Water Quality Variations in Ooty Lake, Tamil Nadu, India using Geospatial Technology

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Abstract:

The present study aims to assess the hydrogeochemical characteristics of groundwater in Ooty lake, Nilgiris district, Tamil Nadu, India. In order to assess the lake water quality, 25 water samples were collected in May 2022. The water samples were analyzed for different hydrogeochemical parameters such as pH, EC TDS, Ca, Mg, Na, K, Cl, HCO3, SO4, PO4, and H4SIO4 using standard procedure. The analytical result reveals that pH, the chemical parameters, Mg, and Ca showed the above permissible limit of WHO standards in few locations. Whereas physical parameters of EC (Electrical Conductivity), TDS and Na, K, SO4, and H4SiO4, HCO3, Cl, NO2, PO4 showed within the permissible limit. Furthermore, the chemical analysis results show the abundance of the major cations in the order Ca >Na>Mg>K. whereas the abundance of anions are in the order HCO3>Cl>SO4 2-. The result obtained in this investigation inferred that the cations in water i.e. sodium, iron, magnesium and potassium are within the permissible limit. And anions such as Silicate, Phosphate, Chlorate and Sulphate are also within the permissible range. The concentration of cation, magnesium (Mg) in the lake water has exceeded the desirable range (30 mg/L, respectively) in few locations and potassium (K) is within the permissible limit. The concentration of anion, Sulphate (SO4) and chloride are within the desirable limit. The major source of bicarbonate are the carbonate rocks containing calcite (CaCO3) and dolomite (CaMg (CO3)2), Calcium (Ca) and Magnesium (Mg) can also be transported from Ca-silicates and Mg-silicates. The piper trilinear plot suggests the increase of Ca and SO4 contents is attributed to dissolution of gypsum and anhydrite, which are commonly found in the quaternary formations of watershed. Ion exchange, dissolution of calcite, semi-arid climate, alkaline condition and weathering are responsible for high concentration of ions exceeding the desirable limit of the study area.

Keywords: Water quality, groundwater, pollution, hydrogeochemical, Ooty

1 Introduction:

The watershed is all of the land and water areas that drain toward a particular waterway or lake. A lake is a reflection of its watershed. More specifically, a lake reflects the watershed’s extent, climate, topography, geology, land use/land cover, soil erodibility, and vegetation. The lakes, their ecosystems and habitats are niches to a wide variety of unique flora and fauna (Moor 1984; Burgis and Mavuti 1987; Chatterjee 1996; Njenga 2004). The lake watershed ‘‘system’’ is a functioning unit with interacting bio-physical, chemical and anthropogenic components.

Lakes water have been utilized as ideal natural laboratories to study a number of hydrogeochemical processes including evaporation, dissolution, mixing, precipitation of minerals and chemical exchange between water, sediment and atmosphere (Njenga 2004). The physiognomies of lake-watershed interaction hinge on a number of parameters. That is why each lake and its watershed are a unique system. The usefulness of water for a particular purpose is determined by the water quality. The environmental conditions of any lake system depend upon the nature of that lake and its exposure to various environmental factors. Therefore, surface water quality depends not only on natural processes i.e. precipitation inputs, erosion, and weathering of crustal materials, etc. but also on anthropogenic influences.

The main reasons which resulted in deteriorate conditions of lakes could be categorized into two classes (Ravi et al. 2013) point sources i.e. pollutants entering from fixed sources (for example, nutrients from wastewater, from municipal and domestic effluents; organic, inorganic and toxic pollutants from industries effluents and storm water runoff) and non-point sources (for example, nutrients through fertilizers, toxic pesticides and others chemicals, mainly from agricultural runoff; organic pollution from human settlements spread over areas along the periphery of the lakes). In recent years, significant research has focused on pollution control in lake water bodies, highlighting the importance of maintaining water quality and the lake ecosystem (Gamze et al., 2003). Lake water is a crucial renewable resource for humanity and the environment, serving civil, industrial, and recreational purposes (Islam et al., 2012). Water quality is assessed based on its physical, chemical, and biological characteristics (Sargaonkar et al., 2003). Streams, lakes, and inland wetlands are interconnected components of watersheds that reflect the ecosystem's physical and chemical conditions, land use patterns, and embedded elements (Morrice et al., 2008).

This approach is useful for examining temporal and spatial variations caused by natural and anthropogenic factors (Islam et al., 2017; Khanday et al., 2021). In the present study, an extensive set of water quality data was collected. The levels of contamination in lake water were examined by evaluating the physico-chemical parameters based on the review of the study area.

2 Study area:

Ooty Lake, situated in the Nilgiris district of Tamil Nadu, India, is a captivating tourist attraction. Located at 11°25'96" N and 75°45'7" E, at an elevation of 2191.30 meters above mean sea level, the lake covers a water surface area of 0.223 square kilometers and has a catchment area of 1112 square kilometers. The region receives an average annual rainfall of approximately 1008.2 mm, with temperatures ranging from a maximum of 25°C to a minimum of 6°C (Parthasarathy, P et al., 2021). Refer to Figure 1 for an illustration of the study area around Ooty Lake.

3 Methodology for Water Sample:

When assessing the water quality of Ooty Lake, a comprehensive approach was employed, integrating water quality analysis (Mushtaq, N., et al., 2020; Dalwani, R., & Gopal, B. 2020).

3.1 Sample Collection:

Water samples were collected from 25 stations for the analysis of physico-chemical parameters. At each location, samples were taken from the lake's surface and the location is marked with GPS and its represented in Table 1. Physico-chemical parameters such as pH, electrical conductivity, total dissolved solids, phosphates, nitrite, chloride, sulfate, calcium, magnesium, and iron were partially tested in the field and further analyzed in the laboratory to assess the lake's pollution status. Standard methods outlined in APHA 2012 were used for parameter estimation.

3.2 Field and Laboratory Measurements:

The basic field measurements such as pH, Total dissolved solids (TDS), Temperature, and electrical conductivity (EC) and laboratory measurements such as bicarbonate, magnesium, calcium, chlorine, sodium, potassium, phosphate, nitrate and dissolved silica were measured using the following methods which is shown in the Table 2.

The secondary factors of groundwater quality indices, such as the Water Quality Index, include drinking and irrigation. The parameters Sodium Adsorption Ratio (SAR), Sodium Soluble Percentage (SSP), and Sodium Percentage (Na%) were calculated based on the fundamental measure for assessing the quality of irrigation water.

The groundwater samples were obtained from the research region in June 2016, specifically during the pre-monsoon period. The collection process followed the standard methods outlined by the American Public Health Association (APHA, 2017). The sampling locations were identified using the global positioning system (GPS), as depicted in Figure 1a. Specimens were gathered from the designated area utilising a 1-liter container, as depicted in Figure 2. The one-litre capacity collecting bottles made of High-Density Polythene (HDPE) were sterilised using aseptic techniques to prevent any unexpected contamination and subsequent alterations in the properties of the groundwater. Prior to collection in the bottle, water samples underwent filtration using Whatman 42 filter paper with a pore size of 2.5 µm. The specimen was stored in a portable refrigeration unit and transported to the laboratory for analysis. The specimens were maintained in a chemical laboratory at a temperature ranging from 4 to 5 degrees Celsius. Prior to examination, the samples underwent pre-filtration in the laboratory.

In this study, a total of 13 parameters related to the quality of surface water were analysed in 25 samples. The analysis was conducted in the laboratory following the standard testing methods (APHA 2017), except for certain parameters such as pH, electrical

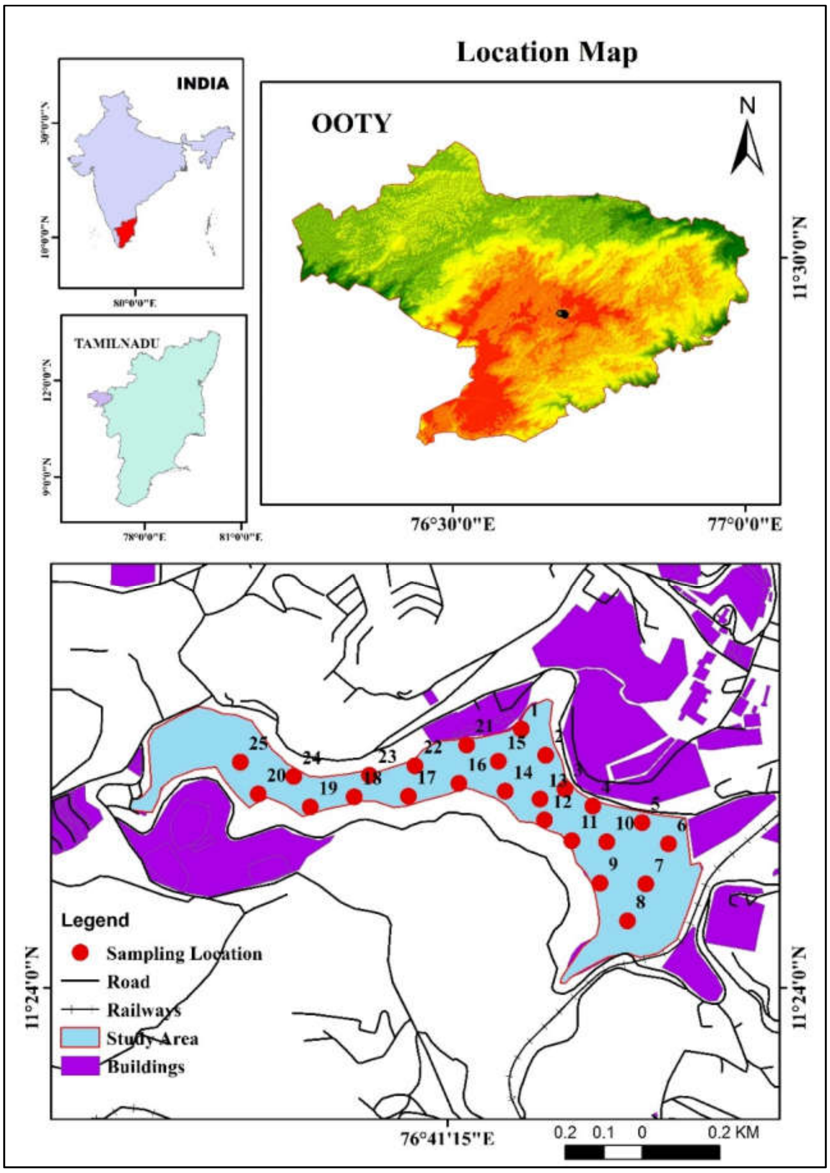


Figure 1 Study area map showing the sampling stations of Ooty Lake

Table 1: Sampling location of Ooty lake

Sample No	Latitude	Longitude
L1S1	11.40603	76.689227
L1S2	11.405421	76.689796
L1S3	11.404633	76.690246
L1S4	11.404235	76.690894
L1S5	11.403851	76.692046
L1S6	11.403355	76.692664
L1S7	11.402421	76.692134
L1S8	11.401561	76.691705
L1S9	11.40244	76.691065
L1S10	11.403401	76.691222
L1S11	11.403429	76.690407
L1S12	11.403912	76.689768
L1S13	11.404398	76.689666
L1S14	11.404583	76.688854
L1S15	11.405278	76.688691
L1S16	11.404764	76.687771
L1S17	11.404466	76.686594
L1S18	11.404451	76.685327
L1S19	11.404214	76.684298
L1S20	11.404516	76.683087
L1S21	11.40566	76.687953
L1S22	11.405174	76.686746
L1S23	11.404954	76.685683
L1S24	11.404926	76.683916
L1S25	11.40526	76.682668

Table 2 : Field and Laboratory Measurements used for the analysis of Lake water

S.no	Element	Method
1	pH	Digital pH meter
2	TDS	Digital pH meter
3	Temperature	Digital pH meter
4	EC	Digital pH meter
5	Bicarbonate	Titration
6	Mg	Titration
7	Ca	Titration
8	chlorine	Titration
9	Sodium	Flame photometry
10	potassium	Flame photometry
11	Phosphate	UV spectrophotometric screening method
12	Sulphate	UV spectrophotometric screening method
13	Dissolved silica	UV spectrophotometric screening method

conductivity, temperature, and total dissolved solids, which were measured on-site using portable devices like pH-meter, EC-meter, and TDS-meter. Calcium, magnesium, bicarbonate, and chloride were determined through volumetric titrations. Sodium and potassium were measured using a flame photometer. Nitrate, phosphate, and silicate were analysed using a Shimadzu 1800 UV spectrophotometer. The correctness of the chemical analysis has been verified through the assessment of charge balance errors, and only samples with an error rate below 5% were deemed acceptable.

The study utilizes the inverse distance weighted (IDW) interpolation technique, which is currently recognised as an efficient method for spatially interpolating groundwater quality parameters. This technique enables the creation of spatial distribution maps. Previous studies by Magesh et al. (2013), Kawo and Shankar (2018), Balamurugan et al. (2020b), and Sarfo and Shankar (2020) have also employed this technique. The weights were determined for different attributes for each location based on distance, considering only the nearest specified locations. The spatial distribution map clearly delineates the distribution of each groundwater quality indicator into separate zones, namely acceptable/desirable and allowable limits, based on the standards set by BIS (2012, 2015) and WHO (2017) for drinking water.

The statistical analysis and correlation matrix of the examined groundwater quality measures have been shown in Tables 1 and 2, respectively.

4. Results and discussion:

The physicochemical properties of Ooty Lake show spatial variations. Table 2 presents the water quality parameters for Ooty Lake. The analytical precision for measuring major ions is within ±5%. The observed charge balance between cations and anions further confirms the data's quality (Table 3), indicating that the contributions of ions not measured are insignificant for maintaining the cation and anion charge balance (Singh, G et al., 2020). The results show that all physicochemical parameters are within limits, though some major ions exceed WHO standards, likely due to anthropogenic activities. Water characteristics are relatively uniform in shallow lakes, which are mixed by winds (Deka, J. P et al., 2015). The abundance and variation in major cations (Ca2+, Mg2+, Na+, and K+) and anions (HCO3, SO4, PO4, NO3, and Cl) in surface water are influenced by weathering, atmospheric precipitation, and possible atmospheric activities, as discussed below.

4.1. Hydrochemistry of the surface water:

The geographic distribution map for the water quality metrics in the research area is generated using ArcGIS software 10.1, as depicted in Figure 2 a–j. This study has analyzed the drinking water standards based on the Bureau of Indian Standards (BIS 2012, 2015) and the World Health Organisation (WHO 2017) references, which are described in Table 4. The parameters determining the quality of ground water are as follows.

4.1.1 The concentration of hydrogen ions (pH).

The indicator is crucial for evaluating the quality and pollution levels of any aquifer system, as it has a strong correlation with other chemical components present in the water. The pH range is used to measure the concentration of hydrogen ions. Pure water has a neutral pH, indicating a balanced concentration of hydrogen ions. In this study, the pH levels ranged from 6.9 (lowest) to 8.5 (highest), which is within the permitted range of 6.5–8.5, with an average of 7.7.

4.1.2 Electrical conductivity (EC)

Indeed, it is a quantification of the capacity of a substance or solution to facilitate the flow of electric current in water. The electrical conductivity (EC) of a water sample is directly proportional to the amount of dissolved material present. The recommended threshold of electrical conductivity (EC) for drinking water is 750 µS/cm. The electrical conductivity in this study ranges from 206 to 318 µS/cm. The presence of a high electrical conductivity (EC) at some locations indicates the potential contamination of lake water due to the introduction of sewage. These locations are in close proximity to the entrance and the boat yard.

4.1.3 Total dissolved solids (TDS)

The weight of residue is determined by evaporating a water sample until it reaches a dry condition. The composition comprises calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, and sulphate. In this study, the range of values observed is from 30.02 to 318 mg/l, which is below the maximum acceptable limit of 500 mg/l for total dissolved solids (TDS) in drinking water according to the Bureau of Indian Standards (BIS). The main sources of Total Dissolved Solids (TDS) are agricultural activities, residential runoff, soil leaching leading to contamination, and point source water pollution from domestic wastes, public toilets, restaurants, and agricultural discharges (Boyd 2000).

4.1.4 Calcium (Ca^{2+})

The aquifer system is infiltrated by the leaching of minerals containing calcium. The calcium concentration in the study area varies between 16 and 106 mg/l, which falls within the acceptable limit of 200 mg/l. The lower quantity of Ca^{2+} in the groundwater is sufficient to facilitate chemical weathering.

4.1.5 Magnesium ion (Mg^{2+})

It is a crucial factor that determines the water's hardness. The concentration in the studied region varies from 1.2 to 51.6 mg/l, slightly exceeding the allowed limit of 100 mg/l.

4.1.6 Sodium ion (Na^{+})

This substance is an extremely reactive alkali metal. It is ubiquitous in the majority of water sources. Various rocks and soils contain sodium compounds that readily dissolve, releasing sodium when exposed to water. The concentration in the research area varies between 16.1 and 19.5 mg/l.

4.1.7 Potassium cation (K^+)

It is found in several minerals and the majority of rocks. A significant number of these rocks have a relatively high solubility and release potassium, resulting in an increase in the concentration of potassium over time in groundwater. The range of values observed in this investigation fluctuates between 8 to 8.7 mg/l.

4.1.8 Chloride ion (Cl^-)

In this investigation, the concentration of Cl^- ranged from 15.95 to 31.9 mg/l, which is below the allowed limit of 250 mg/l. The elevated concentration of chlorine in water poses a significant risk to human health (Pius et al., 2012; Sadat-Noori et al., 2014). The cl – value in the research area is within the acceptable range.

4.1.9 Bicarbonate ion (HCO_3^-)

It is formed through the chemical reaction between carbon dioxide and water on carbonate rocks, specifically limestone and dolomite. The carbon dioxide in the soil has a reaction with the minerals that compose rocks, resulting in the formation of bicarbonate and creating an alkaline environment in the groundwater. The concentration of the substance in the study region ranges from 48.8 to 73.2 mg/l, which falls under the acceptable limit of 600 mg/l.

4.1.10 Sulphate (SO_4^{2-})

Sulphur is dissolved and extracted from rocks that contain gypsum, iron sulphides, and other compounds that contain sulphur. In this investigation, the observed range is from 12.5 to 28 mg/l, which is comfortably within the acceptable threshold of 200 mg/l.

Table 3 Physio chemical characters of surface water of Ooty lake

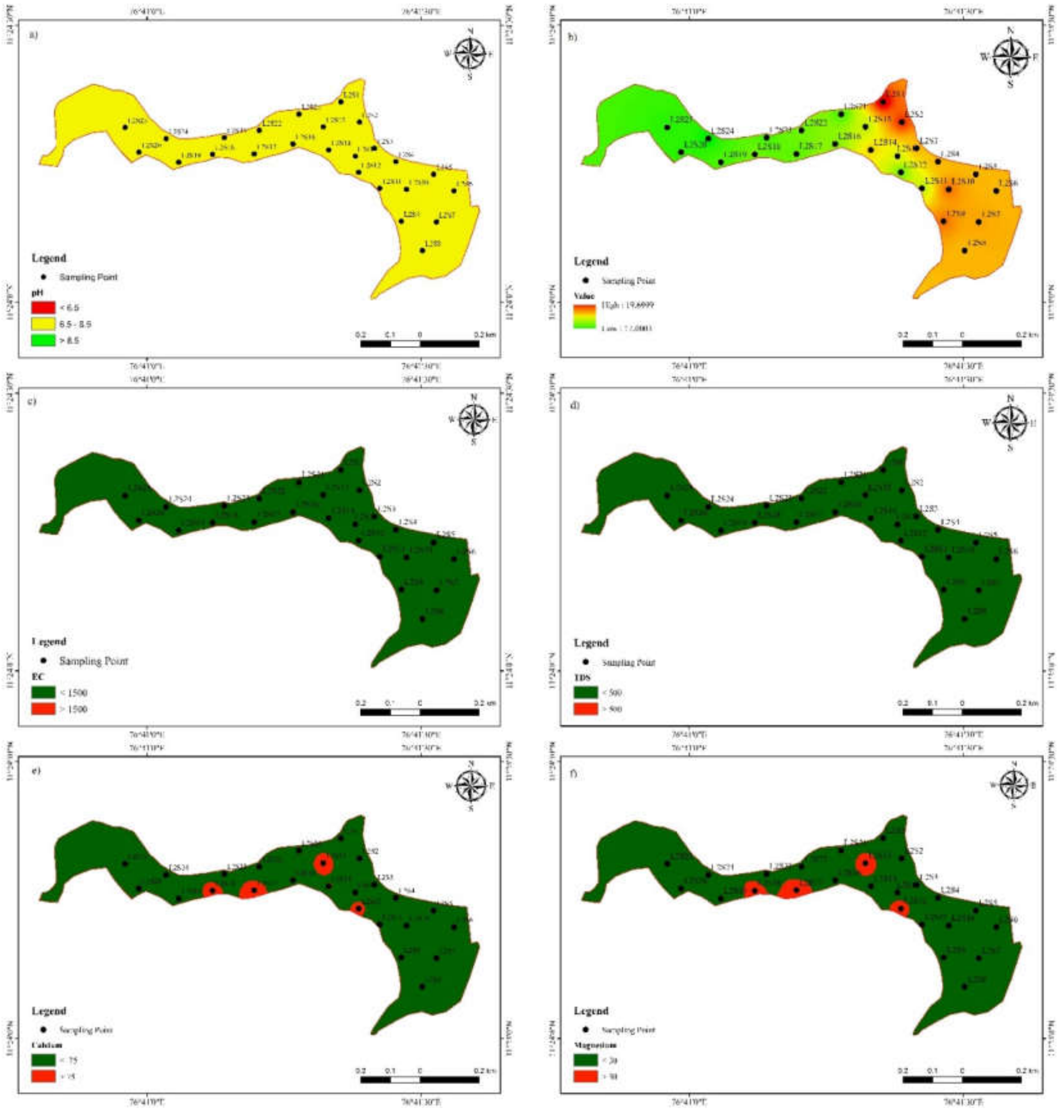
S.No	pH	Temp (°C)	EC	TDS	HCO3	Mg	Ca	Cl	Na	K	SO4	NO3	PO4
L1S1	8.5	19.7	300	150	73.2	4.8	30	26.5875	18.1	8.2	20.4	0.151	5.331
L1S2	7.6	19.4	300	150	54.9	6	36	26.5875	18.1	8.5	16.5	0.132	6.627
L1S3	7.4	18.6	300	150	54.9	1.2	20	26.5875	18.9	8.2	17	0.129	8.714
L1S4	7.2	18.6	318	158	61	13.2	54	26.5875	16.6	8.3	21	0.142	8.502
L1S5	7.2	18.6	318	159	67.1	13.2	34	31.905	18.3	8.4	18	0.148	6.872
L1S6	7.2	18.6	318	159	61	1.2	16	15.9525	18.5	8.3	18	0.146	7.319
L1S7	7.3	18.7	318	159	67.1	2.4	24	21.27	16.5	8.4	19.5	0.14	11.367
L1S8	7.3	18.6	318	159	67.1	16.8	58	26.5875	19.3	8.3	14	0.153	9.009
L1S9	4.3	19	304	154	67.1	2.4	16	15.9525	16.7	8.4	16.5	0.156	6.718
L1S10	4.7	19	301	152	61	27.6	66	21.27	16.1	8.3	18	0.18	6.703
L1S11	5	17.9	299	149	61	22.8	56	26.5875	16.3	8.3	28	0.169	6.771
L1S12	5.2	17.4	299	144	48.8	37.2	84	21.27	16.3	8.3	14.5	0.163	6.286
L1S13	5	18.1	299	149	67.1	30	72	21.27	16.3	8.4	26.4	0.232	6.483
L1S14	4.3	18.4	299	149	61	28.8	76	21.27	18.8	8.4	19.5	0.21	6.168
L1S15	6.9	17.9	299	149	54.9	45.6	100	21.27	16.5	8.4	24.8	0.216	6.147
L1S16	7.6	17.5	257	149	48.8	3.6	22	21.27	16.9	8.5	13	0.227	5.714
L1S17	8	17.3	301	149	54.9	51.6	106	31.905	16.8	8.5	17.5	0.236	5.694
L1S18	7.9	17.4	206	149	54.9	43.2	94	26.5875	17.1	8.6	20.4	0.236	4.942
L1S19	8.5	17.2	306	147	61	1.2	20	31.905	17.1	8.7	18	0.238	4.889
L1S20	8.4	17.1	301	150	67.1	4.8	20	21.27	17.5	8.6	12.5	0.263	5.294
L1S21	8.3	17.2	301	250	61	2.4	28	31.905	16.5	8	15	0.24	6.251
L1S22	8.5	17.4	301	150	61	7.2	18	26.5875	16.4	8.1	16	0.265	6.187
L1S23	7.9	17.2	300	149	67.1	10.8	40	31.905	19.5	8.2	15	0.271	6.221
L1S24	8	17	300	149	48.8	4.8	38	31.905	16.2	8.1	17	0.242	6.032
L1S25	7.6	17.1	300	149	54.9	4.8	34	26.5875	16.2	8	19.6	0.25	6.17

Table 4 Percentage of water sample exceeding water quality and its health impact.

Physicochemical parameters	**Drinking water quality limits**	**Percentage of samples exceeding the drinking water quality limits**	**Health implications**
pH	6.5 to 8.5	24	Mucous membrane
TDS (mg/L)	500	-	Gastrointestinal irritation
Ca^{2+} (mg/L)	75	20	Kidney stones
Mg^{2+} (mg/L)	30	20	Laxative effect
Na^{+} (mg/L)	200	-	Hypertension
K^{+} (mg/L)	12	-	Hyperkalemia
HCO_3^-(mg/L)	300	-	Digestion
Cl^- (mg/L	250	-	Salty taste
SO_4^{2-} (mg/L)	200	-	Bitter taste
NO_3^- (mg/L)	45	-	Blue baby disease

4.2 Spatial distribution pattern

The spatial maps of the water quality metrics have been constructed and their spatial distribution pattern is shown in Figure. 2 a–m. The pH spatial distribution pattern reveals that lake water is in permissible limit in major part throughout the area (Figure 2a). The lake is experiencing Total Dissolved Solids (TDS) levels within the permissible limit throughout the lake (Figure 2d) as a result of inadequate flushing and the presence of highly weathered rock formations. The Total Dissolved Solids (TDS), which shows permissible limit all over the lake (Table 2). The map of Ca^{2+} spatial distribution indicates that there are different concentrations within the acceptable range across the entire study region (Figure 2e) as a result of the presence of alkali feldspar in granite. In a few places, it shows a higher concentration, which is above the permissible limit. Similarly, the distribution of Mg^{2+} is remains within acceptable limits most of the location over the study area, in a few locations of the lake it exceeds the acceptable limit (Figure 2f). The presence of Ca^{2+} and Mg^{2+} ions in the groundwater is likely a result of the leaching process when calcium and magnesium-rich rock formations in the research area release these ions. The concentration of Na^{+} is within the limit of the study area. Despite the fact that the presence of K^{+} is not considerable, its lower concentration within the acceptable range is widespread in the lake. The distribution pattern of the data aligns, to a certain extent, with the TDS and Na^{+} measurements (Figure 2 d, g). The HCO_3^- ion is a crucial quality measure that exhibits within the limit throughout the lake. This association is also evident in the spatial distribution pattern of these parameters (as depicted in Figure 2j). Sulphate (SO_4^{2-}) is a significant quality characteristic. The research area (Figure 2m) contains the substance within the acceptable range. The concentration of chloride is within the limit in the lake water. The spatial distribution map of chloride is depicted in Figure 2i.



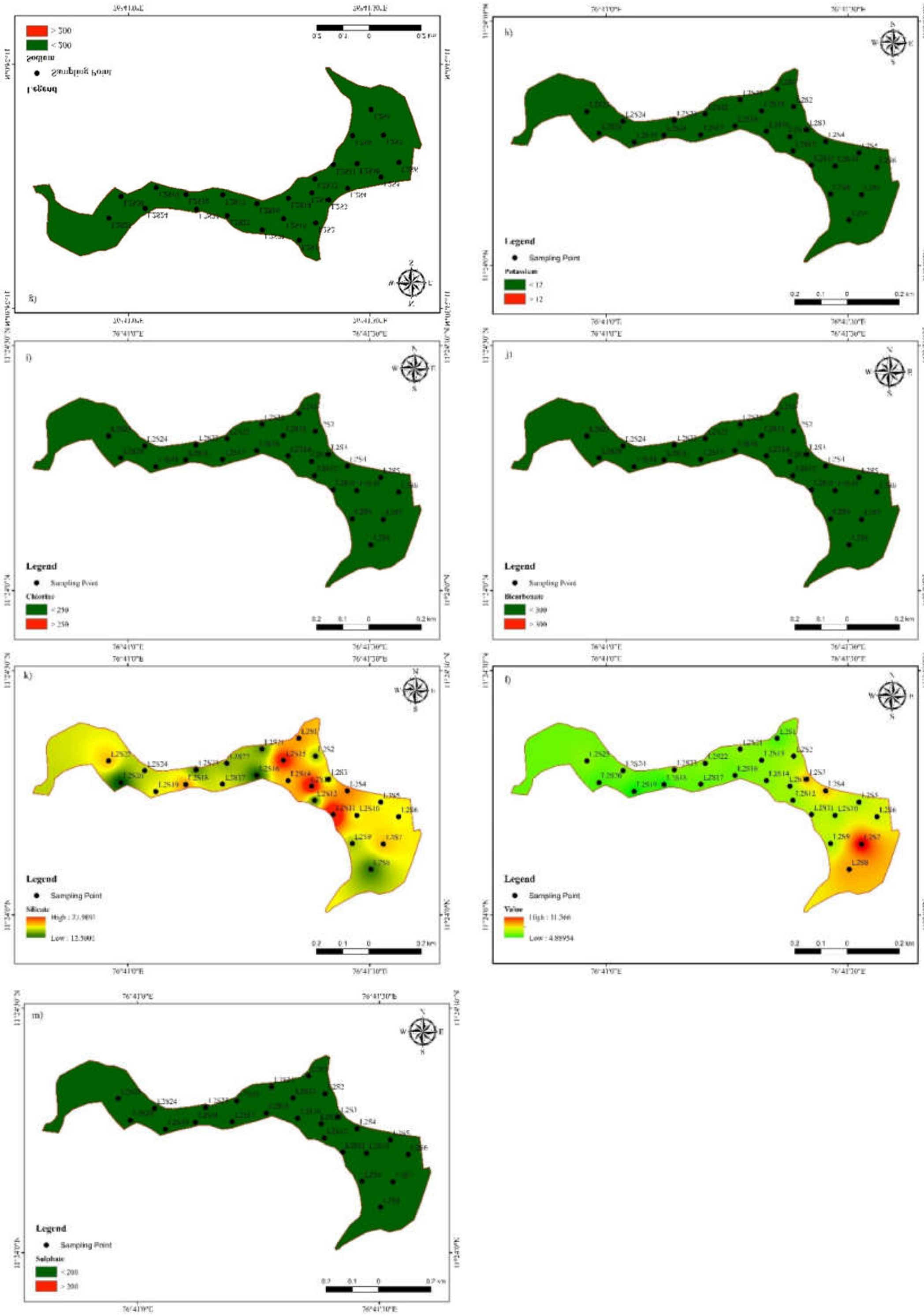


Figure 2 a-m Spatial distribution of physiochemical charatersistics of lake water

5 Conclusion:

Ooty Lake is a freshwater body influenced by chemical weathering and atmospheric precipitation, which govern its major ion chemistry. This study highlights the seasonal behavior of major ions that affect water chemistry either directly or indirectly. The lake's water quality is good concerning pH, EC, and TDS. Significant ions (Cl, PO_4, HCO_3, SO_4, Na^+, K^+, Ca^{2+}, and Mg^{2+}) exhibit increasing trends from monsoon to winter, followed by decreasing trends in summer. The catchment area's shale, silt, sandstone, and quartzite rocks contribute to the specific geochemical characteristics of the water. The congruent dissolution of carbonate minerals primarily controls the water chemistry, with a limited influence from the incongruent weathering of silicate minerals in the surface sediments.

Based on the hydrogeochemical results the physiochemical parameters EC (Electrical Conductivity), TDS and chemical parameters Na, K, Cl, showed the above permissible limit of WHO standards. The presence of measurable amount of SO_4 and PO_4 indicates external inputs from atmospheric deposition and anthropogenic activities. Seasonal fluctuations in environmental factors such as temperature, rainfall, and wind speed influence the water chemistry of Ooty Lake. The water from the Kudapmand Canal, which flows through the agricultural land and ends in Ooty Lake, may also impact the lake's physical and chemical status. Additionally, the lake is significantly affected by anthropogenic activities. The waste disposal from restaurants, public toilets, and household wastes is also a reason for the higher ion concentrations. In summary, variations in major ions regulate the lake's functions and reflect the interconnected nature of the biotic and abiotic factors within the lake ecosystem.

The quality of groundwater was compared with WHO standards and suggested that most groundwater samples are suitable for irrigation purposes but not for drinking. alarming situation of groundwater quality for inhabitants. Therefore, great awareness should be given in order to reduce the avulsion in groundwater quality in the study area.

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