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Water quality assessment on Ooty lake in Nilgiris district

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Abstract

Water quality index is used to express the quality of water on both surface as well as subsurface by integrating various water quality parameters. The present work aimed to evaluate seasonal water quality index for Ooty Lake in the Nilgiris district, TamilNadu India. The physico–chemical parameter of water samples taken during two seasons (winter and summer) were analyzed to categorize the level of pollution in the study area. The results were compared with the water quality standards recommended by Environment Protection Act (2009). Based on the Water Quality Index, Multivariate statistical analyses were applied to identify the group of parameter that influence water quality and to evaluate the type of pollution in the lake. In addition to multivariate statistical analyses, the factor and principal component analysis were applied and the outcome showed that there were three types of pollution influencing the water quality namely, agricultural pollution, organic pollution and domestic waste water pollution. During the winter season, domestic waste water pollution was high, as rainwater flushed out in all the areas of watershed. During this season the lake receives a meager amount of water, and hence, the biological activities taking during the summer season has resulted in higher biological pollution. From the analyses, it was observed that there is no major impact by the agricultural pollution. The cluster analysis showed that there were three cluster values, and from the similarity groups among the sampling sites, it was noticed that direct discharge and improper drainage system of watershed caused more pollution in lakes.

Key words

Cluster analysis, Discriminant analysis, Factor analysis, Lake water quality, Seasonal variation, Water quality index

Introduction

In recent years, there has been a considerable research on pollution control on lake water bodies that emphasise the importance of maintaning water quality and eco system of the lake (Gamze *et al*., 2003). Lake water is essential renewable resource for mankind and the environment. It is used for civil, industrial and recreational purposes (Islam *et al*., 2012). The quality of water is identified regarding its physical, chemical and biological characteristics (Sargaonkar *et al*., 2003). Streams, lakes and inland wetlands are interactive components of the watersheds that reflect the physical and chemical condition of the eco system, the land use pattern and physical characteristics of the landscapes in which they are embedded (Morrice *et al*., 2008). Water quality index is a mathematical instrument used to transform larger quantities of water quality data into a signal number (Stambuk *et.al*., 1998). This provides a simple and understandable tool for managers and decision makers on the quality and possible uses of a given water bodies (Bordalo *et al*., 2001). It serves the purpose to improve the understanding water quality issues by integrating complex data and generating a score that describes the water quality status and evaluate water quality trends to public policy makers (Cude, 2001). This is important regarding increased support for water resources improvement efforts. Water quality index permits assessment of changes in water quality and to identify water trends (Chapman, 1992). Statistical analysis has been applied by many researchers to characterize and evaluate fresh water and sediment quality (Shrestha *et al*., 2007; Kowalkkowskia *et al*., 2006). It is useful to examine temporal and spatial variations caused by natural and anthropogenic factors (Helena *et al.,* 2000; Singh *et al*., 2005). In the present study, a large set of water quality data were collected and subjected to multivariate statistical analysis by discriminant analysis, factor analysis and cluster analysis. Based on the review in the study area. The levels of contamination present in lake water were examined by evaluating the physico–chemical parameters. Also, the water quality of lake was established by WQI value and parameters that represented the pollution in lake by multivariate statistical analysis.

Materials and Methods

Study area : The Ooty Lake is most attractive tourism places in Nilgiris district, Tamilnadu, India. This lake is located at 11°25'96" N and 75°45'7"E at the altitude of +2191.30 m a msl. This lake has 0.223 km^2 of water spread area and 11.12 km^2 of free catchment area. The average annual rainfall is about 1008.2 mm and maximum minimum temperature recorded in the study area is 25 ºC and 6 ºC respectively. The study area of Ooty Lake is shown in Fig. 1.

Methodology : The combined water quality index (Alobaidy *et al*., 2010) and statistical analysis (Edward Ming-Yang Wu *et al*., 2012) were carried out to assess water quality status of Ooty lake.

Sample collection : The samples were collected from each station during summer season (June, 2012) and winter season (Feb-2013) for the analysis of physico-chemical parameters. At each sampling station, water samples were collected from surface 1.5 ft and 3 ft from the following five locations: Entrance of the lake (A), Between lake entrance and Boat house (B), At boat house (C), Middle of the lake (D) and Exit for lake (E). In location 'A' surface (0 feet) and 1.5 feet below, the lake water sample was only collected because at that site silt deposit was high so depth of lake was less. The physico–chemical parameters were partially tested in the field as well as in the laboratory for assessing the pollution status of the lake. The following parameters were studied in field: pH, Electrical conductivity (EC), Dissolved oxygen (DO), Turbidity, Biological oxygen demand (BOD), Chemical oxygen demand (COD), Hardness, Total dissolved solid (TDS), Phosphates (PO_4^{-3}), Nitrite (NO_2^-), Nitrate (NO_3^-), Chloride (Cl^-), Sulphate (SO_4^-), Fluoride (F^{-1}), Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Iron (Fe^{+3}) and Ammonia (NH_3^{-1})

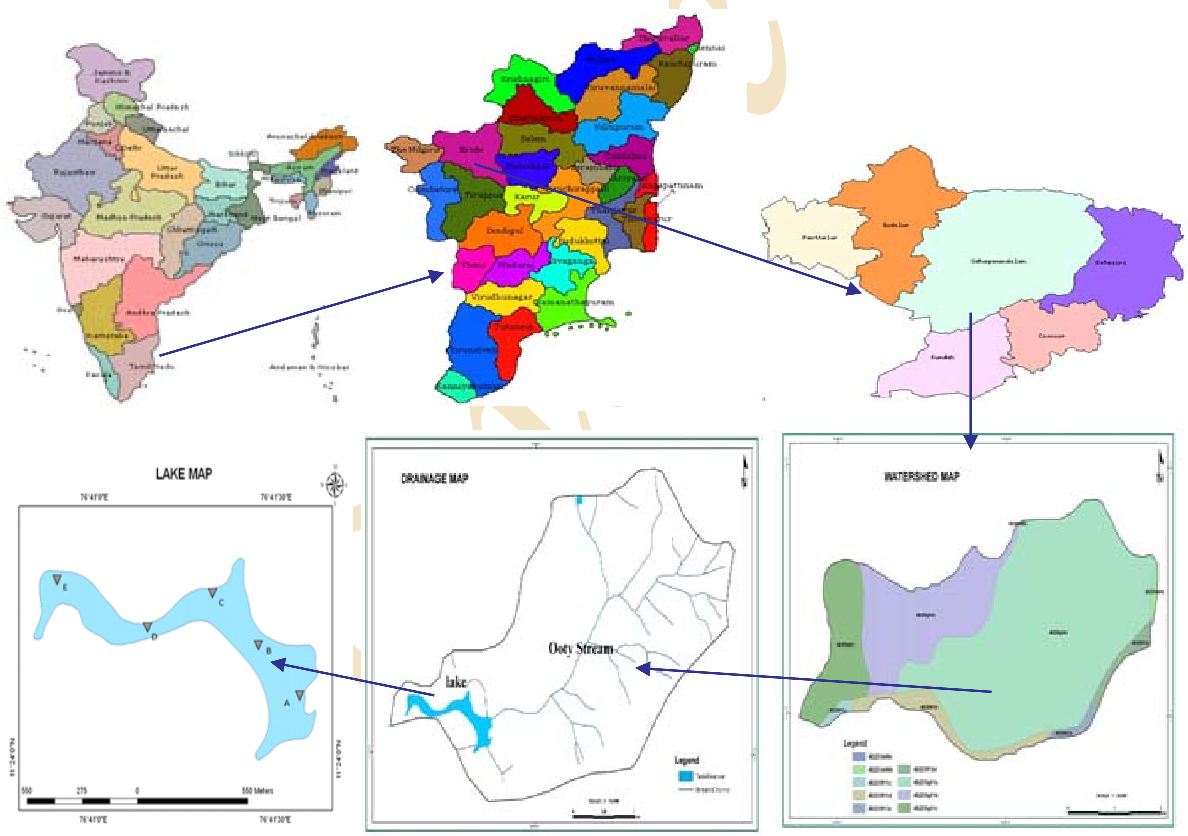

Fig. 1 : Study area map of Ooty lake

Table 1 : Water quality classification based on WQI value

WQI value range	Water quality
0-25	Excellent
25-50	Good
51-75	Bad
75-100	Very bad
Above 100	Unfit

were estimated by the standard methods (APHA 2012).

Water quality index : Water quality index was calculated by weight and rating the physico-chemical parameters (Tiwari *et al*., 1986). The WQI was calculated by the formula given below (Brown *et.al*., 1972) :

$$\text{Quality rating } (Qi) = 100\,((Vn - Vi) / (Vs - Vi)) \quad ...(1)$$

Where, Vs is the standard value, Vi is the ideal value. In most cases Vi was o and pH and DO was 7 and 14.6, respectively; Vn is the water quality parameter.

Relative weight (Wi) was calculated by the following formula :

$$Wi = 1 / Si \quad ...(2)$$

Where, Si is the recommended standard

The overall water quality index was calculated by

$$\text{Water Quality index (WQI)} = \sum (Qi)\, Wi / \sum Wi \text{ (WQI)} \quad ...(3)$$

The suitability of water quality index is rated as follows and given in Table 1.

Statistical analysis : Environmetric method is deemed to be the best approach to avoid misinterpretation of large complex environmental monitoring data (Simeonov *et al*., 2002). The most common environmetric methods used to determine the spatial variability and to identify the pollution sources are (Usman *et al*., 2014) Cluster Analysis, Discriminant Analysis and Principal Component Analysis/Factor analysis. Statistical analysis was carried out by using Statistical package for social science (SPSS version 16). From this analysis, the natural relationship between water quality parameter was established

Discriminant analysis : In Discriminant analysis, the physico – chemical characteristics of lake water were analyzed using maximum, minimum and mean values and it is presented in Table 2 and 3

Principal component analysis/Factor analysis : Water quality variables were grouped using factor analysis and the result are represented by the factor loading matrix Eigen value, total and cumulative variance are shown in Table 4 and 6. The factor analysis generates three significant factors for both seasons

Cluster analysis : Cluster analysis is used to define the similarity of observation by the grouping of entities based on a large number of independent variables and to identify the relationships within a single set of variables.

Table 2 : Discriminant analysis for winter season

Parameters	Minimum	Maximum	Mean
Turbidity (NTU)	3.00	8.00	4.21
Total dissolved solid (mg dm^{-3})	165.00	209.00	179.42
Electrical conductivity (mg dm^{-3})	236.00	298.00	258.21
pH	7.15	7.42	7.27
HCO_3^- (mg dm^{-3})	40.00	54.00	45.57
Total hardness (mg dm^{-3})	47.00	60.00	52.00
Ca^{2+} (mg dm^{-3})	19.00	24.00	20.71
Mg^{2+} (mg dm^{-3})	4.00	6.00	4.71
Fe^{3+} (mg dm^{-3})	0.30	2.00	0.87
NH_3 (mg dm^{-3})	10.00	18.00	13.85
NO_2^{-1} (mg dm^{-3})	0.00	4.00	1.78
NO_3^{-1} (mg dm^{-3})	4.00	7.00	5.28
Cl^{-1} (mg dm^{-3})	38.00	48.00	41.21
F^{-1} (mg dm^{-3})	0.50	0.51	0.50
SO_4^{2-} (mg dm^{-3})	6.00	9.00	7.85
PO_4^{-3} (mg dm^{-3})	1.00	2.00	1.28
Biological oxygen demand (mg dm^{-3})	8.00	15.00	10.47
Chemical oxygen demand (mg dm^{-3})	48.00	68.00	56.57
Dissolved oxygen (mg $dm^{-3)}$	6.00	14.00	9.77

Table 3 : Discriminant analysis for summer season

Parameters	Minimum	Maximum	Mean
Turbidity (NTU)	15.00	147.00	55.21
Total dissolved solid (mg dm^{-3})	255.00	276.00	260.93
Electrical conductivity (mg dm^{-3})	365.00	395.00	373.43
pH	6.85	7.42	7.15
HCO_3^- (mg dm^{-3})	62.00	70.00	65.78
Total hardness (mg dm^{-3})	76.00	90.00	83.07
Ca^{2+} (mg dm^{-3})	23.00	27.00	24.78
Mg^{2+} (mg dm^{-3})	5.00	6.00	5.57
Fe^{3+} (mg dm^{-3})	0.20	22.00	3.67
NH_3 (mg dm^{-3})	20.00	26.00	22.07
NO_2^{-1} (mg dm^{-3})	0.00	3.00	0.21
NO_3^{-1} (mg dm^{-3})	5.00	12.00	8.14
Cl^{-1} (mg dm^{-3})	60.00	68.00	63.35
F^{-1} (mg dm^{-3})	0.50	0.50	0.50
SO_4^{-2} (mg dm^{-3})	8.00	14.00	9.50
PO_4^{-3} (mg dm^{-3})	0.00	2.00	0.57
Biological oxygen demand (mg dm^{-3})	3.00	12.00	7.37
Chemical oxygen demand (mg dm^{-3})	24.00	69.00	39.78
Dissolved oxygen (mg dm^{-3})	2.10	9.20	6.50

Results and Discussion

Season wise physico-chemical composition of fourteen water samples were analyzed for winter and summer season and subjected to statistical analysis. The values were compared with EPA limits (2009) as shown in Table (8) and discussed as follows.

Water chemistry studies : Turbidity directly affects the productivity of surface water because scattering and absorption of light in water depend upon turbidity content of lake water. Turbidity ranged between 4.21 NTU and 55.22 NTU, it was low in winter season and high in summer season. The turbidity values obtained in the present study did not exceed the EPA limit.

Total dissolved solids in water samples ranged between 165 mg dm^{-3} to 209 mg dm^{-3} during winter season. It was noted to be higher in the summer season as an average of 260 mg dm^{-3}. The total dissolved solids values obtained in the present study are within the EPA standards

Electrical conductivity is an indicator for the pureness of water. In the present study, it varied between various from 236 mg dm^{-3} to 298 mg dm^{-3} in winter and 365 mg dm^{-3} to 395 mg dm^{-3} during summer season. The change in conductivity indicates presence of domestic and agricultural pollution in the water. The electrical conductivity in Ooty Lake was found within the acceptable limits of 1000 mg dm^{-3}.

pH is one of the most important factors that serve as an index for the pollution. (Thakar *et a1.*, 2011) The average value of ph was about 7.27 in winter season and 7.15 in summer season. In the present study, pH values were within the EPA limit.

Alkalinity is often related to hardness because the main source of alkalinity is $CaCO_3$. In lake water samples alkalinity ranged between 62 mg dm^{-3} to 70 mg dm^{-3} in summer and 40 mg dm^{-3} to 54 mg dm^{-3} in winter season. The total alkalinity values obtained in the present study were higher compared to EPA standards.

Water hardness results due to the presence of dissolved minerals like calcium, magnesium, iron and manganese. In the present study, the observed average value of total hardness was 83.07 mg dm^{-3} during summer season and 83.07 mg dm^{-3} during winter season. The highest value of 90 mg dm^{-3} was noted in summer season. The total hardness values obtained in the present study were within the EPA limit.

The observed average value of calcium was 20.79 mg dm^{-3} during winter season and 24.78 mg dm^{-3} during summer season. The highest value of 24.78 mg dm^{-3} was during summer season. The quantities of calcium in natural water depends upon the types of rock available in the catchment area. In the present study, calcium values were within the EPA limit.

The main source of magnesium ions are sewage inflow and minerals such as dolomitc which are present as a result of soil erosion. In the present study, the average value of magnesium was 5.57 mg dm^{-3} during summer and 4.17 mg dm^{-3} in winter season, respectively. The magnesium ions in Ooty

Table 4 : Factor analysis value for winter season

Variables	Factor 1	Factor 2	Factor 3
Temperature	0.365	-0.828	-0.182
Turbidity	0.254	0.389	0.588
Total dissolved solid	0.957	0.105	0.051
Electrical conductivity	0.84	0.145	0.197
pH	0.227	-0.188	0.662
Total alkalinity	0.85	-0.149	-0.105
Total hardness	0.95	0.189	-0.045
Ca^{+2}	0.962	0.181	-0.044
Mg^{+2}	0.668	-0.127	-0.258
Fe^{+3}	0.908	-0.093	0.009
NH_3	0.215	-0.113	-0.307
NO_2^{-1}	0.358	0.486	-0.618
NO_3^{-1}	-0.072	0.499	0.783
Cl^{-1}	0.844	0.071	0.012
F^{-1}	-0.341	0.111	0.23
SO_4^{-2}	0.01	0.807	0.246
PO_4^{-3}	0.651	0.156	0.479
Biological oxygen demand	0.089	0.927	-0.067
Chemical oxygen demand	0.084	0.93	-0.089
Dissolved oxygen	-0.364	-0.794	-0.214
E. coli	0.473	0.127	0.114
Eigen value	7.715	4.62	2.186
% Total variance	36.737	21.999	10.408
Cumulative %	36.737	58.736	69.144

Table 5 : Types of pollution based on factor analysis

Factor	Physico-chemical parameters	Types of polluion
1	Total dissolved solid, Electrical conductivity, pH, Total alkalinity, Ca^{+2}, Cl^{-1}, Total hardness, Fe^{+3}, PO_4^{-3}, *E. coli*	Domestic waste water pollution
2	Temperature, Dissolved oxygen, Biological oxygen demand, Chemical oxygen demand, SO_4^{-2}	Organic pollution
3	Turbidity, pH, NH_3, NO_2^{-1}, NO_3^{-1}	Agricultural pollution

lake was found within the acceptable limit of 75 mg dm^{-3}

The main source of iron in natural water is erosion of minerals from rocks and soil. The highest value was noted (22 mg dm^{-3}) during summer season and 4.71mg dm^{2} during winter season. The iron content in Ooty lake was found within the acceptable limit of 1.5 mg dm^{-3}.

Ammonia is an indicator of pollution originating from soil atmosphere and sewage. In present study, average value of ammonia was 22.07 mg dm^{-3} during summer and 13.85 mg dm^{-3} winter season. The highest value of 26 mg dm^{-3} was noted in summer season. In the present study, the ammonia concentration was above the permissible limit of EPA standards during both winter and summer seasons.

Nitrite can be of organic or inorganic origin, and it is a transitional product of nitrogen cycle taking place in natural water. In the present study, high nitrite concentration of 4 mg dm^{-2} was noted in winter season. Nitrite ranged from 0 mg dm^{-3} to 4 mg dm^{-3} during winter season and 0 mg dm^{-3} to 3 mg dm^{-3} during summer season. The nitrite value obtained in the present study exceeded the EPA limits.

Nitrate occurs in water naturally as a result of plant or animal material decomposition, but can also be introduced into water due to human activities. In the present study, nitrate varied from 4 mg dm^{-3} to mg 12 dm^{-3}. The nitrate concentration during both seasons were high compared to the permissible limits of EPA standards.

Chloride is generally present in natural water. In lake water samples, chloride value were within the limits. The observed average value of chloride ions during summer ranged between 60 mg dm^{-3} to 68 mg dm^{-3} and during winter 38 mg dm^{-3} to 48 mg dm^{-3}, respectively. The chloride ions in Ooty lake, however, did not exceed the EPA limit.

Fluorides are present in water due to industrial sewage, agricultural runoff and burning of coal. In this study the concentration of fluoride was 0.5 mg dm^{-3} during both the seasons. The fluoride values obtained in the present study

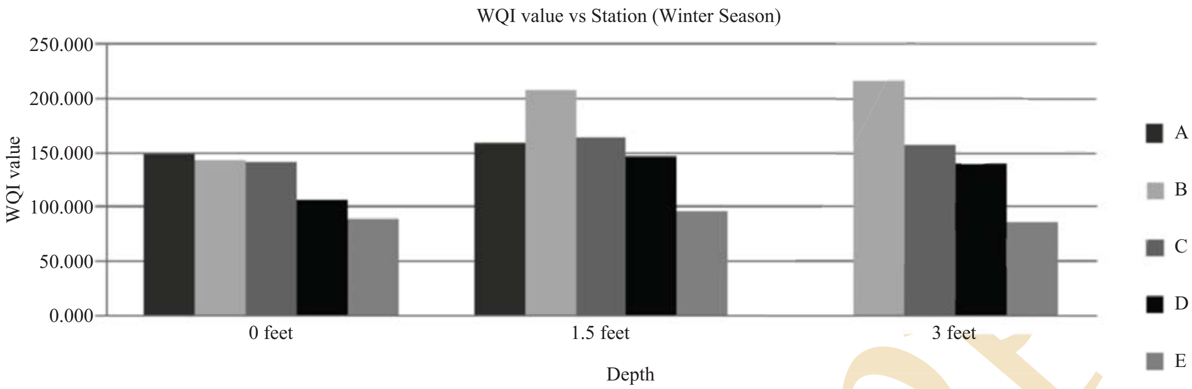

Fig. 2 : WQI Value in Winter Season

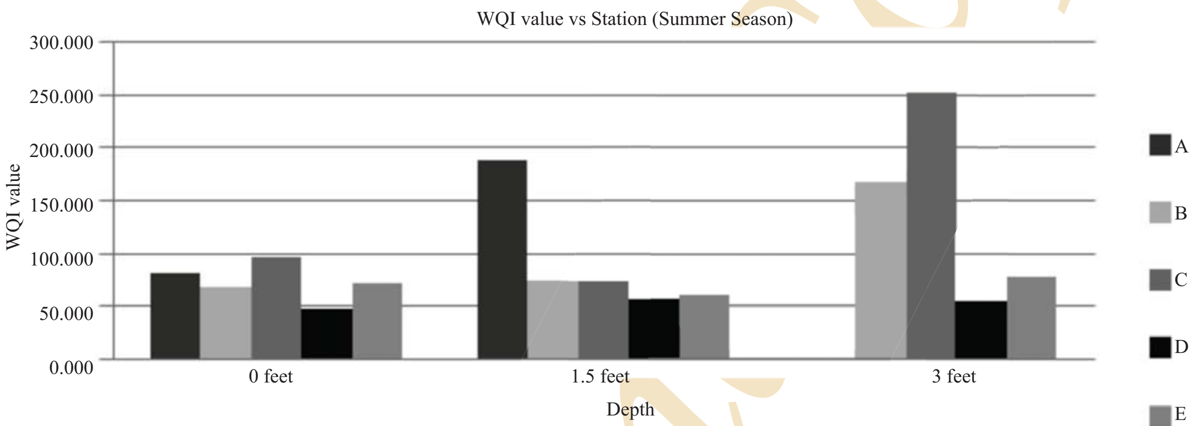

Fig. 3 : WQI value in summer season

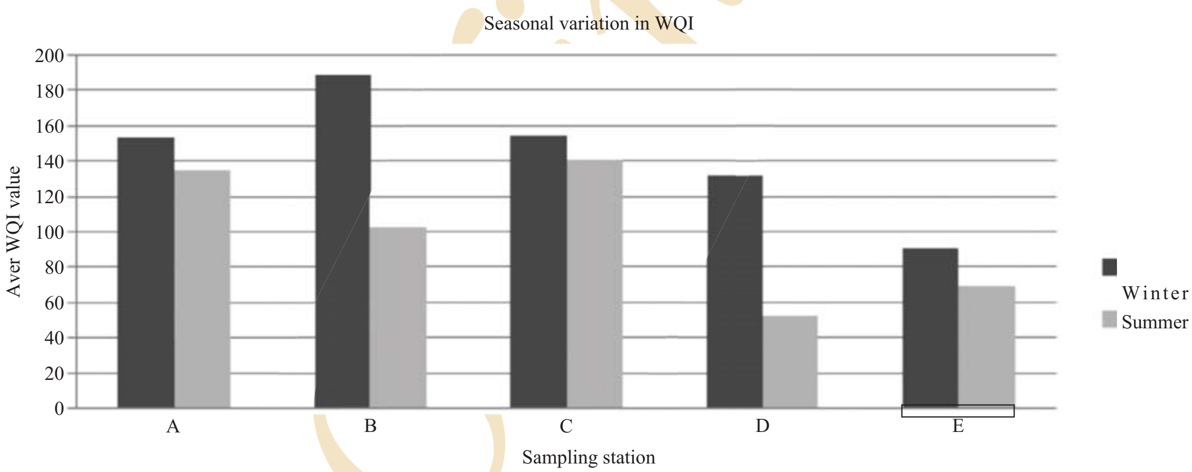

Fig. 4 : Seasonal variation on WQI

were slightly higher than the EPA limit.

Sulphates are one of the least toxic anions. The presence of sulphate ions in drinking water can result in noticeable bitter taste. The observed average value of sulphate ions during summer was 9.5 mg dm^{-3} and 7.85 mg dm^{-3} during winter. The sulphate ions in Ooty Lake are within the EPA limit.

Table 6 : Factor analysis value for summer season

Variables	Factor 1	Factor 2	Factor 3
Temperature	0.714	-0.01	0.552
Turbidity	0.86	0.224	0.301
Total dissolved solids	0.208	0.939	0.056
EC	0.148	0.968	0.137
pH	-0.126	-0.541	-0.329
Total alkalinity	-0.151	0.758	-0.013
Total hardness	0.171	0.632	0.663
$Ca+^{2}$	0.136	0.752	0.527
Mg^{+2}	0.415	0.387	0.703
Fe^{+3}	0.788	0.161	0.115
NH_3	0.506	0.123	0.475
NO_2^-	0.068	-0.237	0.632
NO_3^-	-0.008	-0.407	-0.856
Cl^-	0.294	0.894	0.195
F^-	-0.108	-0.084	-0.434
SO_4^{-2}	0.112	-0.34	-0.775
PO_4^{-3}	0.678	0.307	-0.08
BOD	0.954	-0.122	0.081
COD	0.792	-0.104	0.113
DO	-0.879	-0.169	-0.25
E. coli	0.741	0.179	-0.21
Eigen value	8.79	4.106	2.272
% Total variance	41.856	19.551	10.821
Cumulative %	41.856	61.407	72.227

Table 7 : Types of pollution based on factor analysis

Factor	Physico-chemical parameters	Types of pollution
1	Temp, Tur, Fe^{+3}, NH_3, PO_4^{-3}, BOD, COD, DO, *E. coli*.	Organic pollution
2	TDS, EC, pH, Total alkalinity, Ca^{++}, Cl^-	Domestic waste water pollution
3	TH, Mg^{++}, F^-, NO_2^-, NO_3^-, SO_4^{-2}	Agricultural pollution

Phosphates are sometimes added to drinking water to reduce corrosion and precipitation of certain compounds. The highest value was noted as 2 mg dm^{-3} during both the seasons. The phosphate value obtained in the present study was slightly increased as compared to EPA limit.

BOD is a measure of the quantity of oxygen consumed by microorganisms during decomposition of organic matter. It is the most commonly used parameter for determining the oxygen demand on receiving water of a municipal and industrial discharge. The average BOD value ranged between 7.37 mg dm^{-3}to 10.47mg dm^{-3}. The BOD values were higher than EPA limits

The chemical oxygen demand is the amount of oxygen required for degradation of organic compounds in waste water. The average value of COD was 56.57 mg dm^{-3} during winter season and 39.78 mg dm^{-3} during summer season. The phosphate values obtained in the present study were higher as compared to EPA limit.

Dissolved oxygen is required for many physical and biological processes prevailing in water. It affects the solubility and availability of many nutrient's and therefore productivity of aquatic ecosystem (Wetzel *et al.*, 1983). During the present investigation, dissolved oxygen concentration varied from 6.50 to 9.77 mg dm^{-3}. Highest value of 14 mg dm^{-3}during was noted in winter season. The dissolved oxygen in water samples were in the present study are slightly higher than to EPA limits.

Water quality index : The water quality index value of the study area was computed for winter and summer seasons as shown in Fig. 2 and Fig. 3.The water quality index was highest during winter season because the rain water flushed out all the pollution from the catchment area and discharged into the lake directly. During summer season organic pollution high in the lake due to dumping of domestic waste water in the lake. According to the classification of WQI of Ooty Lake, 78% of the sampling stations were unfit category during winter season, and during summer season 50% of the

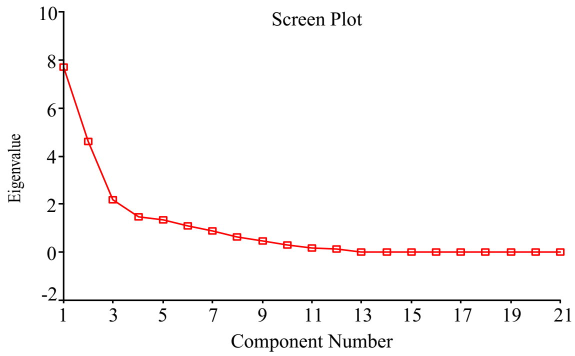

Fig. 5 : Screen plot for Eigen value in winter season

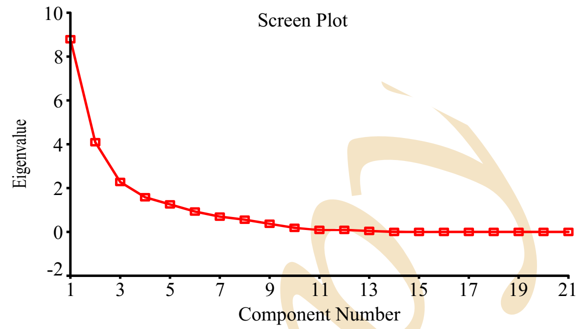

Fig. 6 : Screen plot for Eigen value in summer season

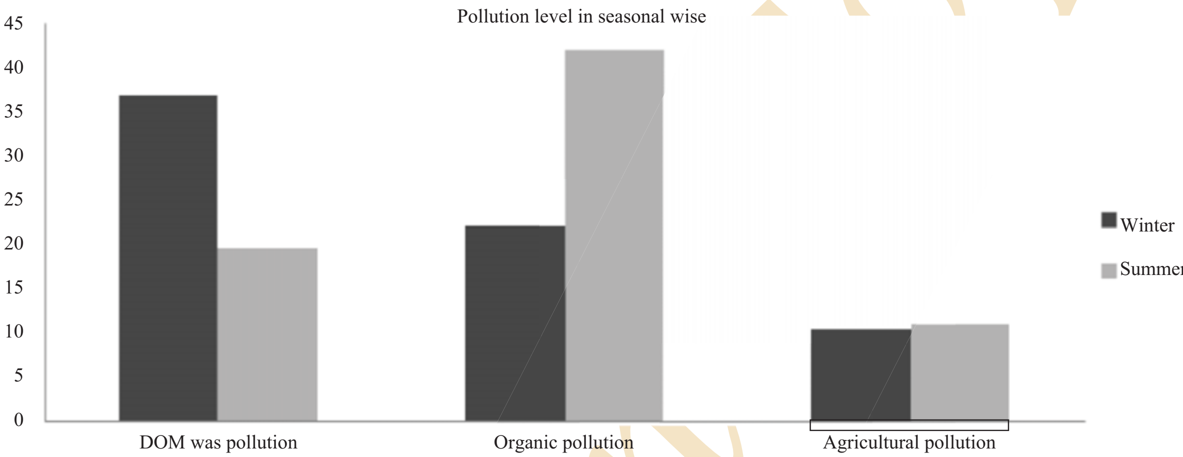

Fig. 7 : Pollution level in seasonal wise

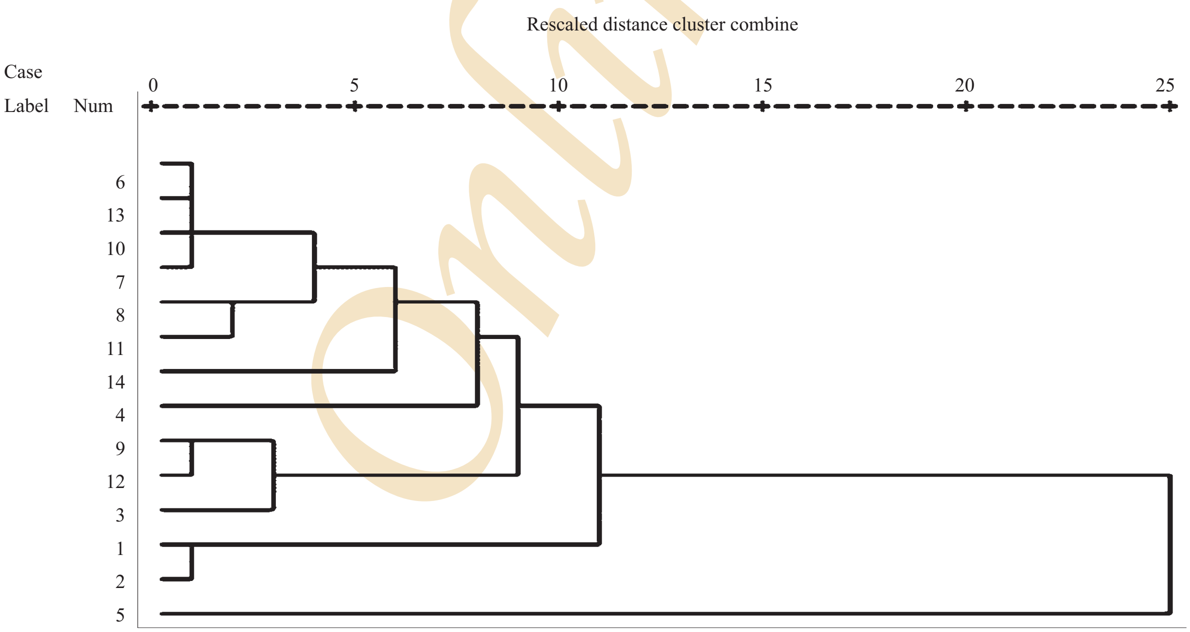

Fig. 8 : Cluster analysis for winter season

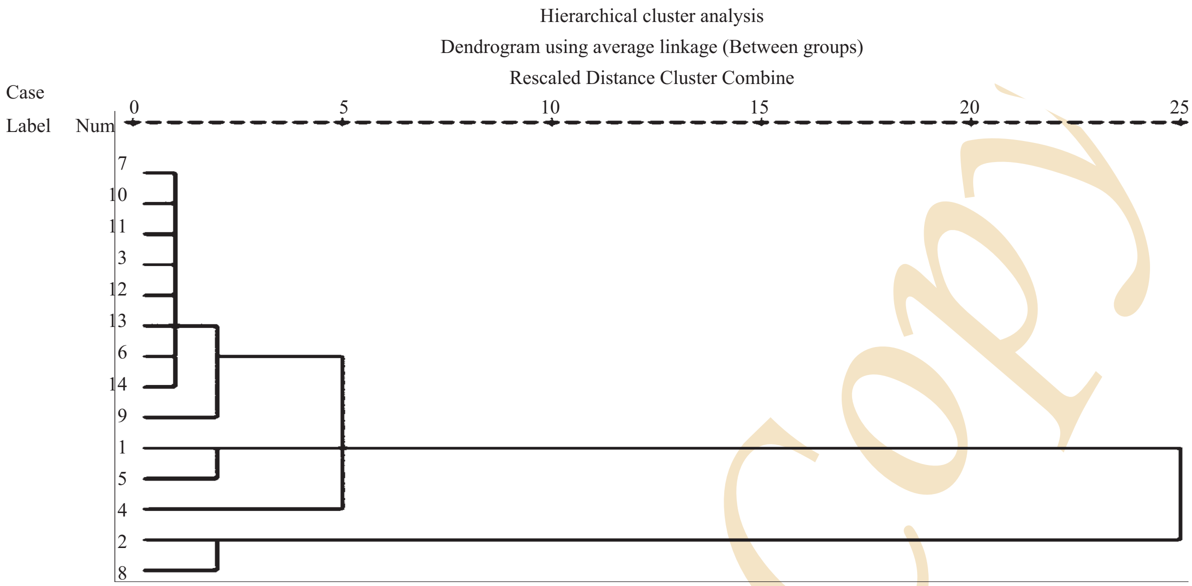

Fig. 9 : Cluster analysis for summer season

samples were in the bad category, 21.42% were in very bad and unfit category.

Statistical analysis : Principal component analysis / Factor analysis : The results of the Principal component analysis are shown in Table 4 and 6. The principal component analysis used varimax rotation (Kuppusamy *et al.*, 2006). Eigen value selection criteria were selected to explain the source of variances as one greater than one (Kiymaz *et al.*, 2014). Principal component analysis yielded three principal components which account for 69.14% and 72.23% in winter and summer season, respectively of the total variance associated with twenty one parameters. The corresponding screen plot are shown in Fig. 5 and 6.

During winter, the first factor explained 36.74% of the total variances with high positive loading in Total dissolved solids (TDS), Electrical conductivity (EC) ,iron, chlorides, and hardness and it is a indication of man made pollution due to domestic waste discharge (Fisher et al., 1997) in the lake. The second factor presented 21.99% of the total variance and is characterized by positive loading in biological oxygen demand, sulphates and chemical oxygen demand. It indicates that the components were related to organic pollution from domestic and industrial wastewater (Fan *et al.,* 2010). The third factor explain a significant proportion 10.41% of the total variance and showed positive loading on nitrate, pH, turbidity and negative loading on nitrite and ammonia. This group of nutrient also reflected the degree of eutrophication and agricultural pollution of the lake.

During summer season, the first factor accounts for 41.86% of the total variance showing strong positive loading on BOD, COD, temperature and turbidity, which revealed that the quality of lake water was affected by organic pollution. The second factor accounts 19.55% of total variance is associated with strong positive loading to TDS, EC, total alkalinity calcium and chloride. These variables accounted for domestic waste water pollution, while third factor presented 10.82% of the total variance showing positive loading with total hardness, nitrite and negatively with fluoride, nitrate and sulphate, respectively. It could be related to agricultural pollution.

Cluster analysis : To compare the compositional pattern of the samples and identify the factor influencing each region, factory analysis was applied to the normalized data sets of cluster 1, cluster 2 and cluster3 separately (Qu Jiang-Qi *et al.*, 2013). The dendrograms shown in fig 8 and fig 9 showed that the cluster value were combined with the values of coefficient of each step. In this analysis the station name was modified as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 instead of A1, A2, B1, B2, B3, C1, C2, C3, D1, D2, D3, E1, E2, E3. The places were grouped based on their cluster values. During winter season, the sampling place B3 was heavily polluted and A1 and A2 were moderately polluted. During summer season, A2 and C3 were heavily polluted as compared with other stations.

The water quality index of Ooty Lake showed heavy pollution during winter season and moderately polluted during summer season. The dominating types of pollution were also identified, based on the factorial and principal component analyses. from the above analysis during winter season, domestic waste water pollution determines in the lake and during summer season, organic / biological pollution is determines in the lake. The water pollution causing parameters, location and the level of pollution in the lake gives a clear indication and better understanding of Lake ecosystem and will help to develop the environment of Ooty Lake.

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