Hydrochemical characteristics and quality assessment of groundwater in Amaravathi river basin of Karur district, Tamil Nadu, South India

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Abstract The hydrochemical study of groundwater in Karur district of the Amaravathi River basin has been carried out to assess the major ion chemistry and groundwater quality for domestic and drinking purposes. Twenty-four groundwater samples were collected, processed, and analyzed for various physico-chemical parameters such as pH; electrical conductivity; total dissolved solids; total hardness; cations such as calcium, magnesium, sodium, and potassium; anions such as bicarbonate, chloride, sulfate, fluoride, nitrate, and phosphate in the laboratory using the standard methods given by the American Public Health Association (Standard methods for the examination of water and wastewater, 21st edn. American Public Health Association, Washington DC, 2005). For quality assessment, the results were compared with water quality standards prescribed by the Bureau of Indian standards (Indian standards specification for drinking water 15:10500. Bureau of Indian Standards, New Delhi, 2003) and World Health Organization (International standards for drinking water. World Health Organization, Geneva, 2005). All the groundwater samples in all three seasons (pre-monsoon, monsoon, and post-monsoon seasons) were not useful for drinking purposes owing to elevated levels of Ca^{2+} , Mg^{2+} , Na^+ , HCO_3^- , and Cl^- . Karl Pearson correlation matrices for 14 variables were performed; EC, TDS, and TH had significant positive

correlations among themselves and also with Ca^{2+} , Mg^{2+} , Na^+ , and Cl^- . pH shows negative correlation with most of the parameters. The piper trilinear diagram showed that groundwater in all three seasons falls into mixed Ca^{2+} – Mg^{2+} – Cl^- type. Concerning water for irrigation purposes, parameters such as percent sodium (% Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), chloro-alkaline indices (CAI I and CAI II), permeability index (PI), magnesium hazard (MH), Kelley's ratio (KR), USSL diagram, Gibbs' ratio (GR), and Wilcox diagram were calculated on the basis of chemical data to evaluate the current status of groundwater in the Amaravathi River basin. Parameters like MH (74 %), KR (75 %), RSC (95 %), and PI (69 %) in all three seasons indicate that the samples are suitable for irrigation and remaining are unsuitable. From USSL diagram, the result reveals that the samples fall in C3-S1 and C4-S1 indicate high to very high-salinity and low-sodium hazards. Wilcox diagram revealed out of 24 samples, sample no. 7, 8, and 11 in pre-monsoon, monsoon, and post-monsoon seasons fall under doubtful to unsuitable and 9 fall under unsuitable zone. The positive CAI values in 66 % samples in all three seasons indicate reverse ion exchange mechanism. The present study may be helpful for further studies concerning water quality issues in this area, where groundwater is a vital for drinking and other activities.

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Introduction

Analysis of any water resources system is crucial because of the modern-day challenges in any of the following themes: drinking, agriculture, urban area, ecosystem,

energy, recreation, etc. Although, climatic change, inhabitants increase and, more recently, broad biofuel production put enormous pressure on the limited available water in a growing number of regions of the globe (Naim Haie 2011). Of the 37 MKm³ of freshwater estimated to be present on the earth, about 22 % exists as groundwater, which constitutes about 97 % of all liquid freshwater potentially available for human use (Foster 1998). Owing to the importance of water, the United Nations has proclaimed the years of 2005–2015 as the international decade for action on “water for life” (UN 2004).

It is a well-known fact that potable safe water is absolutely essential for healthy living. Groundwater is a preferred source of human water supply. It is estimated that approximately one-third of the world's population uses groundwater for drinking purposes (UNEP 1999). For most rural and small communities, groundwater is still the only source of drinking water, because the government water supply does not reach to more than two-thirds of the population (Sharma et al. 2012). In Asia alone, about one billion people are directly dependent upon this resource (Sivasankar and Gomathi 2009). The groundwater resources play a very significant role in meeting the ever increasing demands of the agriculture, industry, and domestic sectors (Saleem 2007). Millions of hand pumps and profound tube wells have been introduced all over India since most recent few decades (1970s) to give safe water rather than microbes influenced water. However, groundwaters have some dissolved chemical constituents, which may be unacceptable due to their chronic health effects, taste, and esthetic reasons (Sankararamakrishnan et al. 2008).

Agriculture is a dominant sector in the economic development of India, as it is the source of sustenance for the majority of the population and contributes 46 % of the gross national product (Kumarasamy et al. 2011). Irrigation is necessary for agricultural production in infertile and semiarid regions where rainfall is not sufficient to uphold crop growth. Irrigated agriculture consumes 60–80 % of the total water usage and contributes nearly 38 % of the global food production.

Understanding the aquifer hydraulic properties and hydrochemical characteristics of water is crucial for groundwater planning and management in the study area. In general, the motion of groundwater along its flow paths below the ground surface increases the concentration of the chemical species (Kortatsi 2007). Hence, the groundwater chemistry could reveal important information about the geological history of the aquifers (Elkrail et al. 2004). Groundwater chemistry, in turn, depends on a number of factors, such as general geology, degree of chemical weathering of various rock types, quality of recharge water, and inputs from sources other than water–rock interaction.

Such factors and their interactions result in a complex groundwater quality (Guler and Thyne 2004).

In this work, physical, hydrogeological, and hydrochemical data from the groundwater system will be integrated and used to determine the main factors which influence the chemistry of groundwater in the Amaravathi River basin area. There is no systematic and scientifically documented evidence of the chemical quality of the suitability of groundwater for domestic and agricultural purpose in this basin. Hence, this paper highlights the ionic and temporal variations in the groundwater quality and to evaluate the suitability of groundwater for drinking and irrigation purpose for a sustainable agriculture and basic human needs.

Study area description

Location

Amaravathi River ascends from Naimakad at a height of 2300 m above mean sea level in the Western Ghats in the Idukki region of Kerala state. It streams toward upper east lastly converges with the waterway Cauvery on its right bank. Amaravathi River lies between north latitudes 11.20° and 12.00° and east longitudes 77.28° and 78.50° at Karur district. The total course of the river is 282 km and covers a total area of 8280 Km² mainly constituting five districts namely Tirupur, Coimbatore, Erode, Dindigul, and Karur in the state Tamil nadu. Amaravathi is a tributary of Shanmuganadhi, Nankanchi, and Kodaganar Rivers, which join at 60, 40, and 20 km upstream of Karur town, respectively. Amaravathi enters into Karur district near Aravakurichi and merges with river Cauvery near Kattali village, and the flow in the river is seasonal from late October to early February.

Drainage

Major part of Karur district is drained by Cauvery River. Amaravathi, Kodavanar, and Nanganji are the important rivers draining the western part of the district and the river Pungar drains in the eastern part of the district. The drainage pattern, in general, is dendritic. All the rivers are seasonal and carry substantial flows during the monsoon period.

Geomorphology and hydrogeology

The entire area of the district is a pediplain. The Rangamalai hills and Kadavur hills occurring in the southern side of the district constitute the remnants of the much denuded Eastern Ghats and rise to the heights of over 1031 m above mean sea level. There are numerous small residual hills represented by Ayyarmalai, Thanthonimalai, and Velayuthampalayam

hills. The general elevation of the area is ranging between 100 and 200 m above mean sea level. The prominent geomorphic units identified in the district are structural hilly, pediments, shallow pediments, buried pediments, and alluvial plain. Karur district is underlain entirely by Archaean Crystalline formations with recent alluvial deposits occurring along the river and stream courses. The hard consolidated crystalline rocks of Archaean age represent weathered, fissured, and fractured formations of gneisses, granites, charnockites, and other associated rocks. Groundwater occurs under phreatic conditions, and the maximum saturated thickness of the aquifer in hard rock formation varies from 15 to 35 m depending upon the topographic conditions. The thickness of alluvial deposit is estimated to be around 10–12 m. The aquifer parameters for the formation hard rock and alluvium are furnished in Table 1.

Soil and vegetation

Red soil is the predominant one covering a major part of the district followed by thin red soil and red loam. The red soil is predominantly seen in Kadavur, Kulithalai, Krishnarayapuram, Thanthoni, and Thogamalai blocks. The thin red soils are seen in Aravakurichi and K. Paramathy blocks. A major portion of the Karur block is covered by red loam. The major crops under cultivation in this area are paddy (16.30 %), groundnut (6.90 %), sugar cane (6.40 %), jowar (22.60 %), and banana (5.30 %). Total geographical area is 289,557 ha of which area utilized for cultivation is 114,554 ha, 37,264 ha land put into non-agricultural uses, and remaining in other activities (Table 2).

Irrigation practices

The data available indicate that an area of about 54,709 ha, which is about 18.89 percent of the total geographical area of the district, is under irrigated agriculture.

Dug wells are the major source of water for irrigation in the district, accounting for about 59.97 % of the total area irrigated in the district. Tube wells account for about 9.48 % of the total area irrigated in the district. On the net area irrigation, the canal irrigates only 29.45 % area. The area irrigated under the tank is 1.10 %.

Rainfall and climate

Amaravathi River basin has four distinct seasons, namely southwest monsoon from June to early September,

Table 2 The nine-fold land use/land-cover statistics for the district (CGWB 2008)

S. No.	Classification	Area (Ha)
1	Forests	6187
2	Barren and uncultivable lands	2901
3	Land put to non-agricultural uses	37,264
4	Cultivable waste	67,831
5	Permanent pastures and other grazing lands	10,801
6	Groves not included in the area sown	1278
7	Current fallows	4774
8	Other fallow lands	46,802
9	Net area sown	111,719
Total		289,557

northeast monsoon from October to December, winter season from January to February, and summer season from March to May. The district receives the rain under the influence of both southwest and northeast monsoons. The northeast monsoon chiefly contributes to the rainfall in the district. Most of the precipitation occurs in the form of cyclonic storms caused due to the depressions in the Bay of Bengal. The southwest monsoon rainfall is highly erratic and summer rains are negligible. The normal annual rainfall over the district from 1901–2011 varies from about 620 to 745 mm, and in 2012, it was 527.6 mm, much less than the normal average of 652.20 mm (Renganathan 2014), and it is the minimum around Aravakurichi (622.7 mm) in the western part of the district. It gradually increases toward eastwards and attains a maximum around Kulithalai (744.6 mm). The district enjoys a tropical climate, and the relative humidities are generally between 40 and 80 %. The mean maximum temperature ranges from 26.7 to 38.56 °C, and the mean minimum temperature ranges from 18.7 to 29.3 °C. The daytime heat is tyrannical and the temperature is as high as 43.9 °C. The lowest temperature recorded is of the order of 13.9 °C (CGWB 2008).

Materials and methods

Groundwater samples were collected from twenty-four deep bore and hand pumps during August (2012), November (2012), and February (2013), representing the pre-monsoon, monsoon, and post-monsoon seasons, respectively. Hand pumps and bore wells for sampling were selected on the basis of industrial unit as well as

Table 1 Range of aquifer parameters

Formation	Specific yield %	Transmissivity m ² /day	Permeability m/day	Yield in LPS
Alluvium	6.8	45–205	2–4.5	8.3–16.66
Hard rock	0.7–2.3	28–75	5–9	1.66–2.5

different land use patterns. The locations of sampling points are shown in Fig. 1. High-density polyethylene bottles were used for sample collection. The samples were filled up to the brim and were immediately sealed to avoid exposure to air and were labeled systematically. The labeled samples were analyzed in the laboratory for various physico-chemical parameters. During sample collection (handling and preservation), standard procedures recommended by the American Public Health Association (APHA 2005) were followed to ensure data quality and consistency.

The pH and electrical conductivity (EC) were measured in situ by using water quality multi-parameter probe (Elico PE 138), and the major ions were analyzed using the standard methods suggested by the American Public Health Association (APHA 2005). Among the analyzed ions, sodium (Na^+) and potassium (K^+) were determined by using Systronics Flame photometer 128. Total hardness (TH) as CaCO_3 , calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), and chloride (Cl^-) were analyzed by volumetric methods, and sulfates (SO_4^{2-}) were estimated by using the spectrophotometer. Fluoride ion was determined by Ion selective electrode (Thermo scientific Orion

4 star). Nitrate and phosphate were determined by brucine and stannous chloride method using spectrophotometer. The accuracy of the results was checked by calculating the ionic balance errors and it was generally within $\pm 5\%$. The hydrogeochemical facies (Piper trilinear diagram) and the Wilcox plot were plotted using the AquaChem 4.0 software. The correlation coefficient is generally used to measure and establish the relationship between two variables. The correlation coefficient matrix is obtained by using R environment software for windows version 2.15.2.

The suitability of groundwater for agricultural and domestic purposes was evaluated by comparing the values of different water quality parameters with those of the World Health Organization (WHO 2005) and Bureau of Indian standards (BIS 2003) guidelines values for drinking water. To assess the suitability of groundwater for irrigation uses, the following hydrochemical parameters were computed by the equations:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}} \quad (1)$$

Fig. 1 Location map of the Amaravathi River basin showing sampling sites

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

$$\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-})}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100 \quad (3)$$

$$\text{KR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \quad (4)$$

$$\text{MH} = \frac{\text{Mg}^{2+} \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \quad (5)$$

$$\text{CAI} - \text{I} = \frac{(\text{Cl}^- - (\text{Na}^+ + \text{K}^+))}{\text{Cl}^-} \quad (6)$$

$$\text{CAI} - \text{II} = \frac{(\text{Cl}^- - (\text{Na}^+ + \text{K}^+))}{(\text{SO}_4^{2-} + \text{HCO}_3^- + \text{CO}_3^{2-} + \text{NO}_3^-)} \quad (7)$$

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (8)$$

$$\text{PS} = \text{Cl}^- + (\text{SO}_4^{2-}/2) \quad (9)$$

$$\text{GR} - \text{I} = \frac{\text{Cl}^-}{(\text{Cl}^- + \text{HCO}_3^-)} \quad (10)$$

$$\text{GR} - \text{II} = \frac{(\text{Na}^+ + \text{K}^+)}{(\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})} \quad (11)$$

All the ionic concentrations in the above equations are expressed in meq/L, while percent sodium and PI in %.

Results and discussion

Hydrogeochemistry

The physico-chemical characteristics of the groundwater samples of the Amaravathi River basin are given in Table 3 with descriptive statistical measures such as mean, minimum, maximum, and standard deviation values of various water quality parameters investigated along with the standards of the World Health Organization (WHO 2005) and Bureau of Indian standards (BIS 2003).

pH

The negative logarithm of hydrogen ion concentration is a numerical expression which denotes the degree to which water is acidic or alkaline in nature. The lower pH values have a tendency to make water corrosive, and higher pH value leads to taste grievance and harmful impact on the eyes and skin (Ravikumar et al. 2013). pH value in groundwater samples ranging from 7.29 to 8.17, 7.33–8.45, and 6.29–7.20 during pre-monsoon, monsoon, and post-monsoon seasons, respectively, indicates the alkaline nature and slightly acidic in post-monsoon season. All the values are well within the permissible limits prescribed by WHO and BIS.

Electrical conductivity

Electrical conductivity is used as an index to represent the available total concentration of soluble salts in water and is a direct function of its total dissolved solids (Gupta et al. 2008). The mean electrical conductivity of the groundwater samples was 3081 $\mu\text{S}/\text{cm}$ (pre-monsoon), 3042 $\mu\text{S}/\text{cm}$ (monsoon), and 3176 $\mu\text{S}/\text{cm}$ (post-monsoon). The classification of electrical conductivity in groundwater is shown in Table 4. According to Langenegger (1990) classification, the majority of the samples falls under saline category. In general, EC depends upon temperature, concentration, and types of ions present (Hem 1985). Relatively higher EC values were recorded in the study area indicating the enrichments of salts in groundwater; pH may also increase the dissolution process which ultimately increases the EC value.

Total dissolved solids

Total dissolved solids indicate the various types of minerals present in water in dissolved form consisting of calcium, magnesium, sodium, potassium, carbonates, bicarbonates, chlorides, sulfate, phosphate, silica, iron, and small amounts of organic matters (Gnanachandrasamy et al. 2014; Ravikumar et al. 2013). TDS in the study area varies from 817 to 4340 mg/L (pre-monsoon), 915 to 4243 mg/L (monsoon), and 1094 to 4346 mg/L (post-monsoon). Davis and Wiest (1966) proposed four classes of water based on TDS for drinking and irrigation purposes (Table 5). None of the samples fall under “desirable for drinking” category, while 79 % in pre-monsoon, 83 % in monsoon, and 79 % in post-monsoon seasons are suitable for irrigation, and the remaining are unfit for drinking and irrigation purposes.

Total hardness

Total hardness of water is a measure of dissolved Ca^{2+} and Mg^{2+} content expressed as CaCO_3 , which is also a reflection of soap-neutralizing power (Li et al. 2013). Water can be classified into four categories by Sawyer and McCarthy (1967): soft (<75 mg/L), moderately hard (75–150 mg/L), hard (150–300 mg/L), and very hard (>300 mg/L) based on the total hardness (Table 6). The results in Table 3 show that groundwater in the present study ranged from 206 to 1060 mg/L (pre-monsoon), 302–917 mg/L (monsoon), and 275–1020 mg/L (post-monsoon). According to the classification, none of the samples belong to soft and moderately hard; 8.30 % (pre-monsoon) and 4.16 % (post-monsoon) belong to hard type; and remaining 91.70 % samples in pre-monsoon, 100 % samples in monsoon, and 95.84 % in post-monsoon

Table 3 Descriptive statistics of groundwater quality of Amaravathi River basin

Parameters	WHO limit	BIS limit	Seasons	No. of samples	Mean	Minimum	Maximum	Standard deviation
pH	7.0–8.5	6.5–8.5	Pre-monsoon	24	7.72	7.29	8.17	0.27
			Monsoon	24	7.93	7.33	8.45	0.33
			Post-monsoon	24	6.77	6.29	7.2	0.27
EC, $\mu\text{S}/\text{cm}$	1000–2000	750–2250	Pre-monsoon	24	3081	1178	6263	1505
			Monsoon	24	3042	1320	6123	1406
			Post-monsoon	24	3176	1579	6270	1425
TDS, mg/L	500	500	Pre-monsoon	24	2137	817	4340	1042
			Monsoon	24	2108	915	4243	974
			Post-monsoon	24	2201	1094	4346	990
TH, mg/L	300	300	Pre-monsoon	24	545	206	1060	228
			Monsoon	24	564	302	917	199
			Post-monsoon	24	569	275	1020	218
Ca^{2+} , meq/L	3.75	3.75	Pre-monsoon	24	9.44	2.6	21.65	5.19
			Monsoon	24	9.06	3.8	20.15	4.13
			Post-monsoon	24	10.13	3.8	23.15	5.21
Mg^{2+} , meq/L	4.165	2.499	Pre-monsoon	24	8.14	2.5	22.5	5.57
			Monsoon	24	8.33	2.83	18.91	5.50
			Post-monsoon	24	7.93	2.75	19.58	4.40
Na^{+} , meq/L	8.696	8.696	Pre-monsoon	24	15.01	2.26	39.61	11.07
			Monsoon	24	15.0	2.54	36.68	10.52
			Post-monsoon	24	15.29	3.44	41.77	10.92
K^{+} , meq/L	0.307	0.307	Pre-monsoon	24	0.44	0.02	1.49	0.42
			Monsoon	24	0.45	0.09	1.43	0.41
			Post-monsoon	24	0.46	0.1	1.47	0.45
HCO_3^{-} , meq/L	1.639	1.639	Pre-monsoon	24	6.95	3.86	11.09	1.73
			Monsoon	24	7.53	4.47	12.39	1.65
			Post-monsoon	24	7.95	3.96	12.26	1.93
Cl^{-} , meq/L	5.634	7.042	Pre-monsoon	24	22.31	3.6	64.78	18.74
			Monsoon	24	21.35	4.5	61.69	17.37
			Post-monsoon	24	22.03	4.98	62.87	17.47
F^{-} , meq/L	0.052	0.052	Pre-monsoon	24	0.049	0.010	0.215	0.042
			Monsoon	24	0.045	0.005	0.210	0.042
			Post-monsoon	24	0.047	0.010	0.200	0.038
SO_4^{2-} , meq/L	4.166	4.166	Pre-monsoon	24	4.06	0.66	7.27	1.83
			Monsoon	24	4.74	1.64	8.04	1.79
			Post-monsoon	24	4.67	1.54	8.75	1.88
NO_3^{-} , meq/L	3.214	3.214	Pre-monsoon	24	0.014	0.000	0.035	0.011
			Monsoon	24	0.076	0.026	0.129	0.028
			Post-monsoon	24	0.075	0.024	0.141	0.030
PO_4^{3-} , meq/L	0.032	0.032	Pre-monsoon	24	0.003	0.001	0.020	0.003
			Monsoon	24	0.004	0.002	0.009	0.002
			Post-monsoon	24	0.002	0.001	0.008	0.001

comprises very hard water. From the results, groundwater in the study area is hard to very hard type. The long-term usage of very high hard water causes health problem such

as prenatal mortality, cardiovascular disorders, urolithiasis, anencephaly, and some types of cancer (Srinivas et al. 2013; Agarwal and Jagetai 1997).

Table 4 Classification of groundwater based on electrical conductivity (Langenegger 1990)

Electrical conductivity ($\mu\text{S}/\text{cm}$)	Category	Groundwater samples		
		Pre-monsoon	Monsoon	Post-monsoon
0–333	Excellent	–	–	–
333–500	Good	–	–	–
500–1100	Permissible	–	–	–
1100–1500	Brackish	3	1	–
1500–10,000	Saline	21	23	24

Table 5 Water quality classification based on TDS (Davis and Wiest 1966)

TDS (mg/L)	Water quality	Percentage of samples		
		Pre-monsoon	Monsoon	Post-monsoon
<500	Desirable for drinking	–	–	–
500–1000	Permissible for drinking	4	4	–
<3000	Useful for irrigation	79	83	79
>3000	Unfit for drinking and irrigation	21	17	21

Calcium and magnesium

Calcium and magnesium are the most abundant elements in groundwater, which exist mainly as bicarbonates, and less significant in the form of sulfate and chloride (Sarath Prasanth et al. 2012). The concentration of Ca^{2+} ion ranges from 2.6 to 21.65 meq/L, 3.8–20.15 meq/L, and 3.8–23.15 meq/L for pre-monsoon, monsoon, and post-monsoon seasons, respectively. The reason for the high concentration of Ca^{2+} in groundwater is attributed by carbonate or silicate weathering. Mg^{2+} ion concentration in the study area ranges from 2.5 to 22.5 meq/L (pre-monsoon), 2.83–18.91 meq/L (monsoon), and 2.75–19.58 meq/L (post-monsoon), and high concentration of Mg^{2+} is due to the leaching process of dolomites, limestones, and gypsum; similar results are achieved by Tay (2012). At the same time, the reverse cationic exchange takes place with sodium reducing the concentration of Ca^{2+} and Mg^{2+} ions (Thomson Jacob et al. 1999). About 75 % of samples in pre-monsoon and monsoon, and 91.6 % of samples in the post-monsoon seasons exceed the permissible limit specified by WHO (2005) and BIS (2003).

Sodium and potassium

Sodium along with chloride is often used to identify the proper mechanisms for acquiring salinity and saline intrusion problem in semiarid regions (Jalali 2006; Dixon and Chiswell 1992). The analytical results show that the concentration of Na^{+} in groundwater samples in pre-monsoon ranges from 2.26 to 39.61 meq/L, while in monsoon season, the minimum value is 2.54 meq/L and maximum value is 36.68 meq/L, and in post-monsoon, it ranged from 3.44 to 41.77 meq/L. High concentration of Na^{+} and K^{+} is supplied from the weathering of Na^{+} and K^{+} feldspar (Kim et al. 2005; Zhang et al. 1995) with carbonic acid by the following reactions.

Excess levels of Na^{+} fluctuated in the process, where Ca^{2+} and Mg^{2+} ions are exchanged with Na^{+} . The

Table 6 Categorization of groundwater based on total hardness (Sawyer and McCarthy 1967)

Total hardness as CaCO_3 (mg/L)	Water type	Range (mg/L)	Percentage of samples		
			Pre-monsoon	Monsoon	Post-monsoon
<75	Soft	–	–	–	–
75–150	Moderately hard	–	–	–	–
150–300	Hard	206–292	8.30	–	4.16
>300	Vary hard	316–1060	91.70	100	95.84

maximum permissible limit for Na^+ in drinking water is 8.696 meq/L, and it reveals that 62.50 % of the samples in pre-monsoon, 66.60 % in monsoon and 70.80 % in post-monsoon exceed the permissible limit of WHO and BIS. From the evocative indications, the intake of high levels of Na^+ in groundwater may cause hypertension, arteriosclerosis, edema and kidney problems (Srinivas et al. 2013; Ramesh and Elango 2012; Raju et al. 2011). Among the cations (Ca^{2+} , Mg^{2+} and Na^+), the potassium concentration remains quite low. The concentration of K^+ is observed between 0.02 and 1.49 meq/L; 0.09 and 1.43 meq/L; and 0.1 and 1.47 meq/L for pre-monsoon, monsoon, and post-monsoon seasons, respectively. The maximum permissible limit of K^+ in drinking water is 0.307 meq/L, and it is found that 45.80 % of the samples in pre-monsoon and 37.50 % in monsoon and post-monsoon exceed the limits of WHO and BIS (Table 3). The runoff from agricultural activities and industrial wastes percolate into the groundwater and thus increases the K^+ content (Singh et al. 2006). The silicate minerals present in the groundwater increase the concentration, but compared with Na^+ , the low concentration of K^+ is due to the more resistance of potash feldspars to chemical weathering and is fixed on clay materials.

Bicarbonate

Bicarbonates and carbonates may originate from many sources such as atmospheric CO_2 ; solution of carbonate minerals and rocks such as calcite and dolomites; weathering of feldspar by carbonic acid; and the reaction of NO_3^- and SO_4^{2-} by organic matter (Awadh and Ahmed 2013). The dissolution reaction (Kim and Kim 2013) of calcite and dolomite can be written as follows:

The HCO_3^- concentration in pre-monsoon ranges from 3.86 to 11.09 meq/L, 4.47–12.39 meq/L in monsoon, and 3.96–12.26 meq/L in the post-monsoon season. All the samples in the study area exceeded the allowable limit of 1.64 and 3.27 meq/L according to WHO and BIS guideline value. Weathering of silicate minerals such as anorthite, Na^+ , and K^+ feldspar additionally increases the concentration of HCO_3^- in groundwater samples from the upstream of the Amaravathi River basin, and in downstream, the relatively high concentration of HCO_3^- is due to the direct mixing of municipal sewages and industrial drainage from Karur region.

Chloride

Chloride is one of the major anions to be found in water from various sources such as weathering, intrusions of salt water, leaching of sedimentary rocks and soils, windblown salt in precipitation, domestic and industrial wastes, and municipal effluents (Karanth 1987; Hem 1985). Potable water should not exceed 5.634 meq/L and 7.0425 meq/L suggested by WHO and BIS. In the study area, the concentration of Cl^- ranged between 3.6 and 64.78 meq/L in pre-monsoon, from 4.5 to 61.69 meq/L in monsoon, while in post-monsoon, it ranges from 4.98 to 62.87 meq/L. About 75 % in both pre-monsoon and monsoon, and 83.33 % in post-monsoon are not suitable for drinking purposes. The highest concentration of Cl^- in water is usually taken as an index of pollution and considered as the origin of groundwater contamination (Loizidou and Kapetanios 1993). Geologically important sources of chloride are appetite, sodalite, connate water, and hot springs (Anithamary et al. 2012; Freeze and Cherry 1979). Higher concentration was observed in the downstream of Amaravathi River basin mainly due to the surface runoff from agricultural land, sewage and municipal wastes, and effluents from dyeing and bleaching industries; same observations were reported by Shin et al. (2011) and Yu and Park (2004).

Fluoride

Fluoride is estimated to be the 13th most abundant element and is widely dispersed in nature (Viswanathan et al. 2009). F^- is an essential micronutrient for human health taken in small quantities (0.5–1.0 mg/L), serving to strengthen the apatite matrix of skeletal tissues and teeth (Sharma et al. 2012; Rafique et al. 2009). The F^- concentration in groundwater of pre-monsoon ranges from 0.010 to 0.215 meq/L, 0.005–0.210 meq/L in monsoon, and 0.010–0.200 meq/L in the post-monsoon season. The World Health Organization and Bureau of Indian standard described the drinking water quality as the permissible limit for F^- is 0.052 meq/L, where in the study area, 29 % of samples in all three seasons exceeding the guideline value. The reason behind for high value recorded in the study area was constituted of the fractured hard rock zone. Anomalous level of F^- in water is widespread in the fractured hard rock zone with pegmatite veins (Viswanathan et al. 2010; Ramesam and Rajagopalan 1985). Fluorite (CaF_2) and calcite (CaCO_3) both contain Ca^{2+} , their solubilities are interdependent, as the resultant conditions that lead to low calcite solubility can also lead to high concentration of F^- in groundwater (Rafique et al. 2008; Kundu et al. 2001). Excessive intake of F^- results in

dental Fluorosis, muscle fiber degeneration, headache, skin rashes, nervousness, and depression (Meenakshi 2006).

Sulfate

Sulfate is one of the important anions present in natural water probably derived from weathering of sulfate and gypsum-bearing sedimentary rocks (Elango et al. 2003). The sulfide minerals add the soluble sulfate into the groundwater through an oxidation process (Ramesh and Vennila 2012). In the present investigation, the concentration of SO_4^{2-} in pre-monsoon season varies from 0.66 to 7.27 meq/L; during monsoon, it is 1.64–8.04 meq/L; and in post-monsoon season, it varied between 1.54 and 8.75 meq/L. The most admirable limit for SO_4^{2-} concentration in drinking water is 4.166 meq/L prescribed by BIS (2003) and WHO (2005). During pre-monsoon and post-monsoon seasons, 50 % of samples exceed the guideline value, while in monsoon it is 66.66 %. Higher concentration of SO_4^{2-} in water may cause respiratory problems and also cause corrosion of metals if water had low alkaline value (Raju et al. 2011).

Nitrate and phosphate

Nitrate and phosphate are the major plant nutrient, and its composition is related to soils, climate and atmospheric inputs, local geology, topography, and human activities related to land use (Awadh and Ahmed 2013; Sparks 2003). The guideline value for NO_3^- concentration in drinking water is 3.214 meq/L recommended by WHO and BIS. In three seasons, all the samples in the study area are well within the permissible limit. The limiting factor of phosphate in natural water for plant growth is approximately 0.0002 meq/L. However, to accelerate the plant growth, farmers use excess phosphate pesticides which result in the contamination of surface and groundwater through runoff and affect aquatic life (Hutak 2000). In the study area, the concentration of phosphate range between 0.001 and 0.020 meq/L in pre-monsoon and from 0.002 to 0.009 meq/L in monsoon season, while in post-monsoon season, it ranges from 0.001 to 0.008 meq/L.

Correlation analysis

Karl Pearson correlation matrix analysis is a useful tool in hydrogeochemical studies that can indicate the associations between individual parameters and thus revealing the overall rationality of dataset and enlightening the links between individual parameters and various controlling factors (Wang and Jiao 2012; Li et al. 2013). A correlation coefficient of <0.5 exhibits poor correlation, 0.5 represents the good correlation, and >0.5 highlights the excellent

correlation (Vasanthavigar et al. 2013). The obtained result is listed in Table 7 which shows positive and negative correlation between various variables.

During pre-monsoon, monsoon, and post-monsoon seasons, high positive correlation of EC, TDS with Cl^- ($r = 0.97, 0.98, 0.97$), Na^+ ($r = 0.91, 0.90, 0.90$), and TH ($r = 0.87, 0.80, 0.82$) is observed, respectively. Some good correlation is also observed between TH and Ca^{2+} ($r = 0.87$), Na^+ and Cl^- ($r = 0.85$), Mg^{2+} and Cl^- ($r = 0.80$), and Ca^{2+} and Cl^- ($r = 0.79$) in pre-monsoon, whereas in monsoon, it is $r = 0.84, 0.86, 0.75$, and 0.76 , respectively. While in post-monsoon, the respective (r) value for the above said parameter is $r = 0.87, 0.82, 0.73$, and 0.85 , respectively. These positive correlations indicate that Na^+ , K^+ , Ca^{2+} , and Mg^{2+} ions are derived from weathering of Na^+ , K^+ feldspar, and dissolution of carbonate minerals. The positive relation between F^- and HCO_3^- ($r = 0.51, 0.62$ and 0.48) in pre-monsoon, monsoon, and post-monsoon indicates when both calcite and fluorite are in contact with water (Mamatha and Rao 2010; Rafique et al. 2008). The possible equation is

The negative correlation of Ca^{2+} , Mg^{2+} with Cl^- ($r = -0.15$ and -0.19) is observed in pre-monsoon, Mg^{2+} with SO_4^{2-} ($r = -0.01$) and HCO_3^- ($r = -0.06$) in monsoon season, and in the post-monsoon, Ca^{2+} and Mg^{2+} shows negative correlation with HCO_3^- ($r = -0.05$ and -0.025). pH shows negative correlation with most of the water quality parameters.

Hydrochemical facies

Piper (1944) proposed a modified trilinear diagram for understanding the hydrogeochemical regime of the study area. The diagram consists of three distinct fields, two triangular fields, and one diamond-shaped field (Fig. 2). The left triangle indicates the percentage of cations and right designates the anions which are expressed in meq/L as a single plot. The plots on the diamond field show the similarities and differences among groundwater samples (Jafar Ahamed et al. 2013).

The triangular cationic field in pre-monsoon indicates that 71 % of samples fall into no dominant type, and 16.50 and 12.50 % samples are in Mg^{2+} and $\text{Na}^+ + \text{K}^+$ type, respectively. From the anionic triangle, 83.50 % samples fall into Cl^- type and the remaining are in no dominant class. Most of the samples in Zone 4 of diamond-shaped field indicate the predominance of mixed Ca^{2+} – Mg^{2+} – Cl^- type followed by Ca^{2+} – Cl^- and Na^+ – Cl^- type. During monsoon season, most of the samples (75 %) are present in no dominant class followed by 12.5 % each of Mg^{2+} and $\text{Na}^+ + \text{K}^+$ type in cationic triangle, whereas in anionic

Table 7 Karl Pearson correlation coefficient for different water quality parameters

Parameters	pH	EC	TDS	TH	Ca	Mg	Na	K	HCO ₃	Cl	F	SO ₄	NO ₃	PO ₄
(a) Pre-monsoon														
pH	1.00	−0.60	−0.60	−0.66	−0.70	−0.48	−0.42	−0.01	−0.03	−0.63	−0.02	−0.10	−0.36	0.32
EC		1.00	1.00	0.87	0.73	0.75	0.91	0.13	0.20	0.97	0.26	0.27	0.12	−0.34
TDS			1.00	0.87	0.73	0.75	0.91	0.13	0.20	0.97	0.26	0.27	0.12	−0.34
TH				1.00	0.87	0.80	0.63	−0.09	−0.12	0.90	0.06	0.14	0.10	−0.37
Ca					1.00	0.53	0.54	−0.16	−0.15	0.79	0.00	0.17	0.07	−0.38
Mg						1.00	0.49	−0.05	−0.19	0.80	0.01	0.10	0.15	−0.31
Na							1.00	0.25	0.39	0.85	0.33	0.32	0.12	−0.21
K								1.00	0.56	0.02	0.02	0.26	0.39	−0.12
HCO ₃									1.00	0.02	0.51	0.10	0.12	−0.20
Cl										1.00	0.14	0.18	0.10	−0.30
F											1.00	0.05	−0.06	−0.05
SO ₄												1.00	0.13	0.00
NO ₃													1.00	0.12
PO ₄														1.00
(b) Monsoon														
pH	1.00	−0.74	−0.74	−0.72	−0.68	−0.78	−0.51	−0.04	−0.01	−0.78	0.13	0.02	−0.05	−0.39
EC		1.00	1.00	0.80	0.76	0.70	0.90	0.13	0.21	0.98	0.29	0.12	−0.09	0.50
TDS			1.00	0.80	0.76	0.70	0.90	0.13	0.21	0.98	0.29	0.12	−0.09	0.50
TH				1.00	0.84	0.81	0.54	−0.13	0.09	0.82	0.17	0.05	−0.22	0.31
Ca					1.00	0.63	0.50	−0.27	0.03	0.76	0.12	0.20	−0.31	0.49
Mg						1.00	0.40	−0.08	−0.06	0.75	0.04	−0.01	−0.05	0.26
Na							1.00	0.25	0.27	0.86	0.36	0.12	−0.06	0.46
K								1.00	0.35	0.05	0.00	−0.05	0.41	−0.11
HCO ₃									1.00	0.05	0.62	0.07	0.49	0.03
Cl										1.00	0.20	0.00	−0.18	0.51
F											1.00	−0.02	0.31	0.04
SO ₄												1.00	0.12	0.14
NO ₃													1.00	−0.14
PO ₄														1.00
(c) Post-monsoon														
pH	1.00	−0.54	−0.54	−0.59	−0.70	−0.63	−0.23	−0.04	0.13	−0.60	0.17	−0.02	0.20	0.09
EC		1.00	1.00	0.82	0.82	0.64	0.90	0.11	0.27	0.97	0.25	0.16	−0.20	−0.02
TDS			1.00	0.82	0.82	0.64	0.90	0.11	0.27	0.97	0.25	0.16	−0.20	−0.02
TH				1.00	0.87	0.75	0.57	−0.14	−0.01	0.86	0.12	0.11	−0.14	0.00
Ca					1.00	0.65	0.56	−0.17	−0.05	0.85	0.11	0.26	−0.22	−0.07
Mg						1.00	0.33	−0.19	−0.25	0.73	−0.03	0.09	−0.08	−0.25
Na							1.00	0.22	0.48	0.82	0.33	0.08	−0.19	0.02
K								1.00	0.40	−0.02	0.15	0.12	−0.03	0.31
HCO ₃									1.00	0.09	0.48	−0.12	0.16	0.52
Cl										1.00	0.15	0.06	−0.23	−0.14
F											1.00	0.06	0.09	0.05
SO ₄												1.00	−0.07	0.08
NO ₃													1.00	0.32
PO ₄														1.00

Bold values indicate that the parameters had significant correlation from marginal to good

triangle 83.50 % samples fall into Cl^- type and remaining 16.50 % are in no dominant class. No HCO_3^- or SO_4^{2-} types were identified. About 62.50 % samples exhibit dominance of mixed chemical character, $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$ type trailed by $\text{Ca}^{2+}\text{--Cl}^-$ and $\text{Na}^+\text{--Cl}^-$ type. In post-monsoon season, most of the samples (75 %) present in zone B indicates no dominant class, 16.5 % is in Mg^{2+} type, and 8.5 % samples follow $\text{Na}^+ + \text{K}^+$ type in the cationic triangular field. About 87.50 % samples in the anionic triangle account for the Cl^- -type and further 12.50 % account for no dominant class. The same observation is obtained in the diamond field compared with the monsoon season. Samples present in zones 4 and 5 indicate the dissolution of sedimentary rocks and Na^+ feldspar minerals, secondary evaporation and ion exchange processes which eventually increase the concentration of milliequivalent percentage of Na^+ and Cl^- , and decrease the percentage of HCO_3^- , SO_4^{2-} , and Ca^{2+} . The results show that mixed $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$ is the predominant type identified and followed by $\text{Ca}^{2+}\text{--Cl}^-$ and $\text{Na}^+\text{--Cl}^-$ type.

Gibbs mechanism for groundwater evolution

The reaction between groundwater and aquifer minerals plays a vital role in water quality, which helps to understand the genesis of groundwater (Bozdog and Gocmez 2013; Prasanna et al. 2010). The mechanism controlling the chemical composition of major dissolved salts in water and

ascertained close relationships between aquifer lithology and water compositional chemistry was proposed by Gibbs (1970) through Gibbs diagram for major cations and anions. This diagram was employed to assess hydrochemical processes such as atmospheric precipitation dominance, rock weathering dominance, and evaporation–crystallization dominance by plotting the weight ratios of $(\text{Na}^+ + \text{K}^+)/(\text{Na}^+ + \text{Ca}^{2+})$ and $\text{Cl}^-/(\text{Cl}^- + \text{HCO}_3^-)$ represented as a function of TDS (Marghade et al. 2012).

Figure 3a illustrates that the majority of groundwater samples in pre-monsoon, monsoon, and post-monsoon seasons fall in the evaporation–crystallization dominance and only a few samples are in rock weathering dominance by plotting $(\text{Na}^+ + \text{K}^+)/(\text{Na}^+ + \text{Ca}^{2+})$ against TDS. Figure 3b shows that 66.60 % in pre-monsoon, 75 % in monsoon and post-monsoon seasons have a plot in the evaporation–crystallization field. Only 33.40 % (pre-monsoon) and 25 % (monsoon and post-monsoon seasons) samples were falling in a rock weathering field, due to weathering of minerals and salt precipitation. But evaporation–crystallization is the dominant field, indicating the secondary evaporation. Groundwater evaporation is a common phenomenon in the Amaravathi River basin. When evaporation increases salinity, the concentration of Na^+ and Cl^- contents also increases by increasing TDS. Anthropogenic activity is also responsible for evaporation due to excess usage of agricultural fertilizers and irrigation return flow, which enhance Na^+ and Cl^- concentrations (Gupta et al. 2008).

Fig. 2 Piper trilinear diagram for groundwater samples

Drinking water suitability

Based on the water quality parameter results, the groundwater samples are not fit for drinking purposes with respect to the high content of TDS, TH, Ca^{2+} , Mg^{2+} , Na^+ , Cl^- , HCO_3^- , and F^- . The dominant cation trend was in the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$, and the dominant anion trend was in the order of $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$. The radial diagram (Fig. 4) shows the ionic trends in groundwater of the Amaravathi River basin; the same result was observed for monsoon and post-monsoon, while monsoon season has some variation due to infiltration and flow rate.

Suitability of groundwater for irrigation purposes

To determine the quality of groundwater for irrigation purposes, some hydrochemical parameters are used such as EC, salinity, sodium absorption ratio (SAR), residual sodium carbonate (RSC), percent sodium, Kelly's ratio (KR), magnesium hazard (MH), potential salinity (PS), chloro-alkaline indices (CAI I and CAI II), and permeability index (PI). Suitability of groundwater for irrigation purpose depends on the dissolved ion constituent, and one important factor which relates to plant growth with water quality is drainage. If the crop production is high, the soil is well drained even if it is highly saline water, but in poorly drained areas, the groundwater is not satisfied even with good water quality (Todd 1980; Richards 1954).

Salinity hazard

Richards (1954) classified groundwater for irrigation uses into four types according to electrical conductivity. The high EC value indicates the enrichments of salt content in water. High salinity leads to the formation of saline soils, which does not support plant growth. During pre-monsoon and monsoon seasons, 37.50 and 62.50 % samples (Table 9) are in high- and very high-salinity category, while in post-monsoon, 33.70 % account for high salinity and remaining fall in very high-salinity category. None of the samples are in excellent-to-medium classes, which indicate the groundwater in the study area is highly saline.

Sodium absorption ratio

Sodium hazard is a tendency of water to replace absorbed $\text{Ca}^{2+} + \text{Mg}^{2+}$ with Na^+ , which is expressed in terms of SAR. The sodium forms alkaline soils with a combination of carbonates and with chloride forms salinity. Exchangeable $\text{Ca}^{2+} + \text{Mg}^{2+}$ ions are replaced by Na^+ , which cause deflocculation and lose permeability of soils (Arveti et al. 2011; Todd 1980). The SAR value in the study area ranges from 1.039 to 15.21 meq/L for pre-monsoon, 0.855–15.39 meq/L in monsoon season, while in post-monsoon it ranges from 1.063 to 17.17 meq/L (Table 8). Seventy-five percent samples in pre-monsoon and 66.70 % samples in monsoon and post-monsoon seasons fall in 0–6 meq/L with no problems (Table 7) on SAR and remaining in the other two categories 6–9 and >9 meq/L having alkalinity problems.

Fig. 3 Mechanism controlling groundwater in Amaravathi River basin

Fig. 4 Radial diagram showing major ion chemistry in groundwater of Amaravathi River basin

USSL diagram

United States salinity diagram was obtained by plotting values of salinity hazard versus alkali hazard values. The USSL (1954) diagram classifies the groundwater quality into sixteen zones to assess the degree of suitability of water for agricultural purposes. From Fig. 5, the salinity hazard (C) can be divided into four sub-zones: C1 (low-salinity hazard, $<250 \mu\text{S}/\text{cm}$), C2 (medium-salinity hazard, 250 to $750 \mu\text{S}/\text{cm}$), C3 (high-salinity hazard, $750\text{--}2250 \mu\text{S}/\text{cm}$), and C4 (very high-salinity hazard, $>2250 \mu\text{S}/\text{cm}$), considering good, moderate, poor, and very poor classes, respectively. The sodium hazard (S) can be classified into four sub-zones such as S1 (low-sodium hazard, <10), S2 (medium-sodium hazard, 10–18), S3 (high-sodium hazard, 18–26), and S4 (very high-sodium hazard, >26) considering them as good, moderate, poor, and very poor classes, respectively.

It was found that 33.30 % in pre-monsoon, 41.70 % in monsoon, and 37.50 % in post-monsoon seasons fall in the zone of C3-S1 indicating high-salinity and low-sodium hazards (Fig. 5); it can be used for irrigation in almost all types of soil with a little danger of exchangeable sodium. Of the samples, approximately 66.70 % in pre-monsoon, 58.30 % in monsoon, and 62.50 % in post-monsoon fall in the zone of C4-S1 indicating very high salinity and low-sodium hazard, and it is not suitable for irrigation under usual conditions. It can be used only on crops that are very tolerant of salt. Extravagant solutes in groundwater water are a typical issue in semi arid regions, where water loss through evaporation is maximal (Ramesh and Elango 2012). Poor drainage allows the water table to rise close to the root zone of plants, causing accumulation of Na^+ salt in the soil solution through capillary rise following surface evaporation. Salt-tolerant plants/crops should be selected for high-saline regions, and the irrigation water must be applied in excess to

provide considerable leaching (Singh et al. 2012) or mixed with surface water to reduce salinity.

Percent sodium

The sodium content is usually expressed in terms of percent sodium or soluble sodium, which is widely used for evaluating the suitability of water for irrigation (Wilcox 1955). Based on $\% \text{Na}^+$, it is classified into five types; excellent, good, permissible, doubtful, and unsuitable (Table 9). The percent sodium content in groundwater varied from 15.60 to 74.99 % in pre-monsoon, 10.92–76.85 % in monsoon, and 14.84–78.36 % in post-monsoon. In general, percent sodium should not exceed 60 %, and above that it was not better for better crop yields. Approximately, 87 % of water samples in pre-monsoon and 83.30 % in monsoon and post-monsoon range from excellent to permissible category, and the remaining are observed in doubtful category.

Wilcox diagram

The suitability of groundwater of the Amaravathi River basin for agricultural purposes was evaluated according to Wilcox diagram. The percent sodium values and corresponding EC values are plotted within the Wilcox diagram and are categorized into five zones, excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable, and unsuitable. Plot of analytical data on Wilcox diagram shows that no one samples fall in excellent to good category in all three seasons, although in pre-monsoon, monsoon, and post-monsoon seasons, 33.30, 25.00, and 12.50 % samples, respectively, are observed in good to permissible category (Fig. 6) and only 4.20 % in monsoon and post-monsoon seasons, respectively, are present in permissible to doubtful zone. In doubtful to unsuitable zone, 29.20 %, 33.30 and 45.80 % samples fall in pre-

Table 8 Basic statistics of groundwater for irrigation purpose

Parameters	Seasons	Mean	Minimum	Maximum	Standard deviation
SAR, meq/L	Pre-monsoon	5.015	1.039	15.21	3.328
	Monsoon	5.156	0.855	15.39	3.354
	Post-monsoon	5.136	1.063	17.17	3.556
Percent Na, %	Pre-monsoon	44.05	15.60	74.99	13.61
	Monsoon	44.78	10.92	76.85	14.87
	Post-monsoon	43.88	14.84	78.36	14.26
PI, %	Pre-monsoon	53.70	25.46	80.52	12.65
	Monsoon	54.40	19.31	82.40	14.18
	Post-monsoon	53.36	24.13	84.36	13.70
KR, meq/L	Pre-monsoon	0.890	0.172	2.921	0.605
	Monsoon	0.942	0.114	3.228	0.680
	Post-monsoon	0.913	0.164	3.530	0.717
MH, meq/L	Pre-monsoon	44.86	23.71	70.88	14.23
	Monsoon	45.48	29.79	72.39	10.29
	Post-monsoon	43.54	26.58	65.31	8.754
PS, meq/L	Pre-monsoon	12.94	2.317	49.66	11.76
	Monsoon	10.25	2.138	28.10	8.846
	Post-monsoon	10.76	2.365	28.51	8.884
CAI—I, meq/L	Pre-monsoon	0.18	−0.39	0.77	0.32
	Monsoon	0.12	−1.21	0.86	0.42
	Post-monsoon	0.14	−0.89	0.81	0.37
CAI—II, meq/L	Pre-monsoon	0.70	−0.43	4.33	1.13
	monsoon	0.52	−0.50	2.36	0.86
	Post-monsoon	0.56	−0.46	2.44	0.89
RSC, meq/L	Pre-monsoon	−10.6	−37.6	−1.75	9.91
	Monsoon	−9.86	−26.6	1.81	8.92
	Post-monsoon	−10.1	−30.5	2.74	9.24
GR—I, meq/L	Pre-monsoon	0.674	0.368	0.933	0.169
	Monsoon	0.656	0.410	0.896	0.164
	Post-monsoon	0.656	0.417	0.903	0.166
GR—II, meq/L	Pre-monsoon	0.583	0.325	0.864	0.138
	Monsoon	0.587	0.241	0.858	0.152
	Post-monsoon	0.572	0.297	0.859	0.132

monsoon, monsoon, and post-monsoon seasons, respectively. In this regard, 37.50 % samples in all three seasons are observed in unsuitable category. When the concentration of Na^+ ion is high in irrigation water, clay particles observe Na^+ displacing Ca^{2+} and Mg^{2+} which eventually reduce the soil permeability, and during wet conditions, water circulation is restricted, and the soil becomes hard when it becomes dry (Jafar Ahamed et al. 2013; Kumar et al. 2007).

Residual sodium carbonate

The high content of bicarbonates and carbonate in excess of Ca^{2+} and Mg^{2+} is expressed as the RSC and influence the groundwater for irrigation (Ragunath 1987; Eaton 1950). Ca^{2+} and Mg^{2+} ions in soil are precipitated by

HCO_3^- and CO_3^- resulting in the high content of sodium ions (Karanth 1987). According to USSL (1954), groundwater of RSC values <1.25 meq/L is safe for irrigation, its marginal lies between 1.25 and 2.50 meq/L, and a value >2.5 meq/L is not suitable for irrigation (Table 9). All the samples in pre-monsoon have RSC value <1.25 meq/L, 95.80 % samples in monsoon and post-monsoon are safe for irrigation, and 4.20 % in monsoon and post-monsoon season fall in the field of doubtful and unsuitable category. Approximately, 95 % samples in all three seasons are safe for irrigation with respect to RSC.

Chloro-alkaline indices

An important factor affecting the groundwater chemistry is ion exchange which is a hard task for hydrogeologists,

Fig. 5 Classification of groundwater based on USSSL diagram

since it regulates the transport of pollutant chemicals in both aquifer and soils (Li et al. 2013). The ion exchange process can be known by chloro-alkaline indices (CAI I and CAI II), also known as a Schoeller index (Schoeller 1977). The CAI can be either positive or negative, if Na^+ and K^+ are exchanged with water with Ca^{2+} and Mg^{2+} in the rock/aquifer soil, both of the above indices are positive indicating the base-exchange phenomenon. If Ca^{2+} and Mg^{2+} are exchanged with water with Na^+ and K^+ in aquifer medium, the indices will be negative, which indicates chloro-alkaline disequilibrium and the reaction as a cation–anion exchange reaction (Table 8). In the present study, 66.70 % of groundwater samples in all three seasons show positive values indicating reverse ion exchange, and only 33.30 % samples having negative value have normal ion exchange. The above observation

reveals that reverse ion exchange is the leading process in the groundwater.

Potential salinity

The concentration of highly soluble salts increases the salinity of the soils, whereas low soluble salts precipitate and accumulate into the soil for successive irrigation (Ogunfowokan et al. 2013). The suitability of water for irrigation is described by Doneen (1964) based on potential salinity. Potential salinity depends on the concentration of Cl^- as well as SO_4^{2-} . The higher the potential salinity value, high will be Cl^- concentration. The average potential salinity value (Table 8) in the study area is 12.94 meq/L (pre-monsoon), 10.25 meq/L (monsoon), and 10.76 meq/L (post-monsoon). The results indicate that

Table 9 Classification of groundwater upon different irrigation parameters

Parameters	Category	Total number of samples			Percentage of samples		
		Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
EC, $\mu\text{S}/\text{cm}$ (Wilcox 1955)							
<250	Low	—	—	—	—	—	—
250–750	Medium	—	—	—	—	—	—
750–2250	High	9	9	8	37.50	37.50	33.30
>2250	Very high	15	15	16	62.50	62.50	66.70
SAR, meq/L (Richards 1954)							
0–6	No problems	18	16	16	75.00	66.70	66.70
6–9	Increase problems	3	5	5	12.50	20.80	20.80
>9	Severe problems	3	3	3	12.50	12.50	12.50
Percent sodium, % (Wilcox 1955)							
<20	Excellent	2	1	1	8.40	4.20	4.20
20–40	Good	10	9	9	41.60	37.50	37.50
40–60	Permissible	9	10	10	37.50	41.60	41.60
60–80	Doubtful	3	4	4	12.50	16.70	16.70
>80	Unsuitable	—	—	—	—	—	—
RSC, meq/L (Richards 1954)							
<1.25	Good	24	23	23	100	95.80	95.80
1.25–2.50	Doubtful	—	1	—	—	4.20	—
>2.50	Unsuitable	—	—	1	—	—	4.20
Kelly's ratio, meq/L							
<1	Suitable	18	18	18	75.00	75.00	75.00
>1	Unsuitable	6	6	6	25.00	25.00	25.00
Magnesium hazard, meq/L							
<50	Suitable	15	18	20	62.50	75.00	83.30
>50	Unsuitable	9	6	4	37.50	25.00	16.70

Fig. 6 Rating of groundwater samples in relation to percent sodium versus electrical conductivity (Wilcox diagram)

groundwater has high PS value and is not suitable for irrigation.

Magnesium hazard

The magnesium hazard value is used to estimate the groundwater for irrigation, having an excess level of Mg^{2+} which damages soil structure, when water contains high Na^+ and high salinity (Rao et al. 2012). Generally, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in the water, but they do not behave identically in soil systems. If MH value exceeds >50 meq/L, it is considered to be harmful to plant growth and is not suitable for irrigation. From the analytical data, the MH value ranges from 23.71 to 70.88 meq/L, 29.79–72.39 meq/L, and 26.58–65.31 meq/L for pre-monsoon, monsoon, and post-monsoon seasons, respectively (Table 8). Based on the above criteria, 37.50, 25.00, and 16.70 % samples from pre-monsoon, monsoon, and post-

monsoon seasons, respectively, are not suitable for agricultural purposes.

Kelly's ratio

Groundwater is classified for irrigation based on Kelly's ratio. Kelly (1946) and Paliwal (1967) calculated this parameter, when Na^+ is measured against Ca^{2+} and Mg^{2+} ions. Water with $\text{KR} > 1.0$ indicates an excess level of Na^+ and greater than 3 is not suitable. About 75 % samples in all three seasons are safe for irrigation (<1.0 meq/L), and 25.00 % of the samples are unsuitable, having a KR value >1.0 (Table 9).

Permeability index

Permeability is greatly influenced by Na^+ , Ca^{2+} , Mg^{2+} , Cl^- , and HCO_3^- contents of the soil, and it is affected by long-term use of irrigation water, with high salt content (Rao et al. 2012; Kumar et al. 2007). Doneen (1964) gave a criteria for assessing the suitability of groundwater for irrigation based on PI. On the basis of PI, it can be classified into three classes: class I, suitable (100 % maximum permeability), class II, marginal (75 % maximum permeability), and class III, unsuitable (25 % maximum permeability). The PI value in the study area ranges from 25.46 to 80.52 %, 19.31–82.40 %, and 24.13 to 84.36 % for pre-monsoon, monsoon, and post-monsoon seasons, respectively (Table 6). About 70.00 and 67.00 % of samples from pre-monsoon, monsoon, and post-monsoon seasons fall in class I and 12.50 % and 8.30 % samples fall in the class II category (Fig. 7), indicating that the water is suitable for irrigation and the remaining are unsuitable.

Conclusion

The groundwater samples of the Amaravathi River basin have been carried out to assess the suitability for drinking and irrigation purposes. The data on parameter-analyzed water samples show elevated level of salt contents, which results in unsuitable for drinking purposes compared with WHO and BIS standards. The dominant constituents of groundwater are as follows: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ for cation and $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$ for anions. Water facies classification shows that 62 % of groundwater samples in all three seasons belong to mixed $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$ type followed by $\text{Ca}^{2+}\text{--Cl}^-$ and $\text{Na}^+\text{--Cl}^-$ type. Evaporation–crystallization is the dominant factor with slight rock weathering dominance as suggested by Gibbs diagram. Some good positive correlation of Na^+ , Ca^{2+} and Mg^{2+} with EC, TDS, TH, and Cl^- is observed, respectively. According to irrigational quality parameters, 70 %

Fig. 7 Classification of irrigation water based on permeability index

of samples are suitable for irrigation in all three seasons with respect to KR, MH, RSC, and PI. From USSS and Wilcox diagram, 30 % of the samples are unsuitable. The continuous usage of these groundwater with high Na^+ , K^+ , and Cl^- leads to low crop yield, and which affects the soil and plant growth. Comparing the groundwater samples from the origin of Karur district, the downstream samples are over-exploited due to continuous mixing of dyeing effluents, municipal wastes, and dump of agricultural and textile wastes directly to the river during the past 11 years. The groundwater in the Amaravathi River basin is in a critical situation, and the government and policy makers should put attention to protect this natural resource from contamination; otherwise, some serious damage will happen to living beings in the future years.

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