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Assessment of Groundwater Quality in Dakshin Mand River Basin, District Satara, Maharashtra (India)

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ABSTRACT

The aim of present study is the analysis of hydrochemical groundwater samples from Dakshin Mand river basin for the suitability of agriculture and drinking purpose. For this purpose 22 representative groundwater samples were collected from dugwells in the Dakshin Mand river basin. Dakshin Mand River is the tributary of Krishna River which covers an area about 213.10 km^2. It is 5th order stream basin having 15.04 km length running over Deccan Trap basalts. The physicochemical parameters such as pH, EC, TDS, Hardness, Ca^{++}, Mg^{++}, Na^+, K^+, $HCO3^-$, Cl^-, SO_4^{2-} and NO_3^- were determined from the groundwater samples. All the obtained results were compared with standard limits recommended by Bureau of Indian Standards (BIS) and World Health Organizations (WHO). Sodium adsorption ratio (SAR), Sodium Percent (Na %), Kelly Ratio (KR) and Residual Soluble Carbonate were used for assessing the suitability of groundwater for irrigation purpose. The sequence of major cations and anions dominance in groundwater from the study area have been observed as $Ca^{++} > Na^+ > Mg^{++} > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$, respectively. The results exhibited water quality deterioration due to anthropogenic activity such as excessive use of fertilizers in agricultural practices and improper waste water drainage system in the studied area.

KEYWORDS: *Hydrochemistry, physicochemical parameters, irrigation water quality, Deccan Basalt, Dakshin Mand River.*

INTRODUCTION

Groundwater is the major fresh water resource with nearly balanced concentration of the salts for human consumption and which is widely used for industry, irrigation and domestic purposes. Groundwater chemistry can be modified by many processes, viz. 1) Atmospheric action in which precipitation and climatic changes are involved. 2) Geogenic activities include weathering and erosional processes of crustal rocks 3) Anthropogenic action in which industrial, domestic and agricultural pollution are included (Kannan and Joseph, 2010; Prasanna et al., 2011). Most of the population in India is depends on groundwater and hence its quality is the major concern related with drinking and agricultural application. Rapid growth of population and industrialization increases demand of groundwater which causes overexploitations of groundwater which causes decline of its level (Rai et al., 2011) along with its pollution (Golekar et al., 2013). Therefore assessment of groundwater quality is much more important because of it is directly connected with human health. Soil productivity and fertility has been affected by groundwater contamination, when waste water is used in agriculture without any treatment (Golekar et al., 2013). Assessment of groundwater quality has been successfully done by many authors (Gupta and Gupta, 1999; Rajas et al., 2005; Rajan and Paneerselvam, 2005; Thakare et al., 2005; Shikha et al., 2007; Golekar et al., 2014; Suryawanshi et al., 2016). The objective of this work is to assess the quality of groundwater of different villages included in Dakshin Mand river basin, which is used for drinking as well as agricultural purposes.

Groundwater is ultimate and most suitable fresh water resource for human consumption in both urban as well as rural areas. Recent year water pollution is an important issue for the environmental aspects especially in urban areas (Golekar et al., 2013). Dakshin Mand River basin has been chosen for hydrogeochemical analysis which is one of the tributary of the river Krishna. The sugar factories and waste water from human settlement areas are responsible for disposing treated and untreated effluents in the Mand river drainage system. This has lead to widespread groundwater contamination. Thus, it is very essential to verify the levels of water pollution and protect this valuable resource so considering this aspect 22 water sampling sites has been selected from Dakshin Mand river basin area and analyze various physicochemical parameters.

Dakshin Mand River basin covers an area about 213.10 km^2 in Karad taluka of Satara district, Maharashtra, India (Fig. 1). The study area of Dakshin Mand basin is bounded by latitudes 17°05' to 17°14' N and longitudes 73°58' to 74°11' E. It forms part of SOI toposheets 47 K/4 and 47 G/16 on the scale 1:50,000. Climate of study area is tropical with three distinct seasons. Temperature varies in the range 39˚C to 42˚C in summer and 12˚C to 20˚C in winter. In monsoon, study area receives 500 to 600 mm rainfall in between period of mid June to mid October.

Geology and Hydrogeology of the study area

Basalt is a main lithological unit in study area which comprises nearly horizontal lava flows of late Cretaceous to early Eocene and intermittent red boles between older and younger lava flows. The Deccan Volcano has erupted close to Cretaceous-Tertiary (K/T) boundary at about 65 Ma (Duncun and Pyle, 1988) and about 500,000 km^2 area of western and central India today is covered by basalt. The type of basaltic lava flows occurring in the studied area as simple type of lava (Aa-Aa type). Gray coloured compact and massive basalt which exhibits fine grained porphyritic texture were observed at few places. Red bole is composed of reddish or reddish brown coloured fine clay with zeolitic pyroclastic boulders which is formed due to weathering of neighboring basalt and volcanic ashes were also observed in the studied area (Ghosh et al., 2006; Wilkins et al., 1994). Different structures of basalt are observed in the study area in which spheroidal weathering is common features. Columnar joints are also found at some places which are formed due to contraction of lava during solidification. Weathered basalt with vertical and inclined joint pattern was observed in basalt, which increases porosity and transmissivity (Deolankar, 1980).

MATERIALS AND METHODOLOGY

The groundwater samples were collected during the month of February (2017) from dugwells in catchment area of Dakshin Mand river basin. The total 22 water samples were collected from private and public water supply system wells of that particular village. Water samples were collected in well cleaned one liter polyethylene sample bottles. The sample locations (longitude and latitude) and altitude of the wells were recorded by the Global Positioning System (Table 1). Water sample collection and the analysis were essentially done by adopting standard procedure (APHA, 1995). pH, EC and TDS were measured immediately on digital water analysis field kit while other parameters such as Ca^{++}, Mg^{++}, Na^{+}, K^{+}, $HCO3^{-}$, Cl^{-}, SO_4^{2-} and NO_3^{-} were determined in the laboratory of Department Geology, Savitribai Phule Pune University, Pune. The obtained data from geochemical analysis were compared with standards prescribed for drinking and irrigation purpose by Bureau of Indian Standards (BIS, 2003) and World Health Organizations (WHO, 1984). Aquachem geoscientific software was used for drawing the various plots like piper trilinear diagram and US Salinity Diagram.

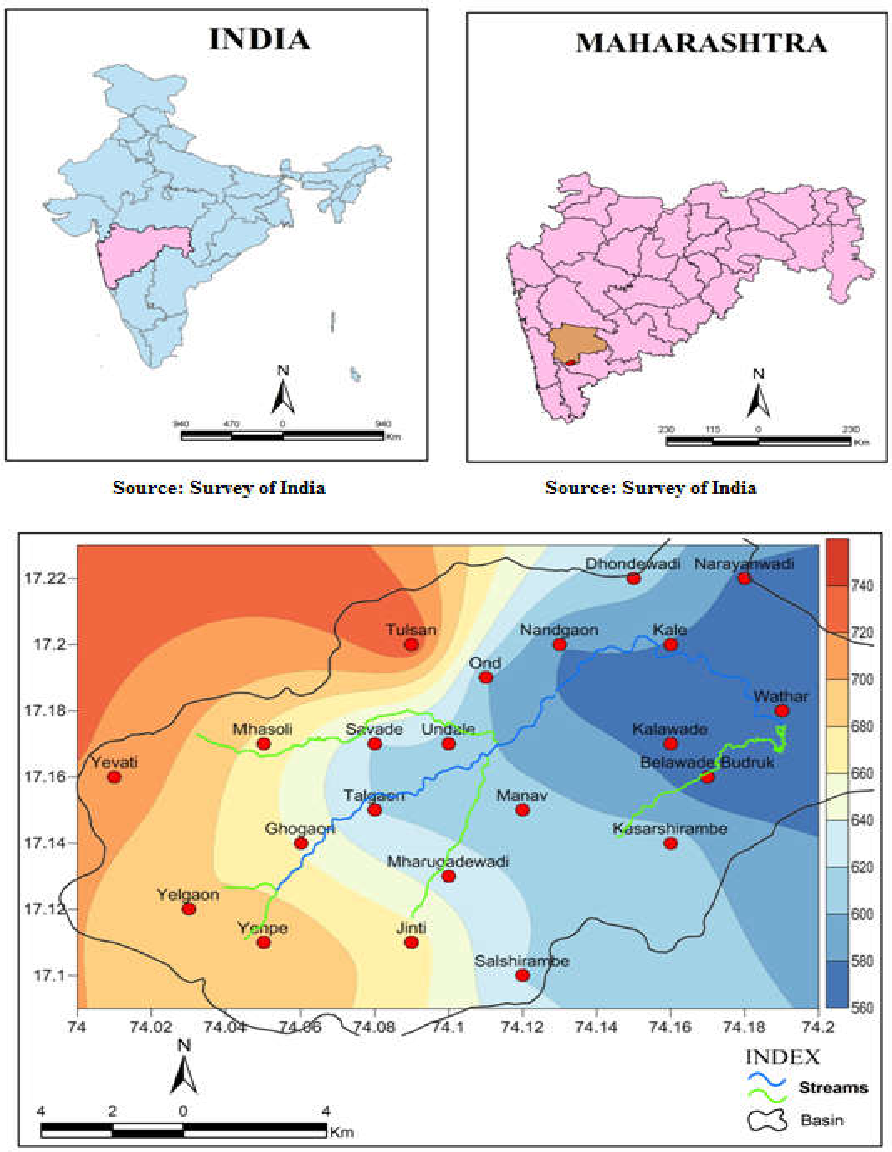

Figure 1: **Location map of the water sampling stations from Dakshin Mand River basin**

RESULT AND DISCUSSION

Analytical result of physicochemical parameter in groundwater samples of the study area were presented in Table 1. The result of irrigation water quality parameters, cation-anion balance and water type of the studied area were presented in Table 2.

Groundwater quality assessment for drinking purpose

Scale which runs from 0 to 14, was used to measure the pH of the water samples. Water sample is said to be acidic when pH value is below 7 while basic when pH value is above 7. Water sample is termed as neutral when measured pH value is 7. The pH value below 6.5 and above 8.5 is considered as aesthetic (WHO, 1984). pH values in the study area ranged from 7.0 to 7.6 with an average of 7.5. Electrical conductivity value below 1500 (µS/cm) can be considered as safe for drinking. A greater than 1500 µS/cm of groundwater can be considered as saline (WHO, 1984; Mondal et al., 2011). Electrical conductivity value of groundwater sample ranged from 484 to 2990 with an average of 1296.6 (µS/cm). Samples from Ond, Wathar, Kalawade, Savade and Kale villages were observed above 1500 (µS/cm). This shows that the water from this well is not within the acceptable limit. Total dissolved solid present in the groundwater when below 500 mg/L (WHO, 1984) can be considered as fresh and safe for drinking. Most of the water samples from the studied area were observed beyond the desirable limit of TDS except five water samples (2, 4, 7, 16 and 22).

Total Hardness is defined as the concentrations of calcium and magnesium ions. A total hardness value varies from 204 to 604 mg/L which indicates that all water samples from Dakshin Mand river basin were crossed the desirable limit of hardness (200 mg/L, WHO -1984). Cl^- values below 200 (mg/L) are considered as suitable for drinking (WHO, 1984). The value of Cl^- ranged from 31.1 to 551.4 mg/L. Nearly 50 percent water samples showing higher Cl^- values than desirable limit (200 mg/L, WHO-1984). SO_4^{2-} values below 200 (mg/L) are considered as suitable for drinking (WHO, 1984). Value of SO_4^{2-} ranged from 15.4 to 311.9 mg/L. The concentration of SO_4^{2-} in Kale and Kalawade villages were observed beyond the desirable limit.

Ca^{2+} and Mg^{2+} are considered as one of the major ions in fresh groundwater. The desirable limits of Ca^{2+} and Mg^{2+} for safe drinking are up to 75 and 30 (mg/L), respectively, according to WHO guidelines (WHO, 1984). Values of theses major ions ranged from 36.8 to 321.7 mg/L (for Ca^{++}) and 13.9 to 74.6 mg/L (for Mg^{++}). Ca^{++} values from all water samples beyond the desirable limit except village Kasarshirambe whereas Mg^{++} values of Wathar, Jinti, Ghogaon, Mhasoli, Undale, Belawade Budruk, Mharugadewadi, Yenape, Yevati, Tulsan, Talgaon and Ond were within the desirable limit. The main cause of higher concentration of calcium is due to Deccan Trap basalt. In basalt, calcium predominantly held in plagioclase feldspar, a solid solution series with anorthite ($CaAl_2 Si_2O_8$) and albite ($NaAlSi_3O_8$) as an end member. The zeolites occurring in the Deccan Traps as secondary minerals and montmorillonite clays holding calcium as an absorbed ion on the mineral surface in soils and rocks may also contribute the calcium into groundwater from the study area (Kumbhar et al., 2017). The basalts is mainly composed of augite minerals, due to weathering of basalts can contribute the magnesium ions in the groundwater from the study area. Hydrochemistry data of water samples indicates that the values of K^+ (< 10 mg/l) and Na^+ (< 200 mg/l) in all water samples within the desirable limits (WHO 1984; Mondal et al., 2011). Only the exceptional case is sample 10 (Undale village) have 101.6 mg/L K was present.

Table 1: Physico-chemical parameters of groundwater samples from Dakshin Mand river basin

Sample ID	Location	Longitude	Latitude	Altitude	pH	EC	TDS	Hardness	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{-}
					-	µs/Cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	Wathar	74.19	17.18	570	7.42	1898.0	1214.7	331.0	178.9	29.6	108.1	0.2	257.5	185.2	260.4	87.3
2	Narayanwadi	74.18	17.22	576	7.56	602.0	385.2	349.0	126.4	34.3	62.9	0.2	284.1	146.7	87.5	23.3
3	Kale	74.16	17.2	579	7.62	2990.0	1913.6	604.0	236.7	74.6	127.0	2.1	551.4	311.9	140.2	11.5
4	Dhondewadi	74.15	17.22	610	7.31	552.0	353.2	440.0	176.8	34.9	45.4	0.2	243.4	143.4	80.1	97.4
5	Ond	74.11	17.19	601	7.53	1803.0	1214.7	342.0	189.8	30.0	48.7	7.8	216.4	85.1	380.1	31.0
6	Savade	74.08	17.17	619	7.59	2865.0	1833.6	370.0	121.1	37.5	34.4	0.2	96.7	60.9	268.4	79.5
7	Tulsan	74.09	17.2	740	7.38	484.0	309.7	307.0	105.1	29.0	20.7	2.8	92.3	40.8	240.8	50.8
8	Mhasoli	74.05	17.17	673	7.51	1232.0	788.4	249.0	128.1	21.5	11.8	0.7	47.3	30.2	410.9	33.4
9	Yevati	74.01	17.16	716	7.42	1103.0	705.9	326.0	96.8	27.9	19.7	0.3	49.8	51.9	300.5	9.8
10	Undale	74.1	17.17	615	7.59	1437.0	919.6	284.0	174.9	22.1	27.5	101.6	259.0	91.1	340.3	36.1
11	Talgaon	74.08	17.15	620	7.61	1312.0	839.6	316.0	142.7	29.3	22.4	1.0	102.1	81.8	370.4	33.1
12	Ghogaon	74.06	17.14	657	7.58	1470.0	940.8	235.0	122.8	16.3	14.7	1.1	59.4	29.3	360.8	7.5
13	Yelgaon	74.03	17.12	679	7.27	958.0	613.1	304.0	108.4	26.8	18.9	0.3	48.1	19.2	360.9	24.1
14	Yenpe	74.05	17.11	700	7.01	706.0	451.8	292.0	105.7	25.1	39.2	0.1	45.3	56.2	340.5	10.8
15	Nandgaon	74.13	17.2	581	7.62	1141.0	730.2	419.0	147.7	44.9	49.4	14.7	207.6	89.4	365.2	35.7
16	Manav	74.12	17.15	610	7.22	709.0	453.7	384.0	182.6	33.8	54.8	8.5	241.0	78.2	400.6	28.6
17	Salshirambe	74.12	17.1	619	7.42	965.0	617.6	349.0	123.9	31.1	27.7	0.9	106.7	49.9	245.1	66.9
18	Mharugadewadi	74.1	17.13	630	7.56	1340.0	875.6	274.0	96.7	24.5	16.6	2.1	39.1	35.3	297.1	17.6
19	Jinti	74.09	17.11	670	7.62	1159.0	741.7	204.0	104.7	13.9	11.0	0.4	31.1	15.4	330.5	22.4
20	Kalawade	74.16	17.17	574	7.31	1987.0	1271.6	424.0	321.7	39.3	62.3	1.5	415.2	278.5	320.5	13.8
21	Belawade (Bk)	74.17	17.16	565	7.53	1192.0	762.8	334.0	147.6	23.6	43.8	0.5	206.6	112.5	160.3	76.7
22	Kasarshirambe	74.16	17.14	610	7.59	621.0	397.4	571.0	36.8	70.1	125.4	2.4	215.5	95.7	156.4	96.8
Maximum		-	-	-	7.6	2990.0	1913.6	604.0	321.7	74.6	127.0	101.6	551.4	311.9	410.9	97.4
Minimum		-	-	-	7.0	484.0	309.7	204.0	36.8	13.9	11.0	0.1	31.1	15.4	80.1	7.5
Average		-	-	-	7.5	1296.6	833.4	350.4	144.4	32.7	45.1	6.8	173.4	94.9	282.6	40.6
WHO desirable limit		-	-	-	6.5 - 8.5	750	500	2000	75	30	200	100	200	200	-	45
BIS desirable limit		-	-	-	6.5 - 8.5	-	1000	300	75	30	-	-	250	400	-	100

Altitude in m.amsl = meter above mean sea level; Latitude and Longitude were given in decimal units of degree minute

Table 2: Cation and anion difference in meq/L, Irrigation water quality parameters and water type of groundwater samples from Dakshin Mand river basin

Sample ID	Sum Cation (meq/L)	Sum anion (meq/L)	Cation anion Difference (meq/L)	SAR	SSP	KR	RSC	Water type
1	16.10	16.79	-0.69	0.70	29.34	0.42	-7.10	Ca-Na-Cl-HCO_3-SO_4
2	11.88	12.87	-0.99	0.45	23.12	0.30	-7.70	Ca-Mg-Na-Cl-SO_4
3	23.55	24.51	-0.96	0.65	23.60	0.31	-15.65	Ca-Mg-Na-Cl-SO_4
4	13.69	12.73	0.96	0.29	14.49	0.17	-10.39	Ca-Mg-Cl-SO_4
5	14.28	14.60	-0.32	0.31	15.11	0.18	-5.72	Ca-HCO_3-Cl
6	10.64	9.67	0.96	0.25	14.13	0.16	-4.73	Ca-Mg-HCO_3-Cl
7	8.61	8.22	0.39	0.16	10.59	0.12	-3.68	Ca-Mg-HCO_3-Cl
8	8.70	9.24	-0.54	0.09	5.93	0.06	-1.43	Ca-HCO_3
9	7.99	7.57	0.43	0.16	10.77	0.12	-2.20	Ca-Mg-HCO_3
10	14.36	15.35	-1.00	0.18	10.21	0.11	-4.98	Ca-Cl-HCO_3
11	10.54	11.19	-0.65	0.16	9.30	0.10	-3.46	Ca-Mg-HCO_3-Cl
12	8.15	8.32	-0.17	0.12	7.91	0.09	-1.56	Ca-HCO_3-Cl
13	8.45	8.06	0.39	0.15	9.78	0.11	-1.70	Ca-Mg-HCO_3
14	9.06	8.20	0.85	0.32	18.91	0.23	-1.76	Ca-Mg-HCO_3
15	13.60	14.27	-0.67	0.32	16.31	0.19	-5.08	Ca-Mg-HCO_3-Cl
16	14.51	15.45	-0.94	0.35	16.74	0.20	-5.33	Ca-Cl-HCO_3
17	9.98	9.14	0.83	0.20	12.15	0.14	-4.73	Ca-Mg-HCO_3-Cl
18	7.62	6.99	0.63	0.14	9.58	0.11	-1.97	Ca-Mg-HCO_3
19	6.86	6.98	-0.11	0.10	7.01	0.08	-0.96	Ca-HCO_3
20	22.07	22.97	-0.91	0.31	12.35	0.14	-14.05	Ca-Cl-SO4-HCO_3
21	11.24	12.03	-0.79	0.31	17.04	0.21	-6.69	K-Mg-SO_4-Cl
22	13.12	12.19	0.93	0.99	41.92	0.72	-5.02	Mg-Na-Cl-HCO_3
Maximum	23.55	24.51	0.96	0.99	41.92	0.72	-0.96	-
Minimum	6.86	6.98	-1.00	0.09	5.93	0.06	-15.65	-
Average	12.04	12.15	-0.11	0.31	15.29	0.19	-5.27	-

Sum = Summation; SAR = Sodium absorption ratio, SSP= Soluble sodium percentage; KR = Kelley's ratio; RSC = Residual soluble carbonate

NO_3^- is most important parameter for assessing the quality of water because the high concentration nitrate in drinking water is risk especially for infants. The source of nitrate is usually seepages from fertilized soil, decaying of plant materials and flooding of the area during monsoon and getting contaminated with fecal material (human waste) a common habit of the villagers. Higher concentration of nitrate in water may be due to extreme use of nitrogenous fertilizers, human waste, animal wastes and manure (Janardhana et al., 2009). The nitrate concentration in water samples from the study area shows ranged from 7.5 to 97.4 mg/L. The desirable limit of NO_3^- for drinking purpose is 45 mg/L (WHO, 1984), it is seen that about 07 water samples were observed beyond the desirable limit. Most of the study area is cultivated by the sugarcane crop. Farmers in the study area usually use chemical fertilizers for better yield such as urea, DAP (Di ammonium phosphate) which contains nitrogen. Excessive use of nitrogenous fertilizers may cause of increase nitrate content in soil and by infiltration in rainy season meets to groundwater aquifers (bore well and dug well) and runoff to the surface water (river), which increases nitrate concentrations in water bodies. Use of such type of nitrate contaminated water for drinking may cause of disease like Methemoglobinemia which is also known as blue baby.

Groundwater quality assessment for Irrigation purpose

For proper growth of crops the adequate amount of water should be given to them hence it became important to supply good quality of water to the crops which is within permissible limit so as to avoid adverse effect on plant. Presence of dissolved salts and their concentration changes the quality of irrigation water. Assessment of the suitability of groundwater for agricultural purpose is mainly based on the estimation of parameters like Sodium absorption ratio (SAR), soluble sodium percent (SSP), Kelly's ratio (KR) and residual soluble carbonate (RSC).

Sodium absorption ratio (SAR)

SAR is calculated by using the following formula (Richard, 1954):

$$SAR = \frac{Na}{\sqrt{(Ca+mg)/2}} \text{ (All values are in meq/L)} \qquad (1)$$

SAR values in water samples ranged from 0.09 to 0.99, which suggest that all the water samples fall under excellent category because ratio less than 10 (Raghunath, 1987).

Residual soluble carbonate (RSC)

RSC is expressed in meq/l units. RSC should not be higher than 1 and preferably less than +0.5 for considering the water use for irrigation. The following formula was used for calculating RSC (Lloyd and Heathcote 1985).

$$\text{RSC index} = [HCO_3 + CO_3] - [Ca + Mg] \qquad (2)$$

RSC ranging from -0.96 to -15.65 with an average percentage is about -5.27. This indicates that all the water samples are of good quality and suitable for irrigation purpose.

Soluble sodium percent (SSP)

SSP was calculated by formula (Todd, 1959),

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

SSP ranging from 5.93 to 41.92 % with average percentage is about 15.29 %. This indicates that all the water samples are of good quality and suitable for irrigation purpose.

Kelley's ratio (KR)
Kelly's ratio is used to calculate quantity of Na^+ against $Ca^{2+}$and Mg^{2+}. The formula used to calculate Kelley's ratio is as follows,

$$KR = \frac{Na}{Ca + Mg} \quad \text{(Kelley et al., 1940)} \qquad (4)$$

Ratio more than one indicates an excess amount of sodium in water, hence water having Kelley's ratio less than one is suitable for irrigation. Kelley's ratio for the study area ranges from 0.06 to 0.72, which suggest suitability of groundwater samples for irrigation purpose.

Graphical representations of water quality data

Piper Trilinear Diagram (1944)
For study of hydrogeochemical facies of groundwater from the study area, the Hill-Piper diagram was used. The Piper Trilinear diagram shows the water type in the study area depicted in Fig. 2. The HCO_3^--Cl^--SO_4^{2-} anion triangle plot show that groundwater samples have bicarbonate dominant with small amount of chloride while Ca^{++}-Mg^{++}-Na^+ cation triangle plot characterized with dominance of Ca^{++} in water samples.

US Salinity Hazard diagram (Wilcox, 1955)
The data plotted on the USSL diagram (Fig. 3) indicates the type of salinity hazards. It is observed that, 06 samples plots in C2S1 category suggesting low sodium and medium salinity hazards and 14 samples fall in C3S1 type suggesting low sodium and high salinity hazards while 2 samples settles in C4S1 type indicates low sodium very high salinity hazard.

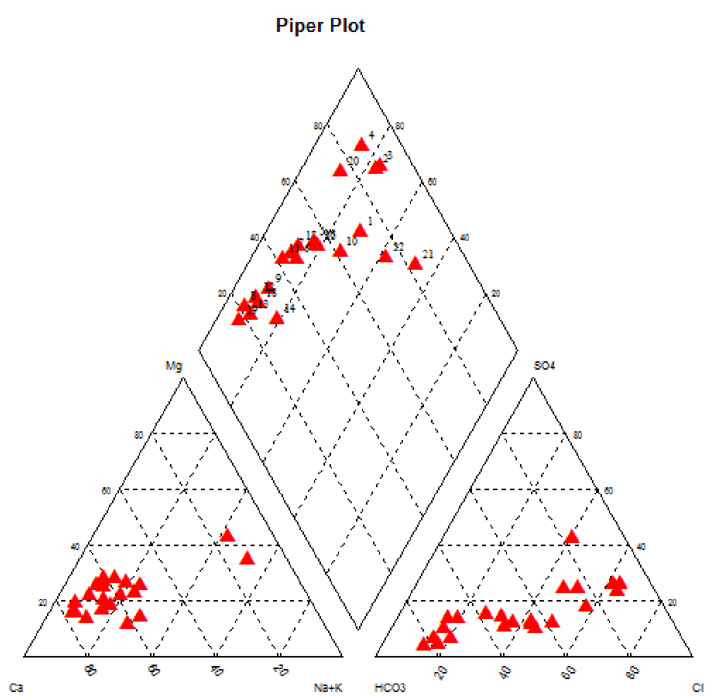

Figure 2: **Piper diagram of water sampling stations from Dakshin Mand River basin**

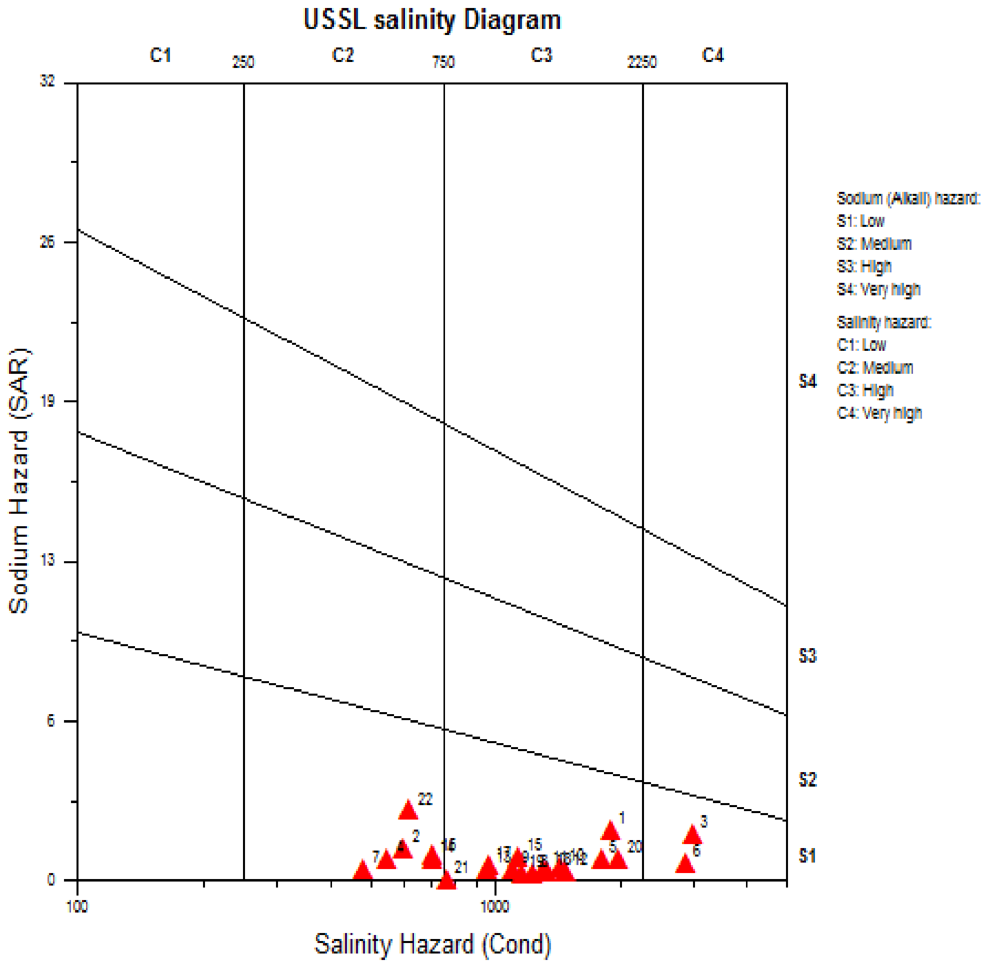

Figure 3: **USSL salinity diagram of water sampling stations from Dakshin Mand River basin**

CONCLUSION

Ca^{++} is the dominant cation in all analysed water samples while bicarbonate and chloride observed as major anion. pH were observed within the permissible limit. Na^{+} and K^{+} values shows that all water samples were observed within the desirable limit which suggests that analysed water is suitable for drinking purpose, except the village Undale where K^{+} concentration is higher than 101.6 mg/L. Ca^{++} with SO_4^{2-} ions contributed in groundwater from the Dakshin Mand river basin due to large scale use of gypsum as chemical fertilizer for sugarcane crops. Groundwater quality is adversely affected at many places due to higher concentration of nitrates. Adequate measures needs to be taken to avoid sanitary practices in open to control the nitrate contamination in the Dakshin Mand basin. Based on results of irrigation water quality parameters such as Sodium absorption ratio (SAR), Soluble Sodium Percent (SSP), Kelly's ratio (KR) and Residual soluble carbonate suggest that all the water samples from study area are suitable for agricultural use.

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