Mysore J. Agric. Sci., 58 (1) : 74-98 (2024)

Assessment of Lake Water Quality and Suitability for Consumption, Irrigation and Industrial Purpose Using Multivariate Statistical Approach, Water Quality Indices (WQI) and Geographic Information System (GIS)

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Received : August 2023
Accepted : November 2023

Abstract

Lakes are important features of earth supporting not only different habitats for flora and fauna but also existence of human settlements by providing water for drinking, irrigation, commercial activities and improving aesthetic value. A study was conducted on Lake Mallasandra to assess its water quality, suitability for various purposes and identify sources and spatial distribution of pollution using newly emerging techniques such as multivariate statistical analysis, Water Quality Indices (WQI) and Geographic Information Systems (GIS). The water samples were collected from 18 sampling points tested for 20 physicochemical parameters during pre-monsoon and post-monsoon seasons. BOD, turbidity, TDS and Total alkalinity exceeded BIS standards in both seasons, while K^+ and NH_4^+ exceeded only in pre-monsoon. Cation concentration followed $Na^+ > Ca^{2+} > K^+ > Mg^{2+} > NH_4^+$ and anion concentration followed $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^- > PO_4^{3-}$. CCME-WQI classified the water as 'marginal' and AM-WQI indicated 'unsuitable for drinking' in pre-monsoon and 'very poor' in post-monsoon. Irrigation water quality indices *viz.*, SAR, Na%, RSC, MH, KI and PS indicated suitable for irrigation, PI indicated moderate suitability and EC indicated non-suitability. Hierarchical cluster analysis formed 3 clusters in pre-monsoon and 2 clusters in post-monsoon, consistent with corresponding AW-WQI graphs. PCA extracted 5 components explaining 84.79 and 87.43per cent of variance in pre-monsoon and post-monsoon season, respectively, indicating that water quality in pre-monsoon may be the result of domestic sewage and agricultural runoff and water quality in post-monsoon is the result of combined effect of organic pollution and geogenic process. The spatial distribution of CCME and AW-WQI revealed that north-eastern part of lake is highly polluted near the inlet. Thus, the combination of these techniques proved to be effective in monitoring and management of water resources.

Keywords : CCME-WQI, AW-WQI, Hierarchical cluster analysis, IDW, spatial distribution

Surface waters are impacted by both natural processes (climate change, mineral oxidation, soil erosion, seawater intrusion) and human activities (domestic wastewater, industrial and agricultural runoff, water diversion projects). Urban areas tend to cultivate more commercial crops intensively, while rural areas focus on less intensive staple food crops (Mir and Gani, 2019 and Lekhashree *et al*., 2016).

Ensuring access to safe drinking water is crucial for preventing health hazards in both rural and urban areas. Compliance with specific physical, chemical, and microbiological standards is essential to guarantee potability. Analyzing the physicochemical properties of surface water is therefore vital to determine its suitability for domestic, irrigation and industrial purposes (Shivayogimath *et al*., 2012). While various international and regional water quality standards exist, they often focus on individual parameters, prompting the development of Water Quality Indices (WQI) globally for comprehensive monitoring (Sun *et al*., 2016).

Water quality index is an effective method expressing the water quality in a simple, stable, reproducible unit of measure and communicates information of water quality status to the general public and decision makers. It thus becomes an important parameter for the assessment and management of surface water (Nasirian, 2007).

Multivariate statistical techniques (MST), such as principal component analysis (PCA), factor analysis (FA), cluster analysis (CA), redundancy analysis (RDA) and discriminant analysis (DA) have been applied to assess spatiotemporal variations and trends in water quality and possible sources of pollutants in surface waters. The combined use of various multivariate statistical approach has been increasingly employed in the assessment of water quality and a valuable tool in the effective management of water resources as well as rapid solution to pollution problems (Alves *et al.,* 2018).

Inverse distance weighted (IDW) method, one of the most commonly used geostatistical and mathematical interpolation techniques provided in GIS software, has been applied for mapping and predicting spatial distribution maps, such as water quality parameters, methane flux and rainfall intensity. In this study, IDW method was used to interpolate the spatial distribution map of water quality index for pre-monsoon and post-monsoon seasons.

This study focuses on Mallasandra Lake in Tumakuru taluk, Tumakuru district, Karnataka, India. Mallasandra Lake is crucial for the local farming community, serving purposes such as irrigation, domestic use and commercial fisheries cultivation. The assessment of water quality in this lake is essential for both public health and ecosystem well-being. The lake receives water from Bheemasandra Lake, which, in turn, is influenced by the outlet of a nearby sewage treatment plant on the outskirts of Tumakuru city. The treated sewage water poses potential risks to downstream lakes, emphasizing the need for a comprehensive evaluation of water quality in this context.

The study aims to (1) assess the physicochemical properties of surface water during pre-monsoon and post-monsoon seasons in 2022, (2) determine water suitability for drinking, irrigation and industrial purposes using various Water Quality Indices (WQI), (3) apply multivariate statistical techniques (Cluster analysis and PCA) to examine the relationship between water quality variables across different sampling locations and (4) visualize water quality variations through GIS techniques and interpolation methods to create WQI maps.

Material and Methods

Study Area

Lake Mallasandra is situated in western part of Tumakuru taluk in Tumakuru district in Karnataka, India located between 13°19′57′′ N and 13°18′53′′ N latitudes and 77°2′19′′ E and 77°1′28′′ E longitudes with surface area of 164.68 hectares and a mean elevation of 703m above MSL (Fig. 1 & 2). It is present in Upper Shimsha watershed boundary of Cauvery basin flooded by river Shimsha having semi-dendritic to dendritic drainage pattern. The study area receives annual average rainfall of about 743mm (2011-2021) and annual average temperature of 27.08°C. The lithology of the study area is dominated by migmatite gneiss and pediment pedi-plain complex. It has semi-arid climatic condition which experiences winter season from January to February, summer season from March to May, monsoon season from June to September and post-monsoon season from October to December. Tumakuru taluk has a population of about 5.92 lakhs (2011 census) and rainfed agriculture is the main occupation producing main crops like ragi, groundnut, maize, jowar, coconut, arecanut etc. The local fishermen also cultivate commercial fisheries in lakes present in study area.

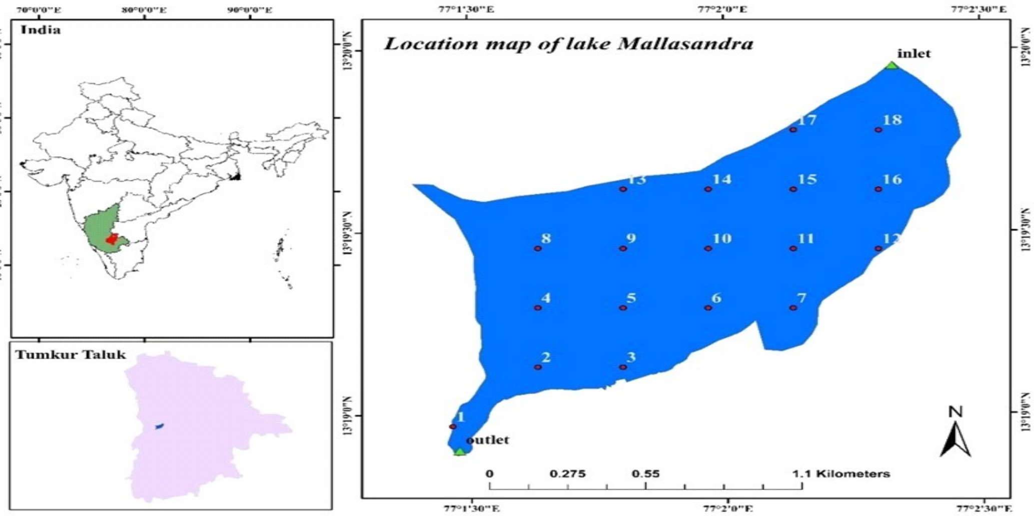

Fig. 1 : Location of study area

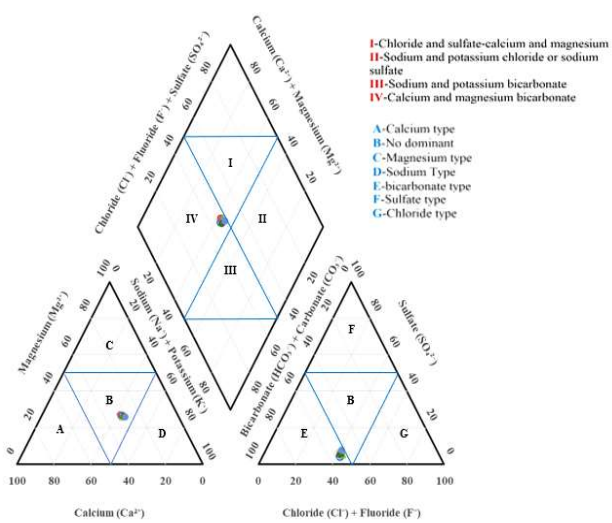

Fig. 2 : Piper diagram of the ionic composition of lake water samples

Sampling Procedure

The water surface area of lake Mallasandra was overlaid with equilateral grids created using fishnet tool in ArcGIS software. A total of 18 sampling points were formed at the centre of each grid within the boundary of the lake and their XY co-ordinates were recorded (Table 1). All the sampling points are equidistant from each other separated by 300 meters which provide uniform spatial coverage of the lake. The water samples were collected by navigating to the sampling points using GPS guided system with the help of local fishermen and motorboat.

The water samples were collected during March dhanush *et al. (2024)* (pre-monsoon) and

TABLE 1

GPS co-ordinates of sampling points

Sampling points	Latitude	Longitude
1	13.31615	77.024379
2	13.31884	77.02717
3	13.31881	77.029938
4	13.32155	77.027192
5	13.32153	77.029961
6	13.3215	77.032729
7	13.32148	77.035497
8	13.32426	77.027215
9	13.32424	77.029983
10	13.32421	77.032752
11	13.32419	77.03552
12	13.32417	77.038288
13	13.32695	77.030006
14	13.32692	77.032774
15	13.3269	77.035543
16	13.32688	77.038311
17	13.32961	77.035565
18	13.32959	77.038334

TABLE 2

Physicochemical parameters and their analytical methods

Parameters	Units	Test Method
pH	pH unit	Electrometric method (Hanna HI 9811-5)
Electrical conductivity	(µS/cm)	Electrometric method (Hanna HI 9811-5)
Dissolved Oxygen	(mg/l)	Electrochemical probe method
Biochemical Oxygen Demand (BOD)	(mg/l)	5-day BOD test
Chemical Oxygen Demand (COD)	(mg/l)	Open reflux method
Total Dissolved Solids (TDS)	(mg/l)	Gravimetric method
Turbidity	(NTU)	Nephlophotometer
Total Suspended Solids (TSS)	(mg/l)	Gravimetric method
Ammoniacal Nitrogen	(mg/l)	Ammonia selective electrode method
Nitrate as NO_3^-	(mg/l)	Ion selective electrode method
Ortho phosphates as PO_4^{3-}	(mg/l)	Stannous Chloride method
Sulphates as SO_4^{2-}	(mg/l)	Spectrophotometric method
Sodium as Na^+	(mg/l)	Flame Emission Photometric method
Potassium as K^+	(mg/l)	Flame Emission Photometric method
Calcium as Ca_2^+	(mg/l)	EDTA Titrimetric method
Magnesium as Mg_2^+	(mg/l)	EDTA Titrimetric method
Total Hardness as $CaCO_3$	(mg/l)	EDTA Titrimetric method
Total Alkalinity as $CaCO_3$	(mg/l)	Indicator method
Chloride as Cl	(mg/l)	Argentometric method
Fluoride as F^-	(mg/l)	Electrochemical Probe method

November (post-monsoon) of 2022 by grab sampling method at a depth of 30cm in 2 litre polyethylene bottles previously soaked in 10 per cent v/v nitric acid for 24 h and rinsed thoroughly with deionized water. All samples were cooled at 4^0C and transported to the laboratory and stored in dark at 4^0C for further analysis. A total of 20 physicochemical parameter were analysed using standard analytical protocol (APHA, 1992). A portable conductivity multi-parameter apparatus was used to measure the pH and EC *in-situ* (Hanna HI 9811-5). The analysed physicochemical parameters and their analytical methods are mentioned in Table 2. In view of quality control, validation of the analytical procedures was carried out by proper calibration of instruments and checking their precision and linearity.

Drinking Water Quality Index

In this study, two different methods of Water quality index (WQI) have been employed by selecting average concentrations of 13 physicochemical parameters measured at each location namely pH, BOD, turbidity, TDS, ammoniacal N, nitrate N, sulphates, calcium, magnesium, Total hardness, Total alkalinity, chloride and fluoride. The standards for drinking water recommended by BIS (Bureau of Indian Standards for Drinking Water, 2012) are used for calculation of WQI.

The Canadian Council of Ministers of the Environment Index (CCME-WQI)

Conceptually, CCME WQI is based on a combination of three factors (Kachroud *et al.,* 2019).

Factor 1 : F1 (*Scope*) - It represents the number of variables, whose objectives are not met

Factor 2 : F2 (*Frequency*) - represents the mean frequency and number of times tested or observed value was out of acceptable limits or standards

Factor 3 : F3 (*Amplitude*) - represents the magnitude of the deviation or values whose objectives are not achieved

$$F1 = \frac{No.\ of\ failed\ variables\ (parameters)}{Total\ No.\ of\ variables} \times 100$$

$$F2 = \frac{No.\ of\ failed\ tests}{Total\ No.\ of\ tests} \times 100$$

$$F3 = \frac{nse}{0.01nse+0.01}$$

The *nse* variable is expressed in 2 steps :

i) Calculation of Excursion $_i$

For the cases in which the test value must not exceed the objective :

$$Excursion_i = \frac{Failed\ Test\ Value}{Objective} - 1$$

For the cases in which the test value must not fall below the objective:

$$Excursion_i = \frac{Objective}{Failed\ Test\ Value} - 1$$

For the cases in which the objective is zero: *Excursion* $_i$ *= failed test value* $_i$

ii) Calculation of *nse* (normalized sum of excursions)

$$nse = \frac{\sum_{i=1}^{n} Excursion}{Total\ No.\ of\ tests} - 1$$

The final value of CCME water quality index is calculated using the following formulation : (Tyagi *et al.,* 2013).

$$CCME\ WQI = 100\ \frac{\sqrt{(F12 + F22 + F32)}}{1.732}$$

Weighted Arithmetic Water Quality Index Method

This method uses the most commonly measured water quality parameters (pH, BOD, COD, DO, P-PO4 3-, N-total, N-NO3-, N-NO2-, N-NH4+, SO4 2- , Cl-, Cr-total, Pb2+, Cd2+, Ni2+, Fe-total, Mn-total, Zn2+, As2+). The method has been widely used by the various scientists (Chauhan and Singh, 2010; Chowdhury *et al.,* 2012) and it is calculated accordingly.

Calculation of unit weight (W_i):

$$W_i = k / Si$$

where,

W_i = unit weight for the n[th] parameter;

Si = standard value for n[th] parameter;

k = proportionality constant.

k = 1/ (“ 1/Si)

Calculation of sub index of quality rating (Q_n)

Q_n = 100 * (Vn - Vi0) / (Si - Vi0)

where,

Q_n = quality rating for the n[th] water quality parameter

Vn = estimated value of the n[th] parameter at a given sampling station

Si = standard permissible value of the n[th] parameter

Vi0 = ideal value of n[th] parameter in pure water

Vi0 = 0 (except pH =7.0 and DO = 14.6 mg/l) (Tripatyand Sahu, 2005)

Calculation of Weighted Arithmetic WQI from the following equation:

$$WQI = “W_i{*}Q_n / “W_i$$

Sodium Adsorption Ratio (SAR) : Also expressed as sodium content or alkali hazard is an important index for determining the suitability of water used in irrigation (Srinivasamoorthy *et al.,* 2014). Excessive sodium in water imparts undesirable effects on the soil properties and decreases soil permeability. High sodium content in water leads to genesis of alkaline soil. The SAR is the measure of the relative proportion of sodium ions to the calcium and magnesium ions in a water sample. SAR is computed using the formula given by U.S. Department of Agriculture Salinity Laboratory in 1954 (Wilcox, 1955).

Sodium Percentage (Na%) : A higher soluble sodium concentration in irrigation water lowers permeability. This term is also referred to as the soluble sodium

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

per cent (SSP) (Wilcox, 1955). It is defined and is also calculated by the following equation.

Residual Sodium Carbonate (RSC) : The quantity of carbonate and bicarbonate in excess of alkaline

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

earth metals is denoted by 'residual sodium carbonate' (RSC) (Sundaray *et al.,* 2009; Ravikumar *et al.,* 2011). When the total carbonate concentration exceeds the sum of calcium and magnesium concentrations, the excess carbonate (residual) concentration is too high, the carbonate ions combine with the calcium and magnesium ions to form a scale, a solid material, which then settles out of the water causing relative abundance of sodium that has detrimental consequences on the plants. It is calculated by the following formula (Wilcox, 1955).

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Magnesium Hazard (MH) : Higher concentration of Mg in irrigation water badly affects the soil quality, making the soil alkaline, resulting in low crop yield (Sundaray *et al.,* 2009). Paliwal (1972) introduced an index 'magnesium hazard' for determining the adverse effects of magnesium in irrigation water using the following formula (Ravikumar *et al.,* 2011).

$$MH = \frac{Mg^{2+} + K^{+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Kelly's Index (KI) is used to determine irrigation water quality. In Kelly's index, sodium measured against calcium and magnesium (Kelly, 1940).

Permeability Index (PI) : The permeability of soil is affected by long-term exposure of irrigation water containing high quantity of sodium, calcium, magnesium and bicarbonate ions (Ravikumar *et al.,* 2011). Doneen (1964) introduced permeability index (PI) for assessing the suitability of irrigation water and is calculated by the following equation:

Potential Salinity (PS) : The salt constantly dissolves in irrigation water increasing salinity. The salinity of the river progressively increases year after year and is a serious issue for downstream water consumers (Basha *et al.,* 2022). The term 'potential salinity' refers to the quantity of salt that builds up in the soil.

$$PS = Cl^{-} + \frac{1}{2}SO_4^{2-}$$

Industrial Water Quality Index

The availability of suitable water for small and large-scale industries is essential for functioning of industrial sector in the era of growing economy. The biggest problems analysed for industrial application of water are Corrosion and encrustation (scaling). Many homes and industries suffer from the undesirable effects of corrosion and encrustation. Therefore, assessment of industrial water quality is essential. The tendency of water to form corrosion and scaling is determined for both pre-monsoon and post-monsoon seasons by a number of indices mentioned below. All the ions are measured in mg/l.

Chloride Sulphate Mass Ratio, $CSMR = \frac{Cl^{-}}{SO4^{2-}}$

Larson-Skold Index, $LSI = \frac{Cl^{-} + SO4^{2-}}{HCO3^{-}}$

Langelier Index, LI = pH – pHs

Where pHs = (9.3 + A + B) – (C + D)

$A = (\log_{10}(TDS) - 1) / 10$

$B = -13.2 \times \log_{10}(°C+273) + 34.55$

$C = \log_{10}(Ca^{2+} \text{ as } CaCO_3) - 0.4$

$D = \log_{10}(\text{alkalinity as } CaCO_3)$

Aggressive Index, $AI = pH + \log_{10}(\text{alkalinity} \times \text{Hardness})$

Ryznar stability Index, RSI = 2pHs – pH

Puckorius scaling Index, PSI = 2pHs m – pHeq

Where pHeq = 1.465 x $\log_{10}$(alkalinity) + 4.54 (pHs is the pH at saturation state of $CaCO_3$; pHeq is the pH at equilibrium)

Multivariate Statistical Analysis

All the 20 water quality parameters measured at 18 sampling locations during two seasons were subjected to multivariate statistical approaches namely Hierarchical Cluster Analysis and Principal Component Analysis using IBM SPSS Statistics 26 software.

Cluster analysis (CA) : CA is a statistical technique whose primary purpose is classification of similar objects into groups based on the characteristics they possess where the number of groups as well as their forms are unknown (Shrestha and Kazama, 2007). In this study, hierarchical agglomerative CA was performed on the normalized data set by means of the Ward's method, using squared Euclidean distances as a measure of similarity and is typically illustrated by a dendrogram (tree diagram). The dendrogram presents a picture of the groups and their proximity to one another, with a dramatic reduction in the dimensionality of the original data for better understanding of governing factors (Alberto *et al.,* 2001).

Principal Components Analysis (PCA) : PCA, a pattern recognition technique, interprets variance within a set of intercorrelated variables by transforming them into a smaller set of independent variables known as principal components. These components, linear combinations of the original variables, provide meaningful information, reduce data dimensionality and summarize statistical correlations among water constituents with minimal loss of original information (Shrestha and Kazama, 2007 and Helena *et al*., 2000). To ensure consistency, all water quality parameters were standardized (z-scale) before PCA analysis, mitigating the influence of different variables and their respective units of measurement.

Water Quality Index Map Using Spatial Interpolation Method

The major advantage of the GIS observations over traditional water quality monitoring measurements is that they provide both spatial and temporal information of surface water characteristics (O'sullivan and Unwin, 2014). Previous studies have proven that Inverse Distance Weighted technique (IDW) has irreplaceable advantages for data estimation in rivers because of its high accuracy, and it is widely used by some authors in pollution modelling (Hough, 2004).

IDW technique is one of the deterministic spatial interpolation methods in geostatistical information. This method determines cell values using a linearly-weighted combination of a set of sample points (Watson, 1985). The IDW formula is used to estimate the unknown of the monitoring station value $Z\hat{}(S_0)$ in location S_0, where n is the number of monitoring stations, given the observed Z(Si) values at the sampled locations Si as shown in Equation

$$Z\hat{}(S_0) = \sum_{i=1}^{n} Wi * Z(Si)$$

Wi is the weight defined as:

$$Wi = \frac{\frac{1}{d_i^k}}{\sum_{i=1}^{n} \frac{1}{d_i^k}} = 1, 2, 3, \ldots\ldots\ldots n$$

Where, $\sum_{i=1}^{n} Wi = 1$

where, d_i is the horizontal distance between the interpolation points and the points observed and k is the power of the distance.

All interpolation calculations were performed with ArcGIS 10.8 software. The WQI values derived from both CCME WQI and Weighted Arithmetic WQI method from 18 sampling points was imported into ArcGIS10.8 software and joined to XY coordinates of each sampling point. IDW method in spatial analyst tool was applied to create WQI map of the lake.

RESULTS AND DISCUSSION

Physicochemical Properties of Water Samples

The water samples collected during pre-monsoon and post-monsoon seasons from lake Mallasandra were analysed for 20 physicochemical properties and the descriptive statistical summary of water quality parameters is shown in the Table 3.

TABLE 3

Descriptive statistics of lake Mallasandra during pre-monsoon and post-monsoon season

Seasons Parameters	Pre-monsoon			Post-monsoon		
	Mean ± sd	Min.	Max.	Mean ± sd	Min.	Max.
pH	7.56 ± 0.32	6.94	7.96	7.81 ± 0.14	7.40	7.98
EC (µs/cm)	934.17 ±29.77	886.20	968.60	813.47 ±58.36	731.33	885.43
DO (mg/L)	4.00 ± 0.51	3.30	4.80	5.39 ± 0.76	4.10	6.40
BOD (mg/L)	10.53 ± 2.66	6.80	14.00	5.65 ± 1.41	3.24	8.18
COD (mg/L)	106.32 ±25.78	66.60	138.04	58.62 ±13.47	36.64	80.56
Turbidity (NTU)	24.19 ± 3.12	19.50	30.50	13.39 ± 2.89	9.00	17.80
TDS (mg/L)	635.24 ±20.24	602.62	658.65	553.16 ±39.69	497.30	602.09
TSS (mg/L)	31.18 ± 4.41	24.00	39.65	18.02 ± 4.13	11.70	24.00
Ammoniacal N NH_4^+ (mg/L)	1.19 ± 0.42	0.65	1.88	0.48 ± 0.17	0.11	0.76
Nitrate NO_3^- (mg/L)	27.30 ± 5.16	20.39	39.42	18.40 ± 3.85	13.79	25.79
Ortho phosphatesPO_4^{3} ” (mg/L)	0.48 ± 0.15	0.21	0.77	0.33 ± 0.12	0.03	0.56
Sulphates SO_4^{2-} (mg/L)	34.55 ± 9.25	23.50	48.88	11.96 ±2.262	7.07	15.86
Sodium Na^+ (mg/L)	84.35 ± 3.39	75.81	88.52	69.36 ± 8.62	60.34	82.15
Potassium K^+ (mg/L)	32.27 ± 1.28	30.11	34.81	10.53 ± 2.45	8.16	14.79
Calcium Ca^{2+} (mg/L)	59.17 ± 1.40	55.84	61.44	46.15 ± 2.10	43.84	50.24
Magnesium Mg^{2+} (mg/L)	30.13 ± 0.85	28.10	31.51	27.05 ± 2.10	24.80	30.73
Total Hardness as $CaCO_3$ (mg/L)	271.87 ± 7.02	255.20	283.20	226.67 ±13.58	212.00	252.00
Total Alkalinity as $CaCO_3$ (mg/L)	282.89 ± 7.10	268.00	292.00	232.00 ±10.53	216.00	248.00
Chloride Cl^- (mg/L)	124.56 ± 4.69	116.00	136.00	111.11 ± 8.96	99.00	125.00
Fluoride F^- (mg/L)	0.56 ± 0.04	0.50	0.65	0.47 ± 0.02	0.44	0.52

The water quality analysis of pre-monsoon period revealed that the pH varied from 6.94 to 7.96 with an average value of 7.56. The minimum and maximum pH was found at sampling point 9 and 15, respectively. The pH value during post-monsoon season ranged from 7.4 to 7.98 with an average value of 7.81indicating that the lake had neutral to slightly alkaline pH in both the seasons. The paired t-test revealed that there is a significant difference in pH values t (17) = - 2.698, p = 0.015 (2 tailed) between seasons. The pH was within the acceptable limit of BIS standards (6.5 - 8.5). The pH is the numerical expression of hydrogen ion concentration that determines the acidic, alkaline or corrosive nature of water which is in turn critical for utilization of almost all essential plant nutrients (Suchithra *et al.,* 2011). EC varied from 886.2 to 968.6 µs/cm with a mean value of 934.17 µs/cm in pre-monsoon period and 731 to 885 µs/cm with an average value of 813.47 µs/cm during post-monsoon season. There was no statistically significant difference between the seasons. The EC values in both seasons were of medium water class for irrigation purpose which may be attributed to considerable concentrations of dissolved ions from sewage and agricultural runoff. The DO ranged from 3.3 to 4.8 mg/l with a mean value of 4 mg/l in pre-monsoon and 4.1 to 6.4 mg/l with a mean of 5.39 mg/l in post-monsoon season. There was no significant difference between the seasons in DO values. The lower value of DO in summer may be due to increased oxygen consumption by living organisms compared to that in post-monsoon season. The BOD values ranged from 6.8 to 14 mg/l with a mean value of 10.5 mg/l in pre-monsoon and it ranged from 3.24 to 8.18 mg/l with a mean of 5.65 mg/l during post-monsoon season and there was no statistically significant difference between the seasons. The BOD values exceeded the BIS standards (5mg/l) in both the seasons which may be due to increased oxygen demand to break down the organic matter released from sewage water. This may be problematic for aquatic life. The COD values varied from 66 to 138 mg/l with a mean value of 106.32 mg/l in pre-monsoon season and it varied from 36 to 80 mg/l with a mean value of 58.62 mg/l in post-monsoon season. There was no significant difference between the seasons. The COD values exceeded the WHO standards (10mg/l) which may be due to organic pollution from domestic sewage from Tumakuru city. Turbidity indicates clarity of the water and is caused by organic and mineral suspended matter and colour producing substances. The turbidity ranged from 19.5 to 30.5 with an average of 24 NTU and 9 to 17.8 NTU with an average value of 13.39 NTU in pre-monsoon and post-monsoon seasons, respectively. It exceeded the WHO standards (5 NTU) considerably. TDS comprise of organic matter, phytoplankton, silt, clay and dissolved salts such as Ca, Na, Mg and Cl which are dissolved in water. The TDS varied from 602 to 658 mg/l with a mean value of 635.2 mg/l during pre-monsoon season. It varied from 497 to 602 mg/l with a mean value of 553 mg/l in post-monsoon season. It exceeded the BIS standards (500 mg/l) in both the seasons. There was no statistically significant difference between the seasons. The TSS varied from 24 to 39 mg/l with an average value of 31 mg/l and 11.7 to 24 mg/l with a mean value of 18 mg/l in pre-monsoon and post-monsoon season, respectively.

Cations and Anions

The mean value of nitrates ranged from 27.3 mg/l in pre-monsoon to 18.4 mg/l in post-monsoon season. This may be linked to agricultural runoff or livestock waste in the riparian areas of the lake. The nitrates concentration was within the BIS standards (45 mg/l) and did not pose any risk to the water quality. The orthophosphates and sulphates had a mean concentration of 0.48 and 34.5 mg/l in pre-monsoon season whereas in post-monsoon season it was 0.33 and 11.96 mg/l in post-monsoon season, respectively. The concentration of sulphates was low and within the BIS standards (200 mg/l). The mean value of chloride was 124 and varied from 116 to 136 mg/l in pre-monsoon season and it varied from 99 to 125 mg/l with a mean value of 111 mg/l in post-monsoon season. The Cl concentration was well within the standards set by BIS (250 mg/l). The mean value of Fluoride was 0.56 mg/l in pre-monsoon season and it was 0.47 mg/l in post-monsoon season. The fluoride concentration was well within the standards set by BIS (1 mg/l).

The ammoniacal nitrogen had a mean concentration of 1.19 mg/l and 0.48 mg/l in pre-monsoon and post-monsoon seasons, respectively. The NH_4^+exceeded the BIS standards (0.5 mg/l) in pre-monsoon period which may be attributed to influx of nutrient rich domestic sewage, agricultural chemicals and fertilizers. The mean value of Na^+ and K^+ was 84 and 32 mg/l, respectively during pre-monsoon season and Na^+ and K^+ was 69 and 10 mg/l in post-monsoon season. The K^+ ion concentration exceeded the WHO standard (12 mg/l) during pre-monsoon season and the Na^+ was within the permissible limits of WHO standard (200 mg/l). The Ca ion concentration varied from 55.6 to 61 mg/l with an average value of 59.17 mg/l in pre-monsoon period and it varied from 43 to 50 mg/l with an average value of 46 mg/l in post-monsoon period. The Ca ion concentration did not exceed the acceptable limits of BIS standard (75 mg/l). The Mg ion concentration had a mean value of 30 and 27.5 mg/l in pre-monsoon and post-monsoon season, respectively and it was close to the permissible limits of BIS standard (30 mg/l). Total alkalinity varied from 268 to 292 mg/l with a mean of 282 mg/l in pre-monsoon period and it varied from 216 to 248 with mean value of 232 mg/l in post-monsoon season. The Total alkalinity value considerably exceeded the BIS standards (200 mg/l) in both the seasons. As the pH of water was slightly alkaline and below 8.3, the Total alkalinity was due to bicarbonate ion (HCO_3^-). The Total hardness had a mean of 271.87 and 226.67 mg/l in pre-monsoon and post-monsoon season, respectively. Total hardness exceeded the BSI standards (200 mg/l) in both the seasons. According to Sawyer and McCarthy, water having total hardness between 150 and 300 mg/l are considered as hard water and hence the water sample in this study is hard water.

The average ion concentrations of cations are in the order $Na^{+} > Ca^{2+} > K^{+} > Mg^{2+} > NH_4^{+}$ indicating that the Na was the dominant cation. The average ion concentrations of anions are in the order $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > F^{-} > PO_4^{3-}$ indicating that the HCO_3^{-} is the dominant anion. The quality of the water comparatively improved as the distance increased from the inlet point of the lake. The BOD, COD, TDS, TSS and all the ions were found to be in higher concentrations towards the North-east direction of the lake indicating higher pollution in this part of the lake. This is attributed to influx of polluted water from Bheemasandra lake which is upstream. The Bheemasandra lake receives water from nearby sewage treatment plant and some of the sewage water directly from the nearby Tumakuru city.

To understand the hydrogeochemical characteristics of the study area and water, the analytical data was plotted on Piper diagram (Piper 1944) (Fig. 2). Piper trilinear diagram has two triangles, one represents cations and the other showing anions and a diamond-shaped area on top illustrates combined position of cations and anions. The diamond-shaped area of Piper diagram is divided into four parts, each part representing and explaining a particular type of variation or domination of cations and anions.

TABLE 4

CCME water quality index of lake Mallasandra

Sample Id	CCME-WQI	Water quality class
1	64.70	Fair
2	61.75	Marginal
3	58.14	Marginal
4	63.28	Marginal
5	63.20	Marginal
6	58.86	Marginal
7	58.72	Marginal
8	57.31	Marginal
9	54.07	Marginal
10	59.13	Marginal
11	54.23	Marginal
12	58.09	Marginal
13	55.42	Marginal
14	53.82	Marginal
15	52.30	Marginal
16	52.32	Marginal
17	52.14	Marginal
18	52.24	Marginal
Average	57.21	Marginal

TABLE 5

Classification of water quality according to Canadian Council of Ministers of the Environment (CCME) method

WQI	Quality Class	Description
0–44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels
45–64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
65–79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
80–94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
95–100	Excellent	Water quality is protected with a virtual absence of threat or impairment, conditions very close to natural or pristine levels.

The four parts are (1) Ca^{2+}–Mg^{2+}–Cl^{-}–SO_4^{2-}, (2) Na^{+}–K^{+}–Cl^{-}– SO_4^{2-}, (3) Na^{+}–K^{+}–HCO_3^{-} and (4) Ca^{2+}–Mg^{2+}–HCO_3^{-}. In cation plot, the samples fell in the zone B (no dominant cation) and in anion plot they fell in zone E (bicarbonate type). All the samples fell in the category (IV) Ca^{2+}–Mg^{2+}–HCO_3^{-} representing a dominance of calcium, magnesium and carbonate ions in the water.

Determination of Water Quality Index

Drinking Water Quality Evaluation

The results of CCME-WQI calculated by taking mean values of 13 parameters from pre-monsoon and post-monsoon season is presented below (Table 4) and the classification of water quality class is shown in Table 5. The water quality index was calculated for each sampling point and the results revealed that all the sampling points ranged between WQI of 45 and 64 belonging to the 'marginal' class except sample 1 which had almost WQI of 65 belonging to 'fair' class. The average CCME-WQI for lake Mallasandra was found to be 57.21. The marginal class denotes that the water quality is frequently threatened or impaired and the conditions often depart from natural or desirable levels. A marginal category of water quality index (WQI) may be due to excessive flow of agricultural and domestic waste and various anthropogenic activities like the inflow of direct sewerage from residential establishments, lack of proper sanitation system, direct disposal of untreated effluents from small scale industries Thus, high priority should be given to water quality monitoring and advanced technologies should be adopted to make water fit for drinking.

The Arithmetic mean WQI was calculated by considering mean values of 13 parameters from each season *i.e.,* pre-monsoon and post-monsoon season (Table 6) and the classification scheme is shown in Table 7. The AM-WQI during pre-monsoon period for all the sampling points was >100 with mean WQI

TABLE 6

Arithmetic weighted water quality index of lake Mallasandra

Season Sample Id	Pre-monsoon		Post-monsoon	
	AW-WQI	Water quality class	AW-WQI	Water quality class
1	126	Unsuitable for drinking	66	Poor
2	130	Unsuitable for drinking	79	Very Poor
3	160	Unsuitable for drinking	44	Good
4	143	Unsuitable for drinking	70	Poor
5	153	Unsuitable for drinking	67	Poor
6	129	Unsuitable for drinking	73	Poor
7	125	Unsuitable for drinking	66	Poor
8	164	Unsuitable for drinking	75	Poor
9	198	Unsuitable for drinking	108	Unsuitable for drinking
10	162	Unsuitable for drinking	111	Unsuitable for drinking
11	242	Unsuitable for drinking	99	Very Poor
12	227	Unsuitable for drinking	107	Unsuitable for drinking
13	224	Unsuitable for drinking	95	Unsuitable for drinking
14	221	Unsuitable for drinking	105	Unsuitable for drinking
15	242	Unsuitable for drinking	120	Unsuitable for drinking
16	267	Unsuitable for drinking	106	Unsuitable for drinking
17	262	Unsuitable for drinking	127	Unsuitable for drinking
18	240	Unsuitable for drinking	118	Unsuitable for drinking
Average	190	Unsuitable for drinking	91	Very Poor

TABLE 7

Water quality rating as per weight arithmetic water quality index method (Tirkey *et al.,* 2015)

Water quality index	Status
0-25	Excellent
26-50	good
51-75	Poor
76-100	Very Poor
Above 100	Unfit/Unsuitable for drinking

of 190 belonging to class 'unsuitable for drinking'. It ranged from 126 at point 1 to 267 at point 17. The AM-WQI during post-monsoon period varied from 44 at sampling point 3 to 127 at point 17 with mean WQI of 91 belonging to class 'very poor'. The sampling points 3 showed good quality, 1,4-8 showed poor quality, 2 and 11 showed very poor quality and the rest of them belonged to class unsuitable for drinking. The variation in WQI between the seasons is attributed to dilution of contaminants after monsoon rains. Hence, the WQI of lake Mallasandra denoted that the water was unsuitable for drinking during pre-monsoon period and was very poor during post-monsoon period.

Irrigation Water Quality Evaluation

The water samples collected during pre-monsoon and post-monsoon seasons were assessed to determine the suitability for irrigation purpose to know the effect of salts and minerals on plants and soil, which may affect plant growth by chemically lowering water intake via osmotic pressure changes or metabolic responses such as those caused by hazardous chemicals. The water quality was evaluated using 8 different indices *viz.*, EC, SAR, RSC, Na%, MH, KI, PI and PS (Table 8) and the classification scheme is shown in Table 9.

The EC of water greatly influences the osmotic pressure of soil solution and uptake of nutrients by plants. The EC of water collected from lake varied from 886.2 to 968.6 with an average value of 934.17 (µs/cm) in pre-monsoon season and it ranged from 731.33 to 885.43 with a mean of 813.47 (µs/cm) in post-monsoon season. According to Wilcox (1955), C1 surface water (low salinity risk) can be used to irrigate most crops and soils. In the case of moderate leaching, secondary water C2 (moderate salinity risk) can be used for irrigation. Water with relatively high salinity (class C3) may be suitable for salt-tolerant plants and water with high salinity (C4) cannot be used for irrigation. All the samples in pre-monsoon period were in C3 class meaning high salinity and usage was marginally doubtful. In post-monsoon season, only 3 samples were in C2 class and 15 samples were in C3 class. Hence, according to salinity hazard (EC), most of the samples were not appropriate for irrigation.

SAR denotes the relative proportion of Na^+ to Ca^{2+} and Mg^{2+} ions in water samples, so that the high content of Ca^{2+} and Mg^{2+} in irrigation water reduces the permeability. This ionic replacement usually results to deflocculation and loss in soil permeability. The mean value of SAR during pre-monsoon and post-monsoon period was 2.23 and 2, respectively which is classified as 'low'. All the samples according to SAR is appropriate for irrigation purpose. Sodium percentage is used to evaluate the soluble sodium content in water for irrigation. An excess of sodium with carbonate ions will help turn the soil into alkaline soil; in contrast, sodium mixed with chloride ions will accelerate the formation of saline soil, which ultimately worsens the infiltration capacity of the soil and reduces plant growth (Varol *et al.,* 2021). The Na% in pre-monsoon ranged from 43.13 to 46.83 with a mean value of 45.27 and all the samples were classified as 'permissible'. On the other hand, it varied from 39.42 to 43.99 with a mean of 41.9 in post-monsoon. 11 per cent of samples were classified as 'good' and 88.8 per cent as 'permissible'. Most of the samples according to Na% is suitable for irrigation purpose with some precautions.

The RSC is a valuable tool for examining the applicability of irrigation water. The RSC of 18 samples under investigation had a mean value of -0.8 and -0.73 in pre-monsoon and post-monsoon respectively. The negative values of RSC indicate that the calcium and magnesium have not been precipitated out (Sundaray *et al.,* 2009). All the samples are classified as 'good' in both the seasons denoting that

TABLE 8

Irrigation water quality indices

Season S. Id	Pre-monsoon								Post-monsoon							
	EC	SAR	Na%	RSC	MH	KI	PI	PS	EC	SAR	Na%	RSC	MH	KI	PI	PS
1	896.3	2.30	46.83	-0.44	45.35	0.72	69.32	3.77	731.3	1.83	40.43	-0.70	48.17	0.63	66.89	3.04
2	901.4	2.16	44.66	-0.75	45.56	0.66	66.87	3.65	739.7	1.84	40.26	-0.78	48.20	0.63	66.30	3.04
3	906.7	2.00	43.13	-0.76	45.63	0.61	65.77	3.88	758.4	1.81	39.64	-0.72	48.24	0.61	65.95	2.89
4	895.4	2.07	44.03	-0.95	45.56	0.63	66.00	3.69	745.9	1.85	40.16	-0.79	48.24	0.62	66.01	2.93
5	901.3	2.20	45.54	-0.60	45.49	0.68	67.88	3.74	753.4	1.80	40.15	-0.50	48.17	0.62	67.46	3.02
6	886.2	2.25	45.67	-0.96	45.63	0.68	66.84	3.64	774.1	1.79	39.42	-0.72	48.24	0.60	65.83	3.13
7	929.7	2.25	45.85	-0.96	45.63	0.68	66.95	3.88	787.2	1.82	40.32	-0.63	48.17	0.62	67.07	3.13
8	933.6	2.28	45.61	-0.84	45.69	0.69	66.95	3.58	773.6	1.84	40.28	-0.66	48.24	0.62	66.54	3.06
9	918.7	2.30	45.75	-0.83	45.63	0.70	67.20	3.78	786.3	1.93	41.29	-0.67	48.27	0.65	66.87	3.18
10	958.5	2.28	45.87	-0.82	45.56	0.70	67.43	4.16	812.8	1.83	40.32	-0.53	48.24	0.62	67.02	3.14
11	944.4	2.27	45.02	-0.79	45.76	0.68	66.58	3.90	831.1	2.20	44.15	-0.40	50.24	0.74	69.56	3.21
12	968.6	2.25	45.91	-0.62	45.56	0.69	67.92	4.03	869.0	2.20	44.71	-0.67	50.23	0.73	68.80	3.38
13	960.4	2.34	46.54	-0.76	45.63	0.71	67.82	3.90	877.5	2.15	43.92	-0.62	50.23	0.71	68.33	3.53
14	961.2	2.22	45.01	-0.78	45.69	0.67	66.74	3.82	873.3	2.25	44.50	-0.72	50.22	0.73	68.03	3.58
15	964.2	2.32	46.17	-0.71	45.69	0.70	67.58	3.97	883.6	2.25	43.87	-1.04	50.21	0.71	66.16	3.61
16	962.5	2.19	44.59	-0.86	45.76	0.66	66.17	4.11	877.3	2.15	42.98	-1.09	50.22	0.68	65.61	3.52
17	962.8	2.23	44.59	-0.87	45.82	0.66	66.01	4.13	882.1	2.23	43.99	-0.89	50.22	0.71	66.78	3.61
18	963.2	2.17	44.13	-1.00	45.82	0.64	65.43	4.05	885.4	2.26	43.88	-0.96	50.22	0.72	66.52	3.65
Min.	886.20	2.00	43.13	-0.44	45.35	0.61	65.43	3.58	731.33	1.79	39.42	-0.4	48.17	0.61	65.95	2.89
Max.	968.60	2.34	46.83	-1.00	45.82	0.72	69.32	4.16	885.43	2.26	43.99	-1.09	50.24	0.74	69.56	3.65
Average	934.17	2.23	45.27	-0.80	45.64	0.68	66.97	3.87	813.47	2.00	41.90	-0.73	49.11	0.66	66.98	3.26

EC – Electrical conductivity, SAR - Sodium Adsorption Ratio, Na% - Sodium percentage, RSC - Residual sodium carbonate, MH - Magnesium hazard, KI - Kelly's index, PI - Permeability Index, PS - Potential Salinity

TABLE 9

Irrigation water quality indices classification scheme

Index	Range	Remark on quality	No. of samples (percentage)		Reference
			Pre-monsoon	Post-monsoon	
Salinity hazard EC (µs/cm)	100 - 250	Excellent	-	-	Wilcox (1955)
	250 - 750	Good	-	3 (16.6)	
	750 - 2250	Doubtful	18 (100)	15 (83.3)	
	> 2250	Unsuitable			
Sodium Adsorption Ratio (SAR)	0 -10	Low	18 (100)	18 (100)	Richards (1954)
	10 - 18	Medium	-	-	
	18 - 26	High	-	-	
	>26	Very high	-	-	
Sodium percentage (Na%)	<20	Excellent	-	-	Wilcox (1955)
	20 - 40	Good	-	2 (11.1)	
	40 - 60	Permissible	18 (100)	16 (88.8)	
	60 - 80	Doubtful	-	-	
	>80	Unsuitable	-	-	
Residual sodium carbonate (RSC)	< 1.25	Good	18 (100)	18 (100)	Eaton (1950)
	1.25 - 2.50	Doubtful	-	-	
	>2.50	Unsuitable	-	-	
Magnesium hazard (MH)	<50	Suitable	18 (100)	10 (55.5)	Paliwal (1972)
	<51	Unsuitable		8 (44.4)	
Kelly's index (KI)	<1	Good	18 (100)	18 (100)	Kelly (1963)
	1–2	Doubtful	-	-	
	>2	Unsuitable	-	-	
Permeability Index (PI)	>75%	Suitable for irrigation	-	-	Doneen (1964)
	25 - 75%	Moderately suitable	18 (100)	18 (100)	
	< 25%	Unsuitable	-	-	
Potential Salinity (PS)	<5	Excellent to Good	18 (100)	18 (100)	Doneen (1964)
	5 - 10	Good to injurious	-	-	
	>10	Injurious to unsatisfactory	-	-	

water samples are suitable for irrigation according to RSC values.

The magnesium hazard index was used in this research to assess irrigation water quality. The mean value of MH in this study was 45.64 and 41.9 in pre-monsoon and post-monsoon season, respectively. All the samples in pre-monsoon period were classified as 'suitable' and 55.5 and 44.5 per cent samples were classified as 'suitable' and 'unsuitable', respectively in post-monsoon season. Accordingly, the water samples during pre-monsoon period were appropriate for irrigation compared to the other season. The Kelley's index (KI) was applied in this research to assess the irrigation water quality. The levels of Na^{+}, Ca^{2+} and Mg^{2+} in water are used to calculate the value of KI. The mean values of KI were 0.68 and 0.66 in pre-monsoon and post-monsoon season, respectively.

All the samples had KI<1 and were classified as 'good' in both the seasons. Permeability index (PI) was introduced by Doneen to express the effects of Na^+, Ca^{2+}, Mg^{2+}, Cl and HCO_3 present in irrigation water on the permeability of the soil. The mean values of PI were 66.97 and 66.98 in pre-monsoon and post-monsoon season, respectively. All the samples from both the seasons had PI between 25 - 75 per cent and were categorised as 'moderately suitable' for irrigation. Doneen (1964) opined that with consistent irrigation, salt with low solubility usually precipitates and accumulates in the soil leading to what is termed as potential salinity. The mean PS of the samples were 3.87 and 3.26 in pre-monsoon and post-monsoon season, respectively. All the samples from both the seasons had PS <5 and were categorised as 'excellent to good' for irrigation purpose.

Industrial Water Quality Evaluation

The suitability of water collected from lake Mallasandra is assessed for industrial application using indices *viz.*, Chloride Sulphate Mass Ratio (CSMR), Larson-Skold Index (LSI), Langelier Index (LI), Aggressive Index (AI), Ryznar Stability Index (RSI) and Puckorious Scaling Index (PSI). The results and classification scheme are depicted in Table 10 and 11. The CSMR is used to evaluate the galvanic corrosivity of water. The mean value of CSMR in pre-

TABLE 10

Industrial water quality indices

Season sample Id	Pre-monsoon						Post-monsoon					
	CSMR	LSI	LI	AI	RSI	PSI	CSMR	LSI	LI	AI	RSI	PSI
1	4.66	0.53	0.25	12.28	6.92	6.21	14.85	0.52	0.60	12.64	6.79	6.81
2	4.64	0.52	0.03	12.06	7.13	6.19	10.24	0.53	0.55	12.60	6.82	6.79
3	4.89	0.54	0.80	12.84	6.34	6.16	10.77	0.48	0.46	12.50	6.90	6.73
4	4.04	0.56	0.17	12.20	7.01	6.26	12.67	0.50	0.55	12.59	6.81	6.75
5	5.28	0.52	-0.12	11.91	7.28	6.18	9.45	0.50	0.58	12.62	6.78	6.73
6	4.93	0.53	0.33	12.36	6.84	6.22	6.62	0.54	0.59	12.64	6.76	6.73
7	4.95	0.57	0.71	12.75	6.45	6.23	8.13	0.54	0.14	12.19	7.24	6.79
8	3.91	0.51	0.35	12.38	6.79	6.15	8.82	0.51	0.44	12.49	6.91	6.70
9	3.20	0.56	-0.21	11.82	7.37	6.18	8.40	0.52	0.40	12.45	6.94	6.66
10	4.38	0.61	0.28	12.32	6.89	6.22	7.26	0.51	0.58	12.63	6.76	6.65
11	4.54	0.54	0.80	12.84	6.32	6.10	8.13	0.50	0.51	12.58	6.83	6.64
12	2.56	0.60	0.39	12.43	6.76	6.16	8.95	0.55	0.41	12.48	6.95	6.70
13	2.95	0.58	0.75	12.79	6.40	6.16	10.33	0.55	0.58	12.65	6.75	6.64
14	3.07	0.56	0.41	12.45	6.73	6.13	8.88	0.56	0.48	12.55	6.83	6.58
15	3.14	0.57	0.83	12.87	6.30	6.11	11.05	0.55	0.50	12.57	6.78	6.53
16	2.66	0.61	0.69	12.73	6.44	6.12	9.52	0.56	0.10	12.17	7.21	6.59
17	2.71	0.60	0.72	12.76	6.40	6.09	8.85	0.55	0.52	12.59	6.76	6.52
18	2.65	0.61	0.16	12.20	6.97	6.13	10.11	0.56	0.60	12.67	6.69	6.54
Min.	2.56	0.51	-0.12	11.82	6.30	6.09	6.62	0.48	0.10	12.17	6.69	6.52
Max.	5.28	0.61	0.83	12.87	7.37	6.26	14.85	0.56	0.60	12.67	7.24	6.81
Average	3.84	0.56	0.41	12.44	6.74	6.17	9.61	0.53	0.48	12.53	6.86	6.67

Chloride Sulphate Mass Ratio (CSMR), Larson-Skold Index (LSI), Langelier Index (LI), Aggressive Index (AI), Ryznar Stability Index (RSI), Puckorious Scaling Index (PSI)

TABLE 11

Industrial water quality indices classification scheme (Egbueri *et al.,* 2020)

Index	Range	Remark on quality	No. of samples (percentage)	
			Pre-monsoon	Post-monsoon
Chloride Sulphate Mass Ratio	< 0.5	Water has no galvanic corrosion potential	-	-
(CSMR)	> 0.5	Water with galvanic corrosion potential	18 (100)	18 (100)
Larson-Skold Index (LSI)	< 0.8	Water has scaling tendency	18 (100)	18 (100)
	0.8 - 1.2	Higher corrosion rates can be obtained	-	-
	> 1.2	High rates of localized corrosion can be expected	-	-
Langelier Index (LI)	< 0	Water is not saturated and has corroding tendency	2 (11.1)	-
	= 0	Water is saturated and has no scaling tendency	-	-
	> 0	Water is supersaturated and has scaling tendency	16 (88.8)	18 (100)
Aggressive Index (AI)	< 10	Water is severely corrosive (highly aggressive)	-	-
	10 - 12	Water is moderately corrosive	2 (11.1)	-
	> 12	Water has scaling tendency and has non-aggressive tendency	16 (88.8)	18 (100)
Ryznar Stability Index	< 5.5	Water has rigorous scaling tendency	-	-
(RSI)	5.5 – 6.2	Water has scaling tendency	-	-
	6.2 – 6.8	Water is balanced, no scaling or corrosiveness	10 (55.5)	8 (44.4)
	6.8 – 8.5	Water has corrosive tendency	8 (44.4)	10 (55.5)
	> 8.5	Water has rigorous corrosive tendency	-	-
Puckorious Scaling Index	< 6	Water has scaling tendency	-	-
(PSI)	6 -7	Water has little scaling and corrosive tendencies	18 (100)	18 (100)
	> 7	Water has significant corrosive tendency	-	-

monsoon period is 3.84 and 9.61 in post-monsoon period. All the water samples are having CSMR > 0.5 indicating that the water has galvanic corrosion potential. LSI index is based on the hydro chemical parameters such as chlorides, sulphates, carbonate alkalinity and bicarbonate alkalinity. The LSI ranged from 0.51 to 0.61 and 0.48 to 0.56 with an average value of 0.56 and 0.53 in pre-monsoon and post-monsoon, respectively. All the 18 samples in this study had < 0.8 LSI and these samples have scaling tendency according to LSI index. Langelier index is developed to evaluate the effect of calcium carbonate in the water distribution systems. This is the major reason for corrosiveness of the water. The amount of free CO_2 in excess amount and its chemical behaviour with Ca and Mg are the most important causes for the corrosive nature of the water. The LI ranged from -0.12 to 0.83 and 0.1 to 0.6 with an average value of 0.41 and 0.48 in pre-monsoon and post-monsoon, respectively. Two samples in pre-monsoon season had LI < 0 indicating that the water is not saturated and has corroding tendency and the rest 16 samples along with all the samples of post-monsoon season had LI > 0 indicating that the water is supersaturated and has scaling tendency. Aggressive Index is a general indicator of water corrosiveness which is used as an alternative method for LI but is less accurate than LI. It depends on the pH, Total alkalinity and calcium hardness. The AI in this study had a mean value of 12.44 and 12.53 in pre-monsoon and post-monsoon, respectively. Two samples in pre-monsoon season had AI between 10 and 12 indicating that the water is moderately corrosive and the rest 16 samples along with all the samples of post-monsoon season had AI > 12 indicating that the water has scaling tendency and has non-aggressive tendency.

The RSI ranged from 6.3 to 7.37 and 6.69 to 7.24 with an average value of 6.74 and 6.86 in pre-monsoon and post-monsoon, respectively. Of all the samples investigated, 10 samples in pre-monsoon and 8 samples in post-monsoon season had RSI between 6.2 and 6.8 indicating that the water is balanced and has no scaling or corrosive tendencies. Subsequently, 8 samples in pre-monsoon and 10 samples in post-monsoon season had RSI between 6.8 and 8.5 indicating that the water has corrosive tendencies. The Puckorious Scaling Index (PSI) considers the relationship between pH and alkalinity of water. Alkalinity of water shows its ability to resist changes in pH that would enhance its acidity. As the acidity of water increases, its corrosivity increases. The PSI reveals the precipitation characteristics and buffering capacity of a water to reach equilibrium (Egbueri *et al.,* 2021). The PSI ranged from 6.09 to 6.26 and 6.52 to 6.81 with an average value of 6.17 and 6.67 in pre-monsoon and post-monsoon, respectively. All the samples of both the seasons had PSI value between 6 and 7 indicating that the water has little scaling and corrosive tendencies.

Multivariate Statistical Analysis

The physicochemical properties of water measured during pre-monsoon and post-monsoon season were subjected to multivariate statistical analysis *viz.*, Hierarchical cluster analysis and Principal component analysis (PCA) to investigate the relationships, sources, association and factors affecting the lake water quality.

Hierarchical Cluster Analysis

In this study, hierarchical agglomerative CA was applied to find out the similarity groups between the sampling stations. It was performed on the normalized data set of physicochemical parameters of both the seasons by means of the Ward's method, using squared Euclidean distances as a measure of similarity and is illustrated by a dendrogram (Fig. 3). The dendrogram clearly groups 18 sampling sites to form 3 clusters: cluster 1 corresponds to sampling points 11 - 18, cluster 2 has sites 8 - 9 and cluster 3 has 1 - 7 and 10th sampling point. The cluster 1 represents those sampling points which are highly polluted and occur in north-eastern part of the lake receiving polluted water from Bheemasandra lake upstream.

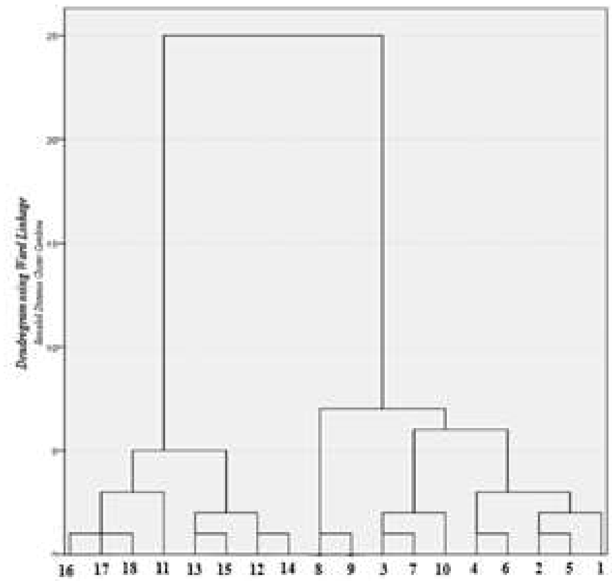

Fig. 3 : Dendrogram of sampling points based on physicochemical parameters (pre-monsoon)

The Arithmetic weighted WQI graph (Fig. 4) also clearly displays the polluted sampling points *i.e.,* 11-18 (WQI > 200) which corresponds to cluster 1 in dendrogram. The cluster 2 represents samples that are moderately polluted (WQI = 164 and 198) which is also displayed in the WQI graph and these points occur away from the inlet point. The cluster 3 represents those points where the pollution was comparatively low (WQI < 164) and occur in south-western part of lake near the outlet The Arithmetic weighted WQI graph also shows the same result with sampling points 1 to 7 having lower WQI values.

Fig. 5 shows the dendrogram of post-monsoon season which cluster the 18 samples into 2 clusters: cluster 1

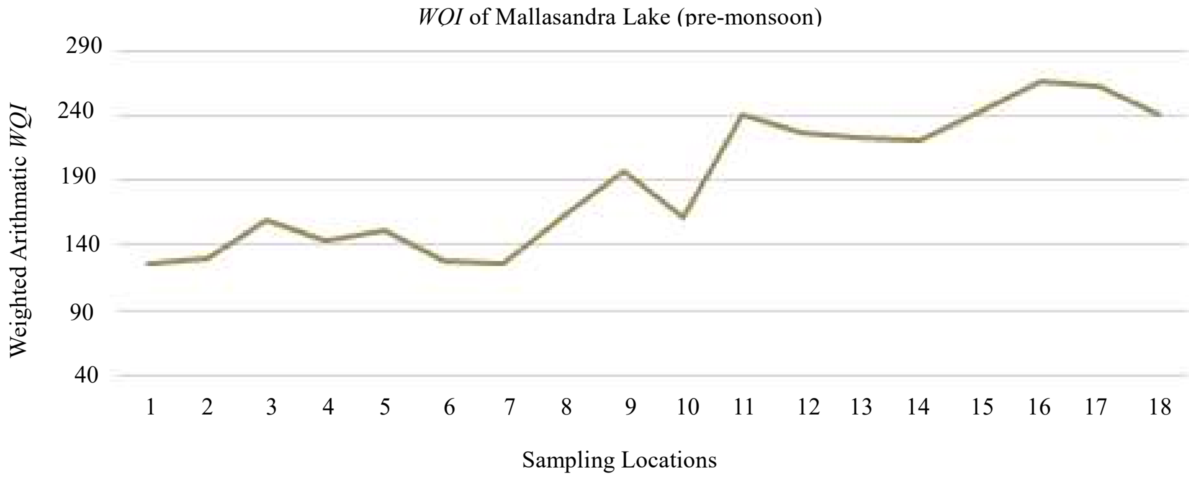

Fig. 4 : Arithmetic weighted water quality index graph (pre-monsoon)

corresponds to the sampling sites 9-18 which are highly polluted and occur in north-eastern part of the lake receiving polluted water from Bheemasandra lake upstream. The Arithmetic weighted WQI graph also clearly displays the polluted sampling points *i.e.,* 9 - 18 (WQI > 100) which corresponds to cluster 1 in dendrogram. The second cluster is represented by sampling points 1 - 8 which are relatively less polluted occur in the south-western part of the lake away from the inlet point.

The Arithmetic weighted WQI graph (Fig. 6) also clearly displays the less polluted sampling points *i.e.,* 1 - 8 (WQI < 100) which corresponds to cluster 2 in

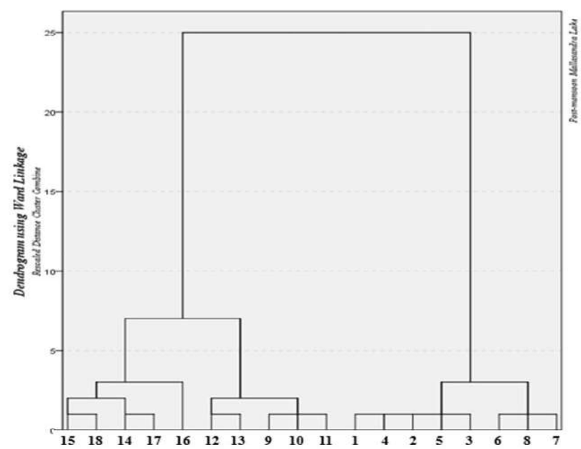

Fig. 5 : Dendrogram of sampling points based on physicochemical parameters (post-monsoon)

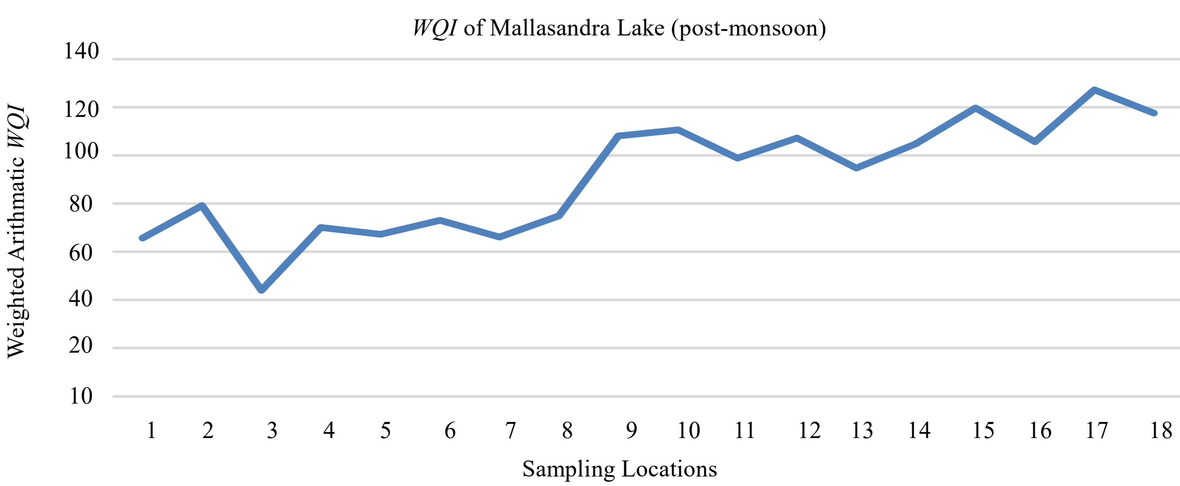

Fig. 6 : Arithmetic Weighted Water Quality Index graph (post-monsoon)

TABLE 12

Rotated factor loadings of principal component analysis (pre-monsoon and post-monsoon)

Season Variables	Pre-monsoon Components					Variables	Post-monsoon Components				
	1	2	3	4	5		1	2	3	4	5
DO	**-0.931**	-0.277	0.046	0.021	-0.008	Magnesium	**0.938**	0.142	0.193	0.051	-0.138
BOD	**0.928**	0.288	0.048	-0.101	0.058	Total Hardness	**0.924**	0.102	0.189	0.186	-0.147
COD	**0.927**	0.285	0.012	0.028	0.005	Calcium	**0.840**	0.026	0.171	0.401	-0.152
Ammonia	**0.879**	0.378	-0.100	0.154	0.081	BOD	**0.832**	0.417	0.108	0.183	0.041
Sulphates	**0.827**	0.239	-0.112	-0.039	0.239	DO	**-0.824**	-0.354	-0.223	0.152	-0.071
TDS	**0.791**	0.240	0.120	0.331	0.342	EC	**0.799**	0.396	0.312	-0.215	-0.169
EC	**0.791**	0.240	0.120	0.331	0.342	COD	**0.755**	0.494	0.063	0.240	0.124
Ortho phosphates	**0.770**	0.328	0.177	0.174	-0.003	Total Alkalinity	**0.723**	0.548	0.195	-0.102	0.071
Nitrate	**0.738**	-0.218	-0.020	0.270	-0.027	TSS	**0.654**	0.164	0.636	0.005	-0.038
Total Alkalinity	**0.694**	0.112	0.300	0.240	0.003	Ortho phosphates	**0.553**	0.540	0.457	-0.136	-0.086
Total Hardness	0.437	**0.870**	-0.047	0.107	0.062	Chloride	**0.548**	0.530	0.160	-0.284	0.418
Calcium	0.437	**0.870**	-0.047	0.107	0.062	Sulphates	0.121	**0.868**	0.010	0.015	-0.241
Magnesium	0.437	**0.870**	-0.047	0.107	0.062	TDS	0.571	**0.666**	0.324	-0.156	-0.234
Fluoride	-0.114	**0.584**	0.500	0.027	-0.252	Fluoride	0.270	**0.608**	0.389	0.028	0.353
TSS	0.042	-0.083	**0.957**	-0.048	-0.059	Nitrate	0.034	0.049	**0.828**	0.002	0.012
Turbidity	0.097	0.006	**0.956**	-0.140	-0.001	Turbidity	0.515	0.255	**0.692**	0.023	-0.048
Chloride	0.182	0.039	-0.166	**0.861**	-0.144	Ammonia	0.274	-0.014	0.006	**0.901**	0.014
pH	0.148	0.241	-0.038	**0.717**	0.412	Sodium	0.514	0.269	0.150	**-0.702**	0.263
Potassium	-0.036	-0.158	-0.330	0.071	**0.850**	Potassium	0.489	0.414	0.425	0.548	-0.048
Sodium	0.350	0.186	0.241	-0.027	**0.565**	pH	-0.215	-0.156	-0.056	-0.076	**0.887**
Eigenvalue	9.819	2.666	1.910	1.378	1.186	Eigenvalue	11.451	2.403	1.261	1.240	1.133
Variance %	49.093	13.332	9.548	6.892	5.929	Variance %	57.255	12.013	6.305	6.198	5.666
Cumulative %	49.093	62.426	71.974	78.866	84.796	Cumulative %	57.255	69.268	75.573	81.771	87.437

dendrogram. Hence, hierarchical cluster analysis can be used effectively to group the water samples with similar characteristics and the monitoring stations listed in clusters 1 - 3 can be used as representative sampling sites to assess the water quality of the lake. Both the approaches produce comparable results and combining them can give more accurate results for surface water quality evaluation and interpretation.

Principal Component Analysis (PCA)

The objective of PCA was primarily to create an entirely new set of variables or components much smaller in number when compared to the original data set of variables. PCA was performed on 20 physicochemical parameters followed by Varimax rotation for both pre-monsoon and post-monsoon season. An eigenvalue gives a measure of significance of the components with the highest eigenvalues being the most significant. Eigenvalues greater than 1 were taken as criterion for extraction of the principal components required to explain the sources of variances in the data (Shrestha and Kazama, 2007).

The PCA performed on 20 parameters of pre-monsoon season resulted in extraction of 5 components with eigenvalue greater than one which explains 84.796 per cent of total variance (Table 12). The scree plot is illustrated in Fig. 7. Based on these percentages, the processes governing the chemical characteristics of lake waters are essentially contained in these five components. PC1 explains 49.09 per cent of total variance with strong factor loadings of DO, BOD, COD, NH_4^+, SO_4^{2-}, TDS, EC, PO_4^{3-} and moderate loadings of NO_3^- and Total alkalinity. PC1 represents organic pollution mainly due to the presence of BOD, COD, NH_4^+, SO_4^{2-}, PO_4^{3-} and NO_3^-. Anthropogenic activities like discharge of nutrient loaded domestic sewage waters and agricultural runoff rich in plant nutrients as a result of chemical fertilizers explains the primary cause of water quality during pre-monsoon season. It also explains EC is mainly influenced by NH_4^+, SO_4^{2-}, PO_4^{3-} and NO_3^- and HCO_3^-. The negative correlation of DO with other parameters explains natural process of oxygen depletion. PC2 accounts for 13.33 per cent of total variance with strong loadings of Total hardness, Ca^{2+}, Mg^{2+} and moderate loading of F^-. PC2 represents the variables that are purely inorganic and hydrochemical which originate from the geological process, indicating geogenic sources. PC3 accounts for 9.54 per cent of total variance dominated by TSS and turbidity that explains the cloudiness and physical appearance of water. PC4

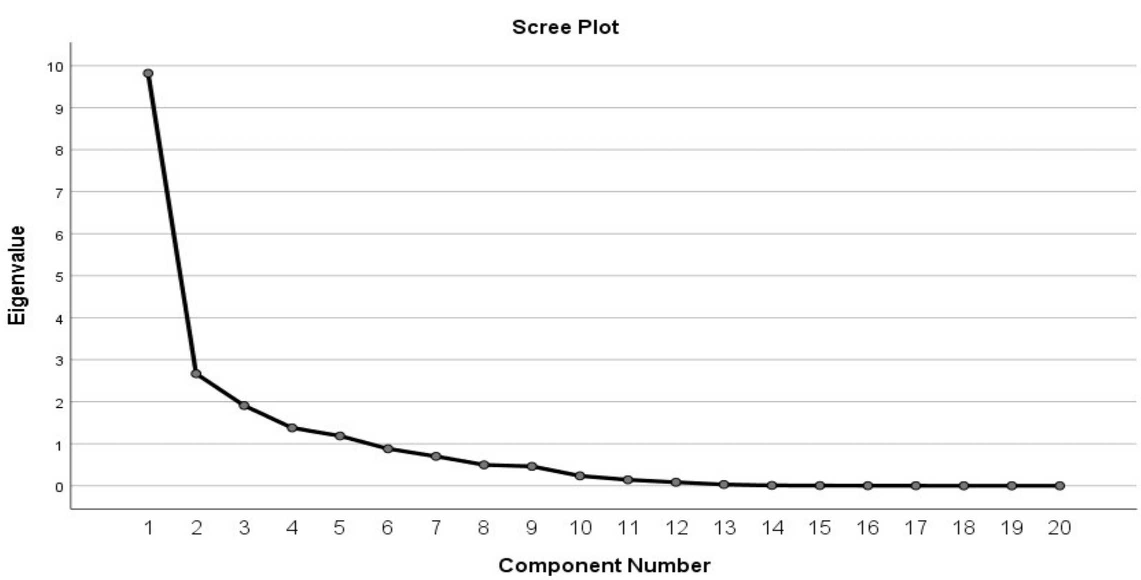

Fig. 7 : Scree plot of principal components (pre-monsoon)

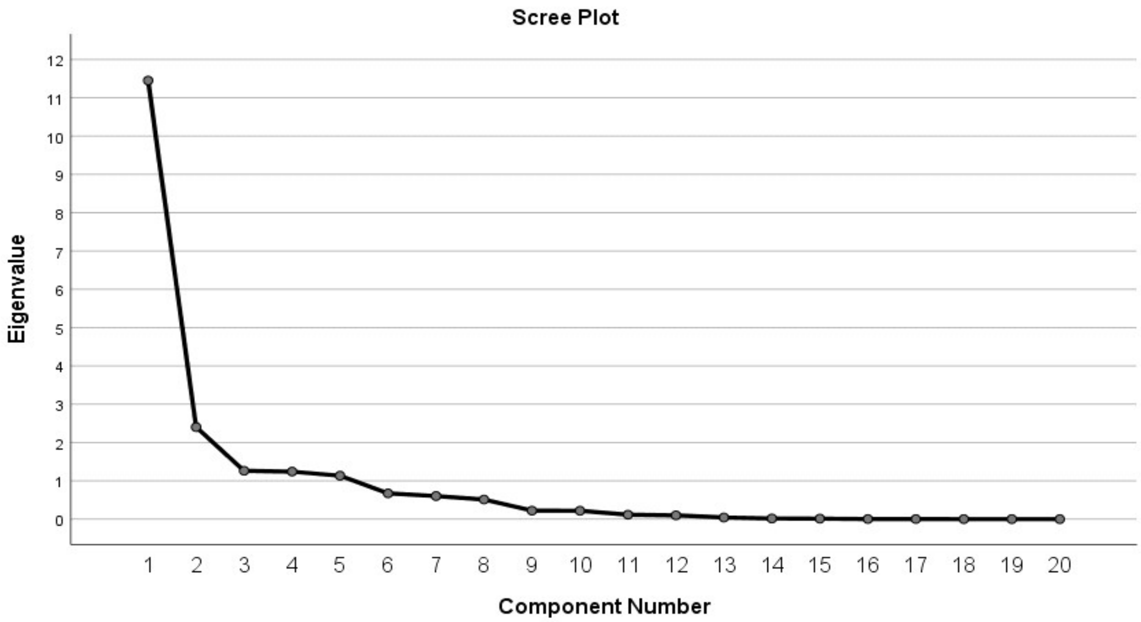

Fig. 8 : Scree plot of principal components (post-monsoon)

and PC per cent accounts for 6.89 and 5.92 per cent of total variance, respectively. PC4 dominated by pH and Cl- whereas PC5 is dominated by K^+ and Na+ which has less influence on water quality. The factor loadings of both PC1 and PC2 explains 62.42 per cent of total variance demonstrating that water quality in pre-monsoon may be the result of domestic sewage and agricultural runoff containing chemical fertilizers.

The eigenvalues, percentage variance, cumulative percentage variance of different components and rotated component loadings of post-monsoon season are given in Table 12. The PCA performed on 20 parameters of post-monsoon season resulted in extraction of 5 components with eigenvalue greater than one which explains 87.437 per cent of total variance. The scree plot is illustrated in Fig. 8. The PC1 accounts for 57.25 per cent of total variance with strong loadings of Mg^{2+}, TH, Ca^{2+}, BOD, DO, EC, COD and moderate loadings of TA, TSS, PO_4^{2-} and Cl^-. PC1 represents combined pollution sources as it includes both organic pollution and inorganic pollution causing parameters. The effects of anthropogenic activities and geological process decide the characteristics of water in post-monsoon period. The presence of Total hardness, Mg^{2+} and Ca^{2+}, HCO_3^-, Cl^-represents hydro chemicals which is geogenic process and the other parameters are related to organic source of pollution. Here, the EC is influenced by Mg^{2+}, HCO_3^-, Cl^-, Ca^{2+} and PO_4^{2-}. PC2 accounts for 12 per cent of Total variance with strong loading of SO_4^{2-} and moderate loadings of TDS and fluoride. PC2 represents the organic pollution mainly from sulphates which can be attributed to pollutants present in domestic sewage. PC3 accounts for 6.3 per cent with loadings of nitrates and turbidity. PC4 accounts for 6.19 per cent with loadings of ammonia and sodium. PC5 accounts for 5.6 per cent with loading of pH. During post-monsoon period, organic pollutants may be diluted due to heavy rainfall and is reflected through PCA. Some of these pollutants have their loadings in PC2 (sulphates), PC3 (nitrates and turbidity) and PC4 (ammonia and sodium) which can be attributed to effects of dilution in water. The factor loadings of both PC1 and PC2 explains 69.26 per cent of total variance demonstrating that water quality in post-monsoon is the result of combined effect of organic pollution and geogenic process.

Spatial Interpolation of WQI

The WQI maps of lake Mallasandra were created using IDW (Inverse distance weighted) technique in ArcGIS software. These maps were created by importing the

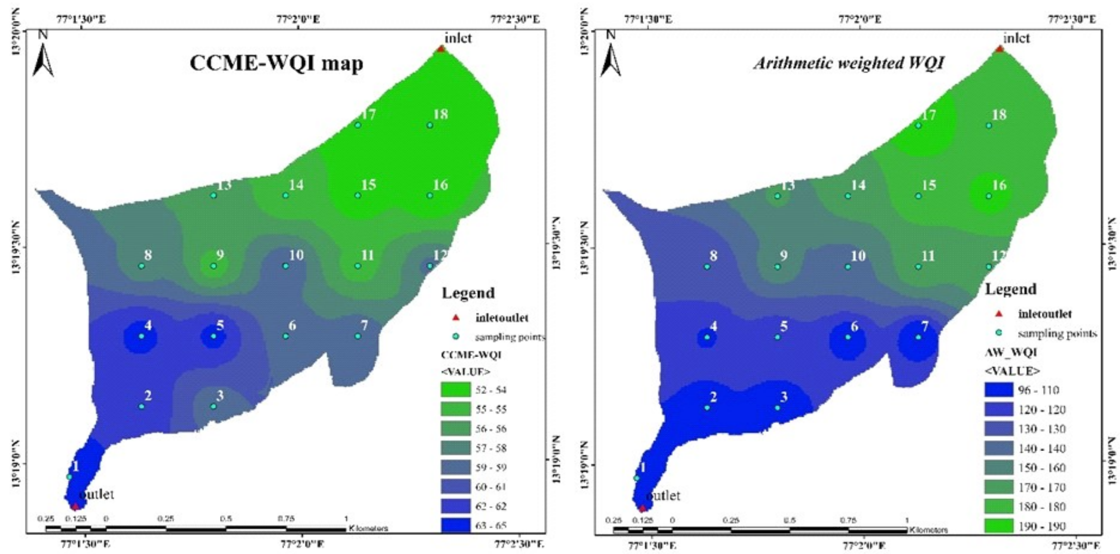

Fig. 9 : Spatial distribution of WQI in lake Mallasandra. CCME-WQI map (left) Arithmetic weighted WQI (right)

CCME_WQI and Arithmetic weighted WQI of each sampling point during both the seasons.

The CCME-WQI map and Arithmetic weighted WQI (AW-WQI) map (Fig. 9) are created by taking the mean values 13 parameters of both pre-monsoon and post-monsoon seasons. The CCME-WQI ranged from 52.14 to 64.7 belonging to 'marginal' class. The attributes of CCME-WQI are classified into 8 classes for better visualization of spatial distribution. The AW-WQI ranged from 96 to 194 categorised as 'unsuitable for drinking'. The attributes of AW-WQI are classified into 8 classes and the north-eastern part of lake is highly polluted which is comparable to that of CCME-WQI map. It can be observed that north-eastern part of the lake is highly polluted near the inlet and the water quality improves comparatively as we proceed away from the

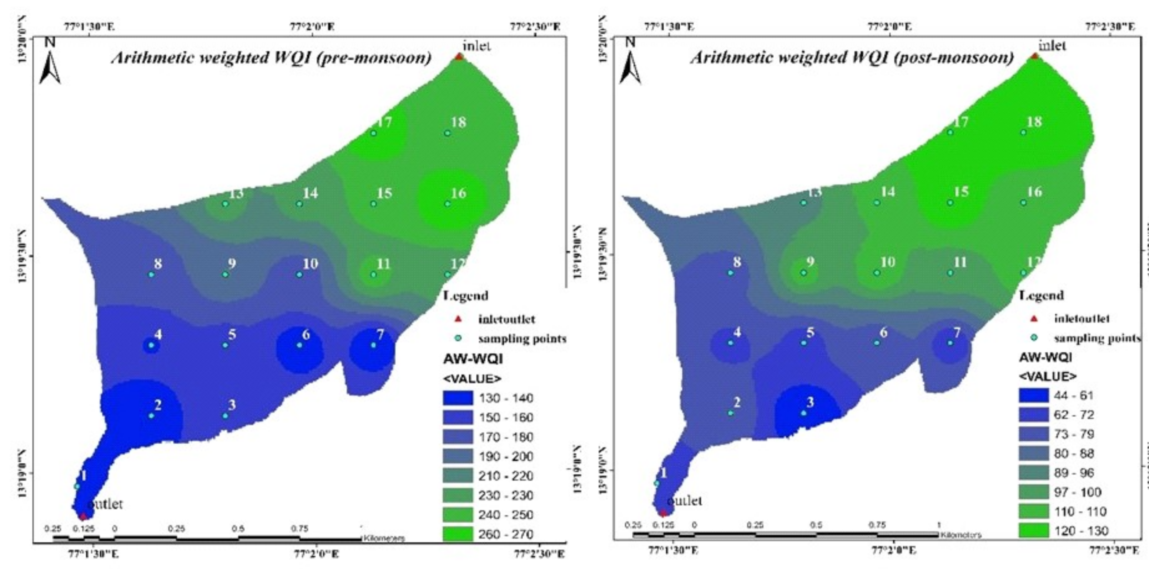

Fig. 10 : Spatial distribution of Arithmetic weighted WQI in lake Mallasandra. Pre-monsoon (left) post-monsoon (right)

inlet Hence, spatial interpolation of WQI can be effectively utilized for better visualization and management of lake water quality. Fig. 10 shows the comparison between Arithmetic weighted WQI map of pre-monsoon and post-monsoon season. The AW-WQI ranged from 126 to 267 and from 44 to 127 during of pre-monsoon and post-monsoon season, respectively.

The results revealed that the BOD, turbidity, TDS and Total alkalinity exceeded the BIS standards in both the seasons whereas K^+ and NH_4^+exceeded in pre-monsoon only. The average ion concentrations of cations are in the order $Na^+ > Ca^{2+} > K^+ > Mg^{2+} > NH_4^+$. The average ion concentrations of anions are in the order $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- >$ F- > PO_4^{3-}. The CCME-WQI of all 18 sampling points ranged from 45 to 64 with a mean value of 57.21 belonging to 'marginal class' indicating that the water quality is frequently threatened or impaired. The AM-WQI during pre-monsoon period was >100 with mean WQI of 190 belonging to class 'unsuitable for drinking'. During post-monsoon period, it varied from 44 to 127 with mean WQI of 91 belonging to class 'very poor'. Irrigation water quality indices *viz.*, SAR, Na%, RSC, MH, KI and PS indicated that the lake water was suitable for irrigation, PI revealed moderate suitability and EC revealed non-suitability of water for irrigation purpose. Industrial water quality indices *viz.*, LSI, LI and AI revealed that the water had scaling tendency, CSMR - galvanic corrosion potential, RSI revealed both balanced water and corrosive tendency and PSI - little scaling and corrosive tendency. During pre-monsoon season, Hierarchical CA formed 3 clusters containing sampling points possessing different levels of pollution (cluster 1: highly polluted, cluster 2: moderately polluted and cluster 3: comparatively low polluted sites). This was in accordance with Arithmetic WQI graph of same season. In post-monsoon season, CA formed 2 clusters (cluster 1: highly polluted sites and cluster 2: comparatively low polluted sites) which was in agreement with the AW-WQI graph of post-monsoon season. The PCA extracted 5 components in both the seasons explaining 84.79 and 87.43 per cent of total variance in pre-monsoon and post-monsoon season, respectively. The PCA demonstrated that water quality in pre-monsoon may be the result of domestic sewage and agricultural runoff containing chemical fertilizers and water quality in post-monsoon is the result of combined effect of organic pollution and geogenic process. The spatial distribution of CCME and AW WQI revealed that north-eastern part of lake is highly polluted near the inlet the use of indices, multivariate statistics and GIS technology has proved to be effective and economically viable for assessing the lake water quality. This research work will help decision and policy makers in monitoring and managing the precious water resources.

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