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Water quality and trophic status of Raipur reservoir in Gwalior, Madhya Pradesh

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Abstract
This study is aimed to assess water quality and trophic status of Raipur reservoir. The range of various parameters of reservoir water (ambient temperature-20.35-41.05^{0}C, water temperature-14.83-31.3^{0}C, transparency-29.46-111.5 cm, turbidity-3.85-15.23NTU, water depth-1.12-4.42 m, colour-transparent-dark brown, electrical conductivity-288.40-421.50 µScm^{-1}, total dissolved solids-179.64-273.58 mg L^{-1}, total suspended solids-84.30-113.95 mg L^{-1}, total solids-263.91-385.04 mg L^{-1}, pH-7.93-9.05, dissolved oxygen-7.49-9.63 mg L^{-1}, free carbon dioxide-nil-9.30 mg L^{-1}, total alkalinity-49.30-105.50 mg L^{-1}, total hardness-102.0-167.75 mg L^{-1}, chlorides-24.10-85.23 mg L^{-1}, sulphates-3.70-12.60 mg L^{-1}, nitrate-nitrogen-0.250-0.870 mg L^{-1}, nitrite-nitrogen-0.033-0.089 mg L^{-1}, inorganic phosphorus-0.029-0.086 mg L^{-1}, silicates-2.70-12.78 mg L^{-1}, ammonia-0.43-1.56 mg L^{-1}, sulphides-0.695-1.44 mg L^{-1}, biochemical oxygen demand-2.65-6.94 mg L^{-1}, chemical oxygen demand-58.7-120.5 mg L^{-1}, calcium-26.85-44.67 mg L^{-1}, magnesium-8.46-18.85 mg L^{-1}, sodium-8.55-16.43 mg L^{-1} and potassium-4.25-7.53 mg L^{-1}) exhibit monthly as well as seasonal fluctuations. The nutrients including calcium, silicates, sulphates, phosphates, nitrates and potassium are in sufficient quantities for the growth of aquatic plants and animals in the reservoir. The above study indicated that the Raipur reservoir is under category of meso-eutrophic water body.
Keywords: Physico-chemical parameters, Trophic status and Raipur reservoir

1. Introduction

Water is one of the most essential natural resources for sustaining life and it is likely to become critically scarce in the coming decades, due to continuous increase in its demand, rapid increase in population and expanding economy of the country. The dynamic and renewable of water resources and the recurrent need for its utilization require water resources to be measured in terms of its flow rates. Accordingly, the importance of water has been recognized and greater emphasis is being laid on its economic use and better management. The surface water and groundwater resources of the country play a major role in agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, navigation, recreational activities, etc. Due to unplanned management, tremendous development of industry and agriculture and disposal of untreated public sewage water, agricultural run off and other human and animal wastes in to rivers, lakes, reservoirs and other water bodies are continuosly deteriorating their water quality and biotic resources (Venkatesan, 2007; Elmaci *et al.,* 2008). The health of lakes and their biological diversity are directly related to health of almost every component of the ecosystem (Indira and Sivaji, 2006; Krishnan et al., 2007; Siddamallayya and Pratima, 2008). Human anthropogenic activities are the main causative agents in the increase of nutrients like phosphates, chlorides and calcium and ultimately lead to eutrophication (Chukwu and Odunzeh, 2006; Shekhar *et al.,* 2008). The performance of trophic status depends on the locality and topography of water bodies. Generally, chlorophyll content, phosphorus, nitrogen load and transparency have been considered for trophic status of any lake. The trophic state is defined as the total weight of biomass in a given water body at the time of measurement. In freshwater bodies nutrients play an important role as their excessive input leads to eutrophication. Luxuriant growth of macrophytic vegetation is also indicative of trophic status of any water body. The present investigation deals with the study of physico-chemical parameters of water of Raipur reservoir, Gwalior.

2. Materials and Methods

2.1 Study Area:

Raipur reservoir was constructed on Swarnrekha river in 1877 by the then Maharaja Shrimant Jiyaji Rao Scindia of Gwalior. The reservoir is situated near Nayagaon village in Gwalior district, Madhya Pradesh. The water of this reservoir is used for irrigating crop fields and for culture fisheries. Geographically, the Raipur reservoir lies on $78^0$03'44.74" E longitudes and $26^0$08'07.63" N latitude (fig 1 and 2).

2.2 Sampling Procedure:

Four sampling stations designated as A, B, C and D were established in the reservoir covering its whole area for the collection of water samples. The physico-chemical characteristics of water of Raipur reservoir were estimated for a period of two years*, i.e.*, from April, 2009 to March, 2011. The reservoir dried from April, 2010 to July, 2010 due to low rains during the rainy season and high summer heat.

2.3 Analytical techniques:

Analytical techniques as described in APHA *et al.* (2005) and Trivedy & Goel (1986) were used for the physico-chemical analysis. The physico-chemical parameters viz., ambient and water temperature were determined by mercury filled centigrade thermometer, depth by measuring tap graduated in meters and centimeters, transparency by Secchi disc, colour by visual estimation, electrical conductivity by conductivity meter, turbidity by nepheloturbidity meter, total dissolved solids, total suspended solids and total solids by gravimetric method, pH by digital pH meter, dissolved oxygen by Winkler's iodometric method, free carbon dioxide by titration method using phenolphthalein solution as an indicator, total alkalinity by titration method using strong acid and methyl orange and phenolphthalein solutions as indicators, total hardness and calcium hardness by ethylene diamine tetra acetic acid (EDTA) titration method using eriochrome black-T and murexide indicators, chlorides by argentometric method, sulphates by turbidimetric method, nitrate-nitrogen by colorimetric method using brucine sulfanilic acid, nitrite by diazotization method inorganic phosphorous by using stannous chloride method, silicate by molybdosilicate method, ammonia by volumetric method, sulphide by precipitation method, biochemical oxygen demand by Winkler's Iodometric method, chemical oxygen demand by reflux condensation method using ferroin as an indicator, magnesium by indirect method and sodium and potassium were estimated with the help of Flame Photometer. Physico-chemical characteristics of water, like ambient and water temperature, depth, transparency, colour, pH, dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, chlorides, calcium and magnesium were determined at the sampling sites immediately after the collection of water samples while rest of the parameters were analyzed in the laboratory within a period of six hours after the collection of water samples.

3. Results and Discussion

The range of variations and mean values along with standard error of physico-chemical characteristics of water during 2009-11 are given in table 1. The seasonal variation of physico-chemical characteristics of water during two years of study are given in table 2. The values of coefficient of correlation (r) between various physico-chemical parameters of water in Raipur reservoir were calculated and have been given in table 3 and trophic status of reservoir have also shown in table 4.

Temperature of a water body depends upon the time of collection, season, water depth and has both direct and indirect effect on the water body. Ambient temperature of Raipur reservoir was observed between 20.4^0C and 41.1^0C. The variations in ambient temperature followed a seasonal climatic pattern. It was highest during late summer and early rainy season and was lowest during winter season throughout the study. Similar range of variation has been shown by Ansari *et al.* (2008), Chinnaiah & Rao (2011) and Khan *et al.* (2012) also.

Water temperature was always less than ambient temperature except during winter. Water temperature was varying from 14.8^0C to 31.3^0C with mean of 25.3 ± 1.14^0C. In the present study, the highest water temperature was noted during the summer season and the lowest was recorded during the winter season. This observation has been true for the several water bodies in India (Narayana *et al.,* 2008; Garg *et al.,* 2009; Verma *et al.,* 2011 and Prabhakar *et al.,* 2012).

Transparency is considered as an important parameter of trophic status of water bodies. It depends on the intensity of sunlight, suspended soil particles, turbid water received from catchment area and density of plankton (Mishra & Saksena 1991). The transparency in Raipur reservoir gradually declined in August and reached to the maximum in November, 2009 and then started decreasing from February, 2010 and by March it was at its minimum. Low values of transparency were observed in rainy season due to accumulation of suspended matter (silt, clay and organic matter) into the water body and high value occurred during winter and summer due to absence of rain, runoff and flood water as well as gradual settling of suspended particles.

In Raipur reservoir, it is observed that turbidity was higher during rainy and then in summer seasons while low turbidity was recorded in the winter season. During summer season, low water level due to evaporation, decaying vegetation, high planktonic growth were responsible for the turbidity. Such observations were also made by Garg *et al.* (2006), Karne & Kulkarni (2009) and Krishnamoorthi *et al.* (2011).

Depth of water followed a seasonal pattern with an impact of ambient temperature and quantum of rains. Lower depth was recorded in summer season and higher depth during rainy season. Dagaonkar & Saksena (1992) has reported the maximum depth of Kailasagar in rainy season and minimum in summer season, low water depth was noticed due to evaporation of water. In Harsi and Ramsagar reservoir, Garg *et al*. (2006 & 2009) reported maximum water level in monsoon period while minimum water level in summer season. This observation has also been true for almost all water bodies in India.

The transparent colour of water was observed in winter season, light green to green colour was observed in the month of February and March, which means good growth of phytoplankton especially of green and blue green algae while green colour was observed in summer season (April, May and June) and brown to dark brown colour was observed in rainy season (July, August and September) suggesting depletion of algal community. Light green to green colour is imparted due to good algal growth of cyanophycean and chlorophycean algae and when their number was reduced, the colour of water became light green in colour in one of the culture tanks at Government fish farm, Gwalior (Saxena & Saksena 2009). In Ramsagar reservoir the colour was found to be turbid in rainy season, green colour in winter season and transparent green colour of water was observed in summer season (Garg *et al*. 2006 & 2009).

The fluctuations in the values of conductivity could be due to variations in the rate of decomposition of organic matter, low level of water caused by evaporation, influx of seepage and nutrients from the drainage basin and also the presence of higher concentration of inorganic salts. The conductivity of Raipur reservoir ranged between 288.4 μScm^{-1} and 421.5 μScm^{-1} with an average of 344.0±8.89 μScm^{-1}. It was higher in summer season and while lower in winter season during two years of study. Olsen (1950) has classified water bodies on the basis of values of conductivity as oligotrophic, mesotrophic and eutrophic. The present findings in relation to electrical conductivity are in conformity with the work of Kaushik & Saksena (1991), Chaurasia & Pandey (2007) and Verma *et al*. (2012). The criterion of Olsen (1950) is applied to Raipur reservoir then the reservoir can be placed under the categories of meso-eutrophic water body.

Total dissolved solids are affected by the geographical location of the water body, drainage, rainfall, deposit organic material at the bottom level, incoming water and nature of biota. The excess amount of total dissolved solids in water disturbed the ecological balance due to osmotic regulation and suffocation caused in aquatic fauna. In various water bodies in India, the total dissolved solids are variable. Kumbhar *et al.,* 2009; Sharma *et al.,* 2010; Chinnaiah & Rao, 2011 and Kalwale & Savale, 2012. In present investigation, total dissolved solids in Raipur reservoir have been observed up to 179.6 mg L^{-1} to 273.6 mg L^{-1} with an average value of 216.9±6.04 mg L^{-1}. Lower values of total dissolved solids were recorded in winter season and higher in summer season throughout the period of two years study. High values of total dissolved solids during summer season may be attributed to increased evaporation due to high temperature and, decrease in water volume. Similar results have also been observed by above workers.

The suspended solids include silt, soil, colloid particles, plankton and other substances. High values of total suspended solids were observed during monsoon months. This is due to increased surface runoff from nearby catchment area. Conforming the observation of Agarwal & Rajwar (2010), the values of total suspended solids in Raipur reservoir were found between 84.3 mg L^{-1} and 114.0 mg L^{-1}. The total suspended solids of water in this reservoir followed a seasonal trend with lower dissolved solids in winter season (December, 2010) and higher total dissolved solids during summer and rainy season (March, 2011 and August, 2010-11) throughout the period of study. This may be because of silt, clay and other suspended particles entering into the water from catchment area in rainy season and the total suspended solids were decreased during winter season due to very less or no turbulence and to the sedimentation process.

In the presence of high total solids water will heat up more rapidly and hold more heat, this in turn, adversely affects aquatic life that has been adapted to a lower temperature regime. Low concentrations of total solids can result in limited growth of aquatic organisms due to nutrient deficiencies. High total solids effect the light penetration and also influence the water quality indirectly and cause imbalance. Throughout the period of this investigation, the total solids in water were found to be highest in summer season (March, 2010-11) and lowest in winter season (December, 2010). The values of total solids in Raipur reservoir, being a small reservoir were higher than reported by Paulose & Maheshwari (2006) in Ramgarh lake (Rajasthan), Saxena & Saksena (2009) in a culture pond (Gwalior) and Khan *et al.* (2012) in Triveni lake in Maharastra.

The pH indicates the intensity of the acidic or basic character of a solution and is controlled by the dissolved chemical compounds and biochemical processes in the solution. The pH >6.0 is indicative of low production, pH between 6.0 and 8.5 is of medium production and more than 8.5 is of high productivity in the water bodies. In the present observations, the Raipur reservoir has shown an alkaline pH range (7.93 to 9.05) throughout the course of study. Kaushik & Saksena (1991), Dagaonkar & Saksena (1992), Kumar *et al.* (2009) and Sinha & Biswas (2011) has also observed similar pH variation in Suraj Kund, Kailasagar, Keenjhar lake and Kalyani lake respectively. The pH of Raipur reservoir water was high in summer season and low in monsoon and winter season. The high pH values during summer are due to high photosynthetic activity of phytoplankton and macrophytes resulting in high production of free carbon dioxide shifting the equilibrium towards alkaline. According to the pH value of water, Venkateswarlu (1983) has classified reservoirs into five categories, *viz.,* acidobiontic, acidophilus, indifferent pH, alkaliphilous and alkalibiontic. If this criterion is applied to Raipur reservoir, then this reservoir can be classified under the category of alkaliphilous water bodies.

The dissolved oxygen play a role of regulator of metabolic activities of organisms and thus governs metabolism of the biological community as a whole and as used as an indicator of trophic status of the water (Saksena & Kaushik 1994). Throughout the present study, dissolved oxygen was ranging from 7.49 mg L^{-1} to 9.63 mg L^{-1} and is within the range reported by earlier workers. In Raipur reservoir, higher values of dissolved oxygen was recorded in summer, this was due to the optimum water temperature regime enhances photosynthesis activities resulting into liberation of oxygen. Similar trends of results have been shown by various workers like Esmaelli & Johal (2005), Gonjari & Patil (2008) and Singh *et al.* (2010). During monsoon and the winter, the level of dissolved oxygen was quite satisfactory, perhaps due to good aeration caused by rain water.

The free carbon dioxide level in water is decreased due to photosynthesis by algae and macrophytes and increased due to the respiration of all aquatic organisms. The presence or absence of the free carbon dioxide in surface water is mostly governed by its utilization by algae during photosynthesis and also through its diffusion from air. In the present study, the free carbon dioxide fluctuated between nil and 9.30 mg L^{-1} with an average value of 3.92±0.71 mg L^{-1}. It may be emphasized that free carbon dioxide was lower in summer and higher in winter seasons. In Raipur reservoir, higher values of free carbon dioxide is possibly due to the decomposition of organic matter, low photosynthetic activity and low precipitation of free carbon dioxide as carbonates. Higher concentration of free carbon dioxide in summer season agrees with the observations made by Sakhare & Joshi (2002), Pazhanisamy & Ebanasar (2008) and Ahangar *et al.* (2012).

Alkalinity of water is a measure of its capacity to neutralized acids and the total alkalinity is the total sum of carbonate and bicarbonate alkalinities. It is generally imparted by the salts of carbonates, bicarbonates, phosphates, nitrates, borates, silicates etc along with hydroxyl ions available in free state. The high alkalinity can be attributed to increased rate of organic decomposition during which free carbon dioxide is liberated and reacts with water to form bicarbonates thereby increasing the total alkalinity (Goel *et al.* 1984). According to Spence (1964), water bodies have been categorized into three major categories based on the values of alkalinity, *viz.,* (i) nutrient poor, (ii) moderately nutrient rich and (iii) nutrient rich. In present study, the value of total alkalinity was ranging from 49.3 mg L^{-1} to 105.5 mg L^{-1} with an average value of 75.07±3.36 mg L^{-1} and accordingly, the level of average total alkalinity was <60.0 mg L^{-1} which confirmed nutrients rich and productive nature of the reservoir. Garg *et al.* (2006 & 2009) in Harsi and Ramsagar reservoirs, Verma *et al.* (2011) in Kankaria lake and Verma *et al.* (2012) in Chandola lake have found total alkalinity with its maximum value in summer and minimum in winter season. Similar results were observed in reservoir under study, the minimum alkalinity was recorded in winter and rainy seasons and maximum in summer season. During summer season the water level of reservoir decreases resulting death and decay of plants and living organisms. It was lower in winter and rainy seasons because of the fact that winter had high photosynthetic rate and in rainy season it is directly affected by the rains.

Total hardness of water is mainly governed by the cations of calcium and magnesium which largely combined with bicarbonates and carbonates (temporary hardness) and with sulphate, chlorides and other anions of minerals (permanent hardness). Sawyer (1960) classified water bodies on the basis of hardness into three categories, *viz.,* soft, moderately hard and hard. In Raipur reservoir, higher values of hardness were observed during summer season and lower during winter season. Higher values of hardness were due to the evaporation of water at higher temperature during summer months, low water level and more anthropogenic activities, while during monsoon months, salts come along with rain water from the catchment area in to the reservoir. This facts has also reported by Singh *et al.* (2010), Sinha & Biswas (2011) and Khan *et al*. (2012). When the values of total hardness of Raipur reservoir are considered in view of observation of Sawyer (1960), this reservoir can be said as soft.

Increased concentration of chloride is always regarded as an indicator of eutrophication and pollution due to sewage and other organic materials. The high chloride contents might be attributed to the presence of large amount of organic matter of both allochthonous and autochthonous origin. The value of chloride recorded in Raipur reservoir range between 24.1 mg L^{-1} to 85.2 mg L^{-1} with an average of 40.6±1.60 mg L^{-1}. High chlorides contents in Raipur reservoir were observed during summer months and low in monsoon months which were due to increased temperature and consequent evaporation of water from the water body especially in summer and runoff water brought salts from catchment area in monsoon. Similar reasons have given by Sharma *et al.* (2010) in Gundolav lake, Kishangarh, Sinha & Biswas (2011) in Kalyani lake and Verma *et al*. (2012) in Chandola lake.

The most important source of ammonia in water bodies is the ammonification of organic matter. In higher concentrations ammonia becomes harmful to fishes and other biota (Trivedy & Goel 1986). It will depend on the temperature and pH of lake water because at higher temperature and pH, a good number of ammonium ions are converted in to ammonia gas, thus enhancing the toxicity of ammonia. In the present study, the ammonia was fluctuating between 0.42 mg L^{-1} and 1.56 mg L^{-1} with an average value of 0.93±0.06 mg L^{-1}. The ammonia was high in summer season, while low in winter season. Garg *et al.* (2006), Krishnamoorthi *et al.* (2011) and Prabhakar *et al.* (2012) have also confirmed this seasonal pattern of Ammonia.

Sulphates are naturally occurring anion present in all kinds of natural waters and primarily compounded to all types of minerals found in watershed and acid rain. They are carried in to the lakes through the rains. It is an important constituent of hardness with calcium and magnesium and is one of the key nutrients in the aquatic environment. In the present investigation, the sulphates were fluctuating between 3.7 mg L^{-1} and 12.6 mg L^{-1} with an average of 7.60±0.54 mg L^{-1} during the period of entire study. It may be mentioned that higher sulphates levels were recorded in summer season and lower in winter season during both the years of study. The high values of sulphates may be due to decay of phytoplankton and aquatic macrophytes or due to oxidation of sulphide or sulphite into sulphate in the presence of photosynthetic sulphur bacteria. The relatively low values of sulphates were measured during winter mainly because of its uptake and accumulation by plankton and aquatic macrophytes as well as bacteria. These results are in conformity with Kirubavathy *et al.* (2005), Khare *et al.* (2007), Krishnamoorthi *et al.* (2011) and Prabhakar *et al.* (2012).

Sulphides are generated by sulphate reducing bacteria. They are considered as indicator of organic pollution in aquatic ecosystems. Mishra (2008) in Gohad reservoir, Saxena & Saksena (2009) in a culture pond, in Tighra reservoir (Uchchariya 2011) have observed a similar variation in sulphides through the seasons. During the period of investigation on Raipur reservoir, the sulphides varied from 0.69 mg L^{-1} and 1.44 mg L^{-1} with an average of 0.96±0.05 mg L^{-1}. The higher sulphides were obtained in early summer (March, 2010) while lower late summer season (June, 2009).

The nitrogen in water occurs as bound forms like nitrate, nitrite, ammonia and organic forms *viz*., urea, amino acids etc. Nitrates are products of oxidation of organic nitrogen by the bacteria present in soil and water where sufficient oxygen is present. High concentration of nitrates are useful in irrigation but their entry into water resources increase the growth of nuisance algae, macrophytes and trigger eutrophication and pollution (Trivedy & Goel 1986). In the present study on Raipur reservoir, the level of nitrate was found to be 0.250 mg L^{-1} and 0.870 mg L^{-1} with an average of 0.623±0.035 mg L^{-1}. Nitrates were present in higher concentration during summer and monsoon while lowest in winter season. Similar opinions were also expressed by workers working on different water bodies (Dagaonkar & Saksena 1992, Garg *et al.* 2006, Sinha & Biswas 2011, Prabhakar *et al*. 2012).

Nitrite represents an intermediate form during de-nitrification and nitrification reactions in nitrogen cycle. It is a very unstable ion and gets converted into either ammonia or nitrate depending upon the conditions of the water. The rich concentration of nitrite-nitrogen (0.033 mgL^{-1} to 0.089 mg L^{-1} with an average of 0.058±0.003 mg L^{-1}) has been observed in this study on Raipur reservoir with greater concentration during summer and monsoon season, due to evaporation of water in summer and due to influx of nutrients from the watershed areas along with runoff water in monsoon and in winter season, kinetics of nitrogen cycling was low due to less decomposition of organic matter and

low water temperature. The pattern of nitrite-nitrogen concentration in this reservoir was quite similar to that which was observed by Thilaga *et al.* (2005), Garg *et al.* (2009 & 2010), Sulthana *et al.* (2011) and Prabhakar *et al.* (2012).
Phosphorous is considered to be the most significant component among the nutrients responsible for eutrophication of a water body, as it is the primary initiating factor. High concentrations of phosphates can indicate the presence of pollution and are largely responsible for eutrophic conditions. Lee *et al.* (1981) have classified the water bodies on the basis of phosphorus contents into five categories, *viz.*, oligotrophic, oligo-mesotrophic, mesotrophic, meso-eutrophic, eutrophic. Phosphorus is rarely found in high concentrations in freshwaters as it is actively taken up by plants. In the present study on Raipur reservoir, the maximum value of phosphorous (0.086 mg L^{-1}) was obtained in monsoon and the minimum (0.029 mg L^{-1}) in winter. Low values of phosphates during the winter season are due to its utilization by microphytes and macrophytes in their growth. Surface runoff from washings of agricultural fields and mixing with the incoming water to the reservoir made higher values of phosphorous in the reservoir. Similar reasons have been projected by Kaushik & Saksena (1999), Ganesan & Sultan (2009) and Prabhakar *et al*. (2012) in their studies. When the criterion of inorganic phosphorus is applied, Raipur reservoir can be placed under eutrophic water body (Lee *et al.* 1981).
Silica occurs mainly as orthosilicate in an undissociated condition. The element is most abundant in sedimentary rocks and therefore, occurs generally in higher concentrations in waters located in such regions. The concentration of silica in natural waters in usually between 1 to 30 mg L^{-1} but may reach as high as 100 mg L^{-1} in hot springs (Trivedy & Goel 1986). In the present study on Raipur reservoir, the silicates at sub-surface level fluctuated from 2.70 mg L^{-1} to 12.7 mg L^{-1} with an average of 7.62±0.69 mg L^{-1}. Higher silicates were observed in rainy and summer seasons while lower in winter season. In rainy season silicate level in water was increased due to silica particles coming to the water body as runoff from surrounding catchments area. Occurrence of low silica in winter was found to be related with their continuous utilization by phytoplankton specially diatoms and lesser decomposition activity due to low water temperature and sedimentation. Such phenomenon of silicates variation has also been reported by many other workers (Kaushik & Saksena 1991& 1994, Garg *et al.* 2006 & 2009, Sulthana *et al.* 2011).
Biochemical oxygen demand is the amount of oxygen required by the living organisms engaged in the utilization and ultimate destruction or stabilization of organic water. It also indicates the presence of microbial activities and dead organic matter on which microbes can feed. In the present study the biochemical oxygen demand during entire period was ranging from 2.65 mg L^{-1} to 6.94 mg L^{-1} with an average of 4.7±0.27 mg L^{-1}. The higher biochemical oxygen demand were recorded during rainy and summer season. A higher value of biochemical oxygen demand indicates maximum consumption of oxygen in mitigating higher organic pollution load. In the present investigation, the values of biochemical oxygen demand were obtained gradually increasing from pre-monsoon and becoming highest in monsoon. This may be due to presence of high amount of organic matter and entry of other allocthonous materials thereby increasing the respiratory activity of the heterotrophic organisms. In winter season, the biochemical oxygen demand values were low which may be due to lesser quantity of organic material in the form of solids and decreased microbial population. Similar observations have been made by Garg *et al.* (2006), Karne & Kulkarni (2009) and Verma *et al.* (2012) on various water bodies.
Chemical oxygen demand is the oxygen consumed by the chemical break down of organic and inorganic substances in water. It is also a measure of the oxygen equivalent to the organic matter content of water that is susceptible to oxidation by a strong chemical oxidant and thus, is a reliable parameter for interpreting the extent of pollution in water or evaluating the pollution load. Therefore, chemical oxygen demand of water increases with increasing organic matter concentration. Throughout the period of present study, the values of chemical oxygen demand were varying from 58.7 mg L^{-1} to 120.5 mg L^{-1} with an average of 87.4±3.68 mg L^{-1}. The chemical oxygen demand was with lower values in winter season and higher values during summer and rainy seasons. Low chemical oxygen demand in the winter season was probably due to higher dissolved oxygen content in this reservoir, as moderate temperature promotes the concentration of dissolved oxygen in the reservoir water. Hence, the requirement of oxygen of reservoir is decreased. Similar observations were taken by many other workers including Tiwari *et al.* (2006), Sharma & Capoor (2010) and Krishnamoorthi *et al*. (2011).
Calcium is one of the most abundant substances of the natural waters. In aquatic environment, calcium serves as a micronutrients for most of the organism. Ohle (1938) classified the water bodies into three categories on the basis of calcium richness: (i) poor, (ii) medium and (iii) rich. The amount of calcium increases during summer season due to rapid evaporation, oxidation and decomposition of organic matter. The calcium content varied from 26.8 mg L^{-1} to 44.6 mg L^{-1} with an average of 36.7±0.93 mg L^{-1} in Raipur reservoir. In present investigation on Raipur reservoir,

maximum calcium contents were observed during summer and minimum during winter season. The level of calcium was low in winter season probably due to its utilization by the biotic community. Evaporation of water due to high temperature, increase of calcium in summer is due to the decomposition of aquatic vegetation and low level of water. This has been corroborated by several workers such as Garg *et al*. (2006) Saxena & Saksena (2009) and Jain *et al.* (2011). Owing to the calcium content in the Raipur reservoir, this can be classified as calcium rich waters (Ohle 1938).

Magnesium is often associated with calcium in all kinds of waters, but their concentrations remain generally lower than the calcium. According to Dagaonkar & Saksena (1992) magnesium is essential for chlorophyll growth and acts as a limiting factor for the growth of phytoplankton. In the present study, the magnesium was varying from 8.46 mg L^{-1} and 18.8 mg L^{-1} with an average of 14.5±0.64 mg L^{-1}. The magnesium was higher in summer and rainy seasons and lower in winter season. This may be due to the uptake of magnesium by phytoplankton and macrophytes in the formation of their chlorophyll-magnesium perphyrin- metal complex and is also used in enzymatic transformations. These results are consistent with the observations obtained by Garg *et al.* (2006), Kumar & Oommen (2009) and Verma *et al*. (2012).

Sodium is occurring naturally in all the water bodies, reaching through weathering of rocks. Industrial wastes and domestic sewage are rich in sodium and add to its concentration in natural waters. Normally, in soft water, percentage of sodium is second to that of calcium. In hard water, it is proportionally less usually falling bellow calcium and magnesium. Throughout the period of present study on Raipur reservoir, the sodium at sub-surface level fluctuated from 8.55 mg L^{-1} to 16.4 mg L^{-1} with an average of 12.2±0.44 mg L^{-1}. An enrichment of sodium contents was found in rainy and summer seasons, while its contents were lesser in winter season. The low value of sodium recorded in winter season in the present study is due to utilization by plankton and other aquatic organisms, while the high values were recorded in summer season due to evaporation of water. Above observations get support from the earlier findings of Garg *et al.* (2006), Saxena & Saksena (2009) and Verma *et al*. (2012).

Potassium in most waters is quite low than sodium and calcium in freshwaters. Under low potassium concentration the growth rate and photosynthesis of algae especially blue green algae becomes poor and respiration is increased (Wetzel 2001). Garg *et al.* (2006 & 2010) have reported a higher concentration of potassium in summer season and lower concentration in monsoon season in Harsi and Ramsagar reservoirs. Prabhakar *et al.* (2012) have observed a higher concentration in summer while lower in winter season in Krishnagiri dam, Rajasthan. In the present study, the potassium was fluctuating from 4.25 mg L^{-1} to 7.53 mg L^{-1} and the average value has been 5.93±0.23 mg L^{-1} during two year study. Although, an irregular pattern of seasonal fluctuation was exhibited by potassium, higher values were obtained in summer season and lower values in monsoon season. A similar variation in potassium has also been obtained by many workers such as Kaushik & Saksena (1999), Garg *et al.* (2006 & 2010) and Prabhakar *et al.* (2012).

Correlation among physico-chemical characteristics

It has been pointed out in several studies that the physico-chemical characteristics influence each other and biological features of the water body. In the present study, ambient temperature showed a high degree of positive correlation with water temperature, fairly high degree of positive correlation with total hardness. A moderate negative correlation was shown by chemical oxygen demand with water temperature. The transparency exhibited a fairly high degree of negative correlation with ammonia, biochemical oxygen demand and sodium, electrical conductivity showed high degree of positive correlation with total dissolved solids, total suspended solids, total solids and total hardness. The total alkalinity showed fairly high degree of positive correlation with sulphides, moderate with chlorides, ammonia and chemical oxygen demand, the sulphides had a moderately high degree of positive correlation with biochemical oxygen demand, chemical oxygen demand and sodium. Sulphate had shown fairly high positive correlation with potassium. Similarly, calcium exhibited a fairly high degree of positive correlation with potassium, while magnesium showed a moderate but positive correlation with sodium. Sodium had low degree of positive correlation with potassium. Such a correlation of physico-chemical parameters has also been exhibited by several workers like Jha & Barat (2003), Kumar *et al.* (2007), Garg *et al.,* (2009 & 2010) and Ahangar *et al.* (2012).

Trophic status of the water body

Nutrient level of any water body is directly related with their trophic status. A lake is usually classified as being in one of three possible classes: oligotrophic, mesotrophic and eutrophic. Both natural and anthropogenic factors can influence a lake or any other water body's trophic index. A water body situated in a nutrient rich region with high net primary productivity may be naturally eutrophic. There have been good number of parameters of water which are used to designate trophic status of a water body. Saksena & Kaushik (1994) have designated Motijheel as mesotrophic, while Suraj kund and Ranital as eutrophic on the basis of physico-chemical characteristics of water. Raghavendra & Hosmani (2002) have reported the growth of phytoplankton in Mandakally lake and pointed out water body is tending fast to become eutrophic. Harsi reservoir was considered as oligo-mesotrophic water body which was due to the fact that no sewage or industrial waste is discharged to the reservoir and no agricultural practices are in vogue in the vicinity of the reservoir (Garg *et al*. 2006). Garg *et al*. (2009) have observed various parameters of Ramsagar reservoir and considered this water body as mesotrophic. Ahangar *et al*. (2012) in Anchar lake and placed the lake under eutrophic water bodies due to the fact that it receive large amount of sewage and waste from neibhouring areas.

In conclusion, various physico-chemical characteristics of Raipur reservoir like transparency, electrical conductivity, pH, free carbon dioxide, total alkalinity, total hardness, calcium, chlorides, phosphates and nitrate-nitrogen have been evaluated with that of the physico-chemical characteristics of water in different trophic status as assigned by various workers (Ohle 1938, Olsen 1950, Alikunhi 1957, Sawyer 1960, Spence 1964, Vollenweider 1968, Reid & Wood 1976, Lee *et al.* 1981, Unni 1983, Venkateswarlu 1983). It has been found that Raipur reservoir can be categorized as meso-eutrophic with rich amount of nutrients which may be due to agricultural practices being done by farmers in surrounding catchment area of this reservoir. Thus, the reservoir may serve as a good habitat for planktonic organisms and can also be very well used for further stocking of Indian major carps for their cultivation.

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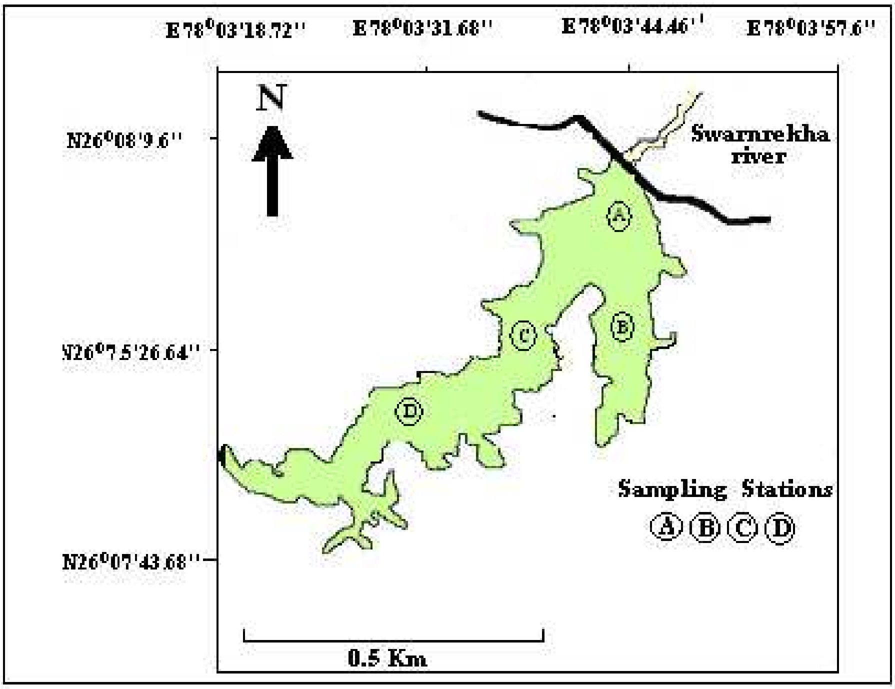

Fig. 1 Showing various sampling stations in Raipur reservoir

Fig. 2 Satellite image of Raipur reservoir (www. google.com)

Table 1 Range of variations and mean with standard error of physico-chemical characteristics of water of Raipur reservoir during April, 2009 to March, 2011

S.N.	Parameters	Unit	2009-2011		
			Minimum	Maximum	Mean ±SE
1.	Ambient temperature	^0C	20.4	41.1	32.6±1.48
2.	Water temperature	^0C	14.8	31.3	25.3±1.14
3.	Depth	m	1.12	4.42	2.89±0.217
4.	Transparency	cm	29.5	111.5	76.5±4.29
5.	Colour		L.G	Green	Green
6.	Electrical conductivity	μScm^{-1}	288.4	421.5	344.0±8.89
7.	Turbidity	NTU	3.85	15.23	9.84±0.77
8.	Total solids	mgL^{-1}	263.9	385.0	315.39±8.25
9.	Total dissolved solids	mgL^{-1}	179.6	273.6	216.9±6.04
10.	Total suspended solids	mgL^{-1}	84.3	114.0	98.5±2.28
11.	pH		7.93	9.05	8.43±0.06
12.	Dissolved oxygen	mgL^{-1}	7.49	9.63	8.65±0.15
13.	Free carbon dioxide	mgL^{-1}	NIL	9.30	3.92±0.71
14.	Total alkalinity	mgL^{-1}	49.3	105.5	75.07±3.36
15.	Total hardness	mgL^{-1}	102.0	167.7	136.7±4.39
16.	Chlorides	mgL^{-1}	24.1	85.2	40.6±1.60
17.	Sulphates	mgL^{-1}	3.7	12.6	7.60±0.54
18.	Nitrate-nitrogen	mgL^{-1}	0.250	0.870	0.623±0.035
19	Nitrite-nitrogen	mgL^{-1}	0.033	0.089	0.058±0.003
20.	Inorganic phosphorous	mgL^{-1}	0.029	0.086	0.054±0.003

21.	Silicates	mgL^{-1}	2.70	12.7	7.62±0.69
22.	Ammonia	mgL^{-1}	0.42	1.56	0.93±0.06
23.	Sulphides	mgL^{-1}	0.69	1.44	0.96±0.05
24.	BOD	mgL^{-1}	2.65	6.94	4.7±0.27
25.	COD	mgL^{-1}	58.7	120.5	87.4±3.68
26.	Calcium	mgL^{-1}	26.8	44.6	36.7±0.93
27.	Magnesium	mgL^{-1}	8.46	18.8	14.5±0.64
28.	Sodium	mgL^{-1}	8.55	16.4	12.2±0.44
29.	Potassium	mgL^{-1}	4.25	7.53	5.93±0.23

Table 2 Seasonal variation of physico-chemical characteristics of water during two years of study (2009-11)

Parameters	Summer season			Rainy season			Winter season		
	Min	Max	Mean± SE	Min	Max	Mean± SE	Min	Max	Mean ±SE
Ambient temperature (^0C)	29.6	38.9	34.68±1.64	35.6	41.1	38.85±0.82	20.3	33.4	26.93±2.0
Water temperature (^0C)	24.2	32.2	26.52±1.60	28.5	30.8	29.6±0.40	14.8	28.4	21.14±1.9
Depth (m)	1.11	2.65	2.02±0.23	1.99	4.42	3.31±0.47	2.39	4.24	3.25±0.23
Transparency (cm)	29.4	82.4	62.9±8.35	58.5	87.1	74.9±4.9	71.8	111.5	89.5±5.6
Electrical conductivity (µS/cm)	311	421	368.7±15.46	330	395	366.4±9.8	288.4	337.7	306.0±5.7
Turbidity (NTU)	8.1	15.2	11.38±1.13	10.1	15	12.5±0.81	3.9	11.9	6.83±0.86
Total solids (mg L^{-1})	284	385	338.7±14.48	302	361	335.8±8.9	263.9	308.6	280.1±5.21
Total dissolved solids (mg L^{-1})	195	274	233.9±11.25	206	247	230.7±6.4	179.6	212.7	191.5±3.7
Total suspended solids (mg L^{-1})	89.6	113	104.8±3.44	95.6	114	105.0±2.7	84.2	95.8	88.6±1.5
pH	7.9	9.1	8.5±0.18	8.2	8.8	8.4±0.08	8.1	8.6	8.36±0.06
Dissolved oxygen (mg L^{-1})	8.52	9.63	9.30±0.16	7.49	8.11	7.8±0.11	8.15	9.4	8.82±0.15
Free carbon dioxide (mg L^{-1})	0.49	4.84	2.95±0.65	2.2	7.81	6.22±1.1	5.06	9.29	6.88±0.61
Total alkalinity (mg L^{-1})	58.1	106.0	85.1±7.73	57.5	79.7	71.1±3.9	49.3	83.1	69.9±4.5
Total hardness (mg L^{-1})	138.0	167.0	147.6±4.60	129	166.0	150.8±5.4	102	142.5	118.5±4.7
Chlorides (mg L^{-1})	36.7	55.7	44.7±3.18	32.5	47.4	40.45±2.2	28.4	41.9	34.2±1.5
Sulphates (mg L^{-1})	5.4	12.6	8.99±1.05	5.53	10.4	8.16±0.83	3.7	8.84	6.01±0.66
Nitrate-nitrogen (mg L^{-1})	0.528	0.870	0.719±0.05	0.61	0.77	0.691±0.02	0.250	0.730	0.515±0.06
Nitrite-nitrogen (mg L^{-1})	0.058	0.231	0.096±0.02	0.05	0.07	0.061±0.002	0.033	0.053	0.042±0.003
Inorganic phosphorous (mg L^{-1})	0.053	0.084	0.066±0.005	0.05	0.16	0.076±0.017	0.029	0.060	0.042±0.003
Silicates (mg L^{-1})	5.3	12.7	8.66±1.07	4.37	12.4	8.68±1.3	2.7	10.7	5.98±1.1
Ammonia (mg L^{-1})	0.82	1.55	1.21±0.11	0.6	1.11	0.90±0.07	0.42	0.94	0.72±0.06
Sulphides (mg L^{-1})	0.72	1.44	1.09±0.12	0.81	0.99	0.90±0.02	0.69	1.09	0.86±0.05
BOD (mg L^{-1})	3.79	6.94	5.10±0.55	3.09	5.66	4.37±0.41	2.65	6.28	4.61±0.48
COD (mg L^{-1})	89.6	121	103.7±4.9	85.5	100	90.4±2.3	58.7	94.8	72.3±3.7

Calcium (mg L^{-1})	37.7	44.7	41.0±1.00	34.4	40.4	36.7±1.0	26.8	38.7	33.7±1.3
Magnesium (mg L^{-1})	7.70	14.1	10.57±0.89	9.9	19.9	13.02±1.8	5.8	14.0	8.53±1.02
Sodium (mg L^{-1})	12.0	16.4	13.53±0.70	11.6	14.3	13.12±0.43	8.55	12.7	10.4±0.49
Potassium (mg L^{-1})	4.92	7.52	6.51±0.41	5.17	6.95	6.24±0.27	4.25	7.37	5.27±0.37

Table 3 Coefficient of correlation (r) between different physico-chemical characteristics of water in Raipur reservoir

Parameters	At	Wt	D	Tra	EC	Tur	TS	TDS	TSS	pH	DO	FCO_2	TA	TH	Cl^-	SO_4	NO_3	NO_2	PO_4	Sil	NH_3	S^-	BOD	COD	Ca^{2+}	Mg^{2+}	Na^+	K^+
Ambient temperature	1.00																											
Water temperature	0.95	1.00																										
Depth	0.03	0.07	1.00																									
Transparency	-0.29	-0.17	0.26	1.00																								
Electrical conductivity	0.62	0.56	-0.35	-0.73	1.00																							
Turbidity	0.60	0.59	-0.32	-0.26	0.74	1.00																						
Total solids	0.62	0.62	-0.36	-0.71	0.99	0.76	1.00																					
Total dissolved solids	0.62	0.54	-0.35	-0.73	0.99	0.75	0.99	1.00																				
Total suspended solids	0.61	0.53	-0.39	-0.65	0.97	0.78	0.97	0.95	1.00																			
pH	0.15	0.25	-0.29	0.18	0.09	0.45	0.12	0.09	0.21	1.00																		
Dissolved oxygen	-0.53	-0.52	-0.47	-0.12	-0.19	-0.27	-0.19	-0.19	-0.18	-0.02	1.00																	
Free carbon dioxide	0.03	-0.03	0.41	-0.30	0.04	-0.37	0.03	0.03	0.01	-0.35	-0.26	1.00																
Total alkalinity	-0.05	-0.06	-0.55	-0.45	0.41	0.48	0.42	0.42	0.43	0.36	0.25	-0.13	1.00															
Total hardness	0.74	0.66	-0.27	-0.62	0.92	0.81	0.92	0.91	0.93	0.19	-0.29	0.07	0.39	1.00														
Chlorides	0.29	0.37	-0.55	-0.17	0.57	0.79	0.59	0.57	0.63	0.56	0.02	-0.41	0.64	0.53	1.00													
Sulphates	0.42	0.51	-0.34	0.13	0.37	0.37	0.40	0.37	0.44	0.62	-0.08	-0.54	0.35	0.43	0.86	1.00												
Nitrate-nitrogen	0.42	0.50	-0.46	-0.13	0.57	0.80	0.58	0.58	0.57	0.27	-0.12	-0.55	0.33	0.57	0.73	0.68	1.00											
Nitrite-nitrogen	0.59	0.55	-0.40	-0.72	0.84	0.65	0.84	0.86	0.82	0.09	-0.05	-0.05	0.45	0.81	0.63	0.45	0.58	1.00										
Inorganic phosphorous	0.61	0.62	0.02	-0.61	0.81	0.59	0.81	0.81	0.77	0.17	-0.35	0.35	0.26	0.82	0.82	0.29	0.42	0.69	1.00									
Silicates	0.34	0.46	-0.22	0.26	0.22	0.64	0.27	0.23	0.89	0.49	-0.21	-0.44	0.24	0.27	0.81	0.91	0.66	0.38	0.22	1.00								
Ammonia	0.27	0.20	-0.53	-0.87	0.80	0.50	0.80	0.81	0.76	0.08	0.21	0.12	0.69	0.73	0.47	0.17	0.41	0.77	0.66	-0.01	1.00							
Sulphides	0.04	0.01	-0.47	-0.66	0.56	0.38	0.57	0.59	0.51	0.23	0.15	0.15	0.77	0.46	0.50	0.19	0.25	0.55	0.46	0.08	0.83	1.00						
BOD	-0.08	-0.18	-0.10	-0.78	0.38	-0.05	0.37	0.39	0.32	-0.09	0.21	0.45	0.44	0.31	-0.05	-0.36	-0.26	0.39	0.39	-0.44	0.67	0.66	1.00					
COD	0.36	0.39	-0.58	-0.47	0.71	0.76	0.72	0.71	0.71	0.32	0.11	-0.32	0.62	0.68	0.83	0.67	0.74	0.83	0.51	0.60	0.75	0.63	0.17	1.00				
Calcium	0.37	0.43	-0.49	-0.19	0.48	0.70	0.50	0.49	0.51	0.36	0.19	-0.49	0.47	0.54	0.75	0.77	0.76	0.68	0.39	0.69	0.46	0.29	-0.08	0.82	1.00			
Magnesium	0.55	0.44	0.14	-0.66	0.69	0.31	0.68	0.68	0.65	-0.14	-0.43	0.61	0.01	0.73	-0.03	-0.16	0.08	0.46	0.80	-0.24	0.55	0.33	0.51	0.15	-0.07	1.00		
Sodium	0.63	0.53	-0.34	-0.76	0.83	0.63	0.83	0.83	0.79	0.18	-0.10	-0.01	0.57	0.80	0.53	0.33	0.38	0.85	0.64	0.17	0.76	0.58	0.53	0.65	0.47	0.50	1.00	
Potassium	0.29	0.32	-0.48	-0.05	0.36	0.75	0.38	0.38	0.37	0.37	0.05	-0.63	0.39	0.41	0.70	0.77	0.80	0.47	0.21	0.72	0.29	0.24	-0.22	0.71	0.79	-0.14	0.36	1.00

Table 4 Trophic status of Raipur reservoir

S.N.	Parameters	Unit	Mean±SE	Trophic status of reservoir	References
1.	Calcium	mg L^{-1}	36.72±0.93	Rich Calcium (>26.0 mg L^{-1})	Ohle (1938)
2.	Electrical Conductivity	µScm^{-1}	344.04±8.89	Mesotrophic (300.0 to 500 µS/ cm)	Olsen (1950)
3.	Total alkalinity	mg L^{-1}	75.07±3.36	Nutrients rich (60.0 mg L^{-1} <)	Alikunhi (1957), Spence (1964)
4.	Total hardness	mg L^{-1}	136.77±4.39	Moderately hard (76.0 to 150.0 mg L^{-1})	Sawyer (1960)
5.	Nitrate-nitrogen	mg L^{-1}	0.62±0.03	Eutrophic (0.15-0.75 mg L^{-1})	Vollenweider (1968)
6.	Free carbon dioxide	mg L^{-1}	3.92±0.71	Soft (nil-4.3 mg L^{-1})	Reid & Wood (1976)
7.	Phosphates	mg L^{-1}	0.054±0.003	Eutrophic (>0.04 mg L^{-1})	Lee *et al.* (1981)
8.	Transparency	Cm	76.59±4.29	Eutrophic (>170.0 cm)	Lee *et al.* (1981)
9.	Chlorides	mg L^{-1}	40.67±1.60	Less domestic Pollution (17.9-57.6 mg L^{-1})	Unni (1983)
10.	pH	-	8.43±0.060	Alkaliphilous (7.5 to 9.0)	Venkateswarlu (1983)
	Trophic status of Raipur reservoir			**Meso-eutrophic**	