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ORIGINAL ARTICLE

Hydrogeochemical characterization and assessment of water suitability for drinking and irrigation in crystalline rocks of Mothkur region, Telangana State, South India

G. Sakram[1] · Narsimha Adimalla[2,3]

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Abstract

The present study confers the chemical quality of groundwater and surface water of Mothkur region, Telangana State, for drinking and irrigational purposes. Mothkur region is geologically occupied by the Archaean crystalline terrain. Most of the population depends on groundwater for their daily needs especially for drinking, house needs and irrigation purposes. For this reason, twenty-five groundwater and five surface water samples were collected and analysed for pH, electrical conductivity, total dissolved solids (TDS), total hardness (TH) bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), fluoride (F^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+). The results are evaluated and compared with WHO and BIS water quality standards. Based on obtained results 32%, 20%, 28% and 4% of groundwater samples are not recommended for drinking with reference to the concentrations of fluoride, TDS, TH and Cl^-, respectively. Base-exchange indices and meteoric genesis indices classified 67% and 33% of the water sources as the Na^+–HCO_3^- type and deep meteoric water percolation type, respectively. Piper trilinear diagram for geochemical classification indicates 44% and 60% of groundwater and surface water samples of Ca^{2+}–Na^+–HCO_3^- type and 29% belong to Na^+–HCO_3^- types. Multivariate graphical methods have been carried out using the United States Salinity Laboratory diagram, Wilcox diagram, sodium adsorption ratio, per cent sodium (%Na), residual sodium carbonate and permeability index which indicate that majority of groundwater samples are useful for irrigation purposes.

Keywords Hydrochemistry · Groundwater quality · Sodium adsorption ratio (SAR) · Per cent sodium (%Na) · Residual sodium carbonate (RSC) · Permeability index (PI) · Mothkur region · South India

Introduction

In recent times, huge population growth, intense urbanization, increasing industries and tremendous agricultural activities all over the world have contributed to tremendous increase in demand for freshwater for household applications, agricultural and industries (Adimalla and Venkatayogi 2018; Alexakis and Tsakiris 2010). Due to insufficient supply of surface water, most of the people in arid and semiarid regions in India are depending primarily on groundwater for their daily needs and irrigation usages. Moreover, groundwater today accounts for a whopping 62.4% of net irrigation needs, 85% of rural drinking water needs and 50% of urban water needs (Raju 1998). He et al. (2015) have estimated that more than 1.5 billion people worldwide rely on groundwater as their chief source of drinking water. Hence, it is concluded that the groundwater is an elixir of life and other hand groundwater resource is facing more problems in

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✉ Narsimha Adimalla
adimallanarsimha@gmail.com

1 Department of Applied Geochemistry, University College of Science, Osmania University, Hyderabad 500 007, Telangana State, India

2 School of Environmental Science and Engineering, Chang'an University, No. 126 Yanta Road, Xi'an 710054, Shaanxi, China

3 Key Laboratory of Subsurface Hydrology and Ecological Effects in Arid Region of the Ministry of Education, Chang'an University, No. 126 Yanta Road, Xi'an 710054, Shaanxi, China

recent years including quality aspects especially in arid and semiarid regions. Specifically, agricultural chemicals, such as, fertilizers, pesticides and other metal pollution, make the water unfit for drinking purposes (Kelly 1997). Therefore, knowledge of hydrogeochemistry of water is very essential to evaluate the water for drinking, irrigation and other needs. Eventually, the quality of groundwater is controlled by many factors such as rainfall, topographic relief, mineral dissolution, mineral solubility, ion exchange, oxidation, reduction, natural and anthropogenic activities such as geological structure and mineralogy of the watersheds and aquifers, the residence time, poor sanitary conditions, application of fertilizers and pesticides for higher crop yields without understanding the chemical characteristics of soils and industrial development without following any appropriate remedial measures (Todd 1980; Appelo and Postma 2005; Drever 1997; Wang et al. 2015; Hajizadeh Namaghi et al. 2011; Sappa et al. 2015). Therefore, it is most essential to monitor the quality of water resources in arid and semiarid regions in India particularly groundwater, which is considered as a principal source for drinking and irrigation purposes.

There are number of studies that have been conducted on groundwater quality assessment in many parts of the arid and semiarid regions. Kaur et al. (2016) have studied the groundwater quality for drinking and irrigation purposes in Malwa region, Punjab. Subramani et al. (2005) have studied groundwater quality and its suitability for drinking and agricultural use in Tamil Nadu. Tamma et al. (2015) have studied hydrochemical assessment of groundwater in Jalandhar district. Thakur et al. (2016) have studied that assessment of groundwater for drinking and agriculture in parts of Punjab. Ravikumar et al. (2012) have studied geochemistry of groundwater quality and its evaluation in Karnataka. Narsimha and Sudarshan (2017a) have studied contamination of fluoride in groundwater in Siddipet and reported high fluoride concentration in southern part of Siddipet, Medak district. Amiri et al. (2015) have reported that groundwater chemistry and its suitability for drinking and agricultural purpose in central Iran. Moreover, in India and many parts of the world, abundant studies have been carried out to assess the geochemical characteristics of groundwater quality with respect of drinking and irrigation (Kudoda and Abdalla 2015; Adimalla et al. 2018a; Murkute 2014; Raju et al. 2011; Dimitris Alexakis 2011; Subba Rao et al. 2012; Sudarshan et al. 2014; Li et al. 2017a, b; Jeevanandam et al. 2006; Li et al. 2012; 2014a, b; Cheng Qian et al. 2016; Sappa et al. 2015; Narsimha and Sudarshan 2013; Salem et al. 2015; Sethy et al. 2016; He et al. 2015; Panaskar et al. 2016). Furthermore, a number of researchers have used electrical conductivity (EC), sodium absorption ratio (SAR), per cent sodium (%Na), residual sodium carbonate (RSC) and permeability index (PI) classifications for irrigation water quality in many parts of the country (Adimalla and Venkatayogi 2018; Adimalla et al. 2018a; Qian et al. 2016; Sappa et al. 2015; Narsimha et al. 2013a, b; Aghazadeh and Mogaddam 2011; Ravikumar et al. 2012; Li et al. 2012). Eventually, Nalgonda district represents a true picture of hard terrain, where there is no sufficient surface water; therefore, most of the district people depend on groundwater for their daily needs. Mothkur region is one of the mandal in Nalgonda district, where people rely on groundwater and observed tremendous increase day by day and with number of water quality issues in various places in this region. This is one of the main reasons to select Mothkur region to evaluate the groundwater and surface water quality issues with main objective to assess the groundwater and surface water quality for drinking and irrigation purposes.

Geology of the study region

The studied area is situated in the northern part of Nalgonda district, Telangana State, South India (Fig. 1) and lies between 17.4147N and 17.4542N latitude and 79.1130E and 79.1561E longitude in Survey of India Toposheet No. 56 O3. The entire Mothkur region is under Archaean crystalline rocks, comparing granites, gneisses, schists and intrusive. The crystalline rocks inherently devoid of primary porosity; however, subsequently, with dynamic process of weathering, the rocks undergo fracturing and fissuring and joints over a period of time, leading to the development of secondary porosity, which forms the source for groundwater. July is the wettest month of the year contributing about 23% of annual rainfall. The mean seasonal rainfall is 562 mm in south-west monsoon (June–September), 139 mm in north-east monsoon (October–December), 7 mm rainfall in winter (January–February) and 43 mm in summer (March–May). About 74.8% of the annual rain fall is received from south-west monsoon period during June–September and 18.5% rainfall contributes from north-east monsoon.

Materials and methods

Twenty-five groundwater and five surface water samples were collected in and around Mothkur region (Fig. 1), Nalgonda district, Telangana, in one-litre polyethylene bottles and stored at 10 °C. All containers used for sampling were washed with 10% nitric acid solution followed by double distilled water. Immediately after sampling, pH and electrical conductivity (EC) were measured in the field with using pH/EC/TDS meter (Hanna HI9811-5). Total dissolved solids (TDS) were calculated from EC multiplied by 0.64 (Brown et al. 1970; Hem 1985). Total hardness (TH) bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), fluoride (F^-),

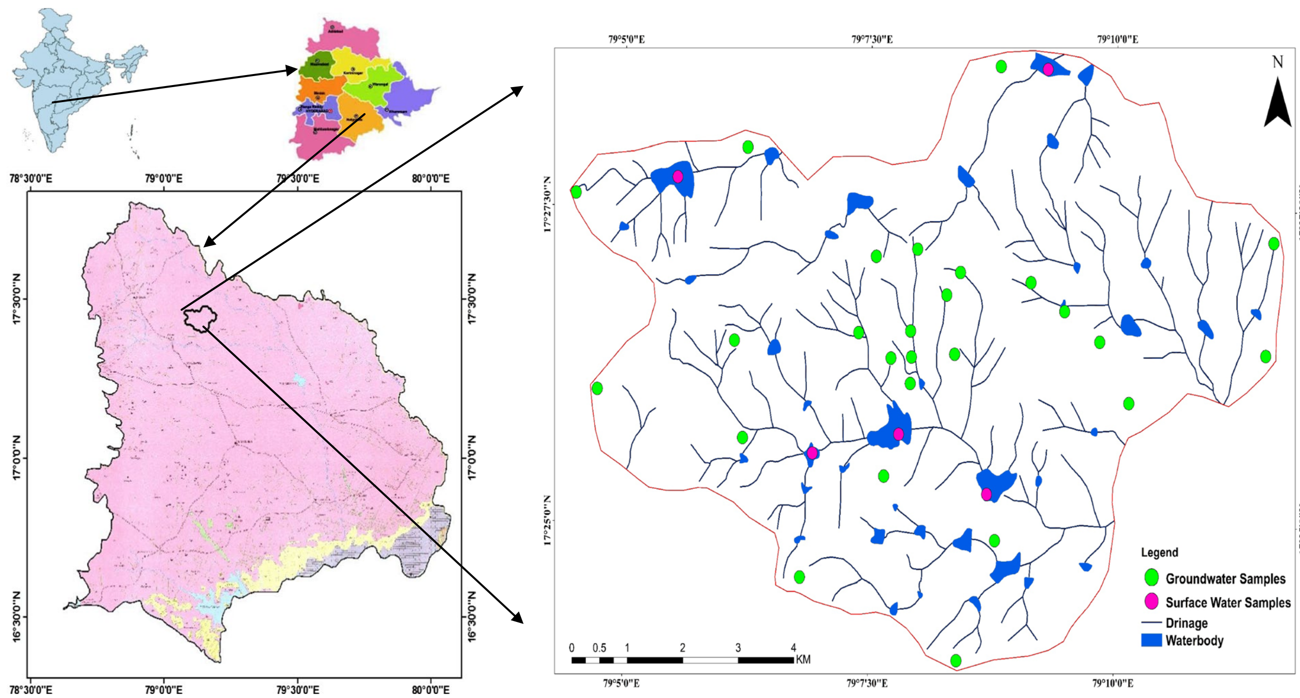

Fig. 1 Groundwater and surface water sampling locations along with drainage map of the Mothkur region, Telangana State, South India

calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) were analysed with using standard methods (APHA 1995), and detailed procedure is presented in Table 1. Analysed water samples precision expressed as per cent relative standard deviation was below 10%, which is within the acceptable limit (Domenico and Schwartz 1990). Moreover, sodium absorption ratio (SAR), percentage sodium (%Na), residual sodium carbonate (RSC) and permeability index (PI) classifications were used for irrigation water quality and calculation methods are presented in Table 1.

Preparation of spatial distribution maps

The base map of the study area was prepared using Survey of India topographic sheet 56 O3 and digitized using ArcGIS10.1 software (Fig. 1). The precise locations of sampling points were marked by using GPS (Garman eTrex 30), and the exact longitudes and latitudes of sampling points were imported in GIS platform for further analysis. Spatial analyst tools extension used to interpolate the inverse distance weighed (IDW) algorithm was an effective tool to prepare the spatial distribution maps of the chemical parameters of water of the study area. The IDW technique has been used widely in global scale to generate the spatial distribution maps for various purposes, especially, identify the high, medium and low chemical elements concentration zones.

Result and discussion

In order to give the general picture of the surface water and groundwater, analytical results are presented in Tables 2 and 3. The pH values of surface water and groundwater of the study area varied from 7.2 to 7.8 and 7.0 to 8.4, respectively, indicating marginally alkaline nature (Tables 2, 3). The obtained electrical conductivity (EC) values of surface water and groundwater samples varied were ranged from 908 to 2860 µS/cm and 676 to 4016 µS/cm at 25 °C, respectively (Tables 2, 3). Concentration of total dissolved solids (TDS) in surface water and groundwater ranged from 595 to 1887 mg/L and 446 to 2650 mg/L, respectively (Tables 2, 3). However, Freeze and Cherry (1979) categorized water on the basis of TDS concentration into four groups which are represented as fresh (TDS < 1000 mg/L), brackish (> 1000 mg/L), saline (> 10,000 mg/L) and brine (100,000 mg/L). Based on this classification, surface water and groundwater fall in fresh category in about 4 and 17 samples only and remaining are in brackish category (Fetter 1990; Table 4). The TH in surface water and groundwater ranges from 285 to 870 mg/L and 280 to 1185 mg/L, respectively (Tables 2, 3). The TH classification according to Sawyer and McCarty (1967) is clearly illustrated in Table 5, and based on this most of the surface and groundwater samples fall in very hard category, which is not useful for drinking purposes (Table 5).

Table 1 Instrumental, titrimetric and calculation methods used for chemical analysis of water samples in Mothkur region, Telangana State

Parameters	Characteristics	Analytical method	Reagents	Unit	References
General	pH	pH/EC/TDS meter	pH 4, 7 and 9.2	–	APHA (1995)
	Electrical Conductivity	pH/EC/TDS meter	Potassium chloride	µS/cm	APHA (1995)
	Total dissolved solids (TDS)	Calculation	EC X (0.55–0.75)	mg/L	Hem (1991)
	Total hardness (as $CaCO_3$)	EDTA titrimetric	EDTA, ammonia buffer and Eriochrome Black-T (EBT) indicator	mg/L	APHA (1995)
Major Cations	Calcium (as Ca^{2+})	EDTA titrimetric	EDTA, sodium hydroxide and murexide	mg/L	APHA (1995)
	Magnesium (as Mg^{2+})	Calculation	MgH = TH-CaH; Mg = MgH X Eq.Wt of Mg X normality of EDTA	mg/L	APHA (1995)
	Sodium (as Na^+)	Flame photometric	Sodium chloride (NaCl) and KCl	mg/L	APHA (1995)
	Potassium (as K^+)	Flame photometric	NaCl and KCl	mg/L	APHA (1995)
Major anions	Bicarbonates (HCO_3^-)	Titrimetric	Hydrosulphuric acid (H_2SO_4), phenolphthalein and methyl orange	mg/L	APHA (1995)
	Chloride (Cl^-)	Titrimetric	Silver nitrate ($AgNO_3$), potassium chromate	mg/L	APHA (1995)
	Fluoride (F^-)	ISE (ion selective electrode; Thermo Orion)	TISAB III and NaF	mg/L	APHA (1995)
	Sulphates (SO_4^{2-})	UV–visible spectrophotometer	HCl, ethyl alcohol, NaCl, barium chloride, sodium sulphate	mg/L	APHA (1995)
Irrigation water	Sodium absorption ratio (SAR)	$\frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$	–	meq/L	Richards (1954)
	Residual sodium carbonate (RSC)	$(CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+})$	–	meq/L	Eaton (1950)
	Per cent sodium (%Na)	$\frac{Na^+ + K^+}{(Ca^{2+}+Mg^{2+}+Na^+ + K^+)} \times 100$	–	%	Wilcox (1955)
	Base-exchange indices (BEI)	$[Na^+ – Cl^-/SO_4^{2-}$	–	meq/L	Matthess (1982)
	Meteoric genesis indices (MGI)	$[(Na^+ + K^+) - Cl^-]/SO_4^{2-}$	–	meq/L	Matthess (1982)
	Permeability index (PI)	$PI = \frac{Na^+ + \sqrt{HCO_3}}{(Ca^{2+}+Mg^{2+}+Na^+)} \times 100$	–	meq/L	Doneen (1964)

Cation and anion chemistry

The major ions like calcium, magnesium, sodium, potassium, bicarbonate, sulphate, nitrate and chloride are present in most of the water having > 1 mg/L (Younger 2007). The major cations according to their decreasing concentration expressed in mg/L are as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Sodium is the most profuse alkali metal. The analytical data reveals that the concentration of Na^+ in surface water and groundwater samples range between 131 and 400 mg/L and 129 and 545 mg/L with an average of 193.6 and 214.8 mg/L, respectively (Tables 2, 3). The maximum allowable limit for Na^+ is 200 mg/L (WHO 1997; BIS 2003). Twelve (BH-1 to BH-5, BH-8, BH-16 to BH-18, BH-21 and BH-25) groundwater samples and one (SW-2) surface water sample have Na^+ concentration above the permissible limit (Tables 2, 3). However, the intake of high levels of Na^+ in groundwater may cause hypertension, arteriosclerosis, circulatory diseases, renal, oedema and kidney problems (Li et al. 2017a, b; Srinivas et al. 2013). The analytical results show that the Ca^{2+} in surface water and groundwater samples varied from 56 to 92 mg/L and 24 to 242 mg/L was on average 72.6 mg/L and 77.2 mg/L, respectively (Tables 2, 3). The maximum admissible limit for Ca^{2+} is 200 mg/L, and all collected samples are well within the maximum tolerable limits except one location as prescribed by WHO (1997) and BIS (2003) (Table 3). Surface water and groundwater samples concentration of K^+ varies from 1 to 4 mg/L and 2 to 6 mg/L, respectively (Tables 2, 3). Moreover, K^+ is an essential nutrient but if ingested in excess may behave as a laxative (Alam et al. 2012). 100% of surface water and groundwater samples are within the recommended limit of 12 mg/L prescribed by WHO (1997) (Table 3). Furthermore, the Mg^{2+} concentration in surface water and groundwater ranges from 25 to 56 mg/L and 15 to 176 mg/L, with a mean value of 38.8 and 42.6 mg/L, respectively (Tables 2,

Table 2 Hydrogeochemical characteristics of groundwater (BH) and surface water (SW) of the Mothkur region, Telangana State, South India

Field label	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	F^-	pH	EC	TDS	TH
SW-1	56	35	131	1	470	80	220	0.68	7.8	1460	964	285
SW-2	92	56	400	4	360	140	545	0.63	7.6	2860	1887	870
SW-3	68	35	145	2	439	76	205	0.69	7.2	1449	956	315
SW-4	60	43	149	2	433	125	215	0.63	7.5	1481	977	325
SW-5	82	25	143	2	408	27	40	0.81	7.5	902	595	310
BH-1	148	90	264	3	488	190	530	1.85	8.4	3000	1980	575
BH-2	41	24	267	3	457	80	315	1.13	8.3	1800	1188	580
BH-3	42	26	212	3	317	118	185	0.86	7.3	1384	913	460
BH-4	46	28	276	2	329	80	315	1.02	7.3	1870	1234	600
BH-5	38	23	205	2	311	117	340	0.97	7.2	1235	815	445
BH-6	38	23	184	2	348	140	120	1.09	7.4	1089	719	400
BH-7	38	23	166	2	366	51	80	1.14	7.3	970	640	360
BH-8	38	23	207	2	439	80	115	1.15	7.3	1183	781	450
BH-9	44	27	159	2	432	35	60	1.49	7.6	933	615	345
BH-10	36	22	170	2	360	55	70	0.98	7.4	960	633	370
BH-11	34	21	173	2	396	58	75	0.99	7.6	1004	663	375
BH-12	24	15	156	2	378	46	65	0.84	7.3	926	611	340
BH-13	48	29	159	2	512	45	65	1.55	7.3	1052	694	345
BH-14	242	67	405	5	402	75	430	0.84	7	2650	1749	880
BH-15	82	30	152	2	299	32	50	1.03	7.2	731	548	330
BH-16	184	176	545	6	628	240	785	1.64	8.1	4016	2650	1185
BH-17	90	85	266	3	463	55	475	1.77	7.8	2335	1541	575
BH-18	88	72	228	3	543	75	415	1.62	7.4	2680	1768	495
BH-19	82	26	143	2	402	25	25	1.1	7.3	838	553	310
BH-20	80	24	138	2	409	18	340	1.04	7.5	820	541	300
BH-21	140	80	272	3	348	52	360	1.78	7.8	2160	1425	680
BH-22	64	40	147	2	457	19	35	1.29	7.5	881	581	320
BH-23	82	18	129	2	433	24	10	0.96	7.2	676	446	280
BH-24	78	29	145	2	366	20	45	1.15	7.5	890	587	315
BH-25	104	44	202	3	329	27	145	1.11	7.4	1160	765	440

Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, F^-, TDS, TH are expressed in mg/L, EC is in μS/cm, pH unites, SW Surface water and BH Bore hole water/groundwater

3). A major portion of the study area (95%) contains Mg^{2+} within its maximum approved limit 150 mg/L, and in about four (SW-1, SW-2, SW-3, SW-4) surface water samples and eight (BH-1, BH-14, BH-16, BH-18, BH-17, BH-21, BH-22, BH-25) groundwater samples the concentration exceeds the maximum desirable limit < 30 mg/L (Table 2). The HCO_3^- is the dominant anion in the study area and surface water and groundwater samples concentration ranges from 360 to 470 mg/L and 299 to 628 mg/L with an average value of 422 mg/L and 408 mg/L, respectively (Tables 2, 3). Deepali et al. (2012) have confirmed that the SO_4^{2-} is one of the naturally occurring and recurrently present in surface and groundwater of leaching from gypsum and other common minerals and at ingestion of higher concentration of SO_4^{2-} may lead to gastrointestinal irritation. So, the present analytical data show that SO_4^{2-} concentration in surface water and groundwater samples varied from 27 to 140 mg/L and 18 to 240 mg/L, with an average value of 89.6 mg/L and 70.3 mg/L, respectively (Tables 2, 3), of which only one sample (BH-16) exceeded the maximum desirable limit 200 mg/L (BIS 2003; WHO 1997; Table 3). Cl^- majorly derives from the different sources such as domestic wastage, industrial wastes, municipal effluents and weathering of rocks, and it is considered as an index of pollution (Karanth 1987; Hem 1985; Loizidou and Kapetanios 1993). The Cl^- content in the surface water and groundwater samples varied from 40 to 545 mg/L and 10 to 785 mg/L, with an average 245 mg/L and 218 mg/L, respectively; 20% of samples from surface water whereas 40% of groundwater samples exceeded the desirable limits (BIS 2003; WHO 1997; Tables 2, 3). However, in the remaining surface water and groundwater samples, the Cl^- concentration is below the maximum permissible limits. Fluoride contamination in groundwater is one of the foremost issues in water quality

Table 3 Minimum, maximum and mean of groundwater and surface water samples from the study area and its analytical data and comparison with the WHO and BIS standards for drinking purposes

	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	F^-
Minimum	7[a]	676	446	280	24	15	129	2	299	18	10	0.84
	7.2[b]	902	595	285	56	25	131	1.4	360	27	40	0.63
Maximum	8.4[a]	4016	2650	1185	242	176	545	6	628	240	785	1.85
	7.8[b]	2860	1887	870	92	56	400	4	470	140	545	0.81
Mean	7.6[a]	1489.7	985.6	470	77.2	42.6	214.8	2.6	408.5	70.3	245	1.22
	7.5[b]	1630.4	1075.8	421	71.6	38.8	193.6	2,3	422	89.6	245	0.69
WHO DL	6.5	–	500	100	75	50	–	–	–	200	200	0.6
% of samples above DL	100[a]	–	96	100	48	24	–	–	–	4	40	100
WHO PL	8.5	–	1500	500	200	150	200	12	–	400	600	1.5
% of samples above DL	Nil[a]	–	20	28	4	4	48	Nil	–	Nil	4	32
BIS DL	6.5	–	500	300	75	30	–	–	–	200	250	1
% of samples above DL	100[b]	–	100	100	40	100	–	–	–	Nil	20	Nil
BIS PL	8.5	–	2000	600	200	100	–	–	–	400	1000	1.2
% of samples above DL	Nil[b]	–	Nil	20	Nil	Nil	–	–	–	Nil	Nil	Nil

Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, F^-, TDS, TH are expressed in mg/L, EC is in µS/cm, pH unites

DL desirable limit, *PL* permissible limit

[a]Groundwater, [b]surface water

Table 4 Distribution of water samples based on the classification of TDS

Water type	TDS concentration (mg/L)	Sample numbers below the limits	% of groundwater	% of surface water
Fresh	< 1000	SW-1, SW-3 to 5, BH-3, BH- 5 to BH-13, BH-15, BH-19, BH-20 BH-22 to BH-25	68	80
Brackish	> 1000	SW-2, BH-1, BH-2, BH-4, BH-14, BH-16 to BH-18, BH-20	32	20
Saline	> 10,000	–	–	–
Brine	100,000	–	–	–

Table 5 Distribution of water samples based on the classification of TH

Water type	TH concentration (mg/L)	Sample numbers below the limits	% of groundwater	% of surface water
Safe	< 75	–	–	–
Moderately hard	75–150	–	–	–
Hard	150–300	SW-1, BH-23	4	20
Very hard	> 300	SW-2 to 5, BH-1 to 22, BH-24, BH-25	96	80

studies (Ayoob and Gupta 2006; Narsimha and Sudarshan 2017a, b; Narsimha 2012). Fluorite (CaF_2) is the only principal mineral of fluorine, mostly present as accessory minerals in granitic and occasionally in alkaline rocks (e.g. syenite and nepheline syenites). Apatite, amphiboles and micas, which are ubiquitous in igneous and metamorphic rocks, contain fair amounts of fluorine in their structure (Handa 1975; Adimalla and Venkatayogi 2017; Wenzel and Blum 1992; Narsimha and Sudarshan 2017a, b). Koritnig (1951) has obviously illustrated that fluoride is percolated in the initial stages of weathering of granite massifs. The maximum acceptance limit of fluoride in drinking water specified by the World Health Organization WHO (1997) is 1.5 mg/L. Fluoride (F^-) is an essential element for human body when consumed in low amount (< 1.5 mg/L) and excess intake of F^- (> 1.5 mg/L) will have adverse effects on human health (Adimalla and Venkatayogi 2017; Adimalla et al. 2018b, c; Narsimha and Sudarshan 2017a, b). Furthermore, continually consumption of water with fluoride concentrations above 1.5 mg/L results in dental fluorosis characterized initially by opaque white patches, staining, mottling and pitting of teeth (Adimalla et al. 2018c; Narsimha and Rajitha 2018; Narsimha 2018; Narsimha et al. 2018; Kundu et al. 2001).

Moreover, F^- concentration in surface water and groundwater of the study area varied from 0.63 to 0.81 mg/L and 0.84 to 1.85 mg/L, with mean value of 0.69 and 1.22 mg/L, respectively (Tables 2, 3). Surface water is within the maximum permissible limits, besides 32% of groundwater samples having higher concentrations above the maximum permissible limits (Table 3). Low content (< 1 mg/L) of fluoride implies near absence of fluoride-bearing minerals, and higher concentrations (> 1.5 mg/L) of fluoride are prominent in the southern part of the study area.

Spatial distribution of physico-chemical parameters

The hydrogeochemical study with geographical information system (GIS) divulges the zones where the quality of water is suitable for drinking and agricultural purposes. In any area around the world, groundwater quality and spatial distribution maps are significant as protective indicators of potential risk environmental health problems. GIS has been widely used to create spatial distribution maps, which are indicators of suitable and unsuitable zones (Sheikh et al. 2017; Sudhakar and Narsimha 2013; Narsimha et al. 2013a, b; Panaskar et al. 2016; Sudarshan et al. 2014; Amiri et al. 2015; Sappa et al. 2015). In this study, spatial distribution maps are prepared for pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), fluoride (F^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+) of the groundwater to delineate the safe and unsafe zones. pH spatial distribution map of the study area is depicted in Fig. 2, and it demonstrates that more than half the area is under alkaline nature. The spatial distribution map of the electrical conductivity in the study area is shown in Fig. 3. Distribution map of TDS is shown in Fig. 4, in which southern part of the study region is having high concentrations up to 2650 mg/L. Figure 5 shows the spatial distribution map of TH. Spatial distribution map indicates that in majority of the locations the TH is above the desirable limit of 100 mg/L and southern part of the study region having higher concentration, which is above the maximum permissible limit of 500 mg/L. Higher concentration of Na^+ was in patches of eastern, western and southern part of the study area, which is clearly illustrated in Fig. 6. Spatial distribution map of Ca^{2+} (Fig. 7) shows that central part of the region is very low in concentration comparing to eastern, western and southern parts. Additionally, the spatial distribution of K^+, Mg^{2+} and HCO_3^- concentration is shown in Figs. 8, 9 and 10 respectively. Spatial distribution of SO_4^{2-} is shown in Fig. 11, and it clearly indicates that the high concentration is in southern and small patches from western part and low concentration is in northern part, and eventually it shows dissimilar concentrations throughout the study region, due to changes in infiltration of rainfall. The concentration of Cl^- was relatively high in eastern and western parts of the study area (Fig. 12). Figure 13 shows the spatial distribution map of fluoride which shows that maximum area is under the permissible limits and southern and eastern parts of the study area is having higher concentration (> 1.5 mg/L) in the study area. Moreover, it is observed that fluoride, bicarbonate, chloride, sulphate, calcium, magnesium, sodium and potassium concentrations are less in surface water when compared to groundwater (Fig. 14).

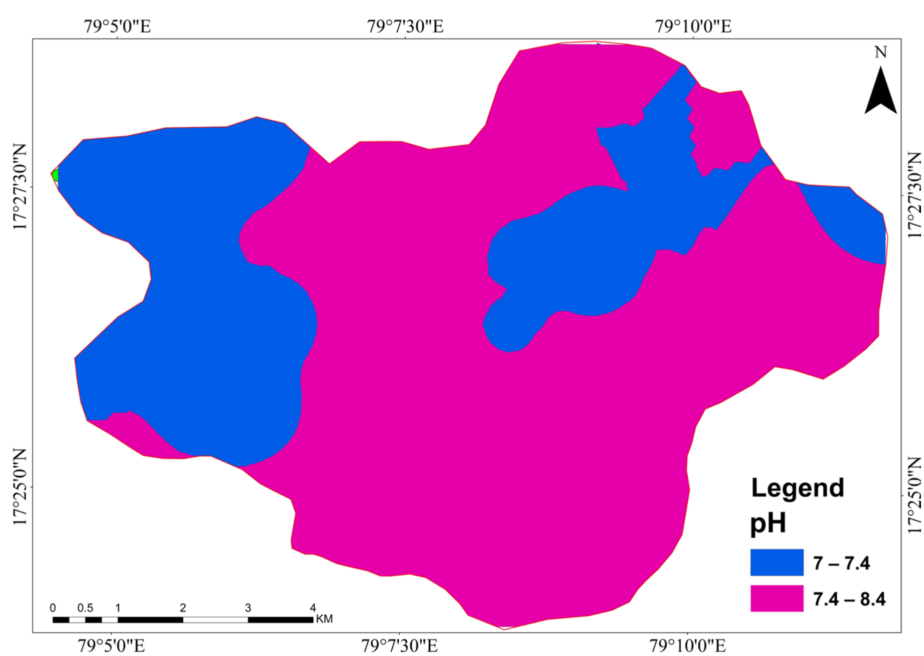

Fig. 2 Spatial Distribution map of pH in Mothkur region, Telangana State, South India

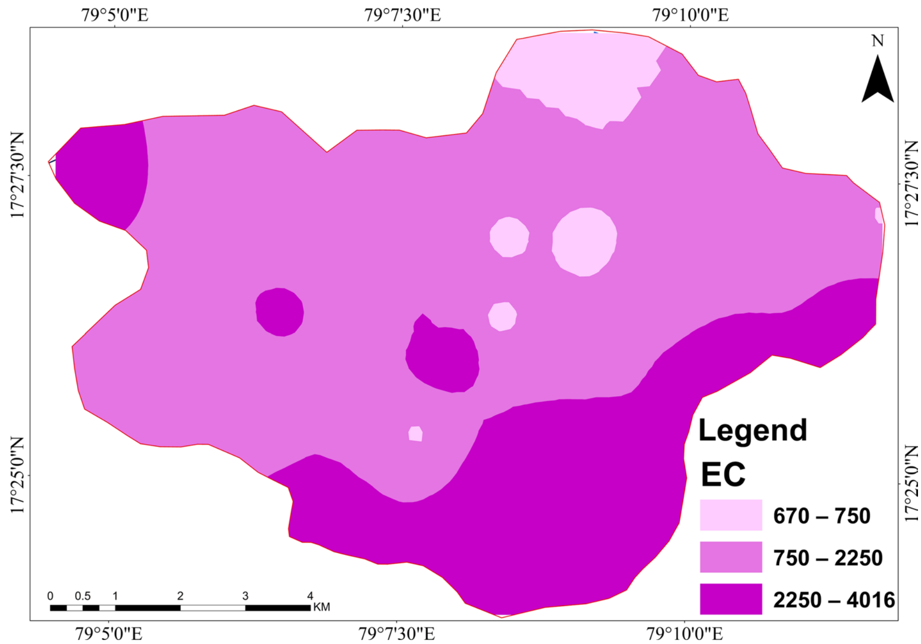

Fig. 3 Spatial distribution map of EC (µS/cm) in Mothkur region, Telangana State, South India

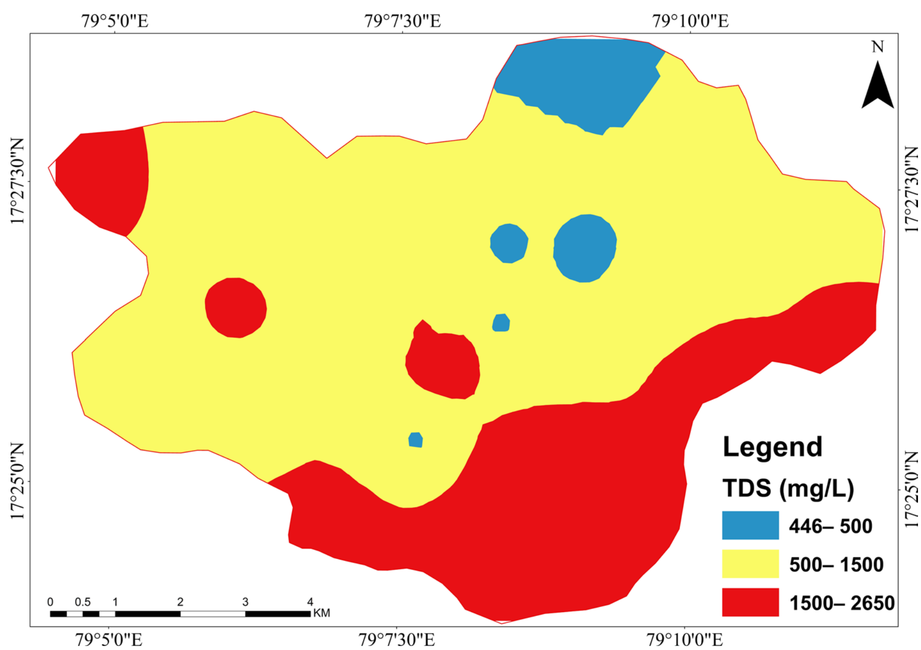

Fig. 4 Spatial distribution map of TDS in Mothkur region, Telangana State, South India

Hydrogeochemical evaluation

The analyses data reveals that the Na^+ concentration is high in the study region. There are two reasons for higher Na^+ concentration, i.e. halite dissolution and silicate weathering. For this, Na^+/Cl^- ratio plays vital and if $Na^+/Cl^- < 1$ the halite dissolution is responsible for high sodium, whereas if $Na^+/Cl^- > 1$, Na^+ is released from silicate weathering (Meybeck 1987). In the present study, the molar ratio Na^+/Cl^- of water samples ranges from 0.63 to 19.89 meq/L, and for 80% of the samples Na^+/Cl^- ratio is more than 1, which indicates that the Na^+ derives from silicate weathering (Stallard and Edmond 1983; Narsimha and Sudarshan 2017a; Fig. 15a; Supplementary material Table 1). Moreover, Na^+ versus TDS scatter plot shown in Fig. 15b reveals that Na^+ concentration shows an increasing trend with increasing TDS and in addition to the weathering of silicate minerals it might be related to the anthropogenic sources such as sewage, domestic waste (Williams et al. 1999; Choi et al. 2005). In addition, $Na^+/(Na^++Cl^-)$ molar ratio was calculated, and 93% of water locations have above 0.5 meq/L (Supplementary

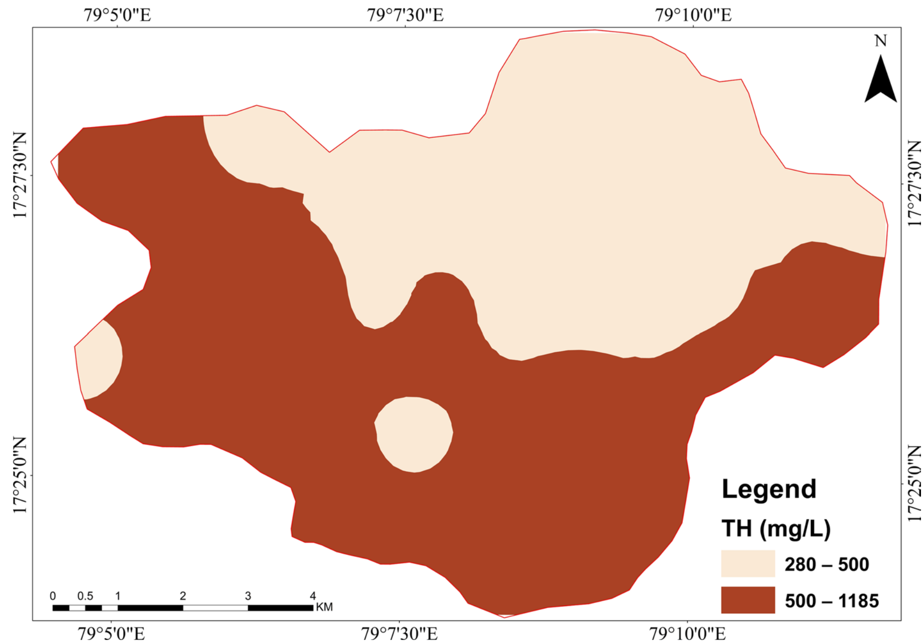

Fig. 5 Spatial distribution map of TH in Mothkur region, Telangana State, South India

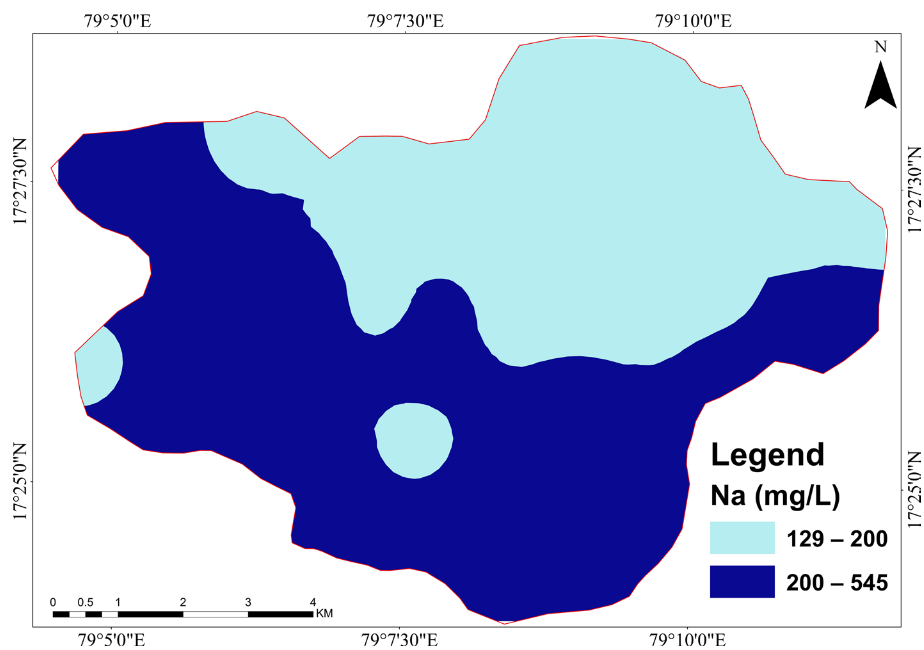

Fig. 6 Spatial distribution map of Na^+ in Mothkur region, Telangana State, South India

material Table 1), which indicates that Na^+ derives not from the halite and other source like silicate weathering (Fig. 15d) and ion exchange process (Hounslow 1995). Furthermore, Jankowski and Acworth (1997) have used Na^+/Cl^- ratio vs EC, which would be an effective indicator to estimate the evaporation dominant process. Hence, Fig. 15c clearly reveals that the trend line is inclined, and Na^+/Cl^- ratio decreases with increasing EC which indicates that evaporation is not the major controlling process in groundwater chemistry in this terrain.

Classification of water samples

IIED (2002) and Soltan (1998) have proposed classification of water based on the milliequivalent per litre (meq/L) content of chloride, sulphate and bicarbonates. The water is normal Cl^- type if Cl^- is < 15 meq/L, normal SO_4^{2-} type if SO_4^{2-} is < 6 meq/L and normal HCO_3^- type if HCO_3^- varies between 2 and 7 meq/L. Detailed distribution of water samples based on the (APHA 1992; IIED 2002; Soltan 1998) classification has showed that the majority of the samples

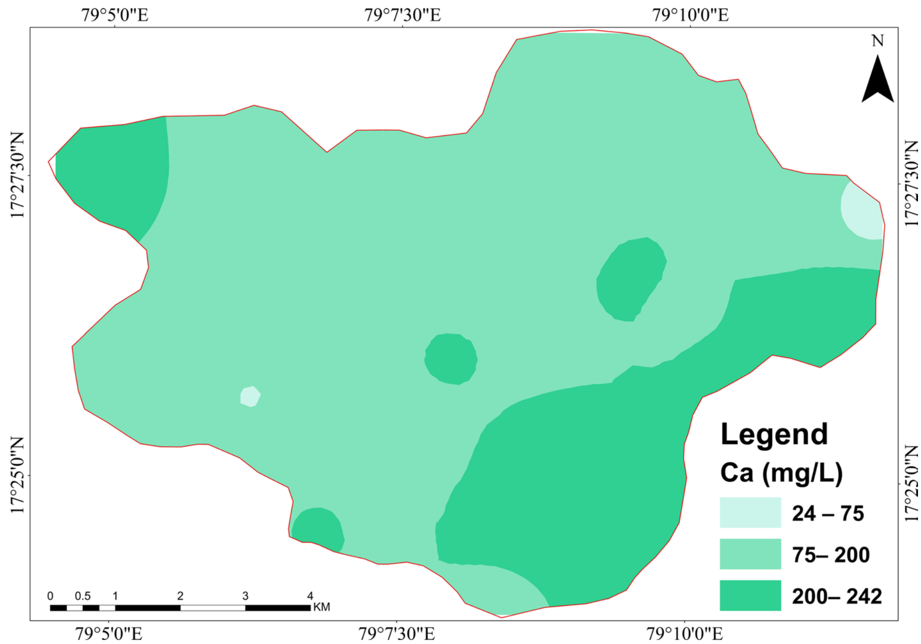

Fig. 7 Spatial distribution map of Ca^{2+} in Mothkur region, Telangana State, South India

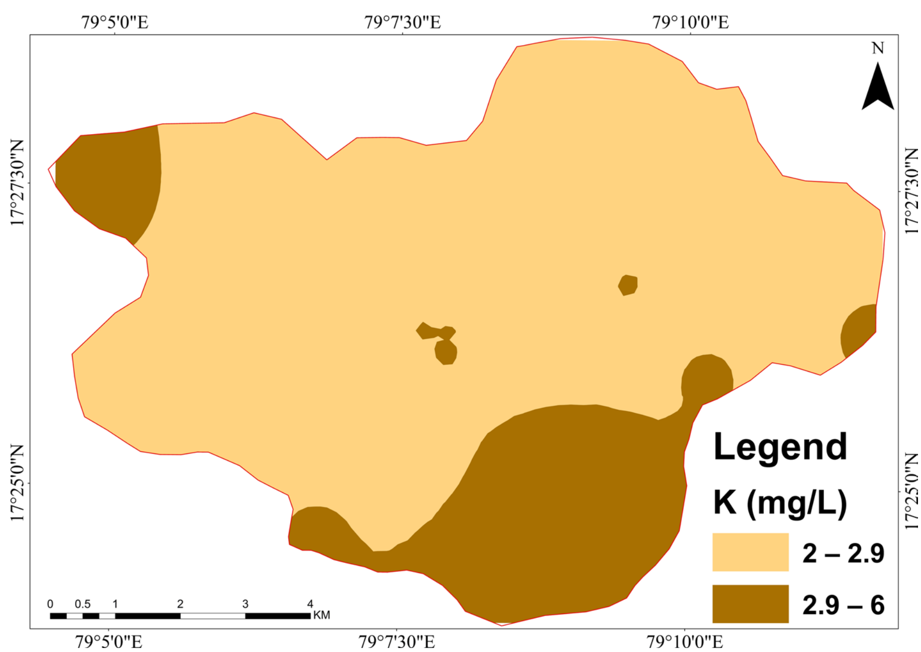

Fig. 8 Spatial distribution map of K^{+} in Mothkur region, Telangana State, South India

belongs to normal sulphate, normal chloride and finally normal bicarbonate (Table 6).

Base-exchange indices (BEI) and meteoric genesis indices (MGI)

The base-exchange indices (BEI) and meteoric genesis indices (MGI) (Matthess 1982; Soltan 1998, 1999) were determined by using Eqs. 1 and 2, respectively. These are very worthwhile for the further classification of groundwater.

$$\mathrm{BEI} = \left[\mathrm{Na}^{+} - \mathrm{Cl}^{-}\right] / \mathrm{SO}_4^{2-} \quad (1)$$

$$\mathrm{MGI} = \left[\left(\mathrm{Na}^{+} + \mathrm{K}^{+}\right) - \mathrm{Cl}^{-}\right] / \ \mathrm{SO}_4^{2-} \quad (2)$$

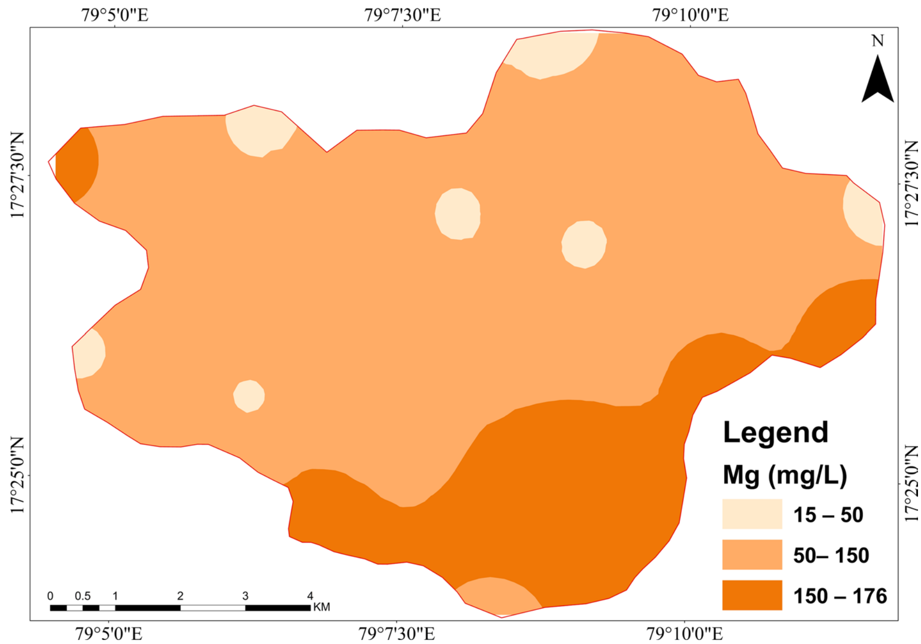

Fig. 9 Spatial distribution map of Mg^{2+} in Mothkur region, Telangana State, South India

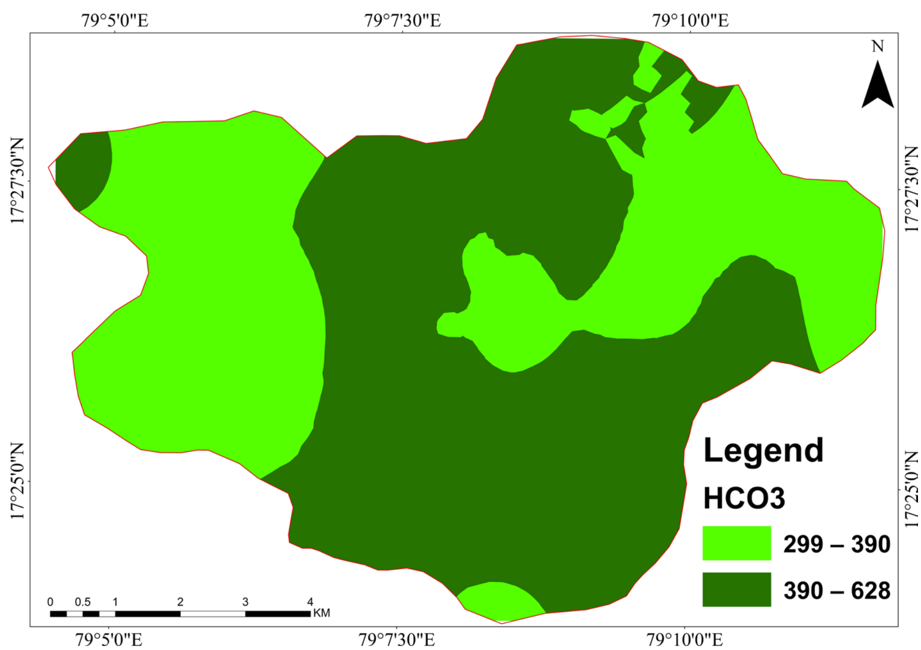

Fig. 10 Spatial distribution map of HCO_3^- in Mothkur region, Telangana State, South India

where all ionic (Na^+, K^+, Cl^-, SO_4^{2-}) concentrations are expressed in meq/L. The water can be arranged in different groups as Na^+–HCO_3^- type if BEI > 1 and Na^+–SO_4^{2-} type with BEI < 1, whereas the water source is of deep meteoric water percolation type if MGI < 1 and MGI > 1 indicates that the water is of shallow meteoric percolation type and also its detailed illustration has been presented in Table 7.

Hydrogeochemical facies and water types

The Piper (1944) trilinear diagram is very useful to reveal the water types based on the ionic composition of surface water and groundwater from the different aquifers (Narsimha and Sudarshan 2017a, b; Adimalla and Venkatayogi 2017; Subba Rao et al. 2012; Li et al. 2012), and it is a very effective tool to identify the chemical relationship in water samples. This diagram contains two triangular charts

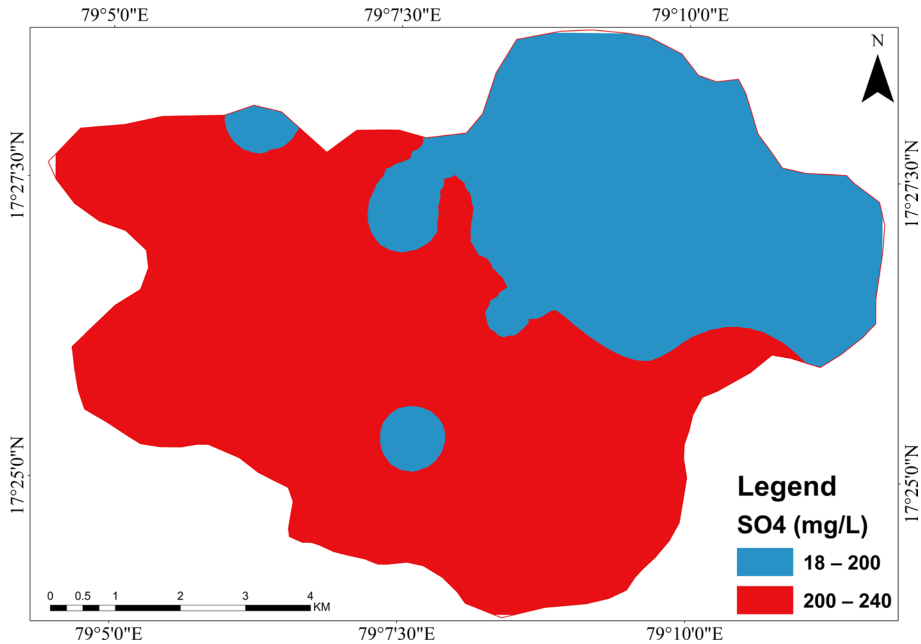

Fig. 11 Spatial distribution map of SO_4^{2-} in Mothkur region, Telangana State, South India

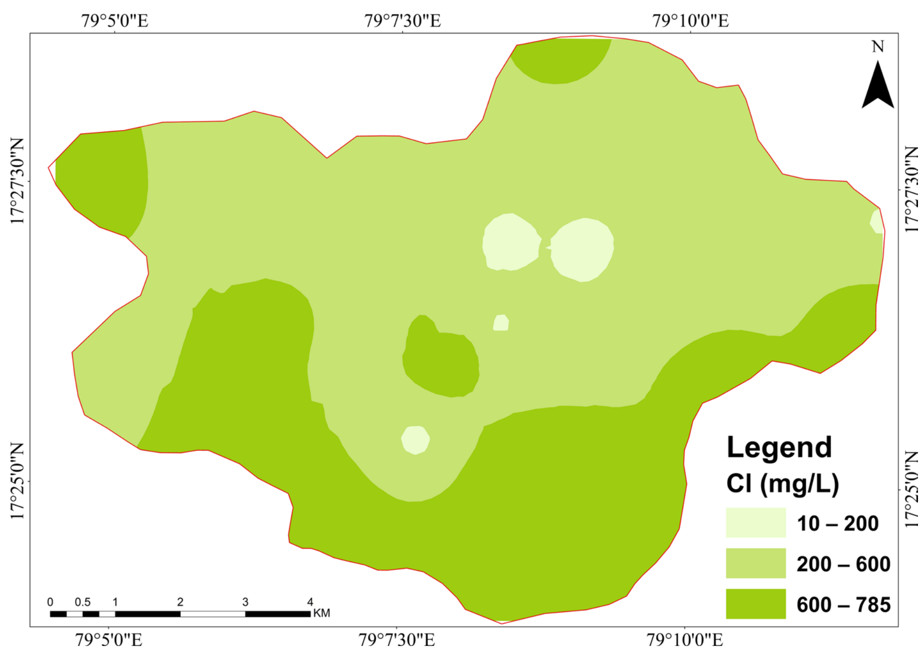

Fig. 12 Spatial distribution map of Cl^- in Mothkur region, Telangana State, South India

for depicting the proportions of cations (Na^+, Ca^{2+}, K^+, Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-), expressed in meq/L. The triangle for cations has 100% Ca^{2+} in the left corner, 100% Na^++K^+ towards the right and 100% Mg^{2+} upwards and for anions it has 100% carbonates and bicarbonates to the left, 100% Cl^- to the right and 100% SO_4^{2-} on top. The obtained chemical data values from the different water samples collected from the study region are plotted on the Piper (1944) diagram Fig. 16. On the basis of Piper diagram, collected water of the study area are divided into six types, that are Ca^{2+}–HCO_3^-, Na^+–Cl^-, mixed Ca^{2+}–Na^+–HCO_3^-, mixed Ca^{2+}–Mg^{2+}–Cl^-, Na^+–Cl^- and Na^+–HCO_3^-. The prevalent water types are mixed Ca^{2+}–Na^+–HCO_3^- > Na^+–Cl^- > Na^+–HCO_3^- identified in the Mothkur region. About 44% and 60% collected groundwater and surface water samples are significantly dominated by mixed Ca^{2+}–Na^+–HCO_3^-, 30% is from Na^+–Cl^- and eventually, 29% of water samples was from Na^+–HCO_3^- (Fig. 16). In the study area, chemical analysis reveals that the HCO_3^- and Na^+ concentrations are high with

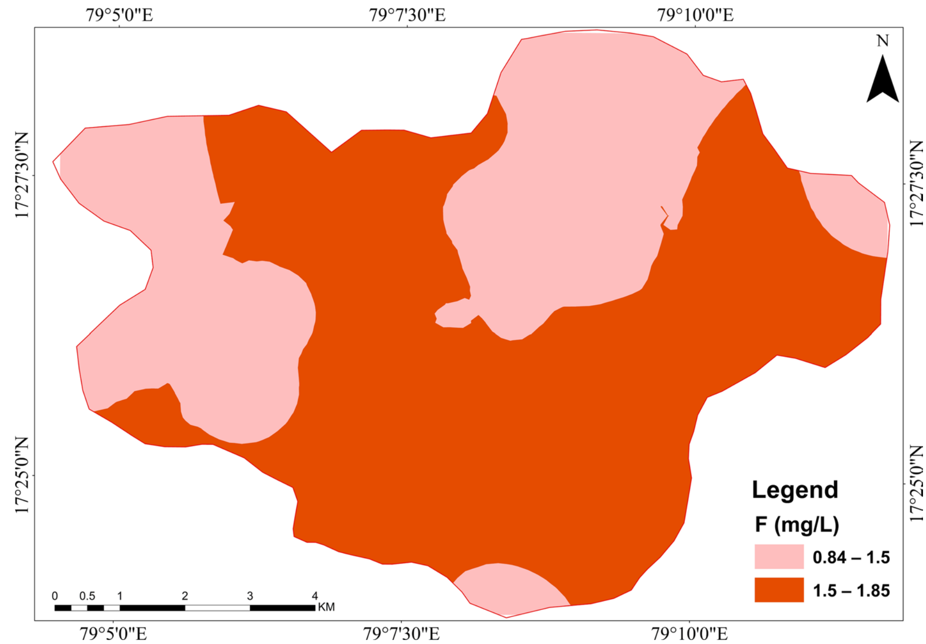

Fig. 13 Spatial distribution map of F^- in Mothkur region, Telangana State, South India

other ions, and it is because of the entire study area occupied by crystalline hard rocks, where silicate minerals are generally present. Therefore, high HCO_3^- and Na^+ concentration and high pH values are controlled by the rock–water interaction (Adimalla and Venkatayogi 2017; Narsimha and Sudarshan 2017a, b).

Multivariate graphical methods for irrigation utility

It is necessary to know the suitability of surface water and groundwater for irrigation/agricultural purposes depending on the effect of mineral constituents of the water on both plants and soils (Wilcox 1955; Richards 1954). For this, the effective multivariate graphical methods are used to determine its suitability for agricultural needs, that are EC, sodium adsorption ratio (SAR), per cent of sodium (%Na), residual sodium carbonate (RSC) and permeability index (PI) playing a vital role in suitability of water for irrigation, and these graphical methods are extensively used all over the world (Li et al. 2014a, 2017b; Sappa et al. 2015; Ghazaryan and Chen 2016; Panaskar et al. 2016; Amiri et al. 2015; Li et al. 2012). The classifications of irrigation water, based on SAR, %Na, RSC and EC are reviewed in Tables 8 and 9. It is well known that EC and SAR are good measures for salinity hazard and sodium hazard to crops, respectively (Tables 9, 10). The US Salinity Laboratory's diagram (1954) is used broadly to assess the irrigation waters, where SAR is plotted against EC (Fig. 17) and shows that 44% and 60% of the groundwater and surface water samples fall in the category of C3S1, indicating water of high salinity and low sodium type, which is very useful for irrigation in almost all types of soils (US Salinity Laboratory Staff 1954; Table 10). However, 32% of the groundwater samples fall in the field of C3S2, indicating high salinity and medium sodium type, which can be used to irrigate salt-tolerant and semi-tolerant crops under favourable drainage conditions (US Salinity Laboratory Staff 1954; Table 10). About 24% of the groundwater and surface water samples fall in the field of C4S2, indicating very high salinity and medium sodium type, and this type of water is not useful for irrigation. Eventually, 40% of the water samples fall in C2S1, indicating medium salinity and low sodium type which can be used for irrigation on all types of soil without danger of exchangeable sodium (Table 10). Moreover, sodium adsorption ratio (SAR) is widely used for determining the suitability of surface water and groundwater for irrigation (Todd 1980; Karanth 1987) and is expressed as below:

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

where Na^+, Ca^{2+} and Mg^{2+} are expressed in meq/L and Richards (1954) classified SAR values into four groups (Table 9). In the present study, the SAR values varied from 3.38 to 8.19 and 3.36 to 4.83 for groundwater and surface water, respectively, indicating that the water of the study area has excellent quality for irrigation (Table 9). In addition, sodium concentration is another significant factor in classifying irrigation water, because sodium reacts with soil to affect the soil permeability and texture. Furthermore, sodium content is usually expressed in terms of per cent

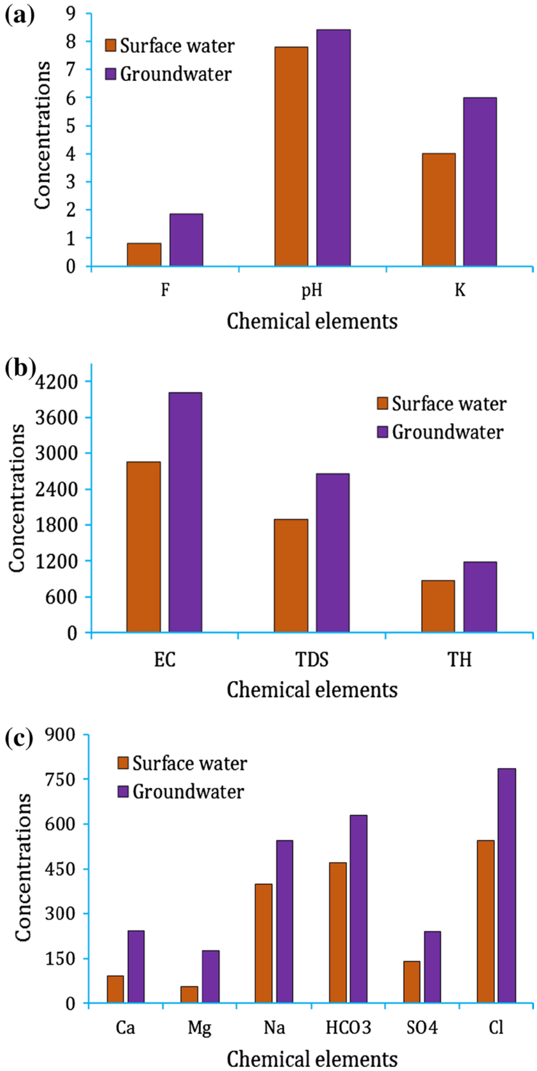

Fig. 14 Physico-chemical parameters concentrations and variation between groundwater and surface water samples in Mothkur region, Telangana State, South India

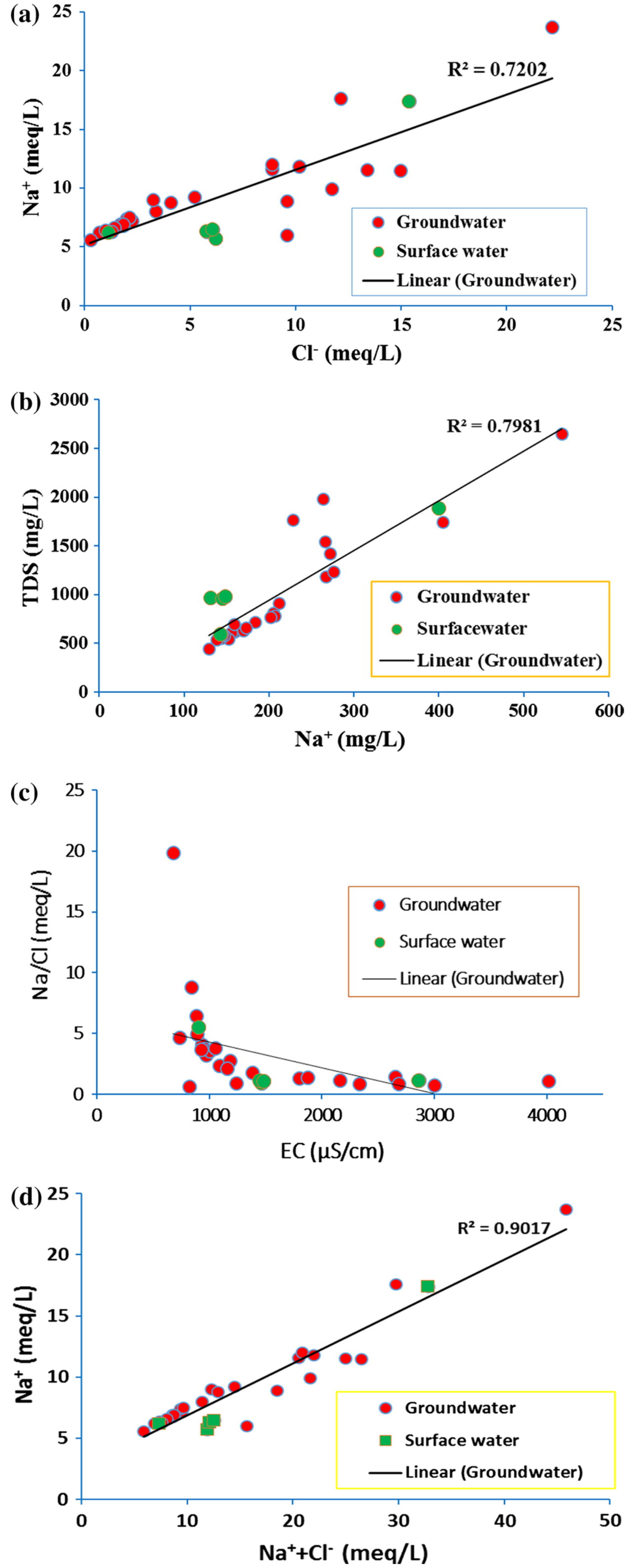

Fig. 15 Relation between **a** Na^+ and Cl^-, **b** Na^+ and TDS, **c** Na^+/Cl^- and EC, **d** Na^+ and $(Na^+ + Cl^-)$

sodium (%Na), which is calculated using the below formula given by Wilcox (1955):

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

where Na^+, K^+, Ca^{2+} and Mg^{2+} are expressed in meq/L. The %Na in the study region ranges from 43.87% to 74.41% and 50.01% to 65.55% in the groundwater and surface water, respectively. About 56% of collected groundwater and 100% surface water are under permissible limits for irrigation, and remaining groundwater samples fall under doubtful category for irrigation (Wilcox 1955; Table 8), since they cause deflocculation and impairment of the tilth and the permeability of soil (Karanth 1989). However, Wilcox

Table 6 Groundwater and surface water classification according to Cl^-, SO_4^{2-} and HCO_3^-

Concentrations (meq/L)	Sample numbers	% of groundwater	% of surface water	Water type
Cl^- (< 15)	SW-1, SW-3 to SW-5, BH-1 to BH-15, BH-17 to BH-25	96	80	Normal
SO_4^{2-} (< 6)	BH-1 to BH-25, SW-1 to SW-5	100	100	Normal
HCO_3^- (2–7)	SW-2, SW-5, BH-1, BH-10, BH-11, BH-12, BH-14, BH-15, BH-19, BH-20, BH-21, BH-24, BH-25, BH-3, BH-4, BH-5, BH-6	60	20	Normal

Table 7 Groundwater and surface water classification according to base-exchange index (BGI) and meteoric genesis index (MGI) criteria

Field label	BEI	Water type	MGI	Water type
SW-1	−0.30	$Na+SO_4$	−0.28	Deep meteoric
SW-2	0.69	$Na+SO_4$	0.73	Deep meteoric
SW-3	0.33	$Na+SO_4$	0.36	Deep meteoric
SW-4	0.16	$Na+SO_4$	0.18	Deep meteoric
SW-5	9.06	$Na+HCO_3$	9.15	Shallow meteoric
BH-1	−0.88	$Na+SO_4$	−0.86	Deep meteoric
BH-2	1.64	$Na+HCO_3$	1.68	Shallow meteoric
BH-3	1.63	$Na+HCO_3$	1.66	Shallow meteoric
BH-4	1.87	$Na+HCO_3$	1.90	Shallow meteoric
BH-5	−0.28	$Na+SO_4$	−0.26	Deep meteoric
BH-6	1.58	$Na+HCO_3$	1.60	Shallow meteoric
BH-7	4.68	$Na+HCO_3$	4.72	Shallow meteoric
BH-8	3.46	$Na+HCO_3$	3.49	Shallow meteoric
BH-9	7.17	$Na+HCO_3$	7.24	Shallow meteoric
BH-10	4.73	$Na+HCO_3$	4.78	Shallow meteoric
BH-11	4.48	$Na+HCO_3$	4.52	Shallow meteoric
BH-12	5.17	$Na+HCO_3$	5.22	Shallow meteoric
BH-13	5.43	$Na+HCO_3$	5.48	Shallow meteoric
BH-14	3.51	$Na+HCO_3$	3.60	Shallow meteoric
BH-15	7.81	$Na+HCO_3$	7.88	Shallow meteoric
BH-16	0.31	$Na+SO_4$	0.34	Deep meteoric
BH-17	−1.60	$Na+SO_4$	−1.53	Deep meteoric
BH-18	−1.15	$Na+SO_4$	−1.10	Deep meteoric
BH-19	10.60	$Na+HCO_3$	10.69	Shallow meteoric
BH-20	−9.58	$Na+SO_4$	−9.44	Deep meteoric
BH-21	1.55	$Na+HCO_3$	1.62	Shallow meteoric
BH-22	13.67	$Na+HCO_3$	13.80	Shallow meteoric
BH-23	10.67	$Na+HCO_3$	10.77	Shallow meteoric
BH-24	12.10	$Na+HCO_3$	12.22	Shallow meteoric
BH-25	8.35	$Na+HCO_3$	8.49	Shallow meteoric

SW surface water, *BH* bore hole water/groundwater

(1955) designed a graphical model for irrigation utility, where water has been classified into five classes which are excellent to good (EG), good to permissible (GP), permissible to doubtful (PD), doubtful to unsuitable (DUS) and unsuitable (Fig. 18). Wilcox diagram (Fig. 18) shows that out of twenty-five groundwater samples, 16% and 20% of the samples belong to excellent to good and good to permissible category, followed by 40% and 20% of the samples belonging to permissible to doubtful and doubtful to unsuitable, and all surface water samples belong to good to permissible category, which are suitable for irrigation (Fig. 18).

Residual sodium carbonate (RSC) of the water reveals that the bicarbonate value is very high compared to other anions (Tables 1, 2). Hence, carbonate ions ($HCO_3^- + CO_3^{2-}$) influence the water quality through the precipitation of alkaline earths ($Ca^{2+} + Mg^{2+}$), where the water in the soil is more concentrated. By this reason estimation of RSC is vital for suitability of irrigation and calculated with following equation (Eaton 1950):

$$\mathrm{RSC} = \left(\mathrm{CO_3^-} + \mathrm{HCO_3^-}\right) - \left(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}\right)$$

where all ionic concentrations are expressed in meq/L. Calculated RSC values ranged from − 13.37 to 3.76 and − 3.30 to 2. 30 meq/L in groundwater and surface water, respectively. About 56% and 80% of collected groundwater and surface water samples are under the safe limits, followed by 20% of water samples that are doubtful for irrigation and its illustration has been given in Table 8.

Permeability index (PI) is another important parameter to estimate the suitability of water for irrigation. Sodium, calcium, magnesium and bicarbonate contents were always influenced soil permeability, and it is defined by the following equation (Doneen 1964; Ragunath 1987):

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

where all the ions are expressed in meq/L. The computed analytical data explains that the 60% and 100% of the collected groundwater and surface water samples fall in class I and 37% in class II, indicating that the groundwater is in good quality for irrigation purposes; only one water sample belongs to class III which is unsuitable for irrigation purposes (Fig. 19; Domenico and Schwartz 1990).

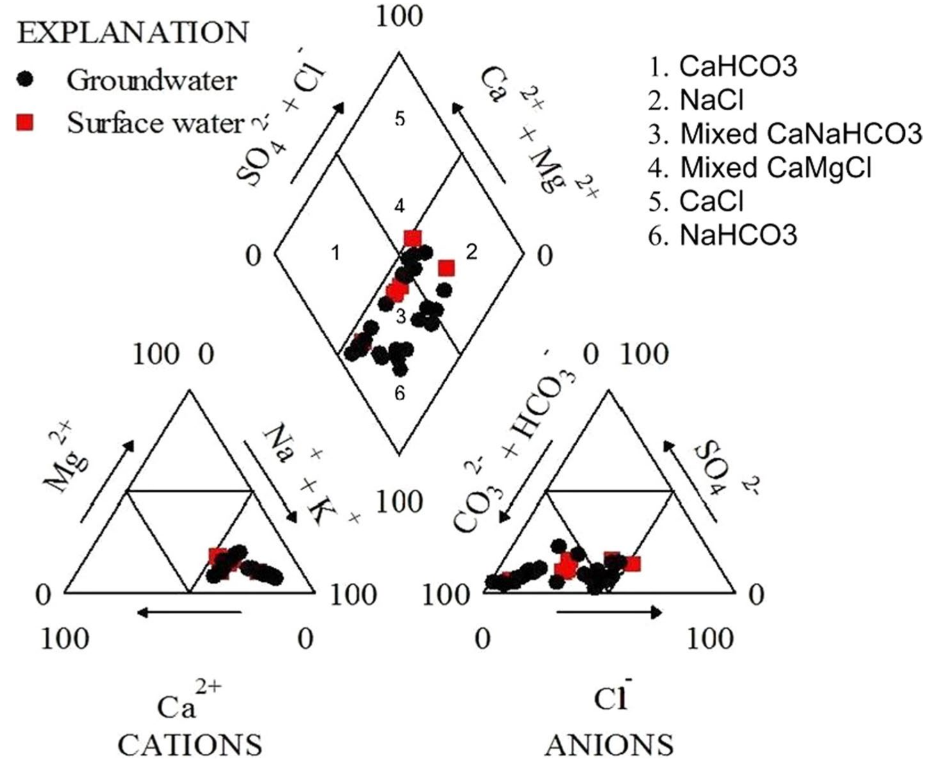

Fig. 16 The piper diagram, graphically displaying the 30 water samples from the Mothkur region, Telangana State, South India

Table 8 Classification of water quality for irrigation on the basis of %Na and RSC in the study region, Telangana State, South India

Classification pattern	Range	Water type	Sample numbers	% of groundwater	% of surface water
Per cent sodium (%Na) (Wilcox 1955) (meq/L)	< 20	Excellent for irrigation	–	–	–
	20–40	Good for irrigation	–	–	–
	40–60	Permissible for irrigation	BH-1, BH-13 to BH-25, SW-1 to SW-5	56	100
	60–80	Doubtful for irrigation	BH-2 to BH-11	44	–
	> 80	Unsuitable for irrigation	–	–	–
Residual sodium carbonate (RSC) (Richards 1954) (meq/L)	< 1.25	Good for irrigation	BH-1, BH-3, BH-4, BH-14 to BH-22, BH-24, BH-25, SW-2 to SW-5	56	80
	1.25 -2.5	Doubtful for irrigation	BH-5, BH-6, BH-7, BH-10, BH-23, SW-1	20	20
	> 2.5	Unsuitable for irrigation	BH-2, BH-8, BH-9, BH-11, BH-12, BH-13	24	–

SW surface water, *BH* bore hole water/groundwater

Conclusions

The groundwater and surface water samples of the Mothkur region have been studied to assess the suitability for drinking and irrigation purposes. The analytical data were compared with WHO and BIS standards to know the suitability. The dominant constituents of water are as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for cation and $Cl^- > HCO_3^- > SO_4^{2-} > F^-$ for anions. The results indicate that Na^+, Mg^{2+}, Cl^- and F^- concentrations are above maximum permissible limits recommended by World health organization (WHO) and Bureau of Indian standards (BIS) in the study region. The US salinity diagram reveals that 44% and 60% of the groundwater and surface water samples fall in

Table 9 Zone classification of water quality for irrigation on the basis of EC and SAR

Classification pattern	Zone range	Water quality	Zone explanation/property	Sample numbers	% of groundwater	% of surface water
SAR concentration (meq/L)	S1 < 10	Excellent	Low-sodium water can be used for irrigation on almost all soils, with little danger of the development of harmful levels of exchangeable sodium	BH-1 to BH-25, SW-1 to SW-5	100	100
	S2 10–18	Good	Medium-sodium water will present an appreciate sodium hazard in fine-textured soils, especially poorly leached soils. Such water may be used safely on coarse-textured or organic soils that have good permeability	–	–	–
	S3 18–26	Permissible	High-sodium water may produce harmful levels of exchangeable sodium in most soils and will require a special soil management like good drainage and leaching, and addition of organic matter	–	–	–
	S4 > 26	Unsuitable	Very high sodium water is generally unsatisfactory for irrigation, unless special action is taken, such as addition of gypsum to the soil	–	–	–
EC concentration (μS/cm)	C1 < 250	Excellent	Low-salinity water can be used for irrigation of most crops on most soils, with little likelihood of soil salinity development. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability	–	–	–
	C2 250–750	Good	Medium-salinity water can be used if a moderate amount of leaching occurs. Crops of moderate salt tolerance can be irrigated with this water without special practices for salinity control	BH-15, BH-23	8	–
	C3 750–2250	Permissible	High-salinity water cannot be used on soils of restricted drainage. Even with adequate drainage, special management for salinity control may be required and crops of good salt tolerance can be selected	SW-1, SW-3 to 5, BH-2 to BH-13, BH-19 to BH-22, BH-24, BH-25	72	80
	C4 > 2250	Unsuitable	Very high salinity water is not suitable for irrigation under ordinary conditions. It can be used only on crops that are very tolerant of salt and only if special practices are followed, including provision for a high degree of adverse effects	SW-2, BH-1, BH-6, BH-14, BH-17, BH-18	20	20

(US Salinity Laboratory Staff 1954)

SW surface water, *BH* bore hole water/groundwater

Table 10 Criteria for water quality for irrigation following the (US Salinity Laboratory Staff 1954), in Mothkur region, Telangana State, South India

Zone	Water type	Sample numbers	% of groundwater	% of surface water	Water quality
C1S1	Low salinity hazard and low sodium hazard	–	–	–	Good
C1S2	Low salinity hazard and medium sodium hazard	–	–	–	Moderate
C1S3	Low salinity hazard and high sodium hazard	–	–	–	Poor
C1S4	Low salinity hazard and very high sodium hazard	–	–	–	Very poor
C2S1	Medium salinity hazard and low sodium hazard	SW-2, SW-5	–	40	Good
C2S2	Medium salinity hazard and medium sodium hazard	–	–	–	Moderate
C2S3	Medium salinity hazard and high sodium hazard	–	–	–	Poor
C2S4	Medium salinity hazard and very high sodium hazard	–	–	–	Very poor
C3S1	High salinity hazard and low sodium hazard	SW-1, SW-3, SW-4, BH-7 to BH-13, BH-19, BH-20, BH-23, BH-24, BH-25	44	60	Moderate
C3S2	High salinity hazard and medium sodium hazard	BH-2, BH-3, BH-4, BH-5, BH-15, BH-22, BH-19, BH-6	32	–	Moderate
C3S3	High salinity hazard and high sodium hazard	–	–	–	Poor
C3S4	High salinity hazard and very high sodium hazard	–	–	–	Very poor
C4S1	Very high salinity hazard and low sodium hazard	–	–	–	Very poor
C4S2	Very high salinity hazard and medium sodium hazard	BH-14, BH-16, BH-17, BH-21, BH-18, BH-1	24	–	Very poor
C4S3	Very high salinity hazard and high sodium hazard	–	–	–	Very poor
C4S4	Very high salinity hazard and very high sodium hazard	–	–	–	Very poor

SW surface water, *BH* bore hole water/groundwater

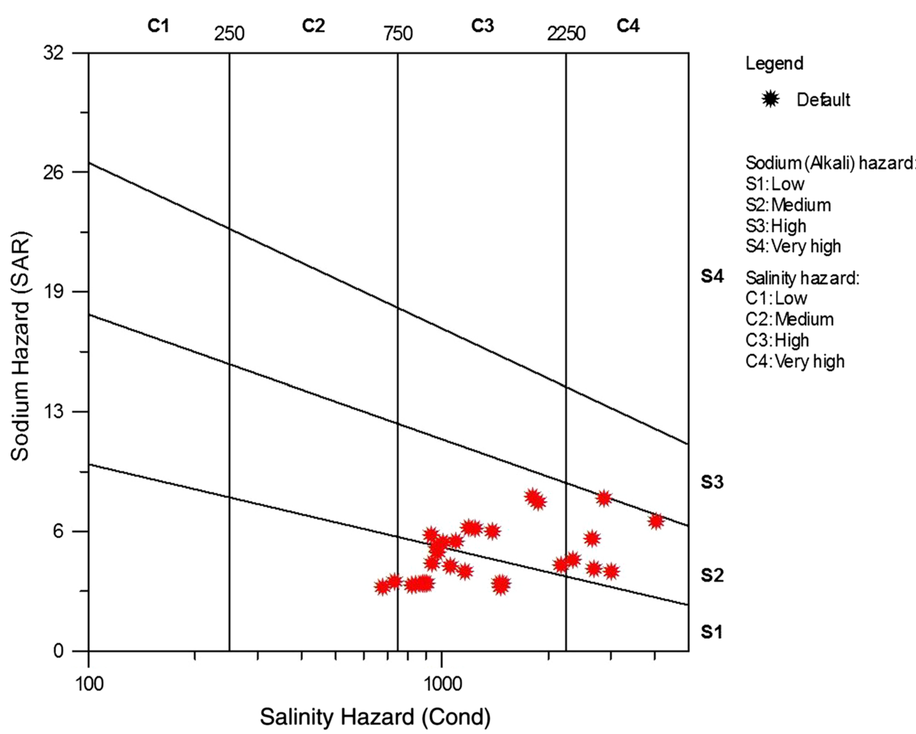

Fig. 17 US salinity diagram for classification of irrigation waters (after Richards 1954), samples from the Mothkur region, Telangana State, South India

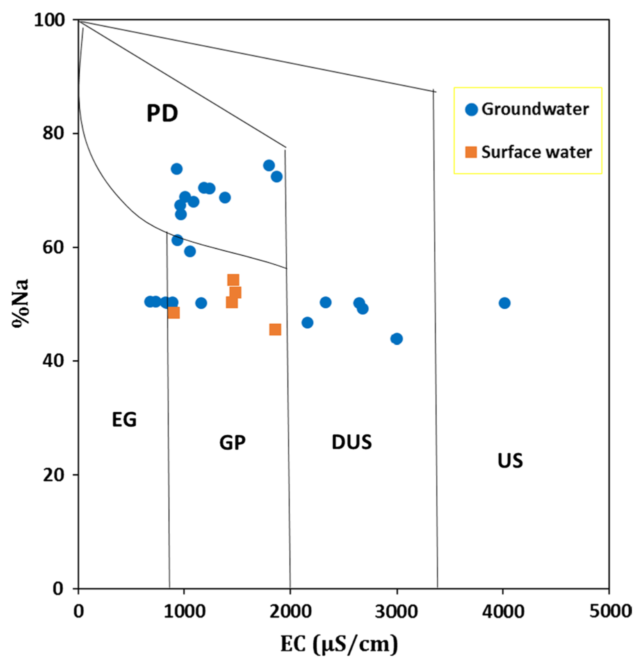

Fig. 18 Wilcox diagram for classification of water based on EC and %Na (EG—excellent to good, GP—good to permissible, DUS—doubtful to unsuitable, PD—permissible to doubtful, US—unsuitable)

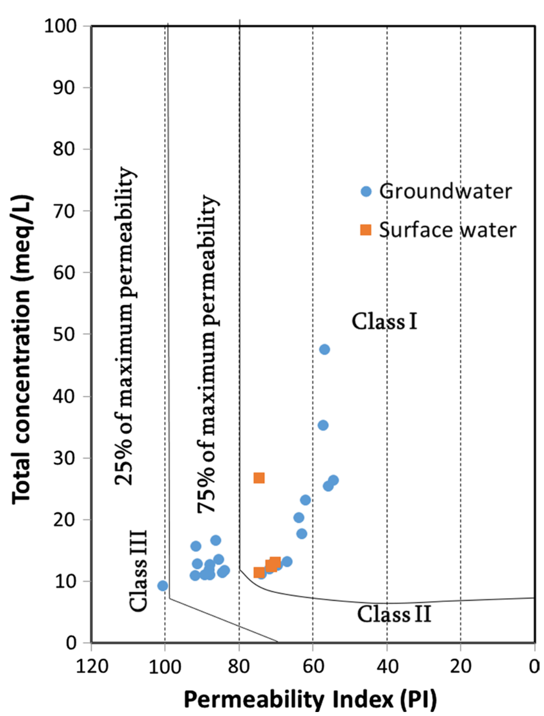

Fig. 19 Doneen (1964) classification of irrigation water quality based on the permeability index

the category of C3S1 and 32% of groundwater samples fall in C3S2 and are useful for irrigation in almost all types of soils. Based on Wilcox classification, 36% of the groundwater samples are suitable for irrigation, 40% and 20% groundwater samples fall in permissible to doubtful and doubtful to unsuitable categories. Moreover, 56% of groundwater and all surface water samples belong to permissible limits based on per cent sodium for irrigation utility. Based on the classification of irrigation water according to residual sodium carbonate values, 56% of the groundwater and all surface water samples belong to good for irrigation purposes. The permeability index indicates that the water of the study area is of good quality for irrigation utility.

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