Hydrogeochemical characterisation and appraisal of groundwater suitability for domestic and irrigational purposes in a semi-arid region, Karnataka state, India

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Abstract

Hydrogeochemical investigations have been carried out in a semi-arid region of Aland taluk of Karnataka State, India. The analysis has been done to examine the quality of groundwater for drinking, domestic and irrigational purposes. In this concern, thirty-two groundwater samples were collected in pre-monsoon (April 2016) and post-monsoon season (November 2016), from the different location within the study area. These samples have been further analysed for different ions such as CO_3^{2-} , HCO_3^- , NO_3^- , Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Fe^{2+} , SO_4^{2-} , Cl^- and F^- to evaluate the hydrochemical behaviour with SSP (sodium soluble percentage), SAR (sodium absorption ratio), % Na (percentage sodium), RSC (residual sodium carbonate), KR (Kelly's ratio), PI (permeability index) and MH (magnesium hazards). These positive and negative ions have been further correlated with the maximum annual rainfall within the study area to find out the variations between these ions for the precipitation. Suitability of groundwater for drinking purposes around the catchment was not suitable except in a few places. Irrigational suitability of groundwater showed that the water is within the limit for irrigation except in a few locations. Wilcox diagram depicts that 90% of the pre-monsoon samples and 65% of the post-monsoon samples fell into excellent to good category zone. US salinity diagram explains that 71% of pre-monsoon samples belong to medium-salinity-hazard to low-sodium-content zones, whereas 50% of post-monsoon samples fall into high-salinity-hazard to low-sodium-content zone. Gibbs's plot showed that the water–rock processes control the geochemistry of the Aland region in both monsoon seasons. Chadha's diagram depicts that 56.25% of the groundwater samples fall under the subfield of $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$ water type with permanent hardness during pre-monsoon season, whereas 50% of groundwater samples falls under the subfield of $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--HCO}_3^-$ water type with temporary hardness during post-monsoon season.

Keywords Groundwater hydrochemistry · Quality analysis · Irrigational suitability · Domestic suitability · Rainfall · Correlation · Semi-arid region

Introduction

The quality of water is an essential factor for controlling water management studies. Generally, anthropogenic and geogenic activities are responsible for groundwater

contamination. Industrial, agricultural and domestic wastes, rainfall pattern and infiltration rate are also responsible for the deterioration of groundwater quality. Once a groundwater system is contaminated, it continues for many years because of the very slow movement of water in them. It may become challenging to monitor their quality by removing the pollutants from the contaminated aquifer (Devi et al. 2009). The degrading groundwater quality has become a severe universal issue for sustainable development (Adimalla and Jianhua 2019; Li et al. 2019), and therefore, it is very important to understand the hydrogeochemical characteristics of groundwater for sustainable resource development and governance (Huzefa et al. 2020). Subsurface water is mostly limited due to the scanty precipitation, which leads to high evaporation and runoff, especially in arid and semi-arid

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regions (Kadam et al. 2020; Camacho Suarez et al. 2015). Almost one-tenth of worldwide diseases occur due to polluted water and poor sanitation (Fewtrell et al. 2007) and there are nearly 2.5 billion of the population without access to clean water (WHO 2011).

The quality of groundwater is controlled by geology, recharged water, water–soil interaction, recharge and discharge conditions of the area, soil–gas interaction and reactions occurring in the aquifer (Biswal and Kalita 2009; Selvakumar et al. 2014). It also plays a significant role in agricultural production and human health condition (Mohammed-Aslam et al. 2016). Polluted drinking water naturally affects the soil–crop–water system. If the deterioration of water quality is not checked at the right time, it will not be suitable for many purposes (Mohammed-Aslam et al. 2016). Geochemical studies generally deal with chemical parameters and its portability for drinking, irrigation and industrial purpose. Sodium absorption ratio (SAR), high salinity and percentage sodium (%Na) play a significant role in the ranking of quality of groundwater for irrigational purposes. Evaluation of hydrochemical quality of groundwater reveals the interaction groundwater with the surrounding rocks and minerals (Gibbs 1970). The demand of freshwater resources has been increased in the Aland region mainly due to the population growth and severe agricultural activities. Moreover, the industrial establishments are attracted in this region, due to special schemes in Hyderabad–Karnataka region, wherein this area is located. Therefore, it has become essential to manage the groundwater deployment in the area. The goals of this study are to evaluate the hydrochemical behaviour and

represent the appropriate picture of present water quality in the study region through SSP, SAR, RSC, KR, PI, MH and %Na values with irrigational and domestic suitability of water quality using US salinity diagram, Wilcox diagram, Gibb's plot and Chadha's plot.

Study area

Amarja Reservoir Catchment comes under Aland Taluk of Northern Karnataka region. The region is well known for water scarcity. It covers an area of 544.76 sq. km and surrounded between latitude $17^{\circ}50'9''\text{N}$ to $17^{\circ}72'20''\text{N}$ and longitude $76^{\circ}45'8''\text{E}$ to $76^{\circ}55'20''\text{E}$ (Fig. 1). The study area comes under semi-arid provinces consisting mainly of basalt with intertrappean beds at some places (Rizvi and Mohammed-Aslam 2018, 2019). The region also contains deep black soils that have been derived from Deccan traps (Rizvi and Mohammed-Aslam 2018, 2019). The summer season is from February and June. The south-west monsoon is from June to September. The month of December comes under the coldest month, having a temperature variation 29.5°C to and 10°C (CGWB 2012). In the peak of summer, the temperature was found raised to 45°C . The relative humidity is about 26% in the summer season and increases by up to 62% in the winter period (CGWB 2012). The area receives an average annual rainfall of about 777 mm, while the minimum yearly rainfall is 342 mm and the maximum yearly rainfall is 1270 mm (CGWB 2012).

Fig. 1 Sampling location map of the study area

Data collection and methodology

A total number of 32 samples were collected from the bore wells and open wells in the study area (Fig. 1). Sampling has been done in both pre-monsoon (April 2016) and post-monsoon (November 2016) seasons. Drinking water samples were collected with high precautions, ensuring that there is no contamination takes place during the time of sampling. Intensive care has been taken during the collection of the water sample from freshwater resources in one-litre bottles. Geographical coordinates and elevation at each location were recorded by using GPS (global positioning system). *ArcGIS* 10.3 software has been used in the study for preparing the geospatial maps. The geospatial maps of physico-chemical parameters were prepared to analyse the distribution pattern within Amarja reservoir catchment by using this software. TDS, pH and EC test were done at the field itself by using TDS, pH and electrical conductivity meters. The analyses of the rest of the parameters were performed in the laboratory within 24 h after the collection of the samples. Magnesium, calcium, sodium, potassium, chloride, fluoride, alkalinity, nitrate, sulphate and total hardness have been analysed for the water samples. The analysis was done based on BIS standards (2012).

Result and discussion

Geochemical characterisation has been evaluated based on sodium soluble percentage, sodium absorption ratio, residual sodium carbonate, percentage sodium, permeability index, Kelly's ratio and magnesium hazards. US salinity diagram was used to categorised salinity hazard zone, whereas water–rock interaction was done based on Gibb's diagram. Chadha's plot was used to understand the hydro-chemical facies of groundwater within the study region. The details of the analysed results are shown in Tables 1 and 2, respectively.

Groundwater suitability for drinking purposes

pH

The pH of analysed samples varies from 7.16 to 8.88 in the pre-monsoon season, whereas it ranged from 7.30 to 8.75 during the post-monsoon season. The spatial distribution map of pH of both seasons is shown in Figs. 2 and 3. According to the BIS guideline (2012), the permissible limit of pH is in the range from 6.5 to 8.5 and 9.38% of the

samples during pre-monsoon, whereas 3.12% during the post-monsoon season were exceeded the maximum permissible limit. Though pH has no direct effect on human health, all biogeochemical reactions are sensitive to the variation of pH (Subba Rao and Krishna Rao 1991).

Electrical conductivity

Electrical conductivity values in the study area range from 168 to 1479 $\mu\text{S}/\text{cm}$ in the pre-monsoon season and it varies from 181 to 1100 $\mu\text{S}/\text{cm}$ during post-monsoon. 40.63% of the samples have shown conductivity values less than 500 $\mu\text{S}/\text{cm}$, 50% were in between 500 and 1000 $\mu\text{S}/\text{cm}$, whereas 9.37% of the groundwater samples have conductivity value more than 1000 $\mu\text{S}/\text{cm}$. Higher amounts of electrical conductivity depend upon temperature, concentration and type of ions present in groundwater (Adimalla and Venkatayogi 2018). Geospatial mapping of the conductivity of both monsoon seasons is shown in Figs. 4 and 5.

Total dissolved solids (TDS)

Higher concentrations of dissolved solids increase the density of water and influence the osmoregulation of freshwater organism (Sharath et al. 2018). The lower concentration of TDS in groundwater is due to the repeated dilution through rainfall and influent nature of surface water bodies (Mohammad Muqtada et al. 2018). TDS values of pre-monsoon season were found in the range from 108 to 947 mg/L and showed the variation from 116 to 704 mg/L during post-monsoon. The acceptable limit of TDS in groundwater is 500 mg/L as per BIS 2012. Only 21.88% of the groundwater samples were exceeded the permissible limit during pre-monsoon season, whereas 34.38% of the samples were above the limit during post-monsoon season. The spatial distribution map of TDS of both the seasons is shown in Figs. 6 and 7. The variation in TDS values may also occur due to Geogenic activities in the region.

Calcium and magnesium

Calcium in the groundwater of the study area varies from 16 to 368.16 mg/L in the pre-monsoon season, whereas 22.4–201.6 mg/L was recorded during post-monsoon season. Only 9.37% of samples were exceeded the permissible limit in the pre-monsoon season, whereas 3.12% were above during post-monsoon season. Spatial distribution map of calcium of both seasons is shown in Figs. 8 and 9. The presence of a large amount of carbon dioxide may increase the solubility of calcium up to 200–300 mg/L with an availability of the bicarbonate (Hem 1985). Magnesium in the groundwater of the study area is varying from 0 to 92.15 mg/L during pre-monsoon season, whereas, during

Table 1 Physicochemical parameters of groundwater samples (pre-monsoon)

S. no.	Location	Latitude (N)	Longitude (E)	Altitude (m)	pH	TDS (mg/L)	EC(μ S/cm)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	Fe ²⁺ (mg/L)	CO ₃ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	F ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	TH (total hardness)
1	Telikuni	17° 37' 15"	76° 33' 48"	2014.2	7.82	298	465	115.2	17.5	12	17.85	0.0152	4.8	190.32	40.02	1.485	22	26.41	220
2	Kinnisultan	17° 36' 51"	76° 36' 39"	2010.6	8.03	309	485	64	32.05	13.76	18.2	0.02	9.6	192.76	38.64	1.494	28	23.01	218
3	Jamga R	17° 38' 31"	76° 36' 32"	2035.8	7.42	451	704	40	60	11.2	19.5	0.025	0	195	45.54	1.366	56	25.56	290
4	Aland	17° 34' 52"	76° 34' 40"	1753.2	7.34	423	660	166.4	28.04	8.94	17.95	0.0152	0	195.2	81.42	1.502	25	31.95	320
5	Gulahalli	17° 31' 44"	76° 31' 10"	1742.4	7.84	448	700	107.2	23.53	12.45	14.84	0.08	4.8	187.88	103.5	1.17	20	33.29	228
6	Jidga	17° 31' 41"	76° 29' 13"	1728	7.2	824	1287	67.2	72.11	11.24	15.64	0.015	0	305	140.76	1.516	64	49.42	372
7	Jamga Khandala	17° 31' 59"	76° 29' 10"	1760.4	8.88	354	553	16	5.51	13.25	16.66	0.07	14.4	56.12	157.32	0.862	12	29.82	42
8	Shakhapur	17° 32' 57"	76° 31' 19"	1684.8	7.76	382	596	105.6	14.52	12.25	19.24	0.022	2.4	156.16	139.38	1.332	17	47.71	190
9	Jheerahalli	17° 34' 1"	76° 31' 8"	1670.4	7.71	947	1479	222.4	5.508	11.14	14.65	0.03	2.4	122	373.98	1.293	17.2	67.73	300
10	Khanapur	17° 33' 57"	76° 28' 47"	1825.2	7.89	607	948	137.6	20.03	12.84	20.02	0.02	4.8	195.2	188.6	1.14	22.5	128.65	252
11	Swaleshwar	17° 33' 25"	76° 26' 33"	1782	7.23	145	226	368.16	61.05	13.7	18.34	0.032	2.4	622.2	330.39	1.237	95	123.96	704
12	Sarasamba	17° 34' 40"	76° 24' 35"	1924.2	7.98	356	556	64	15.03	11	14.5	0.03	7.2	183	65.23	1.285	17	7.2	140
13	Nagelagaon	17° 33' 25"	76° 25' 5"	1879.2	8.52	266	415	24	7.51	12.1	17.25	0.0252	21.6	168.74	168.74	1.97	21.9	33.29	60
14	Sakkarga	17° 32' 42"	76° 24' 33"	1810.8	8.27	270	421	24	5.18	12.62	19.85	0.03	7.2	134.2	83.66	1.64	12	31.95	50
15	Kamanalli	17° 32' 20"	76° 23' 42"	1832.4	7.5	759	1185	105.6	74.61	11.45	18.5	0.0252	2.4	475.8	114.85	1.58	96	53.25	430
16	Kinnihabas	17° 32' 12"	76° 25' 22"	1814.4	8.42	269	420	20.8	1.01	10.5	15.2	0.08	21.6	122	85.08	1.01	20.2	32.38	30
17	Mogha B	17° 31' 18"	76° 27' 1"	1890	7.81	385	601	33.6	2.01	11.84	19.2	0.02	122.4	7.32	59.56	1.123	14	28.54	50
18	Hebli	17° 35' 14"	76° 31' 10"	1722.6	7.16	304	475	38.4	52.08	11	16.68	0.011	12	185.44	35.45	1.498	18	20.87	256
19	Padawali	17° 36' 2"	76° 27' 58"	1798.2	7.34	250	390	28.8	43.56	8.89	18.26	0.005	14.4	122	134.71	1.275	14.12	40.47	210
20	Chincholi K	17° 37' 3"	76° 25' 58"	1848.6	7.71	342	534	24	12.52	11.64	15.88	0.006	12	112.24	70.9	1.226	25.1	11.56	80

Table 1 (continued)

S. no.	Location	Latitude (N)	Longitude (E)	Altitude (m)	pH	TDS (mg/L)	EC(μ S/cm)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	Fe ²⁺ (mg/L)	CO ₃ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	F ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	TH (total hardness)
21	Chincholi B	17° 37' 35"	76° 26' 8"	1949.4	7.7	510	796	56	51.58	12.86	17.2	0.006	7.2	165.92	131.87	1.406	35	27.69	336.72
22	Nirgudi	17° 38' 33"	76° 28' 22"	1870.2	7.24	403	629	57.6	29.54	11.89	18.5	0.0104	12	248.88	60.97	1.432	13.9	21.72	190
23	Khairat	17° 37' 49"	76° 24' 52"	1870.2	7.31	330	515	83.27	24.53	9.84	16.66	0.0105	4.82	195.67	46.79	1.495	19.9	19.73	20.2
24	Varnalwadi	17° 39' 15"	76° 25' 24"	1967.4	7.42	258	403	48	7.51	7.89	15.2	0.0065	7.2	34.16	62.39	1.135	20.2	23.43	90
25	Aloor	17° 41' 29"	76° 25' 47"	2071.8	7.61	271	423	51.2	23.04	9.5	16.25	0.0106	12	158.6	56.72	1.455	25	20.87	156
26	Bolegaon	17° 40' 32"	76° 24' 53"	1981.8	7.34	377	589	46.4	22.03	13.45	19.2	0.002	0	125.2	57.17	1.455	42	25.14	146
27	Chitali	17° 38' 17"	76° 34' 55"	2075.4	7.45	532	831	174.4	26.54	11.88	17.5	0.006	2.4	146.4	144.64	1.318	20	54.1	324
28	Bangerga	17° 39' 26"	76° 35' 29"	1953	7.75	383	598	97.6	26.54	10.5	18.4	0.004	4.8	219.6	32.62	1.401	20.2	43.87	228
29	Bables-war	17° 40' 56"	76° 34' 42"	2079	7.82	312	487	86.4	29.55	13	18.88	0.0065	7.2	161.04	41.12	1.443	79	46.08	226
30	Khajuri	17° 41' 20"	76° 33' 38"	2154.6	7.29	108	168	219.2	92.15	13.2	18.45	0.0065	0	275.72	201.35	1.44	89.9	82.21	642
31	Tadola	17° 31' 13"	76° 31' 55"	2068.2	8.72	625	976	48	0	11.6	17.46	0.006	12	39.04	177.25	0.654	14.12	100.53	56.02
32	Korahalli	17° 30' 46"	76° 33' 32"	1666.8	7.49	307	479	124.8	78.62	11.35	16.89	0.0066	0	173.24	231.13	1.138	65.2	51.97	470

Table 2 Physicochemical parameters of groundwater samples (post-monsoon)

S. no.	Location	Latitude (N)	Longitude (E)	Altitude (m)	pH	TDS (mg/L)	EC (µS/cm)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	Fe ²⁺ (mg/L)	CO ₃ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	F ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	TH (total hardness)
1	Telikuni	17° 37' 15"	Longi-tude	2014.2	7.80	288	450	88	26.54	11.2	14.5	0.026	0	163.48	51.05	1.235	22.4	23.01	216
2	Kinnisultan	17° 36' 51"	76° 33' 48"	2010.6	7.75	603	942	132.8	3.05	13.5	17.1	0.025	0	187.88	83.66	1.245	70.24	38.77	166
3	Jamga R	17° 38' 31"	76° 36' 39"	2035.8	7.63	585	914	78.4	57.09	9.5	16.5	0.001	0	326.96	73.74	1.127	62.4	38.77	326
4	Aland	17° 34' 52"	76° 36' 32"	1753.2	7.3	558	871	139.2	51.52	10.2	13.6	0.006	0	219.6	129.04	1.025	62.1	45.16	380
5	Gulahalli	17° 31' 44"	76° 34' 40"	1742.4	7.51	536	837	148.8	24.54	13.2	16.5	0.05	0	222.04	113.44	1.192	16	31.95	284
6	Jidga	17° 31' 41"	76° 31' 10"	1728	7.47	494	771	96	23.03	9.5	16.87	0.02	0	270.84	49.63	1.273	28	18.32	212
7	Jamga Khandala	17° 31' 59"	76° 29' 13"	1760.4	7.86	542	846	49.6	6.52	8.2	17.2	0.018	0	92.72	175.83	1.167	77	47.71	88
8	Shakhapur	17° 32' 57"	76° 29' 10"	1684.8	7.71	576	900	49.6	51.58	12.6	19.84	0.0066	0	146.4	150.31	1.425	50	56.23	268
9	Jheerahalli	17° 34' 1"	76° 31' 19"	1670.4	7.98	450	703	78.4	35.56	10.5	16.45	0.002	0	222.04	72.32	1.462	25	40.04	240
10	Khanapur	17° 33' 57"	76° 31' 8"	1825.2	7.66	704	1100	91.2	99.66	13.2	18.86	0.003	0	204.96	133.29	1.345	68	55.38	398
11	Swaleswar	17° 33' 25"	76° 28' 47"	1782	7.55	413	645	131.2	23.53	11	17.45	0.02	0	200.08	58.13	1.354	57	27.26	258
12	Sarasamba	17° 34' 40"	76° 26' 33"	1924.2	7.56	512	800	41.6	30.05	11.5	16.82	0.015	0	168.36	58.14	1.426	52	25.56	172
13	Nagelagaon	17° 33' 25"	76° 24' 35"	1879.2	7.93	383	598	83.2	14.52	8.2	13.84	0.042	2.4	134.2	112.02	1.053	60.5	35.78	162
14	Sakkarga	17° 32' 42"	76° 25' 5"	1810.8	7.84	331	517	86.4	14.02	7.5	14.88	0.08	7.2	195.2	34.03	1.403	16	14.48	164
15	Kamanalli	17° 32' 12"	76° 23' 42"	1832.4	7.77	389	607	145.6	14.02	7.5	12.86	0.03	0	204.96	43.96	1.473	56	17.89	238
16	Kinnihabas	17° 32' 12"	76° 25' 22"	1814.4	7.88	490	765	145.6	11.02	11.2	15.84	0.025	12	197.64	58.14	1.263	62	33.65	226
17	Mogha B	17° 31' 18"	76° 27' 1"	1890	8.01	350	546	70.4	1.01	10.5	13.24	0.035	7.2	109.8	72.32	1.348	63	39.19	92
18	Hebli	17° 35' 14"	76° 31' 10"	1722.6	7.91	228	356	38.4	33.05	11.5	17.62	0.015	0	124.44	55.3	1.135	17	19.17	180
19	Padsawli	17° 36' 2"	76° 27' 58"	1798.2	7.85	629	982	92.8	51.08	12.1	16.82	0.0035	0	229.36	113.44	1.535	60	49.84	320

Table 2 (continued)

S. no.	Location	Latitude (N)	Longitude (E)	Altitude (m)	pH	TDS (mg/L)	EC (µS/cm)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	Fe ²⁺ (mg/L)	CO ₃ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	F ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	TH (total hardness)
20	Chincholi K	17° 37' 3"	76° 25' 58"	1848.6	8.24	318	496	24	0.51	10.2	15.52	0.02	0	124.44	70.9	1.414	22	38.34	32
21	Chincholi B	17° 37' 35"	76° 26' 8"	1949.4	7.76	684	1068	22.4	85.64	11.2	18.54	0.003	0	268.4	103.52	1.396	56	35.36	370
22	Nirgudi	17° 38' 33"	76° 28' 22"	1870.2	8.75	498	778	36.8	3.51	10.4	16.5	0.029	0	43.92	187.18	1.121	58	58.79	60
23	Khairat	17° 37' 49"	76° 24' 52"	1870.2	7.97	331	517	121.3	23.07	9.7	14.37	0.016	0	157.1	73.28	1.383	63	39.76	137
24	Varnalwadi	17° 39' 15"	76° 25' 24"	1967.4	7.88	453	707	56	37.06	8.5	17.2	0.0065	0	265.96	39.71	0.928	62	21.73	218
25	Aloor	17° 41' 29"	76° 25' 47"	2071.8	7.37	125	195	116.7	103.8	9.3	12.8	0.01	0	217.8	293.72	1.289	56	79.8	73
26	Bolegaon	17° 40' 32"	76° 24' 53"	1981.8	7.54	612	956	144	53.08	10.5	18.2	0.0012	0	214.72	76.57	1.385	65	63.05	392
27	Chitali	17° 38' 17"	76° 34' 55"	2075.4	7.77	372	581	57.6	53.08	13.2	12.8	0.01	0	163.48	72.32	1.124	23	37.06	284
28	Bangarga	17° 39' 26"	76° 35' 29"	1953	7.6	116	181	201.6	21.03	12.3	10.5	0.006	0	192.76	300.62	1.023	75	87.33	336
29	Bables-war	17° 40' 56"	76° 34' 42"	2079	7.84	325	507	73.6	201.6	11.2	14	0.002	0	207.48	34.03	1.268	30.2	18.74	188
30	Khajuri	17° 41' 20"	76° 33' 38"	2154.6	8.05	341	532	48	49.58	9.8	13.5	0.03	0	204.96	55.3	1.355	22.4	24.28	258
31	Tadola	17° 31' 13"	76° 31' 55"	2068.2	7.81	498	778	158.4	23.04	12.2	17.5	0.006	0	219.6	89.33	1.265	16	30.67	290
32	Korahalli	17° 30' 46"	76° 33' 32"	1666.8	7.98	337	526	113	43.77	11.2	12.76	0.021	0	197.1	53.2	0.761	57	23.31	239

Fig. 2 Geospatial distribution of pH (pre-monsoon)

Fig. 3 Geospatial distribution of pH (post-monsoon)

the post-monsoon season, magnesium values showed variation from 1.01 to 201.6 mg/L. Spatial distribution map of both monsoon seasons is depicted in Figs. 10 and 11. During pre-monsoon season, 31.25% of groundwater sample of the study area has magnesium concentration above the permissible limit, whereas 50% of the samples were exceeded during post-monsoon season.

Sodium and potassium

The concentration of sodium of pre-monsoon seasons was found in the range from 7.89 to 13.76 mg/L, whereas it was in a range from 7.50 to 13.50 mg/L during post-monsoon season. According to the BIS (2012) guidelines, the maximum permissible limit is 200 mg/L, and all the samples were in the allowable limit during both monsoon seasons.

Fig. 4 Geospatial distribution of EC (pre-monsoon) **Fig. 5** Geospatial distribution of EC (post-monsoon)

Geospatial map of both monsoon seasons is shown in Figs. 12 and 13. A higher concentration of sodium in groundwater makes it unsuitable for domestic use and causes severe health problems such as hypertension and kidney disorders in the human body (Adimalla and Venkatayogi 2017). Potassium concentration in groundwater ranges from 14.5 to 20.02 mg/L during pre-monsoon season, whereas it varies from 10.5 to 19.84 mg/L during post-monsoon season. All the groundwater samples were

in the permissible limit. Geospatial distribution map for both the seasons is depicted in Figs. 14 and 15.

Iron

The water with no iron concentration is not considered as healthy because iron always plays a significant role in the nutrition of our body (Sharath et al. 2018). Iron value of pre-monsoon season was found in the range from 0.002

Fig. 6 Geospatial distribution of TDS (pre-monsoon)

Fig. 7 Geospatial distribution of TDS (post-monsoon)

to 0.08 mg/L, whereas the values were found varying from 0.001 to 0.08 mg/L during post-monsoon season. The acceptable permissible limit is 0.3 mg/L as per BIS standard (2012). None of the samples was exceeded to the allowable limit in both monsoon periods. The occurrence of iron strongly depends on the oxidation intensity of medium where it occurs (Hem 1985). Spatial distribution map of iron of both the seasons is shown in Figs. 16 and 17 for better understanding.

Alkalinity (carbonate and bicarbonate)

Carbonate in the groundwater of the study area varies from 0 to 122.4 mg/L during pre-monsoon, whereas it varies from 0 to 12 mg/L during post-monsoon season. The geospatial distribution map of both the seasons is shown in Figs. 18 and 19. Bicarbonate varies from 7.32 to 622.2 mg/L, in the pre-monsoon, whereas it varies from

Fig. 8 Geospatial distribution of calcium (pre-monsoon) **Fig. 9** Geospatial distribution of calcium (post-monsoon)

43.92 to 326.96 mg/L during post-monsoon. Spatial distribution map of bicarbonate concentrations in groundwater is shown in Figs. 20 and 21. All the carbonate value was in the permissible range, but 18.75% of groundwater sample of bicarbonate has higher concentration during pre-monsoon season, whereas 50% were above the allowable limit during post-monsoon season. Geogenic activity may be responsible for the higher concentrations of bicarbonate within the region.

Chloride and fluoride

The chloride values of pre-monsoon season were found in the range from 32.62 to 373.98 mg/L. The permissible limit of chloride in potable water is 250 mg/L (BIS 2012) and only 6.25% of groundwater samples were exceeded the allowable limit during pre-monsoon season. In the post-monsoon season, it varies from 34.03 to 300.62 mg/L and 6.25% of the samples were above the concentration. Leaching of upper soil layers and dry climate may be responsible

Fig. 10 Geospatial distribution of magnesium (pre-monsoon)

Fig. 11 Geospatial distribution of magnesium (post-monsoon)

for the higher concentrations of chloride (Bhardwaj and Singh 2011). Geospatial mapping of chloride of both seasons is shown in Figs. 22 and 23.

The fluoride concentration in groundwater shows a range of 0.65 to 1.97 mg/L. The highest value of fluoride was recorded in Nagelagaon (1.97 mg/L), whereas the lowest value was noted in Tadola village. In the pre-monsoon season, 78.13% of the groundwater samples of the region were above the desirable limit (1.00 mg/L), whereas 15.62% of the groundwater has more than 1.5 mg/L of

fluoride which is the maximum permissible limit for drinking purposes as per BIS standard (2012). During post-monsoon season, the fluoride values varied from 0.76 to 1.54 mg/L. The highest value of fluoride was recorded in Padsawli (1.54 mg/L), whereas the lowest value was in Korahalli village. Spatial distribution pattern of fluoride of both the seasons is depicted in Figs. 24 and 25. 90.63% of the groundwater samples of the study area showed a higher concentration of fluoride above the desirable limit (1.00 mg/L). In contrast, only 3.12% of the groundwater

Fig. 12 Geospatial distribution of sodium (pre-monsoon)

Fig. 13 Geospatial distribution of sodium (post-monsoon)

was above the maximum permissible (1.5 mg/L) limit of fluoride for drinking purposes. The sources of fluoride in the groundwater of the study region is mainly coming from the geological occurrence. The deep circulation of fluoride-rich groundwater between the lateralised basalts could be responsible for the event of fluoride in both the shallow and deeper aquifers (Raymond and Uday 2011). Excess fluoride concentration in groundwater can cause dental and skeletal fluorosis.

Nitrate and sulphate

Nitrate varies from 12 to 96 mg/L in pre-monsoon, whereas it ranged from 16 to 77 mg/L during post-monsoon. It has been noticed that 21.87% of the groundwater sample contains excess nitrate during pre-monsoon season, whereas 65.62% of the samples were above the permissible limit (> 45 mg/L) in the study area, which is not suitable for drinking purpose. Geospatial distribution map has been prepared

Fig. 14 Geospatial distribution of potassium (pre-monsoon)

Fig. 15 Geospatial distribution of potassium (post-monsoon)

for both the monsoon periods for the better understanding of excess nitrate within the region, and it is depicted in Figs. 26 and 27. A higher concentration of nitrate generally occur due to the inappropriate well structure, excessive use of chemical fertiliser or improper disposal of human, and animal waste and the higher concentration of nitrate in groundwater can lead to cancer (Dissanayake et al. 1987).

Sulphide is derived from the reduction of sulphate compounds, dissolved under low-oxygen condition when

anaerobic bacteria are present (Lehr et al. 1980). The sulphate values of pre-monsoon seasons were found in the range from 7.2 to 128.65 mg/L, whereas, during the post-monsoon season, it varies from 14.48 to 87.33 mg/L. According to the BIS standard (2012), the permissible limit of sulphate in potable water is 200 mg/L, and all the samples of the study area were in permissible limit during both the monsoon seasons. Spatial distribution map of sulphate of both seasons is shown in Figs. 28 and 29.

Fig. 16 Geospatial distribution of iron (pre-monsoon) **Fig. 17** Geospatial distribution of iron (post-monsoon)

Total hardness

The hardness of water can be caused by the presence of multivalent metallic cations (Hem 1985). The hardness of water has a significant effect on pH and always substantial in the stability control of pH. The hardness values of pre-monsoon season were found in the range from 20 to 704 mg/L and 32 to 398 mg/L during post-monsoon season. Geospatial distribution of hardness of both seasons is shown in Figs. 30 and 31. Nearly 56.25% of the

groundwater samples were exceeded the permissible limit (BIS 2012) during pre-monsoon season, whereas 62.5% of the samples were found to be above the allowable limit (> 200 mg/L) during post-monsoon season. The higher concentrations of the hardness may occur due to the weathering of calcium bearing minerals or disproportionate use of lime to the soil in agricultural regions.

Table 3 illustrates the percentage-wise drinking water suitability of study area.

Fig. 18 Geospatial distribution of carbonate (pre-monsoon)

Fig. 19 Geospatial distribution of carbonate (post-monsoon)

Hydrochemical facies for groundwater (Chadha's diagram)

Hydrochemical facies of a particular region are always associated with the geology of that region, and the distribution of the facies is influenced by hydrogeological controls (Nagaraju et al. 2016). Hydrochemical facies can be well classified based on Chadha's diagram (Chadha 1999). Chadha's diagram explains the differences in milliequivalent percentage between alkaline earth's

(calcium + magnesium) and alkali metals (sodium + potassium) expressed as percentage reacting value is plotted on the X-axis. The difference in milliequivalent percentage between weak acidic anions (carbonate + bicarbonate) and strong acidic anions (chloride + sulphate) is plotted on the Y-axis. The square or rectangular field depicts the overall character of the water (Nagaraju et al. 2016). The result of the chemical analyses data of all the samples was plotted on Chadha's diagram. The Chadha's plot of pre-monsoon season depicts that 56.25% of the groundwater samples

Fig. 20 Geospatial distribution of bicarbonate (pre-monsoon)

Fig. 21 Geospatial distribution of bicarbonate (post-monsoon)

fall under the subfield of $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$ water type with permanent hardness. The remaining 43.75% of samples fall under the subfield of $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--HCO}_3^-$ water type with temporary hardness (Fig. 32). In the post-monsoon season, the plot depicts that 50% samples fall under the field of $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--HCO}_3^-$ water type with temporary hardness, whereas the remaining 50% samples belong to the subfield of $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$ water type with permanent hardness (Fig. 33).

Gibbs's plot

Gibb's plot is used to characterise the quality of water to precipitation, evaporation/crystallisation and rock–water interaction. In 1970, Gibb's has established a relation water chemistry and aquifers lithology. In Gibb's plot, TDS on y-axis, $\text{Na}^+\text{+K}^+\text{+Na}^+\text{+K}^+\text{+Ca}^{2+}$ on x-axis for cations and $\text{Cl}^-/\text{Cl}^-+\text{HCO}_3^-$ on x-axis for anion are plotted, respectively. It is useful to differentiate the interaction

Fig. 22 Geospatial distribution of chloride (pre-monsoon)

Fig. 23 Geospatial distribution of chloride (post-monsoon)

of groundwater through precipitation or rock evaporation. Gibb's has recognised three kinds of fields which are known as precipitation, evaporation/crystallisation and rock–water interaction. Weathering dominated water would be having higher Ca^{2+} and HCO_3^- concentration, whereas evaporation/crystallisation-controlled water would be having a higher concentration of Na^+ and Cl^- on Gibb's plot. Equations (1) and (2) describe Gibb's ratio for cation and anion, respectively.

$$\text{(For Cation) Gibb's Ratio} = \frac{\text{Na} + \text{K}}{\text{Na} + \text{K} + \text{Ca}} \quad (1)$$

$$\text{(For Anion) Gibb's Ratio} = \frac{\text{Cl}}{\text{Cl} + \text{HCO}_3} \quad (2)$$

where Na, K, Ca, Cl and HCO_3 are expressed in meq/l.

Gibb's plot of both the seasons of different cations and anions is shown in Figs. 34 and 35, respectively. Rock

Fig. 24 Geospatial distribution of fluoride (pre-monsoon)

Fig. 25 Geospatial distribution of fluoride (post-monsoon)

dominance controls are seen for groundwater for both seasons.

Irrigational suitability of groundwater

The irrigational suitability of groundwater can be evaluated through the indices for salinity, chlorinity and sodicity. SAR, RSC, %Na, Kelly's ratio, magnesium hazards, permeability index are the most critical indices in the estimating of groundwater for irrigational suitability. The higher

concentration of sodium always affects the suitability for irrigation on the soil in respect of exchangeable calcium and magnesium ions. It can be evaluated by sodium soluble percentage (SSP), sodium absorption ratio (SAR), residual sodium carbonate (RSC) and %Na indices.

Soluble sodium percentage (SSP)

Sodium in water replaces calcium in the soil through the base exchange process, which is responsible for decreasing

Fig. 26 Geospatial distribution of nitrate (pre-monsoon)

Fig. 27 Geospatial distribution of nitrate (post-monsoon)

the soil permeability (Carroll 1962). Soluble sodium percentage (SSP) values less than or equal to 50 are considered as good quality for irrigation purpose. SSP values greater than 50 are unacceptable for irrigation as the permeability is very low in this case (Table 4). 100% of the samples were in the good quality class of SSP values in both the seasons. SSP can be evaluated by using Eq. (3).

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

where Na, Ca, Mg and Na are expressed in meq/l.

Fig. 28 Geospatial distribution of sulphate (pre-monsoon)

Fig. 29 Geospatial distribution of sulphate (post-monsoon)

Sodium absorption ratio (SAR)

SAR values less than 10 would be suitable for irrigation, whereas greater than 10 would be not comfortable for irrigational purposes (Richards 1954). 100% of groundwater samples of both seasons fall under the excellent class of SAR values (Table 4). SAR can be evaluated by using Eq. (4).

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \quad (4)$$

where Na, Ca and Mg are expressed in meq/l.

Fig. 30 Geospatial distribution of hardness (pre-monsoon)

Fig. 31 Geospatial distribution of hardness (post-monsoon)

Residual sodium carbonate (RSC)

A higher concentration of carbonate causes calcium and magnesium to precipitate as bicarbonate in water (Ravikumar et al. 2011). The hazardous effect of carbonate and bicarbonate in water for agricultural purposes can be determined by residual sodium carbonate (RSC) analysis (Eaton 1950). According to RSC values (Table 4), 90.62% of

groundwater samples belong to the safe category, whereas 9.38% of samples fall under marginal zone during the pre-monsoon season. In the post-monsoon season, 100% of the samples were categorised as a safe class of RSC values. A negative value of RSC indicates the higher concentrations of Ca and Mg in groundwater (Adimalla 2019). RSC can be evaluated (Eaton 1950) by using Eq. (5).

Table 3 Suitability of drinking water in the study area as per BIS-2012 (IS-10500)

S. no.	Parameters	Range	Pre-monsoon		BIS Standard (IS-10500) (Acceptable Limit) Max	Post-monsoon	
			No. of samples	(%)		No. of samples	(%)
1	pH	6.5–8.5	29	90.62	6.5–8.5	31	96.87
		> 8.5	3	9.38		1	3.13
		< 6.5	–	–		–	–
2	EC (µS/cm)	< 500	13	40.62	–	5	15.62
		500–1000	16	50		25	78.13
		> 1000	3	9.38		2	6.25
3	Total dissolved solid (mg/L)	< 500	25	78.12	500	21	65.62
		> 500	7	21.88		11	34.38
4	Calcium (mg/L)	< 75	18	56.25	75	12	37.5
		75–200	11	34.38		19	59.37
		> 200	3	9.37		1	3.13
5	Magnesium (mg/L)	< 30	22	68.75	30	16	50
		30–100	10	31.25		14	43.75
		> 100	–	–		2	6.25
6	Sodium (mg/L)	< 200	32	100	–	32	100
		> 200	–	–		–	–
7	Potassium (mg/L)	< 40	32	100	–	32	100
		> 40	–	–		–	–
8	Iron (mg/L)	< 0.1	32	100	0.3	32	100
		> 0.1	–	–		–	–
9	Alkalinity (mg/L)	Carbonate	< 200	32	200	32	100
			> 200	–		–	–
		Bicarbonate	< 200	26		16	50
			> 200	6		16	50
10	Chloride (mg/L)	< 250	30	93.75	250	30	93.75
		> 250	2	6.25		2	6.25
11	Fluoride (mg/L)	< 1	2	6.25	1.0	2	6.25
		1–1.5	25	78.13		29	90.62
		> 1.5	5	15.62		1	3.13
12	Nitrate (mg/L)	< 45	25	78.13	45	11	34.38
		> 45	7	21.87		21	65.62
13	Sulphate (mg/L)	< 200	32	100	200	32	100
		> 200	–	–		–	–
14	Hardness (mg/L)	< 200	14	43.75	200	12	37.5
		200–500	16	50		20	62.5
		> 500	2	6.25		–	–

$$\text{RSC} = (\text{HCO}_3 + \text{CO}_3) - (\text{Ca} + \text{Mg}) \quad (5)$$

where HCO_3 , CO_3 , Ca and Mg are expressed in meq/l.

Percent sodium (%Na)

Percent sodium (%Na) is also an important parameter to study sodium hazards. Soil permeability is reduced due to

sodium (Joshi et al. 2009). According to the %Na values (Table 4), 75% of samples were grouped into excellent class, 18.75% were in good, and 6.25% were in permissible classes of percentage sodium during pre-monsoon season. In the post-monsoon season, 90.62% of the samples were fallen into excellent, 6.25% samples in the good class, whereas 3.13% of the sample falls under permissible classes of %Na values. %Na can be evaluated (Wilcox 1955) by using Eq. (6).

Fig. 32 Chadha's diagram (pre-monsoon)

Hydrochemical Facies for Groundwater			
1. Alkaline earths exceed alkali metals (Ca+Mg > Na+K)	2. Alkali metals exceeds alkaline earths (Na+K > Ca+Mg)	3. Weak acidic anions exceed strong acidic anions (CO ₃ ²⁻ + HCO ₃ ⁻ > Cl ⁻ + SO ₄ ²⁻)	4. Strong acidic anions exceed weak acidic anions (Cl ⁻ + SO ₄ ²⁻ > CO ₃ ²⁻ + HCO ₃ ⁻)
5. Ca ²⁺ - Mg ²⁺ - HCO ₃ ⁻ Water type (Temporary hardness)	6. Ca ²⁺ + Mg ²⁺ - Cl ⁻ Water type (Permanent hardness)	7. Na ⁺ - Cl ⁻ / SO ₄ ²⁻ Water type (Salinity problem)	8. Na ⁺ - HCO ₃ ⁻ Water Type (Deposit residual sodium carbonate in irrigation use)

$$\%Na = \frac{Na + K}{Ca + Mg + Na + K} * 100$$

$$(6) \quad \text{Kelly's Ratio} = \frac{Na}{Ca + Mg} \quad (7)$$

where Na, K, Ca and Mg are expressed in meq/l.

Wilcox diagram for both seasons is shown in Figs. 36 and 37, respectively.

Kelly's ratio (KR)

Kelly's ratio (KR) is used for determining the sodium hazards on water quality for irrigational purpose (Kelly 1940). Table 4 represents the suitability classification of water for different seasons in the study area based on Kelly's ratio. 100% of the groundwater samples of both the seasons fell into the suitable class of Kelly's ratio values. Kelly's ratio can be evaluated by using Eq. (7).

where Na, Ca and Mg are expressed in meq/l.

Permeability index (PI)

Soil permeability is affected due to through continuous use of water for irrigation as precipitation of certain elements in soil reduces the void space depending upon the quality, thereby hampering the water dynamics (Doneen 1964). Doneen proposed permeability index (PI) for characterising the suitability of irrigational water. It has been categorised into three classes. Class I (> 75%) and Class II (25–75%) represents the waters suitable for irrigation with 75% or more of maximum permeability. In contrast,

Fig. 33 Chadha's diagram (post-monsoon)

Hydrochemical Facies for Groundwater			
1. Alkaline earths exceed alkali metals (Ca+Mg > Na+K)	2. Alkali metals exceeds alkaline earths (Na+K > Ca+Mg)	3. Weak acidic anions exceed strong acidic anions (CO ₃ ²⁻ + HCO ₃ ⁻ > Cl ⁻ + SO ₄ ²⁻)	4. Strong acidic anions exceed weak acidic anions (Cl ⁻ + SO ₄ ²⁻ > CO ₃ ²⁻ + HCO ₃ ⁻)
5. Ca ²⁺ - Mg ²⁺ - HCO ₃ ⁻ Water type (Temporary hardness)	6. Ca ²⁺ + Mg ²⁺ - Cl ⁻ Water type (Permanent hardness)	7. Na ⁺ - Cl ⁻ / SO ₄ ²⁻ Water type (Salinity problem)	8. Na ⁺ - HCO ₃ ⁻ Water Type (Deposit residual sodium carbonate in irrigation use)

Class III (< 25%) characterises the water unsuitable for irrigation with 25% of maximum permeability (Table 4). During pre-monsoon season, 18.75% of the samples enter to the Class III and unfit for irrigation purposes, whereas 68.75% samples belong to Class II and 12.5% fall under the Class I, shows suitability for irrigation purposes with maximum permeability. In the post-monsoon seasons, 34.37% of the samples belong to Class III, whereas 62.5% enter to Class II and 3.13% of the samples enter to the Class I. Permeability index can be evaluated by using Eq. (8).

$$PI = \frac{Na + (\sqrt{HCO_3})}{Ca + Mg + Na} * 100 \quad (8)$$

where Na, HCO₃, Ca and Mg are expressed in meq/l.

Magnesium hazards (MH)

Magnesium and calcium usually maintain a state of equilibrium in groundwater (Adimalla and Venkatayogi 2018). A higher concentration of magnesium in water can affects the soil quality through changing it into alkaline nature. During pre-monsoon season, 78.13% of the samples belong to the suitable class of irrigation according to MH values (Table 4), whereas 21.87% of the samples were categorised as unsuitable. 65.62% of the samples were grouped as a suitable class of irrigation, and 34.38% were belonging to the unsuitable class during post-monsoon seasons. Magnesium hazard ratio can be evaluated (Szabolcs and Darab 1964) by using Eq. (9).

Fig. 34 Gibb's diagram (pre-monsoon), **a** Cations, **b** Anions

$$\text{Magnesium Hazard Ratio} = \frac{\text{Mg}}{\text{Ca} + \text{Mg}} * 100 \quad (9)$$

where Mg and Ca are expressed in meq/l.

Classification of irrigational suitability through US salinity diagram

The electrical conductivity represents salinity hazards, whereas the sodium hazards are described in terms of sodium absorption ratio (SAR) on the USSS chart (USSS 1954). Excess sodium in water produces the undesirable

effects of changing soil properties and reducing soil permeability (Adimalla and Venkatayogi 2018). Decreasing content of ions such as magnesium and calcium are often attributed with an increase in sodium which may result in high SAR values (Mohammad Muqtada et al. 2018). In the pre-monsoon season, 6.25% of groundwater samples fall into C_1-S_1 group of USSS diagram, which represents low-salinity and low-sodium hazard zone, and this water is most suitable for irrigation purposes. 65.63% of samples belong to the category of C_2-S_1 which indicates medium-salinity hazards with low-alkaline water and this can be used for irrigation purposes with little impact of exchangeable sodium

Fig. 35 Gibb's diagram (post-monsoon), **a** Cations **b** Anions

(Adimalla and Venkatayogi 2018). 28.12% samples fall into C_3-S_1 class which stand for high-salinity and low-alkaline water, and this type of water needs extensive treatment before applied to the soil irrigation due to high salinity (Adimalla 2019). During post-monsoon season, 6.25% samples fall into C_1-S_1 class, 40.62% samples belong to C_2-S_1 , and 53.13% samples fall into the category of C_3-S_1 (Figs. 38, 39). High levels of sodium ion in groundwater with relatively low levels of calcium ion are known to affect the sub-surface structure, and degree of water is infiltrating the strata (Sadashivaiah et al. 2008). The summary of groundwater quality for irrigational purposes in both monsoon seasons is given in Tables 5 and 6, respectively.

Domestic suitability using hardness

Domestic suitability of groundwater can be evaluated based on hardness of water (Durfor and Becker 1964). Table 7 represents the domestic suitability classification of water of different seasons based on hardness values in mg/L. In both monsoon seasons, 96.88% of groundwater samples fall into the soft water class, whereas 3.12% samples belong to moderately to hard water zone. Domestic suitability of water using hardness can be calculated (Durfor and Becker 1964) using Eq. (10).

$$\text{Domestic Suitability} = (\text{Ca} + \text{Mg} - \text{HCO}_3) \quad (10)$$

where Ca, Mg and HCO_3 are expressed in mg/L.

Table 4 Classification of groundwater based on irrigational water quality parameters

Parameters	Range	Class	Number of samples			References
			Pre-monsoon	(%)	Post-monsoon (%)	
Electrical conductivity (EC) μS/cm	0–250	Low	2	6.25	2	6.25 Handa (1969)
	251–750	Medium	23	71.88	15	46.87
	750–2250	High	7	21.87	15	46.87
	2251–6000	Very high	0		0	
Total dissolved solids (TDS) mg/L	< 1000	Fresh water	32	100	32	100 Carroll (1962)
	1000–1500	Brackish water	–		–	
Soluble sodium percentage (SSP) (meq/l)	≤ 50	Good quality	32	100	32	100 Carroll (1962)
	> 50	Not suitable	–		–	
Sodium absorption ratio (SAR) (meq/l)	< 10	Excellent	32	100	32	100 Richards (1954)
	10–18	Good	–		–	
	18–26	Permissible	–		–	
	> 26	Doubtful	–		–	
Residual sodium carbonate (RSC) (meq/l)	< 1.25	Safe	29	90.62	32	100 Eaton (1950)
	1.25–2.5	Marginal	3	9.38	–	
	> 2.5	Unsuitable	–		–	
Percentage sodium (%Na)	< 20	Excellent	24	75	29	90.62 Wilcox (1955)
	20–40	Good	6	18.75	2	6.25
	40–60	permissible	2	6.25	1	3.13
	60–80	Doubtful	–		–	
	> 80	Unsuitable	–		–	
Kelly's ratio (KR) (meq/l)	< 1	Suitable	32	100	32	100 Kelly (1940)
	> 1	Unsuitable	–		–	
Permeability index (PI) (meq/l)	Class III (< 25%)	Unsuitable	6	18.75	11	34.37 Doneen (1964)
	Class II (25–75%)	Suitable	22	68.75	20	62.5
	Class I (> 75%)	Suitable	4	12.5	1	3.13
Magnesium hazards (MH)	< 50	Suitable	25	78.13	21	65.62 Szabolcs and Darab (1964)
	> 50	Unsuitable	7	21.87	11	34.38

Industrial suitability

The industrial establishments are attracted in this region, due to special schemes in Hyderabad-Karnataka Region, wherein this area is located. Therefore, industrial Suitability has been done to check whether the samples are fit for the industrial suitability or not. The corrosivity ratio has been used to evaluate industrial usefulness (Table 7). Corrosion represents an electrolytic process through which metal surfaces are corroded (Devi et al. 2009). The result shows that 78.13% of samples were of suitable class (< 1), whereas 21.87% of samples were unsuitable (> 1) during pre-monsoon season. In the post-monsoon season, only 28.12% of groundwater samples fell into a suitable class, whereas 71.88% were into

an unsuitable category. Corrosivity ratio can be evaluated (Badrinath et al. 1984) using Eq. (11).

$$\text{Corrosivity Ratio} = \frac{\frac{\text{Cl}}{35.5} + \frac{\text{SO}_4}{48}}{\frac{\text{CO}_3 + \text{HCO}_3}{50}} \quad (11)$$

where Cl, SO₄, CO₃ and HCO₃ are expressed in mg/L.

Collin's ratio

Collin's ratio (CR) is used to check the suitability of water for drinking purposes. Water is suitable for drinking purposes if CR < 1. Water is considered as contaminated with

Fig. 36 Wilcox diagram (pre-monsoon)

Fig. 37 Wilcox diagram (post-monsoon)

Fig. 38 USSL diagram (pre-monsoon) **Fig. 39** USSL diagram (post-monsoon)

saline water if the values of CR between 1 and 3 and injurious to health if $CR > 6$. 62.5% of samples belong to the suitable class, whereas 37.5% samples were contaminated with saline water in the pre-monsoon season (Table 7). This may result due to the excess fertiliser activity within the region. In the post-monsoon season, 71.88% samples fall into a suitable class, whereas 25% of groundwater samples were contaminated with saline water and 3.12% fall into the healthy risk zone. Collin's ratio (proposed

by Simpson 1946) of water can be calculated by using Eq. (12).

$$\text{Collin's Ratio} = \frac{Cl}{CO_3} + HCO_3 \quad (12)$$

where Cl , CO_3 and HCO_3 are expressed in meq/l.

Domestic and industrial suitability of groundwater of different monsoons is given in Tables 8 and 9, respectively.

Table 5 Pre-monsoon irrigational suitability of groundwater

S. no.	SSP %	SAR	RSC	% Na	Kelly's ratio (KR)	Magnesium hazards (MH)	Permeability index (PI)
1	6.76	0.27	− 3.92	11.96	0.07	20.00	29.63
2	9.30	0.35	− 2.36	15.41	0.10	45.18	36.92
3	6.56	0.26	− 3.74	12.44	0.07	71.17	30.64
4	3.53	0.17	− 7.43	7.39	0.04	21.71	19.77
5	6.90	0.28	− 4.06	11.21	0.07	26.54	29.30
6	4.99	0.23	− 4.29	8.73	0.05	63.85	27.85
7	31.49	0.73	0.15	44.43	0.46	36.17	83.92
8	7.60	0.30	− 3.83	13.66	0.08	18.45	30.43
9	4.02	0.20	− 9.49	6.91	0.04	3.92	15.75
10	6.14	0.27	− 5.17	11.15	0.07	19.33	25.83
11	2.48	0.17	− 13.15	4.35	0.03	21.44	15.77
12	9.73	0.32	− 1.20	16.06	0.11	27.88	44.97
13	22.44	0.55	1.67	34.73	0.29	33.99	93.40
14	25.22	0.61	0.81	39.38	0.34	26.21	93.42
15	4.18	0.21	− 3.54	7.84	0.04	53.76	27.61
16	28.90	0.61	1.60	42.94	0.41	7.40	118.43
17	21.81	0.53	2.35	35.28	0.28	8.96	36.49
18	7.15	0.27	− 2.76	12.73	0.08	69.06	33.24
19	7.14	0.24	− 2.54	14.52	0.08	71.34	33.28
20	18.49	0.48	0.01	29.03	0.23	46.20	68.07
21	7.35	0.30	− 4.08	12.42	0.08	60.25	29.04
22	8.87	0.32	− 0.83	15.71	0.10	45.77	43.53
23	6.47	0.24	− 2.81	12.14	0.07	32.65	33.57
24	10.21	0.28	− 2.22	19.52	0.11	20.48	32.47
25	8.48	0.28	− 1.45	15.68	0.09	42.55	41.60
26	12.39	0.41	− 2.08	20.65	0.14	43.86	42.76
27	4.52	0.22	− 8.42	8.12	0.05	20.03	18.09
28	6.07	0.24	− 3.30	11.60	0.06	30.92	31.30
29	7.72	0.31	− 3.87	13.44	0.08	36.02	29.93
30	3.00	0.19	− 14.02	5.34	0.03	40.89	14.12
31	17.36	0.46	− 1.36	28.38	0.21	0.00	44.91
32	3.74	0.19	− 9.87	6.79	0.04	50.90	16.50

Bold values are representing the 'higher concentration' of the parameters

Rainfall water quality linkage

An attempt has been made to correlate the hydrochemical parameters with the rainfall. In this concern, maximum annual rainfall data in the study area of 2016 were collected from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC) website. The maximum rainfall in Aland was noted in July (108 mm) and September (107 mm), whereas the minimum rain was recorded in January (4.5 mm). Although the region has come under a semi-arid zone, it is also well known for scanty rainfall. Correlation analysis has been done to check the variations of positive and negative ions to the rainfall. Figure 40 depicts the maximum annual

rainfall in the study area. The relationship between rainfall, physical parameters, positive and negative ions of all the location is shown in Figs. 41, 42 and 43, respectively. The result indicates that the rainfall within the study area does not influence water quality. The main reason could be the texture and type of soil presents in the region. The result is further confirmed by the Gibbs's plot of both seasons where it is clearly shown that rock dominance factor is controlling the groundwater chemistry and there is no effect of precipitation. Calcium and magnesium concentrations in groundwater play a significant role in the estimation of groundwater quality, and Mg can give more adverse effects on soils than calcium (Adimalla 2019). Runoff pattern can also influence the water quality.

Table 6 Post-monsoon irrigational suitability of groundwater

S. no.	SSP %	SAR	RSC	% Na	Kelly's ratio (KR)	Magnesium hazards (MH)	Permeability index (PI)
1	6.89	0.27	−3.90	11.53	0.07	33.17	30.04
2	7.85	0.32	−3.81	12.94	0.09	3.64	31.32
3	4.57	0.20	−3.26	8.83	0.05	54.51	30.21
4	3.81	0.19	−7.60	6.60	0.04	37.86	20.10
5	5.72	0.26	−5.82	9.53	0.06	21.35	24.74
6	5.81	0.23	−2.26	11.20	0.06	28.31	35.45
7	10.57	0.29	−1.50	20.89	0.12	17.79	47.12
8	7.53	0.30	−4.32	13.56	0.08	63.12	28.84
9	6.25	0.25	−3.21	11.36	0.07	42.74	32.38
10	4.30	0.23	−9.40	7.64	0.04	64.27	18.05
11	5.33	0.23	−5.22	9.81	0.06	22.79	25.51
12	9.90	0.33	−1.79	16.96	0.11	54.31	42.77
13	6.24	0.22	−3.07	11.71	0.07	22.31	32.21
14	5.62	0.20	−2.03	11.43	0.06	21.08	36.47
15	3.72	0.16	−5.07	7.21	0.04	13.68	24.65
16	5.61	0.24	−4.55	9.83	0.06	11.08	26.37
17	11.25	0.34	−1.56	18.08	0.13	2.31	44.29
18	9.73	0.33	−2.60	17.00	0.11	58.62	37.52
19	5.61	0.25	−5.08	9.76	0.06	47.53	26.31
20	26.31	0.56	0.80	40.36	0.36	3.38	111.05
21	5.63	0.24	−3.77	10.53	0.06	86.29	29.86
22	17.52	0.44	−1.41	29.11	0.21	13.57	50.39
23	5.03	0.21	−5.39	9.02	0.05	23.84	24.17
24	5.94	0.22	−1.49	12.16	0.06	52.13	39.52
25	2.74	0.15	10.81	4.84	0.03	59.41	15.52
26	3.80	0.19	−8.05	7.38	0.04	37.76	19.40
27	7.34	0.30	−4.57	11.06	0.08	60.26	28.27
28	4.33	0.22	−8.65	6.37	0.05	14.65	18.73
29	2.35	0.15	16.87	4.00	0.02	81.84	11.23
30	6.17	0.24	−3.12	10.64	0.07	62.96	32.71
31	5.13	0.24	−6.22	9.06	0.05	19.32	23.47
32	5.00	0.23	−6.02	8.08	0.05	38.93	23.46

Bold values are representing the 'higher concentration' of the parameters

Table 7 Water suitability for different purposes using different parameters

Suitability	Parameters	Range	Class	Number of samples		References
				Pre-monsoon	Post-monsoon	
Domestic suitability	Hardness (mg/L)	< 60	Soft water	31 (96.88%)	31 (96.88%)	Durfor and Becker (1964)
		60–120	Moderately hard water	1 (3.12%)	1 (3.12%)	
		120–180	Hard water	–	–	
		> 180	Very hard water	–	–	
Industrial suitability	Corrosivity ratio (mg/L)	≤ 1	Corrosive	25 (78.13%)	9 (28.12%)	Badrinath et al. (1984)
		> 1	Non-corrosive	7 (21.87%)	23 (71.88%)	
Drinking water suitability	Collin's ratio (meq/l)	≤ 1	Suitable	20 (62.5%)	23 (71.88%)	Simpson (1946)
		1–3	Contaminated with saline water	12 (37.5%)	8 (25%)	
		> 6	Injurious to health	–	1 (3.12%)	

Table 8 Domestic and industrial suitability of groundwater (pre-monsoon season)

Well no.	Location name	Industry suitability using corrosivity ratio	Domestic suitability using hardness	Collin's ratio
1	Telikuni	0.15	− 57.62	0.34
2	Kinnisultan	0.07	− 96.71	0.31
3	Jamga R	0.93	− 95	0.40
4	Aland	1.52	− 0.76	0.72
5	Gulahalli	0.31	− 57.15	0.90
6	Jidga	1.64	− 165.69	0.79
7	Jamga Khandala	0.17	− 34.61	3.17
8	Shakhapur	0.77	− 36.04	1.49
9	Jheerahalli	1.99	105.908	5.07
10	Khanapur	0.69	− 37.57	1.58
11	Swaleswar	1.08	− 192.99	0.91
12	Sarasamba	0.12	− 103.97	0.57
13	Nagelagaon	0.12	− 137.23	1.37
14	Sakkarga	0.19	− 105.02	0.97
15	Kamanalli	0.46	− 295.59	0.41
16	Kinnihabas	0.07	− 100.19	0.88
17	Mogha B	0.01	28.29	0.40
18	Hebli	0.06	− 94.96	0.29
19	Padsawli	0.15	− 49.64	1.53
20	Chincholi K	0.09	− 75.72	0.89
21	Chincholi B	0.27	− 58.34	1.26
22	Nirgudi	0.08	− 161.74	0.38
23	Khairat	0.15	− 87.87	0.39
24	Varnalwadi	0.15	21.35	2.20
25	Aloor	0.08	− 84.36	0.53
26	Bolegaon	1.71	− 56.77	0.79
27	Chitali	0.83	54.54	1.65
28	Bangerga	0.16	− 95.46	0.24
29	Bableshtar	0.13	− 45.09	0.40
30	Khajuri	2.68	35.63	1.26
31	Tadola	0.29	8.96	4.81
32	Korahalli	4.39	30.18	2.30

Bold values are representing the 'higher concentration' of the parameters

Minus sign indicating the soft water using hardness (as CaCO_3)

Conclusion

Drinking water suitability of groundwater around the catchment was not good except at few places. The pH of groundwater was close to the permissible limit in both monsoon seasons with exceeding at some locations. A higher concentration of TDS, Ca, Mg, HCO_3 , Cl, NO_3 and hardness were recorded except in few cases. At most of the locations, fluoride concentrations were close to the permissible limit with

exceeding few places during pre-monsoon and post-monsoon seasons. Fluoride-affected areas in both the monsoon seasons were noticed as Telikuni (1.48 mg/L) village, Kinnisultan (1.49 mg/L), Aland (1.50 mg/L), Jidga (1.51 mg/L), Padsawli (1.54 mg/L), Nagelagaon (1.97 mg/L), Sakkarga (1.64 mg/L), Kamanalli (1.58 mg/L), Hebli (1.49 mg/L), Khairat 91.49 mg/L and Jheerahalli (1.46 mg/L) village. The highest concentration of fluoride was recorded in Nagelagaon (1.97 mg/L) during pre-monsoon and Padsawli

Table 9 Domestic and industrial suitability of groundwater (post-monsoon season)

Well no.	Location name	Industry suitability using corrosivity ratio	Domestic suitability using hardness	Collin's ratio
1	Telikuni	1.17	−48.94	0.54
2	Kinnisultan	1.69	−52.03	0.77
3	Jamga R	0.88	−191.47	0.39
4	Aland	2.09	−28.88	1.01
5	Gulahalli	1.74	−48.7	0.88
6	Jidga	0.66	−151.81	0.32
7	Jamga Khandala	6.42	−36.6	3.26
8	Shakhapur	3.70	−45.22	1.77
9	Jheerahalli	1.29	−108.08	0.56
10	Khanapur	2.40	−14.1	1.12
11	Swaleshwar	1.10	−45.35	0.50
12	Sarasamba	1.29	−96.71	0.59
13	Nagelagaon	0.64	−36.48	1.39
14	Sakkarga	0.08	−94.78	0.28
15	Kamanalli	0.79	−45.34	0.37
16	Kinnihabas	0.09	−41.02	0.45
17	Mogha B	0.18	−38.39	1.00
18	Hebli	1.57	−52.99	0.76
19	Padsawli	1.85	−85.48	0.85
20	Chincholi K	2.25	−99.93	0.98
21	Chincholi B	1.36	−160.36	0.66
22	Nirgudi	14.81	−3.61	7.33
23	Khairat	1.84	−12.73	0.80
24	Varnalwadi	0.59	−172.9	0.26
25	Aloor	4.57	2.7	2.32
26	Bolegaon	1.62	−17.64	0.61
27	Chitali	1.72	−52.8	0.76
28	Bangerga	5.34	29.87	2.68
29	Bableshtar	0.65	67.72	0.28
30	Khajuri	1.01	−107.38	0.46
31	Tadola	1.44	−38.16	0.70
32	Korahalli	1.01	−40.33	0.46

Bold values are representing the 'higher concentration' of the parameters

Minus sign indicating the soft water using hardness (as CaCO_3)

Fig. 40 Maximum annual rainfall in the study area (2016)

village (1.54 mg/L) during post-monsoon. Environmental awareness programme for the health implications of fluoride in the study area may be conducted from time to time by the stakeholders concerned. Highest nitrate concentration was recorded in Kamanalli (96 mg/L) village during pre-monsoon, whereas Jamga Khandala (77 mg/L) village during post-monsoon.

Irrigational suitability of groundwater showed that the water is within the limit for irrigation except in a few locations. The USSL diagram illustrated the salinity hazards and suggested the need for unique soil management before use. Gibb's plot indicates that groundwater chemistry is controlled by rock dominance factor for both seasons. Geochemical classification of groundwater

Fig. 41 Relationship between the maximum rainfall and physical parameters of the study area

Fig. 42 Relationship between the maximum rainfall and positive ions of both the seasons

Fig. 43 Relationship between the maximum rainfall and negative ions of both the seasons

using Chadha's diagram is indicating $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-Cl}^-$ and $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$ water type for both seasons. Correlation analysis showed that water quality within the region is not influenced by rainfall which is further confirmed by Gibb's plot. Overall, the water quality analysis revealed that the groundwater quality of catchment was not good for the public health point of view. Therefore, community awareness programme and steady survey through municipalities' is needed for a safeguard public health. The lower part of the catchment requires proper management for groundwater before utilising for domestic purposes. GIS-based spatial distribution maps are useful in the better understanding of mapping the vulnerable zones of the catchment for adopting a better management strategy.

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Compliance with ethical standards

Conflict of interest None.

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