CGWB, NHR, DHARAMSHALA

Ground Water Quality in Shallow Aquifer of Himachal Pradesh

2024

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, over exploitation 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. The different types of formations are given in following paragraphs.

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^3 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 though 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.

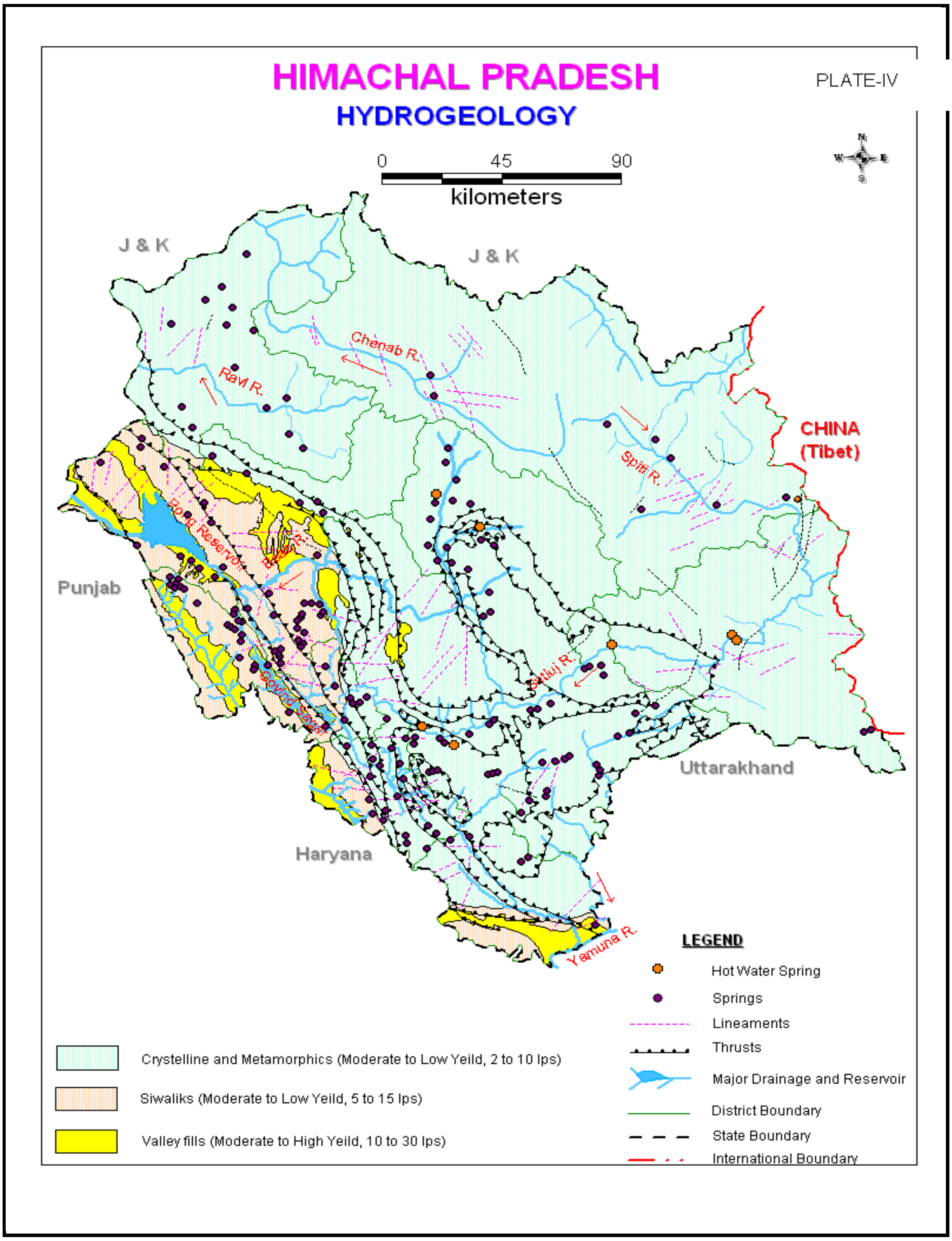

Fig 2.0.1: Himachal Pradesh Hydrogeology Map

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 NO3 etc. Pollutants in the atmosphere can be transported long distances by the wind. These pollutants are mostly washed down by precipitation and partly as dry fall out. Composition of rainwater is determined by the source of water vapors and by the ion, which are taken up during transport through the atmosphere. In general, chemical composition of rainwater shows that rainwater is only slightly mineralized with specific electrical conductance (EC) generally below 50 μS/cm, chloride below 5 mg/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 tend 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_2. 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_2 associated with the percolating water gets gradually exhausted through interaction of water with minerals.

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

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

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

$CH_2O + O_2 \quad = \quad CO_2 + H_2O$

(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_2 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. Saberses’ll. (1976 as quoted in CGWB & CPCB 2000) identified the key water quality parameters according to its various uses **(Table 4.0.1).**

Table 4.0.1: Water quality criteria parameters for various uses (Sayers et.al., 1976)

Public Water supply	**Industrial Water supply**	**Agricultural water supply**	**Aquatic life& wild life water supply**	**Recreation and Aesthetics**
Coliform bacteria Turbidity color, Taste, Odour TDS, CI, F, SO_4 NO_3 ,CN, Trace Metals, Trace Organics Radioactive substances	Processing pH, Turbidity Color, Alkalinity, Acidity, TDS, Suspended solids, Trace metals, Trace Organics Cooling PH, Temp, Silica, Al, Fe, Mg, Total hardness, Alkalinity/Acidity Suspended solids, Salinity	Farms Same as for public supply Live-stock Same as for public supply Irrigation TDS, EC, Na, Ca, Mg, K, B, CI and Trace metals	Temp, DO, pH, Alkalinity, Acidity, TDS Salinity, pH, DCOs, Turbidity Color, Settleable materials, Toxic substances, Nutrients, Floating materials	Recreations Turbidity, Color, Odour, Floating Materials, Settable Materials Nutrients, Coliforms Aesthetics Same as for Recreation and Substances adversely affecting wildlife

4.1 Water Quality Criteria for Drinking Purpose

With the objective of safeguarding water from degradation and to establish a basis for improvement in water quality, standards / guide lines / regulations have been laid down by various national and international organizations such as; Bureau of Indian Standards (BIS), World Health Organization (WHO), European Economic Community (EEC), Environmental Protection Agency (EPA), United States, and Inland Waters Directorate, Canada. The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institutions (ISI) has laid down the standard specification for drinking water during 1983, which have been revised and updated from time to time. In order to enable the users, to exercise their discretion towards water quality criteria, the maximum permissible limit has been prescribed especially where no alternative sources are available. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purposes. The important water quality characteristics as laid down in BIS standard (IS 10500: 2012) are summarized in **Table- 4.1.1.**

Table 4.1.1: Drinking Water Characteristics (IS 10500: 2012)

S. No.	Parameters	Desirable Limits(mg/L)	Permissible Limits(mg/L)
Essential Characteristics			
1	Colour Hazen Unit	5	15
2	Odour	Unobjectionable	-
3	Taste	Agreeable	-
4	Turbidity (NTU)	1	5
5	pH	6.5-8.5	No relaxation
6	Total Hardness, $CaCO_3$	200	600
7	Iron (Fe)	.30	No relaxation
8	Chloride (Cl)	250	1000
9	Residual Free Chlorine	0.2	1
10	Fluoride(F)	1.0	1.5
Desirable Characteristics			
11	Dissolved Solids	500	2000
12	Calcium (Ca)	75	200
13	Magnesium (Mg)	30	100
14	Copper (Cu)	0.05	1.5
15	Manganese (Mn)	0.1	0.3
16	Sulphate (SO_4)	200	400
17	Nitrate (NO_3)	45	No relaxation
18	Phenolic Compounds	0.001	0.002
19	Mercury (Hg)	0.001	No relaxation
20	Cadmium (Cd)	0.003	No relaxation
21	Selenium (Se)	0.01	No relaxation
22	Arsenic (As)	0.01	No relaxation
23	Cyanide (CN)	0.05	No relaxation
24	Lead (Pb)	0.01	No relaxation
25	Zinc (Zn)	5.0	15
26	Hexavalent Chromium	0.05	No relaxation
27	Alkalinity	200	600
28	Aluminum (Al)	0.03	0.2
29	Boron(B)	0.5	2.4
30	Pesticides	Absent	0.001
31	Uranium	0.03	No relaxation

NTU-Nephelometric Turbidity Unit

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 - 4.2.1.**

Table 4.2.1: 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 µs/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 soils having clay10-20%; internally very well drained and Having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4	Light textured soils having clay less than10%; 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.

4.3 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 liter (meq/L).

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

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

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

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

Percentage sodium (%Na):

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

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

The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. 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 - 4.3.1**

Table 4.3.1: 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	-

4.4 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–4.4.1)**. 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 4.4.1: 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	Color (Hazen unit)	5	15	Makes water aesthetically undesirable.
2	Odour	Essentially free from objectionable odour		Makes water aesthetically undesirable.
3	Taste	Agreeable		Makes water aesthetically undesirable.
4	Turbidity (NTU)	1	5	High turbidity indicates contamination/Pollution.
5	pH	6.5	8.5	Indicative of acidic or alkaline water, affects taste, corrosively and the water supply system
6	Hardness as $CaCO_3$ (mg/L)	200	600	Affects water supply system (Scaling), Excessive soap consumption, and calcification of arteries. There is no conclusive proof but it may cause urinary concretions, diseases of kidney or bladder and stomach disorder.
7	Iron(mg/L)	1.0	No relaxation	Gives bitter sweet astringent taste, causes staining of laundry and porcelain. In traces it is essential for nutrition.
8	Chloride(mg /L)	250	1000	May be injurious to some people suffering from diseases of heart or kidneys. Taste, indigestion, corrosion and palatability are affected.
9	Residual Chlorine(mg/L) Onlywhenwateris Chlorinated	0.20	-	Excessive chlorination of drinking water may cause asthma, colitis and eczema.

S. No.	**Parameters**	**Prescribed limits IS:10500,2012**		**Probable Effects**
		Desirable Limit	**Permissible Limit**	
10	Total Dissolved Solids-TDS (mg/L)	500	2000	Palatability decreases and may cause gastro intestinal irritation inhuman, may have laxative effect particularly upon transits and corrosion, may damage water system.
11	Calcium (Ca)(mg/L)	75	200	Causes encrustation in water supply system. While 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_4) (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_3) (mg/L)	45	No relaxation	Cause infant methemoglobinemia (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 diarrhea, chronic toxicity produces nausea, severe abdominal pain, paralysis, mental confusion, visual disturbances, Anemia etc.
19	Zinc (Zn)(mg/L)	5	15	An essential and beneficial element in human metabolism. Taste threshold for Zn occurs atabout5mg/Limpartms astringent Taste to water.
20	Chromium (Cr^6) (mg/L)	0.05	No relaxation	HexavalentstateofChromiumproduceslungtumorscanproducecutaneousandnasalmucousmembraneulcersand dermatitis.
21	Boron(B)(mg/L)	0.5	2.4	Affects central nervous system its salt may cause nausea, cramps, convulsions, coma etc.
22	Alkalinity (mg/L) as$CaCO_3$	200	600	Impart distinctly un pleasant 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 accumulatedindifferentorgansofhumanbodyaffectingimmuneandnervoussystemsmaybe carcinogenic.
24	Phosphate (PO_4) (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_2) (mg/L)	No guidelines		-
28	Nickel (Ni)(mg/L)	0.02		Non-toxic element but may be carcinogenic in animals, can react With DNA resulting in DNA damage in animals.

S. No.	**Parameters**	**Prescribed limits IS:10500,2012**		**Probable Effects**
		Desirable Limit	**Permissible Limit**	
29	Pathogens(a)Total coliform (per100ml) (b) Faecal Coliform(per100 ml)	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	**No relaxation**	Various skin diseases, Carcinogenic
31	Uranium	0.03	**No relaxation**	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 dug wells in a major part of the country and through springs and hand pumps in hilly areas. The main objective of ground water quality monitoring programme is to get information on the distribution of water quality on a regional scale as well as lattice is to create a background data bank of different chemical constituents in ground water.

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

Even though water is the most frequently occurring substance on earth, lack of safe drinking water is more prominent in the developing countries. Due to increasing world population, extraction of groundwater is also increasing for 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.

5.1 Data Validation / Data Quality Control

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

a. Checking of Data Consistency: Checking of the data for consistency by comparing the measurements of a particular parameter over time. This will help identify any changes in the groundwater quality due to measurement methodology or equipment

b. Checking the correlation between EC and TDS:
    a. The relationship between the two parameters is often described by a constant (commonly between 0.55 and 0.95 for freshwater).
    b. Thus: TDS (mg/l) ~ (0.55 to 0.95) x EC (mS/cm).
    c. The value of the constant varies according to the chemical composition of the water. For freshwater, the normal range of TDS can be calculated from the following relationship:
    d. 0.55 conductivity (mS/cm) < TDS (mg/l) < 0.95 conductivity (mS/cm).
    e. Typically, the constant is high for chloride rich waters and low for sulphate rich waters.

c. Checking the cation-anion balance

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

Sum of cations = 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 May (Pre-monsoon 2024), 60 number of ground water samples were collected from Dug wells and Hand Pumps in Una, Solan, Sirmour, Hamirpur, Kangra, Mandi, Kullu and Chmba districts of Himachal Pradesh 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 (CO_3, HCO_3, Cl, NO_3, SO_4) in addition to pH, EC, F, SiO_2, PO_4 and TH as $CaCO_3$ in Centre for Industrial testing and research organization, Village Jawaharpur, Derabasssi, Punjab by following 'Standard analytical procedures' as given in American Public Health Agency (APHA) 23rd Edition 2017 and Bureau Indian Standards (BIS).

The district-wise samples collected are given in the **Table 6.1.1.**

Table: 6.1.1 District wise sample collection.

Region	District	No. of samples collected in Pre-monsoon May, 2024
NHR Dharamshala	Una	17
	Solan	07
	Sirmaur	10
	Hamirpur	01
	Kangra	17
	Mandi	02
	Kullu	01
	Chamba	05

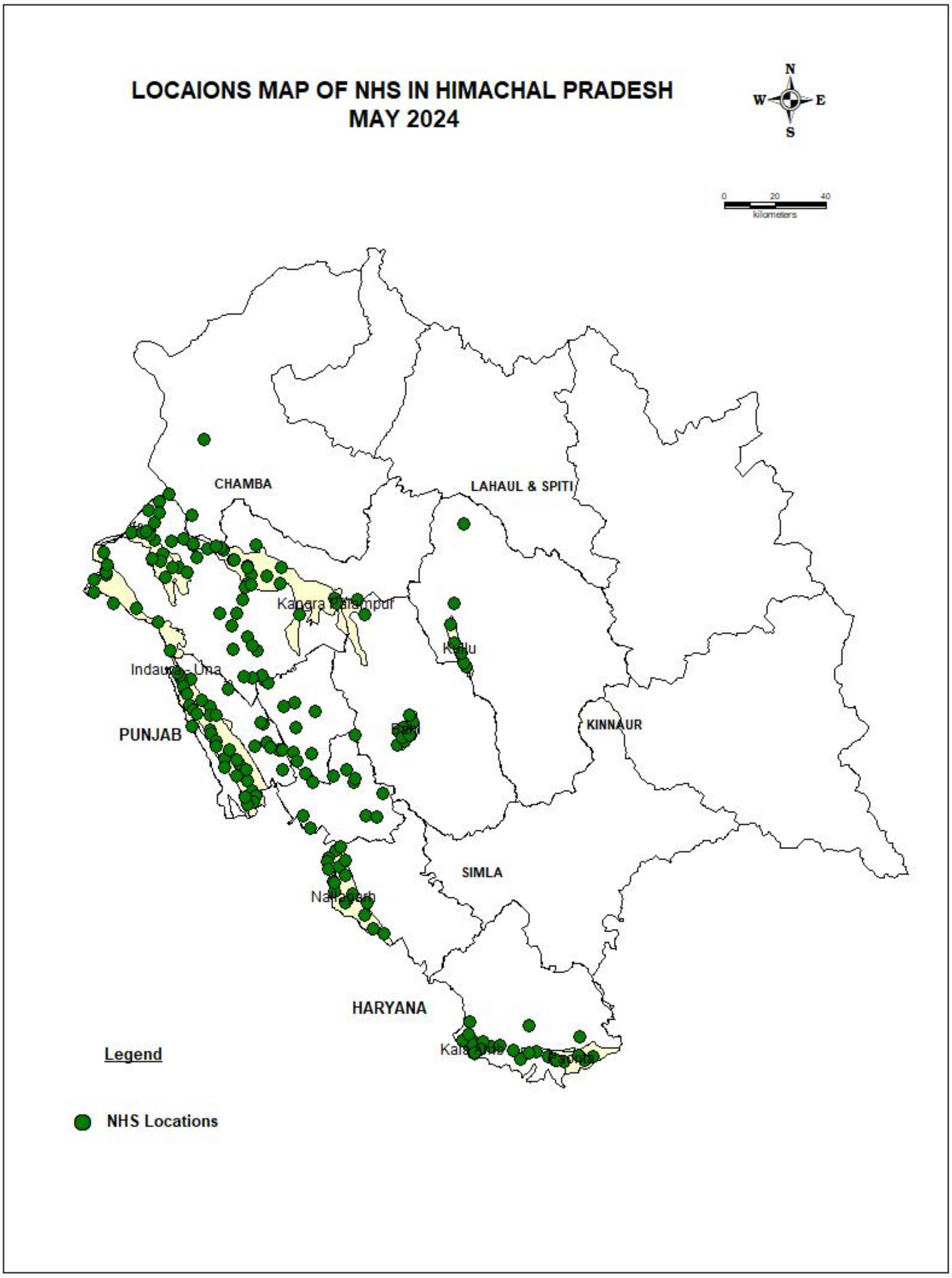

Fig 6.1.1: Locations Map of NHS in Himachal Pradesh 2024

Table-6.1.2 Summarized results of ground water quality ranges, (May 2023)

S. No	Parameters		Range	No. of sample	Percentage
1	Electrical Conductivity (µs/cm) at 25°c	Fresh	< 750	45	75
		Moderate	750- 2250	15	25
		Slightly mineralized	2251- 3000	0	0
		Highly mineralized	> 3000	0	0
2	Chloride (mg/L)	Desirable limit	< 250	58	96.67
		Permissible limit	250-1000	02	3.33
		Beyond permissible limit	> 1000	0	0
3	Fluoride (mg/L)	Desirable limit	< 1.0	56	93.33
		Permissible limit	1.0 - 1.5	02	3.33
		Beyond permissible limit	>1.5	02	1.33
4	Nitrate (mg/L)	Permissible limit	< 45	45	75
		Beyond permissible limit	> 45	15	25

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 ($Ca\text{-}HCO_3$) type when the total dissolved solids of water is below 500 mg/L (corresponding to electrical conductance of 750 µS/cm at 25^0C). They are of mixed cations and mixed anion type when the electrical conductance is between 750 and 3000 µS/cm and waters with electrical conductance above 3000 µS/cm are of sodium chloride (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 hotspot maps of the country have been prepared depicting five 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. 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 µS/cm at 25^{0}C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000 µS/cm at 25^{0}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 µS/cm at 25^{0}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 90.3 to 1923 µS/cm at 25°C. Grouping water samples based on EC values, it is found that 75 % of them have EC less than 750 µS/cm, 25 % have between 750 and 1923 µS/cm.

Table 7.1.1 District-wise percentage of samples having EC >3000 µS/cm during the period of 2017-2024

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 µs/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
2023	228	0	0	0
2024	60	0	0	0

7.2 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 µS/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 µS/cm were 0 %.

7.3 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 table 7.3.1, 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 7.5 mg/L to 680 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 96.66 % of the samples.

Table 7.3.1 District-wise percentage of samples having Chloride >1000mg/L

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
2023	228	0	0	0
2024	60	0	0	0

7.4 FLUORIDE

Fluorine is a fairly common element but it does not occur in the elemental state in nature because of its high reactivity. Fluorine is the most electronegative and reactive of all elements that occur naturally within many types of rock. It exists in the form of fluorides in a number of minerals of which fluorspar, cryolite, fluorite and fluorapatite are the most common. Fluorite (CaF_2) is a common fluoride mineral.

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

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

BIS has recommended an upper desirable limit of 1.0 mg/L of F^- as desirable concentration of fluoride in drinking water, which can be extended to 1.5 mg/L of F in case no alternative source of water is available. 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. 7.4.1. It is observed Ground waters with fluoride above 1.50 mg/L are found mainly in Chamba (Mangla) & Sirmaur (Trilokpur) districts of Himachal Pradesh. 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 I. The list of districts showing localized occurrence of fluoride in ground water in excess of 1.5mg/L is given in table 7.4.1.

The occurrences of fluoride in groundwater beyond permissible limit (1.5 mg/L) have also been shown on the point map as Fig. 7.4.1, district-wise percentage of wells having fluoride >1.5mg/L is shown as a bar diagram in Fig 7.4.2.

Table 7.4.1: Locations Showing F contamination (> 1.5 mg/L)

Pre monsoon Trend				
LOCATION	**District**	**LATITUDE**	**LONGITUDE**	**F (mg/l)**
Mangla	Chamba	32.53305556	76.10444444	6.6
Trilokpur	Sirmaur	30.5400	77.2033333	1.60

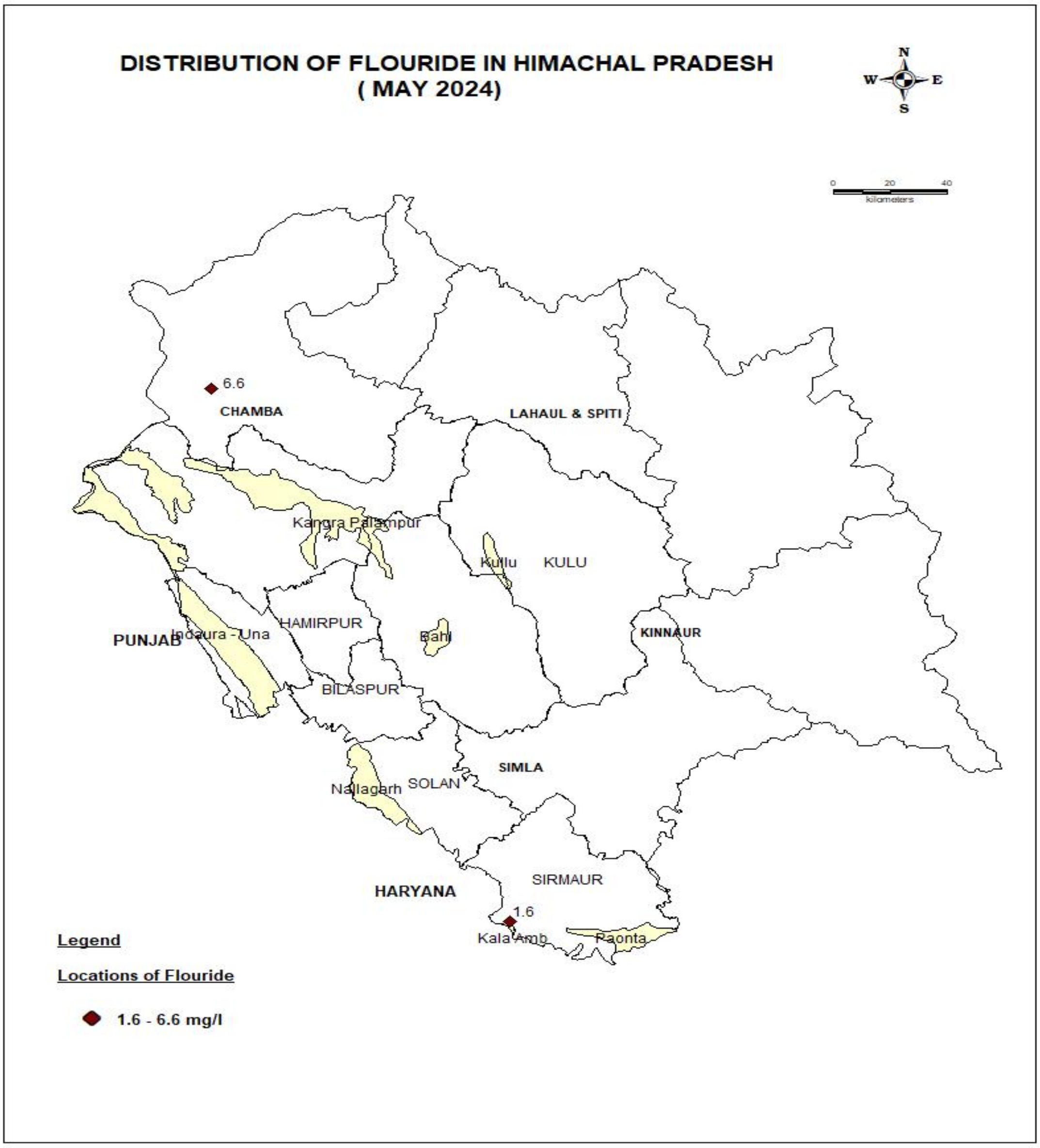

Fig 7.4.1 Locations having Fluoride concentration > 1.5 mg/L in year 2024.

It has been observed (Table 7.4.2) that total number of districts affected by high fluoride in the state has decreased by 1.85 % in 2023 as compared to the data available in previous years. In Chamba District there is one location and one location in Sirmaur district having Fluoride concentration > 1.5 mg/l.

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 2024 were compared and presented in the Table 7.4.1 and Fig 7.4.2 and observed that the percentage of samples exceed the permissible limit of fluoride 1.5 mg/L were ranging between 1.6 – 6.6 mg/L. Trend on fluoride in Himachal Pradesh shows an increasing trend.

Table 7.4.2: Percentage of wells Exceed fluoride >1.5 mg/L during the period of 2017-2024

Year	Total No. of samples analyzed	No. of districts affected by F	Total No. of locations affected by F	% of locations affected by F
2017	33	0	0	0
2018	120	1	1	0.833
2019	120	1	1	0.833
2020	90	1	1	1.11
2021	159	1	1	0.628
2022	168	3	6	3.57
2023	228	3	4	1.75
2024	60	2	2	3.33

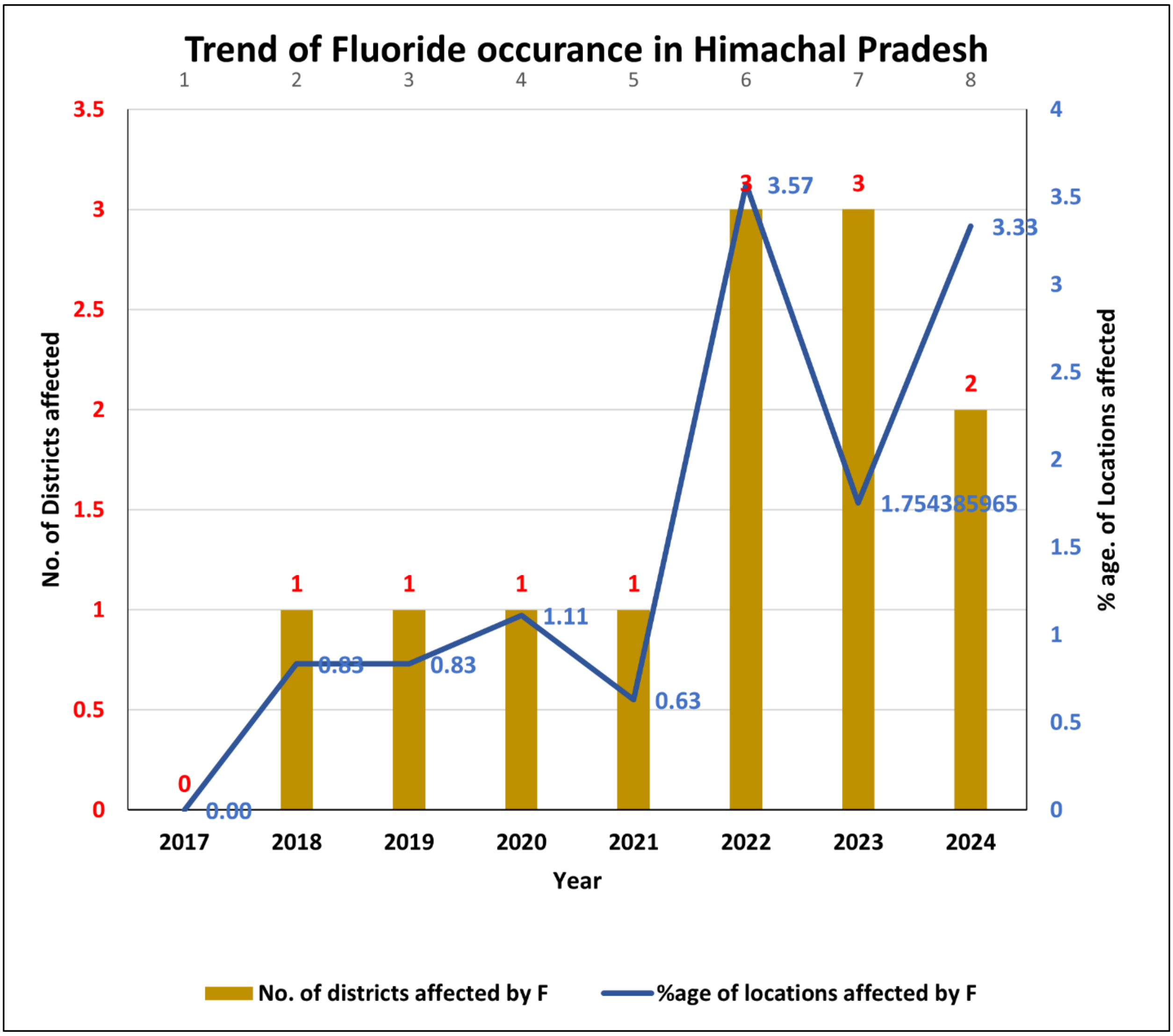

Fig. 7.4.2 Trend of Fluoride occurrence in Himachal Pradesh

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 Aluminum Chloride, Poly Aluminum Hydroxy sulphate and Brushite are some of the frequently used materials in defluorination by precipitation technique. The best example for this technique is the famous Nalgonda technique.

Nalgonda Technique

Nalgonda technique involves addition of 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 defluorination of water. Though they are effective in removing fluoride salts from water, however, there are certain procedural disadvantages that limit their usage on a large scale.

7.5 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 7.5.1 and also given in Annexure-I. Table-7.5.1 shows the locations where nitrate has been found in excess of 45 mg/L in groundwater**.**

	Table-7.5.1 Locations having Nitrate concentration > 45 mg/L during May 2024 (Pre-Monsoon)		
Sr. no	**District**	**Locations**	**NO3 (mg/l)**
1	Kangra	Bod	48.00
2	Kangra	Dehra Gopipur	47.00
3	Una	Una	81.80
4	Una	Badsali	81.30
5	Una	Gagret	80.00
6	Una	Ambota	71.50
7	Una	Daulatapur	47.00
8	Una	Raipur Marwadi	49.00
9	Una	Babehar	61.60
10	Una	Bhadarkhali	61.20
11	Una	Nalagarh	51.00
12	Solan	Kherachak	60.00
13	Solan	Palahi	68.00
14	Solan	Nalagarh	51.00
15	Kullu	Gaduri	72.10

It has been observed (Table 7.5.1) that No. of locations in various districts having high Nitrate (more than 45 mg/l) content in ground water has increased by 6.30% in year 2023 as compared to the data available in previous in 2015 to 2024 years

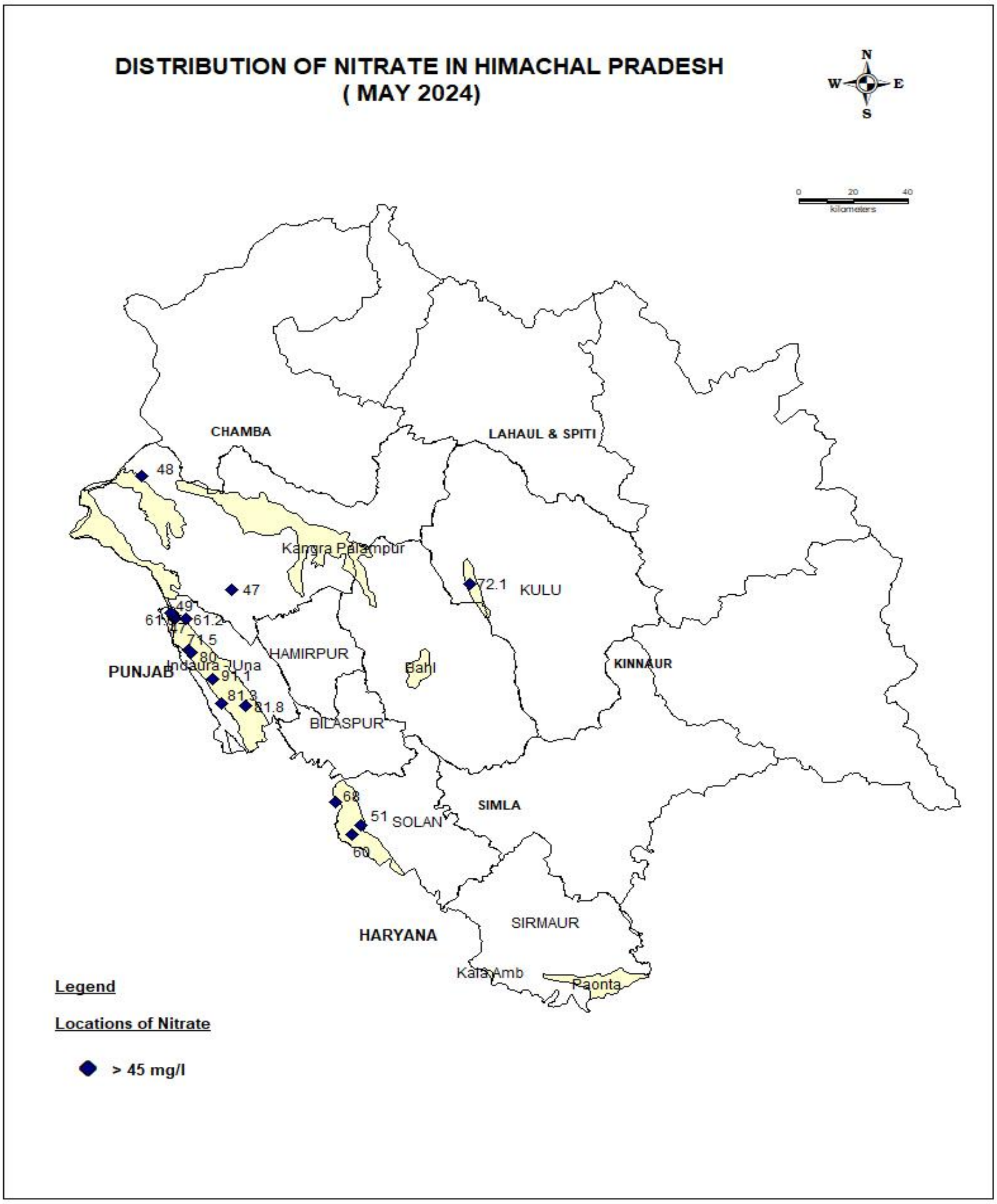

Fig. 7.5.1 Locations having Nitrate concentration > 45 mg/L in year 2024

7.6 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 2023 were compared and presented in the Table 7.6.1 and Fig 7.6.1 and observed that the percentage of samples exceed the permissible limit of nitrate were ranging between 01– 91.01. Trend of Nitrate in Kangra, Una and Solan districts of Himachal Pradesh are shown (Fig 7.6.1, 7.6.2 and Table 7.6.1) increasing trend in comparison to 2022. In 2023 number of samplings have increased and number of districts and locations affected by Nitrate also increased.

Table 7.6.1 Percentage of wells Exceed Nitrate >1.5 mg/L during the period of 2017-2024

Year	Total No. of samples analyzed	No. of districts affected by NO3	Total No. of locations affected by NO3	% of locations affected by NO3
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
2023	228	7	25	10.96
2024	60	4	16	26.66

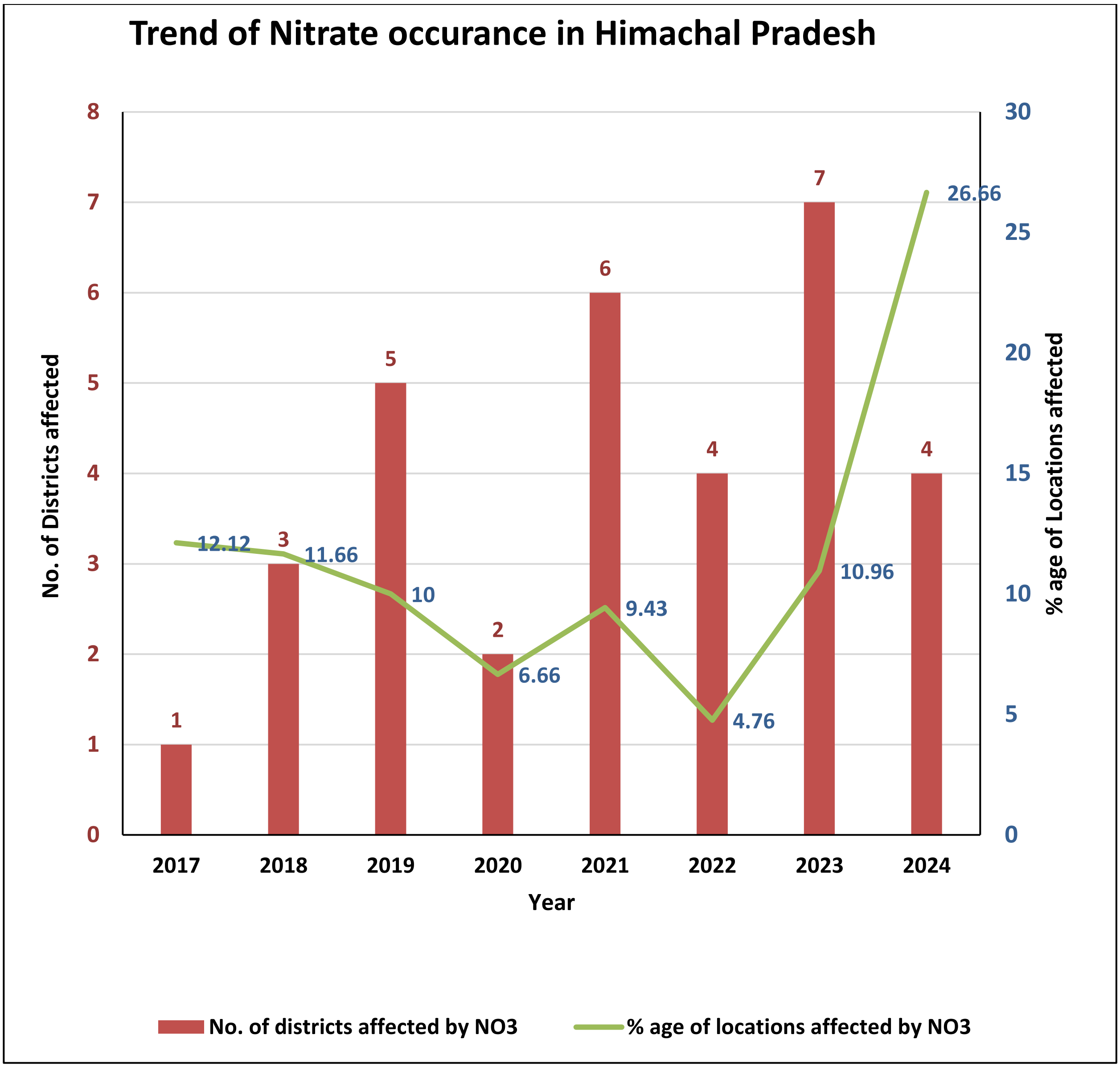

Fig. 7.6.1 Trend of Nitrate occurrence in Himachal Pradesh

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.

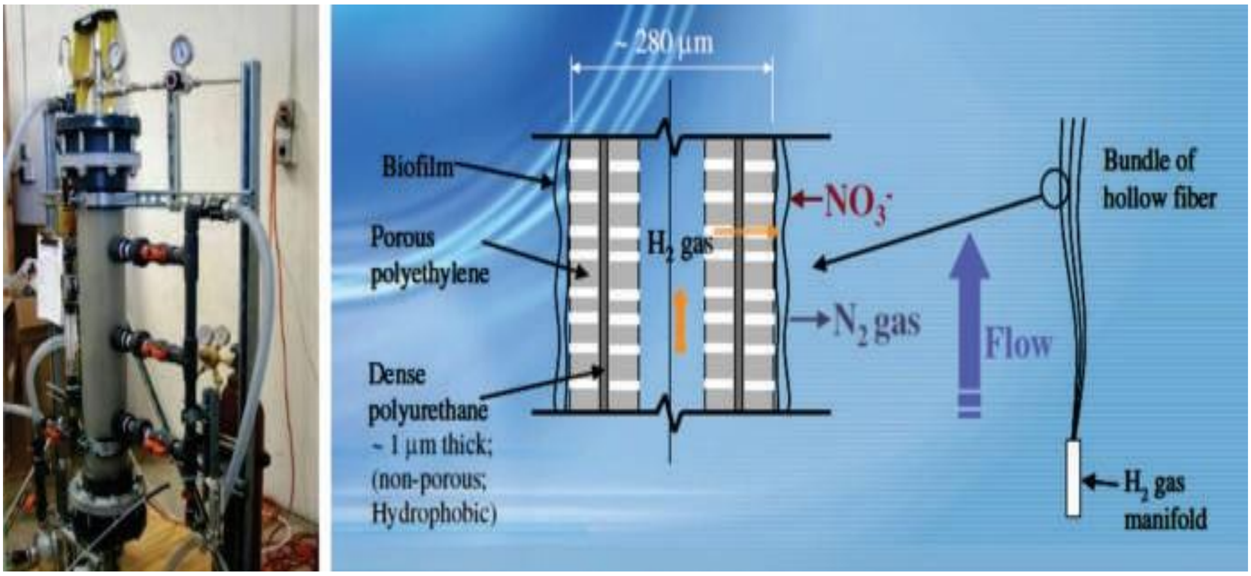

Fig. 7.6.2 Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

7.7 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 $CaCO_3$ in mg/L. Hardness represents the soap-consuming capacity of water. Species that form insoluble compounds with soap Ca, Mg, Organic compounds etc. Total hardness is sum of Ca and Mg and expresses as $CaCO_3$ mg/L in EDTA titration. The two kinds of hardness observed in water.

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

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

Table 7.7.1: Percentage of wells Exceed Total Hardness >600 mg/L during the period of 2017-2024

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
2023	228	0	0	0
2024	60	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

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

NON-CARBONATE (PERMANENT) HARDNESS

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

Removal by Lime-soda, Zeolite or Demineralization Processes

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:

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

The water with regard to SAR is classified into four categories

- **S_1 – 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_2 – 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_3 – 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 gypsiferrous soils the exchangeable sodium could not produce harmful effects.

- **S_4 – 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 range from 0.161 to 29.36. The maximum SAR value has been found at Trilokpur of Sirmaur district. It is apparent from Fig. 8.1 that 95 % samples belong to excellent category (S_1) and only 5 % of samples fall outside low sodium water range i.e. one sample (Nurpur) associated with medium sodium category (S_2) and is permissible for irrigation and one sample (Chikadiyani) falls in high sodium water category (S_3) and in this gypsum is mandatorily be added to soil and last sample (Trilokpuri) falls in very high sodium category (S_4) and is unfit for irrigation.

According to SAR classification, 100% of water samples in Bilaspur, Hamirpur and Mandi fall in excellent category (S_1).

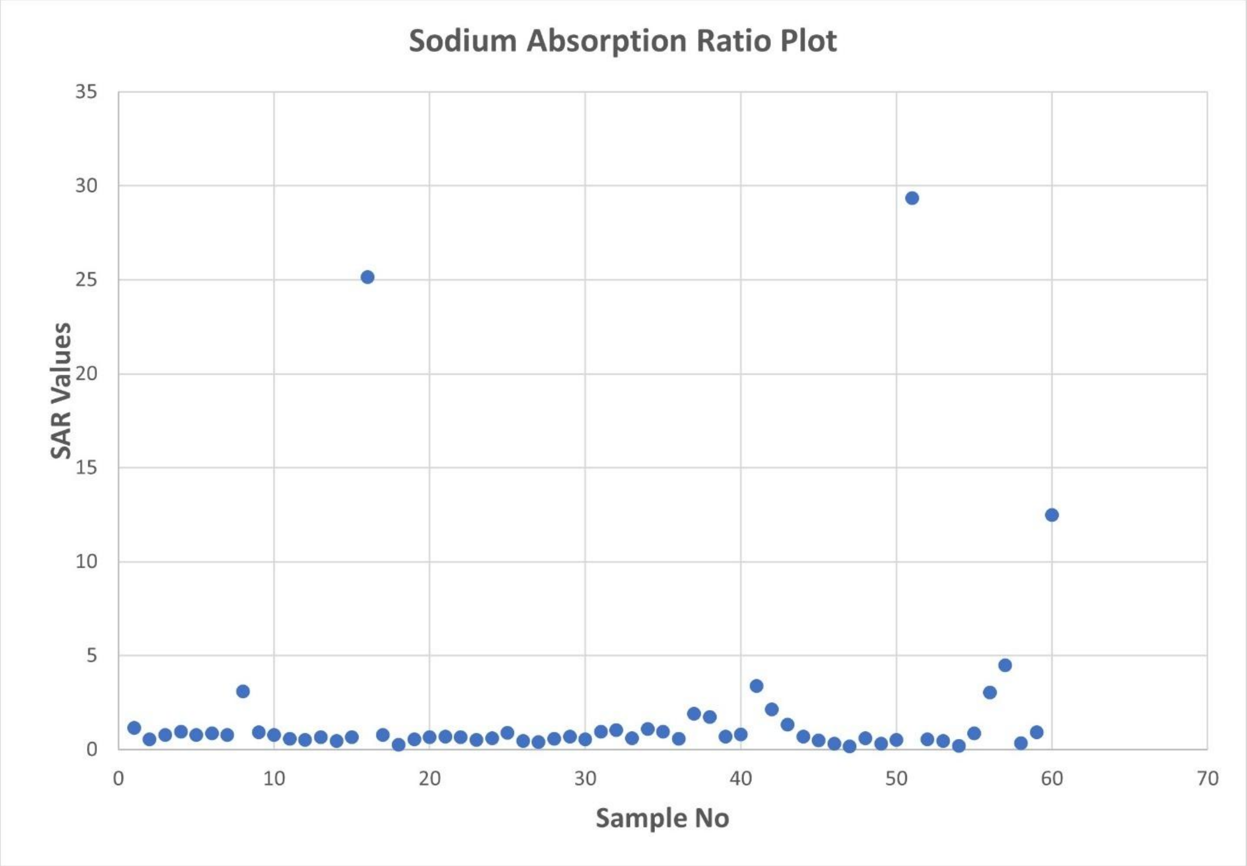

Fig. 8.0.1: SAR Plot with respect to sample number (denotes sample location).

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;

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

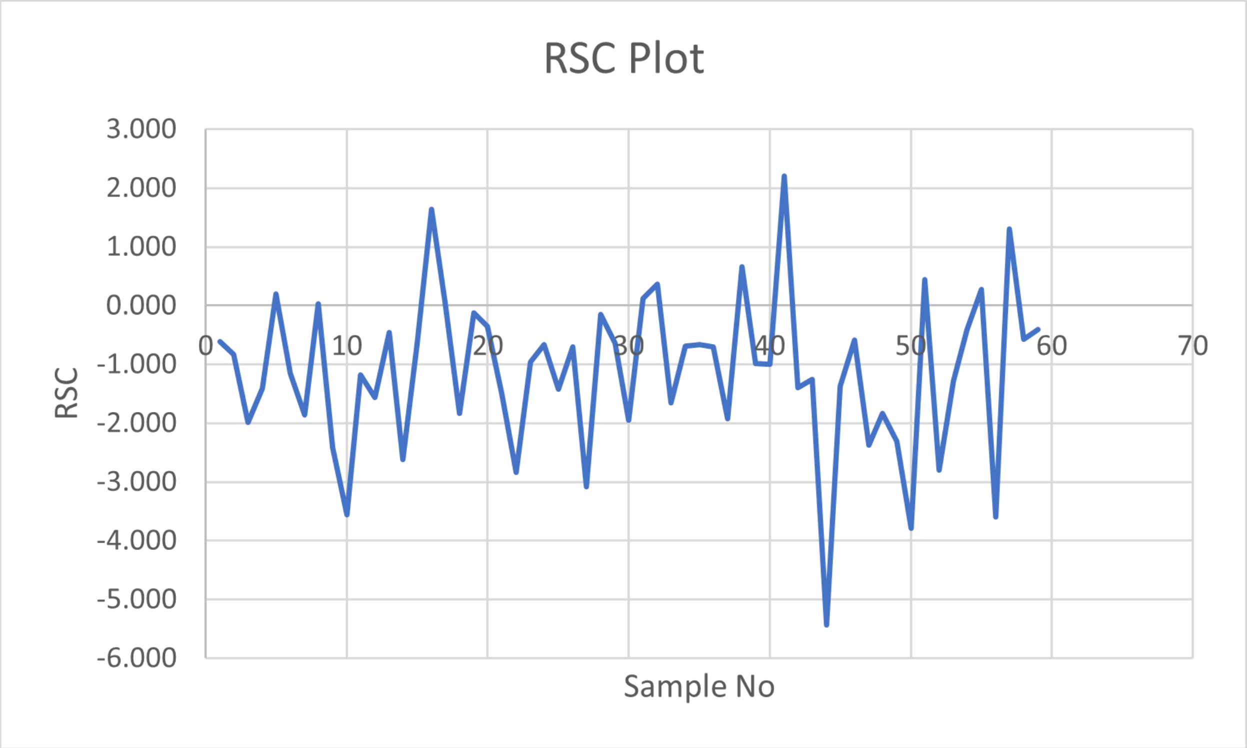

Fig. 8.0.2 RSC values with respect to sample number (denotes sample location).

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. 8.2.2, 95% collected water samples are associated with RSC values less than 1.25 and are safe for use in irrigation practices. 5 % collected samples are associated with RSC values lie between 1.25 and 2.5. While no 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.

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 Hamirpur, Mandi, & Kullu are suitable for irrigation. The ground water samples 5 % of total collected samples from districts Solan, Sirmour, and Chamba RSC values lie between 1.25 and 2.5.

8.1 USSL Diagram

USSL Diagram of Himachal Pradesh for assessment the Irrigation Water Quality

By plotting (Fig. 8.1.1) 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, C_3S_1 and C_3S_2 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.

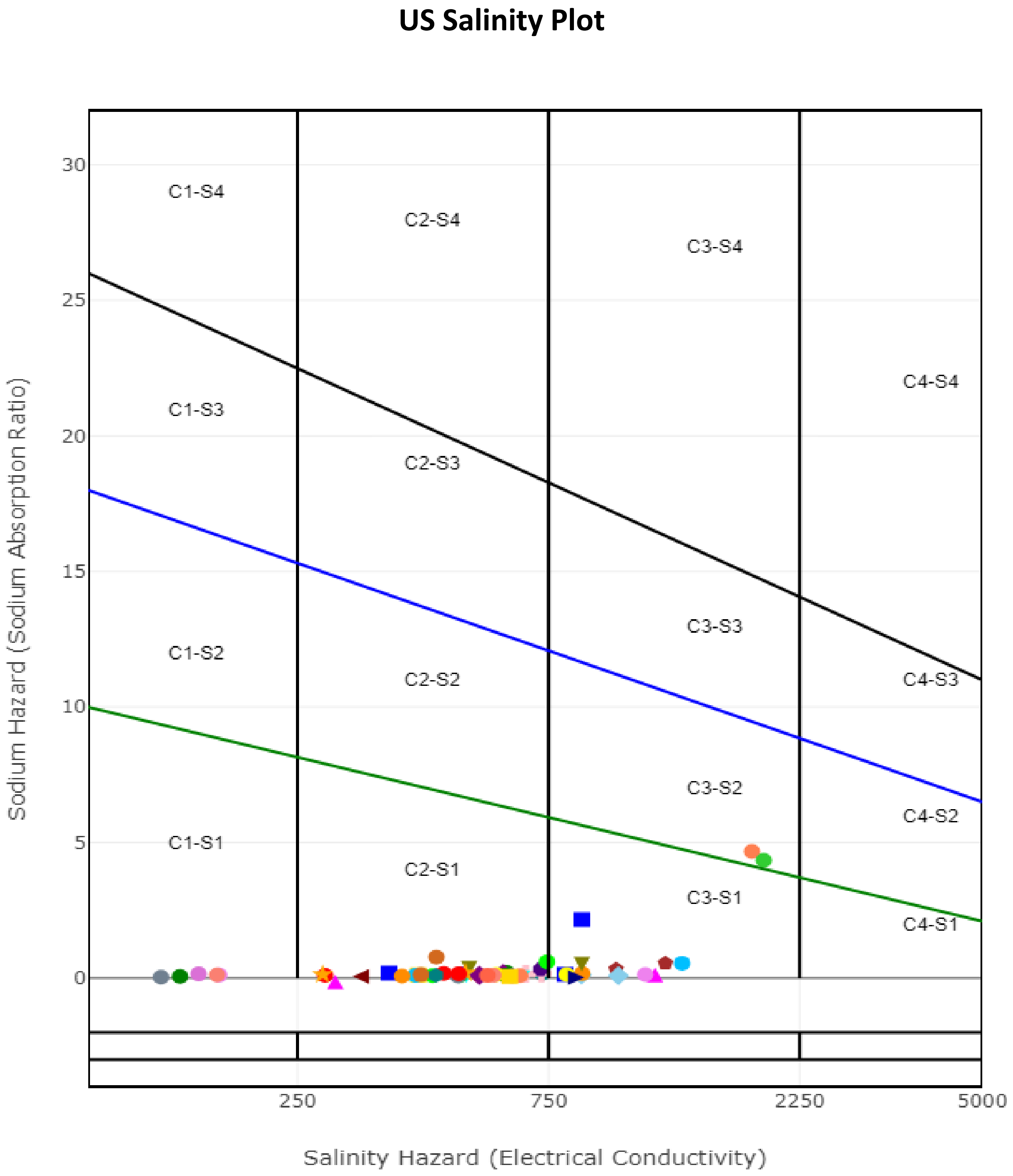

Fig. 8.1.1: Depicting USSL Diagram of Himachal Pradesh State.

8.2 Piper Diagram:

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

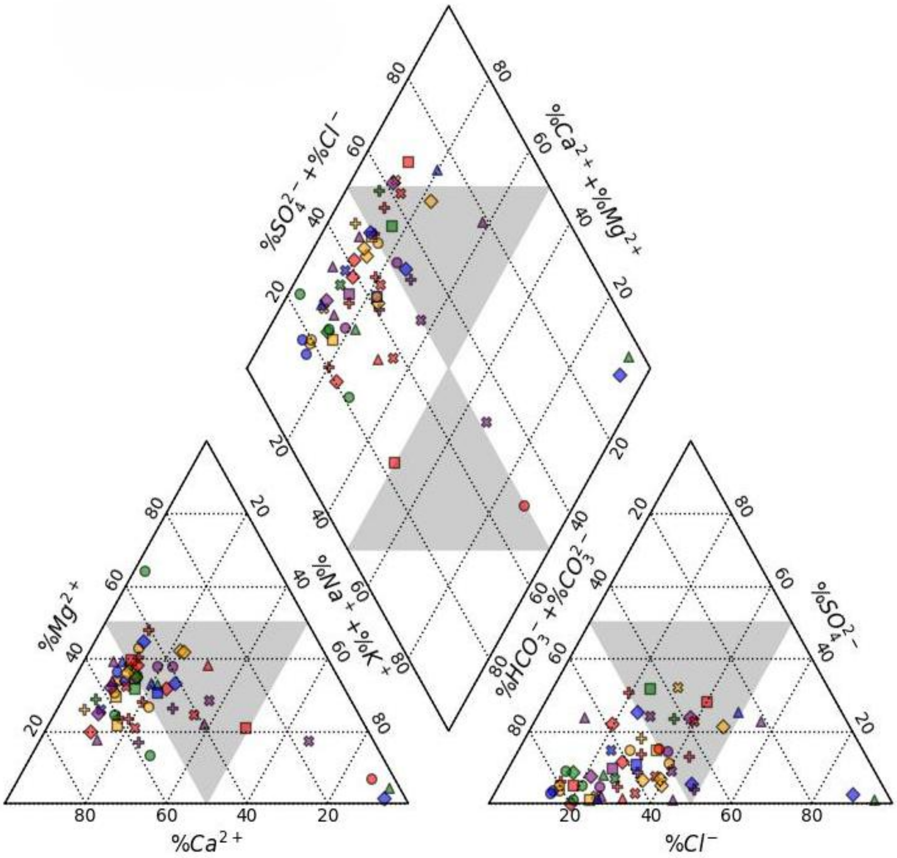

Fig. 8.2.1: Piper diagram of groundwater of Himachal Pradesh.

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 8.2.1) that all type of hydro geochemical facies i.e. Ca-HCO_3, Mg-HCO_3, and mixed type are encountered in the state. Majority of samples are in Ca/-Mg- HCO_3, indicating that groundwater is of fresh.

Annexure 1: Pre-Monsoon NHS May 2024 Results

S. N.	Location	LATTI	LONGITUDE	Ph	EC 25°C, μs/cm	TDS (mg/l)	TH CaCO3 (mg/l)	Ca (mg/l)	Mg (mg/l)	(Na) (mg/l)	(K) (mg/l)	CaCO3 (mg/l)	HCO3 (mg/l)	CaCO3 (mg/l)	CaCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	F (mg/l)	SAR	RSC
1	Bhali	32.22305	76.1075	7.34	624	440	248	84.2	9.1	41.3	15.6	265	323	265	0	49	24	20	0.10	1.142	-0.608
2	Mao	32.26027	76.01055	8.72	282	206	132	37	9.6	14.7	0.8	100	122	90	10	30	15.8	5	0.10	0.557	-0.828
3	BOD	32.28694	75.86972	8.95	806	524	404	112.2	30	35.6	17.2	335	409	300	35	95	22.8	48	0.10	0.771	-1.985
4	Jagir	31.973055	75.90277	8.54	615	404	280	90	13.4	36.2	7.5	250	305	245	5	48	38.8	19	0.20	0.942	-1.412
5	Jagir (Hospital - 1)	31.9688	75.9017	8.37	279	202	124	34	9	19.5	2.8	140	171	120	20	20.5	12.3	10	0.10	0.768	0.196
6	Jagir (Hospital - 2)	31.9729	75.9054	8.97	679	437	346	98	24.5	36.4	2.7	315	384	280	35	49	34.8	8	0.20	0.852	-1.151
7	Jagir (Hospital - 3)	31.9746	75.9028	8.44	730	486	356	96	28.1	34.3	3.3	315	384	310	5	48	38.2	6.0	0.20	0.792	-1.856
8	Ollehriyan	32.074722	75.6375	8.72	1250	842	410	110	32.8	144.6	11.6	465	567	430	35	140	56.4	28	0.30	3.109	0.025
9	Mohtli	32.21277	75.67833	7.95	511	356	206	58	15	30.1	4.5	105	128	105	0	68	64.3	32	0.20	0.911	-2.408
10	Dehra Gopipur	31.88222	76.21527	7.9	812	504	420	98	42.5	36.6	1.0	295	360	295	0	97.5	54.1	47	0.60	0.777	-3.553
11	Hardogri	31.78361	76.29527	8.30	522	342	276	76	21	22.0	2.8	265	323	265	0	38	17.4	4.1	0.25	0.576	-1.178
12	Ratti	31.59972	76.90194	6.90	451	298	208	64	12	16.9	3.8	160	195	160	0	36	28.9	12	0.30	0.508	-1.559
13	Gaagal	31.630277	76.95111	6.85	295	192	114	37	5	16.5	4.9	110	134	110	0	25	9.2	1	0.40	0.676	-0.455
14	Gaduri	31.90333	77.1313	7.04	530	408	260	77	16	17.3	4.5	155	189	155	0	43	82.2	72.1	0.20	0.469	-2.619
15	Pandtehr	32.03722	76.64611	6.37	177.4	128	68	16	7	12.4	2.2	45	55	45	0	23	18.8	1.2	0.52	0.651	-0.637

16	Chikadiyani	32.5985	76.09405	8.73	1826	1223	54	18	2	421.5	7.2	160	195	155	5	584.8	32.4	4.8	0.40	25.152	1.644
17	Mangla	32.53305	76.10444	7.91	90.3	65	30	9	2	10.0	0.1	40	49	40	0	7.5	1.2	2.2	6.6	0.785	0.042
18	15 - Mile, Badagram	32.1491	77.1601	8.23	439	335	218	81	4	8.8	6.5	155	189	155	0	15	63.3	1.1	0.20	0.259	-1.831
19	NHPC Chouk Banikhet	32.5367	75.9365	7.49	92.6	72	38	9	4	7.8	0.4	40	49	40	0	8.0	2.8	18.0	0.18	0.544	-0.123
20	Harotha - Chamba	32.5969	76.0604	8.24	175.8	122.4	66	17	6	12.5	0.3	60	73	60	0	15.5	11.2	20.0	0.20	0.664	-0.359
21	Kathor - Kalan	31.65722	76.11777	8.07	424	315	182	53	12	21.3	1.4	130	159	130	0	23.5	57.2	12.7	0.20	0.688	-1.502
22	Mubarikpur	31.708333	76.0841	7.57	866	669	476	152	23	32.9	1.9	405	494	405	0	50	59.5	30	0.23	0.657	-2.840
23	Bhader Kali	31.77972	76.03888	7.37	508	364	256	75	17	18.6	1.4	255	311	255	0	30	4.8	61.2	0.20	0.505	-0.962
24	Daulatapur	31.778888	75.99722	7.80	555	418	290	87	17	23.3	1.1	310	378	310	0	20	8.4	47	1.00	0.598	-0.660
25	Babehar	31.78972	75.99166	7.50	868	569	364	117	17	39.7	2.0	355	433	355	0	53	16.3	61.6	0.20	0.908	-1.419
26	Raipur Marwadi	31.800277	75.98361	7.41	505	355	256	73	18	16.7	1.0	270	329	270	0	15.5	7.2	49	0.58	0.454	-0.699
27	Ambota	31.67055	76.04805	7.81	639	480	324	101	17	16.6	1.2	205	250	205	0	55	69.5	71.5	0.20	0.402	-3.079
28	Gagret	31.660555	76.06194	8.76	419	340	222	64	15	19.4	1.1	235	287	210	25	15	5.9	80	0.10	0.567	-0.153
29	Kuthera Jaswala	31.605833	76.11805	7.64	429	338	220	62	16	23.8	1.3	230	281	230	0	17	16.4	21.0	0.10	0.697	-0.641
30	Loharli	31.592777	76.126388	7.80	622	434	302	103	11	21.5	2.4	250	305	250	0	28	58.4	41.3	0.20	0.538	-1.948
31	Guglahar	31.566666	76.14333	8.51	474	370	216	65	13	32.5	1.5	255	311	240	15	17	13.4	91.1	0.10	0.963	0.120

32	Panjawar	31.547222	76.14277	8.37	373	272	152	42	11	29.3	1.4	195	238	185	10	18	BLQ(LOQ:0.1)	40	0.8	1.040	0.364
33	Ishpur	31.505555	76.17888	8.05	554	396	264	74	19	22.3	1.7	220	268	220	0	53	16.9	21.2	0.10	0.598	-1.651
34	Badsali	31.477777	76.17888	8.03	521	355	202	58	14	35.5	1.4	205	250	205	0	37	24.1	81.3	0.10	1.086	-0.687
35	Jhankour	31.430555	76.27472	7.41	727	524	350	115	15	40.6	3.6	385	470	385	0	42	3.2	18	1.20	0.946	-0.663
36	Nangran	31.398055	76.29194	8.02	458	353	248	63.3	22	21.0	1.6	260	317	260	0	16	10.4	14	0.10	0.580	-0.708
37	Una	31.46944	76.27083	7.88	1008	687	404	109	32	88.2	1.6	375	458	375	0	127	27.2	81.8	0.30	1.910	-1.927
38	Bagheri	31.194166	76.64194	7.83	725	534	300	105	9	69.2	2.1	405	494	405	0	35	4.1	10.0	0.20	1.741	0.657
39	Phalahi	31.1275	76.611944	7.70	597	422	304	105	10	27.4	1.9	310	378	310	0	39	5.6	68	0.4	0.685	-0.982
40	Mahadeva	31.108333	76.67861	7.54	665	498	336	107	16	33.8	1.4	345	421	345	0	32	14.8	21.3	0.95	0.806	-1.002
41	Dabota	31.087777	76.630555	7.60	745	589	164	46	12	99.5	1.9	335	409	335	0	27	14.1	41.2	0.10	3.378	2.207
42	Nalaagarh	31.044166	76.71194	7.37	1195	855	416	123	26	100.2	0.6	420	512	420	0	147	22.7	51	0.20	2.143	-1.394
43	Kherchak	31.013888	76.67861	7.43	867	632	324	99	19	55.1	3.2	320	390	320	0	51	50.5	60	0.30	1.329	-1.259
44	Theda	31.999722	76.76	7.54	1145	768	544	176	25	37.3	0.7	330	403	330	0	110	126.1	41.5	0.40	0.697	-5.432
45	Akkawala	30.520277	77.28666	7.61	662	510	310	93	19	20.1	2.8	295	360	295	0	30	19.4	1.0	0.20	0.496	-1.370
46	Shibpur	30.475833	77.66972	6.78	318	208	132	36	10.2	8.3	0.9	125	153	125	0	15	1.5	3.8	0.22	0.315	-0.587
47	Khodewala	30.48722	77.705	7.62	878	605	436	80	57	7.7	1.2	385	470	385	0	24	28.5	22.1	0.30	0.161	-2.373
48	Badripur	30.475833	77.66972	7.11	590	402	244	64.1	20.3	21.7	3.2	185	226	185	0	24	69.9	32.0	0.20	0.605	-1.837
49	Dhaula - Kuan	30.501666	77.47305	7.61	633	410	292	94.6	13.5	11.9	1.4	215	262	215	0	39	44.9	14	0.20	0.303	-2.308

50	Sainwala -2	30.53861	77.2522	7.40	1018	742	596	165	44.6	29.3	0.9	495	604	495	0	30	112.4	32	0.50	0.522	-3.791
51	Trilokpur	30.54	77.20333333	8.45	1923	1201	44	8.8	5.3	390.2	2.0	70	85	60	10	680	15.4	2.7	1.60	29.360	0.441
52	Kangoo	31.6863	76.4244	8.10	574	380	250	67.3	20	20.3	0.8	135	165	135	0	57	74.4	12.4	0.40	0.558	-2.792
53	Udaipur	32.5990	76.0941	8.22	395	265	172	42	16	13.7	3.9	130	159	130	0	21	40.2	1.3	0.20	0.456	-1.282
54	Hatkul	32.1026	76.28948	8.06	137.6	94	62	18	4	3.6	1.1	50	61	50	0	14	0.6	20	0.3	0.200	-0.408
55	Kotla			8.87	162.2	105	48	11	5	14.0	1.6	60	73	45	15	13.5	1.2	12	0.13	0.879	0.277
56	STP Kala Amb	30.4993	77.2107	8.17	1345	856	348	104	21.4	130	5.5	205	250	205	0	180	135.7	12	0.40	3.033	-3.591
57	Palion	30.563	77.1895	8.92	459	310	62	15	6	81.2	3.2	145	177	135	10	31	49.9	13	0.20	4.482	1.304
58	BIR	32.05	76.7274	8.77	149.5	98	62	18	4	6.0	1.6	40	49	40	0	14	14.9	15	0.14	0.333	-0.572
59	Anuhi - Salhan	32.219	76.048	7.89	506	330	224	59	19	31.9	3.7	250	305	250	0	30	10.7	20	0.30	0.924	-0.410
60	Meerpur Kotla	30.54076	77.1628	9.01	867	546	38	9	4	179.2	5.0	270	329	240	30	72	58.8	8	0.40	12.496	-0.788