International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2015 Vol. 5 (2) May-August, pp. 32-52/Humane et al.
Research Article

PHYSICOCHEMICAL CHARACTERISTICS AND SURFACE SEDIMENTARY DIATOMS AS INDICATORS OF TROPHIC STATUS OF THE DARNA RESERVOIR, NASHIK, MAHARASHTRA, INDIA

Sumedh K. Humane, *Samaya S. Humane and Rajeshree More
Department of Geology, Rashtrasant Tukadoji Maharaj Nagpur University, Rao Bahadur D. Laxminarayan Campus, Law College Square, Nagpur- 440 001(MS), India
**Author for Correspondence*

ABSTRACT
The physicochemical characteristics and surface sedimentary diatoms of the Darna Reservoir for the pre and the post monsoon seasons were investigated during May 2010 and February 2011 respectively. The pH value indicates alkaline nature of the Darna Reservoir. The calcium content of the reservoir was below 25 mg/l and therefore considered as less rich water bodies. The decline in silica content may be due to absorption of silica by bottom vegetation. The higher values of the phosphorous indicate very poor quality and mesotrophic - eutrophic water of the Darna Reservoir. The concentrations of Na, Fe, Cl, SO_4, K and Zn are well within the desirable limits. The increased concentration of Mg, Ti and K indicates the enhanced soil erosion in the watershed. The higher K content may also be due to excessive use of fertilizers in the adjoing agricultural lands and grape farms. The higher Mg content in the reservoir may be attributed to the developmental activities around reservoir such as dam concretization using cement etc. The high Fe and Si content during pre monsoon season may be due to erosion of magnetite and silica rich soils and the enrichment of iron at the deepest part of the reservoir. The surface sediments (pre and post monsoon seasons) of the Darna Reservoir divulged maximum abundance of *Aulacoseira granulata, Discostella stelligera and Cyclotella ocellata*. Thus, these diatom taxa indicate alkaline, mesotrophic-eutrophic water quality of the Darna Reservoir.

Keywords: *Hydrochemistry, Surface Sediments, Diatoms, Darna Reservoir, Nashik*

INTRODUCTION
Reservoirs are artificial structures designed mainly to preserve water for agriculture, flood control, municipal drinking water or to generate hydroelectric power (Liu *et al.,* 2012). The reservoirs are more like an artificial lake and the thing that made them different from the lakes is that they may contain pumps and discharge gates, which can influence their limnological conditions (Liu *et al.,* 2012). The reservoir can be divided into three zones: a shallow, upstream riverine zone, a transitional zone and a deep lacustrine zone close to the dam on the basis of their distinct longitudinal gradients in their morphology and hydrodynamics (Metre and Callender, 1997). These longitudinal gradients influence the physical, chemical and biological processes that affect sedimentation as well as the diatom assemblages that accumulate in the sediments (Liu *et al.,* 2012). Reservoir sediments are rarely used as environmental archives because of the potential for sediment disturbance by fluctuating water levels. However, rapid rates of sedimentation, proximity to urban centres and often the existence of management records may make them potentially important resources for reconstructing recent, anthropogenically derived environmental change (Shotbolt *et al.,* 2006). The bottom sediments from the reservoir are not very common due to the differences in hydrodynamics of the lakes and reservoirs. Some workers have studied the various ecological aspects of the reservoirs using diatoms and geochemistry (Wang *et al.,* 2008, Liu *et al.,* 2012, Shotbolt *et al.,* 2006).
The Darna Reservoir falls under the toposheet no 46 H/12 and situated in the Nashik district on the North West part of the Maharashtra state (Figure 1). The Nashik district covers an area of about 15530 sq. Km. The entire area of the Nashik district falls in latitude 19º 35´and 20º 50´N and longitude 73º30´ and 74º 55´E in the Survey of India toposheets no 47 E, I and 46 H, L. The Darna reservoir is present at about 20 km from the village Wadivarhe on the Nashik -Mumbai highway and 15 km from the Nashik city. A

masonary dam was constructed by British Government in 1916. The total length of reservoir is 1634m and the maximum height of the dam is 28 m. Physiographically, the western part of the district is represented by highly rugged and dissected terrain of the Western Ghats. The bathymetric variation in the Darna Reservoir is shown in figure 1. The land use pattern helps in interpretation of the possible source of pollution in the reservoirs. The land use pattern of the watershed of the Darna Reservoir clearly shows the dominance of agricultural land and grass land around the reservoir. The agricultural activity is dominated by sugarcane cropping. The fallow land is also associated with the grass land and agricultural land around the reservoir. Ever increasing agricultural activity around the Darna Reservoir is a matter of great concern from ecological and environmental point of view since the modern agricultural practices involves use of synthetic fertilizers which may lead to early or rapid eutrophication of the reservoirs.

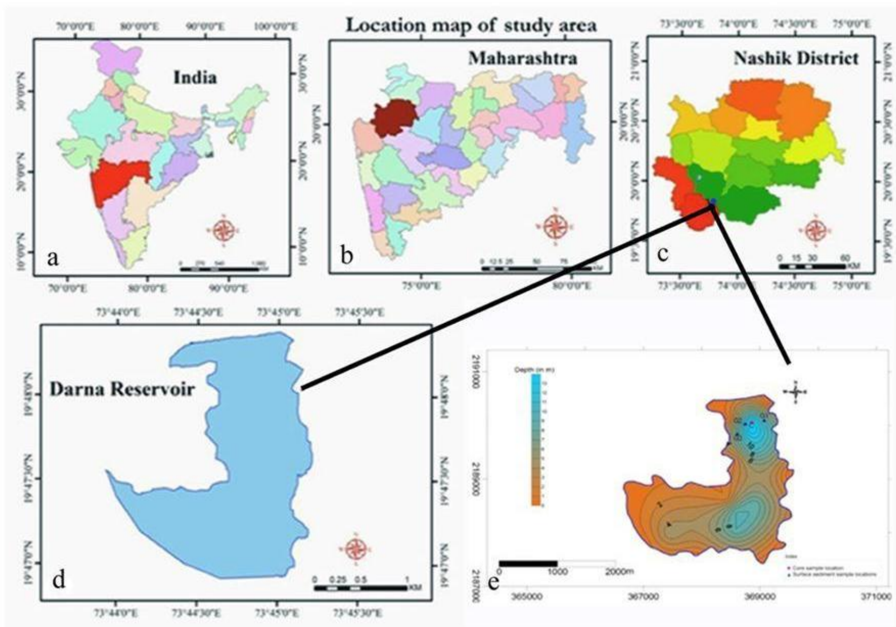


Figure 1: a) Map of India showing location of the Maharashtra State, b) Map of Maharashtra state showing Nashik District, c) Map of Nashik District, d) Ouline map of the Darna Reservoir, e) Bathymetric map of Darna Reservoir

The hydrochemical analysis of the Darna Reservoir revealed the present water quality during the pre and the post monsoon seasons and the extent of the anthropogenic impact on the reservoir. The physicochemical characteristics of many lakes of the Vidarbha region have been extensively studied by various workers (Humane *et al.*, 2009, 2010a, 2010b; 2012a, 2012b; Humane and Humane, 2015; Aprajit, 2013; Badge *et al.*, 2014; Bante, 2014, Bawanwade, 2014, Bihade, 2011; Bramhankar, 2011; Borkar, 2011a; Borkar 2011b, Chalakh, 2014; Chopkar, 2009; Dhargave, 2012; Fadanvis, 2014; Ingewar, 2012; Juare *et al.*, 2014; Kamble *et al.*, 2014). Kumar *et al.*, (2008) have worked on physicochemical characteristics and diatoms as indicator of trophic status of the Kishore Sagar Lake, Rajasthan. Singh *et al.*, (2010) have studied the seasonal diatom variations with reference to physico-chemical properties of water of Mansagar Lake of Jaipur, Rajasthan. Physicochemical parameters of water particularly DO, pH, TH, BOD, COD, TDS, and EC were followed after Trivedi and Goel (1986), APHA (1985) and Sharma and Saini (2003). Bradbury and Metre (1997) have studied a land-use and water-quality history of White Rock Lake reservoir, Dallas, Texas. Sarwar and Wazir (1991) have studied physicochemical characteristics of freshwater ponds of Srinagar, Kashmir.

The geochemical analysis of the bottom sediments from the lakes and reservoirs are mostly carried out to know the source and variation in the sediment input and to prepare the database of the present day input of sediments. The reservoir sediments are good archived for the paleoecological study in particular because rapid rates of sedimentation, proximity to urban centres and often the existence of management records, make them potentially important resources for reconstructing recent, anthropogenically derived environmental change (Shotbolt *et al.,* 2006; Xu *et al.*, 2006, 2007). The quantity and quality of geochemical variables helps to understand which anthropogenic activity have highest impact on the reservoir.

Water quality evaluation using diatoms has become a new tool for environmental implications. The diatoms are microscopic unicellular algae that built complex, beautiful cell wall of silica and have the size 2-500 µm (John, 2014).

Diatoms are used as an indicator of reconstruction of the past and present ecological status due to their high sensitivity to limnological variables such as nutrient concentration, pH, conductivity and well preservation in fossil deposits. Diatoms play an important role for evaluating past and recent water quality and environmental conditions.

The deterioration of lake water quality has been a common environmental concern throughout the world during the later half of the 19^{th} Century (Valpola, 2006). Reservoir sediments are used as important environmental archives and provide temporal records of inputs from both the drainage basin and the atmosphere (Foster *et al.,* 1991; Lees *et al.,* 1997; Callender, 2000; Smol *et al.,* 2005; Audry *et al.*, 2004 and Yeloff *et al.,* 2005).

Several workers have correlated the lake trophic status with the distribution of diatom taxa in the surface sediments (Christie and Smol, 1993; Fritz *et al.*, 1993; Hall and Smol, 1999; Battarbee, 1997; Kelly, 1999; Dixit and Smol, 1994 and John, 2014).

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. Gandhi (1998) reported 129 species of freshwater diatoms from the Chandola Lake of Gujarat. Misra and Shukla (2006) reported some freshwater diatoms from Uttaranchal state. Some species of diatoms from the hot spring of Ladakh was studied by Prasad *et al.,* (1984). Recently, Venkatachalapathy *et al.*, 2013 and 2014 have investigated diatoms and water quality assessment of Yercaud Lake in Tamil Naidu and Waishen River and Loktak Lake of Manipur.

Logannathan *et al.*, (2014) have studied distribution of fresh water diatoms of the Perumal Lake, Tamil Naidu. The polluted and unpolluted zones of river Gomati using diatoms was demarkated by Verma *et al.*, (1996, 2000).

A lot of work has been done to study the past environment using lake sediments. However, there is a lack of work related to the past and present ecological developments on the reservoirs in India especially the the Darna reservoirs of the Nashik district since the construction of the dams. Similarly, there is no record of sediment geochemistry and hydrochemistry of this reservoir. Therefore, the present work is a maiden attempt to investigate the Darna Reservoir of the Nashik District, Maharashtra to understand water quality status and its relationship with diatoms of surface sediments.

MATERIALS AND METHODS

Methodology

The surface sediment (grab) samples (DRG_{1-3}) and water samples (DRW_{1-3}) were collected at the same place from where the water samples of the Darna Reservoir during pre and post monsoon seasons of May 2010 and February 2011 respectively and numbered as DRG_1 and DRW_1 (Lat: N 19^o 48’ 52” N; Long: E 73^o 45’ 14” E), DRG_2 and DRW_2 (Lat: N 19^{o}32’ 92” N; Long: E 73^o 44’ 40” E) and DRG_3 and DRW_3 (Lat: N 19^o 48’4.40” N; Long: E 73^o 44’ 35” E).

Water Samples: A systematic sampling of the water samples from the Darna Reservoir was done during two seasons i.e. Pre-Monsoon and Post- Monsoon. The water samples were collected in the plastic bottles from the Darna Reservoir. The geographic positions of sample locations were specifically noted with the help of GPS. Temperature, pH, Conductivity and DO of the water was measured at the time of sampling. Then, the collected water samples were sent to the laboratory for hydrochemical analysis. The various physicochemical parameters of the water samples such as pH, Electrical Conductivity, Alkalinity, Chloride, Calcium, Magnesium, Nitrate-Nitrogen, Iron, Phosphorous, Aluminium, Manganese, Silica, Sodium, Potassium were measured using several equipment as given below: pH meter (model- 101E), Digital conductivity meter (Model-601), Titrimetric analysis, UV spectrophotometer (make- Systronics, model no. 118), UV-visible spectrophotometer from the Water Quality Envirocare Laboratory, Nashik.

Grab Sediments: The surface sediment (grab) samples were collected from the Darna Reservoir using a heavy stainless steel bucket and kept in a polythene zip-lock bag with proper labels. The X-ray Fluoroscence analysis (XRF) of the powdered surface sediment samples (-170 mesh size) of the Darna Reservoir were analyzed from Wadia Institute of Himalayan Geology, Dehradun, (WIHG) for major major oxides and trace elements (Model: Brucker 58 Tiger) for the post monsoon surface sediments. The pre monsoon surface sediments of the Darna Reservoir were analyzed from Indian Bureau of Mine (IBM), Pilot Plant Nagpur using XRF spectrometry for mjor oxides and trace elements (PW2403-MAGIX, PANlytical).

Maceration of Grab Sediments

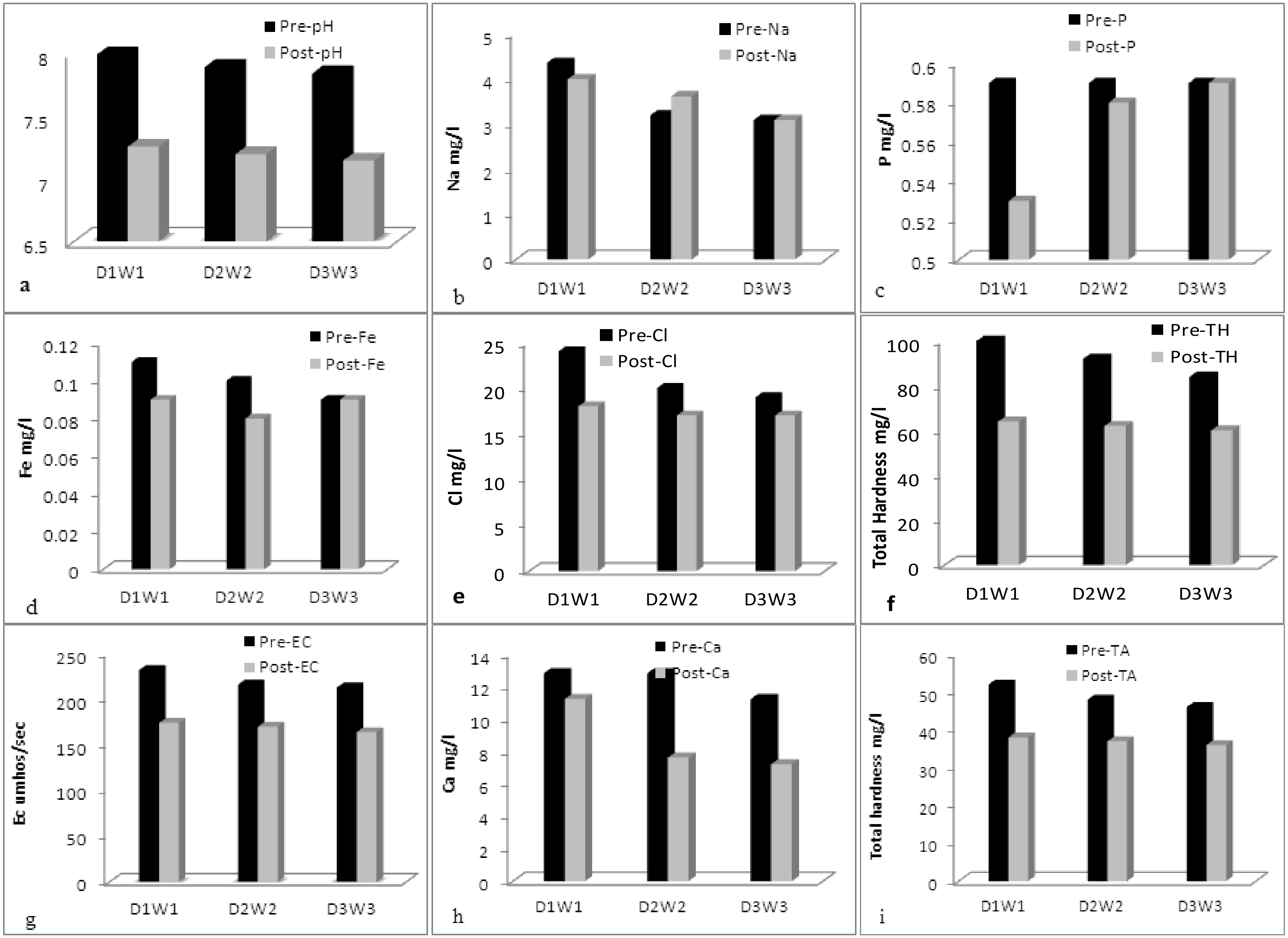
Maceration of surface sediments of both the seasons was done using standard procedure of Batterbee (1986). The diatom slides were studied under Biological Research Microscope (Leica DM 350) at 40x, 63x and 100x (oil immersion) magnifications. Microphotography and identification of diatoms were done followed by their enumeration to understand their response to changing water quality.

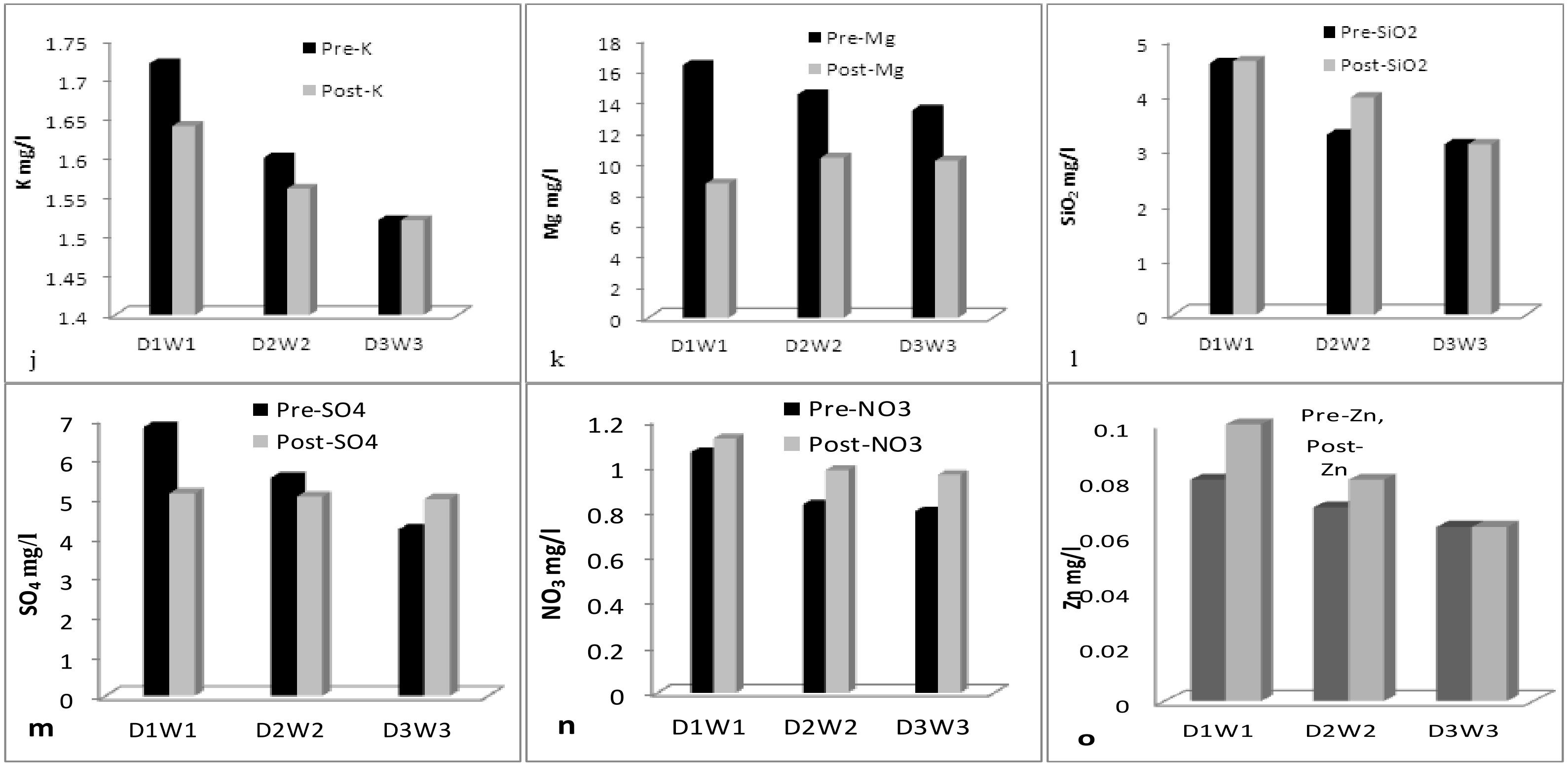
Geological Setting

The catchment area surrounding the Darna Reservoir consists of basalt of the Deccan volcanic province. The Darna Reservoir is mostly surrounded by 6-7 Pahoehoe and Megacryst basaltic lava flows of the Ratangarh Formation of the Sahyadri Group belonging to the Upper Cretaceous to Lower Eocene age and also associated with the Alluvium in the form of discontinuous patches along the banks and flood plains of major rivers like Godavari, Girna and their tributaries (DRM, 2001). Basaltic lava flows occupies about 90% of the area of the district. These flows are normally horizontally disposed over a wide stretch and give rise to table land type of topography also known a plateau. These flows occur in layered sequences and represented by massive unit at the bottom and vesicular unit at the top of the flow. These flows are separated from each other by marker bed known as 'bole bed'. The ground water in the Deccan Trap Basalt occurs mostly in the upper weathered and fractured parts down to 20-25 m depth. At places, these potential zones are encountered at deeper levels in the form of fractures and inter-flow zones (Dhonde, 2009).

RESULTS AND DISCUSSION

Hydrochemistry: The water samples collected from the Darna Reservoir during Pre and Post monsoon seasons from three different locations have been analyzed for various parameters such as pH, conductivity, alkalinity calcium, magnesium, sulphate, nitrate, chloride, sodium, potassium, aluminum, silica, iron, and total phosphorous and total nitrogen (Table 1, Figures 2a - o). The physicochemical characteristics of the Darna Reservoir water show deviations during pre and post monsoon seasons. The calculations of the pair of linear correlation coefficients and the construction of hierarchic dendograms were prepared to know the relationship of the physico-chemical characters, during pre and post monsoon seasons of the Darna Reservoir (Tables 2, 3; Figure 3). The physicochemical characters during pre-monsoon season (Figure 3a) are separated into seven main groups: (I) Zn-N_2, (II) K-PO_4, (III)SiO_2-NO_3, (IV) SO_4-Cl, (V) Fe-Na-Mg-Ca, (VI) EC-TH-TA and (VII) pH-TDD-NH_3 and during the post-monsoon season (Figure 3b) are distinguished into six main groups: (I) Fe-Mg, (II) TDD-NH_3-Zn-N_2-K, (III) SiO_2-NO_3, (IV) SO_4-Cl-Na, (V) EC-Ca-TH-TA and (VI) pH-PO_4.


Pre-pH
Post-pH
8
7.5
7
6.5
D1W1
D2W2
D3W3
a
Pre-Na
Post-Na
Na mg/l
5
4
3
2
1
0
D1W1
D2W2
D3W3
b
Pre-P
Post-P
P mg/l
0.6
0.58
0.56
0.54
0.52
0.5
D1W1
D2W2
D3W3
c
Pre-Fe
Post-Fe
Fe mg/l
0.12
0.1
0.08
0.06
0.04
0.02
0
D1W1
D2W2
D3W3
d
Pre-Cl
Post-Cl
Cl mg/l
25
20
15
10
5
0
D1W1
D2W2
D3W3
e
Pre-TH
Post-TH
Total Hardness mg/l
100
80
60
40
20
0
D1W1
D2W2
D3W3
f
Pre-EC
Post-EC
Ec umhos/sec
250
200
150
100
50
0
D1W1
D2W2
D3W3
g
Pre-Ca
Post-Ca
Ca mg/l
14
12
10
8
6
4
2
0
D1W1
D2W2
D3W3
h
Pre-TA
Post-TA
Total hardness mg/l
60
50
40
30
20
10
0
D1W1
D2W2
D3W3
i



Figures 2: a – o, Physico-chemical parameters of Darna Reservoir (Pre-Monsoon; Post- Monsoon)

Table 1: Water chemistry of the Darna Reservoir (Pre-Monsoon and Post-Monsoon) (mg/l for all the parameters except pH and EC)

Sample No.	pH	EC (umhos/cm)	TA	TH	Ca	Mg	Na	Fe	Cl	SO_4	NO_3 (N)	SiO_2	PO_4 (P)	K	Zn
D1Pre	7.98	232	52	100	12.8	16.3	4.34	0.11	24	6.8	1.06 (0.239)	4.56	0.59(0.188)	1.72	0.08
D2Pre	7.88	216	48	92	12.8	14.4	3.18	0.1	20	5.52	0.83 (0.187)	3.26	0.59 (0.183)	1.6	0.07
D3Pre	7.83	213	46	84	11.2	13.4	3.08	0.09	19	4.21	0.8 0.180)	3.09	0.59 (0.192)	1.52	0.063
Mean	**7.83**	**220**	**46.1**	**84**	**11**	**13.4**	**3.1**	**0.1**	**19**	**4.21**	**0.8 (0.202)**	**3.09**	**0.59 (0.1872)**	**1.5**	**0.06**
D1 Post	7.25	174	38	64	11.2	8.64	3.98	0.09	18	5.12	1.12 (0.252)	4.6	0.53 (0.172)	1.64	0.1
D2Post	7.19	170	37	62	7.6	10.3	3.6	0.08	17	5.04	0.98 (0.221)	3.94	0.58 (0.189)	1.56	0.08
D3Post	7.14	164	36	60	7.2	10.1	3.08	0.09	17	4.98	0.96 (0216)	3.09	0.59 (0.192)	1.52	0.063
Mean	**7.14**	**169**	**36**	**60**	**7.2**	**8.64**	**3.08**	**0.08**	**17**	**4.98**	**0.96 0.230)**	**3.09**	**0.53 (0.184)**	**1.64**	**0.08**

Table 2: Correlation coefficient matrices of various physicochemical parameters in Pre-monsoon water samples of Darna Reservoir

	PH	**Ec**	**Alk**	**Cl**	**SO4**	**Ca**	**Mg**	**NO3**	**TP**	**Fe**	**Na**	**K**	**Si**	**TDD**	**Zn**
PH	1.0000	-0.5439	-0.6897	-0.5792	-0.8180	-0.9954	-0.9954	-0.6990	-0.5084	0.9954	-0.8142	-0.4787	-0.7422	-0.3273	0.996078
EC		1.0000	0.9827	0.9991	0.9276	0.6218	0.6218	0.9803	0.9991	-0.6218	0.9301	0.9971	0.9661	-0.1469	0.962512
Alk			1.0000	0.9897	0.9807	0.7559	0.9999	0.9742	-0.7559	0.9659	0.9659	0.9972	0.9742	-0.3273	0.996078
Cl				1.0000	0.9427	0.6547	0.9878	0.9964	-0.6547	0.9449	0.9930	0.9762	0.9965	-0.5000	0.973223
SO4					1.0000	0.8693	0.9831	0.9112	-0.8693	1.0000	0.8966	0.9926	0.9113	-0.8660	0.99415
Ca						1.0000	0.7643	0.5885	-1.0000	0.8660	0.5605	0.8030	0.5887	-0.8660	0.810885
Mg							1.0000	0.9712	-0.7643	0.9843	0.9625	0.9981	0.9712	-0.0714	0.997131
NO3								1.0000	-0.5885	0.9139	0.9994	0.9544	1.0000	-0.0714	0.87266
TP									1.0000	-0.8660	-0.5605	-0.8030	-0.5887	0.5000	-0.3504
Fe										1.0000	0.8995	0.9934	0.9140	-0.5000	0.99485
Na											1.0000	0.9437	0.9994	-0.0714	0.939162
K												1.0000	0.9545	-0.3974	0.99991
Si													1.0000	-0.1057	0.950436
TDD														1.00	-0.40964
Zn															1

(TDD: Total Diatom Density of Surface Sediments)

Table 3: Correlation coefficient matrices of various physicochemical arameters in Post-monsoon water samples of Darna Reservoir

	PH	Ec	Alk	Cl	SO4	Ca	Mg	NO3	TP	Fe	Na	K	Si	TDD	Zn
PH	1.0000	0.9860	0.9986	0.8910	0.9996	0.9286	-0.8355	0.9372	-0.9508	-0.6141	0.9899	-0.8805	0.9922	0.6934	0.999984
EC		1.0000	0.9934	0.8030	0.9806	0.8538	-0.7323	0.8660	-0.8859	-0.7370	0.9997	-0.7892	0.9991	0.5636	0.986949
Alk			1.0000	0.8660	0.9966	0.9078	-0.8056	0.9177	-0.9333	-0.6547	0.9960	-0.8544	0.9974	0.6547	0.998906
Cl				1.0000	0.9042	0.9959	-0.9939	0.9934	-0.9878	-0.1890	0.8178	-0.9997	0.8751	0.9449	0.888459
SO4					1.0000	0.9392	-0.8515	0.9472	-0.9596	-0.5903	0.9853	-0.8943	0.9880	0.7146	0.999369
Ca						1.0000	-0.9798	0.9997	-0.9979	-0.2774	0.8667	-0.9935	0.8751	0.9113	0.926456
Mg							1.0000	-0.9747	0.9646	0.0795	-0.7493	0.9961	-0.7605	-0.9753	-0.83239
NO3								1.0000	-0.9992	-0.3004	0.8784	-0.9905	0.8865	0.9011	0.939962
TP									1.0000	0.3394	-0.8974	0.9840	-0.9048	-0.8825	-0.94365
Fe										1.0000	-0.7196	0.1666	-0.7077	0.7559	0.046761
Na											1.0000	0.9999	0.9999	0.5844	0.990719
K												1.0000	-0.8145	0.5844	0.989743
Si													1.0000	0.5982	0.689286
TDD														1.0000	0.689286
Zn															1

(TDD: Total Diatom Density of Surface Sediments)

The surface water temperature of the Darna Reservoir ranges from 29°C (Pre-monsoon) and 22°C (post monsoon) respectively. Thus, this reservoir belongs to the typical water body of the tropical latitude, where temperature ranges between 25°C to 30°C in summer and 16°C to 20°C in winter (Das, 1989). The pH of the water sample in pre monsoon season ranges from 7.8 to 7.9 with a mean value of 7.87, whereas it ranges from 7.14 to 7.25 with a mean value of 7.19 in the post monsoon season. The pH of the Darna Reservoir indicates its alkaline nature. The increased pH in the Darna Reservoir may be owed to the breakdown of the organic matter and augmented photosynthetic activity (Kumar *et al.,* 2008; Singh and Mahajan, 1987). The pH of the water also depends upon relative quantity of calcium, carbonate and bicarbonates (Pearsall, 1930 and Zafar, 1966). The alkalinity of the water depends upon the carbonates and bicarbonates content (WLS, 2007). The total alkalinity (Alk mg $CaCO_3$/l) (Figure 2i) of the Darna Reservoir varies from 46-52 mg/l (Pre-monsoon) and 36-38 mg/l (Post-monsoon) (Figure 2i). The alkalinity values more than 100 mg/l indicate nutrititionally rich water (Phillipose, 1960 in Kumar *et al.*, 2008). Thus, the Darna Reservoir indicates moderate trophic status. The electrical Conductivity ranges from 213µmhos/cm to 232 µmhos / cm with a mean value of 220µmhos / cm in pre monsoon and 164µmhos/cm to 174µmhos/cm with a mean value of 169.33µmhos/cm in post monsoon seasons. The pre monsoon water samples of this reservoir show higher EC than the post monsoon waters. The higher values during the pre-monsoon season may be due to the discharge of ions from the decayed organic matter. The electrical conductance above 0.20mS in water is regarded as eutrophic (Rawson, 1960 in Kumar *et al.*, 2008). Thus, the water samples of the Darna Reservoir during pre monsoon seasons were more eutrophic. The alkalinity ranges from 46mg/l to 52mg/l with a mean value of 48.66 mg/l in the pre monsoon samples and ranges from 36 mg/l to 38 mg/l with mean value of 37 mg/l in the post monsoon season. The higher concentration of carbonates may lead to rise in the alkalinity of the water. On the contrary, the high level of calcium, carbondioxides and bicarbonates makes the water less alkaline (Kumar *et al.,* 2008). The hardness of the water depends upon the calcium and magnesium content along with carbonates and bicarbonates (Singh *et al.,* 2010). The hardness of water is controlled by the level of calcium, magnesium, carbonates and bicarbonates associated with chlorides, sulphate and anions of minerals (Kumar *et al.,* 2008). The total hardness of the Darna Reservoir was 84-100mg/l (pre-monsoon) and 60 - 64 mg/l (post-monsoon). The 'nutrients rich' water will have more than 60 ppm hardness (Spence, 1964 in Kumar *et al.*, 2008). Thus, the Darna Reservoir may be classified as 'nutrient rich'. The concentrations Calcium (Ca) and Magnesium (Mg) in the pre-monsoon water samples ranges from 11.2 mg/l to 12.8 mg/l and 13.44 mg/l to 16.32 mg/l with a mean value of are 11.73 mg/l and 14.72 mg/l respectively, whereas the concentrations of Ca and Mg have declined in the post monsoon samples and ranges from 7.2 mg/l to 11.2 mg/l and 8.64 mg/l to 10.32 mg/l with a mean value of 8.6 mg/l and 9.68 mg/l respectively. The average Ca content of the Darna Reservoir ranges from 11 mg/l to 7.2 mg/l during pre and post monsoon seasons respectively (Figure 2h). The calcium concentration above 25 mg/l is considered as "rich" water body (Ohle, 1934). The Ca content of the Darna Reservoir during both the seasons was less than the Mg content. Organic matter and magnesium are having close association with each other (Zafar, 1964). The higher concentration of calcium as compare to magnesium may be due to quicker reaction of CO_2 with calcium salt altering large amount of calcium into dissolved bicarbonates (Kumar *et al.*, 2008). The calcium content of this reservoir was below 25 mg/l and therefore considered as less rich water bodies (Ohle, 1934). The Chloride content in water ranges from 19mg/l to 24mg/l with average value occurs to be 21 mg/l in pre monsoon season and varies from 17mg/l to 18mg/l to with average value of 17.33 mg/l in post monsoon season. The SO_4 ranges from 4.21mg/l to 6.80mg/l with mean value of 5.51 mg/l in pre-monsoon samples with decreased values ranging from 4.98 mg/l to 5.12 mg/l with mean value of 5.04 mg/l in post monsoon season. The silica content of the Darna Reservoir ranges from 3.09 to 4.56 mg/l (pre-monsoon) and 3.09 to 4.6 (post-monsoon) (Figure 2l). The weathering of rocks and soils in the respective watersheds of the reservoirs may be responsible for the increased silica content along with the disintegration of the diatom frustules (Kumar *et al.*, 2008). The silica content of the Darna Reservoir during the pre and post monsoon seasons was lower. Thus, the decrease in the silica content may be due to absorption of silica by bottom vegetation i.e. phytolith like grasses, sponge

Research Article

spicules, cysts and diatoms (Ahl, 1966 in Kumar *et al.*, 2008; Figures 4). The concentration of sodium and potassium content in water was 3.08 mg/l to 4.34 mg/l and 1.52 mg/l to 1.72 mg/l in the pre monsoon water samples with mean value of 3.53 mg/l and 1.61 mg/l, and 3.08 mg/l to 3.98 mg/l and 1.57 to 1.61 mg/l in the post monsoon season with mean value of 3.55 mg/l and 1.57 mg/l respectively. The phosphorus is often the limiting nutrient in water bodies and essential for the aquatic plant and animal growth (Kumar *et al.*, 2008). The common total phosphorous values for the Wisconsin, USA is given in table 4 (WLS, 2007). The total phosphorus content of the Darna Reservoir ranges from 0.1859 to 0.1924 mg/l during pre monsoon and 0.1728 to 0.1924 mg/l during the post monsoon seasons. The higher values of the phosphorous indicate very poor quality of the Darna Reservoir water (Table 4, WLS, 2007). The augmentation in phosphorous content of the water body may be due to the faster decomposion of the organic matter (Kumar *et al.*, 2008; Meena *et al.*, 2007).

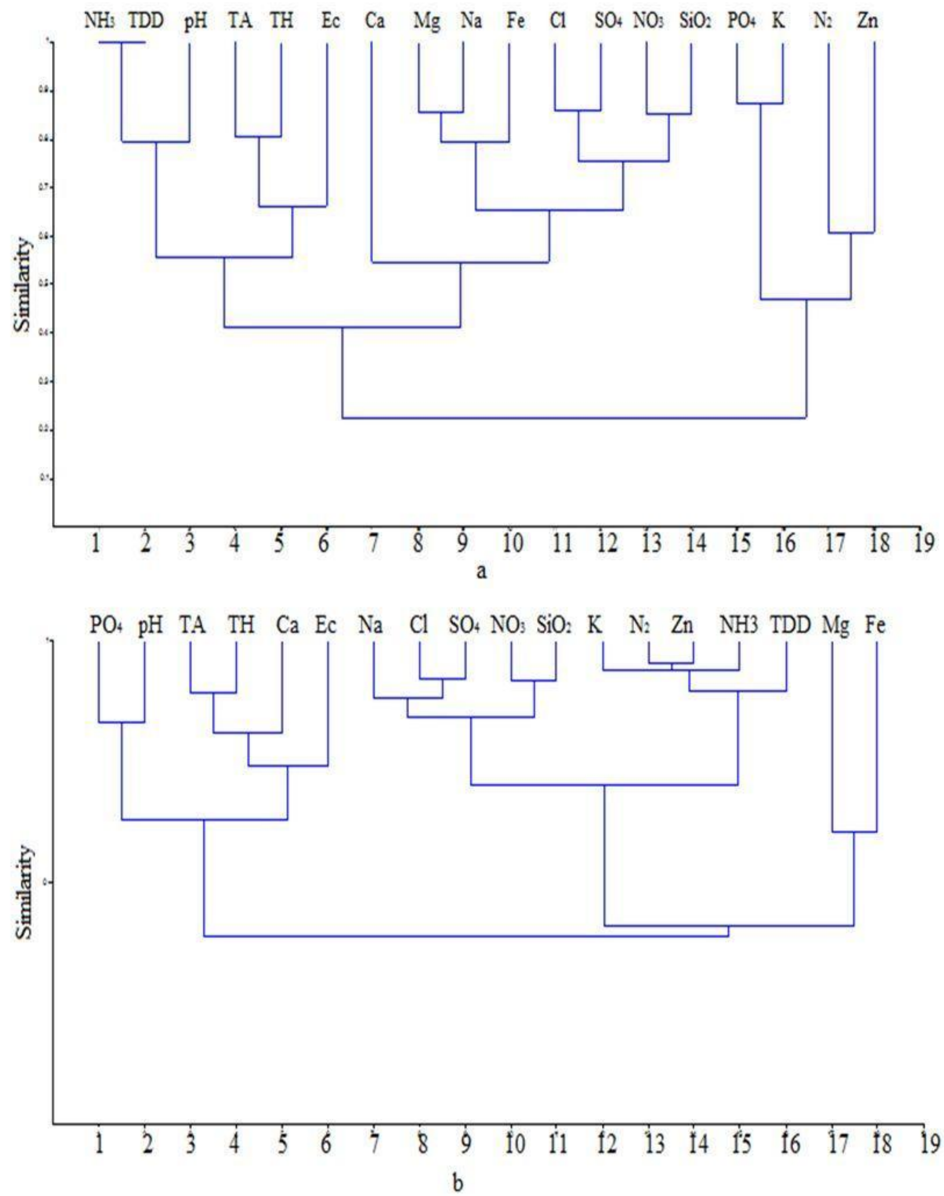
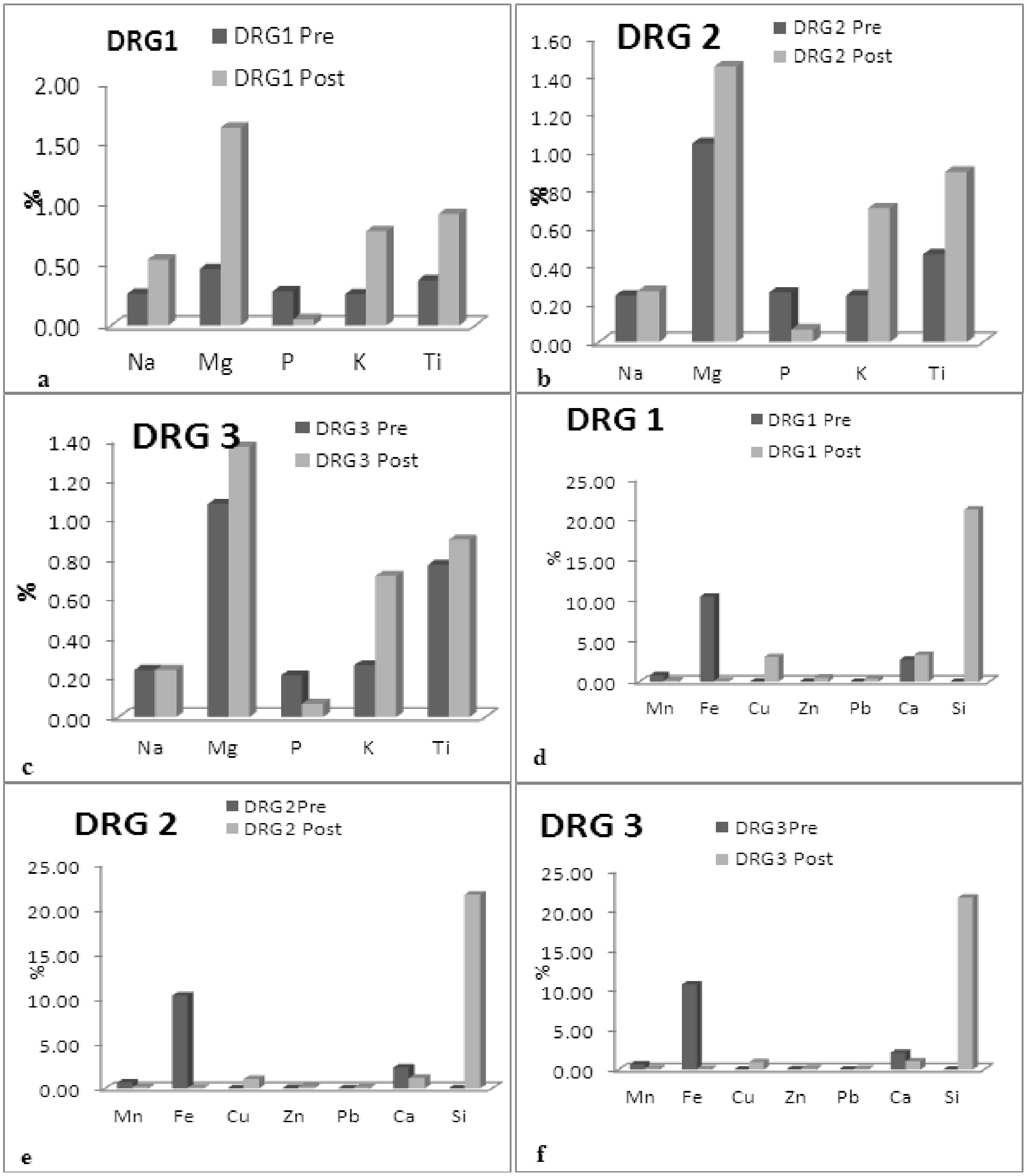


Figure 3: (a – b) Hierarchic Dendograms of correlation matrix of physicochemical parameters in water samples of the Darna Reservoir. a) Premonsoon; b) Post monsoon



Figures 4 a- f: Geochemistry of surface sediments of Darna Reservoir

Table 4: Common total phosphorous values for the Wisconsin, USA (WLS, 2007)

Water Quality	**Total Phosporous values (mg/l)**
Good	< 0.020
Fair	0.020 – 0.050
Poor	0.050 – 0.150
Very Poor	> 0.150

The nitrogen is also a crucial nutrient for the growth of the aquatic plants and organism (Prakash, 1994). The common total nitrogen values for the Wisconsin, USA is given in table 5 (WLS, 2007). The nitrogen

Research Article

content of the Darna Reservoir ranges from 0.1807 to 0.2394 mg/l in (Pre-monsoon) and 0.2168 to 0.2529 mg/l (Post- monsoon). The nitrogen concentrations show oligotrophic status of the Darna Reservoir during pre-monsoon and the post monsoon seasons (Table 5, WLS, 2007). The concentrations of Na, Fe, Cl, SO_4, K and Zn are well within the desirable limits (WHO, 1984; BIS, 2003) in the reservoir (Figures 2 b, d, e, m, j, o). This suggests that water of the Darna Reservoir can be safely used for the domestic purspose and also for drinking purpose after filtering.

The overall hydrochemical investigation suggests the enhanced concentration of the majority of the water parameter at the sample location DRW_1 and shows decreasing trend at DRW_2 and DRW_3. The similar trend was observed during the post monsoon season as well.

Table 5: Common total phosphorous values for the Wisconsin, USA (WLS, 2007)

Water Quality	Total Nitrogen values (mg/l)
Oligotrophic	< 0.4
Mesotrophic	0.4 – 0.6
Eutrophic	0.6 – 1.5
Hyper-eutrophic	> 1.5

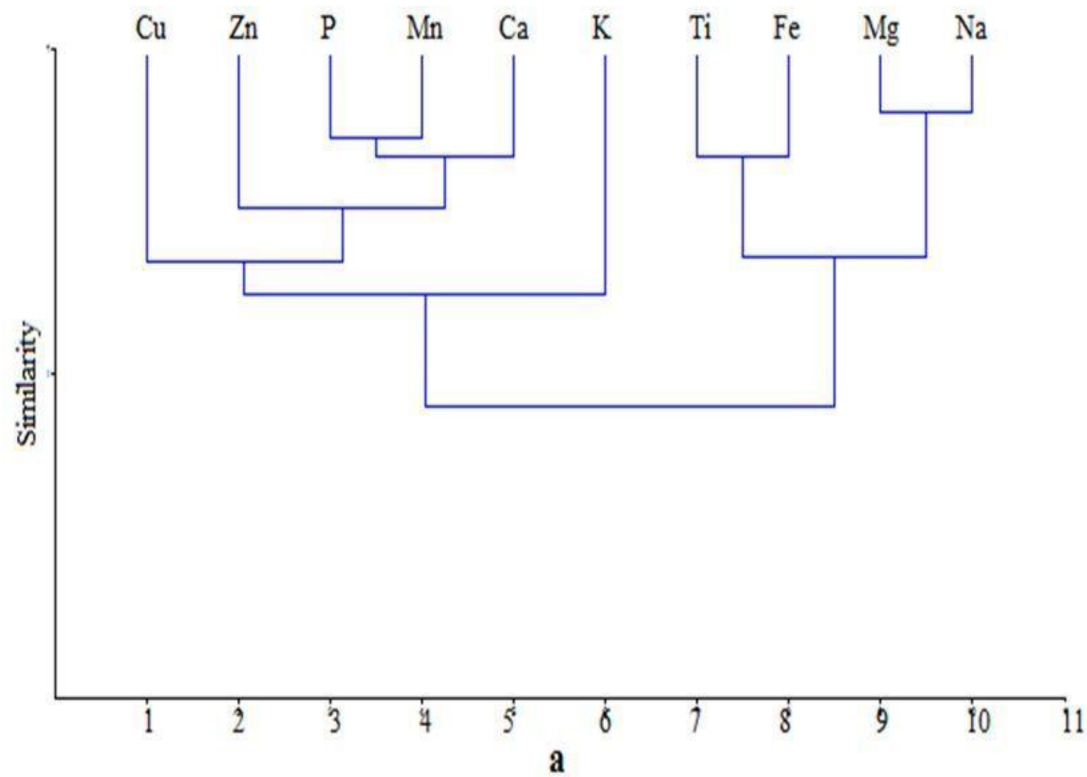
Geochemistry: The geochemical analysis of the surface sediment samples of the Darna Reservoir shows increased values of P_2O_5, Fe_2O_3 and MnO in the post monsoon samples than the pre monsoon samples (Figures 5a-f). A significant increase in the TiO_2 concentration is noted in pre monsoon season (0.62 to 1.49 mg/gm). The post monsoon season indicates enhanced soil erosion and weathering of adjacent rocks and their supply to the reservoir due to increased rainfall. The geochemical elements like SiO_2, Al_2O_3, MgO, K_2O, Cr_2O_3, NiO, ZnO, Rb_2O, SrO, ZrO and BaO show significant increase in the post monsoon sediment samples in the Darna Reservoir. The pair of linear correlation coefficients were computed and hierarchic dendograms were arranged to recognize the association of the major elements and the trace elements (Tables 6 and Figures 6 a - b). These dendograms exibit the relationship of the major and trace elements in the major groups and within the groups as well. For the Darna Reservoir (Figure 6a), the geochemical elements of the surface sediments (pre monsoon) are separated into three main groups: (I) Na – Mg, (II) Fe- Ti and (II) K – Ca – Mn-P-Zn-Cu, while the post monsoon surface sediments (Figure 6b) are categorized in to four main groups: (I) Ti-Pb-Zn-Cu, (II) Fe – Mn, (III) Ca-K-Mg and (IV) Na- P.

Table 6: Major elemental concentrations of Darna Reservoir ((Pre-Monsoon and Post-Monsoon)

Sample No.	Na %	Mg%	P %	K %	Ca %	Ti %	Mn %	Fe %	Cu %	Zn %	Pb %	Si %
D1Pre	0.26	0.46	0.28	0.26	2.72	0.37	0.8	10.49	0.02	0.05	ND*	NA*
D2Pre	0.24	1.04	0.26	0.24	2.32	0.46	0.64	10.34	0.01	0.04	ND*	NA*
D3Pre	0.24	1.07	0.21	0.26	2.11	0.77	0.64	10.67	0.01	0.03	ND*	NA*
Mean	0.25	0.86	0.25	0.25	2.38	0.53	0.69	10.5	0.01	0.04	ND*	NA*
D1 Post	0.54	1.63	0.05	0.77	3.32	0.92	0.16	0.11	3.05	0.53	0.37	21.18
D2Post	0.27	1.45	0.07	0.70	1.16	0.89	0.14	0.10	1.03	0.16	0.11	21.59
D3Post	0.24	1.36	0.07	0.71	1.03	0.89	0.13	0.09	0.92	0.13	0.09	21.57
Mean	0.35	1.48	0.06	0.73	1.84	0.90	0.14	0.10	1.67	0.27	0.19	21.45

(*Note: NA: Not Analyzed; ND: Not Detected)*

Research Article



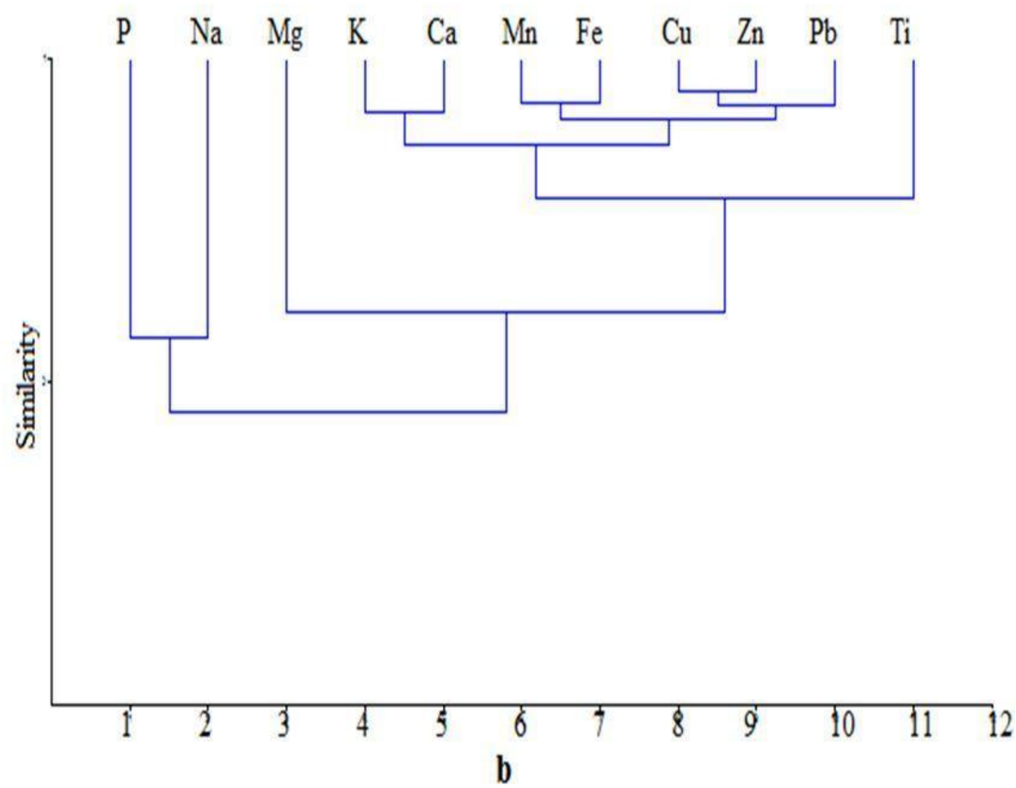


Figure 5 (a – b): Hierarchic dendograms of correlation matrix of geochemical elements of the surface sediments of Darna Reservoir a) the Pre monsoon and b) Post Monsoon

Pre-Monsoon (DR) Genera	**Diatoms species**	**Post-Monsoon (DR) Genera**	**Diatoms species**
1)Aulacoseira	*1) Aulacoseira granulata*	*1)Aulacoseira*	*1)Aulacoseira granulata*
	2) Aulacoseira ambigua		*2)Aulacoseira ambigua*
	3) Aulacoseria islandica		*3)Aulacoseria islandica*
	4) Aulacoseria distans		*4)Aulacoseria distans*
2)Amphora	*5) Amphora ovalis*	*2)Amphora*	*5)Amphora ovalis*
	6) Amphora obtusa		*6)Amphora obtusa*
	7) Amphora australiensis		*7)Amphora australienesis*
3)Achnanthes	*8) Achnanthes brevipes*	*3)Achnanthes*	*8) Achnanthes brevipes*
4)Bacillaria	*9) Bacillaria paxillifer*	*4)Bacillaria*	*9)Bacillaria paxillifer*
5)Caloneis	*10) Caloneis ventricosa*	5)Caloneis	*10)Caloneis ventricosa*
	11) Caloneis bacillum		*11)Caloneis bacillum*
6)Cyclotella	*12)Cyclotella meneghiniana*	*6)Cyclotella*	*12)Cyclotella meneghiniana*
	13)Cyclotella ocellata		*13)Cyclotella ocellata*
7)Cocconeis	*14) Cocconeis placentula*	*7)Cocconeis*	*14)Cocconeis placentula*
8)Cymbella	*15) Cymbella lanceolata*	*8)Cymbella*	*15)Cymbella lanceolata*
9)Discostella	*16) Discostella stelligera*	*9)Discostella*	*16)Discostella stelligera*
10)Diploneis	*17) Diploneis ovalis*	*10)Diploneis*	*17) Diploneis ovalis*
	18) Diploneis smithii		*18) Diploneis smithii*
11)Epithemia	*19)Epithemia turgida*	*11Epithemia*	*19) Epithemia turgida*
12)Encyonema	*20)Encyonema minutum*	*12)Encyonema*	*20) Encyonema minutum*
13)Fragilaria	*21)Fragilaria rumpens*	*13)Fragilaria*	*21) Fragilaria rumpens*
14)Fragilariforma	*22)Fragilari forma constricta*	*14)Fragilariforma*	*22) Fragilariforma constricta*
15)Gomphonema	*23)Gomphonema minutum*	*15)Gomphonema*	*23) Gomphonema minutum*
16)Gyrosigma	*24)Gyrosigma kützingii*	*16)Gyrosigma*	*24)Gyrosigma kützingii*
	25)Gyrosigma spencerii		*25)Gyrosigma spencerii*
17)Nitzschia	*26)Nitzschia* sp.	*17)Nitzschia*	*26)Nitzschia amphibian*
18)Navicula	*27)Navicula viridula*	*18)Navicula*	*27)Navicula viridula*
	28) Navicula radiosa		*28)Navicula radiosa*
			29)Navicula cryptocephala
19)Pinnularia	*29)Pinnularia borealis*	*19)Pinnularia*	*30)Pinnularia borealis*
	30)Pinnularia gibburalia		*31)Pinnularia gibburalia*
	31)Pinnularia gibba		*32)Pinnularia gibba*
20)Planothidium	*32)Planothidium delicatum*	*20)Planothidium*	*33)Planothidium delicatum*
21)Rhopaloidia	*33)Rhopaloidia gibbularia*	*21)Rhopaloidia*	*34)Rhopaloidia gibbularia*

	34)Rhopaloidia gibba		*35)Rhopaloidia gibba*
	35)Rhopalodia musculus		*36)Rhopalodia musculus*
22)Stephanodiscus	*36)Stephanodiscus niagarae*	*22)Stephanodiscus*	*37)Stephanodiscus niagarae*
23)Synedra	*37)Synedra ulna*	*23)Synedra*	*38)Synedra ulna*
24)Surirella	*38)Surirella ovalis*	*24)Surirella*	*39)Surirella ovalis*
	39)Surirella tenera		*40)Surirella tenera*
	40)Surirella angusta		*41)Surirella angusta*
25)Sellaphora	*41)Sellaphora pupilla*	*25)Sellaphora*	*42)Sellaphora pupula*
26)Tryblionella	*42)Tryblionella levidensis*	*26)Tryblionella*	*43)Tryblionella levidensis*
	43)Tryblionella victoriae		*44)Tryblionella victoria*
-	-	27)Eunotia	*45)Eunotia* sp.

Figure 6: Checklist of diatoms recovered from Surface sediments (Pre and Post monsoon) Darna Reservoir (DR)

The surface sediments of the Darna Reservoir clearly show the abundance of Mg, Ti and K (Figures 5 a-c) during the Post monsoon season. On the contrary, the pre monsoon season exhibit high Fe content (Figures 5 d-f). Ca content was comparatively low with its higher values during pre monsoon season (Figures 5 d-f). Ti is the indicator of soil erosion (Garrison and Laliberte, 2010). The Ti content has derived from the soils associated with the dykes belonging to low Ti- tholeiites (Jain and Gupta, 2013). The flows in the Nashik area are mainly composed of plagioclase feldspar, pyroxene, olivine, ilmenite, magnetite, palagonite glass, zeolites, chlorite, chlorophaite and secondary glass (Jain and Gupta, 2013). The Darna Reservoir is mostly surrounded by the agricultural lands and lava flows. Thus, the increased concentration of Mg, Ti and K indicates the enhanced soil erosion in the watershed of the Darna Reservoir. The higher K content may also be due to excessive use of fertilizers in the adjoing agricultural lands and grape farms. The higher Mg content in the reservoir may be attributed to the developmental activities around reservoir such as dam concretization using cement etc. The post monsoon season shows the significantly high content of Si (Figures 5 d-f). The high value of Si may have derived from erosion of soils rich in silica. The flows of the Nashik region contains about 48- 50.25% of SiO_2 (Jain and Gupta, 2013). The P concentrations were higher during pre monsoon season owing to use of fertilizers in the surrounding agricultural lands. The higher Fe content in the reservoir during pre monsoon season may be due to erosion of magnetite rich soils and the enrichment of iron at the deepest part of the reservoir. The decline in the Fe conent may be due to dilution during the post monsoon season.

Diatom analysis: The systematic classifications of diatoms proposed by Round *et al.*, (1990) and John (2014) havw been used in the present research work. The systematic description of diatoms is completely depending on the distinctiveness of frustules i.e. size, shape, structure, symmetry and nature of raphae and density of striae. The sedimentary diatoms recovered from the surface (grab) sediments (Pre and Post monsoon seasons) of the Darna Reservoir are described systematically. The taxonomic work and classification of Mann (1999) have also been exercised in this work. The pre monsoon surface sediments of the Darna Reservoir shows the presence of total 43 species belonging to 26 genera, while the Post-monsoon surface sediments revealed 45 species belonging to 27 genera (Figure 6). The surface (grab) sediments (Pre and Post monsoon seasons) of the Darna Reservoir were studied to recognize the diatom diversity (Figures 7) and the related water quality was compared with the relatively most abundant species. The surface sediments (pre and post monsoon seasons) of the Darna Reservoir divulged maximum abundance of *Aulacoseira granulata, Discostella stelligera* and *Cyclotella ocellata* (Table 7) Thus, these diatom taxa can be used as the indicators of average values of physicochemical parameters to interpret diatom inferred past water quality status after comaring with other lakes and reservoirs of the region. The average values of physicochemical parameters of the Darna Reservoir and associated dominant sedimentary diatom taxa during the pre and post monsoon seasons are shown in Table 7.

Research Article

Table 7: Most abundant diatoms from the surface sediments (PM: Pre Monsoon and PoM: Post Monsoon) of the Darna Reservoir and their preferred range of Physico-chemical parameters

Seasons	Most abundant Diatom species	Physicochemical parameters														
		pH	**EC µmhos/cm**	**Alk mg $CaCO_3$/L**	**Cl mg/l**	**SO_4 mg/l**	**Ca mg/l**	**Mg mg/l**	**NO_3 mg/l**	**TP mg/l**	**Fe mg/l**	**Na mg/l**	**K mg/l**	**Zn mg/l**	**Si mg/l**
PM	*Aulacoseira granulata* *Cyclotella meneghiniana* *Navicula viridula*	7.83	220.00	46.1	19	4.21	18.13	13.4	0.8	0.59	0.09	3.1	1.5	0.06	3.09
PoM	*Aulacoseira granulata* *Cyclotella meneghiniana* *Navicula viridula*	7.14	169.00	36	17	4.98	13.33	8.64	0.96	0.53	0.08	3.08	1.64	0.08	3.09
Average	-	7.48	194.5	41.05	18	4.59	15.73	11.02	0.88	0.56	0.085	3.09	1.57	0.07	3.09

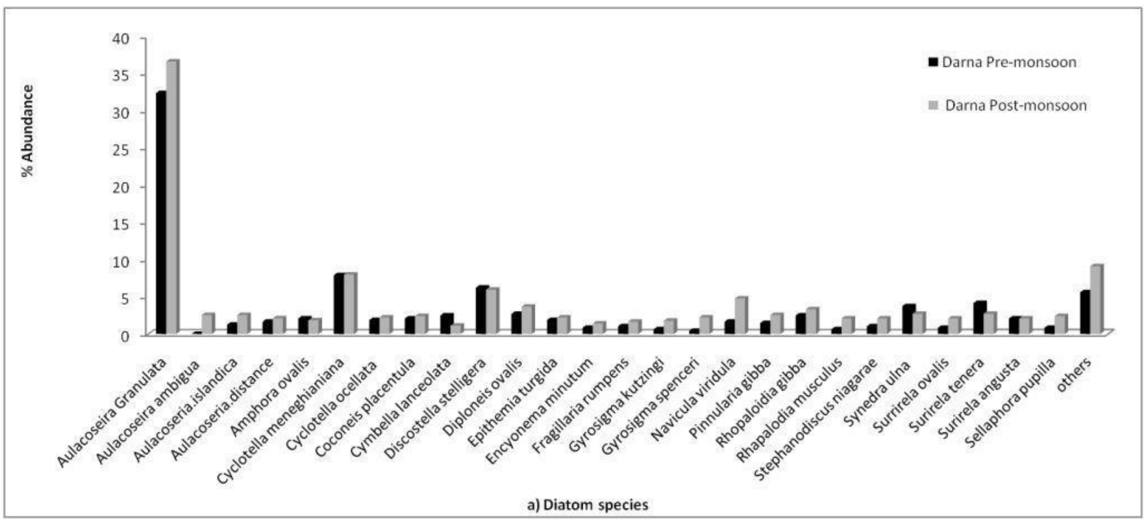


Figure 7: Percent (%) Diatom abundance in surface sediments (grab) of the Darna Reservior

Conclusions

The Darna Reservoir is alkaline nature and the increased pH in the reservoir owed to the breakdown of the organic matter and augmented photosynthetic activity with the relative amount of calcium, carbonate and bicarbonates. It is more eutrophic during pre monsoon season and less rich water body with very poor water quality with reference to calcium content. The low silica content may be due to absorption of silica by bottom vegetation i.e. phytolith like grasses, sponge spicules, cysts and diatoms. The higher values of the phosphorous indicate very poor quality of the Darna Reservoir. The high phosphorous content of the water body may be due to the faster decomposion of the organic matter. The water of this reservoir can be safely used for the domestic purspose and also for drinking purpose after filtering.

The increased concentration of Si, Mg, Ti and K indicates the enhanced soil erosion in the watershed of the Darna Reservoir. The higher K and P content may also be due to excessive use of fertilizers in the adjoing agricultural lands and grape farms. The higher Mg content in the reservoir may be attributed to the developmental activities around reservoir such as dam concretization using cement etc. The higher Fe content in the reservoir during pre monsoon season may be due to erosion of magnetite rich soils and the enrichment of iron at the deepest part of the reservoir.

The surface sediments (pre and post monsoon seasons) of the Darna Reservoir divulged maximum abundance of *Aulacoseira granulata, Discostella stelligera and Cyclotella ocellata*. These diatom taxa indicate alkaline, mesotrophic- eutrophic water quality of the Darna Reservoir. Thus, these diatom taxa can be used as the indicators of average values of physicochemical parameters to interpret diatom inferred past water quality status after comparing with other lakes and reservoirs of the region.

ACKNOWLEDGEMENT

We are thankful to the Head, Postgraduate Department of Geology, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur for providing necessary facilities to carry out this work in the Department. SSH and SKH acknowledge funding received from the University Grants Commission (UGC), New Delhi under the major research project (No. F. 41- 1031/2012 (SR) dated: 26 July 2012). We are also thankful to UGC, New Delhi for SAP- DRS and DST-FIST for financial assistance to the department. The present research paper is an outcome of the Ph.D. work of one of the authors (RM) on “A study of diatoms, geochemistry and water quality of the major reservoirs of the Nashik district, Maharashtra and their ecological development” submitted to Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur.

Repository

All the studied specimens have been kept in the Applied Micropaleontology Laboratory, Department of Geology, RTM Nagpur University, Nagpur. The slides are numbered as DRC1-DRC 70 and DRG1-DRG3 Pre-monsoon DRG1-DRG3 Post-monsoon, GRC1-GRC92, GRG1-GRG3 Pre-monsoon and GRG1-GRG3 Post-monsoon.

REFERENCES

Aparajit NM (2013). Paleolimnological Study of the Naleshwar lake Sindhewahi taluka of the Chandrapur district, Maharashtra, using fossil diatoms, geochemistry and hydrochemistry.Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 80.

Apha Awna and Wpcf (1985). Standard methods for examination of water and waste water, Washington DC. *American Public Health Association* 1-225.

Ariztegui D, Chondrogianni C, Lami A, Guilizzoni P and Lafargue EJ (2001). Lacustrine organic matter and the Holocene paleoenvironmental record of Lake Albano (central Italy). *Journal of Paleolimnology* **26** 283–292.

Audry S, Schafer J, Blanc G and Jouanneau JM (2004). Fifty year sedimentary record of heavy metal pollution (Cd, Zn, Cu, Pb) in the Lot River Reservoirs (France). *Environmental Pollution* **132** 413–426.

Badge YV, Humane SK and Humane SS (2014). Sedimentary Diatoms and Water Quality Appraisal of the Pandharabodi Lake, UmrerTaluka, Nagpur District Maharashtra.*Gondwana Geological Magazine* **15** 17-29.

Bante CR (2014). Records of environmental changes during late Holocene of the Gorewada Lake of the Nagpur district, Maharashtra: a paleolimnological approach.Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 69.

Barahate VP and Tarar JL (1981). The alga flora of Tapi river, Bhusawal, Maharashtra. *Phykos* **20** 75-78.

Barahate VP and Tarar JL (1983). Additions to algal flora of Maharashtra: diatoms from Khandesh-I. *Phykos* **22** 13-17.

Battarbee RW (1986). Diatom analyses. In: *Handbook of Holocene Paleoecology and Paleohydrology* edited by Berglund BE (Wiley, New York) 527-570.

Batterbee RW, Flower RJ, Juggins S, Patrick ST and Stevenson AC (1997). The relationship between diatoms and surface quality in the Hollanandet area of Nord- Trondelag, Norway. *Hydrobiologia* **348** 69-80.

Bawanwade PW (2014). Environmental study of the Ambazari Lake, Nagpur, Maharashtra.Unpublished project report submitted to RTM Nagpur University, Nagpur, 66.

Bihade SP (2011). Ecological study of the Wadgaon Reservoir of Nagpur district, Based on the Sedimentary Diatoms and Geochemistry.Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 67.

BIS (2003). Bureau of Indian Standards, IS 10500- 91, Revised.

Borkar NH (2011b). Diatoms and Geochemical Study of the Tarna Satighat-Lake of the Tarna Village, Umrer, Nagpur District: Ecological Implications. Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 83.

Borkar SS (2011a). Hydrochemistry, Sediment Geochemistry and Diatom study of the Vena Lake of Nagpur District: Ecological Implication. Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 51.

Bradbury JP and Van Metre PC (1997). A land-use and water-quality history of White Rock Lake reservoir, Dallas, Texas. *Journal of Paleolimnology* **17** 227–237.

Bramhankar AD (2011). Paleolimnological study of the Surabardi Lake, Surabardi, Nagpur District, Maharashtra.Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 66.

Callender E (2000). Geochemical effects of rapid sedimentation in aquatic systems: minimal diagenesis and the preservation of historical metal signatures. *Journal of Paleolimnology* **23** 243–260.

Chalakh SP (2014). Environmental study of Gadchiroli Lake, of Gadchiroli District, Maharashtra. Unpublished project report submitted to RTM Nagpur University, Nagpur, 57.

Chopkar AB (2009). Miropalaeontological and Geochemical studies of the late Holocene sediment of the Raghuji Nagar Lake, South Nagpur, Maharashtra. Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 39.

Christie CE and Smol JP (1993). Diatom assemblages as indicators of lake trophic status in the south – eastern Ontario lakes. *Journal of Phycology* **29** 575- 586.

Das SM (1989). *Handbook of Limnology and Water Pollution* (South Asian Publishers) 174.

Dhargave MP (2012). Paleolimnological studies of Ekara Lake, Ekara Village, Sindewahi Taluka, Chandrapur District, Maharashtra. Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 36.

Dhonde UV (2009). Groundwater Information Nashik District Maharashtra. *A report of Central Groundwater Board of India, Government of India, Central Region, Nagpur* 1-18

Dixit SS and Smol JP (1994). Diatoms as indicators in the environmental monitoring and assessment program-surface waters (EMAP-SW). *Environmental Monitoring and Assessment* **31** 275- 306.

DRM (2001). *District Resource Map of Nasik District* (Geological Survey of India).

Fadanvis AV (2014). Water Quality study of the Umred Lake, Nagpur district of Maharashtra using Diatom, Hydrochemistry and Geochemistry. Unpublished project report submitted to RTM Nagpur University, Nagpur, 52.

Foster IDL, Charlesworth SM and Keen DH (1991). A comparative study of heavy metal contamination and pollution in four reservoirs in the English Midlands. *Hydrobiologia* **214** 155–162.

Fritz SC, Juggins S and Battarbee RW (1993). Diatom assemblages and ionic characterization of lakes of the Northern great plains, North America. A tool for reconstructing past salinity and climate fluctuations. *Canada Journal of Fisheries and Aquatic Science* **50** 1844 **-** 1856.

Gandhi HP (1998). Fresh - water Diatoms of Central Gujarat. *Bishen Singh Mahendra Pal Singh, Connaught Place* **23-A** 1-321.

Garrison PJ and Laliberte G (2010). Paleoecological Study of lake Chetac, Sawyer Country.Wisconsin Department of natural resources. *Bureau of Integrated Sciences* 1-17.

Gonzalves EA (1947). The algal flora of the hot springs of Vajreshwari, near Bombay. *Journal of University of Bombay* **16** 22-27.

Hall RI and Smol JP (1999). Diatoms are indicator of Lake Eutrophication. In: *The Diatoms: Application for the Environmental and Earth Sciences*, edited by Stoermer EF and Smoll JP (Cambridge University Press, Cambridge) 168.

Humane Samaya S, Barde U, Humane SK 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 SK, Humane SS, Wankhede AS and Bokde P (2010b). Trophic Status and ecological Studies of the Ambazari Lake, Nagpur, Maharashtra, based on sedimentary diatoms. *Current Science* **99** 816-822.

Humane SK, Humane SS, Wankhede AS 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 SS, Gervabangh MF, Humane SK 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 Sumedh K and Humane Samaya S (2015). 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 Sumedh K., Humane SS, Juare SG 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.

Ingewar MM (2012). Paleolimnological study of the Mansar Lake, Nagpur district, Maharashtra using diatoms and sediment chemistry. Unpublished dissertation thesis submitted to RTM Nagpur University, Nagpur, 52.

Jain PK and Gupta DC (2013). Geochemistry of intrusive rocks of Deccan trap region around Manmad, Nasik, India. *International Journal of Advancement in Earth and Environmental Sciences* **1**(1) 1-13.

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

Juare SG, Humane SK and Humane SS (2014). Recontructing the Relationship of Diatoms and Water Quality Changes in Bodhalkasa Lake, Gondia district, Maharashtra. *Journal of Gondwana Geological Magazine* **15** 85-95.

Kamble S, Humane SK and Humane SS (2014). Seosonal Diatom Diversity with reference to Hydrochemistry and Geochemistry of the Paradgaon Lake, UmrerTaluka, Nagpur District Maharashtra.*Gondwana Geological Magazine Special issue* 41- 52.

Kelly MG (1999). Use of trophic diatom index to monitor eutrophication in rivers. *Water Research* **32**(1) 236-242.

Kumar A, Sharma LL and Aery NC (2008). Physicochemical characteristics and diatoms as indicators of trophic status of Kishore Sagar, Rajasthan. In: *Proceedings of Tal 2007, The Twelfth World Lake Conference* edited by Sengupta M and Dalwani R 1804-1809.

Lees J, Foster I, Jones D, Owens P, Walling D and Leeks G (1997). *Sediment yields in a changing environment: a historical reconstruction using reservoir bottom-sediments in three contrasting small catchments. North York Moors, UK* (IAHS Publication) **245** 169–179.

Liu J, Zhangwen L, Huanjun Z and Han BP (2012). Hydrodynamic change recorded by diatoms in sediments of Liuxihe Reservoir, southern China. *Journal of Paleolimnology* **47** 17-27.

Loganathan P, Pruhantheen, Humane SK and Hussain SM (2014). Distribution of Freshwater Diatoms in the Sediments of the Perumal lake, Cuddalore District, Tamil Nadu. *Gondwana Geological Magazine special issue* **15** 79-84.

Mann DG (1999). The species concept in diatoms. *Phycologia* **38** 437–495.

Meena JS, Sharma R, Sharma V and Sharma MS (2007). Trophic status of lake Picchhola in relation to physicochemical characteristics of its water. *Proceeding of NSL-07* 487.

Misra PK and Shukla SK (2006). Some freshwater diatoms from Uttranchal State. *Journal of Applied Biosciences* **32** (1) 74-80.

Nandkar PB, Marathe KV and Motikhaye BG (1983). Algae in sewage containing pools and oxidation ponds. *Phykos* **22** 37-45.

Ohle W (1934). Chemische and Physikalische untersuchungen norddeutscher. *Archiv für Hydrobiologie* **26** 386-3.

Pearsall WH (1930). Phyto-planktons in the English Lakes. The proportion in the water of some dissolved substances of Biological importance. *Journal of Ecology* **18** 306-320.

Prakash MM (1994). *Journal of Aquatic Biology and Fisheries* **1** 43-47.

Prasad BN, Jaitly YC and Misra PK (1984). Some diatoms from the hot springs of Ladakh. *Geophytology* **14(2)** 156-160.

Round FE, Crawford RM and Mann DG (1990). *The Diatom Biology and Morphology of the Genera* (Cambridge University Press Newyork) 747.

Sarode PT and Kamat ND (1979). Diatoms of Marathwada, Maharashtra-I. *Phykos* **18** 25-32.

Sarode PT and Kamat ND (1980a). The diatomflora of Nagpur, India. *Nova Hedwigia* **32** 797-838.

Sarode PT and Kamat ND (1980b). Diatoms of Marathwada, Maharashtra-II. *Phykos* **19** 197-203.

Sarode PT and Kamat ND (1980c). A new species of *Eunotia*. *Journal of Bombay Natural History Society* **55** 307-308.

Sarode PT and Kamat ND (1983a). Diatoms of Vidarbh, India- I. *Bibliotheca Phycologia* **66** 259-319.

Sarode PT and Kamat ND (1983b). Diatoms of Marathwada, Maharshtra-III. *Phykos* **22** 26-32.

Sarode PT and Kamat ND (1983c). Diatoms of Marathwada, Maharshtra. *Marathwada University Journal of Science* **22** 13-20.

Sarode PT and Kamat ND (1984). *Freshwater Diatoms of Maharashtra* (Saikripa Prakashan, Aurangabad) 338.

Sarwar SG and Wazir A (1991). Physicochemical characteristics of a freshwater pond of shrinagar (Kashmir). *Pollution Research* **10**(4) 223-227.

Sharma LL and Saini VP (2003). *Methods in Aquatic Ecology* (Agrotech Publication Udaipur) 240.

Shotbolt L, Hutchinson SM and Thomas AD (2006). Sediment stratigraphy and heavy metal fluxes to reservoirs in the southernPennine uplands, UK. *Journal of Paleolimnology* **35** 305–322.

Singh M, Lodha P and Singh GP (2010). Seasonal diatom variations with reference to physico-chemical properties of water of manesagar lake of Jaipur, Rajasthan. *Jouranal of Agricultural Sciences* **24**(1) 451-457.

Singh R and Mahajan I (1987). *Journal of Ecology* **14 (2)** 273-277.

Smol JP, Wolfe AP, Birks HJB and Douglash MSV (2005). Climate driven regime shifts in the biological communities of arctic lakes. *Proceeding of National Academy of Science USA* **102** 4397–4402.

Thomas J and Gonzalves EA (1965). Thermal algae of western India, I-VII. *Hydrobiologia* **25** 330-351 and **26** 21-71.

Trivedi RK and Goel PK (1986). *Chemical and Biological Methods for Water Pollution Studies* (Environmental publications, Karad, Maharashtra, India) 1-248.

Valpola S (2006). Lake sediment research as a part of lake management case studies and implications from southern Finland. *Journal of Paleolimnology* **34** 339–348.

Van Metre PC and Callender E (1997). Water-quality trends in White Rock Creek Basin from 1912–1994 identified using sediment cores from White Rock Lake reservoir, Dallas, Texas. *Journal of Paleolimnology* **17** 239–249.

Venkatachalapathy R, Nanthakumar G and Karthikeyan P (2014). Diatom and Water Quality Assessment of the Yercaud lake, Salem District, Tamil Nadu, South India. *Gondwana Geological Magazine special issue* **15** 13-16.

Venkatachalapathy R, Singh MC, Karthikeyan P, Singh S and Sing LS (2013). Diatoms as Indicators of Water Quality in Imphal, Nambul., Waishen Riverns and the Loktak lake, Manipur State, North East India. *Gondwana Geological Magazine special issue* **15** 61-66.

Verma DC, Mehrotra RK and Misra PK (1996). Studies on diatoms of river Gomati, Lucknow. *Geophytology* **25** 27-33.

Verma DC, Mehrotra RK and Misra PK (2000). Blue green algae and diatoms of polluted and unpolluted zone of river Gomati, Lucknow. *International Journal of Tropical Plant Disease* **10** 269-275.

Wang Xisheng, Lovlie R, Su Pu and Fan Xingzhao (2008). Magnetic signature of environmental change reflected by Pleistocene lacustrine sediments from the Nihewan Basin, North China. *Palaeogeography, Palaeoclimatology, Palaeoecology* **260** 452-462.

WHO (1984). World Health Organization, Guidelines for Drinking Water Quality. *Resource of Vidharbha Symposium* 303-315.

WLS (2007). National lake Survey-Wisconsin Results.

Xu H, Hou ZH, AiL and Tan LC (2007). Precipitation at Lake Qinghai, NE Qinghai-Tibet Plateau, and its relation to Asian summer monsoons on decadal/ interdecadal scales during the past 500 years. *Journal of Palaeogeography, Palaeoclimatology, Palaeoecology* **254** 541-549.

Xu H, Li Al, Liangcheng TAN and Zhisheng AN (2006). Stable isotopes in bulk carbonates and organic matter in recent sediments of Lake Qinghai and their climatic implications. *Journal of Chemical Geology* **235** 262-275.

Yeloff DE, Labadz JC and Hunt CO (2005). The suitability of a south Pennine (UK) reservoir as an archive of recentenvironmental change. *Journal of Paleolimnology* **34** 339–348.

Zafar AR (1964). On the ecology of algae in certain fish ponds of Hyderabad, India. 1 physicochemical complexes. *Hydrobiologia* **23** 179-195.

Zafar AR (1966). Limnology of Hussain Sagar Lake, Hyderabad, India. *Phycos* **5** 115-126.