Trophic status and ecological studies of the Ambazari Lake, Nagpur, Maharashstra, based on sedimentary diatoms†

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The fossil diatoms and geochemistry of the lake water and sediments of Ambazari Lake, Nagpur were studied. The diatoms assemblages with the characteristics of different salinity regimes and pH have been identified and grouped from the bottom (unit I) to the top (unit III) of the core. Units I–III indicate that the diatom assemblages existed in the distant past. Whereas unit IV (sediments of the grab and top of the core) represents diatoms assemblages from recent time. The diatoms and sedimentary phosphate from the core suggest that the Ambazari Lake was alkaline to circum-neutral and oligotrophic during the past few decades and has transformed to eutrophic conditions in the present time.

Keywords: Diatoms, lake water, sediments, trophic status.

DIATOMS are microscopic, single-celled algae that build complex cell walls of silica. These tiny algae range between 2 and 500 μm in length or diameter. Because of their sensitivity to limnological variables such as nutrient concentration, pH, conductivity and their extraordinary preservation in fossil deposits, diatoms are powerful indicators of environmental changes in aquatic ecosystems[1]. The present communication deals with the study of the past and present trophic status of the Ambazari Lake, Nagpur city, Maharashtra, with special emphasis on the fossil diatoms and geochemistry of the lake water and sediments to understand the ecology. The Ambazari Lake falls under the toposheet number 55 O/4 and lies between lat. 20°35′–21°44′N and long. 78°15′–79°40′E, covering over 15.4 sq. km (Figure 1 *a–d*). Few small streams adjoining the Ambazari Lake bring waste water from the surrounding area, especially drainage from adjacent industrial area. The trophic status of different lakes using diatom taxa has been studied by various workers[1–3]. So far, no work has been carried out on the geochemistry and diatom enumeration from the core and grab sediment samples of lakes in the Nagpur region, except by Humane *et al.*[4]. The present work fills that gap. The sedimentary nitrates and phosphorus values were analysed using X-ray fluorescence (XRF-WDX; Philips, model-PW 2403) at the Indian Bureau of Mines (IBM), Nagpur.

The Nagpur area is geologically comprised of the Archeans, the Gondwana, the Deccan Traps with the intertrappeans, and soil and alluvium[5–7]. The Ambazari area is geologically comprised of the Deccan Traps ranging in age from the Upper Cretaceous to Lower Eocene[7].

Systematic sampling was done by collecting sediment samples (core and grab) and water samples from the Ambazari Lake and its adjoining stream during pre-monsoon period in June 2008. The sediment and water samples were collected at 10 different localities each, following the longest stretch of the lake and connected stream at an interval of about 250 m. The water samples were collected in the plastic water bottles and grab sediment samples in polythene bags with proper numbering and moved to the laboratory for chemical analysis. The grab sediments and water samples were numbered as ASG1–ASG10 and AW1–AW10 respectively. The conductivity and pH of the lake water were measured in the field during sampling. Maceration of the sediment samples was done to study the diatoms using standard techniques[8].

A core sample was collected from the Ambazari Lake (lat. 21°07′33.1″N and long. 79°01′43.5″E) at the junction of the stream and the lake using a 6 ft long PVC pipe. Lithologically, the recovered core varies in colour from top (dark grey with yellow patches to light grey) to bottom (dark grey), with the fine-grained sediments containing fossils like gastropods and other mollusks. On the top organic matter in the form of rhizomes and lake grass is also seen. The total length of the core is 24.8 cm, which was cut into four sub-samples from the top to the bottom at 6.2 cm interval. These four samples were numbered as ASC1 (unit I), ASC2 (unit II), ASC3 (unit III) and ASC4/AS-grab (ASC4 and AS-grab are considered together as unit IV because of the similarity in the geochemistry and the diatom assemblages; Figure 1 *e*). These sub-samples were then used for geochemical analysis and enumeration of diatom taxa. Units I–III include the diatom assemblages that existed in the distant past. Whereas unit IV represents diatom assemblages from the recent sediments recovered as grab samples.

The hydrochemical studies depict that the alkalinity of the lake water ranges between 124 and 250 mg/l (Figure 2). Near the industrial area the alkalinity is about 224 mg/l (AW1), which progressively decreases near the lake. The conductivity does not vary much and ranges between a minimum of 0.33 and 0.64 μmhos/cm. The lower conductivity value is due to less concentration of acid, base and salts[9]. The pH of the stream and lake water is well within the permissible range, i.e. between 7.8 and 8.6 (Figure 3) because of the waste-water treatment by the industries

†REPOSITORY – The diatom slides used in the present study are kept in the Micropalaeontology Laboratory, Postgraduate Department of Geology, RTM Nagpur University, Nagpur.

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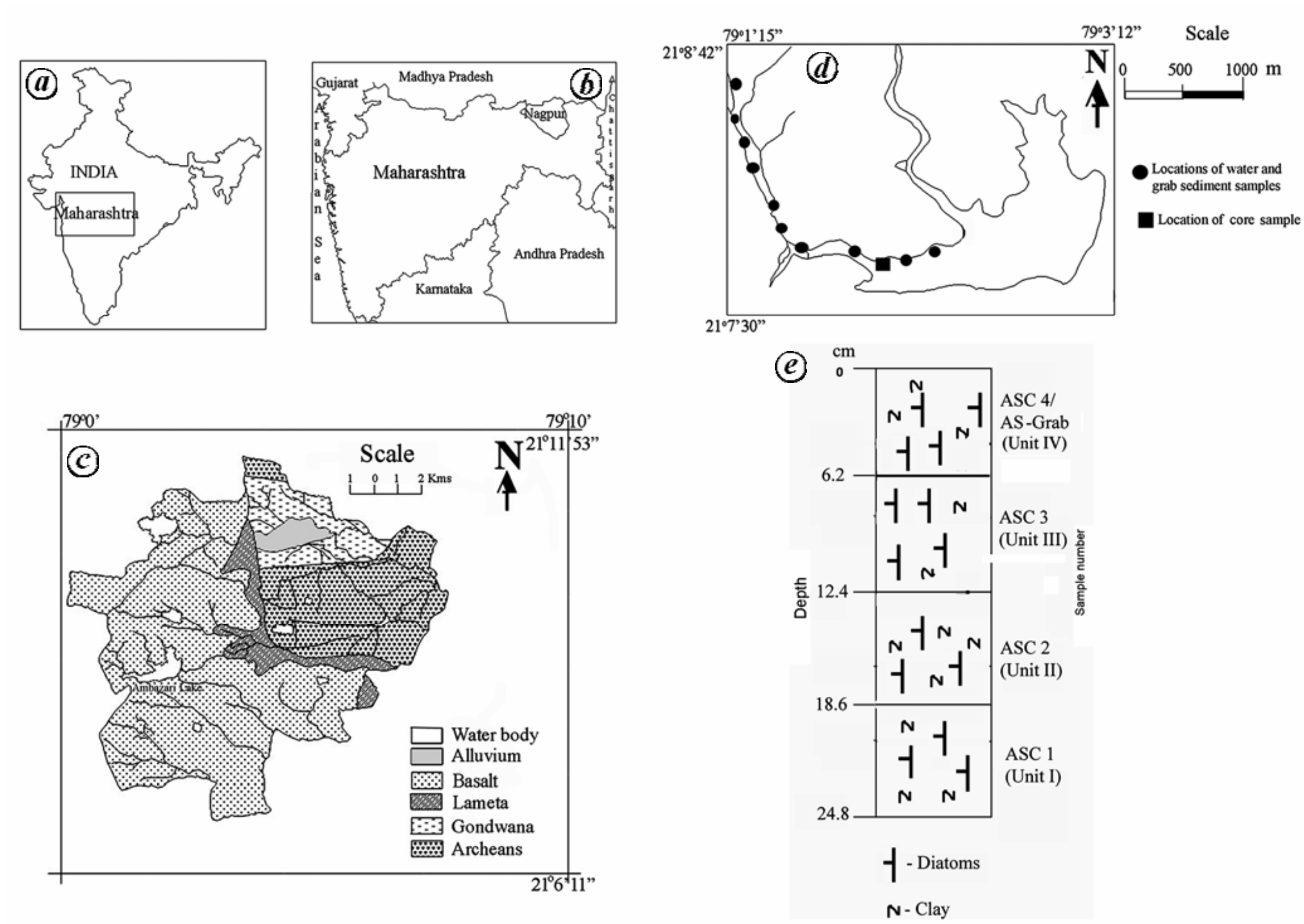

Figure 1. ***a***, Map of India showing the location of Maharashtra. ***b***, Map of Maharashtra showing the location of Nagpur District. ***c***, The Geological map of Nagpur city showing the studied lake (modified after Gwalani *et al.*[5], District Resource Map[6]). ***d***, A sample (water and grab) location map of the Ambazari Lake. ***e***, Schematic diagram of the sediment core recovered from the Ambazari Lake.

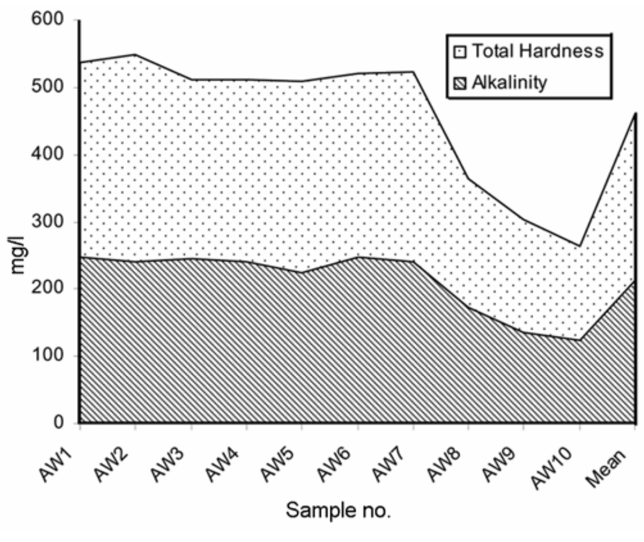

Figure 2. Variation in total hardness and alkalinity of water samples at different locations of the Ambazari Lake.

before its discharge into the lake. Total hardness shows a minimum value of 140 mg/l near the junction where the stream meets the lake and the highest value of 308 mg/l near the discharge site of the industrial effluents (Figure 2). The stream and lake waters have total hardness range well within permissible limits due to treated water being discharged in the lake. The Ca and Mg contents of the stream water range from 70.4 to 27.2 mg/l and 40.06 to 19.53 mg/l respectively (Figure 3) from the stream near the industrial area to the junction of the stream and the lake (Figure 3). Chloride varies from a maximum of 70.8 mg/l to a minimum of 42.4 mg/l, which is much lower than the permissible limit (Figure 3). Similarly, nitrates range between 27.06 and 3.047 mg/l, which is also lower than the permissible limit (Figure 3). However, the nitrogen content in lake water ranges from 0.68 to 6.11 mg/l, indicating eutrophic to hypereutrophic status of the lake (Table 1). The highest nitrogen content was recorded near the industrial area, suggesting that the treated water from the adjacent industries is high in nitrogen content.

The compositional variation of diatom assemblages is used as an indicator of past and present ecological status of the lake (Table 2). In the present work, diatoms have been studied using the classification of Round *et al.*[10]. Overall, 35 species were determined from the grab and

Table 1. Parameters studied in water samples of the Ambazari Lake, Nagpur

Water sample no.	AW1	AW2	AW3	AW4	AW5	AW6	AW7	AW8	AW9	AW10	Mean
	Slightly objectionable										
Conductivity (Mmhos/cm)	0.64	0.64	0.65	0.63	0.63	0.64	0.60	0.45	0.42	0.33	0.56
pH	8.1	7.8	7.8	7.8	8.1	8.1	8.4	8.6	8.5	8.5	8.17
Temperature (°C)	27	27	27	27	28	28	27	28	27	28	–
Alkalinity (mg/l)	248	240	244	240	224	248	240	172	136	124	211.6
Total hardness (mg/l)	288	308	268	272	284	272	284	192	168	140	247.6
Mg content (mg/l)	40.01	27.32	22.44	28.30	29.28	29.28	39.04	23.42	21.47	19.52	28.08
Ca content (mg/l)	70.4	57.6	67.2	62.4	65.6	64	49.6	38.4	32	27.2	53.48
Cl (mg/l)	70.8	56.8	56.8	70.8	56.8	42.4	70.8	56.8	42.4	42.4	56.68
Nitrate (mg/l)	27.06	14.57	21.26	21.82	16.94	8.24	4.53	4.55	3.04	9.10	13.11

Table 2. Correlation of diatom assemblages of grab and core samples with sedimentary phosphorus

Sample no.	P (%)	P (mg/g dry wt)	Diatom assemblage
ASC4/AS Grab (unit IV)	0.10	1.0	*Neidium affine, Hantzschia* sp., *Gyrosigma kuetzingii* Cleve, *Melosira* sp., *Nitzschia* sp. 1, *Nitzschia* sp. 2, *Surirella* sp., *Achanthes* sp., *Melosira granulata* Ralfs, *Frustulia crassinerva* , *Fragilaria construens* Grun, *Nitzschia obtuse* W. Smith, *Nitzcshia recta* Hantzcsh, *Gomphonema intricat*um Kuetz, *Cyclotella antiqua* W. Smith, *Cyclotella* sp., *Cyclotella meneghiania* Kuetz, *Hantzschia* sp.
ASC3 (unit III)	0.14	1.4	*Cymbella tumida* Breb, *Navicula sarcophagus* Gandhi, *Meridion circulare* Agardh, *Rhoicosphenia curvata* Grunow, *Cymbella vidarbhaensis* Sarode and Kamath, *Navicula lamii* Manguin, *Nitzschia* sp. 1
ASC2 (unit II)	0.15	1.5	*Navicula cuspidata* Kuetz, *Rhopalodia parallel* (Grun). O Muell, *Nitzschia obtusa* W. Smith, *Nitzschia* sp. 1, *Fragillaria* sp., *Navicula* sp. 1, *Navicula* sp. 2, *C. antiqua* W. Smith, *Navicula* sp. 3
ASC1 (unit I)	0.09	0.9	*Eunotia arcus* Ehr., *N. sarcophagus* Gandhi

ASC, Ambazari core sediments; AS Grab, Ambazari sediments grab.

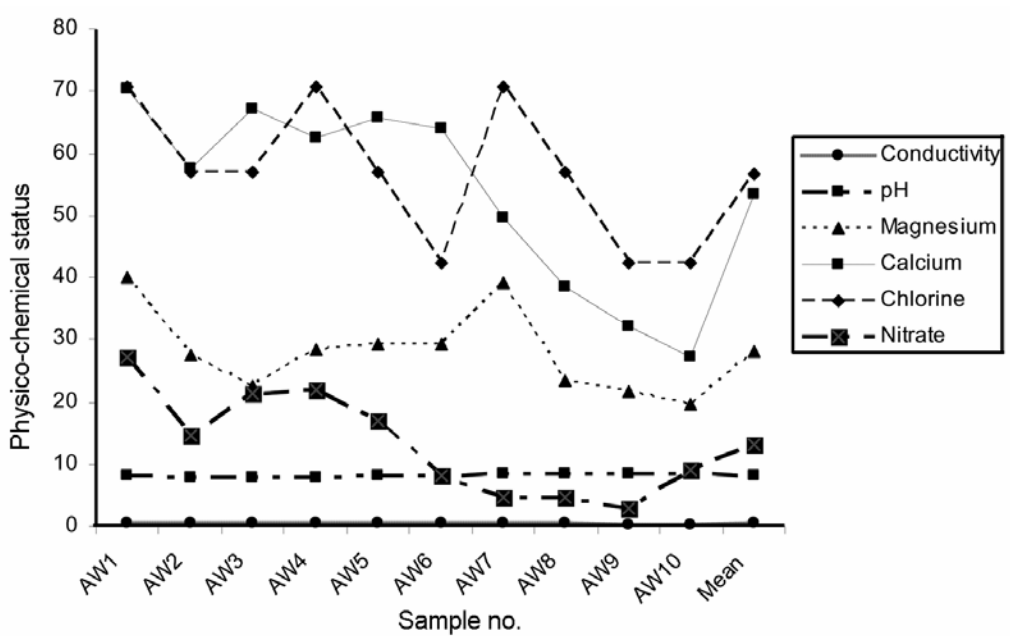

Figure 3. Variation of physico-chemical condition of water samples at different locations of the Ambazari Lake.

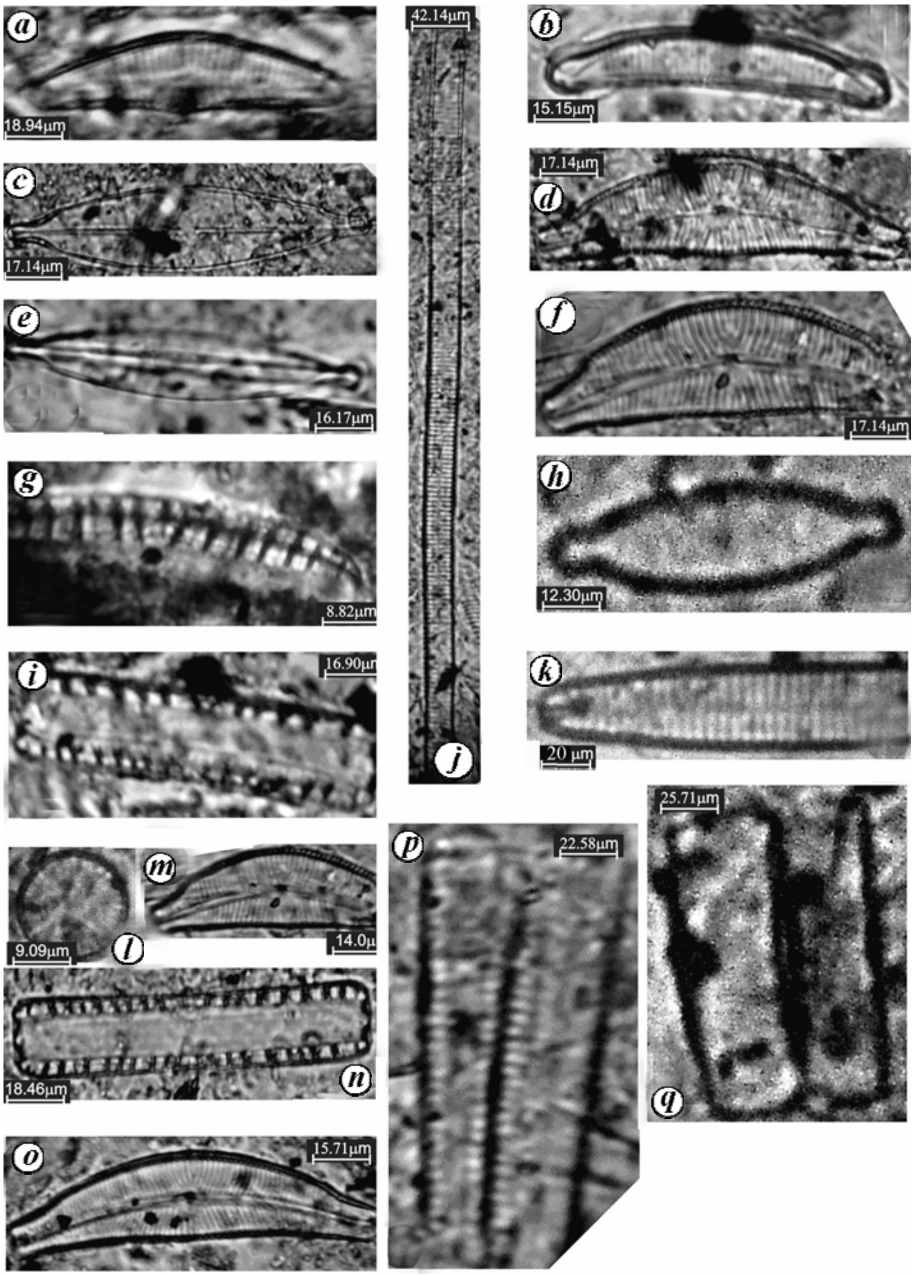

Figure 4. Diatoms from core sediments. ***a***, *Cymbella vidarbhaensis* Sarode and Kamat (PGDG/MF/Diatoms/AL/15); ***b***, *Eunotia arcus* Ehr (PGDG/MF/Diatoms/AL/16); ***c***, *Navicula cuspidata* Kütz (PGDG/MF/Diatoms/AL/17); ***d***, *Cymbella tumida* Breb (PGDG/MF/Diatoms/AL/18); ***e***, *N. cuspidata* Kuetz (PGDG/MF/Diatoms/AL/19); ***f***, *C. tumida* Breb (PGDG/MF/Diatoms/AL/20); ***g***, *Navicula* sp. 1 (PGDG/MF/Diatoms/AL/21); ***h***, *Navicula* sp. 2 (PGDG/MF/Diatoms/AL/22); ***i***, *Navicula sacrophagus* Gandhi (PGDG/MF/Diatoms/AL/23); ***j***, *Nitzschia* sp. (PGDG/MF/Diatoms/AL/24); ***k***, *N. sacrophagus* Gandhi (PGDG/MF/Diatoms/AL/25); ***l***, *Cyclotella meneghiniana* Kütz (PGDG/MF/Diatoms/AL/26); ***m***, *C. tumida* Breb. (PGDG/MF/Diatoms/AL/27); ***n***, *N. sarcophagus* Gandhi (PGDG/MF/Diatoms/AL/49); ***o***, *C. tumida* Breb (PGDG/MF/Diatoms/AL/50); ***p***, *Meridion circulare* (Grev.) Agardh (PGDG/MF/Diatoms/AL/28) and ***q***, *Fragilaria* sp. (PGDG/MF/Diatoms/AL/29).

core samples of the Ambazhari Lake. Species diversity was commonly observed within the genera *Cymbella* (2), *Nitzschia* (6), *Navicula* (6) and *Cyclotella* (3) (Figures 4 and 5). Unit I (24.8–18.6 cm) is marked by the presence of *Eunotia arcus* (6.25%) and *Navicula sarcophagus* (2.60%) (Figure 4 *b*, *i*, *k*, *n*). Diatoms are rare and scarce within this interval. Unit II (18.6–12.4 cm) differs from unit I, with a high diversity of diatom species. This unit is dominated by the genera *Navicula* (15.62%) and *Nitzschia* (9.37%) (Figure 4 *c*, *e*, *g*–*k*, *n*). Out of the nine species in total, one is represented by planktonic raphid pennate diatoms, two by benthic raphid pennate diatoms, three by

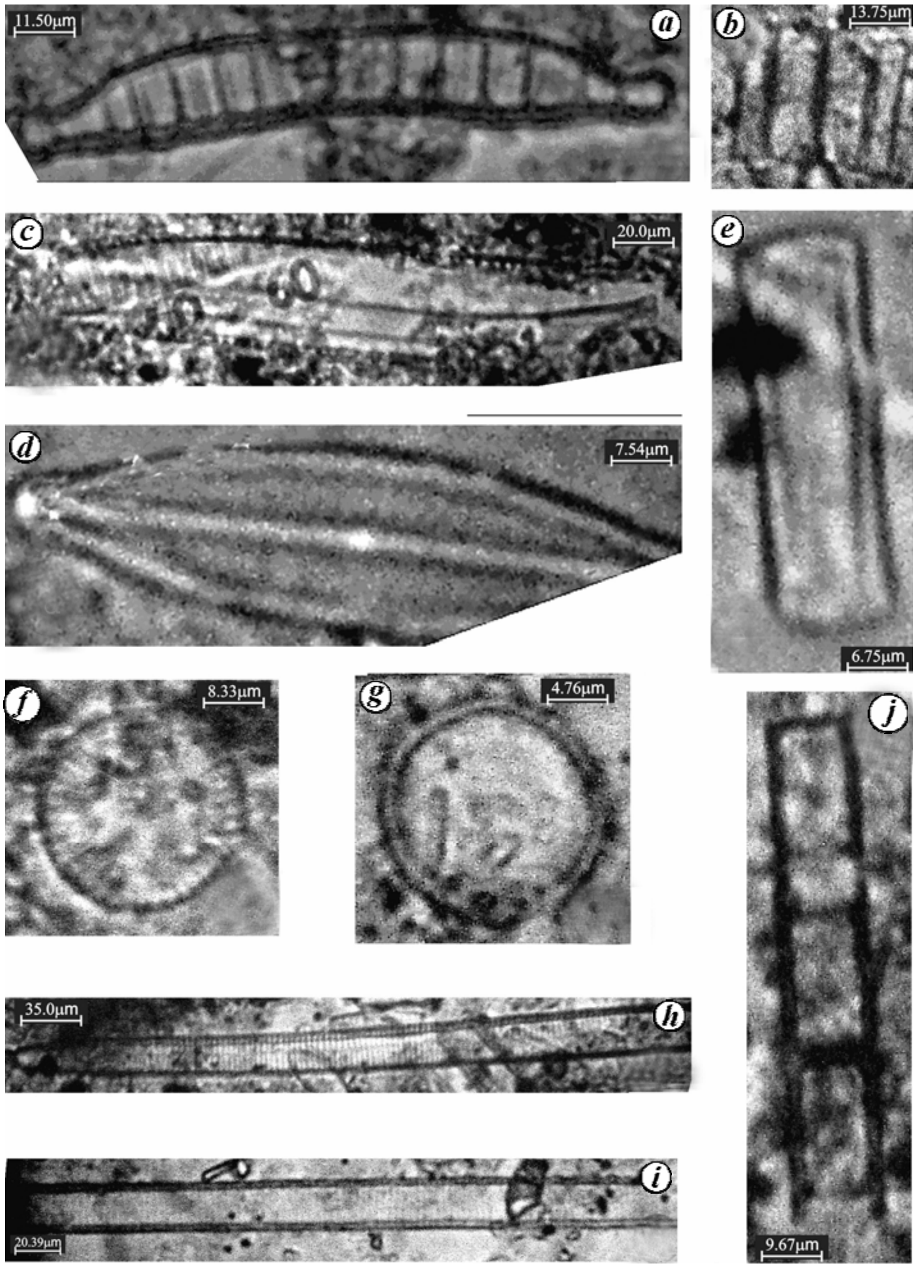

Figure 5. Diatoms from grab sediment samples. ***a***, *Hantzschia* sp. (PGDG/MF/Diatoms/AL/30); ***b***, *Fragilaria construens* (Ehr) Grun (PGDG/MF/Diatoms/AL/40); ***c***, *Gyrosigma kutzingii* (Grun) Cleve (PGDG/MF/Diatoms/AL/41); ***d***, *Neidium affine* (Ehrenberg) Pfitzer (PGDG/MF/Diatoms/AL/42); ***e***, *Melosira* sp. (PGDG/MF/Diatoms/AL/43); ***f***, *Cyclotella meneghiniana* Kütz (PGDG/MF/Diatoms/AL/44); ***g***, *Cyclotella antiqua* W. Smith (PGDG/MF/Diatoms/AL/45); ***h***, *Nitzschia obtusa* W. Smith (PGDG/MF/Diatoms/AL/46); ***i***, *Nitzschia* sp. (PGDG/MF/Diatoms/AL/47) and ***j***, *Melosira granulata* (Ehr) Ralfs (PGDG/MF/Diatoms/AL/48).

planktonic araphid pennate diatoms and a single centric diatom. This unit is followed by unit III (12.4–6.2 cm) with little reduction in diversity from the lower regions. This unit has a total 07 diatom species represented by *Cymbella vidarbhaensis* Sarode, *Cymbella tumida* Breb, *Navicula lamii* Manguin, *Nitzschia* sp. 2, *Navicula sarcophagus* Gandhi, *Meridion circulare* and *Rhoicosphenia curvata* (Figure 4 *a*, *k*, *p*). Of these, three species are of planktonic raphid pennate diatoms, two of planktonic araphid pennate diatoms and one each of benthic raphid and benthic araphid pennate diatoms. Unit IV is represented by the recent diatom assemblage recovered from the bottom of the lake as grab sediment samples (6.2–0 cm). In this unit, 17 species were observed: *Cyclotella antiqua*, *Cyclotella* sp., *Cyclotella meneghiniana*, *Nitzschia recta*, *Hantzschia* sp., *Gyrosigma kuetzingii*, *Gomphonema intricatum*, *Nitzschia obtusa*, *Fragilaria construens*, *Nitzschia* sp. 1, *Nitzschia* sp. 2, *Melosira* sp.,

Table 3. Distribution of diatoms in core and grab samples

Distribution of diatoms (pennate and centrales) in core and grab samples		Distribution of pennates (raphid and araphid) in core and grab samples	
Diatom		Pennate	
Pennate	Centrale	Raphid	Araphid
42	5	10	23
89.4%	10.6%	30.30%	69.69%

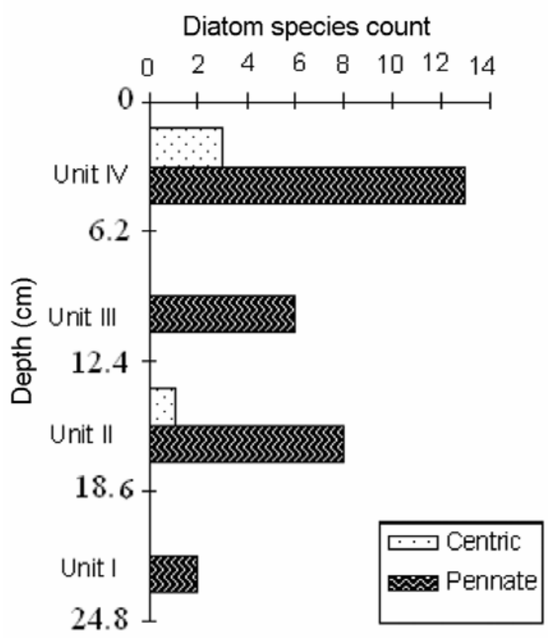

Figure 6. Distribution of centric and pennate diatoms with varying depth (units).

Surirella sp., *Achnanthes* sp., *Melosira granulata*, *Frustulia crassinervia* and *Neidium affine* (Figure 5 *a–j*). Of these 17 species, two belong to raphid planktonic, nine to araphid planktonic pennate diatoms, and three each to benthic araphid pennate and planktonic centric diatoms.

The bottom most core sample is represented by unit I, which includes *E. arcus* and *N. sarcophagus*. The presence of *E. arcus* indicates exclusively acidophilic condition[2], with pH ranging between 5.5 and 7.0. This species also indicates the oligotrophic condition of lakes at the time of deposition of sediments of unit I. The meagre quantity of diatoms in this unit indicates less productivity of the lake at that time. This is also evident from the absence of centric species and presence of only the benthic forms (Table 3). Such a low overall diversity amongst diatoms in unit I indicates stressful conditions (hyper-oligotrophic). The total sedimentary phosphorus in this unit is 0.9 mg/g. The diatom assemblage of unit II indicates oligotrophic to eutrophic condition; particularly, *Rhopalodia* sp. is bound to oligotrophic calcareous waters and is able to bind to nitrates. This is also evident from the actual observed value of nitrates in the sediments, which is lesser than in units I and III. The presence of *C. antiqua* indicates alkaline to circum-nuetral condition. Thus, the pH of the lake has increased with the passage of time. The total sedimentary phosphorus is about 1.5 mg/g. In unit III, the centric : pennate ratio suggests less productive status of the lake[11]. The presence of *Nitzschia* sp. indicates meso-eutrophic condition, which is evident from double the number of planktonic forms than the benthic. The total sedimentary phosphorus in this unit is 1.4 mg/g. In unit IV, i.e. recent grab samples, the highest number of diatom species (about 17) indicates the more productive state of Ambazari Lake in the recent time with the planktic : benthic ratio of 14 : 03, suggesting eutrophic condition of the lake. The presence of *Cyclotella* sp. indicates alkaline to circum-neutral and oligotrophic to eutrophic condition of the lake[11], which is also evident from the pH (about 7) in most of the lake water samples. *G. intricatum* favours oligotrophic condition, whereas *Fragillaria* sp. indicates alkaline eutrophic conditions. The total sedimentary phosphorus in this unit is 1.0 mg/g. The centric to pennate diatom ratio has been changing since the last few decades (Figure 6). Unit I representing the oldest studied sediments of the lake, shows total absence of centric diatoms, contrary to that of pennate. This trend has changed to some extent with the presence of some centric to pennate diatoms in unit II. Again, in unit III, the centric diatoms were absent in contrast to some pennate diatoms. Whereas in the present-day grab sediments, i.e. unit IV centric diatoms have increased in numbers, with the highest abundance of pennate. The productive environment is based on the greater number of centric diatoms along with more pinnate (www.geologyrocks.co.uk). The study of sediment samples of the Ambazari Lake shows the presence of few centric diatoms in some units to total absence in others. Thus, it indicates stressful environments of the Ambazari Lake since the last few decades caused by industrial effluent discharge. Likewise, the sedimentary phosphorus also varies from the older unit to younger one, supporting the variation in the palaeotrophic status of the lake (Figure 7). The planktonic forms are more common in eutrophic lakes (www.geologyrocks.co.uk). The ratio of planktonic to benthic diatoms in the Ambazari Lake has been changing since the last few decades (Figure 8). The oldest unit

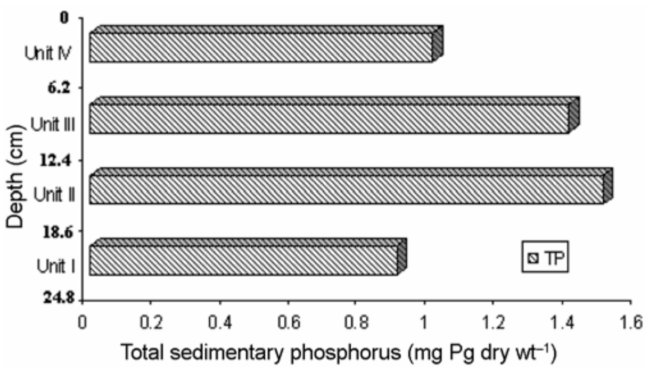

Figure 7. Variation of total sedimentary phosphorus with depth.

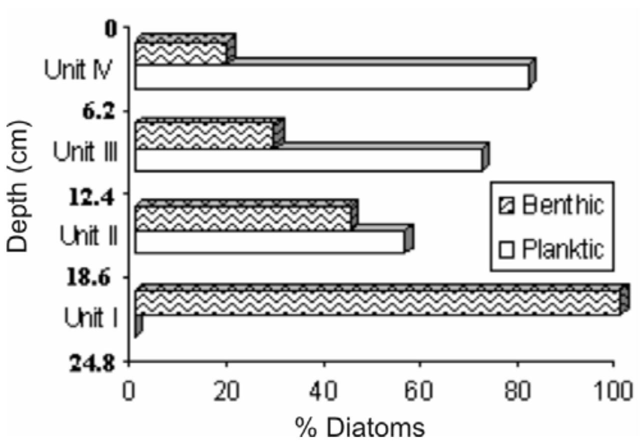

Figure 8. Variation of planktonic and benthic diatoms with depth.

(unit I) shows dominance of benthic diatoms with few plantonic diatoms. The planktic diatoms increased several fold with the sudden decrease in benthic forms in unit II. Unit III shows further decrease in the number of benthic diatoms with increase in the planktonic diatoms. Unit IV shows minor decrease in the benthic diatoms with abundance of planktonic forms again in the present condition. Thus, the planktonic to benthic ratio of diatoms indicates alkaline to circum-neutral and oligotrophic status of the Ambazari Lake since the last few decades to the present-day eutrophic condition.

The alkalinity and pH value of lake water samples clearly depict that the water of the stream that carries the discharged, treated water from the industrial zone is hard and that hardness decreases towards the lake and supports the alkaline with alkalibiontic diatom species, suggesting healthy aquatic growth range. Hence, it can be concluded that the lake water ranges from moderately hard to hard water condition and the discharged water from the industrial zone makes it very hard.

Therefore, it can be summarized that the Ambazari lake was less productive some decades ago, with less supply of nutrients. However, due to urbanization, the lake became more productive with human-induced pollutants through industrial effluents. At present, the lake has eutrophic status and is at the verge of degradation. Further studies are needed for micro-level identification of age and the palaeotrophic status based on diatom transfer function and radiometric dating (^{210}Pb and ^{137}Cs).

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