Full Length Research Article

© 2024, Centre for Advanced Research in Agricultural Sciences
Research Journal of Agricultural Sciences
Volume 15; Issue 01 (Jan–Feb 2024); pp 16–23

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

Evaluation of Ground Water Quality in Long Term Paddy Cultivation: The Central Dry Agricultural Zone of Harihara Taluk, Davanagere District, Karnataka, India

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Received: 22 Sep 2023; Revised accepted: 11 Dec 2023; Published online: 03 Jan 2024

Abstract

An attempt was made to assess the quality and suitability of 60 selected bore well waters in Harihara taluk of Davanagere district of Karnataka, India during pre-monsoon season (April 2022). As per Piper trilinear diagram, 40 % of the samples belong to Ca-Mg-HCO3, 21.7 % to Na-K-HCO3 type, 20 % to Na-K-Cl-SO4 type and 18.3% to Ca-Mg-Cl-SO4 type. HCA yielded four clusters of samples, of which cluster 1 and cluster 2 samples includes the largest numbers of wells accounting for 41.7 and 31.7 % of samples. The samples under these were characterised by the highest salinity, TDS, total hardness, total alkalinity, nitrate, bicarbonate, and sodium levels. Higher salinity and TDS problem are predominant in the study area as 71.67 and 78.34 % of the samples witnessed electrical conductivity and TDS beyond 1000 µS/cm and 500 mg/L respectively. The groundwater samples were also hard to very in nature as the total hardness in 90% of samples was beyond 200 mg/L and fluoride exceeded 1.0 mg/L in 53.33% of the samples. USDA classification indicated that 76.67% of the samples belong to C3S1 and C3S2 categories, indicating the high salinity-low sodium hazard and high salinity-moderate sodium hazard nature of the groundwater.

***Key words*:** Agriculture, Harihara, Cluster analysis, Davanagere, Groundwater, Fluoride, Total hardness, TDS

Water is a unique natural resource among all the resources available on the earth. Being "elixir of life", water is the most vital and reliable requirements for all the living organisms. In spite of this, global consumption of water has recently been doubling, more than twice the rate of human population growth, food production, industrial production, energy production, etc. Alernately, people in many parts of the world are struggling for lack of fresh, potable water for which industrial pollution, population explosion and climate change are heaviliy blamed besides contribution from agricultral inputs and industrialization. Among water resources, groundwater is the utmost important source of water for anthropological activities like drinking, domestic, agricultural, industrial, requirements, etc. [1] due to inadequate freshwater [2]. The accessibility of a good quality water supply is very much needed for human survival both in terms of quantity and quality. Unfortunately, there is no guarantee of perfect groundwater quality owing to influence of geological formations, salt water intrusion and anthropogenic inputs [3-5] like percolation and leaching of pollutants / microbes from sources such as refuse dumps, aqua farms, mines, septic tanks, etc. Sometimes, frequent drought spells in many parts of the world, lack of rains / snowfall, drying of rivers and lakes, water shortages, water famine, water restrictions, etc., can reflect the water crisis across the globe. Hence, the quality of groundwater assumes greater importance in any part of the world as the pollution not only affects water quality but also threats human health, economic development and social prosperity. In recent decades, the drinking of polluted water has raised many health problems such as the toxicity of nitrate, fluoride, arsenic, boron, etc. [6-7] besides radiological hazards from radon and uranium, etc.

The groundwater crisis is not the result of natural factors it has been caused by human activities. During the past two decades, the water level in several parts of the country has been falling rapidly due to an increase in extraction. The number of bore wells drilled for irrigation for both food and cash crops has rapidly increased. India's rapidly rising population and changing lifestyle have also increased the domestic need for water. Human dependence on groundwater has steadily increased as moved away from perennial sources of surface water to harness agricultural lands and in more recent times for developing industries. In view of the above facts, even in the parts of Harihara Taluk, the quality of available potable water resources has deteriorated by extensive agricultural activities and over-exploitation besides anthropogenic activities. Hence, the present study is focused on the assessment of status of groundwater in Harihara Taluk.

Study area

Davangere district covers a geographical area of 5975.97 km^2 and comprises six taluks. A major part of the district lies in the Krishna basin and is drained by Tungabhadra and Chikka Hagari Rivers. The district falls under the central dry agro-climatic zone of the Karnataka state and is categorized as

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Citation: Halesha JH, Prakash KL. 2023. Evaluation of ground water quality in long term paddy cultivation: The central dry agricultural zone of Harihara Taluk, Davanagere district, Karnataka, India. *Res. Jr. Agril. Sci.* 15(1): 16-23.

drought-prone. The district enjoys a semi-arid climate, dryness in the major part of the year and hot summer. In general, the southwest monsoon contributes 58% of total rainfall and the northeast monsoon contributes 22% of rainfall. The remaining 20% of rainfall is received as sporadic rains in the summer months. It receives low to moderate rainfall. Normal annual rainfall varies between 556 mm in Jagalur and 808 mm in Channagiri taluk. Normal climatic parameters of Davangere district are increasing temperature from March to May, usually maximum in April month and minimum temperature that is the coldest month during December (CGWB, 2008).

Groundwater occurs under phreatic and semi-confined conditions in the weathered and fractured rock formations of the 'Peninsular Gneissic Group' of rocks comprising of granites, gneisses and schist. The thickness of the weathered zone varies from 4.0 – 36.74 m. The main source of groundwater occurring in the district is through precipitation and return flow from applied irrigation. Harihara Taluk (Fig 1) falls under the Central Dry Argo-climatic Zone of Karnataka state and is categorized as drought-prone with a semi-arid climate. Dry and hot weather prevails in the significant part of the year. The rainy season lasts from June to September due to the onset of the southwest monsoon. In Harihar taluk, schists are the main water-bearing formation. Groundwater occurs within the weathered and fractured rocks. Groundwater exploration reveals that aquifer systems are encountered from a depth of 21 mbgl to 51 mbgl. In Harihar taluk bore wells were drilled from a minimum depth of 86.55 mbgl to a maximum of 200 mbgl. The depth of the weathered zone ranges from 23 mbgl to 25 mbgl. Yield ranged from 0.07 to 3.28 lps. Transmissivity ranged from 1.0 to 8.0 m2/day. During May 2006 (pre-monsoon season) the minimum depth to water level and the maximum water level was 2.37 mbgl and 8.42 mbgl respectively. During November 2006 (Post-monsoon) water level ranged from 2.27 mbgl to 7.08 mbgl (CGWB, 2008).

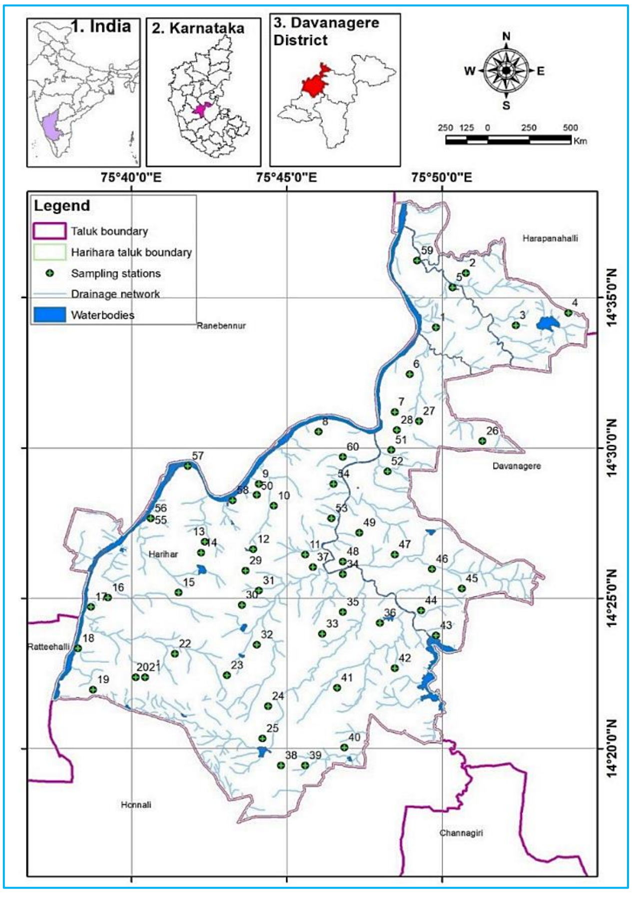

Fig 1 Location map of Harihara taluk showing sampling stations

A major part of the district is covered by red sandy soil and followed by black soil. Red sandy soil is spread throughout the district except in a small area in the northeastern part of the district where the area is covered by black soil. The Red Sandy soil comprises red loams, red sandy, sandy loams and medium black soils. Agriculture is the main occupation and source of income for the people of the taluk as well as the entire district, and the major crops grown in the district are maize, paddy, jowar, ragi, red gram, green gram, groundnut, and sunflower, among which paddy is the most growing crop due to the availability of water to increase the productivity farmers are using chemical fertilizers and pesticides. Rice, wheat, and maize together directly supply more than 50% of all calories consumed by the entire human population in the world; wheat is the leader in area harvested each year with 214 million ha, followed by rice with 154 million ha and maize with 140 million ha. Human Consumption pattern among these is 85% of total production for rice, compared with 72% for wheat and 19% for maize [8].

MATERIALS AND METHODS

A total of 60 groundwater were collected in polyethene bottles of 1 litre from various borewells spread across Harihara taluk (Fig 1) was collected during pre-monsoon season (April 2022). Bore wells were continuously pumped for 10-15 mins. Standard APHA [10] methods were followed during the sampling, labelling, storage, preservation, and transportation of groundwater samples. To prevent changes in equilibrium and adsorption on the inner surface of the bottles, groundwater samples were acidified with 1:1 extra pure HNO_3. The groundwater samples were analyzed for fluoride and nitrate content using HACH DR/890 colorimeter and Elico SL-171 spectrophotometer. A few parameters like pH, EC and TDS were measured at the time of sampling using HACH *HQ30D* portable multi-parameter kit while all other parameters were analyzed after transporting the samples to the laboratory at Department of Environmental Science, Bangalore University, Bangalore. The analytical results were then subjected to statistical analyses, which include descriptive statistics of physico-chemical parameters and Hierarchical cluster analysis. Q-mode type of cluster analysis was performed to check similarities/dissimilarities among the sampling stations thereby data/observations can be grouped into a few segments/clusters so that data within any segment/cluster can be interpreted as similar while data across segments is different. Further, box plots were constructed to demonstrate the spatial variation in the physico-chemical parameters across the clusters.

RESULTS AND DISCUSSION

Groundwater chemistry

All the physico-chemical parameters analyzed in the groundwater samples from Harihara taluk along with descriptive statistics and their respective BIS [9] drinking water quality standards are presented in (Table 1).

In the present study, pH values ranged from 6.25 to 7.75, with an average value of 7.11, illustrating a slightly acidic to slightly alkaline nature (Fig 2A). Among the samples analyzed, 58 samples (viz., 96.7%) recorded pH values within the BIS [9] desirable limit of 6.5-8.5.

The electrical conductivity (EC) of natural water is due to the presence of salts, which dissociate into cations and anions. Electrical conductivity values varied from 273 to 4101 µS/cm, with a mean value of 1438.2 µS/cm (Fig 2B). In the present study, electrical conductivity values were above 1000 and 2000 µS/cm respectively in forty-three (viz., 71.67%) and eight groundwater (viz., 13.3 %) samples, illustrating the salinity problem. Similarly, total dissolved solids ranged between 140 to 2177 mg/L, with a mean value of 756.5 mg/L (Fig 2C). In the study area, 46 samples (viz., 76.67%) recorded TDS values well above BIS [9] desirable limit of 500 mg/L and 8 samples (viz., 3.3%) had higher TDS values above BIS [9] permissible limit of 2000 mg/L.

Table 1 Analytical results for groundwater samples (n=60) from Harihara Taluk

Parameters	Unit	Descriptive statistics			BIS [9] standard limit for drinking water	
		Mean	Min	Max	Requirement (Acceptable limit)	Permissible limit in the absence of an alternate source
pH	-	7.11	6.25	7.75	6.5 – 8.5	No relaxation
Electrical conductivity (EC)	µS/cm	1,438.2	273.0	4,101.0	-	-
Total dissolved solids (TDS)		756.5	140.0	2,177.0	500	2000
Total hardness (as $CaCO_3$)		352.7	109.6	794.9	200	600
Total alkalinity (as $CaCO_3$)		353.8	86.2	560.4	200	600
Calcium (as Ca)		77.5	20.5	170.5	75	200
Magnesium (as Mg)		39.0	14.3	96.3	30	100
Sodium (as Na)		146.5	15.6	579.4	-	-
Potassium (as K)	mg/L	5.3	0.8	14.8	-	-
Phosphate (as PO_4)		0.044	0.017	0.667	-	-
Nitrate Nitrogen (as NO_3)		31.5	10.0	57.0	45	No relaxation
Sulphate (as SO_4)		93.9	13.3	315.0	200	400
Chloride (as Cl)		176.4	27.7	851.9	250	1000
Fluoride (as F)		0.99	0.13	1.38	1.0	1.5
Bicarbonates (as HCO_3)		431.7	105.2	683.8	-	-
Boron (as B)		0.078	0.010	0.250	0.5	1.0
Suitability for irrigation					Excellent water	Good water
Salinity hazard	mg/L	1,438.2	273.0	4,101.0	< 250	< 750
Hardness levels	mg/L	352.7	109.6	794.9	< 75	< 150
Percent Sodium	%	43.79	12.33	69.93	< 20	< 40
Sodium absorption ratio (SAR)	-	3.34	0.49	8.93	< 10	< 18

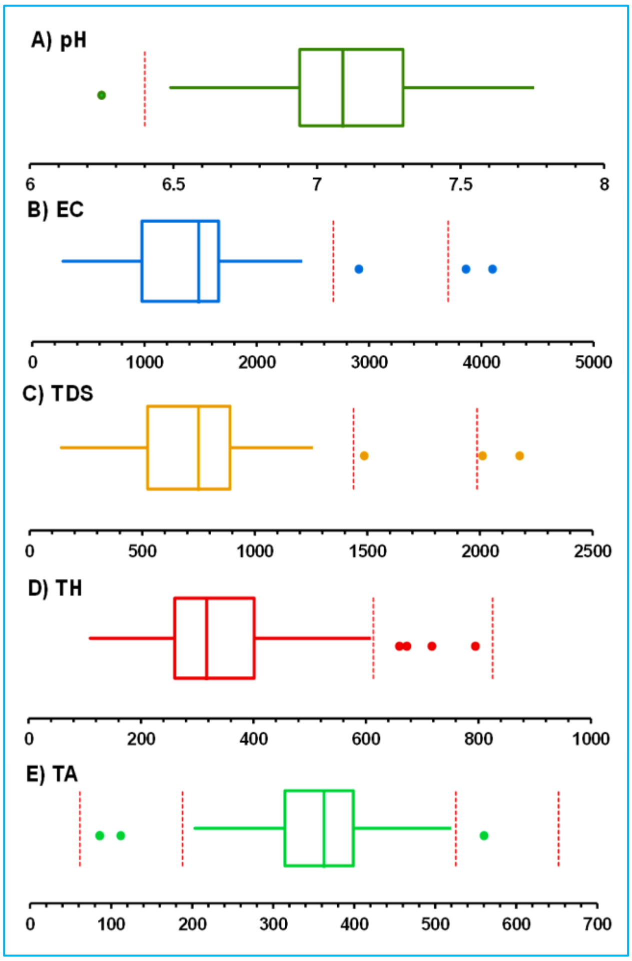

Fig 2 Box plot showing variation in pH, EC, TDS, total hardness, and total alkalinity

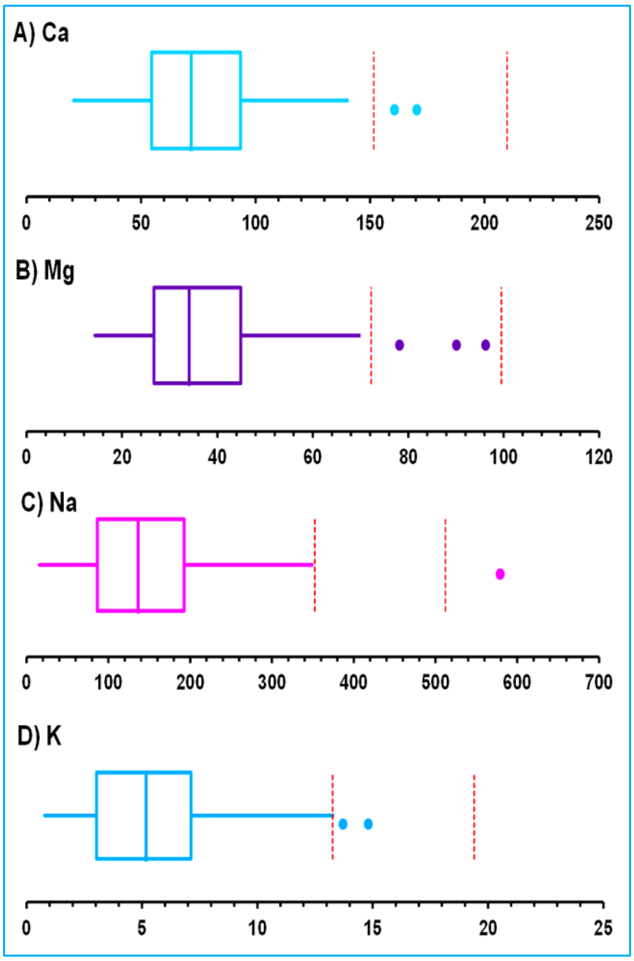

Fig 3 Box plot showing variation in major cations (Ca, Mg, Na, K)

Total hardness (Fig 2D) ranged from 109.6 to 794.9 mg/L (mean: 352.7 mg/L) while total alkalinity (Fig 2E) varied from 86.2 to 560.4 mg/L (mean: 353.8 mg/L) in the groundwater of the study area. Among the samples analyzed, 54 samples (viz., 90%) and 57 samples (viz., 95%) respectively recorded higher total hardness and total alkalinity values above the BIS [9] desirable limit of 200 mg/L. Alternately, only 5 samples showed higher total hardness above the BIS [9] permissible limit of 600 mg/L. None of the samples showed higher total alkalinity above the BIS [9] permissible limit of 600 mg/L.

All natural waters including surface and groundwater contain dissolved ionic constituents, categorized as major cations and major anions. Among major cations, calcium concentration varied from 18.9 to 200.5 mg/L (mean: 77.5 mg/L) and 29 samples (viz., 48.34 %) showed calcium content above BIS [9] desirable limit of 75 mg/L and only one sample (viz., 1.67%) witnessed its values over 200 mg/L (Fig 3A). Magnesium content ranged from 7.6 to 122.0 mg/L (mean: 39.0 mg/L) and it was noticed that 39 (viz., 65.0 %) and 2 samples (viz., 3.33 %) respectively showed magnesium values less than BIS [9] desirable and permissible limits of 30 mg/L and 100 mg/L (Fig 3B). Sodium concentration (Fig 3C) ranged from 15.6 to 579.4 mg/L (mean: 146.5) and high sodium content above 200 mg/L was observed in 16 samples (viz., 26.67%) while the concentration of Potassium ranged between 0.78 to 14.8 mg/L (mean: 5.3 mg/L) in the study area (Fig 3D).

Among the anionic composition, Bicarbonates and chloride dominate in most of the bore wells. Chloride concentration was found to vary between 27.7 to 851.9 mg/L (mean: 176.4 mg/L) and 12 samples (viz., 20 %) showed its levels above BIS [9] desirable limit of 250 mg/L (Fig 4A). Only 03 samples (viz., 5 %) showed higher sulphate (Fig 4B) concentration above BIS [9] desirable limit of 200 mg/L as it ranged from 13.3 to 330 mg/L (mean: 93.9 mg/L). Bicarbonate levels (Fig 4C) in groundwater samples varied between 105.2 to 683.8 mg/L (mean: 431.7 mg/L) while their nitrate (Fig 4D) levels were found to range from 10.0 to 57.0 mg/L (mean: 31.5 mg/L). Only 7 samples (viz., 11.67%) had nitrate levels above BIS [9] standard limit of 45 mg/L. Phosphate (Fig 4E) concentration ranged between 0.017 to 0.667 mg/L (mean: 0.044 mg/L). Fluoride (Fig 4F) in groundwater ranged from 0.13 to 1.38 mg/L (mean: 0.99 mg/L) and the spatial distribution of fluoride in Harihara taluk is presented in (Fig 5). It was observed that 32 samples (viz., 53.33%) had fluoride levels above the BIS desirable limit of 1.0 mg/L.

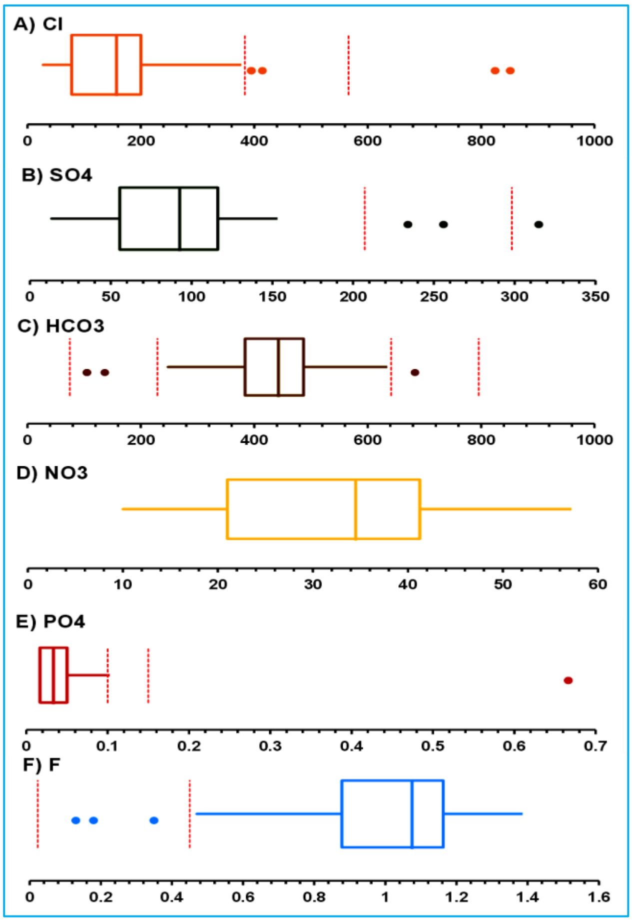

Fig 4 Box plot showing variation in major anions (Cl, SO_4, HCO_3, NO_3, PO_4, F)

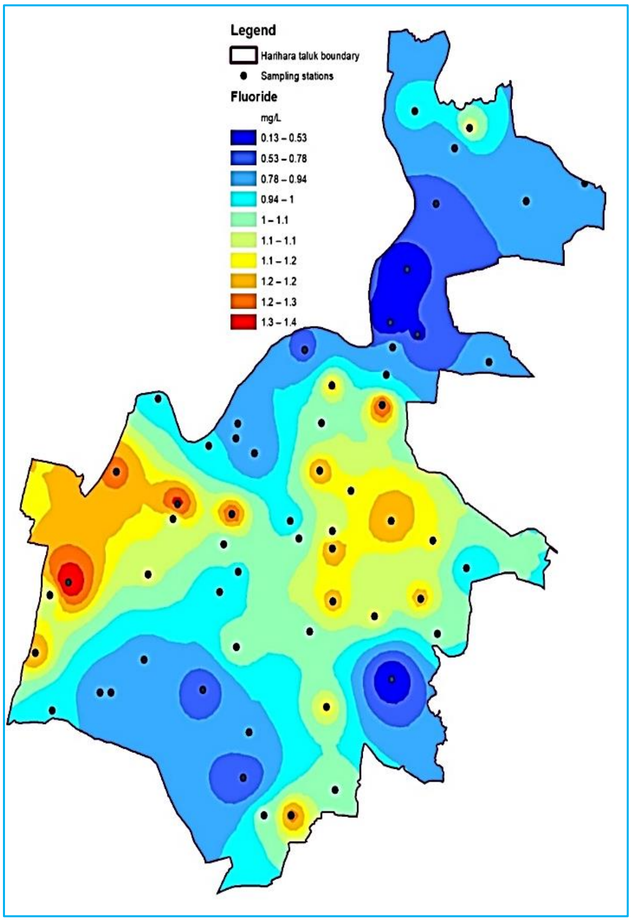

Fig 5 Spatial distribution of fluoride in the Harihara Taluk

Hydrochemical facies

A piper (trilinear) diagram is a specialized graph type for charting the chemistry of water samples and can be used to compare water chemistry data from multiple sources to assess water quality [11-12]. The ternary diagram in the lower left of the plot represents cations (magnesium, calcium, and sodium plus potassium) and the ternary diagram in the lower right represents anions (chloride, sulphate, and carbonate plus bicarbonate). The diamond plot in the middle is a matrix transformation of the two ternary diagrams. Each sample is normalized (sum of cations = 100 and sum of anions = 100), so their relative concentrations are represented as percentages. In other words, the percentage value of each cation group is calculated based on the total concentration of calcium, magnesium, and sodium plus potassium cations; The percentage of each anion group is based on the total concentration of sulphate, chloride, and carbonate plus hydrogen carbonate anions.

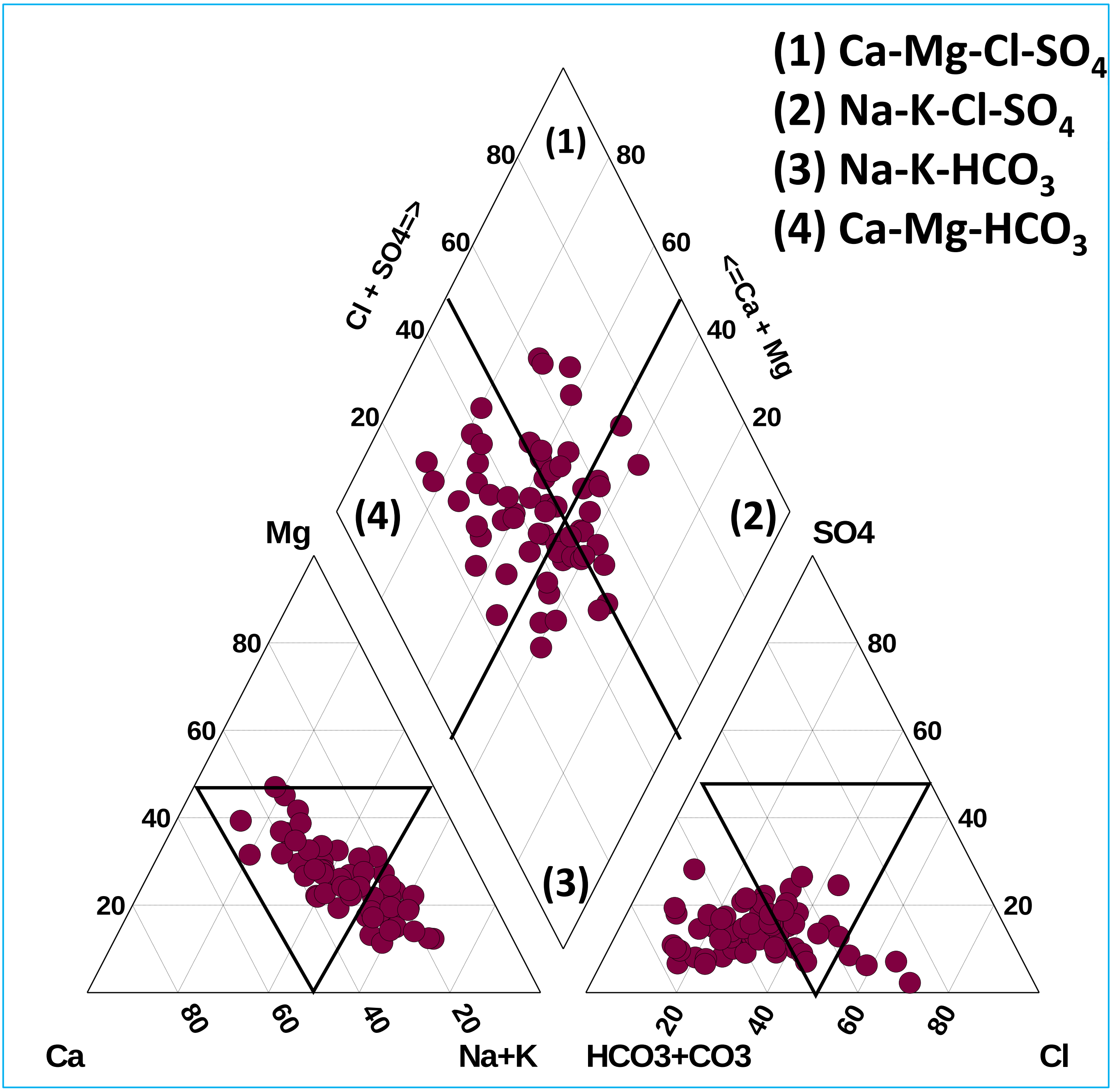

Fig 6 Piper trilinear diagram for groundwater samples

Table 2 Hydrochemical facies types and their percentage

S. No.	Hydrochemical facies types	Sample No.	No. of samples	%
1	Ca-Mg-Cl-SO_4	1, 11, 20, 24, 26, 32, 37, 38, 40, 48, 56	11	18.3
2	Na-K-Cl-SO_4	2, 4, 5, 15, 19, 25, 34, 43, 49, 54, 59, 60	12	20.0
3	Na-K-HCO_3	13, 17, 28, 29, 35, 36, 42, 46, 47, 51, 52, 53, 58	13	21.7
4	Ca-Mg-HCO_3	3, 6, 7, 8, 9, 10, 12, 14, 16, 18, 21, 22, 23, 27, 30, 31, 33, 39, 41, 44, 45, 50, 55, 57	24	40.0

The kind of groundwater can be determined by analyzing the diamond plot in the center of a Piper diagram. Samples in the top quadrant of the diamond are calcium sulphate waters; samples in the left quadrant are calcium bicarbonate waters; samples in the right quadrant are sodium chloride waters; and samples in the bottom quadrant are sodium bicarbonate waters. Accordingly, in the present study, 40% of the samples belong to Ca-Mg-HCO_3, 21.7% to Na-K-HCO_3 type, 20% to Na-K-Cl-SO_4 type and 18.3% to Ca-Mg-Cl-SO_4 type (Table 2, Fig 6).

Groundwater suitability for irrigation

Based on Sawyer and McCarty's [13] classification, nearly 33 groundwater samples (viz., 55%) can be categorized under the very hard water class (viz., TH > 300 mg/L). As per the USSL diagram (Fig 7), nine groundwater samples (viz., 15 %) belong to medium salinity (C2), 46 samples (viz., 76.67%) under high salinity (C3) class and the remaining five samples (viz., 8.33 %) to very high salinity (C4). Alternately, it is also evident from (Fig 7) that 47 samples (viz., 78.33%) belong to the low sodium hazard (S1) and 13 samples (viz., 21.67%) to the medium sodium hazard (S2) class. It can be concluded that groundwater samples belonging to C3 and C4 classes are unsuitable for irrigation.

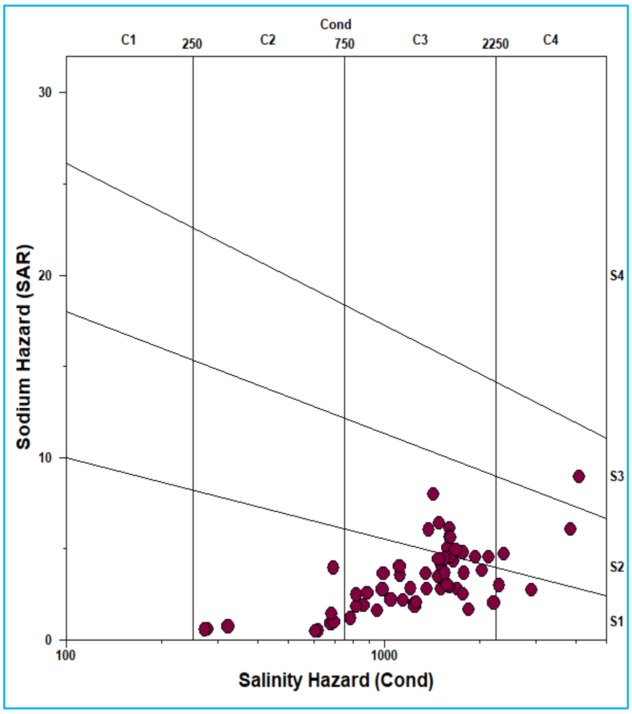

Fig 7 USSL diagram for water classification

Among irrigational water quality parameters, sodium percentage and sodium absorption ratio (SAR) values range between 12.33 to 69.93 (mean: 43.79) and 0.49 to 8.93 (mean: 3.34) respectively (Table 1). Accordingly, 61.67% of the samples showed higher percent sodium (viz., > 40) illustrating their unsuitability for irrigation. Alternately, SAR values being < 10 in all the groundwater samples were excellent for irrigation [14].

Boron toxicity can affect nearly all crops but, like salinity, there is a wide range of tolerance among crops. Since agriculture is being practiced extensively in the study area, an attempt was also made to analyze Boron levels in the groundwater. Boron concentration ranged from 0.010 to 0.25 mg/L (mean: 0.078 mg/L) and all the samples recorded boron levels well below the BIS [9] desirable limit of 0.5 mg/L (Table 1). It is apparent from the boron results that all the groundwater samples are suitable for all types of crops whose sensitivity ranges from sensitive to very tolerant towards boron (viz., Boron < 0.33 mg/L, excellent category).

Hierarchical cluster analysis (HCA)

The HCA has proven to be a multivariate data mining and powerful sample grouping technique for classifying/combining wells into homogenous groups as per the set of user-selected characteristics or attributes or water quality [15-17]. In the present study, Ward's linkage method with squared Euclidean distance was employed to carry out this analysis. In this method, all possible pairs of clusters/groups are combined and the sum of the squared distances within each cluster/group is calculated based on the analysis of variance. This is then summed over all clusters and finally, the combination that gives the lowest sum of squares is chosen. In this way, the Ward method minimizes the sum of squares of any two clusters that can be formed at each step [18]. Finally, the HCA process generates a diagram known as a dendrogram, with the help of which, one can illustrate which clusters have been joined at each stage of the analysis and the Euclidean distance between clusters at the time of joining. If there is a large jump in the Euclidean distance between clusters from one stage to another then this suggests that at one stage clusters that are relatively close together were joined whereas, at the following stage, the clusters that were joined were relatively far apart. This implies that the optimum number of clusters may be the number present just before that large jump in distance. In this way, clusters will exhibit high internal homogeneity as well as high external heterogeneity (Fig 8).

Dendrogram grouping groundwater samples based on hydrochemical parameters resulted in four clusters as shown in (Fig 8). Each sample is described on the x-axis and similarity (based on Euclidean distance) is represented on the y-axis, which illustrates high similarity within the class / cluster and high dissimilarity between different classes / clusters. The groundwater quality characteristics of each cluster are summarized in (Table 3). The first cluster includes the largest number of wells (viz., 25 wells; 41.7 %), with two sub-clusters and three sub-sub-clusters. The water of these wells had the lowest mean values for pH of 6.97 (viz., slightly acidic) and witnessed the worst ground quality since they had the highest mean values for salinity, TDS, total hardness, total alkalinity, nitrate, sulphate, chloride, bicarbonate, calcium, and the sodium concentration of 1932.4 µS/cm, 1010.3 mg/L, 463.8 mg/L, 380.2 mg/L, 37.32 mg/L, 124.78 mg/L, 287.66 mg/L, 463.9 mg/L, 103.14 mg/Lvand 202.34 mg/L respectively (Table 3, Fig 8). The second cluster includes 19 wells (viz., 31.7%) with two sub-clusters and 3 sub-sub-clusters (Fig 8). The wells of this cluster have the second highest salinity among the studied wells since it has a mean concentration of EC, TDS, total hardness, total alkalinity, nitrates, bicarbonates, chlorides, and sodium with means of 1380.8 µS/cm, 730 mg/L, 295.28 mg/L, 395.07 mg/L, 31.53 mg/L, 482.03 mg/L, 135.13 mg/L and 153.09 mg/L respectively (Table 3, Fig 8).

On the other hand, the third and fourth clusters were the smallest groups, both accounting for 13.3 % (viz., 8 wells each) of the analyzed samples (Fig 8). Interestingly, wells of clusters 3 and 4 comparatively showed good groundwater quality since they have moderate salinity, TDS, lower nitrate, sulphate, chlorides, and other ionic concentrations. The third clusters showed a slightly alkaline mean pH value of 7.22, followed by EC, TDS, TA, HCO_3 and NO_3 with means of 935.6 µS/cm, 485.4 mg/L, 344.0 mg/L, 419.7 mg/L and 19.3 mg/L respectively [19]. In contrast, the fourth cluster has a high mean pH value of 7.52 (viz., slightly alkaline), lowest mean values for salinity of 532.6 µS/cm, TDS of 297.5 mg/L, nitrate of 25.4 mg/L and bicarbonate of 223.6 mg/L (Table 3, Fig 8).

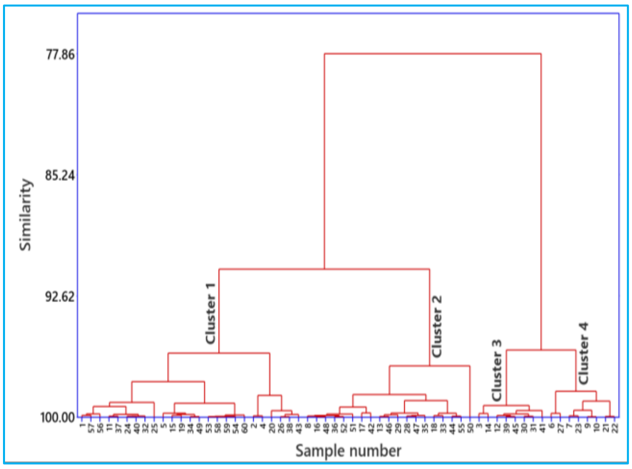

Fig 8 Dendrogram illustrating Hierarchical cluster analysis for 60 wells

Table 3 Hierarchical cluster analysis-based variation in physico-chemical parameters

Parameters	Unit	Cluster 1 (n=25)			Cluster 2 (n=19)			Cluster 3 (n=8)			Cluster 4 (n=8)		
		Sample no.		%	Sample no.		%	Sample no.		%	Sample no.		%
		25 samples (viz., sample no. 1, 2, 4, 5, 11, 15, 19, 20, 24, 25, 26, 32, 34, 37, 38, 40, 43, 49, 53, 54, 56, 57, 58, 59, 60)		41.67	19 samples (viz., sample no. 8, 13, 16, 17, 18, 28, 29, 33, 35, 36, 42, 44, 46, 47, 48, 50, 51, 52, 55)		31.67	8 samples (viz., sample no. 3, 12, 14, 30, 31, 39, 41, 45)		13.33	8 samples (viz., sample no. 6, 7, 9, 10, 21, 22, 23, 27)		13.33
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
pH	-	6.97	6.25	7.41	7.07	6.81	7.45	7.22	7.01	7.45	7.52	7.22	7.75
EC	μS/cm	1932.4	692	4101	1380.79	816	1779	935.6	682.0	1,250.0	532.6	273.0	784.0
Total dissolved solids (TDS)		1010.3	332	2177	730	551	890	485.4	380.0	650.0	297.5	140.0	450.0
Total hardness as $CaCO_3$		463.8	244.1	794.91	295.28	174.81	477.96	274.5	206.3	407.0	220.2	109.6	331.5
Total alkalinity as $CaCO_3$		380.21	203.38	517.33	395.07	245.73	560.44	344.0	250.0	418.2	183.2	86.2	254.4
Calcium as Ca		103.14	49.52	170.49	65.18	30.49	118.2	60.7	41.0	92.8	43.2	20.5	58.6
Magnesium as Mg		50.49	23.39	96.25	32.43	20.04	58.04	30.1	20.5	42.9	27.5	14.3	45.3
Sodium as Na		202.34	88.8	579.4	153.09	79.8	310	76.3	47.9	99.4	26.8	15.6	52.6
Potassium as K	mg/	6.3	1.69	13.72	4.73	1.16	8.12	4.8	2.6	6.8	3.8	0.8	14.8
Phosphate as PO_4	L	0.06	0.02	0.67	0.04	0.02	0.1	0.031	0.017	0.067	0.021	0.017	0.033
Nitrate Nitrogen as NO_3		37.32	12	57	31.53	15	53	19.3	10.0	41.0	25.4	12.0	42.0
Sulphate as SO_4		124.78	34	315	89.01	42	151	76.1	32.0	128.4	26.9	13.3	49.5
Chloride as Cl		287.66	105.8	851.9	135.13	65.2	197.7	59.3	27.7	96.8	43.7	27.7	75.1
Fluoride as F		1.01	0.47	1.25	1.08	0.18	1.38	1.1	0.9	1.3	0.6	0.1	0.9
Bicarbonates as HCO_3		463.9	248.14	631.2	482.03	299.82	683.8	419.7	305.1	510.2	223.6	105.2	310.3
Boron (B)		0.07	0.01	0.15	0.08	0.01	0.25	0.08	0.05	0.13	0.10	0.05	0.21

CONCLUSION

This study evaluated the groundwater quality in the Harihara taluk of Davanagere district using the hydrochemical approach with the assistance of multivariate statistical methods like cluster analysis and irrigational suitability assessment. Piper trilinear diagram illustrated the dominance of Ca-Mg-HCO_3 and Na-K-HCO_3 hydrochemical facies in groundwater samples from Harihara taluk besides the dominance of bicarbonates among anions and Calcium and sodium among cations. The highest variation in groundwater quality was observed concerning parameters like conductivity, TDS, total alkalinity, total hardness, bicarbonates, chlorides, sodium, and calcium. Spatial variation in the Hydrochemistry of the analyzed groundwater was well established by Hierarchical cluster analysis, which helped to uncover similarities between the groundwater sampling stations. As per dendrogram, cluster 1 and cluster 2 samples comprise of largest numbers of wells accounting for 41.7 and 31.7% of samples, whose hydrochemistry was highly influenced by parameters like salinity, hardness, bicarbonates, sodium, etc. Samples falling under these two clusters can be categorized as highly polluted over clusters 3 and 4 samples. Further, higher salinity-low sodium and high salinity-moderate sodium hazards are prevalent in the study area, indicating the irrigation unsuitability of most of the samples owing to salinity, hardness, sodium, etc. Subsequently, the groundwater in Harihara taluk is reasonable for drinking, domestic, industrial and irrigation purposes, after a certain level of treatment before utilization. It additionally should be protected from the probable sources of all contamination by continuous monitoring and management approach.

Acknowledgements

The authors would like to express a sincere gratitude toward the Department of Environmental Science, Jnana Bharathi Campus, Bangalore University-560056 for providing the necessary infrastructure and laboratory facility for sample analysis. The authors would also like to acknowledge backward class welfare department, government of Karnataka for providing necessary financial support by means fellowship to carry out the research work.

Funding sources

The author received backward class welfare department, government of Karnataka financial support for the research work.

Conflict of interest

The author (s) declares no conflict of interest.

LITERATURE CITED

1. Khan N, Malik A, Nehra K. 2021. Groundwater hydro-geochemistry, quality, microbiology and human health risk assessment in semi-arid area of Rajasthan, India: A chemometric approach. *Environmental Monitoring and Assessment* 193(4): Springer, Berlin, Heidelberg, DOI: 10.1007/s10661-021-08979-2.
2. Adimalla N. 2019. Controlling factors and mechanism of groundwater quality variation in semiarid region of South India: An approach of water quality index (WQI) and health risk assessment (HRA). *Environmental Geochemistry and Health* 1–28.
3. Yuan J, Xu F, Deng G, Tang Y. 2008. Using stable isotopes and major ions to identify hydrogeochemical characteristics of karst groundwater in Xide country, Sichuan Province. *Carbonates and Evaporites* 33(2): 223-234.

4. Mukate SV, Panaskar DB, Wagh VM, Baker SJ. 2019. Understanding the influence of industrial and agricultural land uses on groundwater quality in semiarid region of Solapur, India. *Environment, Development and Sustainability* 1–32.
5. Mukate S, Wagh V, Panaskar D, Jacobs JA, Sawant A. 2019. Development of new integrated water quality index (IWQI) model to evaluate the drinking suitability of water. *Ecological Indicators* 101: 348-354.
6. Hossain MG, Reza AS, Lutfun-Nessa M, Ahmed SS. 2013. Factor and cluster analysis of water quality data of the groundwater wells of Kushtia, Bangladesh: implication for arsenic enrichment and mobilization. *Journal of the Geological Society of India* 81(3): 377-384.
7. Pandith M, Kaplay RD, Potdar SS, Sangnor H, Rao AD. 2017. Impact of urbanization coupled with drought situations on groundwater quality in shallow (basalt) and deeper (granite) aquifers with special reference to fluoride in Nanded-Waghala Municipal Corporation, Nanded District, Maharashtra (India). *Environmental Monitoring and Assessment* 189(9): 428.
8. Maclean JL, Dawe DC, Hardy B, Hettel GP. 2002. Rice Almanac: Source book for the most important economic activity on earth. 3rd Edition. Wallingford, United Kingdom: CABI Publishing. pp 257.
9. BIS. 2012. Indian Standards Specification for Drinking Water, BIS: 10500: 2012. Available from: http://www.cgwb.gov.in/Documents/WQ-standards.
10. APHA. 2017. *Standard Methods for the Examination of Water and Wastewater* (23rd Edition). Washington DC: American Public Health Association.
11. Piper AM. 1953. A graphic procedure in the chemical interpretation of water analysis. US Geological Survey Groundwater Note. pp 12.
12. Piper AM. 1945. A graphic procedure in the geochemical interpretation of water analyses. *Trans. Am. Geophy. Union. Applied Geochemistry* 25: 914-928.
13. Sawyer GN, McCarthy DL. 1967. *Chemistry of Sanitary Engineers*. 2nd Edition, McGraw Hill, New York. pp 518.
14. Todd DK. 1959. *Groundwater Hydrology*. John Wily & Sons, Inc., New York.
15. Egbueri JC. 2018. Assessment of the quality of groundwaters proximal to dumpsites in Awka and Nnewi metro-polices: A comparative approach. *Int. Jr. Energy and Water Resources* 2: 33-48
16. Egbueri JC. 2019. Evaluation and characterization of the groundwater quality and hydrogeochemistry of Ogbaru farming district in southeastern Nigeria. *SN Applied Sciences* 1: 851.
17. Subba Rao N, Chaudhary M. 2019. Hydrogeochemical processes regulating the spatial distribution of groundwater contamination, using pollution index of groundwater (PIG) and hierarchical cluster analysis (HCA): A case study. *Groundwater for Sustainable Development* 9: 100238.
18. Ward JH. 1963. Hierarchical grouping to optimize an objective function. *Jr. Am. Statistical Association* 58: 236-244.
19. Adimalla N. 2018. Groundwater quality for drinking and irrigation purposes and potential health risks assessment: a case study from semi-arid region of South India. *Exposure and Health* 11: 109-123.