



Hydrospatial Analysis

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Original Research Paper

Assessment of Groundwater Geochemistry of Vel River basin, Western Maharashtra, India



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Abstract

To study the chemistry of major ion in groundwater from Vel (Velu) River basin, sixty (60) samples of dug wells and bore wells were collected and analyzed using standard techniques given by APHA. It shows order of dominance for cations, $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and in anionic concentration as $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ in groundwater. The pH of groundwater is slightly alkaline (range: pH 7.0 - 8.1), while average values of Electrical Conductivity (EC) is about 2641 $\mu\text{S}/\text{cm}$ indicating high mineralization of groundwater. In general, the cationic concentration (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) of the groundwater increase in the downstream side (from Northwest to South east), suggesting geological control on the composition of groundwater while highest concentration is in lower part of the basin are generally associated with the high salinity. In the major anions, bicarbonate (HCO_3^-) is higher due to rock-water interaction. Average value of chloride is about of 235 mg/L due to discharge zones along with anthropogenic activities. The geochemical data plotted on Piper Trilinear Diagram is showing dominant hydro-chemical facies: $\text{Ca}^{2+} + \text{Mg}^{2+}$, $\text{Na}^+ + \text{K}^+$, $\text{Cl}^- + \text{SO}_4^{2-}$ - HCO_3^- found in 83.3 % samples indicating the alkaline earth exceeding the alkalis and the strong acids exceeds the weak acids. The pH, Total Hardness (TH) and Magnesium (Mg^{2+}) of the samples show more proportion of samples falling above desirable limit. Otherwise the quality of groundwater is good for drinking. The irrigation indices like SAR, KR and SSP were considered to evaluate groundwater suitability for irrigation. Comparing with SAR parameter all samples are excellent to good for irrigation. In SSP, 33.3 % samples are within permissible, while 66.6% samples are doubtful for irrigation purpose. In KR almost all samples (excluding 04 samples in lower side of basin) are suitable for irrigation. So, variations in climate, geology with anthropogenic activities are modifying the groundwater geochemistry of Vel River Basin.

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1 INTRODUCTION

In freshwater, groundwater is very important source on the earth (Brindha et al., 2011) and it is major source for drinking in the rural parts of the developing nations (Brindha et al., 2010; Wagh et al., 2016). The chemistry of groundwater modifies by natural and anthropogenic activities (Wagh et al., 2018). Rock weathering and its dissolution is the most important mechanism that modifies the chemistry of groundwater (Weijden and

Pacheco, 2006; Pawar and Nikumbh, 2007). Along with it, interaction of water with aquifer minerals along the flow path in the sub-surface and evaporation and precipitation of surface waters also modifies its chemistry (Domenico, 1972; Wallick and Toth, 1976; Adimalla et al., 2018; Kadam et al., 2020; Mukate et al., 2020; Kumari and Rai, 2020). Geochemical scatter plots give important clues about the sources of ions

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and pollution in groundwater (Pawar et al., 2008; Wagh et al., 2018; Wagh et al., 2019; Gaikwad et al., 2020).

Due to rapid rise in and growth of agricultural and industrial sectors and demand of groundwater has increased in many folds (Brindha and Elango, 2014; Adimalla et al., 2018; Wagh et al., 2020). Due to this development, pollution of water bodies has been increasing (Brindha and Elango, 2014; Adimalla et al., 2018). If groundwater contains dissolved ions more than standard limit, then it is harmful and unsuitable for use (Pawar et al., 2008; Brindha et al., 2011; Wagh et al., 2019a; Wagh et al., 2020; Kadam et al., 2020; Mukate et al., 2020). So the quality of groundwater for drinking as well as for irrigation purpose also can be studied comparing it with WHO standards and using different parameters like Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Kelly Ratio (KR), respectively.

In absence of any scientific work in the area under investigation except some government organizations like CGWB (2013) and GSDA (2003) and Gaikwad et al., (2018), it is necessary to find out sources and pathways of migration of these ions in the groundwater.

The objectives of this study are to understand the spatial-temporal distribution of major ion in groundwater as well as to identify the geogenic as well as anthropogenic pollution sources in it and to investigate the groundwater quality for drinking and irrigation purposes.

2 STUDY AREA

Study area is Vel (Velu) River basin; a small tributary of Bhima River flows through Pune district (Figure 1). It originates near Matewadi and meets to the Bhima River near the Vitthalwadi. Vel River is on the Northern side of Pune city. Major localities in the basin are Shikrapur, Talegaon Dhamdhare, Peth, Wafgaon, Varude, Vitthalwadi and Pargaon. The basin is bound by 73° 50' to 74° 10.5' E longitudes and 18° 37' to 19° 00' N latitudes and it is a part of Survey of India's (SOI) toposheets No. 47 F/13, 47 J/1 and 47 J/2 of scale 1: 50,000. The study area is about 352.13 sq.km. The major water harvesting structures includes Pargaon and Thitewadi Bhandhra. The average annual precipitation of the basin is about 650 mm (Supekar, 2011). It is also observed that the rainfall is moderately heavy in western part of the study area and decreases rapidly towards lower part of the basin. The temperature ranges from 10 to 32 °C in the basin.

3 MATERIALS AND METHODS

3.1 Geology

The study area is a part of the Deccan Volcanic Provinces (DVP). The DVP covers an area of more than 500,000 km², in central and western India (Powar, 1987). The many workers have studied DVP from chemostratigraphy, mineralogy and geochemistry point of view including Beane et al. (1986), Mitchell and Widowson, (1991), Subbarao et al. (1988), Subbarao et al. (1994), Sethna et al. (1996) and Melluso et al. (1999), etc.

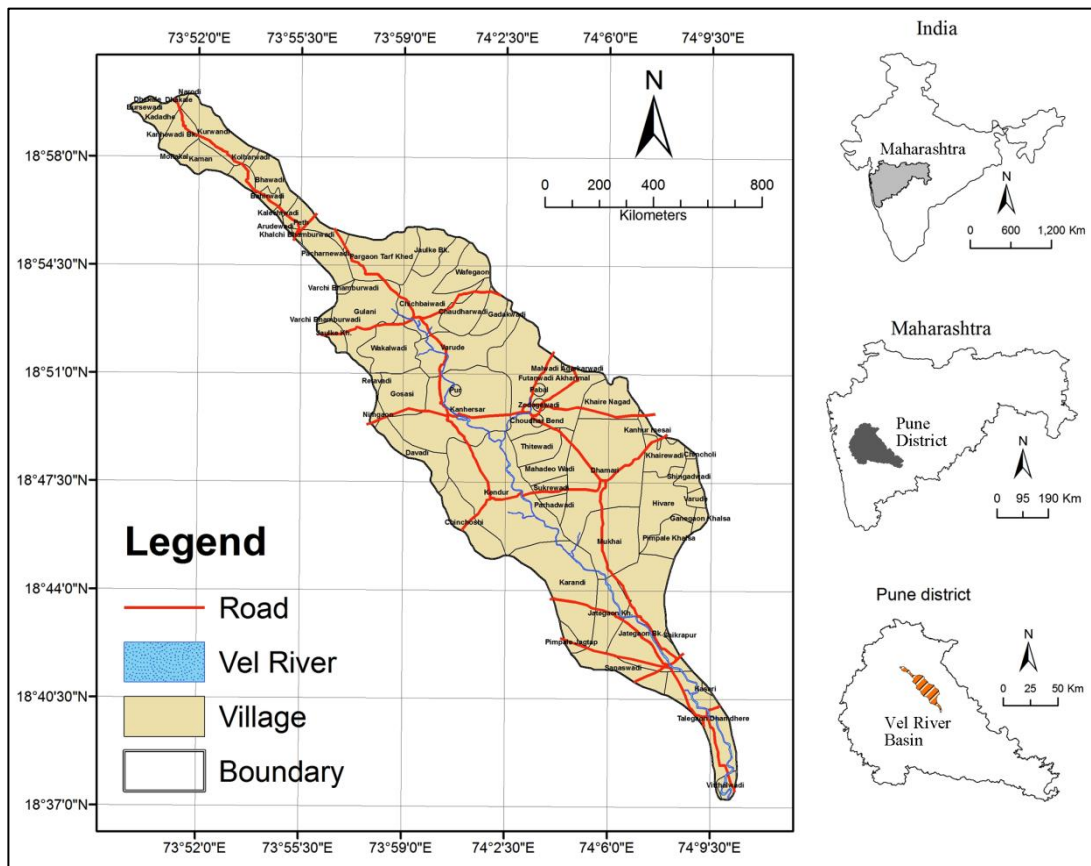


Figure 1. Study area: Vel (Velu) River basin, Maharashtra (India)

The major lithologies exposed in the Vel basin of Lonavala and Diveghat Subgroup of Deccan Trap Supergroup (Figure 2).

The Indrayani and Karla Formation are part of Lonavala Subgroup while Diveghat Formation is from Diveghat Subgroup (GSI, 2001). Diveghat Formation overlies the Karla Formation. It is exposed in the western and north-eastern regions of the study area. Outcrops of this formation are witnessed on the hills and along the hill slopes above 700 m AMSL (Supekar, 2011). It comprises mainly aphyric simple flows of AA type (GSI, 2001). Lava flows of this formation are characterized by presence of vesicular, plagioclase basalt with medium grained groundmass. It is parted from the upper formation by a geomorphic break (Godbole *et al.*, 1996). The Karla Formation occurs mostly in the central part of basin and overlying the Indrayani Formation. It essentially comprises of compound lava flows revealing pahoe-hoe characters (GSI, 2001). The Indrayani Formation is exposed in throughout the study area comprising of simple flows covering more than 80% of the total area.

3.2 Water Samples and Chemical Analysis

The sampling sites were selected to cover accessible part of the Vel River basin. Sixty (60) groundwater

samples of wells and bore wells in different formations were collected using standard procedure for major ions analysis (APHA, 2005; CGWB, 2012; Wagh *et al.*, 2016; Gaikwad *et al.*, 2018; Gaikwad *et al.*, 2020a). The location of water sampling stations in Vel River basin is shown in Figure 3.

Volumetric method was employed for analysis of total alkalinity, total hardness and chloride of water samples from study area are analyzed using the standard methods given by APHA (2005). For the determination of total alkalinity of groundwater samples, acidic-base titration method was used. While for determination of chloride, precipitation argentometric method of titration was used. The complexometric method of titration with EDTA (disodium salt) was used for the analysis of total hardness of groundwater. Sodium (Na^+), Potassium (K^+) and Calcium (Ca^{2+}) were analyzed on the Photometer (Systronics, Make in India) in the Geochemistry Lab, in the Geology Department of Savitribai Phule Pune University (India). While Magnesium (Mg^{2+}) analyzed by gravimetric analysis with the standard methods (APHA, 2005). Anions (Cl^- , HCO_3^- and SO_4^{2-}) were analyzed on High Performance Ion Chromatography (HPIC) using standard Method (Gaikwad *et al.*, 2020b). The physico-chemical analysis of water sample is shown in the Table 1.

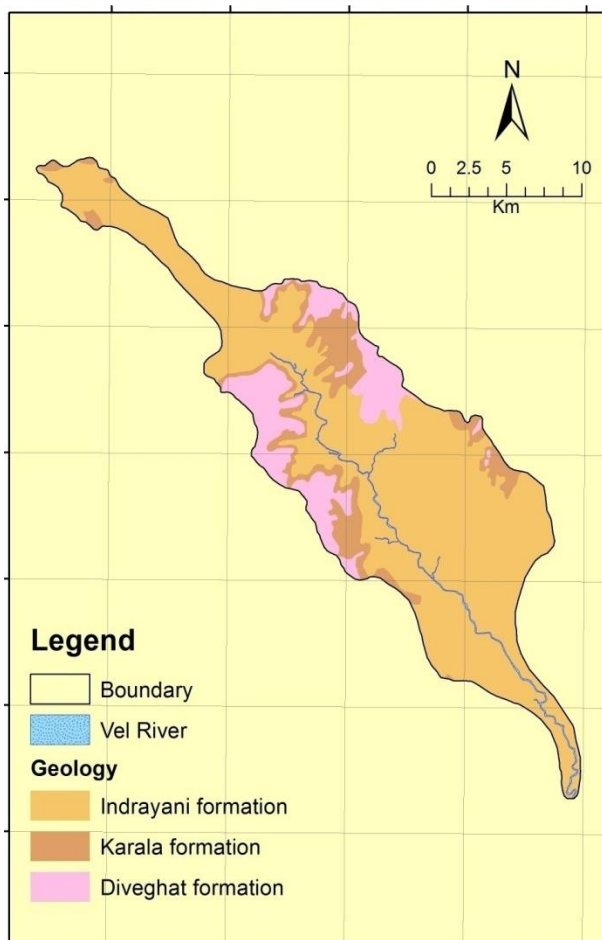


Figure 2. Geology

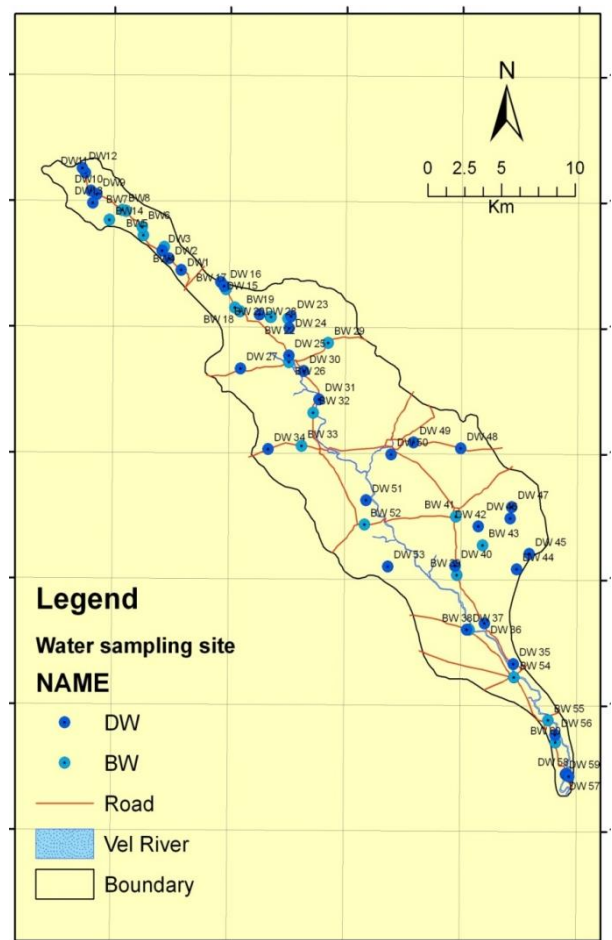


Figure 3. Distribution of groundwater samples

Table 1. Physicochemical analysis of groundwater samples

Sr. No	Ele.(m)	latitude	longitude	pH	EC	TDS	HCO ₃ ⁻	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	SO ₄ ²⁻	TH	CBC%	SSP	Kelly ratio	SAR
DW1	779	18°56.028'	73°55.134'	8	715	458	305	62.7	0.3	39.1	35.1	72.4	13.1	242.29	1.76	36.02	0.56	1.75
DW2	795	18°56.450'	73°54.653'	7.6	925	592	350	67	0.04	56.2	32.4	79.5	11.5	273	1.01	34.89	0.54	1.76
DW3	803	18°56.720'	73°54.394'	7.5	847	542	330	60.2	0.08	48.3	38.4	76.7	12.3	278.66	2.25	31.99	0.47	1.56
BW4	801	18°56.852'	73°54.474'	7.2	1198	767	380	97.6	1.56	65.3	51.4	122	12.6	374.82	4.6	36.09	0.56	2.19
BW5	816	18°57.267'	73°53.662'	7.2	955	611	420	68.4	0.07	72.2	45.4	82.4	11.5	367	4.44	30.58	0.44	1.55
BW6	822	18°57.555'	73°53.614'	7.1	1017	651	490	75.5	0.03	58.6	62.3	85	13.4	402.87	2.85	29.01	0.41	1.64
BW7	840	18°58.130'	73°52.993'	7.2	1752	1121	575	170	0.15	85.5	48.5	210	13.9	413.35	0.07	47.25	0.90	3.64
DW8	840	18°58.171'	73°52.832'	7.2	1004	643	375	55.8	0.11	78.3	45.3	72	11.9	4.6	3.69	24.85	0.33	1.26
DW9	859	18°58.720'	73°51.850'	7.2	838	536	330	68.3	0.01	53.7	50.6	72.4	12.3	342.39	4.9	30.28	0.43	1.61
DW10	857	18°58.843'	73°51.625'	7.3	695	445	375	93.9	0.17	46.6	41.5	59.4	12	287.2	3.9	41.55	0.71	2.41
DW11	867	18°59.496'	73°51.399'	8.1	726	465	400	64	0.05	81.5	35.9	72.4	11.5	366.21	4.8	27.55	0.38	1.45
DW12	850	18°59.665'	73°51.287'	7.5	655	419	350	65.5	0.01	45.6	41.4	56.5	11.2	284	5	33.45	0.50	1.69
DW13	841	18°58.421'	73°51.689'	7.3	670	429	325	60.4	0.03	48.2	39.6	54	11.7	294	4.2	31.72	0.46	1.56
BW14	845	18°57.812'	73°52.339'	7.7	894	572	370	59.3	0.3	50.1	45.5	80.9	11.3	312.64	1.44	29.25	0.41	1.46
DW15	785	18°55.798'	73°56.540'	7.3	657	420	325	62.8	0.07	50.2	39.5	56.8	11.1	297.64	1.8	30.43	0.44	1.56
DW16	785	18°55.600'	73°56.704'	7.8	884	566	325	67.1	0.3	42.8	35.3	62.5	10.9	299.6	4.1	35.26	0.54	1.46
BW17	782	18°55.349'	73°56.873'	7.3	1088	696	275	72.1	0.07	55.4	35.3	98	11.4	283.6	4.3	35.64	0.55	1.86
BW18	770	18°54.698'	73°57.218'	7.9	853	546	220	78.3	0.24	35.5	30.4	118	11.3	213.24	3.42	44.46	0.80	2.33
BW19	763	18°54.566'	73°57.424'	7.3	839	537	520	92.3	1.75	40.1	50.5	79.5	11.3	308.05	-3.71	39.43	0.65	2.29
BW20	765	18°54.365'	73°58.596'	7.7	698	447	420	85.6	0.07	30.3	41.4	49.7	10.7	245.94	0.75	43.11	0.76	2.38
BW21	765	18°54.365'	73°58.625'	7.5	656	420	400	78.8	0.03	33.3	42.3	93.7	11.3	257.58	-4.78	40.02	0.67	2.14
BW22	760	18°54.312'	73°59.281'	7.6	928	594	450	95.1	0.86	45.6	40.5	61.1	11.5	280.61	2.23	42.51	0.74	2.47
DW23	750	18°54.398'	73°59.396'	7.3	1249	799	460	78.7	3.23	58.8	61.2	85.2	11.5	398.89	4.61	30.03	0.43	1.71
DW24	742	18°53.971'	73°59.321'	7.9	825	528	355	85.7	0.32	35.5	35.2	44	10.9	233.44	4.12	44.54	0.80	2.42
DW25	726	18°52.997'	73°59.313'	8	832	532	390	84.7	0.18	48.8	53	107	10.9	340.29	4.29	35.11	0.54	2.00
BW26	714	18°52.760'	73°59.317'	7.4	1126	721	425	93.4	0.62	53.4	42.5	92.3	11.2	308.33	2.77	39.73	0.66	2.31
DW27	742	18°52.521'	73°57.450'	7.3	1095	701	520	100	2.36	65.2	53.5	120	11.1	382.9	-0.34	36.36	0.57	2.23
BW28	801	18°54.454'	73°58.171'	7.7	1447	926	425	111	0.02	62.2	52.4	207	12.2	370.95	-3.31	39.41	0.65	2.50
BW29	756	18°53.453'	74°00.832'	7.9	752	481	360	62.3	0.03	34.4	40.4	45.4	11.2	255.14	2.67	34.74	0.53	1.70
DW30	709	18°52.455'	73°59.886'	7.8	979	627	315	75.5	0.17	45.6	39	82.4	11.7	274.29	4.3	37.44	0.60	1.98
DW31	690	18°51.427'	74°00.480'	7.2	1247	798	375	82.2	7.02	52.6	41.3	108	12.7	301.24	1.65	37.27	0.59	2.06
BW32	686	18°50.954'	74°00.273'	7.3	806	516	350	76.4	0.03	51.2	36.3	71	11.8	277.61	4.2	37.47	0.60	2.00
BW33	687	18°49.764'	73°59.823'	7.3	616	394	375	68.6	0.02	38.1	45.1	51.1	11.8	280.84	4.65	34.77	0.53	1.78
DW34	708	18°49.642'	73°58.522'	7.1	885	566	500	91	0.05	50.1	60.2	76.6	11.4	373.2	3.26	34.71	0.53	2.05
DW35	581	18°41.998'	74°08.056'	7.4	1870	1197	425	120	0.19	96.4	56.3	29.6	12	472.22	2.67	39.72	0.66	2.40
DW36	592	18°43.445'	74°06.935'	7.4	1081	692	455	95.6	0.5	62.4	45.5	112	11.9	343.2	0.73	37.78	0.61	2.25
DW37	591	18°43.215'	74°06.245'	7.2	936	599	470	99	1.64	42.1	52	80.9	11.1	319.37	2.43	40.26	0.67	2.41

BW38	617	18°43.215'	74°06.345'	7.6	796	509	395	81.5	0.2	41	48.1	76.2	11	300.58	3.75	37.13	0.59	2.05
BW39	611	18°45.175'	74°05.861'	7.7	980	627	495	110	0.03	58.4	52.5	93.7	12.2	361	4.45	39.95	0.67	2.53
DW40	620	18°45.494'	74°05.786'	7.5	932	596	455	110	0.01	42.1	56.1	90.9	12.1	311.31	3.51	43.51	0.77	2.72
BW41	642	18°47.262'	74°05.807'	7.4	1395	893	470	143	1.56	41.3	52.7	139	11.4	319.98	3.15	49.33	0.97	3.48
DW42	641	18°46.917'	74°06.679'	7.5	860	550	470	78.9	0.02	38.7	51.2	55.4	11.9	307.62	0.37	22.03	0.28	1.96
BW43	625	18°46.240'	74°06.846'	7.2	1880	1203	475	180	2.69	78.3	48.5	78.5	12.2	395.2	-0.9	49.81	0.99	3.95
DW44	610	18°45.389'	74°08.172'	7.5	1670	1069	530	136	0.63	46	86	170	17.3	467	4.8	38.73	0.63	2.73
DW45	623	18°45.940'	74°08.652'	7.8	854	547	745	195	0	52.1	74.6	200	11.1	437	-2.59	49.16	0.97	4.04
DW46	635	18°47.208'	74°07.905'	7.4	1135	726	515	95.2	0.12	68.6	70.4	121	11	461	4.8	31.01	0.45	1.93
DW47	631	18°47.613'	74°07.970'	7.3	1277	817	610	146	0.13	56.9	61.5	116	11.8	395.56	2.58	44.52	0.80	3.19
DW48	673	18°49.701'	74°05.991'	7.5	1350	864	625	98.6	0.04	73	80.9	95.1	12.7	515.39	4.03	29.40	0.42	1.89
DW49	688	18°49.909'	74°04.159'	7.6	638	408	320	45.6	0.02	38.1	41.3	48.3	11.8	265.09	3.01	27.24	0.37	1.22
DW50	666	18°49.477'	74°03.295'	7.4	821	525	425	59.8	0.02	50.2	42.5	63.9	11.3	300.33	-2.27	30.23	0.43	1.50
DW51	649	18°47.827'	74°02.331'	7.3	884	566	355	52.6	0.02	65	48.9	88	11.9	363.08	4.57	23.95	0.31	1.20
BW52	648	18°46.957'	74°02.269'	7	4850	3104	790	201	10.2	10.4	75.5	272	13.5	570.66	-1.12	43.51	0.77	3.68
DW53	635	18°45.466'	74°03.187'	7.8	1450	928	405	69.4	0.4	43.3	46	63.9	13.1	297.6	1.46	25.25	0.34	1.70
BW54	585	18°41.516'	74°08.082'	7.1	1748	1119	470	181	0.12	95.6	66.5	278	12.9	512.71	4.74	43.43	0.77	3.47
BW55	557	18°39.987'	74°09.403'	7.1	9160	5862	675	402	8.5	201	110	888	12.7	956.6	0.63	47.79	0.92	5.66
DW56	558	18°39.464'	74°09.680'	7.3	5580	3571	460	425	0.69	110	56.5	610	12.4	508.15	4.48	64.64	1.83	8.22
DW57	572	18°38.057'	74°10.093'	7.2	7690	4922	575	450	2.81	140	64.5	827	11.8	616.36	-1.61	61.39	1.59	7.89
DW58	546	18°38.058'	74°10.092'	7.3	4800	3072	710	259	1.03	56.1	96.3	301	11.9	536.96	3.91	51.25	1.05	4.84
DW59	549	18°37.980'	74°10.222'	7.6	5800	3712	740	302	0.68	86.2	71.5	397	12.4	509.72	-0.57	56.33	1.29	5.82
BW60	570	18°39.196'	74°09.698'	7.5	4940	3162	580	296	0.13	46.3	100	372	12.3	654.16	4.34	49.63	0.99	5.04
		Max.		8.1	9160	5862	790	450	10.2	201	110	888	17.3	956.6	5	64.64	1.83	8.22
		Min.		7	616	394	220	45.6	0	10.4	30.4	29.6	10.7	4.6	-4.78	22.03	0.28	1.2
		Average		7.41	2641	1690	528	176	1.44	67.2	64.4	235	12.3	442.91	2.354	38.23167	0.657	2.5755

*All values are in mg/L except pH and EC; values of SSP, SAR and Kelly Ratio are in epm.

4 RESULTS AND DISCUSSION

4.1 Spatial Variation in pH and EC

The high pH reported in the eastern and northern part of the basin while low is in the central parts (Figure 4). The pH is slightly alkaline (range: pH 7.0-8.1) which is due to loss of CO₂ and mineral salts precipitation. High EC (9160 µS/cm) is observed towards lower part in the basin, while low EC value (616 µS/cm) is reported in BW-33 in middle part of the basin (Figure 5). So, an average values of EC (2641 µS/cm) is indicating high mineralization of groundwater (Pawar *et al.*, 2008; Gaikwad *et al.*, 2020a).

4.2 Spatial Variation in Cations

Calcium (Ca²⁺), Magnesium (Mg²⁺), Sodium (Na⁺) and Potassium (K⁺) are the main four cationic constituents in all types of waters (Pawar *et al.*, 2008; Wagh *et al.*, 2016; Gaikwad *et al.*, 2020b).

Increase in Na⁺ concentration from northwest to southeast due to hydro-geomorphological conditions

(e.g., slope) (Figure 6). Low K⁺ (in Figure 7) concentration in groundwater observed due to non-appearance of K-bearing minerals (Subbarao *et al.* 1994; Pawar *et al.*, 2008; Gaikwad *et al.*, 2020a); excluding quiet increase in central part (BW-52) is excessive use of fertilizers (Pawar *et al.*, 2008). Concentration of Mg²⁺ in groundwater ranges from 30.4 to 110.0 mg/L (Figure 9). In lower part of basin, high Mg²⁺ observed due to high salinity zone (Gaikwad *et al.*, 2018).

Elevated Ca²⁺ values are found in lower part of the basin (Figure 8). The average, Na⁺ + Ca²⁺ representing 75.4 % of total cations signify weathering of felsic minerals such as plagioclase feldspar is major supply from lithologies (Pawar *et al.*, 2008; Wagh *et al.*, 2018; Gaikwad *et al.*, 2020a). While, Ca²⁺ + Mg²⁺ values accounts for 51.5 % (range: 28-69%) of the total cations indicating its supply is from olivine and pyroxene (Gaikwad *et al.*, 2020b).

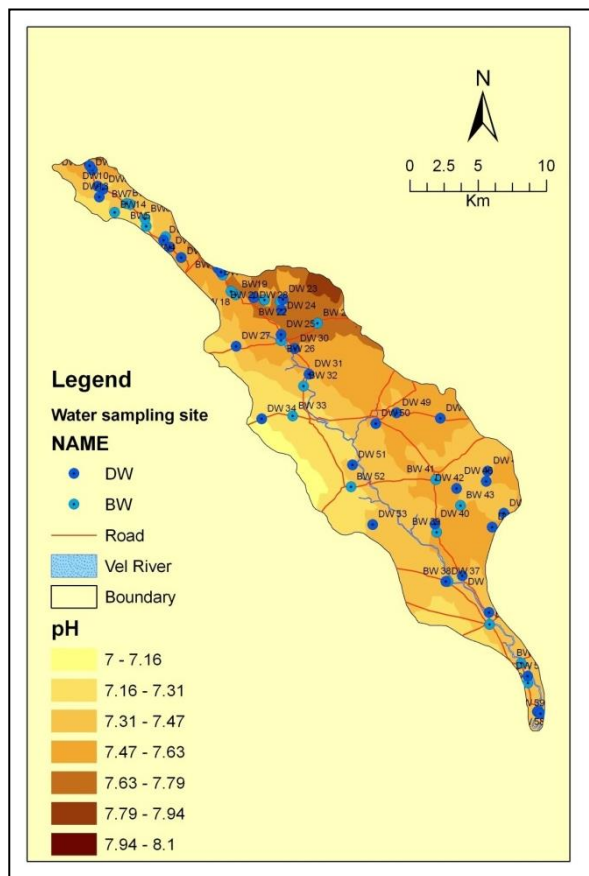


Figure 4. Spatial variation of pH

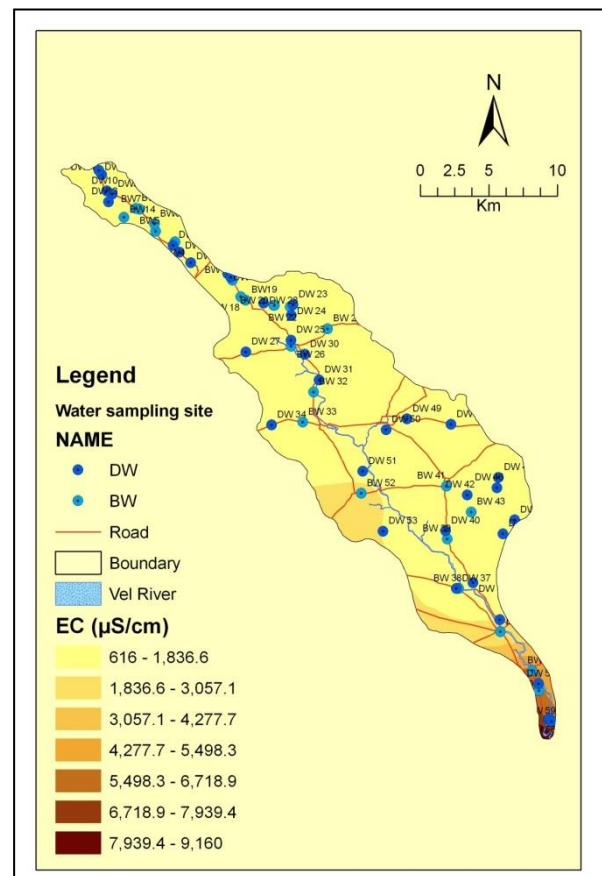
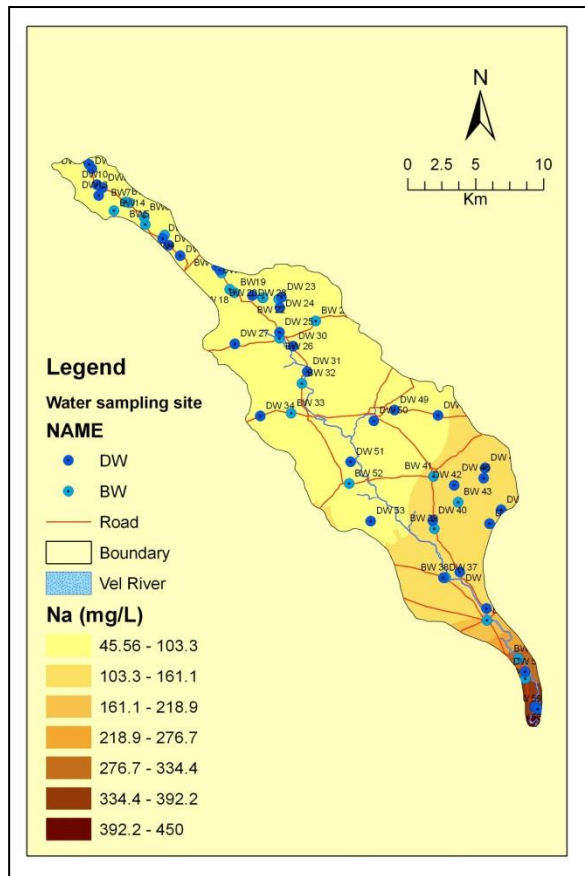
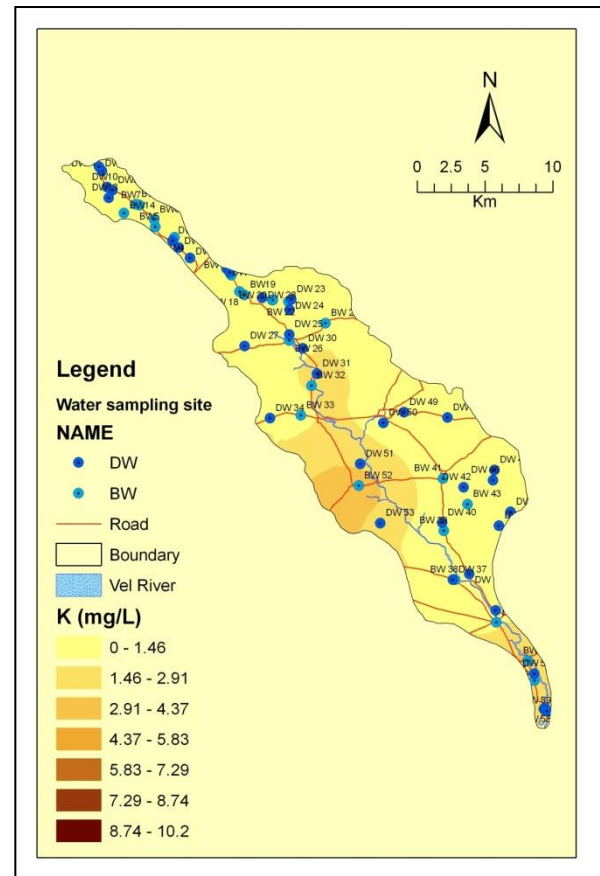
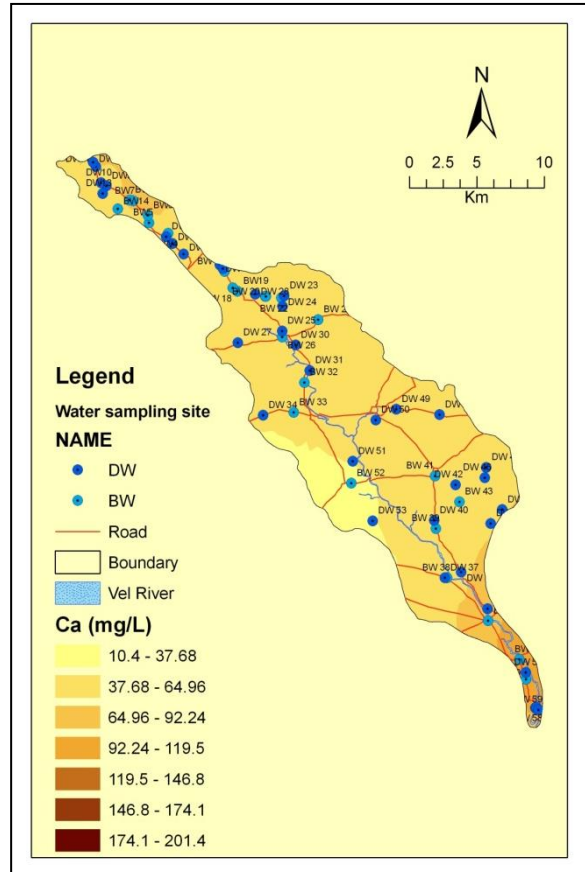
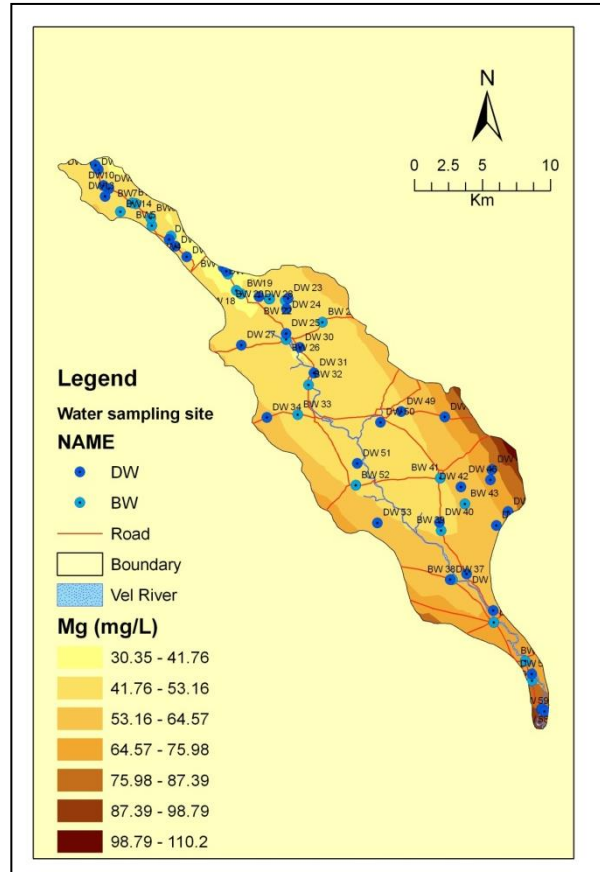


Figure 5. Spatial variation of EC

Figure 6. Spatial variation of Sodium (Na^+)Figure 7. Spatial variation of Potassium (K^+)Figure 8. Spatial variation of Calcium (Ca^{2+})Figure 9. Spatial variation of Magnesium (Mg^{2+})

4.3 Spatial Variation in Anions

In anions, Bicarbonate (HCO_3^-) is the principal anion followed by, Chloride (Cl^-) and Sulphate (SO_4^{2-}).

High values of Bicarbonate (HCO_3^-) are observed in central and upper parts of the study area while low in the southern side. High values of HCO_3^- in groundwater (Figure 11) entail abundant supply of CO_2 by rainwater recharge and availability of larger surface area for rock-water interaction and vice-versa (Matthess and Harvey, 1982; Drever, 1982; Pawar *et al.*, 2008). Chloride ranges from 29.6 to 888 mg/l with average of 235 mg/L. High concentrations of chloride is observed in the lower part of the basin (Figure 10). Thus, lower and high concentrations of Cl^- corresponding with recharge and discharge zones, respectively (Gaikwad *et al.*, 2020b).

High concentration of chloride (888 mg/L in BW-55), is due to the combination of high evaporation, deeper source and use of fertilizers (Figure 10). High

concentrations of SO_4^{2-} are reported in lower part i.e. south central part, while low concentration is in upper part of the basin (Figure 12). But high concentration in central part may be due to the use of excess fertilizers and agricultural runoff (Pawar *et al.*, 2008; Wagh *et al.*, 2018).

4.4 Geochemical Plots

In study of hydrochemical evolution it is imperative to know geological inputs, agricultural activities, precipitation and climatic condition, that are influencing the chemistry of groundwater (Wagh *et al.*, 2018).

The Na^+ vs. Cl^- scatter diagram (Figure 13) shows positive correlation ($r = 0.95$) in post monsoon season indicating combined influence of anthropogenic activities and ion exchange (Gaikwad and Pawar, 2008; Tiwari and Singh, 2014; Wagh *et al.*, 2018; Gaikwad *et al.*, 2020).

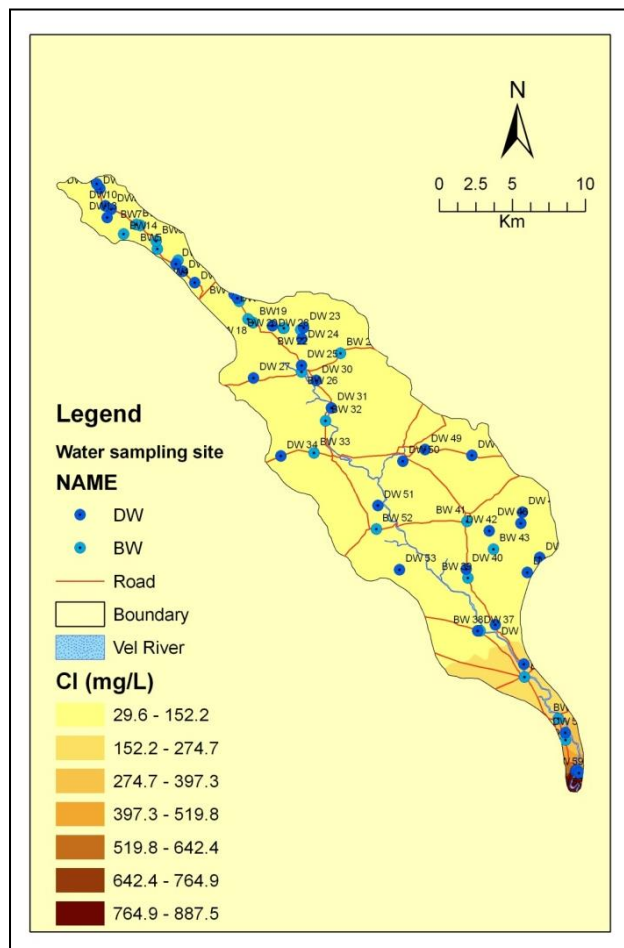


Figure 10. Spatial variation of Chloride (Cl^-)

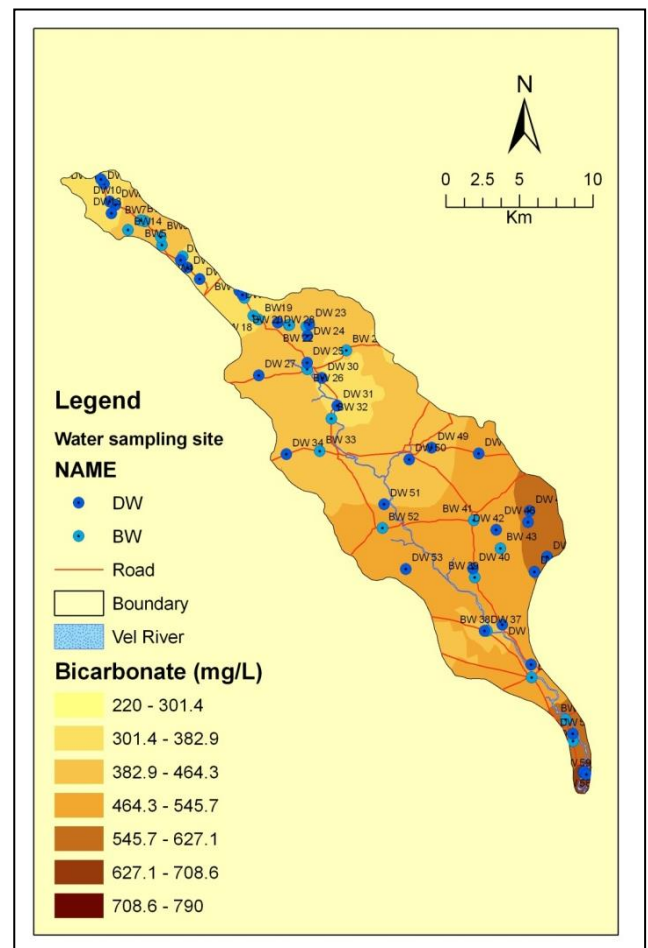
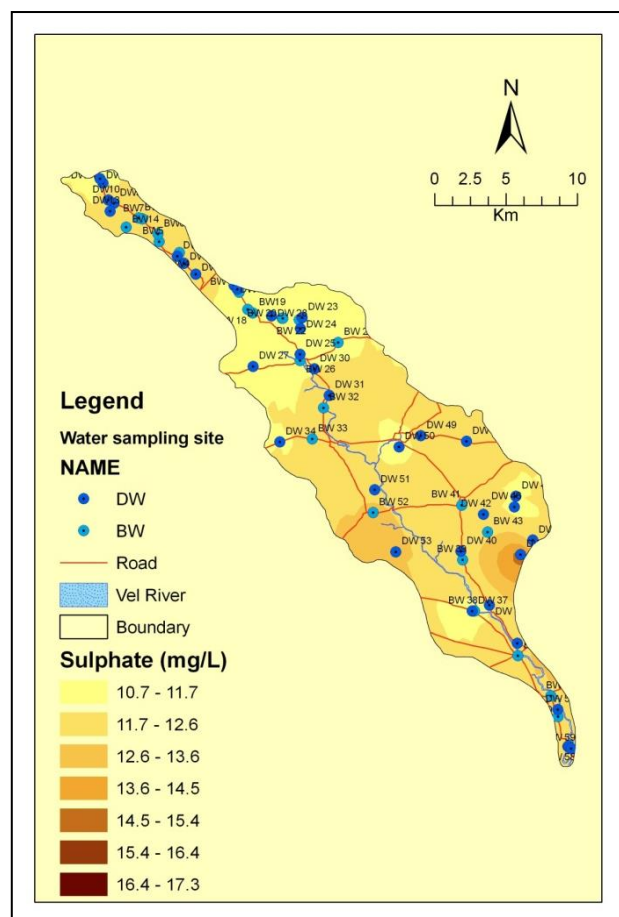


Figure 11. Spatial variation of Bicarbonate (HCO_3^-)

Figure 12. Spatial variation of Sulphate (SO_4^{2-})

Similarly the cross plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. HCO_3^- (Figure 14) depicts a positive correlation ($r = 0.71$), indicating influence of mafic minerals on groundwater geochemistry (Sami, 1992; Pawar et al., 2008; Wagh et al., 2018; Gaikwad et al., 2020a). The cross plot $\text{Na}^+ + \text{K}^+$ vs. HCO_3^- plots also shows positive correlation ($r = 0.64$), suggesting that there is a contribution of ions from felsic lithologies in the area (Figure 17) (Pawar et al., 2008; Gaikwad et al., 2020a).

The plots of $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. $\text{Cl}^- + \text{SO}_4^{2-}$ (Figure 16) and $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. $\text{SO}_4^{2-} + \text{HCO}_3^-$ (Figure 15) also show positive correlation ($r=0.79$ and 0.71 , respectively), indicating that these are preferred ion pairs from silicate and carbonate lithologies (Pawar et al., 2008; Wagh et al., 2018; Gaikwad et al., 2020). The correlation between $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. $\text{Na}^+ + \text{K}^+$ is also positive ($r = 0.76$), suggesting additions of ion from weathering of silicate rocks in the area (Figure 18) (Pawar et al., 2008; Gaikwad et al., 2020a). The

positive correlation coefficients between Ca^{2+} and Mg^{2+} ($r = 0.51$), further confirm this reflecting role of Fe-Mg bearing silicates as their source (Figure 19).

In the $(\text{Ca}^{2+} + \text{Mg}^{2+})$ vs. $(\text{HCO}_3^- + \text{SO}_4^{2-})$ (Figure 15) scatter diagram, the ionic concentrations in meq/L are falling both the side of equiline indicating both carbonate and silicate weathering. Such a plot also shows that $\text{Ca}^{2+} + \text{Mg}^{2+}$ are in excess of HCO_3^- possibly pointing to the process of ion exchange reaction (Rajmohan and Elango, 2004; Wagh et al., 2018).

4.5 Hydrochemical Facies

Physiochemical data of groundwater plotted on Piper Trilinear diagram to know its facies (Piper, 1944). The details are shown on figure 20 and given in table 2. The dominant hydrochemical facies $\text{Ca}^{2+} + \text{Mg}^{2+}$, $\text{Na}^+ + \text{K}^+$; $\text{Cl}^- + \text{SO}_4^{2-}$ HCO_3^- facies, found in 83.3 % samples indicating the alkaline earth is exceeding the alkalis and the strong acids exceeds the weak acids (Table 2).

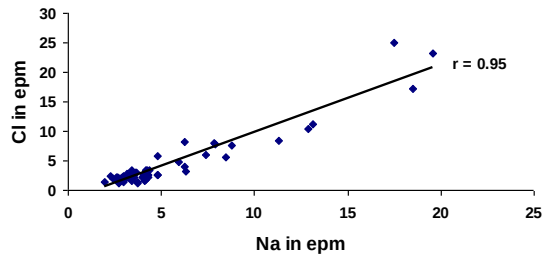
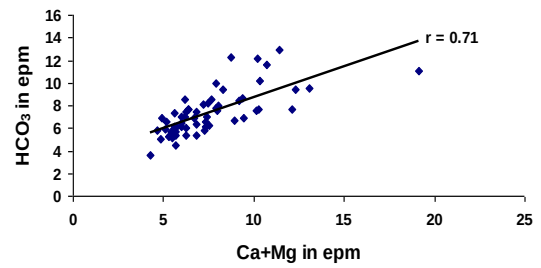
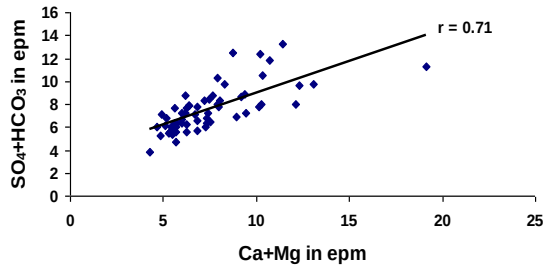
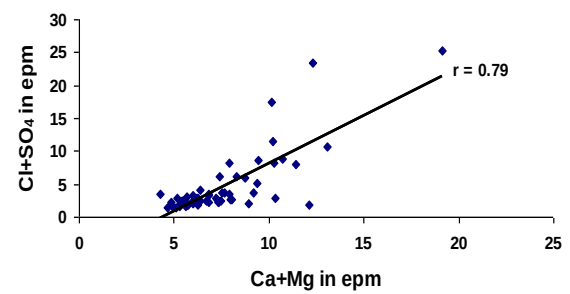
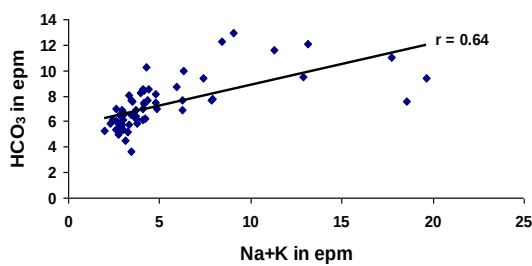
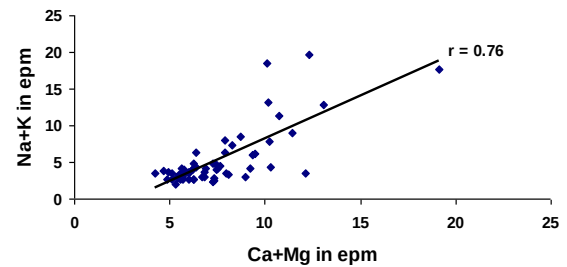
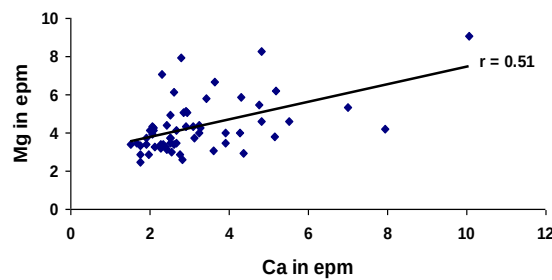
Figure 13. A scatter plot of Na^+ vs. Cl^- Figure 14. A scatter plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. HCO_3^- Figure 15. A scatter plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. $\text{SO}_4^{2-} + \text{HCO}_3^-$ Figure 16. A scatter plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. $\text{Cl}^- + \text{SO}_4^{2-}$ Figure 17. A scatter plot of $\text{Na}^+ + \text{K}^+$ vs. HCO_3^- Figure 18. A scatter plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ vs. $\text{Na}^+ + \text{K}^+$ Figure 19. A scatter plot of Ca^{2+} vs. Mg^{2+}

Table 2. Source wise hydro-chemical facies of groundwater

Hydrochemical Facies	Sample No.	Total
$\text{Ca}^{2+} + \text{Mg}^{2+}$, $\text{Na}^+ + \text{K}^+$, HCO_3^- , $\text{Cl}^- + \text{SO}_4^{2-}$	DW-1, 2, 3, 8, 9, 10, 11, 12, 13, 15, 16, 23, 24, 25, 27, 30, 31, 34, 36, 37, 40, 42, 44, 46, 47, 48, 49, 50, 51, 53	DW-30,
	BW- 4, 5, 6, 7, 14, 17, 18, 19, 20, 21, 22, 26, 28, 29, 32, 33, 38, 39, 41, 52	BW-20
$\text{Na}^+ + \text{K}^+$, $\text{Ca}^{2+} + \text{Mg}^{2+}$, HCO_3^- , $\text{Cl}^- + \text{SO}_4^{2-}$	DW-58, 59, 55	DW-3
$\text{Ca}^{2+} + \text{Mg}^{2+}$, $\text{Na}^+ + \text{K}^+$, $\text{Cl}^- + \text{SO}_4^{2-}$, HCO_3^-	DW-35 BW-54, 55, 60	DW-1, BW-3
$\text{Na}^+ + \text{K}^+$, $\text{Ca}^{2+} + \text{Mg}^{2+}$, $\text{Cl}^- + \text{SO}_4^{2-}$, HCO_3^-	DW-56, 57 BW-43	DW-2, BW-1

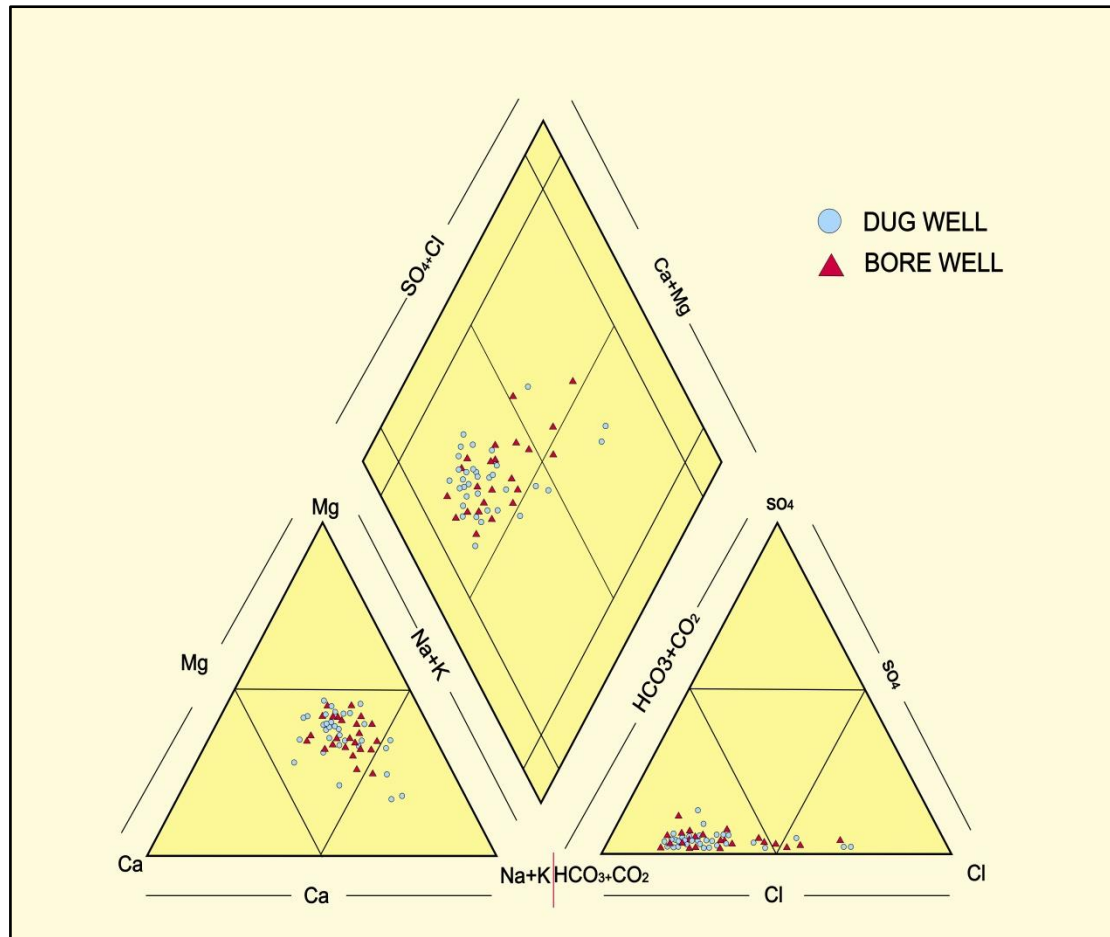


Figure 20. Hydrochemical facies of groundwater on Piper Trilinear Diagram

4.6 Quality of Groundwater

The quality of water is very important to the mankind, because it has a direct link with human health and welfare. As the study area is falls in the zone of low rainfall, high temperature, and drastic evaporation, which modifies the quality naturally with anthropogenic activities and its pollution (Wagh *et al.*, 2020; Gaikwad *et al.*, 2018).

4.7 Groundwater Quality for Drinking Purposes

The water to be used for drinking purposes should be pure from physical, chemical and biological point of view (Nikumbh, 1997). The data compared with World Health Organization standards found that pH, Total Hardness (TH) and Magnesium (Mg^{2+}) of the samples are more % of samples falling above Desirable limit. Otherwise the quality of groundwater is good for drinking (Table 3).

4.8 Groundwater Quality for Irrigation

Total dissolved solids (TDS), proportion of Na^+ , HCO_3^- with Ca^{2+} and Mg^{2+} and toxic substances present in water are major factors for irrigation quality point of view (Alamary, 2005). Along with these, soil

properties, water table depth, slope, climatic condition and crop pattern also affect it. Different parameters like Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Kelly ratio (KR) have been calculated to analyze the quality of water for irrigation. The details of it have been given in Table 1 and 4. It is found that according to the SAR parameters all samples are excellent to good for irrigation. In SSP, 33.3 % samples are permissible, while 66.6% samples are doubtful for irrigation purpose. In KR, almost all samples (excluding 04 samples in lower side of basin) are suitable for irrigation.

The US Salinity Laboratory Staff diagram (USSL, 1954) is used to study water quality for irrigation (Figure 21). About 8.3 % samples classified in C2-S1 category indicating low salinity and sodium hazard, while 85.06 % of samples falling in C3-S1 category indicating low salinity hazard but medium sodium hazards. Remaining 6.6 % samples of the lower reaches of the river are falling in C4-S1 zone indicating very high salinity hazard and low sodium hazard. According to Adimalla and Venkatayogi (2018a) high salinity affects the growth of crops and can create nutritional disorders.

Table 3. Groundwater qualities for drinking purposes (WHO, 1997)

Parameter	Permissible limits	Samples above limit (%)
pH	6.9 - 8.5	100 %
EC	1500 $\mu\text{mhos/cm}$	18.3%
TH	100-500 mg/l	98.3 %
Na ⁺	200-600 mg/l	31.6 %
K ⁺	30 mg/l	0 %
Ca ²⁺	75 - 200 mg/l	15 %
Mg ²⁺	50-150 mg/l	46.6 %
Cl ⁻	200- 600 mg/l	16.6 %
SO ₄ ²⁻	200- 400 mg/l	0 %
HCO ₃ ⁻	----	----

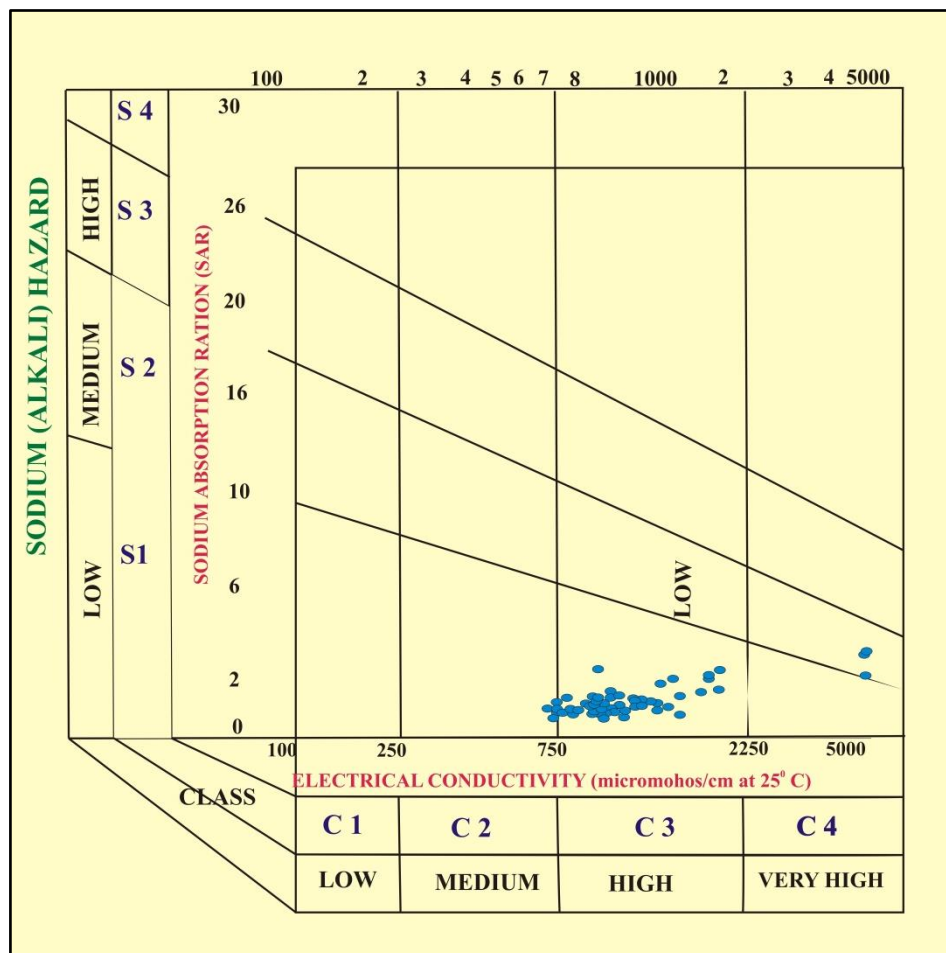


Figure 21. USSL diagram for classification of irrigation water

Table 4. Irrigation quality parameters

Irrigation Quality Parameters (meq/L)	Range	Classification	Number of Samples (%)
Sodium Absorption Ratio (SAR) (Richards, 1954)			
$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$	< 10	Excellent	100 %
	10-18	Good	----
	18-26	Doubtful	----
	>26	Unsuitable	----
Soluble Sodium Percentage (SSP) (Eaton, 1950)			
$SSP = (Na^+) \times 100 / Ca^{2+} + Mg^{2+} + Na^+ + K^+$	< 20	Good	----
	20 - 40	Permissible	33.3 %
	40 - 80	Doubtful	66.6 %
	> 80	Unsuitable	
Kelley's Ratio (KR) (Kelly, 1951)			
$KR = Na^+ / (Ca^{2+} + Mg^{2+})$	<1	Suitable	93.3 %
	>1	Unsuitable	6.6 %

5 SUMMARY AND CONCLUSION

To assess the geochemistry of groundwater and its quality for drinking and irrigation purpose from Vel River basin, Sixty (60) samples of Dug well and Bore well were collected and analyzed using standard techniques. It shows order of dominance for cations: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and in anionic concentration as $HCO_3^- > Cl^- > SO_4^{2-}$ in groundwater. The groundwater pH is slightly alkaline (range: pH 7.0-8.1) while average values of Electrical conductivity (EC) is about 2641 $\mu S/cm$ indicating high mineralization of groundwater. The cationic values in the groundwater increase in the downstream side (from Northwest to Southeast), suggesting geological control on the composition of groundwater while highest concentration is in lower part of the basin are generally associated with the high salinity. In the major anions, bicarbonate (HCO_3^-) is higher due to rock-water interaction. Average value of chloride in is about of 235 mg/L due to discharge zones along with anthropogenic activities. High concentrations of SO_4^{2-} are reported in lower and central part of the basin may be due to the use of excess fertilizers and agricultural runoff. The Na^+ vs. Cl^- scatter diagram shows positive correlation ($r=0.95$) indicating combined influence of anthropogenic activities and ion exchange mechanism. Similarly the cross plot of and $Ca^{2+} + Mg^{2+}$ vs. HCO_3^- depicts a positive correlation ($r=0.71$), indicating influence of mafic minerals on groundwater geochemistry. The cross plot $Na^+ + K^+$ vs. HCO_3^- plots also shows positive correlation ($r=0.64$), suggesting that there is a contribution of ions from felsic lithologies in the area. The plots of and $Ca^{2+} + Mg^{2+}$ vs. $Cl^- + SO_4$ and $Ca^{2+} + Mg^{2+}$ vs. $SO_4 + HCO_3^-$ also showing positive correlation ($r = 0.79$ and 0.71 respectively), indicating that these are preferred ion pairs from silicate and carbonate lithologies. The geochemical data plotted on Piper Trilinear Diagram showing The dominant hydrochemical facies $Ca^{2+} + Mg^{2+}$, $Na^+ + K^+$; $Cl^- + SO_4^{2-}$

HCO_3^- facies, found in 83.3 % samples indicating the alkaline earth is exceeding the alkalis and the strong acids exceeds the weak acids. In drinking water quality, pH, Total Hardness (TH) and Magnesium (Mg^{2+}) of the samples are showing more % of samples falling above desirable limit. Otherwise the quality of groundwater is good for drinking. The irrigation quality indices SAR, KR and SSP were considered to evaluate groundwater suitability for irrigation. Study of SAR parameter showed that all samples are excellent to good for irrigation. In SSP, 33.3 % samples are permissible, while 66.6 % samples are doubtful for irrigation purpose. In KR almost all samples (except 04 samples i.e. 6.6 % in lower side of basin) are suitable for irrigation. In nutshell, groundwater geochemistry of Vel River Basin modified due to variations in climate, geology and anthropogenic activities in the basin.

CONFLICT OF INTEREST

The authors do not have any conflicts of interest.

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ABBREVIATIONS

APHA: American Physical Health Association; **BW:** Bore Well; **DW:** Dug Well; **CGWB:** Central Ground Water Board; **DVP:** Deccan Volcanic Provinces; **GSDA:** Groundwater Survey and Development Agency; **GSi:** Geological Survey of India; **HPIC:** High Performance Ion Chromatography; **KR:** Kelly ratio; **SSP:** Soluble Sodium Percentage; **SAR:** Sodium

Absorption Ratio; **TH**: Total Hardness; **USDA**: United States Department of Agriculture; **USSL**: US Salinity Laboratory Staff diagram; **WHO**: World Health Organization.

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