

HYDROGEOCHEMICAL BEHAVIOUR AND GROUNDWATER SUITABILITY OF VISLON AREA, PART OF WRD WATERSHED, CHANDRAPUR DISTRICT, MAHARASHTRA, INDIA

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ABSTRACT

An attempt has been done to understand the hydrogeochemical characteristics of groundwater from shallow aquifers of Vislon village, a part of WRD watershed (Lat. 20°06'30"N and Long. 79° 07' 00"E). The appropriateness of groundwater has also been checked for various purposes. The groundwater from study area is alkaline and slightly saline in nature. The $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$ was the ascendancy of cations and anions. The earth metals (Ca + Mg) found to exceed the alkali metals (Na + K). The positive correlation interpreted from interrelationship of Na^+ vs Cl^- exhibited, silicate weathering process for liberation of ions in groundwater at rock-water interface. In addition the non-lithological source, anthropogenic inputs were also inferred indicating the agricultural fertilizers and domestic wastewaters. All the groundwater samples from the study area are suitable for drinking as well as domestic use. The groundwater from study area is also suitable for irrigation purpose with negligible exceptions.

KEY WORDS: Hydrogeochemical behaviour, Cation and anions, Rock-water interaction, Groundwater suitability, Vislon village, Chandrapur district, Maharashtra

INTRODUCTION

Water is inevitable constituent for every life, which thrives on the planet earth. The rainfall is the sole source of water, having surface water and groundwater as its two distinct, but complementary parts. Every year, after the spells of monsoon, the groundwater gets replenished beneath the earth surface through infiltration and percolation. This groundwater source, many a times, gets contaminated because of the geogenic contaminants present at the rock-soil interface (Subba Rao 2002; Si *et al.*, 2009; Murkute, 2014). As this interface sets out older and older, the residence time increases and the interaction of water with rock-minerals get prominent, eventually exceeding the contamination levels. A speedy contamination of groundwater sources is generally observed because of its position at shallow aquifers; while the deeper sources are somewhat less susceptible. The groundwater, positioned at deeper depth may also be susceptible

for quick contamination, if the zone of mineralization occurs at that depth.

In addition to geogenic sources, the non-lithological anthropogenic inputs may also deteriorate the quality of groundwater, may be situated at shallow or even deeper depth. The groundwater contamination and its threat to human health has now been a major concern at a global level and hence various studies have been carried out to understand the hydro-geochemical behavior of groundwater (Jalali, 2006; Bharadwaj *et al.*, 2010; Brindha and Elango 2013; Wu *et al.*, 2015; Hirojeet *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 and 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 paucity of the database information on geochemical behavior of groundwater from this area. The study area lies on

western part of watershed, at the tip of south-western boundary of Chandrapur district, Maharashtra, covering 14 villages. This attempt will also assist to understand the suitability of groundwater quality for various purposes.

STUDY AREA DETAILS

The 14 villages sprawled over the Bhadravati Tehsil (Lat. 20°06'30"N and Long. 79° 07' 00"E), Chandrapur District, Maharashtra (Fig. 1) constitute the study area. The area sustains the tropical dry sub-humid climate. The temperature variation ranges from 44°C in summer to 11°C in winter seasons. The study area receives the average rainfall of 1420 mm with 70% humidity of during monsoon season. The prominent wind direction is from South to North. In summer, the wind direction is from East to South and in monsoon from South to East. During winter (October-January), the wind direction changes from North to East.

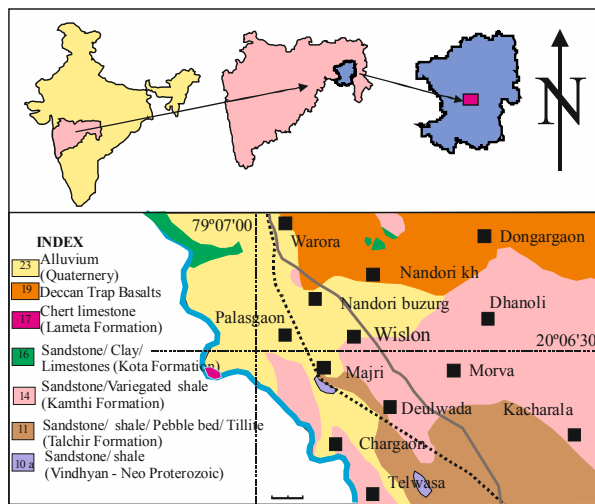


Fig. 1. Location and geological map of study area

The deep pediplain geomorphological unit is observable in the western direction of study area, while low dissected hills are noticeable near Vislon. The slope-category of the study area ranges from 15° to 3° towards north. The Dahiya River meets into the Wardha River, which drains the study area from southwestern boundary.

GEOLOGY AND HYDROGEOLOGY

The oldest rocks in the study area belong to limestone-shale alterations of Penganaga Group that covers south central part of the study area. The

Gondwana Supergroup, comprising Talchir, Barakar and Kamthi sediments, exhibits the non-conformable contact with the underlying Penganaga sequences, covers north central part of the study area. On the western direction, the Deccan basaltic flows, which are thick, tabular and sheet like in form, show the large areal extent. The local and patchy alluvium deposits are also noted in the river beds of study area.

The wells pierced in Penganga limestones have the groundwater discharge of 50 to 300 m³/ day; these wells generally have 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 in tune of 100 to 350 m³/ day to the dug wells. These wells have normal diameter up to 5m and depth ranges from 10 to 15 mbgl (GSDA, 2009; 2015). The wells penetrated in Deccan basaltic disposing deep weathering as well as well developed joints have depth between 5 to 15 mbgl with diameters from 4 to 5.5 m, and have the yield from 75 to 100 m³/ day (GSDA, 2009; 2015).

MATERIALS AND METHODS

25 groundwater samples were collected in polyethylene bottles of 1000 ml capacity from villages of PG1 watershed. The guiding principles of WHO (2011) and BIS (1991) were followed in the standard analytical procedures (Table 1). The customary measures prescribed in American Public Health Association (APHA, 2005) were followed for the various laboratory analyses. The Gibbs variation diagrams (1970) and the Piper trilinear diagram (1953) were depicted to understand the mechanism of rock-water interaction. The charge balance error (CBE %) was rigorously performed after every five samples to retain the known customary standard (CBE <5%; $CBE\% = \frac{[\sum \text{cation} - \sum \text{anion}]}{[\sum \text{cation} + \sum \text{anion}]} \times 100$).

RESULTS AND DISCUSSION

Physical properties and ion concentrations

The temperature recorded in the field from each groundwater samples range from 21.3 to 27 °C. The groundwater is dominantly alkaline in nature, showing pH value varying from 7.2 to 8.4 (Table 1). The electrical conductivity (EC) values grade from 723.8 - 1756.4 $\mu\text{S}/\text{cm}$, while the total dissolved solids

Table 1. Analytical data of cations and anions with physical and computed parameters from study area

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	Nanduri Kh	DW1	7.6	723.8	463.2	350	473.3	82.4	65.2	21.3	1.2	312.7	159.3	174.5	102.4	0.87	0.24	0.21	0.34
2	Nanduri B.	DW2	7.5	724.6	463.7	223	480.6	84.5	65.7	24.5	3.2	301.4	162.5	178.5	105.6	0.87	0.24	0.25	0.35
3	Bhatali 1	DW3	7.6	1625.8	1040.5	311	553.4	125.6	58.4	55.6	5.4	258.6	212.5	182.4	89.3	0.76	0.31	0.33	0.45
4	Bhatali 2	DW4	7.6	1624.7	1039.8	387	558.2	126.7	58.9	51.7	22.6	288.4	231.4	186.3	87.5	0.87	0.36	0.37	0.45
5	Dongargaon	DW5	7.9	1534.7	982.2	254	477.0	98.3	56.4	58.1	21.7	211.6	278.6	212.3	45.6	0.87	0.52	0.45	0.57
6	Dhanoli	DW6	7.8	1189.7	761.4	443	383.3	100.2	32.4	62.5	18.3	212.4	288.7	215.6	43.2	0.85	0.52	0.45	0.58
7	Vislon 1	DW7	7.8	1278.6	818.3	369	368.6	78.4	42.1	78.4	12.4	258.7	267.2	265.6	56.7	0.75	0.35	0.54	0.51
8	Vislon 2	DW8	7.5	1256.4	804.1	567	386.6	81.5	44.6	75.2	6.6	269.1	268.1	269.7	61.2	0.74	0.33	0.50	0.50
9	Vislon 3	DW9	7.5	1264.3	809.2	429	374.6	79.8	42.7	48.6	7.1	257.3	271.5	201.2	56.8	0.85	0.45	0.41	0.51
10	Majri Kh	DW10	7.2	1662.8	1064.2	233	545.4	71.2	89.6	98.3	2.3	288.1	245.7	203.6	71.3	0.61	0.27	0.59	0.46
11	Majri Bz	DW11	7.2	1664.5	1065.3	342	547.0	75.3	87.5	99.4	5.6	302.4	251.2	235.4	89.4	0.63	0.25	0.58	0.45
12	Palasgaon	DW12	7.4	1547.2	990.2	167	809.3	139.4	112.4	92.5	8.7	445.6	223.4	235.6	142.6	0.62	0.17	0.42	0.33
13	Palasgaon	DW13	7.5	1634.8	1046.3	289	859.1	139.8	124.3	94.3	4.5	468.2	234.8	246.7	145.3	0.62	0.17	0.41	0.33
14	Kachrala 1	DW14	7.9	1756.4	1124.1	279	655.0	123.4	84.5	67.3	13.2	423.8	269.3	258.1	123.8	0.80	0.27	0.39	0.39
15	Kachrala 2	DW15	7.5	1452.6	929.7	326	669.0	126.4	86.1	58.6	12.7	421.4	267.4	302.1	125.4	0.83	0.26	0.36	0.39
16	Morwa 1	DW16	7.4	1245.8	797.3	233	460.6	125.7	35.7	102.7	10.7	212.5	223.4	304.7	48.3	0.59	0.23	0.47	0.51
17	Morwa 2	DW17	7.2	1025.7	656.4	212	480.7	132.6	36.4	104.3	11.3	213.6	231.6	256.4	51.2	0.60	0.27	0.47	0.52
18	Vichoda	DW18	7.2	1028.9	658.5	233	644.8	89.5	102.7	68.2	5.5	325.7	269.8	263.1	78.4	0.77	0.31	0.45	0.45
19	Tervanja	DW19	7.7	1345.6	861.2	227	631.4	91.2	98.4	124.6	5.4	257.1	271.2	305.1	82.4	0.56	0.24	0.59	0.51
20	Chargaon 1	DW20	7.3	1365.4	873.9	231	557.3	94.5	78.3	67.3	6.8	266.9	255.3	311.6	123.7	0.76	0.28	0.44	0.49
21	Chargaon 2	DW21	7.4	1545.6	989.2	234	565.5	96.3	79.2	68.7	7.2	309.4	246.5	312.7	135.9	0.75	0.24	0.44	0.44
22	Saywan 1	DW22	7.5	1555.2	995.3	356	433.4	89.4	51.2	46.8	15.2	267.3	233.5	315.4	123.2	0.86	0.29	0.41	0.47
23	Saywan 2	DW23	7.8	1028.4	658.2	351	419.5	88.6	48.3	51.2	14.7	267.8	235.6	178.6	118.9	0.85	0.35	0.43	0.47
24	Deulwada 1	DW24	7.5	1031.8	660.4	322	299.7	60.2	36.4	66.2	12.4	245.1	212.4	179.2	89.3	0.75	0.31	0.57	0.46
25	Deulwada 2	DW25	7.2	1235.7	790.8	323	299.4	62.7	34.8	67.7	9.7	247.3	214.6	183.2	92.4	0.73	0.30	0.55	0.46
		Min	7.2	723.8	463.2	167	368.6	71.20	32.40	21.30	1.20	211.60	159.30	174.50	43.20	0.59	0.17	0.21	0.33
		Max	7.9	1756.4	1124.1	567	859.1	139.80	124.30	104.30	22.60	468.20	288.70	304.70	145.30	0.87	0.52	0.59	0.58
		Avg	7.5	1365.4	873.9	308	534.2	105.36	66.05	70.19	9.85	302.69	240.39	231.10	85.04	0.75	0.30	0.42	0.45
		SD	0.2	318.2	203.7	90	143.8	25.24	27.40	26.08	6.45	85.40	37.20	41.37	34.46	0.11	0.10	0.10	0.08
		CV	2.8	23.3	23.3	29	26.9	23.95	41.48	37.15	65.43	28.21	15.48	17.90	40.53	15.08	34.40	24.19	18.09

Gibbs Cations: (Na+K) / (Na+K+Ca), Gibbs Anions: (Cl/(Cl+HCO₃)), cation and anion values are presented in mg/l.

(TDS) have clustering values between 292.4 to 2184.8 mg/l. As per US Geological Surveys (2000) if TDS values grade up to 1000 mg/l then the water is referred to as fresh water; between 1000 to 3000 mg/l is slightly saline water. This classification brings out that 68% of the groundwater samples are fresh while rests of the sample are slightly saline in nature. Average of total alkalinity (TA) of samples is 308 mg/l; while total hardness (TH) values range from 368.6 to 859.1 mg/l. The Table 1 also exhibits that in 67% of samples TH values are more than TA values; which indicates existence of noncarbonated hardness that cannot be removed easily (Chow, 1964).

The dominance sequence of the cations for groundwater samples from the study area clearly exhibits that Ca^{2+} (values range between 71.2 to 139.8 mg/l) predominates over the other cations $\text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The Mg^{2+} values from the samples vary from 32.4 to 124.3 mg/l. Though the Ca^{2+} concentration is dominant amongst the cations in 12% samples, Mg^{2+} values exceeds it. The Na^+ content ranges between 21.3 to 104.3 mg/l and K^+ values fluctuates between 1.2 to 22.6 mg/l.

The geogenic processes are most of the time responsible for the calcium enrichment in the groundwater, however loss of carbon dioxide, ion exchange processes as well as calcium precipitation at aquifer interface also causes the variation of calcium content in groundwater (Karanth, 1987; Jain *et al.*, 2010; Ahada and 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 corresponds to the geogenic interface while the increase in their concentration beyond the permissible limits as prescribed by WHO (1997) and BIS (2003), certainly reflects the human interventions and may be a threat to human body (Mor *et al.*, 2006).

The dominance sequence shows that HCO_3^- predominates (112.6 – 468.2) over the $\text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$ anions. The SO_4^{2-} content exhibits large variation in values, which varies from 174.5 to 304.7 mg/l. Though, the higher concentration of HCO_3^- primarily corresponds to the geogenic contamination, the elevated values of SO_4^{2-} content certainly divulges anthropogenic contamination through the oxidation of supplementary sulphide-rich minerals supplied in fertilizers (Min *et al.*, 2003;

Chae *et al.*, 2004). The Cl^- concentration varies between 159.3 to 304.7 mg/l and 36% of samples exceed the concentration than the prescribed limit of 250 mg/l (WHO, 2011; BIS, 2012). This excess of Cl^- concentration is an indicator of groundwater contamination (Loizidou and Kapetanos, 1993). The average NO_3^- content in groundwater is 85.4 mg/l and 56% of the samples have its concentration more than the prescribed limit of 45 mg/l (BIS, 2012).

Hydrogeochemical facies

Piper's trilinear diagram (Piper, 1953) is a portrayal of cations and anions that divulges the various combinations of water types. The Piper's trilinear diagram, prepared for the present study (Fig.2), reveals that the 42% of earth metals ($\text{Ca} + \text{Mg}$) exceeded the alkali metals ($\text{Na} + \text{K}$). Conversely, 14%, alkalis ($\text{Na} + \text{K}$) were also found to also exceed the earths ($\text{Ca} + \text{Mg}$). The weak acid ($\text{CO}_3 + \text{HCO}_3$) (45%) surpassed the combination of strong acids ($\text{SO}_4 + \text{Cl}$). In addition, 27% of mixed sectional ($\text{Ca} - \text{Mg} - \text{Cl}$ and $\text{Ca} - \text{Na} - \text{HCO}_3$) and 40% of Combinational hydrochemical facies ($\text{Ca} - \text{Mg} - \text{HCO}_3 - \text{Cl}$ and $\text{Ca} - \text{Na} - \text{HCO}_3 - \text{Cl}$) have been noticed.

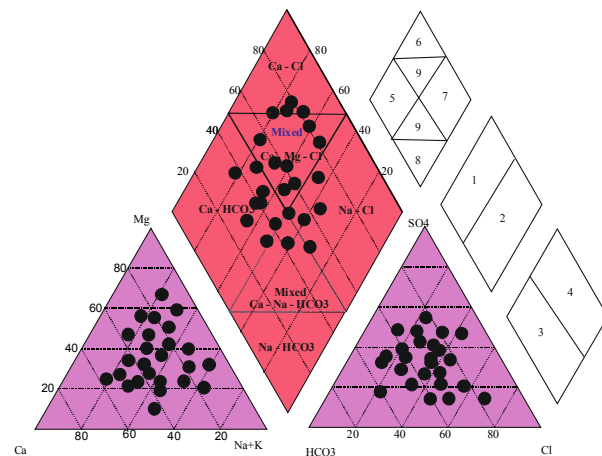


Fig. 2. Piper trilinear diagram for groundwater samples of study area

Rock-water interaction

The cations and anions have distinct behavior at rock-water interface where certain reactions take place. In the present investigation, when the data points of HCO_3^- and Ca^{++} are plotted in terms of scatter diagram (Fig. 3a); a positive correlation ($r^2 = 0.2375$) has been observed; similarly, the scatter diagram of $\text{Na}^+ vs \text{Cl}^-$ (Fig. 3b) also exhibits positive correlation ($r^2 = 0.1537$), 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 and Badhan, 2011). The points above the equiline in scatter diagram of Na^+ vs Cl^- also suggest interventions by human activities (domestic waste, animal waste, septic tanks, etc) in groundwater domain (Murkute and Badhan, 2011). In the $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{SO}_4^{2-} + \text{HCO}_3^-$ interrelationship diagram of (Fig. 3c) all points fall above the equiline ($r^2 = 0.6241$), in addition the dominance of $\text{SO}_4^{2-} + \text{HCO}_3^-$ suggests silicate weathering process for solute generation (Ramesh and Elango, 2011).

The cations like Ca^{2+} , Mg^{2+} , Na^+ and HCO_3^- , Cl^- and SO_4^{2-} anions are released in groundwater regime after irrigation return flow (Karanth, 1987). The negative correlation of NO_3^- and HCO_3^- contents in a scatter diagram clearly reveals anthropogenic interventions. Contrary, in the present investigation the scatter diagram of NO_3^- and HCO_3^- contents (Fig. 3d) points out positive correlation ($r^2 = 0.4567$), which suggests the different sources for release of these ions, where in NO_3^- is liberated due to anthropogenic input while lithological inputs are

attributed to derivation of HCO_3^- in groundwater (Subba Rao and Chaudhary, 2019).

Hydrogeochemistry Controlling Mechanism

The various above mentioned interrelationship diagrams, evidently elucidates the liberation of a range of cations and anions at rock water interface. Hence, all such progressions worked out at rock water interface are referred to as rock dominance (Gibbs, 1970). In addition, the precipitation and evaporation are other two processes, which are also accountable for the discharge of various cations and anions. The Gibb's diagrams, wherein the plotting of TDS against both, the dominant cations [$(\text{Na}+\text{K}) / (\text{Na}+\text{K}+\text{Ca})$] (Fig. 4A) as well as leading anions [$(\text{Cl}/\text{Cl}+\text{HCO}_3)$] (Fig. 4B) is carried out to substantiate 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 study area clearly point out the rock dominance as the main hydrogeochemical controlling mechanism, also influenced by some of the anthropogenic activities (Gibbs, 1970; Ravikumar *et al.*, 2010).

Hydrogeochemical Correlation

The correlation matrix has been computed for pH,

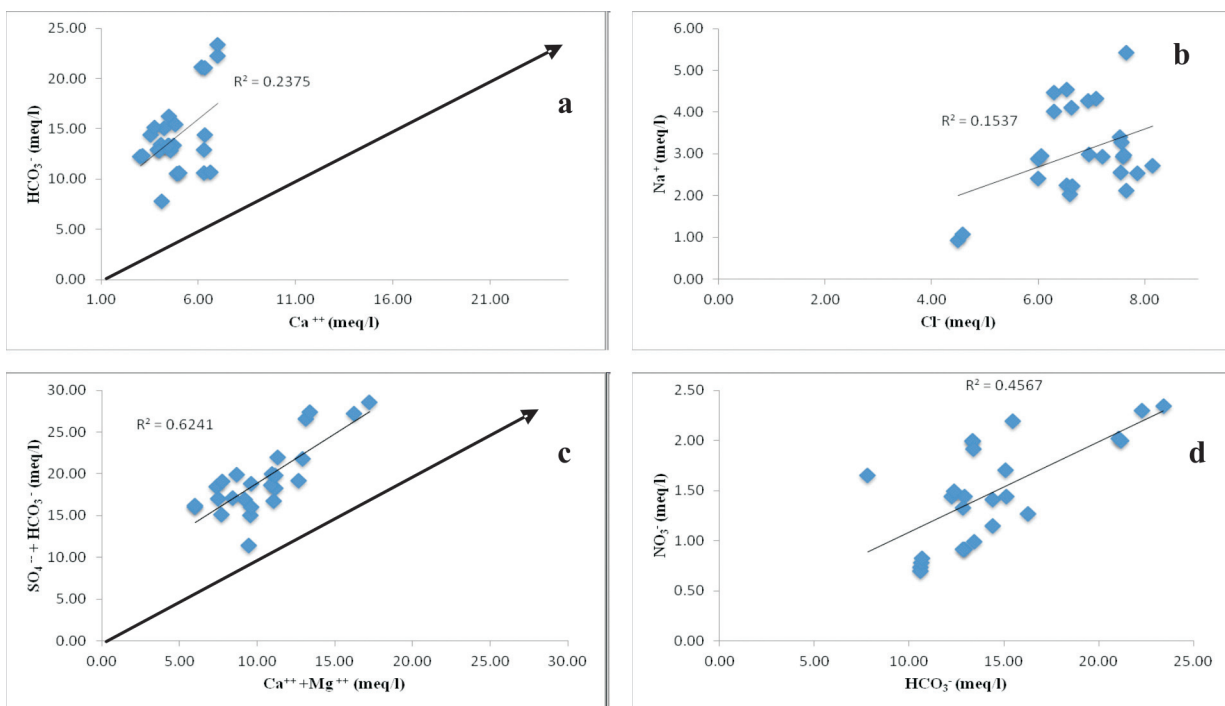


Fig. 3. Inter-ionic relationship between ions. a) interrelationship of HCO_3^- and Ca^{2+} , b) scatter diagram of Na^+ vs Cl^- and c) interrelationship diagram of $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{SO}_4^{2-} + \text{HCO}_3^-$, d) scatter diagram of NO_3^- vs HCO_3^- .

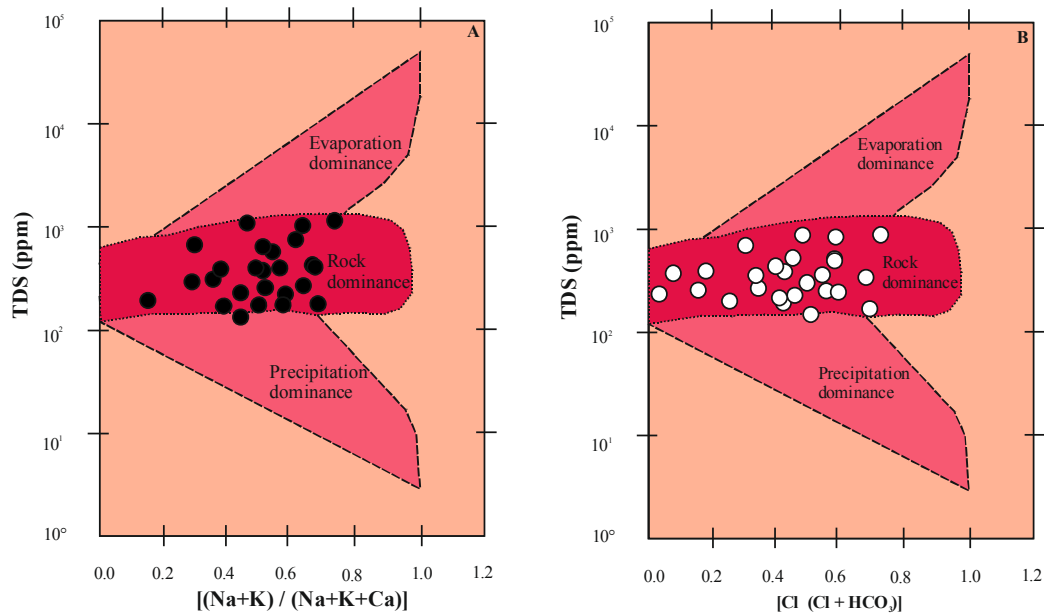


Fig. 4. Gibbs diagram. A) TDS with [(Na+K) / (Na+K+Ca)], B) TDS with [(Cl/Cl+HCO₃)]

EC, TDS, TH, Ca²⁺, Mg²⁺, Na⁺, K⁺, HCO₃⁻, NO₃⁻, SO₄²⁻ and Cl⁻ (Table 2). The positive correlation between TDS with TH (r = 0.68), Ca²⁺ (r = 0.75), Na⁺ (r = 0.72), NO₃⁻ (r = 0.77), SO₄²⁻ (r = 0.71) and Cl⁻ (r = 0.76) suggests the association of hydrochemical processes responsible at rock-water interaction, concomitantly with anthropogenic interventions (Tay *et al.*, 2017, Murkute, 2022). The correlation matrix also point out low correlation between K⁺ with NO₃⁻ (r = 0.27) and SO₄²⁻ (r = 0.31) suggesting the non-lithological source, indicating the agricultural fertilizers and domestic wastewaters (Chacha *et al.*, 2018). Na⁺ has strong positive correlation with both Cl⁻ (r = 0.86) and SO₄²⁻ (r = 0.76), which is indicative of presence of pollution in groundwater of the study area (Barzegar *et al.*, 2017). The HCO₃⁻ having negative

correlation with NO₃⁻ (r = - 0.22) also points out non-geogenic source for NO₃⁻ content (Wu and 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 the permissible limit of 1500 mg/l for EC, which is also a measure of salinity hazard. 64% of the groundwater samples from the study area have EC values less than the prescribed permissible limit indicating their suitability for drinking purpose (Table 3). Remaining 36% of samples exceed this limit, and point out towards the measures to be

Table 2. Correlation matrix of hydrochemical parameters from study area

	pH	EC	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	NO ₃ ⁻	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻
pH	1.00											
EC	-0.21	1.00										
TDS	-0.44	1.00	1.00									
TH	-0.18	0.75	0.68	1.00								
Ca ²⁺	-0.33	0.68	0.75	0.91	1.00							
Mg ²⁺	-0.31	0.41	0.39	0.91	0.67	1.00						
Na ⁺	-0.21	0.71	0.72	-0.34	0.41	0.24	1.00					
K ⁺	-0.28	0.42	0.75	-0.38	0.39	0.34	0.45	1.00				
NO ₃ ⁻	0.29	0.70	0.77	-0.20	0.68	0.38	0.52	0.27	1.00			
HCO ₃ ⁻	0.68	0.29	0.36	-0.31	0.26	-0.25	0.41	0.48	-0.22	1.00		
SO ₄ ²⁻	-0.18	0.71	0.72	0.85	0.79	0.52	0.76	0.31	0.34	0.75	1.00	
Cl ⁻	-0.48	0.76	0.76	0.34	0.66	0.31	0.86	0.51	0.74	0.33	0.48	1.00

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

Parameter	Min	Average	Max	WHO (2011)		BIS (2003) 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. SD – standard deviation, CV – covariance.

taken before drinking the water. The BIS (1991) has the permissible limit of 2000 mg/l for TDS; considering this as upper limit, all the groundwater samples are suitable for drinking purpose. 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 the permissible limit of 600 mg/l for TH, hence all the groundwater samples from study area can be used for domestic purpose without hesitation.

Irrigation Use

The irrigation suitability of groundwater samples was ensured through the parameters, evolved through the mathematical equations (1 to 8), and the computational 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 involves the soil permeability in respect to cations. The SAR values from the study area having the range from 0.4 - 1.4 meq/l infer excellent quality of groundwater for irrigation purpose. The US Salinity Laboratory's diagram (US Salinity Laboratory Staff, 1954) uses SAR values and compares against the salinity hazard (Fig. 5). The plots of the groundwater samples have been noted to cluster in C₃-S₂ (41%) and C₃-S₁ (45%) types, except two plots. The C₃-S₂ type represents the high salinity - medium sodium type, while C₃-S₁ type represents the medium salinity - medium sodium characters. These two categories reveal that the groundwater

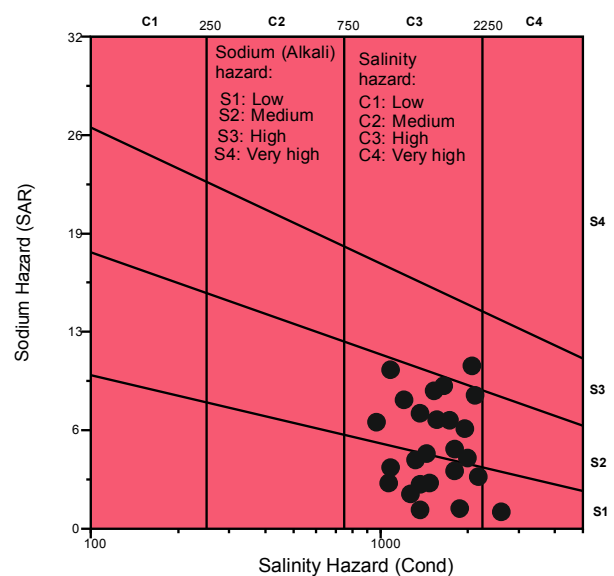


Fig. 5. US Salinity diagram for groundwater samples from PG2 watershed

Table 4. Irrigation suitability indices for groundwater of study area

Sr.No	Village	Sample No	SAR	% Na	RSC	RSBC	SSP	CR	KR	K
1	Nanduri Kh	DW1	1.7	40.6	0.8	0.2	35.9	0.5	0.5	3.2
2	Nanduri B.	DW2	1.7	33.6	0.8	-0.2	35.6	0.5	0.5	3.7
3	Bhatali 1	DW3	0.4	10.3	-0.2	-8.7	9.2	0.6	0.1	8.7
4	Bhatali 2	DW4	0.5	15.7	0.7	-1.8	10.7	0.4	0.1	7.6
5	Dongargaon	DW5	1.0	23.5	0.2	-12.2	18.9	0.5	0.2	8.1
6	Dhanoli	DW6	1.0	67.2	0.4	-10.9	21.0	0.5	0.2	8.7
7	Vislon 1	DW7	1.2	65.3	0.1	-9.1	25.5	0.7	0.3	6.8
8	Vislon 2	DW8	1.4	55.0	0.4	-9.4	30.6	0.7	0.4	4.4
9	Vislon 3	DW9	1.8	42.1	0.7	-2.7	34.5	0.7	0.5	3.7
10	Majri Kh	DW10	1.7	27.1	0.7	-2.8	31.2	0.6	0.4	3.9
11	Majri Bz	DW11	1.1	25.9	0.7	-3.1	23.8	0.6	0.3	5.9
12	Palasgaon	DW12	1.8	21.8	0.4	0.2	28.5	0.5	0.4	4.7
13	Palasgaon	DW13	1.8	30.2	0.5	0.1	29.2	0.5	0.4	4.6
14	Kachrala 1	DW14	1.4	39.6	0.8	-5.6	21.0	0.4	0.2	5.6
15	Kachrala 2	DW15	1.4	30.0	0.8	-4.5	19.8	0.4	0.2	6.0
16	Morwa 1	DW16	1.1	46.6	1.0	-3.5	20.3	0.5	0.2	7.9
17	Morwa 2	DW17	1.0	44.7	1.0	-4.2	18.0	0.5	0.2	7.6
18	Vichoda	DW18	2.1	39.3	0.2	-14.5	34.6	0.8	0.5	3.1
19	Tervanja	DW19	2.1	41.0	0.1	-15.8	34.0	0.7	0.5	2.5
20	Chargaon 1	DW20	1.2	28.5	0.4	-1.6	19.5	0.6	0.2	4.5
21	Chargaon 2	DW21	2.2	32.8	0.0	-5.4	30.7	0.7	0.4	3.2
22	Saywan 1	DW22	1.2	29.7	0.3	-5.6	22.0	0.7	0.3	5.6
23	Saywan 2	DW23	1.3	30.9	0.5	-3.8	22.1	0.6	0.3	6.3
24	Deulwada 1	DW24	1.0	47.2	0.6	-4.5	22.6	0.7	0.2	8.1
25	Deulwada 2	DW25	1.1	46.1	0.6	-4.3	24.4	0.5	0.3	4.8

from study area may pose very slight threat of exchangeable sodium in soil through the water, but even then be utilized for irrigation purpose.

%Na: The %Na in elevated concentration in water causes the obliterating of inner drainage and hence such water is not appropriate for irrigation for longer duration (Simsek and Gunduz, 2007; Murkute, 2014; Chacha *et al.*, 2018). Almost all values of %Na in study area are less than 40 meq/l (except two samples), suggesting their suitability for irrigation purpose.

RSC: The RSC values exceeding the 2.5 meq/l indicates of 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 is unsuitable. As per this scheme all the samples are good in nature, hence can be utilized for irrigation.

RSBC: The high RSC content in water pose deposition of carbonate in soil and deteriorate its fertility (Agoubi *et al.*, 2011). RSBC value above than 10meq/l is unsuitable for irrigation. All the samples from the study area are hence suitable for irrigation (Table 4).

SSP: The higher SSP values lowers down the soil permeability. The SSP values should be less than 50

meq/l. The groundwater samples of the study area have SSP values less than 50 meq/l, hence suitable for irrigation purpose.

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

KR: The water with KR values < 1 shows the suitability; hence the groundwater from the study area is suitable for irrigation purpose.

K: The high K value evaluated for irrigation-use of water represents high salt presence and alkali hazards (Xu *et al.*, 2018; Zhou *et al.*, 2020). The K value exceeding 36meq/l corresponds that water is not suitable for irrigation purpose. The maximum K value obtained for groundwater samples from study area is 8.7 meq/l, suggesting suitability of water towards irrigation use (Table 4).

CONCLUSION

The present study was to understand the hydrogeochemical behaviour and to evaluate the

suitability of groundwater from shallow aquifers around Vislon village. Based upon the various investigations carried out, the conclusions made are as follows:

- i) The maximum electrical conductivity (EC) and TDS values are 1756.4 and 1124.1 mg/l respectively, which suggest that that 67% of groundwater samples from study area are fresh while rests of the sample are slightly saline in nature. The dominance sequence of cations and anions for groundwater samples from the study area is $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$ 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 earths (Ca + Mg). 35% of mixed sectional water types (Ca - Mg - Cl and Ca - Na - HCO_3^-) and 51% of combinational hydrochemical facies (Ca - Mg - HCO_3^- - Cl and Ca - Na - HCO_3^- - Cl) have been noticed from study area.
- iii) The interrelationship of Na^+ vs Cl^- exhibits positive correlation, divulging the reaction of silicate weathering, allowing the liberation of calcium and bicarbonate ions in groundwater at rock-water interface. In the $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{SO}_4^{2-} + \text{HCO}_3^-$ interrelationship diagram, all the points fall above the equiline, suggesting the dominance of $\text{SO}_4^{2-} + \text{HCO}_3^-$ and therefore indicate silicate weathering process for solute generation. The positive correlation of NO_3^- and HCO_3^- suggests the different sources for release of these ions, where in NO_3^- is liberated due to anthropogenic input while lithological inputs are attributed to derivation of HCO_3^- in groundwater.
- iv) The Gibbs diagrams for study area evidently point out the rock dominance as the main hydrogeochemical controlling mechanism along with some inputs of anthropogenic activities observed through presence of NO_3^- . The correlation matrix is showing low correlation between K^+ with NO_3^- and SO_4^{2-} suggesting the non-lithological source, indicating the agricultural fertilizers and domestic wastewaters. While, Na^+ has strong positive correlation with both Cl^- and SO_4^{2-} , which is also indicative of presence of pollution in groundwater of the study area, may be 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 purpose. The suitable TH, values indicate that groundwater samples from study area are appropriate for the domestic purpose without hesitation. The 8 parameters were involved in present study for inferring the suitability of groundwater for irrigation purpose are: SAR, %Na, RSC, RSBC, SSP, CR, KR, K. the values computed for these parameters clearly point out that groundwater from study area is also suitable for irrigation purpose with negligible exceptions.

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