

Suitability of Groundwater for Irrigation Purpose: A case study from Bhadravati Area of Chandrapur District, Maharashtra

Namrata Choudhary², Anjali Kotamkar¹, D. B. Malpe^{1*} and M. K. N. Yenkie²

Department of Geology, R.T.M. Nagpur University, Nagpur, India¹

Department of Chemistry, Laxminarayan Institute of Technology, R.T.M. Nagpur University, Nagpur, India²

Corresponding Author *

ABSTRACT: In India drinking water quality has already reached to its alarming level in various parts of the country. It needs urgent attention and efforts to overcome the problem. A study was conducted in WR-22 watershed of Bhadravati area of Chandrapur district, Maharashtra, India to evaluate the suitability of groundwater for irrigation purpose. The study area is dominated by sedimentary sequence of Gondwana and Lameta rocks with minor occurrences of oldest Vindhyan limestones. Basaltic lava flows of Deccan Volcanic Province overlie the Gondwana sequence and occur as small outliers in the western part of the area, while youngest alluvium mostly occurs along the streams. A total of 33 groundwater samples were collected during pre-monsoon period of 2016 and analysed using standard methods. The analytical result reveals abundance of major ions in the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^- > \text{F}^-$. The water of study area is mostly of Ca-Mg-HCO₃ type, where Alkaline earth exceeds alkalis and weak acids exceed strong acids. Based on USSL diagram groundwater of the area show low sodium hazards, while the salinity hazard varies from moderate to very high. For such area adequate drainage and salt tolerant cropping is required. Most of the samples show their suitability for irrigation when compared with irrigation water quality standards. Proper groundwater quality management strategies are necessary to protect the water resources and further deterioration of groundwater quality.

KEYWORDS: Suitability, Groundwater, Irrigation purpose.

I. INTRODUCTION

Groundwater is one of the most valuable natural resource and important source of water supply throughout the world. The requirement of water for all living beings is utmost important. The unmanaged utilization as well as excessive groundwater exploitation is exclusively responsible for lowering of groundwater levels. Its use in irrigation, industries, municipalities, and rural homes continues to increase. Shortage of groundwater emphasizes the need for accurate estimates of the available subsurface resources and the importance of proper planning to ensure the continued availability of water supplies (Todd [1]).

The availability of good quality of water in high quantity is linked with the food security. However, there are number of places on the earth's surfaces where quality of groundwater is deteriorated, either due to geogenic or anthropogenic activities and groundwater resources are more over not suitable for various purposes. An understanding of the chemical quality of groundwater is essential in determining its usefulness for domestic, industrial and agricultural purposes. Groundwater always contains small amounts of soluble salts. The kind and quality of these salts depend upon the sources for recharge of the groundwater and the strata through which it flows. An excess of soluble salts can be harmful for many crops. Hence, an understanding of the chemistry of groundwater is essential for the evolution of groundwater quality (Mukherjee [2]).

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Geochemical processes, occurring within the groundwater and their reactions with the aquifers materials, are responsible for changes in groundwater chemistry (Drever[3], Hem [4]). The variation in major ion chemistry of groundwater leads to identification of geochemical processes that control the groundwater quality.

In the present work an attempt has been made to study the possible impact of various anthropogenic activities in the study area on the suitability of groundwater for irrigation purpose, which will help in effective implementation of groundwater management practices.

II. STUDY AREA

The study area WR-22 watershed forms the part of the Penganga sub-basin and is located in western part of Chandrapur district, Maharashtra. It lies between latitudes 20°05'30" -20°16'30" and longitude 79°03'0" -79°14'0" and covers part of Survey of India Toposheet Nos. 55P/3 and 55 P/4 (Fig.1). The area experiences semi-arid climate with mean daily maximum temperature of 42.8°C during May and the mean daily minimum temperature of 12.2°C during December. Most of the total annual rainfall occurs during the southwest monsoon season. The study area is situated at about 211m above mean sea level and exhibits moderately dissected topography with few isolated hills. The area is drained by Kondha and TakliNalas. The drainage network is dendritic to sub-dendritic with ephemeral drainages.

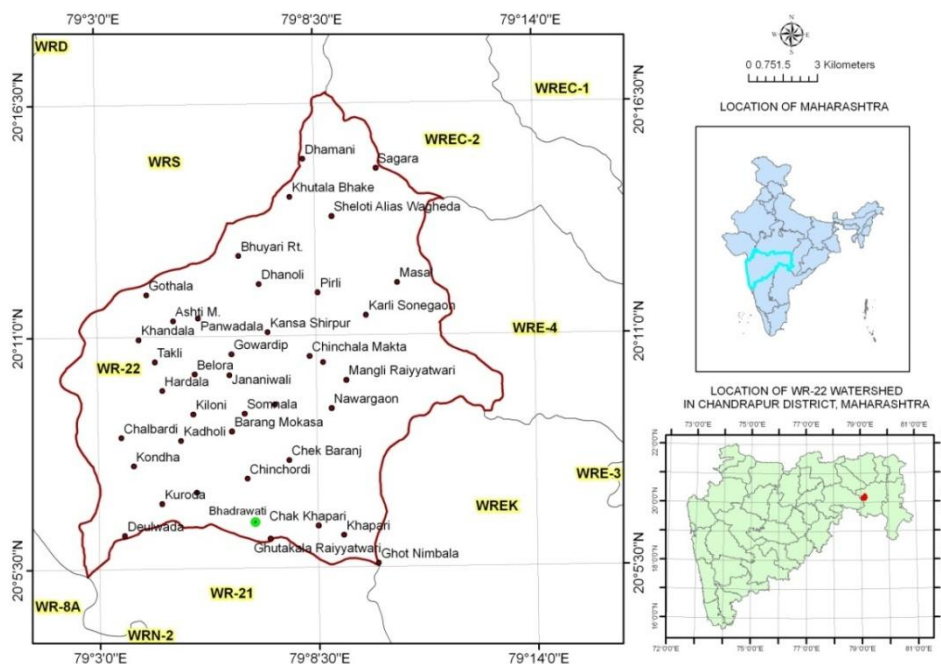


Fig.1. Location Map of study area

Geologically, the area is dominated by Gondwana sedimentary sequence, which is underlain by Vindhyan Supergroup rocks and overlain by Lameta Formation (Fig.2). Gondwanas are represented by older white coloured sandstone, shale and coal sequence of Barakar Formation and younger yellow coloured sandstones of Kamthi Formation. Basaltic lava flows of Deccan Volcanic Province overlie the sedimentary sequence and it is exposed as small outliers along the western part of the area. Alluvium overlies all the older formations (GSI [5]). In the WR-22 watershed, as failure of dug wells is high, therefore only 04 dug wells could be located and studied. The depth to water level in these wells during pre-monsoon varies from 6.4 to 13 mbgl.

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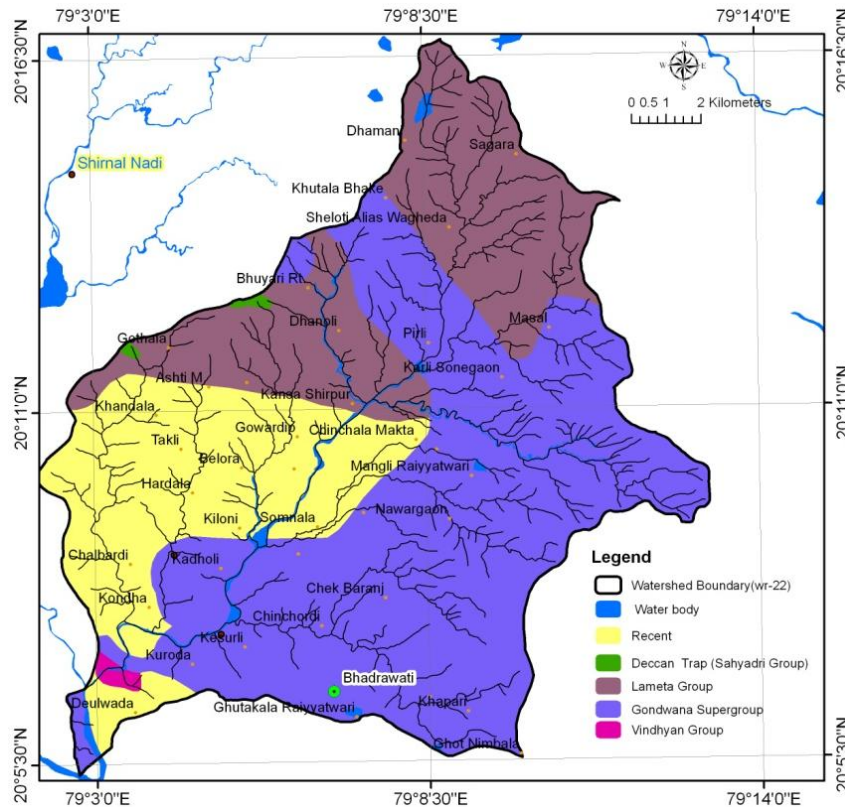


Fig. 2. Geological map of study area

III.METHODOLOGY

In the present work, groundwater samples were collected from 33 wells (4 dug wells and 29 bore wells) during pre-monsoon season of 2016 (Fig.1). For sample collection, polyethylene bottles are used and collected samples are analyzed in the laboratory for various physico-chemical parameters. Standard procedures recommended by American Public Health Association are followed during sample collection, handling, preservation and analysis (APHA [6]). The ionic balance error for studied ions is less than 5%.

IV.RESULTS AND DISCUSSION

1. Physico-chemical Parameters

The results of the analyzed physico-chemical parameters in the present study are presented as Table 1. The pH of the samples ranges from 6.9 to 8.1 with the average value of 7.33 suggesting alkaline nature of groundwater. Electrical conductivity of groundwater is directly related to the concentration and types of ions present in it (Hem [7]). Higher conductivity may be attributed to high salinity and high mineral percentage in groundwater samples (Sanchez-Perez and Tremolieres[8]). In the groundwater of the study area EC varies from 590 to 6800 $\mu\text{S}/\text{cm}$ at 25°C indicating dissolution of minerals. The higher EC values in few samples of the study area indicate enrichment of salts in the groundwater by anthropogenic activities and the geochemical processes prevailing in the area (Choi et al. [9]).

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Table 1: Physico-chemical parameters* of groundwater from study area

Sample ID	pH	EC	TDS	TH	TA	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	F ⁻
WR22-1	7.5	998	518	318	262	57	42	80	30	319	125	21	2	0.77
WR22-2	7.4	2735	1656	964	257	176	126	165	105	314	471	220	236	0.27
WR22-3	7.2	1928	1180	780	392	181	79	142	4	479	274	159	102	0.46
WR22-4	7.7	1275	668	534	313	148	39	60	2	382	154	35	39	0.48
WR22-5	7.5	720	378	323	271	62	41	30	3	331	53	5	19	0.67
WR22-6	7.3	2485	1517	718	402	125	97	261	20	490	358	374	36	0.34
WR22-7	7.2	1975	1130	441	332	90	52	235	6	405	252	134	158	0.27
WR22-8	7.6	1476	893	482	369	107	52	155	5	450	161	133	41	0.39
WR22-9	7.1	2025	1414	728	355	119	103	190	114	433	380	285	6	0.65
WR22-10	6.9	1700	1023	575	434	144	52	160	38	530	187	174	3	0.46
WR22-11	7.2	3999	2838	1775	327	410	180	283	32	399	723	555	455	0.35
WR22-12	7.6	1935	1118	457	215	121	37	227	14	262	377	209	1	0.46
WR22-13	7.2	3999	3208	1442	304	361	129	602	7	371	865	518	540	0.22
WR22-14	7.8	907	513	215	369	43	26	136	2	450	48	11	20	1.72
WR22-15	7.6	1495	885	282	402	60	32	243	5	490	130	137	32	1.97
WR22-16	7.2	3690	2615	980	355	199	116	553	22	433	711	547	250	0.46
WR22-17	7.1	3734	2442	1211	411	230	153	166	309	502	461	297	575	0.43
WR22-18	7.2	3080	1995	1211	360	269	129	208	49	439	560	327	233	0.42
WR22-19	7.4	6800	7759	3032	402	263	570	1550	87	490	1173	3505	365	0.87
WR22-20	7.9	1320	801	185	383	31	26	238	12	467	101	138	1	1.19
WR22-21	6.9	770	409	267	168	82	15	51	18	205	96	10	12	0.14
WR22-22	7	661	322	246	224	70	17	40	3	274	53	1	1	0.16
WR22-23	7.4	1960	1176	564	327	129	58	206	15	399	336	204	27	0.43
WR22-24	7.2	1110	552	441	215	137	23	19	11	262	87	12	131	0.12
WR22-25	7.2	615	343	282	266	98	9	30	1	325	29	3	10	0.25
WR22-26	7	590	328	241	271	62	21	46	2	331	24	1	7	0.28
WR22-27	7.6	1695	1070	364	369	78	41	252	7	450	197	220	27	0.75
WR22-28	8.1	1348	827	333	234	72	37	75	160	285	168	22	150	0.65
WR22-29	7.2	1369	728	431	336	103	42	140	8	410	149	38	43	0.77
WR22-30	7.3	3385	2087	862	280	197	89	473	7	342	635	310	205	0.74
WR22-31	6.9	1645	980	636	280	181	44	94	33	342	183	196	78	0.34
WR22-32	7.4	2180	1229	513	603	33	103	318	11	735	250	39	83	1.64
WR22-33	7.2	2672	2603	201	411	44	191	313	502	502	--	502	502	0.23
Minimum	6.9	590	322	185	168	31	9	19	1	205	--	1	1	0.12
Maxium	8.1	6800	7759	3032	603	410	570	1550	502	735	1173	3505	575	1.97
Average	7.33	2069	1431	668	330	136	84	235	50	403	296	283	133	0.0586

* All values in mg/l, except pH and EC in $\mu\text{S}/\text{cm}$ at 25°C, -- Traces

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Cationchemistry

In the present study, Na^+ is the most dominant ion among the cations and it ranges from 19 to 1550 mg/l. The high Na^+ concentration indicates dissolution and weathering of rock forming minerals like sodium bearing plagioclase, halite and anthropogenic sources like domestic and animal waste (SubbaRao et al. [10]). While, the Mg^{2+} and Ca^{2+} content in the study area varies from 9 to 570 mg/l and 31 to 410 mg/l, respectively. The principal sources of Mg^{2+} and Ca^{2+} in the natural waters are calcium and magnesium bearing minerals in rocks and secondary sources are animal, domestic and industrial wastes. The higher contribution of Na^+ than that of the contribution of Ca^{2+} to the total cations is attributed to the influence of ion exchange processes. The highly variable concentration of K^+ in groundwater samples of study area ranges from 1 to 500 mg/l and indicate the influence of anthropogenic activities.

Anion chemistry

In the groundwater samples of study area, HCO_3^- and SO_4^{2-} are the dominant anions followed by Cl^- and NO_3^- . The primary source of HCO_3^- in the groundwater is dissolution of CO_2 gas likely formed by the anoxic biodegradation of organic matter derived from industrial and domestic sewage, septic tanks and buried waste in landfills (Canter [11]). The concentration of HCO_3^- in the groundwater samples ranges from 205 to 735 mg/l with an average value of 403mg/l. The Cl^- and SO_4^{2-} concentration varies from traces to 1173 mg/l and 1 to 3505 mg/l, respectively. The Cl^- concentration may be resulted due to leaching from soils and the influence of domestic effluents, fertilizers, septic tanks and leachates from landfills (Todd [1]). While, high SO_4^{2-} concentration in some of the groundwater samples indicates the influence of coal bearing rock formations of Gondwana sedimentary sequence. The source of NO_3^- in groundwater is due to decaying organic matter, sewage wastes, leakage of septic tanks and fertilizers (Marghade et al. [12]). The NO_3^- concentration varies from 1 to 575 mg/l with an average value of 133 mg/l. The concentration of F^- varies from 0.12 to 1.97 mg/l and is mostly derived from geogenic sources.

Total dissolved solids and Total hardness

Total dissolved solids (TDS) is the salinity behaviour of groundwater and measure of the total ions in solution. In the study area, TDS values ranges from 322 to 7759 mg/l indicating the influence of anthropogenic activities likely pointed by Na^+ and Cl^- ions (Table 1) (SubbRao et al. [13]). Whereas, water hardness accounts for the Ca^{2+} and Mg^{2+} along with Cl^- , SO_4^{2-} and HCO_3^- . It can be influenced due to the entry of industrial and other domestic effluents into the water source, which comes from the minerals dissolved in water (Islam et al. [14]). The total hardness (TH) as CaCO_3 in the groundwater of the study area ranges from 185 to 3032 mg/l (Table 1).

2. Hydrochemicalfacies

The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the piper trilinear diagram. The nature and distribution of hydrochemicalfacies can be determined by providing insights into how groundwater quality changes within and between aquifers (Piper [15]). The abundance of cations and anions in groundwater samples is $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^- > \text{F}^-$.

Pipers trilinear diagram (Piper [15]) reveals that the water mostly belong to Ca-Mg- HCO_3 type suggesting alkaline earth ($\text{Ca}^{2+} + \text{Mg}^{2+}$) exceeds alkalis ($\text{Na}^+ + \text{K}^+$) and weak acids ($\text{CO}_3^{2-} + \text{HCO}_3^-$) exceed strong acids ($\text{Cl}^- + \text{SO}_4^{2-}$) (Belkhirri et al. [16]) (Fig.3). While, Ca-Mg-Cl, Na-Cl and Ca-Na- HCO_3 water types are also observed in the area. The results indicated the influence of water-rock interaction of the aquifer material and influence of human activities on the aquifer system

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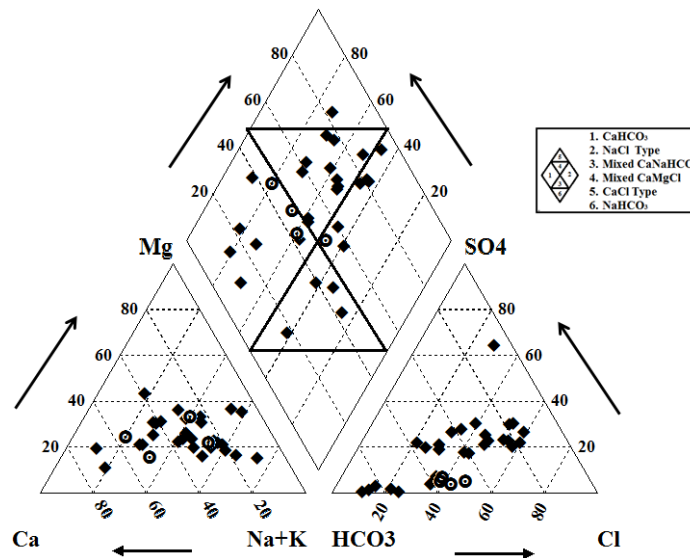


Fig. 3. Piper's plot for the samples of study area (After Piper [15])(● Dug wells, ◆ Bore wells)

3. Irrigation suitability

The parameters such as sodium percentage (Na %), residual sodium carbonate (RSC), permeability index (PI), bicarbonate hazards, Kelly's ratio (KI), magnesium absorption ratio (MAR) were estimated to assess the suitability of water for irrigational purposes. The specifications recommended by US Salinity Laboratory Staff [17] have been used for studying the quality of groundwater for irrigation purposes. The different parameters calculated for the identification of irrigation suitability of groundwater from study area is given in Table 2.

Table 2: Irrigation parameters for the groundwater of study area

Parameter	Range	Classification	No. of Samples	%
Na % (meq/l) [21]	<20	excellent	1	3.04
	20-40	good	9	27.27
	40-60	permissible	11	33.33
	60-80	Doubtful	11	33.33
	>80	Unsuitable	1	3.03
SAR(meq/l)	0-10	excellent	13	39.40
	10-18	good	9	27.27
	18-26	fair	5	15.15
	>26	Poor	6	18.18
RSC (meq/l)	<1.25	good	29	87.88
	1.25- 2.5	Medium	1	3.03
	>2.5	Bad	3	9.09
EC (μS/cm)	< 250	Low Salinity hazard (good)	-	-
	250-750	Medium Salinity hazard (moderate)	4	12.12
	750-2250	High Salinity hazard (poor)	19	57.58
	>2250	V. High Salinity hazard (very poor)	10	30.30
KR (Kelley [18])	<1	Suitable	19	57.58
	>1	Unsuitable	14	42.42
MAR (Ayers and Westcot [19])	<50	Suitable	30	90.91
	>50	Unsuitable	3	9.09

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US Salinity laboratory diagram

US Salinity Laboratory Staff [17] proposed irrigational specifications for evaluating the suitability of water for irrigation use, which shows significant relationship of salinity hazard (EC) and sodium hazard (SAR) (Fig. 4). On this diagram, 15.2% samples fall in the C4S2 and 12.12% samples falls in the C4S1 fields, use of such water samples in the long term will increase both salinity and alkali hazard in the soil (Fig. 4). About 36.4% of groundwater samples fall in C3S1 where the excessive amount of salts can be one of the major problem with water used for irrigation. Such water cannot be used for irrigation with most crops without special treatment for salinity control such as leaching requirement or cropping of salt tolerant plants (Karanth[20]). The rest of the samples falls in C3S2 (18.2%) and C2S1 (18.2%) field. The observations shows that the samples from study area is mostly low sodium water (S1), which can be used for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. The groundwater samples which possess high C3 or very high C4 salinity cannot be used on soils with restricted drainage and special management for salinity control is required even with adequate drainage. Hence, crops with good salt tolerance should be selected (U.S. Salinity Laboratory Staff [17])

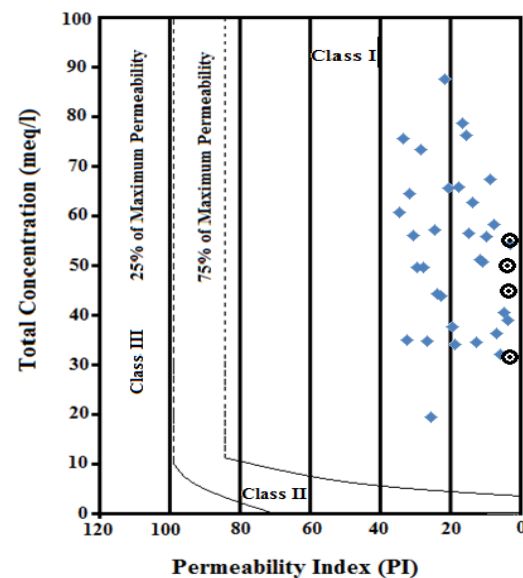
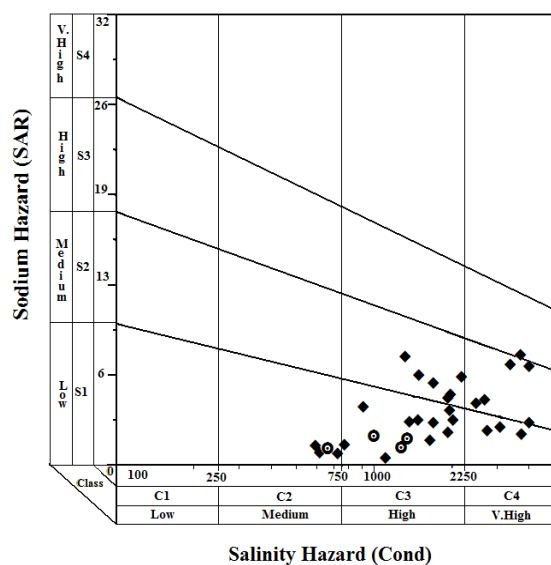


Fig.4. Suitability of groundwater for irrigation in USDA diagram Fig. 5. Plot of permeability index versus total conductance (After U.S. Salinity Laboratory Staff [17]) (● Dug wells, ◆ Bore wells) (○ Dug wells, ◊ Bore wells)

Electrical conductivity (Salinity hazard)

Salinity hazard can be best measured by electrical conductivity as it reflects the TDS in groundwater (Ragunath[21]). It has been observed that, total 29 (87.88%) groundwater samples have high to very high salinity hazard. Irrigation water with high salinity affect plants and agricultural soil physically and chemically through lowering of osmotic pressure in the plant structural cells (Thorne and Peterson [22]). This prevents water from reaching the branches and leaves, thus reducing the agricultural productivity. However, saline water may lead to concentrations of some elements which can be toxic to plants.

Sodium adsorption ratio (SAR)

The Salinity Laboratory of the U.S. Department of Agriculture recommended the SAR for determining the groundwater suitability for irrigation purpose because it is a measure of alkali/sodium hazard to crops (Karanth[20]).

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$$\text{SAR} = \text{Na}^+ / \sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2} \text{ (meq/l)}$$

Electrical conductivity and Na^+ play a vital role in suitability of water for irrigation. Na^+ makes soil alkaline with an association of Cl^- , which does not help in the plant growth. As per the classification of Wilcox [23] (Table 2), 39.40% of the water samples are excellent, 42.42% are good to fair and 18.18% are poor in groundwater quality from the irrigation point of view.

Sodium percentage (Na %)

The Na% is an important factor for studying sodium hazard and it is widely used for evaluating the water quality for irrigation purpose (Wilcox [24]). Generally, Na^+ replaces Ca^{2+} in the soil by base-exchange process, which reduces the quality and permeability of soil and supports little or no plant growth (Obiefuna and Sheriff [25]). The Na% in the samples of study area is calculated using the following formula:

$$\text{Na\%} = (\text{Na} + \text{K} / \text{Ca} + \text{Mg} + \text{Na} + \text{K}) \times 100$$

The classification scheme suggested by Raghunath[21] shows that approximately 63.64% samples are in permissible to excellent quality, while rest of the 36.36% samples found to be doubtful to unsuitable for irrigation purposes (Table 2).

Permeability index (PI)

The soil permeability is affected by long-term use of irrigation water and is influenced by Na^+ , Ca^{2+} , Mg^{2+} and HCO_3^- contents of the soil. Doneen [26] assessed the suitability of water for irrigation based on the PI, which has been calculated by using the formula:

$$\text{PI} = (\text{Na} + \sqrt{\text{HCO}_3}) / (\text{Ca} + \text{Mg} + \text{Na}) \times 100 \text{ (meq/l)}$$

The PI values of the studied samples also indicate that the groundwater is suitable for irrigation. The PI values depict range of 19.56 - 88.12 with an average value of 53.31. All the samples of study area come under the 'class-I' area of Donnen's Chart (Fig. 5), indicating their suitability for irrigation purposes (Doneen [26])

Residual sodium carbonate (RSC)

In water having high concentration of bicarbonate there is tendency for calcium and magnesium to precipitate as carbonate. To meet this effects experimental parameter termed as Residual Sodium Carbonate is used (Eaton [27]). According to Richard [28], the residual sodium carbonate is determined by the formula:

$$\text{RSC} = (\text{HCO}_3^- + \text{CO}_3^{2-}) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \text{ (meq/l)}$$

Eaton [27] and Lloyd and Heathcote [29] classified the waters on the basis of RSC values to identify its suitability for irrigation purpose (Table 2). The RSC values of present study samples show that 87.88% groundwater samples are suitable for the irrigation purpose.

Kelley's ratio (KR)

The Kelley's ratio of unity or 1 is indicative of good quality of water for irrigation, whereas above one is suggestive of unsuitability for agricultural purpose due to alkali hazards (Karanth[30]). Kelly's ratio is used for the classification of water for irrigation purposes and is calculated by using the formula:

$$\text{KR} = \text{Na}^+ / \text{Ca}^{2+} + \text{Mg}^{2+} \text{ (meq/l)}$$

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The Kelley's ratio computed for the study area ranges from 0.12-4.20 meq/l with an average value of 1.12meq/l. The calculated ratios of present studied groundwater samples show that 57.58% samples are suitable and 42.42% samples are not suitable for irrigation purposes (Table 2).

Magnesium absorption ratio (MAR)

Generally, Ca^{2+} and Mg^{2+} maintain equilibrium in natural waters but Mg^{2+} in waters affect adversely in the crop yield (Nagaraju et al. [31]). Paliwal [32] developed an index for calculating the magnesium hazard (MAR), which measures effect of magnesium in irrigated water and is calculated using the formula:

$$\text{MAR} = [\text{Mg}^{2+}/(\text{Ca}^{2+} + \text{Mg}^{2+})] \times 100 \text{ (meq/l)}$$

The computed MAR values in the study area shows that 90.91% groundwater samples are suitable and 9.09% groundwater samples are not suitable for irrigation purposes (Table 2).

V. CONCLUSIONS

Study of physico-chemical parameters of WR-22 watershed suggests that the groundwater of the area is slightly alkaline. The abundance of the major ions is $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^- > \text{F}^-$. The water of study area is mostly of Ca-Mg- HCO_3 type, where alkaline earth exceeds alkalis and weak acids exceed strong acids. The results indicated the influence of water-rock interaction of the aquifer material and influence of human activities on the aquifer system. U.S. Salinity Laboratory Staff diagram shows that the samples from study area are mostly low sodium water which can be used for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. In the present area 87.88% groundwater samples have high to very high salinity hazard. Based on the RSC and PI, the groundwater from the study area is suitable for irrigation purposes. On the basis of SAR 81.82% samples belong to the excellent to good category, while rest belong to poor category and to overcome the problem salt tolerant cropping patterns is suggested. On the basis of Kelly's ratio and MAR most of the samples are suitable for irrigation purpose. In general, assessment of groundwater samples by various methods suggests that the groundwater of the study area is suitable for agricultural activities. It is suggested that to improve the groundwater quality local sanitation system in the area should be improved.

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