

MONTHLY VARIATIONS IN PHYSICO-CHEMICAL PARAMETERS OF WATER OF RAMGARH LAKE, GORAKHPUR (INDIA)

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ABSTRACT : Colour, odour, temperature, pH, salinity, dissolved oxygen (DO), dissolved carbon-di-oxide (DCO₂), biological oxygen demand (BOD), chemical oxygen demand (COD), conductivity, total dissolved solids (TDS), total solids (TS), dissolved solids (DS), suspended solids (SS), fixed solids (FS), volatile solids (VS), chloride, phosphate, sulphate, nitrate, total nitrogen (TN), fluoride as well as oil and grease contents of Ramgarh Lake water were recorded during March 2013-February 2015. Temperature of the water ranged between 17.3±0.4-35.1±0.7°C with minimum 17.3±0.4°C in January and maximum 35.1±0.7°C in June. pH showed alkaline condition during most of the period and ranged between 7.02±0.3-8.49±0.3 while salinity varied from 0.17 to 0.20 ppt with maximum value during October-January. DO content of the water fluctuated between 4.20±0.4-5.91±0.3 mg/L with low value in winter months while DCO₂ varied from 10.2±0.2 to 13.4±0.3 mg/L with low value during October-January. BOD of water ranged between 12.8±2.4-36.2±2.4 mg/l and COD 41.05±4.06-147.4±4.06 mg/L. Conductivity of the water varied between 428.2-770.4 µS/cm suggesting heavy metal load. TDS of the water ranged from 219.4±5.2 to 588±5.2 mg/L with high values during May-August, TS content between 250.0±0.34-766.0±0.34 mg/L with high value during May-June and DS between 216.0±0.34-612.0±0.34 mg/L, the high value in June and August. SS in the water ranged between 18.0±0.34-274.0±0.34 mg/L with the low value in September, November-January, FS between 220.0-624.0 mg/L while VS depicted values between 38.0-269.0 mg/L. Chloride content of the water ranged between 16.0±0.01-60.0±0.01 mg/L, the maximum value (60.0±0.01 mg/L) was recorded during March-April, phosphate 0.46±0.01-1.31±0.01 mg/L with high value in May (1.31±0.01 mg/L) and June (1.22±0.01 mg/L), sulphate 9.90±0.09-34.76±0.09 mg/L, nitrate <1.00±0.06-5.75±0.06 mg/L and total nitrogen 5.04±0.09-12.32±0.09 mg/L. Fluoride content of the water ranged between 0.37±0.05-1.12±0.09 mg/L while oil and grease content 4.0-18.0 mg/mL. The various data have been discussed in relation to the pollution threat to Ramgrah Lake for sustainable development of fisheries.

Key words : Physico-chemical parameters, Ramgrah Lake, Gorakhpur, India.

INTRODUCTION

Ramgarh Lake (Tal), a natural oxbow-lake formed by river Rapti, is situated on the south-east of Gorakhpur (Uttar Pradesh) and covered an area of about 723 ha with catchment area of more than 11,500 ha which is urbanized and thickly populated. Rapti river flows about 2-3 km south-west of the lake. Bichhia (Kuraghat) nullah (7 km), Gordhaiya nullah (10 km), Mohaddipur Power House nullah (4 km), Golf Ground nullah (3 km), Daudpur nullah (12 km), Padleyganj nullah (4 km) and 10 numbers of mini-ducts (8 km) drain into this water body. Though the lake was developed under Tourist Complex Scheme in 1987 with water-sports complex, Buddha museum, planetarium, tourist bungalow and Champa Vihar Park around the area, this area started losing charm and condition of the lake deteriorated in later years as the water area reduced from 723 (in 1970s) to 678 ha and depth from 4.5 (in 1990s) to 3.5 m at present. Pollution threat to the lake comes mainly from residential colonies located in (1) Maharwa-ki-Bari, (2) Navalpura, (3)

Bhagta, (4) Siktaur, (5) Parsahia Tola, (6) Rampur, (7) Buddha Vihar, (8) Sorahia Tola, (9) Bilandpur, (10) Gopalapur, (11) Padleyganj, (12) Champa Park, (13) Mohaddipur, (14) Kuraghat, (15) Jharkhandi Mahedeo, (16) Avas Vikas Colony, (17) Shivpuri and (18) Bhairavpur discharging more than 1,090 quintals of wastes into this water body every day. Generally, the wastes from households contain nitrate and phosphate causing eutrophication in the lake resulting in low dissolved oxygen content (Singh and Singh, 2009). Ramgarh Lake was heavily infested with water hyacinth during the period. On 5 May 2010, pH of the lake became acidic and temperature increased resulting in the decrease in DO to 2.5 ppm and COD 125 ppm causing mass mortality (150 quintals) of fish (Dwivedi and Hasan, 2010). Furthermore, news of fish death also came in 2006 and 2014. The soil of lake is contaminated with heavy metals (Singh *et al.*, 2011). Acetylcholinesterase (as biomarker) activity in the nervous system of snail (*Lymnaea acuminata*) revealed pollution of Ramgarh Lake (Singh,



Fig. 1 : Ramgarh Lake showing the four sampling stations.

2014). Recent studies have shown that water of the lake is highly polluted and unfit for drinking and bathing (Barnwal *et al.*, 2015, 2015). Since thorough understanding of physico-chemical profiles of water is required in regard to the pollution threat for fisheries development, an attempt has, therefore, been made to record the physico-chemical characteristics of Ramgarh Lake which is a commercially important wetland of eastern Uttar Pradesh (Yadava and Sugunan, 1990).

MATERIALS AND METHODS

Physico-chemical parameters of the water samples of Ramgarh Lake were recorded at monthly intervals during March 2013-February 2015 from the 4 sampling stations (S-1, S-2, S-3, S-4) (Fig. 1) (selected based on level of pollution) with the help of Water Analysis Kit (Thermo Scientific - USA) and average values calculated. However, the detailed analysis of water samples collected from the two sampling sites (S-1, S-4) of the lake were also done at CSIR-Indian Institute of Toxicology

Research (IITR), Lucknow following the standard methods of American Public Health Association (APHA, 2012). Care was taken to collect the water samples at approximately same hours of the day during the entire study period.

RESULTS AND DISCUSSION

Average values of physico-chemical parameters of the water samples at 4 sampling stations (S-1, S-2, S-3, S-4) of Ramgarh Lake during March 2013-February 2015 have been summarized in Table 1. However, the results of analysis of water samples collected from the two sampling sites (S-1, S-4) of the lake and analyzed at CSIR-Indian Institute of Toxicology Research (IITR), Lucknow are given in Table 2.

Colour : Colour in natural water may be due to presence of humic acid, felvic acid, metallic ions such as iron and manganese, phytoplankton and weeds. In the present study, the colour (visual observation) of Ramgarh

Table 1 : Physico-chemical parameters of water at 4 sampling stations of Ramgarh Lake.

Station	Water temperature (°C)	pH	DO (ppm)	DCO ₂ (ppm)	Salinity (ppt)	Conductivity (µS/cm)	TDS (mg/l)
March							
S-1	26.4±0.4	7.41±0.3	5.64±0.2	12.2±0.4	0.18	661.8±7.2	392.6±4.2
S-2	26.2±0.7	7.37±0.4	5.38±0.3	12.8±0.2	0.20	653.5±6.5	388.4±3.8
S-3	26.4±0.8	7.55±0.2	5.61±0.3	11.8±0.3	0.20	653.5±8.2	355.3±5.2
S-4	26.5±0.5	7.57±0.4	5.22±0.5	11.6±0.2	0.19	630.7±6.5	342.2±3.8
April							
S-1	28.7±0.3	7.50±0.3	5.42±0.2	12.4±0.3	0.20	632.8±7.6	358.6±3.2
S-2	28.6±0.6	7.49±0.4	5.58±0.3	12.8±0.4	0.18	628.6±6.2	336.8±5.1
S-3	28.4±0.5	7.22±0.5	5.02±0.4	11.9±0.2	0.20	634.4±5.8	332.6±4.2
S-4	28.8±0.4	7.72±0.2	5.16±0.3	11.8±0.4	0.18	618.7±6.7	318.9±3.4
May							
S-1	32.4±0.6	8.17±0.3	5.48±0.3	13.4±0.3	0.17	765.8±8.2	532.8±3.2
S-2	32.6±0.5	8.20±0.2	5.26±0.4	13.1±0.4	0.20	744.4±7.8	512.5±5.4
S-3	32.9±0.4	8.22±0.4	5.66±0.3	12.8±0.2	0.18	741.3±6.2	508.6±4.5
S-4	32.2±0.7	8.14±0.3	5.58±0.2	12.6±0.3	0.19	725.6±8.5	488.4±4.8
June							
S-1	34.2±0.5	8.49±0.3	5.68±0.3	12.2±0.4	0.19	488.7±8.8	588.8±5.8
S-2	34.1±0.4	8.43±0.4	5.88±0.2	12.8±0.2	0.20	457.5±7.5	528.6±4.5
S-3	34.8±0.6	8.19±0.5	5.91±0.3	11.8±0.3	0.18	468.6±7.8	498.5±6.4
S-4	35.1±0.7	8.28±0.6	5.82±0.2	11.6±0.4	0.19	438.4±6.9	478.9±7.2
July							
S-1	30.2±0.7	7.64±0.2	5.42±0.4	12.4±0.3	0.18	557.2±7.2	568.2±5.4
S-2	29.5±0.3	7.23±0.3	5.58±0.2	12.8±0.2	0.20	578.6±6.8	512.8±6.2
S-3	30.2±0.7	7.42±0.4	5.02±0.3	11.9±0.3	0.19	586.4±5.9	543.6±5.9
S-4	29.4±0.5	7.72±0.2	5.16±0.4	11.8±0.4	0.18	547.8±6.2	468.4±6.5
August							
S-1	31.2±0.5	7.64±0.3	5.42±0.3	12.4±0.4	0.18	650.8±5.8	584.2±4.8
S-2	31.5±0.3	7.73±0.2	5.58±0.2	12.8±0.3	0.20	638.7±6.2	532.8±5.6
S-3	31.1±0.7	7.62±0.3	5.12±0.4	11.9±0.2	0.19	645.5±7.4	562.4±6.2
S-4	31.3±0.4	7.78±0.2	5.16±0.3	11.8±0.2	0.18	620.8±6.8	498.5±5.3
September							
S-1	29.6±0.4	7.64±0.3	5.42±0.4	12.4±0.3	0.18	581.7±6.2	343.6±6.1
S-2	29.4±0.5	7.43±0.4	5.58±0.3	12.8±0.3	0.20	546.5±7.8	312.3±4.3
S-3	29.2±0.7	7.48±0.3	5.02±0.5	11.9±0.2	0.19	565.9±6.9	298.7±5.6
S-4	29.1±0.5	7.72±0.2	5.16±0.4	11.8±0.2	0.18	530.6±6.4	255.6±4.8
October							
S-1	28.7±0.3	7.54±0.4	4.60±0.2	11.4±0.3	0.20	470.8±7.2	328.5±5.8
S-2	28.4±0.5	7.41±0.3	4.20±0.4	11.2±0.4	0.20	470.6±5.8	308.3±4.9
S-3	27.6±0.4	7.35±0.4	5.35±0.3	10.2±0.2	0.20	448.6±6.8	324.8±6.3
S-4	27.4±0.6	7.41±0.3	4.68±0.4	11.0±0.3	0.20	446.4±5.2	219.4±5.2
November							
S-1	28.4±0.3	7.92±0.2	4.64±0.2	11.4±0.3	0.20	468.6±6.2	348.7±4.2
S-2	28.2±0.5	7.44±0.3	4.28±0.4	11.9±0.2	0.20	472.5±7.8	321.5±5.8
S-3	27.8±0.2	7.59±0.2	5.64±0.3	10.8±0.3	0.20	452.6±5.8	342.6±6.1
S-4	27.6±0.3	7.51±0.3	5.12±0.4	11.2±0.4	0.20	456.8±7.4	302.5±6.2

Table 1 continued...

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December							
S-1	22.4±0.4	7.41±0.4	4.42±0.4	11.8±0.2	0.20	471.8±7.9	388.4±5.6
S-2	21.8±0.2	7.43±0.3	4.58±0.3	11.5±0.3	0.20	482.5±4.5	336.5±4.8
S-3	22.2±0.5	7.12±0.4	5.12±0.5	11.4±0.4	0.20	450.7±7.2	352.8±6.1
S-4	24.1±0.3	7.02±0.3	5.46±0.3	11.6±0.3	0.20	462.8±5.8	324.2±5.2
January							
S-1	17.3±0.4	7.35±0.2	4.32±0.4	11.2±0.4	0.20	682.6±8.5	456.8±4.2
S-2	17.4±0.5	7.11±0.3	4.46±0.3	11.8±0.3	0.20	687.3±7.2	418.6±5.8
S-3	17.8±0.3	7.26±0.4	4.82±0.2	11.6±0.3	0.20	645.8±5.4	422.4±4.6
S-4	17.8±0.2	7.14±0.5	5.21±0.4	11.2±0.4	0.20	647.9±6.8	392.7±5.2
February							
S-1	19.1±0.5	8.13±0.5	4.88±0.2	11.2±0.4	0.18	721.8±7.9	302.7±5.1
S-2	19.3±0.6	8.28±0.3	4.86±0.3	11.5±0.3	0.20	723.4±6.2	298.4±6.1
S-3	19.2±0.3	8.25±0.2	5.10±0.4	11.8±0.2	0.18	723.9±7.4	293.6±4.8
S-4	19.8±0.2	8.18±0.3	5.54±0.2	11.6±0.3	0.20	689.8±6.9	288.2±5.7

Lake at different sampling sites varied from light green (rainy season) to dark green (winter and summer).

Odour : Odour of water is mainly due to presence dissolved impurities which are often organic in nature. In the present study, the odour of Ramgarh Lake water at sampling sites S-1, S-2 and S-3 was found to be slightly unpleasant whereas at sampling site S-4, it was odourless.

Temperature : It is one of the most important physical factors which regulates natural processes within the environment. The greatest source for variations in water temperature is solar radiation which is absorbed directly by the water. Temperature of Ramgarh Lake water at the four different sites ranged between 17.3±0.4-35.1±0.7°C during the period with minimum 17.3±0.4°C in January and maximum 35.1±0.7°C in June (Fig. 2).

pH : It is usually defined as logarithm of the reciprocal of the concentration of free hydrogen ions. pH of natural water is governed to a large extent by the interaction of H⁺ ions arising from dissociation of H₂CO₃ and from OH⁻ ions produced during the hydrolysis of bicarbonate. pH of Ramgarh Lake water showed alkaline condition during most of the period and ranged between 7.02±0.3-8.49±0.3 at the four different sites, the lowest value in December and highest in June (Fig. 3). However, water samples of the two sites (S-1, S-4) of the lake depicted pH value ranging from 6.56±0.24 (September) to 9.09±0.24 (March-April).

Dissolved oxygen : It is one of the most important parameters in water quality assessment and reflects the physical and biological processes prevailing in the water. Non-polluted surface water is normally saturated with dissolved oxygen. In natural water, dissolved oxygen is the most important chemical factor as regulator of

metabolic processes of plant and animal community and as indicator of water condition. The dissolved oxygen of Ramgarh Lake water at the four sampling stations during the period fluctuated between 4.20±0.4-5.91±0.3 mg/L, lowest value in October and highest in June. Generally, low content of DO in the lake water was observed during winter months (Fig. 4).

Dissolved carbon-di-oxide : Dissolved carbon-di-oxide in the water of Ramgarh Lake at the four sampling stations varied from 10.2±0.2-13.4±0.3 mg/L. Low level of dissolved carbon-di-oxide was observed during winter months (October-January) and highest in May (Fig. 5).

Salinity : Salinity of the water of Ramgarh Lake at the four sampling stations ranged from 0.17-0.20 ppt during the period under report with maximum value during October-January (Fig. 6).

Biological oxygen demand (BOD) : It is the measure of oxygen required by micro-organisms for biological oxidation of organic matter. The BOD test is useful for pollution control management and in evaluation of self-purification capacities which serves as a measure to assess the quality of wastes that can be safely assimilated by the water bodies. Monthly changes in biological oxygen demand (BOD) at the two different sites (S-1, S-4) ranged between 12.8±2.4-36.2±2.4 mg/l during the period., with lowest value in November and highest in March.

Chemical oxygen demand (COD) : It is the measure of oxygen required for chemical oxidation of organic matter. Chemical oxygen demand of the two different sampling sites (S-1, S-4) of Ramgarh Lake varied from 41.05±4.06 (November) and 147.4±4.06 mg/L (April) during the period.

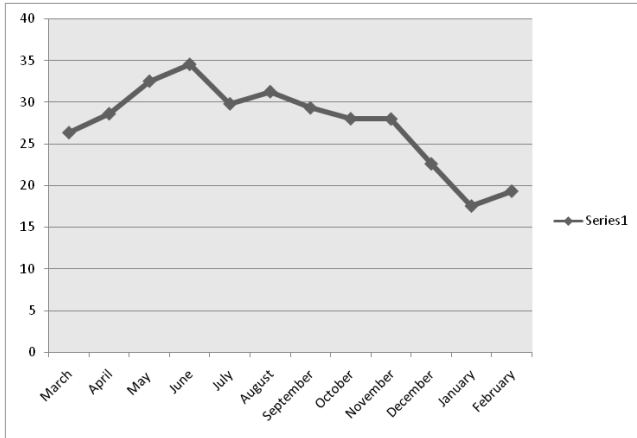


Fig. 2 : Average monthly variations in water temperature of Ramgarh Lake.

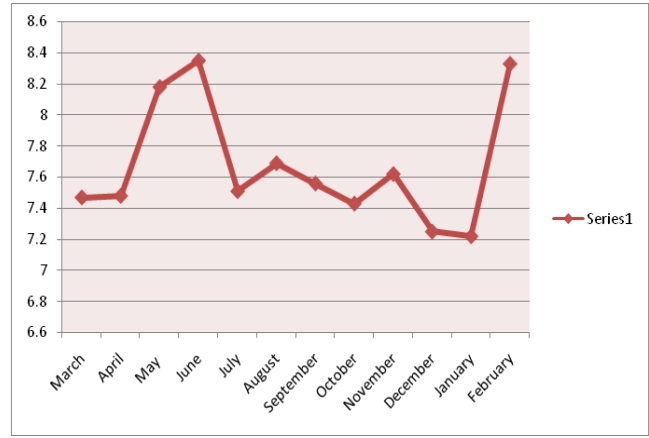


Fig. 3 : Average monthly fluctuations in water pH of Ramgarh Lake.

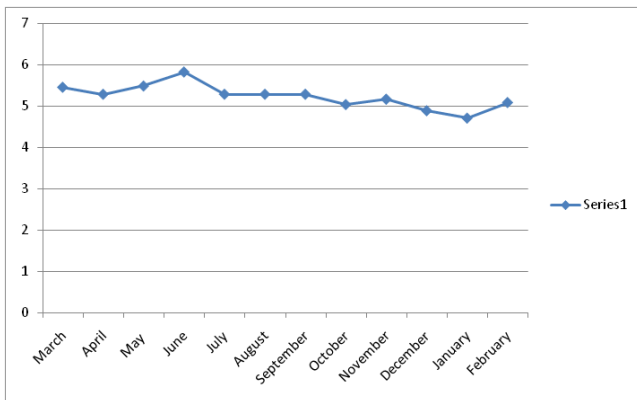


Fig. 4 : Average monthly variations in dissolved oxygen of Ramgarh Lake water.

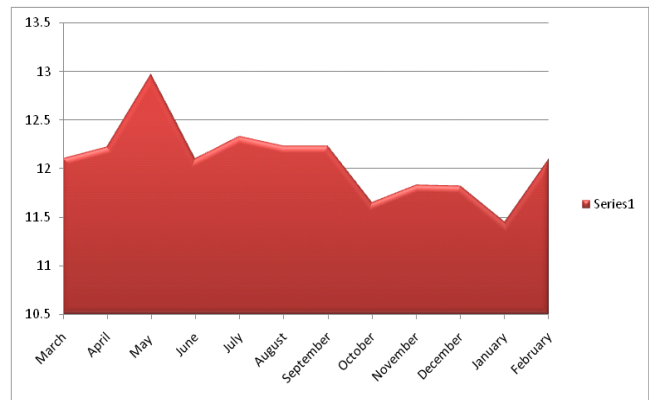


Fig. 5 : Average monthly variations in dissolved carbon-di-oxide in water of Ramgarh Lake.

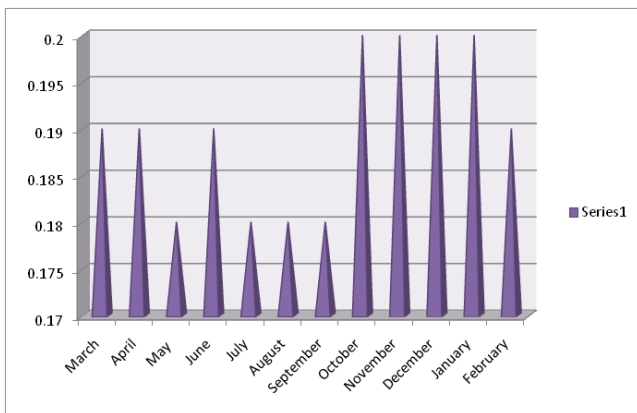


Fig. 6 : Average monthly fluctuations in salinity of Ramgarh Lake water.

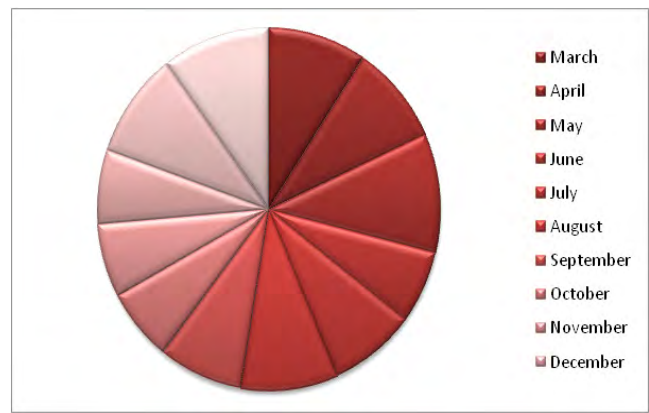


Fig. 7 : Average monthly fluctuations in conductivity of water of Ramgarh Lake.

Conductivity : It is a measure of resistance of a solution to electrical flow which has always been used as a valuable method to estimate the degree of salt contents and total dissolved solid in water. Specific conductivity is an index of the amount of water soluble salts present in water which ranged between 438.4 ± 6.9 -

765.8 ± 8.2 $\mu\text{S}/\text{cm}$ at the four sampling stations of Ramgarh Lake (Fig. 7). However, water samples of the two sites (S-1, S-4) depicted conductivity in the range of 428.2 (June) and 770.4 (May) $\mu\text{S}/\text{cm}$. Generally, the conductivity of Ramgarh Lake water was low during winter month. The present study showed that water of

the lake had fairly high contents of dissolved salts at all the sampling stations suggesting heavy metal load.

Total dissolved solids : Total dissolved solids (TDS) in the water of Ramgarh Lake at the four sampling stations ranged from 219.4 ± 5.2 to 588 ± 5.2 mg/L, the high values were during May-August (Fig. 8).

Total solids : Total solids (TS) in water samples of Ramgarh Lake water at two different sites (S-1, S-4) depicted the value ranging from 250.0 ± 0.34 to 766.0 ± 0.34 mg/L. Generally, the high values were recorded in May, June and August and low during winter months.

Dissolved solids : Dissolved solids (DS) in water of Ramgarh Lake collected at the two different sites (S-1, S-4) showed the value ranging between 216.0 ± 0.34 (September)- 612.0 ± 0.34 mg/L (August). The high values were recorded in June and August.

Suspended solids : Suspended solids (SS) in the water of Ramgarh Lake collected at the two different sites (S-1, S-4) depicted the value ranging between 18.0 ± 0.34 (September)- 274.0 ± 0.34 mg/L (May). The low values were found in September, November, December and January.

Fixed solids : Fixed solids (FS) in the water of Ramgarh Lake collected at the two different sites (S-1, S-4) depicted the value ranging between 220.0 (November)- 624.0 mg/L (May).

Volatile solids : Volatile solids (VS) in the water of Ramgarh Lake collected at the two different sites (S-1, S-4) depicted the value ranging between 38.0 (September)- 269.0 mg/L (May).

Chloride : It occurs naturally in all types of water, however, its concentration remains quite low. The most important source of chloride in water is the discharge of domestic sewage. Chloride content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) ranged from 16.0 ± 0.01 - 60.0 ± 0.01 mg/L, the minimum value in June and maximum (60.0 ± 0.01 mg/L) during March-April.

Phosphate : Phosphate in surface water is normally derived from the leaching of minerals from the rocks or soil, decomposing organic matter and drainage from agricultural areas, especially those which have been fertilized, municipal wastewater treatment plants and certain industrial wastes. Phosphate content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) ranged from 0.46 ± 0.01 - 1.31 ± 0.01 mg/L during the period under report. The high values were recorded in May (1.31 ± 0.01 mg/L) and June (1.22 ± 0.01 mg/L).

Sulphate : It is a naturally-occurring anion in all kinds

of natural water which is found in particularly higher concentration due to accumulation of soluble salt in soil and shallow aquifers. Sulphate content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) ranged between 9.90 ± 0.09 (January) and 34.76 ± 0.09 mg/L (June).

Nitrate : Nitrate represents the highest oxidized form of nitrogen and is an important nutrient in freshwater bodies for growth of phytoplankton. Most of the surface water are, therefore, deficient in nitrate. Nitrate (as NO_3^-) content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) ranged from $<1.00 \pm 0.06$ (June) to 5.75 ± 0.06 mg/L (September) during the period.

Total nitrogen : Total nitrogen content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) varied between 5.04 ± 0.09 (May) to 12.32 ± 0.09 mg/L (June).

Fluoride : Fluoride content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) ranged from 0.37 ± 0.05 (September)- 1.12 ± 0.09 mg/L (May).

Oil and grease : Oil and grease content of the water of Ramgarh Lake at the two sampling stations (S-1, S-4) ranged between 4.0 (March, April)- 18.0 mg/mL (June, August) during the period.

Lake functions are, generally, directly related to their physical, chemical and biological integrity (Wetzel, 19975; Ramachandra, 2002). Limnological studies and variations in physico-chemical characteristics of the freshwater lakes and rivers of the country have been recorded during the past (Swarup and Singh, 1976; Kanungo and Naik, 1987; Jain *et al*, 1996; Gopal and Zutshi, 1998; Pandey *et al*, 1999; Joshi *et al*, 2009; Mishra *et al*, 2012; Sharma and Soni, 2013). Domestic sewage, fertilizer factory and industrial effluents pollute majority of freshwater resources in India (Ghosh *et al*, 1974; Chari, 1985; Jain *et al*, 1995; Lal and Pandey, 1995, 1999; Basheer *et al*, 1996; Gopal and Zutshi, 1998; Moundiotiya *et al*, 2004; Singh and Singh, 2007; Saksena *et al*, 2008; Shiddamallaya and Pratima, 2008; Gupta *et al*, 2011; Jayalakshmi *et al*, 2011; Saxena and Saksena, 2012; Prajapati and Dwivedi, 2013; Yadav *et al*, 2013; Barki and Singa, 2014; Katakwar, 2014; Saini *et al*, 2015; Talwar *et al*, 2015). Such studies of Ramgarh Lake has also been made in the past (Sahai and Sinha, 1969; Sinha, 1969), however, the physico-chemical observations of the lake received much attention during the recent years (Srivastava *et al*, 2006; 2007; Singh and Singh, 2009; Singh *et al*, 2011, 2013, 2014; Singh and Upadhyay, 2012; Tiwari, 2013; Barnwal *et al*, 2014, 2015; Bharati and Pandey, 2015). Temperature of Ramgarh Lake water at

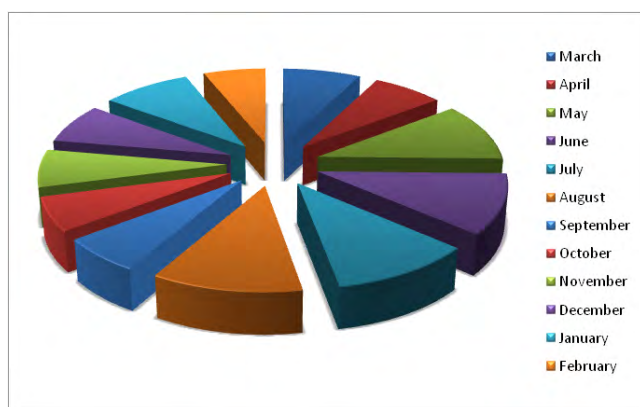


Fig. 8 : Average monthly fluctuations in total dissolved solids (TDS) of Ramgarh Lake water.

the four different sites ranged between 17.3 ± 0.4 – 35.1 ± 0.7 °C during the period with minimum 17.3 ± 0.4 °C in January and maximum 35.1 ± 0.7 °C in June. Similar variations in temperature have also been recorded in other water bodies (Ghosh *et al*, 1974; Basheer *et al*, 1996; Srivastava *et al*, 2003; Chaurasia and Pandey, 2007; Singh and Singh, 2009; Srivastava *et al*, 2009; Mishra *et al*, 2011; Biswas *et al*, 2012; Verma *et al*, 2013; Choudhary *et al*, 2014; Dixit *et al*, 2015), however, water temperature was low in the water bodies located in subtropical Himalyan region (Joshi and Singh, 2001; Agarwal and Raiwar, 2010; Bisht *et al*, 2013). pH of the water collected from the 4 sampling stations of Ramgarh Lake were within the limit of tolerance of fish (Ghosh *et al*, 1974). Srivastava *et al* (2007) and Singh and Singh (2009) recorded alkaline pH (8.0–8.6) of Ramgarh Lake in their studies. Gupta and Pandey (2014) found alkaline pH (8.0–8.5) of the pond water of Surajkund located in Gorakhpur. Further, Ghosh *et al* (1974) and Mishra *et al* (2011) also recorded alkaline pH ranging from 7.30 to 8.90 in a sewage-fed pond near Khardah (Barrackpore) and Rani Lake (Rewa), respectively. Biological oxygen demand (BOD) and chemical oxygen demand (COD) of Ramgrah Lake were more, the values being high during summer and low in monsoon seasons. Chaurasia and Pandey (2007) found high BOD in water ponds of Ayodhya-Faizabad (Uttar Pradesh). Srivastava *et al* (2007), Singh *et al* (2013) and Barnwal *et al* (2014, 2015) also recorded similar observations pertaining to BOD and COD of water of Ramgarh Lake. Manna *et al* (2003) found high BOD in man-made lotic fish culture ponds located in Kalyani (West Bengal). BOD and COD of Rani Lake (Rewa) water varied between 8.14–17.47 and 31.89–54.74 ppm, respectively. The present observations pertaining to BOD and COD variations in Ramgrah Lake are comparable to those recorded for Budha Talab at Chhattisgarh (Biswas *et al*, 2012). BOD and COD are

generally low for unpolluted water bodies (Rajshekhar *et al*, 2007; Agarwal and Raiwar, 2010; Shinde *et al*, 2010; Parte, 2012; Saini *et al*, 2015). Conductivity of Ramgarh Lake water varied between 438.4 ± 6.9 – 765.8 ± 8.2 μ S/ml demonstrating high content of dissolved salts at all the sampling stations while water of the protected Bakhire Lake showed fairly low conductivity (Pandey, 2015).

Generally, total solids, dissolved solids, suspended solids and volatile solids contents of Ramgarh Lake water were a little high and exhibited monthly/seasonal variations with low values during winter months. Shinde *et al* (2010), Parte (2012) and Gupta and Pandey (2014) have also recorded high total solids in water of the several water bodies, however, Agarwal and Raiwar (2010) reported low values (102 ± 0 – 250 ± 2 mg/L) in water of Tehri Dam reservoir (Garhwal-Himalaya). Chloride content of Ramgarh Lake water exhibited low values during monsoon season and high during summer which may probably be due to rise of temperature and evaporation of water (Gonzalves and Joshi, 1946; Parte, 2012). The values of chloride content observed in Rangarh Lake were lower than those reported in the water of Surajkund pond, Gorakhpur (Gupta and Pandey, 2014). Ghosh *et al* (1974) have also recorded higher values of chloride in the sewage-fed pond near Khardah (West Bengal). Seasonal variations in chloride content of other water bodies have also been recorded (Gonzalves and Joshi, 1946; Rajshekhar *et al*, 2007; Shinde *et al*, 2010; Parte, 2012; Gupta and Pandey, 2014). The high chloride content depicts the pollution load, suggesting eutrophication of the lake (Ghosh *et al*, 1974; Barnwal *et al*, 2014, 2015). Phosphate content of the water of Ramgarh Lake is generally low as reported for Budha Talab, Chhattisgarh (Biswas *et al*, 2012), however, the values are much lower as compared to those reported for sewage-fed ponds (Ghosh *et al*, 1974; Basheer *et al*, 1996). Sulphate, nitrate and total nitrogen contents of Ramgarh Lake water were generally more depicting high productivity of the lake (Swarup and Singh, 1976; Pathak *et al*, 2004; Parte, 2012). Similar observations have also been recorded from the sewage-fed pond near Khardah (Barrackpore) (Ghosh *et al*, 1974). The main source of polluting nitrate is domestic sewage (Ramachandra, 2002; Singh and Singfh, 2009) which is getting discharged directly into Ramgarh Lake.

Fluoride is highly toxic to fish and other aquatic organisms (Neuhold and Sigler, 1962; Hamilton and Haines, 1995; Camargo, 2003; Cao *et al*, 2013; Pearcy *et al*, 2015; Singh and Tripathi, 2015), however, water quality variables like hardness, chloride and alkalinity do substantially modify its toxicity (Neuhold and Sigler, 1962;

Table 2 : Physico-chemical parameters of water at the two sampling stations of Ramgarh Lake.

Month	pH	BOD (mg/L)	COD (mg/L)	Total solids (mg/L)	Dissolved solids (mL)	Suspended solids (mL)	Fixed solids (mL)	Volatile solids (mL)	Chloride (mL)	Phosphate as P (mL)	Sulphate as SO ₄ ⁻² (mL)	Nitrate as NO ₃ ⁻ (mL)	Total nitrogen (mL)	Fluoride (mL)	Oil & grease (mL)	Conductivity (µS/cm)
April S-1	9.09± 0.236	34.8±2.4	135.6± 4.06	452.0± 0.345	338.0± 0.345	114.0± 0.345	280.0	172.0	60.0± 0.011	0.46± 0.012	18.9± 0.086	2.63± 0.056	8.96± 0.094	0.82± 0.05	4.0	665.4
S-4	8.96± 0.236	32.4±2.4	147.4± 4.06	464.0± 0.345	310.0± 0.345	154.0± 0.345	298.0	166.0	60.0± 0.011	0.49± 0.012	19.3± 0.086	3.83± 0.056	7.3± 0.094	0.83± 0.05	6.5	625.5
May S-1	7.02± 0.236	35.5±2.4	79.2± 4.06	750.0± 0.345	506.0± 0.345	244.0± 0.345	490.0	269.0	16.0± 0.011	1.31± 0.012	24.7± 0.086	1.83± 0.056	6.16± 0.094	1.04± 0.05	10.0	770.4
S-4	6.92± 0.236	31.0±2.4	70.4± 4.06	704.0± 0.345	430.0± 0.345	274.0± 0.345	624.0	80.0	19.0± 0.011	0.98± 0.012	27.1± 0.086	1.97± 0.056	5.04± 0.094	1.12± 0.05	10.0	710.8
June S-1	6.99± 0.236	25.0±2.4	65.28± 4.06	742.0± 0.345	564.0± 0.345	178.0± 0.345	574.0	168.0	17.0± 0.011	1.22± 0.012	30.9± 0.086	5.55± 0.056	12.32± 0.094	0.98± 0.05	14.0	495.1
S-4	7.20± 0.236	34.0±2.4	81.6± 4.06	618.0± 0.345	466.0± 0.345	152.0± 0.345	466.0	152.0	16.0± 0.011	0.95± 0.012	34.8± 0.086	<1.0± 0.056	5.04± 0.094	0.97± 0.05	16.0	428.2
August S-1	7.05± 0.236	14.5±2.4	70.56± 4.06	766.0± 0.345	612.0± 0.345	152.0± 0.345	614.0	152.0	19.0± 0.011	0.58± 0.012	12.5± 0.086	3.42± 0.056	9.52± 0.094	0.96± 0.05	18.0	628.4
S-4	7.15± 0.236	17.0±2.4	78.4± 4.06	620.0± 0.345	478.0± 0.345	142.0± 0.345	480.0	140.0	19.0± 0.011	0.54± 0.012	13.7± 0.086	4.22± 0.056	7.84± 0.094	0.93± 0.05	16.0	581.2
September S-1	6.56± 0.236	21.6±2.4	74.16± 4.06	250.0± 0.345	216.0± 0.345	34.0± 0.345	242.0	38.0	33.0± 0.011	0.77± 0.012	15.5± 0.086	5.75± 0.056	10.64± 0.094	0.56± 0.05	6.0	588.4
S-4	6.72± 0.236	22.8±2.4	90.64± 4.06	338.0± 0.345	302.0± 0.345	36.0± 0.345	280.0	58.0	36.0± 0.011	0.49± 0.012	17.4± 0.086	5.33± 0.056	10.08± 0.094	0.37± 0.05	4.0	532.7
November S-1	7.92± 0.236	12.8±2.4	41.05± 4.06	320.0± 0.345	296.0± 0.345	24.0± 0.345	220.0	100.0	21.0± 0.011	0.62± 0.012	15.4± 0.086	5.5± 0.056	7.84± 0.094	0.93± 0.05	8.0	498.8
S-4	7.59± 0.236	15.2±2.4	63.4± 4.06	400.0± 0.345	382.0± 0.345	18.0± 0.345	280.0	120.0	25.0± 0.011	0.50± 0.012	17.6± 0.086	4.30± 0.056	8.96± 0.094	0.87± 0.05	10.0	452.4
December S-1	7.41± 0.236	16.4±2.4	62.08± 4.06	370.0± 0.345	316.0± 0.345	54.0± 0.345	256.0	114.0	30.0± 0.011	0.83± 0.012	16.8± 0.086	4.89± 0.056	10.08± 0.094	0.82± 0.05	10.0	488.5
S-4	7.03± 0.236	17.2±2.4	73.7± 4.06	428.0± 0.345	366.0± 0.345	62.0± 0.345	302.0	126.0	34.0± 0.011	0.67± 0.012	19.0± 0.086	5.66± 0.056	11.76± 0.094	0.83± 0.05	10.0	442.6
January S-1	7.35± 0.236	34.0±2.4	81.9± 4.06	336.0± 0.345	298.0± 0.345	38.0± 0.345	232.0	104.0	33.0± 0.011	0.85± 0.012	10.2± 0.086	4.76± 0.056	9.52± 0.094	0.62± 0.05	12.0	680.8
S-4	7.11± 0.236	35.0±2.4	85.3± 4.06	330.0± 0.345	290.0± 0.345	40.0± 0.345	230.0	100.0	31.0± 0.011	0.92± 0.012	9.9± 0.086	4.02± 0.056	8.4± 0.094	0.56± 0.05	18.0	622.4
March S-1	9.09± 0.236	33.5± 20.4	135.6± 4.06	452.0± 0.345	338.0± 0.345	114.0± 0.345	280.0	172.0	60.0± 0.011	0.46± 0.012	18.9± 0.086	2.63± 0.056	8.96± 0.094	0.82± 0.05	4.0	738.5
S-4	8.96± 0.236	36.2±2.4	147.4± 4.06	464.0± 0.345	310.0± 0.345	154.0± 0.345	298.0	166.0	60.0± 0.011	0.49± 0.012	19.3± 0.086	3.83± 0.056	7.3± 0.094	0.83± 0.05	6.5	684.2

Hamilton and Haines, 1995; Camargo, 2003; Percy *et al*, 2015). Its content in the water of Ramgarh Lake ranged between 0.37 ± 0.05 - 1.12 ± 0.09 mg/L. Pradhan *et al* (2014) also found similar fluoride contents in different water bodies of Jaipur. It has been suggested that fluoride concentration as low as 0.5 mg/L can adversely affects fish and aquatic invertebrates and the safe levels below this is recommended in order to protect freshwater organisms from fluoride pollution (Camargo, 2003). Fluoride content in drinking water between 0.8-1.2 mg/L is recommended for prevention of tooth decay and strengthening of skeleton and above 1.5 mg/L causes fluorosis leading to pitting of tooth enamel and deposition in bones (Fawell *et al*, 2006; WHO, 2012). Oil and grease content of the water of Ramgarh Lake fluctuated between 4.0-18.0 mg/mL, the values were high during monsoon season. Oil and grease contains many low and high molecular weight hydrocarbons that are toxic because fish are particularly susceptible to absorbing these compounds due to high oil and fat contents (Stenstrom *et al*, 1986). These compounds get dissolved easily into their tissues through contact with the skin and gills. Effects of these compound on fish larvae range from mortality to abnormal development and deformities. Since the effects of oil can last for many years, these can have devastating effect on local fish population (Irwin, 1997; Inyang *et al*, 2002; FAO, 2012; Islam *et al*, 2013). Effluents containing oil and grease should be treated properly before releasing into the water body (Yu *et al*, 2013). In the water bodies, congenial physico-chemical parameters should be maintained for sustainable fisheries (Wetzel, 1975; Ramachandra, 2002).

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