GROUNDWATER CHEMICAL QUALITY BULLETIN

UTTARAKHAND

ABSTRACT

Periodic ground water quality assessment (Pre-monsoon,2024) highlighting the findings, significant trends and groundwater contamination status

CGWB, UR, Dehradun

1.0 INTRODUCTION

Ground water is an important resource widely used for drinking, irrigation and industrial purpose. Ground Water plays an important role in the sustainable socio-economic development. In regions with scarcity of fresh surface water sources dependence on ground water increases exponentially. 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. The ground water quality is dependent upon chemical characteristic of rocks and minerals composition of aquifer material. Due to redox reaction, ions can be dissolved from minerals by dissolution and crystallization within aquifer and concentrate beyond permissible limits. Poor ground water quality can also be due to excessive use of fertilizers, urbanization and industrial effluent discharge. According to UNESCO more than 80% of health issues are caused due to consumption of poor-quality water. Inorganic contaminants including Salinity, Fluoride, Nitrate, Arsenic, Iron and Uranium are important in determining the suitability of ground water for drinking purposes.

Therefore, periodic ground water quality assessment is important to alert people who utilize it for domestic and irrigation purpose.

Numerous studies have been carried out on the poor quality of groundwater. However, an extensive temporal and spatial study of Haryana State is lacking. Our efforts in the present study are to fulfill the following objectives:

1. To present current GW quality scenario, parameter wise for each district
2. To identify present day hot spots of poor-quality ground water through spatial variation analysis of latest 2023 quality data.
3. To assess temporal variation of ground water quality showing improvement / deterioration during the period from 2020 to 2024, providing insights for effective water quality management measures.

2.0 STUDY AREA

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. As per 2024 Groundwater resource assessment, Total Annual Ground Water Recharge of the State has been assessed as 2.14 bcm and Annual Extractable Ground Water Resource is 1.964 bcm. The Total Current Annual Ground Water extraction is 1.05 bcm and Stage of Ground Water extraction is 53.54 %

The hydrogeology of Uttarakhand is related to geology and physiography. Variable hydrogeological conditions exist in the state due to a wide variation in the geology and land forms. The regional hydrogeological setup can be described on the basis of five hydrogeological units from north to south. (i) Himalayan Region, (ii) Sub-Himalayan Region, (iii) Bhabhar Zone, (iv) Tarai Zone and (v) Central Ganga Plain. The Disposition of Principle Aquifer system of Uttarakhand State is given in the Fig. (1).

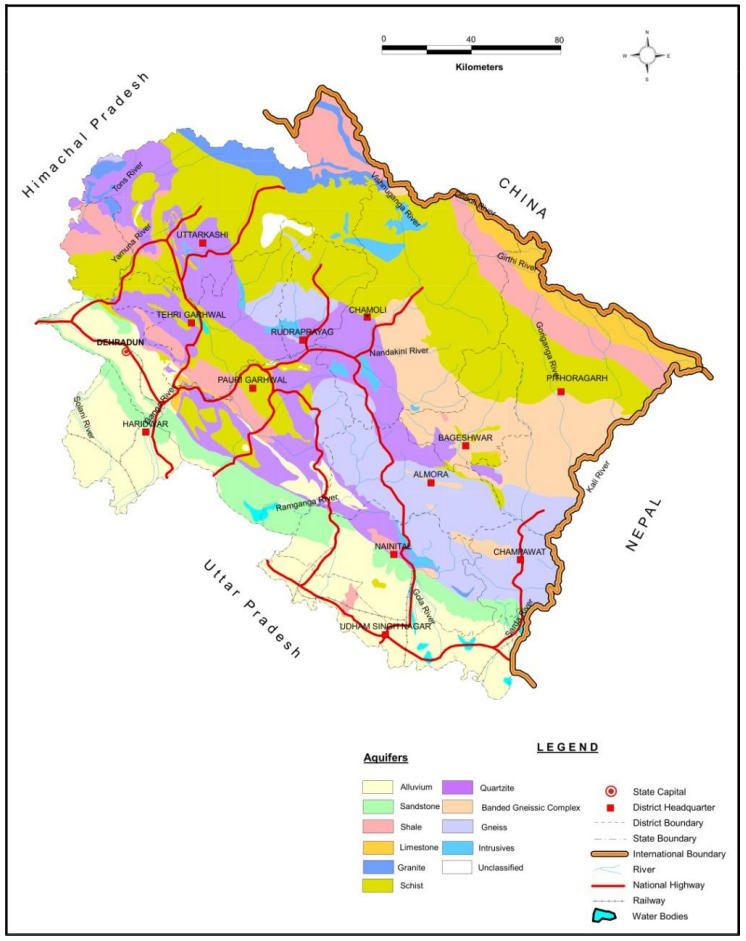

Figure 1: Map showing Disposition of principal aquifer system of Uttarakhand State

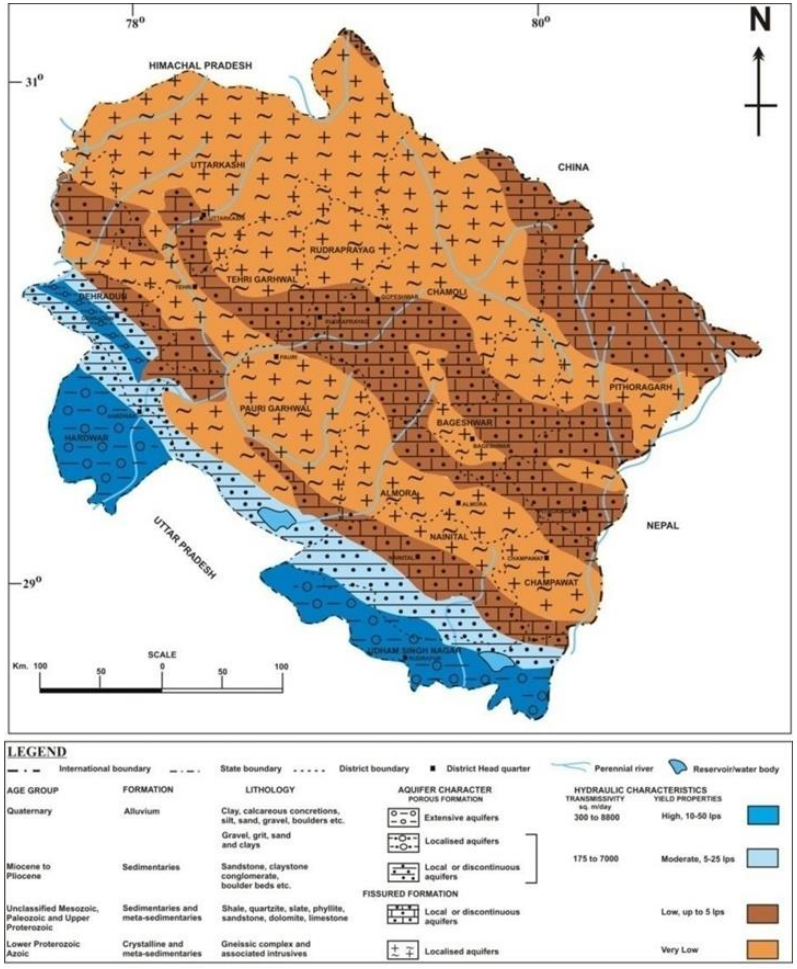

Figure 2: Hydrogeological Map of Uttarakhand State

3.0 GROUND WATER QUALITY MONITORING

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. 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 create a background data bank of different chemical constituents in ground water. The probable causes of deterioration in ground water quality ae depicted in Figure 3.

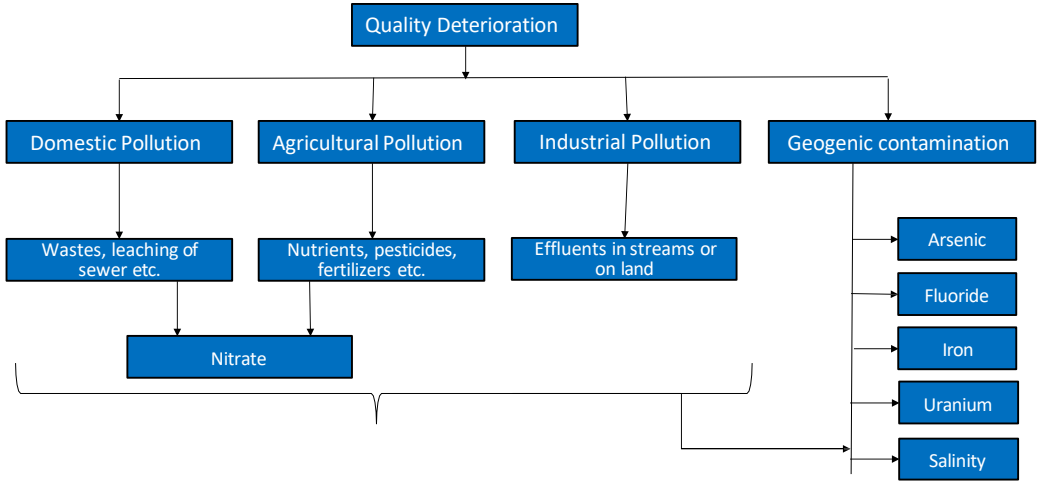

Figure 3: Schematic diagram illustrating the potential factors contributing to the degradation of groundwater quality.

The chemical quality of shallow ground water is being monitored by Central Ground Water Board twice in a year. The district-wise distribution of water Quality Monitoring Stations of CGWB is given in Table 1. The present bulletin is based on the changing scenario in water quality in network observation wells of CGWB in year 2020 and 2024.

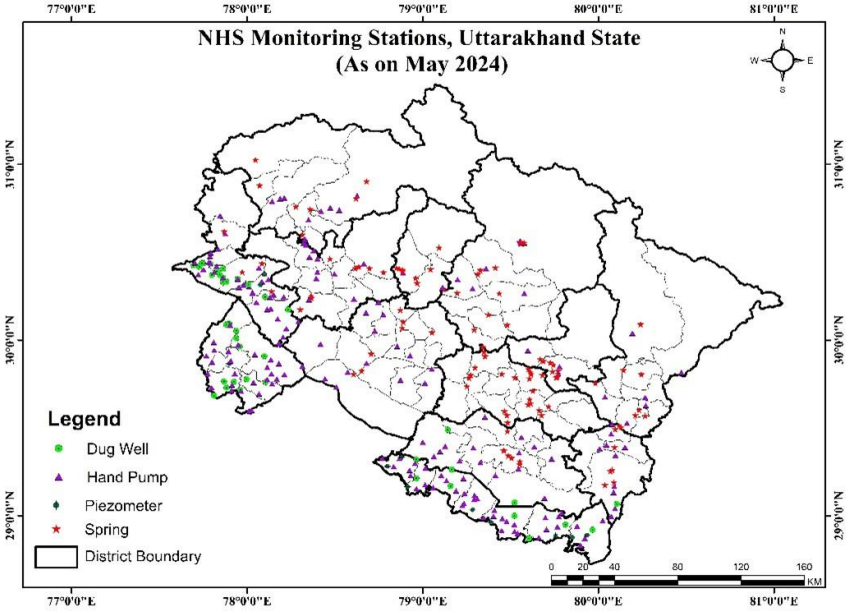

Figure 4: Chemical Quality Sampling Stations in Uttarakhand State (May 24)

Table 1: District wise distribution of water Quality Monitoring Stations

S. No.	District	No. of Sampling Locations				
		2020	2021	2022	2023	2024
1	Dehradun	44	49	47	51	36
2	Nainital	19	20	20	20	21
3	Almora	29	29	26	26	28
4	Haridwar	43	43	42	41	29
5	Champawat	4	4	4	4	8
6	Pauri Garhwal	0	2	2	2	18
7	Uttarkashi	13	13	13	13	14
8	Udham Singh Nagar	46	46	46	46	34
9	Bageshwar	0	0	0	0	9
10	Chamoli	0	0	0	0	14
11	Pithoragarh	0	0	0	0	9
12	Rudraprayag	0	0	0	0	6
13	Tehri Garhwal	0	0	0	5	15
Total		198	206	200	208	241

4.0 GROUND WATER QUALITY SCENARIO

The main objectives of ground water quality monitoring are to assess the suitability of ground water for drinking purposes as the quality of drinking water is a powerful environmental determinant of the health of a community. Bureau of Indian Standards (BIS) vide its document IS: 10500:2012, Edition 3.2 (2012-15) has recommended the quality standards for drinking water. The ground water samples collected from phreatic aquifers are analyzed for all the major inorganic parameters. 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.

Nevertheless, occurrence of high concentrations of some water quality parameters such as Salinity (EC), Fluoride, Nitrate, Iron, and Arsenic the changes in water quality based on these parameters have been observed in the various parts of Uttarakhand State.

4.1 QUALITY ASSESSMENT OF GROUNDWATER IN UNCONFINED AQUIFERS

Unconfined aquifers are extensively tapped for water supply and irrigation across the state therefore; its quality is of paramount importance. The chemical parameters like TDS, Fluoride, Nitrate, Iron, Arsenic and Uranium etc are main constituents defining the quality of ground water in unconfined aquifers. Therefore, presence of these parameters and the changes in chemical quality with respect to these in ground water in samples collected during NHS monitoring 2020 & 2023 are discussed below.

1. Electrical Conductivity (> 3000 µS/cm)

2 Fluoride (>1.5 mg/litre)

3. Nitrate (>45 mg/litre)

4. Iron (>1.0 mg/litre)

5. Arsenic (>0.01 mg/litre)

6. Uranium (>30 ppb)

Table 2: Summarized results of groundwater quality ranges, (May 2023)

S. No	Parameters		Range	No. of sample	Percentage
1	Electrical Conductivity µs/cm at 25°c	Fresh	< 750	217	90.04
		Moderate	750-2250	23	9.54
		Slightly mineralized	2251-3000	1	0.41

		Highly mineralized	> 3000	0	0
2	Chloride mg/L	Desirable limit	< 250	240	99.59
		Permissible limit	251-1000	1	0.41
		Beyond permissible limit	> 1000	0	0
3	Fluoride mg/L	Desirable limit	< 1.0	235	97.5
		Permissible limit	1.0 - 1.5	2	0.82
		Beyond permissible limit	>1.5	4	1.68
4	Nitrate mg/L	Permissible limit	< 45	230	95.44
		Beyond permissible limit	> 45	11	4.56

4.1.1 THE ELECTRICAL CONDUCTIVITY

Electrical conductivity or Total dissolved solids or Salinity is the dissolved salt content in a water body. Different substances dissolve in water giving it taste and odor. Electrical conductivity represents total number of cations and anions present in groundwater, indicating ionic mobility of different ions, total dissolved solids and saline nature of water.

In general water having EC < 1500µS/cm, is considered as fresh water, EC 1500 –15000µS/cm, is considered as brackish water and >15000µS/cm is considered as saline water. 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, quantity of rainfall and above all, the climate of the area. BIS has recommended a drinking water standard for total dissolved solids a limit of 500mg/I corresponding to EC of about 3000 US/cm at 25°C) that can be extended to a TDS of 2000mg/I (corresponding to EC of about 3000 US/cm at 25°C) in case of no alternate source. Water having TDS more than 2000 mg/litre are not suitable for drinking purposes.

Distribution of Electrical Conductivity (EC)

It is apparent from the Fig. 5 and 6 that majority of the waters have EC values less than 750µS/cm at 25^{0}C in the state. Groundwater with EC ranging between 750 and 2250 µS/cm at 25^{0}C falling under 'permissible' range are observed only in 23 samples and EC ranging between 2251 µS/cm to 3000 µS/cm at 25^{0}C falling under "Slightly Mineralized" range is observed in 1 sample at Maldeota, Dehradun District.

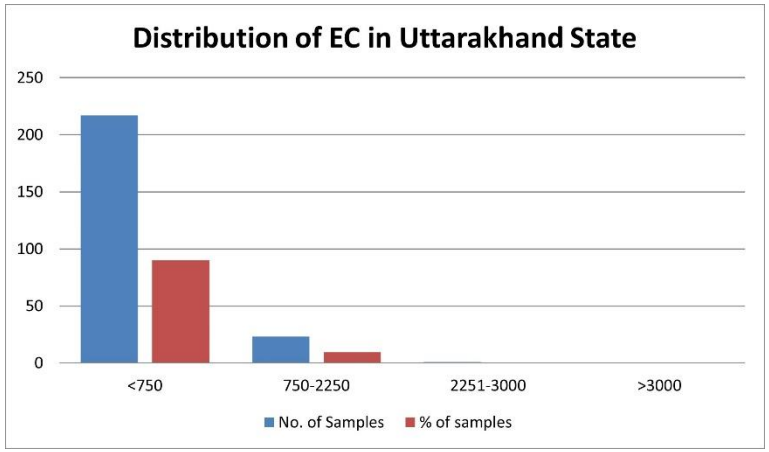

Figure 5: Graph showing distribution of EC in the Uttarakhand State

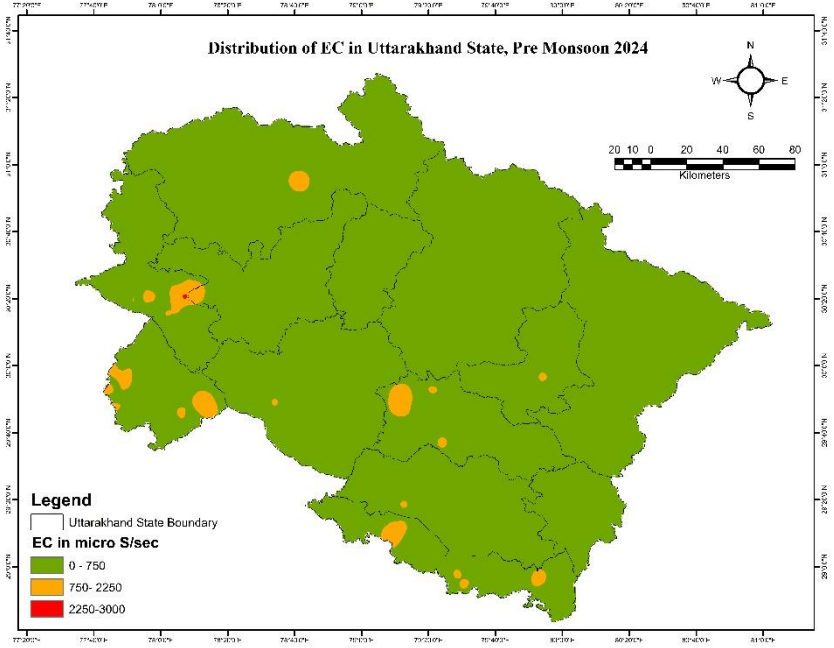

Figure 6: Map showing distribution of EC in the Uttarakhand State based on pre-monsoon 2024 data

4.1.2 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.

PRESENT DAY SCENARIO IN UTTARAKHAND W.R.T NITRATE (NO_3)

Distribution of Nitrate (NO3)

The probable sources of nitrate contamination of ground water are through excessive application of fertilizers, bacterial nitrification of organic nitrogen, and seepage from animal and human wastes and atmospheric inputs.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. As per the fig. 7 and 8, eleven samples (4.56% of the total) of the state (Bhagwanpur, Dhalupuri of Haridwar district, Tarikhet, Lamgora of Almora district, Kiccha and Sarasariya of Udham Singh Nagar district, Dashaithal of Pithoragarh District, Khetikhan of Champawat District and Kapkot and Galayi of Bageshwar District) shows nitrate concentration more than 45 mg/l.

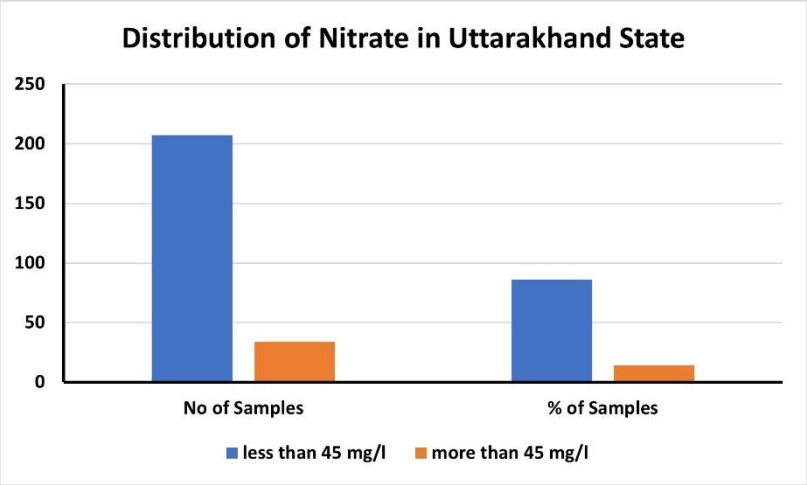

Figure 7: Graph showing distribution of Nitrate in Uttarakhand state based on NHS 2024 Data

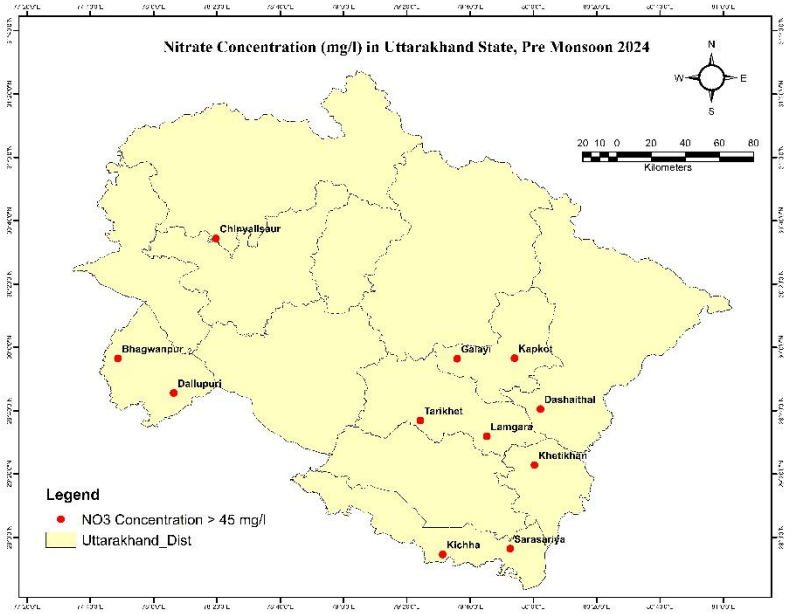

Figure 8: Map showing distribution of Nitrate in Uttarakhand state based on NHS 2024 Data

TEMPORAL VARIATION OF NO3 IN GROUND WATER DURING THE PERIOD FROM 2019 TO 2024

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 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), 5 samples out of 208 samples (2023) and 11 samples out of 241 samples (2024) analyzed. As per table-3 rising trend in the nitrate concentration is observed from 2019 to 2024. 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 2019 to 2024 is representing an increasing trend with a slope of 0.2 degree. Mainly the wells of Haridwar, Udham Singh Nagar, Bageshwar, Pithoragarh, Champawat and the springs of Almora (lifeline of hilly region) are showing Nitrate concentration in ground waters exceeding the permissible limit.

Table 3: Frequency distribution of Nitrate in shallow aquafer in Uttarakhand State (2019-2024)

Year	No. of districts affected by NO3	No. of locations affected by NO3	Total Number of samples analysed	% samples affected by NO3
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
2024	7	11	241	4.56

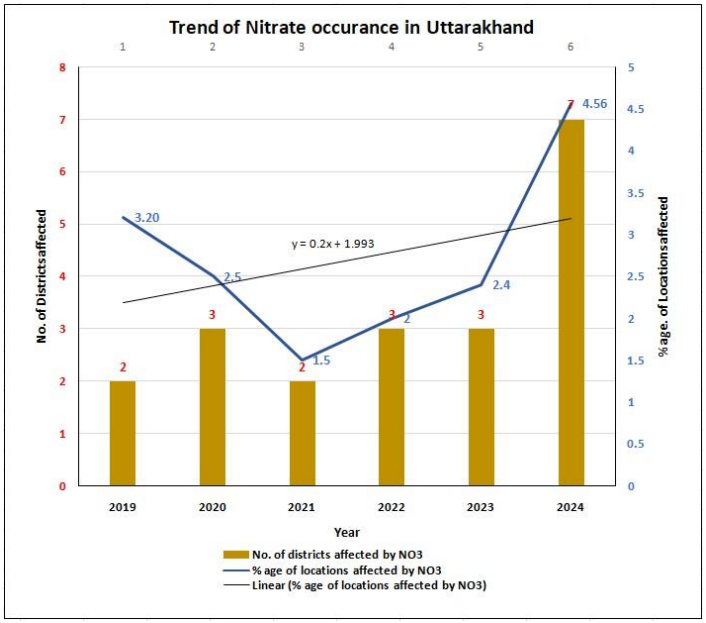

Figure 9: Trend of Nitrate in shallow ground water of Uttarakhand (NHS-2019-2024)

4.1.3 FLUORIDE

Fluorine does not occur in the elemental state in nature because of its high reactivity. It exists in the form of fluorides in a number of minerals of which Fluorspar, Cryolite, Fluorite & Fluorapatite are the most common.

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 groundwater in small amount. The type of rocks, climatic conditions, nature of hydro geological strata and time of contact between rock and the circulating groundwater affect the occurrence of fluoride in natural water.

BIS has recommended a desirable limit of 1.0 mg/l of fluoride concentration in drinking water and maximum permissible limit of 1.5 mg/l in case no alternative source of drinking water is available. It is well known that small amount of fluoride (**upto**1.0 mg/l) have proven to be beneficial in reducing tooth decay. However, high concentrations (>1.5mg/l) have resulted in staining of tooth enamel while at still higher levels of fluoride (> 5.0 mg/l) further critical problems such as stiffness of bones occur. Water having fluoride concentration more than 1.5mg/l is not suitable for drinking purposes. High Fluoride >1.5mg/l is mainly attributed due to geogenic conditions. The fluoride content in ground water from observation wells in a major part of the State is found to be less than 1.0 mg/l.

Distribution of Fluoride (F)

Fluoride in small amounts in drinking water is beneficial for the dental health while in large amounts it is injurious. The fluoride content in groundwater from observation wells in a major part of the state is found to be less than 1.0 mg/L. The distribution of ground water samples with fluoride concentration more than 1 mg/L have been depicted on the map as Fig. 8.4. Only two sample (Siyalsu of Rudrapur district and Ramsod Gaon of Pauri Garhwal District) of the state (0.82% of the total) is showing fluoride concentration in the range of 1-1.5 mg/l. However, four samples (Dhalnagaon, Syalde of Almora district, Garur of Bageshwar District and Gangnani Spring of Uttarkashi District) of the state (1.68 % of total) are showing fluoride concentration more than 1.5 mg/l.

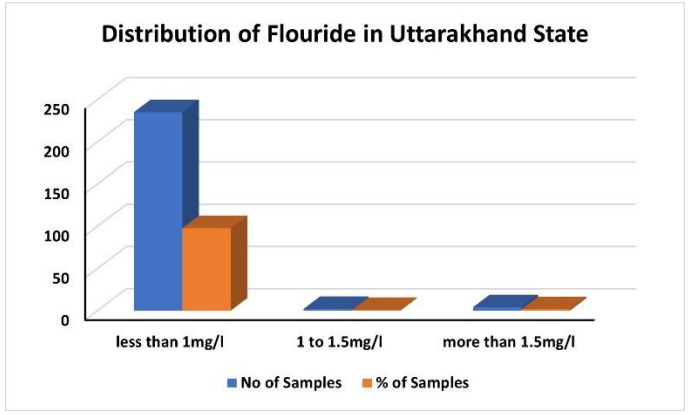

Figure 10: Graph showing distribution of Fluoride in the Uttarakhand State

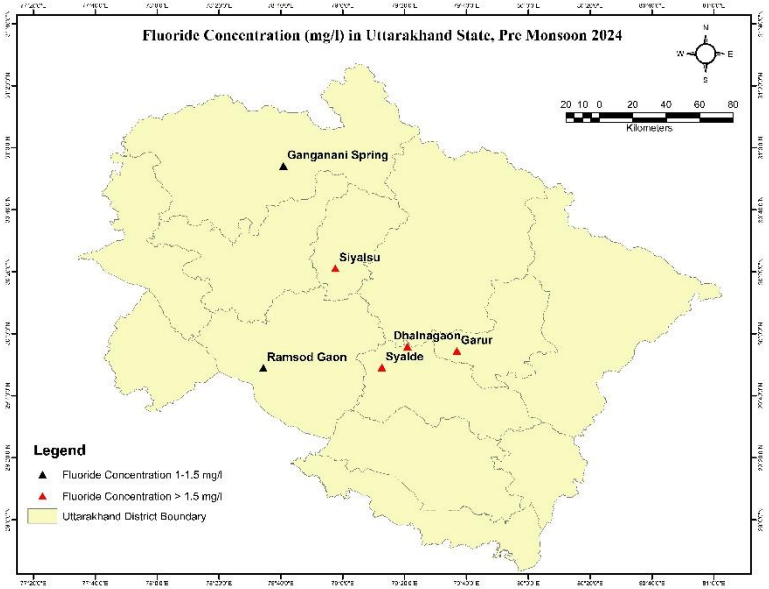

Figure 11: Graph showing distribution of Fluoride in the Uttarakhand State

4. HEAVY METAL

4.1. ARSENIC

Arsenic, a naturally occurring element, is widely distributed throughout the Earth's crust and can be found in various environmental mediums such as water, air, food, and soil. It exists in two primary forms: organic and inorganic. While natural processes like biological activities, weathering reactions, and volcanic emissions contribute to arsenic release, human activities also play a significant role. Anthropogenic sources include mining activities, fossil fuel combustion, the use of arsenical pesticides, herbicides, and crop desiccants, as well as arsenic additives in livestock feed, especially poultry feed. Although the use of arsenical products like pesticides and herbicides has declined over recent decades, their use in wood preservation remains common. The maximum permissible limit for arsenic according to the Bureau of Indian Standards (BIS) is 10 parts per billion (ppb).

PRESENT DAY SCENARIO IN UTTARAKHAND W.R.T ARSENIC

Distribution of Arsenic (As)

The map showing distribution of Arsenic in ground water of India (Fig 12) 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.

Table 4: 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	Almora	Hawalbagh	DharaNaula
2	Pauri Garhwal	Dwarikhal	Farsula
3	Chamoli	Ghat	Ghat
4	Chamoli	Tharali	Tharali
5	Uttarkashi	Chinyalisaur	Chinyalisaur
6	Uttarkashi	Ganganani	Ganganani Spring
7	Almora	Sult	Sult
8	Haridwar	Khanpur	Khanpur
9	Haridwar	Bhagwanpur	Bhagwanpur
10	Almora	Takula	Takula
11	Chamoli	BanjBagd	BanjBagd
12	Haridwar	Laksar	Laksar
13	Almora	Tarikhet	Patali Malla

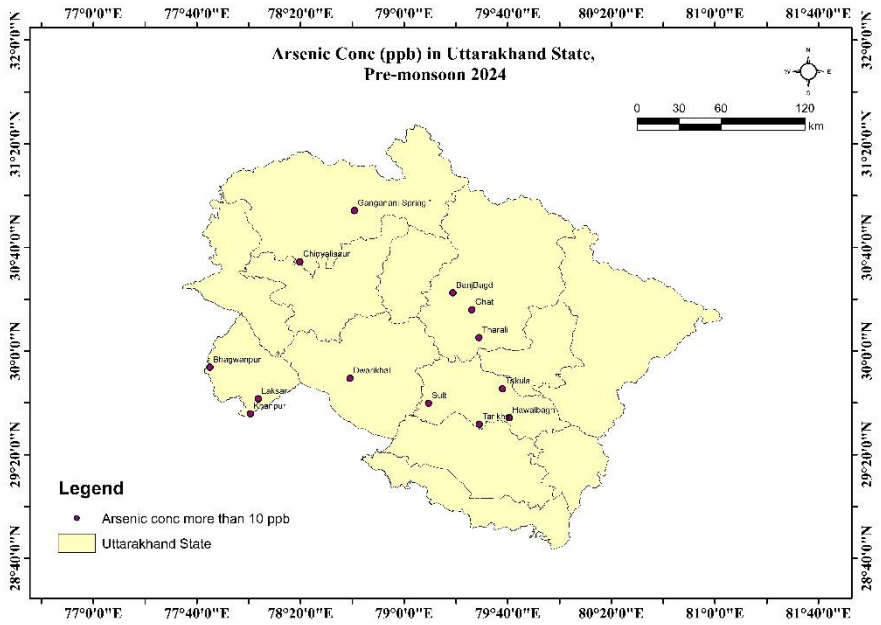

Figure 12: Map showing District-wise distribution of Arsenic in the Ground Water Samples of Uttarakhand State

TEMPORAL VARIATION OF ARSENIC IN GROUND WATER

High Arsenic >0.01 mg/l mainly attributed due to geogenic and anthropogenic conditions and As>0.01 mg/l, have been observed in 06 sample out of 198 (2020), 09 samples of 206 (2021),10 samples out of 200 (2022), 8 samples out of 208 (2023) and 13 samples out of 241 (2024) samples analyzed.

Table 5: Frequency distribution of Arsenic in shallow aquafer in Uttarakhand State (2019-2024)

Year	No. of districts affected by As	No. of locations affected by As	Total Number of samples analyzed	%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
2024	**5**	**13**	241	5.39

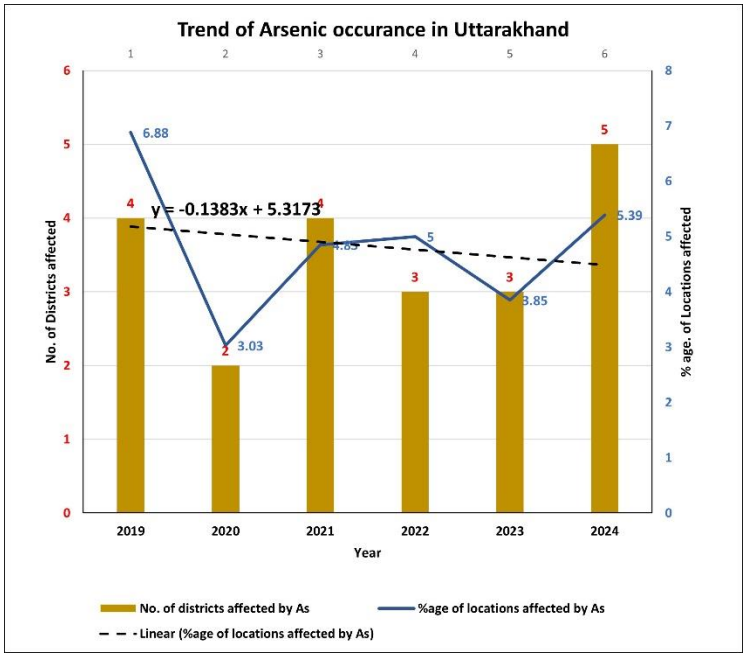

Figure 13: Trend of Arsenic in shallow ground water of Uttarakhand (NHS2019-2024)

4.2 IRON

Iron is a common constituent in soil and ground water. It is present in water either as soluble ferrous ion the insoluble ferric iron. Water containing ferrous iron is clear and colorless 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 ground water 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 less than 1.0 mg/litre as per the BIS Standard for drinking water.

PRESENT DAY SCENARIO IN UTTARAKHAND W.R.T IRON

Distribution of Iron (Fe)

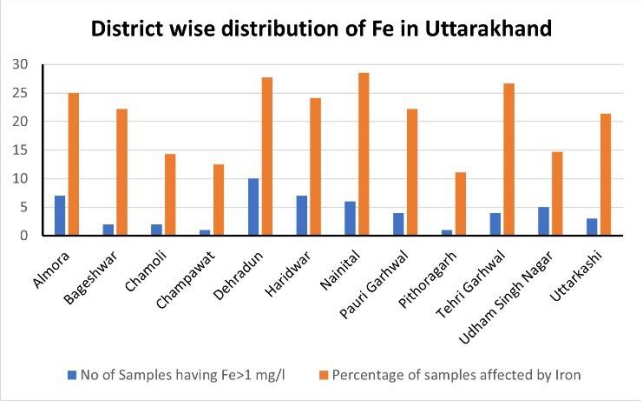

Figure 14: Graph showing District-wise distribution of Iron in the Ground Water Samples

Table 6: 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	Almora	7	28	25.00
2	Bageshwar	2	9	22.22
3	Chamoli	2	14	14.29
4	Champawat	1	8	12.50
5	Dehradun	10	36	27.78
6	Haridwar	7	29	24.14
7	Nainital	6	21	28.57
8	Pauri Garhwal	4	18	22.22
9	Pithoragarh	1	9	11.11
10	Tehri Garhwal	4	15	26.67
11	Udham Singh Nagar	5	34	14.71
12	Uttarkashi	3	14	21.43

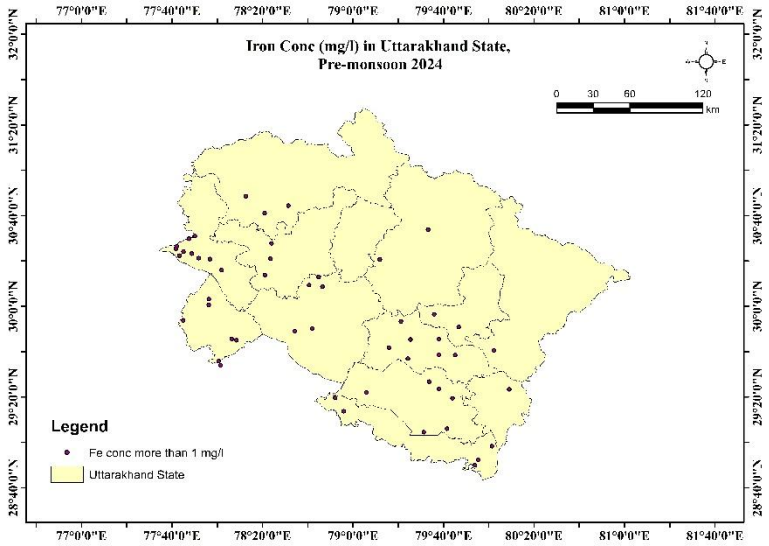

Figure 15: Map showing distribution of Iron in the Ground Water Samples of Uttarakhand State

TEMPORAL VARIATION OF IRON IN GROUND WATER

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 2024) is showing higher concentration of iron having trend with a slope of 0.13 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. 15.

Table 7: 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 analyzed	%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**
2024	**12**	**52**	241	**21.57**

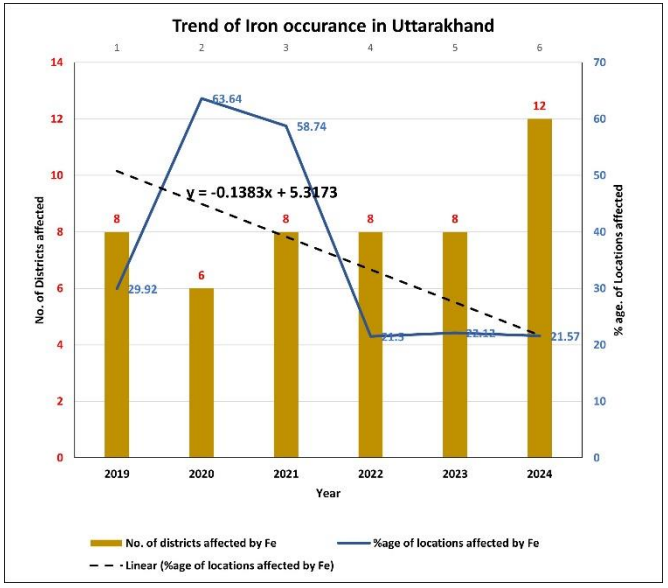

Figure 16: Trend of Iron in shallow ground water of Uttarakhand (NHS2019-2024)

SUMMARY

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-HCO3 types of groundwater. The general chemical quality reveals that most of the wells contain low dissolved mineral contents and hence, groundwater in Uttarakhand state is fresh and potable.

On the basis of chemical analysis results of 241 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