Suitability Assessment of Deep Groundwater for Drinking and Irrigation Use in the Parts of Hoskote and Malur Taluks, Karnataka (India)

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Groundwater samples from thirty four bore wells used for drinking and irrigation in parts of Hoskote and Malur taluks, Karnataka State (India), were collected and geochemically analysed during December 2014. The hydrochemical characteristics was dominated by Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} (58.82%) and Ca^{2+}-Mg^{2+}-HCO_3^- (38.24%), with alkaline earth (Ca+Mg) exceeding alkalies (Na+K) and strong acidic anions dominating weak acidic anions. Weathering of rock-forming minerals regulated chemistry of the groundwater in the study area as indicated by Gibbs plot. The groundwater chemistry in the study area is influenced by silicate dissolution of host rock with contribution from weathering of carbonate rocks while positive CAI values indicated exchange of Na and K from the water with Mg and Ca of the rocks in the study area. The Ca^{2+}/Mg^{2+} molar ratio plot further supported the fact that dissolution of calcite with effect of silicate minerals contributes calcium and magnesium to 97.06% of the groundwater. SAR, percent sodium, WQI and permeability index values demonstrated the suitability of a majority of the samples for irrigation.

Keywords: *Malur, Hoskote, Piper diagram, Wilcox diagram, WQI.*

1   Introduction

Access to potable water is critical for the development of civilization, for human survival, for meeting several needs for human, fauna and flora species and to establish a database for planning future development strategies of water resources. Groundwater resources are said to be of good quality, but contact with geological formation and composition of soil minerals influences the quality of water extracted (Amfo-Otu, Agyenim, & Nimba-Bumah, 2014). In major parts of India, groundwater is being used as a major source of potable water for drinking, agricultural and industrial purposes, whose quality is getting deteriorating day-by-day due to increasing population, human activities, growing demand, catchment degradation, etc. (Someshwar Rao, Purushothaman, Gopal Krishan, Rawat, & Kumar, 2014). Variation of groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Kanagaraj, Sridhar, Gopal, Shanmugasundharam, & Sangunathan, 2014). Dissolved salts and other constituents are found to occur naturally in groundwater, depending on the geochemistry of the underlying aquifer (Al-Zarah, 2007). At the same time, the environmental impacts of human activity like unused fertilisers, pesticides, sewage water and discharge of industrial effluents are considered as potential anthropogenic sources responsible for contamination of the groundwater (Venugopal, Giridharan, Jayaprakash, & Periakali, 2009). Overall, water quality gets modified along the course of the movement of water through several factors such as evaporation, transpiration, vegetation, oxidation/reduction, cation exchange, dissociation of minerals, precipitation, mixing of waters, leaching of

fertilizers and manure, pollution and biological processes (Appelo & Postma, 1999). The presence of different chemical and physical constituents in excess of their permit limits for various uses can create health hazards and environmental problems (Al-Zarah, 2007) and hence the water quality analysis is critical in ensuring that water consumed by the population meets the required quality standards (Amfo-Otu et al., 2014). The extent of contamination can be addressed by hydrogeochemical study involving the identification of chemical processes responsible for controlling groundwater chemistry, and many problems normally arise due to indiscriminate use of ground water over long periods. Detailed knowledge of the geochemical evolution of groundwater and assessing the water quality status for special use are the main objective of any water monitoring study.

The groundwater is being over-exploited for agricultural and industrial activities, and extensive eucalyptus plantations have resulted in the depletion in groundwater table in the part of Hoskote and Malur taluks. The present study is a baseline attempt on the hydrogeochemical characterisation of 34 groundwater wells wherein the study aimed to evaluate variations of bore well water quality and/or assess their suitability for drinking and irrigation purposes by analysing physicochemical parameters besides water quality index, sodium absorption ratio and sodium percent, etc. Further, various ionic molar ratios were calculated in order to determine the rock types responsible for controlling geochemistry of groundwater in the study area.

2   Materials and methods
2.1   Study area

The study area is located in between Hoskote taluk of Bangalore rural district and Malur taluk of Kolar district, which are listed under over-exploited blocks in Karnataka state, where groundwater exploitation exceeds recharging. The study area with varying elevation of 800–1500 m falls under south-eastern dry zone of the tenfold agro-climatic zone of Karnataka. The study area falls between the Cauvery and Krishna River basins and is drained by three small rivers (Koppakode, Pinakini and Ponnaiyar), which carry water only during the rainy season. The study area is characterised by various geological formations belonging mainly to the Archean followed by Palaeocene to recent periods. Major rock groups present in the study area are the Peninsular Gneisses complex. 99.93% of the total area is covered by Migmatites and Granodiorite – Tonalitic Gneiss rock type while Laterite rock type can be seen as small patches towards the northern part of the study area. The lineaments and the joints with orientation toward the NNE–SSW are prominent in this area, responsible for partial controlling of the groundwater flow in the region. It experiences a semi-arid subtropical climate, characterised by typical monsoon tropical weather with hot summers and mild winters. The year is normally divided into four seasons. They are a) dry season during Jan–Feb, b) pre-monsoon season during Mar–May, c) southwest monsoon season during Jun–Sep and d) post or northeast monsoon season during Oct–Dec. Annual mean rainfall of 680–890 mm. Major soil type in the study area is clayey soil.
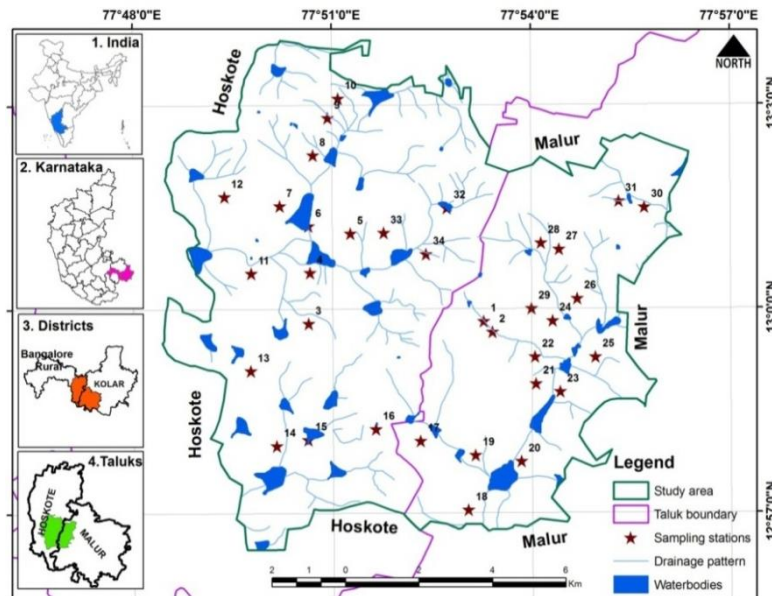

Figure 1.   Location map of the study area.

2.2   Sampling and laboratory analysis

Groundwater quality inventory survey was undertaken in the study area by collecting 34 groundwater samples from tube wells using clear acid-washed polyethylene bottles during post-monsoon season in the 3rd week of December 2014. America Public Health Association (APHA) (2005) prescribed standard methods were employed for collecting, preservation, transportation of samples to laboratory and analysis of groundwater samples. Parameters such as EC, TDS, pH were measured

instantly at the time of collection of groundwater samples while other parameters like total alkalinity, total hardness, major cations (Ca, Mg, Na, K) and anions (HCO₃, SO₄, Cl, NO₃, F, PO₄) were analysed in laboratory. The results were compared and interpreted by the established Bureau of Indian Standards (BIS) (1998) water quality standards for safe multiple use of groundwater with minimal pollution problems. The analytical data were used to calculate parameters like Sodium absorption ratio, percent sodium and Water quality index, which were finally used for the categorisation and assessing the suitability of water for utilitarian purposes and for ascertaining various factors on which the chemical characteristics of water depend.

2.3 Irrigational quality parameters

The groundwater samples were assessed for their suitability for irrigation employing Water quality index, Percent sodium (%Na), Sodium absorption ratio (SAR) and Permeability index (PI). Chloroalkaline indices were used to determine the type of exchange groundwater and its host environment.

Todd & Mays (2005) expressed %Na (Percent sodium) as shown in equation 1.

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

(1)

Richards (1954) expressed SAR (Sodium absorption ratio) as shown in equation 2.

$$SAR \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

(2)

Doneen (1964) and Ragunath (1987) expressed Permeability index (PI) as shown in equation 3.

$$PI = \frac{\left(Na^+ + \sqrt{HCO_3}\right) \times 100}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)}$$

(3)

Schoeller (1977) introduced chlorine-alkaline indices CAI1 and CAI2 to determine the type of exchange groundwater and its host environment (i.e. from rock to groundwater or vice versa) during residence or travel, which are calculated using the formulae 4 and 5:

$$CAI1 = \left(Cl - (Na + K)\right)/Cl$$

(4)

$$CAI2 = \frac{\left(Cl - (Na + K)\right)}{(HCO_3 + SO_4 + NO_3 + CO_3)}$$

(5)

where all the ionic concentrations are in milliequivalents per litre (meq/l).

2.4 Water quality index (WQI)

Water quality index (WQI) is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water. WQI was calculated by adopting Weighted Arithmetical Index method (Table 1) considering thirteen water quality parameters (i.e. pH, EC, TDS, total alkalinity, total hardness, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, F^-) in order to assess the degree of groundwater contamination and suitability. WQI is calculated as the weighted sum of the different subindex scores, which is given by equation 6:

$$WQI = \sum_{i=1}^{n} C_i P_i$$

(6)

where n represents the total number of parameters; P_i is the weight assigned to parameters (an indicator of its relative importance for aquatic life/human water use), $P_i = K/S_n$; constant of proportionality, $K = 1/\sum_{i=1}^{n} S_n$; C_i is the value assigned to parameters after normalization (subindex), $C_i = \left((V_{actual} - V_{ideal})/(V_{standard} - V_{ideal})\right) \times 100$. V_{actual} is estimated value of the ith parameter from the laboratory analysis; S_n and $V_{Standard}$ is BIS recommended standard desirable value of the ith parameter. V_{ideal} is the ideal value of ith parameter in pure water (pH = 7), and for the other parameters it is equivalent to zero.

3 Results and discussion
3.1 Major ion chemistry

The mean, minimum and maximum concentrations of major cations and anions and other physicochemical parameters of groundwater of the study area are presented in Table 1.

Groundwater in the study area is slightly acidic to alkaline in nature with pH ranging from 6.76 to 8.23 (mean: 7.55). According to BIS (1998), the range of desirable pH values of water prescribed for drinking purpose is 6.5–8.5 and there are no water samples with pH values outside of the desirable ranges. Electrical conductivity, which is an indirect measure of ionic strength and mineralization of natural water, showed large variation, mainly due to geochemical processes prevailing in this region. The conductivity of groundwater samples ranged from 269 to 2.962 μS/cm (mean: 982.65 μS/cm), illustrating that these values are well below the BIS desirable limit of 2.000 μS/cm except for two samples.

Table 1.   Analytical details on ground water quality in the study area.

Sl. no.	Parameter	Unit	BIS standards (1998)		Mean	Min	Max
			Desirable limits	Permissible limits			
1	pH	-	6.5–8.5	-	7.55	6.76	8.23
2	Electrical conductivity	μS/cm	2000	3000	982.65	269	2962
3	Total dissolved solids	mg/l	1000	2000	613.17	167.9	1848.3
4	Total Alkalinity (as $CaCO_3$)	mg/l	-	600	244.70	120	570
5	Total Hardness (as $CaCO_3$)	mg/l	300	600	285.29	70	770
6	Calcium (as Ca^{2+})	mg/l	75	200	76.0	20	236
7	Magnesium (as Mg^{2+})	mg/l	30	100	23.25	4.88	58.56
8	Sodium (as Na^+)	mg/l	-	200	50.85	16.78	90.41
9	Potassium (as K^+)	mg/l	-	10	5.97	1.23	26.77
10	Fluorides (as F^-)	mg/l	1.0	1.5	0.47	0.2	1.0
11	Chlorides (as Cl^-)	mg/l	250	1000	163.20	40	730
12	Sulphates (as SO_4^{2-})	mg/l	200	400	93.05	23.34	285.35
13	Nitrates as (NO_3^-)	mg/l	45	100	7.37	1.2	25.0
14	Phosphates (as PO_4^{3-})	mg/l	-	0.3	0.098	0.018	0.219
15	Bicarbonate (as HCO_3^-)	mg/l	-	-	298.54	146.4	695.4
16	Sodium absorption ratio	-	<10	26	1.36	0.75	2.29
17	Percent sodium	%	<40	60	29.59	19.95	51.91
18	Water quality index	-	<50	75	21.65	7.89	38.93
19	Chloroalkaline index – 1	-	-ve / +ve	-	0.34	-0.60	0.78
20	Chloroalkaline index – 2	-	-ve / +ve	-	0.29	-0.16	1.30

The concentration of total dissolved solids varies from 167.9 to 1,848.3 mg/l (mean: 613.17 mg/l) and only two samples were having dissolved solids content above the desirable limit of 1,000 mg/l. Further, based on World Health Organization (WHO) (1993) recommendations, water containing 500 mg/l of dissolved solids is suitable for domestic use and water containing more than 1,500 mg/l dissolved solids is likely to contain enough of certain constituents to cause noticeable taste or make the water undesirable or unsuitable for drinking. Accordingly, 97.06% of the ground water samples were considered suitable for drinking purposes. Total alkalinity values were in the range of 120–570 mg/l (mean: 244.7 mg/l), while total hardness values ranged from 70 to 770 mg/l (mean: 285.29 mg/l). Alkalinity values were below the BIS permissible limit of 600 mg/l, but thirteen samples were considered as very hard water as their total hardness value was above the standard limit of 300 mg/l.

Among alkaline earth metals, the concentration of calcium and magnesium ranged from 20 to 236 mg/l (mean: 76 mg/l) and from 4.88 to 58.56 mg/l (mean: 23.25 mg/l), respectively. None of the samples showed higher magnesium content while only one sample had calcium content above the permissible limit of 200 mg/l. Among alkali metals, sodium and potassium concentrations were found to vary from 16.78 to 90.41 mg/l (mean: 50.85 mg/l) and from 1.23 to 26.77 mg/l (mean: 5.97 mg/l), respectively. Sodium content was within the standard limit of 200 mg/l while potassium was above the standard limit of 10 mg/l in two samples.

The concentration of chloride and bicarbonate ranged from 40 to 730 mg/l (mean: 163.2 mg/l) and from 146.4 to 695.4 mg/l (mean: 298.54 mg/l), respectively. Higher chloride content was noticed in five groundwater samples: they showed chloride content above the desirable limit of 250 mg/l while higher concentration of HCO_3 indicates the contribution from chemical weathering of silicate and carbonate rocks. Sulphate and nitrate values ranged from 23.34 to 285.35 mg/l (mean: 93.05 mg/l) and from 1.2 to 25 mg/l (mean: 7.37 mg/l), respectively. Nitrate was within the standard limit of 45 mg/l in all the samples analysed while sulphate concentration was above the desirable limit of 200 mg/l in 3 samples. Fluoride and phosphate concentrations were within their respective standard limit of 1.5 and 0.3 mg/l as their concentration was in the range of 0.2 to 1.0 (mean: 0.47) and 0.018 to 0.219 mg/l (mean: 0.098 mg/l), respectively.

3.2   Classification of groundwater

The geochemical evolution of groundwater can be understood by plotting the milliequivalent concentrations of major cations and anions in the Piper trilinear diagram (Piper, 1994). The cations and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydrogeochemical facies. The results plotted on the Piper's diagram reveal that the plot shows that 97.06% of the samples fall in the alkaline earth (Ca+Mg) and exceed alkalies (Na+K), and 61.76% of the samples fall in the strong acids and exceed the weak acid type. The major hydrochemical facies in the study area belong to Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} (58.82%) followed by Ca^{2+}-Mg^{2+}-HCO_3^- (38.24%) and Na^+-K^+-HCO_3^- (2.94%). The diamond plot (Figure 2) can further be divided into five zones (A, B, C, D and E) in order to distinguish different types of groundwater. In zones A, B, C and D, two groups of anions and cations are dominant. It is further evident from Figure 2 that most of the groundwater samples (61.76%) are in zone E (mixed zone) wherein

groundwater types cannot be identified as neither anions nor cations dominant (Todd & Mays, 2005) and having no cation-anion pair exceeding 50%. Samples plotting in zone B (35.3%) belong to the temporary hardness class illustrating reverse / inverse ion exchange (Davis & Dewiest, 1966) responsible for the controlling of the chemistry of the groundwater. The remaining (2.94%) fall under zone A and belong to the permanent hardness category, with an indication of groundwater from formations that are composed of limestone and dolomite or from active recharge zones with short residence times (Hounslow, 1995). None of the samples fall under zone C and D and hence samples originating from halite dissolution (saline) or Alkali carbonate enrichment are absent.
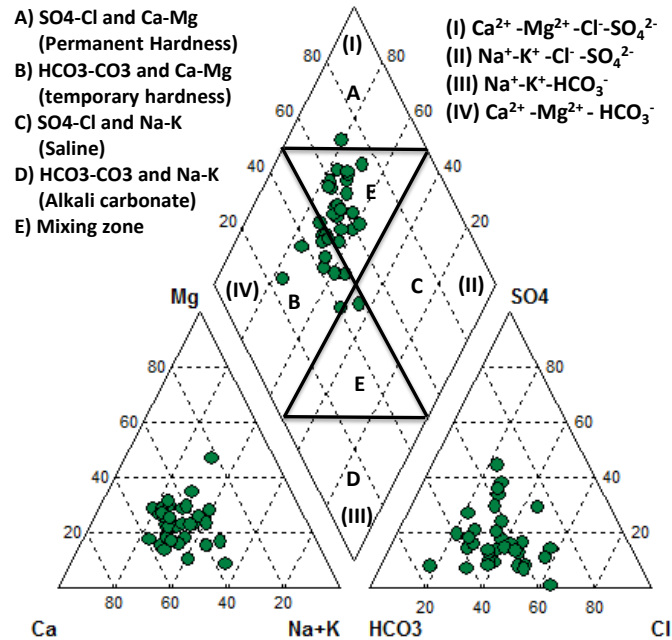
Figure 2.   Piper Trilinear diagram showing variation in hydrochemical facies.

3.3   Water-rock interaction

The chemical data of groundwater samples are plotted in the Gibbs diagram to understand and differentiate the influences of rock-water interaction, evaporation and precipitation (Gibbs, 1970). It was established that the chemical weathering of rock-forming minerals is the influencing factor in controlling groundwater chemistry as indicated by plotting of samples at the centre of Gibbs plot, although very few samples fall in the evaporation zone (Figure 3).

Cation concentrations and ratios can trace water–rock interaction processes, such as mineral weathering and cation exchange (Han et al., 2009). In this connection, plotting of Ca/Na vs Mg/Na and HCO_3/Na plots could assist in the determination of the rock types contributing for geochemistry of groundwater in the study area (Gaillardet, Dupre, Louvat, & Allegre, 1999). Accordingly, the groundwater chemistry in the study area follows silicate–carbonate mixing trend (Figure 4), mainly governed by the weathering of silicate rocks with a contribution from the carbonate rocks and it continues to take place until thermodynamic equilibrium is established.
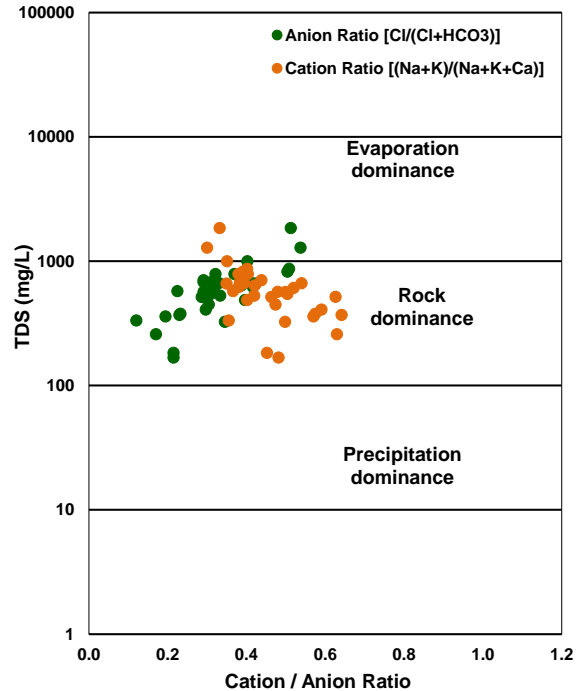

Figure 3.   Log TDS vs (Na+K)/(Na+K+Ca) and Log TDS vs Cl/(Cl+HCO₃) plots showing dominant source of groundwater chemistry.
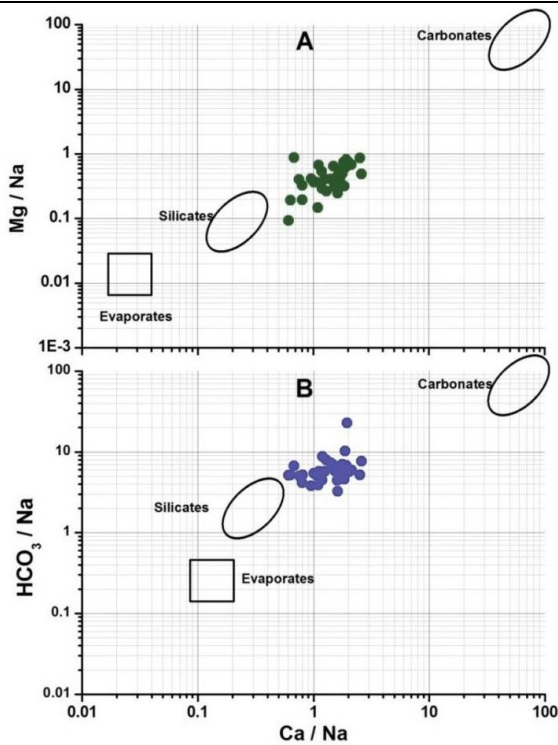
Figure 4. (A) Mg/Na vs Ca/Na and (B) HCO₃/Na vs Ca/Na showing the major rock source for water chemistry in the study area (end-member compositions of carbonates and silicates are from Gaillardet et al., 1999).

The dominance of $SO_4 + HCO_3$ over $Ca + Mg$ is an indicator of silicate weathering, whereas the abundance of $Ca + Mg$ is an indicator of reverse ion exchange (Elango & Kannan, 2007). In other words, the abundance of Ca^{2+} and Mg^{2+} in the groundwater could be related to the presence of carbonate rock in an aquifer, while weathering of carbonate and silicates may contribute Ca^{2+} and Mg^{2+} in the groundwater.

This inference is also attested from the $(Ca + Mg)$ vs $(HCO_3 + SO_4)$ scatter diagram (Figure 5) wherein most of the sample points lie below the aquiline with a few along the incline and above. This identifies that silicate weathering is the main source for bicarbonate ion in the ground water; whereas, a few points above the aquiline indicate carbonate weathering (Datta, Bhattacharya, & Tyagi, 1996). The dissolution of calcite and dolomite can be shown by the groundwater's Ca^{2+}/Mg^{2+} molar ratio (Figure 6). A Ca^{2+}/Mg^{2+} molar ratio that is equal to one indicates dissolution of dolomite rocks (Mayo & Loucks, 1995) while a greater ratio may represent a more dominant calcite contribution from the rocks. A Ca^{2+}/Mg^{2+} ratio greater than 2 may represent the dissolution of silicate minerals into the groundwater (Katz, Coplen, Bullen, & Hal Davis, 1997). While 52.94% of the groundwater samples had a Ca^{2+}/Mg^{2+} ratio between 1 and 2 (Figure 6), which indicated that the dissolution of calcite, 44.12% of the samples had a higher ratio than 2, which showed the effect of silicate minerals that contribute calcium and magnesium to the groundwater (Mayo & Loucks, 1995). Only a few samples (around 2.94%) were indicative of the dissolution of dolomite with Ca^{2+}/Mg^{2+} ratio < 1. Furthermore, the sample that clusters along 1:1 halite dissolution line indicates their origin from halite dissolution (Figure 7). But, some falls below the aquiline show clear dominance of Cl over Na, indicating a source other than halite dissolution. The removal of Na from the groundwater system may be attributed to the reverse ion exchange processes (Rajmohan & Elango, 2004). But Loni et al. (2014) is of the opinion that Na^+ ions should show relative abundance over Cl^- ion in the presence of silicate weathering, which is not the case in the present case in certain groundwater samples.
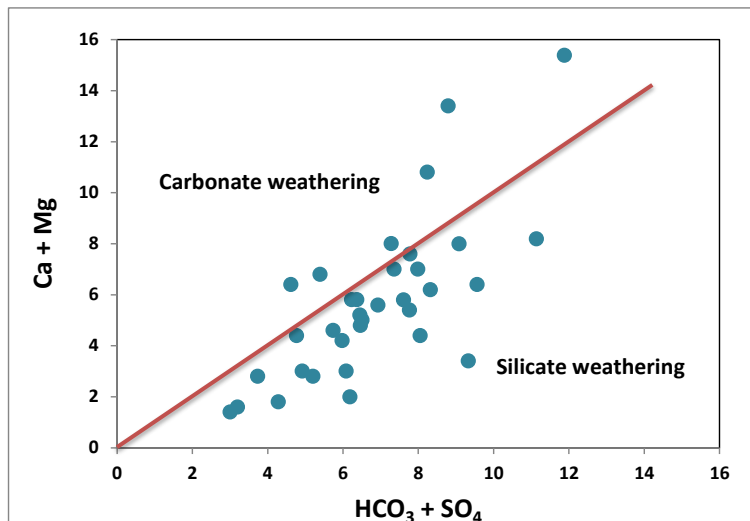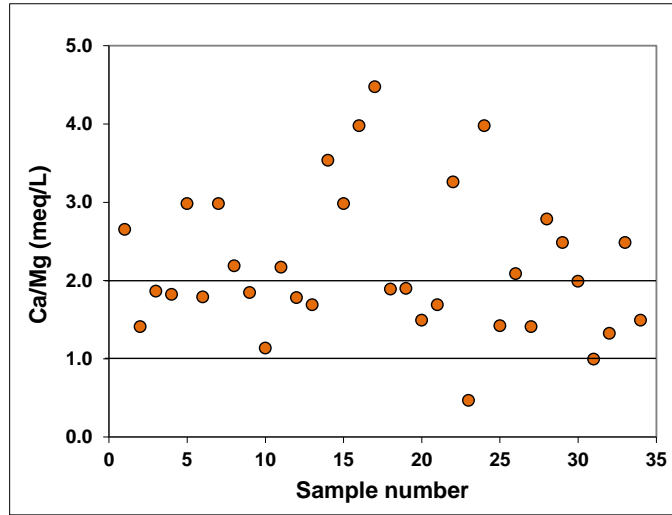

Figure 5. (Ca+Mg) vs (HCO₃+SO₄) scatter diagram.

Figure 6.   Distribution of Ca^{2+}/Mg^{2+} molar ratio in the study area.
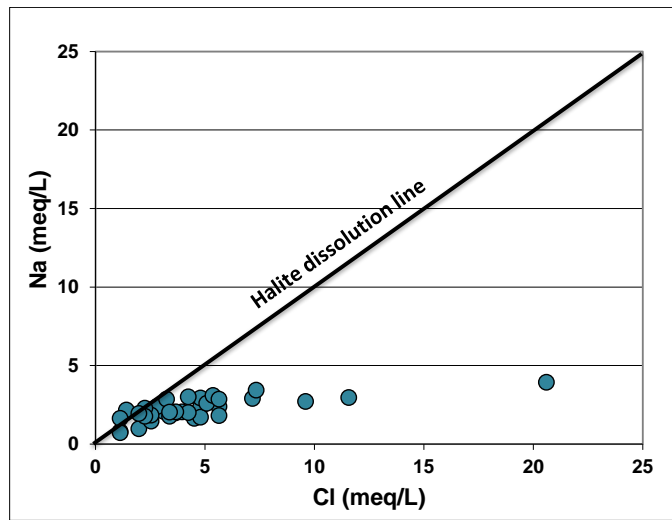

Figure 7.   Na vs Cl plot.

The positive CAI values (viz., mean CAI-1 = 0.34 and mean CAI-2 = 0.29) in 88.24% of the groundwater samples indicated that the concentration of calcium and magnesium in the study area is due to rock weathering, wherein there is an exchange of Na and K from the water with Mg and Ca of the rocks in the study area (Figure 8). Remaining 11.76% of the samples having negative CAI values showed an opposite ion exchange process, involving the exchange of Mg and Ca of the waters with Na and K of the rocks. These groundwater with a base exchange reaction in which the alkaline earth has been exchanged for Na^+ ions (Handa, 1969) and having higher HCO_3^- concentration over alkaline earth (viz., $HCO_3^- > Ca^{2+} + Mg^{2+}$) (Ravikumar, Somashekar, & Angami, 2011) are referred to as base exchange-softened water.
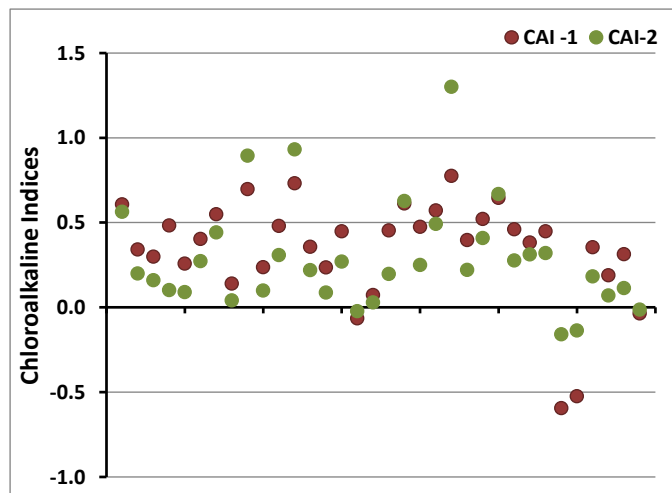
Figure 8. Variation in chloroalkaline indices.

3.4 Irrigational quality assessment

To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending on their hydrochemical properties based on various parameters like conductivity, TDS, SAR, %Na, WQI, etc. Based on the salinity hazard classification, the majority of the groundwater samples (70.59%) belong to from doubtful to unsuitable category, while the remaining samples (29.41%) belong to the good water quality category (Table 2). Davis & DeWiest (1966) have also classified groundwater depending on their hydrochemical properties on the basis of TDS such as values up to 500 mg/l render the water desirable for drinking, whereas values ranging from 500 to 1,000 mg/l render the water permissible for drinking. Based on this classification, 61.76% of groundwater samples fall under permissible range for drinking and irrigation purpose while 32.35% of samples are considered safe.

The role of sodium in the classification of groundwater for irrigation was emphasised because of the fact that sodium reacts with the soil and as a result, clogging of particles takes place, thereby reducing the permeability (Domenico & Schwartz, 1990). Na is an important cation which in excess deteriorates the soil structure and reduces crop yield as long-term use of irrigation water, influenced by the Na^+, Ca^{2+}, Mg^{2+}, and HCO_{3-} contents of the soil, affect the soil permeability. Percent sodium values ranged from 17.95 to 51.91 (mean: 29.59) and 91.17% were considered suitable (excellent to good class) for irrigation values as their percent sodium values were below 40 (Table 2). In contrast, Sodium absorption ratio (SAR) varied from 0.75 to 2.29 (mean: 1.36) illustrating that all the samples safe for irrigation as their SAR value was within 10 (Table 2).

Table 2. Groundwater classification for irrigation purpose.

Parameter	Range	Water Quality Class	No. of samples	Range	%
EC or Salinity (µS/cm) hazard classification	100–250	Excellent	-	-	-
	250–750	Good	10	269–717	29.41
	750–2,250	Doubtful	23	780–2055	67.65
	> 2,250	Unsuitable	1	2962	2.94
Total dissolved solids (TDS) (Davis & DeWiest, 1966)	< 500	Desirable for drinking	11	167.9–486.7	32.35
	500–1,000	Permissible for drinking	21	514.8–997.8	61.76
	1,000–3,000	Useful for irrigation	2	1282.3–1848.3	5.88
	> 3,000	Unfit for drinking and irrigation	-	-	-
% Na based classification (Wilcox, 1955)	< 20	Excellent	2	19.95–19.65	5.89
	20–40	Good	29	20.55–38.66	85.29
	40–60	Permissible	3	43.09–51.91	8.82
	60–80	Doubtful	-	-	-
	> 80	Unsuitable	-	-	-
SAR based Classification (Richards, 1954)	< 10	Excellent	34	0.75–2.29	100
	10–18	Good	-	-	-
	19–26	Doubtful / fair poor	-	-	-
	> 26	Unsuitable	-	-	-
Water Quality Index	0–25	Excellent	24	7.89–24.7	70.59
	26–50	Good	10	26.22–38.93	29.41
	51–75	Poor (Moderately polluted)	-	-	-
	76–100	Very poor (Severely polluted)	-	-	-
	> 100	Unsuitable (Unfit for consumption)	-	-	-

Wilcox plot can also classify water based on the Na% with respect to other cations (viz., salinity hazard) that are present in water (Figure 9). It is observed that most of the samples from the study area fall in the excellent to good classes for irrigation purpose. Of the 34 samples, 26.47% of the samples fall in excellent to good, 67.65% of samples fall in good to permissible and few samples (5.88 %) fall in doubtful to unsuitable category. Further, Sodium hazard (SAR) and salinity hazard (conductivity) were mapped using U.S. Department of Agriculture (USDA) diagram (Figure 10), which revealed that majority of groundwater samples belong to C3S1 (67.65%) and C4S1 (2.94%) water type, demonstrating showed high and very high salinity and low sodium indicating high salinity-low sodium and very high salinity-low sodium types respectively. The samples belonging to C2S1 type revealing medium salinity-low sodium content accounted for 29.41%.
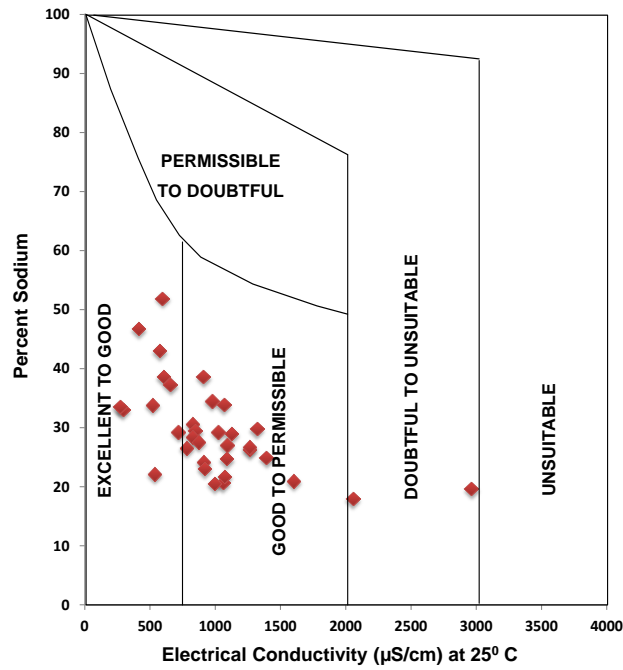
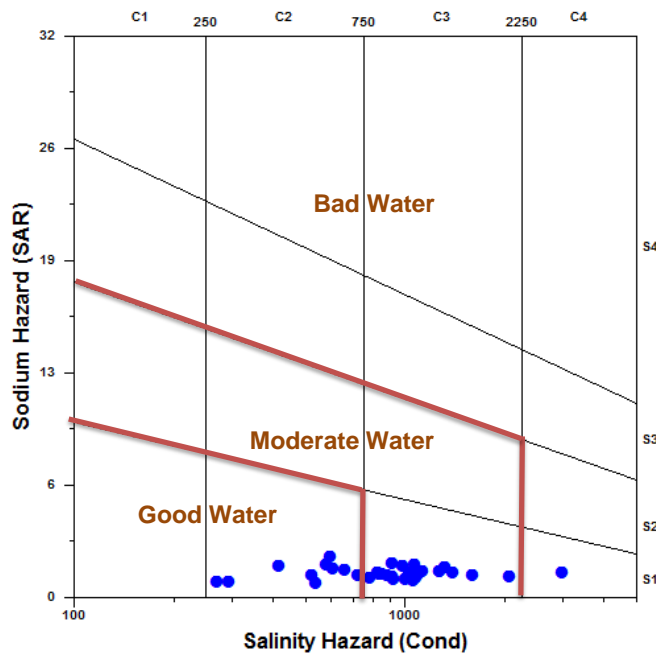*Figure 9.   Percent sodium vs EC plot (after Wilcox 1995).*

Figure 10. U.S. Salinity hazard diagram (after Richards, 1954).

The permeability index value ranged from 32.82 to 107.03 (mean: 62.66) and it is apparent from Figure 11 that majority of groundwater samples (82.35%; 32.82 ≥PI ≤ 78.76) falling under class 1 and 2 (WHO, 1989) were considered suitable for irrigation. The water quality index values ranged from 7.89 to 38.93, with a mean value of 21.65. Among 34 groundwater samples analysed, 70.59% of the samples belong to excellent category and remaining 29.41% of samples belong to good category illustrating that these water samples are safe for drinking and other utilitarian purposes (Figure 12).
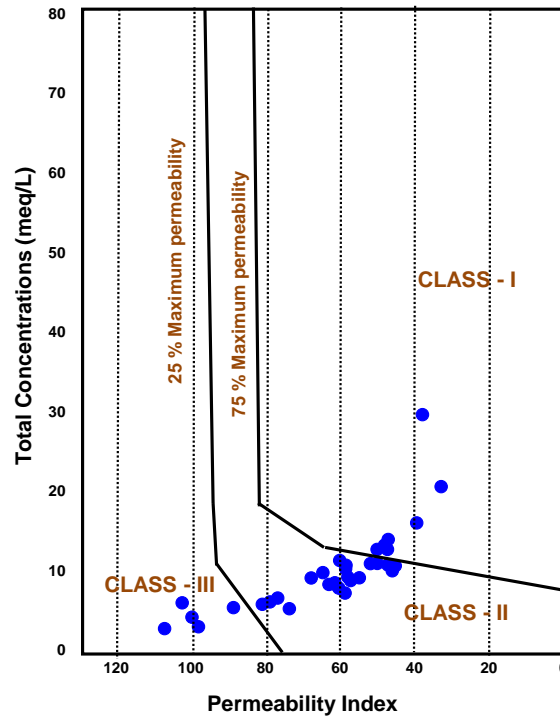
Figure 11. Doneen (1964) classification of irrigation water based on the permeability index.
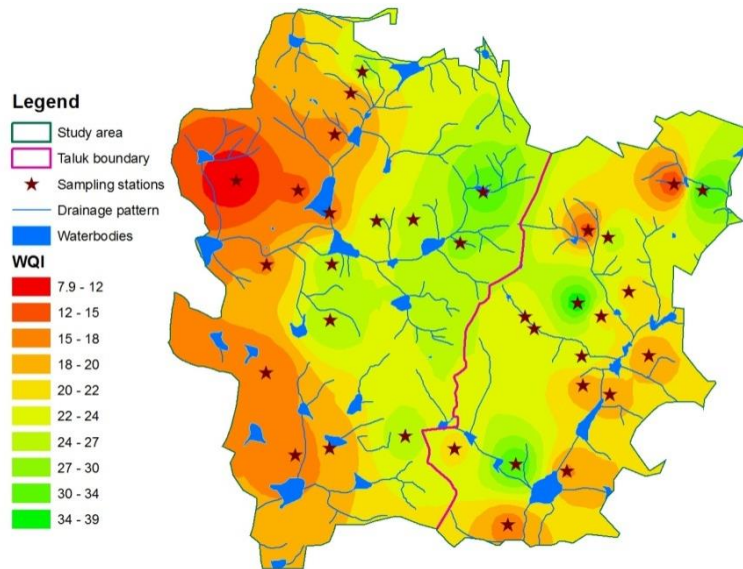

Figure 12. Spatial distribution in WQI value in the study area.

4   Conclusions

The major hydrochemical facies noticed in the study area are Ca^{2+} -Mg^{2+} -Cl^--SO_4^{2-} (58.82%) and Ca^{2+} -Mg^{2+} - HCO_3^- (38.24%), with 97.06% of the samples having alkaline earth (Ca+Mg) exceeding alkalies (Na+K) and 61.76% of the samples with dominant strong acidic anions over weak acidic anions. Piper trilinear diagram classified majority of groundwater samples (61.76%) as mixed water type, with groundwater type that cannot be identified as neither anions nor cations are dominant. Only few samples (35.3%) belong to the temporary hardness class illustrating reverse / inverse ion exchange. Lithology via chemical weathering of rock-forming minerals played an important role in regulating chemistry of groundwater in the study area as revealed by Gibbs plot. Positive CAI values in majority of the groundwater samples indicated that the concentration of calcium and magnesium in the study area are due to rock weathering while silicate and carbonate chemical weathering (viz., calcite minerals) is responsible for higher HCO_3 concentration. Overall, the groundwater chemistry is dominated by the dissolution of silicate rocks with contribution from carbonate rocks in the study area and ion exchange. In spite of having high / very high salinity hazard and/or dissolved solids in the study area, the majority of the groundwater samples were suitable for irrigation based on the percent sodium, SAR, PI and WQI values, which may require better drainage to combat salinity problems.

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Giliųjų gruntinių vandenų *Hoskote* ir *Malur* rajonų vietovėse, Karnatakos valstijoje (Indija) tinkamumo gerti ir naudoti drėkinimui tyrimas

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2014 m. gruodžio mėn. Indijos Karnatakos valstijoje, *Hoskote* ir *Malur* rajonų vietovėse, buvo paimti mėginiai iš 34 geriamajam vandeniui ir drėkinimui naudojamų šulinių ir buvo ištirtos geocheminės gruntinio vandens savybės. Hidrocheminėje charakteristikoje daugiausia vyravo Ca^{2+} -Mg^{2+} -Cl^- -SO_4^{2-} (58,82 %), Ca^{2+} -Mg^{2+} -HCO_3^- (38,24 %); šarminių žemių metalai (Ca+Mg) viršijo šarminių metalų (Na+K) kiekį; didelio rūgštingumo anijonų buvo daugiau nei mažo rūgštingumo anijonų. Remiantis Gibbso diagrama buvo nustatyta, kad gruntinio vandens chemines savybes lėmė uolienas sudarančių mineralų erozija. Gruntinio vandens cheminėms savybėms įtakos turėjo silikatų išplovimas iš uolienų ir karbonatinių uolienų erozija, o teigiamos CAI reikšmės parodė Na ir K, esančių vandenyje, pasikeitimą su uolienose esančiais Mg ir Ca. Ca^{2+}/Mg^{2+} molinis santykis patvirtino tai, kad dėl kalcito išplovimo kartu su silikatų mineralais 97,06 % Ca ir Mg patenka į gruntinius vandens. SAR, natrio koncentracija, WQI ir pralaidumo indekso reikšmės parodė daugumos mėginių tinkamumą drėkinimui.

Raktiniai žodžiai: *Malur*, *Hoskote*, Piperio diagrama, *Wilcox* diagrama, WQI.