केंद्रीय भूमिजल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण विभाग,

जल शक्ति मंत्रालय

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

CONTRIBUTOR:

MS. ANJALI KUSHWAHA, SCIENTIST- C

UNDER SUPERVISION OF

SH. PRASHANT RAI, REGIONAL DIRECTOR

CENTRAL GROUND WATER BOARD
UTTARANCHAL REGION, DEHRADUN
AAP 2024-25

STATE HYDROCHEMICAL REPORT,
UTTARAKHAND STATE

CONTENTS

TABLES

FIGURES

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 Zanskar 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.

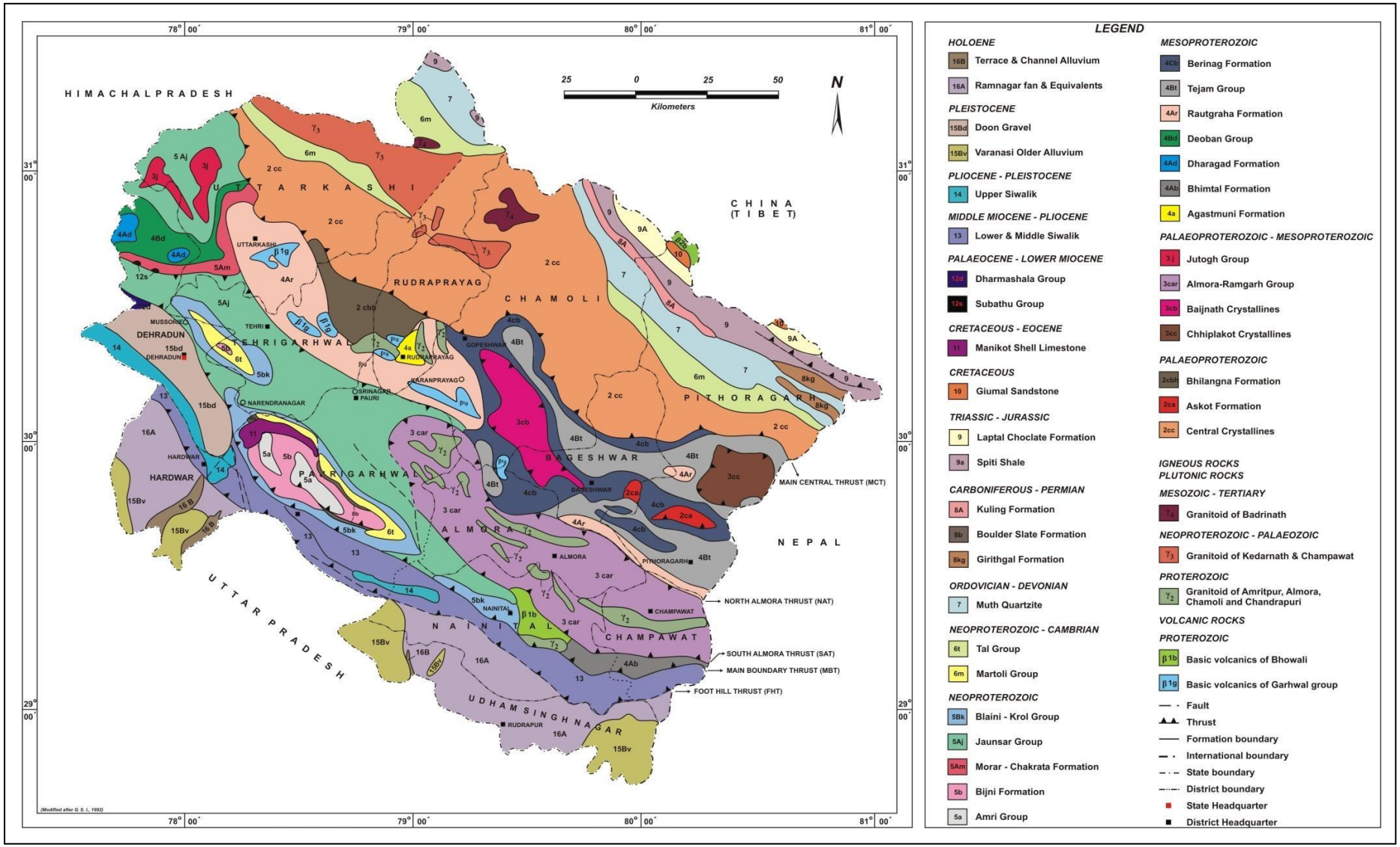


Fig. 2.1: Geological Map of Uttarakhand State (after GSI, 2002)

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.

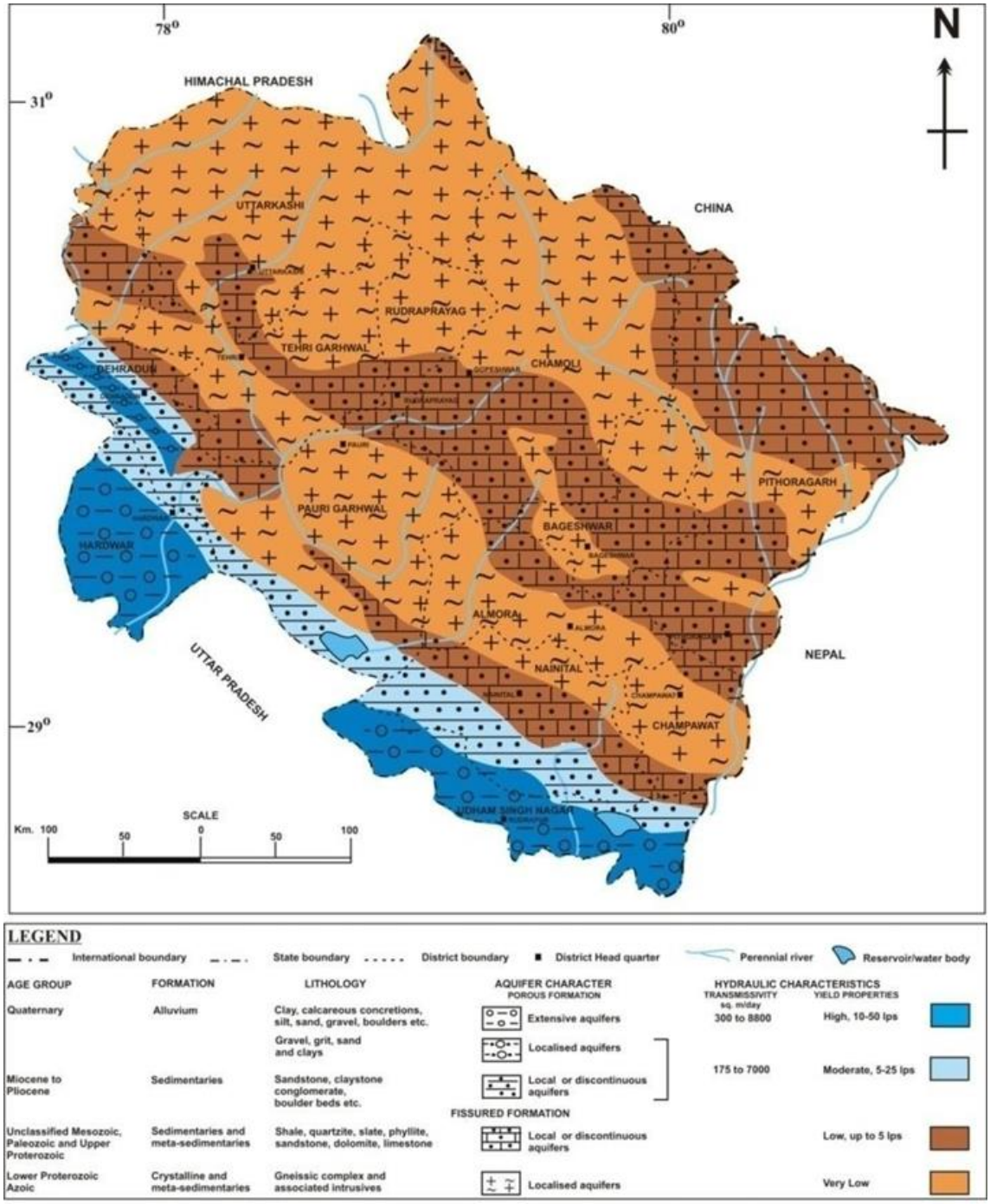


Fig.3.1: Hydrogeological Map of Uttarakhand State

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, 02, CO2, CH4, CO, SOx, NOx 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 HCO_3 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/I 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/1). 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-HCQ3 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.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$H^+ + \text{Feldspar} + H_2O \longrightarrow \text{Clay} + H_4SiO_4 + \text{Cation}$$

The oxygen present in this water is used for the oxidation of organic matter that subsequently generates CO_2 to form H_2CO_3. This process goes on until oxygen is fully consumed.

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O$$

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, CI, 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, AI, Fe, Mg, Total hardness, Alkalinity / Acidity Suspended solids, Salinity	Farmstead Same as forpublic supply Live-stock Same as for public supply Irrigation TDS, EC, Na, Ca, Mg, K, B, CI 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 downby 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	Color 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 ifsulphate 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 µs/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).

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

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;

$$\mathbf{RSC} = (\mathbf{HCO3} + \mathbf{CO3}) - (\mathbf{Ca} + \mathbf{Mg})$$

(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.

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

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 fordrinking 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 alkalinewaters, affects taste, corrosivity and the water supply system
6	Hardness as CaCO3 (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 CaCO3	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 causevomiting and diarrhea, stimulate secondary hyperthyroidism andbone loss
25	Sodium (Na)(mg/L)	No guidelines		Harmful to persons suffering From cardiac, renal andcirculatory diseases.
26	Potassium (K) (mg/L)	No guidelines		An essential nutritional elementbutits 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 DNAdamage in animals.
29	Pathogens (a)Total coliform (per 100ml) (b) Faecal Coliform (per100ml)	nil		Cause water borne diseases like coliform Jaundice, Typhoid, Cholera etc. produce infections involving skin mucous membraneof 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) ~ (0.55 to 0.95) x 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 conductivity (mS/cm) < TDS (mg/l) < 0.95 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 eight (208) normative water samples collected during pre-monsoon period (May 2023) and fifty-three (53) samples from the trend stations 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, Tehri Garhwal, 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 6.0.

Table 6.0: District wise breakup of Ground Water Sampling locations (as on May 2023)

S. No.	District	No. of Sampling
1	Dehradun	51
2	Nainital	20
3	Almora	26
4	Haridwar	41
5	Champawat	4
6	Pauri Garhwal	2
7	Uttarkashi	13
8	Udham Singh Nagar	46
9	Tehri Garhwal	5

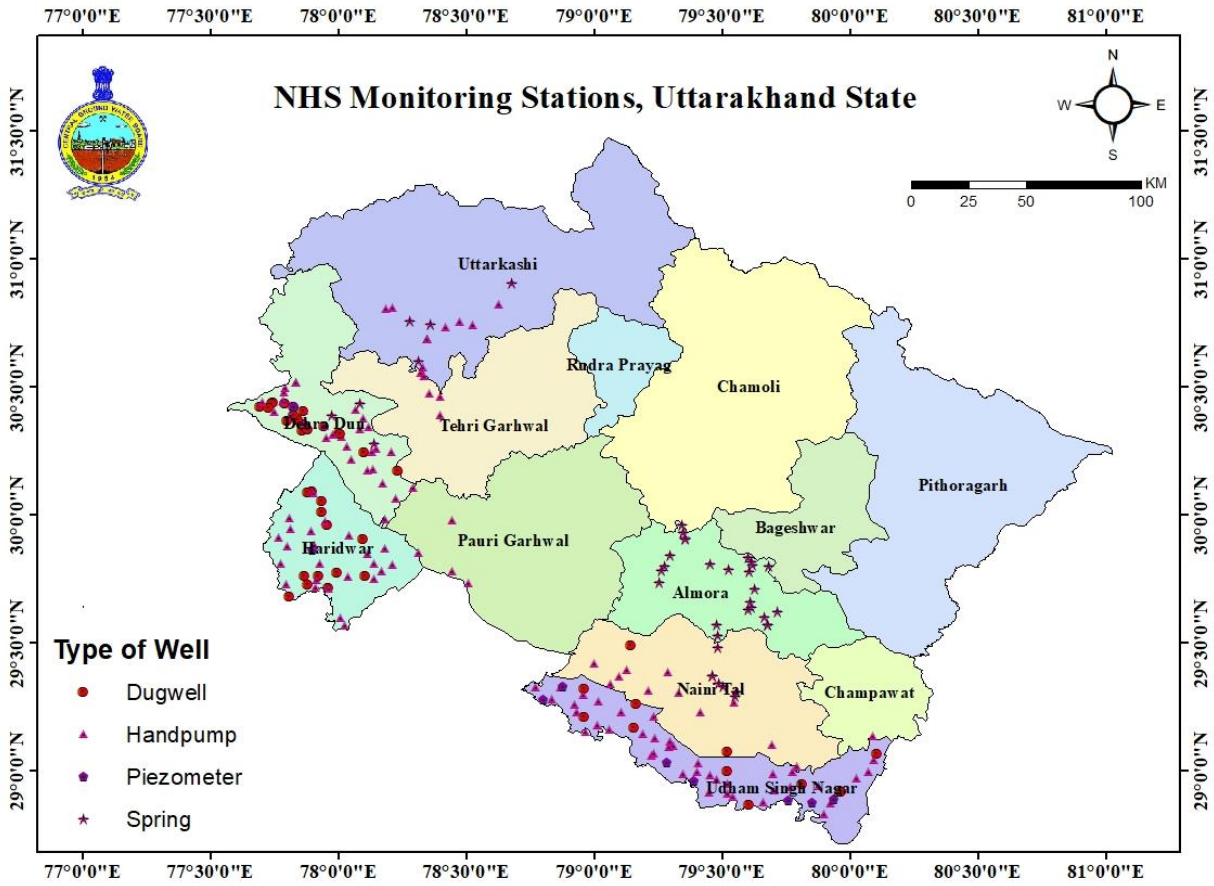


Fig. 6.1: Map showing Ground Water Monitoring stations during NHS Pre-monsoon 2023

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 **208** Groundwater Monitoring wells were monitored for water quality during May 2023 representing pre-monsoon water quality. The summarized results of groundwater quality ranges are given in **Table -7.1 .**

Table - 7.1. Summarized results of groundwater quality ranges, (May 2023)

S. No.	Parameter	Unit		Range		BIS standard for Drinking water	
			Average	Min	Max	Acceptable Limit	Permissible Limit
1	pH	……..	7.89	7.24	8.94	6.5-8.5	No relaxation
2	Specific Conductance	µS/cm @ 25^0C	538	103	2072	1000	3000
3	Chloride	mg/l	23.67	3.55	362.1	250	1000
4	Fluoride	mg/l	0.27	0	1.68	1	1.5
5	Nitrate	mg/l	8.04	0	168.9	45	No relaxation
6	Total hardness as $CaCO_3$	mg/l	207.57	25	650	200	600
7	Calcium	mg/l	47.96	4	156	75	200
8	Magnesium	mg/l	21.04	1.2	62.4	30	100
9	Sulphate	mg/l	35.08	0	700.6	200	400
10	Sodium	mg/l	27.94	0	372.5	-	-
11	Potassium	mg/l	4.33	0	82.1	-	-
12	Arsenic	ppb	2.07	0	92.2	10	No relaxation
13	Iron	mg/l	1.75	0	43.33	1	No relaxation
14	Uranium	ppb	0	0	30	30	No relaxation

Table - 7.2. Summarized results of groundwater quality ranges, (May 2023)

S. No	Parameters		Range	No. of sample	Percentage
1	Electrical Conductivity	Fresh	< 750	175	84.13
		Moderate	750- 2250	33	15.87

	µs/cm at 25°c	Slightly mineralized	2251- 3000	0	0.00
		Highly mineralized	> 3000	0	0.50
2	Chloride mg/L	Desirable limit	< 250	207	99.52
		Permissible limit	251-1000	1	0.48
		Beyond permissible limit	> 1000	0	0.00
3	Fluoride mg/L	Desirable limit	< 1.0	206	99.04
		Permissible limit	1.0 - 1.5	1	0.48
		Beyond permissible limit	>1.5	1	0.48
4	Nitrate mg/L	Permissible limit	< 45	203	97.60
		Beyond permissible limit	> 45	5	2.40

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 μS/cm at 25^0C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000 μS/cm at 25^0C) 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 μS/cm at 25^0C) 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.

Maximum EC value of 2072µS/cm at 25^0C observed at Maldeota Handpump of Dehradun district. It is apparent from the Fig. 8.1 and 8.2 that majority of the waters having EC values less than 750µS/cm at 25^0C in the state.

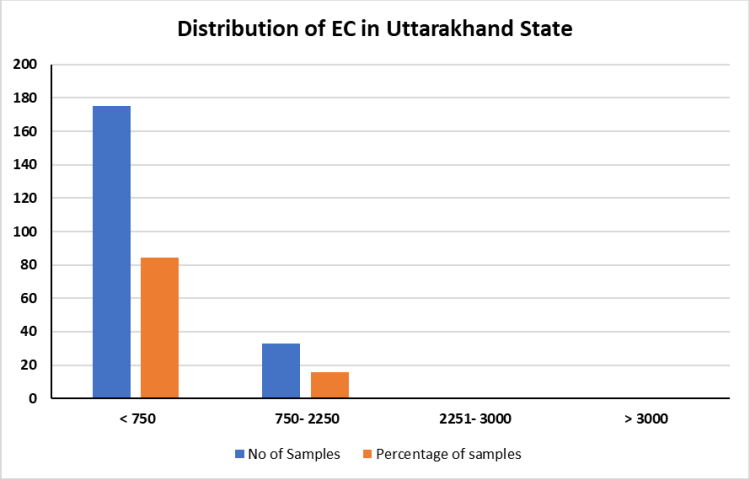


Fig. 8.1: Graph showing distribution of EC in the Uttarakhand State

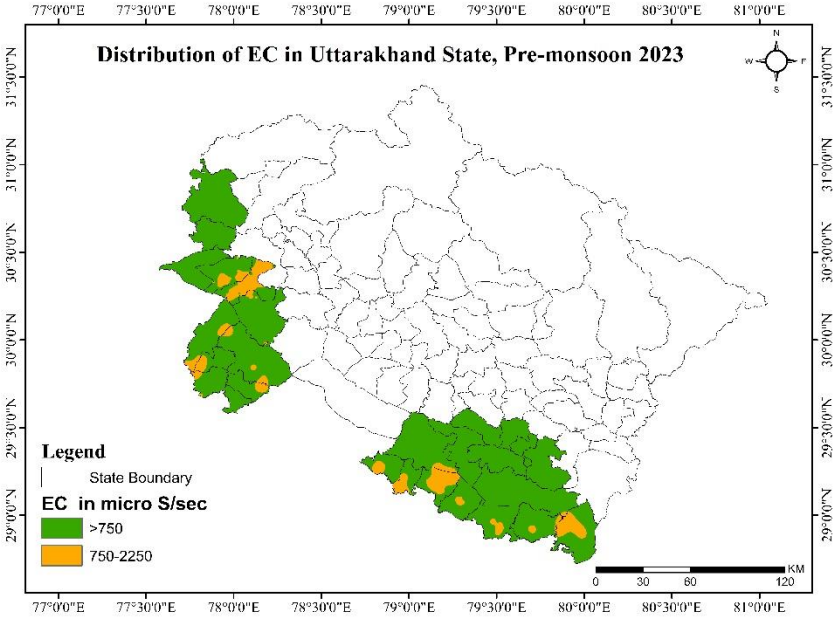


Fig. 8.2 Map showing distribution of EC in the Uttarakhand State

Groundwater with EC ranging between 750 and 2250 µS/cm at 25^0C falling under 'permissible' range are observed only in 33 samples.

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.

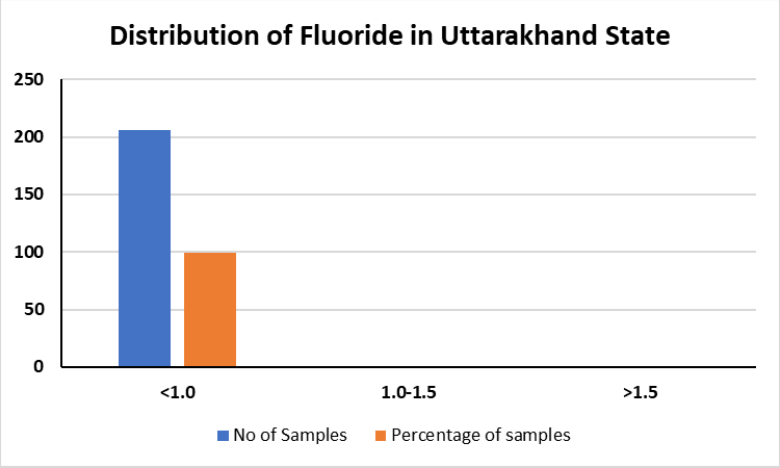


Fig. 8.3: Graph showing distribution of Fluoride in the Uttarakhand State

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 one sample (Jaspur of Udham Singh Nagar district) of the state (0.5% of the total) is showing fluoride concentration in the range of 1-1.5 mg/l. However, only one sample (Dhalnagaon of Chaukhutiya block of Almora district) is showing fluoride concentration more than 1.5 mg/l.

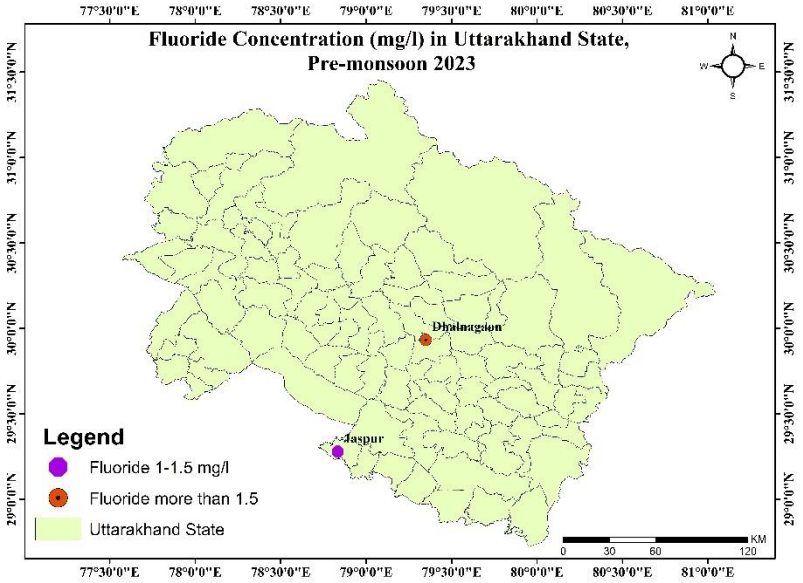


Fig. 8.4: Map showing distribution of Fluoride in the Uttarakhand State

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), Amberllte 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.

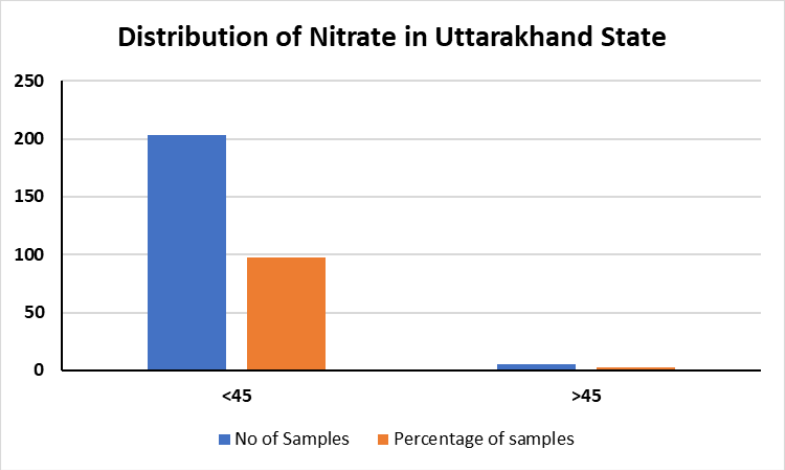


Fig. 8.5: Graph showing distribution of Nitrate in the Ground Water Samples of Uttarakhand State

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 five samples (2.4% of the total) of the state (Bandarjud, Bhikhampur of Haridwar district, Dharanaula spring of Almora district, and Kiccha and Sarasariya of Udham Singh Nagar district) showing nitrate concentration more than 45 mg/l.

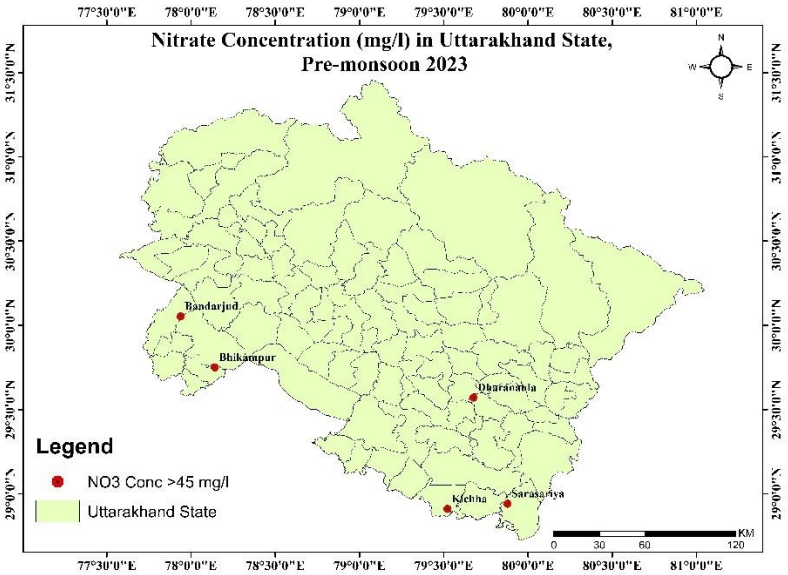


Fig. 8.6: Map showing distribution of Nitrate in the Ground Water Samples of Uttarakhand State

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 169 mg/l from Bandarjud of Haridwar 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 out of 206 sample (2021) ,4 samples out of 200 (2022) and 5 samples out of 208 (2023) 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-HCO_3 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 2023 is representing an increasing trend with a slope of 0.08 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 NO3**	**No. of locations affected by NO3**	**Total Number of samples analysed**	**% samples affected by NO3**
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
2023	3	5	208	2.4

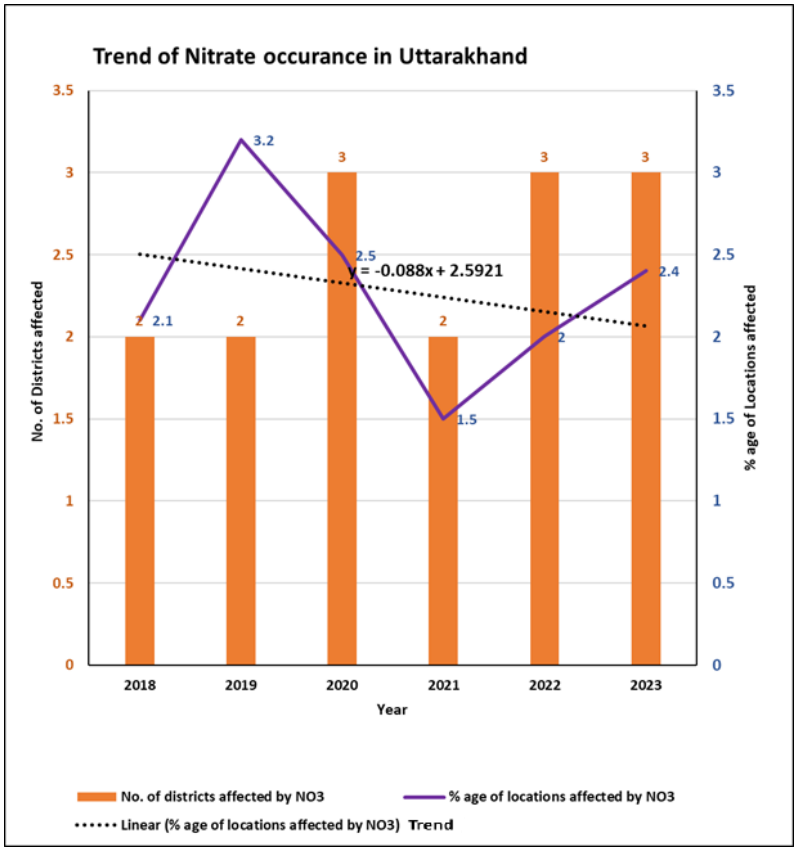


Fig. 8.7: Trend of Nitrate in shallow ground water of Uttarakhand (NHS-2018-2023)

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.

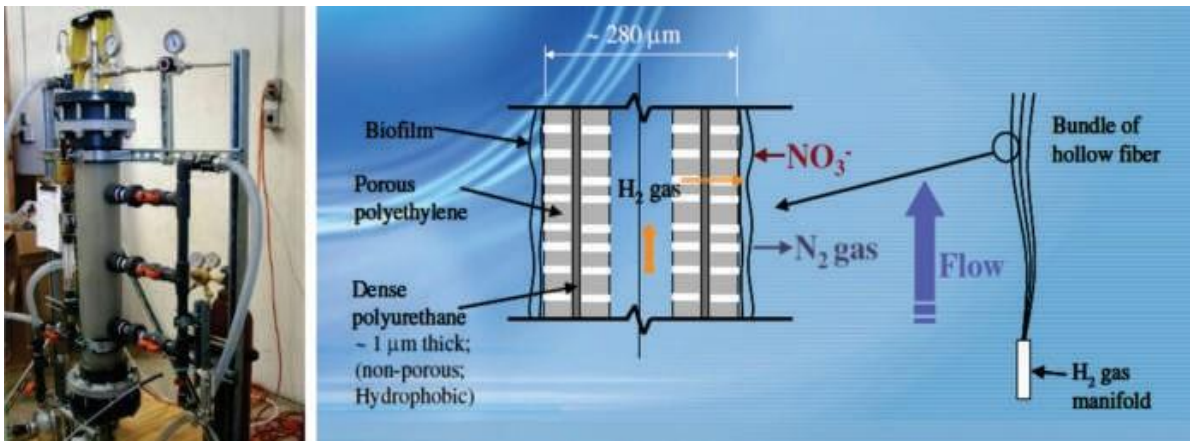


Fig. 8.8: Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

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	16	51	31.37
2	Haridwar	10	41	24.39
3	Pauri Garhwal	1	2	50.00
4	Almora	1	26	3.85
5	Udham Singh Nagar	7	46	15.22
6	Nainital	3	20	15.00
7	Champawat	3	4	75.00
8	Uttarkashi	2	13	15.38
9	Tehri Garhwal	1	5	20.00

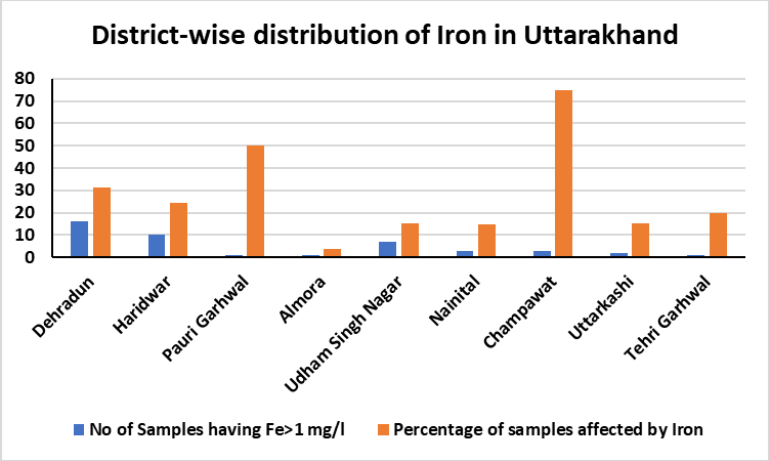


Fig. 8.9: Graph showing District-wise distribution of Iron in the Ground Water Samples of Uttarakhand State

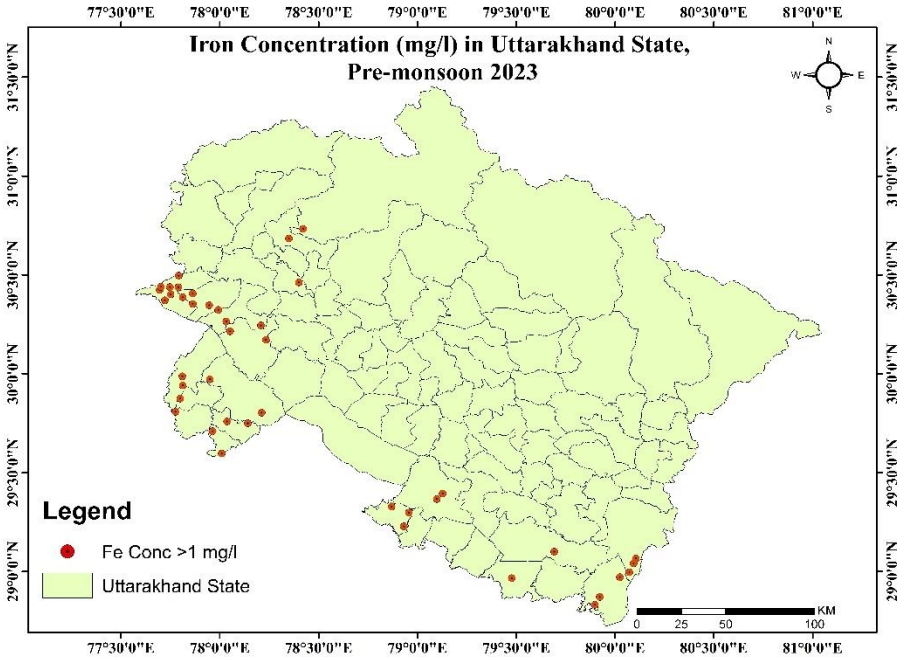


Fig. 8.10: Map showing District-wise distribution of Iron in the Ground Water Samples of Uttarakhand State

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), 43 samples out of 200 (2022) and 46 samples out of 208 samples analysed. Around 39% of the samples (from 2019 to 2023) is showing higher concentration of iron having trend with a slope of 5.7 degree. This may be due to rusting in the handpumps and poor well assembly. High Fe in shallow ground water of Uttarakhand shown in Fig. 8.9.

Table 8.2: Frequency distribution of Iron in shallow aquafer in Uttarakhand State (2019-2023)

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**
2023	**8**	**46**	208	**22.12**

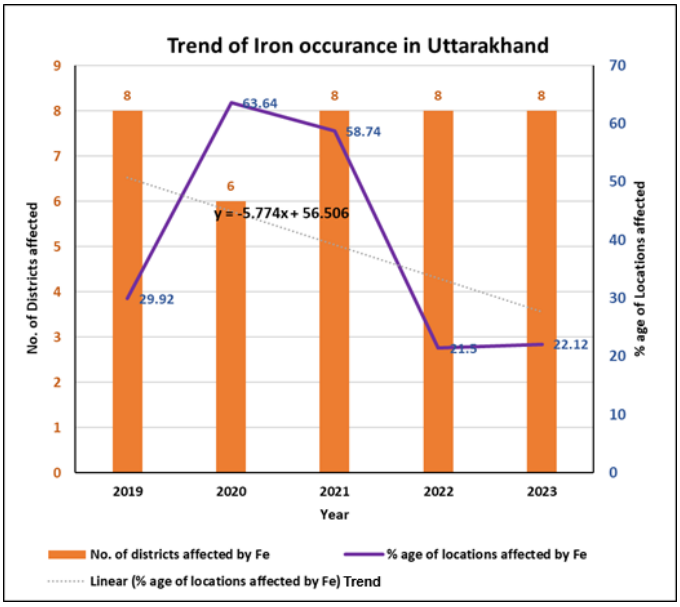


Fig. 8.11: Trend of Iron in shallow ground water of Uttarakhand (NHS2019-2023)

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 $Fe(OH)_3$. 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.

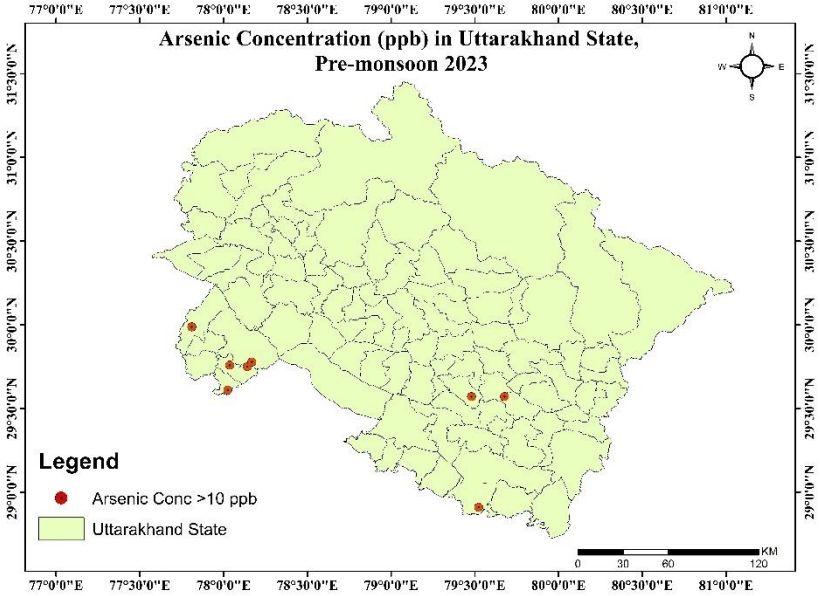


Fig. 8.12: Map showing District-wise distribution of Arsenic in the Ground Water Samples of Uttarakhand State

Table8.3 : 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	Haridwar	Laksar	Bhikampur
2	Almora	Hawalbagh	Dharanaula
3	Haridwar	Khanpur	Dallawala
4	Haridwar	Bhagwanpur	Bahabalpur
5	Haridwar	Bahadrabad	Bhogpur
6	Haridwar	Laksar	Laksar
7	Udham Singh Nagar	Rudrapur	Kichha
8	Almora	Tarikhet	Patali Talla

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),10 samples out of 200 (2022) and 8 samples out of 208 (2023) 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
2023	**3**	**8**	208	3.85

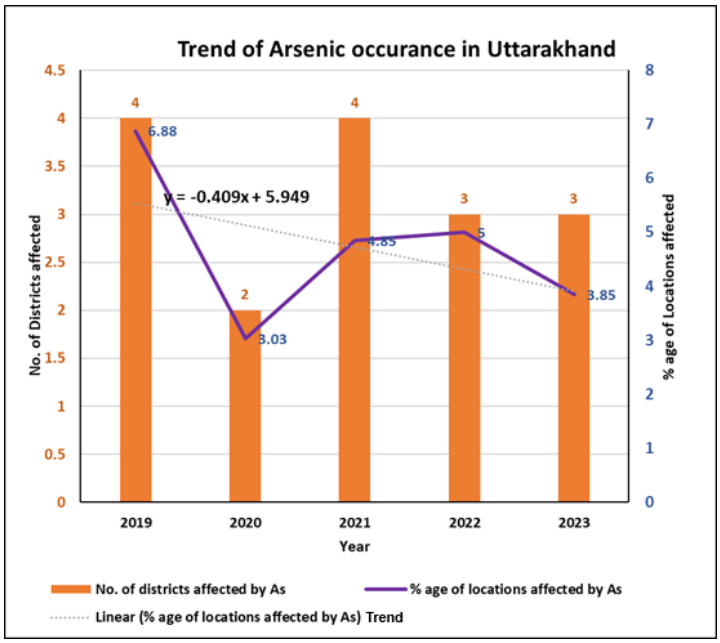


Fig. 8.13: Trend of Arsenic in shallow ground water of Uttarakhand (NHS2019-2023)

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 priory 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 electrodialysis 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 $CaCO_3$ 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 CaC03 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 number 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 locations 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=650 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

$Ca(HCO_3)_2$ + Mg Bicarbonate $Mg(HCO_3)_2$. Removal by Boiling or adding Lime

NON-CARBONATE (PERMANENT) HARDNESS

Calcium Sulfate $CaSO_4$ + Magnesium Sulfate $MgSO_4$ & Calcium Chloride $CaCl_2$ + Magnesium Chloride $MgCl_2$

Removal by Lime-soda, Zeolite or Demineralization Processes

9.0 SUITABILITY OF GROUNDWATER FOR IRRIGATION PURPOSE

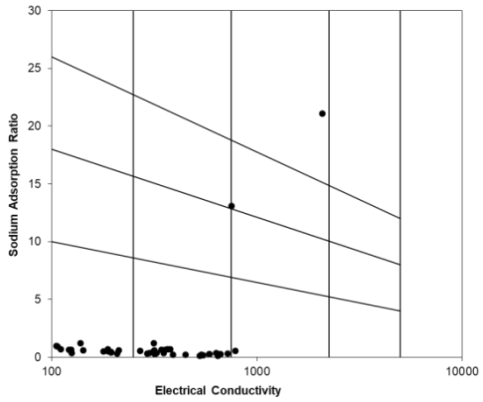
The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation purposes. Plants grown by irrigation absorb and transpire the water but leave nearly all the salts behind in the soil, where they accumulate and eventually prevent plant growth. Excessive 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.

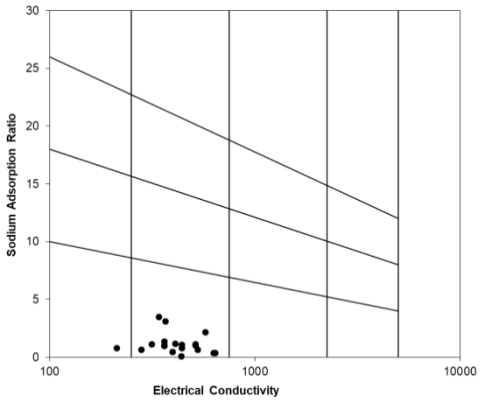
In addition to problems caused by excessive concentration of dissolved solids (TDS), certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations viz. Residual Sodium Carbonate (RSC). The potential hazards to crop growth are salinity,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

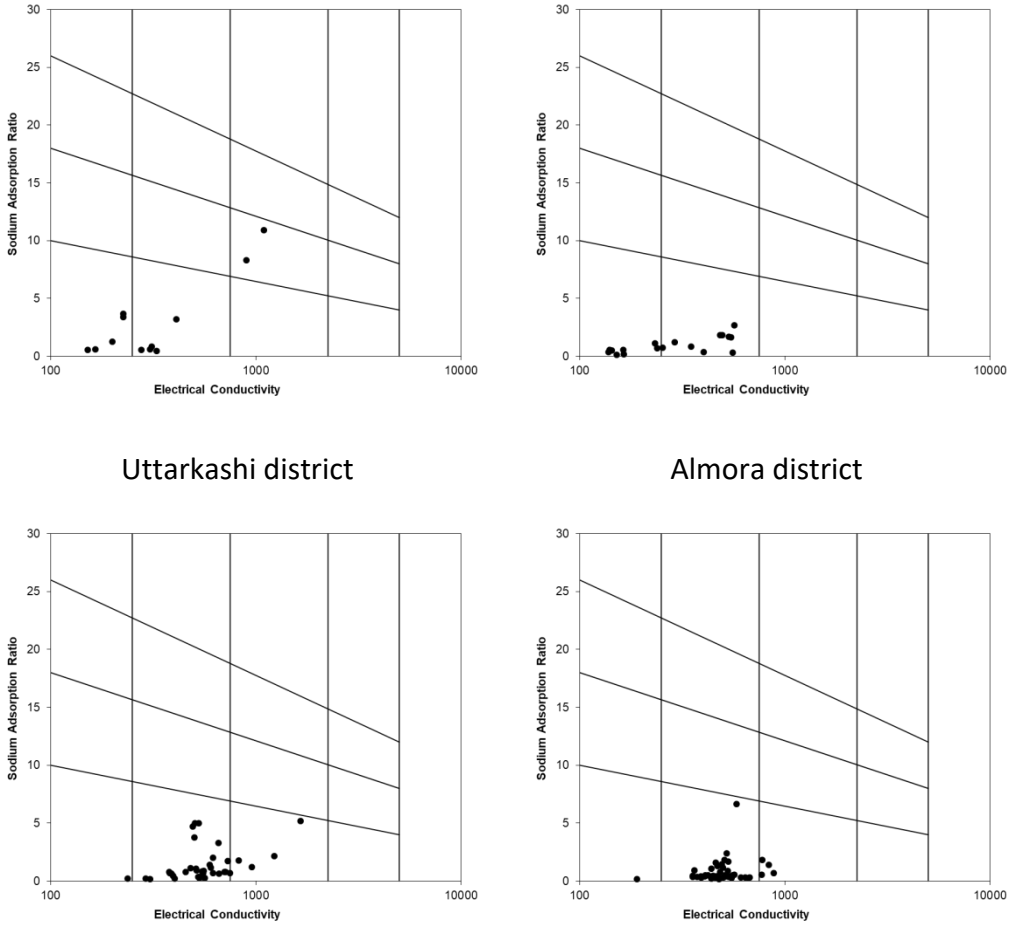


Fig 9.1: U S Salinity Diagram for the NHS pre monsoon-2023 samples of Uttarakhand state

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

$$RSC = (HCO3 + CO3) – (Ca + Mg)$$

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 94.23% samples.

Table 9.1: RSC range in the groundwater samples of Uttarakhand

RSC RANGE (meq/l)	NO OF SAMPLES	PERCENTAGE
<1.25	196	94.23
1.25-2.5	9	4.33
>2.5	3	1.44

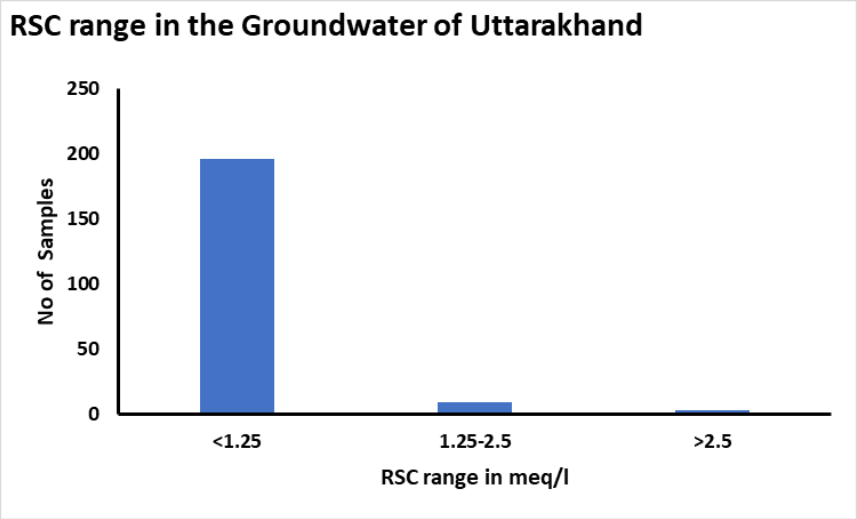


Fig 9.2: RSC range in Ground Water Samples of Uttarakhand

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 Mg^{2+} and Ca^{2+} 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	116	55.77
20-40	71	34.13

>40-60	16	7.69
>60-80	3	1.44
>80	2	0.96

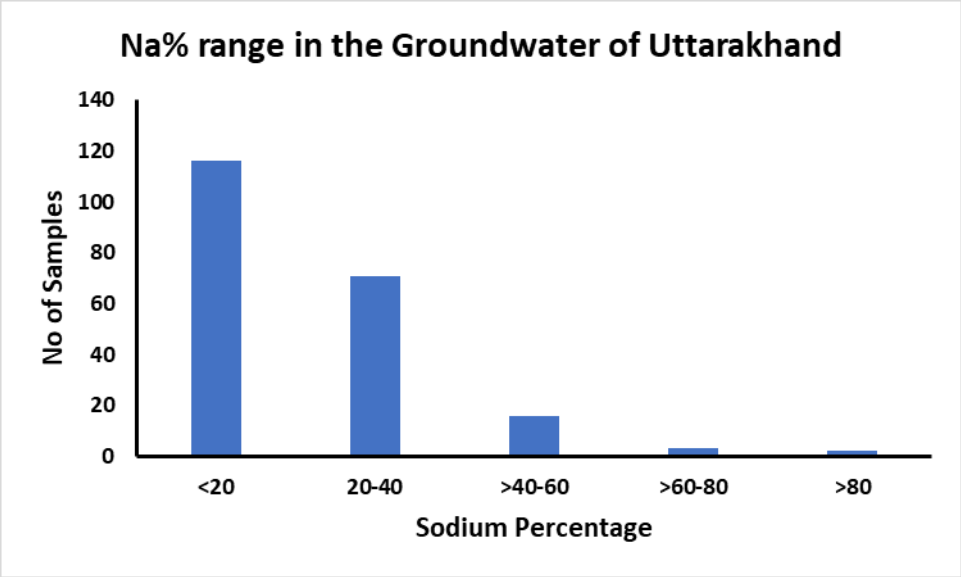


Fig 9.3: Na% range in Ground Water Samples of Uttarakhand

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	208	100

>10-18	0	0
>18-26	0	0
>26	0	0

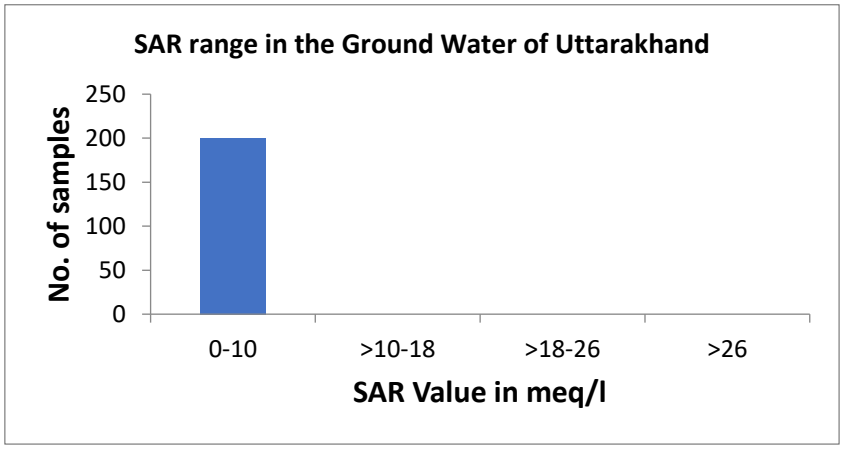


Fig 9.4: SAR range in Ground Water Samples of Uttarakhand

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.

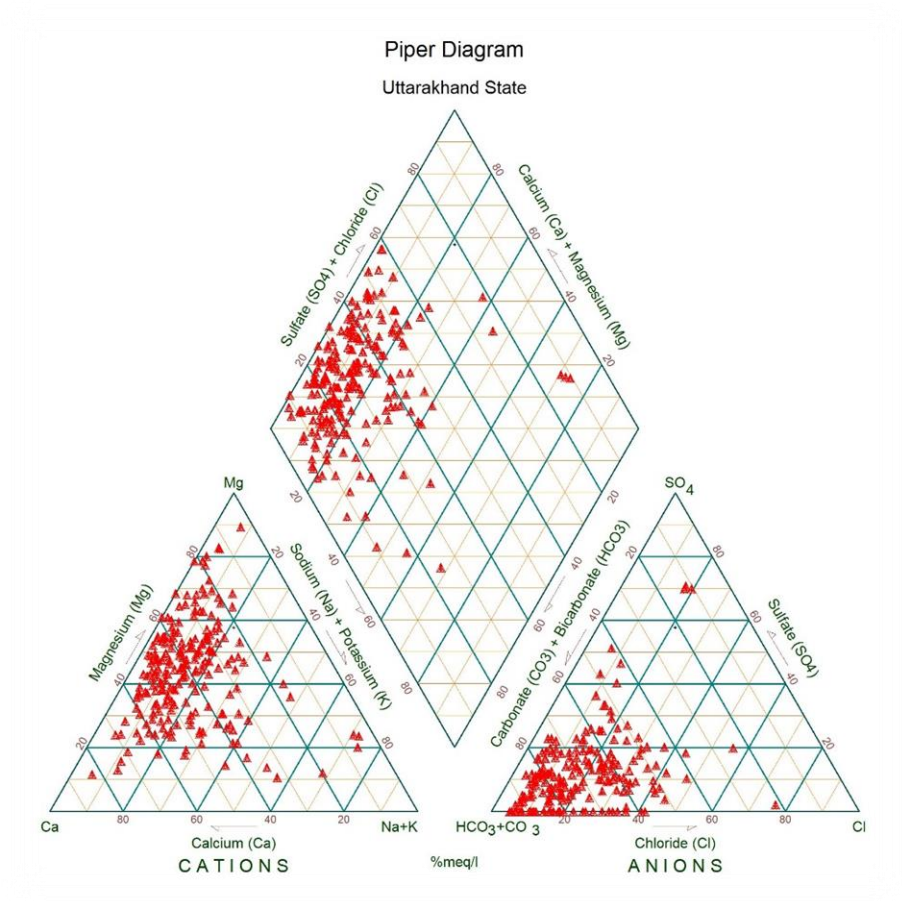


Fig. 10.1: Piper Diagram showing General Chemical Quality of Uttarakhand State

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 areidentified 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 inthis category
1	Alkaline earth (Ca+Mg) exceeds Alkalies(Na+K)	97.12
2	Alkalies exceeds alkaline earths	2.88
3	Weak acids (CO_3+HCO_3) exceed strongacids (SO_4+Cl)	99.0
4	Strong acids exceed weak acids	1.0
5	Magnesium bicarbonate type	90.38
6	Calcium chloride type	1.44
7	Sodium chloride type	1.44
8	Sodium bicarbonate type	0
9	Mixed type (No cation-anion exceed 50%)	6.74

From the above table, it can be easily inferred that the groundwater of Uttarakhand state is dominated by Ca-Mg cations and CO_3-HCO_3 anions with magnesium bicarbonate type of water.

10.1 Durov Diagram

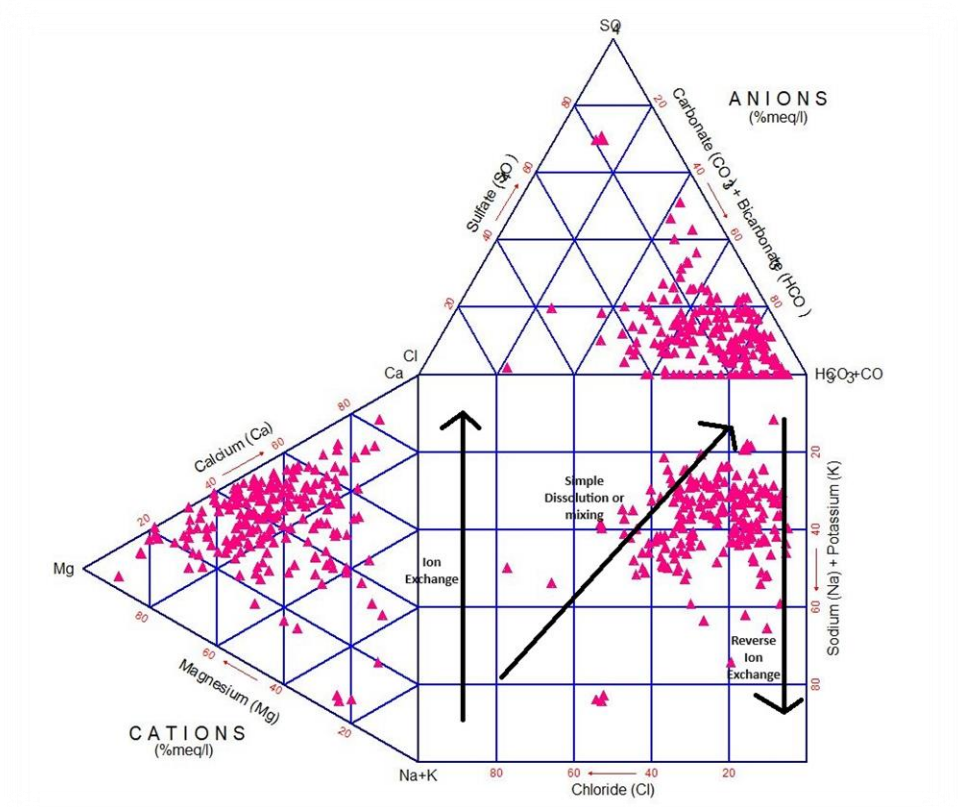


Fig 10.2: Durov Diagram showing dominating agents responsible for the chemical quality of Uttarakhand State

As per the Durov Plot, Majority of the samples of the Uttarakhand state are lying in the region of Reverse Ion Exchange dominated with Na-K cations and CO3-HCO3 anions while some of the samples (around 40%) are lying the zone of Simple Dissolution which indicated supremacy of weathering of rocks with some influence of evaporation-crystallisation i.e. showing recharging type of fresh water.

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-HCO_3 and Ca-HCO_3 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

The assignment was carried out under the overall supervision of Sh. Prashant Rai, Regional Director, CGWB, UR, Dehradun. The author is grateful to him for his consistent guidance and immense support. The authors express their sincere thanks to the chemists of CGWB, NR, Lucknow for analysis of water samples and officers of CGWB, UR, Dehradun who have carried out NHS monitoring of Dehradun District. Sincere thanks and appreciations also go to our colleagues who have willingly helped out with their abilities. Thanks are also due to Ms. Divya Verma, LDC for the typological work and overall formatting of the report.

REFRENCES

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, Washighton DC, USA, 1954.

ANNEXURE 1: Ground Water Chemical Quality Data of Uttarakhand State for Pre-monsoon 2023

S. No.	District	Block	Location	pH	EC µS/cm at 25°C	Ca	Mg	Na	K	CO_3	HCO_3	Cl	F	NO_3	SO_4	TH	SiO_2	PO_4
1	Haridwar	Bahadrabad	Bhoopatwala	7.99	784	72	38	41	4.0	0	354	43	0.13	18	45	340	24	0
2	Haridwar	Bahadrabad	Shyampur	7.87	655	84	26	17	2.8	0	281	36	0.00	27	38	320	20	0
3	Haridwar	Bahadrabad	Rasiyabad Churaha	7.91	573	76	20	18	1.5	0	268	21	0.00	0	49	275	24	0
4	Haridwar	Bahadrabad	Dallupuri	7.86	597	92	12	12	1.9	0	323	14	0.00	5.4	33	280	19	0
5	Haridwar	Bahadrabad	Laldhang	7.93	695	100	17	27	2.4	0	317	21	0.00	24	57	320	15	0
6	Haridwar	Bhagwanpur	Iqbalpur	7.89	1413	156	62	38	9.1	0	537	107	0.19	0	160	650	28	0
7	Haridwar	Narsan	Jhabreda	7.97	1046	100	28	55	7.1	0	403	121	0.11	0	18	365	29	0
8	Haridwar	Narsan	Lakhnauta	8.38	437	40	22	18	2.7	15	189	14	0.39	0	0	190	29	0
9	Haridwar	Narsan	Gurukul Narsen	8.25	419	60	9.6	6.6	3.2	0	189	18	0.24	0	36	190	27	0
10	Haridwar	Roorkee	Khera Jat	8.15	794	64	43	39	9.6	0	342	64	0.00	7.9	49	340	39	0
11	Haridwar	Narsan	Libhrahedi	8.24	474	56	19	9.0	5.8	0	171	36	0.10	9.5	37	220	21	0
12	Haridwar	Bahadrabad	Sarai	7.61	537	64	19	16	3.3	0	220	32	0.46	36	38	240	22	0
13	Haridwar	Bahadrabad	Bahadrabad	7.86	494	72	17	10	0.0	0	220	28	0.56	22	32	250	15	0
14	Haridwar	Roorkee	Malakpur Majra	8.20	628	52	11	72	2.2	0	293	71	0.81	0	0	175	23	0
15	Haridwar	Roorkee	Roorkee	8.17	412	28	17	37	2.8	0	183	28	0.69	0	20	140	25	0
16	Haridwar	Narsan	Landhaura	7.81	562	48	25	37	3.1	0	299	21	0.59	14	12	225	32	0

17	Haridwar	Roorkee	Sikhar	7.72	453	52	24	6.9	3.2	0	244	7.1	0.52	13	23	230	29	0
18	Haridwar	Narsan	Mudlana	8.08	359	56	3.6	11	3.6	0	195	7.1	0.70	0	18	155	24	0
19	Haridwar	Roorkee	Nizampur	7.72	448	64	14	7.1	3.3	0	232	14	0.47	8.5	28	220	30	0
20	Haridwar	Laksar	Hussainpur	7.96	648	40	4.8	90	3.6	0	360	21	0.56	0	8.4	120	23	0
21	Haridwar	Laksar	Laksar	7.81	597	48	12	56	4.2	0	323	11	0.42	0	30	170	21	0
22	Haridwar	Khanpur	Govardhanpur	7.78	619	24	19	89	4.8	0	366	14	0.32	0	0	140	18	0
23	Haridwar	Khanpur	Khanpur	8.06	497	36	12	56	8.0	0	305	14	0.66	0	0	140	17	0
24	Haridwar	Khanpur	Dallawala	8.10	421	16	3.6	71	5.3	0	214	14	0.61	0	17	55	19	0
25	Haridwar	Bahadrabad	Jassodharpur	7.82	612	60	31	19	3.2	0	293	28	0.60	13	42	280	18	0
26	Haridwar	Bahadrabad	Shahpur Shitlakhera	7.83	606	60	34	12	5.8	0	305	21	0.69	11	39	290	17	0
27	Haridwar	Bahadrabad	Bhogpur	7.49	881	92	19	34	82	0	390	57	0.57	12	60	310	22	0
28	Haridwar	Laksar	Bhikampur	7.95	953	72	30	74	42	0	403	78	0.63	68	5.3	305	19	0
29	Haridwar	Bahadrabad	Dhanpura	7.76	845	64	34	51	33	0	299	71	0.49	38	50	300	22	0
30	Haridwar	Bahadrabad	Panjanheri	7.77	478	56	19	15	4.9	0	220	28	0.47	9.2	32	220	12	0
31	Haridwar	Bhagwanpur	Chudiala	8.02	491	36	25	31	2.8	0	256	21	0.89	0	13	195	23	0
32	Haridwar	Bhagwanpur	Bhagwanpur	8.14	581	40	19	55	1.4	0	317	14	0.56	0	0	180	22	0
33	Haridwar	Bhagwanpur	Bahabalpur	8.05	741	84	13	42	2.2	0	439	11	0.50	0	0	265	19	0
34	Haridwar	Roorkee	Imlikhera	8.09	628	32	29	48	1.7	0	366	14	0.86	0	0	200	17	0
35	Haridwar	Bhagwanpur	Jaswawala	7.70	656	56	25	40	16	0	342	28	0.66	10	0	245	24	0
36	Haridwar	Bhagwanpur	Kota Muradnagar	7.70	688	52	37	37	2.3	0	378	21	0.48	0	9.9	285	24	0
37	Haridwar	Bahadrabad	Rathora	7.69	690	60	29	41	1.6	0	378	21	0.67	0	0	270	25	0
38	Haridwar	Bahadrabad	Bandarjud	7.38	1161	124	24	59	22	0	305	92	0.43	169	50	410	19	0
39	Haridwar	Bhagwanpur	Bugawala	7.64	586	80	19	9.6	1.5	0	329	14	0.41	20	0	280	20	0

40	Haridwar	Bhagwanpur	Sahidwala Grant	7.75	526	76	9.6	7.9	1.2	0	250	14	0.43	35	5.0	230	18	0
41	Haridwar	Bhagwanpur	Budhwa Shahid	7.61	487	60	23	8.3	1.3	0	262	11	0.45	22	0	245	21	0
42	Almora	Hawalbagh	Itola	7.84	165	18	2.4	12	1.1	0	73	11	0.00	0	0	55	23	0
43	Almora	Hawalbagh	Bhagtola	7.62	180	20	2.4	13	0.0	0	92	7.1	0.00	0	0	60	21	0
44	Almora	Someshwar	Mehergaon	7.39	112	12	3.6	5.1	0.0	0	55	7.1	0.00	0	0	45	10	0
45	Almora	Someshwar	Bhoolgaon	7.99	821	66	36	33	18	0	390	28	0.25	35	15	315	12	0
46	Almora	Takula	Chanoda	7.74	287	22	19	3.3	0.0	0	140	7.1	0.00	0	12	135	15	0
47	Almora	Takula	Guruda	7.37	144	12	9.6	0.0	0.0	0	67	11	0.13	0	0	70	9.0	0
48	Almora	Takula	Channi Bartola	8.09	115	12	3.6	4.4	1.3	0	55	7.1	0.00	0	0	45	10	0
49	Almora	Tarikhet	Golucheena	7.62	235	28	4.8	10	4.4	0	122	7.1	0.16	0	7.3	90	24	0
50	Almora	Hawalbagh	Jholi	8.81	160	12	2.4	15	2.0	12	31	14	0.00	0	9.0	40	21	0
51	Almora	Hawalbagh	Katarmal	7.31	291	28	7.2	18	5.1	0	73	28	0.00	23	22	100	31	0
52	Almora	Tarikhet	Baniyadiggi	8.62	227	22	3.6	18	0.0	6	79	14	0.31	0	6.2	70	20	0
53	Almora	Tarikhet	Patali Talla	7.91	317	40	6.0	14	1.8	0	146	14	0.16	5.9	12	125	17	0
54	Almora	Tarikhet	Patali Malla	8.02	415	52	9.6	16	1.1	0	171	21	0.00	20	16	170	17	0
55	Almora	Hawalbagh	Dharanaula	7.30	597	44	7.2	65	12	0	92	71	0.00	77	47	140	28	0
56	Almora	Hawalbagh	Palna	8.07	147	12	3.6	13	1.9	0	55	11	0.15	6.2	5.3	45	33	0
57	Almora	Takula	Paitsaal	7.24	127	8.0	1.2	15	2.1	0	55	7.1	0.00	0	5.2	25	32	0
58	Almora	Someshwar	Dudholi	7.54	103	10	3.6	4.6	0.0	0	43	7.1	0.00	0	0	40	9.0	0
59	Almora	Someshwar	Lodh	8.88	174	14	8.4	6.9	0.0	12	54	7.1	0.00	0	5	70	20	0
60	Almora	Chaukhutiya	Peepal Dhar	7.69	485	48	28	0.0	0.0	0	268	11	0.00	0	0	235	10	0
61	Almora	Chaukhutiya	Dhalnagaon	7.97	594	38	23	41	10	0	275	25	1.7	0	17	190	11	0
62	Almora	Chaukhutiya	Simalkhet	8.07	380	40	19	3.7	1.6	0	189	14	0.00	13	5.2	180	9.0	0

63	Almora	Chaukhutiya	Dhansari	8.05	412	40	24	2.4	0.0	0	232	7.1	0.00	0	0	200	9.0	0
64	Almora	Chaukhutiya	Deepakot	8.68	227	20	2.4	23	1.7	6	55	21	0.21	8.1	5.6	60	38	0
65	Almora	Bhikiasain	Ramghat	7.57	255	24	4.8	19	2.8	0	92	18	0.25	0	17	80	25	0
66	Almora	Someshwar	Deghat	8.91	125	12	2.4	9.6	0.0	9	24	3.6	0.00	0	5.5	40	23	0
67	Almora	Bhikiasain	Naula	8.94	555	48	12	46	11	21	134	32	0.20	19	29	170	26	0
68	Champawat	Champawat	Tanakpur	7.43	610	68	22	20	0.0	0	293	21	0.13	16	18	260	21	0
69	Champawat	Champawat	Banbasa	7.89	505	60	17	12	2.6	0	220	21	0.00	0	30	220	24	0
70	Champawat	Champawat	Bastia	7.73	539	92	4.8	7.9	1.2	0	293	7.1	0.15	7.4	8.7	250	20	0
71	Champawat	Champawat	Bichai	7.71	614	64	31	6.7	2.3	0	354	7.1	0.00	0	5.0	290	24	0
72	Nainital	Ramnagar	Belprao	7.75	718	52	46	16	1.5	0	354	7.1	0.15	0	53	320	22	0
73	Nainital	Ramnagar	Dohniya	7.86	328	12	29	5.7	1.2	0	116	11	0.00	0	46	150	0	0
74	Nainital	Haldwani	Kaladhungi	7.74	654	56	41	6.4	1.3	0	305	14	0.11	0	48	310	16	0
75	Nainital	Haldwani	Lamachaur	8.18	307	28	12	12	1.1	0	159	7.1	0.00	0	0	120	5.0	0
76	Nainital	Haldwani	Kathgodam	7.95	695	88	9.6	37	4.4	0	342	14	0.16	16	24	260	15	0
77	Nainital	Bhimtal	Ranibagh	7.84	399	44	17	8.1	1.7	0	207	14	0.14	0	8.7	180	31	0
78	Nainital	Bhimtal	Salari	8.12	284	32	12	3.7	1.8	0	140	7.1	0.00	0	8.1	130	15	0
79	Nainital	Bhimtal	Dgaon	7.74	414	40	16	16	1.6	0	214	7.1	0.00	0	8.3	165	14	0
80	Nainital	Bhimtal	Jyolikot	7.84	371	36	14	15	2.8	0	159	14	0.00	14	24	150	12	0
81	Nainital	Bhimtal	Kudaghat	8.17	536	32	43	0.0	0.0	0	256	7.1	0.00	5.4	43	260	5.0	0
82	Nainital	Bhimtal	Sipahi dhara	8.26	670	24	58	10	3.1	0	207	21	0.00	7.4	114	300	7.0	0
83	Nainital	Bhimtal	Garam Pani	7.88	213	20	12	2.1	0.0	0	104	7.1	0.00	0	0	100	10	0
84	Nainital	Haldwani	Khaat Baans	7.42	630	64	14	39	7.9	0	329	21	0.21	16	0	220	11	0

85	Nainital	Haldwani	Lalkuan	7.84	717	80	22	29	2.7	0	342	14	0.20	21	32	290	28	0
86	Nainital	Ramnagar	Peeru Madara	7.89	524	60	17	18	1.6	0	268	14	0.00	7.0	16	220	22	0
87	Nainital	Ramnagar	Chilkiya	8.05	480	36	29	12	2.5	0	232	14	0.00	0	17	210	14	0
88	Nainital	Ramnagar	Maldhan Colony	8.08	534	52	19	25	0.0	0	305	7.1	0.39	0	6.1	210	24	0
89	Nainital	Ramnagar	Dhela	7.47	592	48	14	53	1.1	0	317	14	0.13	0	14	180	21	0
90	Nainital	Ramnagar	Ram Nagar	7.55	667	46	40	22	3.6	0	366	11	0.00	0	0	280	17	0
91	Nainital	Ramnagar	Garjiya	7.90	480	60	12	17	2.3	0	220	18	0.18	5.1	27	200	12	0
92	Dehradun	Raipur	Kanwali	7.80	447	20	31	25	1.3	0	171	39	0.37	0	45	180	0	0
93	Dehradun	Raipur	Kuanwala	7.78	761	92	38	4.7	1.4	0	256	14	0.46	12	141	390	11	0
94	Dehradun	Raipur	Niranjanpur	7.63	973	112	43	31	1.1	0	427	50	0.48	38	70	460	25	0
95	Dehradun	Raipur	Harbanswala	7.86	561	52	32	10	0.0	0	287	18	0.36	0	43	265	7.7	0
96	Dehradun	Raipur	Tarla Nagal	8.04	629	72	32	4.6	0.0	0	336	21	0.47	12	25	315	16	0
97	Dehradun	Raipur	Nanurkhera	8.35	1975	16	34	363	9.5	12	134	92	0.88	0	689	180	0	0
98	Dehradun	Raipur	Maldeota	8.39	2072	24	29	373	9.6	6	146	107	0.88	0	701	180	0	0
99	Dehradun	Raipur	Gularghagti	7.90	783	92	43	5.0	1.4	0	250	14	0.45	12	191	410	12	0
100	Dehradun	Raipur	Ladpur	8.32	2004	20	34	347	9.7	12	146	92	0.82	0	673	190	0	0
101	Dehradun	Raipur	Soda Saroli	8.35	292	20	12	15	1.5	6	73	11	0.35	5.2	37	100	21	0
102	Dehradun	Raipur	Bhopalpani	8.13	374	36	19	16	1.1	0	183	14	0.37	0	23	170	31	0
103	Dehradun	Raipur	Rishikesh	7.99	416	44	22	8.5	1.2	0	195	14	0.48	6.0	41	200	19	0
104	Dehradun	Doiwala	Lal Tappar	8.07	470	40	31	7.0	1.3	0	207	21	0.42	0	57	230	9.3	0
105	Dehradun	Doiwala	Duggiawala	7.68	288	20	18	14	0.0	0	134	14	0.46	0	16	125	17	0

106	Dehradun	Doiwala	Khandgaon	8.13	398	40	22	7.0	1.3	0	159	14	0.41	0	62	190	9.4	0
107	Dehradun	Doiwala	Kotimachak	7.75	198	16	11	11	0.0	0	98	14	0.57	0	0	85	13	0
108	Dehradun	Doiwala	Khadiri	7.86	406	40	14	23	1.1	0	159	21	0.43	28	31	160	29	0
109	Dehradun	Doiwala	Bhaniawala	7.95	430	52	19	7.5	1.0	0	195	14	0.50	7.3	43	210	20	0
110	Dehradun	Doiwala	Mathrowala	7.97	742	84	34	16	2.2	0	305	36	0.39	0	105	350	11	0
111	Dehradun	Doiwala	Chandmari	8.12	700	84	31	4.5	1.6	0	220	21	0.36	0	153	340	15	0
112	Dehradun	Sahaspur	Rampura	7.38	281	32	10	11	1.0	0	104	14	0.37	17	32	120	31	0
113	Dehradun	Sahaspur	Jhajra	7.54	276	28	12	13	1.1	0	134	21	0.46	0	0	120	27	0
114	Dehradun	Sahaspur	Selakui	7.40	275	20	16	16	1.1	0	116	21	0.41	0	11	115	36	0
115	Dehradun	Sahaspur	Selakui	7.24	287	24	14	15	0.0	0	116	21	0.42	13	11	120	31	0
116	Dehradun	Sahaspur	Nanda ki Chowki	7.78	1645	124	31	161	2.3	0	305	362	0.38	0	19	440	12	0
117	Dehradun	Sahaspur	Redapur	7.30	439	44	8.4	35	1.0	0	201	36	0.43	0	0	145	24	0
118	Dehradun	Sahaspur	Shankarpur	7.74	186	16	8.4	13	0.0	0	67	14	0.39	7.1	16	75	39	0
119	Dehradun	Sahaspur	Baronwala	7.86	650	68	34	8.6	0.0	0	268	21	0.34	20	72	310	21	0
120	Dehradun	Sahaspur	Chhorba	7.67	185	12	10	13	0.0	0	85	14	0.35	5.1	5.7	70	37	0
121	Dehradun	Sahaspur	Telpura	7.73	745	96	36	8.4	0.0	0	366	21	0.43	7.8	60	390	19	0
122	Dehradun	Sahaspur	Sahaspur	7.28	215	16	10	13	0.0	0	98	14	0.31	0	0	80	28	0
123	Dehradun	Sahaspur	Purukulgaon	7.88	432	52	17	7.8	0.0	0	165	11	0.48	0	70	200	20	0

124	Dehradun	Sahaspur	Khandoli	7.67	140	8.0	9.6	5.9	1.0	0	61	14	0.37	0	0	60	30	0
125	Dehradun	Sahaspur	Bhatta	8.06	528	32	48	4.8	0.0	0	220	21	0.39	0	60	280	8.5	0
126	Dehradun	Vikasnagar	Herbertpur	7.55	323	40	13	6.4	2.6	0	134	14	0.32	7.0	25	155	16	0
127	Dehradun	Vikasnagar	Dharmawala	7.75	335	32	14	12	1.1	0	159	18	0.46	5.1	0	140	44	0
128	Dehradun	Vikasnagar	Sabhawala	8.65	381	24	22	18	8.3	18	61	21	0.42	33	21	150	12	0
129	Dehradun	Vikasnagar	Singhniwala	7.96	761	88	41	10	1.3	0	354	21	0.45	17	77	390	24	0
130	Dehradun	Vikasnagar	Ramgarh	7.83	790	92	36	9.6	1.1	0	348	25	0.43	17	88	380	23	0
131	Dehradun	Vikasnagar	Judli	7.69	483	44	22	16	0.0	0	281	7.1	0.42	0	0	200	28	0
132	Dehradun	Vikasnagar	Badripur	8.09	380	4.0	38	11	0.0	0	220	7.1	0.00	0	7.4	170	24	0
133	Dehradun	Vikasnagar	Vikas Nagar	7.47	235	36	3.6	7.7	1.1	0	85	14	0.00	8.1	23	105	28	0
134	Dehradun	Vikasnagar	Dakpatthar	7.87	413	44	17	21	1.8	0	220	21	0.00	0	15	180	13	0
135	Dehradun	Vikasnagar	Barothiwala new Jan 2021	7.82	175	16	7.2	11	0.0	0	73	14	0.00	6.2	7.1	70	34	0
136	Dehradun	Vikasnagar	Dhakrani	7.92	190	16	12	5.5	1.1	0	79	11	0.00	0	20	90	11	0
137	Dehradun	Vikasnagar	Timli	7.49	271	28	13	8.6	2.7	0	146	14	0.00	0	0	125	20	0
138	Dehradun	Vikasnagar	Baluwala	8.67	241	24	9.6	9.9	0.0	18	41	14	0.00	5.9	16.6	100	34	0
139	Dehradun	Vikasnagar	Luxmipur	7.49	153	12	7.2	9.8	0.0	0	73	14	0.00	0	0	60	20	0
140	Dehradun	Vikasnagar	Dudhli	7.91	326	40	9.6	14	1.2	0	183	18	0.00	0	0	140	9.1	0
141	Dehradun	Vikasnagar	Jamuna Pull	7.40	258	20	17	8.6	1.2	0	73	21	0.00	29	21	120	27	0
142	Dehradun	Vikasnagar	Haripur	8.35	378	56	7.2	15	2.3	18	85	21	0.00	12	27	170	20	0

143	Uttarkashi	Chinyalisaur	Chinyalisaur	7.89	440	40	12	31	11	0	171	36	0.00	33	18	150	22	0
144	Uttarkashi	Chinyalisaur	Dharasu	8.31	399	52	12	13	7.9	18	146	14	0.21	0	13	180	20	0
145	Uttarkashi	Chinyalisaur	Nagal	8.02	204	28	7.2	3.3	0.0	0	98	18	0.00	0	6.3	100	15	0
146	Uttarkashi	Dunda	Devidhar	7.76	293	32	12	11	0.0	0	165	14	0.18	0	7.0	130	18	0
147	Uttarkashi	Dunda	Ratodi Sar	7.81	197	24	7.2	3.6	2.1	0	85	14	0.00	5.7	9.3	90	20	0
148	Uttarkashi	Dunda	Dunda	8.11	394	48	17	4.3	3.4	0	220	7.1	0.18	0	19	190	19	0
149	Uttarkashi	Naugaon	Barkot	8.03	389	60	4.8	12	0.0	0	226	14	0.00	0	0	170	18	0
150	Uttarkashi	Naugaon	Sharukhet	7.69	285	28	12	16	1.5	0	110	28	0.11	9.8	13	120	18	0
151	Uttarkashi	Bhatwari	Uttarkashi	7.31	415	40	17	22	7.1	0	195	28	0.00	0	18	170	15	0
152	Uttarkashi	Bhatwari	Ganeshpur	7.64	358	48	12	7.6	4.1	0	159	14	0.23	0	30	170	12	0
153	Uttarkashi	Bhatwari	Maneri	8.00	180	20	8.4	3.1	2.6	0	73	14	0.00	0	7.1	85	17	0
154	Uttarkashi	Bhatwari	Charethi	8.22	240	28	9.6	6.2	4.2	0	116	18	0.31	0	12	110	14	0
155	Uttarkashi	Bhatwari	Ganganani Spring *	8.71	255	32	9.6	2.9	3.7	24	64	14	0.34	0	11	120	9.0	0
156	Tehri Garhwal	Tehri Garhwal	Chinyaligaud	8.25	257	32	4.8	10	0.0	0	122	18	0.13	0	0	100	5.1	0
157	Tehri Garhwal	Tehri Garhwal	Uniyalgaon	8.50	452	48	22	16	1.7	18	183	14	0.43	0	10	210	14	0
158	Tehri Garhwal	Tehri Garhwal	Kotidobhal	8.21	336	48	9.6	7.7	0.0	0	171	14	0.00	5.5	5.1	160	19	0
159	Tehri Garhwal	Tehri Garhwal	Kunar Valley	8.33	320	32	18	4.8	0.0	18	110	14	0.15	0	0	155	10	0
160	Tehri Garhwal	Tehri Garhwal	Dharkut	7.98	384	40	9.6	26	0.0	0	110	43	0.11	38	17	140	22	0
161	Pauri Garhwal	Dugadda	Trilokpur	7.66	252	28	7.2	11	1.8	0	122	14	0.00	0	0	100	14	0

162	Pauri Garhwal	Dugadda	Kaudia Kotdwar	7.38	602	84	12	19	1.5	0	281	21	0.00	18	28	260	12	0
163	Udham Singh Nagar	Khatima	Kanchanpur (Majhola) HP	7.84	687	64	22	41	2.7	0	403	7.1	0.26	0	0	250	31	0
164	Udham Singh Nagar	Khatima	Khatima	7.77	1054	80	22	93	22	0	403	78	0.50	40	29	290	30	0
165	Udham Singh Nagar	Khatima	Sarasariya	7.32	1301	88	30	112	38	0	409	107	0.18	109	35	345	32	0
166	Udham Singh Nagar	Khatima	Chakarpur	7.44	380	48	12	8.3	0.0	0	189	14	0.35	0	0	170	34	0
167	Udham Singh Nagar	Khatima	Barianjaniya	7.40	499	60	9.6	27	1.5	0	281	7.1	0.36	0	9.4	190	26	0
168	Udham Singh Nagar	Sitarganj	Sitarganj	7.79	880	76	29	58	2.2	0	329	92	0.14	0	30	310	28	0
169	Udham Singh Nagar	Sitarganj	Nanak Mata	7.84	700	60	29	30	9.5	0	354	14	0.91	0	33	270	30	0
170	Udham Singh Nagar	Sitarganj	Kalyanpur	7.89	480	56	9.6	27	1.3	0	268	7.1	0.14	0	6.1	180	28	0
171	Udham Singh Nagar	Sitarganj	Tukri	7.92	520	64	14	18	1.0	0	293	7.1	0.28	0	8.8	220	22	0
172	Udham Singh Nagar	Sitarganj	Begur Mod	7.81	542	40	26	28	0.0	0	293	7.1	0.45	0	18	210	23	0
173	Udham Singh Nagar	Sitarganj	Bidora	7.69	419	48	14	13	1.4	0	232	7.1	0.15	0	8.3	180	33	0
174	Udham Singh Nagar	Sitarganj	Dhyanpur	8.00	530	64	12	24	1.4	0	305	7.1	0.00	0	0	210	28	0

175	Udham Singh Nagar	Rudrapur	Bara	8.13	502	36	26	23	1.6	0	268	7.1	0.34	0	19	200	26	0
176	Udham Singh Nagar	Rudrapur	Kichha	8.35	1057	56	41	56	72	15	311	50	0.17	94	44	310	30	0.92
177	Udham Singh Nagar	Rudrapur	Kamaria Pakki	7.94	527	40	24	18	19	0	256	7.1	0.30	5.2	35	200	28	0
178	Udham Singh Nagar	Rudrapur	Gangapur	7.87	520	60	17	17	2.4	0	268	7.1	0.19	7.1	23	220	26	0
179	Udham Singh Nagar	Rudrapur	Shantipuri	7.80	462	52	12	22	2.2	0	232	7.1	0.15	5.8	25	180	28	0
180	Udham Singh Nagar	Rudrapur	Patthar Chatta	7.84	654	52	26	37	2.9	0	342	7.1	0.14	0	30	240	27	0
181	Udham Singh Nagar	Rudrapur	Rudrapur	7.79	520	60	12	26	2.6	0	244	21	0.27	0	27	200	30	0
182	Udham Singh Nagar	Rudrapur	Kanakpur	7.95	884	80	36	29	19	0	390	28	0.35	0	60	350	22	0
183	Udham Singh Nagar	Rudrapur	Rajpura	7.95	779	80	26	34	2.0	0	268	71	0.38	0	51	310	25	0
184	Udham Singh Nagar	Rudrapur	Pipaliya	7.94	444	56	17	4.8	1.5	0	220	7.1	0.38	0	21	210	28	0
185	Udham Singh Nagar	Rudrapur	Jhagarpuri	8.10	597	32	48	7.1	1.8	0	293	7.1	0.15	0	46	280	27	0
186	Udham Singh Nagar	Rudrapur	Mahabir Nagar	7.85	1054	48	62	55	15	0	354	57	0.14	0	120	380	19	0

187	Udham Singh Nagar	Rudrapur	Kopa Signal	7.92	574	40	38	11	2.2	0	317	7.1	0.18	0	11	260	22	0
188	Udham Singh Nagar	Rudrapur	Beria Daulat	8.16	481	24	41	4.1	1.5	0	232	7.1	0.11	0	45	230	24	0
189	Udham Singh Nagar	Rudrapur	Bhagwanpur	7.89	464	56	12	18	2.1	0	244	7.1	0.22	0	17	190	28	0
190	Udham Singh Nagar	Rudrapur	Pattharpui	8.07	694	44	48	15	1.7	0	317	11	0.21	0	49	310	27	0
191	Udham Singh Nagar	Rudrapur	Barkhera Pande	7.84	1235	72	48	67	69	0	488	71	0.22	34	76	380	23	1.4
192	Udham Singh Nagar	Rudrapur	Lalpuri	7.71	689	60	31	27	1.6	0	342	7.1	0.11	5.5	44	280	28	0
193	Udham Singh Nagar	Bazpur	Bazpur	7.86	791	44	58	20	1.4	0	390	7.1	0.16	0	51	350	28	0
194	Udham Singh Nagar	Bazpur	Jharkhandi	7.74	970	52	60	44	1.1	0	488	7.1	0.15	9.4	41	380	26	0
195	Udham Singh Nagar	Bazpur	Jogipura	7.94	671	68	31	16	1.0	0	305	7.1	0.15	0	60	300	27	0
196	Udham Singh Nagar	Bazpur	Banna Khera	7.72	851	52	55	22	1.2	0	390	7.1	0.16	0	76	360	20	0
197	Udham Singh Nagar	Bazpur	Pritpur	7.87	944	80	41	44	1.4	0	476	14	0.20	0	39	370	28	0
198	Udham Singh Nagar	Bazpur	Badaripur	7.94	856	48	58	27	1.2	0	390	14	0.16	0	65	360	19	0

199	Udham Singh Nagar	Bazpur	Sultanpur Patti	7.91	572	56	29	11	1.0	0	262	11	0.13	0	37	260	27	0
200	Udham Singh Nagar	Bazpur	Kashipur	7.74	1051	56	41	90	2.3	0	451	64	0.23	0	41	310	30	0
201	Udham Singh Nagar	Bazpur	Bharatpur	7.72	521	20	22	55	1.2	0	281	7.1	0.76	0	0	140	15	0
202	Udham Singh Nagar	Bazpur	Dhanauri Patti	7.76	484	64	12	12	1.2	0	244	7.1	0.17	6.2	14	210	23	0
203	Udham Singh Nagar	Bazpur	Durgapur	7.78	699	60	34	26	1.7	0	366	21	0.40	0	15	290	20	0
204	Udham Singh Nagar	Bazpur	Shand Khera	7.83	439	48	12	21	1.5	0	220	7.1	0.12	0	14	170	26	0
205	Udham Singh Nagar	Jaspur	Jaspur	7.98	888	32	29	111	1.0	0	427	50	1.0	0	16	200	19	0
206	Udham Singh Nagar	Jaspur	Patrampur	7.76	649	48	29	36	0.0	0	366	7.1	0.62	0	0	240	24	0
207	Udham Singh Nagar	Jaspur	Angadpur	7.94	644	40	34	36	1.0	0	366	7.1	0.61	0	0	240	23	0
208	Udham Singh Nagar	Jaspur	Missarwala	7.54	495	56	14	21	1.6	0	281	7.1	0.21	0	5.5	200	26	0