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# GROUND WATER QUALITY EVALUATION IN DOON VALLEY, DEHRADUN

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**ABSTRACT**

The ground water quality of Doon valley, Dehradun has been studied during 1996 to examine the suitability of water for drinking and irrigation purposes. Twelve water samples representing the shallow ground water of the valley were collected during pre-monsoon and post-monsoon seasons and analysed for various constituents, viz., pH, conductance, total dissolved solids, alkalinity, hardness, chloride, sulphate, phosphate, sodium, potassium, calcium and magnesium. 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 valley. 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, majority of the samples were found to be of calcium bicarbonate type. In the Piper trilinear diagram, majority of the groundwater samples of the study area fall in the $Ca$-$Mg$-$HCO_3$ hydrochemical facies. As per the U.S. Salinity Laboratory Classification of irrigation water, the water is fit for irrigation purpose.

## 1.0 INTRODUCTION

### 1.1 General

Protection and management of ground water quality 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 activity 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.

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. It is absolutely necessary to ascertain the potability of water before it is used for human consumption.

The mechanism of ground water pollution is quite different than that of surface water and is more complicated. Unlike the surface water pollution, pollution of ground water is difficult to detect. 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.

India is a country where major population resides in unaccessible villages and unavailability of safe potable water is one of major reasons for ill health of the people. Pollution of ground water in urban areas is reported due to intensive extraction of ground water through tube wells which create suction of filthy surface water into the aquifer (Sharma, 1991).

Thus constant monitoring of ground water quality is needed so as to record any alteration in the quality and outbreak of health disorders.

Contaminated ground water generally show increased levels of various constituents. Handa (1986a,b) studied the hydrogeochemical zones in a few places in India and indicated that the chemical composition of ground water was affected by the land use practices. A similar situation has been reported in most of the metropolitan cities with growing urban centres (Kakar, 1988). A study carried out in Madras basin (Ramachandran et al., 1991) also revealed the influence of agrochemicals on ground water quality of cultivated areas. Elango et al. (1992) studied the ground water quality in south Madras with respect to domestic and irrigational purposes. Ravichandran and Pundarikanthan (1991) studied the ground water quality of Madras city with reference to polluted waterways of the city. Gupta and Pathak (1994) studied the resource availability and quality assessment of ground water in rural areas around Rewa city (M.P.). 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 industrial units in the area.

In western Uttar 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 parts of western Utter Pradesh has been discussed (Jain et al., 1996a,b). Some preliminary studies were also reported on Doon valley by Kathait and Sawhney (1991).

Increased use of water in the face of impairment of natural environment and ecology, reduction in discharges of springs and streams and deforestation and attendant erosion have greatly affected the hydrological regime and environment of the Doon valley. Inadequate recharge resulting in lesser discharge of the springs and wells and increased demand of water is creating scarcity of water for the townships of Dehradun, Rishikesh, Raiwala, Doiwala, Dakpathar and Vikasnagar located in Doon valley. Ground water plays an important role in solving this periodic water crisis and as it also serves as a source of uncontaminated water, methods for locating good aquifers must become more efficient in the less studied Himalayan belts. Further, the importance of ground water in the Doon valley can be understood from the situation that 76% of the total supply of domestic water in the city comes from the ground water and so far more than 200 tubewells and 250 dugwells have been drilled in the entire Doon valley for the augmentation of drinking and irrigation water supply. Overexploitation of ground water may lower the water table and reduce the saturated thickness of the aquifer. Therefore, the study of ground water quality has been undertaken to understand the geochemical evolution of water and aspects of pollution, if any, in the Doon valley.

The present report gives detailed account of chemical composition of ground water of Doon valley with reference to the suitability of water for various uses and classify them on the basis of different classification schemes.

## 1.2 Scope 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.

Doon valley depends mainly on its ground water sources for drinking water supply. The main concern of the present study is to examine the ground water quality of the valley. This includes a description of the chemical composition of ground water and its spatial variability. Studies were conducted in order to evaluate the suitability of ground water for drinking and irrigation purposes. Samples from twelve wells, representing the shallow unconfined aquifers, were sampled and water analysis performed for the major ionic composition. The data was analysed, 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 valley. The study has been carried out with the following objectives :

- To see the suitability of water for various uses particularly drinking and irrigation purposes.
- To delineate the bad water quality zones for irrigation and drinking purposes, if any.
- 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 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 STUDY AREA

Doon valley extends for a length of about 80 km with its average width of 20 km occupying an area of about 2245 $km^2$. The area lies between longitude 77°35'E to 78°19'E and latitude 29°57'30" N. It is located between the rivers Yamuna and Ganga in the north-western limit of state Uttar Pradesh and adjoining the state of Himachal Pradesh. The valley comprises of mainly 6 sub watersheds: Asan(left), Asan(right), Suarna Tons, Song, Ramau and Chandrabhaga. A north-south divide roughly corresponding to Mussoorie-Saharanpur road bifurcates the valley into two major subwatersheds of Song and Asan which flow to their master systems in the east and west respectively.

### 3.1 Climate

The valley enjoys a salubrious climate almost throughout the year. The summer maximum and minimum temperature vary from 36.6°C to 16.7°C while the winter maximum and minimum range between 23.4°C and 5.2°C respectively. The total annual rainfall is about 1800 mm of which bulk precipitates in the months of July-August.

### 3.2 Physiography

In the Siwalik range of Outer Himalaya, there are a number of longitudinal valleys, called the Duns. One of the largest is the Doon Valley (Dehradun). The Doon valley is a synclinal depression between the Lesser Himalayan mountains in the north and Sub-Himalayan Siwalik hills in the south. Aligned parallel to the general trends of the Himalaya, it is a veritable intermontane valley, bottom of which is filled up with thick detritus shed from overlooking hill slopes. Broadly the Doon valley can be divided into three different slopes; northeastern slopes of the Siwaliks, Doon valley proper and southwestern slopes of outer Himalayan range. The northeastern slopes of Siwaliks are quite steep in higher reaches and have easy gradient lower down. These are cut by a large number of short, shallow and bouldery streams which carry their discharge into Asan, Suswa and

Song rivers. The southwestern slopes are very steep and carry poor vegetation.

### 3.3 Geology

Geological structure of Doon valley is characterised by two major faults, crustal and fractures along which rock slabs of mountain mass have been uplifted and moved southward. The Doon valley and the Siwalik range is principally composed of the rocks of the Siwalik Group. The rocks of the Siwalik Group are classified into the Lower, the Middle and the Upper Siwaliks. The southern limb of the Doon valley and the Siwalik range are made of the Middle and the Upper Siwaliks. The Middle Siwalik are composed of 1500-1800 m thick fluviatile sediments. They consists of sandstone-mudstone couplets in the lower part and a multistorey sandstone complex in the upper part with few pebbly horizons to the top. This sequence of the Middle Siwalik passes transitionally upward into thickly bedded conglomerate of the Upper Siwalik. The conglomerates are composed of predominantly of pebbles and boulders of sandstone, limestone and quartzite derived from the Lower Himalaya - similar to that of Mussoorie range. The Lower Siwalik is exposed on limited outcrops on the northern limb of the Doon valley. It is made of purple clay and sandstone. The rocks of Siwalik Group are overlain by the Doon Gravels. The Doon Gravels, comprising of poorly consolidated gravel, sand and boulders with clay bands, fill up the large part of the Doon valley. The thickness of Doon Gravels is variable from 50 metres to maximum 600 metres in the central of the valley.

### 3.4 Geohydrology

Geohydrologically, the Doon valley is divided into three zones namely Lesser Himalayan zone, Synclinal Central zone and Siwalik zone. The springs are potential source of water in the Doon valley. The discharge of these springs varies from 1 to 2594 X 10 l/day during lean period and 3 to 4582 X 10 l/day during peak discharge time. The depth of water table varies from 3 to 90 m below ground level whereas it is shallowest in the central part of the valley (Asan river) and deepest close to the water divide of Asan and Song rivers and near Kaulagarh. Perched conditions of shallow water table of local extent are also present in the valley. The monthly variation in the water table is from 1.50 to 12 m bgl. The regional ground water flow in the fractured parts of the aquifers and through the colluvial and fluvial deposits in the Lesser Himalayan region is approximately in the south, southeast and southwest direction, where as in the Siwalik region groundwater flows in north and northeast direction. This flow pattern is locally modified by fractures, faults, colluvial and fluvial deposits which have created local flow system. Further, the water table data and contours suggest that the groundwater gradient is towards both Ganga and Yamuna.

## 3.5 Drainage Pattern

There is a strong drainage net with majority of streams flowing only seasonally. The various types of drainage patterns have a profound control of bed rock geology. For example in heterogeneous bed rock the pattern tends to be dendritic to subdendritic as in the Lesser Himalayan country, whereas in homogeneous lithology with gentle slope the stream are structured in the parallel pattern as in southern piedmont slopes. Likewise based on slop-geology relationship the other drainage patterns are dendro-trellis, subparallel-subdendritic etc.

## 3.6 Soil type

The area mainly consists of a thick unit of soils, boulders, pebbles interbedded with clay bands known as Doon gravels. Sub-montaine soils of the region are derived from sand stones and shales and some of them are transported and alluvial in nature. It consists of mostly dark-grey soils, varying from loam to sandy-loam, single-grained in structure and generally rich in organic matter. The soil of the valley consists of 23% clay, 38% silt and 40% sand.

## 3.7 Land Use Pattern

The rich vegetation cover is predominant in the foot hills of Siwaliks. The bulk of forests in the Doon valley lie along two belts running roughly northwest to southeast separately by Asan river in the west and Suswa and Suarna in the east. These belts are bound in the north west by Yamuna and in the east by Ganga and southwest by main Siwalik ridge. Forests in the Doon valley on both side of Asan and Song rivers are on flat and gentle slopping areas. The landforms of the area can be divided as mountains, piedmont zones, Siwaliks and terraces. There exists a strong relationship between landforms and slope of the area.

The valley has a great potential for forests particularly in lower parts. Several centuries ago it must have been covered by dense forests. interspread with swampy grasslands. The main representative forests include North Indian tropical moist deciduous; Tropical freshwater swamps; North Indian tropical dry deciduous; Subtropical pine forests; and Himalayan moist temperate forests.

## 4.0 EXPERIMENTAL METHODOLOGY

### 4.1 Sampling and Preservation

To achieve the objectives of the study, twelve samples representing the ground water 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.

### 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 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 1 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 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. 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 1. 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 |

## 5.0 RESULTS AND DISCUSSION

The chemical composition of ground water samples collected from different wells (Fig. 1) in Doon valley during pre-monsoon (June 1996) and post-monsoon (November 1996) seasons is given in Table 2 and 3 respectively alongwith Indian standards for drinking water.

### 5.1 Water Quality Evaluation for Domestic Purpose

The pH value in the study area lies in the range 6.5 to 7.3, which is well within the limits prescribed by WHO (1994)and BIS (1993) for various uses of water including drinking water and other domestic supplies.

The electrical conductivity (EC) 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 168 to 1187 $\mu$S/cm during pre-monsoon season and from 173 to 1177 $\mu$S/cm during post-monsoon season with about 25% samples having conductivity value above 1000 $\mu$S/cm.

The total dissolved solids (TDS) ranged from 108 to 760 mg/L during June 1996 (Table 2) and from 100 to 589 mg/L during November 1996 (Table 3), with about 25% samples having TDS value beyond the desirable limit of 500 mg/L. The TDS value beyond the desirable limit of 500 mg/L was found at the village of Majra and Raiwala during both pre-monsoon post-monsoon seasons.

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 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

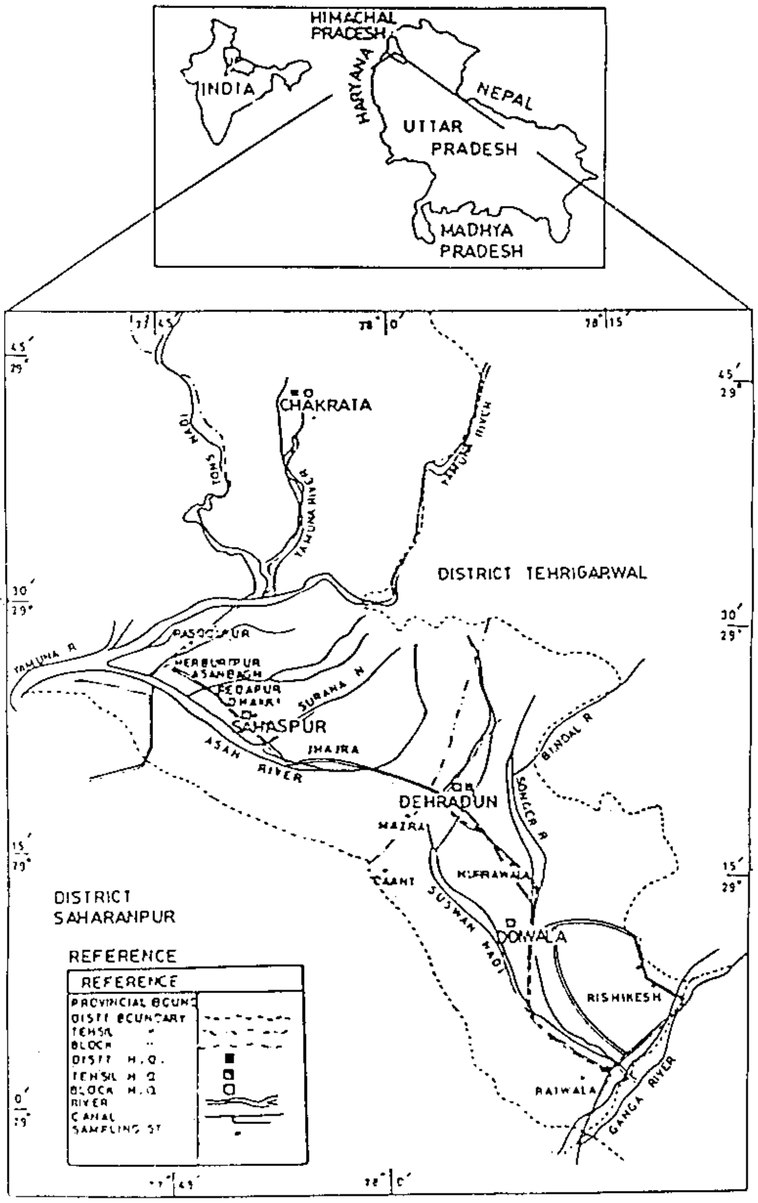


**Fig. 1. Study Area and Sampling Locations**

Table 2. Hydro-chemical Data for the Ground Water Samples (June 1996)

| Parameter | Values | | | |
|---|---|---|---|---|
| | Min. | Max. | Mean | BIS Standards* |
| pH | 6.7 | 7.3 | 7.0 | 6.5-8.5 |
| Conductance, µS/cm | 168 | 1187 | 479 | - |
| TDS, mg/L | 108 | 760 | 307 | 500 |
| Alkalinity, mg/L | 60 | 366 | 157 | - |
| Hardness, mg/L | 64 | 440 | 192 | 300 |
| Chloride, mg/L | 8 | 90 | 30 | 250 |
| Sulphate, mg/L | 6 | 180 | 52 | 150 |
| Phosphate-P, mg/L | 0.25 | 1.14 | 0.41 | - |
| Nitrate, mg/L | 8.0 | 57 | 20 | 45 |
| Sodium, mg/L | 5 | 64 | 19 | - |
| Potassium, mg/L | 1.4 | 104 | 15 | - |
| Calcium, mg/L | 15 | 112 | 47 | 75 |
| Magnesium, mg/L | 7 | 39 | 19 | 30 |

IS-10500-1983

Table 3. Hydro-chemical Data for the Ground Water Samples (November 1996)

| Parameter | Values | | | |
|---|---|---|---|---|
| | Min. | Max. | Mean | BIS Standards* |
| pH | 6.4 | 7.3 | 6.8 | 6.5-8.5 |
| Conductance, µS/cm | 173 | 1177 | 607 | - |
| TDS, mg/L | 100 | 589 | 310 | 500 |
| Alkalinity, mg/L | 62 | 416 | 184 | - |
| Hardness, mg/L | 30 | 420 | 187 | 300 |
| Chloride, mg/L | 6 | 96 | 37 | 250 |
| Sulphate, mg/L | N.D. | 160 | 44 | 150 |
| Phosphate-P, mg/L | N.D. | 0.74 | 0.12 | - |
| Nitrate-N, mg/L | 6.2 | 146 | 39 | 45 |
| Sodium, mg/L | 4.0 | 127 | 32 | - |
| Potassium, mg/L | 0.2. | 136 | 22 | - |
| Calcium, mg/L | 14 | 132 | 54 | 75 |
| Magnesium, mg/L | 8 | 33 | 17 | 30 |

* IS-10500-1983

considerable amounts from the action of carbonates upon the basic materials in the soil. The alkalinity values in the study area varies from 60 to 366 mg/L during June 1996 (Table 2) and from 62 to 416 during November 1996 (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 4.9 and 63.6 mg/L during June 1996 and between 4.0 and 127.0 mg/L during November 1996 (Table 3). 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 25% of the total samples analysed and thereby making the water unsuitable even for domestic applications.

The upper limits for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1983). In ground water of the Doon valley, calcium and magnesium ranges from 15 to 112 and from 7 to 39 mg/L respectively during June 1996 (Table 2). The same were found to be in the range 14 to 132 and 8 to 33 mg/L respectively during November 1996 (Table 3). Toxicity due to these two ions are shown by 25% 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 total hardness as $CaCO_3$ ranges between 64 to 440 mg/L during June 1996 (Table 2) and between 30 to 420 mg/L during November 1996. From the hardness point of view, more than 25% 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 Majra only.

## 5.2 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.

### 5.2.1 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 ($\mu S/cm$) |
|---|---|---|
| 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 108 to 760 mg/L during June 1996 (Table 2) and from 100 to 589 mg/L during November 1996 (Table 3). More than 25% 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

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 the valley are given in Tables 4 and 5. 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 0.14 to 1.52 during June 1996 (Table 4) and from 0.19 to 3.78 in November 1996 (Table 5). As evident from Table 4 and 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.

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 5 to 37% during June 1996 (Table 4) and from 6 to 64% during November 1996 (Table 5). The sodium percentage values are well within the prescribed limit of 60% except at village Dhakki. This confirms that the ground water of the study area at almost all places is free from any sodium hazard.

## 5.3 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

Table 4. Values of Sodium Adsorption Ratio and Sodium Percentage (June 1996)

| S.No. | Sample Location | SAR | Na% |
|---|---|---|---|
| 1. | Rasoolpur | 0.25 | 13 |
| 2. | Herburtpur | 0.36 | 18 |
| 3. | Asanbagh | 0.41 | 23 |
| 4. | Redapur | 0.85 | 31 |
| 5. | Dhakki | 0.94 | 26 |
| 6. | Sahaspur | 0.80 | 34 |
| 7. | Jhajhra | 0.51 | 23 |
| 8. | Majra | 0.86 | 34 |
| 9. | Daant | 0.19 | 06 |
| 10. | Raiwala | 1.52 | 37 |
| 11. | Rishikesh | 0.38 | 13 |
| 12. | Hurrawala | 0.14 | 05 |

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

| S.No. | Sample Location | SAR | Na% |
|---|---|---|---|
| 1. | Rasoolpur | 0.19 | 10 |
| 2. | Herburtpur | 0.51 | 22 |
| 3. | Asanbagh | 0.44 | 20 |
| 4. | Redapur | 2.08 | 45 |
| 5. | Dhakki | 3.78 | 64 |
| 6. | Sahaspur | 0.82 | 33 |
| 7. | Jhajhra | 0.40 | 16 |
| 8. | Majra | 0.87 | 40 |
| 9. | Daant | 0.21 | 62 |
| 10. | Raiwala | 1.63 | 39 |
| 11. | Rishikesh | 0.58 | 16 |
| 12. | Hurrawala | 0.20 | 06 |

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 sets of samples collected during June and November 1996.

### 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 twelve samples have been studied using Stiff classification and the results of the same are given in Tables 6 and 7. Majority of the samples of the Doon valley were found to be of calcium bicarbonate type

### 5.3.2 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

Table 6. Summarized Results of Water Classification (June 1996)

| S. No. | Sample Location | Stiff Classification | Piper Trilinear Classification | U.S.Salinity Laboratory Classification |
|---|---|---|---|---|
| 1. | Rasoolpur | Calcium bicarbonate | Ca-Mg-Cl-$SO_4$ | C1-S1 |
| 2. | Herburtpur | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C1-S1 |
| 3. | Asanbagh | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C1-S1 |
| 4. | Redapur | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C2-S1 |
| 5. | Dhakki | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C2-S1 |
| 6. | Sahaspur | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C1-S1 |
| 7. | Jhajhra | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C1-S1 |
| 8. | Majra | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C3-S1 |
| 9. | Daant | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C2-S1 |
| 10. | Raiwala | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C3-S1 |
| 11. | Rishikesh | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C2-S1 |
| 12. | Hurrawala | Calcium bicarbonate | Ca-Mg-$CO_3$-$HCO_3$ | C2-S1 |

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

| S. No. | Sample Location | Stiff Classification | Piper Trilinear Classification | U.S.Salinity Laboratory Classification |
|---|---|---|---|---|
| 1. | Rasoolpur | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C1-S1 |
| 2. | Herburtpur | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C1-S1 |
| 3. | Asanbagh | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C1-S1 |
| 4. | Redapur | Sodium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C3-S1 |
| 5. | Dhakki | Sodium bicarbonate | $Na\text{-}K\text{-}CO_3\text{-}HCO_3$ | C3-S1 |
| 6. | Sahaspur | Magnesium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C1-S1 |
| 7. | Jhajhra | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C2-S1 |
| 8. | Majra | Calcium bicarbonate | $Ca\text{-}Mg\text{-}Cl\text{-}SO_4$ | C3-S1 |
| 9. | Daant | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C3-S1 |
| 10. | Raiwala | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C3-S1 |
| 11. | Rishikesh | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C2-S1 |
| 12. | Hurrawala | Calcium bicarbonate | $Ca\text{-}Mg\text{-}CO_3\text{-}HCO_3$ | C2-S1 |

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 the ground water samples of Doon valley have been plotted on trilinear diagram for the two sets of samples (Fig. 2 and 3) and results are summarized in Table 6 and 7. 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 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

Table 8. Sample Identification for Piper Trilinear and Wilcox Diagrams

| Well No. | Location | Label |
| --- | --- | --- |
| 1. | Rasoolpur | 1 |
| 2. | Herburtpur | 2 |
| 3. | Asanbagh | 3 |
| 4. | Redapur | 4 |
| 5. | Dhakki | 5 |
| 6. | Sahaspur | 6 |
| 7. | Jhajhra | 7 |
| 8. | Majra | 8 |
| 9. | Daant | 9 |
| 10. | Raiwala. | A |
| 11. | Rishikesh | B |
| 12. | Hurrawala | C |

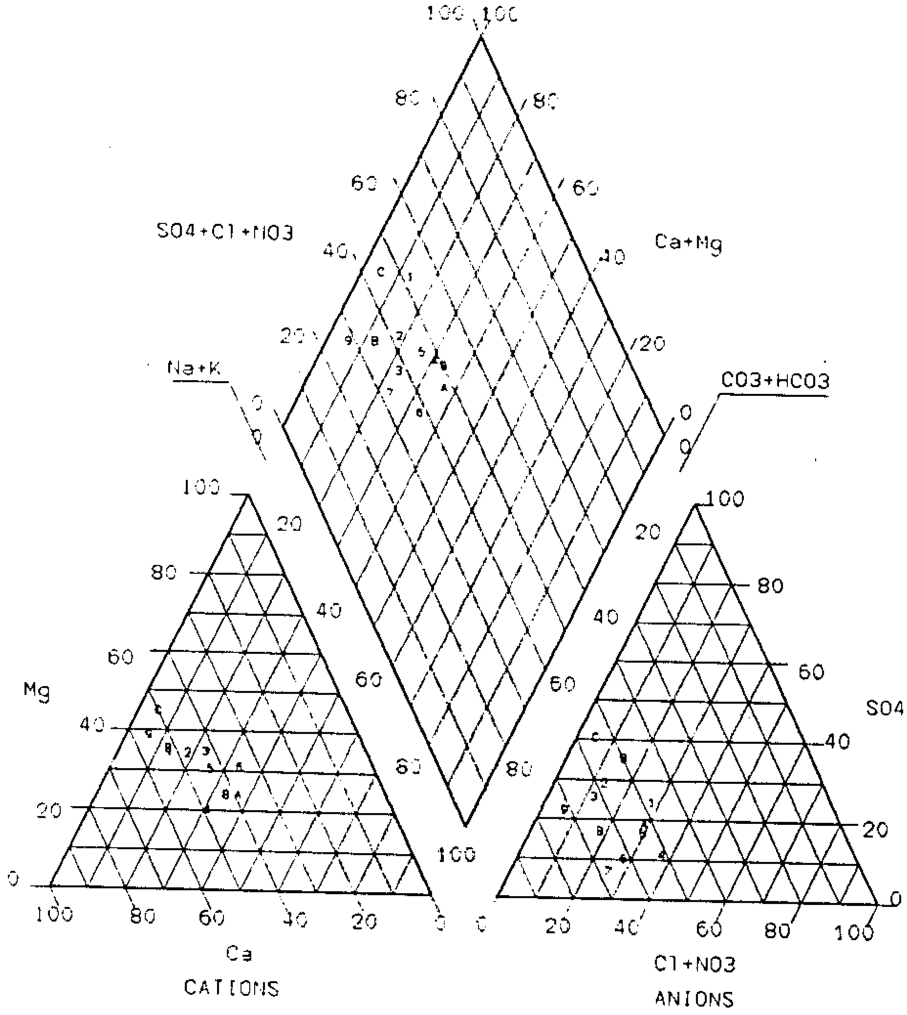


**Fig. 2. Piper Trilinear Diagram Showing Chemical Character of Ground Water (June 1996)**

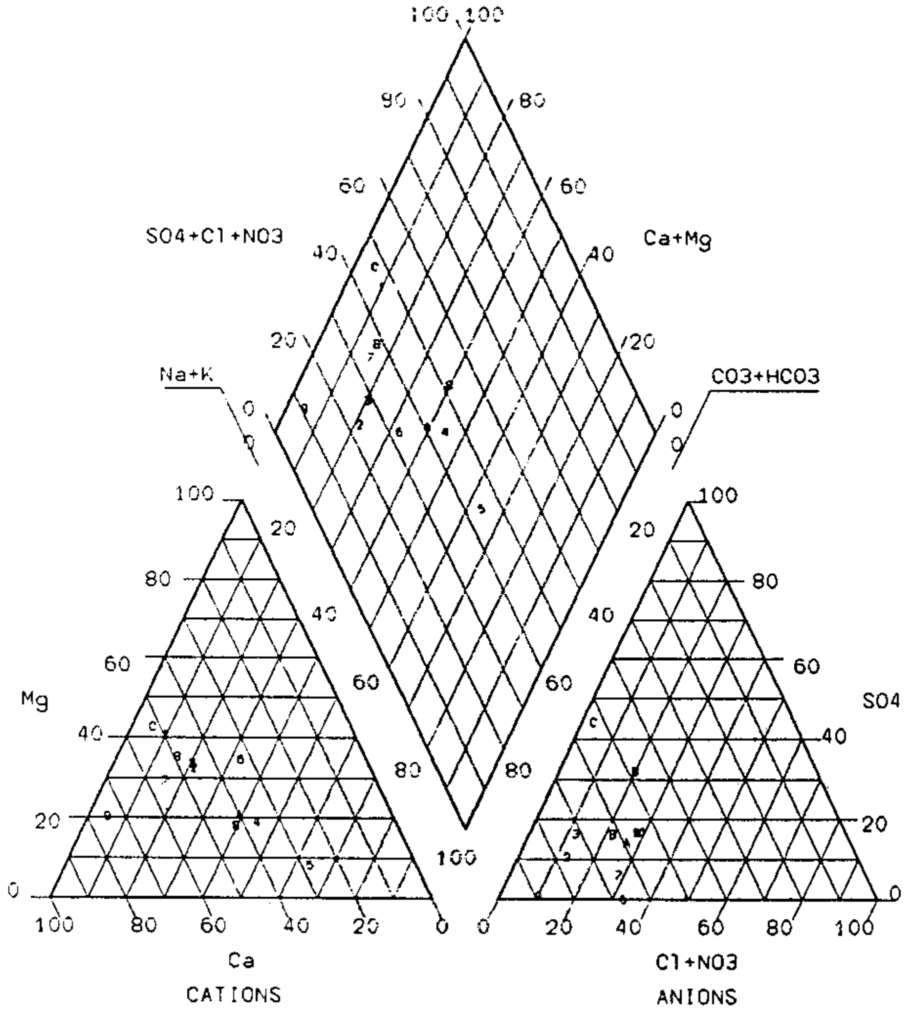


**Fig. 3. Piper Trilinear Diagram Showing Chemical Character of Ground Water (November 1996)**

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 Dhakki village was found to be under the Na-K-$HCO_3$ hydrochemical facies during the post monsoon season.

### 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 electrical conductivity of water expressed in $\mu S/cm$.

The chemical analysis data of all the water 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 June 1996, five samples were found to be of C1-S1 type (low salinity and low SAR), five samples of C2-S1 type (medium salinity and low SAR). Both these types of water are suitable for irrigation purposes. The two samples at village Majra and Raiwala 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 post monsoon season, due to base flow contribution the salinity of the ground water has some what increased, which resulted in C3-S1 type of water in about 50% of water samples of the study area. Such type of water may create salinity problems in areas where soil permeability is poor.

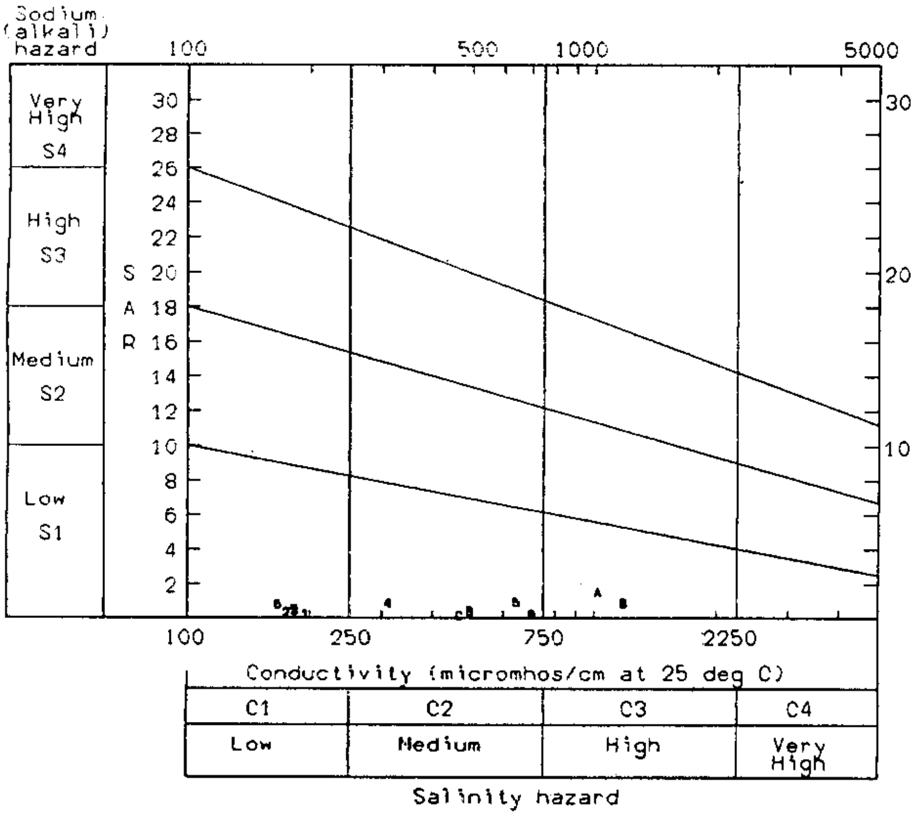


**Fig. 4. U.S. Salinity Laboratory Classification (Wilcox Diagram, June 1996)**

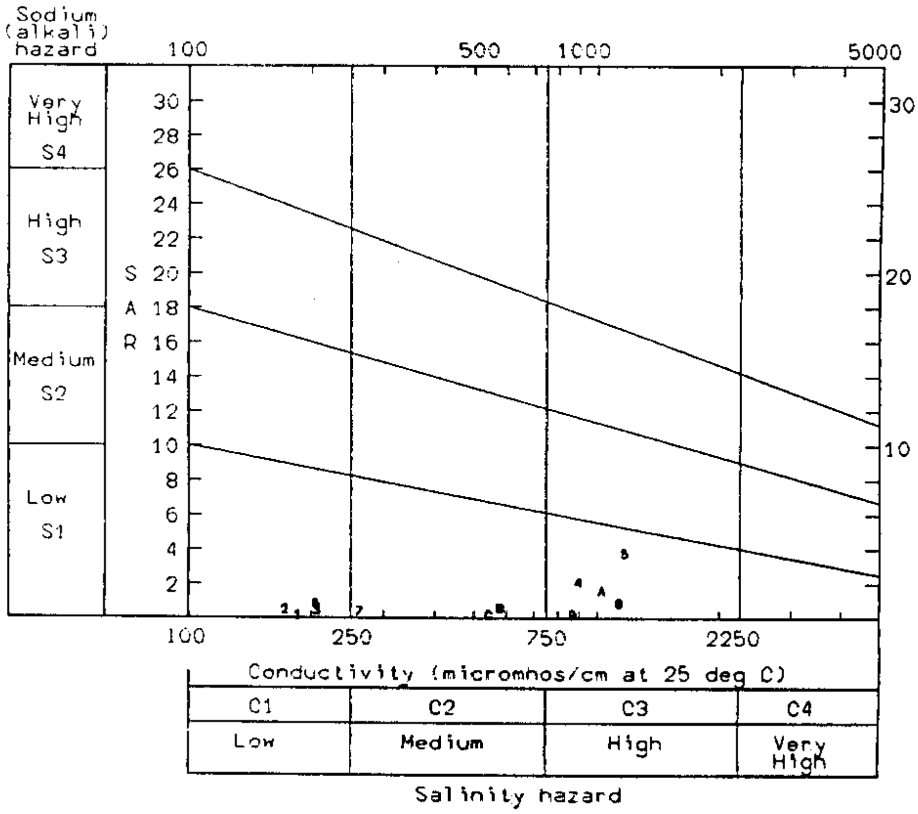


**Fig. 5. U.S. Salinity Laboratory Classification (Wilcox Diagram, November 1996)**

## 6.0 CONCLUSION

The suitability of the ground water of the Doon valley has been demonstrated on the basis of standards prescribed by BIS and WHO. The water is generally good with TDS value ranging from 100 to 760 mg/L. Bicarbonate is the dominant anion and calcium is the dominant cation. The water in the valley is suitable for drinking and irrigational purposes. The slight higher values of some constituents at Majra, Raiwala and Dhakki may be attributed to some local contamination. The shallow aquifers are rich in bicarbonates due to geology of the area. The ground water of the study area is of calcium 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.

It is recommended that study should be continued for two to three years on quarterly basis to have a good understanding of ground water quality in the area. Bacteriological analysis should be carried out in detail to further this work.

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