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GROUND WATER QUALITY MONITORING AND EVALUATION IN SAGAR DISTRICT, M.P.

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ABSTRACT

A hydrochemical study of the ground water of district Sagar has been carried out during 1996 to examine the suitability of water for drinking and irrigation purposes. Thirty five water samples representing the shallow ground water of the region were collected during pre-monsoon and post-monsoon seasons in the month of June and November 1996 respectively. Various parameters, viz., pH, conductance, total dissolved solids, alkalinity, hardness, chloride, sulphate, phosphate, sodium, potassium, calcium and magnesium, have been determined for each sample. The data was analysed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types were identified. The results of the study provide information needed for ground water quality management in the region. The values of sodium adsorption ratio indicate that ground water of the area falls under the category of low sodium hazards.

The ground water of the region has also been classified on the basis of Stiff, Piper trilinear and U.S. Salinity Laboratory classifications. These classifications allowed to characterize the samples of ground water according to their hydrochemical facies and their quality for agricultural use. Majority of the samples of the study area fall in the Ca-Mg-HCO_3 hydrochemical facies. The ground water is acceptable for irrigation purpose.

1.0 INTRODUCTION

1.1 General

Ground water is important as a source of drinking water as well as for irrigation and industrial use. Ground water is a major resource and is often readily available than surface water. Most of the population uses ground water as its primary source of drinking water.

Ground water quality is usually defined in terms of the concentration of its chemical constituents relative to a variety of potential uses. The four simple ground water classification (Freeze and Cherry, 1979) based on total dissolved solids (TDS) are:

Category	TDS (mg/L)
Fresh water	0 - 1,000
Brackish water	1,000 - 10,000
Saline water	10,000 - 100,000
Brine water	More than 100,000

As water moves through the hydrologic cycle it interacts with the atmosphere, soils and subsurface geologic formations. This affects its chemical composition and constituent concentrations. Freeze and Cherry (1979) discussed how precipitation that is naturally slightly acidic (pH = 5.6) causes chemical reactions with geologic materials. Through this process the natural recharge of an aquifer may add from 10 to 50 mg/L TDS to the ground water. Acid rain with a pH as low as 3.5 could even greater increase in the TDS of ground water.

Rain water percolating through soil may increase in acidity due to plant decomposition and microbial respiration producing carbon dioxide. The chemical quality of ground water depends upon its age and the geologic formations encountered in its flow history. The leaching of soils, organic matter, and rocks is influenced by pH. Carbonate formations can increase the magnesium, calcium and bicarbonate content of ground water due to the dissolution of calcite ($CaCO_3$) and dolomite [$Mg.Ca(CO_3)_2$]. Aluminosilicate minerals can increase the concentration of sodium, potassium, magnesium, calcium and silicon hydroxide in the percolating water. Ground water quality is often described in terms of hardness and salinity. Hardness reflects the calcium and magnesium content and is usually expressed as the equivalent amount of calcium carbonate. It can be used to assess the appropriateness of ground water for domestic and industrial use.

Ground water can become contaminated in a multitude of ways, including some of the most ordinary human activities. Prevalent sources of contamination include: (i) waste disposal; (ii) storage transportation and handling of commercial materials; (iii) mining operations; (iv) agricultural operations; and (v) other non-point sources. Contaminants may range in type from simple inorganic ions to complex synthetic organic chemicals. Excessive depletion of ground water also cause intrusion of water having undesirable quality. The details of ground water pollution sources have been described in an earlier report (Jain et. al., 1995).

An emerging ground water pollution source of potentially large national importance is non-point source pollution. Traditionally attention has been given to the surface water implications of non-point source pollution from both urban and rural areas. The ground water pollution potential of the land application of fertilizers and pesticides in both urban and rural areas is potentially significant. There are many locations in agricultural areas where nitrate and pesticide levels in ground water have been noted as being excessive. This potential source is a major concern and need proper attention due to the increasing agricultural activities.

Ground water contamination is typically a local phenomenon affecting the uppermost aquifers. Contamination problems vary from region to region with the depth of water table and are influenced by climate, population density, intensity of industrial and agricultural activities and the hydrogeology of the region. The kind and concentration of dissolved constituent depends on the source of salts and sub-surface environment.

Sharma (1991) has reported pollution of ground water in urban areas due to intensive extraction of ground water through tube wells which create suction of filthy surface water into the aquifer. Gupta and Pathak (1994) studied the resource availability and quality assessment of ground water around Rewa city in Madhya Pradesh. Sharma et al. (1995) examined the ground water quality of various villages within the municipal limits of Gwalior and reported no threat to ground water sources as there are no potential industrial units in the area. The study of nitrate contents in rural areas of Nagpur has been conducted by Joshi et. al. (1995). Kataria (1994, 1995) studied the silica content in ground water of Bhopal district and evaluated the quality of ground water for domestic applications. Physico-chemical analysis of sub-surface water of Vidisha city (Shrivatson, 1989) indicate that water needs treatment to make it suitable for domestic and industrial applications. Drinking water quality in Bhopal district and Raisen district was reported by Modi (1990) and Sunil (1991) respectively.

The present report gives detailed description of chemical characteristics of ground water of Sagar district in Madhya Pradesh with special reference to suitability of water for drinking and irrigation purposes. The ground water of the region has also been classified on the basis of different classification schemes. These classifications allowed us to characterize the samples of ground water according to their hydrochemical facies and their quality for agricultural use.

1.2 Scope of the Study

The protection and management of ground water is emerging as a great public concern in India. People are becoming more conscious about the nature of ground water and its usage with concern for its future utility when affected not only by our waste disposal activities but also by its current uses of extravagance and over-exploitation especially in urban areas.

An important aspect of urbanisation is the increase in demand and creation of potential with possibility of pollution of ground water. The present study attempts to evaluate the quality of ground water in Sagar district with particular reference to drinking and irrigation purposes. The study will provide necessary input data base for ground water management of the region.

2.0 STUDY AREA

Sagar district having a geographical area of 10.23 lakhs hac, falls in the state of Madhya Pradesh between 78°00' to 79°16' East longitude and 23°10' to 24°19' North latitude covering Survey of India toposheet No. 54L, 54P, 55I, and 55M (Fig. 1). Out of the 10.23 lakh hac land, the district has a culturable land of about 7.29 lakh hac. Sagar district comprises seven tehsils namely Sagar, Khurai, Deori, Banda, Rehali, Bina and Garhakota and divided into eleven blocks.

The area enjoys a pleasant climate in the subtropical climate zone. Moderate to extreme heat is observed during the summer season. The mean maximum temperature varies from 40 to 42°C, while mean minimum temperature varies between 11 to 8°C. The area is influenced by south-west monsoon. The rain starts from mid of June and goes upto mid of October. The mean annual rainfall for Sagar station is 1215 mm.

The area falls under Bundelkhand plateau as per broad physiographical classification. The physiographically the area falls under Piedmont plain pediment, longitudinal ridges and flood plain. The topography of the area is rolling to undulating with plain. The land slope is characterised by flat topped hillocks. This topography is a result of the variation in hardness of different flows. The hard portions forming the top of the terraces and hillocks, the soft part are eroded away.

Due to rolling and undulating topography, the upland area is having excessive surface drainage which has resulted in severe loss of surface soil and hence expose the parent material. The soils removed from uplands get accumulated on the valley land. The valley lands are moderately to poorly drained. The natural drains are limited in number and the drainage density is low. The uplands have a dendetric drainage pattern.

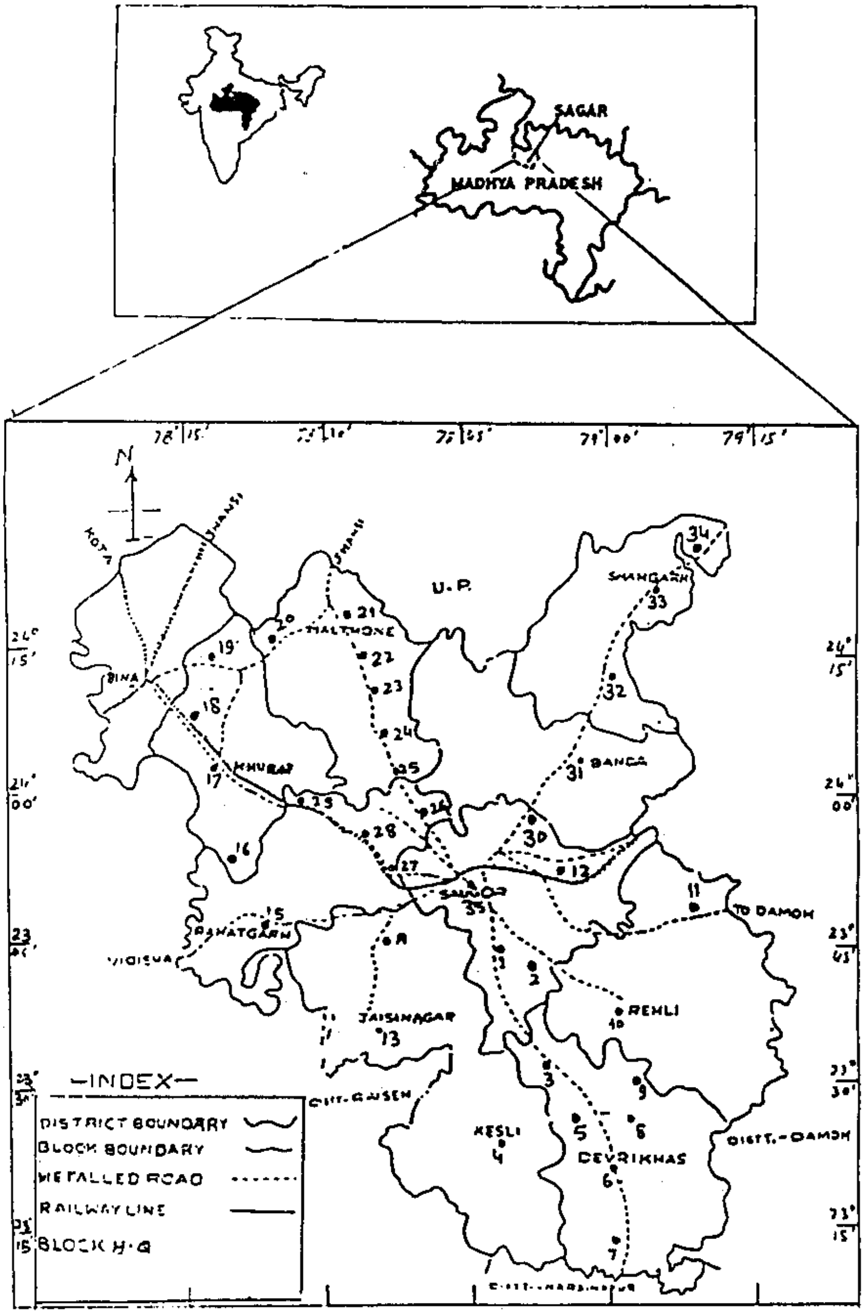

Fig. 1. Study Area and Sampling Locations

Sagar has been mapped under lower and upper Vindhyan system on geological mineral map of Madhya Pradesh. The important rock formation in the area are Vindhyan sand stone, Quartizitic sand stone, lime stone and Deccan trap called basalt. Basalt rocks overlie the Vindhyan sand stone. Lower Vindhyan are represented by quarzitic sand stone and shales where as upper Vindhya consists of sand stone and shales with subordinate limestone. Lameta limestone is also found in lower reaches. This basic rock formation mainly governs the soil characteristics of the watershed.

The major part of the area is occupied by basaltic rocks. In this basaltic terrain out crops of quartzite sandstone occurs as intens and these belong to the Rewa group of the Vindhyan super group. The other formations which are found in the area are Lametas and Bijawar.

The soils of the area have been derived from basaltic parent material and are classified under medium black soils under broad classification of Indian soils. Alluvium is also found in the area along the streams and river banks. The area falls in predominantly mono-cropped area, Rabi being the principle crop season. The main crops grown in the area are Wheat, Gram, Masoor, Jawar, Makka etc.

Forty four percent of the district falls in Ken sub-basin of Ganga basin, fifty three percent in Betwa sub-basin of Yamuna basin and three percent in Narmada basin. The area comes under the major east Yamuna Basin and subbasins of river Bewas, Dhasan and Sonar. The river Bewas, Dhasan and Sonar are the main rivers in the area. These rivers are perennial in nature but the discharge decreases considerably during the summer season. There are many small perennial and non-perennial streams which drain the surface water of the area to main rivers during the monsoon. Table 1 gives the catchment area of different rivers along with their total length in the district.

Table 1. Catchment Area of Different Rivers in Sagar District

Sub-basin	River	Catchment Area in Distt(000 ha)	Percentage of Catchment Area in Distt	Length of River in Distt.(Km)
Ken	Upper-Sonar	165.1	16.13	111
	Bewas	133.1	13.00	48
	Kopra	56.0	5.47	64
	Bearma	96.5	9.44	13
Betwa	Bina	100.6	9.83	93
	Jammi	25.8	2.52	27
	Naren	158.6	15.50	33
	Dhasan	251.2	24.55	148
Narmada	Sindhor	36.3	3.56	36

Source: Water Resources Development, Sagar District, 1985.

Ground water in the area occurs generally under water table conditions. The main natural recharge to the ground water is from precipitation, influent seepage from streams during rainy season and seepage from small tanks, with maximum contribution from rainfall.

According to M.P. State Ground Water Surveying Department, and data as collected in the year 1984, (Ground Water Survey, Bhopal, 1987), the net amount of utilisable ground water in the district is 1,21,880 hac m whereas annual ground water draft is 11,802 hac m. The remaining amount of 1,10,078 hac m is still available for future use. Ground water survey work in the district was started by M.P. State Ground Water Surveying Department, unit Sagar, in the year 1973. Initially 50 permanent observation wells were selected in the whole district scattered in different blocks and in different geological formations. From the year 1985, 50 more observation wells were selected and the static water level measurements of these wells is being recorded.

3.0 EXPERIMENTAL METHODOLOGY

3.1 Sampling and Preservation

To achieve the objectives of the study, thirty five samples representing the ground water of the region were collected from the study area by dip (or grab) sampling method during pre-monsoon (June 1996)) and post-monsoon (November 1996) seasons. The wells from which samples have been collected, are being extensively used for drinking and other domestic purposes. Some parameters like temperature, pH and conductance were measured in the field at the time of sample collection using portable kits. For other parameters, samples were collected in clean polyethylene bottles, preserved by adding an appropriate reagent and brought to the laboratory for chemical analysis.

3.2 Materials and Methods

All chemicals used in the study were of analytical reagent grade (Merck/BDH). Aqueous solutions of were prepared from the respective salts. Double distilled water was used throughout the study. All glassware and other containers were thoroughly cleaned by soaking in detergent and finally rinsed with double distilled water several times prior to use.

Physico-chemical analysis were conducted following standard methods (APHA, 1985; Jain and Bhatia, 1987). Table 2 summarizes the analytical methods used in this study alongwith detection limit for each method. Field measurements included electrical conductivity (EC), pH and water temperature. The EC was determined using a conductivity meter (HACH) calibrated with a standard solution; the pH and temperature were measured using a HACH pH meter.

Chloride was determined by argentometric method in the form of silver chloride. Alkalinity was determined by volumetric method using sulfuric acid as titrant and phenolphthalein and methyl orange as indicators. Total hardness was determined by EDTA titrimetric method. Nitrogen in the form of nitrate was determined in the ultraviolet range using UV-VIS spectrophotometer (Milton Roy Model 21 UVD). Sodium and potassium were determined by flame-emission method using flame photometer (Toshniwal Model RL 01.02). Phosphate was estimated by stannous chloride method in the form of molybdenum blue while sulphate by turbidimetric method in the form of barium sulphate crystals. Ionic balance was determined, the error in the ionic balance for all the samples was <10%.

Table 2. Summary of Analytical Methods and Equipment Used

Parameter	Analytical method/ Equipment used	Detection Limit
pH	pH meter	0.1 unit
Conductivity	Conductivity meter	1 μS/cm
TDS	Proportional electric conductivity	0.1 mg/L
Alkalinity	Volumetry with sulfuric acid	0.1 mg/L
Hardness	Volumetry with EDTA complexation	0.1 mg/L
Calcium	Titrimetry with EDTA complexation	0.1 mg/L
Magnesium	Titrimetry with EDTA complexation	0.1 mg/L
Chloride	Titrimetric with mercuric nitrate	0.1 mg/L
Sulphate	Turbidimetric	0.1 mg/L
Phosphate	Ascorbic acid	0.01 mg/L
Sodium	Flame-emission	0.1 mg/L
Potassium	Flame-emission	0.1 mg/L

4.0 RESULTS AND DISCUSSION

The chemical composition of ground water samples collected from different open wells (Fig. 1) in Sagar district during pre-monsoon (June 1996) and post-monsoon (November 1996) seasons is given in Table 3 and 4 respectively alongwith Indian standards for drinking water.

4.1 Water Quality Evaluation for Domestic Purpose

The pH value in the study area lies in the range 7.1 to 8.0 during pre-monsoon season and from 7.9 to 8.8 during post-monsoon season, indicating alkaline nature of ground water of the region. The pH values of most of the samples are within the limits prescribed by WHO (1994)and BIS (1993) for various uses of water including drinking water and other domestic supplies.

The values of electrical conductivity (EC) are is used as a criterion for expressing the total concentration of soluble salts in water. The conductivity value in the study area varies widely from 158 to 2170 µS/cm during pre-monsoon season and from 298 to 2682 µS/cm during post-monsoon season with about 50% samples having conductivity value above 1000 µS/cm. The high values of conductivity indicate high mineralization in the region.

The total dissolved solids (TDS) ranged from 158 to 2170 mg/L during pre-monsoon season (Table 3) and from 191 to 1717 mg/L during post-monsoon season (Table 4), with about 57% samples having TDS value beyond the desirable limit of 500 mg/L. Only one sample at village Parsoriya crosses the maximum permissible limit of 1500 mg/L during the post-monsoon season.

Water containing more than 500 mg/L of TDS in not considered desirable for drinking water supplies, though more highly mineralised water is also used where better water in

Table 3. Hydro-chemical Data for the Ground Water Samples of Sagar District (June 1996)

Parameter	Values			
	Min.	Max.	Mean	BIS Standards*
pH	7.1	8.0	7.5	6.5-8.5
Conductance, µS/cm	158	2170	1056	-
TDS, mg/L	101	1389	676	500
Alkalinity, mg/L	86	678	337	-
Hardness, mg/L	66	836	361	300
Chloride, mg/L	4	300	96	250
Sulphate, mg/L	1.0	83	28	150
Phosphate-P, mg/L	0.06	1.74	0.36	-
Sodium, mg/L	14	135	65	-
Potassium, mg/L	0.3	80	14	-
Calcium, mg/L	18	277	81	75
Magnesium, mg/L	4	143	39	30

IS-10500-1983

Table 4. Hydro-chemical Data for the Ground Water Samples of Sagar District (November 1996)

Parameter	Values			
	Min.	Max.	Mean	BIS Standards*
pH	7.9	8.8	8.4	[illegible].5-8.5
Conductance, μS/cm	298	2682	1079	-
TDS, mg/L	191	1717	691	500
Alkalinity, mg/L	117	649	344	-
Hardness, mg/L	129	1212	442	300
Chloride, mg/L	6	293	86	250
Sulphate, mg/L	3	138	40	150
Phosphate-P, mg/L	0.05	1.57	0.38	-
Sodium, mg/L	18	103	51	-
Potassium, mg/L	ND	1.0	0.22	-
Calcium, mg/L	38	359	118	75
Magnesium, mg/L	7	77	36	30

IS-10500-1983

not available. For this reason, 500 mg/L as the desirable limit and 1500 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1983).

The presence of carbonates, bicarbonates and hydroxides is the most common cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amounts from the action of carbonates upon the basic materials in the soil. The alkalinity values in the study area varies from 86 to 678 mg/L during pre-monsoon season (Table 3) and 117 to 1717 during post-monsoon season (Table 4). The high alkalinity value in the study area is due to the action of carbonate ions upon the basic materials in the soil.

The upper limits for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1983). In ground water of the Sagar district, calcium and magnesium ranges from 18 to 277 and from 4 to 143 mg/L respectively during pre-monsoon season. The same were found to be in the range 38 to 359 and 7 to 77 mg/L respectively during post-monsoon season (Table 4). Toxicity due to these two ions are shown by 50% of the samples during pre-monsoon season and by 65% samples during post-monsoon season.

Calcium and magnesium along with their carbonates, sulphates and chlorides makes the water hard, both temporarily and permanent. A limit of 300 mg/L has been recommended for potable waters (BIS, 1983). The total hardness as $CaCO_3$ ranges between 66 to 836 mg/L during pre-monsoon season (Table 3) and between 129 to 1212 mg/L during post-monsoon season (Table 4). From the hardness point of view, more than 75% of the total samples analysed belong to hard water category and is not suitable for many domestic applications.

The sodium concentration in the ground water varies from 14 to 135 mg/L during pre-monsoon season and from 18 to

103 mg/L during post-monsoon season. The sodium concentration more than 50 mg/L makes the water unsuitable for domestic use. The concentration of sodium is higher than the one required for domestic applications in about 50% of the total samples analysed and thereby making the water unsuitable even for domestic applications.

Limits to chloride content have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended for drinking water supplies (BIS, 1983; WHO, 1984). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride content in the study area is well within the limits prescribed for drinking water supplies for most of the samples.

A limit of 150 mg/L sulphate has been suggested for drinking water supplies (BIS, 1983). Sulphate content more than 150 mg/L is objectionable for many domestic purposes. Water containing more than 500 ppm sulphate tastes bitter and beyond 1000 ppm, it has purgative effect. The sulphate content in the ground water of the study area lies well below the permissible limit for drinking purpose and other domestic applications.

In general the ground water of the region present a very low natural quality, being generally hard. Therefore, a high concentration of major cations and anions exist.

4.2 Water Quality Evaluation for Irrigation Purpose

The quality of irrigation water depends primarily on the total concentration of dissolved constituents. The usefulness of water for irrigation has been evaluated on the basis of total concentration of soluble salts and relative proportion of sodium to other cations and discussed in the following section.

4.2.1 Total Concentration of Soluble Salts

Water used for irrigation always contains certain amount of dissolved substances which, as a general collective term, are called salts (TDS). They include relatively small but important amounts of dissolved solids originating from dissolution or weathering of the rocks and soils and dissolving of lime, gypsum and other salt sources as water passes over or percolates through them. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The total concentration of soluble salts in irrigation water can thus be expressed for the purpose of classification of irrigation water as follows:

Zone	TDS (mg/L)	Conductivity (μS/cm)
Low Salinity Zone	< 200	< 250
Medium Salinity Zone	200-500	250-750
High Salinity Zone	500-1500	750-2250
Very High Salinity Zone	1500-3000	2250-5000

In the study area the TDS value varies from 101 to 1389 mg/L during pre-monsoon season (Table 3) and from 191 to 1717 mg/L during post-monsoon season (Table 4). More than 50% samples of the study area falls under high salinity zone, such water should not be used on soils with restricted drainage. Special management for salinity control may be required and plants with good salt tolerance should be selected.

4.2.2 Relative Proportion of Sodium to Other Cations

The sodium or alkali hazard in the use of a water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio (SAR), (Richards, 1954) :

$$SAR = \frac{Na^{+}}{[(Ca^{++} + Mg^{++})/2]^{0.5}}$$

The sodium percentage is calculated as;

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{++} + Mg^{++} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

The values of SAR and sodium percentage of the ground water samples of Sagar district are given in Tables 5 and 6. Calculation of SAR for a given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicate little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazard for a given SAR.

The value of SAR in the ground water samples of the study area ranged from 0.37 to 3.00 during pre-monsoon season (Table 5) and from 0.53 to 1.76 in post-monsoon season (Table 6). As evident from Table 5 and 6, the ground water of the study area falls under the category of low sodium hazards,

Table 5. Values of Sodium Adsorption Ratio and Sodium Percentage (June 1996)

S.No.	Sample Location	SAR	Na%
1.	Bhamori Bika	1.28	29.0
2.	Dhana	1.07	28.4
3.	Surkhi	0.65	14.3
4.	Kesli	0.68	14.0
5.	Chewala	0.71	16.4
6.	Deori	0.99	23.5
7.	Maharajpur	0.79	22.1
8.	Kopara	2.11	34.8
9.	Chandpur	0.86	14.7
10.	Rehali	2.49	39.1
11.	Garahakota	1.72	24.2
12.	Parsoriya	0.87	13.4
13.	Jaisinagar	0.68	19.3
14.	Sehora	3.00	51.9
15.	Rahatgarh	1.86	26.9
16.	Barodiyanonagar	1.11	43.5
17.	Khurai	2.57	38.9
18.	Kulbai	1.99	39.9
19.	Basahari	1.09	24.2
20.	Khiriya	0.77	20.6
21.	Malthone	1.30	35.8
22.	Barodiyakalan	1.09	29.3
23.	Rajwas	1.72	35.2
24.	Pali	1.17	32.1
25.	Bandri	1.99	35.8
26.	Ranipur	0.70	20.0
27.	Naryaoli	0.37	30.9
28.	Jarua Kheda	0.93	20.7
29.	Sumreri	1.38	28.9
30.	Karrapur	1.16	24.4
31.	Banda	2.89	54.1
32.	Rurawan	0.74	31.6
33.	Shahgarh	2.21	35.8
34.	Hirapur	2.04	34.6
35.	Sagar	2.62	44.9

Table 6. Values of Sodium Adsorption Ratio and Sodium Percentage (November 1996)

S.No.	Sample Location	SAR	Na%
1.	Bhamori Bika	0.90	18.4
2.	Dhana	0.53	13.1
3.	Surkhi	0.57	11.5
4.	Kesli	0.55	10.6
5.	Chewala	0.85	16.3
6.	Deori	0.66	14.7
7.	Maharajpur	1.54	27.8
8.	Kopara	0.88	17.0
9.	Chandpur	1.06	16.9
10.	Rehali	1.90	28.8
11.	Garahakota	1.38	19.2
12.	Parsoriya	0.68	9.0
13.	Jaisinagar	0.58	15.5
14.	Sehora	1.76	28.1
15.	Rahatgarh	1.28	21.5
16.	Barodiyanonagar	0.57	14.0
17.	Khurai	1.50	25.0
18.	Kulbai	1.64	33.9
19.	Basahari	0.98	18.8
20.	Khiriya	1.00	20.6
21.	Malthone	0.83	22.7
22.	Barodiyakalan	0.88	14.7
23.	Rajwas	1.31	27.7
24.	Pali	1.33	31.3
25.	Bandri	0.65	21.5
26.	Ranipur	0.63	15.4
27.	Naryaoli	0.86	29.2
28.	Jarua Kheda	1.10	18.2
29.	Sumreri	1.28	26.6
30.	Karrapur	0.82	17.1
31.	Banda	1.70	29.9
32.	Rurawan	1.70	23.7
33.	Shahgarh	1.33	29.4
34.	Hirapur	1.26	18.7
35.	Sagar	1.45	22.2

which reveals that the ground water of the study area is free from any sodium hazard.

As per the BIS standards, a maximum limit of 60% is recommended for irrigation water. The sodium percentage in the study area was found to vary from 13.4 to 54.1% during pre-monsoon season (Table 5) and from 9.0 to 33.9% during post-monsoon season (Table 6). The sodium percentage values are well within the limit prescribed for irrigation purpose. Both SAR values and sodium percentage values indicate that the ground water of Sagar district is free from any sodium hazard.

4.3 Classification of Water

The diagrams of Stiff (1951), Piper trilinear (1953) and Wilcox (1955) are used to characterize the samples of water according to their hydrochemical facies and quality of irrigation purpose. Stiff classification (Stiff, 1951) is used to classify the type of water based on dominant cations and anions. Piper classification (1953) is used to express similarity and dissimilarity in the chemistry of different water samples based on the dominant cations and anions. U.S. Salinity Laboratory Classification (Wilcox, 1955) is used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate and salt tolerance of crop. The results of all the aforesaid classifications are discussed in the following sections.

4.3.1 Stiff Classification

The Stiff classification (Stiff, 1951) is used to define the type of water based on the presence of dominant cations and anions. The Stiff graphical method plots four major cations (Ca, Mg, Na+K, Fe) on the left side and four major anions (HCO_3+CO_3, SO_4, Cl, NO_3) on the right side. The original Stiff plot connects the points on the diagram and produces a pattern which, when compared to another analysis, is useful in making comparisons of waters. In modified Stiff diagram the length of each line defines the concentration of a particular cation and anion. Concentrations on the diagram are expressed in milliequivalent (meq) per liter. Since iron and nitrate are normally present in insignificant concentrations, most natural waters can be represented as solutions of three major cations (calcium, magnesium, sodium with or without potassium) and three major anions (bicarbonate plus carbonate, sulphate, chloride with or without nitrate).

The chemical analysis data of all the samples have been studied using Stiff classification and the results of the same are given in Tables 7 and 8 for the two sets of samples collected during pre-monsoon and post-monsoon seasons. Majority of the samples of the Sagar district were found to be of calcium bicarbonate type or magnesium bicarbonate type. Few scattered samples were also found to be of sodium bicarbonate, calcium chloride, magnesium chloride and sodium chloride types.

4.3.2 Piper Trilinear Classification

Piper classification (1953) is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of a water as it passes through an area, and related geochemical problems. For the Piper trilinear diagram, ground water is treated substantially as though it contained three cation constituents (Mg, Na+K and Ca) and three anion constituents (Cl, SO_4 and HCO_3). The diagram is useful in presenting graphically a group of analysis on the same plot.

The diagram combines three distinct fields of plotting two triangular fields at the lower left and lower

Table 7. Summarized Results of Water Classification (June 1996)

Classification/Type	Samples
Stiff Classification	
Calcium bicarbonate	1-4,6,7,9,17,21,24-26,28,29,32.
Magnesium bicarbonate	5,13,18-20,22,27,30.
Sodium bicarbonate	8,10,16,23,31,33-35.
Calcium chloride	12,15.
Magnesium chloride	11.
Sodium chloride	14.
Piper Trilinear Classification	
Ca-Mg-HCO_3	1,3-8,10,13,16-24,26-30,32-35.
Ca-Mg-Cl-SO_4	2,9,11,12,15,25.
Na-K-HCO_3	31.
U.S. Salinity Laboratory Classification	
C1-S1	32.
C2-S1	1,2,5,6,13,16,18-21,23,24,26, 29.
C3-S1	3,4,7-12,14,15,17,22,25,27,28, 30,31,33-35.
C4-S1	

Table 8. Summarized Results of Water Classification (November 1996)

Classification/Type	Samples
Stiff Classification	
Calcium bicarbonate	1-10,12-26,28-35.
Magnesium bicarbonate	27.
Calcium chloride	11.
Piper Trilinear Classification	
Ca-Mg-HCO_3	1-10,13,16-35.
Ca-Mg-Cl-SO_4	11,12,14,15.
Na-K-HCO_3	-
U.S. Salinity Laboratory Classification	
C1-S1	-
C2-S1	2,6,13,16,18,21,23-27,29,32,33.
C3-S1	1,3-5,7-11,14,15,17,19,20,22,28,30,31,34,35.
C4-S1	12.

Table 9. Sample Identification for Piper Trilinear and Wilcox Diagrams

Well No.	Location	Label
1.	Bhamori Bika	1
2.	Dhana	2
3.	Surkhi	3
4.	Kesli	4
5.	Chewala	5
6.	Deori	6
7.	Maharajpur	7
8.	Kopara	8
9.	Chandpur	9
10.	Rehali	A
11.	Garahakota	B
12.	Parsoriya	C
13.	Jaisinagar	D
14.	Sehora	E
15.	Rahatgarh	F
16.	Barodiyanonagar	G
17.	Khurai	H
18.	Kulbai	I
19.	Basahari	J
20.	Khiriya	K
21.	Malthone	L
22.	Barodiyakalan	M
23.	Rajwas	N
24.	Pali	P
25.	Bandri	Q
26.	Ranipur	R
27.	Naryaoli	S
28.	Jarua Kheda	T
29.	Sumreri	U
30.	Karrapur	V
31.	Banda	W
32.	Rurawan	X
33.	Shahgarh	Y
34.	Hirapur	Z
35.	Sagar	a

right respectively and an intervening diamond-shaped field. All three fields have scales reading in 100 parts. In the triangular field at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na) are plotted as a single point according to conventional trilinear coordinates. The three anion groups (HCO_3, SO_4, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a ground water. The central diamond-shaped field is used to show the overall chemical character of the ground water by a third single-point plotting, which is at the intersection of rays projected from the plottings of cations and anions. The position of this plotting indicates the relative composition of a ground water in terms of the cation-anion pairs that correspond to the four vertices of the field. The three trilinear plottings will show the essential chemical character of a ground water according to the relative concentrations of its constituents.

The Piper trilinear diagram for the two sets of samples are shown in Fig. 2 and 3 and the results are summarized in Table 7 and 8. The cation plots in the diagram reveals that, majority of the samples falls in no dominant type followed by calcium type. The anion plots in the diagram indicate that majority of the samples fall in bicarbonate type. These two trilinear plots indicate that the ground water of the study area are of calcium, bicarbonate and no dominant types.

The Piper trilinear diagram combines three different areas for plotting, two triangle areas (cation and anion) and an intervening diamond shaped area (combined field). Using this diagram waters can be classified into four different hydrochemical facies. Majority of the samples of the study area falls in Ca-Mg-HCO_3 facies during both the surveys. Few samples of the study area also belong to Ca-Mg-Cl-SO_4

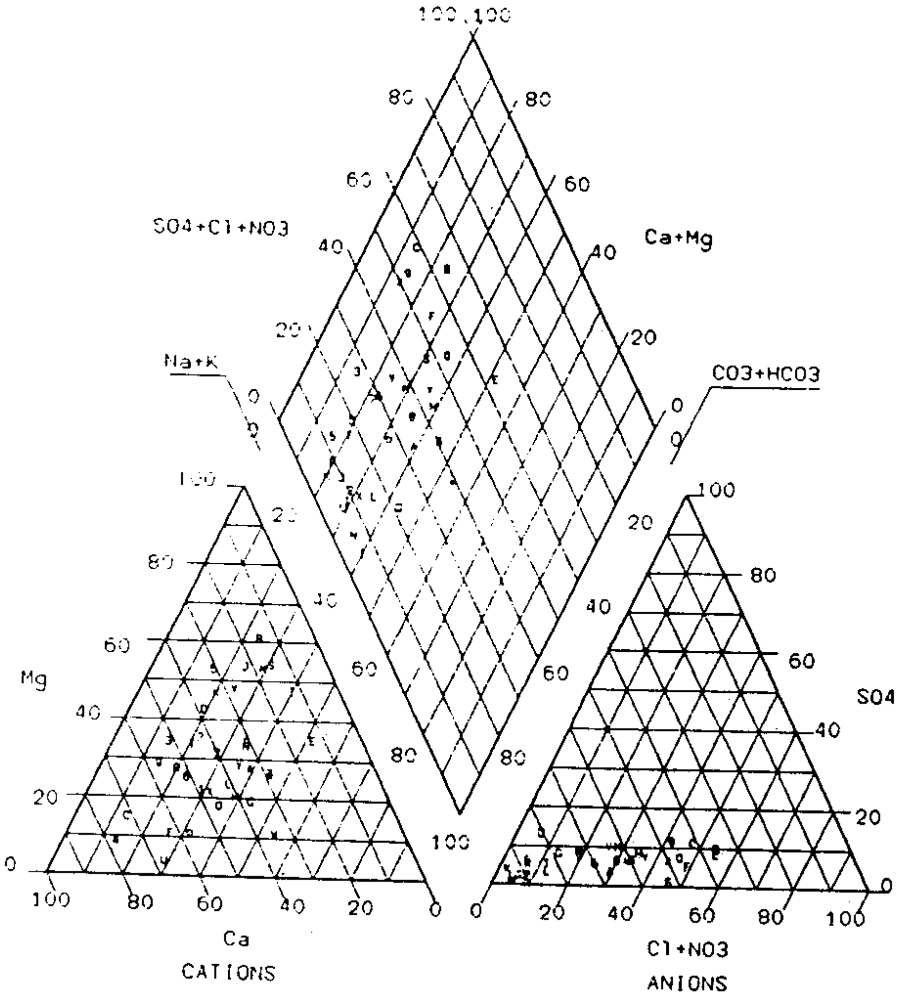

Fig. 2. Piper Trilinear Diagram Showing Chemical Character of Ground Water (June 1996)

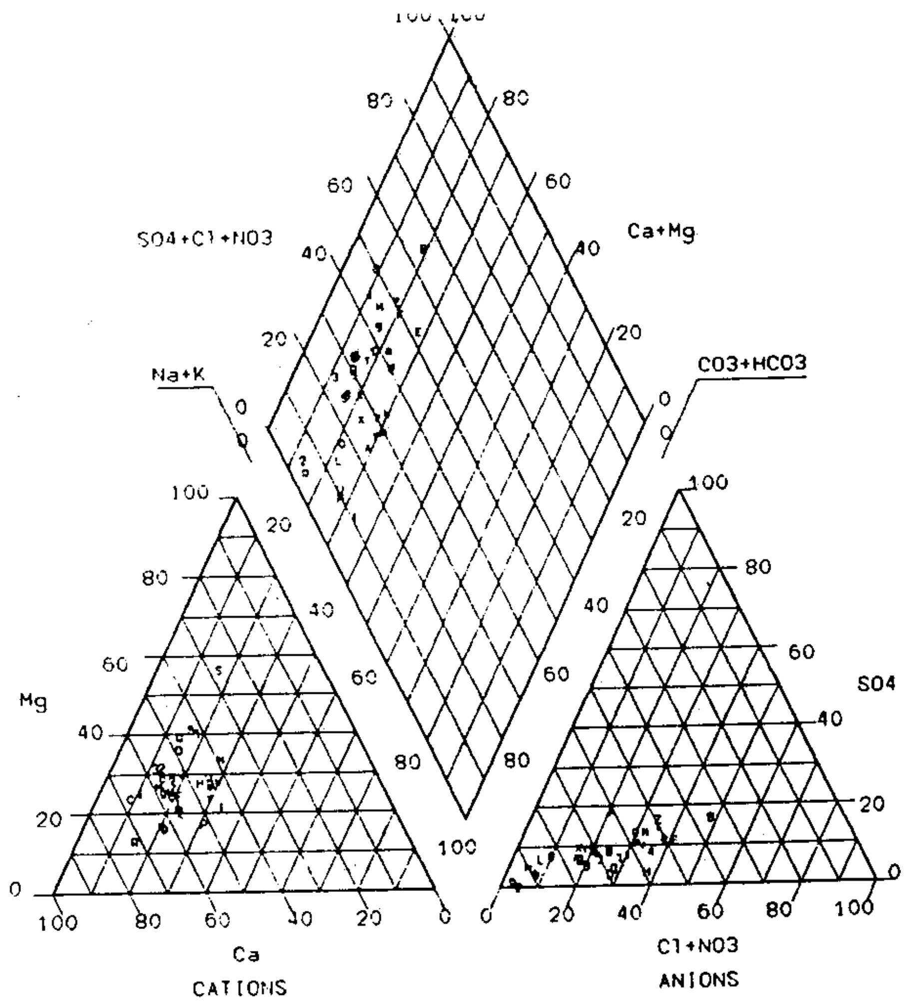

Fig. 3. Piper Trilinear Diagram Showing Chemical Character of Ground Water (November 1996)

hydrochemical facies. The grouping of samples according to their hydrochemical facies clearly indicate predominance of calcium bicarbonate type of water and falls under the Ca-Mg-HCO_3 hydrochemical facies.

4.3.3 U.S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by sodium absorption ratio (SAR). A diagram for use in studying the suitability of groundwater for irrigation purposes, named after Wilcox (1955), is based on the sodium adsorption ratio (SAR) and electrical conductivity of water expressed in μS/cm.

The chemical analysis data of all the water samples have been plotted on Wilcox diagram for the two sets of data (Fig. 4 and 5) and the results of the same have been summarized in Tables 7 and 8. According to this classification, the predominant class (more than 50%) in the region is C3-S1, that is appropriate for the irrigation but with a certain risk of salination of the grounds if there is not a good drainage. One sample was found to be of C1-S1 type (low salinity and low SAR) and fourteen samples of C2-S1 type (medium salinity and low SAR), which are of more acceptable quality for irrigation. Nevertheless, the sodium contents are low in all the samples, i.e., the region is without any risk of sodification. Almost same trend was found in post-monsoon season.

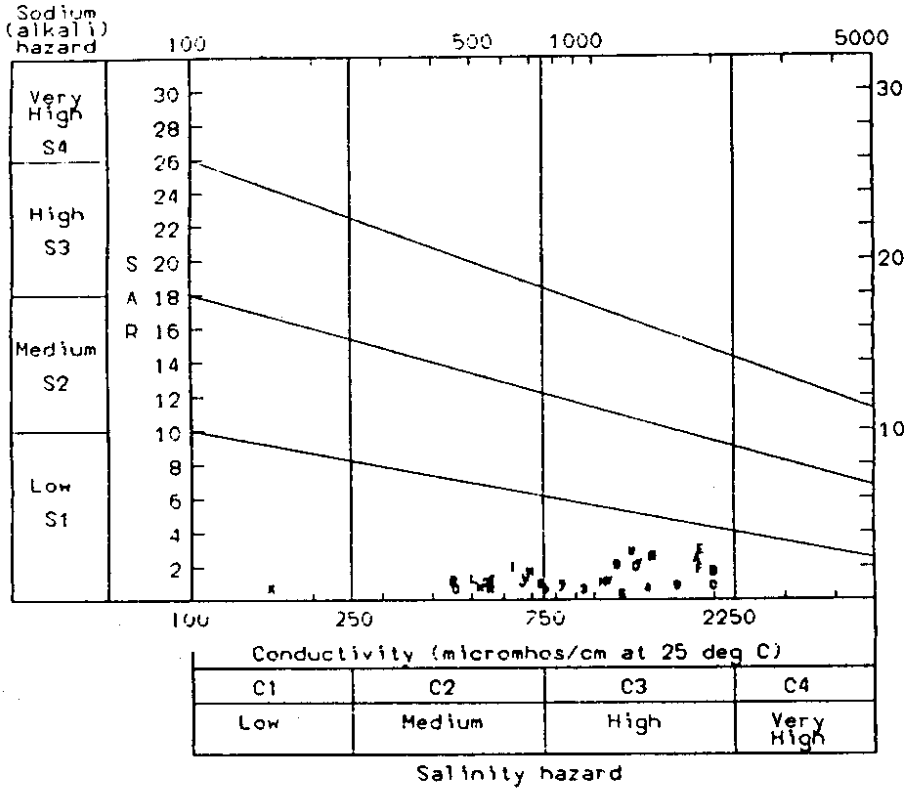

Fig. 4. U.S. Salinity Laboratory Classification (Wilcox Diagram, June 1996)

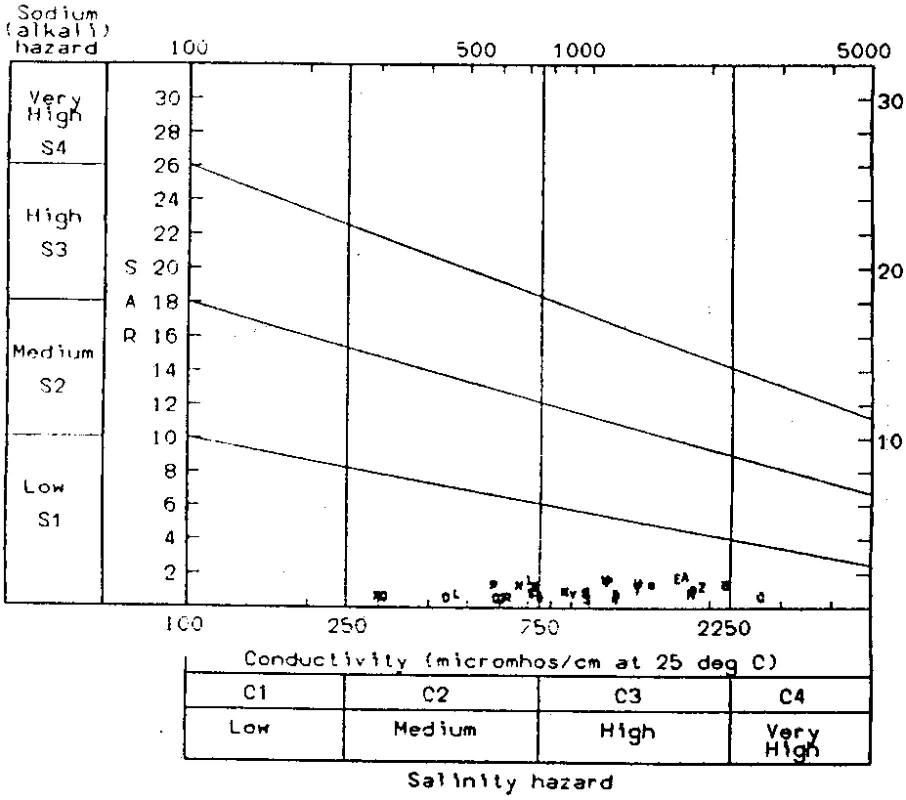

Fig. 5. U.S. Salinity Laboratory Classification (Wilcox Diagram, November 1996)

5.0 CONCLUSION

The suitability of the ground water of the Sagar district has been demonstrated on the basis of standards prescribed by BIS and WHO. More than 50% water samples shows TDS value beyond the desirable limit of 500 mg/L. However, only one sample in the post-monsoon season exceeds the maximum permissible limit for drinking purpose. The shallow aquifers are rich in bicarbonates due to geological conditions of the area. The ground water of the region present a very low natural quality, being generally hard. Therefore, a high concentration of major cations exist (Ca > 75 mg/L and Na > 50 mg/L) in more than 50% of total samples analysed. The grouping of samples according to their hydrochemical facies clearly indicate predominance of calcium bicarbonate type of water and falls under the Ca-Mg-HCO hydrochemical facies. The U.S. Salinity Laboratory classification of irrigation water indicate that the ground water of the region is of acceptable quality in general without any risk of sodification.

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