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RESPONSE OF SEDIMENTARY DIATOMS AND PHYTOLITHS TO WET/ DROUGHT EVENTS SINCE LAST ~ 100 YEARS IN THE CATCHMENT OF GHODAJHARI LAKE, CHANDRAPUR DISTRICT, MAHARASHTRA: A PALEOLIMNOLOGICAL APPROACH

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ABSTRACT

The core sediments of the Ghodajhari Lake of the Chandrapur District, Maharashtra has disclosed 50 species of diatoms belonging to 23 genera in the present findings. The Ghodajhari Lake revealed the common planktonic diatoms, such as *Aulacoseira granulata*, *Discostella stelligera* and *Cyclotella meneghiniana* and benthic diatoms such as *Nitzschia microcephala*, *Amphora ovalis* and *Pinnularia abujensis*. The variations in diatom diversity of the lake would be in response to changes in dry and wet period that existed in its watershed. The diversity in the lakes is mainly noticed during the wet period. Thus, relatively small size diatoms also indicate dry periods/ less rainfall. The dominant phytolith types are cross, dumbell and trapezoid. The data of diatom size variations and phytolith types of this lake relatively supports the actual precipitation confirming the existence of relationship of mean linear diameter (MLD) of diatoms with the wet and dry periods over the studied region.

Keywords: Diatoms, phytoliths, paleocology, Ghodajhari Lake, Maharashtra.

INTRODUCTION

Diatoms have been very commonly used as the vital paleoecological and paleoclimatic proxy due to their sensitivity to changes in the physico-chemical conditions of waters (Smol, 1988; Gasse *et al.*, 1989; Fritz *et al.*, 1991; Smol *et al.*, 1991). The study on the changes in the ecological status of lakes owing to the myriad human activities encompass a relatively short history such as initial studies (Stockner and Benson 1967; Digerfeldt, 1972), trophic state (Agbeti and Dickman, 1989; Hoff *et al.*, 2014; Saros *et al.,* 2014), acidity (Battarbee, 1986), climate (Halfman *et al.*, 1992; Ali *et al.*, 2018), lake development (Whitehead *et al.*, 1989), phosphorus concentrations (Hall and Smol, 1992) and anthropogenic effects (Schmidt and Simola, 1991; Dubois *et al.*, 2017). The concentrations of biogenic silica in the sediments can be used to interpret the trophic status and productivity of the water bodies including the extent of isolation received by the region (Qiu *et al.*, 1993; Colman *et al.*, 1995). Paleolimnological techniques, using diatom assemblages as biomonitors of aquatic change, provide an effective approach to supply missing historical data (Battarbee *et al.*, 1990: Dixit *et al.*, 1992a; Charles *et al.*, 1994; Dixit and Smol, 1994; Randsalu-Wendrup *et al.,* 2016). The sedimentary diatom assemblages have been used successfully to evaluate water quality trends resulting from lake acidification and concentrations of dissolved organic carbon (DOC), lake eutrophication and salinity associated with climatic changes (Anderson *et al.*, 1993, Christie and Smol, 1993: Hall and Smol, 1993). Diatoms based inference models for phosphorus reconstructions have been developed and are widely used (Anderson *et al.*, 1993; Bennion *et al.*, 1995). The diatoms temperature transfer functions have been developed from several regions of the globe (Bigler and Hall, 2002). In a few studies, diatoms have been applied to estimate Holocene-scale patterns of temperature change (Korhola *et al.*, 2000; Joynt and Wolfe, 2001). The increase in chemical nutrient compounds like phosphorous and nitrogen is commonly observed in various lakes of India. The trophic status of the lake using the diatoms taxa were studied by various workers (Hall and Smol, 1999 and Fritz *et al.*, 1993; McGowan *et al.*, 2016; Jenny *et al.*, 2016; Mills *et al.*, 2017; Okech *et al.*, 2018).

Gonzalves (1947) was the pioneering worker on diatoms from the Maharashtra State. Thomas and Gonzalves (1965) recorded 98 diatoms from the eight hot springs of Maharashtra. Sarode and Kamat (1979, 1980a, b, c, 1983a, b, c) gave detailed description of 227 species of diatoms for the first time from Vidarbha and Marathwada regions of the Maharashtra state. Nandkar *et al.* (1983) described diatoms from sewage and oxidation ponds of Nagpur. Barahate and Tarar (1981, 1983) have recorded a few diatoms from Khandesh (Now Jalgaon region of Maharashtra). Sarode and Kamat (1984) described freshwater diatoms of Maharashtra in a monograph. Gandhi (1998) reported 129 species of freshwater diatoms from the Chandola Lake of Gujarat. Prasad *et al.* (1984) have reported some species of diatoms from the hot spring of the Ladakh region. Venkatachalapathy *et al.* (2013 and 2014) have investigated diatoms and water quality assessment of Yercaud Lake in Tamil Naidu and Waishen Rivers and Loktak Lake of Manipur. Logannathan *et al.* (2014) have studied distribution of fresh water diatoms of the Perumal Lake, Tamil Naidu. Humane *et al*. (2009, 2010b, 2012a, 2012b, 2015a and 2015b) and Humane and Humane (2015a, b and c) have reported various diatom taxa from the different lakes of the central India and analyzed their trophic status. Humane *et al.* (2010a) have studied the environmental implication of the sedimentary diatoms of the Vena River.

The mid rib of the aquatic grasses is usually associated with the microscopic structures made up of opaline silica, called as phyoliths (Singh *et al.,* 2007; Pearsall, 2000; Piperno *et al.,* 1998;

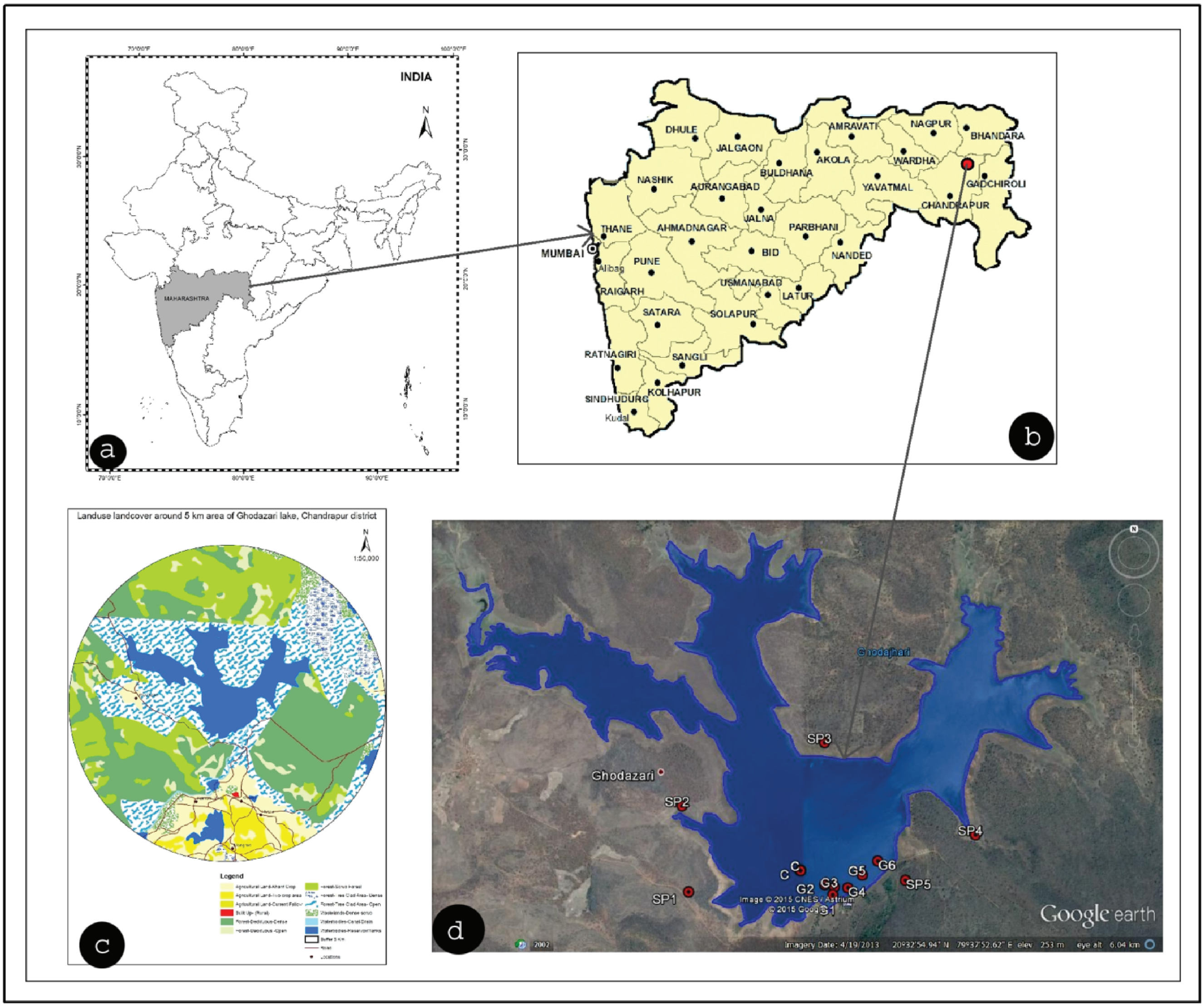


Fig. 1: a) Map of India showing the location of the Maharashtra state, b) Map of the Maharashtra State showing the location of Chandrapur District and location of Ghodajhari Lake, c) Land use land cover in the catchment area of the Ghodajhari Lake, Chandrapur District and d) Google image of Ghodajhari Lake showing location of Core Sample (c).

Twiss, 1992). The variations in the morphological characteristic features of the fossil phytoliths belonging to the subfamilies of Poaaceae (covering C3 grasses: cool season with high soil moisture and C4 grasses: warm season with low soil moisture) are used as the proxy indicators of paleoclimatic and monsoonal changes due to their sensitivity to ecological deviations (Singh *et al.,* 2007; Kajale and Eksambekar, 2001). Thus, monsoonal changes may be interpreted on the basis of variations in the relative percentage of different morphological patterns of phytoliths. In the present research, an attempt has been made to investigate the responses of diatoms associated with phytoliths to the changing wet and dry events in the catchment area of the Ghodajhari Lake.

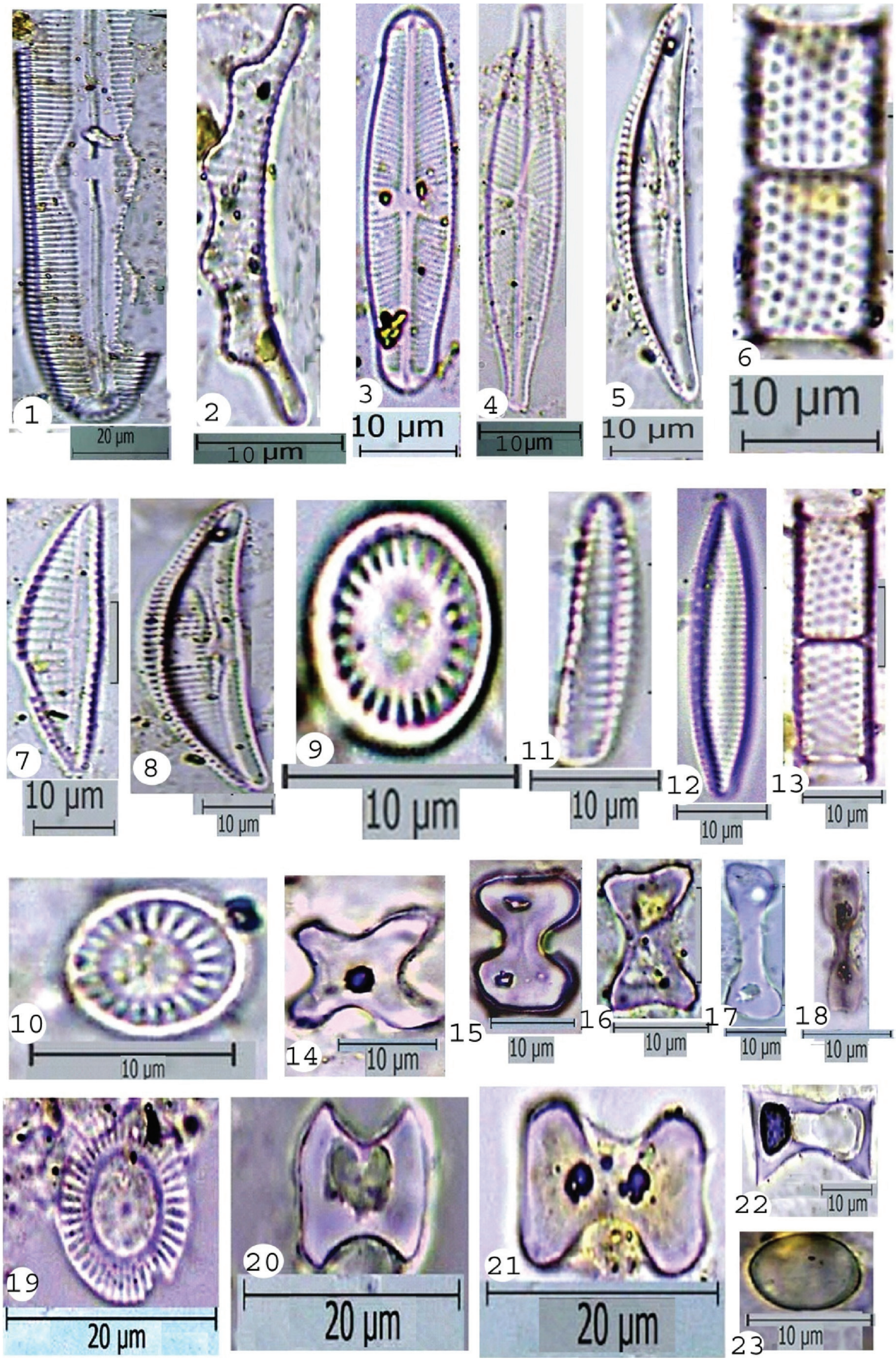
STUDY AREA

The Ghodajhari Lake of the Nagbhid Taluka, Chandrapur District falls in the eastern part of the Maharashtra state covering

EXPLANATION OF PLATE I

Fig. 1. ***Pinnularia abunjensis*** (Valve view) (GLC-68), Fig. 2. ***Eunotia camelus*** (Valve view) (GLC-68), Fig. 3. ***Sellaphora pupila*** (Valve view) (GLC-68), Fig. 4. ***Navicula radiosa*** (Valve view) (GLC-67), Fig. 5. ***Amphora ovalis*** (Valve view) (GLC-68), Fig. 6. ***Aulacoseira granulata*** (Girdle view) (GLC-69), Fig. 7. ***Amphora normanii*** (Valve view) (GLC-68), Fig. 8. ***Amphora ovalis*** (Valve view) (GLC-68), Fig. 9. ***Discostella stelligera*** (Girdle view) (GLC-67), Fig. 10. ***Cyclotella ocellata*** (Girdle view) (GLC-68), Fig. 11. ***Gomphonema gracile*** (Valve view) (GLC-51), Fig. 12. ***Navicula cryptocephala*** (2) (Valve view) (GLC-67), Fig. 13. ***Aulacoseira granulata*** (Girdle view) (GLC-66), Fig. 14. Phytolith (cross-type)(GLC-28), Fig. 15. Phytolith (dumbell) (GLC-67), Fig. 16. Phytolith (Trapezoid) (GLC-54), Fig. 17. Phytolith (dumbell) (GLC-41), Fig. 18. Phytolith (dumbell) (GLC-41), Fig. 19. *Discostella stelligera* (Valve view) (GLC-67), Fig. 20. Phytolith (cross-type) (GLC-63), Fig. 21. Phytolith (dumbell) (GLC-8), Fig. 22. Phytolith(Trapezoid) (GLC-12), Fig. 23. Chrysophycean algal cyst (GLC-16)

Plate I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an area of about 5.366 sq. km. The study area falls between the latitude N19^{o} 5'to 20^{o} 35' and longitude 79^{o}6' to 79^{o}53'E (Fig. 1a-d). It has a circumference of approximately 30-32 kms. It has a small embankment of 731.1 m. long, 3.6 m width and 20.04 m high. The average depth of the lake is 13.5 m. The catchment area of the Ghodajhari Lake is about 90.65 Km^{2}. The Ghodajhari Lake is a part of the Wainganga Sub-Basin of the Godavari Basin.

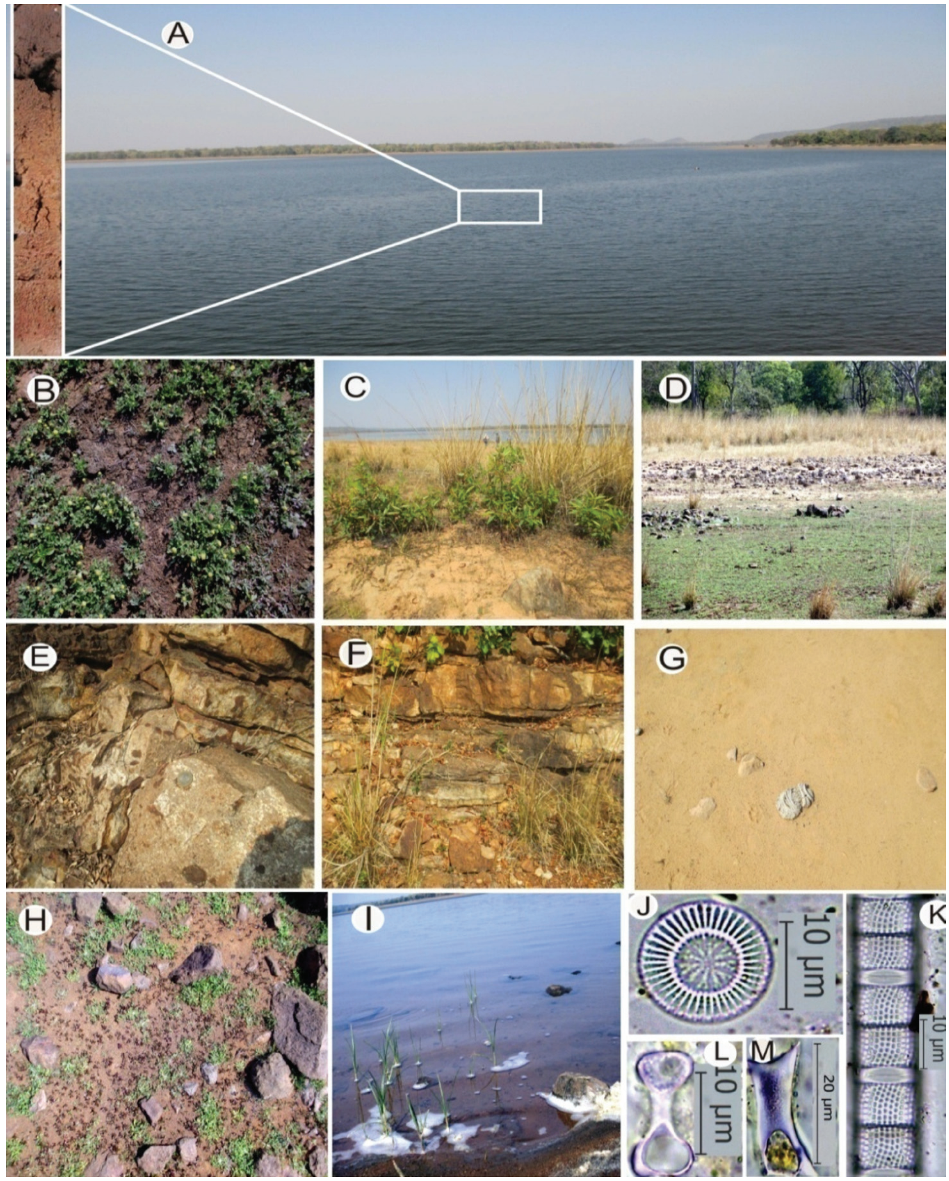

Fig. 2: A) A view of Ghodajhari Lake with 49 cm long core (a), B) moist land near the lake with aquatic herbs, C) variety of grasses grown on the sandy soil along the lake shore, D) variation in the type of vegetation along lake shore, E) sandstones exposed near the lake, F) Weathered sandstones, G) fine sand of the lake shore with shell fragments, H) herbs grown on the sandy soil near the lake shore, I) Polluted water of the lake near shore**,** J) ***Discostella stelligera***, K) ***Aulacoseira granulata,*** ***L***) Dumbell shaped Phytolith and M) Trapezoidal Phytolith

LAND USE PATTERN

The land use pattern of the Ghodajhari Lake indicates that the area around it is mostly dominated by the open forest tree clad area, dense forest tree clad area, dense deciduous forest, open deciduous forest, scrub forest followed by small portion of agricultural land-fallow land, agricultural land with two crops and agricultural land with Kharif crop. The land use map also shows that there is just a little patch of Rural Built Up in entire area (Fig. 1c). The Ghodajhari Lake alongwith the adjoining lithology, agricultural lands, animals excrements, soils, aquatic plants, vegetal matter, diatoms and other microfossils are shown in figure 2.

GEOLOGICAL SETTING

The Ghodajhari Lake is mainly surrounded by the sandstones of the Neoproterozoic age belonging to the Vindhyan Super group and granite gneiss with magmatic gneiss (crystalline and older metamorphic) and Deccan Trap Basalt (DRM, 2000). The Vindhyan Supergroup comprises of pinkish red to light red, fine to medium grained, hard compact sandstone of Neo- proterozoic age (1600-570 my.) The youngest formation studied in the area is laterite of Recent to subrecent age of less than 1 Ma (Ravindra Kumar, 1991). The small patches of laterites were observed nearby the lake (DRM, 2001).

MATERIALS AND METHOD

Sample Collection

In January 2013, a sediment core was recovered from the Ghodajhari Lake using a gravity corer. The total length of the core recovered from the Ghodajhari Lake was 49 cm (Fig. 3). The color of the entire core is from dark brown to light brown. The top of the core section is having dark color indicating the presence of comparatively high percent of organic matter in this layer. Due to the sandy texture the bands or streaks are not clearly visible; however, some fine dark streaks are visible with lense at the depth of 33 cm to 40 cm. The overall grain size of the core is silty sand. The entire core is marked by the presence of small and big air pockets throughout its length. The sediment core shows high porosity in the top layers and declines from the top to the bottom. However, few fragments of rotten plant root/stem are also seen in top 20 cms which were sampled separately. The top 10 cm sediment core was sub sampled at the intervals of 0.5 cm each, while remaining part of the sediment core was cut at the interval of 1 cm each. Few shell fragments have also been observed as macrofossils. The presence of the porosity in the sediment core may be because of presence of comparatively more concentration of sands.

Sample Processing

For making a diatom slide, the prepared or macerated samples were taken in a dropper and put on a cover slip of 22mm x 40mm and spread by needle and allowed to dry naturally. After drying the cover slips were mounted on the glass slides using DPX mountant and again dried for few days. After the slides were perfectly dried the slides were observed under Leica DM-350 Biological Research Microscope using 40x, 63xand 100x (oil immersion) magnifications and photographed. Calibrated scale was also given on one side of the microphotographs of diatoms to know the size of the diatom. After microphotography, the plates of diatoms were prepared followed by identification up to the species level. Each slide was traversed horizontally and at least 300 valves were counted. In order to avoid the over estimation, only valve > 50% intact were counted. For the elongate species, only one end of the frustules were counted and diatoms were identified up to species level (Battarbee, 1986). The systematic classifications and identification of diatoms proposed by Gandhi (1998), Round *et al.* (1990) and John (2014) have been followed in the present research work. From the Ghodajhari Lake, three diatom zones and six sub-zones were identified for major species abundance using constrained cluster analysis (CONISS) with the computer program Tilia, (Grim, 1991). The diatoms diversity can be measured with the effective number of taxa in every sample (Hill, 1973). The diversity of diatoms for each sample i.e. Hill's N2 of the Ghodajhari Lake was computed by means of the program C2 1.5 (Juggins, 2007).

Age Determination using ^{210}PB Dating

The core sediments of the Ghodajhari Lake were powdered up to -170 mesh size for the ^{210}Pb dating. This powdered sediment samples were analyzed using Alpha Spectrometry, Canbera (make) from the My Core Scientific Laboratory, Canada (Kamble, 2015, Table 1).

RESULT AND DISCUSSION

Diatom Analysis

The present research work has divulged 50 diatom species belonging to 23 genera from the core sediments of the Ghodajhari Lake of the Chandrapur District, Maharashtra. Some of the selected diatom taxa along with phytolith forms and algal cyst are shown in plate I (figs. 1-23). Out of total 50 diatom taxa found in the Ghodajhari Lake core, 21 species have attained a maximum abundance of >1% in at least one sample (Fig. 4). The present Diatom assemblages were categorized as 1) Planktonic diatoms, such as *Aulacoseira granulata* (~ 0.22 – 46.25%), *Discostella stelligera* (~3.72%) and *Cyclotella meneghiniana* (~ 2.63- 2.69%) and with benthic diatoms such as *Nitzschia microcephala* (~ 0.12 – 28.44%), *Amphora ovalis* (~ 4.29- 24.98%) and *Pinnularia abujensis* (0.95 – 3.34%). The planktonic diatoms were dominated by *A. granulata* whereas benthic diatoms were dominated by *Nitzschia microcephala, Amphora ovalis* and *Pinnularia abaujensis. A. granulata* was abundant during ~ 1996-2014 A.D. and progressively increased on the top of the core (~1962AD and above), whereas in contrast *A. ovalis* and *Nitzschia microcephala* were preponderant during ~ 1953 to 1972AD. The phytolith forms such as cross types (Pl. I, Fig. 14), bilobate (Pl. I, Figs. 15-18, 21), collapsed saddle (Pl. I, Figs. 20, 22) and cysts (Pl. I, Fig. 23) was very dominating during the entire history of the sediment core of the Ghodajhari Lake.

Zone I (49 - 34 cm: ~1924 -1950 AD) was devoid of major diatom presence except meager presence of *Cyclotella ocellata* (~4.22% on average) during ~ 1942-1943AD. It is predominated by the presence of various types of phytoliths (~95.78% on average). Zone II (34 – 10 cm: ~ 1950-1994 AD) was divided into three sub zones. Zone II-a (34 -27 cm: ~ 1950

Table 1. Results of ^{210}Pb dating from the core sediment samples of Ghodajhari Lake.

Section Top (cms)	Depth of core bottom (cms)	Precision 1 STD%	Interpolate Pb-210 (Bq/g)	Pb-210xs (Bq/g)	Pb-210xs in the core (Bq/cm2)	Mass Pb-210xs (Bq)	Age at top of section (year)	CRS Sed. Accum. Rate (g/m2/yr)	CV in SAR %	STD in date (years)
2014.3	14-Apr-14									
0.0	0.5	4.7	0.077	0.071	5.229	69.816	2014	4383	11	0
0.5	1.0	5.2	0.091	0.085	3.642	64.587	2012	3394	10	0
1.0	5.0		0.051	0.045	18.144	60.945	2010	6027	Interpolated	
5.0	5.5	14.0	0.011	0.005	0.203	42.800	1999	35920	112	18
5.5	6.0	11.3	0.011	0.005	0.219	42.597	1998	36784	113	18
6.0	10.0		0.017	0.011	4.216	42.378	1998	16650	Interpolated	
10.0	10.5	8.6	0.024	0.018	0.753	38.162	1995	9704	36	7
10.5	11.0	10.6	0.015	0.009	0.406	37.409	1994	18777	67	13
11.0	21.0		0.016	0.010	9.561	37.003	1994	16817	Interpolated	
21.0	22.0	9.6	0.017	0.011	0.967	27.442	1984	11395	56	17
22.0	31.0		0.020	0.014	11.027	26.475	1983	8226	Interpolated	
31.0	32.0	9.2	0.024	0.018	1.423	15.448	1966	3835	35	17
32.0	41.0		0.016	0.010	7.917	14.025	1963	6592	Interpolated	
41.0	42.0	13.4	0.007	0.001	0.053	6.109	1936	26953	563	441
42.0	48.0		0.014	0.008	3.480	6.055	1936	3402	Interpolated	
48.0	49.0	7.9	0.021	0.015	1.287	2.575	1908	773	40	43
			0.021	0.015	1.287	1.287				

– 1963 AD) was distinguished by dominance of the benthic diatom species *Nitzschia microcephala* (~28.44%, on average), *A. ovalis* (~24.98%, on average). Other abundant species were *G. pumilum* (~12.10% on average), *G. gracile* (~6.46% on average) and *Achnanthidium minutissimum* (~5.95% on average). The planktonic diatom species with abundance in this zone was represented *by C. meneghiniana* (~2.69% on average) and *A. granulata* (~0.22% on average). The average ratio of planktonic and benthic taxa (P/B) was 0.036 in this zone. Zone II-b (27 – 22 cm: ~ 1963 - 1971 AD) show the initial presence of planktonic diatom taxa, *A. granulata* (~11.92% on average) and minor appearance of two benthic diatoms *Encyonema minutum* (~3.25% on average) and *Pinnularia abaujensis* (~2.17% on average). This zone is dominated by different kinds of phytoliths with some chrysophyte cysts (~22% on average). The P/B ratio was 2.19. Zone II-c (22 – 10 cm: ~1971-1994 AD) represents the increased concentration of *A. granulata* (~14.03% on average). The planktonic diatom taxa were also appeared in this zoen, such as *Stephanodiscus niagareae* (~3.49% on average), *Cyclotella ocellata* (~ 1.82 % on average) and *Cyclotella meneghiniana* (~2.63% on average). The benthic diatom species found in this zone were *Pinnularia abaujensis* (~3.34 % on average) and *Synedra ulna* (~1.49% on average). The average P/B ratio was 1.18 in this zone. Zone III (10 - 0 cm: ~ 1994- 2014 AD) was divided in to two sub-zones. Zone III-a (~10-05cm; ~1994-2005) was characterized by abundance of planktonic diatom taxa, *A. granulata* (~33.68 % on average). The benthic diatom species *A. ovalis* (~ 4.71% on average). This zone was predominated by different phytolith forms. The average of P/B ratio was 0.79. Zone III-b (5 – 0 cm; ~2005-2014 AD) represents presence of most dominating diatom taxa, *A. granulata* (~46.25 % on average) associated with *Stephanodiscus niagareae* (~7.02 % on average) and *Cyclotella ocellata* (~3.03 % on average). The common benthic diatom species found in this zone are *A. ovalis* (~4.29 % on average) and *P. abaujensis* (~3.07 % on average). The population of phytolith forms and chrysophyte cysts has been declined in this zone (~18.41% on average). The average P/B ratio was 3.01 in this zone (Fig. 4).

Biological Indicator

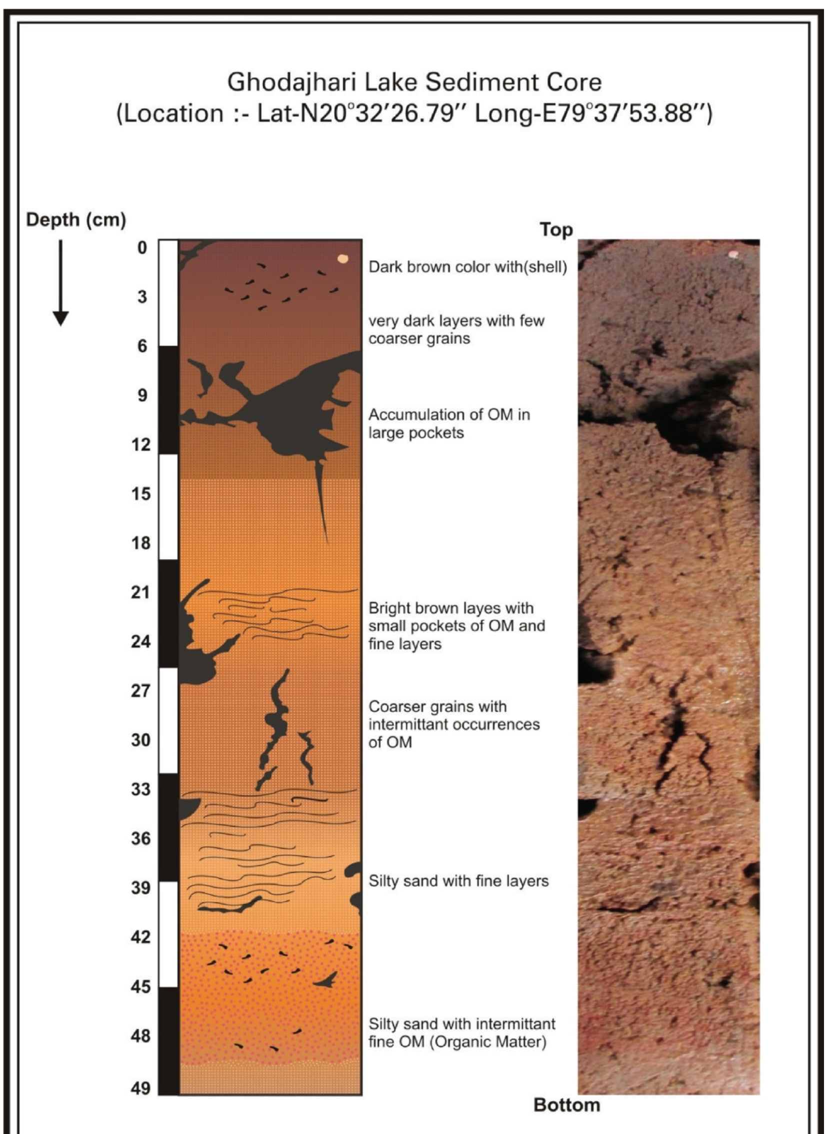

Fig. 3. Ghodajhari Lake Core Profile and Core section.

A stratigraphic profile of the biotic indicators, Hill's N2, benthic and planktonic diatoms percentage and Mean Linear Diameter (MLD) of diatoms for the Ghodajhari Lake is shown in (Fig. 5). The maximum flux rate of diatom for the Ghodajhari Lake was 7346X10^5 valves m^{-2} $year^{-1}$ was observed during ~1953 AD till ~1957 AD and again at the top of the core the diatom flux rate was enhanced to higher (5051 X10^5 valves m^{-2} $year^{-1}$). The planktonic and benthic (P/B) ratio of the Ghodajhari Lake shows dominance of the benthic assemblages during 38- 35cm (~ 1942 -1948 AD), 26-21 cm (~ 1964-1973AD), 19-15cm (~ 1976-1985 AD), 13-11cm (~ 1989-1992 AD) and 8 - 0 cm (~ 1998- 2013 AD), while benthic diatom taxa were abundant during remaining period (Fig. 5). The diatom diversity is mainly dependent upon the analysis of the effective number of taxa in each sample (Hill, 1973). The diatom diversity for each sample i.e. Hill's N2 of both the lakes was calculated using the program C2 1.5 (Juggins, 2007). Hill's N2 diversity of the siliceous microfossils from the Ghodajhari Lake was higher in 16 –14 cm (~ 1981 – 1986 AD), 11 – 09 cm (~ 1992 – 1996 AD) and highest at 3 – 0 cm (~ 2008 – 2013 AD) at the top of the core (Fig. 5).

The MLD of the diatom valves throughout the Ghodajhari Lake sediment cores showed the varying diatoms size during different periods. The percentage of four diatoms valve size categories (i.e. small: < 10µm; medium: 11-25µm: large- 26-50µm and very large: > 50µm) were considered for their correlation with the precipitation in the catchment area (www.tropmet.res.in/static_page.php; Fig. 5). The percentage of medium sized (10-50 µm) valves diameter showed a discrete increase throughout the Ghodajhari Lake barring few years (Fig. 5). The Ghodajhari Lake showed the dominance of the medium sized diatoms ~1950 to 2013 AD, while, large size diatoms were abundant during ~ 1956-2013 AD.

The diatom shift of the Ghodajhari Lake may have been due to the changing nutrient input during wet and dry periods. The distinct changing patterns of the planktonic and benthic diatom species of the core sediments of the Ghodajhari Lake also support the above fact. The phytoliths of Dumbell, Saddle and Cross forms were dominant during ~ 1924 to 1953 AD indicating existence of warm and dry period (Singh *et al.*, 2007). *Nitzschia microcephala* was predominated during ~ 1953-1962AD. It is commonly found in alkaliphilous waters with pH above 7 and tolerant to heavy organic pollution and mesosaprobous condition (www.environment_agency.gov.uk). Thus, the Ghodajhari Lake was alkaliphilous and tolerant to heavy organic pollution with mesosaprobous condition during ~ 1953-1962 AD. The actual annual rainfall and mean summer rainfall data also corroborates this finding (www.tropment.res.in/static.page.php). The data of diatom size variations of this lake relatively supports actual rainfall confirming the existence of relationship of mean linear diameter (MLD) of diatoms with the wet and dry periods over the watershed of the Ghodajhari Lake.

The phytoliths of Dumbell, Saddle and Cross forms were again become predominant during ~ 1962-1972 AD, which indicates moderately pronounced dry period. Different *Aulacoseira* species favor to thrive in the less transparent eutrophic waters owing to their lower light saturation intensity (Talling, 1957). Minor presence of *Aulacoseira granulata* also supports the presence of meso eutrophic waters during ~ 1962-1972 AD in the core. The dry seasoned phytoliths were again become most abundant during ~ 1972-1996 AD, with further rise in the population of *A. granulata,* which indicates prevalence of wet and dry period with meso eutrophic waters during ~ 1972-1996 AD in the core. The planktonic and benthic forms showed their minor presence during this time. *A. granulata* have a preference to survive in the increased nitrogen levels of waters (Kilham and Kilham, 1978). The Ghodajhari Lake shows maximum profusion of *A. granulata* during ~1996-2014 AD, with decline in all other planktonic and benthic forms. This period represents highly eutrophic waters with high nitrogen content in the Ghodajhari Lake. Thus, overall the differences in aquatic habitat, amount of dry and wet periods may have resulted in different diatom responses in the Ghodajhari Lake.

CONCLUSIONS

The variations in diatom diversity of the Ghodajhari Lake would be in response to changes in dry and wet period existed in its watershed with the changing supply of the nutrients. The diversity of the diatoms and phytoliths in the Ghodajhari Lake is mainly noticed during the wet period. Thus, the relatively small size diatoms also indicate dry periods/ less rainfall. The data of diatom size variations of this lake relatively supports actual rainfall confirming the existence of relationship of mean linear diameter (MLD) of diatoms with the wet and dry periods over the watershed of the Ghodajhari Lake. Similarly, the Dumbell, Saddle and Cross shape phytoliths also corroborates moderately pronounced dry period. The dominance of *A. granulata* also represents highly eutrophic waters with high nitrogen content in the Ghodajhari Lake.

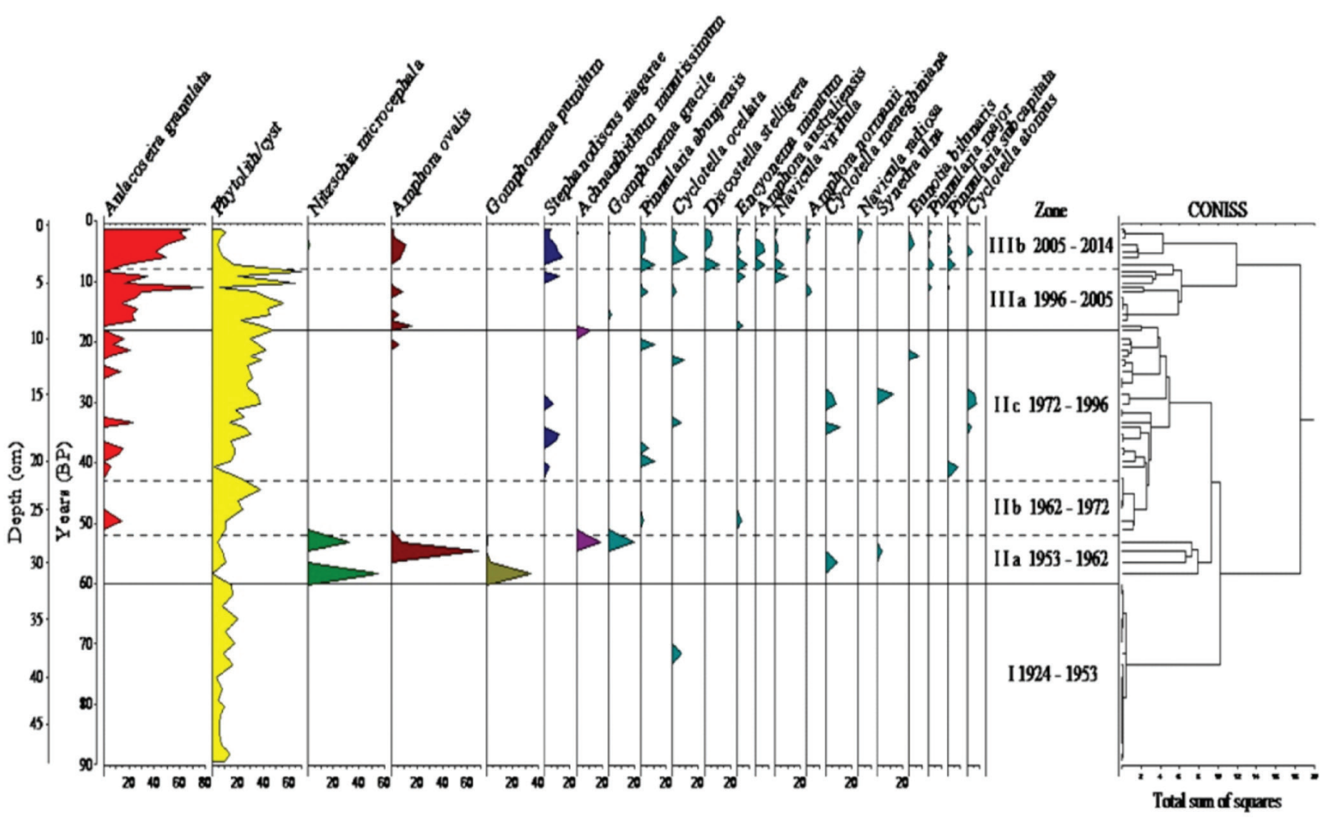

Fig.4. Diatom succession in the Ghodajhari Lake between (1924 and 2014 A. D.). Only the major taxa (Species with ≥ 1 % in at least one sample) were shown. The right is the Constrained incremental sum of squares (CONISS).

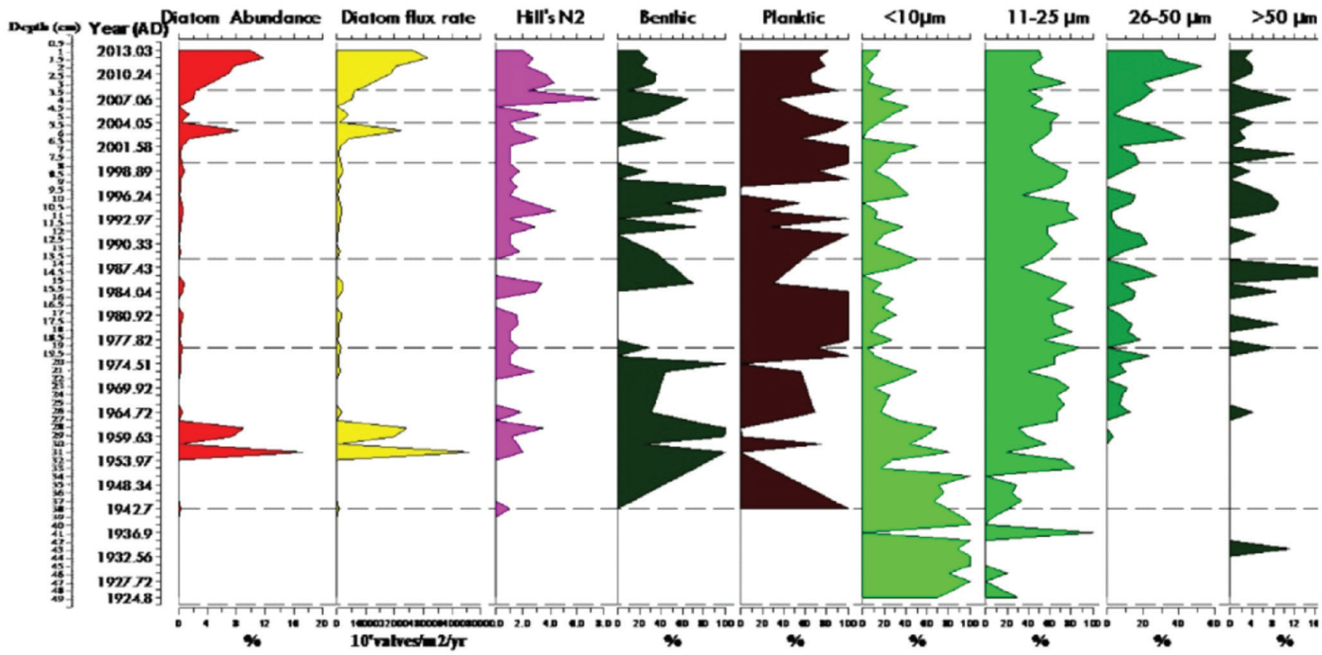

Fig. 5. Diatom abundance, Diatom flux rate, Hill's N2, Benthic and Planktonic taxa and Diatom Valve Size vs Depth and chronology for Ghodajhari Lake.

REPOSITORY

The diatom specimens studied in the present work are kept in the Applied Micropaleontology Laboratory of the Post Graduate Department of Geology, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur.

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REFERENCE

Agbeti, M. and Dickman, M. 1989. Use of lake fossil diatom assemblages to determine historical changes in trophic status. *Canadian Journal of Fisheries and Aquatic Sciences*, **46**: 1013–1021.

Ali, S. N., Thakur, B., Morthekai, P., Farooqui, S., Phartiyal, B., Seth, P. and Sharma, A. 2018. Diatom diversity under extreme climate: A study from Zanskar Valley, NW Himalaya, India. *Journal of the Palaeiontological Society of India*, **63(1)**: 119-126.

Anderson, N. J., Rippey, B. and Gibsey, C. E. 1993. .A comparisons of sedimentary and diatom-inferred phosphorous profiles: implications for defining pre-disturbance nutrient conditions. *Hydrobiologia*, **253**: 357-366.

Barahate V. P. and Tarar J. L., 1981. The alga flora of Tapi River, Bhusawal, Maharashtra. *Phykos*, **20:** 75-78.

Barahate, V. P. and Tarar, J. L. 1983. Additions to algal flora of Maharashtra: diatoms from Khandesh-I. *Phykos*, **22:** 13-17.

Battarbee, R. W. 1986. Diatom analyses. *In*: Handbook of Holocene paleoecology and paleohydrology. Berglund, B.E., ed. Wiley, New York, 527-570.

Batterbee, R. W., **Mason, J., Renberg, I. and Talling, J. F.** 1990. Paleolimnology and Lake acidification. *The Royal Society, London*.

Bennion, H., Wunsam, S. and Schmidt, R. 1995. The variation of diatom-phosphorus transfer functions: an example of Mondsee, Austria. *Freshwater Biology,* **34**: 271-283.

Bigler, C. and Hall, R. I. 2002. Diatoms as indicators of climatic and limnological change in Swedish Lapland: a 100-lake calibration set and its validation for paleoecological reconstruction. *Journal of Paleolimnology*, **27**: 97–115.

Charles, D. F., Smol, J. P. and Engstrom, D. R. 1994. Paleolimnological approaches to biological monitoring. *In:* Biological monitoring of aquatic systems. S. L. Loeb and A. Stacie (*Eds.). CRC Press, Boca Raton, Fla.*, 233–293.

Christie, C. E. and Smol, J. P. 1993. Diatom assemblages as indicators of lake trophic status in the south – eastern Ontario lakes. *Journal of Phycology*, **29**: 575- 586.

Colman, S. M., Peck, J. A., Karabanov, E. B., Carter, S. J., Bradbury, J. P., King, J. W. and Williams, D. F. 1995. Continental climate response to orbital forcing from biogenic silica records in Lake Baikal. *Nature*, **378**: 769–771.

Digerfeldt, G. 1972. The post-glacial development of Lake Trummen: regional vegetation history, water level changes and palaeolimnology. *Folia Limnol Scand*, **16**:1–104

Dixit, S. S., Smol, J. P., Kingston, J. C. and Charles, D. F. 1992. Diatoms: powerful indicators of environmental change. *Environmental Science and Technology*, **26**: 22–33.

Dixit, S. S. and Smol, J. P. 1994. Diatoms as indicators in the environmental monitoring and assessment program- Surface waters (EMAP-SW). *Environmental Monitoring Assessment.* **31**: 275-306.

DRM 2000. District Resource Map of Bhandara and Gondia Districts. Geological Survey of India.

Fritz, S. C., Juggins, S. and Battarbee, R. W. 1993. Diatom assemblages and ionic characterization of lakes of the Northern great plains, North America. A tool for reconstructing past salinity and climate fluctuations. *Canadian Journal of Fisheries and Aquatic Sciences*, **50**: 1844 - 1856.

Fritz, S. C., Juggins, S., Battarbee, R. W. and Engstrom, D. R. 1991. Reconstruction of past changes in salinity and climate using a diatom based transfer fuction. *Nature,* 706-708.

Gandhi, H. P. 1998. Fresh-water Diatoms of Central Gujarat. *Bishen Singh Mahendra Pal Singh* , Connaught Place, **23**-A: 1-321.

Gasse, F.V. Ledee, Massault M. and Fontes, **J. C.** 1989. Water - level fluctuations of Lake Tanganyika in phase with oceanic changes during the last glaciation and deglaciation. *Nature*, **342**: 57-59

Gonzalves, E. A. 1947. The algal flora of the hot springs of Vajreshwari, near Bombay. *Journal of University Bombay*, **16:** 22-27.

Halfman, J. D., Jacobson, D. F., Cannella, C. M., Haberyan K. A. and Finney, B. P. 1992. Fossil diatoms and the mid to late Holocene paleolimnology of Lake Turkana, Kenya: a reconnaissance study. *Journal of Paleolimnology*, **7**: 23–35.

Hall, R. I. and Smol, J. P. 1999. Diatoms are indicator of Lake Eutrophication. In the Diatoms: Application for theenvironmental and Earth Sciences, Stoermer E. F., Smoll, J.*P, eds. Cambridge University Press, Cambridge,* 168p.

Hall, R. I. and Smol, J. P. 1993. The influence of catchment size on lake trophic status, during the Hemlock decline and recovery (4800-3500 BP) in southern Ontario Lakes. *Hydrobiologia,* **269-270**: 371-390

Hall, R. I. and Smol, J. P. 1992. A weighted-averaging regression and calibration model for inferring total phosphorus concentration from diatoms in British Columbia (Canada) lakes. *Freshwater Biology*, **27**: 4117–4434.

Hill, M. O. 1973. Diversity and evenness: a unifying notation and its consequences. *Ecology*, **54:** 427-432.

Humane, S. K., Humane, S. S., Wankhede, A. S. and Desai, N. 2009. An assessment of The changes during recent History of the Phutala Lake, Nagpur, Maharashtra. Based on the diatoms and geochemistry. *Gondwana Geological Magazine*, **24(1):** 57-62.

Humane, S. S. and Humane, S. K. 2015a. Trophic Status Appraisal of the Ekara Lake, Sindewahi Taluka, Chandrapur District, Maharashtra, India using the surface water, geochemistry and sedimentary diatoms. In: Developments in Earth Sciences: A Proceeding of International Conference on Recent Development in Stratigraphy, Pune, *Development in Earth Sciences*: ICRDS-15; ISBN: 978-95-5137-944-7.

Humane, S. S. and Humane, S. K. 2015b. Paleoecological study of the Mansar Lake, Nagpur District, Maharashtra, India through sedimentary diatoms and geochemistry. In: Developments in Earth Sciences: A Proceeding of International Conference on Recent Development in Stratigraphy, Pune. *Development in Earth Sciences*: ICRDS-15; ISBN: 978-95-5137-944-7

Humane, S. S. and Humane, S. K. 2015c. Paleoecological Appraisal of the Ramtek Lake, Nagpur district Maharashtra, India with special emphasis on diatoms and sediment geochemistry. International *Journal of Geology, Earth and Environmental Sciences*, **5(1)**: 107-121.

Humane, S. S., Gervabangh, M. F., Humane, S. K. and Wankhede, A. 2010a. Environmental Implications of the Sedimentary Diatoms of the Vena River near Hingna-Gumgaon Area of the Nagpur District, Maharshtra. *Gondwana Geological Magazine*, **25 (1):** 139-148.

Humane, S. S., Humane, S. K. and Mude, S. 2015a. Water Quality, geochemistry and diatom inferred trophic status of the Raghuji Lake, South Nagpur, Maharashtra. In: Developments in Earth Sciences: A Proceeding of International Conference on Recent Development in Stratigraphy, Pune. *Development in Earth Sciences*: ICRDS-15, 47-59.

Humane, S. K., Humane, S. S. and More, R. 2015b. Physicochemical characteristics and surface sedimentary diatoms as indicators of trophic status of the Darna Reservoir, Nashik, Maharashtra, India. *International Journal of Geology, Earth and Environmental Science.* **5(2)**: 32-52.

Humane, Sumedh K., Humane, S. S., Juare, S. G. and Hajare, G. 2012a. Spatial variability in water quality, geochemistry and surface sediment diatom assemblages in the Mahadula-Silewara area, Nagpur district, Maharashtra.*In: 'Crystal', Proceeding on "Recent Trends in Chemical and Geological Sciences and its relevance to environmental Conservation (NSRTCGSEC Proceedings)*, 129-155.

Humane, Samaya S., Barde, U., Humane, S. K. and Kamble, S. 2012b. Paleoecology of the Madhuganga Lake, mohpataluka, Nagpur District, Maharashtra, India: Significance of Sedimentary Diatoms and Geochemistry in monitoring water quality and land use pattern. *Bionano Frontiers*, **5(2-II):** 104-112.

Humane, S. K., Humane, S. S., Wankhede, A. S. and Bokde, P. 2010b. Trophic Status and ecological Studies of the Ambazari Lake, Nagpur, Maharashtra, based on sedimentary diatoms. *Current Science*, **99:** 816-822.

John, J. 2014. Diatoms as Tools for Assessment of Water Quality and Environmental Change-Present and Past. *Gondwana Geological Magazine,* **15**: 1-12.

Joynt, E. H. III and Wolfe, A. P. 2001. Paleoenvironmental inference models from sediment diatom assemblages in Baffin Island lakes (Nunavut, Canada) and reconstruction of summer water temperature. *Canadian Journal of Fisheries and Aquatic Sciences,* **58**: 1222–1243.

Juggins, S. 2007. C_2 version 1.5.0: a program for plotting and visualising stratigraphic data. University of Newcastle, UK, Newcastle.

Kajale, M. D. and Eksambekar, S. P. 2003. Phytolith approach for investigating ancient occupations at Balathal, Rajasthan, India. Part 1: Evidence of crops exploited by initial farmers. *In*: *Applications in Earth Sciences and Human History* (*Eds*. Meunier, J. D. and Colin, F.), A. A. Balkema, Lisse, pp. 199–204.

Kamble, Sonal D. 2015. Sedimentary diatoms and other multi-proxy paleolimnological studies of the Paradgaon Lake of Nagpur District and the Ghodajhari Lake of the Chandrapur District, Maharashtra for trophic status and paleoclimatic interpretations. Unpublished Ph. D. thesis in Geology (Faculty of Science), RTM Nagpur University, Nagpur, 124p.

Kilham, S. S. and Kilham, **P.** 1978. Natural community bioassays: predictions of results based on nutrient physiology and competition. *Verh International Ver Limnology*, **20:** 68–74.

Korhola, A., Weckstrom, J., Holmstrom, L., Erasto, P. 2000. A Quantitative Holocene climatic record from Diatoms in Northern Fennoscandia. *Quaternary Research,* **54:** 284-294.

Loganathan, P., Pruhantheen, Humane, S. K. and Hussain, S. M. 2014. Distribution of Freshwater Diatoms in the Sediments of the Perumal lake, Cuddalore District, Tamil Nadu. *Gondwana Geoloical Magazine*, **15:** 79-84.

Nandkar, P. B., Marathe, K. V. and Motikhaye, B. G. 1983. Algae in sewage containing pools and oxidation ponds. *Phykos*, **22:** 37-45.

Perasall, D. M. 2000. *Palaeoethnobotany – A Handbook of Procedures*, Academic Press, San Diego.

Piperno, D. R. and Pearsall, D. M. 1998. The silica bodies of tropical American grasses: Morphology, taxonomy and implications for grass systematics and fossil phytoliths identification. *Smithsonite Contribution of Botany*, **85:** 1–40.

Prasad, B. N., Jaitly, Y. C. and Misra, P. K. 1984. Some diatoms from the hot springs of Ladakh. *Geophytology,* **14(2):** 156-160.

Qiu, L. Q., Williams, D. F., Gvorzdkov, A., Karabanov E. and Shimaraeva, M. 1993. Biogenic Silica Accumulation and Paleoproductivity in the Northern Basin of Lake Baikal during the Holocene. *Geology*, **21**: 25–28.

Ravindra Kumar, 1991. Historical Geology and Stratigraphy of India. New Age International Publication, pp. 176-184.

Round, F. E., Crawford, R. M. and Mann, D. G. 1990. The diatom biology and morphology of the genera. *Cambridge University Press Newyork,* 747p.

Sarode, P. T. and Kamat, N. D. 1980c. A new species of *Eunotia*. *Journal of Bombay Natural History Society*, **55**: 307-308.

Sarode, P. T. and Kamat, N. D. 1983a. Diatoms of Vidarbha, India-I. *Bibliotheca Phycologia,* **66:** 259-319.

Sarode, P. T. and Kamat, N. D. 1983b. Diatoms of Marathwada, Maharshtra-III. *Phykos*, **22**: 26-32.

Sarode, P. T. and Kamat, N. D. 1979. Diatoms of Marathwada, Maharashtra-I. *Phykos*, **18:** 25-32.

Sarode, P. T. and Kamat, N. D. 1980a. The diatom flora of Nagpur, India. *Nova Hedwigia*, **32:** 797-838.

Sarode, P. T. and Kamat, N. D. 1980b. Diatoms of Marathwada, Maharashtra-II. *Phykos*, **19:** 197-203.

Sarode, P. T. and Kamat, N. D. 1983c. Diatoms of Marathwada, Maharshtra. *Marathwada University Journal of Science,* **22**: 13-20.

Sarode, P. T. and Kamat, N. D., 1984. Freshwater diatoms of Maharashtra, *Saikripa Prakashan* , Aurangabad, 338 p.

Schmidt, R. and Simola, H. 1991. Diatomeen, pollen und sedimentmikro stratigraphische Untersuchungen zur anthropogenen Beeinflussung des Hoellerer Sees. *Aquatic Sciences*, **53**: 74–89.

Smol, J. P. 1988. Paleoclimate proxy from freshwater arctic diatoms. *Verh Internaional Ver Limnology*, **23**: 837-844.

Singh, V., Prasad, V. and Chakraborty, S. 2007. Phytoliths as indicators of monsoonal variability during mid-late Holocene in mainland Gujrat,western India. *Current Science*, **92:** 12-25.

Smol, J. P., Walker and Leavitt, P. R. 1991. Paleolimnology and hindcasting climatic trends. *Verh International Ver Limnology*, **24**: 1240-1246.

Stockner, J. G. and Benson, W. W. 1967. The succession of diatom assemblages in the recent sediment of Lake Washington. *Limnology and Oceanography*, **12**: 513–552.

Talling, J. F. 1957. Photosynthetic characteristics of some freshwater plankton diatoms in relation to underwater radiation. *New Phytologist,* **56:** 38-50.

Thomas, J. and Gonzalves, E. A., 1965. Thermal algae of western India, I-VII. *Hydrobiologia University Bombay,* **16:** 22-27.

Twiss, P. C. 1992. Predicted world distribution of C3 and C4 grass phytoliths. In: *Phytolith Systematics*. *Emerging Issues: Advances in Archaeological and Museum Science* (Eds. Mulholland, S. C. and Rapp Jr., G.), **1**: 113–128.

Venkatachalapathy, R., Nanthakumar, G. and Karthikeyan, P. 2014. Diatoms and water Quality Assessment of the Yercaud lake, Salem District, Tamil Nadu, South India. *Gondwana Geological Magazine*, **15:** 13-16.

Venkatachalapathy, R., Singh, M. C., Karthikeyan, P., Singh, S. and Sing, L. S. 2013. Diatoms as indicators of water quality in Imphal, Nambul, Waishen Rivers and the Loktak Lake, Manipur State, North East India. *Gondwana Geological Magazine*, **15:** 61-66.

Whitehead, D. R., Charles, D. F., Jackson, S. T., Smol, J. P. and Engstrom, D. R. 1989. The development history of Adirondack (N.Y.) Lakes. *Journal of Paleolimnology*, **2**: 185–206.

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www.tropment.res.in/static.page.php

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