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Groundwater quality evaluation for irrigation application in Mandsaur region, Madhya Pradesh, India

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ABSTRACT

The chemical analysis of 22 water samples collected from representative open dug-wells existing in the Mandsaur area of Madhya Pradesh, India, was carried out for evaluating the quality of irrigation water. For this purpose, its colour, odour, taste, pH, total hardness, electrical conductivity, ionic concentrations, and various other parameters were determined. The calculated values of per cent sodium, Kelley's ratio, sodium adsorption ratio, residual sodium carbonate and magnesium hazard indicate that except at a few places, the groundwater, in general, is suitable for irrigation.

The sodium adsorption ratio and electrical conductivity values were plotted on the U. S. Salinity Diagram. The plots of these parameters indicate that 8 samples fall in CS type (Medium Salinity and Low Sodium hazards), and 14 samples belong to C type (High Salinity and Low Sodium hazards). In general, the groundwater is favourable for irrigation use. The values of electrical conductivity and sodium percentage determined in respect of groundwater samples of Mandsaur were also plotted on the Wilcox Diagram. Based on this diagram, 4 samples represent Excellent to Good categories, whereas 18 samples indicate Good to Permissible categories. Based on this classification the groundwater of Mandsaur area, in general, is suitable for irrigation application.

INTRODUCTION

Groundwater is dynamic, replenishable, and vital earth resource. It acts as an elixir of life and contains some minerals or salts in solutions, derived from the rock during its weathering and erosion. Sedimentary rocks as compared to igneous rocks contribute a substantial amount of dissolved salt in groundwater. Groundwater may be contaminated by heavy metals and toxic organic substances. Hence the monitoring of groundwater quality is essential for irrigation to achieve the target of optimum growth of agriculture.

India is mainly an agricultural country and is dependent on water resources for irrigation. It has been estimated that groundwater contributes to the irrigation of 29 million ha out of more than 70 million ha of cultivated land being irrigated. The groundwater resources are sufficient to provide assured irrigation to nearly 40 million ha (Valdiya 1987). The monitoring of groundwater quality for irrigation purpose is essential with a view to obtain an optimum growth of agriculture. Realising the significance of contamination-free groundwater supply for irrigation, the quality of shallow groundwater from Mandsaur Township located in the Malwa region of Madhya Pradesh, constituting part of Deccan Volcanic Province, India, is discussed herein.

The hydrogeochemical study was carried out in the vicinity of Mandsaur Township which is bounded by latitudes 24°0' and 24°5'N and longitudes 75°0' and 75°10'E (Survey of India Topographic Map No. 45P/4, Fig. 1). It is characterised by the existence of a typical Deccan Trap topography exhibiting plateau plains with gentle to steep slopes. The plateau tops are covered by scrubby forest and have rather thin soil cover with altitudes ranging from 421 m to 471 m. The surface drainage is mainly provided by the Shivna River and its tributaries which become dry during summer. The average annual rainfall is 645.2 mm. The temperature varies from 9.3 °C to 45 °C with an average of 27 °C whereas the relative humidity ranges from 25% to 70%.

The earlier geological investigations were carried out by Heron (1935) and Roy Chaudhary (1955). Preliminary hydrogeological studies were conducted by Joshi (1977), Mishra (1998), and Kulhada (2001).

HYDROGEOLOGICAL SETUP

Geologically, the Mandsaur area is occupied the Aravalli Group, Delhi Group, Deccan Traps, and Recent sediments. The Aravalli Group is represented by the Binota Shales whereas the Jhiran Sandstone unit constitutes the Delhi Group. The Deccan Traps comprise three types of basaltic lava flows developed under a thin blanket of black-cotton soil. The characteristic structural features include the presence of joints, lineaments, and fractures. The alluvium and laterite are developed along the course of the Shivna River.

The occurrence of groundwater has been observed both under unconfined and confined conditions in the basaltic terrain and alluvial zones along the Shivna River course. The groundwater in adequate quantity is found in weathered, jointed, and fractured zones of basaltic lava flows (Deccan Traps), quartzose sandstone (Delhi Group), shale and

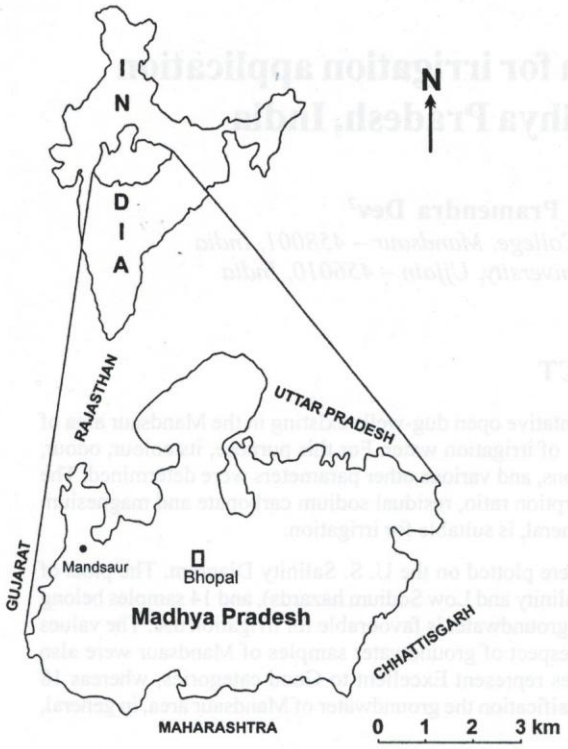

Fig. 1: Location map of Mandsaur area, Mandsaur district, Madhya Pradesh, India

sandstone (Vindhyan Group), and alluvium. The monitoring of groundwater levels indicates a variation range from 1.25 to 17.0 m below the ground level during the post- to pre-monsoon interval. The groundwater movement is mainly towards the Shivna River.

METHODOLOGY OF CHEMICAL ANALYSIS

The determination of chemical quality of groundwater occurring in the Mandsaur area has been carried out on the basis of representative 22 samples collected from dug-wells by following the standard procedure adopted by Rainwater and Thatcher (1960), American Public Health Association (1975), and Greenberg et al. (1985). The determined ionic concentration values and computed parameters were recorded (Tables 1, 2) and the U. S. Salinity Diagram and Wilcox Diagram were employed for the quality assessment of groundwater for irrigation applications.

COMPUTATION OF PARAMETERS

Sodium Percentage

Sodium content is generally expressed in per cent sodium, which is also represented as Sodium Percentage or soluble sodium (percentage). The Sodium Percentage (SP) is determined as follows:

$$\% Na = (Na + K)\ 100 / (Ca + Mg + Na + K)$$

where the concentrations are expressed in equivalents per million.

The sodium concentration in groundwater plays a significant role in determining the suitability of water for irrigation purpose. Fetter (1990) remarked that the excess of sodium percentage in irrigation water replaces the calcium and magnesium of soil because due to the excess of sodium percentage the base exchange action will be reduced.

In the present study, the determined values of sodium percentage reveal a range from 23.906% (Sample no. 1 from Bugliya) to 59.099 % (Sample no. 11 from Boharakhen). As it exceeds 50% in some of the samples, sodium plays an important role in replacing the concentration of Ca and Mg in the soil.

Sodium Adsorption Ratio

The sodium adsorption ratio (SAR) is determined on the basis of the ionic concentrations of Na, K, Ca, and Mg. The SAR is calculated using the following expression:

$$SAR = Na/(Ca + Mg)/2$$

The SAR plays a considerable role in the assessment of groundwater quality for agricultural use. In the Mandsaur area, this ratio has been calculated on the basis of the ionic concentration of sodium, calcium, and magnesium (Table 2). It has been observed that the SAR varies from 0.382 (Sample No. 17 from Chhayan) to 2.605 (Sample no. 3 from Gujarda).

Kelley's Ratio: Kelley et al. (1940) proposed the procedure for the determination of potassium and sodium problem in irrigation water based on the following expression.

$$\text{Kelley's Ratio} = Na/(Ca+Mg)$$

where ionic concentration of sodium, calcium, and magnesium are expressed in equivalent per million (epm). In the present study area, Kelley's ratio varies from 0.108 (Sample no. 17 from Chhayan) to 0.957 (Sample no. 3 from Gujarda).

Residual Sodium Carbonate

The term residual sodium carbonate (RSC) is used to express the carbonate and bicarbonate hazard on water quality. The RSC is also known as Eaton's Index and is calculated by the following formula.

$$RSC = (CO_3 + HCO_3) - (Ca+Mg)$$

The concentration of all the ions is recorded in epm. According to Eaton (1950) in the water having excess ions of carbonate and bicarbonate, calcium and magnesium will yield much greater amount of alkali as compared to its sodium adsorption ratio and as a result permeability of soil is decreased (Khare and Dev 2003). The RSC value ranges from 0.050 (Sample No. 13 from Degaonkala) to 7.254 (Sample No. 9 from Mandsaur).

Table 1: Chemical analysis results of groundwater samples from Mandsaur area

S. N.	Location	pH	EC (micro mhos/cm)	TDS (epm)	K (epm)	Na (epm)	Ca (epm)	Mg (epm)	HCO_3 (epm)	CO_3 (epm)	SO_4 (epm)	Cl (epm)	NO_3 (epm)
1	Bugliya	7.8	860	559	0.320	1.283	3.094	2.007	4.999	0.895	0.686	3.366	0.072
2	Bulgeri	7.7	840	546	0.805	2.153	2.096	2.710	3.688	0.660	0.506	2.186	0.056
3	Gujarda	7.5	500	325	1.598	3.545	1.896	1.806	3.196	0.572	0.439	0.296	0.153
4	Rewas-Dewara	7.5	600	572	0.804	2.157	2.098	3.713	3.134	0.833	0.639	2.187	0.169
5	Dawat kheri	7.8	880	390	2.083	3.980	4.790	1.903	5.08I	0.156	0.830	4.725	0.202
6	Majeti	8.8	630	409	2.237	3.588	3.692	1.405	3.032	0.543	0.493	2.045	0.137
7	Malyakheri	7.5	922	599	1.086	2.892	4.091	2.107	6.720	1.303	0.999	1.269	0.156
8	Mandsaur	8.1	690	448	1.529	3.371	2.994	1.606	8.946	0.411	0.315	3.315	0.105
9	Mandsaur	8.5	800	528	0.807	2.588	1.497	3.613	11.821	0.543	0.415	1.481	0.734
10	Mandsaur	8.5	820	533	1.240	2.718	2.099	2.208	7.457	1.334	1.023	5.148	0.089
11	Boharakheri	8.5	821	533	1.828	3.501	1.899	1.789	3.688	0.889	0.682	2.750	0.057
12	Panpur	7.8	644	416	1.086	3.373	2.096	2.007	2.868	0.556	0.427	6.418	0.106
13	Degaonkala	7.7	844	548	1.725	3.984	3.697	2.208	5.015	0.895	0.686	4.796	0.071
14	Majra-Bariyakheri	9.1	576	374	1.598	3.588	2.096	2.205	3.032	0.685	0.526	1.975	0.154
15	LohariShekh	8.3	820	533	2.083	3.982	1.796	4.616	4.946	0.569	0.436	2.045	0.347
16	Lohari Shripat	7.8	860	559	1.524	3.110	3.700	2.188	3.524	0.688	0.528	3.738	0.726
17	Chhayan	7.7	840	546	1.700	0.674	2.894	3.312	4.589	0.822	0.630	2.045	0.155
18	Rasul Pura	7.5	500	325	1.521	0.678	3.094	1.004	4.015	0.719	0.551	5.148	0.139
19	Changli	7.5	800	572	2.238	2.936	3.693	2.509	2.540	0.526	0.404	1.975	0.092
20	Arniya Nizamuddin	7.8	680	390	0.754	2.109	1.796	3.011	6.638	0.543	0.937	2.609	0.158
21	Dhakarkheri	8.9	670	435	0.294	1.718	1.896	1.801	2.950	0.534	0.414	4.372	0.144
22	Buchakheri	8.3	828	538	1.572	3.545	2.096	3.285	3.971	0.776	0.605	3.385	0.172
	Minimum	**7.5**	**500**	**325**	**0.294**	**0.674**	**1.497**	**1.004**	**254**	**0.156**	**0.414**	**0.296**	**0.056**
	Maximum	**9.1**	**922**	**599**	**2.238**	**3.982**	**4.79**	**4.616**	**11.821**	**1.334**	**1.023**	**6.418**	**0.734**

Table 2: Computation of chemical parameters of groundwater samples from Mandsaur area

S. No.	KR	Na%	SAR	RSC	Mg-H*
1	0.252	23.906	0.803	0.793	39.345
2	0.448	38.099	1.388	-0.458	56.388
3	0.957	58.146	2.605	0.066	48.784
4	0.371	33.755	1.265	-1.844	63.896
5	0.595	47.531	2.175	-1.456	28.433
6	0.704	53.333	2.247	-1.522	27.565
7	0.467	39.092	1.642	1.825	33.995
8	0.733	51.579	2.228	4.757	34.913
9	0.506	39.918	1.619	7.254	70.705
10	0.631	47.889	1.852	4.484	51.265
11	0.949	59.099	2.578	0.889	48.509
12	0.822	52.079	2.345	-0.679	48.915
13	0.675	49.156	2.318	0.050	37.392
14	0.834	54.664	2.446	-0.584	51 .267
15	0.621	48.609	2.223	-0.897	71.990
16	0.528	44.041	1.812	-1.676	37.160
17	0.108	27.669	0.382	-0.795	53.368
18	0.165	34.921	0.473	0.636	24.490
19	0.473	45.482	1.667	-3.136	40.455
20	0.439	37.327	1.360	2.374	62.638
21	0.465	35.243	1.263	-0.213	48.715
22	0.659	48.743	2.161	-0.634	61.048
Minimum	**0.108**	**23.906**	**0.382**	**0.050**	**24.49**
Maximum	**0.957**	**59.099**	**2.605**	**0.254**	**72 .990**

*Mg-H = Magnesium hazard

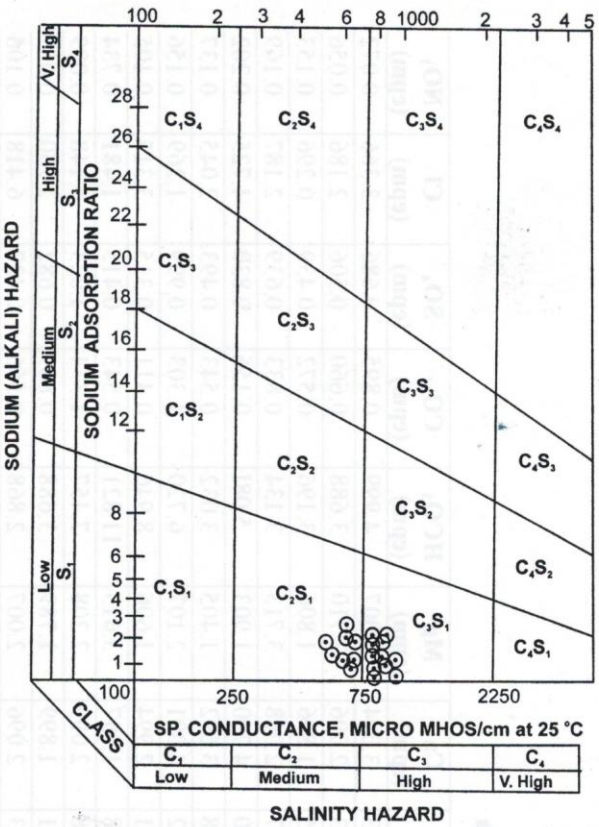

Fig. 2: Application of groundwater for irrigation in the Mandsaur area

Magnesium hazard

The magnesium hazard in irrigation has been studied by Paliwal (1972) using the ratio:

Mg Hazard = (Mg x 100)/(Ca +Mg)

In the study area, the determined values of Mg-hazard range from 24.490 (Sample no. 18 from Rasul Pura) to 71.990 (Sample no. 15 from Lohan Shekh).

INTERPRETATION OF QUALITY

The evaluation of irrigation quality of groundwater depends on a number of factors such as mineral constituents of water, texture and composition of soil, climate and irrigation practices. The water for irrigation use should be free from soluble salts and concentrations of specific chemical substances that may be a hazard to soil with respect to salinity, alkalinity and toxicity hazards (Khare and Dev 2003). Several classifications have been proposed for delineation of water quality for irrigation applications.

Wilcox (1948) on the criteria of sodium percentage values suggested a classification of irrigation water into five categories based on electrical conductivity (EC), soluble sodium per cent (SSP), and boron concentration. Wilcox (1955) proposed another classification for irrigation water quality assessment into five classes as excellent, good, permissible, doubtful and unsuitable. U. S. Salinity Laboratory Staff (1954) and Wilcox (1955) Diagrams are in wide usage for the interpretation of irrigation water quality.

In the Mandsaur area, the computation of chemical parameters of groundwater reveals that the sodium percentage (Na%) values are within a range of 23.284 to 61.073% indicating that the water can be used for irrigation purpose (Wilcox 1955). The determined EC values exhibiting a variation from 500 to 922 micromhos (Table 3) are within the upper permissible limit of EC for safe crop (Bhumbla and Abrol 1972). Kelley et al. (1940) suggested that the water having a less than unity value of Kelley's ratio (KR) is favourable for irrigation use and if it is 2 or more the water is unsuitable whereas the waters within the values of 1 to 2 are considered marginal. In the study area, the determined values of Kelley's ratio are within the range of 0.108 to 0.957 and hence suitable for irrigation. The SAR varies from 0.382 to 2.616. These values are within the recommended permissible limits.

The RSC values are within the range of 0.050 to 7.254. It has been observed that the water having more than 2.5 epm of RSC is unsuitable for irrigation, whereas the waters containing less than 1.25 epm of RSC are safe (U. S. Salinity Laboratory Staff 1954). In the study area, most of the samples have residual sodium carbonate values of less than 2.5

Table 3: Physical properties of groundwater samples from Mandsaur (OL: Odourless; CL: Colourless; TL=Tasteless)

Sample No.	Well No.	Location	Odour	Colour	Taste	Specific conductivity (Micro mhos/cm)	pH	TDS (ppm)
1	6	Bugliya	OL	CL	TL	860	7.8	559
2	9	Bulgeri	OL	CL	TL	840	7.7	546
3	16	Gujarda	OL	CL	TL	500	7.5	325
4	19	Rewas-Dewara	OL	CL	TL	600	7.5	572
5	28	Dawat kheri	OL	CL	TL	180	7.8	390
6	29	Majeti	OL	CL	TL	630	8.8	409
7	34	Ma	OL	CL	TL	922	7.3	599
8	36	Maiadsaur	OL	CL	TL	690	8.1	448
9	31	Mandsaur	OL	CL	TL	800	8.5	528
10	44	Mandsaur	OL	CL	TL	820	8.5	533
11	48	Boharakberi	OL	CL	TL	821	8.5	533
12	49	PMnpur	OL	CL	TL	644	7.8	416
13	56	Degaonbh	OL	CL	TL	844	7.7	548
14	60	Majra- Bariyakher	OL	CL	TL	576	9.1	374
15	61	LohariShekh	OL	CL	TL	820	8.3	533
16	62	Lohari Shripat	OL	CL	TL	860	7.8	559
17	63	Chhayan	OL	CL	TL	840	7.7	546
18	64	Rasul Pura	OL	CL	TL	500	7.5	325
19	68	Changli	OL	CL	TL	800	7.5	572
20	73	Arniva Nizamuddin	OL	CL	TL	680	7.8	390
21	88	Dhakarkheri	OL	CL	TL	670	8.9	435
22	140	Buchakheri	OL	CL	TL	828	8.3	538
					Range	**500 to 922**	**7.5 to 9.1**	**325 to 599**

indicating that the groundwater is favourable for irrigation. A few samples analysed from the Mandsaur town reveal higher values of residual sodium carbonate (4.484 to 7.254) and hence are unsuitable for irrigation.

The determined values of Mg-hazard range from 24.490 to 71.990. It has been pointed out by Paliwal (1972) that Mg-hazard is developed in the soil when this ratio exceeds 50. In the Mandsaur area, most of the samples are revealing an Mg-hazard ratio of less than 50 indicating that the water is suitable for irrigation. A few samples exhibit higher values of Mg-hazards (i.e. 51.261 to 71.990) and hence are unsuitable for irrigation. The water with high Mg ratio adversely affects the growth of plants. It is pointed out that the higher concentration of Mg-hazard can be reduced by adding lime to the irrigation water.

U. S. Salinity Diagram

The U. S. Salinity Diagram based on EC values (Salinity hazards) and SAR values (Sodium hazards) helps in determining the quality of groundwater for irrigation use. Based on the plots of EC values on U. S. Salinity Diagram, the water can be classified into four types: C_1 = Low Salinity Water (suitable for most crops on most soils with some leaching); C_2 = Medium Salinity Water (suitable for most crops with moderate salinity); C_3 = High Salinity Water (suitable for sodium resistant plans with adequate drainage); and C_4 = Very High Salinity Water (normally unsuitable for irrigation, but may occasionally be used under special conditions).

Based on the values of sodium adsorption ratio (SAR) the water can be classified in the following four types: S_1 = Low Sodium Water (suitable for almost all soils with less danger); S_2 = Medium Sodium Water (normally suitable for permeable coarse textured soils, may create sodium hazards in fine textured soils with poor leaching conditions); S_3 = High Sodium Water (needs special management practice such as soil management, good drainage, high leaching, and addition of organic matter); and S_4 = Very High Sodium Water (normally unsuitable for irrigation. Special reclamations are to be adopted for use of this water).

The determined values of SAR and electrical conductivity in the groundwater samples of the Mandsaur area (Tables 1 and 2) have been plotted on the U.S. Salinity Diagram (Fig. 2). The plot indicates that 8 samples fall in C_2S_1 type (Medium Salinity and Low Sodium hazards), and 14 samples belong to C_3S_1 type (High Salinity and Low Sodium Hazards). In general the groundwater is suitable for irrigation use.

Wilcox Diagram

Wilcox (1955) has classified groundwater in five categories as (1) Excellent to Good, (2) Good to Permissible, (3) Permissible to Doubtful, (4) Doubtful to Unsuitable and (5) Unsuitable. The Wilcox Diagram has been frequently used for the delineation of water quality for irrigation use.

The values of electrical conductivity and sodium percentage in the groundwater samples of the Mandsaur area (Tables 1, 2) were plotted on the Wilcox Diagram

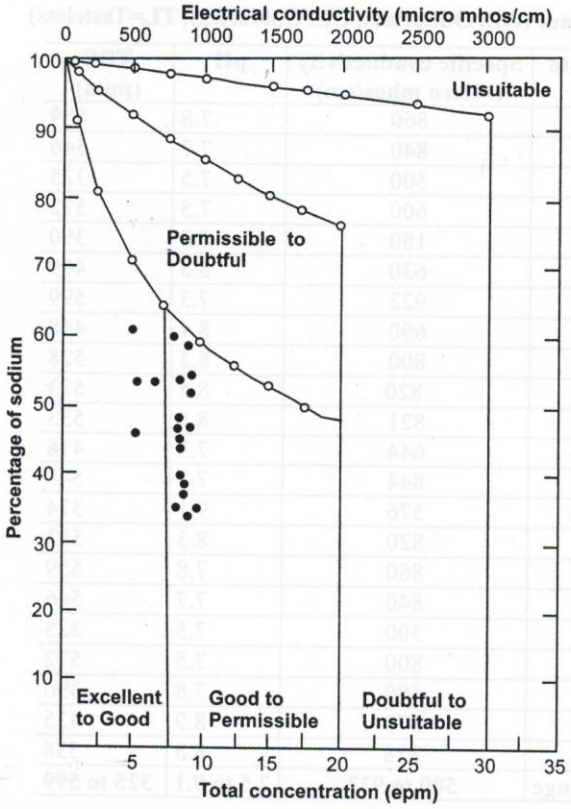

Fig. 3: Quality classification of groundwater for irrigation (Wilcox Diagram) use in Mandsaur area, Mandsaur district, (M. P.)

(Fig. 3). It has been observed that 4 samples represent Excellent to Good categories whereas 18 samples indicate Good to Permissible categories. Based on this classification the groundwater of the Mandsaur area, in general, is suitable for irrigation application.

CONCLUSIONS

The evaluation of groundwater quality for irrigation purpose in the Mandsaur area was conducted on the basis of chemical analysis of 22 dug-well water samples. The computed values of sodium percentage, Kelley's ratio, SAR, RSC, Mg-hazard indicate that except at a few places such as the Mansaur town, Rewas Dewara, Lohari Shekh, Chhayan, Arniya Nizammuddin, and Buchakheri, the groundwater, in general, is suitable for irrigation.

The plots of electrical conductivity versus sodium adsorption ratio on U. S. Salinity Diagram indicate that the groundwater is of C_2S_1 (Medium Salinity and Low Sodium hazards) and C_3S_1 (High Salinity and Low Sodium hazards) types and is suitable for irrigation. The plots of sodium percentage versus electrical conductivity on the Wilcox Diagram reveal that the groundwater is of Excellent to Good and Good to Permissible categories and it is favourable for irrigation use. At places where there are hazardous ionic concentrations, the water can be utilised for irrigation after proper treatment.

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