella* sp. and *Navicula* sp.

**Keywords** Diatoms · Total organic carbon · Eutrophication · Limnology · Clay mineralogy

## Introduction

Fluvial transport of sediments incorporates both internal and external materials into lake basins, and such transported material could preserve important environmental information about lakes and their catchments (Liu et al. 2017; Meyers 2003). Physical and chemical compositions of sediment being deposited in lake basins are cumulatively influenced by catchment lithology, climate, weathering and erosion processes, and thus, lake sediments provide an imperative archive to study the past and present environmental changes (Lone et al. 2018a). Sedimentation in lake basins forms a distinct depositional pattern resulted due to differential hydrological regimes, physical and chemical weathering of catchment rocks and sediment transportation and deposition through multiple waterways (Vijayaraj and Achyuthan 2015). Lake sediments play a significant role in controlling the organic matter (OM) concentrations in aquatic environments, as they are one of the major repositories of OM (Hou et al. 2014; Lone et al. 2018b). Lake surface sediments also contribute nutrients to the water column above them and thus lead to benthic–pelagic coupling and influence primary productivity in aquatic systems. The lake sediments can also store large amounts of OM and affect the oxygen content of bottom water (Anderson et al. 2013; Meyers and Ishiwatari 1993). OM and organic carbon in lake basins are mainly derived from the particulate detritus of plants, and only a small per cent is contributed from the animal tissue (Meyers and Lallier-Verges 1999). Within aquatic ecosystems, surface sediments have an important function as an efficient natural trap for diverse substances (including contaminants)

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and also as a natural regulator of the processes that occur in the lake floor (Jorgensen 1996).

Morphological parameters, such as bathymetry, volume, land-use and land-cover pattern around the lake catchment, significantly influence nutrient concentrations or eutrophication status of a lake basins (Silvino and Barbosa 2015). Total organic carbon (TOC), nitrogen (N) and phosphorus (P) as nutrients play a vital role in maintaining and defining the tropic status in different lacustrine environments (Meyers and Ishiwatari 1993; Meyers and Lallier-Verges 1999). The ratio of TOC to N (C/N ratio) has been widely used as an indicator of the source of OM in sediments (Meyers and Lallier-Verges 1999; Lone et al. 2018c). Nutrient concentration (mainly N, P and TOC) derived from either terrestrial source or autochthonous source is the major factor resulting in widespread degradation of ecological structure and function of lake ecosystems (Saluja and Garg 2017). Lake ecosystems are strongly influenced by dissolved organic matter, autochthonous flora and fauna and terrestrial vegetation and pollutant inputs derived from the catchment areas (Solomon et al. 2015). However, terrestrial inputs into the lake basins have accelerated substantially in recent decades as a result of increasing anthropogenic influences.

Diatom investigation is an essential proxy to study spatial and temporal environmental changes in lake basins, as this diverse and ecologically important phytoplankton groups can withstand widespread changes in environmental conditions such as pH, nutrients, organic pollution, acidity and salinity (Ramanibai and Ravichandran 2013; Shah et al. 2017; Babeesh et al. 2019). Owing to the sensitivity to pollution and other changes, diatom assemblages have now been widely used as a proxy for environmental monitoring assessment and they also reflect the relative eutrophic condition and organic pollution level in lake basins (Shah et al. 2017). The modern distribution and ecological relationships of diatoms can be used to interpret the environment in which the fossils of these organisms were once thriving. Increasing anthropogenic impact has polluted freshwater ecosystems due to overexploitation associated with environmental changes. Investigations on the spatial distributions of diatom assemblages in lake surface sediments and on the factors controlling diatom diversity could help in inferring the modern eutrophication status of the lake basins (Wang et al. 2015).

Lake sediments always contain certain levels of organic elements due to natural processes, but excessive loading of such elements above natural standard levels results in pollution and a threat to the lake environment (Ekengele et al. 2017). Over the recent past, climate coupled with environmental variations due to anthropogenic activities has become an important controlling factor affecting the lake ecosystems. As a result of these changes, lake ecosystems have experienced significant degradation due to human activities performed in the context of overpopulation, overexploitation and development. Thus, understanding of spatial concentrations and variation in organic nutrients and diatom diversity allows for the identification of appropriate remedial measures for ecosystem restoration.

Akkulam-Veli Lake faces severe problems of siltation, nutrient loading and surface pollutants from diverse catchment sources (Sajinkumar et al. 2017; Sheela et al. 2012, 2013; Navami and Jaya 2013; Abhijna and Biju 2015). Sustainable management of this lake requires reliable data and information regarding the present environmental conditions prevailing within the lake. Till date, no data on the organic elements from the lake surface sediments have been presented. Further, the key factors involving the sources and distribution of OM, and diatom diversity is also lacking from this ecologically important lake environment. Specifically, the objectives of the study were to understand the spatial distribution of diatom assemblages, C/N ratio, clay minerals and source of OM and $CaCO_3$ in order to have a preliminary knowledge of the present environmental status of the lake basin.

## Study area

The Akkulam-Veli Lake (Fig. 1a, b) (8°25′ N–8°35′N; 76°50′ E–76°58′E) is located on east cost of the Arabian sea in Kerala state of southern India. It is a medium-sized (3.2 km long) lake with an area of around 1 $km^2$ and an average depth of ~4 m. Due to its location along the path of the southwest monsoons, this area receives first showers of monsoon rains during early June and it also receives precipitation in October caused by northeast monsoons. This area records an average air temperature of 26.6 °C and an annual average rainfall of 1774 mm (Data source: https://en.climate-data.org/asia/india/kerala/thiruvananthapuram-2783/). The catchment area of the Akkulam-Veli lake basin is dominated by tropical humid climate with copious precipitation, and such climate supports strong physical and chemical weathering, thus resulting in alteration of catchment lithology.

The lake is separated from the Arabian Sea by a sand bar, which is usually open during monsoon season (Sajinkumar et al. 2017). The surroundings of the lake are composed of laterite hillocks and tertiary sediments (Sheela et al. 2012), and the catchment area of the lake is a part of Kerala Khondalite Belt (KKB) characterized by the presence of khondalites and charnockites (Sajinkumar et al. 2017). The major rock types around the lake basin are garnetiferous biotite, garnet–biotite gneiss with migmatite, coastal sand and alluvium, sandstone and clay.

Water to the Akkulam-Veli lake basin is contributed by three stream inlets (Amayizhanchan Thodu River, Parvathi Puthan channel and Parvathy Puthanaar channel).

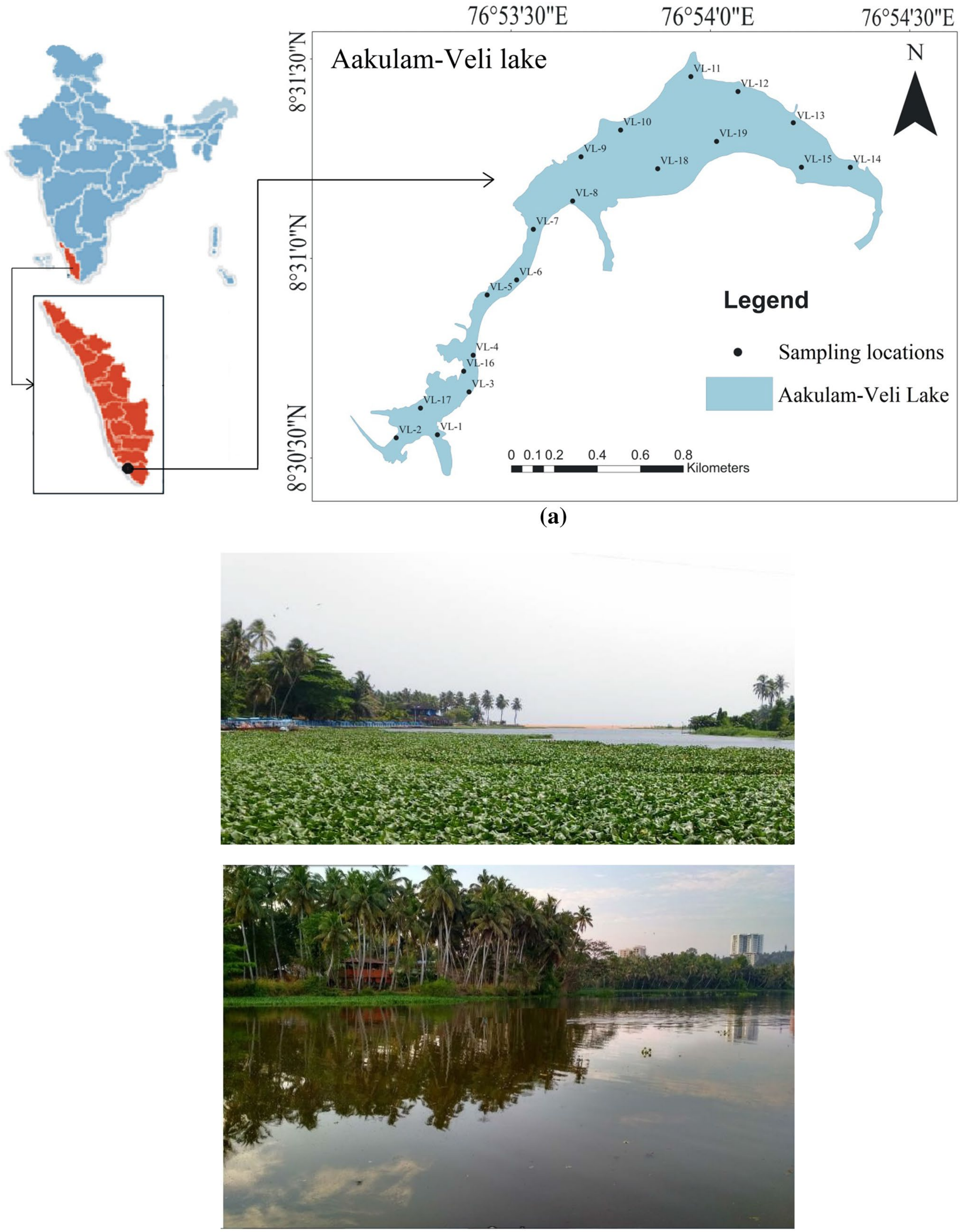


**Fig. 1** **a** Location map of the study area. **b** Photographs of the Akkulam-Veli Lake

Anthropogenic activities due to dense urbanization in the area have resulted in heavy metal pollution in these channels (Swarnalatha et al. 2013). Besides that, the lake water quality is also deteriorating by the discharge of sewage, sullage and garbage into the lake. Since the south Indian states face crucial water shortage at present, it is very important to attempt to study the aquatic ecosystem of this lake basin which must be monitored to avoid any excessive contamination.

## Materials and methods

A total of 19 surface sediment samples were collected covering the entire lake using long-handled stainless steel scoop. The sampling sites were selected in relation to their accessibility from the shore, anthropogenic activities around the lake catchments and the water inlets entering into the lake. At each sampling point, at least 500 g of sediments was collected, stored in polyethylene bags and transported to the laboratory immediately and were dried at 45 °C in the oven. The sampling locations were obtained using the Garmin global positioning system (GPS) (Table 1). Textural studies on the sediments were performed for sand, silt and clay distributions following the procedure of (Ingram 1970) and are presented as ternary plot in Fig. 2. Total organic carbon (TOC) and nitrogen (N) were analysed in a Thermo Scientific Flash 2000 CHNS-O analyzer at the Department of Geology, Anna University, Chennai. Prior to the analysis, the samples were de-carbonized with a 1M hydrochloric acid (HCl) solution, and neutralized with de-ionized water. Dried samples between 10.5 and 11 mg were then packed in tin capsules and combusted at 950 °C using CHNS-O elemental analyser. Blank samples (tin capsules), standard BBOT (2.5-Bis (5-tert-butyl-2-benzo-oxazol-2-yl) thiophene) and standard soil samples with known elemental composition were run prior and in between the samples to account for instrument calibration and precision. The analytical precision of this method, expressed in terms of standard deviation, is < 1%. $CaCO_3$ concentration was determined by the titration method following (Gaudette et al. 1974; Loring and Rantala 1992). The data of all the above-mentioned parameters are presented in percentage values (Table 1) and plotted by spline method using ArcGIS 10.1 (ESRI Software Inc.) to understand their spatial distribution pattern, interrelationships and relation with catchment area. For clay mineralogy, clay fraction from five samples (VL-3, VL-5, VL-9, VL-12 and VL-15) were separated and analysed for XRD analysis for phase discrimination at Department of Physics, Anna University.

Seven samples (VL 1, VL 8, VL 9, VL 12, VL15, VL 17 and VL 18) selected covering entire lake area of lake were analysed for diatom analysis in Department of Zoology,

**Table 1** Location, sand, silt, clay, TOC, N percentage and C/N ratio of Akkulam-Veli lake floor samples

| S. no. | Latitude | Longitude | Sand% | Silt% | Clay% | TOC | N | C/N | $CaCO_3$% |
|---|---|---|---|---|---|---|---|---|---|
| VL-1 | 8.509303 | 76.888589 | 97.04 | 0.95 | 2.01 | 1.60 | 0.25 | 6.28 | 1 |
| VL-2 | 8.509175 | 76.886864 | 97.63 | 1.18 | 1.18 | 0.14 | 0.16 | 0.87 | 0.5 |
| VL-3 | 8.511092 | 76.889911 | 95.05 | 1.85 | 3.09 | 0.29 | 0.23 | 1.26 | 2.25 |
| VL-4 | 8.512625 | 76.890083 | 94.87 | 1.03 | 4.10 | 0.29 | 0.18 | 1.63 | 1 |
| VL-5 | 8.515142 | 76.890667 | 50.19 | 11.96 | 37.85 | 0.28 | 0.52 | 0.55 | 1.5 |
| VL-6 | 8.515769 | 76.8919 | 3.60 | 30.60 | 65.80 | 1.01 | 0.38 | 2.69 | 2.5 |
| VL-7 | 8.517886 | 76.8926 | 34.87 | 9.97 | 55.16 | 2.07 | 0.31 | 6.58 | 6.5 |
| VL-8 | 8.519064 | 76.894242 | 97.52 | 0.93 | 1.55 | 0.75 | 0.28 | 2.69 | 0.5 |
| VL-9 | 8.520914 | 76.894592 | 12.61 | 9.00 | 78.39 | 3.23 | 0.72 | 4.49 | 3.5 |
| VL-10 | 8.522028 | 76.896247 | 32.77 | 14.74 | 52.49 | 3.43 | 0.50 | 6.89 | 1.5 |
| VL-11 | 8.524261 | 76.899183 | 10.54 | 9.52 | 79.93 | 1.56 | 0.39 | 4.04 | 1.5 |
| VL-12 | 8.523639 | 76.901156 | 11.27 | 7.36 | 81.38 | 7.60 | 0.61 | 12.42 | 7 |
| VL-13 | 8.522728 | 76.903508 | 20.22 | 3.66 | 76.12 | 7.69 | 0.68 | 11.37 | 4 |
| VL-14 | 8.520472 | 76.905853 | 5.26 | 5.42 | 89.31 | 2.52 | 0.48 | 5.21 | 5 |
| VL-15 | 8.520478 | 76.903808 | 14.77 | 15.63 | 69.60 | 3.96 | 0.39 | 10.10 | 3.5 |
| VL-16 | 8.511956 | 76.889686 | 96.32 | 0.48 | 3.20 | 1.14 | 0.16 | 7.14 | 2 |
| VL-17 | 8.510417 | 76.887881 | 97.13 | 0.62 | 2.25 | 0.37 | 0.48 | 0.77 | 2.5 |
| VL-18 | 8.519772 | 76.897967 | 25.35 | 20.49 | 54.17 | 3.72 | 1.08 | 3.46 | 1.5 |
| VL-19 | 8.521336 | 76.900658 | 16.03 | 22.82 | 61.15 | 0.11 | 1.08 | 0.10 | 6.5 |
| Maximum value | 97.63 | 30.60 | 89.31 | 7.69 | 1.08 | 12.42 | 7 | | |
| Minimum value | 3.60 | 0.48 | 1.18 | 0.11 | 0.16 | 0.10 | 0.5 | | |
| Average value | 48.05 | 8.85 | 43.09 | 2.20 | 0.47 | 4.66 | 2.86 | | |

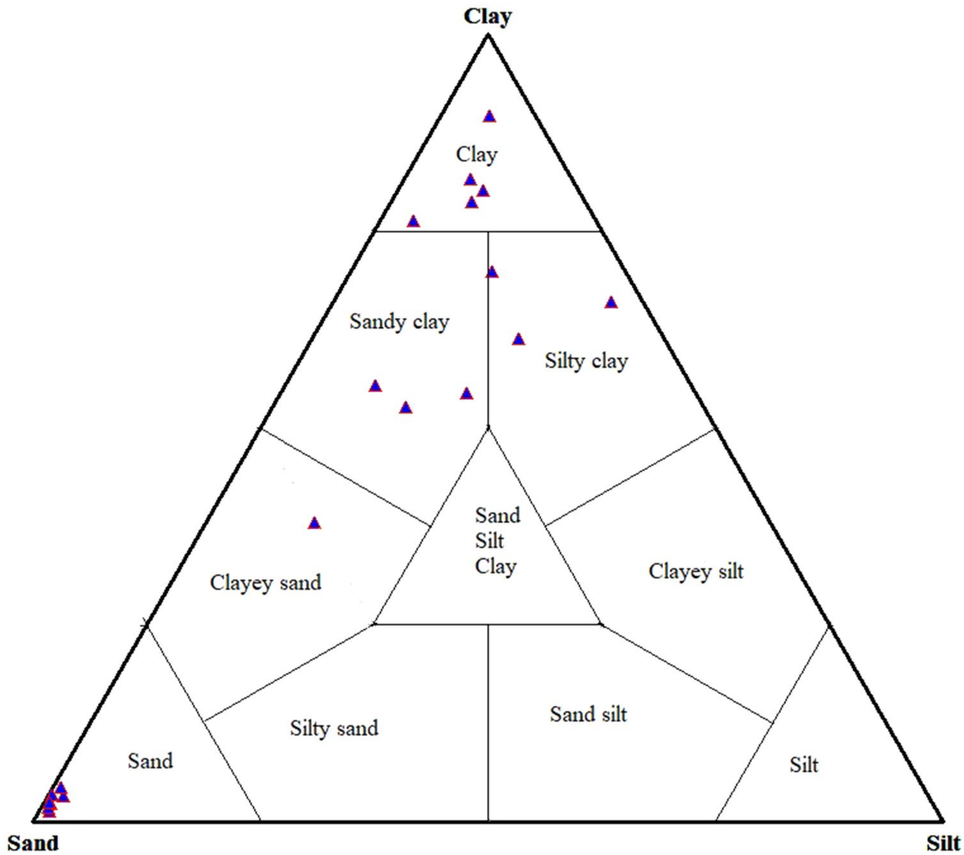


**Fig. 2** Ternary plot showing the relative percentage of sand silt and clay particles of the Akkulam-Veli lake floor sediments

university of Madras, following the protocols of (Hasle 1978) and (Round et al. 1990) with a few minor modifications. For this purpose, 0.5 gm of each sediment sample was treated with 10 ml of saturated potassium permanganate solution for 48 h in glass test tubes followed by the addition of 35% hydrochloric acid. After the addition of HCl, the test tubes containing samples were kept in a hot water bath at 90 °C for 1–2 h until the solution turned yellow. In the third step, 1–2 ml of hydrogen peroxide drops was added to solution to ensure complete oxidation. The samples were finally centrifuged at 2500 rpm for 10 min for the supernatant extraction. Diatom slides were observed under 40×–100× resolution in the Department of Zoology, University of Madras, Chennai. Diatom specimens were identified with the help of authentic literature following Hasle (1978); John (2012); Round et al. (1990); Ramanibai and Jeyanthi (2010) and online data bases collected from the European diatom and the Western diatom database collections (https://westerndiatoms.colorado.edu/). An average of 7–10 diatoms were observed per slide in one drop (1 drop is equal to 0.05 ml) of the 1 ml supernatant solution extracted from each sample.

## Results

### Sediment grain size

The grain size spatial distribution maps (Fig. 3a–c) in the Akkulam-Veli Lake display prominent zones of the different sediment fractions formed by the differential water energy. More than 70% of the lake surface area towards north-eastern side displays low percentage of sand; however, all the areas towards south-western side (Veli part), adjacent to the beach, show domination of sand fraction, reflecting high water energy condition by wave action. The sand fraction is also dominant near the confluence of Parvathi Puthan River with the lake towards the southern side. Out of 19 samples, 11 samples consist of more than 50% of clay content (Table 1). Higher clay content (89%) was observed in the VL-14 towards the eastern margin of the lake near confluence of Amayizhanchan Thodu River reflecting the stagnant flow of the river water. Around 70% of the lake area towards north-eastern (Akkulam part) is dominated by clay only due to the stagnant water conditions. Silt fraction in the lake is comparatively low and does not dominate prominent lake area.

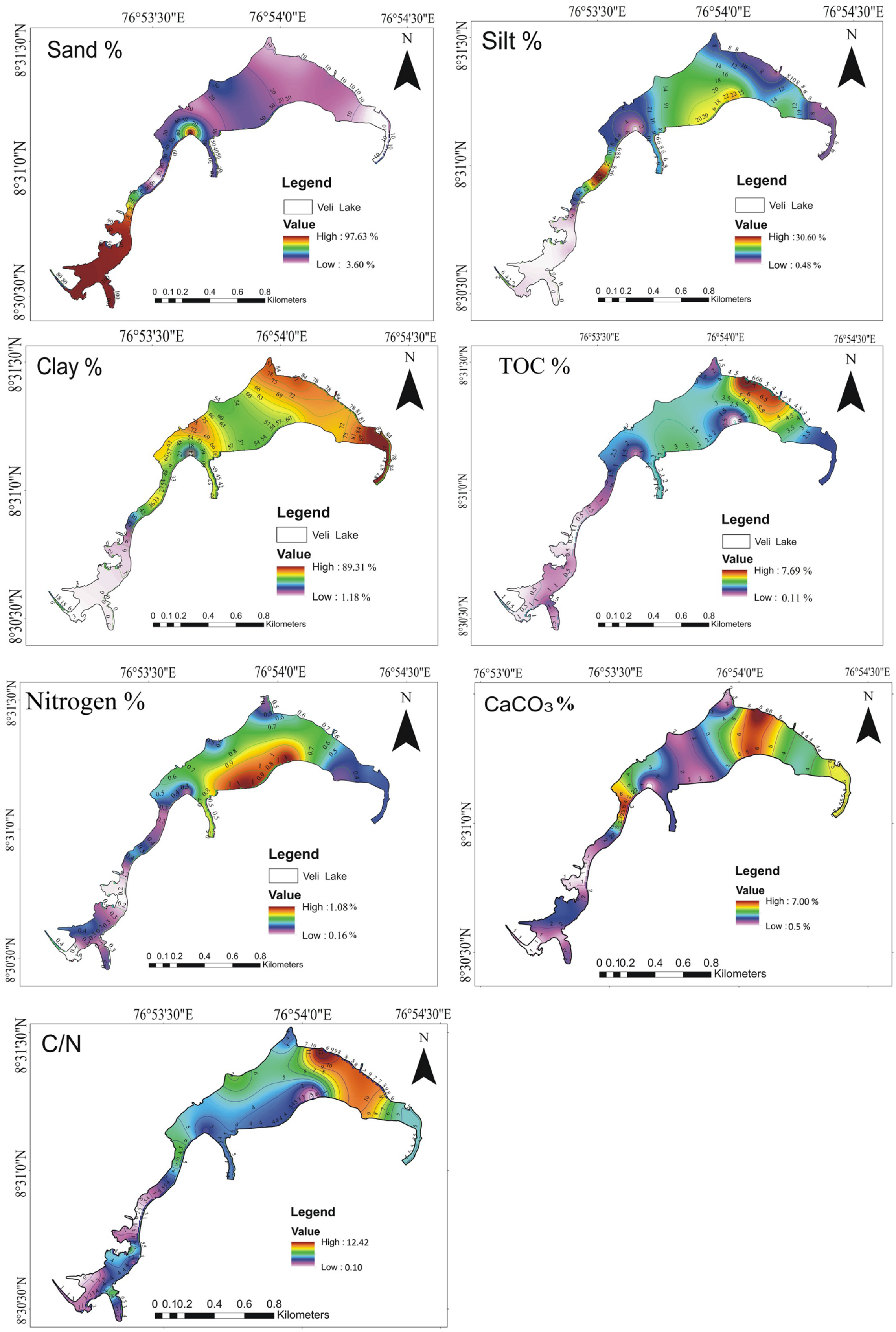


**Fig. 3** Special distribution of sand, silt, clay, TOC N, $CaCO_3$ and C/N in Akkulam-Veli Lake

### TOC, N, C/N ratio and $CaCO_3$

TOC in the lake sediments ranged from 0.11 to 7.69%. The overall trend of spatial distribution map (Fig. 3d) shows enrichment of TOC in lake sediments towards the north-eastern part, while the sediments from the south-western part show less than 0.5% TOC content, and thus are depleted. N (Fig. 3e) in the lake shows similar trend like TOC and is enriched in north-eastern part and poor in south-western part; it also shows a high content towards the south-eastern side, which could be a possible site for the N to enter the lake through urban sewage. The C/N (carbon/nitrogen) ratio of the lake sediments (Fig. 3g) ranges from 0.10 to 12.42%. The lake catchments do not comprise of any calcium carbonate lithology, and the $CaCO_3$ content in the lake sediments (Fig. 3f) ranges from 0.5 to 7%. Most of the lake surface shows restricted value of $CaCO_3$ up to 3%. However, certain area towards north-eastern side and a small area near middle of the lake show high percentage of CaCO3 up to 7%.

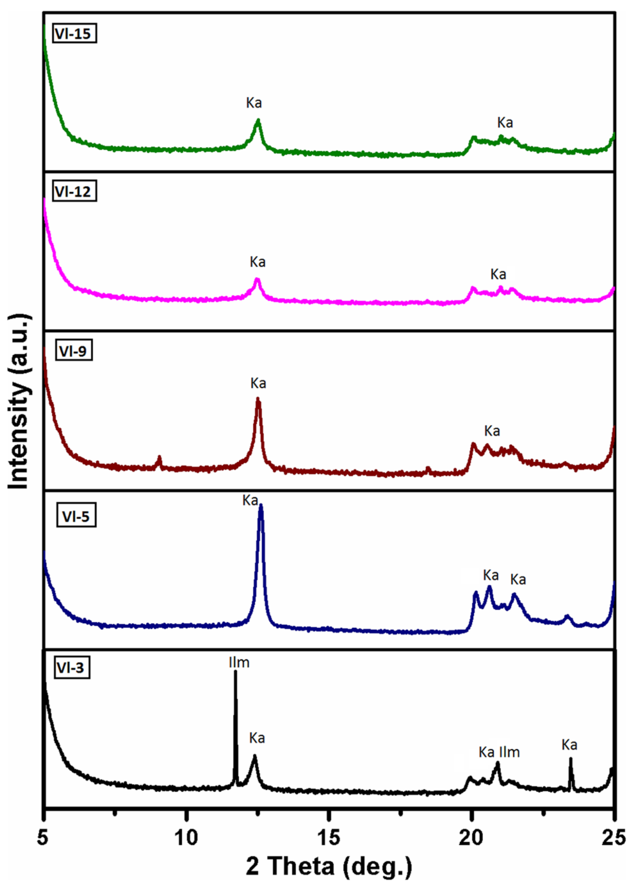


**Fig. 4** XRD data obtained on clay fraction of the samples (*Ka* Kaolinite, *Ilm* Ilmenite)

### Clay mineralogy

XRD analysis carried out on clay fraction of five samples showed comparatively similar trend in graph (Fig. 4). All the samples indicate the presence of high proportion of Kaolinite, and in addition, sample VL-3 close to the beach side showed the presence of Ilmenite, a titanium-bearing mineral.

### Diatoms

Seven samples analysed for diatoms showed rich diversity of diatoms in the lake. Overall, a total of 18 diatom species were identified from the lake sediments. The species identified are presented in Fig. 5 and include (1) *Actinocyclus normanii*, (2) *Amphora holsatica*, (3) *Amphora ovalis*, (4) *Ardissonea* sp., (5) *Cyclotella atomus*, (6) *Cyclotella meneghiniana*, (7) *Cyclotella striata*, (8) *Diadesmis confervacea*, (9) *Diploneis finnica*, (10) *Krasskella*, (11) *Navicula* sp. *(girdle view)*, (12) *Navicula elongtoids*, (13) *Navicula yarrensis*, (14) *Pinnularia* sp., (15) *Pliocaenicus*, (16) *Pseudo-nitzschia*, (17) *Stauroforma*, (18) *Tabularia fasciculate.*

## Discussion

Distribution maps for sand, silt and clay fractions of Akkulam-Veli lake sediments (Fig. 3) reflect two dissimilar depositional environments displaying natural sorting of the sediments due to differential water energy regimes. Predominance of sand is observed towards the south-western side (Veli part), reflecting course grain sediment being deposited by frequent back water currents from the sea shore. The north-eastern side (Akkulam part) is exclusively dominated by clay fraction, with minor mixture of silt fraction in middle of the lake, thus indicating the stagnant water condition in this major part of the lake. Following the Shepard (1954) classification of grain size, the lake floor sediments are dominantly clay and silty clay fractions. Out of 19 samples, only 10 samples show less than 25% sand content. Following the clay, sand was found to be the second most dominant sediment grain fraction. The distribution maps for the TOC follow similar trend such as sand and clay in the lake, with sand-dominated area showing the presence of low amount of TOC, while the clay-dominant area shows adherence of relatively high amount of TOC with the sediments (Shah et al. 2017). The reason for occurrence of high TOC content with fine sediments is that they offer higher surface area for adherence of organic matter, and the stagnant water condition of the area supports higher vegetation growth and later allows settling of organic matter that has relatively low

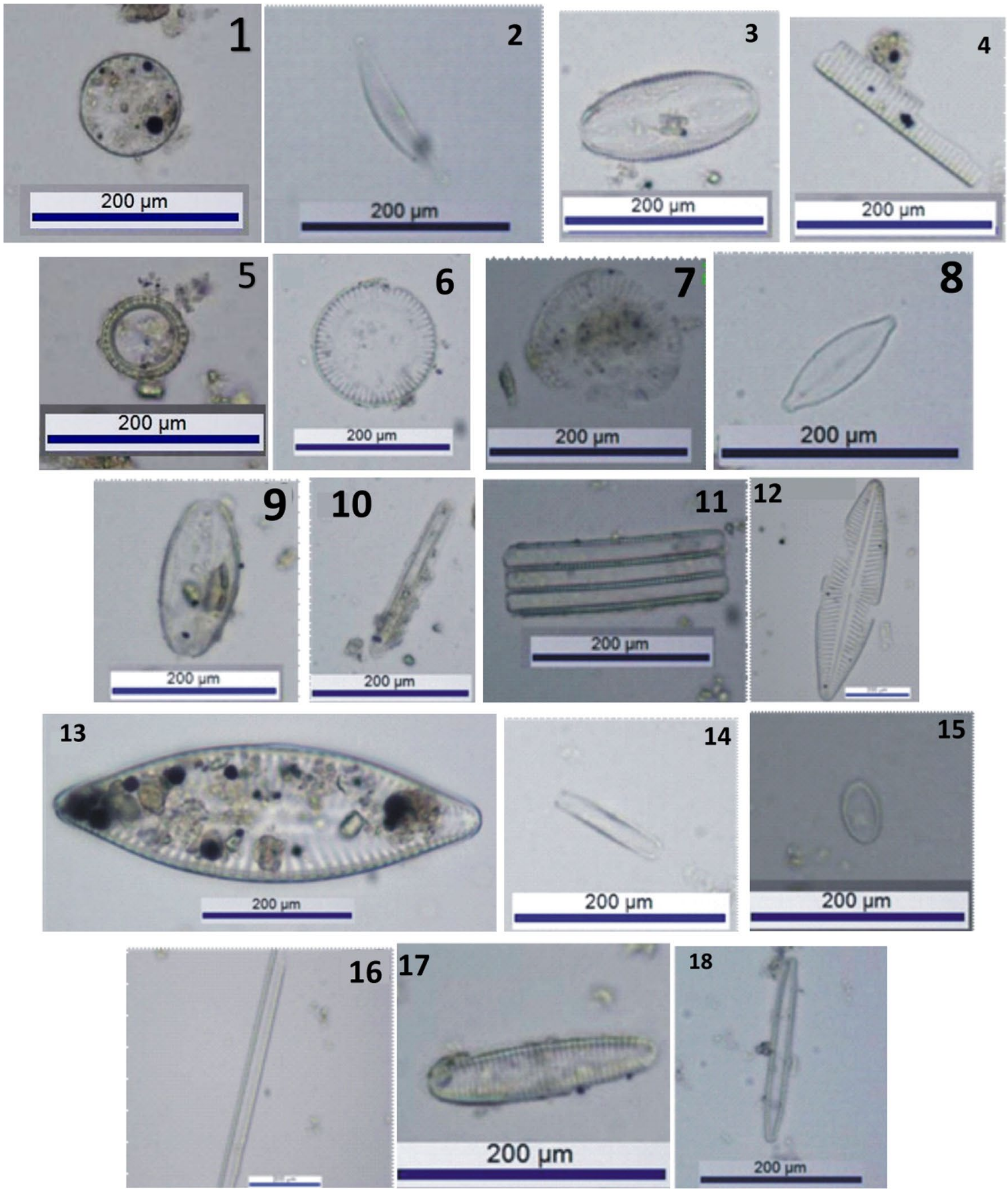


**Fig. 5** Diatom species observed in Akkulam-Veli lake sediments. (1) *Actinocyclus normanii*, (2) *Amphora holsatica*, (3) *Amphora ovalis*, (4) *Ardissonea* sp., (5) *Cyclotella atomus*, (6) *Cyclotella meneghiniana,* (7) *Cyclotella striata*, (8) *Diadesmis confervacea*, (9) *Diploneis finnica*, (10) *Krasskella*, (11) *Navicula* sp. *(girdle view)*, (12) *Navicula elongtoids*, (13) *Navicula yarrensis*, (14) *Pinnularia* sp., (15) *Pliocaenicus*, (16) *Pseudo-nitzschia*, (17) *Stauroforma*, (18) *Tabularia fasciculata*

density. The TOC content of the samples ranges from 0.11 to 7.69%. However, almost half of the samples contain more than 2% TOC, which indicates increasing organic pollution. Since the TOC and N are fixed by vegetation in specific proportion, the total nitrogen in the lake sediments follows the trend of TOC and is enriched in north-eastern part and poor in south-western part, attributed by the differential sorting of the sediment fraction by differential water energy. The lake observes very high content (more than 1%) of N towards the south-eastern side; it possibly enters the lake water through untreated urban sewage, thereby further increasing the eutrophication level of the lake, as low availability in aquatic environment is the only reason to suppress vegetation growth.

The C/N ratio of the lake sediments ranges from 0.10 to 12.42%. Values less than 4 in nine samples out of 19 clearly indicate the addition of nitrogen to the lake from its catchment areas since the minimum C/N ratio of organic matter produced by vegetation is 4 and it is observed by aquatic plants. The low C/N ratio near the confluence of the rivers with the lake waters shows similar effect. Most of the area of the lake surface is affected by the addition of nitrogen; however, the addition of high amount of nitrogen to lake towards south-eastern side is prominent in C/N distribution map and it also affects the south-western side, since the flow of the lake water is towards that side. As the lake catchments do not comprise of any exclusive calcium carbonate lithology, most of the lake surface shows restricted value of $CaCO_3$ up to 3%. However, certain area towards north-eastern side and a small area near the middle of the lake show rich percentage of $CaCO_3$ up to 7%, which could be a result of $CaCO_3$ shell accumulation from organisms thriving in the lake waters. The distribution of $CaCO_3$ in the lake surface sediments shows that the lakes have developed multiple environments, and each support growth and dwelling of specific aquatic species within it.

The correlation matrix is presented in Table 2. Sand observes negative correlation with silt (−.70), clay (−.98), $CaCO_3$ (−.59) and TOC (−.60). The sand dominates the south-western area of the lake that encounters occasional back water currents from the sea. The negative correlation of these components with sand-dominated area is due to differential environments of the lake. The north-eastern area shows stagnant conditions and observes high silt, clay, $CaCO_3$ and TOC, while the south-western sand-dominated area shows opposite environment. The N does not show a significant negative correlation in the sand-dominated area like other components, because the input of nitrogen by sewage through Parvathy Puthan canal in this area neutralizes that effect. Silt shows a significant positive correlation with clay (.56) and TOC (.56). Clay also shows a significant positive correlation (.55) with TOC indicating the adherence of organic matter with the fine particles because of clay and silt together offering higher surface area for the adherence of organic matter. Clay shows significant positive correlation (.62) with $CaCO_3$, and $CaCO_3$ shows significant positive correlation with TOC (.42) and nitrogen (.67); it could be the result of growth and development of carbonate shell-bearing organisms in stagnant waters of the lake that also support the deposition of clay fractions.

The results obtained from XRD analysis show the presence of high proportion of Kaolinite. This comes from the surrounding lithology as a result of intensive chemical weathering in the tropical state. One sample (VL-3), located close to the beach, also shows the presence of Kaolinite and in addition to that it also shows the presence of Ilmenite, a titanium-bearing mineral that comes in lake with beach sands during tidal intrusion into the lake.

The lake surface sediments show rich diversity of diatoms dwelling in the lake. Lake is dominated by the freshwater diatoms. Among a total of 18 diatom species that were identified from the lake sediments, five species are reported mostly from marine water which were observed mostly in the south-western part of the lake because of the saline water intrusion during high tide. Ten identified species live in freshwater, which were observed along the north-eastern as well as the middle part of the lake. The other three species are mostly observed in brackish waters and were present in the lake towards the south-western side. The list of identified diatom species, their sample wise distribution and origin are presented in supplementary Table 1. The ratio of planktonic to benthic diatom species preserved within lake sediments is commonly used to infer past lake-level history, with an increased abundance of plankton species that are generally indicative of high lake levels. Palmer (1969) has used several diatom species for organic pollution modelling, and the method is now followed worldwide. According to Palmer (1969) organic pollution index modelling, a score of 0–10 indicates a lack of organic pollution, 10–15 shows moderate organic pollution, while a score of 15–20 indicates probable high organic pollution, and more than 20 confirms the high organic pollution in water. The diatom species dominating in the Akkulam-Veli Lake such as *Cyclotella sp. and Navicula* sp. have been assigned a Palmer (1969) organic pollution index of 1–3. Very high population

**Table 2** Correlation matrix of the grain size and organic matter, $CaCO_3$, TOC, N and C/N in Akkulam-Veli lake surface sediment

| | Sand | Silt | Clay | $CaCO_3$ | TOC | N | C/N |
|---|---|---|---|---|---|---|---|
| Sand | 1 | | | | | | |
| Silt | −0.701 | 1 | | | | | |
| Clay | −0.983 | 0.559 | 1 | | | | |
| CaCO3 | −0.59 | 0.257 | 0.62 | 1 | | | |
| TOC | −0.604 | 0.561 | 0.558 | 0.426 | 1 | | |
| N | −0.139 | −0.073 | 0.18 | 0.671 | −0.245 | 1 | |
| C/N | −0.39 | −0.067 | 0.471 | 0.418 | 0.02 | 0.394 | 1 |

(140–200 diatoms per sample) and wide distribution of diatom species such as *Cyclotella* sp. and *Navicula* sp. confirm high organic pollution in the lake. The excessive growth of the diatoms and lake vegetation is observed in the lake, and it is a result of high nutrient availability and other favourable physico-chemical factors.

## Conclusions

This study on the Akkulam-Veli lake floor sediments reveals that the lake is dominated by sand towards the Veli part and clay and silt towards the Akkulam part. The lake has developed multiple environments, each dwelling-specific biodiversity. Moderate C/N ratio of the sediments indicates high vegetation growth in the lake and suggests that only minor amount of organic matter from terrestrial sources finds its way in the lake. High amount of N is being added to the lake through urban sewage that is increasing its eutrophication level. XRD analysis reveals the presence of high amount of Kaolinite mineral towards the Akkulam part suggesting intensive weathering of the surrounding catchment rocks. The diatom analysis reveals diverse species dwelling in the lake, and high population and wide distribution of species such as *Cyclotella* and *Navicula* display high organic pollution. This demands careful planning for mitigation and monitoring of environmental pollution of the Akkulam-Veli Lake.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Human and animal rights** This work does not contain any studies with human participants or animals performed by any of the authors.



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