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GROUND WATER QUALITY MONITORING AND EVALUATION IN DISTRICT HARDWAR, U.P.

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PREFACE

The quality of ground water is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring. Therefore, determination of ground water quality is important from the point of view to see the suitability of water for a particular use, e.g., public water supply, irrigation, industrial applications, fish culture and power generation etc.

The ground water quality problems are more acute in the areas which are densely populated and thickly industrialized and have shallow ground water table. Keeping in view these factors, the Environmental Hydrology Division of the Institute undertook the study on ground water pollution in district Hardwar. The report presents an analysis of the ground water quality data of district Hardwar. The problematic zones are delineated and spatial distribution of ground water contamination attempted. An attempt has also been made to classify the ground water of the area on the basis of different classification schemes.

The report has been prepared by Dr. C. K. Jain, Scientist 'C' under the work programme of 1995-96. Other scientists involved in the study include Sri. Daya Ram, Scientist 'B' and Dr. K. K. S. Bhatia, Scientist 'F' of Environmental Hydrology Division.

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DIRECTOR

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ABSTRACT

The physico-chemical characteristics of ground water in different villages of district Hardwar, Utter Pradesh, have been studied during 1995 to examine the suitability of water for irrigation and domestic applications. Twenty five water samples representing the shallow ground water of the area were collected and analysed for various constituents, viz., pH, conductance, total dissolved solids, alkalinity, hardness, chloride, sulphate, phosphate, sodium, potassium, calcium and magnesium. Higher values of certain constituents at few places indicate the water is not suitable for domestic applications. From the hardness point of view, more than 50% of the total samples analysed belongs to hard water category. The values of sodium adsorption ratio indicate that ground water of the area falls under the category of low sodium hazards.

An attempt has also been made to classify the quality of ground water on the basis of Stiff, Piper trilinear and U.S. Salinity Laboratory classifications. As per the Stiff classification, most of the samples were found to be of either calcium or magnesium bicarbonate type. In the Piper trilinear diagram, majority of the groundwater samples of the study area fall in the $Ca\text{-}Mg\text{-}HCO_3$ hydrochemical facies. According to the U.S. Salinity Laboratory Classification of irrigation water, most of the samples fall under water type C2-S1 (medium salinity and low SAR) and C3-S1 (high salinity and low SAR). It is recommended that any water source must be thoroughly analysed and studied before being used for domestic applications and proper water management strategies should be adopted for agricultural and other developmental activities.

1.0 INTRODUCTION

1.1 General

Ground water is used for domestic supply, industries and agriculture in most parts of the world as it is a replenishable resource and has inherent advantages over surface water. There has been a tremendous increase in the demand for fresh water due to growth in population. The rapid growth of urban areas has affected the ground water quality due to over exploitation of resources and improper waste disposal practices. Hence there is always a need for and concern over the protection and management of ground water quality.

Further, with increasing environmental pollution it is absolutely necessary to ascertain the potability of water before it is used for human consumption. Water is one of the major carrier of several diseases of both chemical and bacteriological origins and hence careful assessment of the quality of water is essential. The quality of ground water is usually described according to its physico-chemical characteristics. Therefore, evaluation of ground water quality to determine the abiotic and biotic factors have been attracted considerable attention in the last few years.

The mechanism of ground water pollution is quite different than that of surface water and is more complicated. Surface water pollution is rapid and becomes evident in comparatively short times from perceptible changes in colour, taste, odour and at times by dead aquatic life. The process of ground water pollution is comparatively much slow and the time lag between pollution discharge at land and when pollutants reach ground water may be several years or decades.

The untreated surface and shallow ground waters are the main source of domestic water supply in the rural areas of our country. Water from these sources is often heavily polluted through the municipal and industrial wastes, surface washings, seepage from cesspools, septic tanks and manure pits, exposing the population to the dangers of water borne diseases.

The wide range of contamination sources is one of the many factors contributing to the complexity of ground water quality assessment. It is important to know the geochemistry of the chemical-soil-groundwater interactions in order to assess the fate and impact of chemicals discharged into the ground. Contaminated ground water generally show increased levels of various constituents. Nitrate contents upto 50-100 mg/L are not exceptional in contaminated ground water (Csaki and Endredi, 1981; Zoeteman, et al., 1981). Leachate of domestic waste tips may contain concentrations in the order of g/L of Na, K, NH_4, Cl and CO_3/HCO_3 (Kooper et al., 1981). High levels of nitrate (more than 45 mg/L) may cause methenoglobinemia or blue baby disease, and fluoride more than 1.5 mg/L can cause dental, skeletal and non-skeletal manifestations. High levels of sodium can be hazardous to the agricultural activities. Hence it becomes necessary to evaluate the ground water quality of an area to assess its suitability for various uses.

In western Utter Pradesh rapid industrial and agricultural growth has taken place during the last two-three decades. This is likely to multiply manifold in near future with increasing industrial and agricultural activities in the area. In an earlier paper ground water quality in western Utter Pradesh has been discussed. The present paper discusses the results of chemical analysis of ground water of district Hardwar with reference to the suitability of water for various uses and classify them on the basis of different classification schemes.

1.2 Scope and Objectives of the Study

The quality of ground water varies from place to place with the depth of water table. It also vary with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it. The kind and concentration of dissolved solid depends on the source of salts and sub-surface environment.

In western Utter Pradesh rapid industrial and agricultural growth has taken place during the last two to three decades. This is likely to become manifold in near future with increasing industrialization and agricultural development in this region. Therefore, It was proposed to take up the ground water quality monitoring in district Hardwar. Samples from twenty five wells, representing the shallow unconfined aquifers, were collected and analysed for various constituents. The present study demarcate the water quality variations at different places in district Hardwar. The study has been carried out with the following three objectives :

1. To see the suitability of water for various uses particularly drinking and irrigation purposes.

2. To delineate the bad water quality zones for irrigation and drinking purposes.

3. To assess extent of contamination through regular monitoring of ground water quality.

2.0 SOURCES OF GROUND WATER CONTAMINATION

The sources of ground water contaminants may be broadly grouped into the following categories:

- Waste disposal activities that use the subsurface as a pollutant receptor, such as hazardous waste landfills, industrial waste ponds and lagoons, waste water land treatment operations and deep well disposal systems.

- Agricultural activities involving intentional application of fertilizers and other chemicals to the land.

- Industrial and commercial operations involving the handling of large quantities of chemical substances which may be accidently released into the subsurface in significant amount as the result of leaks and spills occurring during transport, storage and utilization activities.

- Urban runoff and polluted surface water.

2.1 Waste Disposal Activities

The forms of domestic wastes which can adversely effect the ground water quality are sewage and solid wastes. Solid wastes (mostly garbage and industrial waste) is disposed in landfills where it decomposes and produces a leachate that can contaminate underlying ground water. Landfills range from unmanaged dumps where refuse is piled up with little or no regard for environmental effects, to carefully designed and operated "Sanitary" landfills. The amount of leachate produced in a landfill depends on the amount and distribution of rainfall, hydraulic conductivity of cover soil (if any), evaporation from cover soil and freezing and thawing. If the soil below the fill is relatively impermeable, percolation of leachate to underlying ground water is retarded. The chemical composition of landfill leachate depends on the nature of the refuse, on the leaching rate and on the age of the fill. The hardness of leachate and contaminated ground water is due to the dissolution of Ca and Mg compounds by CO_2 (which forms carbonic acid) produced by the decomposition of the refuse. The type of leachate produced depends upon the type of refuse. Landfills are point source of pollution and the leachate movement in the sub soil forms a narrow band or plume, unless of course, the ground water is stagnant.

Sewage wastes enters the ground intentionally from septic tanks, cesspools and systems where sewage is applied to land for crop irrigation, ground water recharge or simply disposal. Unintentional entry of sewage into the underground environment include leakage from sewers, sewage lagoons and from streams or dry washes in which sewage effluent is discharged. The capability of soil to remove suspended and dissolved constituents from sewage is utilized in land treatment systems, where sewage is applied to land with sprinklers, irrigation furrows or borders, or infiltration basins.

Injection of liquid wastes, mainly of industrial origin, has been widely adopted as a waste disposal practice. The purpose of this procedure is to isolate hazardous substances from the biosphere. As the discharge of pollutants to rivers and lakes has become increasingly objectionable, and as legislation for protection of surface water resources have become more stringent, the use of deep permeable zones for liquid waste disposal has become an increasingly attractive waste management option for many industries.

Deep injection of liquid wastes causes a point source of ground water pollution and contaminates the deeper aquifers, otherwise safe from pollution. Due to deep injection, the pollutants traverse relatively a thin column of soil and also the time lag between the pollution discharge and arrival of pollutants to ground water is reduced.

2.2 Agricultural Activities

Modern agriculture is based on extensive use of fertilizers and pesticides to obtain high crop yield. Some of the chemicals applied to farm land, however, move down with the deep percolating water from the root zone and can contaminate underlying groundwater. Manure piles, feedlots and similar concentrations of animal waste are other possible sources of ground water contamination. Deep percolation water from irrigation fields in arid region tends to have high salt content, which adversely affects underlying ground water. With the exception of manure piles, agriculture is an area of diffuse source of ground water contamination. In humid areas the major contaminant is nitrate, where as TDS and NO_3 are of most concern in arid irrigated areas.

High levels of potassium and nitrate in ground water in several parts of the country can be attributed to excessive use of fertilizers. Several insecticides which are applied to the land, can also be leached into ground water system. Excess of irrigation water as a result of leaching of salts from soils may also increase several constituents in ground water. Accumulation of excreta of farm animals and its leaching during monsoon recharge also adversely affect ground water quality.

2.3 Industrial and Commercial Operations, Leakage and Spills

Gasoline and other petroleum products can enter soils and aquifers from leaking pipelines or storage tanks and from accidents involving tank, trucks or rail road cars. Most ground water contamination cases are caused by underground tanks from gasoline stations. The potential contaminants entering ground water formations from leaking depends on the type of effluent disposed. The main problem of petroleum contamination of ground water is taste. Toxicity is not a problem because the water is already undrinkable due to taste and odour well before concentrations reach toxic levels.

2.4 Urban Runoff and Polluted Surface Water

Many streams receive municipal and industrial waste water. Seepage of such water into underlying ground water may adversely affect ground water quality. Urban runoff may infiltrate directly into the ground through pavements after it has reached a stream, or via recharge pits or "dry wells" constructed for disposal of storm runoff. Movement of contaminated or saline water in inland aquifers, sea water intrusion due to excessive withdrawals in coastal aquifers and recharge of water contaminated by air pollution may also adversely affect ground water quality.

3.0 DESCRIPTION OF THE STUDY AREA

The area under study is a part of the Indogangetic plains and lies between latitude 29^0 30'N - 30^0 15'N and longitude 77^0 45'E - 78^0 20'E in the western Utter Pradesh (Fig. 1). Physiographically the area is generally flat except for the Siwalik hills in the north and north east. The area is devoid of relief features of any prominence except for deep gorges cut by nalas and rivers flowing through the area. The area is bounded by river Yamuna in the west and river Ganga in the east.

The climate of the area as that of the greater part of Indian subcontinent is characterised by moderate type of subtropical monsoonic climate. The average annual rainfall in the area is about 1000 mm, major part of which is received during monsoon period. The major landuse is agriculture and there is no effective forest cover. The soils of the area are loam to silty loam and are free from carbonates.

The most common ground water structure in the area are shallow and deep tubewells. Dugwells are also used as source for drinking water as well as irrigation, but to a lower extent. The ground water body is contained in fine to coarse-grained sands recharged by rainfall. Other sources of ground water replenishment are infiltration from rivers, canals and return flow from irrigation and inflow from the neighbouring areas.

Based on the lithological logs and water table fluctuation data, two types of aquifers have been delineated in the area. The upper one is the shallow unconfined aquifer which generally extends to depths around 25 m. The deeper aquifers are confined to semi-confined in nature and located at depths around 30 to 140 m, below ground level separated by three to four aquifers at average depths of 30 to 55 m, 65 to 90 m, and 120 to 140 m. Water table contours in the area indicate the southward trend of ground water flow in unconfined and confined aquifers.

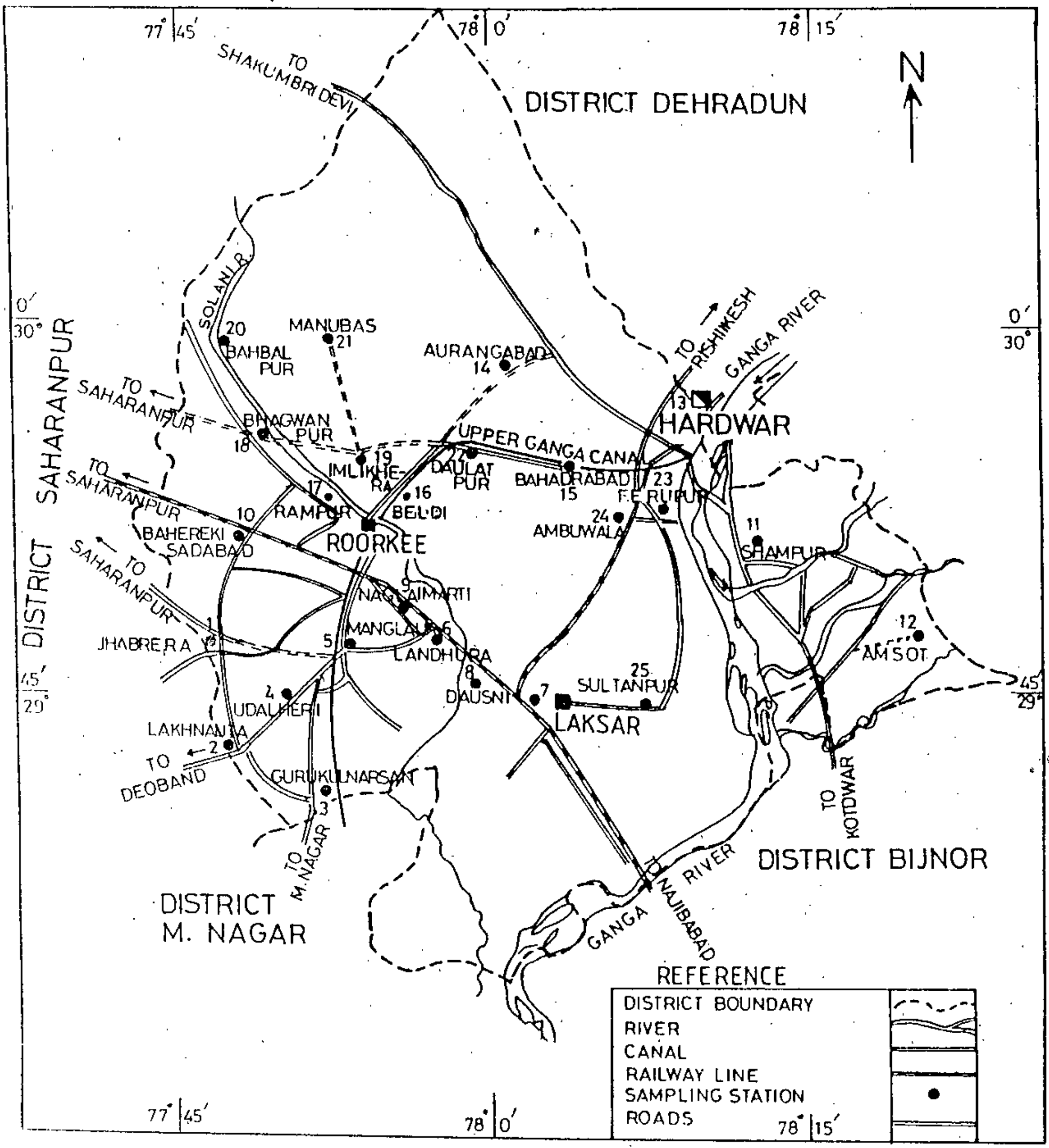

FIG.1. STUDY AREA AND SAMPLING LOCATIONS

INDEX OF THE OBSERVATION WELLS AS SHOWN IN FIG. 1

Well No.	Location
1.	Zhabrera
2.	Lakhnauta
3.	Narson
4.	Udlehri
5.	Manglour
6.	Landhora
7.	Laksar
8.	Dosni
9.	Nagla Imerti
10.	Baheri Ki Sadabad
11.	Shyampur
12.	Amsot
13.	Hardwar
14.	Aurangabad
15.	Bahadrabad
16.	Beldi
17.	Rampur
18.	Bhagwanpur
19.	Imelikhera
20.	Bhabhelpur
21.	Manubas
22.	Daulatpur
23.	Ferupur
24.	Ambuwala
25.	Sultanpur

4.0 METHODOLOGY

4.1 Sampling and Preservation

Twenty five water samples were collected from different wells covering district Hardwar by dip (or grab) sampling method during July and December 1995. The wells from which samples have been collected, are being extensively used for domestic and irrigation 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 in the sampling kits for detailed chemical analysis.

4.2 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 glasswares 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). Some parameters like temperature, pH and electrical conductance were determined in the field at the time of sample collection using portable meters.

Chloride was estimated by argentometric method in the form of silver chloride. Alkalinity was determined by volumetry using sulfuric acid as titrant and phenolphthalein and methyl orange as indicators. Total hardness and calcium hardness were determined by EDTA titrimetric method while magnesium hardness was calculated by deducting calcium hardness from total hardness. Calcium (as Ca^{++}) was calculated by multiplying calcium hardness with 0.401 while magnesium (as Mg^{++}) by multiplying magnesium hardness with 0.243. 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.

The summary of analytical methods and equipment used in the study are given in Table 1.

Table 1. Summary of Analytical Methods and Equipment Used

Parameter	Analytical method/Equipment used
pH	pH meter
Conductivity	Conductivity meter
TDS	Proportional electric conductivity
Alkalinity	Volumetry with sulfuric acid
Hardness	Volumetry with EDTA complexation
Calcium	Titrimetry with EDTA complexation
Magnesium	Titrimetry with EDTA complexation
Chloride	Titrimetric with mercuric nitrate
Sulphate	Turbidimetric
Phosphate	Ascorbic acid
Sodium	Flame-emission
Potassium	Flame-emission

5.0 RESULTS AND DISCUSSION

In the present study, ground water quality at different places (Fig. 1) in district Hardwar, Utter Pradesh, have been studied during July and December 1995. The hydrochemical data for the two sets of samples collected are presented in Table 2 & 3 respectively. Water level observations were also made during both the surveys.

5.1 Water Quality Evaluation for Domestic Purpose

On the domestic front, water is required for drinking, cooking, washing and bathing. The toxicity is due to excessive total dissolved solids, chloride, sulphate, sodium, potassium, calcium and magnesium etc. The level of concentration and the toxicity caused by these constituent is discussed below.

A pH range of 6.5 to 8.5 is normally acceptable as per guidelines suggested by WHO (1984) and BIS (1983). The pH value in the study area was always found towards alkaline side and lies in the range 7.0 to 8.2 (Table 2 & 3), which is well within the limits prescribed by WHO and BIS for various uses of water including drinking water and other domestic supplies.

The electrical conductivity value 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 370 to 2030 μS/cm during July 1995 (Table 2) and from 407 to 2670 μS/cm during December 1995 (Table 3) with about 50% samples having electrical conductivity value in the range 1000 to 2000 μS/cm.

Total dissolved solids (TDS) indicate the general nature of water quality or salinity. 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 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 TDS value

Table 2. Hydro-chemical Data for the Ground Water Samples (July 1995)

S. No.	Sample Location	W.L. (m)	pH	Cond µS/cm	TDS	Alk	Hard	Cl	SO4	PO4	Na	K	Ca	Mg
1.	Zhabrera	7.65	7.0	1577	1009	734	552	70	6	4.10	78	36	115	64
2.	Lakhnauta	8.30	7.1	1571	1005	732	486	117	5	9.40	80	92	87	65
3.	Narson	4.90	7.1	951	609	308	456	52	80	0.34	25	1	83	60
4.	Udlehri	4.50	7.5	1750	1120	744	700	141	13	4.60	60	95	161	72
5.	Manglour	13.30	7.7	1340	858	416	414	109	74	1.40	58	72	64	62
6.	Landhora	16.80	7.1	480	307	208	216	10	19	0.12	19	2	38	29
7.	Laksar	-	7.2	597	382	256	260	13	26	0.16	14	16	67	23
8.	Dosni	4.00	7.4	699	447	256	390	26	42	1.33	30	28	58	40
9.	Nagla Imerti	-	7.4	626	401	272	308	18	12	0.16	8	3	81	26
10.	Baheri Ki Sadabad	-	7.7	401	257	208	198	3	2	0.09	9	3	48	19
11.	Shyampur	6.90	7.5	618	396	272	326	7	27	0.17	6	6	87	26
12.	Amsot	2.20	8.2	370	237	176	192	6	30	0.22	9	2	55	14
13.	Hardwar	5.20	7.7	496	317	172	206	23	42	0.66	13	14	47	21
14.	Aurangabad	10.80	7.5	615	394	292	306	8	6	0.15	7	6	95	17
15.	Bahadrabad	7.00	7.5	1622	1038	512	560	128	75	1.07	52	23	184	24
16.	Beldi	-	7.5	1038	664	368	422	68	38	0.83	25	12	98	43
17.	Rampur	8.00	7.2	1917	1227	523	670	203	50	2.33	98	30	199	42
18.	Bhagwanpur	9.70	7.1	893	572	386	356	12	19	0.77	17	5	77	40
19.	Imelikhera	12.00	7.7	561	359	245	178	91	19	0.34	49	2	22	30
20.	Bhabhelpur	3.70	7.3	857	549	355	380	49	45	0.36	23	4	115	23
21.	Manubas	14.20	7.2	1320	845	414	360	98	4	0.36	40	15	90	33
22.	Daulatpur	7.00	7.2	531	340	260	172	4	8	0.88	40	15	47	13
23.	Ferupur	4.30	7.3	1195	765	375	253	51	13	1.01	39	76	40	37
24.	Ambuwala	4.00	7.7	970	621	342	297	55	20	2.02	25	74	49	42
25.	Sultanpur	4.00	7.4	2030	1300	507	296	81	95	3.30	52	76	119	24

All values are expressed in mg/L unless otherwise indicated.
- Hand pump sample, water level could not be determined.

Table 3. Hydro-chemical Data for the Ground Water Samples (December 1995)

S. No.	Sample Location	W.L. (m)	pH	Cond µS/cm	TDS	Alk	Hard	Cl	SO4	PO4	Na	K	Ca	Mg
1.	Zhabrera	6.30	7.9	1430	915	700	507	64	8	0.50	64	34	177	16
2.	Lakhnauta	7.10	7.7	1497	958	610	430	110	3	3.40	68	94	146	16
3.	Narson	3.20	7.4	1172	750	358	536	80	116	0.90	40	4	165	30
4.	Udlehri	3.70	7.6	2210	1414	904	830	174	78	3.10	48	89	320	8
5.	Manglour	12.20	7.9	1416	906	416	397	126	52	0.40	48	50	26	81
6.	Landhora	15.90	7.7	464	297	216	190	8	8	0.40	30	12	17	36
7.	Laksar	-	7.4	1999	1279	991	1105	74	230	0.20	46	23	402	25
8.	Dosni	3.20	8.1	851	545	446	308	12	4	0.50	52	25	39	51
9.	Nagla Imerti	14.20	7.6	529	339	239	225	26	8	0.55	34	18	56	21
10.	Baheri Ki Sadabad	-	8.2	407	261	151	79	2	6	0.10	18	14	18	8
11.	Shyampur	6.60	7.6	693	444	305	361	8	23	0.40	9	5	96	29
12.	Amsot	-	7.7	801	513	427	434	4	32	0.10	26	10	138	22
13.	Hardwar	7.00	8.1	661	423	230	279	32	39	0.30	22	16	27	52
14.	Aurangabad	6.75	7.6	920	589	381	464	48	25	0.07	11	17	119	41
15.	Bahadrabad	6.20	7.7	2160	1382	546	747	106	180	0.66	46	86	239	37
16.	Beldi	4.50	7.6	1044	668	405	445	15	34	0.21	34	28	76	25
17.	Rampur	6.10	7.9	2670	1709	426	1067	449	240	0.10	83	40	377	31
18.	Bhagwanpur	6.90	7.6	1330	851	600	405	34	84	0.30	93	43	146	10
19.	Imelikhera	10.20	7.5	504	323	279	181	4	7	0.04	34	15	31	25
20.	Bhabhelpur	3.00	7.6	751	481	265	286	76	16	0.07	43	19	55	36
21.	Manubas	12.20	7.6	1156	740	404	400	104	36	0.05	40	16	104	35
22.	Daulatpur	6.60	7.7	614	393	326	249	6	5	0.63	29	14	46	32
23.	Ferupur	4.00	7.9	1402	897	451	481	96	78	0.64	44	62	61	80
24.	Ambuwala	3.70	7.8	1094	700	416	363	66	92	0.29	39	54	12	81
25.	Sultanpur	3.90	7.6	1201	969	574	590	160	135	0.88	68	90	209	17

All values are expressed in mg/L unless otherwise indicated.
- Hand pump sample, water level could not be determined.

in the ground water of district Hardwar varies from 237 to 1300 mg/L during July 1995 (Table 2) and from 261 to 1709 mg/L during December 1995 (Table 3), with about 50% samples having TDS value beyond the desirable limit of 500 Mg/L. The maximum value of TDS was obtained at the village of Rampur during both the surveys.

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 172 to 744 mg/L during July 1995 (Table 2) and from 407 to 991 during December 1995 (Table 3). The high alkalinity value in the study area is due to the presence of excessive bicarbonate ions.

The sodium concentration in the ground water varies between 6 and 98 mg/L during July 1995 and between 9 and 93 mg/L during December 1995 (Table 3). Sodium concentration more than 50 mg/L makes the water unsuitable for domestic use. It is evident from Table 2 & 3 that the concentration of sodium is higher than the one required for domestic applications in about 25% of the total samples analysed and thereby making the water unsuitable even for domestic applications.

Calcium, magnesium and total hardness in the water are inter-related and hence combined in the description. The upper limits for calcium and magnesium for drinking water and domestic use are 75 and 30 mg/L respectively (BIS, 1983). In ground water of the area under study, calcium and magnesium ranges from 22 to 199 and from 13 to 72 mg/L respectively during July 1995 (Table 2). The same were found to be in the range 12 to 402 and 8 to 81 mg/L respectively during December 1995 (Table 3). Toxicity due to these two ions are shown by more than 50% of the samples investigated in the study area.

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 ground water in the area contains these ions in quite high concentrations. The total hardness as $CaCO_3$ ranges between 172 to 700 mg/L during July 1995 (Table 2) and between 79 to 1105 mg/L during December 1995. From the hardness point of view, more than 50% of the total samples analysed belongs to hard water category and is not suitable for many 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. A concentration of more than 250 mg/L of chloride makes the water unsuitable for a number of domestic applications. The chloride content in the study area is well within the limits prescribed for drinking water supplies.

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 value for domestic applications except at few places only.

5.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. A good quality water has the potential to cause maximum yield under good soil and water management practices. However, the quality of irrigation water depends primarily on its silt and salt content. The usefulness of water for irrigation is mainly evaluated based on the following criteria.

5.2.1 Total Concentration of Soluble Salts

Water used for irrigation always contains measurable quantities 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 237 to 1300 mg/L during July 1995 (Table 2) and from 261 to 1709 mg/L during December 1995 (Table 3). 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.

5.2.2 Relative Proportion of Sodium to Other Cations

While a high salt concentration in water leads to formation of a saline soil, a high sodium leads to development of an alkali soil. 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 cationexchange 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.

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 ranges from 0.15 to 1.65 during July 1995 (Table 4) and from 0.21 to 2.01 in December 1995 (Table 5). As evident from Table 4 & 5, the ground water of the study area falls under the category of low sodium hazards, which reveals that the ground water of the study area is free from any sodium hazard.

The sodium percentage in the study area was found to vary from 6.0 to 41.9% during July 1995 (Table 4) and from 4.7 to 42.2% during December 1995 (Table 5). As per the BIS standards, a maximum sodium percentage of 60 is recommended for irrigation water. This again confirms that the ground water of the study area is free from any sodium hazard.

Table 4. Values of Sodium Adsorption Ratio and Sodium Percentage (July 1995)

S.No.	Sample Location	SAR	Na%
1.	Zhabrera	1.45	28.2
2.	Lakhnauta	1.58	37.6
3.	Narson	0.51	11.0
4.	Udlehri	0.99	26.5
5.	Manglour	1.24	34.5
6.	Landhora	0.56	17.1
7.	Laksar	0.38	16.3
8.	Dosni	0.74	24.6
9.	Nagla Imerti	0.20	6.5
10.	Baheri Ki Sadabad	0.28	10.6
11.	Shyampur	0.15	6.0
12.	Amsot	0.28	10.2
13.	Hardwar	0.40	18.6
14.	Aurangabad	0.17	6.8
15.	Bahadrabad	0.96	20.4
16.	Beldi	0.53	14.2
17.	Rampur	1.65	27.3
18.	Bhagwanpur	0.39	10.9
19.	Imelikhera	1.60	37.9
20.	Bhabhelpur	0.51	12.6
21.	Manubas	0.80	17.7
22.	Daulatpur	1.33	38.3
23.	Ferupur	1.07	41.9
24.	Ambuwala	0.63	33.4
25.	Sultanpur	1.14	34.7

Table 5. Values of Sodium Adsorption Ratio and Sodium Percentage (December 1995)

S.No.	Sample Location	SAR	Na%
1.	Zhabrera	1.22	26.2
2.	Lakhnauta	1.43	38.4
3.	Narson	0.74	14.5
4.	Udlehri	0.72	20.7
5.	Manglour	1.05	29.7
6.	Landhora	0.95	29.7
7.	Laksar	0.60	10.4
8.	Dosni	1.28	31.9
9.	Nagla Imerti	0.97	29.8
10.	Baheri Ki Sadabad	0.89	42.2
11.	Shyampur	0.21	6.9
12.	Amsot	0.53	13.6
13.	Hardwar	0.56	19.3
14.	Aurangabad	0.22	8.8
15.	Bahadrabad	0.72	21.8
16.	Beldi	0.86	27.3
17.	Rampur	1.10	17.8
18.	Bhagwanpur	2.01	38.8
19.	Imelikhera	1.10	34.0
20.	Bhabhelpur	1.11	29.1
21.	Manubas	0.87	21.0
22.	Daulatpur	0.97	24.5
23.	Ferupur	0.86	26.6
24.	Ambuwala	0.89	29.8
25.	Sultanpur	0.40	4.7

5.3 Classification of Water

Different accepted and widely used graphical methods such as Stiff diagram, Piper trilinear diagram and Wilcox diagram are adopted in the present investigations to classify the ground water of the study area. 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 pages and compiled in Tables 6 and 7 for the two surveys conducted.

5.3.1 Stiff Classification

The Stiff classification (Stiff, 1951) is used in the present study 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 milliequivalents (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 twenty five

Table 6. Summarized Results of Water Classification (July 1995)

S.No.	Sample Location	Stiff Classification	Piper Trilinear Classification	U.S. Salinity Laboratory Classification
1.	Zhabrera	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
2.	Lakhnauta	Sodium bicarbonate	Ca-Mg-HCO_3	C3-S1
3.	Narson	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
4.	Udlehri	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
5.	Manglour	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
6.	Landhora	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
7.	Laksar	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
8.	Dosni	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
9.	Nagla Imerti	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
10.	Baheri Ki Sadabad	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
11.	Shyampur	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
12.	Amsot	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
13.	Hardwar	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
14.	Aurangabad	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
15.	Bahadrabad	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
16.	Beldi	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
17.	Rampur	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
18.	Bhagwanpur	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
19.	Imelikhera	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
20.	Bhabhelpur	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
21.	Manubas	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
22.	Daulatpur	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
23.	Ferupur	Sodium bicarbonate	Ca-Mg-HCO_3	C3-S1
24.	Ambuwala	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
25.	Sultanpur	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1

Table 7. Summarized Results of Water Classification (December 1995)

S.No.	Sample Location	Stiff Classification	Piper Trilinear Classification	U.S. Salinity Laboratory Classification
1.	Zhabrera	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
2.	Lakhnauta	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
3.	Narson	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
4.	Udlehri	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
5.	Manglour	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
6.	Landhora	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
7.	Laksar	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
8.	Dosni	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
9.	Nagla Imerti	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
10.	Baheri Ki Sadabad	Sodium bicarbonate	Ca-Mg-HCO_3	C2-S1
11.	Shyampur	Calcium bicarbonate	Ca-Mg-HCO_3	C2-S1
12.	Amsot	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
13.	Hardwar	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
14.	Aurangabad	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
15.	Bahadrabad	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
16.	Beldi	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
17.	Rampur	Calcium chlorite	Ca-Mg-Cl-SO_4	C4-S1
18.	Bhagwanpur	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
19.	Imelikhera	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
20.	Bhabhelpur	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
21.	Manubas	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1
22.	Daulatpur	Magnesium bicarbonate	Ca-Mg-HCO_3	C2-S1
23.	Ferupur	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
24.	Ambuwala	Magnesium bicarbonate	Ca-Mg-HCO_3	C3-S1
25.	Sultanpur	Calcium bicarbonate	Ca-Mg-HCO_3	C3-S1

samples have been studied using Stiff classification and the results of the same have been given in Tables 6 & 7. It is evident from Table 6 & 7 that out of the twenty five samples analysed, seventeen samples were found to be of calcium bicarbonate type, six samples of magnesium bicarbonate type and two samples of sodium bicarbonate type in July 1995 survey. However during December 1995 survey, fourteen samples of calcium bicarbonate type, nine samples of magnesium bicarbonate type and one samples each of sodium bicarbonate and calcium chloride type.

5.3.2 Piper Trilinear Classification

Piper (1953) developed a form of trilinear diagram which 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 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 chemical analysis data of all the twenty five samples have been plotted on trilinear diagram for both the surveys (Fig. 2 & 3) and results are summarized in Table 6 & 7. The cation plots in the diagram reveals that, majority of the samples falls in calcium type, followed by no dominant type. The anion plots in the diagram indicate that almost all 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. One sample of Rampur village was found to be under the Ca-Mg-Cl-SO_4 hydrochemical facies during the December survey.

5.3.3 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 conductivity of water expressed in µS/cm.

The chemical analysis data of all the twenty five samples have been plotted on Wilcox diagram for the two sets of data (Fig. 4 & 5) and the results of the same have been summarized in Table 6 & 7. It is evident from Table 6 that during

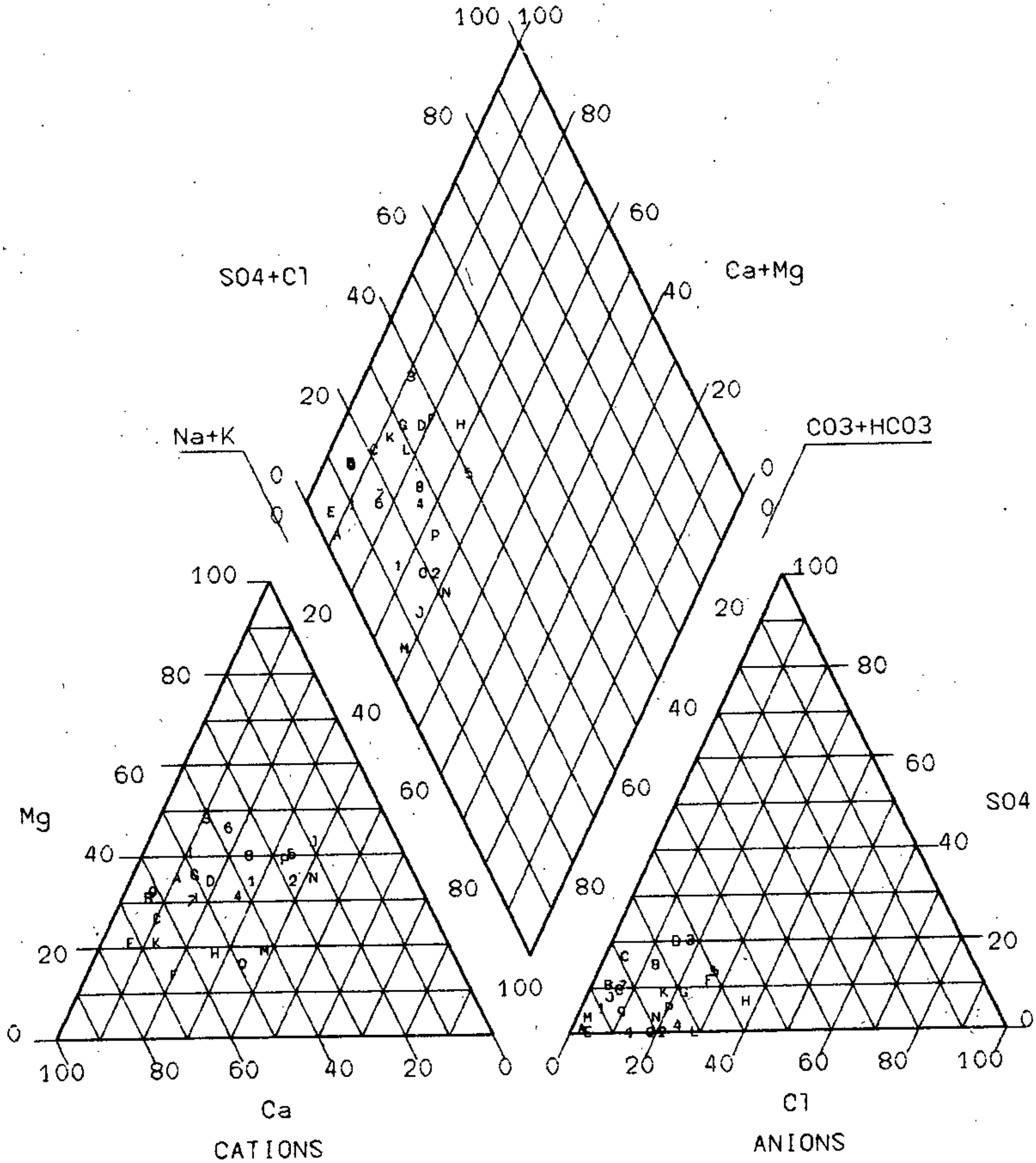

Fig. 2. Piper Trilinear Diagram Showing Chemical Character of Ground Water (July 1995)

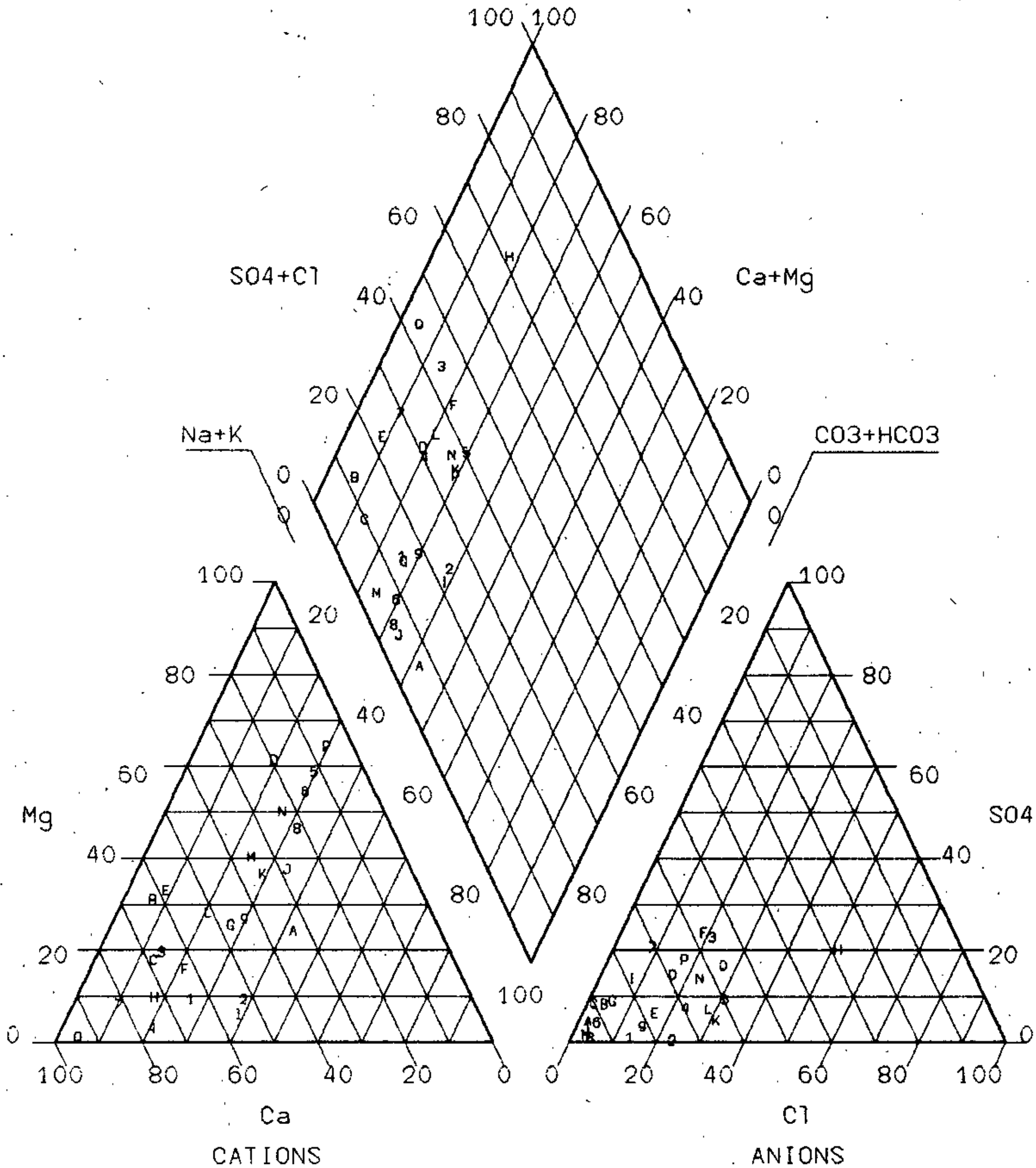

Fig. 3. Piper Trilinear Diagram Showing Chemical Character of Ground Water (December 1995)

SAMPLE IDENTIFICATION FOR PIPER TRILINEAR DIAGRAM

Well No.	Location	Label
1.	Zhabrera	1
2.	Lakhnauta	2
3.	Narson	3
4.	Udlehri	4
5.	Manglour	5
6.	Landhora	6
7.	Laksar	7
8.	Dosni	8
9.	Nagla Imerti	9
10.	Baheri Ki Sadabad	A
11.	Shyampur	B
12.	Amsot	C
13.	Hardwar	D
14.	Aurangabad	E
15.	Bahadrabad	F
16.	Beldi	G
17.	Rampur	H
18.	Bhagwanpur	I
19.	Imelikhera	J
20.	Bhabhelpur	K
21.	Manubas	L
22.	Daulatpur	M
23.	Ferupur	N
24.	Ambuwala	O
25.	Sultanpur	P

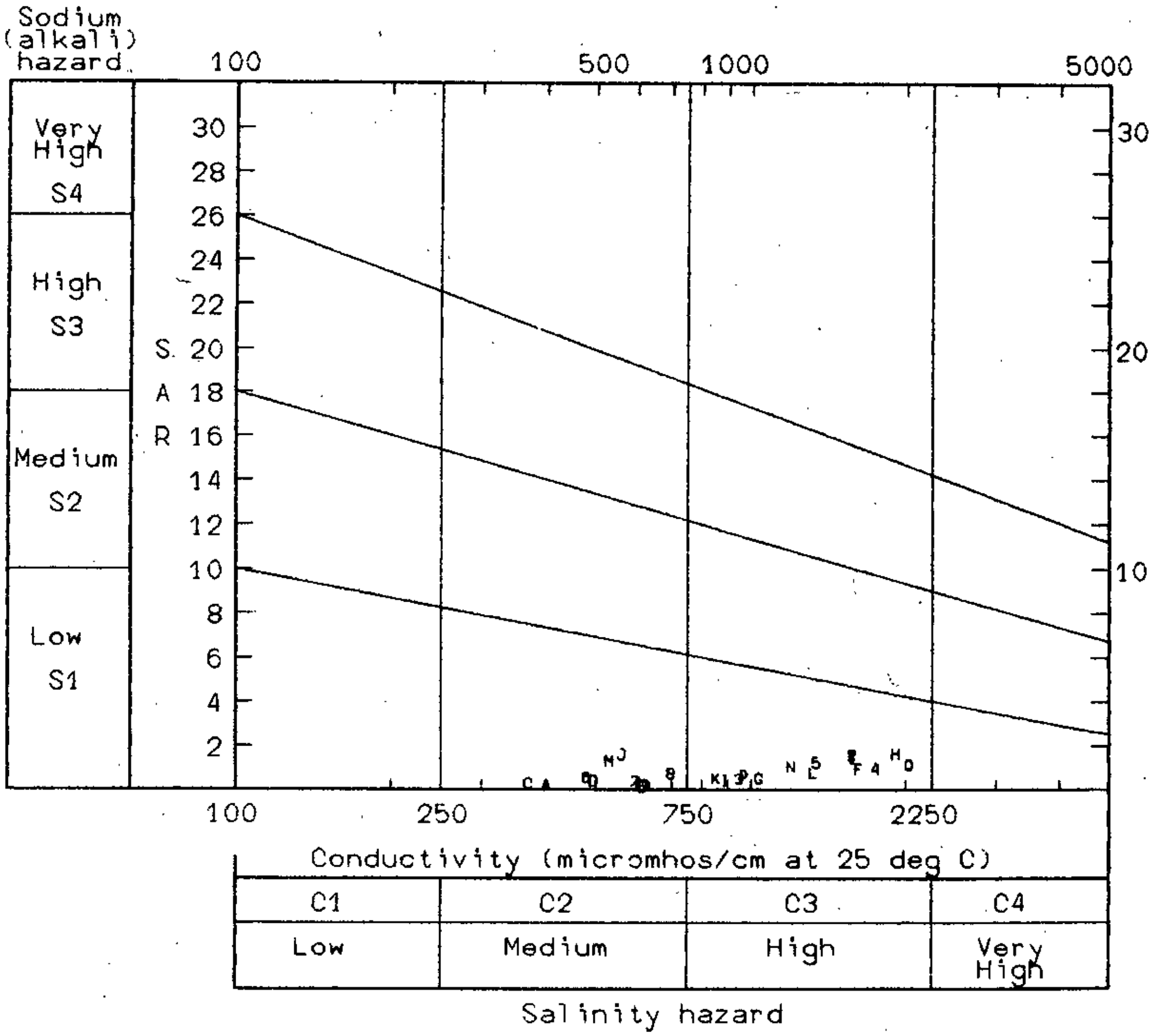

Fig. 4. U.S. Salinity Laboratory Classification
(Wilcox Diagram, July 1995)

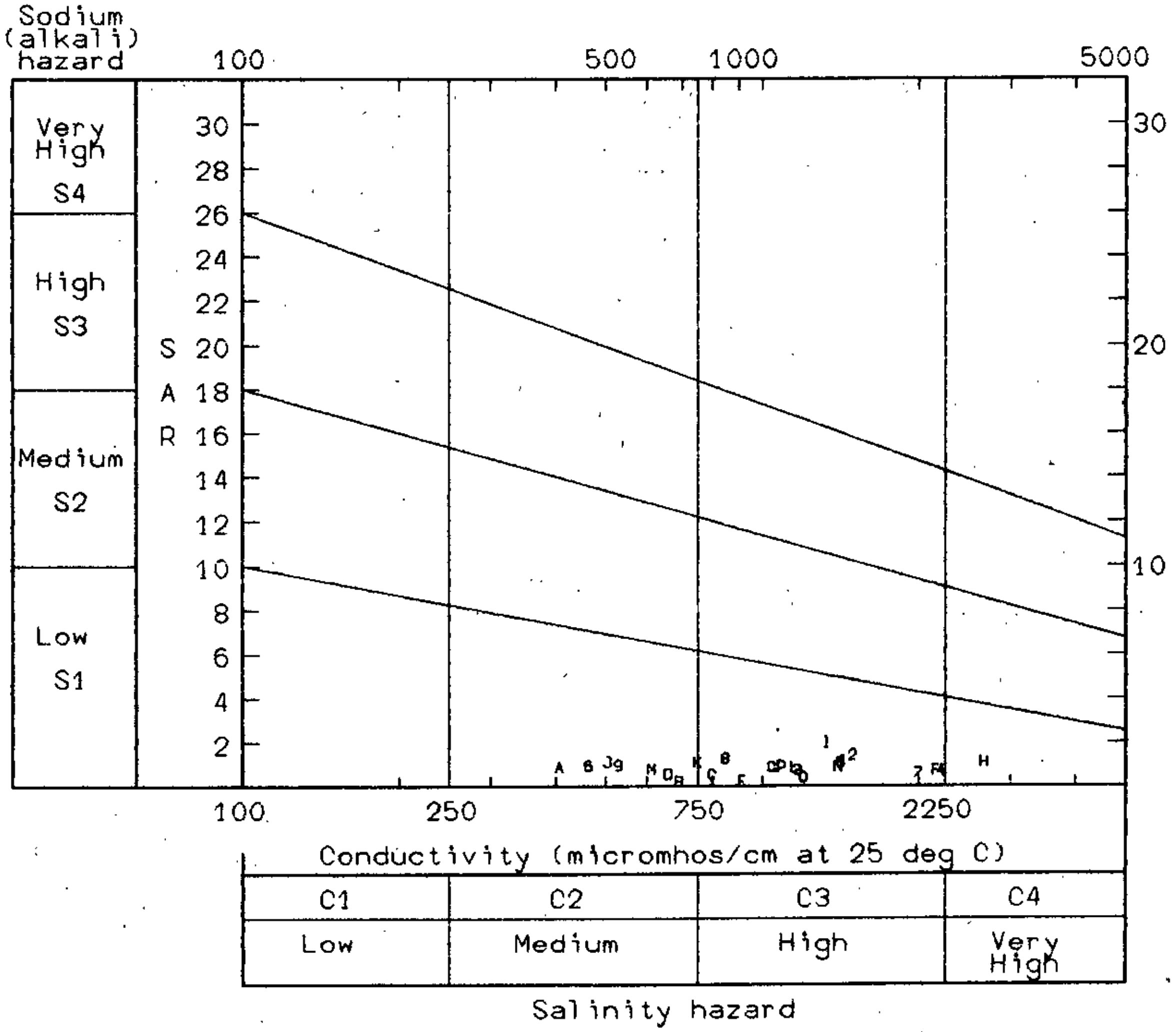

Fig. 5. U.S. Salinity Laboratory Classification
(Wilcox Diagram, December 1995)

SAMPLE IDENTIFICATION FOR WILCOX DIAGRAM

Well No.	Location	Label
1.	Zhabrera	1
2.	Lakhnauta	2
3.	Narson	3
4.	Udlehri	4
5.	Manglour	5
6.	Landhora	6
7.	Laksar	7
8.	Dosni	8
9.	Nagla Imerti	9
10.	Baheri Ki Sadabad	A
11.	Shyampur	B
12.	Amsot	C
13.	Hardwar	D
14.	Aurangabad	E
15.	Bahadrabad	F
16.	Beldi	G
17.	Rampur	H
18.	Bhagwanpur	I
19.	Imelikhera	J
20.	Bhabhelpur	K
21.	Manubas	L
22.	Daulatpur	M
23.	Ferupur	N
24.	Ambuwala	O
25.	Sultanpur	P

July 1995, out of the twenty five samples analysed, eleven samples were found to be of C2-S1 type (medium salinity and low SAR) which is suitable for irrigation purposes, fourteen samples were found to be of C3-S1 type (high salinity and low SAR), which is also fit for irrigation purpose in general, but may cause some problem where the soil permeability is very poor.

During December 1995 survey, eight samples were found to be of C2-S1 (medium salinity and low SAR) which is suitable for irrigation purpose, sixteen samples were found to be of C3-S1 type (high salinity and low SAR), which is also fit for irrigation purpose in general, but may cause some problem where the soil permeability is very poor and one sample of C4-S1 type (very high salinity and low SAR). High salinity is harmful for the plant growth and changes the soil structure, permeability and aeration which in turn effects the plant growth and yield of crop considerably.

6.0 CONCLUSION

The study is focused on the variation of ground water quality in the area. From the results of the study it is concluded that the quality of ground water varies from place to place with the depth of water table. It also shows significant variations from one season to another. The water in shallow aquifers is rich in bicarbonates and alkaline earth metals. The higher values of various constituents at many places make the water unfit for domestic applications. The ground water of the study area is of calcium and/or magnesium bicarbonate type and falls under the $Ca-Mg-HCO_3$ hydrochemical facies. The U.S. Salinity Laboratory classification of irrigation water indicate that in general water can be safely used for irrigation with most crops on most soils, but may cause some problem if the soil permeability is very poor. 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.

It is recommended that any water source must be thoroughly analysed and studied before being used for drinking and other domestic applications and proper water management strategies should be adopted for agricultural and other developmental activities. Study should be continued for two to three years on quarterly basis to have a good understanding of ground water contamination in the area. Bacteriological analysis should be carried out in detail to further this work.

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