

# Ground Water Quality in Shallow Aquifer of Himachal Pradesh

2023

**REPORT ON**  
**GROUND WATER QUALITY IN SHALLOW**  
**AQUIFER OF HIMACHAL PRADESH**

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## 1.0 INTRODUCTION

The quality of groundwater is a very sensitive issue. Groundwater is never pure and contains varying amounts of dissolved solids, the type and concentration depend on its source, surface and sub-surface environment, rate of ground water movement, the residence time, the solubility of minerals present and the amount of dissolved carbon dioxide. In addition to the natural changes, anthropogenic activities such as sewage disposal, agricultural practices, industrial pollution etc. also contribute significantly to changes in groundwater quality. Once the contaminants have entered to the sub-surface geological environment, they may remain concealed for many years and may get dispersed over wide areas. Weathering of rock and mineral solubility controls the major ion composition of ground water. With increasing anthropogenic activities, a substantial amount of dissolved matter is added to groundwater. 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, climatologically and topographic settings. Water-bearing rock formations (aquifers), range in age from Achaean 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.

A diverse range of dissolved inorganic compounds present in different concentrations characterizes groundwater. These compounds originate from the chemical and biochemical interactions between water and geological substances. Inorganic impurities such as salinity, chloride, fluoride, nitrate, iron, and arsenic play a crucial role in assessing the suitability of groundwater for drinking purposes.

## 2.0 HYDROGEOLOGY

Almost all types of the formations form the groundwater horizon depending upon the degree of weathering, depositional sequence and structural set up and topographic locations. These formations are having primary or secondary porosities. Broad classification of the formations forming aquifers is discussed below and is summarized in Table 4.

### **Unconsolidated Formations:**

These are occurring either as major/minor/valley/piedmont deposits. The major valley fills are Nurpur – Jawali – Nagrota Surian, Pragpur – Dadasiba, Palampur – Kangra valley fills in Kangra district, Shathlai and Sir khad in Hamirpur district, Balh valley in Mandi district, Una valley in Una district, Nalagarh valley in Solan district, Paonta valley in Sirmaur district, Spiti valley in Lahaul and Spiti district. Ground water occurs under phreatic to semi-confined conditions in these deposits. In some of the valleys like Indora – Nurpur valley in Kangra district and Balh valley in Mandi district, confined aquifers are encountered.

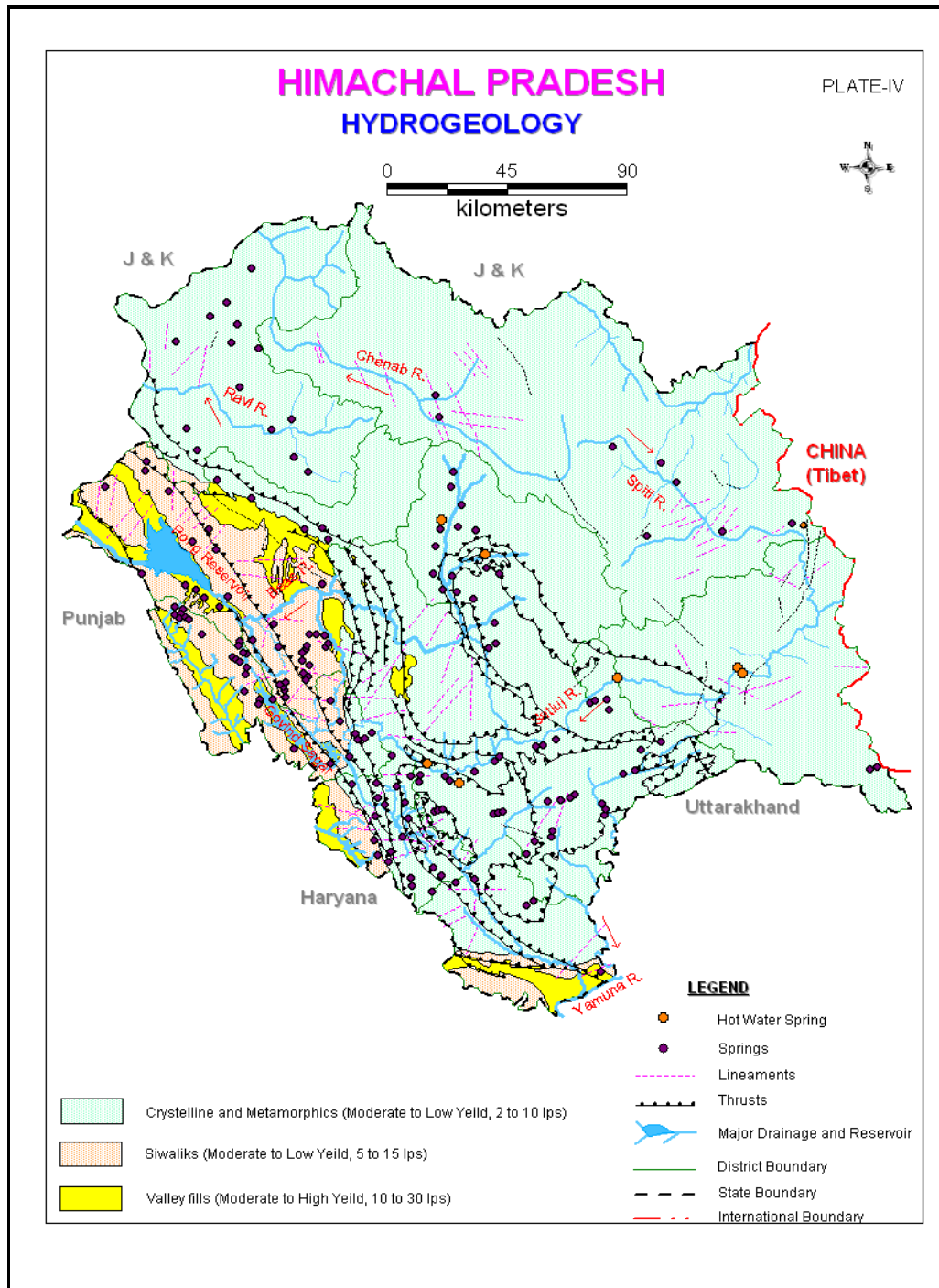
The thickness of valley fills in Paonta, Una, Nalagarh, Nurpur and Andaura terrace are generally more than 100 m whereas in other valley fills it is within 100 m. Groundwater occurs under unconfined to confined conditions. Depth to water level varies from 20 to about 60 m bgl. Artesian flowing conditions also exist in lower and central part of Una valley, lower part of Nurpur, Andaura and Balh valley fills. Ground water occurs under unconfined conditions in shallow valley fill areas developed along the river / streams as discontinuous aquifers in Kangra, Hamirpur, Sirmaur and Solan districts. Depth to water level varies from 5 to 20 m bgl. Ground water is developed through shallow and deep tube wells. The discharge of the tube wells varies up to 40 lps but generally ranges between 15 to 25 lps. There are about 500 tube wells constructed including exploratory wells of CGWB in the valley fill deposits both for drinking and irrigation purposes. A large number of boreholes with hand pumps also exist in the state.

### **Semi consolidated and Consolidated Formations**

Fissured formations are divided into following two units viz. Semi-consolidated or Sedimentary and Consolidated or Metamorphic. Younger or tertiary formations are constituted by Siwaliks, Dagshai and Dharamshala formations. These are represented by sandstone, shales and clays. Older formations of Precambrian to Mesozoic are represented by granites, gneisses, schists, phyllites etc. Fracture zones and contact zones form the important aquifers in the low topographic areas with poor to moderate yields. The yield of the tubewells constructed along the fault / fracture / contact zones varies from less than 1 to 40 m<sup>3</sup> per hour. These fracture or fault zones are forming potential ground water zones. Central Ground Water Board has

constructed one exploratory well in fissure formation along the fault zone and has yielded a discharge of 20 lps.

Groundwater in hard rock areas is either developed through bore wells or springs. Springs are yielding sometimes more than 40 lps and utilized for both drinking and irrigation purposes. Weathered mantle in low topography areas also form poor aquifers. In some areas percolation wells are also constructed. Bowries are also constructed in oozing out spring zones for collecting the water to fulfill the domestic water needs.



### **3.0 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.

#### **3.1 CHEMISTRY OF RAINWATER**

The atmosphere is composed of water vapors, dust particles and various gaseous components such as  $N_2$ ,  $O_2$ ,  $CO_2$ ,  $CH_4$ ,  $CO$ ,  $SO_4$ , and  $NO_3$  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  $50 \mu S/cm$ , chloride below  $5 mg/l$  and  $HCO_3$  below  $10 mg/l$ . Among the cations, concentration of Ca, Mg, Na & K vary considerably but the total cations content is generally below  $15 mg/l$  except in samples contaminated with dust. The concentration of sulphates and nitrates in rainwater may be high in areas near industrial hubs.

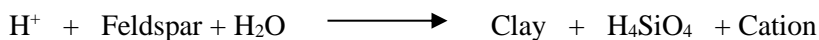
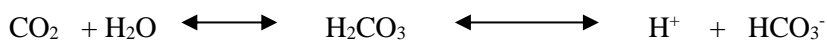
#### **3.2 CHEMISTRY OF SURFACE WATER**

Surface water is found extremely variable in its chemical composition due to variations in relative contributions of ground water and surface water sources. The mineral content in river water usually bears an inverse relationship to discharge. The mineral content of river water tends to increase from source to mouth, although the increase may not be continuous or uniform. Other factors like discharge of city wastewater, industrial waste and mixing of waters can also affect the nature and concentration of minerals in surface water. Among anions, bicarbonates are the most important and constitute over 50% of the total anions in terms of milli equivalent per liter (meq/l). In case of cations, alkaline earths or normally calcium predominates but with increasing salinity the hydro chemical facies tends to change to mixed cations or even to Na- $HCO_3$  type.

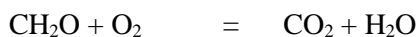
### 3.3 CHEMISTRY OF GROUND WATER

The downward percolating water is not inactive, and it is enriched in CO<sub>2</sub>. 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 CO<sub>2</sub> associated with the percolating water gets gradually exhausted through interaction of water with minerals.



The oxygen present in this water is used for the oxidation of organic matter that subsequently generates CO<sub>2</sub> to form H<sub>2</sub>CO<sub>3</sub>. This process goes on until oxygen is fully consumed.



(Organic matter)

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 CO<sub>2</sub> 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.

### 4.0 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 ground water 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 ground water 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 4.0: Water quality criteria parameters for various uses (Sayers et.al., 1976)**

<b>Public Water supply</b>	<b>Industrial Water supply</b>	<b>Agricultura l water supply</b>	<b>Aquatic life&amp; wild life water</b>	<b>Recreation and Aesthetics</b>
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			<b>supply</b>	
ColiformbacteriaTurbiditycolour, Taste, OdourTDS, Cl,F,SO <sub>4</sub> NO <sub>3</sub> , CN, Trace Metals, Trace Organics Radioactive substances	<b>Processing</b> pH, Turbidity Colour, Alkalinity, Acidity, TDS, Suspended solids, Trace metals, Trace Organics <b>Cooling</b> PH, Temp, Silica, Al, Fe, Mg, Total hardness, Alkalinity/Aci dity Suspended solids, Salinity	Farms Same as for public supply Live-stock Same as for public supply Irrigation TDS, EC, Na, Ca, Mg, K, B ,Cl and Trace metals	Temp, DO, pH, Alkalinity, Acidity, TDS Salinity, pH, DCOs, Turbidity Colour,Set tleablemat erials,Toxi csubstance s,Nutrients ,Floatingm aterials	Recreations Turbidity, Colour, Odour,Floating Materials,Setta bleMaterialsNu trients,Colifor ms Aesthetics Same as for Recreation and S u b s t a n c e s adversely affecting wildlife

#### 4.1 Water Quality Criteria for Drinking Purpose

With the objective of safe guarding water from degradation and to establish a basis for improvement in water quality, standards / guide lines / regulations have been laid down by various national and international organizations such as; Bureau of Indian Standards (BIS), World Health Organization (WHO), European Economic Community (EEC), Environmental Protection Agency (EPA), United States, and Inland Waters Directorate, Canada. The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institutions (ISI) has laid down the standard specification for drinking water during 1983, which have been revised and updated from time to time. In order to enable the users, to exercise their discretion towards water quality criteria, the maximum permissible limit has been prescribed especially where no alternative sources are available. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purposes. The important water quality characteristics as laid down in BIS standard (IS 10500: 2012) are summarized in **Table- 4.1**

**Table 4.1: Drinking Water Characteristics (IS 10500: 2012)**

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

NTU-Nephelometric Turbidity Unit

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

## 4.2 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 - 4.2**.

**Table 4.2: Safe Limits for electrical conductivity for irrigation water (IS: 11624-1986)**

S. No.	Nature of soil	Crop Growth	Upper permissible safe limit of electrical conductivity in water $\mu\text{s/cm}$ at 25°C
1	Deep black soil and alluvial soils having 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 soil having clay 10-20%; internally very well drained and Having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4	Light textured soils having clay less than 10%; soils that have excellent Internal and surface drainage system.	Semi-tolerant	6000
		Tolerant	8000

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.

### 4.2.1 SODIUM ADSORPTION RATIO (SAR) & RESIDUAL SODIUM CARBONATE (RSC)

The clay minerals in the soil adsorb divalent cations like calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conducive for plant growth. Sodium reacts with soil to reduce its permeability. In case the irrigation water is sodium dominant, the clay lattice is filled with sodium ions due to ion exchange. Such soils become impermeable and sticky and as such the cultivation becomes difficult to support plant growth. However, the cation exchange process is reversible and can be controlled either by adjusting the

composition of water or by soil amendment by application of gypsum, which releases cations (Calcium) to occupy the exchange position. The tendency of water to replace adsorbed calcium and magnesium with sodium can be expressed by the Sodium Adsorption Ratio (SAR), where all the ion concentrations are in milli-equivalents per litre (meq/L).

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

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

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

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

#### Percentage sodium (%Na):

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

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

The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. Here commended classification with respect to Electrical Conductivity, Sodium content, Sodium Adsorption Ratio, and Residual Sodium Carbonate, under customary irrigation conditions has been depicted in **Table - 4.2.1**.

**Table 4.2.1: 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	

### 4.3 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 drinking water supplies to avoid impact on human health (**Table–4.2.3**). 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 4.2.3: Effects of water quality parameters on human health when used for drinking purpose**

S. No.	Parameters	Prescribed limits IS:10500,2012		Probable Effects
		Desirable Limit	Permissible Limit	
1	Colour (Hazenunit)	5	15	Makes water aesthetically undesirable
2	Odour	Essentially free from objectionable odour		Makes water aesthetically undesirable
3	Taste	Agreeable		Makes water aesthetically undesirable
4	Turbidity (NTU)	1	5	High turbidity indicates contamination/Pollution.
5	pH	6.5	8.5	Indicative of acidic or alkaline water, affects taste, corrosively and the water supply system
6	Hardness as CaCO <sub>3</sub> (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.
7	Iron(mg/L)	1.0	No relaxation	Gives bitter sweet astringent taste, causes staining of laundry and porcelain. Intracities 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.

S. No.	Parameters	Prescribed limits IS:10500,2012		Probable Effects
		Desirable Limit	Permissible Limit	
11	Calcium (Ca)(mg/L)	75	200	Causes encrustation in water supply system. While insufficiency causes a severity 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 essentials and 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 (SO <sub>4</sub> ) (mg/L)	200	400	Causes gastro intestinal irritation along with Mg or Na, can have a cathartic effect on users, concentration morethan750mg/L may have laxative effect along with Magnesium.
15	Nitrate (NO <sub>3</sub> ) (mg/L)	45	No relaxation	Cause infant methaemoglobinemia (blue babies) at very high concentration, causes gastric cancer and affects adversely Central nervous system and cardio vascular system.
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.

S. No.	Parameters	Prescribed limits IS:10500,2012		Probable Effects
		Desirable Limit	Permissible Limit	
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 5mg/L imparts astringent taste to water.
20	Chromium (Cr <sup>6</sup> ) (mg/L)	0.05	No relaxation	Hexavalent state of Chromium produces lung tumors and can produce cutaneous and nasal mucous membrane ulcers and dermatitis.
21	Boron (B) (mg/L)	0.5	2.4	Affects central nervous system its salt may cause nausea, cramps, convulsions, coma etc.
22	Alkalinity (mg/L) as CaCO <sub>3</sub>	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 <sub>4</sub> ) (mg/L)	No guidelines		High concentration may cause vomiting and diarrhea, stimulate secondary hyperthyroidism and bone loss
25	Sodium (Na)(mg/L)	No guidelines		Harmful to persons suffering from cardiac, renal and circulatory diseases.
26	Potassium (K)(mg/L)	No guidelines		An essential nutritional element but its excessive amounts is cathartic
27	Silica (SiO <sub>2</sub> ) (mg/L)	No guidelines		-
28	Nickel (Ni)(mg/L)	0.02		Non-toxic element but may be carcinogenic in animals, can react with DNA resulting in DNA damage in animals.



S. No.	Parameters	Prescribed limits IS:10500,2012		Probable Effects
		Desirable Limit	Permissible Limit	
29	Pathogens(a) Total coliform (per100ml) (b) Faecal Coliform(per1 00ml)	nil		Cause water borne diseases like coliform Jaundice, Typhoid, and Cholera etc. produce infections involving skin mucous membrane of eyes, ears and throat.
30	Arsenic	0.01	<b>No relaxation</b>	Various skin diseases, Carcinogenic
31	Uranium	0.03	<b>No relaxation</b>	Kidney disease, Carcinogenic

## 5.0 GROUND WATER QUALITY MONITORING

The International Standard Organization (ISO) has defined monitoring as, "The programmed process of samplings, measurements and subsequent recording or signaling 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 dugwells 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 irrigation, 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.

### 5.3 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 freshwater).
  - b. Thus:  $TDS (mg/l) \sim (0.55 \text{ to } 0.95) \times EC (mS/cm)$ .
  - c. The value of the constant varies according to the chemical composition of the water. For freshwater, the normal range of TDS can be calculated from the following relationship:
  - d.  $0.55 \text{ conductivity } (mS/cm) < TDS (mg/l) < 0.95 \text{ conductivity } (mS/cm)$ .
  - e. Typically, the constant is high for chloride rich waters and low for sulphate rich waters.
- c. **Checking the cation-anion balance**

When a water quality sample has been analysed for the major ionic species, one of the most important validation tests can be conducted: the cation-anion balance.

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

where:

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

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

The Electronic charge balance is expressed as follows:

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

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

## 6.0 GROUND WATER QUALITY SCENARIO IN HIMACHAL PRADESH

Evaluation of ground water quality through concentration of its physical, chemical and biological parameters is essential to determine its suitability for the intended use. It helps not only in finding its suitability; it also helps in taking effective remedial measures for its improvement on scientific lines. In most of rural and semi-urban areas of Himachal State, ground water is a major resource for drinking, irrigation and industrial applications especially in areas where surface water is inadequate or unavailable. Acknowledging the importance of this aspect of ground water, Central Ground Water Board, Northern Himalayan Region (CGWB, NHR) Dharamshala annually monitors the ground water quality through dedicated Ground Water Monitoring Stations consisting of dug wells, tube wells and/or PZ of shallow depth.

### 6.1 Sampling & Analysis

During June 2022 (Pre-monsoon), 466 number of ground water samples were collected from these structures spread uniformly over 09 districts and no specific treatment such as acidification or filtration was given at the time of sampling. The water samples were analyzed for major cations (Ca, Mg, Na, K) and anions ( $\text{CO}_3$ ,  $\text{HCO}_3$ , Cl,  $\text{NO}_3$ ,  $\text{SO}_4$ ) in addition to pH, EC, F,  $\text{SiO}_2$ ,  $\text{PO}_4$  and TH as  $\text{CaCO}_3$  in Regional Chemical Laboratory of CGWB, NWR Chandigarh by following 'Standard analytical procedures' as given in American Public Health Agency (APHA) 23<sup>rd</sup> Edition 2017 and Bureau Indian Standards (BIS).

The district-wise chemical analysis data of the samples are given in the Annexure - IX. The summarized results of ground water quality ranges are given in **Table - 6.1**.

**Table-6.1. Summarized results of ground water quality ranges, (May 2022)**

S. No	Parameters		Range	No. of sample	Percentage
1	Electrical Conductivity $\mu\text{s/cm}$ at $25^\circ\text{C}$	Fresh	< 750	181	38.84
		Moderate	750- 2250	150	32.19
		Slightly mineralized	2251- 3000	96	8.37
		Highly mineralized	> 3000	96	20.60
2	Chloride mg/L	Desirable limit	< 250	312	66.95
		Permissible limit	250-1000	114	24.46
		Beyond permissible limit	> 1000	40	8.58
3	Fluoride mg/L	Desirable limit	< 1.0	362	77.68
		Permissible limit	1.0 - 1.5	53	11.37
		Beyond permissible limit	>1.5	51	10.94
4	Nitrate mg/L	Permissible limit	< 45	390	83.69
		Beyond permissible limit	> 45	76	16.31

The groundwater samples collected from dug wells and hand pumps tapping phreatic aquifers are analyzed for all the major inorganic parameters. Based on the results, it is found that ground water of the state is mostly of calcium bicarbonate ( $\text{Ca-HCO}_3$ ) type when the total dissolved solids of water is below 500 mg/L (corresponding to electrical conductance of 750  $\mu\text{S/cm}$  at  $25^\circ\text{C}$ ). They are of mixed cations and mixed anion type when the electrical conductance is between 750 and 3000  $\mu\text{S/cm}$  and waters with electrical conductance above 3000  $\mu\text{S/cm}$  are of sodium chloride ( $\text{Na-Cl}$ ) type. However, other types of water are also found among these general classifications, which may be due to the local variations in hydro-chemical environments due to anthropogenic activities. Nevertheless, occurrence

of high concentrations of some water quality parameters such as salinity, chloride, fluoride, iron, arsenic and nitrate have been observed in some pockets in the state.

## **7.0 GROUND WATER QUALITY HOT SPOTS IN UNCONFINED AQUIFERS OF INDIA**

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 country 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. Chloride (> 1000 mg/L)
- III. Fluoride (>1.5 mg/L)
- IV. Nitrate (>45mg/L)
- V. Iron (>1.0mg/L)
- VI. Arsenic (>0.01 mg/L)
- VII. Uranium (>0.03 mg/L)
- VIII. Total Hardness (>600 mg/L)

### **7.1 Electrical Conductivity**

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

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

Salinity always exists in ground water but in variable amounts. It is mostly influenced by aquifer material, solubility of minerals, duration of contact and factors such as the permeability of soil,

drainage facilities, and quantity of rainfall and above all, the climate of the area. The salinity of groundwater in coastal areas in addition to the above may be due to air borne salts originating from air water interface over the sea and also due to over pumping of fresh water which overlays saline water in coastal aquifer systems.

BIS has recommended a drinking water standard for total dissolved solids a limit of 500 mg/L (corresponding to EC of about 750  $\mu\text{S}/\text{cm}$  at 25<sup>0</sup>C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000  $\mu\text{S}/\text{cm}$  at 25<sup>0</sup>C) in case of no alternate source. Water having TDS more than 2000 mg/L is not suitable for drinking purpose. In Fig 7.1.1, the EC values (in  $\mu\text{S}/\text{cm}$  at 25<sup>0</sup>C) 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. The EC value of ground waters in the State varies from 175 to 1100  $\mu\text{S}/\text{cm}$  at 25<sup>0</sup>C. Grouping water samples based on EC values, it is found that 95.04 % of them have EC less than 750  $\mu\text{S}/\text{cm}$ , 4.96 % have between 750 and 1100  $\mu\text{S}/\text{cm}$ .

Year	Total No. of samples analyzed	No. of districts affected by EC	Total No. of locations affected by EC	% of locations affected by EC (EC > 3000 $\mu\text{S}/\text{cm}$ )
2017	33	0	0	0
2018	120	0	0	0
2019	120	0	0	0
2020	90	0	0	0
2021	159	0	0	0
2022	168	0	0	0

**Table 7.1.1 district-wise percentage of samples having EC >3000  $\mu\text{S}/\text{cm}$  during the period of 2017-2022**

### 7.1. TREND ON ELECTRICAL CONDUCTIVITY

Trend analysis determines whether the measured values of the water quality variables increase or decrease during a time period. The Electrical Conductivity (EC) of groundwater is contributed by all the dissolved ionic constituents. Therefore, it is a measure of the total ionic content of the water. It could be used as a source of inorganic pollution indicator as most of the inorganic compounds are present as ions in water. Hence, EC was taken to assess the trend of ground water quality in India. The

percentage of well exceeds the electrical conductivity more than 3000  $\mu\text{S}/\text{cm}$  for the period of 2017 to 2022 were compared and presented in the Table 7.1.1 and observed that the percentage of samples exceed the permissible limit of 3000  $\mu\text{S}/\text{cm}$  were 0 %.

## 7.2 CHLORIDE

Chloride is present in all-natural waters, mostly at low concentrations. It is highly soluble in water and moves freely with water through soil and rock. In ground water the chloride content is mostly below 250 mg/L except in cases where inland salinity is prevalent and in coastal areas.

BIS (Bureau of Indian Standard) have recommended a desirable limit of 250 mg /L of chloride in drinking water; this concentration limit can be extended to 1000 mg/L of chloride in case no alternative source of water with desirable concentration is available. However, ground water having concentration of chloride more than 1000 mg /L are not suitable for drinking purposes.

In Fig 7.2.1, the concentration of chloride (in mg/L) in ground water from observation wells have been used to show distribution patterns of chloride in different ranges of suitability. Chloride content of ground water normally follows the distribution pattern of EC and it ranges from 7.0 mg/L to 231 mg/L in the entire State. Chloride concentration above 400 mg/L gives salty taste to water and based on these aesthetic considerations, BIS has recommended a desirable limit of 250 mg/L for chloride in drinking water. This limit can be extended to 1000 mg/L in case of absence of a source with desirable concentration. Grouping of samples in these categories based on chloride content, it is found that Chloride is less than 250 mg/L in 100 % of the samples.

Year	Total No. of samples analyzed	No. of districts affected by Cl	Total No. of locations affected by Cl	% of locations affected by Cl (Cl > 1000 mg/L)
2017	33	0	0	0
2018	120	0	0	0
2019	120	0	0	0
2020	90	0	0	0
2021	159	0	0	0
2022	168	0	0	0

**Table 7.2.1 District-wise percentage of samples having Chloride >1000mg/L**



### 7.3 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 fluorite, cryolite, fluorite and fluorapatite are the most common. Fluorite ( $\text{CaF}_2$ ) 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 caries*. 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  $\text{F}^-$  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. Waters having fluoride concentration of more than 1.5 mg/L are not suitable for drinking purposes.

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 1.5 mg/L have been depicted on the map as Fig. 7.3.1. It is observed Ground waters with fluoride above 1.50 mg/L are found mainly in Chamba (Udaipur Chakdiyani), Una (Daulatpur, Jankaur, Ishpur, Babeher) & Sirmour (Trilokpur) districts of the State. It is worth mentioning that high fluoride waters are encountered in areas where high salinity is encountered and extensive agriculture activities are predominant. Extensive use of phosphatic fertilizers, which have fluoride as impurity can be the potential source of the fluoride while geogenic sources also play important role in fluoride concentration in the ground water. The details of locations where fluoride concentration more than 1.5 mg/l is given in Annexure III. The list of districts showing localized occurrence of fluoride in ground water in excess of 1.5mg/L is given in table 7.3.1

The occurrences of fluoride in groundwater beyond permissible limit (1.5 mg/L) have also been shown on the point map as Fig. 7.3.1, district-wise percentage of wells having fluoride >1.5mg/L is shown as a bar diagram in Fig 7.3.2.

LOCATION	District	LATITUDE	LONGITUDE	F
DAULATAPUR	UNA	31.7788889	75.9972222	1.60
BABEHR	UNA	31.7897222	75.9916667	1.70
ISHPUR	UNA	31.5055556	76.1788889	2.30
JANKAUR	UNA	31.4305556	76.2747222	2.60
TRILOKPUR	SIRMAUR	30.54	77.2033333	2.20
CHIKADIYANI	CHAMBA	32.5985	76.0940556	6.40

**Table 3.7.1: Locations Showing F contamination (> 1.5 mg/L)**

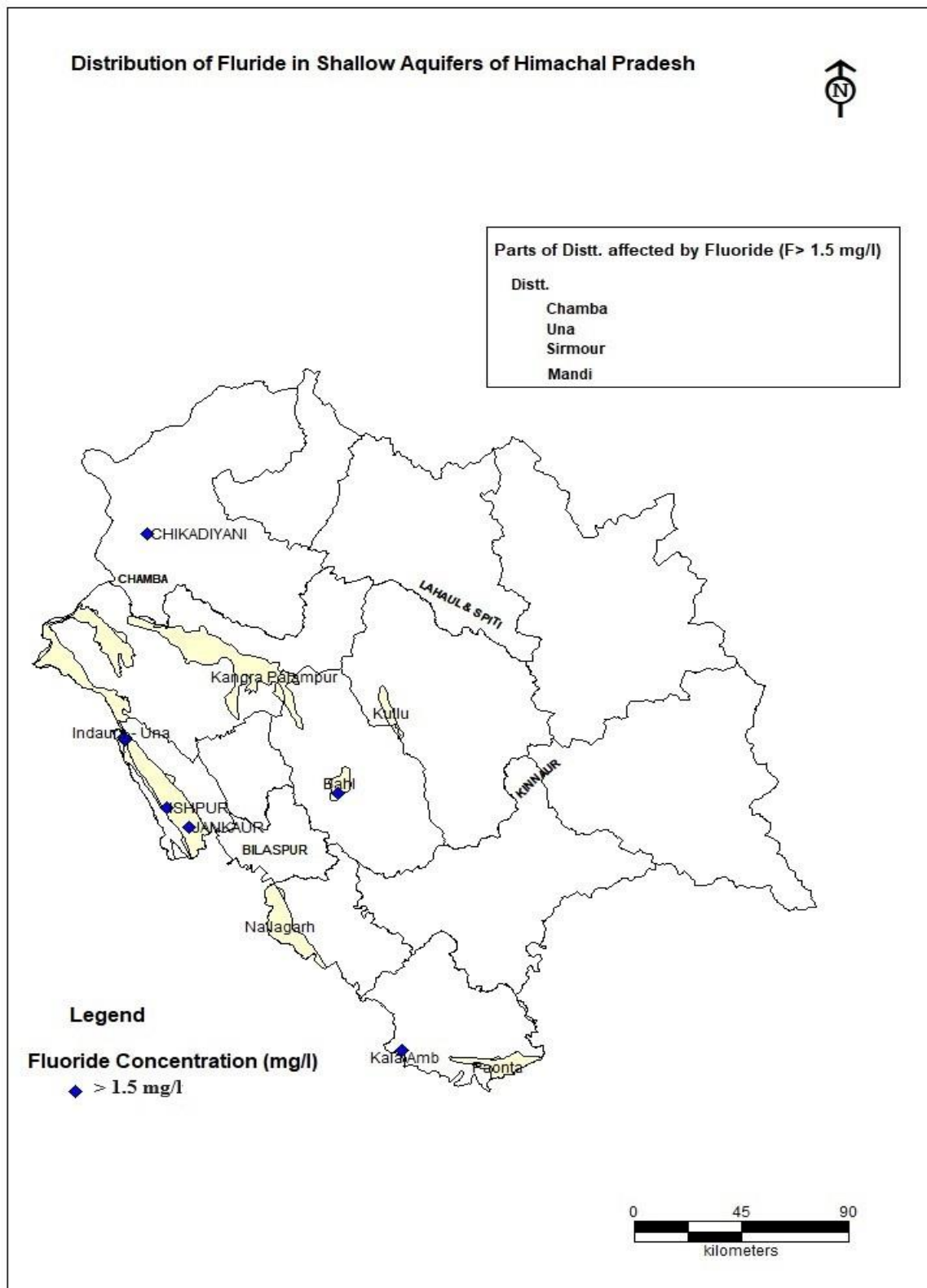


Fig 7.3.1 Locations having Fluoride concentration > 1.5 mg/L during May 2022.

It has been observed (Table 7.3.3) that total number of districts affected by high fluoride in the state has increased by 2.737 % in 2022 as compared to the data available in 2015. In Una District the increase in the no. of locations is a matter of concern.

The occurrence of fluoride in groundwater is mainly due to weathering and leaching of fluoride bearing minerals from rocks and sediments. To assess the trend of ground water pollution due to geogenic activity, the percentage of well exceeds the permissible limit of 1.5mg/L for the period of 2017 to 2022 were compared and presented in the Table 7.3.3 and Fig 7.3.4 and observed that the percentage of samples exceed the permissible limit of fluoride 1.5 mg/L were ranging between 1.6 – 6.4 mg/L. Trend on fluoride in Himachal Pradesh shows an increasing trend.

<b>Year</b>	<b>Total No. of samples analysed</b>	<b>No. of districts affected by F</b>	<b>Total No. of locations affected by F</b>	<b>% of locations affected by F</b>
<b>2017</b>	33	0	0	0
<b>2018</b>	120	1	1	0.833
<b>2019</b>	120	1	1	0.833
<b>2020</b>	90	1	1	1.11
<b>2021</b>	159	1	1	0.628
<b>2022</b>	168	3	6	3.57

**Table 7.3.2: Percentage of wells Exceed fluoride >1.5 mg/L during the period of 2017-2022**

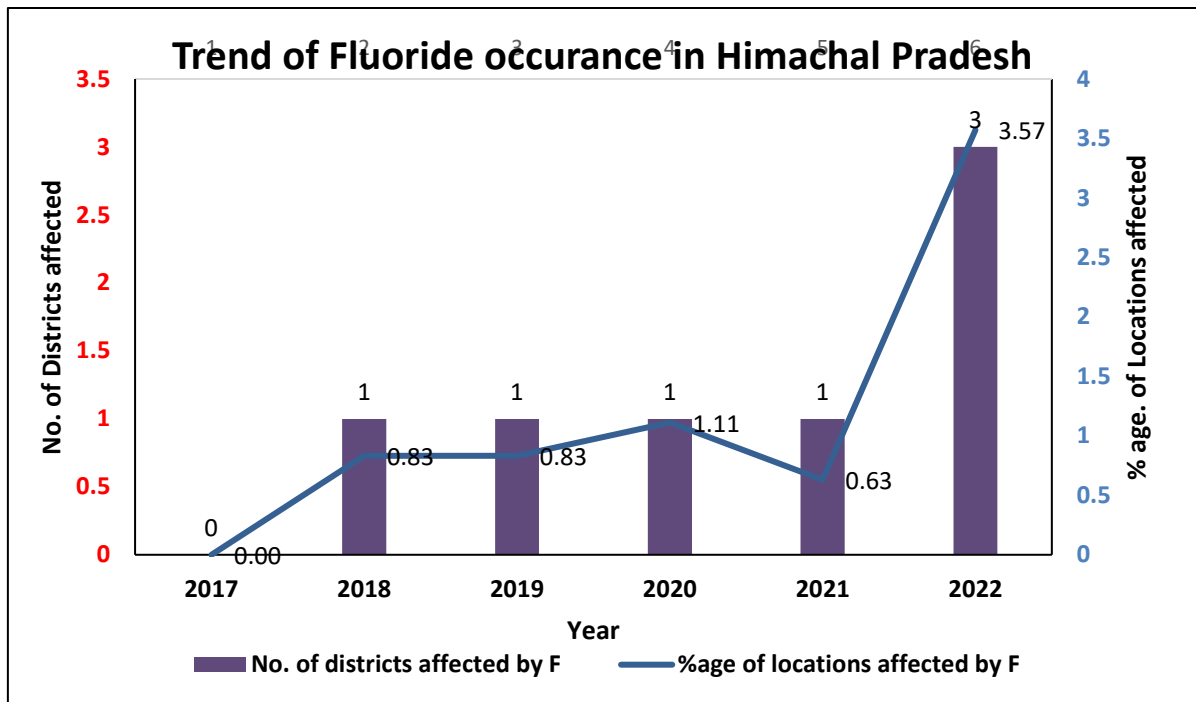


Fig. 7.3.2 Trend of Fluoride occurrence in Himachal Pradesh

### Remedial Measures for Fluoride

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

#### (a) Adsorption and ion exchange

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

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

**Ion-Exchange resins:** Synthetic chemicals, namely, anion and cation exchange resins have been used for fluoride removal. Some of these are Polyanion (NCL), Tul-sion A - 27, Deacedite FF (IP), Amberlite IRA 400, Lewatit MIH - 59, and Amberlite XE - 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. Aluminum salts (eg. Alum), lime, Poly Aluminium Chloride, Poly Aluminum Hydroxy sulphate and Brushite are some of the frequently used materials in defluoridation by precipitation technique. The best example for this technique is the famous Nalgonda technique.

#### ***Nalgonda Technique***

Nalgonda technique involves addition of Aluminum 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 Aluminum Chloride (PAC) and Poly Aluminum Hydroxy Sulphate (PAHS).

### **(c) Membrane techniques**

Reverse osmosis, nano filtration, dialysis and electro dialysis are physical methods that have been tested for defluoridation 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.

## **7.4 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.

The occurrences of Nitrate in ground water beyond permissible limit (45 mg /L) have been shown on the map as a point source Fig 7.4.1 and also given in Annexure-IV. Table-7.4.1 shows the locations where nitrate has been found in excess of 45 mg/L in groundwater.

LOCATION	DISTRICT	LONGITUDE	LATITUDE	NO3
BHALI	KANGRA	76.1075	32.2230556	<b>60</b>
BOD	KANGRA	75.86972222	32.2869444	<b>83</b>
KATHGARH	KANGRA	75.63472222	32.1172222	<b>130</b>
BHADRAKALI	UNA	76.03888889	31.7797222	<b>78</b>
AMBOTA	UNA	76.04805556	31.6705556	<b>58</b>
PALAH	SOLAN	76.61194444	31.1275	<b>53</b>
THEDA	SOLAN	76.76	31.9997222	<b>47</b>
KATHOR-KALAN	UNA	76.11777778	31.6572222	<b>51</b>
MUBARIKPUR	UNA	76.08416667	31.7083333	<b>66</b>
DAULATAPUR	UNA	75.99722222	31.7788889	<b>116</b>
RAIPUR MARWADI	UNA	75.98361111	31.8002778	<b>53</b>
KUTHERA JASWALAN	UNA	76.11805556	31.6058333	<b>57</b>
BADSALI	UNA	76.17888889	31.4777778	<b>143</b>
NANGRAN	UNA	76.29194444	31.3980556	<b>87</b>
MAHADEVA	SOLAN	76.67861111	31.1083333	<b>57</b>
KHODEWALA	SIRMAUR	77.705	30.4872222	<b>45</b>
MOHTLI	KANGRA	75.67833333	32.2127778	<b>84</b>
KANGOO	HAMIRPUR	76.42444444	31.6863889	<b>54</b>
KANED	MANDI	76.91361111	31.5788889	<b>57</b>
ISHPUR	UNA	76.17888889	31.5055556	<b>47</b>
LOHARLI	UNA	76.12638889	31.5927778	<b>51.98</b>
LOHARA	MANDI	76.94527778	31.5886111	<b>47.33</b>

BANGROTU	MANDI	76.91972222	31.6108333	<b>61</b>
GADAURI	KULLU	77.13138889	31.9033333	<b>61</b>
KULLU	KULLU	77.11527778	31.9647222	<b>48</b>
SAINWALA II	SIRMAUR	77.25222222	30.5386111	<b>51</b>
SHIBPUR	SIRMAUR	76.17888889	31.5055556	<b>90</b>
DHAULAKUAN	SIRMAUR	77.47305556	30.5016667	<b>55</b>
AKKWALA	SIRMAUR	77.28666667	30.5202778	<b>56</b>
PANJAWAR	UNA	76.14277778	31.5472222	<b>51</b>
DEHRA GOPIPUR	KANGRA	76.21527778	31.8822222	<b>71</b>
GUGLEHAR	UNA	76.14333333	31.5666667	<b>48</b>
KUTHERA JASWAN	UNA	76.11805556	31.6058333	<b>70</b>
GAGRET	UNA	76.06194444	31.6605556	<b>66</b>
UNA	UNA	76.27083333	31.4694444	<b>64</b>
MAGAN PURA	SOLAN	76.353697	31.563052	<b>237</b>
NALAGARH	SOLAN	76.71194444	31.0441667	<b>46</b>
DABOTA	SOLAN	76.637	31.08	<b>55</b>
BAGHERI	SOLAN	76.64194444	31.1941667	<b>55</b>
SHIBPUR	SIRMAUR	76.17888889	31.5055556	<b>49</b>
BADIRPUR	SIRMAUR	77.66972222	30.4758333	<b>55</b>
KHERACHAK	SOLAN	76.67861111	31.0138889	<b>160</b>

**Table 7.4.1 Locations having Nitrate concentration > 45 mg/L during May 2022**

It has been observed (Table 7.4.1) that No. of locations in various districts having high Nitrate (more than 45 mg/l) content in ground water has decreased by 4.60% in year 2022 as compared to the data available in year 2015.



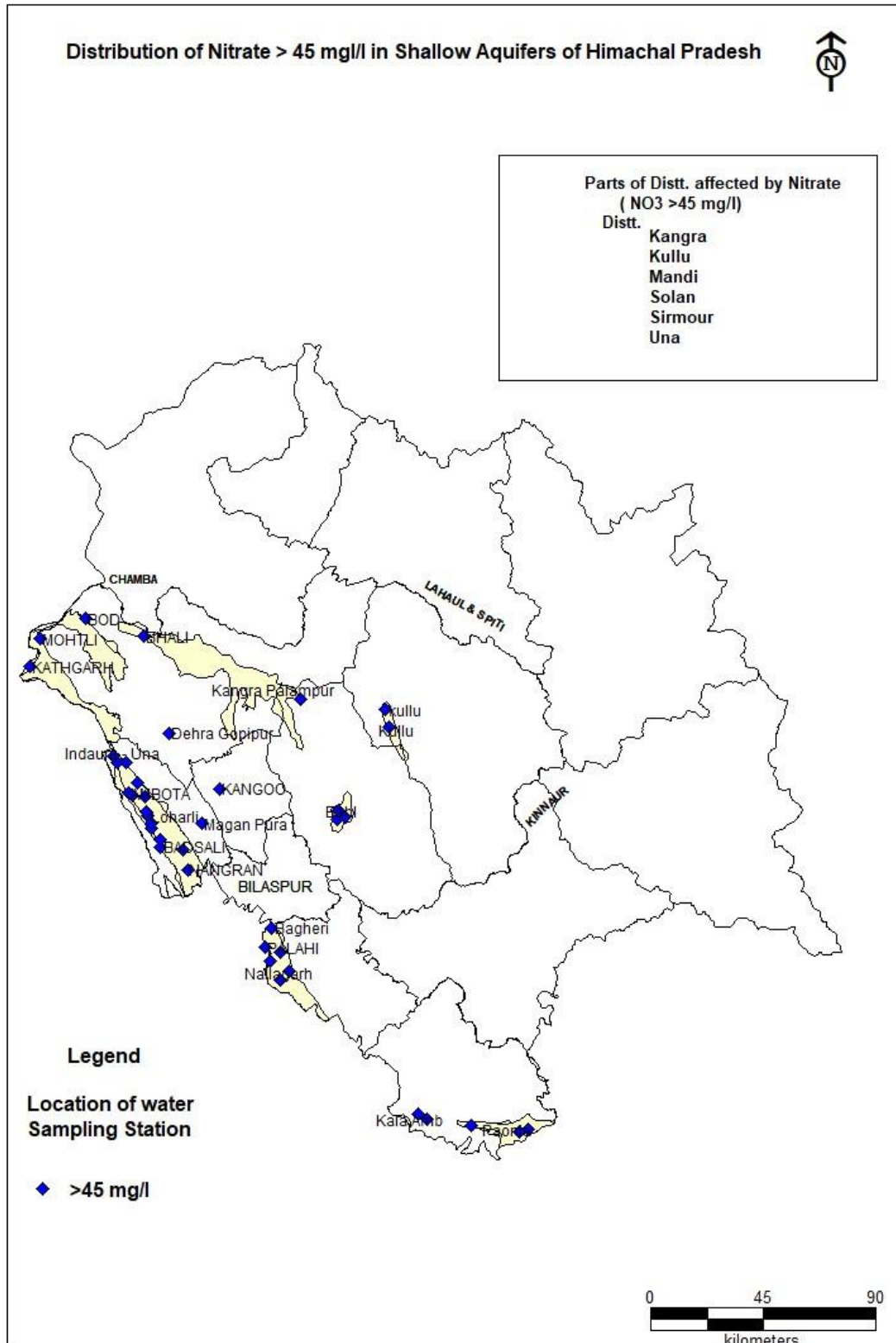


Fig. 7.4.1 Locations having Nitrate concentration > 45 mg/L during May 2022

#### 7.4 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. The percentage of well exceeds the permissible limit of 45mg/L for the period of 2017 to 2022 were compared and presented in the Table 7.4.5 and Fig 7.4.5 and observed that the percentage of samples exceed the permissible limit of nitrate (> 45 mg/L) were ranging between 12.12 – 4.76 %. Trend of Nitrate in Una and Solan districts of Himachal Pradesh are shown (Fig 7.4.6 and 7.4.7) decreasing trend.

Year	Total No. of samples analyzed	No. of districts affected by NO <sub>3</sub>	Total No. of locations affected by NO <sub>3</sub>	% of locations affected by NO <sub>3</sub>
2017	33	1	4	12.12
2018	120	3	15	12.5
2019	120	5	12	10
2020	90	2	6	6.66
2021	159	6	15	9.43
2022	168	4	8	4.76

**Table 7.4.2: Percentage of wells Exceed Nitrate >1.5 mg/L during the period of 2017-2022**

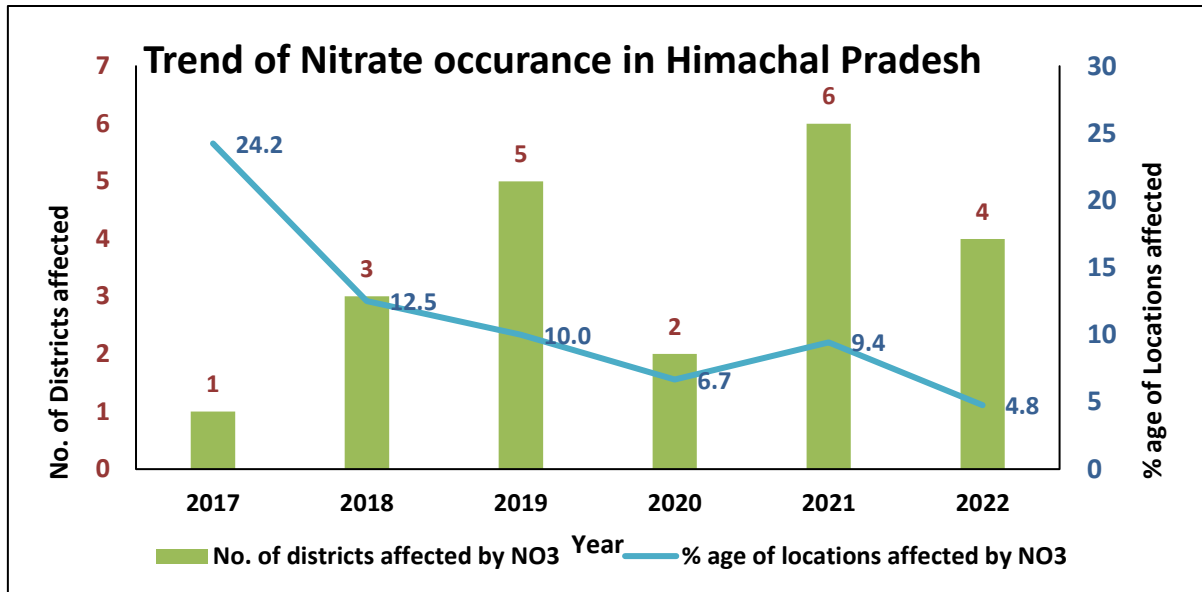


Fig. 7.4.2 Trend of Nitrate occurrence in Himachal Pradesh

### 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

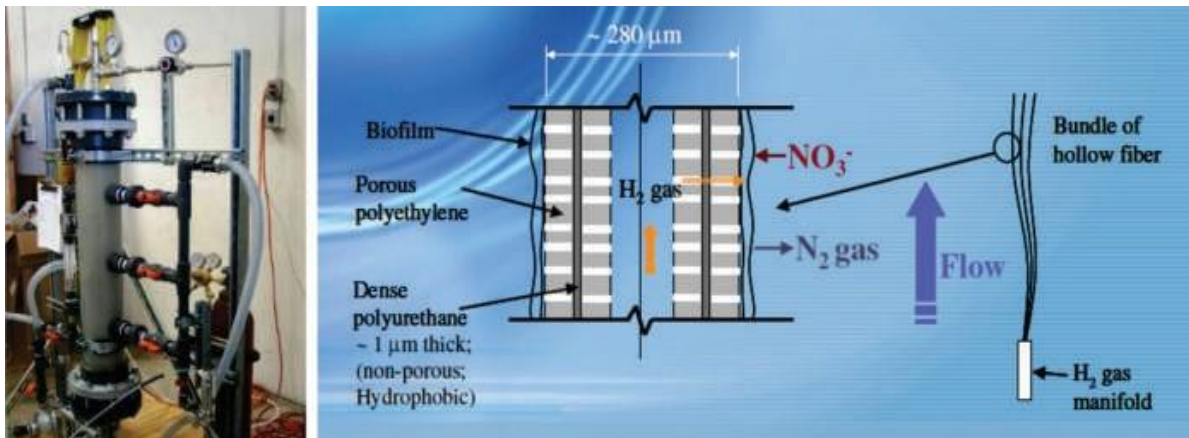
This greatly reduces expenses and helps to provide safer drinking water to larger numbers of people.

**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 filtrations 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 do 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. 7.4.8** Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

## 7.5 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 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 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 0.3 mg/L as per the BIS Standard for drinking water. The occurrences of iron in ground water beyond permissible limit ( $> 0.30$  mg /litre) have been shown on the map as point sources (Fig 7.5.1). It is based on the chemical analysis of water samples mostly collected from the groundwater observation wells/ hand pumps. The details of the sampling sources are given in Annexure-V.

The summary list of districts in which iron in ground water is found to exceed the permissible limits for drinking water in localized areas is shown in Table 7.5.1.

LOCATION	DISTRICT	LONGITUDE	LATITUDE	Fe (mg/L)
NANGRAN	UNA	76.29194444	31.39805556	0.744
BAWAL	UNA	76.30666667	31.54805556	20.074
RAJLI PANJAL	UNA	76.405	31.53638889	10.810
BHATOLI	SOLAN	76.60833333	31.16527778	10.731
AKKAWALA	SIRMAUR	77.28666667	30.52027778	4.645
SAINWALA-2	SIRMAUR	77.25222222	30.53861111	0.694
KATHGARH	KANGRA	75.63472222	32.11722222	0.661
KANGOO	HAMIRPUR	76.42444444	31.68638889	0.526
BARSAR MAIRE	HAMIRPUR	76.46472222	31.52805556	0.518
GUTKAR	MANDI	76.94416667	31.65722222	1.031
DEHRA GOPIPUR	KANGRA	76.21527778	31.88222222	0.369
MAO	KANGRA	76.01055556	32.26027778	0.417
PANDTEHR	KANGRA	76.64611111	32.03722222	2.974
HARDOGRI	KANGRA	76.29527778	31.78361111	5.084
BIJHRI	HAMIRPUR	76.53944444	31.52277778	2.317
SAINWALA I	SIRMAUR	77.51111111	30.49194444	6.062
GAAGAL	MANDI	76.96138889	31.63027778	0.396
RATI	MANDI	76.90194444	31.59972222	0.417

**Table 7.5.1: Locations showing Fe contamination ( $> 0.3$  mg/L)**

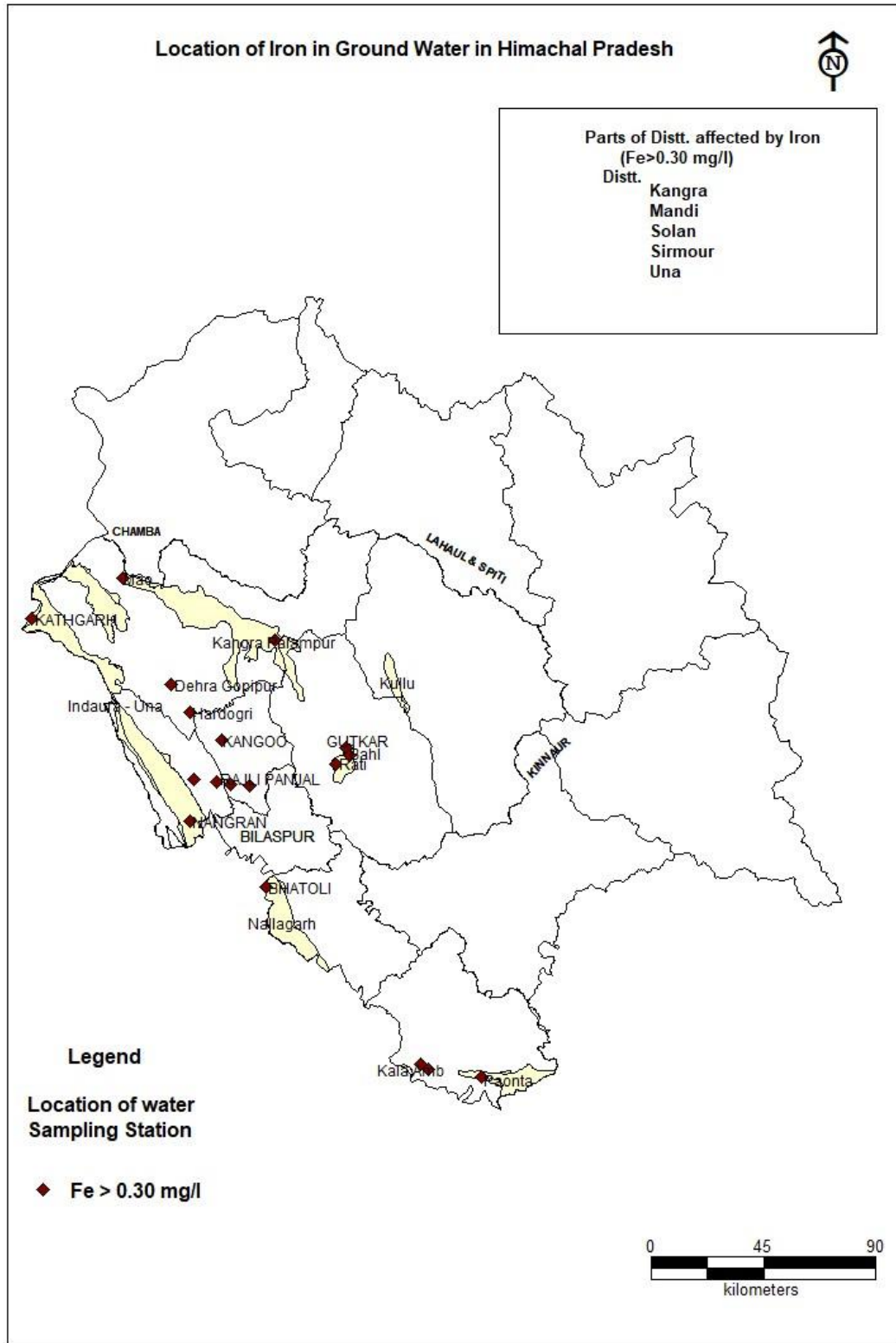


Fig 7.5.1 Map showing areas of Iron contaminated (> 0.30mg/L) groundwater in Himachal Pradesh (NHS 2022)

Year	Total Number of samples analysed	No. of districts affected by Fe	Total No of locations affected by Fe	% of locations affected by Fe (Fe > 0.30 mg/L)
2019	120	5	10	8.33
2020	90	0	0	0
2021	159	0	0	0
2022	168	5	10	5.95

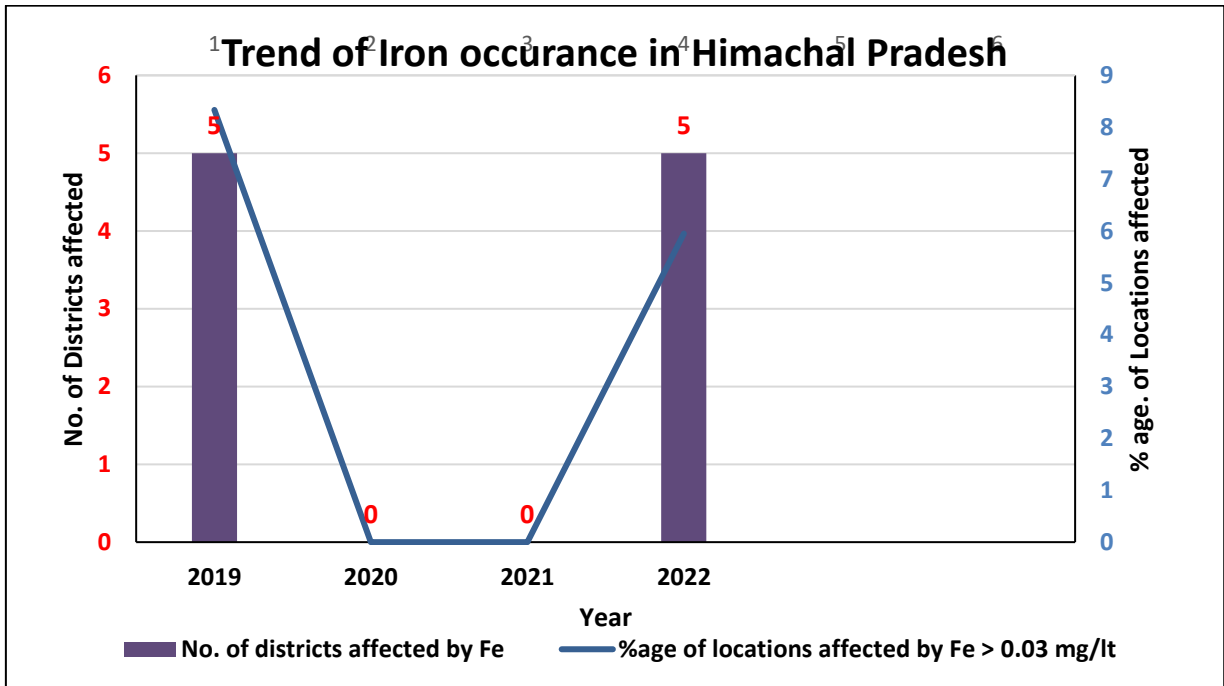


Fig. 7.5.2 Trend of Iron occurrence in Himachal Pradesh

### 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 ( $\text{Fe}^{2+}$ ) is oxidized to ferric iron ( $\text{Fe}^{3+}$ ), which readily forms the insoluble iron hydroxide complex  $\text{Fe}(\text{OH})_3$ . Manganese ( $\text{Mn}^{2+}$ ) is oxidized to ( $\text{Mn}^{4+}$ ), which forms insoluble ( $\text{MnO}_2$ ). 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.

Electro media 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 bisulfate.

**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 aluminum 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.

## 7.6 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.

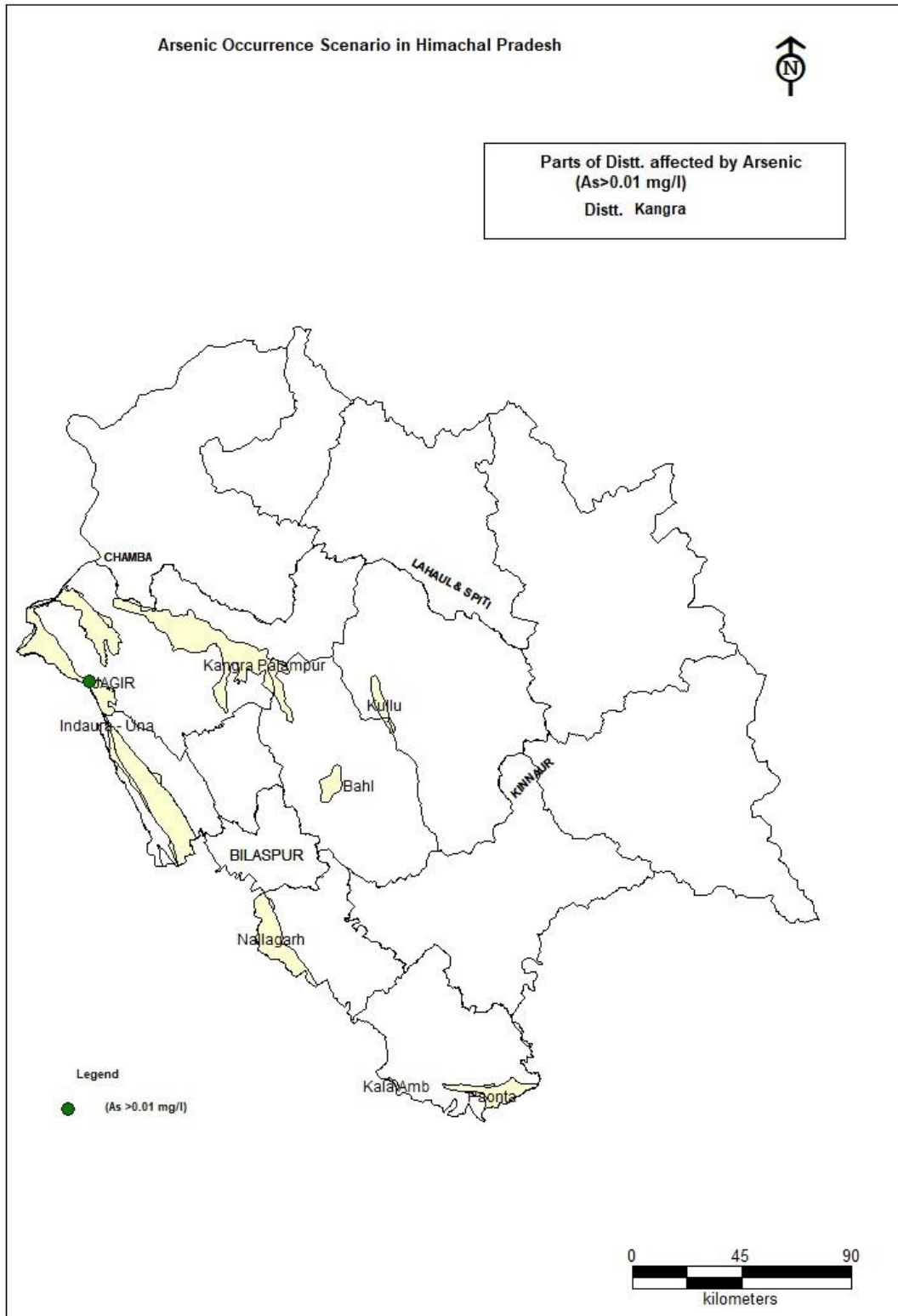
The occurrence of Arsenic in ground water was first reported in 1980 in West Bengal in India. In West Bengal, 79 blocks in 8 districts have Arsenic beyond the permissible limit. The most affected areas are on the eastern side of Bhagirathi River in the districts of Malda, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas and western side of the districts of Howrah, Hugli and Bardhman. The occurrence of Arsenic in ground water is mainly in the aquifers upto 100 m depth. The deeper aquifers are free from Arsenic contamination.

Apart from West Bengal, Arsenic contamination in groundwater has been found in the states of Assam, Bihar, Chhattisgarh, Himachal Pradesh, Jharkhand, Karnataka, Punjab, and Uttar Pradesh. The occurrence of Arsenic in the states of Bihar, West Bengal and Uttar Pradesh is in alluvial formations but in the state of Chhattisgarh, it is in the volcanic rocks exclusively confined to N-S trending Dongargarh-Kotri ancient rift zone. It has also been reported in Golaghat, Jorhat, Lakhimpur, Nagaon, Nalbari, Sibsagar, Sonitpur district of Assam.

The map showing distribution of Arsenic in ground water of Himachal Pradesh (Fig 7.6.1) 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. The detail of the location is given in Annexure-VIII and locations exceed the limit of 0.01mg/L (10 ppb) are given in Annexure VI. The point sources are plotted on the map (Fig 7.6.1). Districts having Arsenic > 0.01 mg/L in Ground Water in the State of Himachal Pradesh are shown in Table-7.6.1.

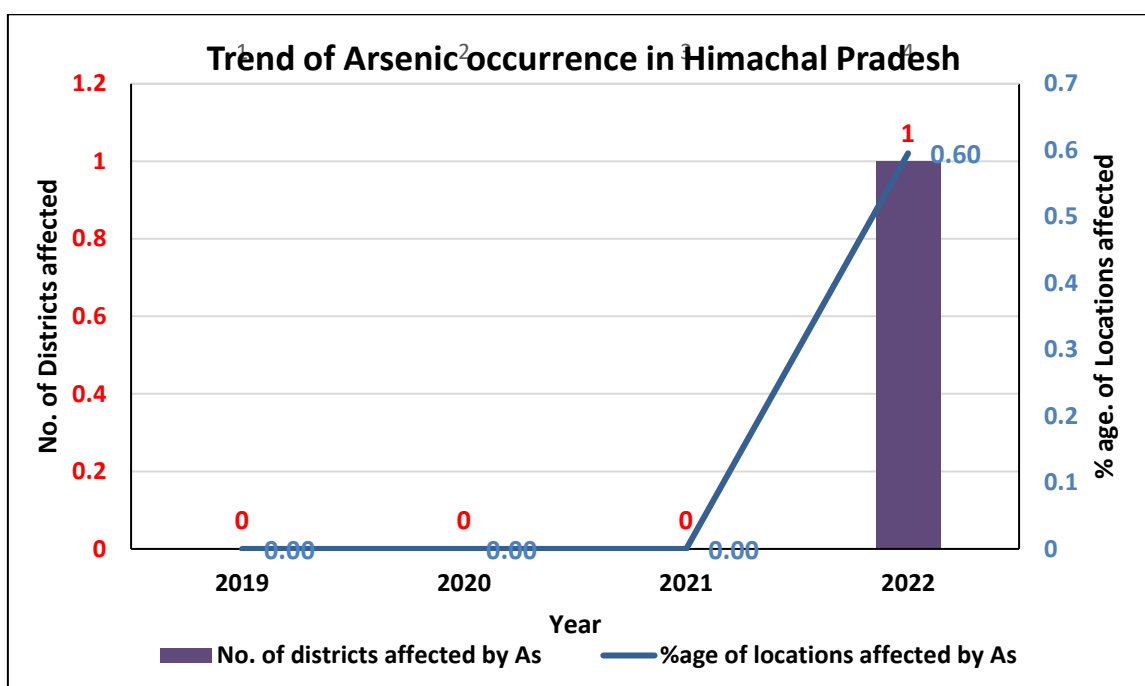
LOCATION	DISTRICT	LONGITUDE	LATITUDE	As
JAGIR	KANGRA	75.90277778	31.9730556	0.024671

**Table 7.6.1: Locations showing Arsenic contamination (> 10 ppb or > 0.01 µg/L)**



**Fig 7.6.1** Map showing areas of Arsenic contaminated (> 10 ppb) groundwater in Himachal Pradesh (NHS 2022)

Year	Total Number of samples analysed	No. of districts affected by As	Total No of locations affected by As	% of locations affected by As (As >0.01 mg/L)
2019	120	0	0	0
2020	90	0	0	0
2021	159	0	0	0
2022	168	1	1	0.59



**Fig: Trend of Arsenic occurrence in Himachal Pradesh**

### 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 hydrolyzing 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 modeling 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.

## 7.7 URANIUM

Uranium occurs naturally in groundwater and surface water. Being a radioactive mineral, high uranium concentration can cause impact on water, soil and health. Uranium has both natural and anthropogenic source that could lead to the aquifer. These sources include leaching from natural deposits, release in mill tailings and emissions from the nuclear industry, combustion of coal and other fuels and the use of phosphate fertilizers that contains uranium and contribute to ground water pollution. Uranium enters in human tissues mainly through drinking water, food, air and other occupational and accidental exposures. Intake of uranium through air and water is normally low, but in circumstances in which uranium is present in a drinking water source, the majority of intake can be through drinking water.

Water with uranium concentration above the recommended maximum permissible concentration of 30 ppb (BIS,10500:2012) is not safe for drinking purposes as it can cause damage to internal organs, on continuous intake. Elevated uranium concentrations in drinking water have been associated with many epidemiological studies such as urinary track cancer as well as kidney toxicity. A recent study, found a strong correlation between uranium concentration in drinking water and uranium in bone, suggesting that bones are good indicators of uranium exposed via ingestion of drinking water. Therefore, such studies trigger further assessment of uranium's adverse health effects on humans and/or the environment for countries where elevated uranium concentration in drinking water has been observed. Hence, it becomes important to study the level of uranium in drinking water for health risk assessment.

Uranium concentration in the shallow ground water varies primarily due to recharge and discharge, which would have dissolved or leached the uranium from the weathered soil to groundwater zone. High uranium concentrations observed in groundwater may be due to local geology, anthropogenic activities, urbanization and use of phosphate fertilizers in huge quantity for agriculture purpose.

Studies have shown that phosphate fertilizer possess uranium concentration ranging from 1 mg/kg to 68.5 mg/kg (Brindha K et al., 2011). Hence, the phosphate fertilizers manufactured from phosphate rocks may also contribute uranium to ground water in agriculture region. In ores, uranium is found as uranite ( $\text{UO}_2^{2+}$ ) and pitchblende ( $\text{U}_3\text{O}_8^{2+}$ ) or in the form of secondary minerals (complex oxides, silicates, phosphates, vanadates).

**Table 7.7.1** Summary of uranium concentrations in different types of rocks

<b>Rocks</b>	<b>Range(mg/kg)</b>
<b>Granite</b>	3.4
<b>Limestone/dolomite</b>	2.2
<b>Argillaceous shale</b>	3.7
<b>Sediments</b>	1.4-53
<b>Phosphates</b>	30-100

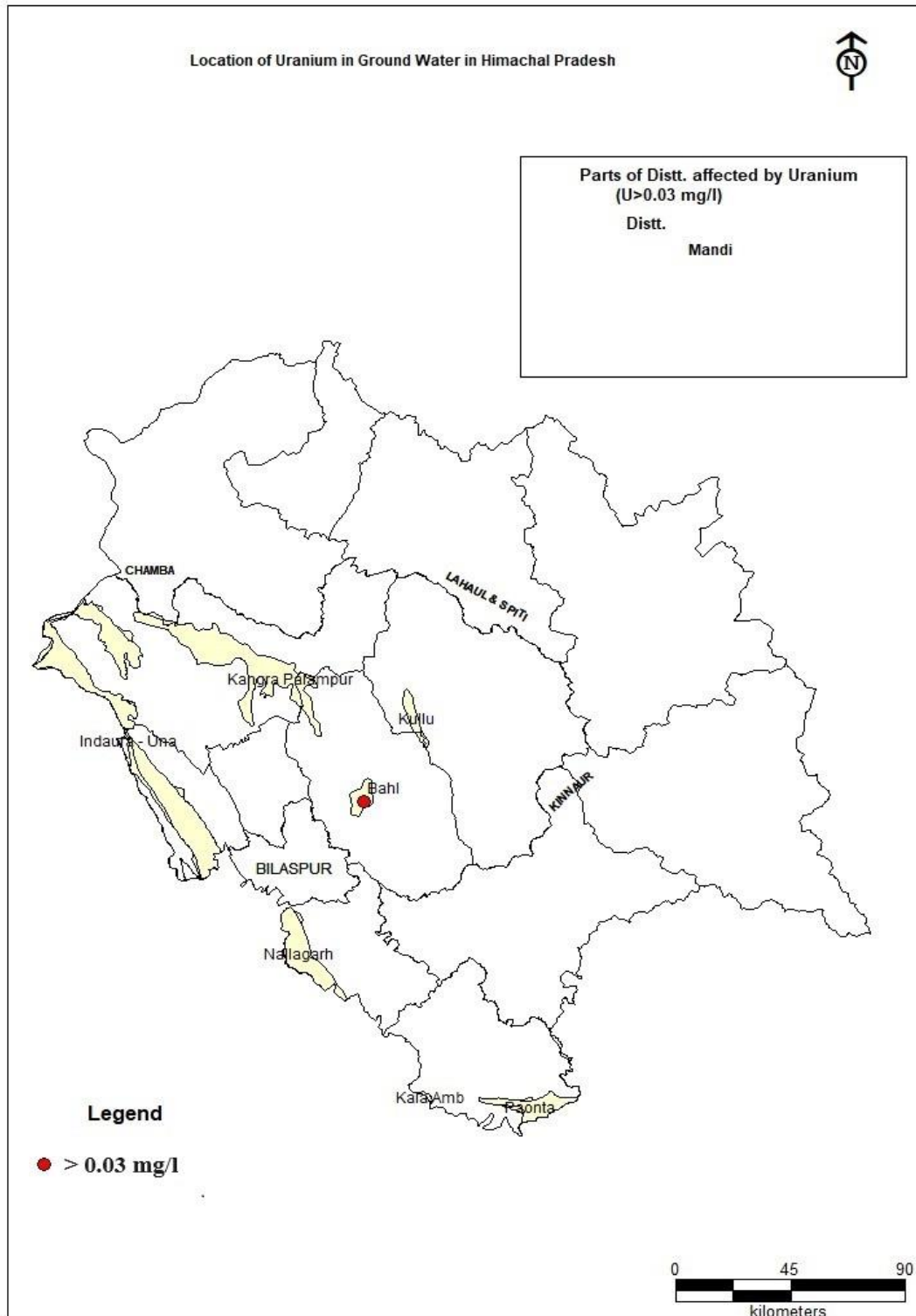
**Table 7.7.2 Standards and guidelines for uranium in drinking water in various countries.**

Sl. No	Country / agency	guideline value ( $\mu\text{g/L}$ )	Reference
1	Australia	GV 17	NHMRC, Australia (2011)
2	Bulgaria	ML 60	European Food Safety Authority (2009)
3	Canada	MAC 20	Health Canada (2019)
4	Finland	RV 100	European Food Safety Authority (2009)
5	India	RBL 60	AERB, India (2004)
6	India	PL 30	BIS,2012
7	Malaysia	MAV 2	Ministry of Health Malaysia (2004)
8	USA	MCL 30	USEPA (2011)
9	WHO	PGV 30	WHO 2011

*GV, Guideline value; ML, Maximum limit; MAC, Most acceptable concentration; RV, Recommended value; RBL, Radiological based limit; PL, Permissible Limit; MAV, Maximum acceptable value; MCL, Maximum contaminant level; PGV, Provisional guideline value*

To assess the Uranium concentration and distribution in the ground water, Central Ground Water Board (CGWB) had decided to carry out Uranium sampling of its National Hydrograph Network Stations (NHNS) in the entire country during Pre-monsoon monitoring (May,2019). Accordingly, in the state, continuous ground water sampling is being done on yearly basis. In line with this the sampling was also done Pre-monsoon monitoring (May 2022). The sample collection and storage were done according to the standard protocols prescribed by APHA (2017). The groundwater samples were collected in plastic bottles after having been filtered through 0.45- $\mu\text{m}$  filter paper. For the cations and uranium analyses, groundwater samples were immediately acidified below pH 2 by adding nitric acid to prevent precipitation and adsorption to the container walls. Uranium (U) was detected using Inductively Coupled Plasma Mass-spectrometry. To ensure quality control, duplicate and standard checks were performed on every ten samples. In addition, a trace element standard reference material was examined. District wise no. of locations affected by Uranium (>30 ppb) and maximum value observed is given in Table 7.7.3.





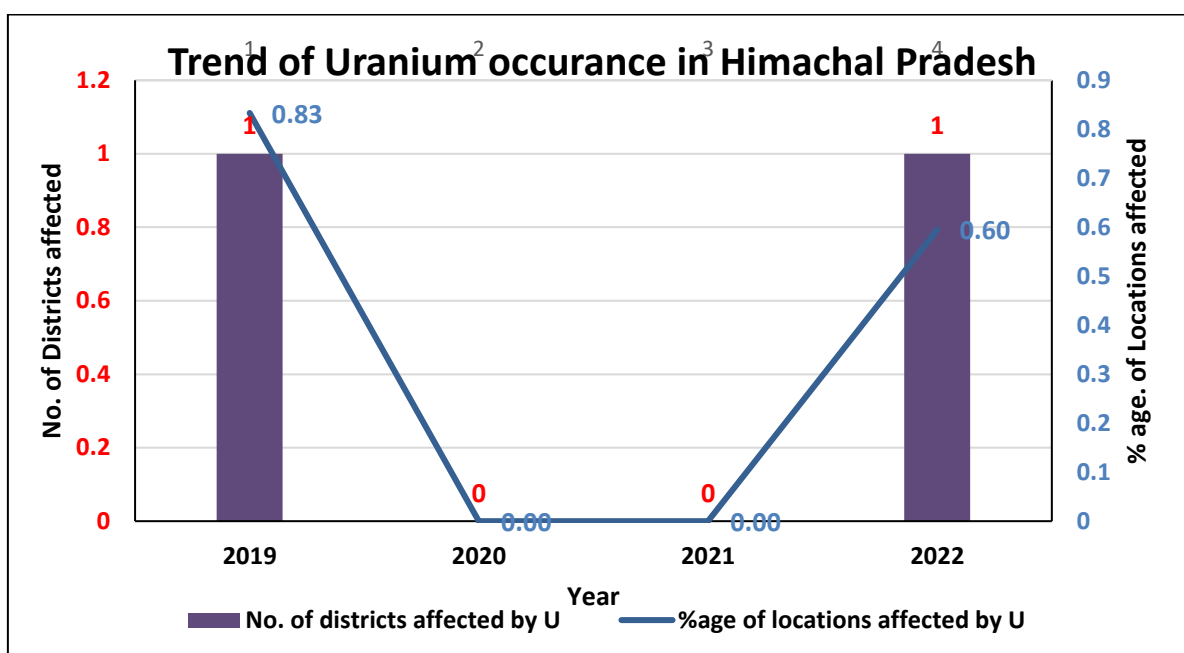
**Fig 7.7.1** Map showing areas of Uranium contaminated (> 30 ppb) groundwater in Himachal Pradesh (NHS 2022)

LOCATION	DISTRICT	LONGITUDE	LATITUDE	U
LOHARA	MANDI	76.94527778	31.5886111	0.128

**Table 7.7.3: Districts Having Uranium >0.03 mg/L (>30ppb) in Ground Water in State of H. P.**

Uranium concentration found only one location in the entire state during Pre-monsoon monitoring (May 2022), indicating that uranium concentrations in groundwater widely vary by several orders of magnitude. Large variations seen in Uranium concentrations could be due to the wide variation of geographical locations or regional differences in the hydrogeochemical characteristics of groundwater.

Year	Total Number of samples analysed	No. of districts affected by U	Total No of locations affected by U	% of locations affected by U (U >0.03 mg/L)
2019	120	1	1	0.833
2020	90	0	0	0
2021	159	0	0	0
2022	168	1	1	0.595



The occurrences of Uranium in groundwater beyond permissible limit (30 ppb) have been displayed on the map (Fig.7.7.1). Enhanced uranium concentration in groundwater may be due to geogenic inputs. The enhanced elemental concentration of uranium is usually found in hard rocks due to the partial melting and fractional crystallization of magma which enables uranium to be concentrated in silicate rocks. In addition, the high Uranium concentration in districts Mandi may be due to leaching through

soil by heavy use of fertilizers in the agriculture lands. Since in an extensive concentration of bicarbonate and phosphate have also been observed in groundwater samples of H. P., this may be a reason for high concentration observed in groundwater samples from shallow depths as phosphate and bicarbonates present in soil enhance the leaching and mobility of uranium.

## REMEDIAL MEASURES

Finding a remedy for the uranium contaminated groundwater effectively and thoroughly, has become need of day. Remediation technologies can be classified into physical, chemical and biological methods. Bioremediation is divided into plant and microorganism methods. Each method consists of both advantages and disadvantages and the appropriate mitigation techniques should be need based.

Adsorption has high removal efficiency, but costs are also higher. The coagulation process is simple and comparatively economical, but the standard effluent concentration is hard to reach, so there is a need for follow-up treatment. Combined with adsorption, coagulation can remove 99% of U. The extraction process can remove effluent U concentrations of less than 0.05mg / L, but it will produce a lot of sludge. Reverse osmosis is referred as a best technology, but due to its high cost it cannot be used on community scale. The evaporation method is simple and effective, the removal rate is high, but there are high costs and sludge needs that must be dealt with. A review of various treatment technologies for Uranium removal from water and their technical achievability as reported by various researchers are given below in Table 7.7.4

### 7.7.5 Comparison of treatment methods for removal of Uranium.

Treatment Method	Technical Achievability (%)
Coagulation/filtration at high pH (10+)	> 95
Lime softening	85-99
Anion exchange	99
Reverse osmosis	>95
Activated alumina	90
Coagulation/filtration	80-89

(Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India).

## 7.8 TOTAL HARDNESS

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<sub>3</sub> 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 CaCO<sub>3</sub> mg/L in EDTA titration. The two kind of hardness observed in water.

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

The hardness in water is derived largely from contact with the soil and rock formations. Rain water as it falls upon the earth is in capable of dissolving the tremendous amount of solids found in many natural waters. People with kidney and bladder stones should avoid high content of calcium and magnesium in water (K. R. Karanth, 1997). The BIS permissible limit of hardness is 300 – 600 mg/L. The total hardness in groundwater was observed in a many part of the state. It is observed that there is no location in the Himachal Pradesh where the total hardness in ground water exceeds 600 mg/L.

Year	Total Number of samples analysed	No. of districts affected by TH	Total No of locations affected by TH	% of locations affected by TH (TH >600 mg/L)
2017	33	0	0	0
2018	120	0	0	0
2019	120	0	0	0
2020	90	0	0	0
2021	159	0	0	0
2022	168	0	0	0

### 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**

$\text{Ca}(\text{HCO}_3)_2 + \text{Mg}$  Bicarbonate  $\text{Mg}(\text{HCO}_3)_2$ . Removal by Boiling or adding Lime

**NON-CARBONATE (PERMANENT) HARDNESS**

Calcium Sulfate  $\text{CaSO}_4 + \text{Magnesium Sulfate } \text{MgSO}_4$  & Calcium Chloride  $\text{CaCl}_2 + \text{Magnesium Chloride } \text{MgCl}_2$

Removal by Lime-soda, Zeolite or Demineralization Processes

**8.0 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 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. In areas where natural drainage is inadequate, the irrigation water infiltrating the root zone will cause water table to rise excessively. In addition to problems caused by excessive concentration of dissolved solids, certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations. Irrigation indices viz. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) have been evaluated to assess the suitability of ground water for irrigation purposes.

**Alkali Hazard**

In the irrigation water, it is characterized by absolute and relative concentrations of cations. If the sodium concentrations are high, the alkali hazard is high and if the calcium & magnesium levels are high, this hazard is low. The alkali soils are formed by the accumulation of exchangeable sodium and are characterized by poor tilt and low permeability. The U.S. Salinity laboratory has recommended the use of sodium adsorption ratio (SAR) as it is closely related to adsorption of sodium by the soil.

SAR is derived by the following equation:

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

The water with regard to SAR is classified into four categories

➤ **S<sub>1</sub> – Low Sodium Water** (SAR <10)

Such waters can be used on practically all kinds of soils without any risk or increase in exchangeable sodium.

➤ **S<sub>2</sub> – Medium Sodium Water** (SAR 10-18)

Such waters may produce an appreciable sodium hazard in fine textured soil having high cation exchange capacity under low leaching.

➤ **S<sub>3</sub> – High Sodium Water** (SAR >18-26)

Such waters indicate harmful concentrations of exchangeable sodium in most of the soil and would require special management, good drainage, high leaching and addition of organic matter to the soil. If such waters are used on gypsiferous soils the exchangeable sodium could not produce harmful effects.

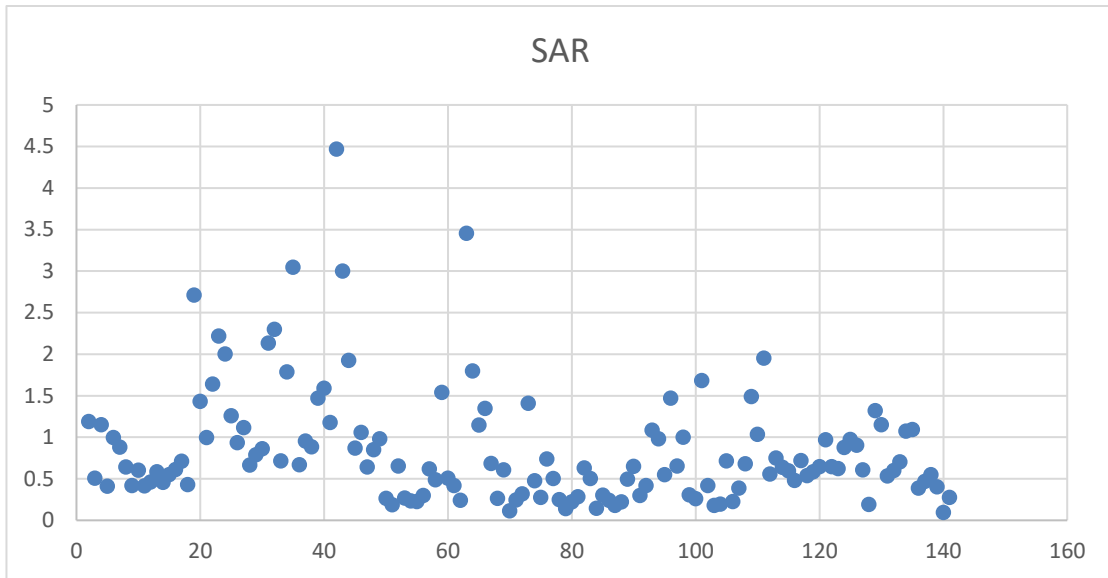
➤ **S<sub>4</sub> – Very High Sodium Waters** (SAR >26)

Generally, such waters are unsatisfactory for irrigation purposes except at low or perhaps at medium salinity where the solution of calcium from the soil or addition of gypsum or other amendments makes the use of such waters feasible.

The computed SAR values ranges from 0.2 to 4.4. The maximum SAR value has been found at Mahadeva of Solan district. It is apparent from Fig. 8.2 that 95 % samples belong to excellent category (S<sub>1</sub>) and only 5% (or negligible) water samples are associated with medium sodium category (S<sub>2</sub>) and is suitable for irrigation.

According to SAR classification, 100% of water samples in Bilaspur, Hamirpur and Mandi fall in excellent category (S<sub>1</sub>). While in considerable proportion of samples in different districts are associated with medium sodium hazard and can be classified as good category(S<sub>2</sub>) for irrigation use (Table 8.1)

**Table 8.1:** Summary of irrigation quality of the groundwater samples in various districts based on SAR classifications.

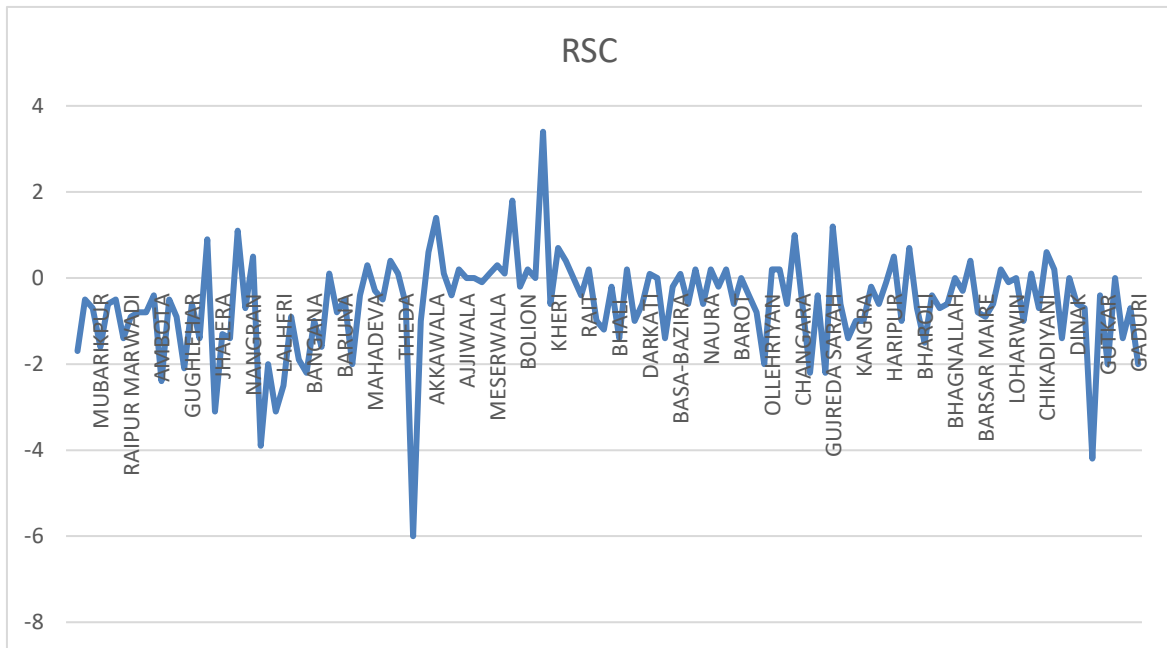


**Figure 8.2:** Percentage of samples with respect to SAR values.

#### **Residual Sodium Carbonate (RSC)**

If the enriched carbonate (residual) concentration becomes relatively high, carbonates get together with calcium and magnesium to form precipitates. The relative abundance of sodium in comparison to alkaline earths and the quantity of bicarbonate and carbonate in excess of alkaline earths also influences the suitability of water for irrigation. This excess is represented in terms of “Residual Sodium Carbonate” (RSC). The highly soluble sodium carbonate known as residual sodium carbonate (RSC) is defined as;

$$RSC = (HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+})$$



**Figure 8.3:** Percentage of samples with respect to RSC values.

Waters with high RSC produces harmful effects on plant development and is not suitable for irrigation. Waters associated with  $RSC < 1.25$  are of excellent irrigation quality and can be safely applied for irrigation for almost all crops without the risks associated with residual sodium carbonate (Wilcox et al., 1954). If the RSC values lie between 1.25 and 2.5, the water is of an acceptable quality for irrigation. Waters associated with RSC values higher than 2.5 are not acceptable for irrigation. In fig. 8.3, 98% collected water samples are associated with RSC values less than 1.25 and are safe for use in irrigation practices. While 2% water samples are associated with RSC values more than 2.5 and are unsuitable for irrigation. The water with high RSC values if applied for irrigation causes soil to become infertile owing to deposition of sodium. Table 8.4 summarizes the irrigation quality of the groundwater samples in various districts based on RSC values.

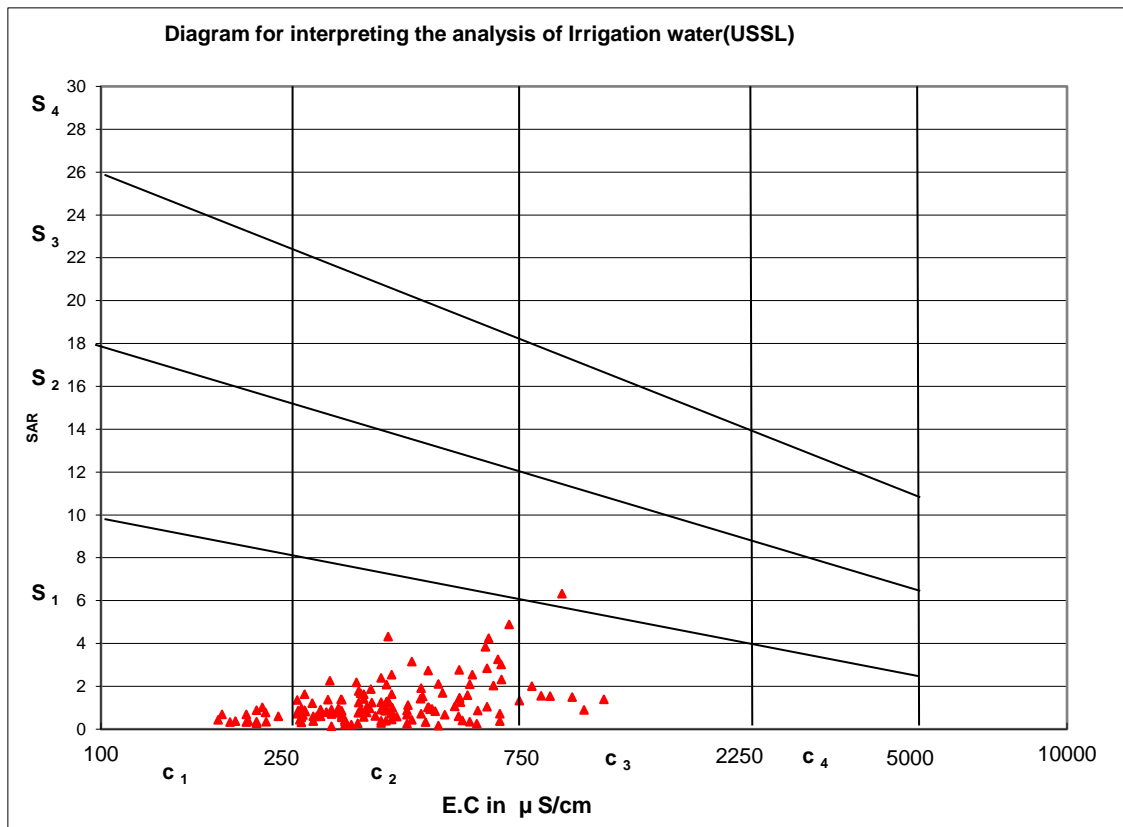
Waters associated with  $RSC < 1.25$  are of excellent irrigation quality and can be safely applied for irrigation for almost all crops without the risks associated with residual sodium carbonate, 100 % of ground waters from Bilaspur, Chamba, Hamirpur, Solan, Mandi, Una & Kullu are suitable for irrigation. The waters from districts of Sirmour (Akkawala, Kodewala Sainwala), Kangra (Gurjerada Sarah) associated with RSC values higher than 2.5 are not acceptable for irrigation.



## 8.1 USSL Diagram

### USSL Diagram of Himachal Pradesh for assessment the Irrigation Water Quality

By plotting the values of EC and SAR in USSL diagram, it is observed that ground water occurring in the State falls majorly under  $C_2S_1$  classes of irrigation waters. Some ground water also falls under  $C_1S_1$  and  $C_3S_1$ . As majority of water sample falls under  $C_2S_1$  classes of irrigation waters, it indicates that most of these waters are suitable for irrigating mostly all type of crops on all soils. Such waters when used continuously for irrigation, they are not likely to cause any salinity hazards.



**Figure 8.4: Depicting USSL Diagram of Himachal Pradesh State (Interpretation Diagram created by NWR, Chandigarh)**

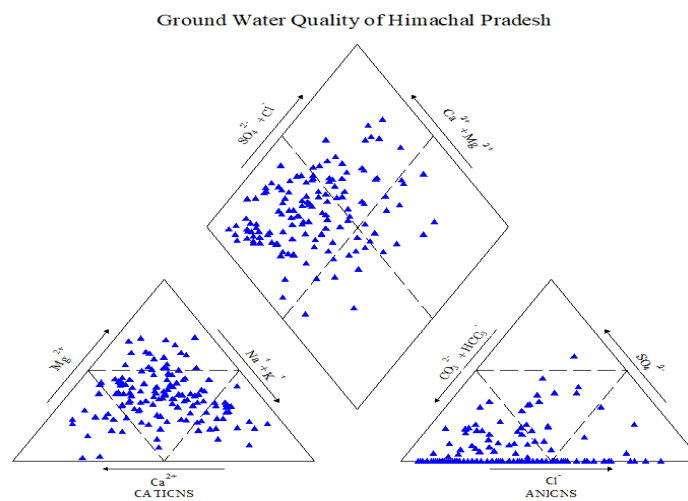
## 8.2 Piper Diagram:

### 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, hydro chemical 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 Himachal Pradesh, cation chemistry is dominated by calcium and Magnesium is followed by sodium and Potassium. In anion side bicarbonate is dominating anion followed by chloride and sulphate.

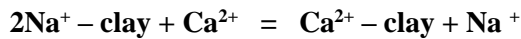
The facies mapping shows (Fig 8.5) that all type of hydro geochemical facies i.e. Ca-HCO<sub>3</sub>, Mg-HCO<sub>3</sub>, CaCl<sub>2</sub> and mixed type are encountered in the state. Majority of samples are in Ca/-Mg- HCO<sub>3</sub>, indicating that groundwater is of fresh type.



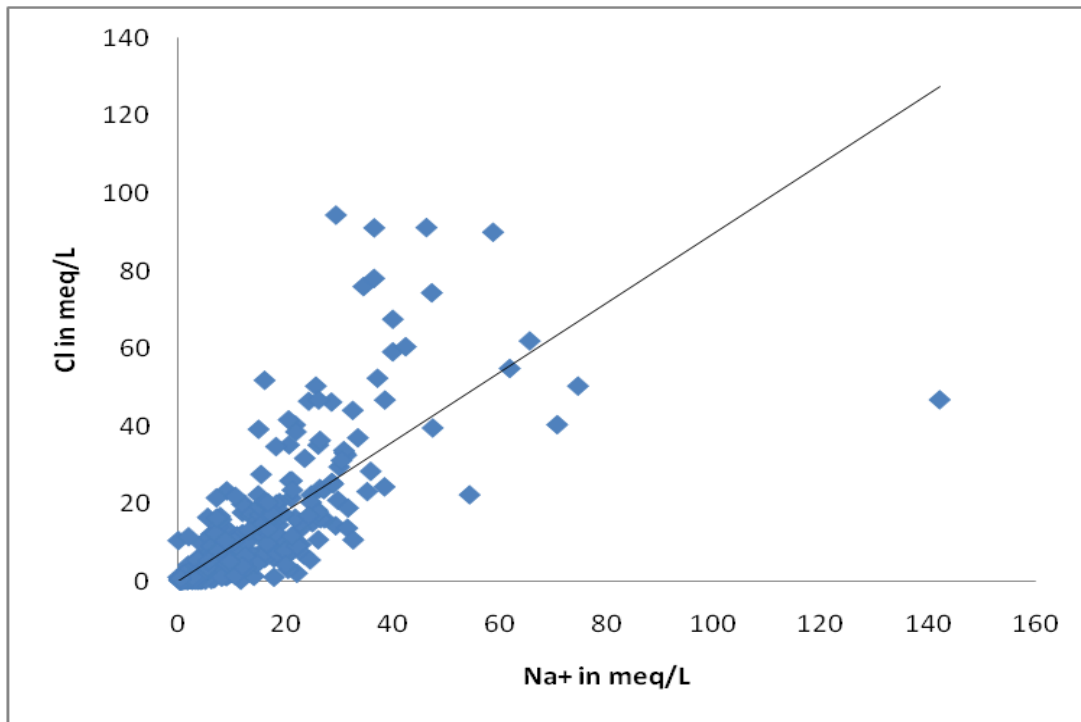
**Fig- 8.5 Piper diagram of groundwater of Himachal Pradesh. (Interpretation Diagram created by NWR, Chandigarh)**

### 9.0 X-Y Plot:

If halite dissolution is responsible for the sodium, the  $\text{Na}^+/\text{Cl}^-$  ratio is approximately one, whereas a ratio greater than one, it is typically interpreted as  $\text{Na}^+$  released from Silicate weathering reaction. In the water samples of the shallow aquifers of India, 28% of the samples fall along the equilibrium in the  $\text{Na}^+/\text{Cl}^-$  plot, indicating common source of halite for both the ions (Fig.9.2). In the water samples of the shallow aquifers of India, 45.4% of the samples have molar ratio greater than one indicating ion exchange is the major process. It is where Na montmorillonite clay reacts with calcium and magnesium and releases sodium (sometimes called natural softening).



The observed  $\text{Na}^+/\text{Cl}^- < 1$ , may be attributed to groundwater interaction with connate seawater in coastal areas and  $\text{Cl}^-$  enrichment from anthropogenic sources such as irrigation return flows or domestic waste disposal in another area. Bivariant plot of Uttar Pradesh, Bihar and Jharkhand is shown in Fig.9.2a & 9.2b.



**Fig. 8.6: Plot for Na versus Cl in groundwater samples of Himachal Pradesh (Interpretation Diagram created by NWR, Chandigarh)**