Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 22 | No. 2 | pp. 755-765 | 2023

Original Research Paper

https://doi.org/10.46488/NEPT.2023.v22i02.018

Open Access Journal

Hydrogeochemical Characteristics and Suitability of Groundwater for Drinking and Irrigation from Shallow Aquifers of PG1 Watershed in Chandrapur District of Maharashtra

S. S. Deshpande and Y. A. Murkute†
Postgraduate Department of Geology, Nagpur University, Law College Square, Nagpur-44000, India
†Corresponding author: Y. A. Murkute; yogmurkute@rediffmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 16-09-2022
Revised: 05-11-2022
Accepted: 12-11-2022

Key Words:
Hydrogeochemical characteristics
Rock-water interaction
Groundwater suitability
PG1 watershed

ABSTRACT

An endeavor has been made to understand the hydrogeochemical characteristics of groundwater from shallow aquifers of the PG1 watershed (latitudes 19°38'30" to 19°50'30" N and longitudes 79°04'00" to 79°11'00" E). The appropriateness of groundwater has also been checked for various purposes. The groundwater from the study area is alkaline and slightly saline. The $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and $HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-}$ was the ascendancy of cations and anions. The earth metals (Ca + Mg) exceeded the alkali metals (Na + K). The positive correlation interpreted from the interrelationship of Na^{+} *vs* Cl^{-} exhibited a silicate weathering process for the liberation of ions in groundwater at the rock-water interface. In addition to the non-lithological source, anthropogenic inputs were inferred, indicating the agricultural fertilizers and domestic wastewater. All the groundwater samples from the study area are suitable for drinking and domestic use. The groundwater from the study area is also suitable for irrigation with negligible exceptions.

INTRODUCTION

Water is an indispensable commodity of every life that sustains on planet earth. Rainfall is the source of water and has two phases, *viz*, surface water and another is groundwater. Every year, after the spells of monsoon, groundwater gets replenished beneath the earth's surface. This groundwater source is often contaminated because of the geogenic contaminants present at the rock-soil interface (Subba Rao 2002, Si et al. 2009, Murkute 2014). As the residence time increases, the interaction of water with rock minerals gets pronounced, and the concentrations of contaminants increase in many folds. The groundwater sources at shallow aquifers are more susceptible to swift contamination, while the deeper sources are less vulnerable. However, the groundwater positioned at a deeper depth may get contaminated quickly if a zone of mineralization occurs at that depth. In addition to geogenic sources, anthropogenic inputs may also deteriorate the quality of groundwater situated at shallow or even deeper depths. Groundwater contamination and its threat to human health have now been a major concern at a global level (Jalali 2006, Bhardwaj et al. 2010, Brindha & Elango 2013, Wu et al. 2015, Herojeet et al. 2015, Thilagavathi et al. 2015, Xu et al. 2018, Li et al. 2012, 2018, Duraisamy et al. 2018, Sreedevi et al. 2018, Adimalla & Qian 2019, Singh et al. 2019, Wang et al. 2019, Eyankware et al. 2020).

In the present paper, an attempt has been made to understand the rock-water interaction at the shallow aquifer depths since there was a lack of database information on the geochemical behavior of groundwater from this area. The PG1 watershed lies on the southwestern boundary of Chandrapur district, Maharashtra, covering 17 villages. This endeavor will also enable us to understand the suitability of groundwater quality for various purposes.

STUDY AREA

The study area is located in the southwestern part of Chandrapur district in Maharashtra. It is bounded by latitudes 19°38'30" to 19°50'30"N and longitudes 79°04'00" to 79°11'00"E (Fig. 1), covering 314 km^2 area. The study area experiences semi-arid climatic conditions, where the temperature rises to 48°C in the summer (middle March-middle June), while the temperature drops down gradually up to 8°C in December and January. The rainy season starts mid-June and extends to September, with an average annual rainfall of 1132.21 mm. The dendritic drainage pattern drains the entire area from the south towards the north direction, where run-off merges into the Penganga River in the watershed's northern part.

Geology and Hydrogeology

The Penganga Group of rocks (limestone-shale and limestone

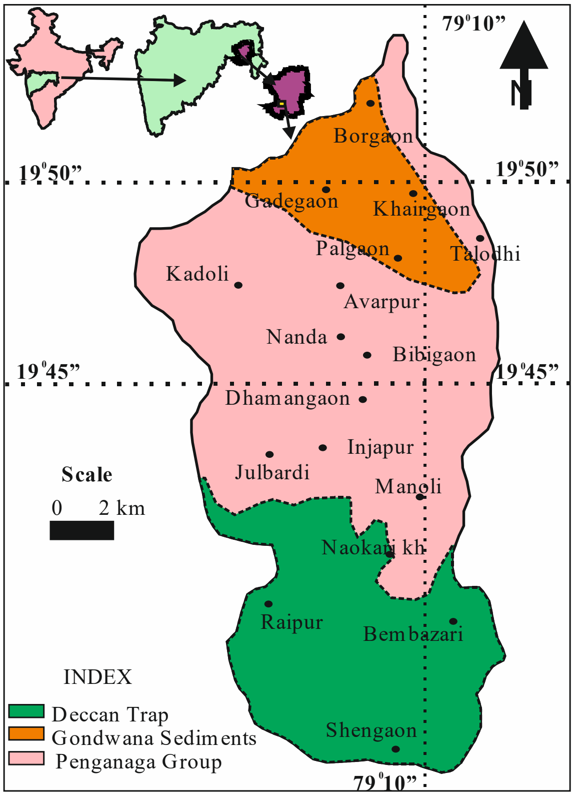

Fig. 1: Location and geological map of the study area with groundwater sampling sites.

sequences belonging to the Penganga Group of Godavari valley) located at a whole central-northern part of the watershed forms the base for the upper geological formations. The rocks of the Lower Gondwana Group (Talchir, Barakar and Kamthi formations) crop out at the northeastern boundary, while Deccan Trap Basalts cover the entire southern part of the study area. Local patches of alluvium, soil, and laterite are also discernible (not seen in Fig. 1).

The wells pierced in Penganga limestone have a groundwater discharge of 50 to 300 $m^3.day^{-1}$; these wells generally have a depth between 7 to 18 meters below ground level (mbgl) and diameters ranging from 2.5 to 5.5 m (GSDA 2009, 2015). The Gondwana formations have enhanced capacities of groundwater discharge to the tune of 100 to 350 $m^3.day^{-1}$ to the dug wells. These wells have a normal diameter of up to 5m and depth ranges from 10 to 15 mbgl (GSDA 2009, 2015). The wells penetrated in Deccan basaltic disposing of deep weathering, and well-developed joints have depths between 5 to 15 mbgl with diameters from 4 to 5.5 m and yield from 75 to 100 m^3day^{-1} (GSDA 2009, 2015).

MATERIALS AND METHODS

Seventeen groundwater samples were collected in polyethylene bottles of 1000 mL capacity from villages of the PG1 watershed. The guiding principles of WHO (2011) and BIS (2012) were followed in the standard analytical procedures (Table 1). The customary measures prescribed by American Public Health Association (APHA 2005) were followed for the various laboratory analyses. The Gibbs (1970) variation diagrams and the Piper (1953) trilinear diagram were depicted to understand the mechanism of rock-water interaction.

RESULTS AND DISCUSSION

Physical Properties and Ion Concentrations

The field temperature recorded from each groundwater sample ranges from 23 to 28°C. The groundwater is dominantly alkaline in nature, showing pH values varying from 7.7 to 8.4 (Table 1). The electrical conductivity (EC) values grade from 456.8 to 3413.7 $\mu s.cm^{-1}$, while total dissolved solids (TDS) values range between 292.4 to 2184.8 $mg.L^{-1}$. As per US Geological Surveys (2000), if TDS values grade up to 1000 $mg.L^{-1}$, then the water is referred to as freshwater; between 1000 to 3000 $mg.L^{-1}$ is slightly saline water, and between 3000 to 10000 $mg.L^{-1}$ is moderately saline. This classification shows that 29% of groundwater

Table 1: Analytical data of cations and anions with physical and computed parameters from the PG2 watershed.

Sr. no	Village	Sample No	pH	EC	TDS	TA	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	CA-I	CA-II	Gibbs Cations	Gibbs Anions)
1.	Kadoli	DW1	7.8	781.2	500.0	350	353.5	54.8	52.8	44.7	8.1	352.8	71.8	23.8	14.5	0.49	0.09	0.49	0.17
2.	Dhamamgaon	DW2	7.7	526.7	337.1	223	284.4	50.8	38.4	23.8	1.2	223.6	35.7	17.2	12.7	0.37	0.05	0.33	0.14
3.	Bibigaon	DW3	8.2	899.6	575.7	311	474.9	63.2	77.3	29.1	1.4	312.5	103.2	38.6	10.8	0.73	0.21	0.33	0.25
4.	Nanda phata	DW4	8.2	945.9	605.4	387	434.1	63.6	67.1	32.8	1.3	383.5	77.9	42.7	22.4	0.60	0.10	0.35	0.17
5.	Palgaon	DW5	7.7	2208.5	1413.4	254	517.3	65.4	86.3	93.7	42.3	259.8	369.4	94.2	44.8	0.86	0.80	0.68	0.59
6.	Awarpur	DW6	7.9	2912.6	1864.1	443	427.4	79.6	55.7	209.4	3.3	439.6	294.4	170.9	1.3	0.30	0.14	0.73	0.40
7.	Gadegaon	DW7	8.3	878.4	562.2	369	333.1	38.6	57.7	88.2	1.2	362.4	75.3	44.8	9.1	-0.16	-0.03	0.70	0.17
8.	Talodhi	DW8	8.4	2756.5	1764.2	567	514.4	78.5	77.6	215.6	103.4	549.2	440.3	98.2	44.7	0.75	0.47	0.80	0.44
9.	Khairgaon	DW9	7.9	3413.7	2184.8	429	470.6	81.3	65.2	93.8	2.7	299.7	423.4	92.7	43.8	0.78	0.76	0.54	0.59
10.	Injapur	DW10	7.9	609.4	390.0	233	307.6	61.7	37.4	25.1	1.3	274.3	51.2	19.9	38.5	0.54	0.08	0.30	0.16
11.	Bembazari	DW11	7.7	857.7	548.9	342	330.3	62.4	42.5	22.8	2.3	342.7	35.7	13.8	5.7	0.43	0.04	0.29	0.09
12.	Naokari Kh.	DW12	8.3	511.3	327.2	167	257.9	48.7	33.2	17.9	4.8	163.2	41.8	42.3	2.2	0.69	0.14	0.32	0.20
13.	Shengaon	DW13	8.2	818.7	524.0	289	373.2	56.3	56.7	19.2	1.2	183.8	21.5	1.3	1.1	0.16	0.02	0.27	0.10
14.	Borgaon	DW14	7.8	608.5	389.4	279	249.7	68.4	19.2	14.9	1.1	279.7	37.2	6.5	1.3	0.63	0.08	0.19	0.12
15.	Raipur	DW15	8.1	1167.9	747.5	326	479.6	98.7	56.8	39.2	1.4	325.6	155.8	34.2	13.7	0.76	0.32	0.29	0.32
16.	Manoli Kh.	DW16	8.3	456.8	292.4	233	237.5	51.7	26.4	18.9	1.3	227.2	27.7	4.9	1.3	0.36	0.04	0.28	0.11
17.	Julbardi	DW17	7.9	867.4	555.1	212	374.4	86.3	38.7	16.3	1.2	210.3	79.6	27.8	18.9	0.81	0.25	0.17	0.27
		Min	7.7	456.8	292.4	167	237.5	38.60	19.20	14.90	1.10	163.20	21.50	1.30	1.10	-0.16	-0.03	0.17	0.09
		Max	8.4	3413.7	2184.8	567	517.3	98.70	86.30	215.60	103.40	549.20	440.30	170.90	44.80	0.86	0.80	0.80	0.59
		Avg	8.0	1248.3	798.9	318	377.6	65.29	52.29	59.14	10.56	305.29	137.76	45.52	16.87	0.53	0.21	0.41	0.25
		SD	0.2	942.7	603.4	101	93.9	15.42	18.90	63.71	25.88	97.30	146.06	44.49	16.26	0.27	0.25	0.20	0.16
		CV	3.0	75.5	75.5	32	24.9	23.62	36.14	107.72	245.07	31.87	106.02	97.73	96.36	50.21	117.32	48.42	63.94

Gibbs Cations: (Na+K)/(Na+K+Ca), Gibbs Anions: ($Cl/(Cl+HCO_3)$), cation and anion values are presented in $mg.L^{-1}$.

samples are fresh, while the rest are slightly saline. The samples' average total alkalinity (TA) is 318 $mg.L^{-1}$, while total hardness (TH) values range from 237.5 to 517.3 $mg.L^{-1}$. Table 1 also exhibits that in 75% of samples, TH values are more than TA values, indicating noncarbonate hardness that cannot be removed easily (Chow 1964).

The dominance sequence of cations for groundwater samples from the study area is $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. The Ca^{2+} values range between 38.6 to 98.7 $mg.L^{-1}$, and Mg^{2+} values vary from 19.2 to 86.3 $mg.L^{-1}$. Though the Ca^{2+} concentration is dominant amongst the cations, in 3 groundwater samples, Mg^{2+} values exceed it. The Na^{+} content ranges between 14.9 to 215.6 $mg.L^{-1}$, and K^{+} values fluctuate between 1.1 to 103.4 $mg.L^{-1}$.

The geogenic processes are mostly responsible for the calcium enrichment in the groundwater. However, loss of carbon dioxide, ion exchange processes, and calcium precipitation at the aquifer interface also causes the variation of calcium content in groundwater (Karanth 1987, Jain et al. 2010, Ahada & Suthar 2018). Similarly, the leaching of magnesium-bearing minerals and ion exchange processes at the rock-water interface is liable for the behavioral change in magnesium content (Thivya et al. 2018). The sodium and potassium concentration within the permissible limits represents the geogenic interface, while the increase in their concentration beyond the permissible limits as prescribed by WHO (2011) and BIS (2012), certainly reflects human interventions and may be a threat to the human body (Mor et al. 2006, Murkute 2022).

The dominance sequence of anions is $HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-}$; where in HCO_3^{-} and SO_4^{2-} contents vary from 163.2 to 549.2 $mg.L^{-1}$ and 1.30 to 170.9 $mg.L^{-1}$ respectively. Though the higher concentration of HCO_3^{-} primarily corresponds to geogenic contamination, the elevated values of SO_4^{2-} content certainly divulges anthropogenic contamination through the oxidation of supplementary sulfide-rich minerals supplied in fertilizers (Min et al. 2003, Chae et al. 2004). The Cl^{-} concentration varies between 21.5 to 440.3 $mg.L^{-1}$, and 40% of samples exceed the prescribed limit of 250 $mg.L^{-1}$ (WHO 2011, BIS 2012). This excess of Cl^{-} concentration indicates groundwater contamination (Loizidou & Kapetanios 1993). The average NO_3^{-} content in groundwater is 17.64 $mg.L^{-1}$, and all the samples have a concentration less than the prescribed limit of 45 $mg.L^{-1}$ (BIS 2012).

Hydrogeochemical Facies

Piper's trilinear diagram (Piper 1953) depicts cations and anions, which divulges the combination of water types. The trilinear diagram (Fig. 2), prepared for the present study, reveals that the earth metals (Ca + Mg) exceeded the alkali metals (Na + K); however, in seldom, alkalis (Na + K) also

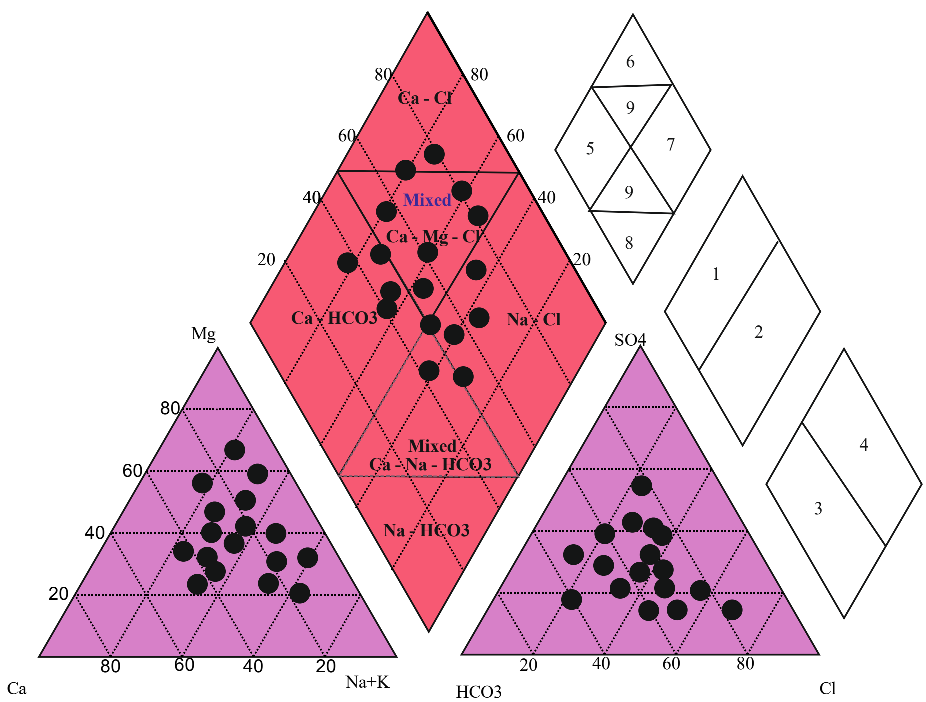

Fig. 2: Piper trilinear diagram for groundwater samples of the study area.

exceeded the alkaline earth (Ca + Mg). The weak acid (CO_3 + HCO_3) (35%) surpassed the combination of strong acids (SO_4 + Cl). In addition, 27% of mixed sectional (Ca-Mg-Cl and Ca-Na-HCO_3) and 46% of combinational hydrochemical facies (Ca-Mg-HCO_3-Cl and Ca-Na-HCO_3-Cl) have been noticed.

Rock-Water Interaction

The cations and anions have distinct behavior at the rock-water interface where certain reactions occur. In the present investigation, when the data points of HCO_3^- and Ca^{++} are plotted in terms of scatter diagram (Fig. 3a), a negative correlation has been observed; conversely, the scatter diagram of Na^+ *vs* Cl^- (Fig. 3b) exhibits a positive correlation, which divulges the reaction of silicate weathering, liberating calcium and bicarbonate in groundwater at rock-water interface (Lakshmanan et al. 2003). The minerals, namely feldspars, pyroxenes, and amphiboles from igneous and metamorphic rocks, while the calcite and clay minerals from sedimentary rocks are the primary sources of Ca^{2+} in groundwater samples (Todd 1995, Murkute & Badhan 2011). The points above the equiline in the scatter diagram of Na^+*vs* Cl^- also suggest interventions by human activities (domestic waste, animal waste, septic tanks, etc.) in the groundwater domain (Murkute & Badhan 2011). In the Ca^{2+}+ $Mg^{2+}$and SO_4^{2-}+ HCO_3^- interrelationship diagram of (Fig. 3c), all points fall above the equiline. In addition, the dominance of SO_4^{2-} + HCO_3^- suggests a silicate weathering process for solute generation (Ramesh & Elango 2011).

The cations like Ca^{2+}, Mg^{2+}, Na^+ and HCO_3^-, Cl^- and SO_4^{2-} anions are released in groundwater after irrigation return flow (Karanth 1987). The negative correlation of NO_3^- and HCO_3^- contents in a scatter diagram reveals anthropogenic interventions. Contrary, in the present investigation, the scatter diagram of NO_3^- and HCO_3^- contents (Fig. 3d) points out a positive correlation, which suggests the different sources for the release of these ions, where NO3$^-$ is liberated due to anthropogenic input while lithological inputs are attributed to a derivation of HCO_3^- in groundwater (Subba Rao & Chaudhary 2019).

Hydrogeochemistry Controlling Mechanism

The interrelationship diagrams above explain the liberation of various cations and anions at the rock-water interface. Hence, all such processes worked out at the rock-water interface are called rock dominance (Gibbs 1970). In addition, precipitation and evaporation are other processes that liberate various cations and anions. The Gibb's diagrams, wherein the plotting of TDS against both the dominant cations [(Na+K) / (Na+K+Ca)] (Fig. 4A), as well as dominant

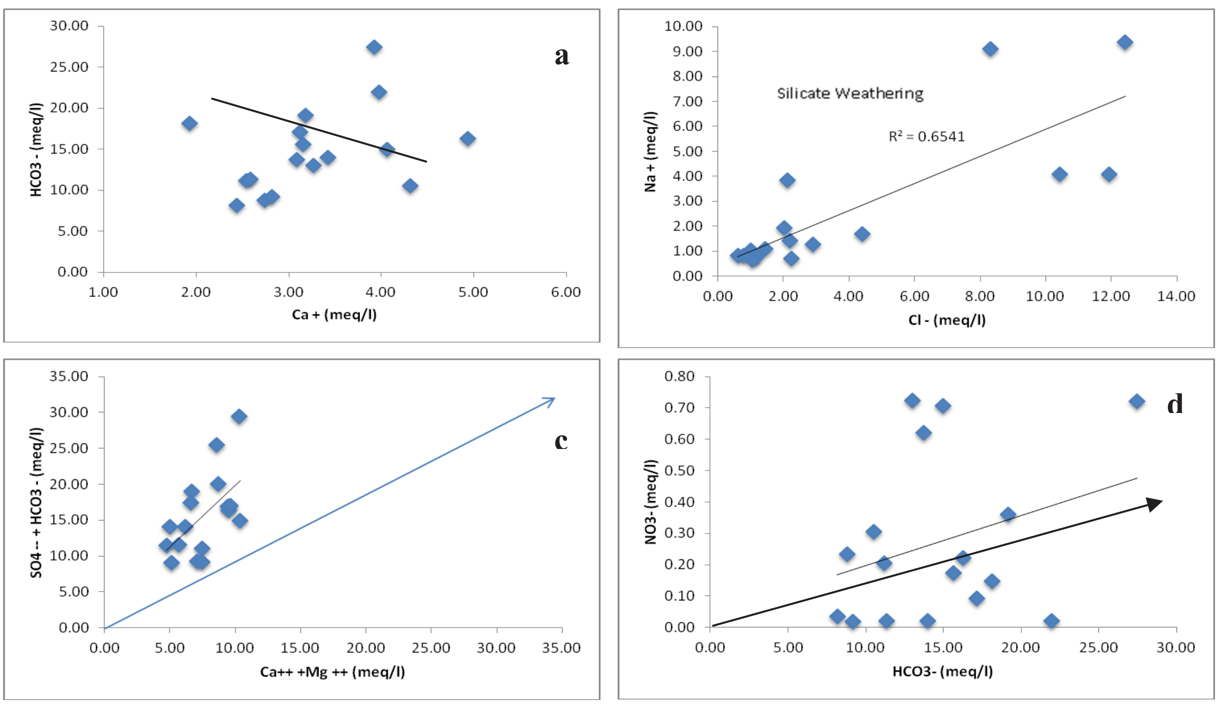

Fig. 3: Inter-ionic relationship between ions. a) scatter diagram of HCO_3^- and Ca^{2+}, b) scatter diagram of Na^+vs Cl^- and c) scatter diagram of Ca^{2+}+ $Mg^{2+}$and SO_4^{2-}+ HCO_3^-, d) scatter diagram of NO_3^-vs HCO_3^-.

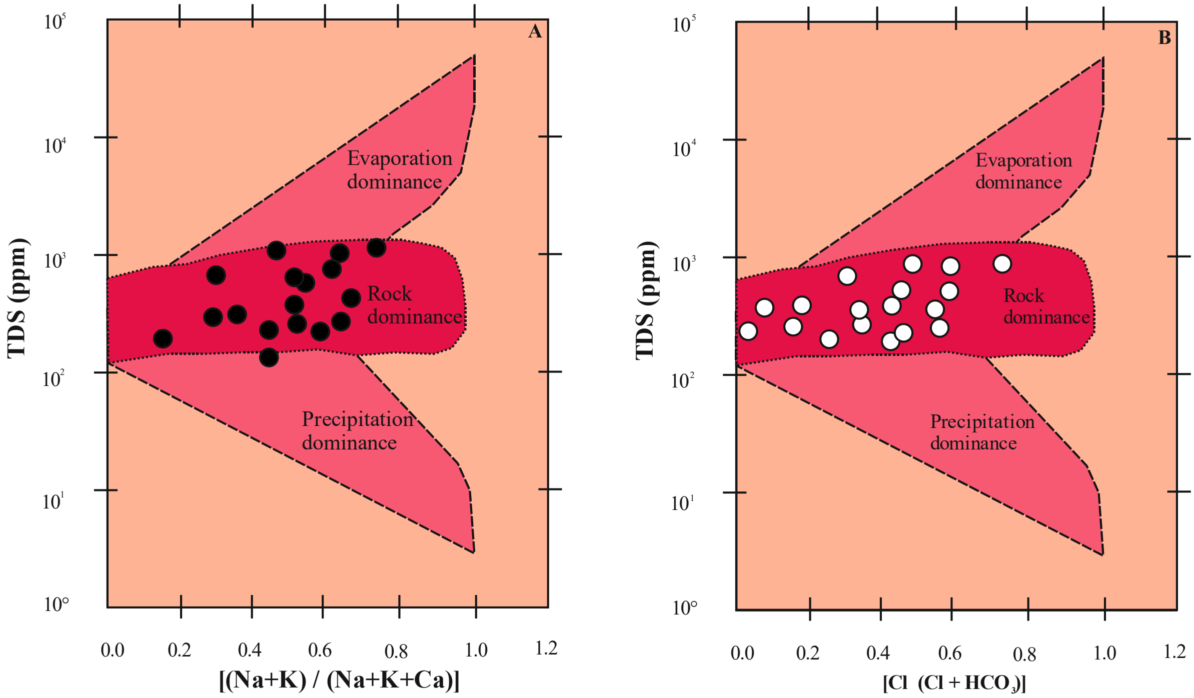

Fig. 4: Gibbs diagram (A) TDS with [(Na+K)/(Na+K+Ca)], (B) TDS with [(Cl/Cl+HCO3)].

anions [(Cl/Cl+HCO_3)] (Fig. 4B), is carried out to confirm the hydrogeochemical controlling mechanism of dissolved cations and anions with the precipitation dominance, rock dominance, and evaporation dominance (Gibbs 1970). The Gibbs diagrams plotted for the groundwater samples from the study area point out that some anthropogenic activities also influence rock dominance as the main hydrogeochemical controlling mechanism (Gibbs 1970, Ravikumar et al. 2010).

Hydrogeochemical Correlation

The correlation matrix has been computed for pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, NO_3^-, SO_4^{2-} and Cl^- (Table 2). The positive correlation between TDS with TH, Ca^{2+}, Na^+, NO_3^-, SO_4^{2-} and Cl^- suggests the association of hydrochemical processes responsible for rock-water interaction, concomitantly with anthropogenic interventions (Tay et al. 2017, Murkute 2022). The correlation matrix

Table 2: Correlation matrix of hydrochemical parameters from the study area.

	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	NO_3^-	HCO_3^-	SO_4^{2-}	Cl^-
pH	1.00											
EC	-0.23	1.00										
TDS	-0.41	1.00	1.00									
TH	-0.28	**0.73**	**0.66**	1.00								
Ca^{2+}	-0.41	**0.67**	**0.73**	**0.94**	1.00							
Mg^{2+}	-0.26	0.38	0.42	**0.93**	**0.65**	1.00						
Na^+	-0.17	**0.73**	**0.73**	-0.32	0.38	0.21	1.00					
K^+	-0.25	0.46	**0.74**	-0.35	0.41	0.33	0.43	1.00				
NO_3^-	0.31	**0.68**	**0.79**	-0.18	**0.65**	0.37	0.54	0.23	1.00			
HCO_3^-	0.**66**	0.32	0.32	-0.29	0.22	-0.28	0.39	0.45	-0.19	1.00		
SO_4^{2-}	-0.13	**0.69**	**0.75**	**0.83**	**0.77**	0.53	**0.77**	0.33	0.33	**0.73**	1.00	
Cl^-	-0.43	**0.79**	**0.77**	0.31	**0.69**	0.29	**0.84**	0.52	**0.75**	0.31	0.45	1.00

also indicates a low correlation between K^+ with NO_3^- and SO_4^{2-} suggesting the non-lithological source, indicating the agricultural fertilizers and domestic wastewaters (Chacha et al. 2018). Na^+ has a strong positive correlation with both Cl^- and SO_4^{2-}, which indicates the presence of pollution in the groundwater of the study area (Barzegar et al. 2017). The HCO_3^- having a negative correlation with NO_3^- also points out the non-geogenic sources for NO_3^- content (Wu & Sun 2016).

Groundwater Suitability

Drinking and Domestic Use

The groundwater suitability has been checked with desirable and permissible limits suggested by WHO (2011) and BIS (2012) (Table 3). The WHO (2011) has suggested a permissible limit of 1500 $mg.L^{-1}$ for EC, which is also a measure of salinity hazard. All the groundwater samples from the study area have EC values less than the prescribed permissible limit indicating their suitability for drinking purposes (Table 3). The BIS (2012) has a permissible limit of 2000 $mg.L^{-1}$ for TDS; considering this as the upper limit, all the groundwater samples are suitable for drinking except one (Khairgaon). Generally, the concentration of TH content is used as the parameter to decide the utility of groundwater for domestic use (Karanth 1987, Todd 1995). The BIS (2012) has suggested a permissible limit of 600 $mg.L^{-1}$ for TH. Hence, all the study area's groundwater samples can be used for domestic purposes without hesitation.

Irrigation Use

The irrigation suitability of groundwater samples was ensured through the parameters, evolved through the mathematical expressions in equations 1 to 8, and results are presented in Table 4.

Sodium Absorption Ratio (SAR); $SAR = Na^+/\sqrt{[(Ca^{2+}+Mg^{2+})/2]}$ …(1)

Percent Sodium (%Na); $\% Na = Na^+ + K^+/(Ca^{2+} + Mg^{2+} + Na^+ + K^+) \times 100$ …(2)

Residual Sodium Carbonate (RSC); $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$ …(3)

Residual Sodium Bicarbonate (RSBC); $RSBC = HCO_3^- - Ca^{2+}$ …(4)

Soluble Sodium Percentage (SSP); $SSP = [(Na^++K^+)/(Ca^{2+}+Mg^{2+}+Na^++K^+)] \times 100$ …(5)

Corrosivity Ratio (CR); $CR = [(Cl^- / 35.5) + 2 (SO_4^{2-} /96)] /2 (HCO_3^- + CO_3^{2-}/100)$ …(6)

Kelley's Ratio (KR); $KR = Na^+/(Ca^{2+}+Mg^{2+})$ …(7)

Synthetic Harmful Coefficient (K); $K = 12.4\ TDS+SAR$ …(8)

SAR: It measures soil permeability with respect to cations. The SAR values from the study area range from 0.4 -4.4 $meq.L^{-1}$, inferring the excellent quality of groundwater for irrigation purposes. The US Salinity Laboratory's diagram (US Salinity Laboratory Staff 1954) uses SAR values and compares with the salinity hazard (Fig.5). The plots of the groundwater samples have been noted to cluster in C_3-S_2(41%) and C_3-S_1 (47%) types, except one plot. The C_3-S_2 type represents the high salinity - medium sodium type,

Table 3: Range of cations and anions with desirable and permissible limits.

Parameter	Min	Average	Max	WHO (2011)		BIS (2012) IS: 10500		SD	CV
				Desirable (DL)	Permissible (PL)	Desirable (DL)	Permissible (PL)		
pH	7.7	8.0	8.4	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2	0.2	3.0
EC	456.8	1248.3	3413.7	750	1500	-	-	942.7	75.5
TDS	292.4	798.9	2184.8	500	1500	500	2000	603.4	75.5
TA	167.0	318.5	567.0	100	500	200	600	100.9	31.7
TH	237.5	377.6	517.3	100	500	300	600	93.9	24.9
Ca^{++}	38.6	65.3	98.7	75	200	75	200	15.4	23.6
Mg^{++}	19.2	52.3	86.3	30	150	30	100	18.9	36.1
Na^+	14.9	59.1	215.6	50	200	-	-	63.7	107.7
K^+	1.1	10.6	103.4	100	200	-	-	25.9	245.1
HCO_3^-	163.2	305.3	549.2	200	600	200	600	97.3	31.9
Cl^-	21.5	137.8	440.3	250	600	250	1000	146.1	106.0
SO_4^{--}	1.3	45.5	170.9	200	600	200	400	44.5	97.7
NO_3^-	1.1	17.6	56.8	-	50	45	100	17.8	101.1

Cation and anion values are presented in $mg.L^{-1}$. SD – standard deviation, CV – covariance.

Table 4: Irrigation suitability indices for groundwater of study area.

Sr.No	Village	Sample No	SAR	% Na	RSC	RSBC	SSP	CR	KR	*K*
1.	Kadoli	DW1	1.0	29.0	0.2	-2.1	23.8	0.1	0.3	3.9
2.	Dhamamgaon	DW2	0.6	8.3	0.7	1.0	15.8	0.1	0.2	4.4
3.	Bibigaon	DW3	0.6	12.5	0.8	3.0	12.0	0.1	0.1	7.9
4.	Nanda phata	DW4	0.7	11.7	1.3	6.5	14.4	0.1	0.2	7.1
5.	Palgaon	DW5	1.8	123.7	0.3	-0.1	35.6	0.5	0.4	6.3
6.	Awarpur	DW6	4.4	31.3	1.7	6.1	52.0	0.4	1.1	3.4
7.	Gadegaon	DW7	2.1	15.5	1.4	10.4	36.7	0.1	0.6	2.1
8.	Talodhi	DW8	4.1	290.2	2.1	11.8	61.0	0.4	0.9	3.4
9.	Khairgaon	DW9	1.9	20.4	0.7	-1.3	30.7	0.5	0.4	9.3
10.	Injapur	DW10	0.6	8.6	0.9	1.4	15.5	0.1	0.2	5.0
11.	Bombezari	DW11	0.5	11.4	1.3	4.7	13.8	0.0	0.1	8.1
12.	Naokari Kh.	DW12	0.5	16.6	0.4	-1.6	15.1	0.1	0.2	5.4
13.	Guwariguda	DW13	0.4	9.4	0.2	-2.1	10.4	0.0	0.1	9.7
14.	Belampur	DW14	0.4	5.7	1.1	0.3	11.9	0.0	0.1	7.6
15.	Gadchandur	DW15	0.8	11.7	0.8	-3.5	15.4	0.2	0.2	7.7
16.	Manoli kh	DW16	0.5	7.2	0.8	1.0	15.3	0.0	0.2	4.4
17.	Nagrala	DW17	0.4	7.7	0.4	-6.7	9.0	0.1	0.1	12.1
Min			0.4	5.7	0.2	-6.7	9.0	0.0	0.1	2.1
Max			4.4	290.2	2.1	11.8	61.0	0.5	1.1	12.1
Average			1.3	36.5	0.9	1.7	22.8	0.2	0.3	6.3
SD			1.26	70.95	0.545	4.883	15.28	0.16	0.29	2.672
CV			99.8	194.3	60.76	289.5	66.92	91.	92.1	42.13

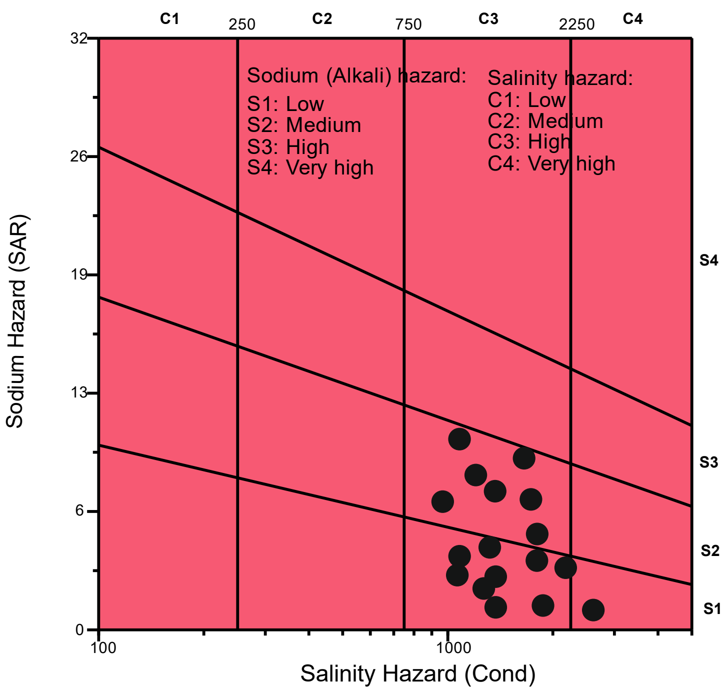

Fig. 5: US Salinity diagram for groundwater samples from the PG1 watershed.

while the C_3-S_1 type represents the medium salinity - medium sodium characters. These two categories reveal that the groundwater from the study area may pose a slight threat of exchangeable sodium, but even then can be utilized for irrigation purposes.

%Na: The %Na in higher concentration in water causes the obliterating of inner drainage, and hence such water is not appropriate for irrigation for a longer duration (Simsek & Gunduz 2007, Murkute 2014, Chacha et al. 2018). Almost all values of %Na in the study area are less than 20 meq.L^{-1} (except two samples), suggesting their suitability for irrigation purposes.

RSC: The RSC values exceeding 2.5 meq.L^{-1} indicate its harmful nature to the growth of plants. Generally, RSC values are categorized as RSC < 1.25, as good; 1.25 to 2.5 as doubtful and > 2.5 as unsuitable. As per this scheme, all the samples (except one) are good and can be used for irrigation.

RSBC: The high RSC content in water poses carbonate deposition in soil and deteriorates its fertility (Agoubi et al. 2011). RSBC value above 10 meq.L^{-1} is unsuitable for irrigation. Except for one sample, all the samples from the study area are suitable for irrigation (Table 4).

SSP: The higher SSP values lower the soil permeability. The SSP values should be less than 50 meq.L^{-1}. The groundwater samples of the study area (except one sample) have SSP values less than 50 meq.L^{-1}, hence suitable for irrigation purposes.

CR: The water with CR values < 1 is suitable for irrigation without the threat of corrosiveness; hence, all the groundwater samples from the study area are suitable for irrigation (table 4), and water can be transported to longer distances for irrigation activity.

KR: The water with KR values < 1 is suitable for irrigation. Except for one, groundwater from the study area is suitable for irrigation.

***K*:** The high *K* value evaluated for irrigation-use of water represents the high salt presence and alkali hazards (Xu et al. 2018, Zhou et al. 2020). The *K* value exceeding 36 meq/l corresponds to the fact that water is not suitable for irrigation purposes. The maximum *K* value obtained for groundwater samples from the study area is 12.1 meq.L^{-1}, suggesting the suitability of water for irrigation use (Table 4).

CONCLUSIONS

The present study was to understand the hydrogeochemical characteristics and to evaluate the suitability of groundwater from shallow aquifers of the PG1 watershed. Based upon the various investigations carried out, the conclusions made are as follows:

i) The maximum electrical conductivity (EC) and TDS values are 3413.7 and 2184.8 mg.L^{-1}, respectively, which suggest that 29% of groundwater samples from the study area are fresh, while the rests of the sample are slightly saline in nature. The dominant sequence of cations and anions for groundwater samples from the study area is $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$ respectively.

ii) The trilinear diagram prepared for the present study reveals that the earth metals (Ca + Mg) exceeded the alkali metals (Na + K); however, in some cases, alkalis (Na + K) also exceeded the alkaline earth (Ca + Mg). 27% of mixed sectional water types (Ca - Mg - Cl and Ca - Na - HCO_3) and 46% of combinational hydrochemical facies (Ca - Mg - HCO_3 - Cl and Ca - Na - HCO_3 - Cl) have been noticed from the study area.

iii) The interrelationship of Na^+ *vs* Cl^- exhibits a positive correlation, divulging the reaction of silicate weathering, allowing the liberation of calcium and bicarbonate ions in groundwater at the rock-water interface. In the Ca^{2+}+ $Mg^{2+}$and SO_4^{2-}+ HCO_3^- interrelationship diagram, all the points fall above the equiline, suggesting the dominance of $SO_4^{2-} + HCO_3^-$ and, therefore, indicate silicate weathering process for a solute generation. The positive correlation of NO_3^- and HCO_3^- suggests the different sources for releasing these ions, where NO_3^- is liberated due to anthropogenic input, while lithological inputs are attributed to the derivation of HCO_3^- in groundwater.

iv) The Gibbs diagrams far study area point out the rock dominance as the main hydrogeochemical controlling mechanism along with some inputs of anthropogenic activities observed through NO_3^-. The correlation matrix shows a low correlation between K^+ with NO_3^- and SO_4^{2-} suggesting the non-lithological source, indicating the agricultural fertilizers and domestic wastewater. While, Na^+ has a strong positive correlation with both Cl^- and SO_4^{2-}, which also indicates the presence of pollution in the groundwater of the study area, which may be a non-geogenic source.

v) All the groundwater samples from the study area have EC values less than the prescribed permissible limit indicating their suitability for drinking purposes. The suitable TH values indicate that groundwater samples from the study area are appropriate for domestic purposes without hesitation. The 8 parameters involved in the present study for inferring the suitability of groundwater for irrigation purposes are: SAR, %Na, RSC, RSBC, SSP, CR, KR, *K*. The values computed for these parameters point out that groundwater from the study area is also suitable for irrigation purpose with negligible exceptions.

ACKNOWLEDGEMENTS

The authors thank Dr. A.P. Dharashivkar and Dr. V.V. Solanki, Groundwater Survey and Development Agency (GSDA), for their technical support during fieldwork and valuable suggestions. The authors gratefully acknowledge the anonymous reviewer for constructive suggestions and comments in the manuscript.

REFERENCES

Adimalla, N. and Qian, H. 2019. Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicol. Environ. Saf., 176: 153-161.

Agoubi, B., Kharroubi, A. and Abida, H. 2011. Hydrochemistry of groundwater and its assessment for irrigation purpose in coastal Jeffara aquifer, southeastern Tunisia. Arab. J. Geosci.,6: 1163-1172.

Ahada, C.P.S. and Suthar, S. 2018. Assessing groundwater hydrochemistry of Malwa Punjab, India. Arab. J. Geosci., 11: 17.

American Public Health Association (APHA) 2005. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Water Pollution Control Federation, American Water Works Association, Water Environment Federation, Washington DC.

Barzegar, R., Moghaddam, A.A., Tziritis, E., Fakhri, M.S. and Soltani, S. 2017. Identification of hydrogeochemical processes and pollution sources of groundwater resources in the Marand Plain, northwest of Iran. Environ. Earth. Sci., 76: 297.

Bhardwaj, V., Singh, D.S. and Singh, A.K. 2010. Water quality of the Chhoti Gandak River using principal component analysis, Ganga plain. J. Earth Syst. Sci., 119(1): 117-127.

BIS (2012). Indian Standard Drinking Water Specifications. IS: 10500. Bureau of Indian Standards, New Delhi.

Brindha, K. and Elango, L. 2013. Geochemistry of fluoride rich groundwater in a weathered granitic rock region, Southern India. Water Qua. Expo. Health, 5(3): 127-138.

Chacha, N., Njau, K.N., Lugomela, G.V. and Muzuka, A.N.N. 2018. Hydrogeochemical characteristics and spatial distribution of groundwater quality in Arusha well fields, northern Tanzania. Appl. Water Sci., 8: 1-23.

Chae, G.T., Kim, K., Yun, S.T., Kim, K.H., Kim, S.O., Choi, B.Y., Kim, H.S. and Rhee, C.W. 2004. Hydrogeochemistry of alluvial groundwaters in an agricultural area, an implication for groundwater contamination susceptibility. Chemosphere, 55: 369-378.

Chow, V.T. 1964. Handbook of Applied Hydrology. McGraw-Hill, New York.

Duraisamy, S., Govindhaswamy, V., Duraisamy, K., Krishinaraj, S., Balasubramanian, A. and Thirumalaisamy, S. 2018. Hydrogeochemical characterization and evaluation of groundwater quality in Kangayam taluk, Tirupur district, Tamil Nadu, India, using GIS tech. Environ. Geochem. Health, 16: 183 https://doi.org/10.1007/s10653-018-0183-z.

Eyankware, M.O., Aleke, C.G., Selemo, A.O.I. and Nnabo, P.N. 2020. Groundwater for sustainable development hydrogeochemical studies and suitability assessment of groundwater quality for irrigation at Warri and environs, Niger delta basin, Nigeria. Ground. Sustain. Dev., 10: 100293.

Gibbs, R.J. 1970. Mechanism of controlling world water chemistry. Science, 17: 1088-1090.

GSDA. 2009. Dynamic Groundwater Resources of Maharashtra Detailed Report (as of 2007-08). Groundwater Surveys and Development Agency, Water Supply and Sanitation Department, Government of Maharashtra and Central Ground Water Board, Central Region, Nagpur, 228p.

GSDA. 2015. Report on Dynamic Groundwater Resources of Maharashtra Detailed Report (as of 2007-08). Groundwater Surveys and Development Agency, Water Supply and Sanitation Department, Government of Maharashtra and Central Ground Water Board, Central Region, Nagpur, 732p.

Herojeet, R., Rishi, M.S. and Kishore, N. 2015. Integrated approach of heavy metal pollution indices and complexity quantification using chemometric models in the Sirsa Basin, Nalagarh valley, Himachal Pradesh, India. Chin. J. Geochem., 34: 620-633.

Jain, C.K., Bandyopadhyay, A. and Bhadra, A. 2010. Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India. Environ. Monit. Assess., 166: 663-676.

Jalali, M. 2009. Geochemistry characterization of groundwater in an agriculture area of Razan, Hamadan, Iran. Environ. Geol., 56: 1479-1488.

Karanth, K.R. 1987. Groundwater Assessment Development and Management. Tata McGraw Hill Publishing Company Ltd, New Delhi, p. 468.

Lakshmanan, E., Kannan, R. and Senthilkumar, M. 2003. Major ion chemistry and identification of hydrogeochemical processes of groundwater in a part of Kancheepuram District, Tamil Nadu, India. Environ. Geosci., 10(4): 157-166.

Li, P., Wu, J. and Qian, H. 2012. Groundwater quality assessment based on rough sets attribute reduction and TOPSIS method in a semi-arid area, China. Environ. Monit. Assess., 184: 4841-4854.

Li, P., Wu, J., Tian, R., He, S., He, X., Xue, C. and Zhang, K. 2018. Geochemistry, hydraulic connectivity and quality appraisal of multilayered groundwater in the Hongdunzi coal mine, Northwest China. Mine Water Environ., 37: 222-237.

Loizidou, M. and Kapetanios, E.G. 1993. Effect of leachate from landfills on underground water quality. Sci. Tot. Environ., 128: 69-81.

Min, J.H., Yun, S.T., Kim, K., Kim. HS and Kim, D.J. 2003. Geologic controls on the chemical behavior of nitrate in riverside alluvial aquifers, Korea. Hydrol. Process, 17: 1197-1211.

Mor, S.K., Ravindra, R.P., Dahiya and Chandra, A. 2006. Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environ. Monit. Assess., 118: 435-456.

Murkute, Y.A. 2014. Hydrogeochemical characterization and quality assessment of groundwater around Umrer Coal Mine area, Nagpur District, Maharashtra, India. Environ. Earth Sci., 72: 4059-4073.

Murkute, Y.A. 2022. Major ion chemistry and assessment of groundwater quality around Gangpur Village, Nagpur District, Maharashtra, India. J. Geosci. Res., 7(1): 112-120.

Murkute, Y.A. and Badhan, P.P. 2011. Fluoride contamination in groundwater from Bhadravati Tehsil, Chandrapur District, Maharashtra. Nature Environ. Pollut. Technol., 10(2): 255-260.

Piper, A.M. 1953. A graphical procedure in the Geochemical Interpretation of water analyses. Am. Geophy. Union Trans., 25: 914-923.

Ramesh, K. and Elango, L. 2011. Groundwater quality and suitability for domestic and agricultural use in the Tondiar river basin, Tamil Nadu, India. Environ. Monit. Assess., 184: 3887-3899.

Ravikumar, P., Venkatesharaju, K., Prakash, K.L. and Somashekar, R.K. 2010. Geochemistry of groundwater and groundwater prospects evaluation, Anekal Taluk, Bangalore urban district, Karnataka, India. Environ. Monit. Asess., 16: 721. https://doi.org/10.1007/s10661-010-1721-z.

Si, J., Feng, Q., Wen, X., Su, Y., Xi, H. and Chang, Z. 2009. Major ion chemistry of groundwater in the extremely arid region of northwest China. Environ. Geol., 57: 1079-1087.

Simsek, C. and Gunduz, O. 2007. IWQ Index: A GIS-integrated technique to assess irrigation water quality. Environ. Monit. Assess., 128: 277-300.

Singh, G., Rishi, M.S., Herojeet, R., Kaur, L. and Sharma, K. 2019. Evaluation of groundwater quality and human health risks from fluoride and nitrate in the semi-arid region of northern India. Environ. Geochem. Health, 6: 449. https://doi.org/10.1007/s10653-019-00449-6

Sreedevi, P.D., Sreekanth, P.D., Ahmed, S. and Reddy, D.V. 2018. Appraisal of groundwater quality in a crystalline aquifer: A chemometric approach. Arab. J. Geosci., 12: 517. https://doi.org/10.1007/s12517-018-3480-z.

Subba Rao, N. 2002. Geochemistry of groundwater in parts of Guntur district, Andhra Pradesh, India. Environ. Geol., 41: 552-562.

Subba Rao, N. and Chaudhary, M. 2019. Hydrogeochemical processes regulating the spatial distribution of groundwater contamination, using pollution index of groundwater (PIG) and hierarchical cluster analysis (HCA): A case study. Ground. Sustain. Dev., 10: 238. https://doi.org/10.1016/j.gsd.2019.100238.

Tay, C.K., Hayford, E.K. and Hodgsoni, I.O.A. 2017. Application of multivariate statistical technique for hydrogeochemical assessment of groundwater within the Lower Pra Basin, Ghana. Appl. Water Sci., 7: 1131-11150.

Thilagavathi, N., Subramani, T., Suresh, M. and Karunanidhi, D. 2015. Mapping of groundwater potential zones in Salem Chalk Hills, Tamil Nadu, India, using remote sensing and GIS techniques. Environ. Monit. Assess., 43: 1514. https://doi.org/10.1007/s10661-015-4376-y.

Thivya, C., Chidambaram, S., Thilagavathi, R., Venkatraman, Ganesh, N., Panda, B. and Prasanna, M.V. 2018. Short-term periodic observation of the relationship of climate variables to groundwater quality along the KT boundary. J. Clim. Chang., 4: 77-86.

Todd, D.K. 1995. Groundwater Hydrology. John Wiley and Sons, NY.

US Geological Survey. 2000. Classification of Natural Ponds and Lakes. US Department of the Interior, US Geological Survey, Washington, DC

US Salinity Laboratory Staff. 1954. Diagnosis and Improvements of Saline and Alkali soils. US Department of Agriculture Handbook, USDA, p. 160

Wang, L., Mei, Y., Yu, K., Li, M. and Hu, X. 2019. Anthropogenic effects on the hydrogeochemical characterization of the shallow groundwater in an arid irrigated plain in northwestern China. Water (Switzerland), 11: 11. https://doi.org/10.3390/w11112247

WHO. 2011. Guidelines for Drinking-Water Quality 216. World Health Organization, Geneva, Switzerland, pp. 303-304.

Wu, J. and Sun, Z. 2016. Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, mid-west China. Expo Health, 8(3): 311-329.

Wu, J., Li, P. and Qian, H. 2015. Hydrochemical characterization of drinking groundwater with special reference to fluoride in an arid area of China and the control of aquifer leakage on its concentrations. Environ. Earth Sci., 73: 8575-8588.

Xu, Y., Dai, S., Meng, K., Wang, Y., Ren, W., Zhao, L., Christie, P. and Teng, Y. 2018. Occurrence and risk assessment of potentially toxic elements and typical organic pollutants in contaminated rural soils. Sci. Tot. Environ., 30: 618-629.

Zhou, Y., Li, P., Xue, L., Dong, Z. and Li, D. 2020. Solute geochemistry and groundwater quality for drinking and irrigation purposes: A case study in Xinle City, North China. Geochemistry, 20: 1256. https://doi.org/10.1016/j.chemer.2020.125609.