Appl Water Sci (2016) 6:149–167
DOI 10.1007/s13201-014-0214-6

ORIGINAL ARTICLE

Assessment of groundwater quality for drinking and irrigation use in shallow hard rock aquifer of Pudunagaram, Palakkad District Kerala

V. Satish Kumar · B. Amarender · Ratnakar Dhakate · S. Sankaran · K. Raj Kumar

Received: 24 February 2014 / Accepted: 10 June 2014 / Published online: 15 June 2014

Abstract Groundwater samples were collected for pre-monsoon and post-monsoon seasons based on the variation in the geomorphological, geological, and hydrogeological factors for assessment of groundwater quality for drinking and irrigation use in a shallow hard rock aquifer of Pudunagaram area, Palakkad district, Kerala. The samples were analyzed for various physico-chemical parameters and major ion chemistry. Based on analytical results, Gibbs diagram and Wilcox plots were plotted and groundwater quality has been distinguished for drinking and irrigation use. Gibbs diagram shows that the samples are rock dominance and controlling the mechanism for groundwater chemistry in the study area, while Wilcox plot suggest that most of the samples are within the permissible limit of drinking and irrigation use. Further, the suitability of water for irrigation was determined by analyzing sodium adsorption ratio, residual sodium carbonate, sodium percent (%Na), Kelly's ratio, residual sodium carbonate, soluble sodium percentage, permeability index, and water quality index. It has been concluded that, the water from the study area is good for drinking and irrigation use, apart few samples which are exceeding the limits due to anthropogenic activities and those samples were indisposed for irrigation.

Keywords Sodium absorption ratio (SAR) · Kelly's ratio (KR) · Residual sodium carbonate (RSC) · Soluble sodium percentage (SSP) · Permeability index (PI) · Water quality index (WQI)

V. Satish Kumar (✉) · B. Amarender · R. Dhakate · S. Sankaran · K. Raj Kumar
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
e-mail: satishkumar3113@gmail.com

Introduction

Groundwater is generally less susceptible to contamination than surface water; it is usually highly mineralized in its natural state. As water moves slowly through the subsurface porous media, it can remain for extended periods of time in contact with minerals present in the soil and bedrock and become saturated with dissolved solids from these minerals. This dissolution process continues until chemical equilibrium is reached between the water and the minerals with which it is in contact. The resource can be optimally used and sustained only when the quantity and quality of the groundwater is assessed. In this present scenario, the increasing population is leading to the over exploitation of resources resulting to their decline. One such commodity is the scarcity of the water resources. The anthropogenic disturbances through industrial and agricultural pollution, increasing consumption and urbanization degrade the groundwater and impair their use for drinking, agricultural, industrial and domestic uses (Carpenter et al. 1998; Jarvie et al. 1998; Simeonov et al. 2003).

The problems with groundwater quality are more acute in areas that are densely populated and thickly industrialized and have shallow groundwater tube wells (Shivran et al. 2006). Geochemical studies of groundwater provide better understanding of possible changes in quality as development progresses. The suitability of groundwater for domestic and irrigation purposes is determined by its geochemistry. Quality being on a high note for the survival of the humans as well as all the living beings made us to switch over to the methods for assessing the groundwater quality. There is no doubt that water and sustainable development is inextricably linked.

A number of studies on groundwater and surface water quality with respect to drinking and irrigation purposes have been carried out in different parts of India and around the world with reference to major ion chemistry, trace element chemistry and through multivariate statistical techniques. Naik et al. (2009) carried out the groundwater study in Koyna river basin and conclude that the groundwater samples are dominated by alkaline earth elements, the shallow aquifers groundwater samples are generally $Ca–HCO_3$ and $Ca–Mg–HCO_3$ type, whereas deeper aquifer groundwater samples are $Ca–Mg–HOC_3$ and $Na–HCO_3$ type. Most of the groundwater sample is generally fit for drinking and irrigation purposes. Takem et al. (2010) carried out groundwater study from springs and bore wells in a alluvial aquifer and conclude that the area is contaminated with nitrate pollution due to anthropogenic activities. Purushotham et al. (2011) has carried out similar studies of groundwater and conclude that the groundwater deteriorated due to rapid urbanization. Suyash and Pawar (2011) has carried out accentuation of heavy metals in groundwater and its spatio-temporal variation through using GIS techniques in Ankaleshwar industrial estate, India and conclude that the GIS techniques have facilitated the monitoring of spatio-temporal behaviors of heavy metals and site-specific accretion pattern using raster and color composite maps of shallow groundwater system.

Recently various researchers have carried out groundwater study for drinking and irrigation water standards using different indices and plots (Rao and Rao 2010; Rao et al. 2012; Bhardwaj and Sen Singh 2011; Prasanna et al. 2011; Akbal et al. 2011; Nosrati and Van Den Eeckhaut 2012; Sharma et al. 2012; Gupta et al. 2012). Besides these, Machender et al. (2013) have carried out groundwater and surface water study in a Chinnearu river basin to distinguish the groundwater and surface water for drinking and irrigation use. He concludes that most of the groundwater samples are within permissible limits of drinking and irrigation use. The samples that have higher concentration are due to water–rock interaction. Besides these, extensive studies on water quality have been carried out by various workers (Majumdar and Gupta 2000; Dasgupta and Purohit 2001; Khurshid et al. 2002; Sujatha and Reddy 2003; Aravindan et al. 2004, 2010; Sreedevi 2004; Sunitha et al. 2005; Subba Rao 2006; Shankar et al. 2010, 2011).

To evaluate the groundwater quality and to have sustainable development a proper quality assessment has to be carried out. The main objective of the article is to determine the groundwater quality for drinking and irrigation purposes, and compared the chemical analysis data of the groundwater with the water quality standards.

Study area

The Pudunagaram study area, Palakkad District, Kerala, lies between 10°38′–10°42′N Latitude and 76°37′–76°43′E Longitude in Survey of India Toposheet No. 58 B/10. Topographically, the study area is a midland and has flat topography. The elevation is varying from 75 to 125 m above mean sea level. Elevation is gradually increasing from west to east in the study area (Fig. 1). The soil type is laterite at the hills and in midland regions. Midland area is thickly cultivated with paddy, coconut, arecanut, cashew and pepper. The study area experiences humid type of climate and very hot during the month from March to June

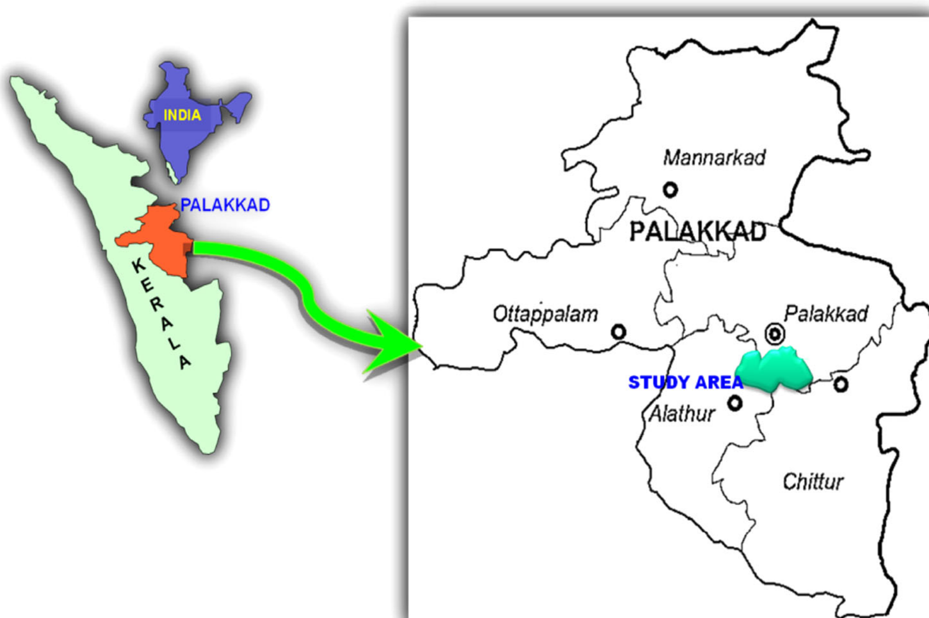


Fig. 1 Location map of the study area

and receive maximum rainfall during the south-west monsoon followed by the north-east monsoon. About 75 % of the annual rain is received from south-west monsoon period during June–September and 25 % rainfall contributes from north-east monsoon. During the period December–May, practically no rain is received. The temperature of the study area ranges from 20 to 45 °C. The maximum temperature recorded at Palakkad is 43 °C. The average annual rainfall of the study is about 2,348 mm.

Geology and hydrology of the study area

Palakkad district is underlain by Archaean metamorphic rock complex. They include the granulite group, the gneisses, and the schist. Intrusive of pegmatites and quartz veins are also common in the NE part of the district (Soman 1977). The general geologic succession encountered in the study area is given in Table 1 (CGWB 2005). The Archaean crystallines are the major rock types encountered in the study area. This includes Charnockites, khondalites, calc-granulites, hornblende gneiss, migmatites, and gneisses. Half of the study area is covered with the Hornblende-Biotite. Gneiss rocks of migmatite complex, having essential mineral composition of Hornblende and Biotite Proterozoic age pegmatite and quartz vein, which are acidic intrusives, are also common in the NE part of the study area. Hornblende-biotite gneiss rocks are widely distributed in the study area (Fig. 2).

Table 1 Geological successions of Palakkad District, Kerala (CGWB 2005)

Age	Lithological units
Recent	Top soil, valley fill, and riverine alluvium
Subrecent	Laterite
Archean	Pegmatites, quartz vein, dolerite, gabbro, granites, quartz-mica schist, hornblende biotite, gneiss, ultramafics, charnockite, and khondalits

The study area, in general, enjoys a humid tropical climate. Three distinct spells of seasons dominate the area, viz., pre-monsoon, monsoon, and post-monsoon. The rainfall decreases from west towards east of the study area, varying from 2,850.0 mm at Mannarkkad in the west to 1,757.0 mm at Chittur near the southeastern part. The annual average rainfall of Palakkad district is 2,106.6 mm (Source IMD, India). Palakkad district receives a total annual rainfall of around 7,348 mm. The rainfall in Palakkad District is not uniform. The variation is so high on the silent valley receives more than 7,000 mm rainfall whereas eastern part of Attappadi and Chittur receives only a meager 700 mm rainfall. The major rainfall is received during June to September in the south-west monsoon (71 %). But the north-east monsoon contributes only about 18 %. The distribution of rainfall during year 2005–2009 is given in Table 2. District experiences two types of climate with semi-humid climate on the eastern part and humid climate on the western part. (Source:https://sites.google.com/a/iiitmk.ac.in/palakkad/rainfall-and-climate).

As a part the study, well inventory has been carried out for 30 observation wells during post-monsoon (October 2009) and pre-monsoon (April 2010) (Tables 3, 4). The depth to water level measured in monitoring wells during October 2009 varies from 1 to 18 m (bgl) (Fig. 3a). Hydrology of the study area indicates that periphery of eastern part of study area is having deeper water levels ranging from 3 to 7 m and towards the western part of study area the water level is ranging from 3 to 16 m, apart

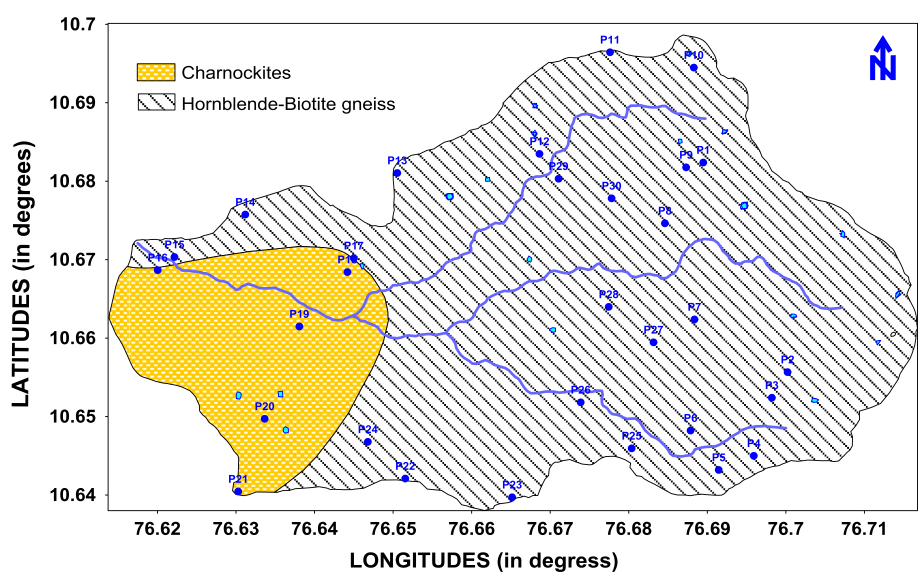


Fig. 2 Geological map of the study area showing groundwater sample locations

Table 2 Annual and monthly rainfall of Palakkad District for the year 2005–2010

Year/months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
2005	14.32	15.81	9.57	169.20	83.05	353.04	690.48	222.53	272.07	140.32	98.26	61.47	2,130.12
2006	19.93	0	95.13	69.35	297.18	385.56	406.44	293.67	193.39	217.56	157.16	0	2,135.37
2007	2.25	12	38.50	81.27	91.63	507.75	726.46	350.18	395.77	282.56	33.33	32	2,553.7
2008	10.00	33.62	141.41	31.52	27.98	298.46	289.69	170.57	171.61	352.30	21.93	2.25	1,551.34
2009	0	0	68.34	10.68	97.91	193.88	727.41	203.06	236.27	183.84	209.71	11.1	1,942.2
2010	16.57	0	24.90	136.45	81.05	317.43	387.13	211.90	203.93	253.39	220.48	12.86	1,866.09

Table 3 Water level and physico-chemical analyses of groundwater samples of study area collected during Post-monsoon (October 2009)

Well no.	WL (m)	EC	pH	TDS (mg/L)	T. Alkl. (mg/L)	T.H (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Cl (mg/L)	F (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)
P1	3.3	1,477	7.6	945	310	376	186	310	41	14	227	0.8	82	42	60	64
P2	7.75	776	7.3	497	135	272	81	135	12	2	168	0.3	46	38	4.4	2.1
P3	4.35	414	7.1	265	131	140	79	131	15	ND	44	0.4	22	20	28.8	1.7
P4	3.65	879	7.8	563	332	232	199	332	23	10	84	0.7	53	24	156	5.4
P5	3.45	1,648	7.6	1,055	183	340	110	183	48	14.4	375	0.6	78	35	100	2.2
P6	1.9	1,039	7.4	665	183	336	110	183	15	0.2	239	0.4	53	50	27.6	3.3
P7	3.85	1,465	7.1	938	389	376	233	389	31	ND	255	0.6	80	43	92	6
P8	3.65	310	6.1	198	83	72	50	83	17	10.1	32	0.2	18	7	36	2.6
P9	2.95	875	7.2	560	227	288	136	227	86	5.5	104	0.5	61	33	28.4	9
P10	2.7	2,010	7.0	1,286	362	404	217	362	19	4	510	0.8	162	0	76	3.4
P11	2.35	266	6.7	170	92	80	55	92	16	3.9	24	0.4	13	12	29.2	1.1
P12	0.9	634	7.7	406	188	228	113	188	25	4.2	84	0.5	48	26	40.2	6.3
P13	2.75	1,963	6.7	1,256	114	408	68	114	23	38.9	494	0.2	72	55	108	5.6
P14	16.1	630	7.7	403	231	252	139	231	32	ND	56	0.4	53	29	34	5.9
P15	4.3	436	7.6	279	140	140	84	140	12	4.7	48	0.5	27	17	33.2	6
P16	3	454	7.3	291	127	144	76	127	25	2.4	52	0.4	19	16	37.2	1.6
P17	1.4	242	6.6	155	74	40	45	74	10	4.7	32	ND	11	3	22.8	1.7
P19	5.53	111	6.5	71	48	28	29	48	4	1.7	16	ND	5	4	12	1.5
P20	2.15	638	7.6	408	240	288	144	240	17	3.2	76	0.6	45	43	23.6	1.4
P21	2.27	107	7.5	68	52	36	31	52	2	ND	15	0.2	8	4	12	0.1
P22	2.55	836	7.1	535	227	212	136	227	34	7.76	92	0.5	56	17	80	110
P23	3.22	412	7.4	264	144	140	86	144	19	ND	36	0.4	32	15	36.8	3.3
P24	1.65	358	7.4	229	122	128	73	122	13	4.3	32	0.6	20	18	24.8	0.4
P25	2.1	2,390	7.6	1,530	397	1,056	238	397	29	1.2	734	0.6	168	155	72	1.1
P26	1.01	426	7.2	273	192	156	115	192	17	ND	24	0.6	38	15	24	2.8
P27	2.25	811	7.2	519	214	168	128	214	33	4.5	116	0.4	35	19	42.4	1.5
P28	2.35	565	6.7	362	131	144	79	131	21	ND	96	0.2	29	17	43.2	0.8
P29	2.45	3,000	7.2	1,920	376	744	225	376	81	14.8	881	0.5	219	48	100	8.2
P30	2.25	1,196	7.8	765	210	344	126	210	79	17.5	207	0.6	53	52	52	5.1
Min	0.9	107	6.1	68	48	28	29	48	2	0.2	15	0.2	5	0	4.4	0.1
Max	16.1	3,000	7.8	1,920	397	1,056	238	397	86	38.9	881	0.8	219	155	156	110
Ave	3.38	951	7.23	581.93	194.96	261.10	116.93	194.96	27.55	7.90	177.68	0.47	55.37	29.55	49.53	9.10
SD	2.80	792	0.42	460.60	101.97	214.59	61.06	101.97	21.43	8.49	220.93	0.16	49.86	28.93	35.03	22.55

T. Alkl total alklanity, *T.H* total hardness, *Min* minimum, *Max* maximum, *Ave* average, *SD* standard deviation

Table 4 Water level and physico-chemical analyses of groundwater samples of study area collected during Pre-monsoon (April 2010)

Well no.	WL (m)	EC	pH	TDS (mg/L)	T. Alkal (mg/L)	T.H (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Cl (mg/L)	F (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)
P1	5.95	1,483	7.7	949	339	372	204	339.2	57	7	228	1.2	91	35	188	44
P2	NA	969	6.9	620	161	316	97	161.12	16	5	140	0.6	56	43	68	2
P3	4.93	468	6.6	300	127	140	76	127.2	13	1	192	0.6	24	19	32	1
P4	5.40	496	7.0	317	110	144	66	110.24	11	2	52	0.7	30	17	32	1
P5	3.27	1,273	7.0	815	225	248	135	224.72	23	4	108	1.0	43	34	78	1
P6	2.65	871	6.7	557	157	268	94	156.88	15	1	220	0.6	67	24	58	3
P7	4.75	1,491	6.7	954	343	328	206	343.44	32	1	384	1.0	80	31	174	2
P8	6.60	470	6.6	301	123	80	74	122.96	23	1	240	0.7	18	9	68	1
P9	5.07	1,025	7.1	656	212	300	127	212	92	3	120	0.9	61	36	110	3
P10	4.20	815	7.1	522	191	160	114	190.8	12	1	128	1.5	32	19	102	1
P11	4.26	397	7.0	254	98	80	59	97.52	18	2	44	1.3	16	10	38	0
P12	2.30	859	7.3	550	195	280	117	195.04	1	1	120	0.6	59	32	46	2
P13	5.10	1,917	7.0	1,227	187	272	112	186.56	32	25	412	0.7	72	22	312	1
P14	NA	734	7.6	470	208	256	125	207.76	40	1	52	0.5	62	24	24	2
P15	4.28	508	7.7	325	136	136	81	135.68	11	0	64	0.6	29	16	40	3
P16	5.14	720	8.1	461	195	240	117	195.04	75	1	52	1.1	67	17	40	2
P17	2.30	243	6.9	156	68	56	41	67.84	9	1	36	0.2	14	5	26	1
P19	NA	446	7.1	285	157	140	94	156.88	9	1	44	0.7	42	9	25	1
P20	2.45	540	7.1	346	165	196	99	165.36	24	1	48	1.0	32	28	19	1
P21	3.72	178	6.7	114	85	64	51	84.8	15	1	12	0.5	14	7	11	0
P22	7.10	810	7.3	518	170	184	102	169.6	2	6	96	0.6	50	15	74	49
P23	NA	439	7.6	281	157	136	94	156.88	14	1	67	0.8	27	17	34	2
P24	2.27	361	6.9	231	119	116	71	118.72	10	1	28	0.8	24	14	20	1
P25	2.85	480	6.9	307	144	164	86	144.16	15	0	36	0.6	37	17	25	1
P26	NA	490	7.1	314	178	172	107	178.08	17	0	24	1.0	45	15	23	4
P27	4.56	876	7.1	561	216	180	130	216.24	34	0	116	0.9	34	23	112	2
P28	4.63	769	7.1	492	178	192	107	178.08	11	0	112	0.4	48	18	68	2
P29	4.05	3,380	6.9	2,163	394	904	237	394.32	52	2	1,119	0.4	310	31	388	3
P30	4.05	983	7.3	629	191	224	114	190.8	42	1	132	1.0	35	33	100	6
Min	4.05	178	6.9	492	178	180	107	178.08	11	0	112	0.4	34	18	68	2
Max	4.63	3,380	7.3	2,163	394	904	237	394.32	52	25	1,119	1	310	33	388	6
Ave	4.32	904	7.10	961.25	244.75	375.0	147.0	244.86	34.75	0.75	369.75	0.68	106.75	26.25	167.0	3.25
SD	1.34	759	0.36	403.35	73.68	155.44	44.35	73.79	21.38	4.68	210.85	0.29	53.58	9.81	87.26	11.61

T. Alkl total alklanity, *T.H* total hardness, *Min* minimum, *Max* maximum, *Ave* average, *SD* standard deviation

from that middle part of the area is having a shallow water level of 1–3 m. In pre-monsoon (April 2010), the water level varies from 2 to 8 m below ground level (Fig. 3b). The water level above mean sea level varies from 64 to 116 m which follows topographic trend. The elevation is gradually increasing from west to east and the flow direction is from east towards the west of study area. According to the pumping test survey which has been carried out in few locations of the study area, the transmissivity values which ranged from 38.5 to 176 m^2/day and, hydraulic conductivity values ranged from 8.22 to 176 m/day.

Materials and methods

In order to assess the physico-chemical parameters, a total of 30 shallow groundwater (dug wells) samples were collected covering the Pudunagaram area, Palakkad District, Kerala, have been selected (Fig. 2). The water samples were collected for post-monsoon (October, 2009) and pre-monsoon (April, 2010) seasons with in situ measurement of pH and EC. Water samples were collected in a plastic container of 1-L capacity for detailed chemical analysis from all observation dug wells. These containers were washed thoroughly with distilled water and dried before

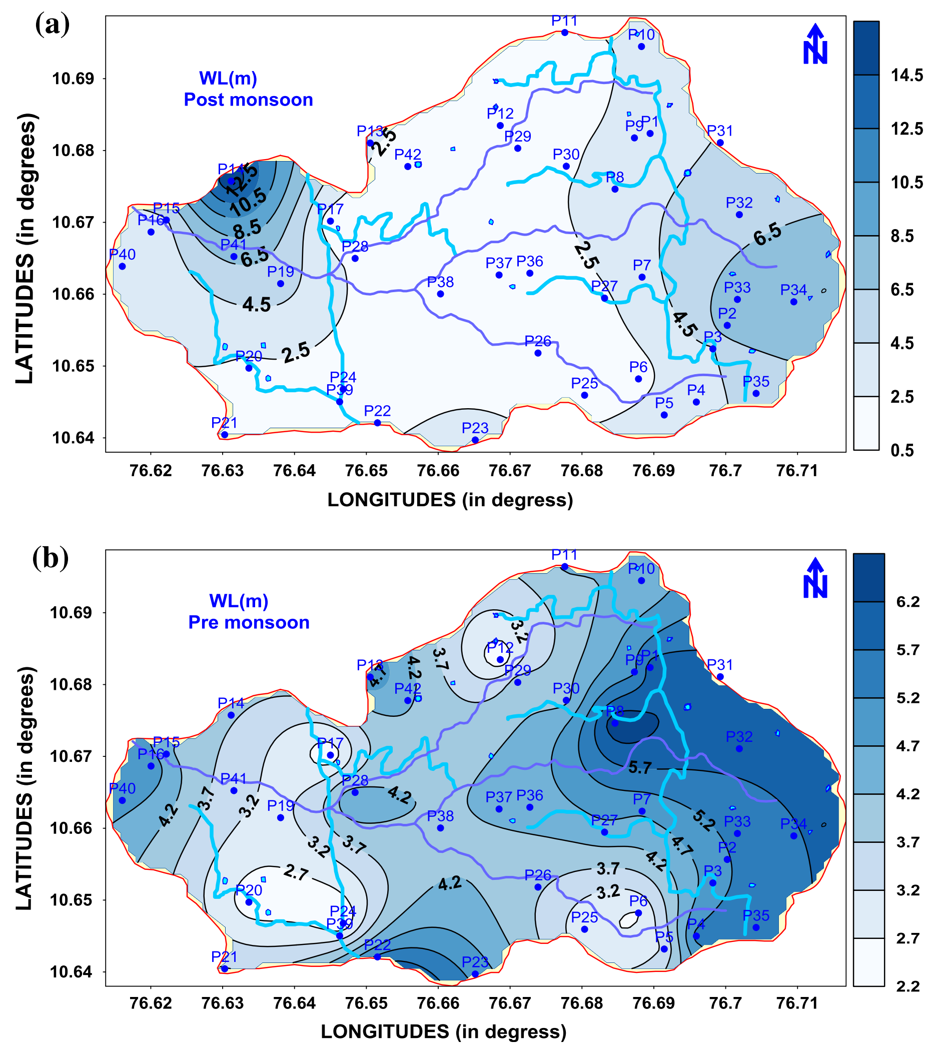


Fig. 3 **a**, **b** Variation of depth to the water level (bgl) for post-monsoon (October 2009) and pre-monsoon (April 2010) in the study area

being filled with water samples. The containers were numbered serially along with a proper record of well/sample location, date, static water level, and prior to the sampling. Groundwater samples were collected after the well was subjected to pumping for at least 5–10 min to obtain the composite sample. The pH and EC of the groundwater of the wells were measured by using HACH HQ40d and its in situ values are recorded. The samples were collected and stored below 4 °C and analyzed in the Centre for Water Resources Development and Management (CWRDM) Calicut, Kerala. Total dissolved solids (TDS) were calculated from EC with cation factor of multiple 0.64 (Brown et al. 1970). Water samples collected in the field were analyzed for chemical constituents, such as Total dissolved solids (TDS), Total hardness (TH), Calcium (Ca), Magnesium (Mg), Total alkalinity (TA), Carbonates (CO_3), Bicarbonates (HCO_3), Sodium (Na), Potassium (K), Chloride (Cl), Nitrate (NO_3), and Sulfates (SO_4), were analyzed following the standard procedure of (APHA 1995). The analytical results were evaluated in detail and compared with water quality guidelines of WHO (1984). A brief description of the physico-chemical attributes of groundwater is discussed. EC, pH, chloride (Cl^-), fluoride (F^-), and nitrate (NO_3^-) were analyzed using multiple parameters ion meter model Thermo Orion 5 Star. Sulfate (SO_4^{-2}) was measured using a double beam UV–Vis spectrophotometer model Perkin Elmer Lambda 35 by turbid-metric, stannous chloride, and molybdosilicate, respectively. Sodium (Na^+), potassium (K^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}) were analyzed using flame photometer model CL-378 (Elico, India). Total hardness was determined by EDTA titrimetric method. TDS was measured gravimetrically. Total carbonate and bicarbonate alkalinities were measured by acid–base titration.

Result and discussion

The analytical results of physical and chemical parameters of the groundwater of the present study are shown in

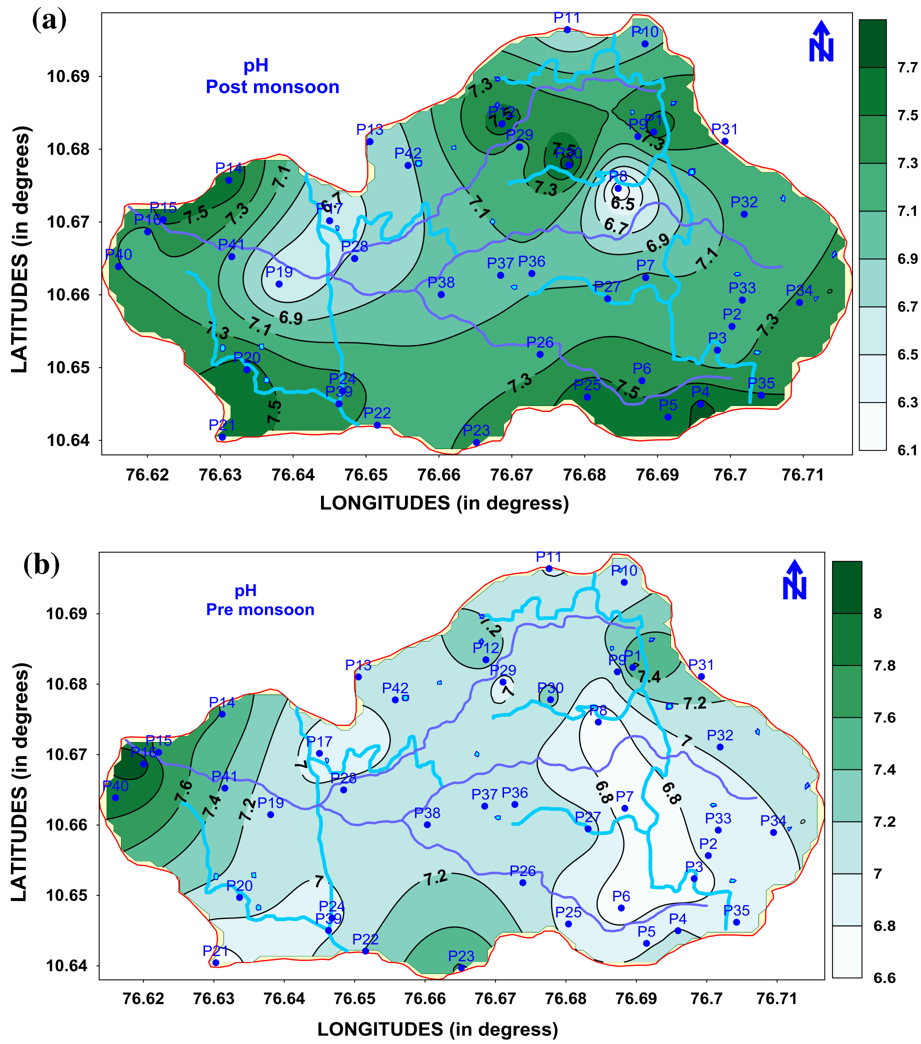


Fig. 4 **a**, **b** Variation of pH for post-monsoon (October 2009) and pre-monsoon (April 2010) in the study area

(Tables 3, 4). These were compared with the standard guideline values as recommended by the WHO for drinking and public health purposes. The water levels in the study area are very shallow ranging from 3.38 m in post-monsoon to 4.25 m in pre-monsoon as mentioned in (Tables 3, 4). The fluctuation of water level from post-monsoon to pre-monsoon is very low; the effect on TDS concentration is also very low. A brief description of the important physico-chemical attributes of groundwater are discussed.

Hydrogen ion (pH)

The seasonal average of pH shows a neutral value of 7.15. In post-monsoon, pH value ranging from 7.0 to 7.5 is covering major area from western part of study area towards the eastern side. The value with 7.4–7.6 is covered at the peripheral of study area. In pre-monsoon, pH value ranging from 6.6 to 8.1 in major part from west towards east has been covered with a range of 7.0–7.3 as in (Fig. 4a, b). A patch in the south-east part of study area is ranging from 6.6 to 7.0. This low value of pH is to some extent the influences of fertilizers like ammonium sulfate and super phosphate in agriculture (Appelo and Postma 2005).

Total dissolved solids (TDS)

The value of TDS plays a vital role in the groundwater whether the water is potable or for domestic use. The samples are falling well within the permissible limits (500–2,000 mg/L). The pre-monsoon samples of 44 % and in post-monsoon samples of 44 % are exceeding the limits (Table 5). EC is directly related to TDS, the locations showing high contents of EC support higher TDS concentration. The variation of TDS for post-monsoon and pre-monsoon is shown in (Fig. 5a, b). The major source for TDS is due to livestock waste, landfills and dissolved minerals, and iron and manganese.

Table 5 Quality of groundwater samples from Palakkad study area for drinking purpose (BIS standards)

Parameter	Desirable limit	Post-monsoon samples (%)		Pre-monsoon samples (%)	
		Within limits	Exceed limits	Within limits	Exceed limits
pH	6.5–8.5	100	–	100	–
EC	300 (μmhos/cm)	13.7	86.3	3.4	96.6
TDS	500 (mg/L)	55.2	44.8	55.2	44.8
Total alkalinity	200 (mg/L)	58.6	41.4	75.8	24.2
Total hardness	200 (mg/L)	44.8	55.2	58.6	41.4
So_4	200 (mg/L)	100	–	100	–
No_3	45 (mg/L)	100	–	100	–
Cl	250 (mg/L)	79.3	20.7	89.6	10.4
F	1.0 (mg/L)	100	–	86.2	13.8
Ca	75 (mg/L)	79.3	20.7	86.7	10.3
Mg	30 (mg/L)	38	62	72	28
Na	200 (mg/L)	100	–	93.1	6.9

Electrical conductivity (EC)

The EC values in post-monsoon are ranging from 107 to 3,000 μs/cm and as so in pre-monsoon from 178 to 3,380 μs/cm. The average EC value in post-monsoon is 909.3 μs/cm and pre-monsoon value is 844.5 μs/cm. The EC values in pre-monsoon shown 93 % of wells out of limit and in post-monsoon 86 % of wells are out of limits as there are some anthropogenic activities been carried out. The higher value of EC is observed in observation well No. 29, which is located close to a stream along the road, in Pudunagaram village showing its limits more than 3,000 in both monsoon seasons.

Total alkalinity

Total alkalinity is the measure of the capacity of water to neutralize a strong acid. The major source for alkalinity is due to landfills and pipe lines. The permissible limit of alkalinity is 200 mg/L. In pre-monsoon, 24 % of samples are out of limits, and in the post-monsoon, 41 % of samples are out of limits (Table 5). The value of alkalinity is 60 mg/L indicating hard water, which makes the fresh water unpalatable (Fig. 6a, b).

Total hardness (TH)

Total hardness value is between 150 and 300 mg/L means the water is hard and the value >300 mg/L means it is very hard (Todd 2001). The pre-monsoon samples of 31 % are out of limits, and in post-monsoon, 17 % of samples are out of limits (Table 5). The major source for hardness is due to calcium and magnesium in the soil and aquifer minerals. High concentration of TH in water may cause kidney stone and heart disease in human. The maximum permissible limits of water quality for drinking as given by BIS (1991) and WHO (1993) is 600 mg/L (Fig. 7a, b).

Nitrate

Nitrate in the study area is found to be comparatively very low in concentration. However, the season wise averages show slightly higher values during post-monsoon. The peak values registered during pre-monsoon and post-monsoon are 25.1 and 38.9 mg/L, respectively, and all of the samples are within the permissible limit. Being loosely bound to soils, nitrate is expected to be more in runoff and hence its concentration increases during rainy seasons (Rao et al. 2004).

Calcium and magnesium

Among the cations, Ca content shows seasonal variation and majority of the samples in all the seasons fall within the permissible limit (75 mg/L). Among the total samples, 20.6 % in post-monsoon and 68.9 % in pre-monsoon seasons register values beyond the permissible limit. The content of Ca spreads between 5 and 219 mg/L, and 20 to 776 mg/L averaging 55 and 144.6 mg/L during post-monsoon and pre-monsoon, respectively. The content up to 1,800 mg/L does not impair any physiological reaction in man (Lehr et al. 1980). High concentration of Ca is not desirable in washing, laundering, and bathing. Although the sources of Ca in groundwater resources are mainly the crystalline limestone associated with khondalitic rocks, the prolonged agricultural activities prevailing in the study area may also directly or indirectly augment the mineral dissolution in groundwater (Bohlke 2002). The content of Mg is comparatively less than that of Ca. The Mg exhibits gradual increase in concentration from post-monsoon to pre-monsoon seasons. Of the total samples, 10.34 % in post-monsoon, show concentrations outside the permissible limit. The geochemistry of the rock types may have an influence in the concentration of Mg in groundwater.

Sodium and potassium

Na is one of the important naturally occurring cations and its concentration in fresh waters is generally lower than that of Ca and Mg. But in the present investigation, the average concentration of Na is comparatively higher than that of Ca and Mg. Previous studies (CGWB 2005) in the same area

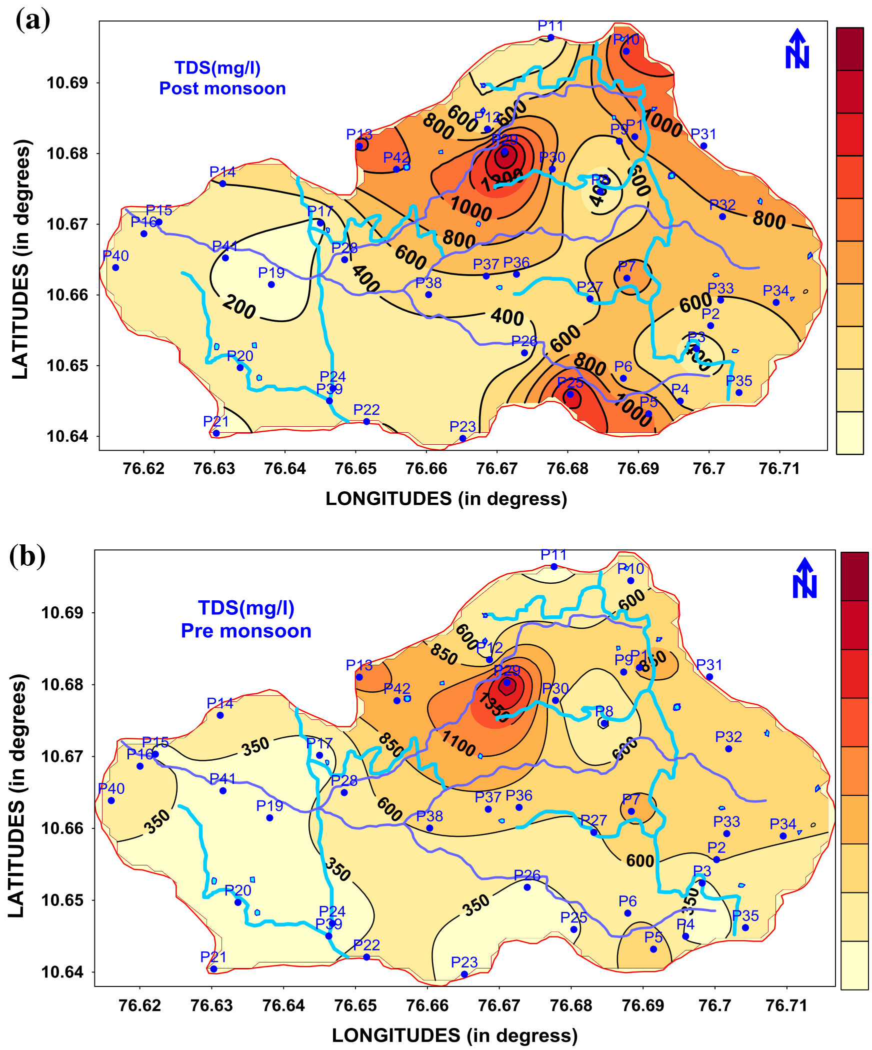


Fig. 5 **a**, **b** Variation of total dissolved solids (TDS) for post-monsoon (October 2009) and pre-monsoon (April 2010) in the study area

also corroborate these results. For aesthetic reason, the guideline value given by WHO is 200 mg/L. Comparatively higher values were recorded in pre-monsoon with the values range between 10.8 and 388 mg/L and 4.4 and 156 mg/L in post-monsoon with the averages of 88.2 and 51.5 mg/L, respectively. Sample No. 29 in pre-monsoon registered value above the permissible limit. Since the eastern parts are covered mainly by hornblende-biotite gneiss and are migmatised, the geological influence on the concentration of the cations is well understood (Soman 1977). The concentration of K shows very low values in all the seasons with the averages of 6.1 in pre-monsoon and 12 mg/L post-monsoon. Though, most of the source rocks contain approximately equal amounts of Na and K, and both are released during weathering, a part of the K go into clay structure and thereby its concentration gets reduced in water. However, sample Nos. 1 and 22 throughout the study period, 44 and 48.5 in pre-monsoon and 64 and 110 in post-monsoon registered values above the drinking water standard of 12 mg/L (Griffioen 2001; WHO 1993). Potassium contamination in groundwater can result from the application of inorganic fertilizer at greater than agronomic rates. Loss of nutrients, including K, from agricultural land have been identified as one of the main causative factors in reducing water quality in many parts of arid and semi-arid regions (WHO 1993; Jalali 2005; Kolahchi and Jalali 2006).

Chloride (Cl)

The principal sources of chloride are animal organic matter, sewage from drainages and refuse. The usage of huge fertilizer for paddy cultivation also plays a vital role as the source of chloride. The maximum permissible limit for Cl in drinking water is 250–1,000 mg/L (WHO 1993). In the pre-monsoon, 10 % of samples are out of limits, and in the post-monsoon, 20 % of samples are out of limits as in (Fig. 8a, b) and Table 5.

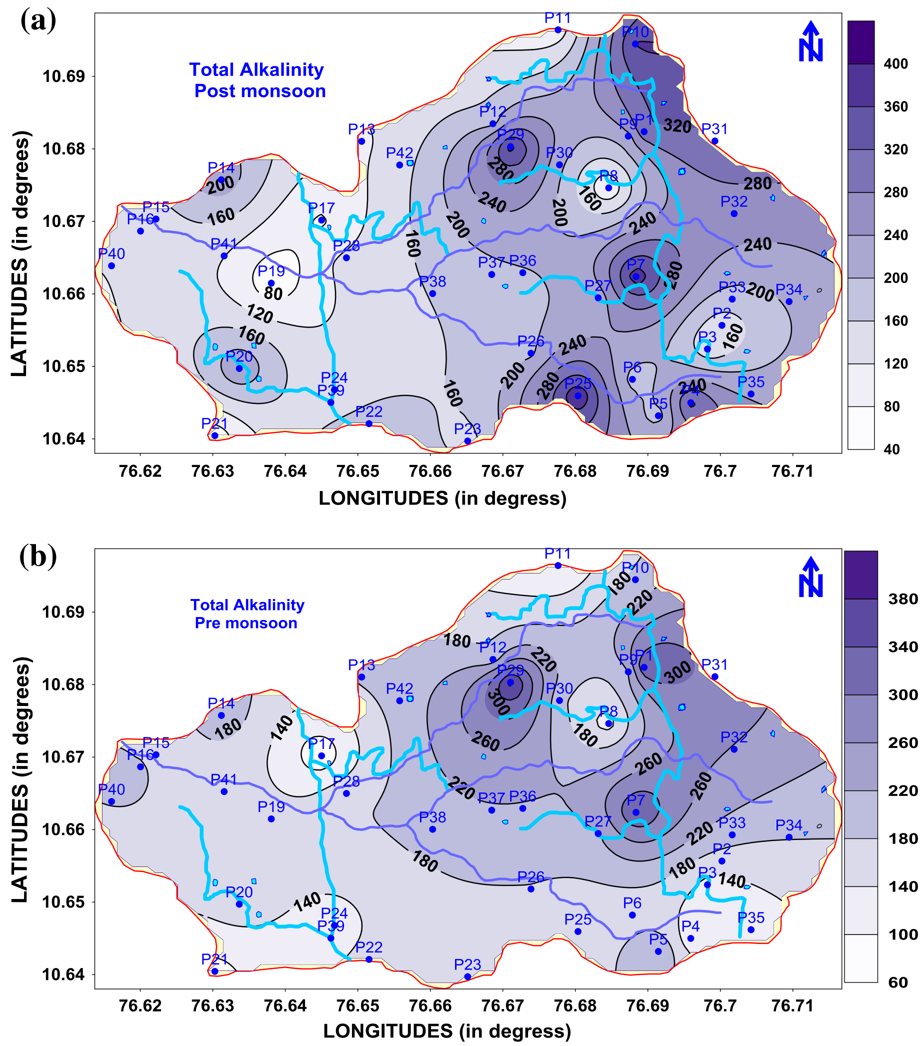


Fig. 6 a, **b** Variation of total alkalinity for post-monsoon (October 2009) and pre-monsoon (April 2010) in the study area

Water quality criteria for irrigation

Water quality for irrigation refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water can be determined to know its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkalinity conditions in an irrigated area. Good quality of water (good soil and water management practices) can promote maximum crop yield. The suitability of water for irrigation depends upon TDS (salinity) and the sodium content in relation to the amounts of calcium and magnesium or SAR (Alagbe 2006). The suitability of groundwater for irrigation use was evaluated by calculating salinity (EC), sodium absorption ratio (SAR), Kelly's ratio (KR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), permeability index (PI), and water quality index (WQI).

Classification of groundwater on salinity (EC)

Salinization is one of the most prolific adverse environmental impacts associated with irrigation. Saline condition severely limits the choice of crop, adversely affect crop germination and yields and can make soils difficult to work. Excessive solutes in irrigation water are a common problem in semi-arid areas where water loss through evaporation is maximum. Salinity problem encountered in irrigated agriculture are most likely to arise where drainage is poor. This allows the water table to rise close to the root zone of plants, causing the accumulation of sodium salts in the soil solution through capillary rise following surface evaporation of water. The higher the EC, the less suitable is water available to plants, because plants can only transpire ''pure'' water and usable plant water in the soil solution decreases dramatically as EC increases. The amount of water

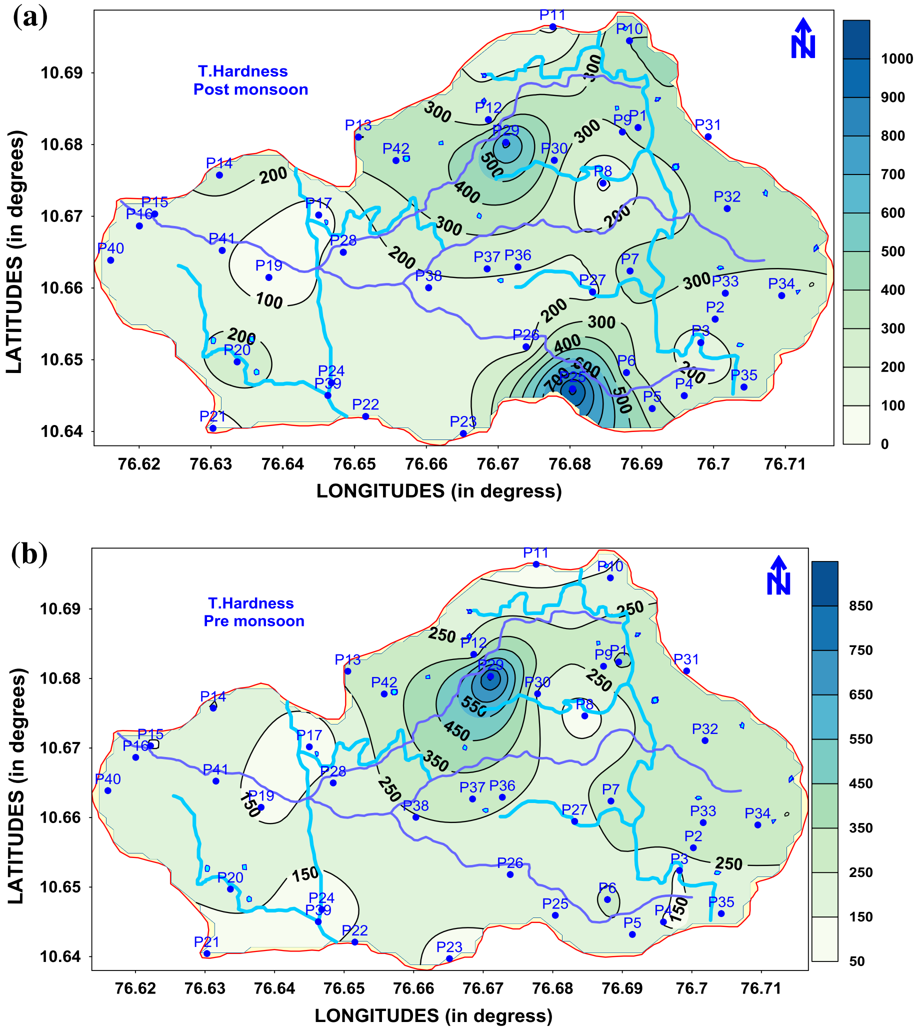


Fig. 7 **a**, **b** Variation of total hardness (TH) for post-monsoon (October 2009) and pre-monsoon (April 2010) in the study area

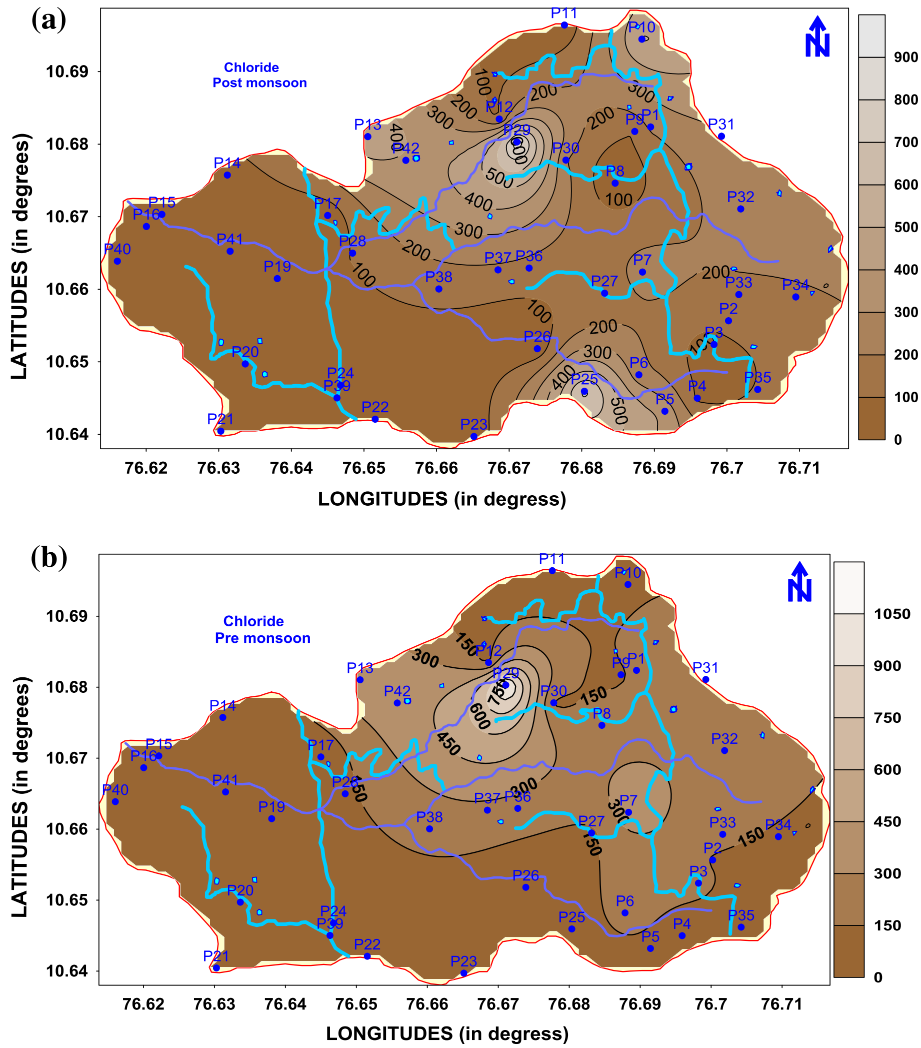
transpired through a crop is directly related to yield; therefore, irrigation water with high EC reduces yield potential. The electrical conductivity (EC) of the groundwater in the study area varies from 178 to 3,380 µS/cm and 107–3,000 µS/cm in pre-monsoon and post-monsoon, respectively (Tables 3, 4). Based on the EC, the groundwater of study area has been classified into four classes (Handa 1969) (Table 6). The total concentration of soluble salts in irrigation water can be expressed as low (EC = <250 µS/cm), medium (250–750 µS/cm), high (750–2,250 µS/cm), and very high (>2,250 µS/cm); and classified as C1, C2, C3 and C4 salinity zones, respectively (Richards 1954; Singh et al. 2011). While a high salt concentration (high EC) in water leads to formation of saline soil and a high sodium concentration leads to development of an alkaline soil.

In Wilcox diagram (Fig. 9), the EC is taken as salinity hazard and SAR as alkalinity hazard, shows low alkalinity hazard (S1) and Medium-high salinity hazard (C2–C3) for majority of groundwater samples from both seasons. However, two samples from post-monsoon (P25 and P29) fall in S1–C4, while a sample from pre-monsoon (P28) falls in S2–C4 and a sample (P14) from pre-monsoon falls in S2–C3, which represent medium alkalinity hazard and high to very high salinity (C3–C4). It seems that there is a gradual increase in both alkalinity and salinity characters from the groundwater samples during pre- to post-monsoon periods due to long-term precipitation and water–rock interaction in space and time.

Sodium adsorption ratio (SAR)

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (SAR). Sodium concentration is important in classifying the water for irrigation purposes because sodium concentration can reduce the soil permeability and soil structure (Todd 1980; Domenico and Schwartz 1990). The sodium adsorption ratio values for each water sample were calculated by using following equation (Richards 1954).

Fig. 8 **a**, **b** Variation of chloride (Cl) for post-monsoon (October 2009) and pre-monsoon (April 2010) in the study area



$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{(\mathrm{Ca} + \mathrm{Mg})/2}} \tag{1}$$

where the concentration are reported in milligrams per liter.

The waters having SAR values <10 are considered excellent, 10–18 as good, 18–26 as fair, and above 26 are unsuitable for irrigation use (USDA 1954). In the present study, a total of 25 samples from post-monsoon and 20 samples from pre-monsoon fall in excellent class, i.e. the SAR values <10. The post-monsoon four samples fall in good class and from pre-monsoon seven water samples. Well No P4 in post-monsoon and P13 in pre-monsoon fall in fair class. The samples that are graded as excellent and good are used for irrigation. Based on sodium percentage, the prominent groundwater samples are suitable for irrigation (Table 6).

Residual sodium carbonate (RSC)

In water having high concentration of bicarbonate, there is tendency for calcium and magnesium to precipitate as carbonate. To meet these effects experimental parameters termed as RSC (Eaton 1950) was used. Residual sodium carbonate is calculated as follows:

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

If RSC exceeds 2.5 meq/L, the water is generally unsuitable for irrigation. If the value of RSC is between 1.25 and 2.5 meq/L, the water is marginally suitable, while a value <1.25 meq/L indicates good water quality (USDA 1954). It is observed from Table 6 that, all the samples from post-monsoon and 25 samples from pre-monsoon fall in good class which is safe for usage. The four samples (P8, P10, P21, and P27) from pre-monsoon fall in doubtful class.

Table 6 Classification of groundwater sample for irrigation use on the basis of EC, SAR, RSC, KR, and SSP

Parameters	Range	Water class	Samples (%)	
			Post-monsoon	Pre-monsoon
EC	250	Excellent	Nil	Nil
	251–750	Good	33	17
	751–2,250	Permissible	67	61
	2,251–6,000	Doubtful	Nil	17
SAR	10	Excellent	100	100
	18	Good	Nil	Nil
	18–26	Doubtful	Nil	Nil
	26	Unsuitable	Nil	Nil
RSC	<1.25	Good	95	95
	1.25–2.50	Doubtful	Nil	Nil
	2.5	Unsuitable	05	05
KR	<1	Suitable	22	25
	1–2	Marginal suitable	08	04
	>2	Unsuitable	Nil	Nil
SSP	<50	Good	86	75
	>50	Unsuitable	14	25

Soluble sodium percentage (SSP)

Wilcox (1955) has proposed classification scheme for rating irrigation waters on the basis of SSP. The SSP was calculated by using following formula:

$$\mathrm{SSP} = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na}} \times 100 \quad (3)$$

The values of SSP <50 indicate good quality of water and higher values (i.e. >50) show that the water is unsafe for irrigation (USDA 1954). It is observed from (Table 6) that, the seven samples (P16, P22, P11, P19, P8, P17, and P4) from post-monsoon exceeds above 50, whereas in the case of pre-monsoon, there are only four samples (P10, P27, P8, and P13), which are above 50. All the groundwater samples have SSP values <50, which can be graded as good quality for irrigation.

Kelly's ratio (KR)

The Kelly's ratio of unity or <1 is indicative of good quality of water for irrigation whereas above one is suggestive of unsuitability for agricultural purpose due to alkali hazards (Karanth 1987). Kelly's ratio was calculated by using the following expression

$$\mathrm{KR} = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}} \quad (4)$$

It is observed from Table 6 that, the eight samples (P21, P16, P22, P11, P19, P8, P17, and P4) from post-monsoon exceeds above unity, whereas in the case of pre monsoon, there are only four samples (P10, P27, P8, and P13), which are above unity. The other samples in the study area are good for irrigation regarding alkali hazards.

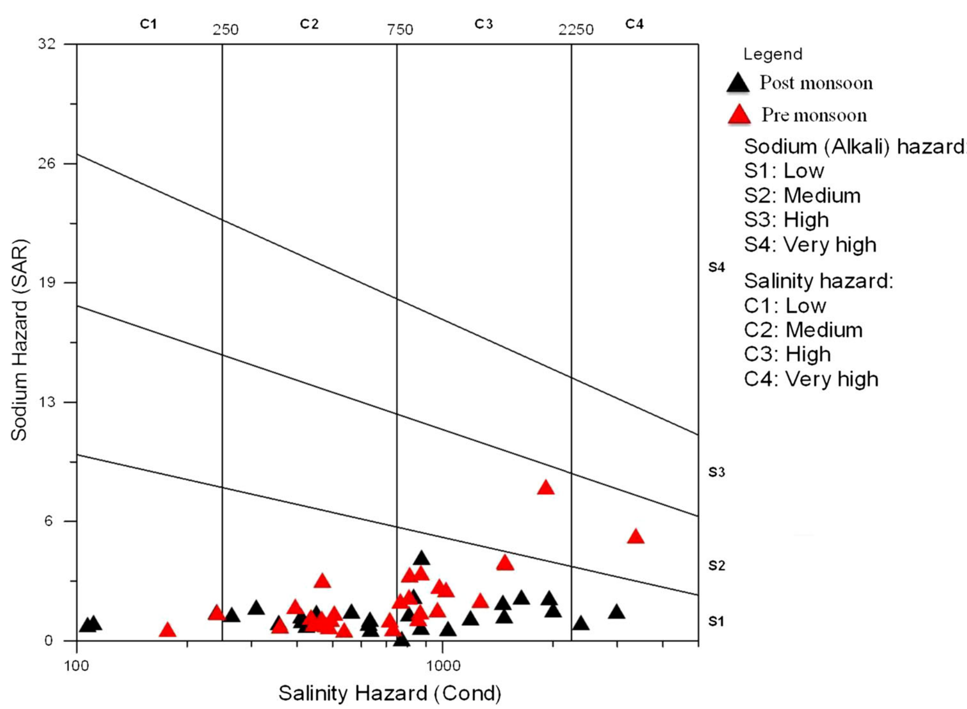


Fig. 9 Classification of groundwater based on Wilcox diagram for post-monsoon (October 2009) and pre-monsoon (April 2010) periods

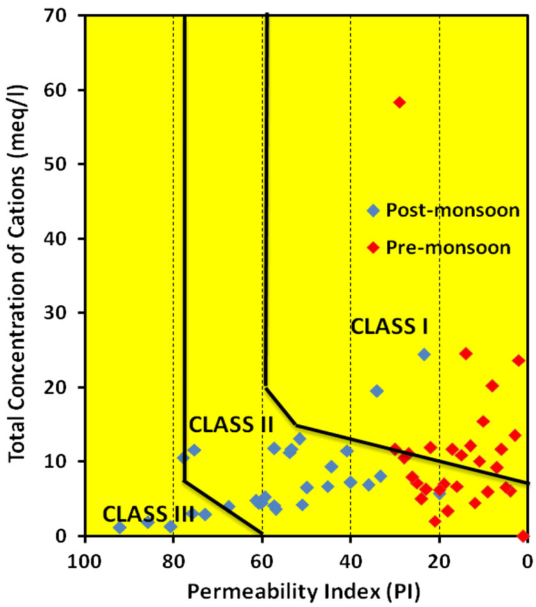


Fig. 10 Doneen Plot for groundwater samples for post-monsoon (October 2009) and pre-monsoon (April 2010) periods

Permeability index (PI)

Long-term use of irrigation water affects soil permeability. It depends on various factors like total soluble salt, sodium, calcium, magnesium, and bicarbonate content of the water. Doneen (1964) classified irrigation waters into three classes based on the PI. The PI has been computed and plotted on Doneen chart (Fig. 10) and is formulated as

$$PI = \frac{(Na + K) + \sqrt{HCO_3}}{Ca + Mg + Na + K} \times 100 \quad (5)$$

All the ions are represented in meq/L. As per the PI of groundwater samples in the study area fall in the fields of Class I and II and are described as having excellent to good permeability (Fig. 12). However, the entire water samples are classified as having excellent (Class I) permeability from both pre- and post-monsoon (Fig. 10).

Water quality index (WQI)

Water quality index is important because it arises first from the need to share and communicate with the public in a consistent manner of monitoring ambient water. Second, it is associated with the need to provide a general means of comparing and ranking various bodies of water throughout the region. One of the benefits of the index is elimination of jargon and technical complexity in describing water quality. The index strives to reduce an analysis of many factors into a simple statement. The WQI is founded on three issues involving the measurement of the attainment of water quality objectives. The factors are (1) number of objectives that are not met, (2) frequency with which objectives are not met, and (3) the amount by which objectives are not met. The WQI was calculated for groundwater and surface water samples for pre-monsoon and post-monsoon period taking into consideration six parameters, namely pH, electrical conductivity, total dissolved solids, nitrates, sulfates and total hardness. The weighted arithmetic WQI was calculated as follows and given in Table 7 for post-monsoon and pre-monsoon period, respectively.

$$WQI = \left[\sum (q_i \cdot w_i) / \sum w_i\right] \quad (6)$$

Further, water quality status based on WQI (Ramakrishnaiah et al. 2009; Bhuven et al. 2011; Kushtagi and Srinivas 2012) was classified as excellent (WQI <50), good (WQI = 50–100), poor (WQI = 100–200), very poor (WQI = 200–300), and water unsuitable for drinking and irrigation (WQI >300). Water samples of the study area fall in the category of excellent and good water with a percentage of 10.34 in post-monsoon and 3.44 in pre-monsoon, while the rest were unsuitable for drinking and irrigation use (Table 8).

Gibbs plot

The groundwater quality for drinking and irrigation purposes was assessed based on WHO (1984), standards. The quality of groundwater is significantly changed by the influence of weathering and anthropogenic inputs. The Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics (Gibbs 1970). Three distinct fields, such as precipitation dominance, evaporation dominance, and rock–water interaction dominance areas are shown in the Gibbs diagram. The predominant samples for both post- and pre-monsoon fall in the rock–water interaction dominance field of the Gibbs diagram (Fig. 11a, b). The rock–water interaction dominance field indicates the interaction between rock chemistry and the chemistry of the percolation waters under the subsurface.

$$\text{Gibbs ratio I (for anion)} = Cl/(Cl + HCO_3) \quad (7)$$

$$\text{Gibbs ratio II (for cation)} = Na^{+} + K^{2+}/(Na^{+} + K^{2+} + Ca^{2+}) \quad (8)$$

Hydrochemical facies

The hydrochemical evolution of groundwater can be understood by plotting the major cations and anions in piper trilinear diagram (Piper 1944). This diagram reveals similarities and dissimilarities among groundwater samples because those with similar qualities will tend to plot

Table 7 Calculation of SAR, KR, RSC, SSP, PI, and WQI of groundwater for post-monsoon and pre-monsoon period

Well ID	Post-monsoon period							Pre-monsoon period						
	SAR	SSP	KR	RSC	PI	WQI (WHO)	WQI (BIS)	SAR	SSP	KR	RSC	PI	WQI (WHO)	WQI (BIS)
P1	7.638	32.717	0.49	−1.661	57.24	273.933	363.039	16.395	41.686	0.715	−1.971	50.59	263.164	558.555
P2	0.677	4.960	0.05	−3.013	19.97	190.438	204.995	7.113	27.118	0.372	−4.700	32.63	215.112	338.380
P3	6.224	40.218	0.67	−0.379	57.21	98.143	135.236	5.141	28.970	0.408	0.009	39.43	89.533	147.072
P4	25.125	66.924	2.02	1.226	75.31	187.217	372.563	4.705	25.699	0.346	−1.165	34.81	92.257	155.859
P5	13.280	46.863	0.88	−2.864	53.68	264.527	397.420	9.256	35.451	0.549	−0.057	42.57	192.312	314.484
P6	3.857	21.236	0.27	−3.456	33.34	250.836	289.940	7.606	33.276	0.499	−0.916	41.33	130.016	228.447
P7	11.742	42.839	0.75	−0.574	53.32	237.524	363.244	16.186	42.948	0.753	−0.096	47.80	202.836	472.528
P8	10.306	59.603	1.48	0.248	75.72	19.013	67.983	13.242	56.319	1.289	1.547	65.87	53.884	147.141
P9	4.145	23.231	0.30	−0.351	39.97	182.060	239.150	11.347	36.918	0.585	−2.881	42.32	201.488	386.340
P10	8.454	31.987	0.47	−1.750	40.84	123.972	276.789	14.466	50.635	1.026	1.324	57.72	123.242	263.313
P11	8.349	54.417	1.19	0.220	72.82	47.897	84.827	7.621	43.320	0.764	0.739	54.68	59.276	116.573
P12	6.598	35.128	0.54	−1.015	49.86	164.305	222.039	4.848	20.348	0.255	−2.974	27.23	183.327	286.408
P13	13.531	45.879	0.85	−5.893	51.55	353.680	482.946	31.018	60.659	1.542	−4.073	63.38	249.139	656.918
P14	5.311	29.320	0.41	−0.634	45.22	166.820	220.896	2.570	11.920	0.135	−2.264	19.70	159.747	248.922
P15	7.023	42.624	0.74	−0.285	60.81	116.584	158.688	6.046	31.360	0.457	0.042	41.72	117.393	185.595
P16	8.863	51.360	1.06	0.285	67.61	95.654	142.161	4.195	17.885	0.218	−2.759	24.63	158.104	274.213
P17	8.580	61.755	1.61	0.604	85.74	14.332	44.938	5.752	38.887	0.636	0.264	51.78	29.477	73.139
P19	5.756	57.999	1.38	0.299	92.07	41.746	46.397	3.303	18.030	0.220	−0.220	27.60	65.860	135.894
P20	3.566	21.231	0.27	−1.795	35.97	0.319	16.533	2.892	17.880	0.218	0.670	30.43	138.095	178.795
P21	4.923	50.251	1.01	0.482	80.64	216.654	250.253	2.950	28.723	0.403	1.519	53.46	22.410	43.841
P22	13.197	52.121	1.09	−0.502	77.82	42.929	56.697	8.890	34.810	0.534	−1.243	51.90	125.483	252.878
P23	7.625	44.135	0.79	0.229	60.11	125.552	234.932	5.292	28.927	0.407	0.933	40.41	116.720	177.416
P24	5.655	39.203	0.64	−0.160	56.95	90.092	141.378	3.363	21.702	0.277	0.187	33.64	68.947	114.418
P25	5.669	18.249	0.22	−4.504	23.51	109.070	139.329	3.352	18.467	0.227	−0.811	27.78	88.973	152.766
P26	4.663	31.177	0.45	0.602	50.96	726.355	837.096	2.866	15.263	0.180	−0.334	26.26	87.160	158.075
P27	8.112	43.693	0.78	0.459	59.39	82.693	123.342	15.289	51.065	1.044	1.726	58.17	142.574	296.493
P28	8.979	48.274	0.93	−0.084	61.40	125.045	183.054	8.201	33.090	0.495	−0.977	40.22	114.817	236.054
P29	8.657	27.261	0.37	−8.357	34.01	81.695	139.702	19.314	32.466	0.481	−27.041	34.29	385.734	1,138.107
P30	7.200	33.267	0.50	−1.872	44.34	379.303	574.543	12.854	45.241	0.826	−0.209	52.79	190.212	329.913

Table 8 Water quality classification based on WQI value

Class	WQI value	Water quality status	Post-monsoon (%)	Pre-monsoon (%)
I	<50	Excellent	10.34	3.44
II	50–100	Good water	13.79	3.44
III	100–200	Poor water	24.13	37.93
IV	200–300	Very poor water	27.58	27.58
V	>300	Unsuitable water	24.13	27.58

together as groups (Todd 2001). This diagram is very useful in bringing out chemical relationships among groundwater in more definite terms (Walton 1970). The geochemical evolution can be understood from the Piper plot, which has been divided into six subcategories viz. Type-I (Ca^{2+}–Mg^{2+}–HCO_3^- type), Type-II (Na^+–Cl^-type), Type-III (Mixed Ca^{2+}–Na^+–HCO_3^- type), Type-IV (Mixed Ca^{2+}–Na^+–Cl^- type), Type-V (Ca^{2+}–Mg^{2+}–Cl^- type) and Type-VI (Na^+–HCO_3^- type).

As per the classification of Piper diagram, the groundwater samples from the study area for post-monsoon (October 2009) are classified into the hydrochemical facies which are arranged in the decreasing order of abundance as Type-I (Ca^{2+}–Mg^{2+}–HCO_3^- type), Type-III (Mixed Ca^{2+}–Na^+–HCO_3^- type) and Type-V (Ca^{2+}–Mg^{2+}–HCO_3^-). Whereas the II, IV and VI types of groundwater samples are far less in post-monsoon period (Fig. 12). During pre-monsoon (April 2010), the samples are classified into Type-I (Ca^{2+}–Mg^{2+}–Na–Cl–HCO_3^- type), Type-III (Mixed Ca^{2+}–Na^+–Cl–HCO_3^- type) and Type-V (Ca^{2+}–Mg^{2+}–HCO_3^-).

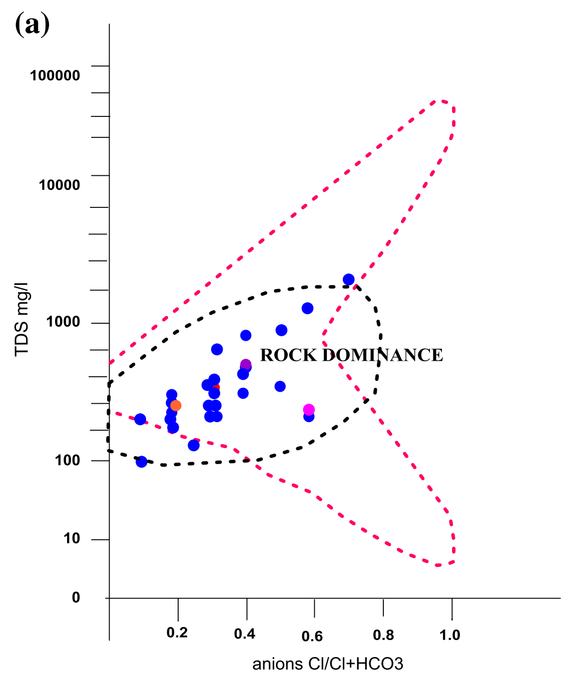
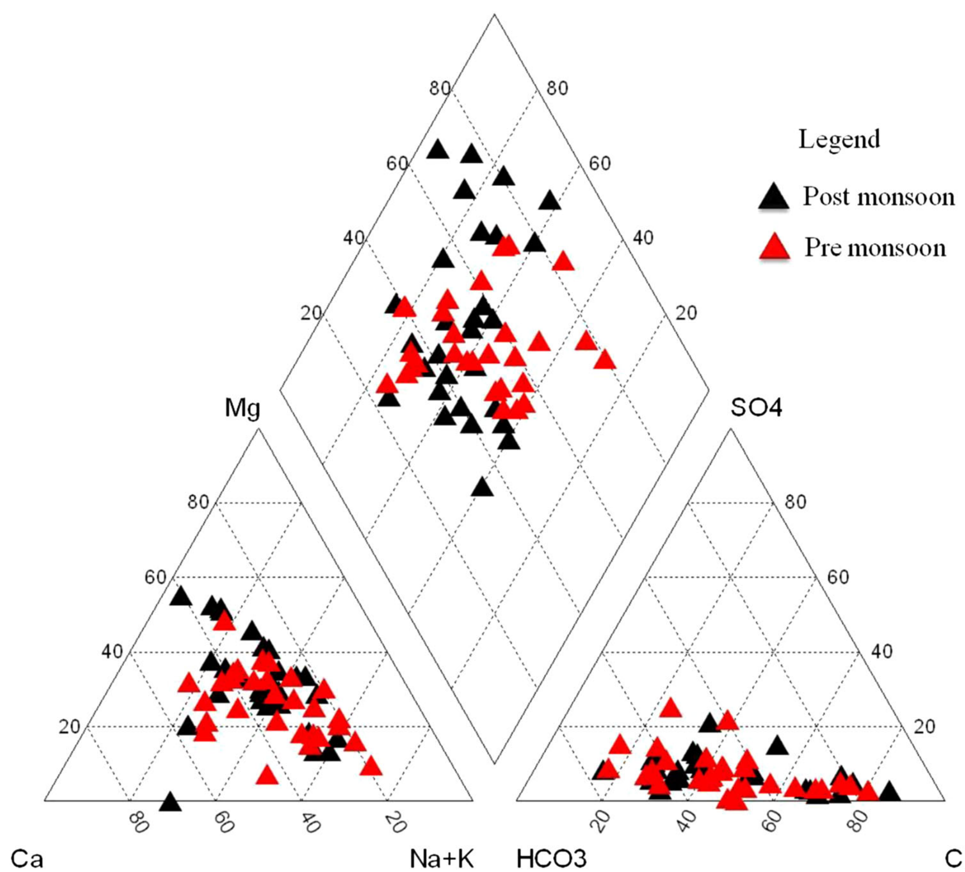


Fig. 11 **a**, **b** Gibbs Plots for groundwater samples for post-monsoon (October 2009) and pre-monsoon (April 2010) periods

Fig. 12 Piper Trilinear Plots for groundwater samples for post-monsoon (October 2009) and pre-monsoon (April 2010) periods



From another point of view, 100 % of the plots clustered in Type-I ($Ca + Mg + Na - Cl + HCO_3$) facies of the Piper's diagram. In this study, the dominant ions are Cl, Na with Ca, and HCO_3 ions following. Generally, groundwater tends to acquire chemical compositions similar to that of seawater (that is more dissolved and relative increase in

Table 9 Cross correlation matrix of water quality data for post-monsoon season (October-2009)

	pH	EC	TDS	HCO_3	Cl	F	NO_3	SO_4	Na	K	Ca	Mg
pH	1	0.17	0.17	0.39	0.09	0.53	−0.12	0.25	0.14	0.06	0.19	0.34
EC		1	1	0.76	0.97	0.37	0.47	0.58	0.68	0.11	0.95	0.75
TDS			1	0.76	0.97	0.37	0.47	0.58	0.68	0.11	0.95	0.75
HCO_3				1	0.65	0.72	0.07	0.51	0.64	0.22	0.82	0.66
Cl					1	0.24	0.38	0.47	0.57	0	0.94	0.76
F						1	−0.2	0.28	0.37	0.23	0.44	0.3
NO_3							1	0.36	0.59	0.13	0.23	0.14
SO_4								1	0.38	0.19	0.53	0.33
Na									1	0.23	0.58	0.36
K										1	0.11	−0.02
Ca											1	0.73
Mg												1

Table 10 Cross-correlation matrix of water quality data for pre-monsoon season (April-2010)

	pH	EC	HCO_3	Cl	F	NO_3	SO_4	Na	K	Ca	Mg
pH	1	0	0.18	−0.22	0.25	−0.02	0.35	−0.07	0.31	−0.02	0.11
EC		1	0	0	0	0	0	0	0	0	0
HCO_3			1	0.70	0.22	0.12	0.53	0.74	0.27	0.77	0.65
Cl				1	−0.17	0.23	0.3	0.89	−0.009	0.91	0.34
F					1	−0.01	0.29	−0.02	0.12	−0.17	0.19
NO_3						1	0.10	0.56	0.19	0.11	0.14
SO_4							1	0.42	−0.06	0.40	0.44
Na								1	0.15	0.79	0.42
K									1	0.09	−0.09
Ca										1	0.40
Mg											1

chloride ion) the longer it remains underground and the further it travels.

Correlation analyses

A high correlation coefficient means a good relationship between two variables, and a correlation coefficient around zero means no relationship. Positive values of *r* indicate a positive relationship while negative values indicate an inverse relationship. The correlation coefficient matrix of analyzed ions for post-monsoon (October 2009) and pre-monsoon (April 2010) seasons is shown in Tables 9 and 10. The correlation coefficient matrix was calculated and it has been observed that during post-monsoon season (October 2009), the correlation between HCO_3 and EC/TDS; Cl and EC/TDS; HCO_3 and F; Na with EC/TDS; Ca with EC/TDS; and Mg with EC/TDS shows with high positive correlation, and during pre-monsoon season (April 2010) the correlation between HCO_3 with Cl; Na with Cl; Ca with Cl; and Ca with Na shows high correlation, while for other parameters shows weak negative or no correlation.

Conclusion

The concentrations of cations and anions are within the allowable limits for drinking water standards except a few samples. The suitability of water for irrigation is evaluated based on SAR, RSC, and salinity hazards. Most of the sample falls in the suitable range for irrigation purpose based on SAR, KR, SSP, and RSC values, but few samples that are exceeding the permissible limits are observed to be in different kind of geological and anthropogenic activities were carried out near the samples in the study area. Based on hydrochemical facies, most water type dominates in the study area is Na–Ca–CO_3–HCO_3–Cl facies during post-monsoon seasons. From the different plots, it is observed that the groundwater samples are alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed the alkalis (Na^+ and K^+) and strong acids (Cl^- and SO_4^-) exceed the weak acids (HCO_3 and CO_3). Gibb's diagram reveals that most of the groundwater sample fall in the rock dominance field. The subsurface water chemistry indicates the dominance of interaction between rock chemistry and the chemistry of the percolation waters. The correlation coefficient between HCO_3 with EC/TDS; Cl and EC/TDS; HCO_3 and F; Na with EC/TDS; Ca with EC/TDS; Mg with EC/TDS; HCO_3 with Cl; Na with Cl; Ca with Cl; and Ca with Na shows strong positive correlation.

Acknowledgments The authors express their thanks to Director, NGRI, Hyderabad for his continuous support for the research activity. Authors are also thankful to the staff of the Kerala Government for their help rendered and cooperated during the field work. Authors are also thankful to the honorable reviewers for their scientific comments to improve the content of the manuscript. Authors are thankful to the Editor and the Handling Editor of the Journal for their cooperation and encouragement.

References

Akbal F, Gurel L, Bahadir T, Guler I, Bakan G, Buyukgungor H (2011) Water and sediment quality assessment in the mid-Black Sea coast of Turkey using multivariate statistical techniques. Environ Earth Sci 64(5):1387–1395

Alagbe SA (2006) Preliminary evaluation of hydrochemistry of the Kalambain Formation, Sokoto Basin, Nigeria. Environ Geol 51:39–45

APHA (1995) Standard methods for the examination of water and waste water, 19th edn. APHA, Washington DC

Appelo CAJ, Postma D (2005) Geochemistry, groundwater and pollution, 2nd edn. Balkema publishers, Leiden, p 404

Aravindan S, Manivel M, Chandrasekar SVN (2004) Ground water quality in the hard rack area of the Gadilam river basin, Tamil Nadu. J Geol Soc India 63(6):625–635

Aravindan S, Shankar K, Poovalinga Ganesh B, Dharani Rajan K (2010) Hydrogeochemical mapping of in the hard rock area of Gadilam River basin, using GIS technique, Tamil Nadu. Indian J Appl Geochem 12(2):209–216

Bhardwaj V, Sen Singh D (2011) Surface and groundwater quality characterization of Deoria District, Ganga Plain, India. Environ Earth Sci 63(2):383–395

Bhuven NT, Macwan JEM, Soni Chirag K (2011) Assessment of water quality index of small lake in south Gujarat region, India. In: Proceedings of ISEM-2011, Thailand

BIS (1991) Specifications for drinking water IS: 10500:1991, Bureau of Indian Standards, New Delhi. In the soils of Tallinn (Estonia). Environ Geoche Health 22:173–193

Bohlke JK (2002) Groundwater recharge and agricultural contamination. Hydrogeol J 10:153–179

Brown E, Skougstand MW, Fishman MJ (1970) Methods for collection and analyses of water samples for dissolved minerals and gases. In: Techniques of Water Resources Investigation of the US Geological Survey 5

Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH (1998) Non point of surface waters with phosphorous and nitrogen. Ecol Appl 8(3):559–568

CGWB (2005) District Groundwater Management Studies of Palghat District, Kerala. In: Technical Report Series, Report No. 25/KR/CGWB/2004–05

Dasgupta AM, Purohit KM (2001) Status of surface and groundwater quality of Mandiakadar-Part II: agricultural utilities. Pollut Res 20(2):219–225

Domenico PA, Schwartz FW (1990) Physical and chemical hydrology. Wiley, New York

Doneen LD (1964) Notes on water quality in agriculture. Published as a water science and engineering paper 4001, Department of Water Science and Engineering, University of California

Eaton FM (1950) Significance of carbonates in irrigation waters. Soil Sci 69:123–133

Gibbs RJ (1970) Mechanism controlling world water chemistry. Science 170:795–840

Griffioen J (2001) Potassium adsorption ratios as an indicator for the fate of agricultural potassium in groundwater. J Hydrol 254:244–254

Gupta S, Nayek S, Saha RN (2012) Major ion chemistry and metal distribution in coal mine pit lake contaminated with industrial effluents: constraints of weathering and anthropogenic inputs. Environ Earth Sci 67(7):2053–2061

Handa BK (1969) Description and classification of media for hydrogeochemical investigations. In: Symposium on groundwater studies in arid and semi-arid region. Roorkee

Jalali M (2005) Nitrates leaching from agricultural land in Hamadan, western Iran. Agric Ecosyst Environ 110:210–218

Jarvie HP, Whitton BA, Neal C (1998) Nitrogen and phosphorous in east coast British rivers: Speciation, sources and biological significant. Science Total Environ pp 210–211, 79–109. (World Acad Sci Eng Technol 52 2009 482)

Karanth KR (1987) Ground water assessment, development and management. Tata McGraw Hill Publishing Company Ltd., New Delhi, p 720

Khurshid SH, Hasan N, Zaheeruddin M (2002) Water quality status and environmental hazards in parts Environ Monit Assess of Yamuna-Karwan sub-basin of Aligarh-Mathura district, Uttar Predesh, India. J Appl Hydrol 14(4):30–37

Kolahchi Z, Jalali M (2006) Effect of water quality on the leaching of potassium from sandy soil. J Arid Environ 68:624–639

Kushtagi S, Srinivas P (2012) Studies on chemistry and water quality index of ground water in Chincoli Taluk, Gulbarga dist., Karnataka, India. Int J Environ Sci 2(3):1154–1160

Lehr JH, Gass TE, Pettyjohn WA, De Marre J (1980) Domestic water treatment. Mc Graw-hill Book Co., New Delhi, p 655

Machender G, Dhakate R, Reddy MN, Panduranga Reddy I (2013) Hydrogeochemical characteristics of Surface water (SW) and Groundwater (GW) of the Chinnaeru river basin, Northern part of Nalgonda District, Andhra Pradesh, India. Environ Earth Sci. doi:10.1007/s12665-013-2665-8 (ONLINE)

Majumdar D, Gupta N (2000) Nitrate pollution of ground water and associated human health disorders. India J Environ Health 42(1):28–39

Naik PK, Awasthi AK, Anand AVSS, Behera PN (2009) Hydrogeochemistry of the Koyna River basin, India. Environ Earth Sci 59(3):613–629

Nosrati K, Van Den Eeckhaut EM (2012) Assessment of groundwater quality using multivariate statistical techniques in Hashtgerd Plain, Iran. Environ Earth Sci 65(1):331–344

Piper AM (1944) A graphical procedure in the geochemical interpretation of water analysis. Trans Am Geophys Union 25:914–923

Prasanna MV, Chidambaram S, Gireesh TV, Ali TVJ (2011) A study on hydrochemical characteristics of surface and sub-surface water in and around Perumal Lake, Cuddalore district, Tamil Nadu, South India. Environ Earth Sci 63(1):31–47

Purushotham D, Prakash MR, Rao AN (2011) Groundwater depletion and quality deterioration due to environmental impacts in Maheshwaram watershed of R.R. District, AP (India). Environ Earth Sci 62(8):1707–1721

Ramakrishnaiah CR, Sadashivaiah C, Ranganna G (2009) Assessment of water quality index for the groundwater in Tumkar Taluk, Karnataka State, India. E-J Chem 6(2):523–530

Rao NS, Rao PS (2010) Major ion chemistry of groundwater in a river basin: a study from India. Environ Earth Sci 61(4):757–775
Rao PM, Sekhar P, Yadav YS (2004) Water Quality Studies on Kolleru Lake and Its Infalling Drains of A.P., India. In: Kumar Arvind (ed) Water pollution. APH Publishing Corporation, New Delhi, p 171
Rao NS, Subrahmanyam A, Kumar SR, Srinivasulu N, Rao GB, Rao PS, Reddy GV (2012) Geochemistry and quality of groundwater of Gummanampadu sub-basin, Guntur District, Andhra Pradesh, India. Environ Earth Sci 67(5):1451–1471
Richards LA (ed) (1954) Diagnosis and improvement of saline and alkali soils. In: USDA Handbook no. 60, Washington, pp 160
Shankar K, Aravindan S, Rajendran S (2010) GIS based groundwater quality mapping in Paravanar River Sub-Basin, Tamil Nadu, India. Int J Geomat Geosci 1(3):282–296
Shankar K, Aravindan S, Rajendran S (2011) Hydrogeochemistry of the Paravanar River Sub-basin, Cuddalore District, Tamil Nadu. E-J Chem 8(2):835–845
Sharma A, Singh AK, Kumar K (2012) Environmental geochemistry and quality assessment of surface and subsurface water of Mahi River basin, western India. Environ Earth Sci 65(4):1231–1250
Shivran HS, Dinesh Kumar D, Singh RV (2006) Improvement of water quality though biological denitrification. J Environ Sci Eng 48(1):57–60
Simeonov V, Stratis JA, Samara C, Zachariadis G, Voutsa D, Anthemidis A, Sofoniou M, Kouimtzis TH (2003) Assessment of the surface water quality in Northern Greece. Water Res 37:4119–4124
Singh AK, Tewary BK, Sinha A (2011) Hydrochemistry and quality assessment of ground-water in Part of NOIDA Metropolitan City, Uttar Pradesh. J Geol Soc India 78:523–540
Soman K (1977) Geology of Kerala. Geological Society of India, Bangalore, p 280
Sreedevi PD (2004) Groundwater quality of Pageru river basin, Cuddepah district, Andhra Pradesh. J Geol Soc India 64(5):619–636
Subba Rao N (2006) Seasonal variation of groundwater quality in a part of Guntur district, Andhra Pradesh, India. Environ Geol 49:413–429
Sujatha D, Reddy RB (2003) Quality characterization of groundwater in the south-eastern part of the Ranja Reddy district, Andhra Pradesh, India. Environ Geol 44(5):579–586
Sunitha V, Sudarsha V, Reddy RB (2005) Hydrogeochemistry of groundwater, Gooty area, Anantapur district, Andhra Pradesh, India. Pollut Res 24(1):217–224
Suyash K, Pawar NJ (2011) Site-specific accentuation of heavy metals in groundwaters from Ankaleshwar industrial estate, India. Environ Earth Sci 64(2):557–566
Takem GE, Chandrasekharam D, Ayonghe SN, Thambidurai P (2010) Pollution character-ristics of alluvial groundwater from springs and bore wells in semi-urban informal settlements of Douala, Cameroon, Western Africa. Environ Earth Sci 61(2):287–298
Todd DK (1980) Groundwater Hydrology, 2nd edn. Wiley, New York, p 535
Todd DK (2001) Groundwater hydrology. Wiley, Canada, pp 280–281
USDA (1954) Diagnosis and improvement of saline and alkali soils. U.S. Salinity Laboratory Staff, Government Printing Office, Washington, DC
Walton WC (1970) Groundwater resources evaluation. McGraw-Hill Book Co., New York
WHO (1984) Guidelines to drinking water quality. World Health Organisation, Geneva 186
WHO (1993) Guidelines for drinking water quality 1 Recommendations, 2nd edn. World Health Organization, Geneva
Wilcox LV (1955) Classification and use of irrigation waters. US Department of Agriculture Circular 969, Washington, DC, p 19