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SPATIAL DISTRIBUTION OF DIATOMS AND ORGANIC MATTER OF THE LAKE FLOOR SEDIMENTS, KARLAD, NORTH KERALA

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ABSTRACT

Diatoms constitute one of the most diverse and ecologically important groups of phytoplankton. Diatom variations within the lake are often used as an important tool for lake environmental monitoring. Furthermore, because the diatom silica cell walls do not decompose, diatoms in lake and marine sediments are often used to interpret conditions that prevailed in the past. For this purpose, lake floor sediments, Karlad lake, North Kerala, located on the pathway of the SW monsoon, were collected during 2013-2015 and analyzed for diatoms, textural, organic matter (OM) and Carbon analyses. The *Aulacoseira alpigena* was the most abundant and diverse genus, followed by *Encyonema latum, Pinnularia mayor, Navicula cryptocephala*, and *Epithemia Sorex.* It is seen that the entire Karlad lake sediments are mainly sandy silt and sandy clay, however, at fewer stations silt dominates. Textural analysis of the lake floor sediments of Karlad Lake reveals that northern and eastern part of the lake is dominated by sand and is shallow while the central part of the lake is dominated by mud, supporting a thicker water column. The C/N ratio (2.07 to 33.27) indicates a mixed source of total organic carbon (TC) both from the terrestrial input as well as lake aquatic plant/weed source. We also observed high diatom diversity in the Karald Lake, indicating that diatoms may be more relevant in these ecosystems than generally considered.

Keywords: Diatoms, Spatial distribution of sediments, Lake floor sediments, Sediment texture, mixed origin of Organic Matter, C/N ratio

INTRODUCTION

Lakes are major depo-centers for water, carbon and sediments. The lake sediments hold signatures for understanding the processes that have operated in the catchment area. Lake sediments also provide a continuous, higher resolution archive of the past year. Hence, lake sediments can be used for understanding paleoenvironmental shifts. Sediment accumulation in the lake depends on the available sources of suspended sediment load, the transport efficiency of inflowing streams and within lake processes consequent upon water circulation, turbulence and lake shoreline stability (Pennington 1991, Dearing and Foster, 1993). Lake sediments are composed mainly of clastic material (clay, silt, and sand sizes), organic debris, chemical precipitates, or combinations of these (Pennington, 1991; Dearing and Foster, 1993). Their relative abundance depends upon the nature of the local drainage basin, climate and sediment flux from the catchment area. Sediments are an important carrier of nutrients and promote plant and algae growth. In lakes, there is a balance between sediments entering, circulating within the lake and being used to support aquatic life. When the quantity of sediment becomes elevated in lake water due to soil erosion or man-made activities, it can contribute to oxygen depletion in the water by promoting the growth of algae and plants. Too much suspended or free floating sediment decrease, the amount of light that penetrate through the lake waters and this can affect the health of aquatic organisms and the chemistry of lake waters in general.

Diatoms are algae with distinctive, transparent cell walls of silicon dioxide hydrated with a small amount of water ($SiO_2 + H_2O$). Silica is the main component of glass and hydrated silica is very like the mineral opal, making these algae, often called "algae in glass houses" more like "algae in opal houses" (Battarbee, 1986). The cell wall is called frustules and consists of two halves called valves. Since silica is impervious, diatoms have evolved elaborate patterns of perforations in their valves to allow nutrient and waste exchange with the environment (Battarbee, 1986). These valve patterns are beautiful and also helpful for classifying diatoms. Diatoms grow as single cells or form filaments and simple colonies. Diatoms are abundant in nearly every habitat where water is found – oceans, lakes, streams, mosses, soils, even the bark of trees. These algae form part of the base of aquatic food webs in marine and freshwater habitats. Assemblages of diatom species are often specific to particular habitats and can be used to characterize those habitats.

In general, diatom species are very sensitive to water chemistry in which they live. In particular, species have distinct ranges of pH and salinity where they grow (Armstrong and Brasier, 2005). Diatoms also have ranges and tolerances for other environmental variables, including nutrient concentration, suspended sediment, flow regime, elevation, and different types of anthropogenic interferences. As a result, diatoms are used extensively in environmental assessment and monitoring. Plethora of work has been carried out on the east African lakes using diatoms (Heckey and Kilham, 1973; Armstrong and Brasier, 2005). Studies carried out on different proxies such as pollen, diatom, charred grass cuticles and oxygen isotope records from diatomic silica; suggest that East Africa was characterized by warm and moist conditions amid rapid climatic changes during the early to middle Holocene period (Heckey and Kilham, 1973). Detailed work on diatoms have proved that rapid vegetation changes occurred due to human activity produced remarkable changes in the land (Kutzbach *et al*., 1996, Doherty *et al*., 2000).

Diatoms are one of the algal groups with siliceous shell and thus can be preserved for a long time in the sediments of the aquatic environment (Wang *et al*., 2010). Usually, they are sensitive to changes in water quality and thus have been commonly used for the studies of lake environment and palaeolimnology (Wu *et al*., 1997). Various organic matter components of lake sediments retain source information and thereby contribute to the palaeolimnological record. Carbon/Nitrogen ratios of total organic matter reflect original proportions of algal and land derived material (Meyers *et al*., 1993) and thus reflects on the productivity of diatoms and carbon recycling. There is no work till date on the palynomorphs of the Karlad lake, north Kerala. The lake is located on the pathway of the southwest monsoonal rains and hence any fluctuation in the intensity of the monsoon will reflect in the lake algal productivity and the food web within the lake. Hence, the main objective of this study was to understand the source of carbon, organic matter and the diatom assemblage reflecting the health of the lake.

For this purpose, in the present study, the source of sediments and environmental changes have been inferred using the lake floor sediments collected from the Karlad Lake, Kerala. The region around the Karlad lake receives intense southwest monsoon (SWM) rains. Hence, any variation in the intensity and amount of precipitation would be reflected in the sediment deposition, its characteristics and lake nutrient distinctiveness. For this purpose, lake floor sediment were collected and analysed for various textural, organic matter (OM), carbon analyses and diatom assemblage.

STUDY AREA

The Karlad lake, Kerala (11^{0}39'21.49"N and 75^{0}58'52.17"E) is a fresh water, quadrilateral-shaped basin, situated at a high elevation (756 m.a.s.l) in Wayanad district. The lake lies in the eastern highland and is bordered by the Banasura hills in the south. The lake is located at Thariode, nearly 16 kms north of Pookode Lake (Fig. 1). The maximum length and width of the lake are 249 m and 186 m respectively. The landform units characterized around the lake are alluvial plains, flood plains, valley fill, linear ridge, hill crest, sloping terrain, rocky slope and hilly terrain (Vinayachandran and Joji, 2007). The flood plain and valley fill are the major fluvial landforms, whereas the moderately sloping terrain, highly sloping terrain, rocky slope, linear ridge and hill crest are main denudation landform units. The Kabani river and its three main tributaries are the major river system that course past the lake (Vinayachandran and Joji, 2007). The bedrock exposed around the lake is predominantly the Peninsular shield rocks of Archean age and these are i) the Peninsular gneiss complex, ii) the Migmatite complex, iii) the Charnockite group and iv) Wayanad group. The Wayanad group of supracrustal rocks includes garnet-Sillimanite- biotite gneiss with or without graphite, Kyanite, Kyanite-Fuchsite-

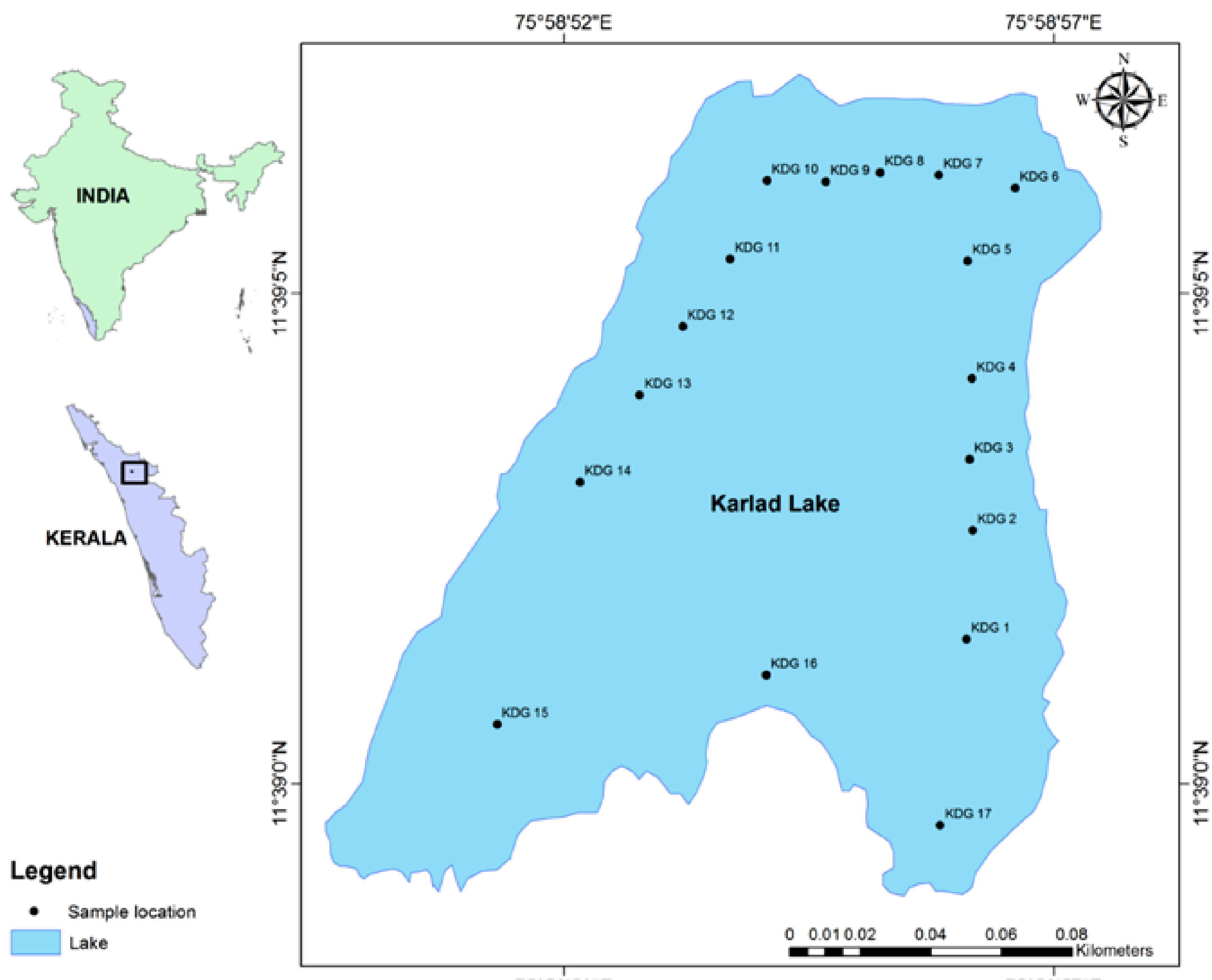

Fig. 1. Location map of the study area.

Muscovite-quartz-schist, hornblende-biotite schist and gneiss, amphibolites bands, quartz-sericite schist/quartz mica schist and meta ultramafics, representing the upper amphibolites to lower granule facies metamorphism (GSI, 2005).

The Karlad Lake experiences salubrious climate with an annual average rainfall of 2000 mm yr^{-1} (India Meteorological Department). The SW and NE monsoons contribute rainfall in the area with 80% of the rainfall from SW monsoon. During the summer, the temperature goes up to a maximum of 35 ^{o}C (95 ^{o}F) and during the cold season the temperature goes down to 07 ^{o}C (47 ^{o}F).

Laterites formed over the hornblende biotite gneiss are exposed in patches around the Karlad lake and are largely reddish brown in colour, formed under tropical monsoonal climate. The organic matter (OM) in the soil is very less with moderate nitrogen, phosphorous and potash. The pH of the soil ranges between 5.5 and 6.5 and texture is clayey loam to silty loam with 5 to 20% of coarse lateritic pisolitic fragments (Vinayachandran and Joji, 2007). The soil pH ranges between 5.3 and 6.3 and is slightly acidic in nature. Brown hydromorphic soil (BHS) is mainly observed between undulating topography around the lake and its catchment area. The BHS is very deep brownish in colour with sandy loam to clayey texture (Vinayachandran and Joji, 2007).

MATERIALS AND METHODS

In the present study, in total of 17 lake floor sediment samples was collected using a Van Veen grab sampler mounted on a hired tourist boat and the sampling station locations were determined using the Global Positioning System (GPS). Textural analyses were carried out by the pipette method of Krumbein and Pettijohn (1938) (Figs. 2 and 3). Calcium carbonate ($CaCO_3$) and OM content were determined using LOI method put forward by Loring and Rantala (1992) and Heiri *et al*., (2001) respectively. TC, TN percentages were determined using CHNS-O, 2400 series II instrument at the Department of Geology, Anna University (Fig. 4). Diatom analysis was conducted following Battarbee (1986) (Figs. 5 and 6). Arc GIS software was applied to plot the spatial distribution pattern of the sediment texture and diatom assemblage. Diatom species were identified and their abundance counted. Statistical assessment of the data was carried out using principal components analysis (PCA) and cluster analysis with the program IBM SPSS (Table 4, Table 5, Fig. 8, Fig. 9).

RESULTS

The sand and mud content in the sediment sample of the Karlad Lake are presented in (Table 1, Fig. 2, and Fig. 3). Based on the granulometric composition of the sediments, the lake surface sediment is dominated by the sandy silt and sandy clay, however, except in a few locations where silt dominates, these stations support a deep water column. In the Karlad Lake, it is observed that sand is dominant along the north and eastern direction of the lake (Fig. 2). Mainly, based on the sample stations the sand content varied from a minimum of 10.4% at KLD-11 (North northwestern part of the lake) to a maximum of 74.2% at KLD-2 (North eastern part of the lake).

The OM and CO_3 percentages vary from 3.8 at KLD-2 (North eastern part of the lake) -13.8% at KLD-5 (North northeastern part of the lake) and 0.2-1% (very low carbonate content) respectively (Table 1). The TC percentage varied from a minimum of (1.56%) at KLD-13 (North western part of the lake) to a maximum of (6.56%) at KLD-8 (Northern part of the lake).

The diatom assemblage is represented by 12 infraspecific taxa listed in Table 2 and Table 3 and presented in Fig. 5. Most of the species identified were in an excellent state of preservation; however, very few of them were fragmented. The diatom species abundance varied within stations from a minimum of 22 numbers at KLD-13 (North west part of the lake) to a maximum of 73 numbers at KLD-5 (North east part of the lake). The taxa of the genus *Aulacoseira alpigena*, *Navicula cryptocephala*, and *Pinnularia maior* are plentiful and widely distributed in the lake (Fig. 6). The diatom species have been classified according to their class, order, phylum, kingdom and family (Table 3).

The centric frustules of *Aulacoseira alpigena* are linked to one another by spines to form filaments. The shape of the linking and separation spines and the relationship between spines were important characters that distinguish species within *Aulacoseira*. *Eunotia pectinalis* is the common variety of microorganisms; their

Table 1: Textural analysis, CO_3%, OM%, TC% and TN% in Karlad Lake.

Sample ID	Latitude	Longitude	Sand%	Mud%	OM%	CO_3%	TC%	TN%	C/N
KLD-1	11°39'01.32"N	75°58'56.20"E	37.2	62.8	4.4	0.4	3.02	0.63	4.76
KLD-2	11°39'02.32"N	75°58'56.26"E	74.2	25.8	3.8	0.4	3.08	0.21	14.41
KLD-3	11°39'02.97"N	75°58'56.23"E	26.8	73.2	5.0	0.4	2.17	0.52	4.18
KLD-4	11°39'03.71"N	75°58'56.25"E	54.4	45.6	5.8	0.6	3.91	0.67	5.84
KLD-5	11°39'04.79"N	75°58'56.21"E	30	70	13.8	0.4	3.83	0.48	7.91
KLD-6	11°39'05.46"N	75°58.56.65"E	24.8	75.2	5.0	0.2	4.37	0.18	24.15
KLD-7	11°39'05.58"N	75°58'55.95"E	55.8	44.2	6.2	0.2	4.46	0.13	33.27
KLD-8	11°39'05.60"N	75°58'55.41"E	47.6	52.4	7.0	0.2	6.56	0.55	11.82
KLD-9	11°39'05.52"N	75°58'54.91"E	49	51	7.2	0.2	5.02	0.53	9.56
KLD-10	11°39'05.53"N	75°58'54.37"E	28.6	71.4	6.0	1.0	4.65	0.6	7.78
KLD-11	11°39'04.81"N	75°58'54.03"E	10.4	89.6	7.4	0.8	4.67	0.86	5.46
KLD-12	11°39'04.19"N	75°58'53.56"E	16	84	7.8	0.8	1.64	0.63	2.61
KLD-13	11°39'03.56"N	75°58'53.20'E	44.2	55.8	7.8	0.6	1.56	0.5	3.01
KLD-14	11°39'02.76"N	75°58'52.65"E	28	72	5.8	0.8	6.0	0.92	6.51
KLD-15	11°39'00.54"N	75°58'51.89"E	33.4	66.6	5.2	0.6	2.17	0.56	3.87
KLD-16	11°39'00.99"N	75°58'54.36"E	23	77	6.6	0.8	1.82	0.88	2.07
KLD-17	11°38'59.61'N	75°58'55.96"E	24.2	75.8	6.6	0.6	5.89	0.87	6.74

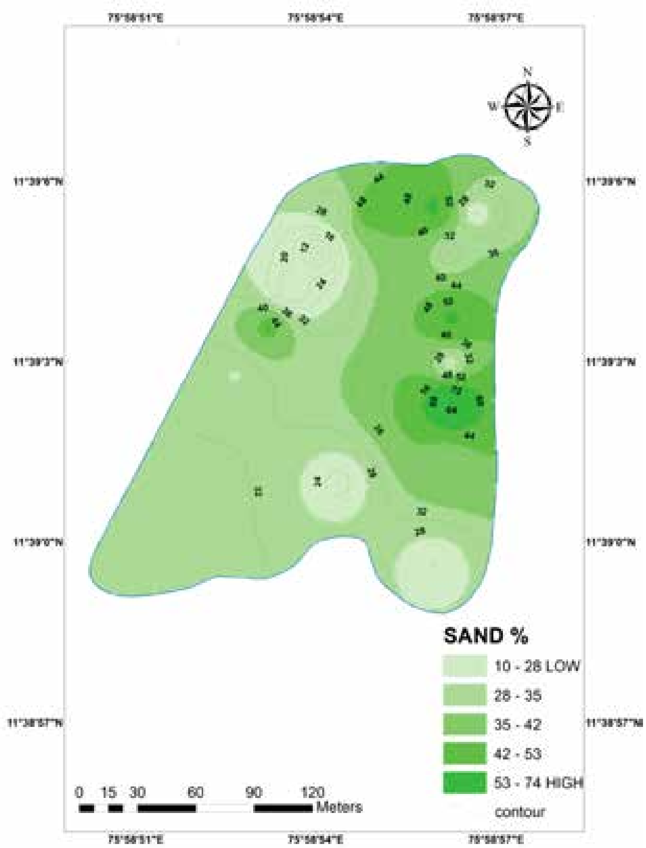

Fig. 2. Spatial distribution map of sand content within the Karlad Lake.

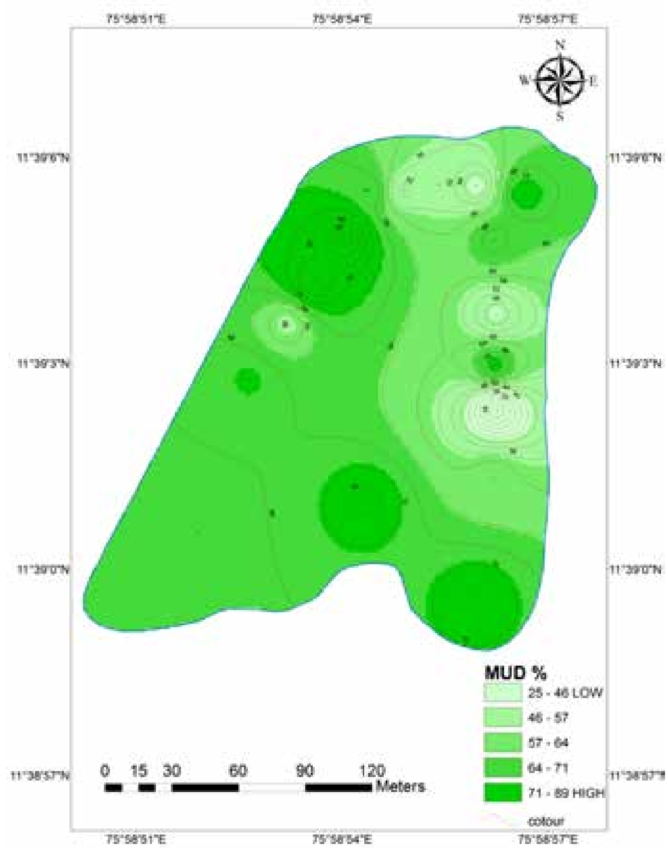

Fig. 3. Spatial distribution map of mud content in the Karlad Lake.

valves are dorsiventral and symmetrical to the transapical axis. *Pinnularia maior* is an elongated, elliptical unicellular organism. Their cell walls are composed chiefly of pectin substances on a rigid silica framework. A large central vacuole is present with the nucleus suspended in its center by a transverse cytoplasm bridge. In *Cymbella amplificata*, the valves are moderately dorsi-ventral with arched dorsal margins and weakly concave ventral margins with a slightly tumid center. Axial area is about 3 to 4 times wider than the raphe and follows the median line of the valve. *Encyonema latum* is a freshwater diatom species; its valves are strongly dorsi-ventral and the dorsal margin broadly arched, while the ventral margin is only slightly expanded. *Navicula cryptocephala* was live cells with two, symmetrically positioned, plate-like chloroplasts, extending almost to the apices in healthy individuals. The central area is more or less rounded, slightly wider than long. This genus formerly included a great range of taxa, some of which have been transferred to other genera: *Aulacoseira, Paralia, Orthoseira* and *Ellerbeckia.*

Table 2: Diatom counts at each location.

Species	Loc-1	Loc-2	Loc-3	Loc-4	Loc-5	Loc-6	Loc-7	Loc-8	Loc-9	Loc-10	Loc-11	Loc-12	Loc-13	Loc-14	Loc-15	Loc-16	Loc-17
Aulacoseira alpigena	9	2	5	2	9	19	5	3	1	6	3	3	2	4	18	3	12
Eunotia pectinalis	3	0	1	2	2	1	1	1	0	6	4	4	3	6	5	6	8
Pinnularia maior	5	9	8	0	9	12	8	8	9	4	4	11	0	2	3	3	4
Cymbella amplificata	2	2	4	3	7	1	4	1	4	10	6	0	2	6	1	1	3
Encyonema latum	0	4	8	12	9	10	11	11	1	4	4	6	1	5	4	5	6
Epithemia sorex	6	0	10	0	6	8	8	4	9	4	3	5	1	4	2	7	10
Eunotia incisa	5	0	1	0	4	5	1	9	7	3	5	5	2	0	3	6	6
Cyclotella distinguenda	2	0	0	0	0	6	2	0	1	0	0	0	3	3	0	1	1
Fragilaria crotonensis	0	11	9	1	1	0	9	1	3	7	1	11	5	1	6	3	4
Navicula cryptocephala	4	5	4	1	20	11	4	3	0	1	2	6	0	5	4	9	4
Frustulia amphipleuroides	7	1	3	2	6	0	3	12	1	5	0	1	3	3	0	1	4
Melosira lineata	1	2	2	1	0	0	2	3	0	0	3	5	0	3	2	0	4

Table 3: Diatom classifications.

Kingdom	Phylum	Class	Order	Family	Genus	Species
Chromista	Bacillariophyta	Coscinodiscophyceae	Aulacoseirales	Aulacoseiraceae	*Aulacoseira*	***Aulacoseira alpigena***
Chromista	Bacillariophyta	Bacillariophyceae	Eunotiales	Eunotiaceae	*Eunotia*	***Eunotia pectinalis***
Chromalveolata	Heterokontophyta	Bacillariophyceae	Naviculales	Pinnulariaceae	*Pinnularia*	***Pinnularia maior***
Chromista	Bacillariophyta	Bacillariophyceae	Cymbellales	Cymbellaceae	*Cymbella*	***Cymbella amplificata***
Chromista	Bacillariophyta	Bacillariophyceae	Cymbellales	Gomphonemataceae	*Encyonema*	***Encyonema latum***
Chromista	Bacillaiophyta	Bacillaiophyceae	Rhopalodiales	Rhopalodiaceae	*Epithemia*	***Epithemia sorex***
Chromista	Bacillariophyta	Bacillariophyceae	Eunotiales	Eunotiaceae	*Eunotia*	***Eunotia incisa***
Chromista	Bacillariophyta	Mediophyceae	Stephanodiscales	Stephanodiscaceae	*Cyclotella*	***Cyclotella distinguenda***
Chromista	Bacillariophyta	Bacillariophyceae	Fragilariales	Fragilariaceae	*Fragilaria*	***Fragilaria crotonensis***
Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	*Navicula*	***Navicula cryptocephala***
Chromista	Bacillariophyta	Bacillariophyceae	Naviculales	Amphipleuraceae	*Frustulia*	***Frustulia amphipleuroides***
Chromista	Bacillariophyta	Coscinodiscophyceae	Melosirales	Melosiraceae	*Melosira*	***Melosira lineata***

DISCUSSION

In the lake, sand is dominant in the northern and eastern sides of the lake (Fig. 2) and varies from a minimum of (10.4%) at KLD-11 (North northwestern part of the lake) to a maximum of (74.2%) at KLD-2 (north eastern part of the lake). The high silt (69.6%) content is prevalent along the north, northwestern part of the lake (KLD-11) while the clay content varies from a minimum of (20%) towards the northeast and north of the lake (KLD-2,9,10,11) to a maximum of (60%) towards northeastern and south and southeastern part of the lake (KLD-1,5,6).

OM constitutes a minor, but an important fraction of lake detritus. It originates from the complex mixture of carbohydrates, lipids, proteins and other biochemical produced by organisms that have lived in lakes and its watershed. The primary source of organic matter to lake sediments is from the particulate detritus of plants; only a few per cent come from animals. Plants can be divided into two chemical distinctive groups on the basis of their biochemical compositions (1) non vascular plants that contain little or no carbon-rich cellulose and lignin, such as phytoplankton, and (2) vascular plants that contain a large proportion of these fibrous tissues, such as grasses, shrubs and

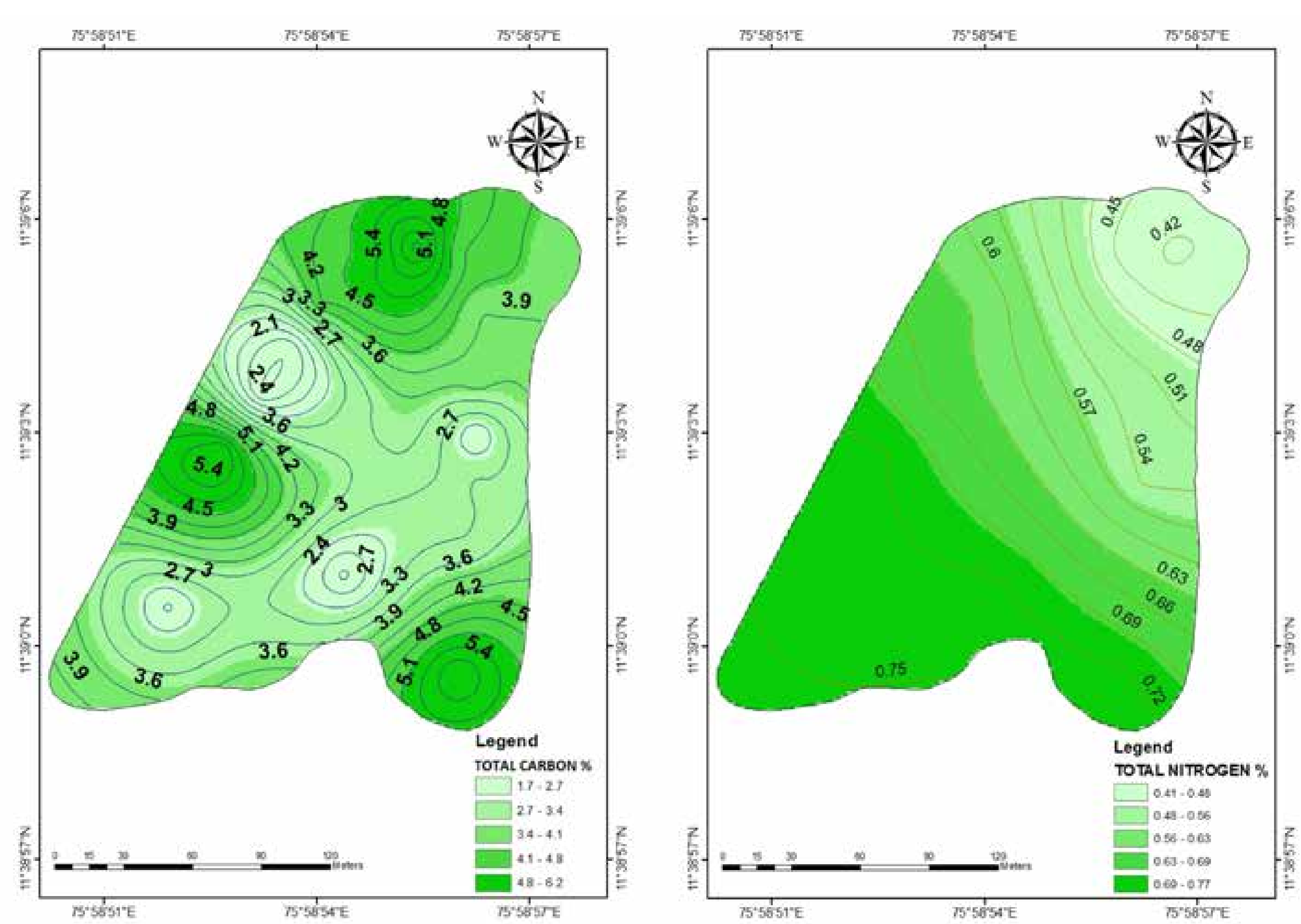

Fig. 4. Spatial distribution map of TC and TN content at different stations in the Karlad Lake.

Table 4: Correlation matrix of diatom with sand, mud, TC and TN.

	Sand	Mud	TC	TN	AA	EP	PM	CA	EL	ES	EI	CD	FC	NC	FA	ML
Sand	1															
Mud	-1.000**	1														
TC	-.126	.126	1													
TN	-.200	.200	-.384	1												
Aulacoseira alpigena (AA)	.063	-.063	.279	.068	1											
Eunotia pectinalis (EP)	-.573*	.573*	.240	.033	.131	1										
Pinnularia maior (PM)	.405	-.405	-.013	-.080	.358	-.751**	1									
Cymbella amplificata (CA)	-.305	.305	.175	-.081	.012	-.197	.201	1								
Encyonema latum (EL)	-.603*	.603*	-.026	-.071	.044	.748**	-.477	.210	1							
Epithemia sorex (ES)	.020	-.020	.081	.178	.065	-.591*	.488*	.172	-.549*	1						
Eunotia incisa (EI)	-.157	.157	-.220	.270	.389	.163	.002	-.153	.188	-.172	1					
Cyclotella distinguenda (CD)	.091	-.091	-.013	.190	.296	-.284	.483*	.115	-.264	.260	-.049	1				
Fragilaria crotonensis (FC)	-.361	.361	.497*	.127	.188	-.012	.236	.249	.030	.456	.038	.104	1			
Navicula cryptocephala (NC)	-.343	.343	.096	.283	.264	.221	-.114	.125	.084	.308	-.254	-.096	.395	1		
Frustulia amphipleuroides (FA)	-.073	.073	.288	-.175	.095	-.274	.440	.396	-.066	.096	-.196	-.009	.228	-.032	1	
Melosira lineate (ML)	.334	-.334	-.208	-.043	.019	-.510*	.725**	-.090	-.226	.187	.043	.319	.205	-.302	.067	1

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

trees. These latter types of plants exist on land near lakes and in the shallow parts of the lakes as bottom rooted emergent vegetation. The range of organic matter and carbonates are 3.8-13.8% and 0.2-1% (very low carbonate content) are respectively. It is observed that organic matter is dominant in the southeast and southwest parts of the lake. Mainly, based on the sample stations, the organic matter content is varied from a minimum of 3.8% at KLD-2 (Northeastern part of the lake) to a maximum of 13.8% at KLD-5 (North and northeastern parts of the lake). The major part of the lake is covered with organic matter contents.

Carbon and nitrogen as nutrients play a vital role in maintaining trophic levels in lake ecosystems. The dry weight ratio of total organic carbon to total nitrogen (C/N ratio) has been used as an indicator of the source of OM in sediments. Variant of C: N ratios within sediments have aided to determine temporal and spatial distribution of organic matter, steroid compounds and lignin phenols changes in sources of organic matter to lakes. The presence or absence of cellulose in the plant is the main sources of organic matter to the lake that influence the C/N ratios. Nonvascular aquatic plants have low C/N ratios, typically between 4 and 10, whereas vascular land plants, which contain cellulose, have C/N ratios of 20 and greater. Origin of sedimentary OM from aquatic as opposed to land sources can be distinguished by the characteristics of C/N ratio compositions of algae and vascular plants (Knicker, 2004). The C/N ratio in the sediment sample of the Karlad lake shows a wide variation from 2.07 to 33.27. It is observed that C/N ratio is dominant in the northern side of the lake (KLD-7) and the least content of C/N ratio (2.07) is found in the south, southwest side of the lake (KLD-16). Phytoplanktons have low C/N ratios commonly between 4 and 10, whereas vascular land plants, which are cellulose-rich and protein-poor, have a C/N ratio of 20 and greater. Based on these we infer that the C/N ratio >20 indicate an external contribution of materials, i.e. from the catchment area such as weathering of rocks and plant detritus flowing into the lake. This is apart from *in situ* lake productivity. The sediment texture and the C/N ratio indicate a strong correlation between the elemental composition of C and N also supporting the view that greater than 10 % of the nutrients are terrestrial in origin.

In the lake sediments, twelve species of diatoms were identified (Table 2). Of these, several of them were pinnate in shape compared to centric. The taxa of the genus *Aulacoseira alpigena*, *Encyonema latum, Pinnularia maior, Navicula cryptocephala*, and *Epithemia sorex* were observed to be amongst the most successful and most widely distributed diatoms in the Karlad Lake. *Aulacoseira* species are planktic and need a high amount of wave action to keep them in photic zone. Hence, the abundance of *Aulacoseira* can be interpreted as a time of increased windiness or storminess and this genus also requires a higher amount of silica, as the valves are large and robust; for this reason, it is possible that increased precipitation, through increased storminess, brought silica into the lake by way of runoff from the basin.

Cluster analysis shows that the texture of the sediments is associated with the distribution of the diatoms and nutrients; and these are closely associated with each other (Fig.7). The correlation matrix of the all the measured parameters suggests that sand has a strong significant bivariant relationship with mud. Sand shows a negative correlation with diatom species like *Eunotia pectinalis* and *Encyonema latum* at a level of 95% (0.05%), but mud shows a positive significant correlation with the same diatom species. *Eunotia pectinalis* diatom species has a strong positive correlation with *Encyonema latum* (confidence level of 99%), and also it shows a negative relation with *Pinnularia maior*.

Principal component analysis of all the variables, including sand, mud, TC, TN, CO_3 content, C/N ratio and the diatom species extracted seven components with Eigen values >1.0, which

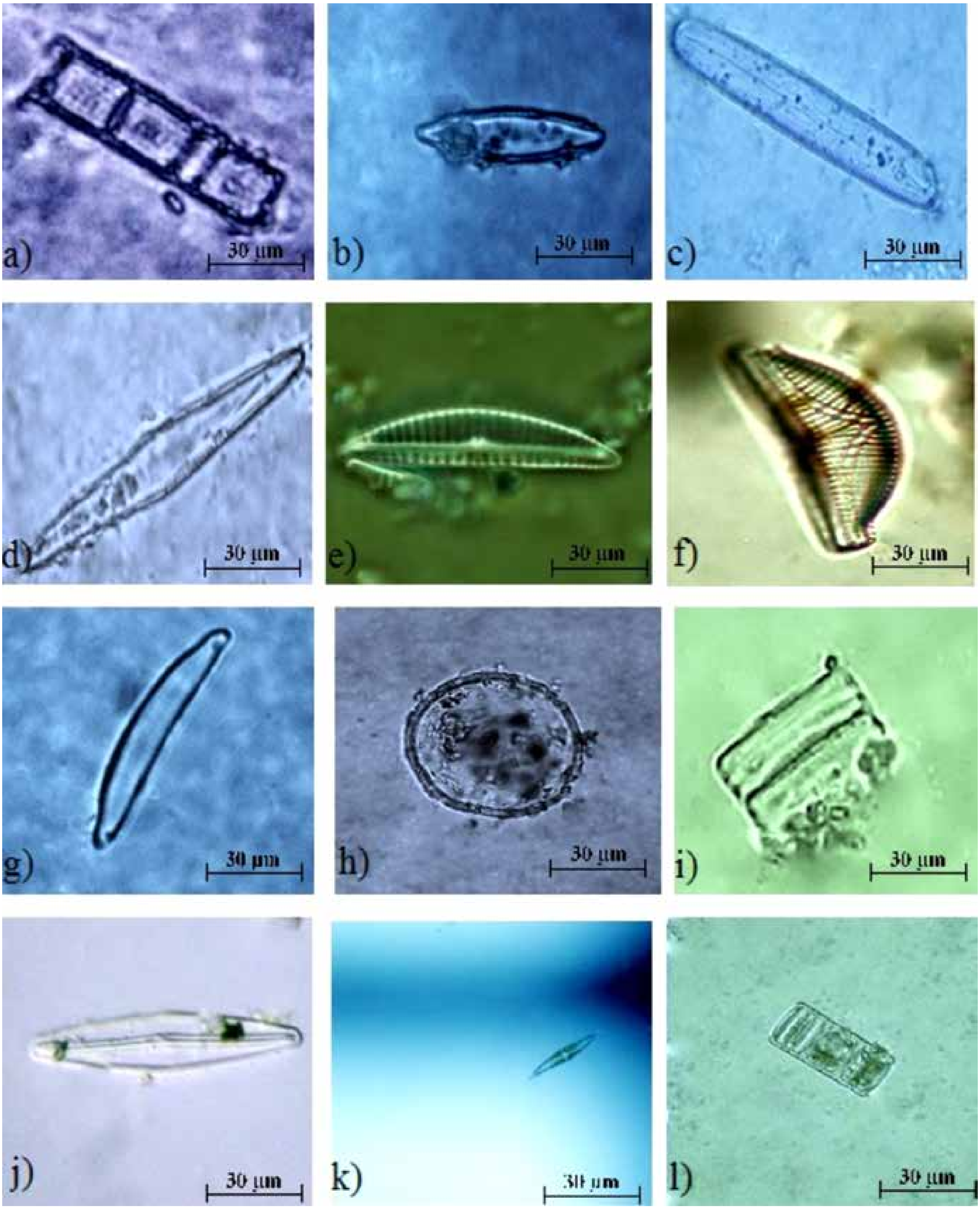

Fig. 5. Identified diatom species **a).** *Aulacoseira alpigena* **b).** *Eunotia pectinalisa* **c).** *Pinnularia maior* **d).** *Cymbella amplificata* **e)**. *Encyonema latum* **f).** *Epithemia sorex* **g).** *Eunotia incisa* **h).** *Cyclotella distinguenda* **i).** *Fragilaria crotonensis* **j).** *Navicula cryptocephala* **k).** *Frustulia amphipleuroides* **l).** *Melosira lineata*

Table 5: Eigenvalues from the PCA for all the parameters.

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.33	22.79	22.79	4.33	22.79	22.79
2	3.17	16.66	39.45	3.17	16.66	39.45
3	2.18	11.49	50.94	2.18	11.49	50.94
4	1.95	10.28	61.22	1.95	10.28	61.22
5	1.59	8.36	69.57	1.59	8.36	69.57
6	1.40	7.39	76.96	1.40	7.39	76.96
7	1.05	5.51	82.47	1.05	5.51	82.47
8	0.87	4.59	87.06			
9	0.65	3.41	90.47			
10	0.58	3.06	93.53			
11	0.45	2.36	95.89			
12	0.41	2.14	98.02			
13	0.23	1.21	99.23			
14	0.13	0.68	99.92			
15	0.01	0.08	99.99			
16	0.00	0.01	100.00			
17	0.00	0.00	100.00			

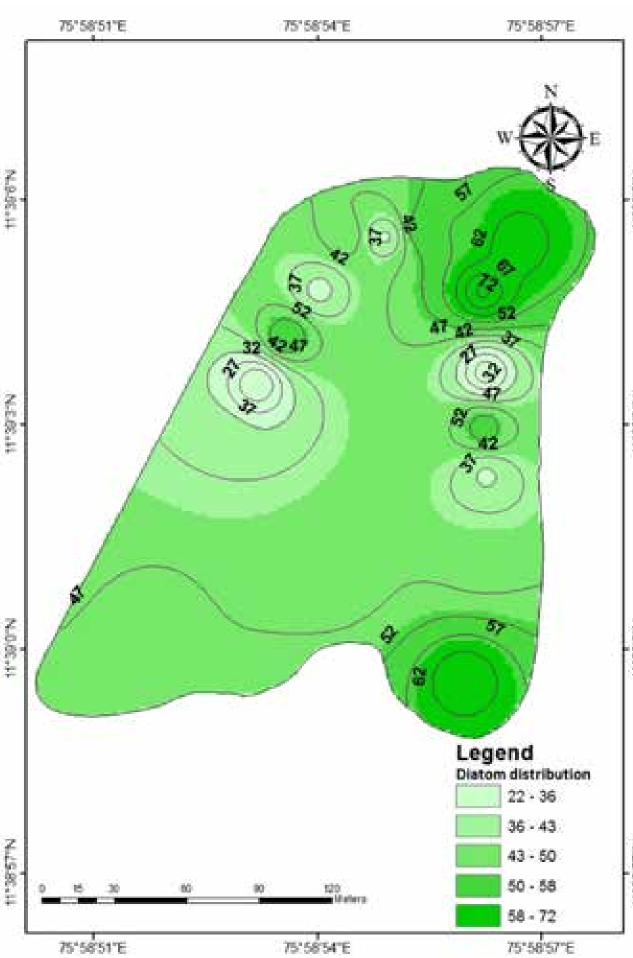

Fig. 6. Spatial distribution map of Diatom abundance in Karlad Lake.

accounted for 82.47% of the variance (Table 5). The first Eigen vector (22.79%) is represented by diatom species like *Epithemia sorex*, *Aulacoseira alpigena*, *Cyclotella distinguenda*, *Eunotia incisa, Melosira lineate* with negative correlation. The second Eigen vector (16.66%) is controlled by TC, and diatoms such as *Pinnularia maior, Encyonema latum, Cymbella amplificata, Frustulia amphipleuroides Fragilaria crotonensis,* CO_3 and C/N ratio showing significant correlation indicating their affinity (Fig. 8). The third Eigen factor accounts for 11.49% of the variance and is controlled by OM and mud, clustering these factors due to mud and its fine particulate structure that has a higher surface area enabling adsorption of organic matter. The fourth Eigen factor accounts for 10.28% of the variance represented by TN and *Eunotia pectinalis* indicating that this diatom species have a greater affinity to TN. All the diatom species and their genera identified in this study are the oldest non-marine diatom forms that date back from the Late Cretaceous Period; however, they continue to occur in recent sediments and are abundant in the Karlad fresh water lake.

CONCLUSIONS

Karlad Lake reveals that the northern and eastern sectors are dominated by sand and central sector is dominated by fine fractions. The sand is deposited due to the high sediment influx from the catchment area, while the fine fractions settled through a deeper water column within the lake. The C/N ratio obtained in this study varies widely from 2.07 to 33.27 indicating terrestrial as well as lake aquatic organic matter source. The taxa of the genus *Aulacoseira, Navicula* and *Pinnularia* are amongst the most successful and widely distributed diatoms maintaining the health of the lake.

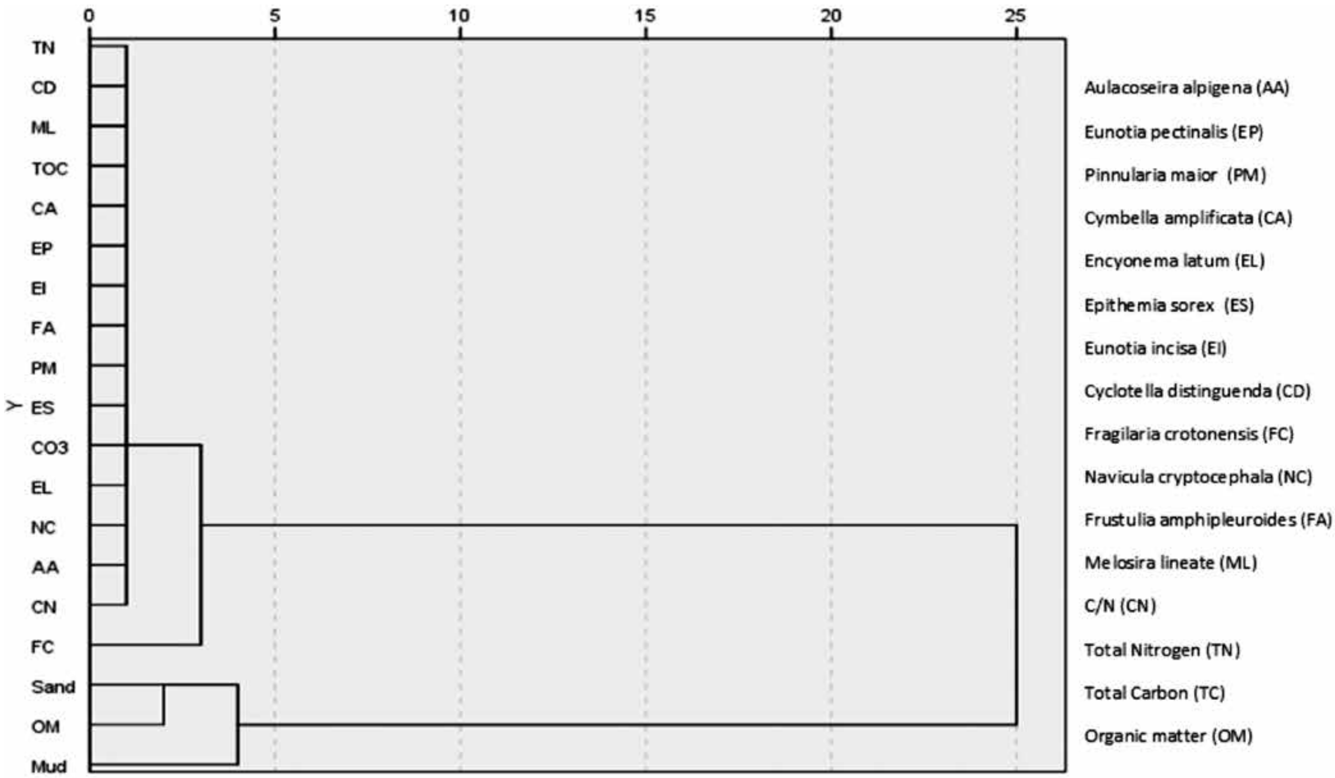

Fig. 7. Cluster analysis of diatoms with all the other parameters.

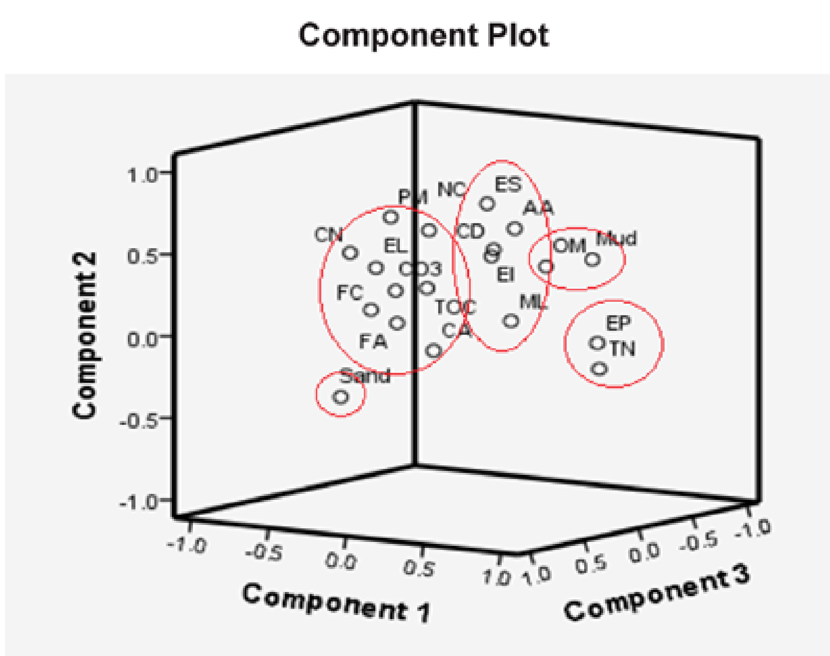

Fig. 8. PCA analysis of diatoms with all the other parameters.

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