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Suitability of Groundwater for Irrigation Purpose: A Case Study from WRN-1 Watershed from Wani Area, Yavatmal District, Maharashtra

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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. On similar line, a study was conducted in WRN1 watershed of Wani Taluka of Yavatmal district, Maharashtra, central India to evaluate the effects of groundwater quality. The study area possesses varied geological formations ranging from Penganga limestones, Gondwana Supergroup rocks, Lameta Group rocks, basaltic lava flows, Quaternary alluvium and black soils. A total of 31 groundwater samples were collected during post-monsoon period and analysed using standard methods. The groundwater quality assessment has been carried out by evaluating the physicochemical parameters. Groundwater has been assessed by studying its suitability for irrigation purpose. The analytical result reveals abundance of major ions in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+ = HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. The water of study area is mostly of Ca^{2+} - HCO_3^- type where Alkaline earth exceeds alkalis and weak acids exceed strong acids. The USSL diagram suggests, groundwater is free from sodium hazards but the salinity hazard highly varies throughout the study area. For such area adequate drainage and salt tolerant cropping is required. Some of the samples showed its unsuitability 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

Water sources have always been a precious commodity, being most vital and natural resources for life and are backbone of socio-economic development of the country. The available source of surface water is limited; moreover, it is under tremendous pressure due to pollution in many parts of the world, hence groundwater became an alternate and vital source in the perspective of water supply (Jyothi Prakash et al. [1]).

The quality of groundwater is most commonly affected by domestic and industrial waste disposal, land use and improper sanitation. Many authors have studied in detail the suitability of groundwater for irrigation purposes in different parts of the country (Satishkumar et al. [2]; Balaji et al. [3]; Selvakumar et al. [4]; Srinivas et al. [5]; Subba Rao et al. [6] and others). However, little work has so far been carried out about the suitability of groundwater for irrigation purpose in the study area.

The present attempt is, thus, focused on 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.

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II. STUDY AREA

The study area WRN-1 watershed is located in the southeastern part of Yavatmal District of Maharashtra State. It lies between the longitude $78^{\circ}50'50''$ to $79^{\circ}08'50''$ and latitude of $19^{\circ}51'40''$ to $20^{\circ}02'30''$ and covers an area of 425km^2 (Fig.1). Nirgudanala is the major stream forming WRN-1, which in turn contribute water to Wardha River. The average annual rainfall of the area is 770mm. The area experiences tropical climate with the maximum temperature up to 45degree in the month of April and May. The area exhibits undulating topography with dissected plateau and very few isolated hills.

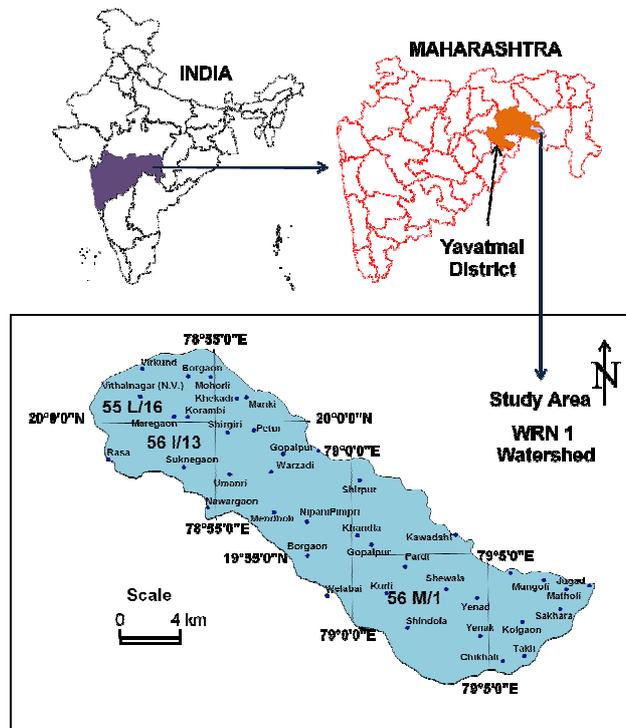


Fig. 1. Location map of study area

Geologically, the study area is dominated by Penganga limestones of Neoproterozoic age, which are mostly represented by grey to pink limestones (Fig. 2). Penganga rocks are overlain by Permo-Carboniferous Kamthi Formation of Gondwana Supergroup and are represented by yellow coloured hard sandstone with minor shale. Gondwanas are overlain by basaltic lava flows of Deccan Volcanic Province, mostly represented by black, grey, vesicular and massive basalts. Quaternary alluvium and black soils overlies basalts (GSI [7]).

III.METHODOLOGY

In the present work, groundwater samples were collected from 31 wells during post-monsoon season (Fig.1). For sample collection, polyethylene bottles were used and collected samples were analyzed in the laboratory for various physicochemical parameters. Standard procedures recommended by the American Public Health Association were followed during sample collection, handling, preservation and analysis (APHA [8]). The ionic balance error for studied ions is within $\pm 5\%$.

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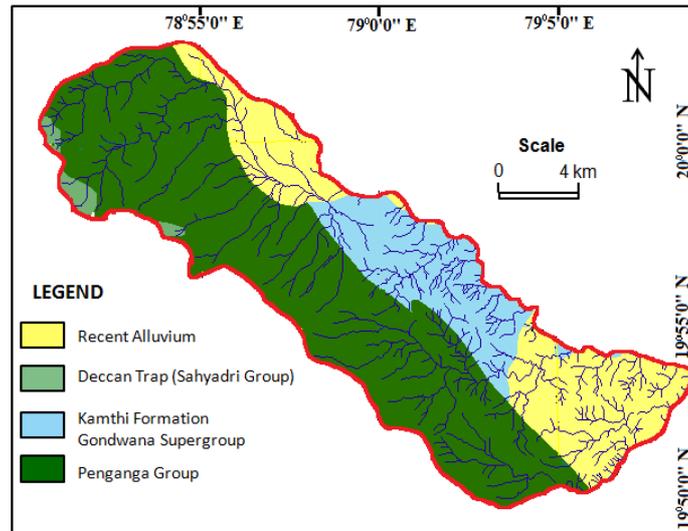


Fig. 2. Geological map of study area

IV. RESULTS AND DISCUSSION

1. Physical parameters

The physio-chemical data of the samples analyzed is given in the Table 1. The pH of the deep aquifer samples ranges from 6.9 to 7.8 with an average of 7.0. For groundwater, conductivity is directly related to the concentration of ions present in it. Higher conductivity may be attributed to high salinity and high mineral percentage in groundwater samples (Sanchez-Perez and Tremolieres [9]). In deep aquifers, the EC values ranges from 760 to 7517 $\mu\text{S}/\text{cm}$ at 25°C indicating dissolution of minerals. The large variation in EC is attributed to anthropogenic activities and to geochemical processes prevailing in the area (Choi et al. [10]).

Cation chemistry

Among the cations, Ca^{2+} is the most dominant constituent in the groundwater of the study area. It varies from 74 to 444 mg/l in deep aquifers. The concentration of Mg^{2+} ranges from 9 to 219mg/l. The principal sources of Mg^{2+} in the natural waters are magnesium-bearing minerals in rocks and secondary sources are animal, domestic and industrial wastes. In the study area, the Na^+ concentration ranges from 12 to 931 mg/l. The factors, which are responsible for high concentration of Na^+ are weathering of rock forming minerals like sodium plagioclase, halite and anthropogenic sources like domestic and animal waste. The concentration of K^+ in groundwaters of study area is highly variable and ranges 0.5 to 544 mg/l.

Anion chemistry

In the groundwater samples of study area, Cl^- and HCO_3^- are the dominant anions followed by SO_4^{2-} and NO_3^- . The high Cl^- concentration in groundwater comes from weathering of minerals like halite and other sources such as domestic effluents, fertilizers, septic tanks and leachates from landfills (Loizidou and Kapetanios [11]). It varies from 28 to 1711 mg/l in deep aquifers. In groundwater primary source of HCO_3^- is the dissolution of minerals like calcite and dolomite present in Penganga limestones and secondary sources can results from dissolution of CO_2 gas likely formed by the anoxic biodegradation of organic matter that can be derived from industrial and domestic sewage, septic tanks and buried waste in landfills (Canter [12]). In the study area, HCO_3^- ranges between 354 to 885 mg/l in deep aquifers.

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The source of NO_3^- in groundwater is due to decaying organic matter, sewage wastes, leakage of septic tanks and fertilizers (Merghade et al. [13]). The NO_3^- concentration varies from 1 to 1054 mg/l in groundwater from deep aquifers.

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

S.No	pH	EC	TDS	TH	TA	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
1	7.4	7517	4685	1520	410	252	216	931	23	500	1711	308	992
2	7.9	3460	2113	935	295	174	122	338	5	360	536	731	27
3	7.3	1900	1027	610	360	104	85	112	9	439	241	177	80
4	7.4	3200	1908	850	560	188	92	275	33	683	398	242	338
5	6.9	5200	3345	1605	415	302	207	394	18	506	646	784	741
6	6.9	5080	3143	2010	725	444	219	263	34	885	234	452	1054
7	7.3	4860	3140	990	475	186	128	532	115	580	760	324	805
8	7.8	4060	2832	720	530	104	112	244	544	647	440	438	626
9	7.2	1210	674	450	425	153	16	55	5	519	67	78	40
10	7.3	2510	1683	420	400	104	39	352	6	488	185	195	556
11	7.2	3300	1970	665	525	220	28	375	55	641	540	311	120
12	6.9	4380	2608	770	650	162	89	578	41	793	795	346	199
13	7.2	1230	703	500	405	130	43	34	23	494	85	79	62
14	7.2	1310	724	540	445	130	52	44	2	543	107	47	70
15	7.4	1210	658	435	473	130	27	55	22	576	71	64	1
16	7.5	760	382	335	328	78	34	12	1	400	28	26	2
17	7.3	1260	665	300	425	74	28	159	4	519	89	19	33
18	7.5	1800	963	820	390	284	27	40	1	476	241	73	59
19	7.4	1070	581	430	425	116	34	29	15	519	50	23	55
20	7.3	980	565	370	390	134	9	21	44	476	43	25	51
21	7.2	1090	618	370	448	74	45	19	86	546	36	28	58
22	7.1	1210	689	350	495	74	40	38	114	604	64	29	28
23	7.1	1910	1142	715	398	216	43	75	30	485	270	77	188
24	7.1	1270	688	520	310	124	51	49	4	378	149	85	36
25	7.5	2070	1267	785	290	122	117	90	4	354	234	179	344
26	7.4	1425	804	515	390	100	64	72	5	476	121	91	113
27	6.9	3640	2365	780	580	88	136	319	206	708	405	232	624
28	6.8	3770	2458	930	375	86	174	306	156	458	504	360	643
29	6.9	928	485	390	378	112	27	25	1	461	36	38	16
30	7.1	910	459	370	370	92	34	31	4	451	43	27	2
31	6.9	1440	786	495	589	106	56	52	68	719	78	58	8
Min	6.9	760	382	300	290	74	9	12	0.5	354	28	17	1
Max	7.8	7517	4685	2010	725	444	219	931	544	885	1711	784	1054
Avg.	7	2450	1488	693	441	150	77	191	54	538	297	192	257

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

Total dissolved solids and Total hardness

Total dissolved solids (TDS) in the study area ranges from 382 to 4685 mg/l in deep aquifers indicating dissolution of minerals (Choi et al. [10]). Ca^{2+} and Mg^{2+} along with Cl^- , SO_4^{2-} and HCO_3^- , accounts for water hardness. High hardness is usually undesirable because it can cause lime build up (scaling) in pipes and also in water heaters, which over the time will decrease water heater efficiency and decrease lathering of soap. The total hardness (TH) as CaCO_3 ranges from 300 to 2010 mg/l in deep aquifers.

2. Hydrochemical facies

The hydro-chemical evolution of groundwater can be understood by plotting the major cations and anions in Piper Trilinear diagram (Piper [14]). The abundance of cations and anions in groundwater samples is $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+ = \text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$.

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Pipers trilinear diagram (Piper [14]) reveals that the water mostly belong to the Ca-Mg-HCO₃⁻ type suggesting alkaline earth (Ca²⁺ + Mg²⁺) exceeds alkalis (Na⁺ + K⁺) and weak acids (CO₃²⁻ + HCO₃⁻) exceed strong acids (Cl⁻ + SO₄²⁻) (Fig.3). 70-85% of the samples show the dominance of calcium and magnesium as major cations and bicarbonate and carbonate as major anion. The Ca²⁺, Mg²⁺ and HCO₃⁻ indicate the temporary hardness and alkalinity.

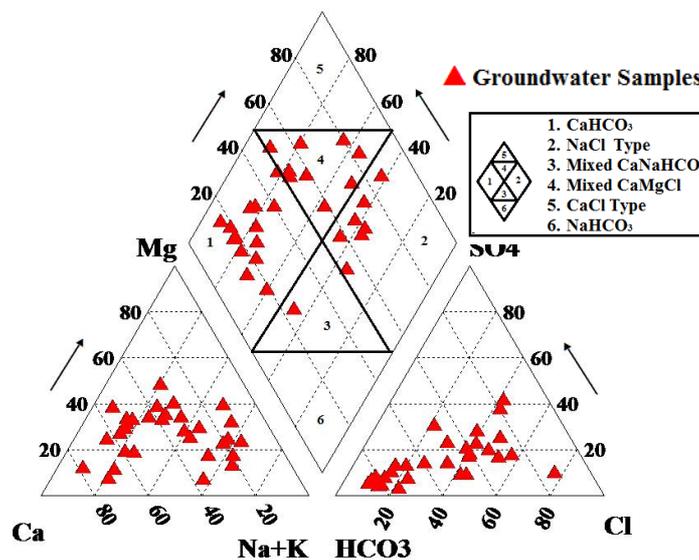


Fig.3. Chemical facies of groundwater from study area in Piper diagram

3. Irrigation Suitability

The parameters such as Sodium Adsorption Ratio (SAR), Sodium Percentage (Na %), Residual Sodium Carbonate (RSC), Permeability Index (PI) were estimated to assess the suitability of water for irrigational purposes. The specifications recommended by US Salinity Laboratory Staff (U.S. Salinity Laboratory Staff [15]) have been used for studying the quality of groundwater for irrigation purposes.

Electrical conductivity (Salinity Hazard)

Salinity hazard can be best measured by electrical conductivity as it reflects the TDS in groundwater (Ragunath [16]) (Table 2). It has been observed that, total 13 (41.8%) 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 [17]). This prevents water from reaching the branches and leaves, thus reducing the agricultural productivity.

Sodium adsorption ratio (SAR)

For determining the groundwater suitability for irrigation Sodium Adsorption Ratio (SAR) is an important parameter because it is a measure of alkali/sodium hazard to crops (Karanth[18]).

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

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Electrical conductivity and Na⁺ play a vital role in suitability of water for irrigation. High salt content forms saline soils, which takes up Na⁺ from the soil in exchange of Ca²⁺ and Mg²⁺, causing deflocculation and impairment of the tilth and permeability of soils (Hem [19]). Na⁺ makes soil alkaline with an association of Cl⁻, which does not help in the plant growth. As per the classification of Wilcox [20] (Table 2), 54.8% of the water samples are excellent in water quality, 19.3% are good to fair in water quality and 25.8% are poor in groundwater quality from the irrigation point of view. Excess Na⁺ in groundwater gets adsorbed in soil particles, changing soil properties and also reduces soil permeability (Ayers and Bronson [21]).

Table 2: Irrigation parameters for the groundwaters of study area

Parameter	Range	Classification	No. of Samples	%
Na % (meq/l) Ragunath[16]	0-20	excellent	3	9.6
	20-40	good	12	38.7
	40-60	permissible	7	22.5
	60-80	Doubtful	9	29
	>80	Unsuitable	-	-
SAR(meq/l)	0-10	excellent	17	54.8
	10--18	good	2	6.4
	18-26	fair	4	12.9
	>26	Poor	8	25.8
RSC (meq/l)	<1.25	good	27	87
	1.25- 2.5	Medium	2	6.4
	>250	Bad	2	6.4
EC (µS/cm)	< 250	Low Salinity hazard (good)	-	-
	250-750	Medium Salinity hazard (moderate)	18	58
	750-2250	High Salinity hazard (poor)	2	6.4
	>2250	V.High Salinity hazard (very poor)	11	35.4
PI (Doneen[22])	Class I	Max. Permeability	1	3.2
	Class II	75% of Max. Permeability	29	93.5
	Class III	25% of Max. Permeability	1	3.2

US salinity laboratory diagram

The chemical data of the study area is plotted in salinity hazard (EC) vs sodium hazard (SAR) diagram of U.S. Salinity Laboratory Staff [15], widely used for judging the water quality for irrigation (Fig. 4). On this diagram, about 70 % 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. 22.5 % of samples falls in C4S2 field, use of such water samples in the long term will increase both salinity and alkali hazard in the soil (Fig. 4). Whereas only two samples fall in C4S3 which shows water of very high salinity hazard and high sodium hazard. Such waters can be suitable for plants, after taking special soil management measures, such as good drainage and leaching, and addition of organic matter (Karanth[23]).

Residual sodium carbonate (RSC)

The soil permeability decreases as Ca²⁺ and Mg²⁺ get fixed in the soil by the process of base-exchange. The RSC is defined as the excess of CO₃⁻ and HCO₃⁻ amount over the alkaline earths (Ca²⁺ and Mg²⁺). RSC evaluates the water quality for irrigation purpose along with US Salinity Laboratory's diagram. The RSC can be computed as-

$$(\text{Na}_2\text{CO}_3) = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \text{ (meq/l)}$$

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Eaton [24] and Lloyd and Heathcote [25] suggested the classification of irrigation water on the basis of RSC values (Table 2), the data reveals that 87% of groundwater samples falls under good water classification hence, are suitable for irrigation purposes.

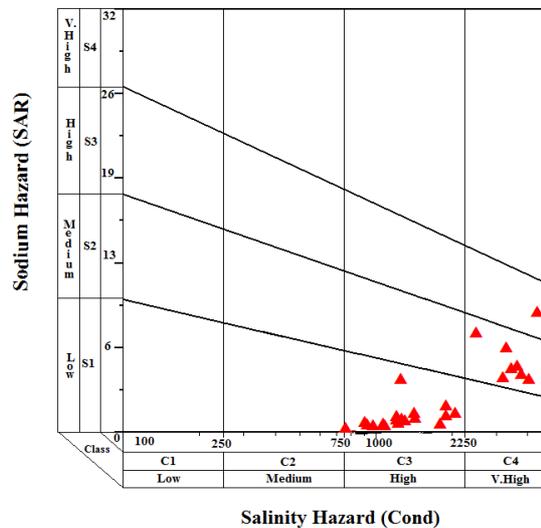


Fig.4.Suitability of groundwater for irrigation in USDA diagram (After US Salinity Laboratory Staff [15])

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. Ragnath [16] has evolved a criterion for assessing the suitability of water for irrigation based on PI, which has been calculated by using the formula-

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

According to PI values (Table 2), the groundwaters can be designated as class II (25-75%) in 93.5% samples and remaining as class I (>75%) of Doneen's chart (Domenico and Schwartz [26]).

Sodium percentage (Na %)

The sodium percent is an important factor for studying sodium hazard and it is widely used for evaluating the suitability of water quality for irrigation (Wilcox [27]).The Na% in the samples of study area is calculated by using the formula-

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

Subsequently, the samples are classified by Raghunath for identifying their water types (Table2) (Raghunath [16]). It is evident that approximately 29% of the total samples of study area show 'Doubtful' water, while rest of the samples is found to be suitable for irrigation purposes. Excess sodium concentration in groundwater produces undesirable effects because Na reacts with soil to reduce its permeability and support little or no plant growth (Vasanthavigar et al. [28]).

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V. CONCLUSIONS

Interpretation of water quality analysis reveals that the groundwater in study area is slightly alkaline, hard to very hard. The abundance of the major ions is $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+ = \text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$. Ca-HCO₃ and Ca-Mg-HCO₃ are the dominant types and Alkaline earths slightly exceed alkalis and weak acids exceed strong acids. Based on U.S. Salinity Laboratory Staff diagram about 70 % of groundwater samples fall in C3S1, 22.5 % of samples fall in C4S2 field, whereas only two samples fall in C4S3 which shows water of very high salinity hazard and high sodium hazard. Based on the RSC and PI, the groundwater in the study area is suitable for irrigation purposes. On the basis of SAR 54% of samples belong to the excellent, 26% samples belong to poor category and to overcome this salt tolerant cropping patterns is suggested. Assessment of water samples from various methods indicate that groundwater in study area is suitable for agricultural activities. The local sanitation system in the area must be improved to ensure better groundwater quality

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