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Central Ground Water Board
Uttaranchal Region
Ministry of Jal Shakti
Department of Water Resources, River Development and Ganga
Rejuvenation



STATE HYDROCHEMICAL REPORT
UTTARAKHAND

UTTARANCHAL REGION
DEHRADUN



Central Ground Water Board
Ministry of Jal Shakti
Department of Water Resources, RD & GR
Government of India



REPORT ON
STATE HYDROCHEMICAL REPORT
Uttarakhand State

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**STATE HYDROCHEMICAL REPORT,
UTTARAKHAND STATE**

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1 INTRODUCTION

Water is the most common liquid on Earth. Water is a transparent and nearly colourless chemical substance that is the main constituent of Earth's streams, lakes, and oceans, and the fluids of most living organisms. On Earth, 96.5% of the planet's crust water is found in seas and oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapour, clouds (formed of ice and liquid water suspended in air). Only 2.5% of this water is fresh water, and 98.8% of that water is in ice (excepting ice in clouds) and groundwater. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) is contained within biological bodies and manufactured products. A greater quantity of water is found in the earth's interior.

Ground water is an essential and vital component of our life support system. The ground water resources are being utilized for drinking, irrigation and industrial purposes. However, due to rapid growth of population, urbanization, industrialization and agriculture activities, ground water resources are under stress. There is growing concern on the deterioration of ground water quality due to geogenic and anthropogenic activities.

India is a vast country with varied hydrogeological situations resulting from diversified geological, climatological and topographic settings. Water-bearing rock formations (aquifers) range in age from Achaeans to Recent. The natural chemical composition of ground water is influenced predominantly by type & depth of soils and subsurface geological formations through which ground water passes. Ground water quality is also influenced by contribution from the atmosphere and surface water bodies.

Quality of ground water is also influenced by anthropogenic factors. For example, overexploitation of ground water in coastal regions may result in sea water ingress and consequent increase in salinity of ground water, excessive use of fertilizers and pesticides in agriculture and improper disposal of urban/industrial waste can cause contamination of ground water resources.

Uttarakhand State lies between 28°43'20" – 31°28'00" N Latitude and 77°34'06" – 81°01'31" E Longitude and has a total geographical area of 53,483 sq. km. The state has been divided into two Divisions and thirteen developmental blocks. Uttarakhand has a diverse hydrogeological set up. In order to assess the impact of continuously increasing stress on the ground water regime and to categorize various hydrogeological units in the State, systematic monitoring of ground water levels and spring discharge are being carried out four times in a year by the Central Ground Water Board, Uttaranchal Region, Dehradun through the Ground Water Monitoring Stations, which included periodic measurement of Springs discharge in the hilly terrain.

Chemical analysis of water samples, collected from selected locations within the state once in a year during the month of May (pre-monsoon monitoring), is being carried out to check whether any significant change is taking place in groundwater quality in time and space.

Ground water contains a wide variety of dissolved inorganic chemical constituents in various concentrations, resulting from chemical and biochemical interactions between water and the geological

materials. Inorganic contaminants including Salinity, Chloride, Fluoride, Nitrate, Iron and Arsenic are important in determining the suitability of ground water for drinking purposes.

2 GEOLOGY

The state of Uttarakhand has distinct geological attributes with a wide spectrum of rock types ranging in age from Achaean to Quaternary. Based on the diversity of geological processes in time and space, the state can be subdivided into two major physiographic-cum-tectonic units, viz.

- 1) Gangetic Alluvial Plain
- 2) Himalayan Mountain Belt.

A brief description of the geology of Uttarakhand is given below.

1) Gangetic Alluvial Plain

Gangetic Alluvial Plain, a part of the Indo-Gangetic Foreland Basin, occupies the southernmost part of the state. This zone consists of Quaternary fluvial sediments also known as Ganga Alluvium. Subsurface investigations in this belt have revealed a thick pile of alluvium resting unconformably over the Siwalik succession of Neogene to early Pleistocene Period. The thickness of alluvium increases towards north and attains its maximum adjacent to the *Foot Hill Fault* (FHF), which marks the northern limit of the youngest foreland basin in India i.e. the Ganga Fore deep Basin. The Ganga Fore deep sediments extend up to the south of depositional boundary of the Siwalik succession and rests over Precambrian cratonic rocks of Peninsular Indian Shield.

2)Himalayan Mountain Belt.

The Himalayan Mountain Belt is a part of the global mobile belt of Mesozoic to Cenozoic age that is believed to have evolved through the convergence of active Indian Plate and passive Eurasian Plate during the continent-continent lithospheric collision. It has a wide spectrum of rocks of sedimentary, metamorphic and igneous origin. Late Proterozoic (Neoproterozoic) to early Cenozoic crustal sequences form a small part of Himalaya, whereas the main mountain chain consisting predominantly of Proterozoic rocks represents a part of the Indian Shield. The Proterozoic crystalline rocks have been affected by various orogenic episodes of Mesozoic to Cenozoic Period and show signs of multiple phases of deformation and metamorphism.

Uttarakhand State is a part of Western Himalaya. Four distinct tectonic zones, each characterized by specific geological attributes and bounded by prominent dislocation zones can be recognized in Uttarakhand Himalaya from south to north. A brief description of the zones is given below:

2.1) Outer Himalaya or Sub Himalaya

This zone constitutes of a thick Cenozoic sedimentary pile ranging in age from Paleocene to Upper Pleistocene. Its northern and southern boundaries are delimited by the *Main Boundary Thrust* (MBT) and the *Foot Hill Fault* (FHF) also known as the *Main Frontal Thrust* (MFT), respectively. This zone consists predominantly of continental molasses sediments of Siwalik Group ranging in age from Middle Miocene to Upper Pleistocene. The Siwalik Group has been subdivided into the Lower Siwalik, Middle Siwalik and Upper Siwalik. The Lower Siwalik consists of fine to medium grained sandstone with clay, the Middle

Siwalik is formed of medium grained sandstone with calcareous concretions and sandy clay and the Upper Siwalik consists predominantly of conglomerate with lenticular outcrops of sandstone and minor clay. The elevation of this zone ranges from 250 to 800 m above mean sea level and width varies from 25 to 100 km. This zone is also characterized by a number of flat-floored structural valleys such as the *Doon Valley*.

2.2) Lesser Himalaya

The litho-units lying between the Main Boundary Thrust (MBT) in the south and the *Main Central Thrust* (MCT) in the north are included under the Lesser Himalayan Zone, which has the greatest exposed width of about 80 km in the Garhwal and Kumaun regions of Uttarakhand. The rocks of this zone are overlain by crystalline thrust sheets in the form of large klippe masses occupying mostly the higher topographical levels of the mountain ranges. Regionally metamorphosed Proterozoic rocks emplaced by granites of variable ages along with weakly metamorphosed to unmetamorphosed sedimentary rocks (quartzites with interbedded volcanics, carbonates associated with slate, quartzite and shale) occur extensively in this zone. The granitoids are associated with volcano sedimentary sequence (Bhimtal Formation) and are emplaced along with the predominantly metamorphic and metasedimentary rocks of this zone, forming large-scale nappes like the Almora- Ramgarh nappe, Baijnath-Askot nappe and Garhwal nappe.

2.3) Central or Higher Himalaya

This zone consists of thick slabs of Proterozoic crystalline rocks, which thrust southward along the *Main Central Thrust* (MCT), over-riding the Lesser Himalayan Zone. This zone is a 10-15 km wide sequence of metamorphic rocks and granites. This zone represents the Proterozoic basement that has been reactivated due to crustal shortening during the continent-continent collision of the Himalayan Orogeny. The metamorphic rocks exposed in this zone show progressive regional metamorphism ranging from green schist facies to upper amphibolite facies. Both foliated and non- foliated granitoids are emplaced in different structural and tectonic levels within the regionally metamorphosed crystalline.

2.4) Tethys Himalaya

This zone is occupied by the thick sedimentary sequence ranging in age from Late Precambrian (Neoproterozoic) to Lower Eocene. Sediments of marine facies, characteristic of continental shelf to continental slope environments of the Tethys Sea regime, are the predominant litho types of this zone. In Uttarakhand, this zone is well exposed in the Zaskar Mountains and mountain ranges of Kumaun region. This zone is separated from the Central Crystalline by Dar-Martoli Fault, with the Lower Martoli Formation representing the base of Phanerozoic, which is broadly folded and faulted with several local thrusts. The rock sequence comprises phyllite, mica schist and quartzite with lenticular outcrops of limestone.

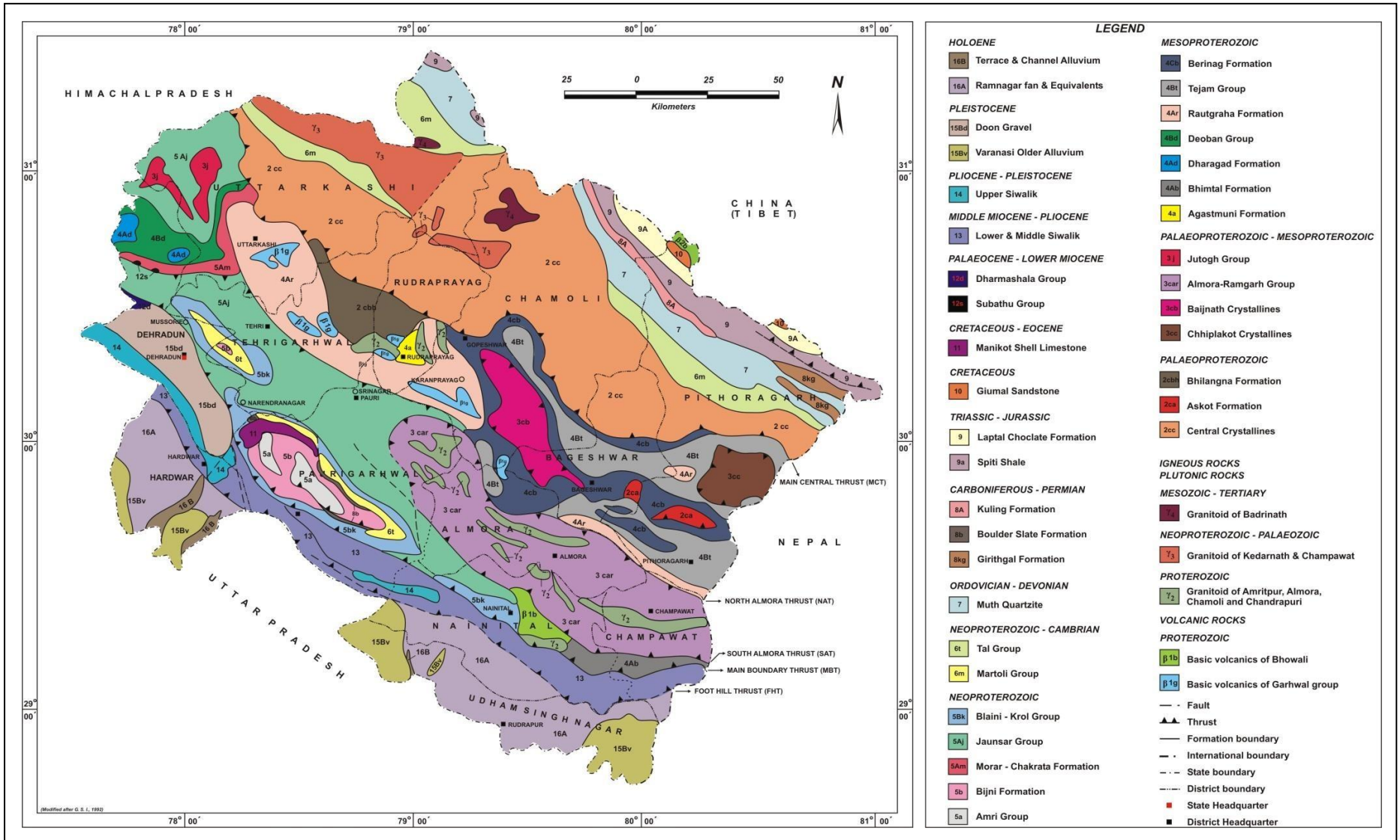


Fig. 2.1: Geological Map of Uttarakhand State (after GSI, 2002)

3 HYDROGEOLOGY

Uttarakhand State has a very diverse hydrogeological set-up. However, this hilly state can broadly be classified into two hydrogeological regimes namely Gangetic Alluvial Plain and Himalayan Mountain Belt. The description of these two types of hydrogeological-cum-physiographic units with further subdivisions is given below:

1. Gangetic Alluvial Plain

The Gangetic Alluvial Plain is a vast expanse of alluvium of Tertiary and Quaternary age. Alluvium is a generalized term for detrital unconsolidated sediments comprising predominantly of clay, silt, sand and gravels formed on river beds, flood plains, alluvial fans etc. This zone is very promising from the hydrogeological point of view having substantial water resource. This unit can be subdivided into three distinct hydrogeological regimes from south to north, viz. Axial Belt, Tarai and Bhabar.

1.1 Axial Belt

This unit, also called as the Alluvial Plains, is demarcated by the termination of alluvial fans that grade further down slope into vast alluvial plains. This zone is composed of a mixture of gravel, sand, silt and clay deposited in alternating layers. The aquifers present in this zone are of unconfined to confined nature. The area, in general, has good ground water resource potential but overexploitation of ground water reserve at places has resulted in the decline of water levels and needs implementation of artificial recharge methods. Drilling in this zone can be best accomplished by Rotary Drilling method having high drilling rate and hence, requiring less time for drilling.

1.2 Tarai

This is a generalized term for a sedimentary unit consisting of a mixture of gravel, sand and clay (sometimes also referred to as Tarai Formation). The boundary between Tarai and Bhabar is demarcated by the presence of springs forming a linear pattern, thus delineating a “spring line”. Due to the highly porous and permeable nature of the constituting material of sedimentary origin, many potential aquifers having groundwater of good chemical quality exist in this area. Two types of aquifers can be found in this zone –

- a) Unconfined Aquifers down to depths of 30 meters below ground level (m bgl) and
- b) Confined Aquifers that occur at depths greater than 30 m bgl under very high hydrostatic pressure.

The tubewell tapping these aquifers generally exhibit free flowing conditions with hydraulic head sometimes as high as 10 m agl and discharge of 5000 lpm.

1.3 Bhabhar

A mixture of clastic material having different size fractions (e.g., boulder, pebble, gravel, sand, silt and clay) constitutes this unit, which is also referred to as Bhabar Formation. Bhabar zone is also a promising hydrogeological entity though the occurrence of ground water at deeper levels (generally greater than 100 m bgl) poses a problem for ground water exploitation. Central Ground Water Board has constructed 28 deep tube wells (with discharge as high as 5540 lpm) by percussion drilling method in this zone of the state. Perched water bodies having smaller water resource potential are frequently encountered in this zone.

2. Himalayan Mountain Belt

This is a part of the Alpine-Himalayan Mountain Chain and constitutes a major part of the total geographical area of Uttarakhand. This zone is also known as Extra-Peninsular Region. The belt trends northwest – southeast with roughly parallel mountain ranges spanning across the state. This region can be further subdivided into five tectonic units from south to north. These units are Outer Himalaya, Lesser Himalaya, Central Himalaya, Tethyan Himalaya and Indus Suture Zone. However, the Indus Suture Zone does not fall within the geographical area of Uttarakhand State. A brief description of the remaining four units that falls in the state is as follows:

2.1 Outer Himalaya (Siwalik Mountain Range)

This unit is composed dominantly of sandstone, ferruginous shale and clay and is younger in age as compared to the other units of the belt. The general elevation of the zone is less than 1000 m above mean sea level. Due to the semi-consolidated nature of rocks, potential ground water bearing formations are present in areas, which have a good weathered mantle and highly fractured/jointed rocks. In the Siwaliks, a number of valleys have also been developed as a result of tectonic activities (e. g. Doon Valley), which are very important from the hydrogeological point of view. The Doon Valley was formed as an Intermontane Valley within the Siwalik Group of rocks in a foreland propagating thrust system. The Lower, Middle and Upper Siwaliks are exposed in the area, and the Doon Gravels, a post-Siwalik Formation, were deposited with the evolution of the valley. The Doon Gravels are thickly bedded coarse clastic fan deposit of late Pleistocene and Holocene age. The Central Ground Water Board has successfully constructed 11 deep tubewell, with discharge ranging from 252 to 3197 lpm in the Doon Valley of Dehradun district. The water levels in these aquifers range from 20 m bgl in the southern part of the valley to about 100 m bgl in the northern part.

2.2 Lesser Himalaya

This zone is represented by mountains bounded by Main Boundary Thrust (MBT) in the south and Main Central Thrust (MCT) in the north having an elevation ranging between 1000 and 3000 m above mean sea level. This unit is dominantly composed of metasedimentary rocks and minor plutonic intrusive (granitoids). Springs form the most important source of ground water in this zone. In these formations, ground water occurrence is restricted to the weathered residuum and the highly fractured/jointed zones of the area. Several hand pumps have been installed successfully in this zone. At a few places, especially in the river valleys, tubewell having low to moderate discharges have also been successfully constructed.

2.3 Central Himalaya

The Central Himalayan zone lies to the north of Main Central Thrust (MCT) with an elevation ranging from 5000 to 8000 m above mean sea level. Both cold water and hot water (thermal) springs are present in this zone. So far, a total of 25 thermal springs have been investigated with temperatures ranging from 32°C to 70°C and discharge varying between 60 to 600 lpm, corresponding to 5th order and 4th order as per Meinzer's Classification of spring discharge. Due to highly inaccessible, snow-covered areas in this zone and a very steep hydraulic gradient, the possibility of ground water development is negligible.

2.4. Tethys Himalaya

Situated to the north of Central Himalayan zone, this zone is predominantly occupied by the highly fossiliferous sedimentary rocks ranging in age from Precambrian to Jurassic.

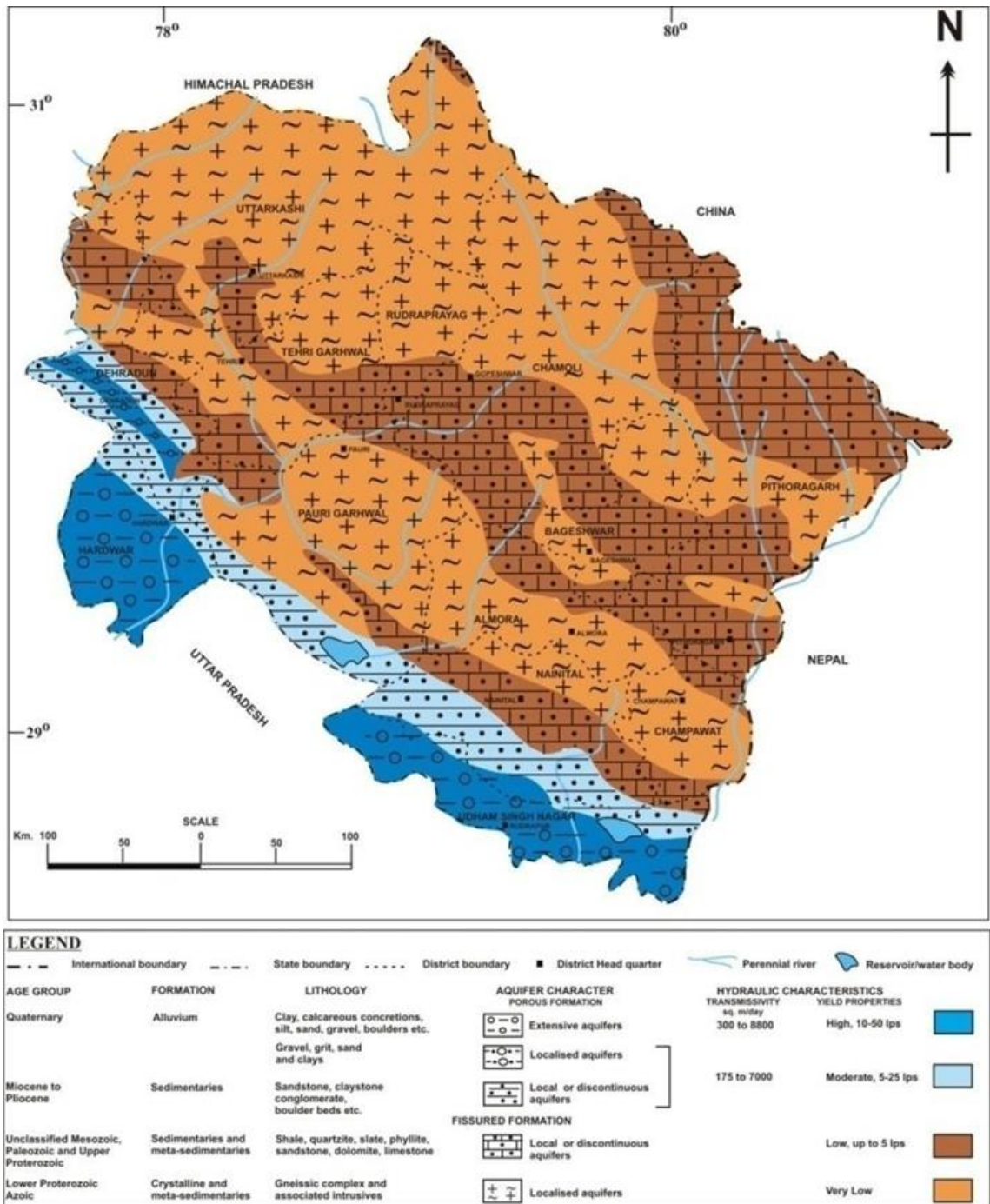


Fig.3.1: Hydrogeological Map of Uttarakhand State

4 HYDROCHEMISTRY

Hydrochemistry is an interdisciplinary science that deals with the chemistry of water in the natural environment. Professional fields such as chemical hydrology, aqueous chemistry, hydrochemistry, water chemistry and hydro-geochemistry are all more or less synonyms. The classical use of chemical characteristics in chemical hydrology is to provide information about the regional distribution of water qualities. At the same time, hydrochemistry has a potential use for tracing the origin and history of water. The hydrochemistry can also be of immense help in yielding information about the environment through which water has circulated. Hydrochemistry can be helpful in knowing about residence times, flow paths and aquifer characteristics as the chemical reactions are time and space dependent. It is essential to study the entire system like atmospheric water (rainwater), surface water and ground water simultaneously in evaluating their hydrochemistry and pollution effect.

4.1 CHEMISTRY OF RAINWATER

The atmosphere is composed of water vapors, dust particles and various gaseous components such as N₂, O₂, CO₂, CH₄, CO, SO_x, NO_x etc. Pollutants in the atmosphere can be transported long distances by the wind. These pollutants are mostly washed down by precipitation and partly as dry fall out. Composition of rainwater is determined by the source of water vapors and by the ion, which are taken up during transport through the atmosphere. In general, chemical composition of rainwater shows that rainwater is only slightly mineralized with specific electrical conductance (EC) generally below 50 μS/cm, chloride below 5 mg/litre and HCO₃ below 10 mg/litre. Among the cations, concentration of Ca, Mg, Na & K vary considerably but the total cations content is generally below 15 mg/l except in samples contaminated with dust. The concentration of sulphates and nitrates in rainwater may be high in areas near industrial hubs.

4.2 CHEMISTRY OF SURFACE WATER

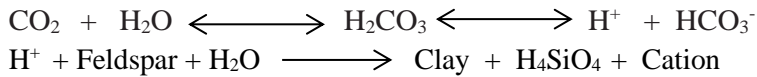
Surface water is found extremely variable in its chemical composition due to variations in relative contributions of ground water and surface water sources. The mineral content in river water usually bears an inverse relationship to discharge. The mineral content of river water tends to increase from source to mouth, although the increase may not be continuous or uniform. Other factors like discharge of city wastewater, industrial waste and mixing of waters can also affect the nature and concentration of minerals in surface water. Among anions, bicarbonates are the most important and constitute over 50% of the total anions in terms of milli equivalent per liter (meq/l). In case of cations, alkaline earths or normally calcium predominates but with increasing salinity the Hydrochemical facies tends to change to mixed cations or even to Na-HCO₃ type.

4.3 CHEMISTRY OF GROUND WATER

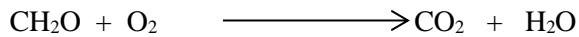
The downward percolating water is not inactive, and it is enriched in CO₂. It can also act as a strong weathering agent apart from general solution effect. Consequently, the chemical composition of ground water will vary depending upon several factors like frequency of rain, which will leach out the salts, time of stay of rain water in the root-zone and intermediate zone, presence of organic matter etc. It may also be pointed out that the water front does not move in a uniform

manner as the soil strata are generally quite heterogeneous. The movement of percolating water through larger pores is much more rapid than through the finer pores. The overall effect of all these factors is that the composition of ground water varies from time to time and from place to place.

Before reaching the saturated zone, percolating water is charged with oxygen and carbon dioxide and is most aggressive in the initial stages. This water gradually loses its aggressiveness, as free CO₂ associated with the percolating water gets gradually exhausted through interaction of water with minerals.



The oxygen present in this water is used for the oxidation of organic matter that subsequently generates CO₂ to form H₂CO₃. This process goes on until oxygen is fully consumed.



Apart from these reactions, there are several other reactions including microbiological mediated reactions, which tend to alter the chemical composition of the percolating water. For example, the bicarbonate present in most waters is derived mostly from CO₂ that has been extracted from the air and liberated in the soil through biochemical activity. Some rocks serve as sources of chloride and sulphate through direct solution. The circulation of Sulphur, however, may be greatly influenced by biologically mediated oxidation and reduction reactions. Chloride circulation may be a significant factor influencing the anion content in natural water.

5 WATER QUALITY CRITERIA

The available quality of groundwater is the resultant of all the processes and reactions, which taken place since the condensation of water in the atmosphere to the time it is retrieved in the form of groundwater from its source. The water has excellent capability to accumulate substances in soluble form as it moves over and into the land resource, from the biological processes and from human activities. Urbanization, agricultural development and discharges of municipal and industrial residues significantly alter characteristics of groundwater resource. The prevailing climatic conditions, topography, geological formations and use and abuse of this vital resource have significant effect on the characteristics of the water, because of which its quality varies with locations.

The definition of criteria and standards for water quality vary with the type of use. The characteristic of water required for human consumption, livestock, irrigation, industries etc., have different water quality requirements. The term water quality criteria may be defined as the ‘‘Scientific data evaluated to derive recommendations for characteristics of water for specific use’’. The term standard applies to any definite rule, principle or measure established by any statutory Authority. The distinction between criteria and standards is important, as the two are neither interchangeable nor they become synonyms for the objective or goal. Realistic standards are dependent on criteria, designated uses and implementation as well as identification and monitoring procedure. The changes in all these factors may provide a basis for alteration in standards. In formulation of water quality criteria, the selection of water quality parameters depends on its use. Sayers, et. al. (1976 as quoted in CGWB & CPCB 2000) identified the key water quality parameters according to its various uses (Table 4.0).

Table 5.0: Water quality criteria parameters for various uses (Sayers et.al., 1976)

Public Water supply	Industrial Water supply	Agricultural water supply	Aquatic life & wild life water supply	Recreation and Aesthetics
Coliform bacteria Turbidity colour, Taste, Odour TDS, Cl, F, SO ₄ NO ₃ , CN, Trace Metals, Trace Organics Radioactive substances	Processing pH, Turbidity Colour, Alkalinity, Acidity, TDS, Suspended solids, Trace metals, Trace Organics Cooling PH, Temp, Silica, Al, Fe, Mg, Total hardness, Alkalinity/ Acidity Suspended solids, Salinity	Farmstead Same as for public supply Live-stock Same as for public supply Irrigation TDS, EC, Na, Ca, Mg, K, B, Cl and Trace metals	Temp, DO, pH, Alkalinity, Acidity, TDS Salinity, pH, DCOs, Turbidity Colour, Settleable materials, Toxic substances, Nutrients, Floating materials	Recreations Tem, Turbidity, Colour, Odour, Floating Materials, Settable Materials Nutrients, Coliforms Aesthetics Same as for Recreation and Substances adversely affecting wild life

5.1 Water Quality Criteria for Drinking Purpose

With the objective of safeguarding water from degradation and to establish a basis for improvement in water quality, standards / guide lines / regulations have been laid down by various national and international organizations such as; Bureau of Indian Standards (BIS), World Health

Organization (WHO), European Economic Community (EEC), Environmental Protection Agency (EPA), United States, and Inland Waters Directorate, Canada. The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institutions (ISI) has laid down the standard specification for drinking water during 1983, which have been revised and updated from time to time. In order to enable the users, to exercise their discretion towards water quality criteria, the maximum permissible limit has been prescribed especially where no alternative sources are available. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purposes. The important water quality characteristics as laid down in BIS standard (IS 10500: 2012) are summarized in **Table - 5.1**

Table 5.1: Drinking Water Characteristics (IS 10500: 2012)

S. No.	Parameters	Desirable Limits (mg/L)	Permissible limits (mg/L)
Essential Characteristics			
1	Colour Hazen Unit	5	15
2	Odour	Unobjectionable	-
3	Taste	Agreeable	-
4	Turbidity (NTU)	1	5
5	pH	6.5-8.5	No relaxation
6	Total Hardness, CaCO ₃	200	600
7	Iron (Fe)	1.0	No relaxation
8	Chloride (Cl)	250	1000
9	Residual Free Chlorine	0.2	1
10	Fluoride (F)	1.0	1.5
Desirable Characteristics			
11	Dissolved Solids	500	2000
12	Calcium (Ca)	75	200
13	Magnesium (Mg)	30	100
14	Copper (Cu)	0.05	1.5
15	Manganese (Mn)	0.1	0.3
16	Sulphate (SO ₄)	200	400
17	Nitrate (NO ₃)	45	No relaxation
18	Phenolic Compounds	0.001	0.002
19	Mercury (Hg)	0.001	No relaxation
20	Cadmium (Cd)	0.003	No relaxation
21	Selenium (Se)	0.01	No relaxation
22	Arsenic (As)	0.01	No relaxation
23	Cyanide (CN)	0.05	No relaxation
24	Lead (Pb)	0.01	No relaxation
25	Zinc (Zn)	5.0	15
26	Hexavalent Chromium	0.05	No relaxation
27	Alkalinity	200	600
28	Aluminum (Al)	0.03	0.2
29	Boron (B)	0.5	2.4
30	Pesticides	Absent	0.001
31	Uranium	0.03	No relaxation

NTU- Nephelometric Turbidity Unit.

N.B. The fluoride limits vary with average annual temperature of the areas. Similarly, the limits for magnesium are based on sulphate contents of water. When sulphate content is 250 mg/L or above, the magnesium should be between 30 and 50 mg/L but if sulphate is lower, higher content of magnesium is permissible.

5.2 Water Quality Criteria for Irrigation Purpose

Water quality plays a significant role in irrigated agriculture. Many problems originate due to inefficient management of water for agriculture use, especially when it carries high salt loads. The effect of total dissolved salts in irrigation water (measured in terms of electrical conductance) on crop growth is extremely important. Soil water passes in to the plant through the root zone due to osmotic pressure and the plants root able to assimilate water and nutrients. Thus, the dissolved solid contents of the residual water in the root zone also have to be maintained within limits by proper leaching. These effects are visible in plants by their stunted growth, low yield, discoloration and even leaf burns at margin or top. The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are presented in **Table - 5.2**.

Table 5.2: Safe Limits for electrical conductivity for irrigation water (IS:11624-1986)

S. No.	Nature of soil	Crop Growth	Upper permissible safelimit of electrical conductivity in water $\mu\text{s/cm}$ at 25°C
1	Deep black soil and alluvial soilshaving clay content more than 30%; soils that are fairly to moderately well Drained	Semi-tolerant	1500
		Tolerant	2000
2	Textured soils having clay contents of 20-30%; soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3	Medium textured soils having clay 10-20%; internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000

In addition to problems caused by total amount of salts, some of the specific ions like sodium, boron and trace elements, if present in water in excess, also render it unsuitable for agricultural use.

5.2.1 Sodium ADSORPTION RATIO (SAR) & RESIDUAL SODIUM CARBONATE (RSC)

The clay minerals in the soil adsorb divalent cations like calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conducive for plant growth. Sodium reacts with soil to reduce its permeability. In case the irrigation water is sodium dominant, the clay lattice is filled with sodium ions due to ion exchange. Such soils become impermeable and sticky and as such the cultivation becomes difficult to support plant growth. However, the cation exchange process is reversible and can be controlled either by adjusting the composition of water or by soil amendment by application of gypsum, which releases cations (Calcium) to occupy the exchange position. The tendency of water to replace adsorbed calcium and magnesium with sodium can be expressed by the Sodium Adsorption Ratio (SAR), where all the ion concentrations are in milli-equivalents per litre (meq/L).

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

When, water having high bicarbonates and low calcium and magnesium is used for irrigation purpose, precipitation of calcium and magnesium as carbonate takes place, changing the residual water to high sodium water with sodium bicarbonate in solution. It is termed as Residual Sodium Carbonate (RSC) which is expressed as;

$$\text{RSC} = (\text{HCO}_3 + \text{CO}_3) - (\text{Ca} + \text{Mg})$$

(Where all the ions' concentrations are in milli equivalents / litre).

5.2.2 Percentage sodium (%Na):

Percentage sodium (%Na) is an indication of the soluble sodium content of the groundwater and also used to evaluate Na hazard. In all natural waters, %Na is a common parameter to assess its suitability for irrigation purposes since sodium reacts with the soil to reduce permeability.

$$\% \text{Na} = \frac{(\text{Na} + \text{K})}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} * 100$$

The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to Electrical Conductivity, Sodium content, Sodium Adsorption Ratio, and Residual Sodium Carbonate, under customary irrigation conditions has been depicted in **Table – 5.3**.

Table 5.3: Guidelines for evaluation of quality of irrigation water

Water Class	Alkalinity hazards		
	SAR IS:11624-1986	RSC (meq/L) IS:11624-1986	%Na Wilcox
Low	< 10	< 1.5	< 20
Medium	>10 – 18	1.5 – 3	20 - 60
High	>18 – 26	3 - 6	> 60
Very High	> 26	> 6	

5.3 Effects OF Water Quality Parameters on Human Health and Distribution for Various Users

It is essential to ensure that various constituents are within prescribed limits in drinkingwater supplies to avoid impact on human health (Table – 5.4). Man, life forms and domestic animals are affected by alteration in water quality due to natural or anthropogenic reasons. The effect of these substances depends on the quantity of water consumed per day and their concentration in water.

Table 5.4: Effects of water quality parameters on human health when used for drinking Purpose

S. No.	Parameters	Prescribed limits IS:10500, 2012		Probable Effects
		Desirable Limit	Permissible Limit	
1	Colour (Hazen unit)	5	15	Makes water aesthetically undesirable
2	Odour	Essentially free from objectionable odour		Makes water aesthetically undesirable
3	Taste	Agreeable		Makes water aesthetically undesirable
4	Turbidity (NTU)	1	5	High turbidity indicates contamination / Pollution.
5	pH	6.5	8.5	Indicative of acidic or alkaline waters, affects taste, corrosivity and the water supply system
6	Hardness as CaCO ₃ (mg/L)	200	600	Affects water supply system (Scaling), Excessive soap consumption, and calcification of arteries. There is no conclusive proof but it may cause urinary concretions, diseases of kidney or bladder and stomach disorder.

S. No.	Parameters	Prescribed limits IS:10500, 2012		Probable Effects
		Desirable Limit	Permissible Limit	
7	Iron (mg/L)	1.0	No relaxation	Gives bitter sweet astringent taste, causes staining of laundry and porcelain. In traces it is essential for nutrition.
8	Chloride (mg/L)	250	1000	May be injurious to some people suffering from diseases of heart or kidneys. Taste, indigestion, corrosion and palatability are affected.
9	Residual Chlorine (mg/L) Only when water is Chlorinated	0.20	-	Excessive chlorination of drinking water may cause asthma, colitis and eczema.
10	Total Dissolved Solids-TDS (mg/L)	500	2000	Palatability decreases and may cause gastro intestinal irritation in human, may have laxative effect particularly upon transits and corrosion, may damage water system.
11	Calcium (Ca) (mg/L)	75	200	Causes encrustation in water supply system. While in sufficiency causes a severe type of rickets, excess causes concretions in the body such as kidney or bladder stones and irritation in urinary passages.
12	Magnesium (mg) (mg/L)	30	100	Its salts are cathartics and diuretic. High concentration may have laxative effect particularly on new users. Magnesium deficiency is associated with structural and functional changes. It is essential as an activator of many enzyme systems.
13	Copper (Cu) (mg/L)	0.5	1.50	Astringent taste but essential and beneficial element in human metabolism. Deficiency results in nutritional anemia in infants. Large amount may result in liver damage, cause central nervous system irritation and depression. In water supply it enhance corrosion of aluminum in particular
14	Sulphate (SO4) (mg/L)	200	400	Causes gastro intestinal irritation along with Mg or Na, can have a cathartic effect on users, concentration more than 750 mg/L may have laxative effect along with Magnesium.
15	Nitrate (NO3) (mg/L)	45	No relaxation	Cause infant methaemoglobinaemia (blue babies) at very high concentration, causes gastric cancer and affects adversely central nervous system and cardiovascular system.

S. No.	Parameters	Prescribed limits IS:10500, 2012		Probable Effects
		Desirable Limit	Permissible Limit	
16	Fluoride (F) (mg/L)	1.0	1.50	Reduce dental carries, very high concentration may cause crippling skeletal fluorosis.
17	Cadmium (Cd) (mg/L)	0.003	No relaxation	Acute toxicity may be associated with renal, arterial hypertension, itai-itai disease, (a bone disease). Cadmium salt causes cramps, nausea, vomiting and diarrhea.
18	Lead (Pb) (mg/L)	0.01	No relaxation	Toxic in both acute and chronic exposures. Burning in the mouth, severe inflammation of the gastro-intestinal tract with vomiting and diarrhoea, chronic toxicity produces nausea, severe abdominal pain, paralysis, mental confusion, visual disturbances, anaemia etc.
19	Zinc (Zn) (mg/L)	5	15	An essential and beneficial element in human metabolism. Taste threshold for Zn occurs at about 5 mg/L imparts astringent taste to water.
20	Chromium (Cr6) (mg/L)	0.05	No relaxation	Hexavalent state of Chromium produces lung tumors can produce cutaneous and nasal mucous membrane ulcers and dermatitis.
21	Boron (B) (mg/L)	0.5	2.4	Affects central nervous system its salt may cause nausea, cramps, convulsions, coma etc.
22	Alkalinity (mg/L) as CaCO ₃	200	600	Impart distinctly unpleasant taste may be deleterious to human being in presence of high pH, hardness and total dissolved solids.
23	Pesticides: (mg/l)	Absent	0.001	Imparts toxicity and accumulated in different organs of human body affecting immune and nervous systems may be carcinogenic.
24	Phosphate (PO ₄) (mg/L)	No guideline		High concentration may cause vomiting and diarrhea, stimulate secondary hyperthyroidism and bone loss
25	Sodium (Na)(mg/L)	No guidelines		Harmful to persons suffering From cardiac, renal and circulatory diseases.
26	Potassium (K) (mg/L)	No guidelines		An essential nutritional element but its excessive amounts is cathartic

S. No.	Parameters	Prescribed limits IS:10500, 2012		Probable Effects
		Desirable Limit	Permissible Limit	
27	Silica (SiO ₂) (mg/L)	No guidelines		-
28	Nickel (Ni) (mg/L)	0.02		Non-toxic element but may be carcinogenic in animals, can react with DNA resulting in DNA damage in animals.
29	Pathogens (a) Total coliform (per 100ml) (b) Faecal Coliform (per 100ml)	nil		Cause water borne diseases like coliform Jaundice, Typhoid, Cholera etc. produce infections involving skin mucous membrane of eyes, ears and throat.
30	Arsenic	0.01	No relaxation	Various skin diseases, Carcinogenic
31	Uranium	0.03	No relaxation	Kidney disease, Carcinogenic

6 GROUND WATER QUALITY MONITORING

The International Standard Organization (ISO) has defined monitoring as, "The programmed process of samplings, measurements and subsequent recording or signalling or both, of various water characteristics, often with the aim of assessing, conformity to specified objectives". A systematic plan for conducting water quality monitoring is called Monitoring Programme, which includes monitoring network design, preliminary survey, resource estimation, sampling, analysis, data management & reporting.

Monitoring of ground water quality is an effort to obtain information on chemical quality through representative sampling in different hydrogeological units. Ground Water is commonly tapped from phreatic aquifers through dug wells in a major part of the country and through springs and hand pumps in hilly areas. The main objective of ground water quality monitoring programme is to get information on the distribution of water quality on a regional scale as well as lattice is to create a background data bank of different chemical constituents in ground water.

One of the main objectives of the ground water quality monitoring is to assess the suitability of ground water for drinking purpose. The quality of drinking water is a powerful environmental determinant of the health of a community. The problem of the quality of water resources in general, and groundwater resources in particular, is becoming increasingly important in both industrialized and developing nation. In developing countries like India, the essential concerns as regards water resources are their quantity, availability, sustainability and suitability. Groundwater plays a leading role because it has of fundamental importance to all living beings.

Even though water is the most frequently occurring substance on earth, lack of safe drinking water is more prominent in the developing countries. Due to increasing world population, extraction of groundwater is also increasing for irrigations, industries, municipalities and urban and rural households' day by day. During dry season extensive withdrawal of groundwater for irrigation purpose is lowering the water table in the aquifer and also changing the chemical composition of water.

The physical and chemical quality of ground water is important in deciding its suitability for drinking purposes. Bureau of Indian Standards (BIS) formally known as Indian Standard Institute (ISI) vide its document IS: 10500:2012, Edition 3.2 (2012-15) has recommended the quality standards for drinking water. On this basis of classification, the natural ground water of India has been categorized as desirable, permissible and unfit for human consumption.

From the analytical results, it is seen that majority of water samples collected from observation / monitoring wells of CGWB in a major part of the country fall under desirable or permissible category and hence are suitable for drinking purposes. However, a small percentage of well waters are found to have concentrations of some constituents beyond the permissible limits. Such waters are not fit for human consumption and are likely to be harmful to health on continuous use.

6.1 Data Validation / Data Quality Control

Groundwater quality data validation is an essential step in ensuring the reliability and accuracy of the data. Here are some of the main steps for groundwater quality data validation.

- a. **Checking of Data Consistency:** Checking of the data for consistency by comparing the measurements of a particular parameter over time. This will help identify any changes in the groundwater quality due to measurement methodology or equipment
- b. **Checking the correlation between EC and TDS:**
 - a. The relationship between the two parameters is often described by a constant (commonly between 0.55 and 0.95 for freshwaters).
 - b. Thus: $TDS (mg/l) \sim (0.55 \text{ to } 0.95) \times EC (mS/cm)$.
 - c. The value of the constant varies according to the chemical composition of the water. For freshwaters, the normal range of TDS can be calculated from the following relationship:
 - d. $0.55 \text{ conductivity (mS/cm)} < TDS (mg/l) < 0.95 \text{ conductivity (mS/cm)}$.
 - e. Typically the constant is high for chloride rich waters and low for sulphate rich waters.
- c. **Checking the cation-anion balance**
When a water quality sample has been analysed for the major ionic species, one of the most important validation tests can be conducted: the cation-anion balance.

$$\text{Sum of cations} = \text{sum of anions}$$

where:

cations = positively charged species in solution (meq/l)

anions = negatively charged species in solution (meq/l)

The Electronic charge balance is expressed as follows:

$$\text{Electronic Charge Balance (ECB \%)} = \frac{[\sum \text{ cations} - \sum \text{ anions}]}{[\sum \text{ cations} + \sum \text{ anions}]} \times 100$$

All concentrations should be in epm. Error charge balance has been computed for the chemical results of 2022-23 and analysis showing more than 10% ECB has not been accepted as it indicates that there has been an error made in at least one of the major cation/anion analyses.

6.2 GROUND WATER QUALITY MONITORING STATIONS

Two hundred (200) water samples collected during pre-monsoon period (May 2022) for normal, heavy metals and Arsenic analysis were deposited at Chemical Laboratory, North Region, Lucknow. The water samples were collected from ground water monitoring stations like hand pumps and springs in Dehradun, Haridwar, Pauri Garhwal, Udham Singh Nagar, Nainital, Almora, Champawat and Uttarkashi districts. Since, the dug wells are not in use, water samples were collected from hand pumps nearby areas. District-wise break up of sampling locations is given in table 6.2.

Table 6.0: District wise breakup of Ground Water Sampling locations

S. No.	District	No. of Sampling
1	Dehradun	47
2	Nainital	20
3	Almora	26
4	Haridwar	42
5	Champawat	4
6	Pauri Garhwal	2
7	Uttarkashi	13
8	Udham Singh Nagar	46

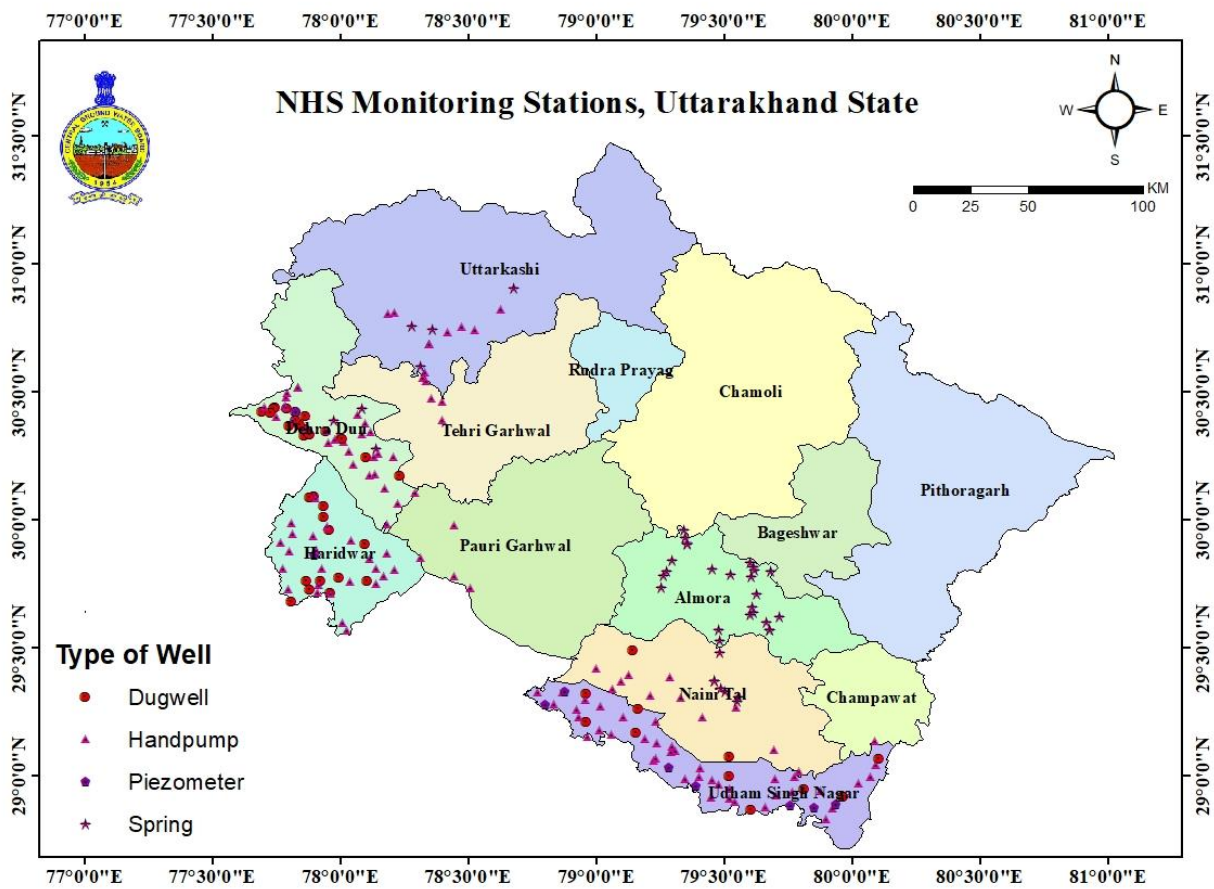


Fig. 6.1: Map showing Ground Water Monitoring stations during NHS Pre-monsoon 2022

7.0 GROUND WATER QUALITY SCENARIO IN UTTARAKHAND

The quality of groundwater in India has been evaluated by sampling and analysis of water samples collected from Groundwater Monitoring wells. About **200** Groundwater Monitoring wells were monitored for water quality during May 2022 representing pre-monsoon water quality. The summarized results of groundwater quality ranges are given in **Table - 6.1**.

Table - 7.0. Summarized results of groundwater quality ranges, (May 2022)

S. No	Parameters		Range	No. of sample	Percentage
1	Electrical Conductivity µs/cm at 25°C	Fresh	< 750	179	89.5
		Moderate	750- 2250	20	10
		Slightly mineralized	2251- 3000	0	0
		Highly mineralized	> 3000	1	0.5
2	Chloride mg/L	Desirable limit	< 250	200	100
		Permissible limit	251-1000	0	0
		Beyond permissible	> 1000	0	0
3	Fluoride mg/L	Desirable limit	< 1.0	197	98.5
		Permissible limit	1.0 - 1.5	2	1
		Beyond permissible	>1.5	1	0.5
4	Nitrate mg/L	Permissible limit	< 45	196	98
		Beyond permissible	> 45	4	2

The chemical quality of groundwater of shallow and deep aquifers in Uttarakhand State varies widely depending on physiography, soil textures and geology of the area. As per the Piper-Trilinear, Modified Piper diagram, the aquifers are mostly dominated by Ca-Mg-HCO₃ and Ca-HCO₃ types of groundwater. The general chemical quality reveals that most of the wells contain low dissolved mineral contents and hence, groundwater in Uttarakhand state is fresh and potable.

8.0 GROUND WATER QUALITY HOT SPOTS IN UNCONFINED AQUIFERS OF UTTARAKHAND STATE

Unconfined aquifers are extensively tapped for water supply across the state therefore; its quality is of paramount importance. The chemical parameters like TDS, Chloride, Fluoride, Iron, Arsenic and Nitrate etc. are main constituents defining the quality of ground water in unconfined aquifers. Therefore, presence of these parameters in ground water beyond the permissible limit in the absence of alternate source has been considered as groundwater quality hotspots.

Groundwater quality hot spot maps of the state have been prepared depicting six main parameters based on their distribution shown on the separate maps. These maps depict the spatial distribution of the following constituents in ground water tapping the unconfined aquifers.

- I. Electrical Conductivity
- II. Fluoride (>1.5 mg/L)
- III. Nitrate (>45mg/L)
- IV. Iron (>1.0mg/L)
- V. Arsenic (>0.01 mg/L)
- VI. Total Hardness (>600 mg/L)

8.1 Electrical Conductivity

Conductivity measurements are used routinely in many industrial and environmental applications as a fast, inexpensive and reliable way of measuring the ionic content in a solution. For example, the measurement of product conductivity is a typical way to monitor and continuously trend the performance of water purification systems. In many cases, conductivity is linked directly to the total dissolved solids (TDS).

Salinity is the saltiness or dissolved salt contents of a water body. Salt content is an important factor in water use. Salinity can be technically defined as the total mass in grams of all the dissolved substances per Kilogram of water. Different substances dissolve in water giving it taste and odour. In fact, humans and other animals have developed senses which are, to a degree, able to evaluate the potability of water, avoiding water that is too salty or putrid.

Salinity always exists in ground water but in variable amounts. It is mostly influenced by aquifer material, solubility of minerals, duration of contact and factors such as the permeability of soil, drainage facilities, and quantity of rainfall and above all, the climate of the area. The salinity of groundwater in coastal areas in addition to the above may be due to air borne salts originating from air water interface over the sea and also due to over pumping of fresh water which overlays saline water in coastal aquifer systems.

BIS has recommended a drinking water standard for total dissolved solids a limit of 500 mg/L (corresponding to EC of about 750 $\mu\text{S}/\text{cm}$ at 25⁰C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000 $\mu\text{S}/\text{cm}$ at 25⁰C) in case of no alternate source. Water having TDS more than 2000 mg/L is not suitable for drinking purpose. In Fig 8.1, the EC values (in $\mu\text{S}/\text{cm}$ at 25⁰C) of ground water from observation/monitoring wells have been used to show distribution patterns of

electrical conductivity in different ranges of suitability for drinking purposes. It is apparent from the Fig. 8.1 and 8.2 that majority of the waters having EC values less than $750\mu\text{S}/\text{cm}$ at 25°C in the state.

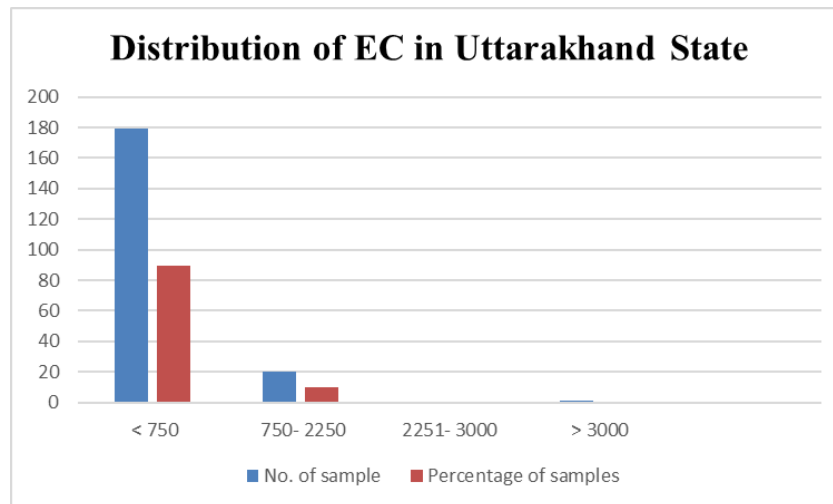


Fig. 8.1: Graph showing distribution of EC in the Uttarakhand State

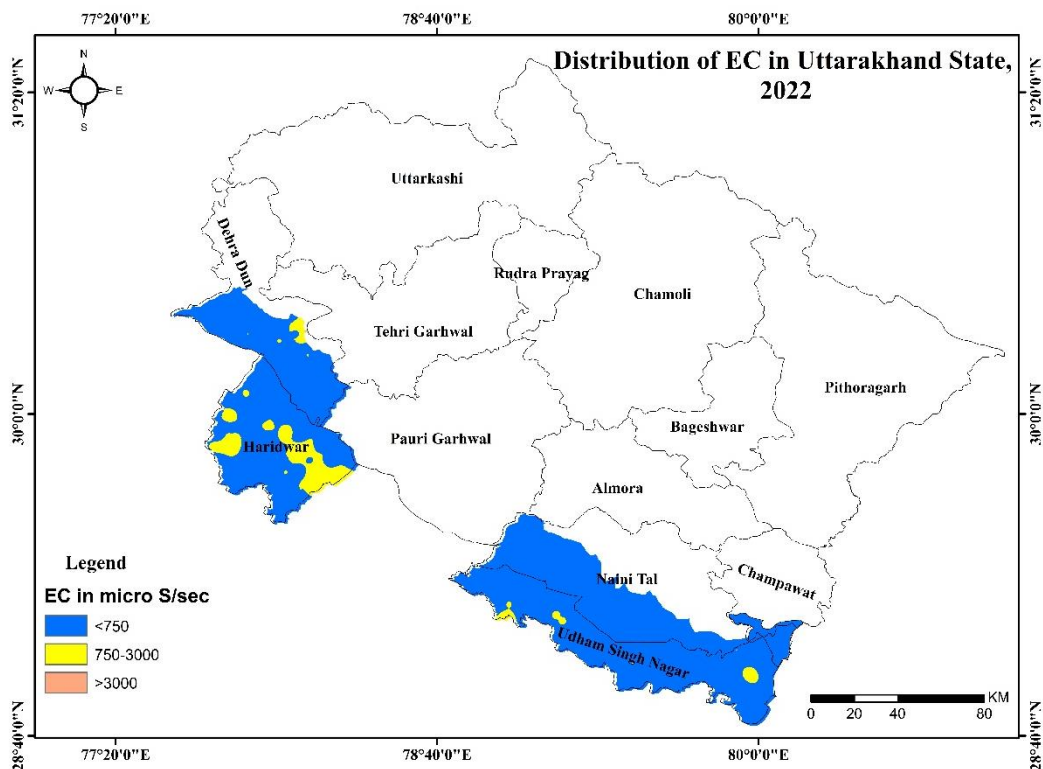


Fig. 8.2 Map showing distribution of EC in the Uttarakhand State

Groundwater with EC ranging between 750 and $3000\mu\text{S}/\text{cm}$ at 25°C falling under ‘permissible’ range are observed only in 20 samples. However, in some cases, relatively high values of EC in excess of $3000\mu\text{S}/\text{cm}$ are observed in only one location (Maldeota) of Dehradun district.

8.2 Fluoride

Fluorine is a fairly common element but it does not occur in the elemental state in nature because of its high reactivity. Fluorine is the most electronegative and reactive of all elements that occur

naturally within many types of rock. It exists in the form of fluorides in a number of minerals of which fluorspar, cryolite, fluorite and fluorapatite are the most common. Fluorite (CaF_2) is a common fluoride mineral.

Most of the fluoride found in groundwater is naturally occurring from the breakdown of rocks and soils or weathering and deposition of atmospheric particles. Most of the fluorides are sparingly soluble and are present in ground water in small amounts. The occurrence of fluoride in natural water is affected by the type of rocks, climatic conditions, nature of hydrogeological strata and time of contact between rock and the circulating ground water. Presence of other ions, particularly bicarbonate and calcium ions also affect the concentration of fluoride in ground water.

It is well known that small amounts of fluoride (less than 1.0 mg/L) have proven to be beneficial in reducing tooth decay. Community water supplies commonly are treated with NaF or fluorosilicates to maintain fluoride levels ranging from 0.8 to 1.2 mg/L to reduce the incidence of *dental carries*. However, high concentrations such as 1.5 mg/L of F and above have resulted in staining of tooth enamel while at still higher levels of fluoride ranging between 5.0 and 10 mg/L, further pathological changes such as stiffness of the back and difficulty in performing natural movements may take place.

BIS has recommended an upper desirable limit of 1.0 mg/L of F^- as desirable concentration of fluoride in drinking water, which can be extended to 1.5 mg/L of F in case no alternative source of water is available. Water having fluoride concentration of more than 1.5 mg/L are not suitable for drinking purposes.

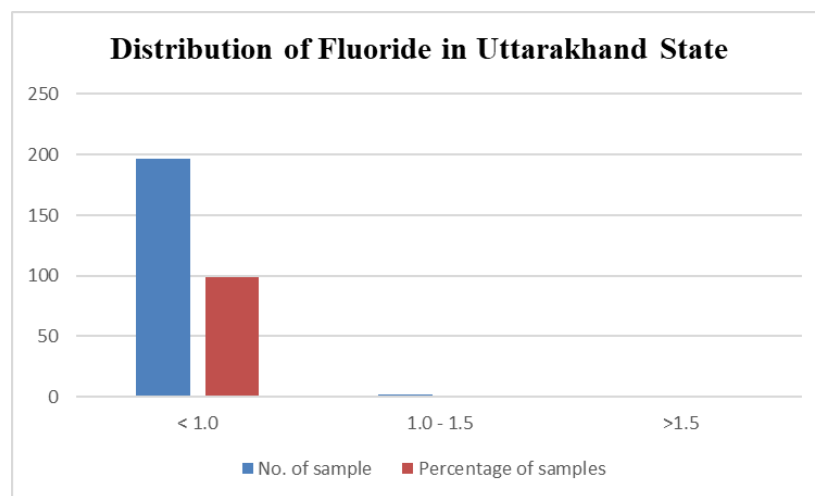


Fig. 8.3: Graph showing distribution of Fluoride in the Uttarakhand State

The fluoride content in groundwater from observation wells in a major part of the state is found to be less than 1.0 mg/L. The distribution of ground water samples with fluoride concentration more than 1 mg/L have been depicted on the map as Fig. 8.4. Only two samples of the state (1% of the total) is showing fluoride concentration in the range of 1-1.5 mg/l. However, only one sample (Gangnani spring of Uttarkashi district) is showing fluoride concentration more than 1.5 mg/l.

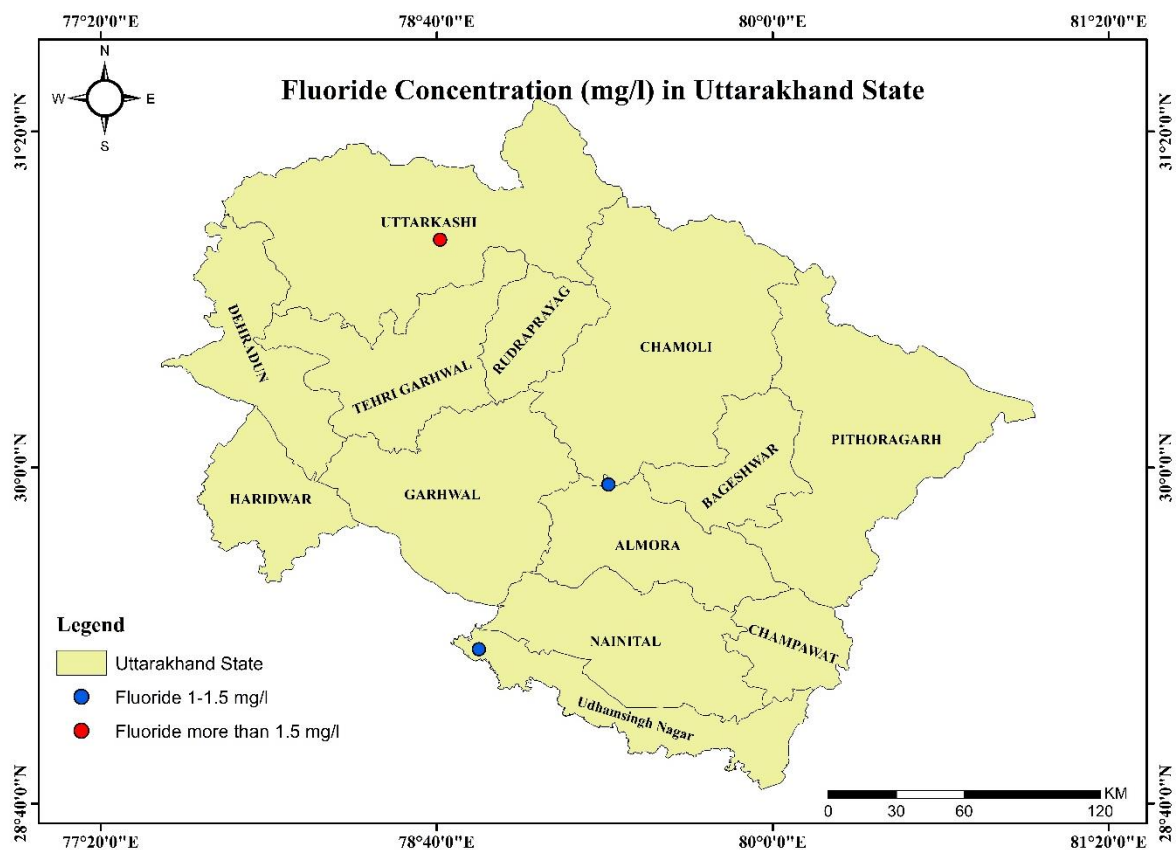


Fig. 8.4: Map showing distribution of Fluoride in the Uttarakhand State

8.2.1 Remedial Measures for Fluoride

The fluoride remedial measures broadly adopted are ex-situ techniques. They can be classified into three major categories.

(a) Adsorption and ion exchange

This technique functions on the adsorption of fluoride ions onto the surface of an active agent such as activated alumina, red mud, bone char, brick pieces column, mud pot and natural adsorbents where fluoride is removed by ion exchange or surface chemical reaction with the solid bed matrix.

Activated alumina: Activated alumina is a highly porous aluminum oxide exhibiting high surface area. Alumina has a high preference for fluoride compared to other anionic species, and hence is an attractive adsorbent. The crystal structure of alumina contains cation lattice discontinuities giving rise to localized areas of positive charge which makes it attract various anionic species. It also does not shrink, swell, soften nor disintegrate when immersed in water. The maximum absorption capacity of activated alumina for fluoride is found to be 3.6 mg F/g of alumina.

Ion-Exchange resins: Synthetic chemicals, namely, anion and cation exchange resins have been used for fluoride removal. Some of these are Polyanion (NCL), Tul-sion A - 27, Deacedite FF (IP), Amberlite IRA 400, LewatitMIH - 59, and AmberliteXE - 75. These resins have been used in chloride and hydroxy form. The fluoride exchange capacity of these resins depends upon the ratio of fluoride to total anions in water.

(b) Coagulation-precipitation

Precipitation methods are based on the addition of chemicals (coagulants and coagulant aids) and the subsequent precipitation of a sparingly soluble fluoride salt as insoluble. Fluoride removal is accomplished with separation of solids from liquid. Aluminium salts (eg. Alum), lime, Poly Aluminium Chloride, Poly Aluminium Hydroxy sulphate and Brushite are some of the frequently used materials in defluorination by precipitation technique. The best example for this technique is the famous Nalgonda technique.

Nalgonda Technique

Nalgonda technique involves addition of Aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. It is opined that this technique is preferable at all levels because of the low price and ease of handling, is highly versatile and can be used in various scales from household level to community scale water supply.

The Nalgonda technique can be used for raw water having fluoride concentration between 1.5 and 20 mg/L and the total dissolved solids should be <1500 mg/L, and total hardness < 600 mg/L. The alkalinity of the water to be treated must be sufficient to ensure complete hydrolysis of alum added to it and to retain a minimum residual alkalinity of 1 - 2 meq/L in the treated water to achieve a pH of 6.5 - 8.5 in treated water. Several researchers have attempted to improve the technique by increasing the removal efficiency of fluoride using Poly Aluminium Chloride (PAC) and Poly Aluminium Hydroxy Sulphate (PAHS).

(c) Membrane techniques

Reverse osmosis, nanofiltration, dialysis and electro dialysis are physical methods that have been tested for defluorination of water. Though they are effective in removing fluoride salts from water, however, there are certain procedural disadvantages that limit their usage on a large scale.

8.3 Nitrate

Nitrate is a naturally occurring compound that is formed in the soil when nitrogen and oxygen combine. The primary source of all nitrates is atmospheric nitrogen gas. This is converted into organic nitrogen by some plants by a process called nitrogen fixation. Dissolved Nitrogen in the form of Nitrate is the most common contaminant of ground water. Nitrate in groundwater generally originates from non-point sources such as leaching of chemical fertilizers & animal manure, groundwater pollution from septic and sewage discharges etc. It is difficult to identify the natural and man-made sources of nitrogen contamination of ground water. Some chemical and micro-biological processes such as nitrification and denitrification also influence the nitrate concentration in ground water.

As per the BIS Standard for drinking water the maximum desirable limit of Nitrate concentration in ground water is 45 mg/L with no relaxation. Though, Nitrate is considered relatively non-toxic, a high nitrate concentration in drinking water is an environmental health concern arising from increased risks of methemoglobinemia particularly to infants. Adults can tolerate little higher concentrations. The specified limits are not to be exceeded in public water supply. If the limit is exceeded, water is considered to be unfit for human consumption.

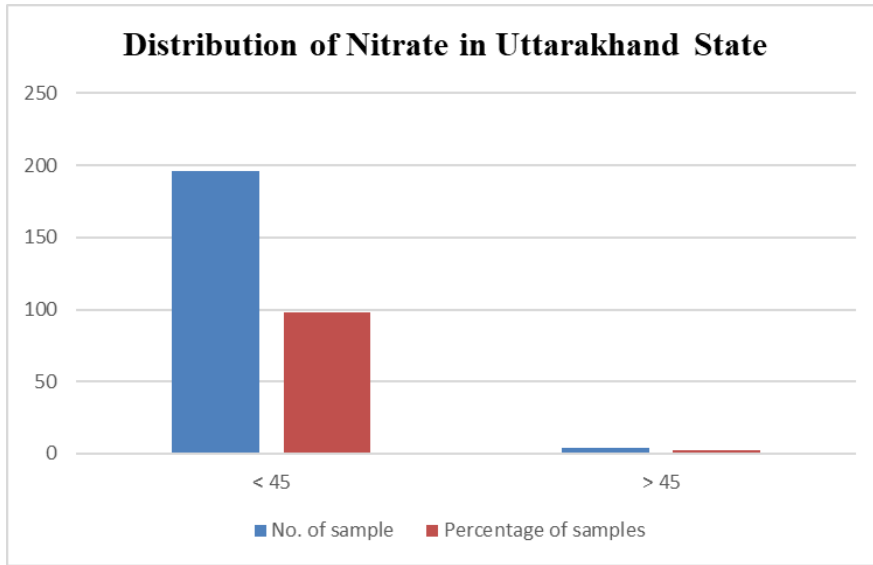


Fig. 8.5: Graph showing distribution of Nitrate in the Ground Water Samples of Uttarakhand State

The occurrences of Nitrate in ground water beyond permissible limit (45 mg /L) have been shown on the map as a point source Fig 8.6. As per the fig. 8.5 and 8.6, only four samples of the state (Dhanpura, Bhikhampur of Haridwar district, Dharanaula spring of Almora district and Dunda of Uttarkashi district) showing nitrate concentration more than 45 mg/l.

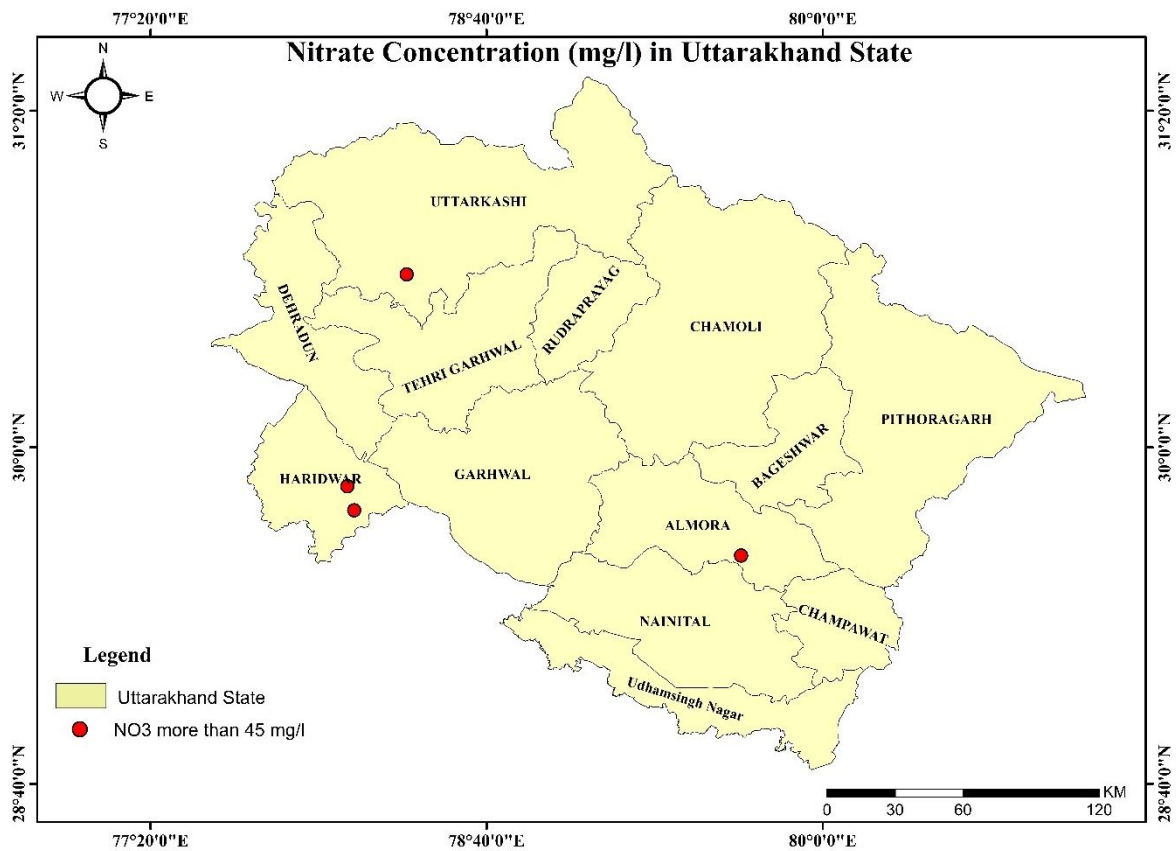


Fig. 8.6: Map showing distribution of Nitrate in the Ground Water Samples of Uttarakhand State

8.3.1 Trend on Nitrate

Trend analysis determines whether the measured values of the water quality variables increase or decrease during a time period. Nitrate is one of the major indicators of anthropogenic sources of pollution. Nitrate is the ultimate oxidized product of all nitrogen containing matter and its occurrence in groundwater can be fairly attributed to infiltration of water through soil containing domestic waste, animal waste, fertilizer and industrial pollution. As the lithogenic sources of nitrogen are very rare, its presence in ground water is almost due to anthropogenic activity. Hence, nitrate was taken to assess the trend of ground water quality in India due to anthropogenic activity.

Maximum Nitrate pollution has been detected as 119 mg/l from Dharanaula spring of Almora District Nitrate above the permissible limit i.e. 45 mg/l have been observed in 03 sample out of 144 (2018), 6 samples out of 189 (2019), 5 sample out of 198 samples (2020), 3 sample our of 206 sample (2021) and 4 samples out of 200 samples analyzed. As per **table-8.0** rising trend in the nitrate concentration is observed from 2018 to 2022. Here in Uttarakhand state, as per the Piper Plot, the dominant facies type in the region is Ca-Mg-HCO₃ type. Generally, the samples collected from the wells of Uttarakhand state is representative of unconfined to semi-confined aquifers. This type of facies is typical of shallow & fresh ground water and indicative of recharge area. This indicate that the nitrate in the Ground Waters of Uttarakhand state may be due to leaching from landfill sites, leakage from sewers, septic tank leakage, fertilizers used in farm field etc.

The nitrate concentration data of Uttarakhand state from 2018 to 2022 is representing an increasing trend with a slope of 0.21 degree. Mainly the wells of Haridwar, Udham Singh Nagar and the springs of Almora (lifeline of hilly region) are showing Nitrate concentration in ground waters exceeding the permissible limit.

TABLE 8.0: Frequency distribution of Nitrate in shallow aquafer in Uttarakhand State (2018-2022)

Year	No. of districts affected by NO ₃	No. of locations affected by NO ₃	Total Number of samples analysed	% samples affected by NO ₃
2018	2	3	144	2.1
2019	2	6	189	3.2
2020	3	5	198	2.5
2021	2	3	206	1.5
2022	3	4	200	2.0

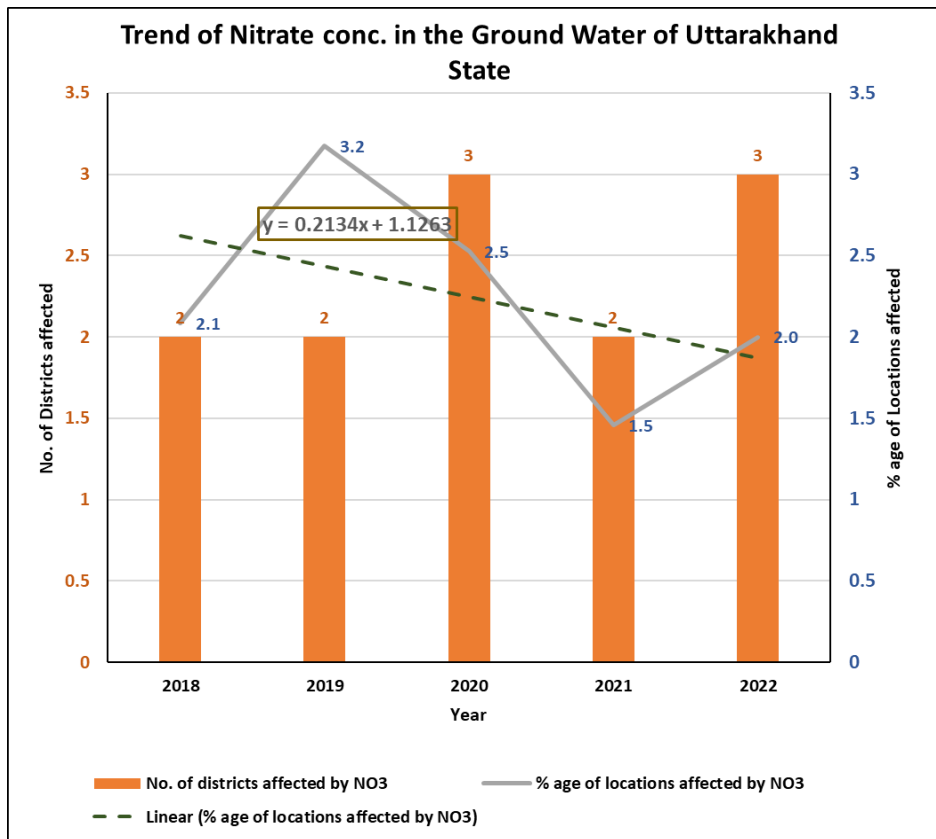


Fig. 8.7: Trend of Nitrate in shallow ground water of Uttarakhand (NHS-2018-2022) Remedial Measures for Nitrate

For removal of nitrate both non-treatment techniques like blending and treatment processes such as ion-exchange, reverse osmosis, biological denitrification and chemical reduction are useful. The most important thing is that neither of these methods is completely effective in removing all the nitrogen from the water.

a) Methods involving no treatment: In order to use any of these options the nitrate problem must be local-scale. Common methods are –

- Raw water source substitution
- Blending with low nitrate waters

This greatly reduces expenses and helps to provide safer drinking water to larger numbers of people.

b) Methods involving Treatment:

They are as follows:

- Adsorption/Ion Exchange
- Reverse Osmosis
- Electrodialysis
- Bio-chemical Denitrification (By using denitrifying bacteria and microbes)
- Catalytic Reduction/Denitrification (using hydrogen gas)

The mechanism of nitrate pollution in subsurface porous unconfined/confined aquifer is governed by complex biogeochemical processes. Apart from recharge conditions, groundwater chemistry may be impacted by the mineral kinetics of water-rock interactions. Consequently, suitable nitrate removal technologies should be selected. Nitrate is a very soluble ion with limited potential for co-precipitation or adsorption. This makes it difficult such as chemical coagulation, lime softening and filtration which are commonly used for removing most of the chemical pollutants such as fluoride, arsenic and heavy metals. According to King et al., 2012 nitrate treatment technologies can be classified in two categories in two categories, i.e. nitrate reduction and nitrate removal options. Nitrate removal technologies involve physical processes that does not necessarily involve any alteration of the chemical state of nitrate ions. Bio-chemical reduction options aim to reduce nitrate ions to other states of nitrogen, e.g. ammonia, or a more innocuous form as nitrogen gas. In-situ bioremediation is also effectively used in used in nitrate treatment of contaminated groundwater. Reverse Osmosis, catalytic reduction and blending are effective methods for nitrate removal from groundwater. For nitrate removal, operating trans-membrane pressure of RO unit generally ranges from 20 to 100 bar.

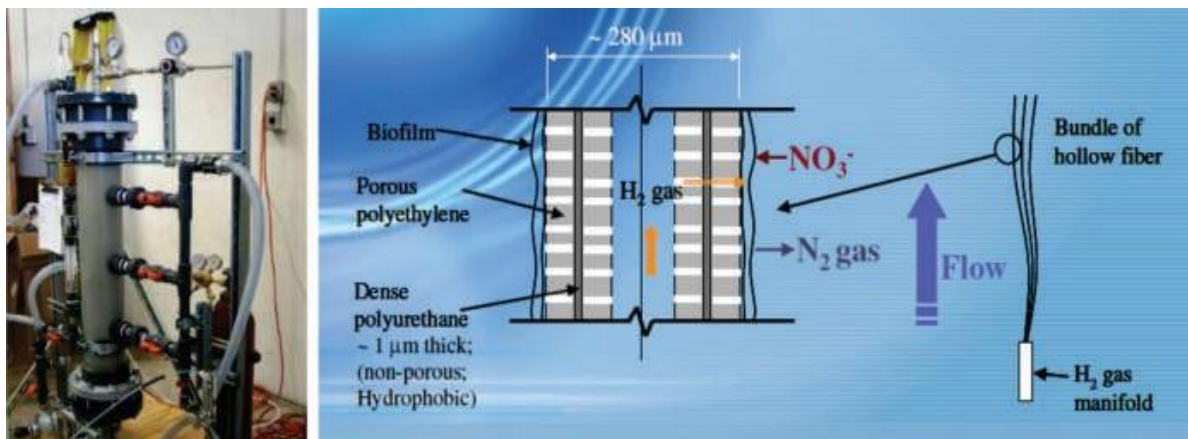


Fig. 8.8: Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

8.4 Iron

Iron is a common constituent in soil and ground water. It is present in water either as soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colourless because the iron is completely dissolved. When exposed to air, the water turns cloudy due to oxidation of ferrous iron into reddish brown ferric oxide.

The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. It is contributed to groundwater mainly from weathering of ferruginous minerals of igneous rocks such as hematite, magnetite and sulphide ores of sedimentary and metamorphic rocks.

The permissible Iron concentration in ground water is 1.0 mg/L as per the BIS Standard for drinking water. The occurrences of iron in ground water beyond permissible limit (> 1.0 mg /liter) have been shown on the maps as point sources (Fig 8.10). It is based on the chemical analysis of water samples mostly collected from the groundwater observation wells/ springs/ hand pumps.

Table 8.1: District-wise distribution of Iron concentration in Ground Water

S.No.	District	No of Samples having Fe>1 mg/l	Total no of samples collected	Percentage of samples affected by Iron
1	Dehradun	15	47	31.91
2	Haridwar	10	42	23.81
3	Pauri Garhwal	1	2	50.00
4	Uttarkashi	5	13	38.46
5	Almora	1	26	3.85
6	Udham Singh Nagar	8	46	17.39
7	Nainital	2	20	10.00
8	Champawat	1	4	25.00

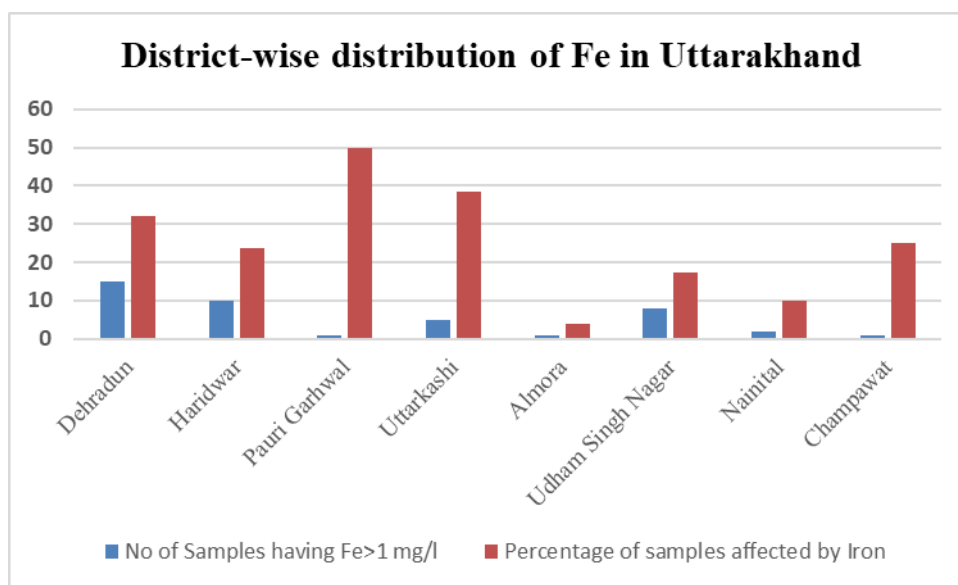


Fig. 8.9: Graph showing District-wise distribution of Iron in the Ground Water Samples of Uttarakhand State

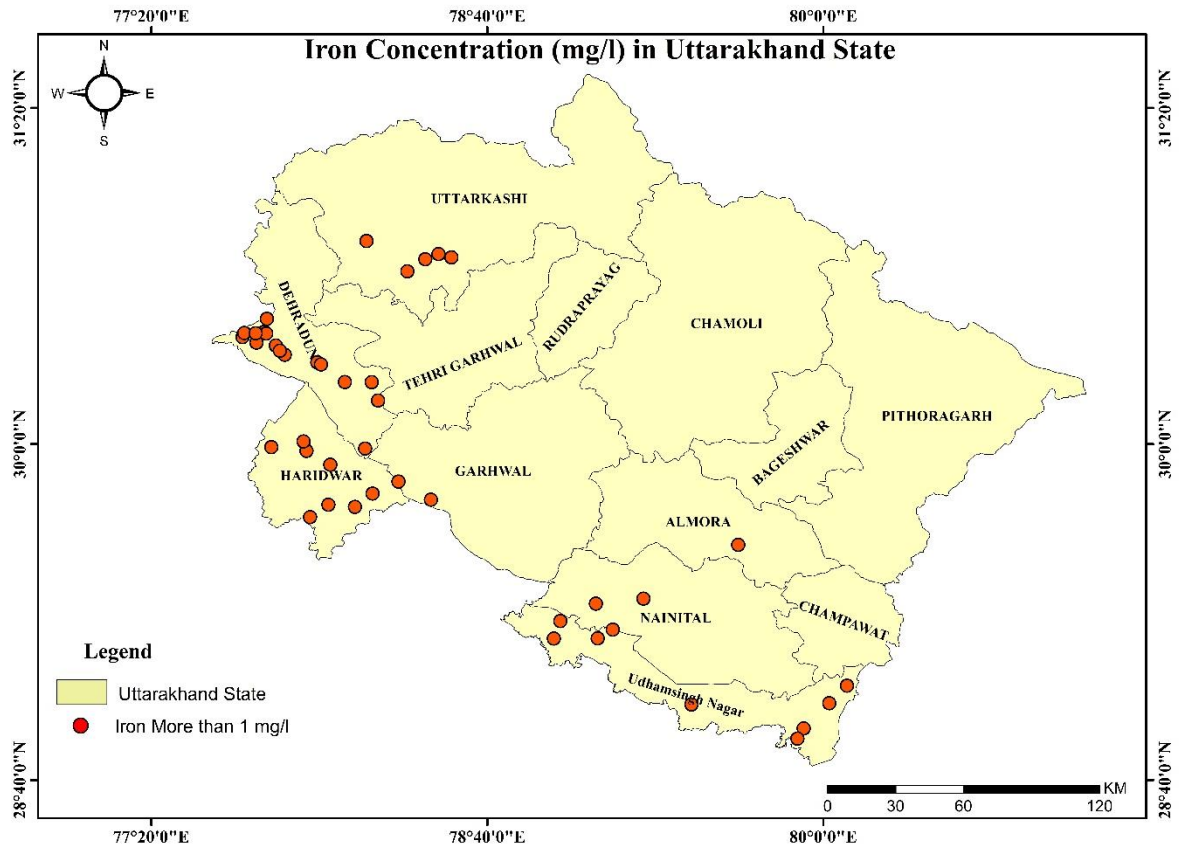


Fig. 8.10: Map showing District-wise distribution of Iron in the Ground Water Samples of Uttarakhand State

8.4.1 Trend on Iron

High Iron >0.3 mg/l mainly attributed due to geogenic and anthropogenic conditions and Fe >0.3 mg/l, have been observed in 38 water samples out of 127 (2019) and 126 sample out of 198 (2020), 121 samples out of 206 (2021) and 43 samples out of 200 (2022) samples analysed. Around 50% of the samples (from 2019 to 2021) is showing higher concentration of iron having trend with a slope of 3.01 degree. This may be due to rusting in the handpumps and poor well assembly. High Fe in shallow ground water of Uttarakhand shown in Chart-5 (NHS-2019-2022).

Table 8.2: Frequency distribution of Iron in shallow aquifer in Uttarakhand State (2019-2022)

Year	No. of districts affected by Fe	No. of locations affected by Fe	Total Number of samples analysed	%age of locations affected by Fe
2019	8	38	127	29.92
2020	6	126	198	63.64
2021	8	121	206	58.74
2022	8	43	200	21.50

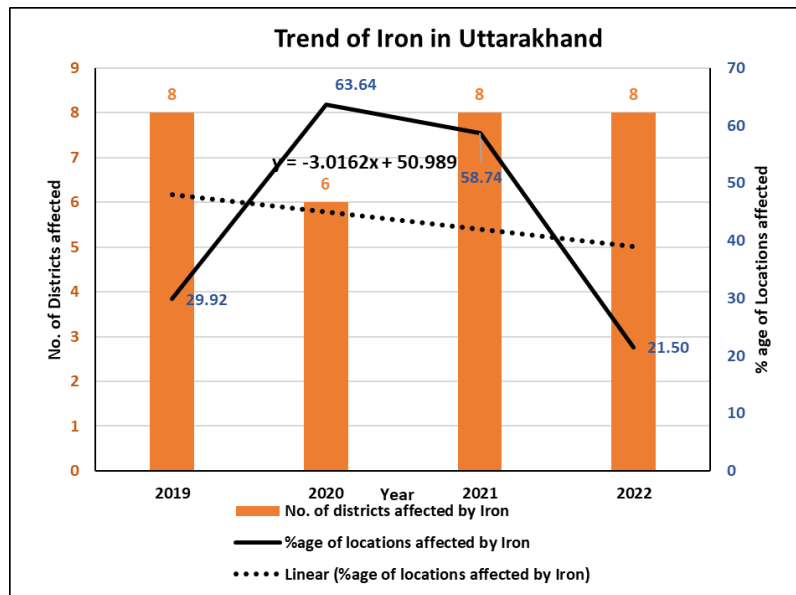


Fig. 8.11: Trend of Iron in shallow ground water of Uttarakhand (NHS2019-2022)

8.4.2 Remedial Measures for Iron/Manganese

a) **Oxidation and filtration:** Before iron and manganese can be filtered, they need to be oxidized to a state in which they can form insoluble complexes. Ferrous iron (Fe^{2+}) is oxidized to ferric iron (Fe^{3+}), which readily forms the insoluble iron hydroxide complex $\text{Fe}(\text{OH})_3$. Manganese (Mn^{2+}) is oxidized to (Mn^{4+}), which forms insoluble (MnO_2). The common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate and ozone. The dose of potassium permanganate, however, must be carefully controlled. Too little permanganate will not oxidize all the iron and manganese, and too much will allow permanganate to enter the distribution system and cause a pink color.

Ozone may be used for iron and manganese oxidation. Ozone may not be effective for oxidation in the presence of humic or fulvic materials. If not dosed carefully, ozone can oxidize reduced manganese to permanganate and result in pink water formation as well. Manganese dioxide particles, also formed by oxidation of reduced manganese, must be carefully coagulated to ensure their removal. A low-cost method of providing oxidation is to use the oxygen in air as the oxidizing agent. Water is simply passed down a series of porous trays to provide contact between air and water. No chemical dosing is required. This method is not effective for water in which the iron is complexed with humic materials or other large organic molecules.

Oxidation and Filtration Method for Fe and Mn Removal from Ground Water In general, manganese oxidation is more difficult than iron because the reaction rate is slower. A longer detention time (10 to 30 minutes) following chemical addition is needed prior to filtration to allow the reaction to take place. Manganese greensand is by far the most common medium in use for removal of iron and manganese through pressure filtration. Greensand is a processed material consisting of nodular grains of the zeolite mineral glauconite. The material is coated with manganese oxide. The ion exchange properties of the glauconite facilitates the bonding of the coating. This treatment gives the media a catalytic effect in the chemical oxidation reduction reactions necessary for iron and manganese removal. This coating is maintained through either continuous or intermittent feed of potassium permanganate.

Anthra/sand (also iron-man sand) are other types of media available for removal of iron and manganese. They consist of select anthracite and sand with a chemically bonded manganese oxide coating.

Electromedia is a proprietary multi-media formulation which uses a naturally occurring zeolite and does not require potassium permanganate regeneration. Finally, macrolite, is a manufactured ceramic material with a spherical shape and a rough, textured surface. The principal removal mechanism is physical straining rather than contact oxidation or adsorption. Each medium has its advantages and disadvantages. Selection of a medium and oxidant should be based on pilot testing in which all necessary design criteria can be determined.

b) Ion Exchange Ion exchange should be considered only for the removal of small quantities of iron and manganese because there is a risk of rapid clogging. Ion exchange involves the use of synthetic resins where a pre-saturate ion on the solid phase (the “adsorbent,” usually sodium) is exchanged for the unwanted ions in water. One of the major difficulties in using this method for controlling iron and manganese is that if any oxidation occurs during the process, the resulting precipitate can coat and foul the media. Cleaning would then be required using acid or sodium bisulphate.

c) Combined Photo-Electrochemical (CPE) Method Different processes, such as electrochemical (EC), photo (UV), and combined photo-electrochemical (CPE) methods are used. A cell containing aluminium electrode as anode, graphite electrode as cathode and UV lamp are used and filled with waste water enriched with iron and manganese as an electrolytic solution. A limited quantity of sodium chloride salt is added to enhance the electric conductivity through the solution. A comparison between different methods was undertaken to evaluate the applied conditions and the efficiency of Fe and Mn removal at different times and initial concentrations. The results revealed that CPE method was the best choice for the simultaneous removal of both iron and manganese in a short time < 10 min.

d) Sequestration is the addition of chemicals to groundwater aimed at controlling problems caused by iron and manganese without removing them. These chemicals are added to groundwater at the well head or at the pump intake before the water has a chance to come in contact with air or chlorine. If the water contains less than 1.0 mg/L iron and less than 0.3 mg/L manganese, using polyphosphates followed by chlorination can be an effective and inexpensive method for mitigating iron and manganese problems. No sludge is generated in this method. Below these concentrations, the polyphosphates combine with the iron and manganese preventing them from being oxidized. Any of the three polyphosphates (pyrophosphate, tripolyphosphate, or metaphosphate) can be used. Applying sodium silicate and chlorine simultaneously has also been used to sequester iron and manganese. However, while this technique is reliable in the case of iron treatment, it has not been found to be effective in manganese control.

8.5 Arsenic

Arsenic is a naturally occurring trace element found in rocks, soils and the water in contact with them. Arsenic has been recognized as a toxic element and is considered a human health hazard. The occurrence of Arsenic in ground water was first reported in 1980 in West Bengal in India.

The map showing distribution of Arsenic in ground water of India (Fig 8.13) has been generated from the data on arsenic concentration in water samples mostly collected from the groundwater observation wells/ hand pumps, Arsenic contaminated areas have been shown as points based on findings of Central Ground Water Board.

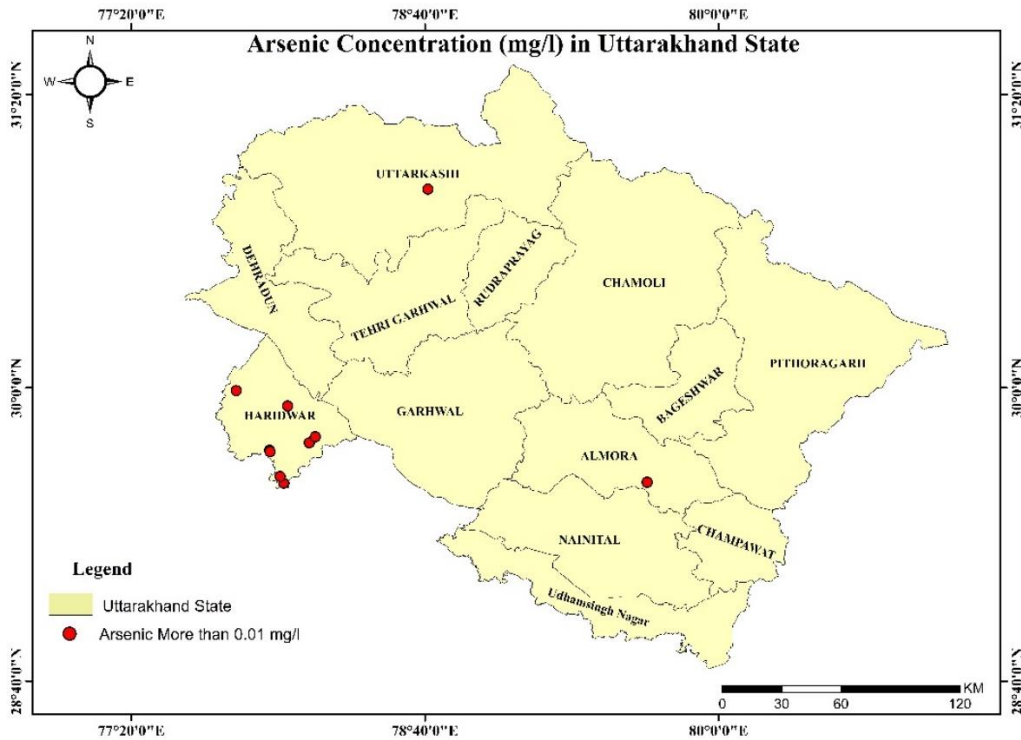


Fig. 8.12: Map showing District-wise distribution of Arsenic in the Ground Water Samples of Uttarakhand State

Table 8.3 : Locations having Arsenic >0.01 in Ground Water in Different districts of Uttarakhand

S.No.	District	Block	Locations having As>0.01 mg/l
1	Uttarkashi	Bhatwari	Ganganani Hotspring
2	Almora	Hawalbagh	DharaNaula Spring
3	Haridwar	Khanpur	Dallawala
4	Haridwar	Bhagwanpur	Bahabalpur
5	Haridwar	Bahadrabad	Bahadrabad
6	Haridwar	Roorkee	Mohammadpur
7	Haridwar	Laksar	Bhikampur
8	Haridwar	Khanpur	Khanpur
9	Haridwar	Bahadrabad	Bhogpur
10	Haridwar	Khanpur	Govardhanpur

8.5.1 Trend on Arsenic:

High Arsenic >0.01 mg/l mainly attributed due to geogenic and anthropogenic conditions and As>0.01 mg/l, have been observed in 13 water samples out of 189 (2019) and 06 sample out of 198 (2020), 09 samples of 206 (2021) and 10 samples out of 200 (2022) samples analyzed.

TABLE 8.4: Frequency distribution of Arsenic in shallow aquafer in Uttarakhand State (2019-2022)

Year	No. of districts affected by As	No. of locations affected by As	Total Number of samples analysed	%age of locations affected by As
2019	4	13	189	6.88

2020	2	06	198	3.03
2021	4	10	206	4.85
2022	3	10	200	5.00

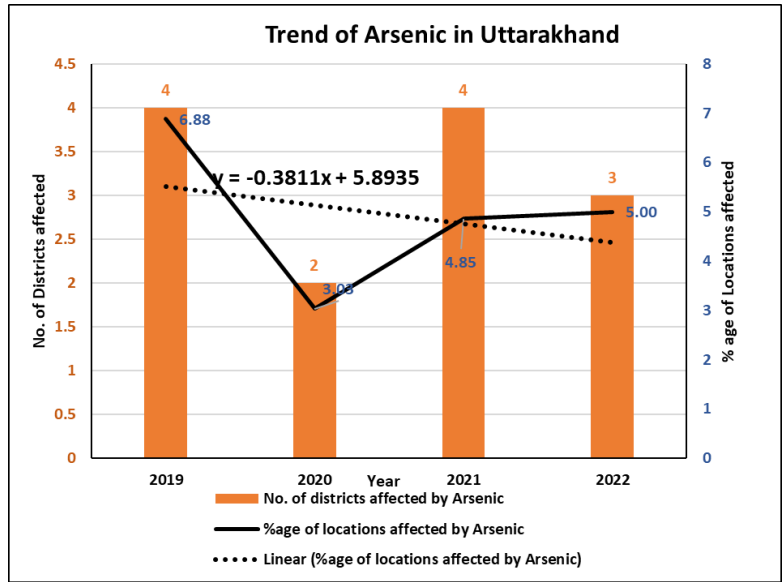


Fig. 8.13: Trend of Arsenic in shallow ground water of Uttarakhand (NHS2019-2022)

8.5.2 Remedial Measures for Arsenic

a) **Precipitation processes-** includes coagulation/filtration, direct filtration, coagulation assisted microfiltration, enhanced coagulation, lime softening, and enhanced lime softening. Adsorption co-precipitation with hydrolysing metals such as Al^{3+} and Fe^{3+} is the most common treatment technique for removing arsenic from water. Sedimentation followed by rapid sand filtration or direct filtration or microfiltration is used to remove the precipitate. Coagulation with iron and aluminium salts and lime softening is the most effective treatment process. To improve efficiency of this method, a priori oxidation of As (III) to As (V) is advisable. Hypochlorite and permanganate are commonly used for the oxidation. Atmospheric oxygen can also be used, but the reaction is very slow. The major techniques based on this process include; Bucket treatment unit, Fill and draw treatment unit, Tubewell-attached arsenic treatment unit and Iron arsenic treatment unit.

b) **Adsorptive processes-** Adsorption on to activated alumina, activated carbon and iron/ manganese oxide based or coated filter media. Adsorptive processes involve the passage of water through a contact bed where arsenic is removed by surface chemical reactions. The activated alumina-based sorptive media are being used in Bangladesh and India. No chemicals are added during treatment and the process relies mainly on the active surface of the media for adsorption. Granular ferric hydroxide is a highly effective adsorbent used for the adsorptive removal of arsenate, arsenite, and phosphorous from natural water. In the Sono 3-Kolshi filter, used in Bangladesh and India zero valent iron fillings, sand, brick chips and wood coke are used as adsorbent to remove arsenic and other trace elements from groundwater.

c) **Ion-exchange processes-**This is similar to that of activated alumina, however, in this method the medium is synthetic resin of relatively well-defined ion exchange capacity. In these processes, ions held electrostatically on the surface of a solid phase are exchanged for ions of similar charge dissolved in

water. Usually, a synthetic anion exchange resin is used as a solid. Ion exchange removes only negatively charged As (V) species. If As (III) is present, it is necessary to oxidise it.

d) Membrane processes- This includes nano-filtration, ultrafiltration, reverse osmosis and electro dialysis in which synthetic membranes are used for removal of many contaminants including arsenic. They remove arsenic through filtration, electric repulsion, and adsorption of arsenic-bearing compounds.

e) Arsenic safe alternate aquifers-This technique advocates tapping of safe alternate aquifers right within the affected areas. In India except at Rajnandgaon in Chhattisgarh state, the vast affected areas in the Gangetic Plains covering Bihar and Uttar Pradesh as well as Deltaic Plains in West Bengal is marked by multiaquifer system. The sedimentary sequence is made up Quaternary deposits, where the aquifers made up of unconsolidated sands which are separated by clay/sandy clay, making the deeper aquifer/aquifers semi-confined to confined. The contamination is confined in the upper slice of the sediments, within 80 m and affecting the shallow aquifer system. At places, like Maldah district of West Bengal single aquifer exists till the bed rock is encountered at 70-120 m bgl.

Detailed CGWB exploration, isotope and hydro-chemical modelling carried out by CGWB along with other agencies like BARC has indicated that the deep aquifers (>100 m bgl) underneath the contaminated shallow aquifer, have been normally found as arsenic free. Long duration pumping tests and isotopic studies in West Bengal and Bihar have indicated that there is limited hydraulic connection between the contaminated shallow and contamination free deep aquifers and the ground water belong to different age groups having different recharge mechanisms. The deep aquifers in West Bengal, Bihar and Uttar Pradesh have the potential to be used for community-based water supply.

8.6 Total Hardness as CaCO₃

Total hardness is predominantly caused by cations such as calcium and magnesium and anion such as bicarbonate and sulphate. Total hardness is defined as the sum of calcium and magnesium both expressed as CaCO₃ in mg/L. Hardness represents the soap-consuming capacity of water. Species that form insoluble compounds with soap Ca, Mg, Organic compounds etc. Total hardness is sum of Ca and Mg and expresses as CaCO₃ mg/l. EDTA titration. The two kinds of hardness observed in water.

- Temporary hardness is due to Carbonate.
- Permanent hardness is due to Sulphate, Chloride or Nitrate.

The hardness in water is derived largely from contact with the soil and rock formations. Rain water as it falls upon the earth is in capable of dissolving the tremendous amount of solids found in many natural waters. People with kidney and bladder stones should avoid high content of calcium and magnesium in water (K. R. Karanth, 1997). The BIS permissible limit of hardness is 300 – 600 mg/L.

Table 8.5: Number of location having total hardness > 600 mg/L in Uttarakhand State

S. No.	District	No. of locations having TH> 600 mg/L
1	Haridwar	1 (Iqbalpur, TH=695 mg/l)

8.6.1 Removal of total hardness

A few methods to remove hardness from water are,

- Chemical Process of Boiling Hard Water.

- Adding Slaked Lime (Clark's Process)
- Adding Washing Soda.
- Calgon Process.
- Ion Exchange Process.
- Using Ion Exchange Resins.

CARBONATE (TEMPORARY) HARDNESS also known as Ca Bicarbonate

Ca(HCO₃)₂ + Mg Bicarbonate Mg(HCO₃)₂. Removal by Boiling or adding Lime

NON-CARBONATE (PERMANENT) HARDNESS

Calcium Sulfate CaSO₄ + Magnesium Sulfate MgSO₄ & Calcium Chloride CaCl₂ + Magnesium Chloride MgCl₂

Removal by Lime-soda, Zeolite or Demineralization Processes

9.0 SUITABILITY OF GROUNDWATER FOR IRRIGATION PURPOSE

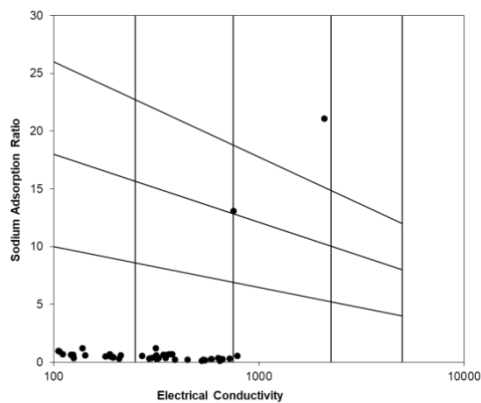
The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation purposes. Plants grown by irrigation absorb and transpire the water but leave nearly all the salts behind in the soil, where they accumulate and eventually prevent plant growth. Excessive concentrations of solute interfere with the osmotic process by which plant root membranes are able to assimilate water and nutrients. CaCO_3 has low solubility, it may precipitate harmlessly but the bulk of residual solutes present a disposal problem that must be solved effectively to maintain productivity of the irrigated soil. In areas where natural drainage is inadequate, the irrigation water infiltrating the root zone will cause water table to rise excessively.

The crop productivity depends on the quality of the water used for irrigation. Water suitability for irrigation needs to be evaluated on the basis of hazards it can create in the soil, affecting yield & quality of crops.

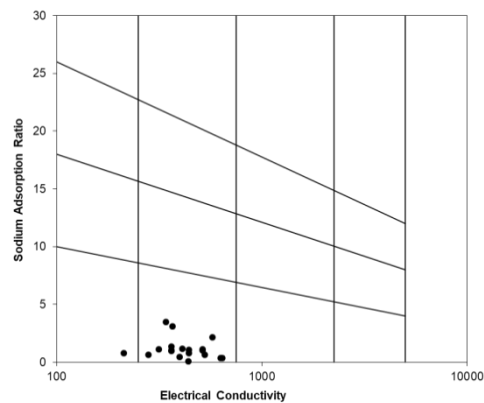
In addition to problems caused by excessive concentration of dissolved solids (TDS), certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations viz. Residual Sodium Carbonate (RSC). The potential hazards to crop growth are salinity, sodicity, alkalinity & toxicity.

9.1 ELECTRICAL CONDUCTANCE

The Electrical Conductivity is a reflection of the concentration of various chemical constituents in ground water and gives the overall quality of ground water for its various uses like irrigation.



Dehradun district



Nainital district

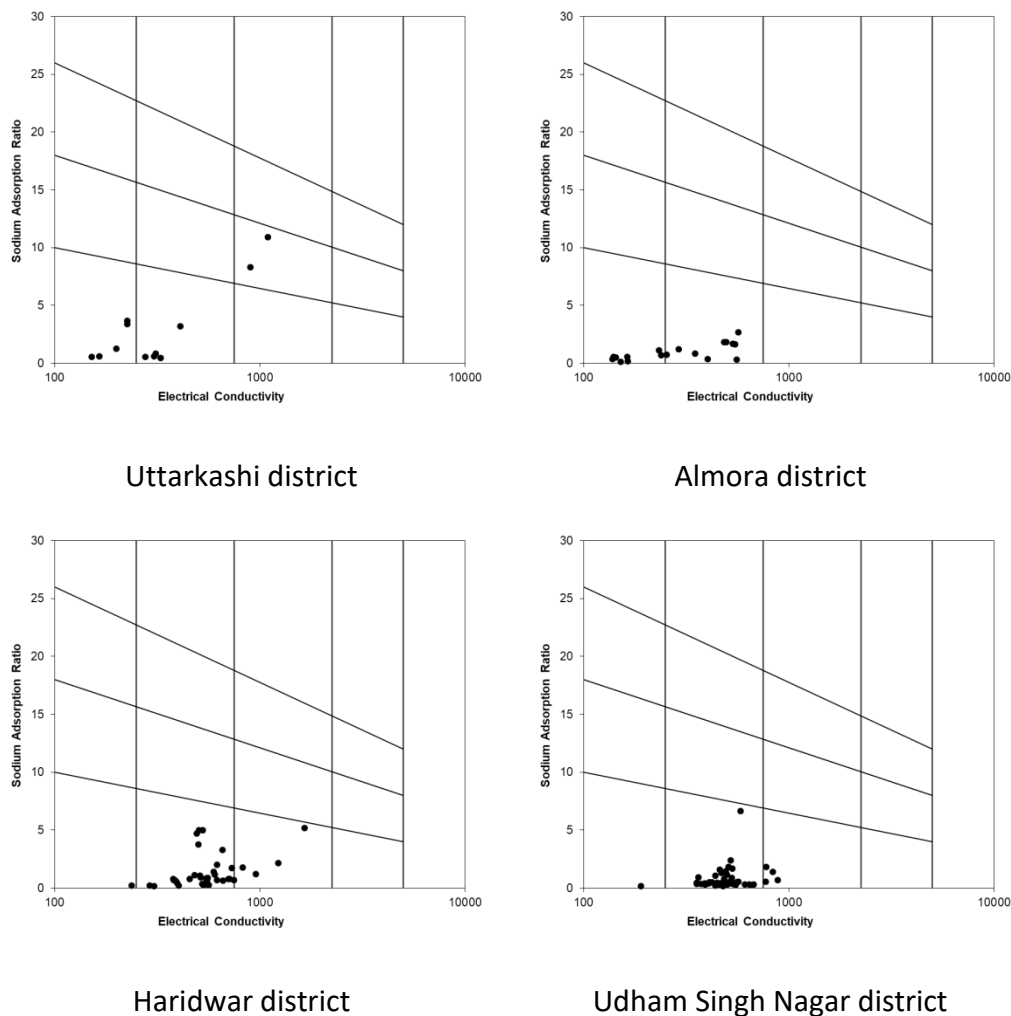


Fig 9.1: U S Salinity Diagram for the NHS pre monsoon-2022 samples of Uttarakhand state

Table 9.0: Characterization of groundwater of Uttarakhand State on the basis of U S Salinity diagram

Sl. No.	Subdivision of the diagram	Percentage of samples in this category	Districts	Interpretation
1	C1S1	16	Almora (40%), Uttarkashi (38%), Dehradun (35%)	Low salinity and Low Sodium hazard
2	C2S1	69	Dehradun (58%), Uttarkashi (46%), Almora (60%), Udaham Singh Nagar (89%),	Medium Salinity and Low Sodium hazard

			Nainital (94%), Haridwar (87%)	
3	C3S1	5	Haridwar (11%), Dehradun (2%), Udham Singh Nagar (8%)	High Salinity and Low Sodium Hazard
4	C3S2	1	Uttarkashi (15%)	High Salinity and Medium Sodium hazard

As per the U S salinity diagram, major ground water samples of Uttarakhand state i.e. Dehradun, Uttarkashi, Almora, Udham Singh Nagar districts is falling in the C2S1 region which indicates its suitability for irrigation purposes on all types of soils. Groundwater in some parts of Almora, Uttarkashi and Dehradun districts fall in C1S1 types i.e. medium salinity and low sodium hazard. Groundwaters that fall within the C1-S1 and C2-S1 region can be used for irrigation on all types of soil with little danger of the development of harmful levels of exchangeable sodium. However, C3-S1 water types of high salinity and low sodium content occurred in few parts of Haridwar, Dehradun and Udham Singh Nagar districts and this water could only be used to irrigate certain semi-tolerant crops.

9.2 Alkalinity Hazard or Residual Sodium Carbonate (RSC):

When carbonate or bicarbonate concentration in irrigation water is relatively higher than the alkaline earth metals, there is tendency for calcium and magnesium ions to precipitate as carbonates in the soil, thereby reducing the level of calcium and magnesium ions and increasing the relative levels of sodium in the soil. The highly soluble sodium carbonate (black alkali) known as residual sodium carbonate (RSC) is defined as

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

Where concentrations are expressed in meq/l.

On computation of chemical analysis shows that the Residual Sodium Carbonate value are less than 1.25 in nearly 93.5% samples.

Table 9.1: RSC range in the groundwater samples of Uttarakhand

RSC RANGE (meq/l)	NO OF SAMPLES	PERCENTAGE
<1.25	187	93.50
1.25-2.5	10	5.00
>2.5	3	1.50

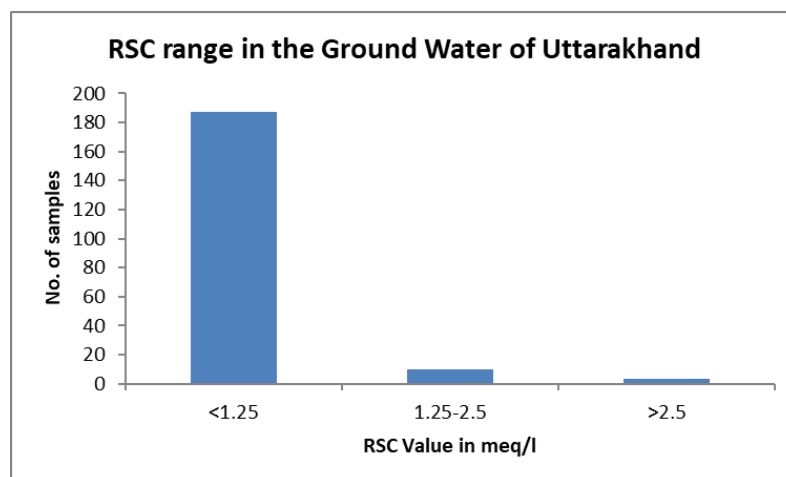


Fig 9.2: RSC range in Ground Water Samples of Uttarakhand

9.3 SOLUBLE SODIUM PERCENTAGE (Na%):

According to Nagarju et al., the percentage of soluble sodium is an important parameter in classifying irrigation water in terms of soil permeability.

Soluble sodium percentage (SSP) can be calculated by employing the equation given by Todd. The ionic concentration was presented in meq L⁻¹:

$$SSP = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100.$$

Sodium ion present in irrigation water tends to be exchanged by Mg²⁺ and Ca²⁺ ions present in clay particles. This exchange process reduces the permeability of soil and causes poor internal drainage and hardening of soil, which further adversely affects the soil quality and seedling emergence. Additionally, high levels of sodium encourage combination of sodium with chloride and carbonates generating salinity and alkalinity in soils. Excessive soil salinity and alkalinity are harmful for plant growth and crop productivity.

The classification of irrigation water based on soluble sodium percentage (SSP) is given by Todd. He classified the irrigation water quality into 5 categories (excellent, good, permissible, doubtful, and unsuitable).

In the present study, the soluble sodium percentage varied from 0.3 to 78% with an average of 16.41%, which suggested that all the groundwater samples had excellent to good quality for irrigation purpose.

Table 9.2: Na% range in the groundwater samples of Uttarakhand

% Na RANGE	NO OF SAMPLES	PERCENTAGE
<20	139	69.5
20-40	45	22.5
>40-60	10	5
>60-80	6	3
>80	0	0

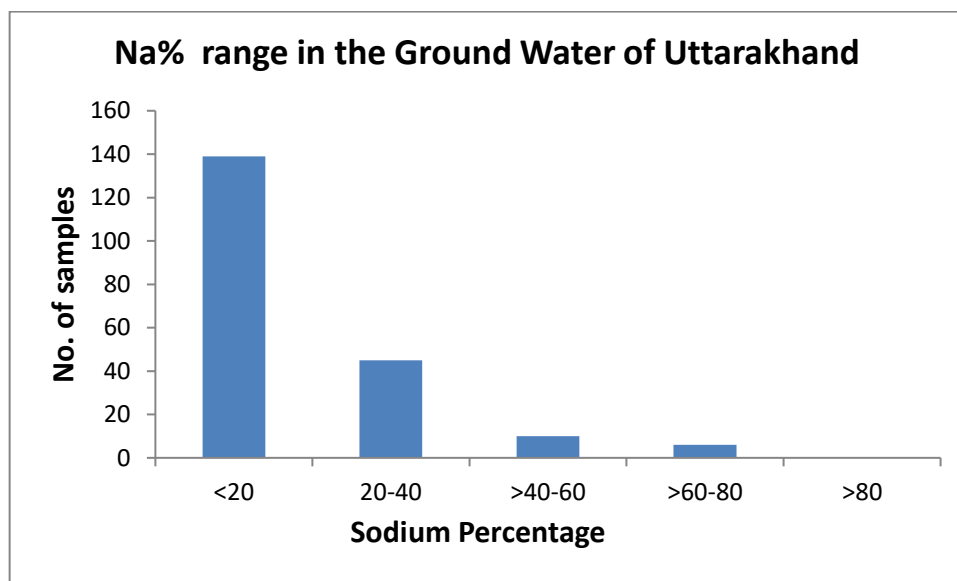


Fig 9.3: Na% range in Ground Water Samples of Uttarakhand

9.4 SODIUM ABSORPTION RATIO (SAR):

According to Gholami and Srikantaswamy, the alkali or sodium hazard can be expressed in terms of sodium adsorption ratio. Sodium hazard is the main parameter for assessment of groundwater suitability for irrigation purpose. Sodium-enriched groundwater is unsuitable for irrigation of agricultural lands. Biswas et al. reported that excess sodium in water produces undesirable effect of changing soil permeability and water infiltration due to breakdown in the physical structure of the soil.

SAR can be calculated using the given equation. Concentration of the ions was expressed in meq L⁻¹.

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

The SAR values ranging from 0 to 10 is measured as excellent, 10–18 is measured as good, and values greater than 18 is measured as unsuitable for irrigation purpose.

In the present study, the SAR values ranged between 0 and 6.9 with an average value of 0.63 and, thus, the ground water of Uttarakhand state belonged to an excellent category for irrigation purpose.

Table 9.3: SAR range in the groundwater samples of Uttarakhand

SAR RANGE (meq/l)	NO OF SAMPLES	PERCENTAGE
0-10	200	100
>10-18	0	0
>18-26	0	0
>26	0	0

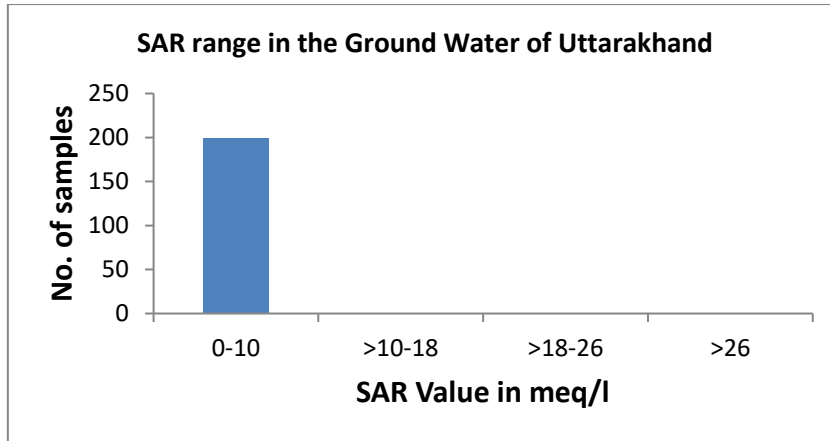


Fig 9.4: SAR range in Ground Water Samples of Uttarakhand

10.0 Piper Diagram

Piper diagram (Piper 1944) describes the process responsible for the evolution of hydrogeochemical parameter in groundwater. Based on the major cation and major anion content in the water samples and plotting them in the trilinear diagram, hydrochemical facies could be identified. Hydro-chemical facies are very useful in investigating diagnostic chemical character of water in hydrologic systems. Different types of facies within the same group formations are due to characteristic ground water flow through the aquifer system and effect of local recharge. The types of facies are inter-linked with the geology of the area and distribution of facies with the hydrogeological controls. Hydrochemical facies are delineated by plotting percentage reacting value of major ions on tri-linear diagrams know as Piper Diagram. In India, cation chemistry is dominated by calcium is followed by sodium and Potassium. In anion side bicarbonate is dominating anion followed by chloride and sulphate.

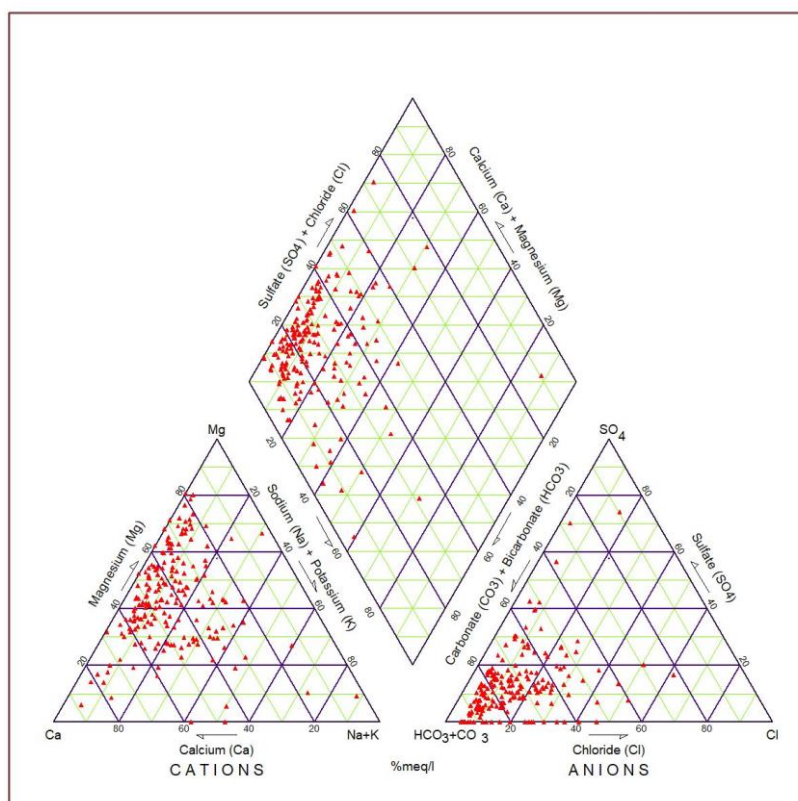


Fig. 10.1: Piper Diagram showing General Chemical Quality of Uttarakhand State

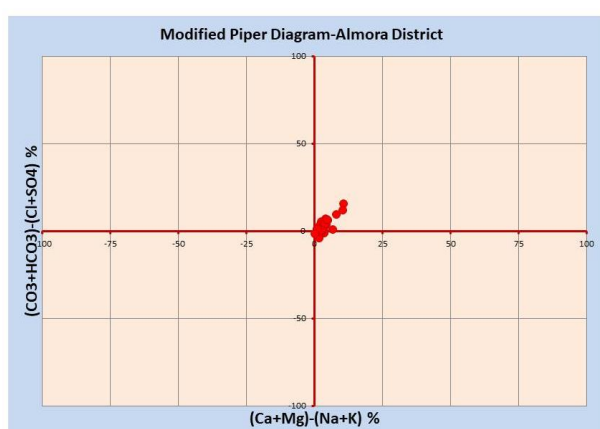
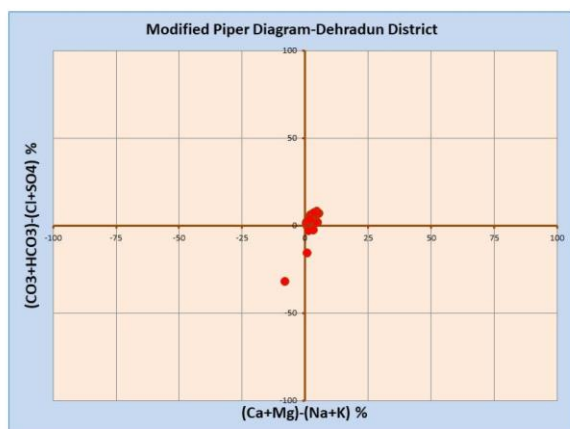
Chemical data of representative samples from the NHS samples of Uttarakhand State presented by plotting them on a Piper-tri-linear diagram for pre-monsoon. These diagrams reveal the analogies, dissimilarities and different types of water in the state, which are identified and listed in Table No. 10.1

Table 10.0: Characterization of groundwater of Uttarakhand State on the basis of Piper-Trilinear diagram

Subdivision of the diamond	Characteristics of corresponding subdivisions of diamond-shaped fields	Percentage of samples in this category
1	Alkaline earth (Ca+Mg) exceeds Alkalies(Na+K)	97.5
2	Alkalies exceeds alkaline earths	2.5
3	Weak acids (CO ₃ +HCO ₃) exceed strong acids (SO ₄ +Cl)	93.5
4	Strong acids exceed weak acids	6.5
5	Magnesium bicarbonate type	92
6	Calcium chloride type	1
7	Sodium chloride type	0.5
8	Sodium bicarbonate type	0.5
9	Mixed type (No cation-anion exceed 50%)	6

From the above table, it can be easily inferred that the groundwater of Uttarakhand state is dominated by Ca-Mg cations and CO₃-HCO₃ anions.

10.1 Modified-Piper Diagram (Chadha's Diagram)



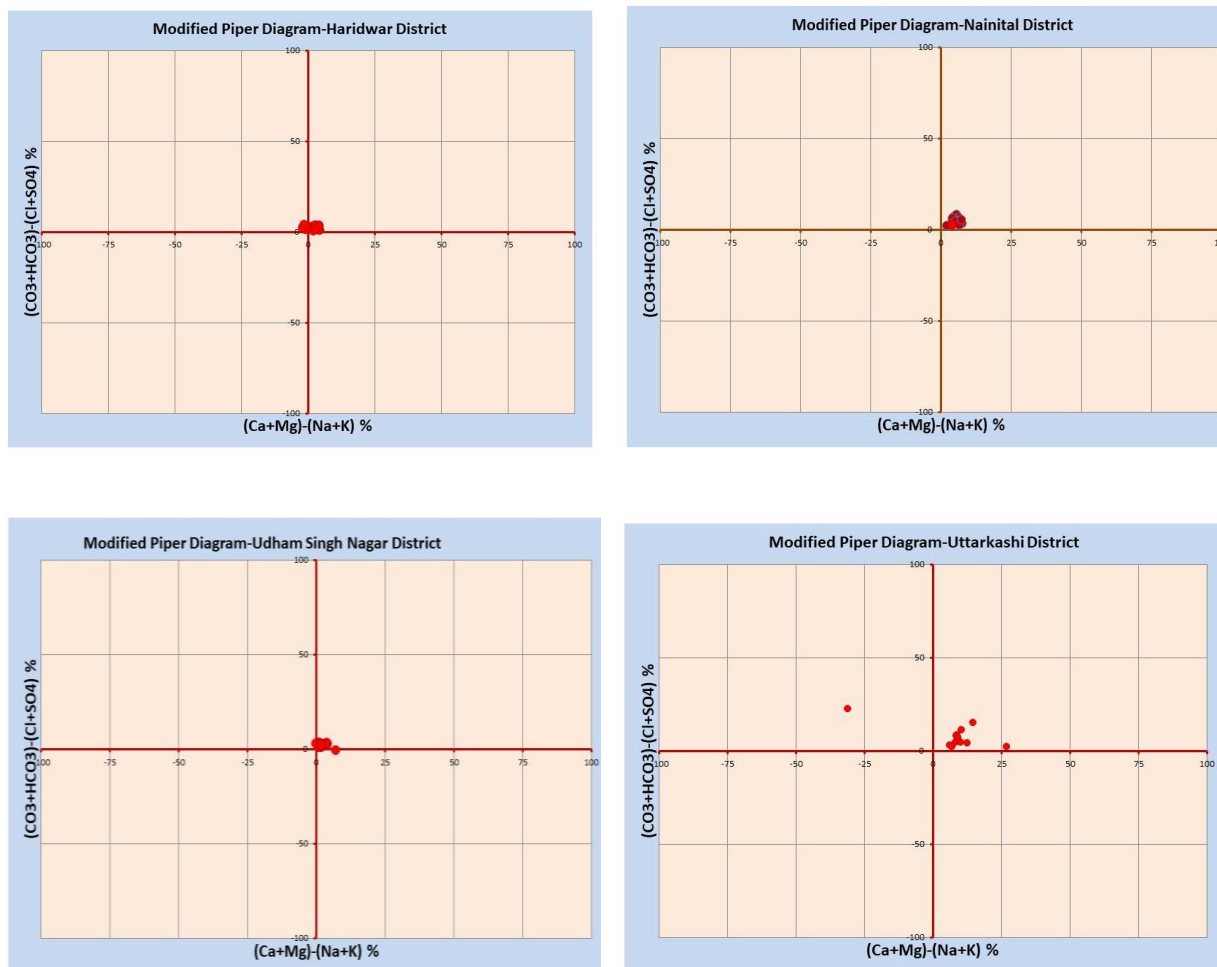


Fig 10.2: Modified Piper Diagram (Chadha's Diagram) showing general chemical quality of Uttarakhand State

The square or rectangular field in the above diagram describes the overall character of the water. The proposed diagram has all the advantages of the diamond-shaped field of the Piper diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end-product water), and other related hydrochemical problems.

In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type. From the analysis of Modified Piper Diagram, it can be inferred that the majority of the samples of Uttarakhand state is of **Alkaline earths exceed alkali metals and Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively**. Such water has temporary hardness. The positions of data points in the above diagrams represent $Ca^{2+}-Mg^{2+}-HCO_3^-$ type, $Ca^{2+}-Mg^{2+}$ -dominant HCO_3^- type, or HCO_3^- dominant $Ca^{2+}-Mg^{2+}$ -type waters.

11.0 Groundwater Quality of Deeper Aquifers of Uttarakhand

The chemical composition of ground water is derived from different sources and the relationship of ground water composition to source rock type is well known. Human activities may modify water composition extensively through direct effects of pollution and indirect results of ground water development. Chemical quality of ground water occurring in shallow and deeper aquifers are varying in concentration but limited to permissible limit except few parameters such as nitrate which significantly changed from beyond the permissible limit at shallow aquifer but goes down to acceptable limit at deeper aquifer (Table-29). The water, in general, is potable and slightly alkaline. To study the chemical quality of deeper aquifer, 17 groundwater samples (Table-30) were collected from exploratory wells and analyzed them for major ions and trace elements.

The range of chemical quality parameters are given in Table-30. The chemical parameter wise suitability of ground water for drinking purpose as per IS 10500:2012 is given below. The suitability of groundwater of the area for drinking purposes has been assessed as per the guide line laid down by Indian Standard Drinking Water Specification (BIS, 2012), which assure, in general, the protection of human health. Accordingly, the concentration of various major and trace elements in the groundwater samples of the study area are compared with the drinking water standard of Indian Standard Drinking Water Specification (BIS, 2012) as summarized in Table- 11.1.

Table 11.0 Chemical Constituents of Deeper Aquifer

S. No	Chemical Constituent	Range (mg/l) of Deeper Aquifer	Drinking Water Standard (BIS, 2012)	
			Acceptable Limit	Permissible Limit
1	pH	6.52 – 8.31	6.5 - 8.5	No relaxation
2	EC ($\mu\text{S}/\text{cm}$ at 25 ^o C)	245-916	750	3000
3	Calcium (mg/l)	22-85	75	200
4	Magnesium (mg/l)	9-55	30	100
5	Fluoride (mg/l)	0-0.15	1.0	1.5
6	Nitrate (mg/l)	1.65-7.32	45	No relaxation
7	Chloride (mg/l)	4-20	250	1000
8	TH as CaCO ₃ (mg/l)	119-434	300	600
9	Copper (mg/l)	BDL	0.05	1.5
11	Zinc (mg/l)	BDL	5	15
12	Iron (mg/l)	BDL	0.30	1.00
13	Manganese (mg/l)	BDL	0.1	0.3
14	Chromium (mg/l)	BDL	0.05	No relaxation
15	Arsenic (mg/l)	BDL	0.01	0.05

Table-29 shows that all the chemical constituents/parameters of ground water samples collected from deeper aquifer are well within the permissible limit and their concentrations significantly reduced with respect to the shallow aquifer e.g., in shallow aquifer the maximum values of electrical conductivity and nitrate are 2000 $\mu\text{S}/\text{cm}$ and 110 mg/l respectively but in deeper aquifer their maximum values reduced to 916 $\mu\text{S}/\text{cm}$ and 7.32 mg/l respectively. Ground water from deeper aquifer is generally suitable for drinking, domestic and Irrigation purposes in Uttarakhand state.

CONCLUSIONS

The chemical quality of groundwater of shallow and deep aquifers in Uttarakhand State varies widely depending on physiography, soil textures and geology of the area. As per the Piper-Trilinear, Modified Piper diagram, the aquifers are mostly dominated by Ca-Mg-HCO₃ and Ca-HCO₃ types of groundwater. The general chemical quality reveals that most of the wells contain low dissolved mineral contents and hence, groundwater in Uttarakhand state is fresh and potable.

On the basis of chemical analysis results of 200 ground water samples, the chemical quality of ground water of Uttarakhand State by and large is found to be suitable for drinking purposes (as per BIS 2012).

Considering the parameters responsible for suitability of ground water of Uttarakhand it is observed that it is generally fit for irrigation purposes as per Electrical conductivity, Residual Sodium Carbonate, Sodium Absorption, and US Salinity Diagram.

ACKNOWLEDGEMENTS

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REFERENCES

1. APHA (2017), “Standard Methods for the Examination of Water and Wastewater (22th Ed.)”. Washington, Dc: American Public Association.
2. A. Nagarju, S. Suresh, K. Killaham, and K. A. Hudson-Edwards, “Hydrogeochemistry of waters of manampeta barite mining area Cuddapah Basin, Andhra Pradesh India,” *Journal Turkish Journal Engineering Environmental Science*, vol. 30, pp. 203–219, 2006.
3. BIS. (2012). *Drinking water specification IS: 10500:2012*. New Delhi: Bureau of Indian Standards.
4. B. Herman, *Groundwater Hydrology*, International Student Edition), Boston, MA, USA, 1978.
5. Central Ground Water Board, NWR Chandigarh, Ground Water Quality Standard Report
6. Central Ground Water Board, Faridabad (2018), Ground Water Quality in Shallow aquifers of India
7. Chadha DK (1999) A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data *Hydrogeology Journal* 7:431–439
8. D. K. Todd, *Ground Water Hydrology*, John Wiley and Sons Publications, New York, NY, USA, 3rd edition, 1995.
9. Freeze, R.A., and Cherry, J.A., 1979, *Groundwater*: New Jersey, Prentice Hall.
10. Jaganathan V, Tamta SR, Srikantha NP (1991) Behaviour of groundwater level and quality in Karnataka State during 1979–88. Central Ground Water Board, Ministry of Water Resources, Government of India, New Delhi
11. Hem, J.D., 1985, *Study and interpretation of the chemical characteristics of natural water* (3rd ed.): U.S. Geological Survey, Water Supply Paper.2254.
12. H. M. Raghunath, *Ground Water*, Vilely Easteren Ltd., New Delhi, India, 2nd edition, 1987.
13. Karanth KR (1987) *Assessment, development and management of groundwaters*, 1st edn. Tata McGraw Hill, New Delhi
14. L.V. Wilcox, (1955), “Classification and Use of Irrigation Waters”, U.S. Department of Agriculture Circle, Amer. J. of Science, Vol,8, No.3, pp. 123128.
15. M. N. Tijani, “Hydrogeochemical assessment of groundwater in Moro area, Kwara state, Nigeria,” *Environmental Geology*, vol. 24, no. 3, pp. 194–202, 1994.
16. N. Manivasagam (1984), *Physico-Chemical Examination of Water, Sewage And Industrial Effluents*, PragatiPrakashan, Meerut.
17. Piper AM (1944) A graphic procedure in geochemical interpretation of water analyses. *Trans Am Geophys Union* 25: 914– 923
18. S. A. Durov, “Classification of natural waters and graphic representation of their composition,” *Doklady Akademii SSSR*, vol. 59, pp. 87–90, 1948.
19. S. Gholami and S. Srikantaswamy, “Analysis of agriculture impact on the Curvery river water around KRS Dam,” *World Applied Science Journal*, vol. 6, pp. 1157–1169, 2009.

20. S. N Biswas, H. Mohabey, and M. L. Malik, "Assessment of the irrigation water quality of river Ganga in Haridwar district," *Asian Journal of Chemistry*, vol. 16, 2002.
21. US Salinity Laboratory, *Staff Diagnosis and Improvement of Saline and Alkali Soil*, vol. 160, U. S. Dept. Agriculture, Washigton DC, USA, 1954.

ANNEXURE 1: Ground Water Chemical Quality Data of Uttarakhand State for Pre-monsoon 2022 (Shallow Aquifers)

S. No.	Block	Location	pH	EC μS/cm at 25°C	CO ₃	HCO ₃	Cl	F	NO ₃	SO ₄	TH	Ca	Mg	Na	K	SiO ₂	PO ₄	Fe	As
					mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
DEHRADUN DISTRICT																			
1	Sahaspur	Khandoli	7.4 3	65	0	24	7	0.19	BD L	BD L	20	4.0	2.4	6.4	BD L	29	0	BDL	BDL
2	Sahaspur	Nanda ki Chowki	7.7 2	294	0	159	11	BD L	BD L	BD L	130	36	9.6	12	BD L	23	0	BDL	BDL
3	Sahaspur	Jhajra	7.4 8	189	0	85	11	BD L	9.4	10	60	16	4.8	20	BD L	31	0	1.224	BDL
4	Sahaspur	Selakui	7.6 3	175	0	73	11	BD L	BD L	10	60	12	7.2	14	1.1	32	0	3.580	BDL
5	Sahaspur	Rampura	7.8 3	184	0	98	11	BD L	BD L	BD L	60	16	4.8	19	BD L	10	0	3.329	BDL
6	Sahaspur	Sahaspur	7.5 2	149	0	49	7	BD L	8.1	16	40	16	0.0	15	BD L	36	0	BDL	BDL
7	Sahaspur	Shankarपुर	7.3 9	156	0	73	11	BD L	BD L	7.5	40	12	2.4	21	BD L	23	0	29.34	BDL
8	Sahaspur	Redapur	7.6 6	127	0	61	4	BD L	5.2	5.3	40	8	4.8	12	BD L	35	0	0.198	BDL
9	Sahaspur	Chhorba	7.6 1	133	0	61	7	BD L	5.9	5.9	40	12	2.4	15	BD L	35	0	BDL	BDL
10	Vikas Nagar	Luxmipur	7.6 7	124	0	61	11	BD L	BD L	BD L	30	12	0.0	17	BD L	8.0	0	7.429	BDL
11	Vikas Nagar	Baluwala	7.5 9	187	0	85	11	BD L	BD L	BD L	55	14	4.8	16	1.1	7.0	0	11.27 3	BDL
12	Vikas Nagar	Barothiwala	7.4 7	156	0	67	7	BD L	8.3	8.1	50	14	3.6	12	BD L	35	0	BDL	BDL
13	Vikas Nagar	Vikas Nagar	7.4	222	0	85	7	BD L	7.3	21	80	24	4.8	14	1.1	26	0	BDL	BDL
14	Vikas Nagar	Jamuna Pull	7.3 7	217	0	55	11	BD L	30	21	80	24	4.8	13	1.3	25	0	0.989	BDL
15	Vikas Nagar	Haripur	7.7 2	394	0	177	11	BD L	10	22	160	48	9.6	16	2.2	16	0	0.990	BDL
16	Vikas Nagar	Dakpatthar	7.8 8	418	0	177	21	0.12	BD L	26	165	44	13	21	1.8	11	0	16.31 4	BDL

17	Vikas Nagar	Dhakrani	7.7 5	161	0	79	7	BD L	BD L	6.4	55	16	3.6	13	1.2	7.0	0	10.57 5	BDL
18	Vikas Nagar	Herbertpur	7.5 7	220	0	73	11	BD L	16	23	90	28	4.8	11	1.9	20	0	0.068	BDL
19	Raipur	Kanwali	7.8 6	646	0	262	28	BD L	BD L	69	280	44	41	22	1.5	11	0	4.872	BDL
20	Raipur	Harbanswala	7.9 4	546	0	256	18	BD L	BD L	40	250	44	34	13	1.0	9.0	0	5.161	BDL
21	Sahaspur	Telpura	7.6 9	699	0	281	14	BD L	22	80	335	74	36	7.8	1.1	23	0	0.176	BDL
22	Sahaspur	Badowala	7.6 2	740	0	305	11	0.11	21	91	355	84	35	9.4	1.0	24	0	BDL	BDL
23	Sahaspur	Singhniwala	7.6 3	699	0	268	21	BD L	16	101	330	78	32	18	1.1	21	0	0.383	BDL
24	Sahaspur	Ramgarh	7.6 9	768	0	311	14	BD L	14	110	370	100	29	14	1.0	24	0	0.238	BDL
25	Sahaspur	Sabhawala	7.8 6	455	0	159	18	0.11	37	21	160	44	12	17	11	18	0.54	BDL	BDL
26	Vikas Nagar	Badripur	7.6 3	322	0	177	4	0.10	BD L	8.9	125	38	7.2	17	BD L	23	0	12.05 4	BDL
27	Vikas Nagar	Dharmawala	8.0 1	412	0	189	18	BD L	BD L	14	125	60	6	26	16	24	0	0.629	BDL
28	Vikas Nagar	Judli	7.8 9	466	0	281	7	BD L	BD L	BD L	200	46	20	19	BD L	34	0	32.70 8	BDL
29	Raipur	Purukulgaon	7.9 5	407	0	140	7	BD L	BD L	73	175	48	13	14	BD L	19	0	BDL	BDL
30	Raipur	Bhatta	7.9 9	608	0	262	18	BD L	7.2	70	300	106	8.4	9.0	1.0	8.0	0	BDL	BDL
31	Raipur	Tarla Nagal	7.7 6	886	0	183	7	0.20	BD L	298	450	50	78	9.0	1.7	9.0	0	0.560	BDL
32	Raipur	Nanurkhera	7.8 1	519	0	275	11	0.81	BD L	23	250	50	30	5.8	1.0	8.0	0	0.511	BDL
33	Raipur	Maldevta	8.3 7	3094	6	195	124	BD L	BD L	105 0	110	14	18	620	15	3.0	0	BDL	BDL
34	Raipur	Soda Sarauli	8.3 8	356	6	43	64	0.14	6.5	32	105	30	7.2	28	1.6	19	0	BDL	BDL
35	Raipur	Bhopalpani	7.8 5	412	0	146	7	0.16	BD L	68	165	52	8.4	17	1.3	27	0	BDL	BDL
36	Doiwala	Kotimaichak	7.6 4	206	0	98	7	0.13	BD L	7.0	75	14	9.6	13	1.1	10	0	1.700	BDL
37	Raipur	Gularghati	7.8	788	0	214	11	BD L	5.4	198	395	92	40	4.4	1.5	12	0	0.052	BDL

38	Raipur	Kuanwala	7.7 4	384	0	177	18	BD L	BD L	17	165	48	11	12	1.8	22	0	41.93 1	BDL
39	Doiwala	Mothorowala	7.1 5	178	0	61	11	BD L	11	8.8	50	14	3.6	11	5.8	27	0	0.095	BDL
40	Doiwala	Dudhli	7.6 5	298	0	153	11	BD L	BD L	9.6	125	30	12	12	2.2	5.0	0	0.587	BDL
41	Doiwala	Chandmari	7.7 3	688	0	244	7	BD L	7.5	122	345	78	36	4.2	1.9	14	0	BDL	BDL
42	Doiwala	Bhaniawala	7.9 9	644	0	220	11	BD L	BD L	103	310	78	28	3.2	1.8	14	0	BDL	BDL
43	Doiwala	Dujjiawala	7.8 3	199	0	104	4	BD L	BD L	10	65	14	7.2	17	BD L	5.0	0	2.771	BDL
44	Doiwala	Rishikesh	7.9 5	413	0	177	11	BD L	6.1	40	195	50	17	8.0	1.4	18	0	0.059	BDL
45	Doiwala	Khadak Maaf	7.7 1	393	0	128	21	BD L	28	36	155	34	17	21	1.3	27	0	BDL	BDL
46	Doiwala	Lal Tappar	8.0 6	499	0	220	7	BD L	BD L	65	250	56	26	7.3	1.4	14	0	0.310	BDL
47	Doiwala	Niranjanpur Mandi	7.6 9	841	0	354	43	BD L	21	36	390	74	49	13	1.2	16	0	BDL	BDL

HARIDWAR DISTRICT

48	Bhagwanpu r	Budhwa Shahid	8.0 3	889	0	476	18	BD L	24	5.8	395	132	16	19	15	17	0.34	0.132	0.00 1
49	Bhagwanpu r	Sahidwala Grant	7.6 2	530	0	244	11	BD L	37	14	235	62	19	13	1.4	19	0	BDL	BDL
50	Bhagwanpu r	Bugawala	7.6 9	558	0	317	7	BD L	17	6.2	265	70	22	7.1	1.7	19	0	0.076	BDL
51	Bahadrabad	Bandarjud	7.6 6	538	0	311	7	BD L	17	5.3	245	52	28	17	1.6	22	0	0.294	BDL
52	Bahadrabad	Rathora	7.8 1	625	0	390	7	0.21	BD L	16	265	44	37	42	1.7	22	0	1.116	BDL
53	Bhagwanpu r	Kota Muradnagar	7.7 6	611	0	390	11	BD L	BD L	13	275	40	42	38	2.5	21	0	1.939	BDL
54	Bhagwanpu r	Jaswawala	7.5 9	919	0	433	39	0.15	9.9	61	310	66	35	58	48	18	0	BDL	0.00 3
55	Roorkee	Imlikhera	8.0 4	575	0	336	11	0.23	BD L	10	160	28	22	66	2.3	17	0	0.192	BDL
56	Bhagwanpu r	Bahabalpur	7.8 1	801	0	433	11	0.10	BD L	24	310	58	40	39	2.3	17	0	2.661	0.03 1

57	Bhagwanpur	Bhagwanpur	8.19	667	0	342	7	0.31	BDL	33	175	40	18	72	1.6	21	0	0.317	BDL
58	Bhagwanpur	Chudiala	8.14	565	0	268	21	0.53	BDL	24	210	42	25	32	3.3	23	0	0.332	BDL
59	Bhagwanpur	Iqbalpur	7.51	1485	0	488	96	BDL	37	158	695	152	76	20	8.2	25	0	0.217	0.001
60	Narsan	Jhabreda	8.11	566	0	293	18	0.57	BDL	15	225	46	26	23	5.2	25	0	0.141	0.002
61	Narsan	Lakhnauta	7.76	707	0	317	25	BDL	21	36	325	74	34	12	4.3	33	0	0.470	BDL
62	Narsan	Gurukul Narsen	7.95	400	0	189	11	0.17	BDL	34	190	54	13	6.4	3.4	25	0	BDL	0.004
63	Roorkee	Khera Jat	7.82	420	0	226	7	0.18	BDL	27	200	72	4.8	8.5	5.2	15	0	0.113	BDL
64	Narsan	Libhrahedi	7.79	317	0	122	14	0.32	6.9	31	145	42	9.6	3.5	5.2	19	0	0.054	BDL
65	Roorkee	Roorkee	7.98	635	0	336	21	0.37	6.4	14	275	72	23	23	4.0	28	0	0.200	0.009
66	Bahadradab	Bahadradab	7.76	812	0	317	46	0.33	BDL	70	315	88	23	43	2.4	17	0	14.427	0.020
67	Bahadradab	Sarai	7.78	601	0	250	21	0.18	33	37	275	74	22	11	3.6	21	0	BDL	0.002
68	Roorkee	Malakpur Majra	8.14	615	0	348	7	0.37	BDL	BDL	175	46	14	61	2.4	23	0	0.520	0.002
69	Narsan	Landhaura	7.69	640	0	336	7	0.18	13	19	275	60	30	21	3.5	31	0	0.442	BDL
70	Roorkee	Sikhar	7.75	564	0	305	11	BDL	12	11	250	36	38	15	4.5	24	0	0.083	0.002
71	Narsan	Mudlana	7.89	380	0	207	4	0.44	BDL	16	170	46	13	7.9	4.1	16	0	0.08	0.004
72	Roorkee	Nizampur	7.74	580	0	299	7	0.14	9.3	29	280	74	23	5.0	3.8	29	0	0.323	BDL
73	Laksar	Hussainpur	7.71	550	0	323	7	0.24	BDL	BDL	230	28	38	23	4.9	25	0	0.585	0.009
74	Laksar	Laksar	7.75	760	0	372	32	0.36	BDL	27	260	74	18	51	9.1	20	0	3.147	0.008
75	Roorkee	Mohammadpur	7.72	430	0	244	11	0.36	BDL	8.7	190	54	13	13	5.0	25	0	0.389	0.015
76	Khanpur	Govardhanpur	7.75	720	0	427	7	0.26	BDL	BDL	180	38	20	82	5.4	19	0	4.180	0.013
77	Khanpur	Khanpur	7.82	595	0	311	7	0.38	BDL	6.0	125	34	9.6	69	6.5	17	0	0.054	0.013

78	Khanpur	Dallawala	7.8	584	0	305	14	0.26	BD L	16	120	52	2.4	76	6.0	20	0	0.086	0.04 7
79	Bahadradab	Jassodharpur	7.7 1	670	0	323	18	0.15	8.8	41	310	42	49	13	4.6	17	0	0.051	BDL
80	Bahadradab	Shahpur Shitlakhera	7.6 8	651	0	311	18	BD L	BD L	38	280	58	32	12	23	14	0	0.146	BDL
81	Bahadradab	Bhogpur	7.6 4	1415	0	653	53	BD L	8.3	71	450	102	47	43	137	24	0	0.141	0.01 3
82	Laksar	Bhikampur	7.7 5	1073	0	445	50	0.35	64	47	300	76	26	76	68	16	0	3.744	0.01 4
83	Bahadradab	Dhanpura	7.5 9	1104	0	397	53	0.16	98	55	400	92	41	43	44	24	0	0.210	0.00 4
84	Bahadradab	Panjanheri	8.2 4	530	0	244	14	0.15	12	31	235	58	22	12	5.8	13	0	0.133	0.00 2
85	Bahadradab	Bhoopatwala	7.8 5	700	0	311	25	0.21	8.5	52	325	68	37	13	1.4	14	0	1.192	BDL
86	Bahadradab	Shyampur	7.6 1	631	0	293	18	0.16	25	31	280	64	29	15	3.5	21	0	BDL	0.00 2
87	Bahadradab	Dudhadayalwala	7.6 7	580	0	293	11	0.10	BD L	30	250	58	25	18	2.3	24	0	1.663	BDL
88	Bahadradab	Dallupuri	7.7 6	478	0	238	7	BD L	6.6	31	215	64	13	12	1.9	18	0	0.798	BDL
89	Bahadradab	Laldhang	7.7 1	650	0	275	25	BD L	BD L	46	270	68	24	22	2.5	10	0	13.49 7	BDL
PAURI GARHWAL DISTRICT																			
90	Dugadda	Trilokpur	7.6 9	455	0	256	7	BD L	BD L	8.4	205	62	12	9.6	2.0	13	0	1.874	BDL
91	Dugadda	Kaudia Kotdwar	7.6 7	570	0	262	21	BD L	21	27	265	82	14	11	1.5	14	0	0.339	BDL
UTTARKASHI DISTRICT																			
92	Naugaon	Sharukhet	7.5 6	121	0	73	4	BD L	BD L	BD L	45	14	2.4	10	BD L	10	0	22.31 2	BDL
93	Naugaon	Barkot	7.6 9	290	0	146	18	0.21	BD L	BD L	115	26	12	15	BD L	7.0	0	0.166	BDL
94	Bhatwari	Nagal	7.6 3	166	0	98	4	0.14	BD L	6.2	80	20	7.2	3.2	BD L	12	0	BDL	BDL
95	Dunda	Dharasu	7.9 3	450	0	232	11	0.23	BD L	9.9	160	48	9.6	23	7.4	16	0	BDL	0.00 5
96	Chinyalisaur	Chinyalisaur	7.6 6	601	0	281	21	0.19	28	21	260	66	23	20	2.5	18	0	0.402	BDL

97	Dunda	Devidhar	7.7 3	270	0	146	4	0.23	BD L	11	115	24	13	10	BD L	16	0	25.87 8	BDL
98	Bhatwari	Dunda	7.8 4	517	0	195	25	0.13	54	22	240	62	20	9.7	2.3	19	0	0.201	BDL
99	Bhatwari	Ratodi Sar	7.6 1	112	0	55	4	BD L	BD L	6.1	50	14	3.6	2.8	1.3	14	0	BDL	BDL
10 0	Dunda	Uttarkashi	7.6 9	310	0	134	18	BD L	5.6	17	125	30	12	13	7.5	16	0	4.340	BDL
10 1	Naugaon	Ganeshpur	7.4 2	121	0	61.01	7.1	BD L	BD L	BD L	60.048	16.03 2	4.9	BD L	3.9	5.9	nd	8.329	BDL
10 2	Bhatwari	Maneri	7.5 5	277	0	122.02	7.1	0.34	BD L	32	130.10 4	40	7.3	3.0	4.2	8.5	nd	2.048	0.00 7
10 3	Bhatwari	Charethi	7.6 5	214	0	109.81 8	7.1	0.24	BD L	12	90	28	4.9	6.6	4.3	15	nd	0.077	BDL
10 4	Bhatwari	Ganganani	7.7 3	988	0	463.67 6	57	2.80	6.1	28	110	32	7.3	176	17	64	nd	0.054	0.02 8
ALMORA DISTRICT																			
10 5	Tarikhet	Patali Talla	7.9 2	440	0	183.03	14	0.19	20	16	190	24	32	9.0	1.1	22	nd	BDL	0.00 8
10 6	Tarikhet	Patali Malla	7.8 9	322	0	158.62 6	14	0.06	7.5	12	140	44	7.3	10	1.9	18	nd	BDL	0.01 0
10 7	Tarikhet	Goluchheea	7.7 8	222	0	122.02	7.1	0.13	BD L	6.4	90	24	7.3	8.5	4.5	23	nd	BDL	BDL
10 8	Hawalbagh	Jholi	7.1 9	120	0	37	14	BD L	BD L	7.6	40	12	2.4	8.0	2.0	25	nd	BDL	BDL
10 9	Hawalbagh	Katarmal	7.3 5	250	0	73	21	BD L	20	19	90	28	4.9	13	4.7	32	nd	BDL	BDL
11 0	Hawalbagh	DharaNaula	7.5 2	545	0	98	57	0.07	90	42	150	4.0	34	51	14	28	0.4	BDL	0.07 0
11 1	Hawalbagh	Palna	7.4 2	160	0	49	21	0.11	6.2	5.7	50	60	2.4	13	2.0	34	nd	BDL	0.00 5
11 2	Takula	Paitsaal	7.2 0	114	0	49	7.1	0.05	BD L	5.7	40	4.0	7.3	8.2	2.2	32	nd	BDL	0.00 1
11 3	Someshwar	Deghat	8.0 2	154	0	61	14	0.05	BD L	11	60	12	7.3	8.8	2.3	24	nd	BDL	BDL
11 4	Bhikiasain	Naula	7.9 0	604	0	256	28	0.16	31	29	230	64	17	33	12	24	0.33	0.054	0.00 1
11 5	Bhikiasain	Ramgath	7.6 1	235	0	85	14	0.14	BD L	19	80	24	4.9	14	2.9	21	nd	0.094	BDL
11 6	Chaukhtiy a	Deepakot	7.4 0	225	0	73	21	0.10	12	6.4	70	20	4.9	17	1.9	35	0.38	0.052	0.00 2

117	Chaukhutiy a	Peepal dhar	7.82	436	0	256	14	BDL	BDL	BDL	230	40	32	BDL	BDL	11	nd	0.076	BDL
118	Chaukhutiy a	Dhansari	7.92	371	0	220	7.1	BDL	BDL	BDL	200	40	24	BDL	BDL	9.1	nd	0.077	BDL
119	Chaukhutiy a	Dhalnagaon	8.00	510	0	281	7.1	1.30	BDL	15	200	44	22	26	8.0	12	nd	0.077	BDL
120	Chaukhutiy a	Semalkhet	8.02	370	0	195	14	BDL	BDL	5.6	180	40	19	2.4	1.8	8.8	nd	0.065	BDL
121	Someshwar	Dudholi	7.10	89	0	37	7.1	BDL	BDL	BDL	40	12	2.4	1.9	BDL	8.5	nd	1.414	BDL
122	Chaukhutiy a	Khagsapani	7.02	98	0	49	7.1	BDL	BDL	BDL	50	8.0	7.3	BDL	BDL	8.2	nd	0.107	BDL
123	Someshwar	Lodh	7.22	154	0	85	7.1	BDL	BDL	BDL	70	20	4.9	6.0	1.0	21	nd	0.769	BDL
124	Takula	Chinoda	7.65	181	0	110	3.5	0.08	BDL	BDL	90	20	9.7	3.0	BDL	15	nd	0.063	BDL
125	Takula	Guruda	7.48	102	0	49	7.1	0.09	BDL	BDL	50	12	4.9	BDL	BDL	9.6	nd	0.060	BDL
126	Takula	Channi Bartola	7.23	101	0	49	7.1	BDL	BDL	BDL	50	8.0	7.3	1.9	1.4	11	nd	0.867	BDL
127	Someshwar	Mehargaon (Someshwar)	7.41	149	0	61	14	BDL	5.7	BDL	80	16	9.7	BDL	BDL	10	nd	BDL	BDL
128	Someshwar	Bhoolgaon	7.63	680	0	354	21	0.12	30	14	330	64	41	9.9	17	13	nd	0.051	BDL
129	Hawalbagh	Bhagtola	7.80	168	0	85	7.1	BDL	BDL	BDL	60	20	2.4	9.8	1.2	21	nd	BDL	BDL
130	Hawalbagh	Itola	7.48	160	0	85	7.1	BDL	BDL	BDL	60	16	4.9	9.4	1.2	22	nd	BDL	BDL
UDHAM SINGH NAGAR DISTRICT																			
131	Jaspur	Angadpur	7.88	578	0	354	7.1	0.46	BDL	BDL	230	40	32	39	1.2	22	nd	BDL	BDL
132	Jaspur	Patrampur	8.07	595	0	378	7.1	0.59	BDL	BDL	260	60	27	31	0.9	22	nd	0.460	BDL
133	Jaspur	Jaspur	8.20	669	0	427	7.1	1.10	BDL	BDL	110	20	15	115	1.1	16	nd	BDL	BDL
134	Jaspur	Missarwala	7.85	432	0	256	7.1	0.14	BDL	BDL	190	48	17	19	1.8	19	nd	10.781	BDL
135	Jaspur	Durgapur	7.79	611	0	342	21	0.22	BDL	18	290	56	36	20	2.5	18	nd	1.602	BDL
136	Kashipur	Barkhare Pande	7.98	1162	0	451	71	0.16	38	95	400	92	41	77	41	23	2.1	BDL	0.002

137	Kashipur	Bharatpur	8.14	563	0	342	7.1	0.54	BDL	7.1	180	36	22	55	2.0	19	nd	0.076	BDL
138	Kashipur	Dhanauri Patti	8.06	476	0	268	14	0.08	BDL	12	220	64	15	9.7	1.3	22	nd	0.143	BDL
139	Kashipur	Kashipur	7.81	799	0	329	64	0.22	BDL	34	230	56	22	82	2.4	25	nd	BDL	BDL
140	Kashipur	Sultanpur Patti	8.02	514	0	268	7.1	BDL	BDL	35	260	64	24	7.2	1.3	24	nd	0.153	BDL
141	Kashipur	Shankhera	7.58	435	0	220	7.1	BDL	BDL	14	180	48	15	8.7	1.8	21	nd	0.105	0.002
142	Bazpur	Pritpur	7.53	715	0	415	7.1	BDL	BDL	38	370	68	49	11	1.5	26	nd	0.085	BDL
143	Bazpur	Jogipura	7.57	680	0	366	11	0.15	BDL	52	330	52	49	18	1.5	25	nd	2.968	BDL
144	Bazpur	Banna khera	7.60	712	0	378	7.1	0.14	BDL	55	360	68	46	14	1.4	18	nd	3.853	BDL
145	Bazpur	Jharkhandi	7.63	733	0	403	7.1	0.08	8.8	41	380	56	58	7.2	1.2	24	nd	0.081	BDL
146	Bazpur	Bazpur	7.61	772	0	415	7.1	0.11	5.8	58	390	56	61	15	1.7	27	nd	BDL	BDL
147	Bazpur	Badaripur	7.68	776	0	378	18	0.09	BDL	60	370	56	56	19	1.9	18	nd	0.988	0.003
148	Gadarpur	Baria Daulat	7.72	607	0	317	11	0.13	4.6	45	300	56	39	7.4	1.6	22	nd	0.309	BDL
149	Gadarpur	Patharpuri	7.73	645	0	329	7.1	0.13	BDL	51	310	48	46	13	1.9	23	nd	0.309	BDL
150	Gadarpur	Jhagarpuri	7.92	664	0	366	7.1	0.06	BDL	48	320	52	46	14	2.0	25	nd	0.073	BDL
151	Gadarpur	Mahabir Nagar	7.68	743	0	354	7.1	0.05	BDL	72	380	48	63	5.4	1.8	24	nd	0.076	BDL
152	Gadarpur	Kopa Signal	7.73	583	0	329	7.1	0.08	BDL	28	290	52	39	4.9	2.0	20	nd	0.184	BDL
153	Gadarpur	Lalpuri	7.56	594	0	305	7.1	BDL	5	43	300	56	39	7.2	1.8	24	nd	0.051	BDL
154	Gadarpur	Bhagwanpur	7.84	456	0	244	7.1	0.22	BDL	17	210	48	22	8.4	2.4	24	nd	0.10	BDL
155	Rudrapur	Rudrapur	7.83	381	0	195	7.1	0.17	BDL	24	170	24	27	8.5	3.2	25	nd	BDL	BDL
156	Rudrapur	Patthar Chatta	7.88	515	0	293	7.1	0.14	BDL	21	260	72	19	7.4	3.1	26	nd	BDL	BDL
157	Rudrapur	Kamaria Pakki	7.77	429	0	207	14	0.29	BDL	28	180	40	19	15	7.1	24	nd	0.060	BDL

158	Rudrapur	Gangapur	7.69	450	0	244	7.1	0.14	5.5	22	210	52	19	7.6	2.7	26	nd	0.094	BDL
159	Rudrapur	Kanakpur	7.77	763	0	378	21	0.25	BDL	54	330	64	41	22	26	19	nd	3.478	0.002
160	Rudrapur	Kichha	7.91	355	0	171	7.1	0.17	BDL	23	150	36	15	8.9	1.7	24	nd	BDL	0.001
161	Rudrapur	Rajpura	7.63	451	0	207	7.1	0.13	5	25	200	56	15	5.9	2.6	28	nd	0.112	BDL
162	Rudrapur	Shantipuri	7.88	624	0	232	43	0.30	BDL	43	270	72	22	15	2.1	26	nd	0.112	BDL
163	Rudrapur	Pipiliya	7.88	440	0	244	7.1	0.32	BDL	27	210	60	15	10	1.7	27	nd	0.152	BDL
164	Rudrapur	Bara	8.02	455	0	256	7.1	0.30	BDL	20	200	44	22	22	1.7	24	nd	0.908	BDL
165	Sitarganj	Begur Mod	7.86	493	0	281	7.1	0.41	12	21	210	52	19	27	1.0	22	nd	0.455	BDL
166	Sitarganj	Nanak Mata	7.84	668	0	354	11	0.72	BDL	38	300	76	27	23	8.3	24	nd	BDL	BDL
167	Sitarganj	Dhyanpur	7.63	426	0	244	11	BDL	BDL	BDL	190	56	12	11	1.6	23	nd	0.055	BDL
168	Sitarganj	Tukri	7.72	454	0	268	7.1	0.07	BDL	9.3	210	60	15	12	1.1	22	nd	0.051	BDL
169	Sitarganj	Bidora	7.79	415	0	244	7.1	0.08	BDL	8.7	180	48	15	14	1.5	24	nd	0.699	BDL
170	Sitarganj	Sitarganj	7.63	402	0	232	7.1	0.05	BDL	9.3	180	44	17	11	2.0	24	nd	BDL	BDL
171	Sitarganj	Kalyanpur	7.61	377	0	220	7.1	0.09	BDL	7.8	180	52	12	7.8	1.4	22	nd	0.169	BDL
172	Khatima	Sara Sariya	7.78	650	0	390	7.1	0.29	BDL	16	190	52	15	77	2.4	22	nd	0.733	0.001
173	Khatima	Khatima	7.67	980	0	415	64	0.34	38	26	330	84	29	66	26	28	nd	BDL	0.001
174	Khatima	Kanchanpuri (Majhola)	7.93	645	0	403	7.1	0.06	BDL	BDL	260	64	24	38	3.0	29	nd	1.407	0.008
175	Khatima	Barianjaniya	7.97	530	0	305	7.1	0.12	BDL	7.7	260	76	17	6.4	1.6	21	nd	1.417	0.007
176	Khatima	Chakarpur	7.87	373	0	183	21	0.34	BDL	BDL	160	56	4.9	7.8	BDL	19	nd	2.254	0.006
NAINITAL DISTRICT																			
177	Ramnagar	Maldhan Colony	7.94	498	0	305	7.1	0.32	BDL	6.4	240	56	24	16	1.0	22	nd	BDL	BDL

178	Ramnagar	Peeru Madara	7.83	335	0	159	7.1	0.09	6.9	18	140	40	9.7	7.9	1.8	20	nd	BDL	BDL
179	Ramnagar	Chilkiya	7.71	470	0	268	14	BDL	BDL	11	240	44	32	8.0	2.5	7.4	nd	4.219	BDL
180	Ramnagar	Dhela	7.55	478	0	268	7.1	BDL	BDL	15	200	68	7.3	20	1.1	19	nd	BDL	BDL
181	Ramnagar	Garjiya	7.59	475	0	220	11	0.10	BDL	22	200	60	12	8.0	2.9	12	nd	BDL	BDL
182	Ramnagar	Ramnagar	7.49	524	0	293	11	0.12	8.9	8.8	240	48	29	14	2.9	18	nd	BDL	BDL
183	Ramnagar	Belparao	7.67	697	0	378	7.1	0.12	BDL	54	360	72	44	10	1.6	23	nd	BDL	BDL
184	Ramnagar	Dhoniya	7.54	664	0	293	7.1	0.11	BDL	73	320	76	32	7.8	1.3	17	nd	1.218	BDL
185	Haldwani	Kaladhungi	7.93	495	0	207	7.1	0.10	4.5	59	230	24	41	4.6	1.3	17	nd	0.250	BDL
186	Haldwani	Lamachaur	7.85	481	0	268	7.1	0.14	10	12	240	72	15	4.4	1.8	22	nd	BDL	BDL
187	Haldwani	Lalkuan	7.53	538	0	268	14	0.13	15	26	250	96	2.4	6.8	3.1	27	nd	BDL	BDL
188	Haldwani	Khatbaans	7.41	465	0	256	7.1	BDL	11	9.7	210	72	7.3	9.0	1.6	15	nd	0.255	BDL
189	Haldwani	Kathgodam	7.40	404	0	232	7.1	0.10	BDL	5.3	170	44	15	12	1.6	13	nd	0.112	BDL
190	Bhimtal	Dogaon	7.65	353	0	159	11	BDL	12	21	150	40	12	8.4	2.9	13	nd	BDL	BDL
191	Bhimtal	Jyolikot	7.82	496	0	232	7.1	BDL	5.9	44	250	28	44	BDL	0.8	5.1	nd	BDL	BDL
192	Bhimtal	Kudagath	7.96	706	0	281	18	BDL	7.4	78	330	52	49	7.8	3.0	7.3	nd	BDL	BDL
193	Bhimtal	Sipahi dhara	7.75	248	0	110	7.1	BDL	BDL	9.5	100	28	7.3	2.6	2.0	13	nd	BDL	0.003
194	Bhimtal	Salari	7.76	353	0	195	7.1	0.13	BDL	8.7	170	40	17	3.5	1.6	28	nd	BDL	BDL
195	Bhimtal	Ranibagh	7.42	522	0	256	18	0.11	16	22	230	64	17	13	4.1	16	nd	0.227	BDL
196	Bhimtal	Garam Pani	7.90	196	0	110	3.5	0.10	BDL	BDL	90	28	4.9	BDL	0.8	10	nd	BDL	BDL
CHAMPAWAT DISTRICT																			
197	Champawat	Banbasa	7.68	468	0	207	21	0.10	BDL	35	220	48	24	6.8	9.3	21	nd	0.097	0.001

19 8	Champawat	Bichayee	7.5 5	483	0	293	11	BD L	BD L	6.2	240	44	32	4.2	2.4	22	nd	3.935	0.00 1
19 9	Champawat	Tanakpur	7.4 8	530	0	256	14	0.10	17	18	240	64	19	10	0.9	19	nd	0.092	BDL
20 0	Champawat	Bastia	7.5 3	456	0	244	7.1	BD L	9.7	9.6	210	76	4.9	5.2	1.1	22	nd	BDL	BDL

ANNEXURE 2: Ground Water Chemical Quality Constituents of Deeper Aquifer, Uttarakhand State

S.No.	Location Details	pH	EC μS/cm at 25°C	TDS	CO3	HCO3	Cl	F	NO3	SO4	TH	Ca	Mg	Na	K
					mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Patrampur	7.63	711.2	434.2	Nil	323	6.71	0.09	3.01	29.1	249.13	60.33	24.47	62.16	0.9
2	Karanpur	7.99	565	344.7	Nil	218.2	7.01	0	1.65	25.4	166.1	52.1	8.86	66.54	1.32
3	Mahuadabra	7.4	563.2	324.1	Nil	212.22	13.2	0.09	3.83	22.86	230.9	58.63	21.02	63.22	1.1
4	Shivlalpur	7.51	476	297.6	Nil	202.1	9.83	0.09	2.43	16.5	152.8	43.2	11.1	56.84	0.99
5	UJS Bazpur	8.31	916	592	Nil	394.1	19.5	0.15	7.32	30.9	433.6	84.9	55.1	80.3	5.1
6	Pipliya Bazpur	7.22	540	320.6	Nil	219.8	11.62	0.1	2.7	19.8	180.7	43.2	18.1	60.11	1
7	Pipliya Gadarpur	7.79	782	476.4	Nil	236.9	7.8	0.11	4.1	36.6	337.1	80	34.1	69.52	1.78
8	Sakainiya	7.76	680	428.1	Nil	299.3	5.47	0.06	3.82	24.2	287.6	50.4	40.3	61.02	1.3
9	Azadnagar	7.53	722	429.3	Nil	325	4.03	0.05	2.65	30.1	303.3	52.5	42.8	60.32	2.1
10	AN Jha School	6.52	439.8	266.9	Nil	181.5	10.45	0.07	3.01	18.76	161.4	41.4	14.42	60.76	1.67
11	Bara	7.74	245	203.5	Nil	104.6	5.7	0.09	3.23	15.7	119.3	33.68	8.74	56.44	0.87
12	Nanak Matta	7.78	684.3	250.8	Nil	292.3	13.3	0.1	1.94	22.38	250.88	69.47	22.71	67.54	2.18
13	Nayagaon	6.6	360	210.1	Nil	128.1	8.55	0.09	1.82	23.7	140.3	22.1	21.2	59.43	1.11
14	Bijti	7.85	576.8	351	Nil	246.2	5.7	0.11	2.75	22.84	215.8	50.5	22.28	63.2	1.67
15	Chandanpura	7.53	722	429.3	Nil	325.9	4.03	0.05	2.65	30.1	303.2	52.5	42.8	60.32	2.11
16	Charubeta	7.29	583	347.2	Nil	240.9	9.64	0.09	2.96	17.8	212.1	40.1	27.8	63.98	1.21
17	Mohammadpur Bhuria	7.27	609	376.2	Nil	268	9.81	0.13	3.09	21.7	213.2	41.2	27.4	56.71	1.03

