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ORIGINAL ARTICLE

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Spatio-temporal dynamics of groundwater quality using hydro-chemical and geospatial techniques in Chikkaballapura taluk, Karnataka, India

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ABSTRACT

A research study was conducted to assess the groundwater quality of sixty-eight bore wells and hydrochemistry in the Chikkaballapura taluk of Karnataka, India during the pre-monsoon (March 2022) and post-monsoon (November 2022) seasons. The analysis showed the pH of the well water to range from slightly acidic to slightly alkaline. The borewells exhibited a range of salinity from low to high (i.e., EC < 3000 µS/cm), fresh to slightly saline (i.e., TDS $< 3,000$ mg/L), and low to very hard in terms of water hardness. The fluoride concentration in the water was below 0.7 and 0.9 mg/L respectively during the pre-monsoon and post-monsoon seasons. Water Quality Index (WQI) revealed that groundwater was suitable for drinking purposes in 64.7% and 63.3% samples, respectively during pre- and post-monsoon seasons. Analysis using Piper's trilinear diagram revealed that the dominant hydro-chemical facies were Ca-Mg-HCO_3, while Schroller's diagrams indicated the concentration of alkaline earth metals (Ca + Mg) exceeding that of alkali metals (Na + K), and weak acidic anions ($HCO_3 + CO_3$) surpassed strong acidic anions ($Cl + SO_4$). The ascendancy of anions and cations was as follows: $HCO_3 > Cl > SO_4 > NO_3$; $Ca > Na > Mg > K$. Furthermore, the Gibbs plot suggested that rock weathering processes played a significant role in controlling the chemistry of the groundwater. Most groundwater samples were belong to excellent and good class for irrigation purposes based on parameters such as SAR, percent sodium, SSP, magnesium hazard, and RSC values, indicating their suitability for irrigation. The classification of the groundwater from the study area, according to the USSL classification of irrigation water, fell into the C1S1 (low salinity and low sodium hazard), C2S1 (medium salinity and low sodium hazard), and C3S1 (high salinity and low sodium hazard) classes.

HIGHLIGHTS

- Dominant hydro-chemical facies or water type is Ca-Mg-HCO_3.
- The ionic ascendancy was in the order of $HCO_3 > Cl > SO_4 > NO_3$ and $Ca > Na > Mg > K$.
- WQI indicated drinking water suitability accounted for 64.7% and 63.3% of pre- and post-monsoon samples.
- Irrigation suitability was detailed by SAR, percent sodium, SSP, MH, and RSC values.
- Parameters falling under Factor 1 with 69.5 % (PRM) and 78.6 % (POM) of total variance have controlled groundwater chemistry.

1 | INTRODUCTION

In arid and semi-arid parts of the world, groundwater usage has been considerably increased for drinking, irrigation, and industrial purposes. The groundwater quality is deteriorating due to (a) natural geogenic origins like dissolution or weathering of the rocks and soil and (b) anthropogenic activities like land use changes, increased dumping of industrial effluent, mining, agricultural runoff, interaction with sewage, percolation of leachate, etc. Anthropogenic impact on natural environments, especially aquatic ecosystems, is increasingly concerning. Further, the presence of toxic metals, pesticides, and elements like fluoride and nitrate in groundwater has increased public health risks concerns across the globe. Continued irrigation practices, industrial application, and increased population and urbanization have put enormous pressure on the extraction and overuse of these valuable resources, leading to water shortage, water crisis and deterioration of groundwater quality, threatening human health and economic development (Das *et al.,* 2023). Alternately, crop growth mainly depends on ground-water supply for irrigation in several arid and semi-arid areas. The irrigation suitability of groundwater depends on the effects of constituent mineral elements of water on both the plant and soil (Richards, 1954) besides the quality of water used for irrigation and its chemistry, soil types, plant tolerance to salt levels, climate, soil drainage characteristics, etc. (Yadav *et al.,* 2020). Finally, rainfall and drought assessment are critical for monitoring water supply trends, determining the likelihood of drought occurrence, and regulating irrigation water for consistent crop development (Singh *et al.,* 2023). Further, excessive quantities of dissolved ions in irrigation water affect plants and agricultural soils and thus reduce productivity (Ravikumar *et al.,* 2011); hence, evaluating groundwater suitability for irrigation is essential. Hydro-geochemical studies of groundwater have been important in evaluating groundwater quality as they help researchers understand groundwater's geochemical evolution mechanisms and determine the dominant factors governing its chemistry. Alternatively, GIS has become an effective tool for storing, analysing, and presenting spatial data, and to make decisions in various domains, including environment and engineering. Many researchers across the globe extensively employed hydro-geochemical studies in combination with geospatial techniques to demonstrate spatio-temporal variations in groundwater quality and groundwater usability, trends in irrigation suitability across seasons, etc.

The study area selected for the present study, Chikkaballapura taluk, is one of Karnataka's over-exploited and drought-prone taluks, with declining water levels and yields (CGWB, 2012). Agriculture is the major occupation of the people in the Chikkaballapura taluk, depending entirely upon rainfall and groundwater resources for crop production due to a lack of perennial water sources. Furthermore, the Government of Karnataka has initiated supplying treated wastewater from Bangalore to fill irrigation tanks in Kolar and Chikkaballapura districts, recharging groundwater levels and making water available for irrigation. Hence, an attempt was made in the present study (a) to identify the dominant hydro-chemical facies, (b) to evaluate groundwater suitability for drinking and irrigation purposes and (c) to delineate the factors governing groundwater chemistry and d) to demonstrate spatiotemporal variation in few important parameters using geospatial analysis.

2 | MATERIALS AND METHODS

2.1 | Study Area

Chikkaballapura district is the eastern gateway to Karnataka, which was newly formed by bifurcating the old Kolar district into Chikkaballapura and Kolar districts. The district is administratively divided into six Taluks, namely, Gauribidanur, Begepalli, Gudibande, Sidlaghatta, Chikkaballapura, and Chintamani. Chikkaballapura, the District headquarters, is a major grain, grape, and silk cultivation hub. Agriculture is the major occupation of the district, with Kharif (viz., maize, tur, ragi, and vegetables) and rabi crops (viz., ragi, groundnut, maize, horse gram, sunflower and fruits). Chikkaballapura taluk of Chikkaballapura district has a geographical area of 634.8 km^2 and geographically extended between 13^0 20' 10.7” N and 13^0 39' 59.4” N latitudes and 77^0 36' 4.7” E and 77^0 52' 20.2” E longitudes. The elevation profile ranges from 249 to 911 meters AMSL (above mean sea level). It is covered in parts of the Survey of India toposheet Nos. 57G/10, 57G/11, 57G/14 and 57G/15. Chikkaballapura taluk with adjacent taluks of Gudibande taluk on the North, Devanahalli taluk on the South,

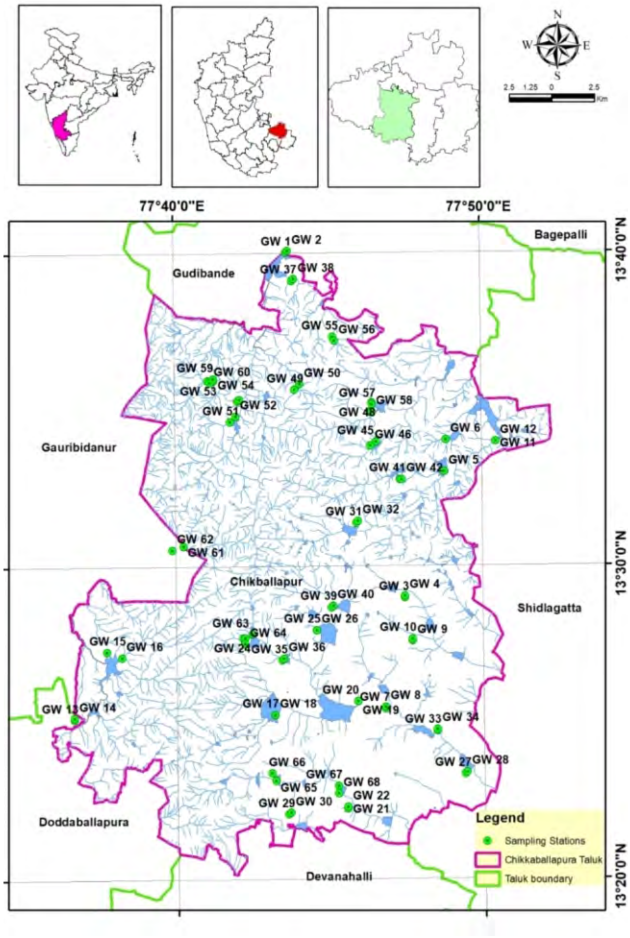

FIGURE 1 **Location map of study area showing groundwater sampling stations**

Sidlaghatta taluk on the East and Gauribidanur taluk on the Western side (Fig. 1). Chikkaballapura taluk falls under Karnataka's Eastern dry agro-climatic zone, categorized as drought-prone with semiarid to arid conditions. As per the rainfall data from Indian Meteorological Department (IMD), Bengaluru, the mean annual rainfall ranged from 282.6 to 849.0 mm between 1990-2022 across fourteen rain gauge stations in the Chikkaballapura taluk. Usually, April and May are the hottest months, with temperatures as high as 40° C. They are generally lowest during December, being as low as 10°C. Western part of the taluk is covered with undulating hills, plain terrain, and plateaus. The depth of irrigation bore wells range from 100 to 300 mbgl and the yield of bore wells ranges from 0.5 to 20 m^3/hour.

The taluk is drained by three seasonal and smaller rivers, the Ponnaiyar, Palar, and Pennar, which carry water only during the rainy season (CGWB, 2012). Palar flows in an NW-SE direction and begins in the Ambajidurga hillocks in the Chintamani Taluk. High dendritic density characterises the drainage. The Pennar river travels Northward through parts of Chikkaballapura taluk, beginning in the Doddaballapura taluk in Bangalore Rural district. The North Pinakani river rises from the Nandi hills of Chikkaballapura taluk and flows North. In addition, the South Pinakani river rises from the Nandi hills and flows through the taluks of Chikkaballapura and Sidlaghatta. Arkavathi, a tributary of the Cauvery, also rises from the Nandi hills and flows through the Chikkaballapura taluk for 2.8 km. Chikkaballapura taluk encompasses major soil types like red sandy, loamy, and lateritic. The study area is occupied mainly by the Banded Gneissic Complex (BGC), and the major water-bearing formations are granites, granitic-gneiss, laterites, and schists. Small patches of Laterites are seen in Chikkaballapura taluk, and the alluvium type of rock formations dominate river courses. Fractures or lineaments run mostly in the NE-SW trend in the Chikkaballapura district (CGWB, 2012). The groundwater occurs under water table conditions in the weathered zone and is confined to semi-confined conditions in the fractured hard rock formations.

2.2 | Groundwater Sample Collection and Analysis

Polyethene bottles (1 litre capacity) were used for collecting sixty-eight borewell groundwater samples across Chikkaballapura taluk (Fig. 1) during the pre-monsoon (March, 2022) and post-monsoon (Nov, 2022) seasons. Bore wells were uninterruptedly pumped for 10-15 minutes before collecting the representative samples. Groundwater samples were acidified with 1:1 extra pure HNO_3 to prevent changes in equilibrium in groundwater chemistry. Parameters like pH, EC, and TDS were analysed in the field using a portable HACH HQ30D multi-parameter kit. The remaining parameters (viz., TH, TA, Ca, Mg, Na, K, SO_4, Cl, HCO_3, NO_3, F, PO_4) were analysed after transporting the samples using ice boxes (refrigerating them at 4°C) to the Dept. of Environmental Science laboratory, Bangalore University, Bangalore. Sodium and potassium were analysed using µ-Controller based flame photometer (Systronics Type-128). TH of water was determined through titration with an EDTA conjoining Eriochrome Black-T indicator (APHA, 2017), and total alkalinity was measured as $CaCO_3$ through titration with a phenolphthalein and methyl orange indicator (APHA, 2017). Cl^- concentration was determined using Argentometric titration, and the fluoride was analysed using a HACH DR/890 colorimeter. Nitrates, sulphates, and phosphates in groundwater samples were analyzed using Elico SL-171 spectrophotometer employing PDA, barium chloride, and ammonium molybdate methods, respectively. Standard (APHA, 2017) water and wastewater analysis methods were employed during the sample collection, labelling, preservation, storing, transportation and analysis of the groundwater samples.

2.2.1 | Water quality index (WQI)

The WQI was calculated for all groundwater samples of the pre-and post-monsoon seasons using the equations given below. Each parameter selected for the WQI calculation was assigned different weights based on their influence and importance in water chemistry. Relative weights were calculated for each parameter and are given in Table 1.

$$W_r = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad ...(1)$$

$$Q_i = \frac{C_i}{S_i} \times 100 \quad ...(2)$$

$$SI_i = W_r \times Q_i \quad ...(3)$$

$$Q_{i\,pH,DO} = \frac{C_i - V_i}{S_i - V_i} \times 100 \quad ...(4)$$

TABLE 1 Weight and relative weight of physicochemical parameters

S.No.	Parameters	BIS standard limit (IS:10,500-2012)	Weight (wi)	Relative weight (wi)
1	pH	6.5-8.5	4	0.114
2	TDS	500	4	0.114
3	TH	300	3	0.086
4	TA	200	2	0.057
5	SO_4	200	2	0.057
6	Cl	250	3	0.086
7	F	1	4	0.114
8	NO_3	45	4	0.114
9	Ca	75	2	0.057
10	Mg	30	2	0.057
11	Na	200	3	0.086
12	K	10	2	0.057
	Total		35	1.000

$$WQI = \sum SI_i \quad ...(5)$$

2.2.2 | Hydro-chemical facies and evolution

Relative concentrations of major anions (chloride, sulphate, carbonate, bicarbonate) and major cations (viz., magnesium, calcium, sodium, potassium) expressed in milli equivalents per litre were employed to construct Piper trilinear diagram (Piper, 1944) and Schoeller diagram (Schoeller, 1960). A Piper trilinear diagram can be used to discern the major water types to illustrate factors controlling groundwater chemistry data from multiple sources. The Piper trilinear diagram represents a combination of anions and cations triangles on a common baseline with a diamond shape between them. This can be used to understand the origin of the water represented by the analysis and to characterize different water types. The Piper diagram divided water into four basic types according to their placement near the four corners of the diamond. The Schoeller diagram permits the total concentrations of cations and anions of different water samples to be represented on a single semi-logarithmic graph to visualize the trends in the water quality data. Hence, ionic dominance in groundwater and major hydro-chemical facies were reproduced in the Schoeller and Piper Trilinear diagrams. Gibbs plots (Gibbs, 1970) are graphical representation plotted by using the ratio of cations [(Na + K) / (Na + K + Ca)] and anions [Cl/(Cl+ HCO_3)] against TDS to confirm the hydro-geochemical controlling mechanism of dissolved cations and anions concerning the precipitation, rock weathering and evaporation dominances.

2.3 | Statistical analysis and GIS maps

Descriptive Statistical analysis and Principal Component analysis were performed on analytical dataset using SPSS v22.0 software. Principal Component analysis was performed using the extraction methods of Varimax rotation and Kaiser Normalization to interpret the geochemical dataset to understand the factors controlling groundwater chemistry. Spatio-temporal distribution maps were prepared using ArcGIS v10.1 software. The Inverse Distance Weighted (IDW) interpolation method, available under the geostatistical analyst tool of ArcGIS software, was employed to create spatial-temporal distribution maps. By default, the interpolation method classifies map parameters and generates a spatial-temporal distribution map having 10 classes.

3 | RESULTS AND DISCUSSION

Descriptive statistical data such as minimum, maximum, and mean values of physio-chemical parameters of groundwater samples for pre- and post-monsoon seasons of Chikkaballapura taluk are shown in Table 1 along with their respective drinking water quality standards (BIS, 2012).

pH determines the basicity or acidity of the solution, and long-term exposure to acidic waters can erode metal water supply system pipes and raise the concentration of heavy metals in the water. Hence, the estimation of pH is a pre-requisite in any water quality monitoring project. In the study area, pH values in groundwater samples ranged from 6.10 to 7.93 (mean: 7.23) and 5.9 to 7.80 (mean: 7.04) during pre- and post-monsoon seasons, respectively. It was observed that 92.65 and 91.17 % of samples showed pH values within the (BIS, 2012) permissible limit of 6.5 to 8.5, illustrating a slightly acidic to slightly alkaline nature and the remaining 7.35 and 8.83 % of the pre-and post-monsoon groundwater samples recorded pH deviating from BIS standard limit.

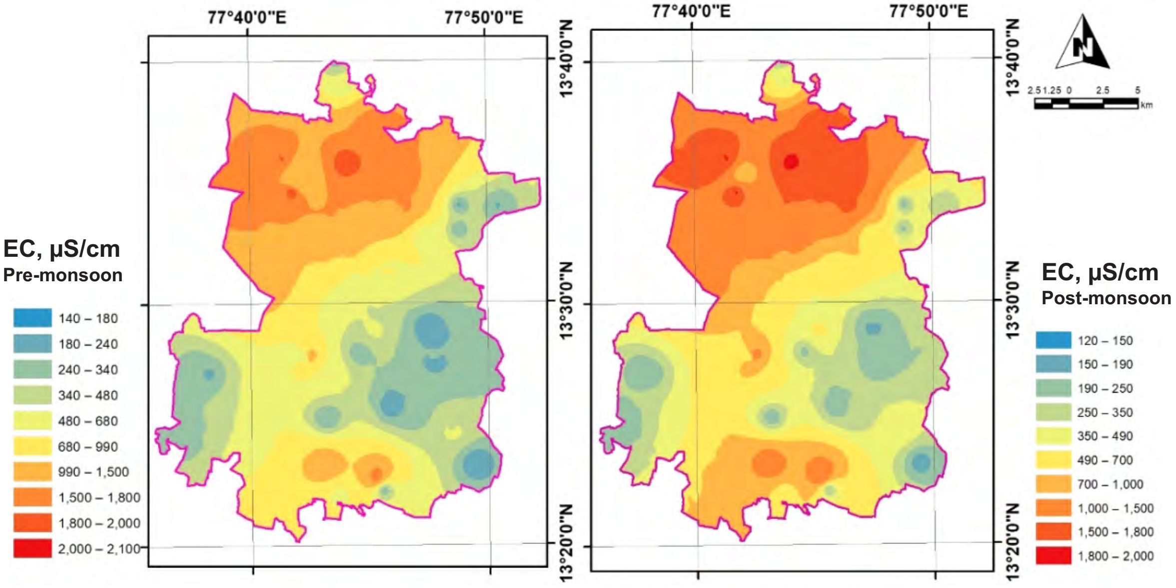

FIGURE 2 Spatiotemporal distribution in electrical conductivity in Chikkaballapura taluk

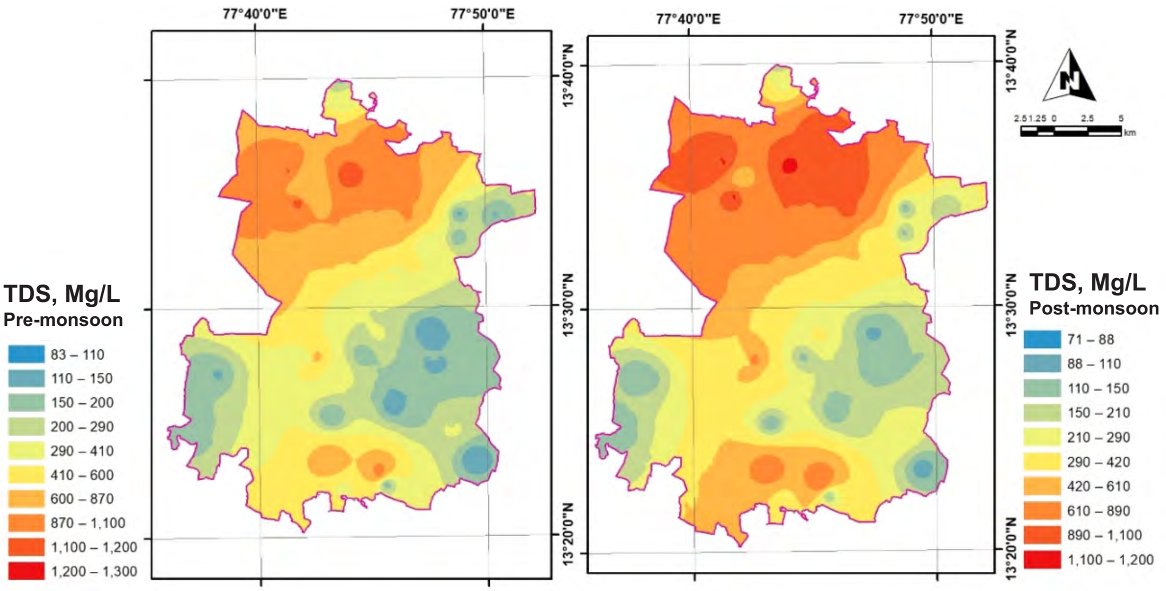

FIGURE 3 **Spatiotemporal distribution in TDS in Chikkaballapura taluk**

Natural waters tend to have electrical conductivity (EC) due to salts dissociating into anions and cations. The total ionic contents of groundwater water can significantly impact the water's suitability for consumption. The spatio-temporal distribution pattern of EC in the study area is shown in Fig. 2, and the electrical conductivity values ranged from 138.7 to 2109.7 µS/cm (mean: 782.1 µS/cm) during pre-monsoon and 118.4 to 2000.4 µS/cm (mean: 759.6 µS/cm) during the post-monsoon season. Higher electrical conductivity of groundwater indicates the influence of the weathering of aquifer material and the impact of human activity-induced groundwater pollution.

Drinking water with high electrical conductivity tends to have higher total dissolved solids concentration as there exists a direct relationship between these parameters. In the present study, pre- and post-monsoon groundwater samples recorded the total dissolved solids (Fig. 3) in the range of 83.24 to 1265.8 mg/L (mean: 469.2 mg/L) and 71.1 to 1200.3 mg/L (mean: 455.8 mg/L) respectively. Upon comparison with the BIS (2012) permissible limit of 2000 mg/L, all the groundwater samples were found to have TDS values well below the BIS standard limit. According to the salinity classification of Hem (1970), 85.29 and 14.71 % of the pre-monsoon samples are freshwater (viz., TDS <1000 mg/L) and slightly saline water (viz., 1000 >TDS < 3000 mg/L). Similarly, 86.76 % and 13.24 % of samples were fresh and slightly saline water during post-monsoon.

The hardness of water is mainly caused by the occurrence of carbonates, bicarbonates, sulphate, chlorides, and nitrates of calcium and magnesium. Drinking water with a high total hardness content can harm human health, including renal disease, gastrointestinal issues, urine concentration, and artery calcification (Kumar and Maurya, 2023). It was observed that 57.35 % and 58.83 % of the groundwater samples during pre- and post-monsoon periods had total hardness (Fig. 4) below the desirable limit of 200 mg/L (BIS, 2012) as they ranged respectively from 46.5 to 637.3 mg/L (mean: 250.2 mg/L) and 38.7 to 653.2 mg/L (mean: 252.7 mg/L). Further, 5.88 and 8.82 % of pre- and post-monsoon samples showed higher total hardness over 600 mg/L (BIS, 2012). Alternately, total alkalinity values varied from 40.0 to 620.0 mg/L (mean: 228.0 mg/L) and 32.0 to 620.0 mg/L (mean: 234.9 mg/L) for the pre-and post-monsoon seasons samples. Total alkalinity below the desirable limit of 200 mg/L (BIS, 2012) was noticed in 42 samples (viz., 61.77 %) and 41 samples (viz., 60.3 %) during pre and post-monsoon seasons. In contrast, one sample during pre-monsoon and two samples during post-monsoon samples recorded total alkalinity levels over 600 mg/L.

3.1 | Major Ions Chemistry

All natural waters (*viz.,* surface and groundwater) contain dissolved ionic constituents, categorized as major cations and major anions. Among major cationic compositions, calcium and sodium were the dominant ones, followed by magnesium and potassium, and the order of cation abundance was Ca > Na > Mg > K. Among the anionic composition, bicarbonates and chloride are the dominant anions, followed by sulphate and nitrate, and the order of abundance was $HCO_3 > Cl > SO_4 > No_3$.

The concentration of Calcium varied from 12.0 to 164.6 mg/L (mean: 64.6 mg/L) and 10 to 160.0 mg/L (mean: 61.9 mg/L) for pre- and post-monsoon groundwater samples. It was observed that 35.29% of pre- and post-monsoon

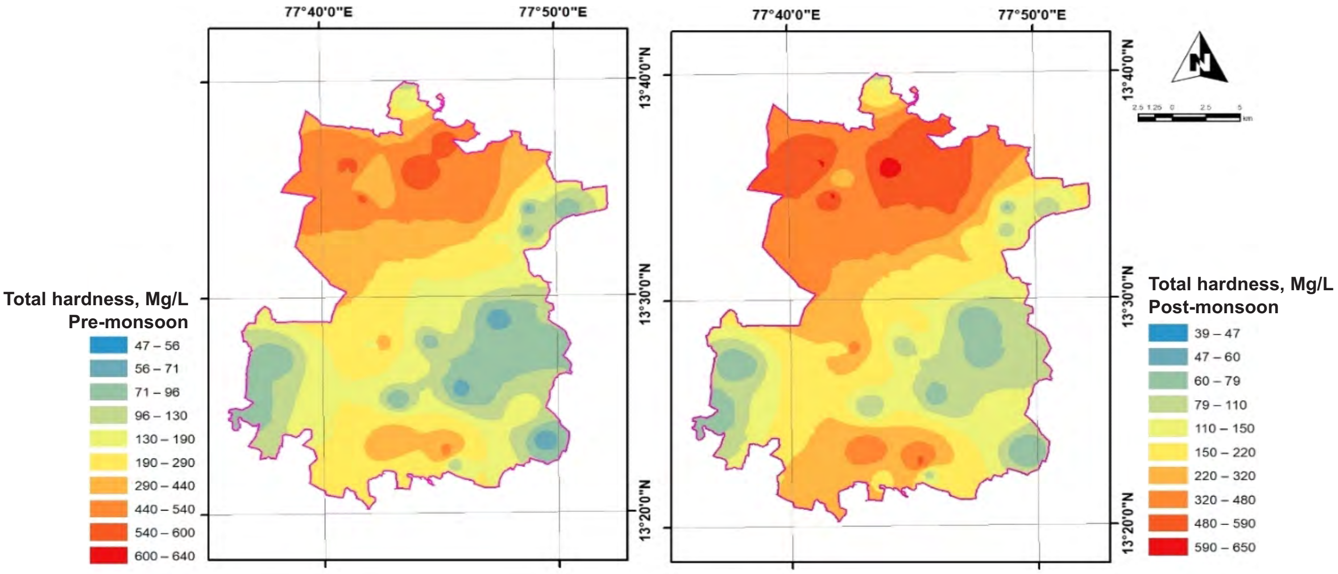

FIGURE 4 Spatiotemporal distribution in total hardness in Chikkaballapura taluk

TABLE 2 Descriptive statistics of analytical results of groundwater (n = 68) from Chikkaballapur taluk

Parameters	Unit	Obtained Analytical results (n=68)						BIS (IS:10,500-2012) standard limit for drinking water	
		Pre-monsoon (PRM-2022)			Post-monsoon (POM-2022)				
		Mean	Min	Max	Mean	Min	Max	Desirable limit	Permissible limit in the Absence of an alternate source
pH	---	7.23	6.10	7.93	7.04	5.90	7.80	6.5 - 8.5	No Relaxation
Electrical conductivity (EC)	µS/cm	782.1	138.74	2109.7	759.6	118.4	2000.4	---	----
Total dissolved solids (TDS)	mg/L	469.2	83.24	1265.8	455.8	71.1	1200.3	500	2000
Total hardness (as $CaCO_3$)		250.2	46.46	637.29	252.7	38.7	653.2	200	600
Total alkalinity (as $CaCO_3$)		228.0	40.00	620.00	234.9	32.0	620.0	200	600
Calcium (as Ca)		64.6	12.00	164.60	61.9	10.0	160.0	75	200
Magnesium (as Mg)		21.5	4.00	54.87	23.8	3.3	61.5	30	100
Sodium (as Na)		44.1	9.00	120.00	44.6	8.0	131.5	---	----
Potassium (as K)		4.4	1.00	30.00	8.9	1.6	26.3	---	----
Phosphate (as PO_4)		0.225	0.018	1.00	0.18	0.014	0.80	---	----
Nitrate Nitrogen (as NO_3)		10.6	1.00	32.33	9.5	1.5	24.6	45	No Relaxation
Sulphate (as SO_4)		41.1	3.40	133.70	20.6	3.3	53.3	200	400
Chloride (as Cl)		54.5	9.00	152.00	51.0	8.0	128.0	250	1000
Fluoride (as F)		0.3	0.00	0.70	0.2	0.0	0.9	1.0	1.5
Bicarbonates (as HCO_3)		278.2	48.8	756.4	286.5	39	756.4	---	----
Water Quality Index (WQI)	---	41.1	6.95	108.97	47.3	8.66	120.1	< 25	< 50

samples had calcium concentration above the BIS (2012) desirable limit of 75 mg/L but well below the BIS (2012) permissible limit of 200 mg/L. Magnesium concentration varied from 4.0 to 54.9 mg/L (mean: 21.5 mg/L) and 3.3 to 61.5 mg/L (mean: 23.8 mg/L) during both seasons, well below their permissible limits of 100 mg/L (BIS, 2012). Sodium concentration during pre-monsoon was 9.0 to 120.0 mg/L (mean: 44.1 mg/L) and 8.0 to 131.5 mg/L (mean: 44.6 mg/L) during post-monsoon samples. Potassium concentration varied between 1.0 to 30.0 mg/L (mean: 4.4 mg/L) and 1.6 to 26.3 mg/L (mean: 8.9 mg/L) during the pre and post-monsoon seasons in the study area.

Chloride concentration varied between 9.0 to 152.0 mg/L (mean: 54.5 mg/L) and 8.0 to 128.0 mg/L (mean: 51.0 mg/L) during pre- and post-monsoon seasons, respectively. It was apparent that chloride levels in groundwater during both seasons were below the desirable limit of 250 mg/L (BIS, 2012). Bicarbonate levels in pre- and post-monsoon groundwater samples varied between 48.8 to 756.4 mg/L (mean: 278.2 mg/L) and 39.0 to 756.4 mg/L (mean: 286.5

mg/L). The sulphate concentration varied from 3.4 to 133.7 mg/L (mean: 41.1 mg/L) for pre-monsoon samples and 3.3 to 53.3 mg/L (mean: 20.6 mg/L) for post-monsoon samples. It was evident from the results that all the samples showed sulphate concentration below the BIS (2012) desirable limit of 200 mg/L during both pre and post-monsoon seasons. The nitrates in groundwater samples ranged between 1.0 to 32.3 mg/L (mean: 10.6 mg/L) and 1.5 to 24.6 mg/L (mean: 9.5 mg/L) during pre and post-monsoon seasons, respectively, and were well below the standard limit of 45 mg/L (BIS, 2012) during both the seasons. Fluoride ranged from BDL to 0.7 mg/L (mean: 0.3 mg/L) and BDL to 0.9 mg/L (mean: 0.2 mg/L) during the seasons, as mentioned earlier. None of the samples had fluoride levels above the BIS desirable limit of 1.0 mg/L during both seasons. Phosphate concentration ranged between 0.018 to 1.00 mg/L (mean: 0.225 mg/L) for pre-monsoon season and 0.014 to 0.80 mg/L (mean: 0.18 mg/L) for post-monsoon season.

3.2 | Hydro-chemical Facies

The Piper trilinear diagram revealed the dominance of Ca-Mg-HCO_3 hydrochemical facies during both the pre- and post-monsoon season for Chikkaballapura taluk (Fig 5 & 6). In a similar study in the Sirdala block of Nawada district by Kumar and Maurya (2023), Ca–Mg–HCO_3 hydrochemical facies were dominant in 45% of the samples, followed by Na–K–HCO_3, Ca–Mg–Cl–SO4 and Na–K–Cl–SO4 with 23.34, 21.67, and 9.99% of the total sample, respectively. Similarly, the dominance of Ca–Mg–HCO_3 water type was reported by Ravikumar *et al.* 2011 in the Markandeya river basin, Belgaum district, Karnataka. Further, the dominance of alkaline earth metals (Ca + Mg) over alkali metals (Na + K) and weak acidic anions (HCO_3) over strong acidic anions (SO_4 + Cl) was also apparent from these figures. These findings indicated that indirect base exchange reactions are regulating the groundwater chemistry, attributed to the dissolution of carbonate minerals such as dolomite and calcite (Ravikumar *et al.,* 2013) in the study area. Schoeller diagram (Fig. 7 and 8) demonstrated the supremacy of cationic and anionic concentrations in the order Ca > Na > Mg > K and HCO_3 > Cl > SO_4 > NO_3, respectively. The ionic distribution pattern in the Schoeller diagrams has backed the prevalence of Ca-Mg-HCO_3 water type in the study area.

3.3 | Mechanism Controlling Hydrogeochemistry

Gibbs plots (Fig. 9) specify that the water chemistry of all the groundwater samples of the study region is principally influenced by rock weathering during both pre- and post-monsoon seasons. This clearly indicates the dissolution of rock minerals (Ravikumar *et al.,* 2011) at the rock-water interface, thereby controlling the chemical composition of groundwater.

3.4 | Groundwater Suitability for Drinking

The WQI values ranged from 6.95 to 108.97 (mean: 41.1) and 8.66 to 120.10 (mean: 47.3) during pre- and post-monsoon seasons (Fig. 10). Among 68 groundwater samples analyzed, 64.7 and 63.3 % belong to the excellent to good category, illustrating groundwater suitability for drinking purposes. The remaining 35.3% and 36.7 % of the groundwater samples demonstrated their unsuitability for drinking purposes owing to the high concentrations of salinity, TDS, total hardness, total alkalinity, etc.

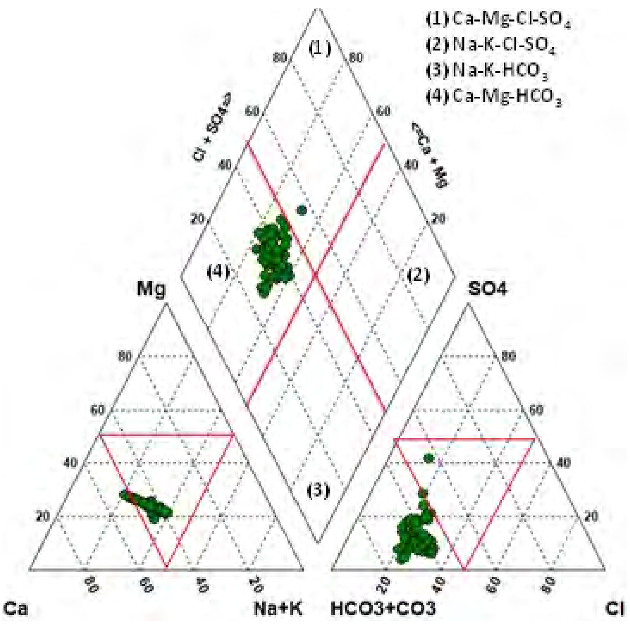

FIGURE 5 Piper trilinear diagram for the pre-monsoon season

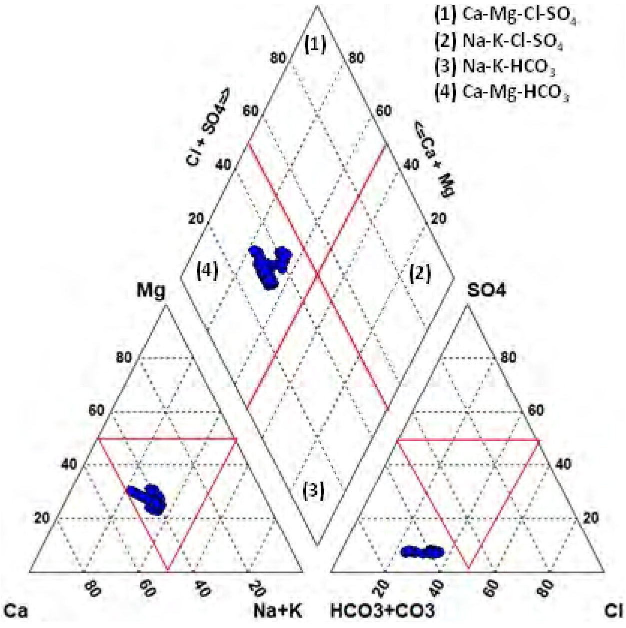

FIGURE 6 Piper trilinear diagram for the post-monsoon season

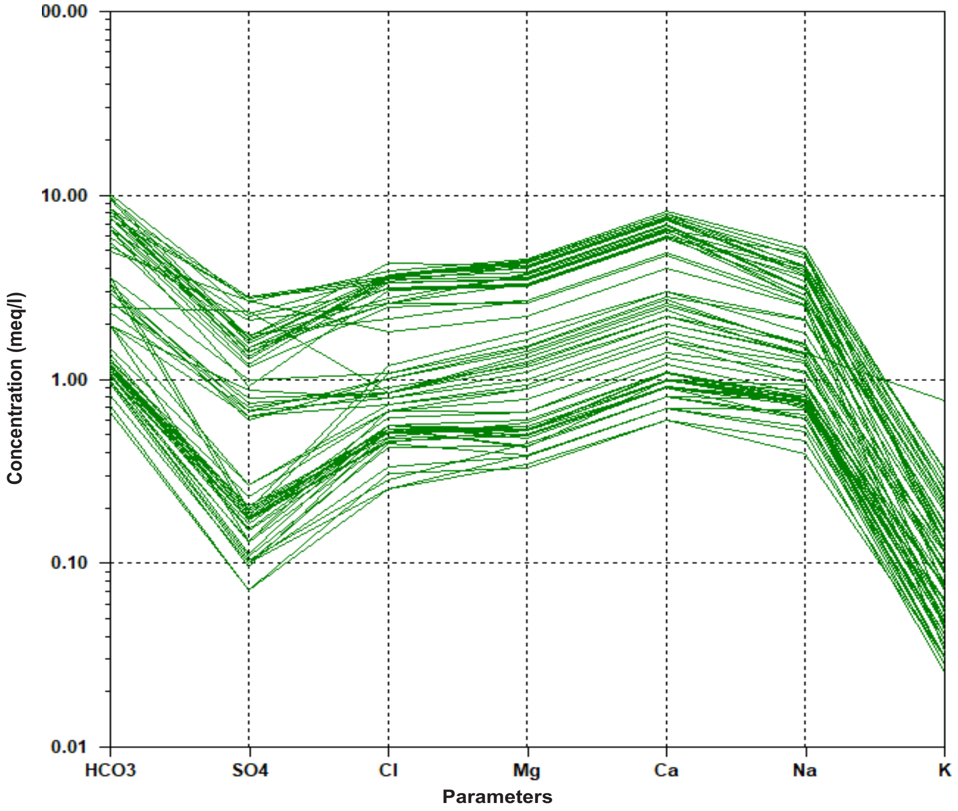

FIGURE 7 **Schoeller diagram showing the dominance of cations and anions (Pre-monsoon)**

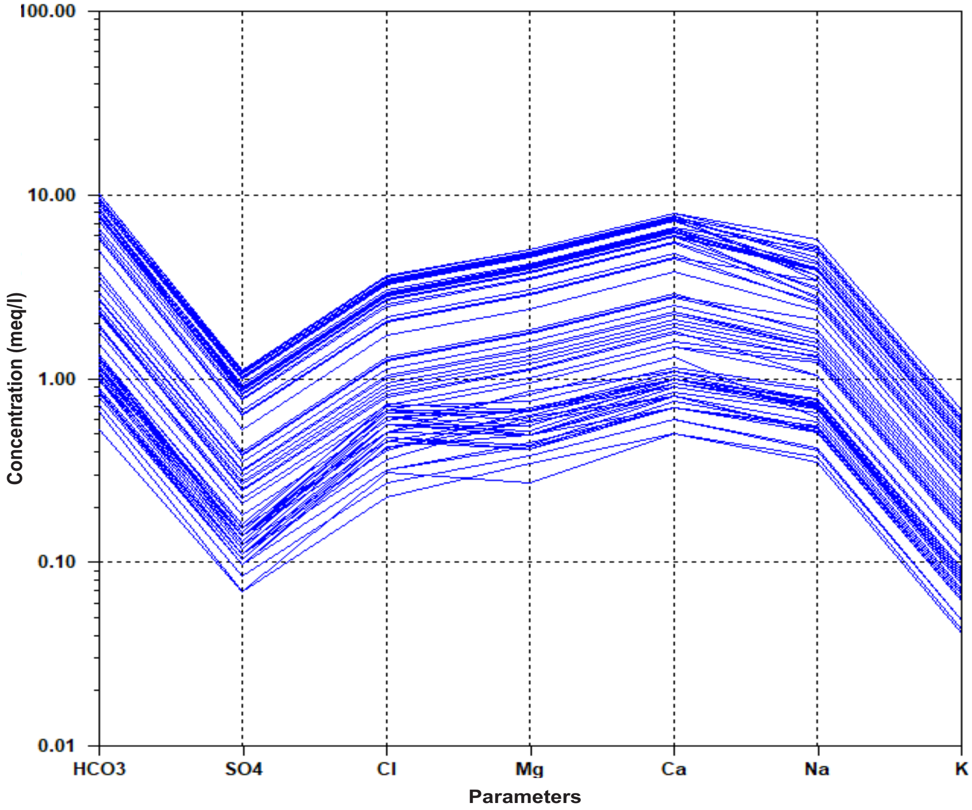

FIGURE 8 **Schoeller diagram showing the dominance of cations and anions (Pre-monsoon)**

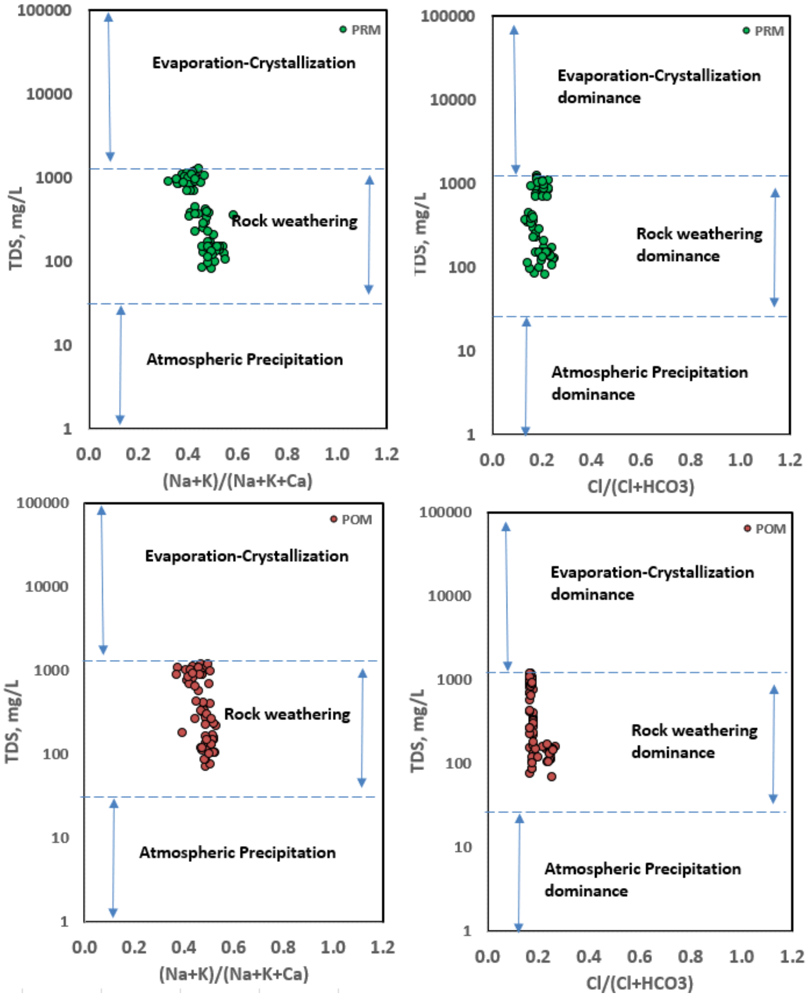

FIGURE 9 Gibbs plot for groundwater samples from Chikkaballapura taluk

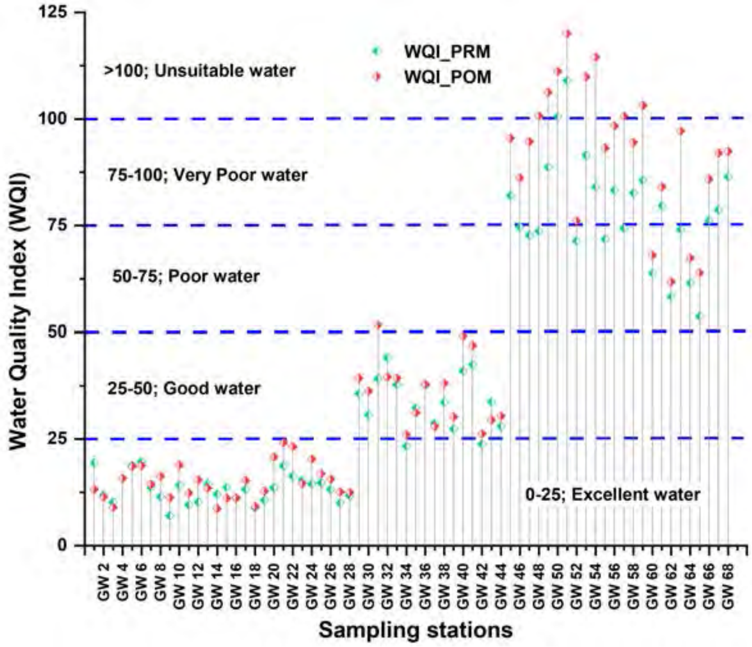

FIGURE 10 Spatio-temporal variation in WQI in the lake waters

TABLE 3 Rotated factor loadings and communalities

	Pre-monsoon					Post-monsoon				
Variable	PC1	PC2	PC3	PC4	Communality	PC1	PC2	PC3	PC4	Communality
Ca	**0.961**	-0.183	-0.121	-0.137	0.991	0.989	0.081	0.107	0.028	0.998
Mg	**0.961**	-0.183	-0.123	-0.136	0.991	0.989	0.083	0.106	0.021	0.997
Na	**0.962**	-0.194	-0.060	-0.043	0.969	0.978	0.057	0.087	0.015	0.967
K	0.345	-0.882	-0.202	-0.060	0.942	0.978	0.057	0.087	0.015	0.967
Cl	**0.958**	-0.176	-0.061	-0.136	0.971	0.987	0.065	0.132	0.031	0.996
TA	**0.962**	-0.190	-0.109	-0.128	0.990	0.990	0.086	0.098	0.023	0.998
HCO_3	**0.962**	-0.190	-0.109	-0.128	0.990	0.990	0.086	0.098	0.023	0.998
SO_4	**0.887**	-0.132	-0.019	0.175	0.836	0.989	0.081	0.107	0.028	0.998
NO_3	**0.787**	-0.212	-0.231	-0.083	0.725	0.989	0.081	0.107	0.028	0.998
PO_4	0.138	-0.175	-0.955	-0.020	0.963	0.211	0.925	-0.002	0.316	1.000
F	**0.721**	0.163	-0.307	0.191	0.676	-0.004	0.967	0.008	-0.253	1.000
EC	**0.970**	-0.195	-0.100	-0.093	0.997	0.991	0.080	0.103	0.024	1.000
TDS	**0.970**	-0.195	-0.100	-0.093	0.997	0.991	0.080	0.103	0.024	1.000
TH	**0.961**	-0.183	-0.122	-0.137	0.991	0.989	0.082	0.107	0.025	0.998
pH	-0.126	0.050	0.013	**0.976**	0.971	-0.194	-0.001	-0.981	-0.001	1.000
Variance	**10.426**	**1.219**	**1.197**	**1.157**	**13.999**	**11.786**	**1.863**	**1.093**	**0.171**	**14.914**
% Var	**0.695**	**0.081**	**0.080**	**0.077**	**0.933**	**0.786**	**0.124**	**0.073**	**0.011**	**0.994**

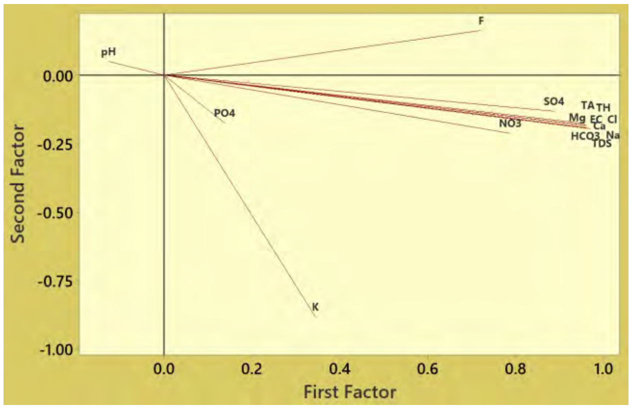

FIGURE 11 Loading plot for pre-monsoon season samples

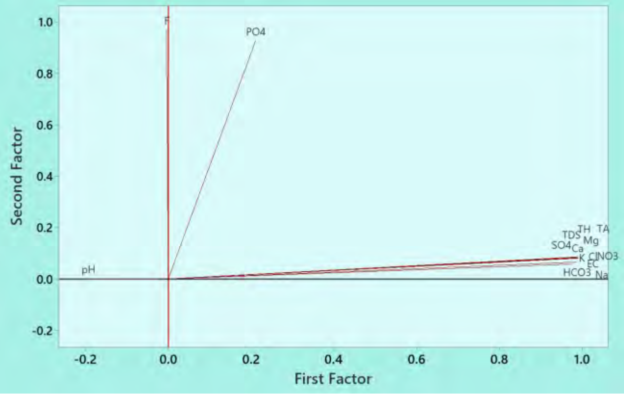

FIGURE 12 Loading plot for post-monsoon season samples

3.5 | Principal Component Analysis (PCA)

Principal component analysis (PCA) is a dimensionality-lessening technique frequently employed to reduce the dimensionality of large datasets. It reduces a large variable group into a set of new, smaller variables known as principal components, retaining the majority of the original information of the extensive set. These combinations are constructed in such a way so that the majority of the information in the original variables is compressed or squeezed into the first components, and the new variables (i.e., main components) are uncorrelated. PCA attempts to include as much information as feasible in the first component, then as much information as possible in the second, and so on.

Table 3 summarizes the outcome of the principal component analysis, including the loadings, eigenvalues and variance elucidated by each factor. PCA analysis yielded four principal components (PC1, PC2, PC3 and PC4) with higher eigenvalues of 1.0 or more, accounting for 69.5, 8.1, 8.0 and 7.7 % of the total variance during PRM season, respectively, and 78.6, 12.4, 7.3 and 1.1 % of the total variance during POM season respectively. Consequently, loading plots determined that the physio-chemical parameters loaded under PC1 had strongly favourable loading (>0.75) (Fig. 11 and 12) and were mainly responsible for regulating the hydrochemistry of groundwater in the study area.

3.6 | Groundwater Suitability for Irrigation

The chemical components of drinking water are crucial in determining its appropriateness since they impact human health. Based on salinity hazard values (USSL, 1954), 33.8, 30.9 and 35.3 % of the groundwater samples during pre-monsoon and 29.4, 35.3 and 35.3 % of groundwater samples

TABLE 4 Classification of Groundwater samples based on electrical conductivity and total hardness

Parameter	Water class	USSL class	PRM- (n = 68)		POM (n = 68)	
			No. of samples	Range (%)	No. of samples	Range (%)
EC	Excellent (<250 µS/cm)	Low (C1)	23	138.7-249.6 (33.8)	20	118.4-248.1 (29.4)
	Good (250-750 µS/cm)	Medium (C2)	21	251.2-741.2 (30.9)	24	253-725.9 (35.3)
	Permissible (750-2250 µS/cm)	High (C3)	24	1150.5-2109.7 (35.3)	24	947.4-2000.4 (35.3)
	Doubtful (>2250 µS/cm)	Very high (C4)	---	---	---	---
TH	Soft (<75 mg/L)	---	16	46.5 - 71.4 (23.5)	16	38.7-73.6 (23.5)
	Moderately hard (75-150 mg/L)		17	75.1-139.4 (25.0)	18	77.1-147.0 (26.5)
	Hard (150-300 mg/L)		11	154.9-240.5 (16.2)	10	155.1-236.8 (14.7)
	Very hard (>300 mg/L)		24	309.1-637.3 (35.3)	24	310.3-653.2 (35.3)

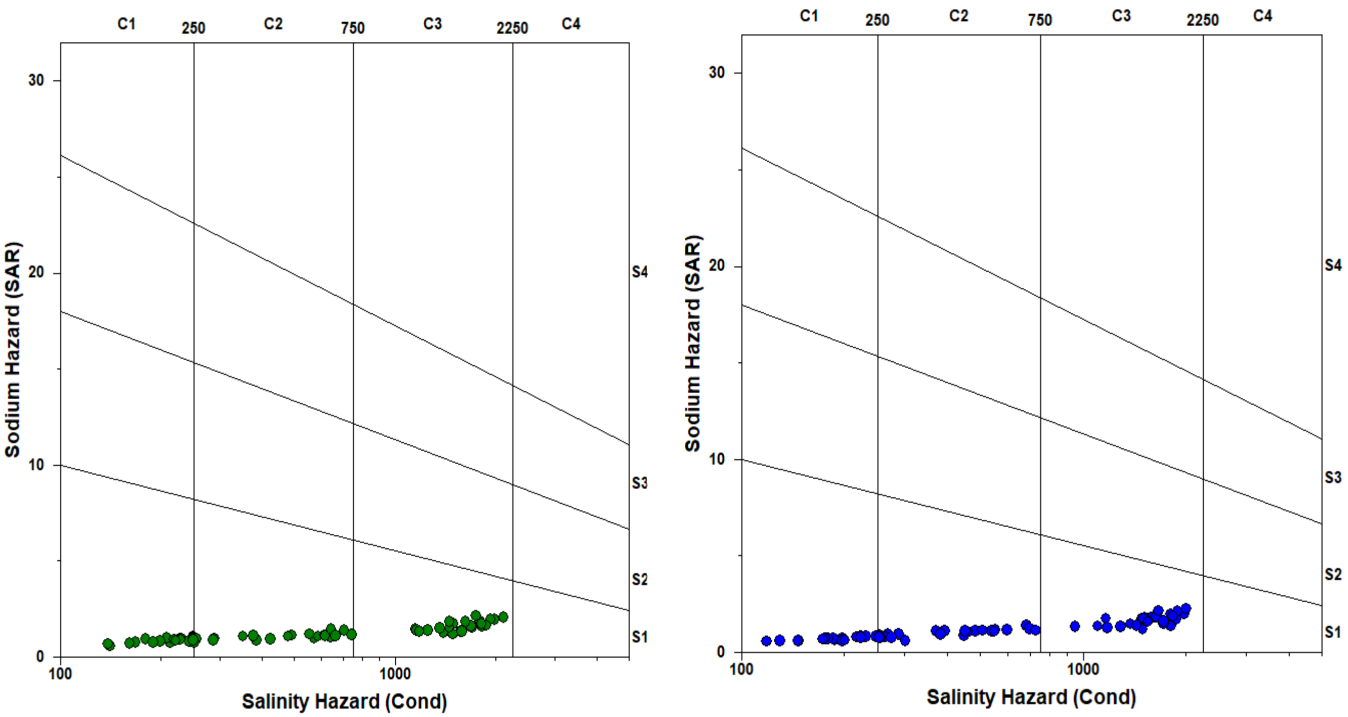

FIGURE 13 US Salinity diagram for groundwater samples from Chikkaballapura taluk

during post-monsoon, respectively, belong to excellent (< 250 µS/cm; C1 – low salinity), good (250-750 µS/cm; C2 – medium salinity), and permissible (750-2250 µS/cm; C3 - high salinity) categories (Table 4). This demonstrated that a higher percentage of groundwater during pre- and post-monsoon seasons witnessed medium to high salinity hazards. Similarly, classification based on total hardness values, 23.5, 25.0, 16.2 and 35.3 % of the groundwater samples during pre-monsoon and 23.5, 26.5, 14.7 and 35.3 % of groundwater samples during post-monsoon, respectively, fall under soft, moderately hard, hard, and very hard classes. In similar case studies, Ravikumar *et al.* (2011) reported high salinity-low sodium (C3S1) water type in 59.57 % of the samples in Markandeya River basin while Kumar and Maurya (2023) categorized the groundwater samples as soft (18.46%), slightly hard (70.7%), hard (18.4%) and very hard (7.6%) in Sirdala block of Nawada district.

Sodium adsorption ratio (SAR) is a better measure of the suitability of water for irrigation, and it denotes the relative contribution of sodium ions in exchange reactions with the soil. The SAR values range from 0.57 to 2.15 (mean: 1.18) and 0.56 to 2.25 (mean: 1.15) in the groundwater of Chikkaballapur taluk during pre- and post-monsoon seasons, respectively (Table 5). It is evident that all groundwater samples analysed belong to the low sodium (S1) class and can be used to irrigate all types of soils (U.S. Salinity Laboratory, 1954). Further, USSL diagram classified 33.8, 30.9 and 35.3 % of pre-monsoon samples and 29.4, 35.3 and 35.3 % of post-monsoon samples to fall under C1S1 (viz., low salinity and low sodium hazard), C2S1 (viz., medium

TABLE 5 Groundwater suitability for irrigation quality parameters

Parameters	Formula	Unit	Obtained Analytical results (n=68)						Classification	
			Pre-monsoon (PRM-2022)			Post-monsoon (POM-2022)				
			Mean	Min	Max	Mean	Min	Max	Excellent water	Good water
Salinity hazard (USSL, 1954)	----	µS/cm	782.1	138.74	2109.7	759.6	118.4	2000.4	< 250	< 750
Hardness levels (Todd, 1980)	$\text{TH (CaCO3)}\,\frac{\text{mg}}{\text{L}} = 2.5\ \text{Ca}^{2+} + 4.1\ \text{Mg}^{2+}$	mg/L	250.2	46.46	637.29	252.7	38.7	653.2	< 75 (soft)	< 150 (moderately hard)
Percent Sodium or sodium percentage (Wilcox, 1995)	$\%\text{Na} = \left(\frac{\text{Na}^{+} + \text{K}^{+}}{\text{Na}^{+} + \text{K}^{+} + \text{Ca}^{2+} + \text{Mg}^{2+}}\right) \times 100$	%	31.5	20.88	40.07	31.4	22.5	36.1	< 20	< 40
Sodium absorption ratio (SAR) Richards (1954)	$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}$	---	1.18	0.57	2.15	1.15	0.56	2.25	< 10 (low)	< 18 (medium)
Magnesium hazard (MH or MAR) (Szabolcs and Darab, 1964)	$\text{MH} = \left(\frac{\text{Mg}^{2+}}{\text{Ca}^{2+} + \text{Mg}^{2+}}\right) \times 100$	---	35.3	30.01	37.68	38.8	35.5	43.8	< 50 (suitable)	----
Residual sodium carbonate (RSC) (Ragunath, 1987)	$\text{RSC} = (\text{CO}_3 + \text{HCO}_3) - (\text{Ca}^{2+} + \text{Mg}^{2+})$	meq/L	-3.46	-8.84	-0.62	-3.61	-9.44	-0.46	< 1.25 (suitable)	
Soluble sodium percentage (SSP)	$\text{SSP} = \left(\frac{\text{Na}^{+}}{\text{Na}^{+} + \text{Ca}^{2+} + \text{Mg}^{2+}}\right) \times 100$	%	30.2	20.61	38.76	29.1	20.7	33.6	<50 (suitable)	

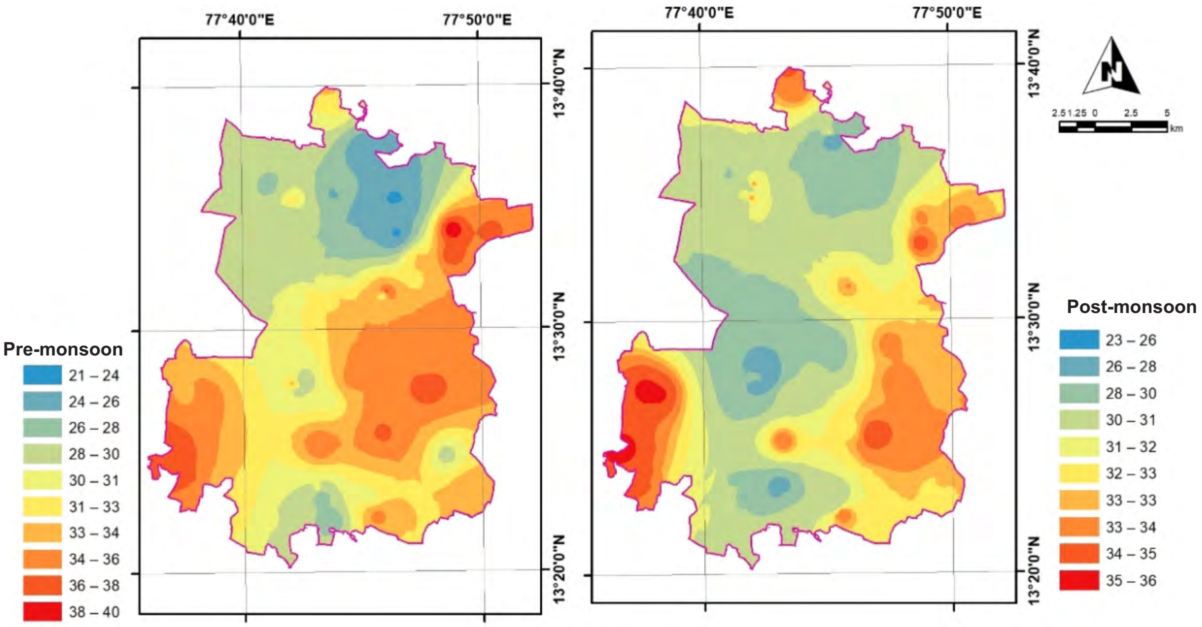

FIGURE 14 Spatio-temporal distribution in Percent sodium in Chikkaballapura taluk

salinity and low sodium hazard), and C3S1 (viz., high salinity and low sodium hazard) classes as shown in Fig. 13.

Residual sodium carbonate (RSC) refers to the high bicarbonate ion concentration in irrigation water, which increases soil pH, causes plant toxicity, and affects the mineral nutrition of plants. RSC precipitates calcium and magnesium in soil and increases sodium content in the soil. The RSC values ranged from (-8.84) to (-0.62) with a mean value of (-3.46) during the pre-monsoon season and (-9.44) to (-0.46) with a mean value of (-3.61) during the post-monsoon season (Table 5). All the RSC values were <1.25 (Eaton, 1950) in the study area during both seasons, thus rendering the water suitable for irrigation.

A magnesium absorption ratio higher than 50 in groundwater is detrimental and unsuitable for irrigation as it adversely affects crop yield by making the soils more alkaline (Szabolcs and Darab, 1964). In the study area, the Magnesium Absorption Ratio (MAR) or Magnesium hazard (MH) values varied between 30.0 to 37.7 (mean: 35.3) and 35.5 to 43.8 (mean: 38.8) during pre- and post-monsoon seasons (Table 5). Accordingly, 100 % of pre- and post-monsoon season samples were suitable during pre- and post-monsoon seasons as magnesium absorption ratio values were below 50.

The irrigation water quality classifications based on the values of sodium percentage (Wilcox, 1995) can also be used for suitability assessment. Sodium percentage values varied between 20.9 to 40.1 (mean: 31.5) and 22.5 to 36.1 (mean: 31.4), respectively, during pre- and post-monsoon seasons (Table 5). It is evident that 100 % of pre- and post-monsoon season samples were excellent to good quality (viz., sodium percentage < 40) for irrigation (Fig. 14). Soluble sodium percentage (SSP) values ranged from 20.6 to 38.8 (mean: 30.2) and 20.7 to 33.6 (mean: 29.1) during pre- and post-monsoon seasons and were well below 50, illustrating their suitability.

4 | CONCLUSIONS

The present study was conducted to understand the hydro-geochemical characteristics and evaluate groundwater suitability by collecting and analysing 68 bore well samples. The dominant hydro-geochemical facies was Ca-Mg-HCO_3, with alkaline earth metals and weak acidic anions surpassing alkalis and strong acidic anions. Fluoride concentration was well below the desirable limit of 1.0 mg/L during pre- and post-monsoon seasons. During the study periods, 64.7 and 63.3% of the groundwater samples were safe for drinking and other utilitarian purposes. The remaining bore wells were categorized as unsuitable, attributed to higher salinity, TDS, hardness, and total alkalinity values. PCA analysis illustrated that 80% of the physio-chemical parameters loaded under PC1 were having strong positive loading (>0.75) during both the seasons and were responsible for controlling groundwater chemistry. USSL classification of groundwater samples revealed that 35.3 % during pre- and post-monsoon were C3S1 water type (viz., high salinity-low sodium hazard water), which may need to be applied for croplands with proper drainage. The remaining groundwater samples belong to C1S1 (low salinity and low sodium hazard) and C2S1 (medium salinity and low sodium hazard) water types during both seasons and were suitable for irrigation. Similarly, soft to moderately hard water accounted for 48.5% and 50 % of pre- and post-monsoon season samples, compared to 51.5% and 50 % of samples under hard to very hard water. Sodium adsorption ratio, residual sodium carbonate, magnesium hazard and percent sodium and soluble sodium percentage values confirmed groundwater suitability for irrigation as all the samples analysed fall under excellent to good water classes. As public health is directly connected to drinking water quality, its systematic and regular monitoring is essential to discern the extent of the groundwater pollution rate.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

CONFLICT OF INTEREST

The author declare no conflicts of interest.

AUTHOR'S CONTRIBUTION

The corresponding author (Tanaya S. Murthy) designed and performed the experiments, analysed, and tabulated the data of the findings of the work. The author has contributed to the final manuscript preparation.

REFERENCES

APHA. 2017. Standard Methods for the Examination of Water and Wastewater (23^{rd} ed.). Washington DC: American Public Health Association.

BIS. 2012. Indian Standards Specification for Drinking Water, BIS: 10500: 2012. http://www.cgwb.gov.in/Documents/WQ-standards.pdf.

CGWB. 2012. Central Ground Water board - Groundwater Information booklet - Chikkaballapur district, Karntaka, Ministry of Water Resources, Government of Karnataka.

Das, M., Nayak, A.K., Verma, O.P. and Sethi, R. 2023. Assessment and processing of groundwater quality from various land uses-a case study in Odisha. *Indian Journal of Soil Conservation,* 51(1): 1-8.

Eaton, F.M. 1950. Significance of carbonates in irrigated waters. *Soil Science,* 69:127-128.

Gibbs, R.J. 1970. Mechanisms Controlling World's Water Chemistry. *Science,* 170:1088-1090. https://doi.org/10.1126/science.170.3962.1088.

Hem, J.D. 1970. Groundwater hydrology. McGraw-Hill, Kogakusha, Ltd, Tokyo, 480p.

Kumar, A., and Maurya, N.S. 2023. Groundwater quality assessment using the WQI and GIS mapping: suitability for drinking and irrigation usage in the Sirdala block of Nawada district. *Water Supply*, 23(2): 506-525.

Piper, A.M. 1944. A graphic procedure in the geochemical interpretation of water-analyses. *Eos, Transactions American Geophysical Union*, 25(6), pp.914-928.

Ragunath, H.M. 1987. Groundwater, 2nd ed. Wiley Eastern Ltd., New Delhi, India.

Ravikumar, P, Somashekar, R.K. and Angami, M. 2011. Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya river basin, Belgaum district, Karnataka State, India. *Environmental Monitoring and Assessment,* 173(1-4): 459-487. https://doi.org/10.1007/s10661-010-1399-2.

Ravikumar, P., Prakash, K.L. and Somashekar, R.K. 2013. Evaluation of water quality using geochemical modeling in the Bellary Nala Command area, Belgaum district, Karnataka State, India. *Carbonates and Evaporites*, 28: 365-381, doi: 10.1007/s13146-012-0124-3.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. US Department of Agriculture, Agri. Hand book 60, Washington USA.

Schoeller, H. 1960. "Salinity of groundwater, evapotranspiration and recharge of aquifers". IASH pulls. France.

Singh, K.R., Gupta, A. and Kumar, M. 2023. Water management for supplemental irrigation based on rainfall characteristics of Ranchi district, India. *Indian Journal of Soil Conservation,* 51(1) 41-49 DOI : 10.59797/ijsc.v51.i1.148.

Szabolcs, I. and Darab, C. 1964. The influence of irrigation water of high sodium carbonate content on soils. In: Szabolics I (ed) Proceedings of 8th international congress soil science sodics soils research institute of soil science and agricultural chemistry, Hungarian Academy of Sciences, ISSS Trans II, pp 802-812.

Todd, D.K.1980. Groundwater hydrology, 2nd ed. Wiley, New York USA.

USSL. 1954. U.S. Salinity Laboratory Staff - Diagnosis and improvement of saline and alkali soils. USDA Agriculture Hand Book No. 60, U.S. Government Printing Office, Washington, D. C. USA.

Wilcox, L.V. 1995. Classification and Use of Irrigation Waters. U.S.D.A Circular No. 960, Washington DC, 19.

Yadav, G.K., Jagdhani, A.D., Sawale, D.D., Yadav, K., Kumawat, C. and Dadhich, S.K. 2020. Assessment of irrigation water quality of agriculture technical school, Manjri farm, Pune. *Indian Journal of Soil Conservation,* 48(3): 262-268.

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