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Ground Water Quality in Shallow Aquifer of Haryana

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Department of Water Resources, River Development and Ganga Rejuvenation
Ministry of Jal Shakti

REPORT ON

GROUND WATER QUALITY IN SHALLOW AQUIFER OF HARYANA

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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

Three geological groups are represented in the state viz. Pre-Cambrian, Tertiary and Quaternary. The Quaternary group comprises of Alluvium which occupies 98% of the area of the state. The tertiary group is represented by the outermost zone of the Siwalik system composed mainly of sandstones, clay and boulders. The rocks of Pre-Cambrian age which form part of the Aravalli hill ranges are exposed in Gurgaon, Mewat and Faridabad districts and as small outcrops in other Southern districts. The thickness of alluvium deposits decreases from North to South. All the three major physiographic units viz. Peninsula, Extra-Peninsula and Indo-Gangetic areas, terminating in the hard rock formations of Delhi systems (Pre-Cambrian age) towards South, Siwaliks system (Tertiary age) in the North and in between the alluvial formations (Recent to sub recent age) are observed in the state.

In the extra peninsular region (northern part of Panchkula district) Siwalik System (Upper Tertiary) and Sabathu Series (Lower Tertiary) are exposed. Sabathu comprises of greenish grey and red gypseous shales with thin bands of sand stones and limestone. Shales and limestone are richly fossiliferous. Siwaliks system comprises of mainly greywacke, sandstones, grits, clays, siltstones, conglomerates and pseudo-conglomerates. These are fluviatile deposits and are rich in mammalian fossils. The area in Panchkula, Ambala &Yamunanagar is underlain by the ‘Kandi, Sirowal and the Alluvium. The Kandi belt which forms the upper higher portions of the composite fan deposits is 2 to 4 kms wide running more or less parallel to the Shivalik foothills. The sediments comprise boulders, pebbles, gravel and sand with clays mixed in varying proportions. Sirowal belt and the adjoining Gangetic plain on the south of the Kandi belt are underlain by silt, fine to medium sand and clays. Gravel and pebbles also occur occasionally. The area in Gurgaon district is underlain by the rocks of Delhi system and by Quaternary alluvium. The Ajabgarh shales and quartzite form the basement in the western part of the area where the thickness of alluvium is very less. In Hisar and Bhiwani districts area is underlain by unconsolidated sediments of Quaternary age. The sediments comprise sand, silt clay and kankar. In Sonipat, Jind, Karnal and Kurukshetra districts the area is underlain by alluvium deposits of Quaternary age. Alluvium comprises clay, silt, and sands of various grades, kankar, gravel and pebbles. The alluvium deposits are generally lenticular in shape. In Mohindergarh and part of Bhiwani districts the following geological succession is met. Recent to sub Recent- Alluvium and windblown sands etc, Post Delhi intrusive- Pegmatite, quartz veins, granites etc. Algonquian Delhi system-Ajabgarh Series Kushalgarh Limestone, Alwar Series. The alluvium in the area belonging to the Older Alluvium comprises of sand, silt, clay loam and kankar. Newer alluvium is mainly confined to the sides of the river natiural water courses. The alluvium is the fresh water deposit of the Indo-Gangetic river system. The sub-aerial deposits are represented by the talus material on the hill slopes and windblown sands. Rohtak district is underlain by alluvium deposits of Quaternary age. The alluvium overlies the rocks of Algonquians system outcrops of which are seen outside the district. The alluvium consists of clay, silt and various grades of sand. Windblown sand occurring as sand dunes is often seen overlaying the alluvium in various parts of the district. 20 The unconsolidated alluvial sediments cover around 98% of the state while hard rock's cover just around 2% area of the state. Alluvial deposits are of older and newer types and consist chiefly of clay, silt and fine to medium sand. Other deposits are piedmont deposits, which are confined to a narrow zone, about 2 to 4 kms wide, between Siwalik Hills and alluvial plains. Sand dunes are found in the districts of Bhiwani, Mohindergarh, Hissar and Sirsa Coarse sand, gravels and boulders are found to occur in piedmont areas and in the adjacent alluvial tracts. These deposits have developed in the north part of Ambala district. The thickness of alluvial sediments is more than 600 m. and along Yamunanagar-Karnal stretch it is reported to be more than 3000 m. However, the thickness of sediments progressively decreases towards Delhi and hard rock areas of Bhiwani, Gurgaon, Faridabad and Mahendergarh districts.

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 tends to change to mixed cations or even to $Na\text{-}HCO_3$ 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. 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)

Public Water supply	Industrial Water supply	Agricultural water supply	Aquatic life& wild life water supply	Recreation and Aesthetics
ColiformbacteriaTurbiditycolour,Taste,OdourTDS,CI,F,SO_4NO_3, CN, Trace Metals, Trace Organics Radioactive substances	**Processing** pH, Turbidity Colour, Alkalinity, Acidity, TDS, Suspended solids, Trace metals, Trace Organics **Cooling** PH, Temp, Silica, AI, Fe, Mg, Total hardness, Alkalinity/Acidity Suspended solids, Salinity	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 Colour,Settleablematerials,Toxic substances, Nutrients,Floatingmaterials	Recreations Turbidity,Colour,Odour,FloatingMaterials,SettableMaterialsNutrients,Coliforms Aesthetics Same as for Recreation and Substances 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)
Essential Characteristics			
1	Colour Hazen Unit	5	15
2	Odour	Unobjectionable	-
3	Taste	Agreeable	-
4	Turbidity(NTU)	1	5
5	pH	6.5-8.5	No relaxation
6	Total Hardness,$CaCO_3$	200	600
7	Iron(Fe)	1.0	No relaxation
8	Chloride(Cl)	250	1000
9	Residual Free Chlorine	0.2	1
10	Fluoride(F)	1.0	1.5
Desirable Characteristics			
11	Dissolved Solids	500	2000
12	Calcium(Ca)	75	200
13	Magnesium(Mg)	30	100
14	Copper(Cu)	0.05	1.5
15	Manganese(Mn)	0.1	0.3
16	Sulphate (SO_4)	200	400
17	Nitrate(NO_3)	45	No relaxation
18	Phenolic Compounds	0.001	0.002
19	Mercury(Hg)	0.001	No relaxation
20	Cadmium(Cd)	0.003	No relaxation
21	Selenium(Se)	0.01	No relaxation
22	Arsenic(As)	0.01	No relaxation
23	Cyanide(CN)	0.05	No relaxation
24	Lead(Pb)	0.01	No relaxation
25	Zinc(Zn)	5.0	15
26	Hexavalent Chromium	0.05	No relaxation
27	Alkalinity	200	600
28	Aluminum(Al)	0.03	0.2
29	Boron(B)	0.5	2.4
30	Pesticides	Absent	0.001
31	Uranium	0.03	No relaxation

NTU-Nephelometric Turbidity Unit

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

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 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	Mediumtexturedsoilshavingclay10-20%;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.

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

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

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

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

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

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

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 - 4.2.1.**

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	Hardnessas $CaCO_3$ (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. Intracesitis 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	ResidualChlorine(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	Causesencrustationinwatersupplysystem.Whileinsufficiencycausesaseveretypeofrickets,excesscausesconcretions 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 laxativeeffect along with Magnesium.
15	Nitrate (NO_3)(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 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(per100ml)	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 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 irrigations, industries, municipalities and urban and rural households' day by day. During dry season extensive withdrawal of groundwater for irrigation purpose is lowering the water table in the aquifer and also changing the chemical composition of water.

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

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

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

c. Checking the cation-anion balance

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

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 HARYANA

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 Haryana 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, North Western Region (CGWB, NWR) Chandigarh annually monitors the ground water quality through dedicated Ground Water Monitoring Stations consisting of dug wells, tube wells and/or hand pumps 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 22 districts (Samples of Bhiwani and Charkhi Dadri are shown under Bhiwani district) of Haryana 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 Regional Chemical Laboratory of CGWB, NWR Chandigarh by following 'Standard analytical procedures' as given in American Public Health Agency (APHA) 23rd 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 µs/cm at 25°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	Desirable limit	< 250	312	66.95

S. No	Parameters		Range	No. of sample	Percentage
	mg/L	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 (Ca-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 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 µS/cm at 25^0C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000 µS/cm at 25^0C) in case of no alternate source. Water having TDS more than 2000 mg/L is not suitable for drinking purpose. In Fig 7.1.1, the EC values (in µS/cm at 25^0C) of ground water from observation/monitoring wells have been used to show distribution patterns of electrical conductivity in different ranges of suitability for drinking purposes. The EC value of ground waters in the State varies from 92 to 13400 µS/cm at 25°C. Grouping water samples based on EC values, it is found that 38.84 % of them have EC less than 750 µS/cm, 40.56 % have between 750 and 3000 µS/cm and the remaining 20.60 % of the samples have EC above 3000µS/cm. The map showing aerial distribution of EC with intervals corresponding to limits assigned for desirable, permissible and unsuitable classes of waters indicates that desirable class of waters occur throughout the state in patches but in high proportion is in northern and central parts of the State. The ground water occurring in the southern, central and some part in west comprising of parts of Sirsa, Hisar, Jind, Jhajjar, Rohtak, Bhiwani, Mewat, Mahendragarh, Rewari and Faridabad districts is mostly saline and is not suitable for drinking purpose in terms of Electrical Conductance Table 7.1.1 shows the list of districts affected by high EC water (EC > 3000 µS/cm) and these areas are water quality hot spots from salinity point of view. District-wise percentage of wells having EC >3000 µS/cm is shown as a bar diagram in Fig 7.1.1 and the occurrences of Electrical Conductivity in ground water beyond permissible limit (>3000 µS/cm) have been shown on the contour map as Fig 7.1.2, the percentage groundwater samples in various EC range is also illustrated in Fig 7.1.3. locations details are given in Annexure-I.

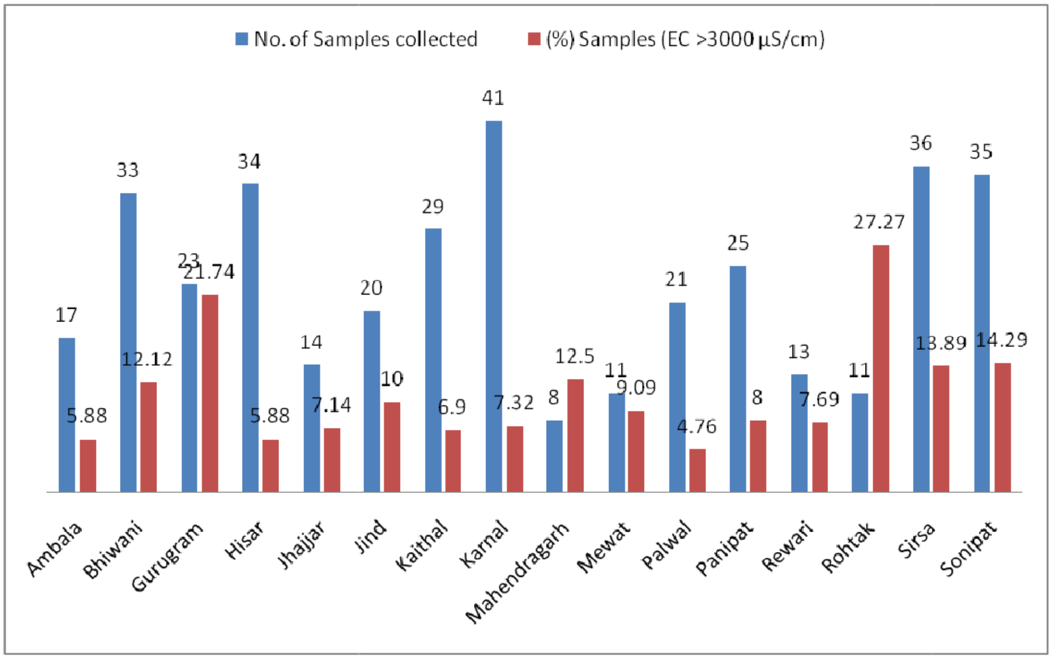
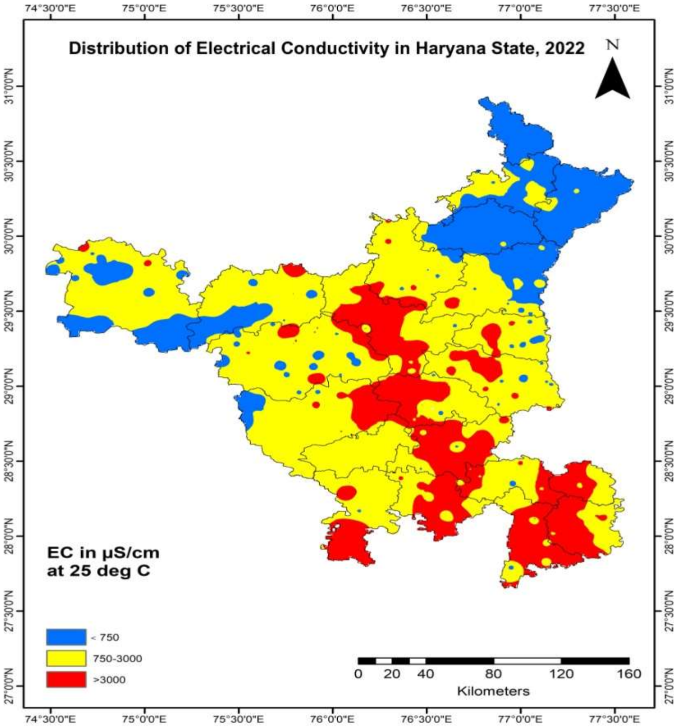


Fig 7.1.1 District-wise percentage of wells having EC >3000 µS/cm.

Table 7.1.1 District-wise percentage of samples having EC 2251-3000 µS/cm

Sr. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (EC 2251-3000 µS/cm)	(%) Samples (EC 2251-3000 µS/cm)
1	Ambala	17	1	5.88
2	Bhiwani	33	4	12.12
3	Gurugram	23	5	21.74
4	Hisar	34	2	5.88
5	Jhajjar	14	1	7.14
6	Jind	20	2	10.00
7	Kaithal	29	2	6.90
8	Karnal	41	3	7.32
9	Mahendragarh	8	1	12.50
10	Mewat	11	1	9.09
11	Palwal	21	1	4.76
12	Panipat	25	2	8.00
13	Rewari	13	1	7.69
14	Rohtak	11	3	27.27
15	Sirsa	36	5	13.89
16	Sonipat	35	5	14.29
		371	39	10.51

Fig 7.1.2 Spatial distribution of Electrical Conductivity during June 2022.



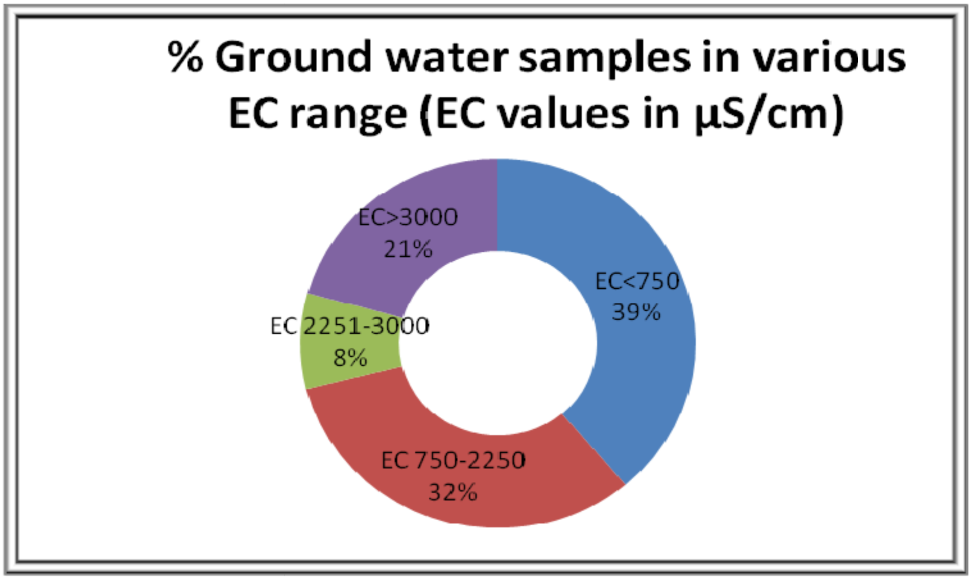


Fig 7.1.3 Percentage groundwater samples in various EC range (Haryana).

Table 7.1.2: Districts Affected by Salinity (High EC) in Groundwater in the State of Haryana.

S. No.	State	Parts of districts having EC > 3000 µS/cm.
1.	Haryana	Bhiwani
2.	Haryana	Faridabad
3.	Haryana	Fatehabad
4.	Haryana	Gurugram
5.	Haryana	Hisar
6.	Haryana	Jhajjar
7.	Haryana	Jind
8.	Haryana	Kaithal
9.	Haryana	Karnal
10.	Haryana	Mahendragarh
11.	Haryana	Mewat
12.	Haryana	Palwal
13.	Haryana	Panipat
14.	Haryana	Rewari
15.	Haryana	Rohtak
16.	Haryana	Sirsa
17.	Haryana	Sonipat

Table 7.1.3: Comparative change in number of locations having EC > 3000 µS/cm in the state Haryana

S. No.	District	Nos. of locations having EC > 3000 µS/cm.		
		2015	2022	Increase/Decrease
1.	Ambala	0	0	0
2.	Bhiwani	6	8	+2
3.	Faridabad	3	6	+3
4.	Fatehabad	1	1	0
5.	Gurgaon	3	6	+3
6.	Hisar	6	9	+3
7.	Jhajjar	5	8	+3
8.	Jind	0	8	+8
9.	Kaithal	5	5	0
10.	Karnal	0	1	+1
11.	Kurukshetra	0	0	0
12.	Mahendergarh	3	2	-1
13.	Mewat	5	6	+1
14.	Palwal	5	10	+5
15.	Panchkula	0	0	0
16.	Panipat	1	4	+3
17.	Rewari	3	6	+3
18.	Rohtak	5	4	-1
19.	Sirsa	4	2	-2
20.	Sonepat	7	10	+3
21.	Yamunanagar	0	0	0
	Total	**62**	**96**	**+34**

No. of Locations with EC>3000 µS/cm during 2015 & 2022

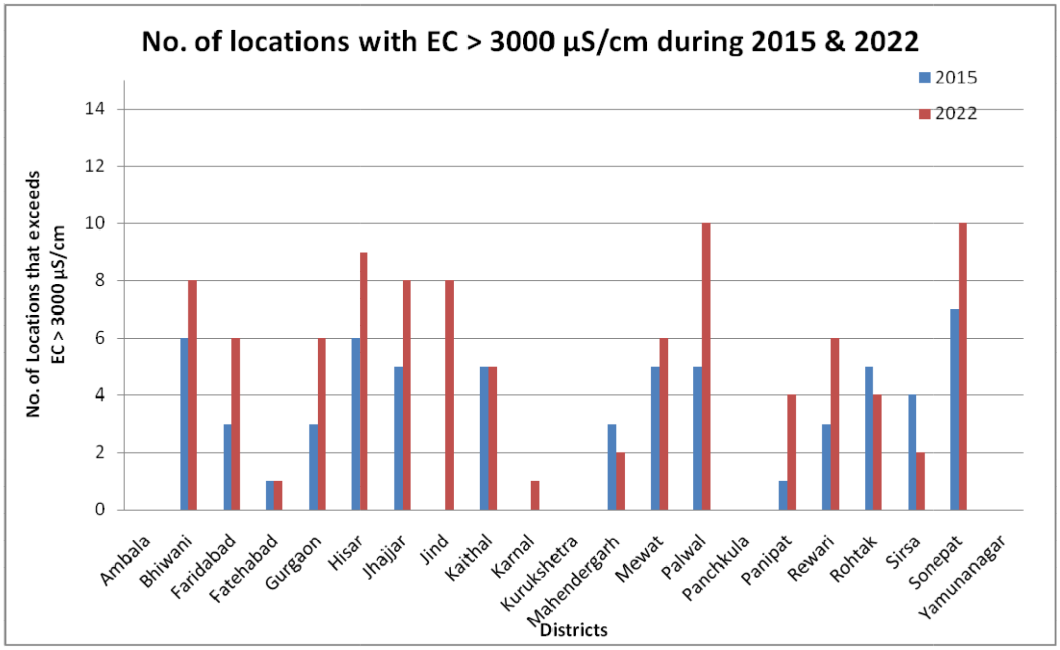


Fig. 7.1.4 Comparison on No of Locations exceed EC >3000 µS/cm during 2015 and 2022.

In comparison to 2015 (Table 7.1.3), it has been observed that the no. of locations having EC more than 3000 µS/cm in various districts has increased in 2022 by 2.04 %. Locations having EC > 3000 µS/cm has increased in no. of districts. However, in some districts it has decreased also, which may be because of dilution in that particular area.

7.1.1 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 µS/cm for the period of 2017 to 2022 were compared and presented in the Table7.1.4 and Fig 7.1.5 and observed that the percentage of samples exceed the permissible limit of 3000 µS/cm were ranging between 20-26 % .Trend on water quality for Electrical conductivity (EC) prepared for the state of Haryana is showing a slightly decreasing trend (Fig. 7.1.5). Trend on Electrical Conductivity in Faridabad and Gurugram districts of Haryana show (Fig 7.1.6 & 7.1.7) decreasing trend.

Table 7.1.4: Percentage of wells Exceed EC>3000 µS/cm during the period of 2017-2022

Year	Total No. of samples analysed	No. of districts affected by EC	Total No. of locations affected by EC	% of locations affected by EC (EC > 3000 µs/cm)
2017	420	16	94	22.4
2018	449	18	105	23.4
2019	447	16	103	23
2020	420	10	88	21
2021	466	16	101	21.7
2022	465	17	96	20.6

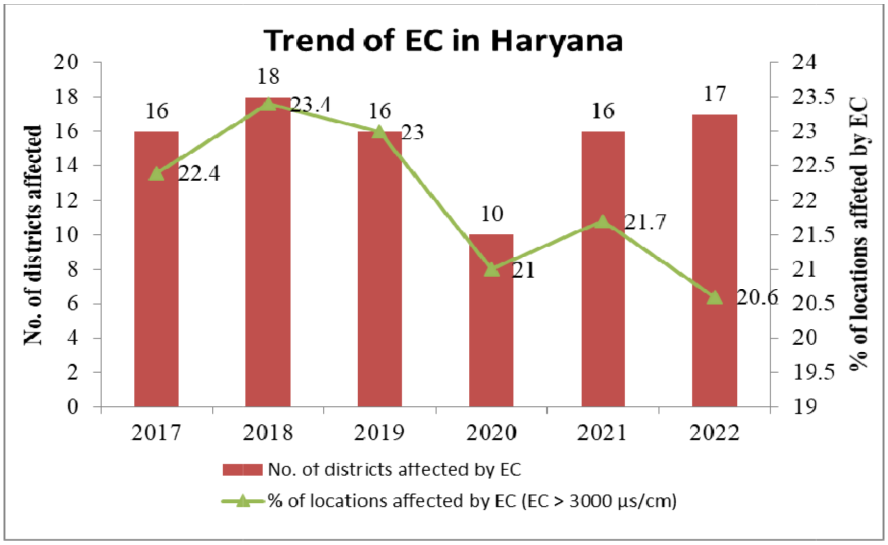


Fig. 7.1.5 Trend of Electrical Conductivity occurrence in Haryana

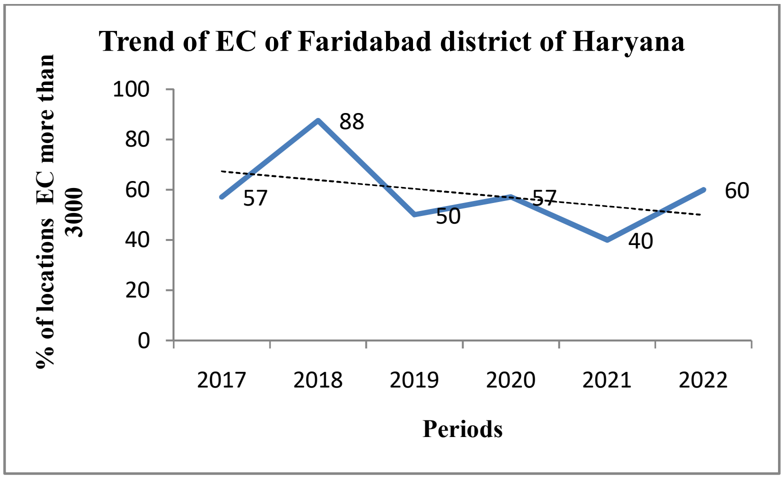


Fig. 7.1.6 Trend on Electrical Conductivity in Faridabad district for the period of 2017-2022

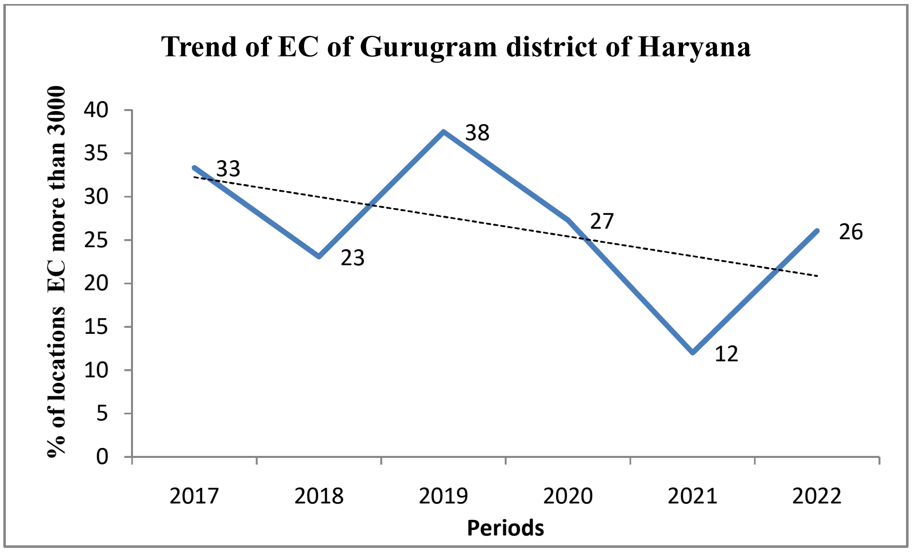


Fig. 7.1.7 Trend on Electrical Conductivity in Gurugram district for the period of 2017-2022

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 7.10 mg/L to 3346 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 66.95 % of the samples, between 250 and 1000 mg/L in 24.46 % samples and only 8.58 % of the samples are found to have Chloride above 1000 mg/L. Map showing spatial distribution of Cl contents in ground water (Fig 3) indicates that Cl is below 250 mg/L in most of the districts, it is between 250 and 1000 mg/L in Sirsa, Bhiwani, Hisar, Fatehabad, Mahendragarh, Mewat, Palwal and Faridabad districts. Cl is more than 1000 mg/L in isolated places in Sirsa, Sonipat, Hisar, Jind, Jhajjar, Rohtak, Bhiwani, Mahendragarh, Mewat, Palwal, Faridabad, Rewari and Gurugram districts.

The occurrences of chloride in ground water beyond permissible limit (1000 mg/L) have been shown on the contour map as Fig 7.2.1, district-wise percentage of wells having chloride >1000 mg/L is shown as a bar diagram in Fig 7.2.2 and also given location details in Annexure-II.

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

Sr. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (Cl >1000 mg/l)	(%) Samples (Cl >1000 mg/l)
1	Ambala	17	0	0.00
2	Bhiwani	33	2	6.06
3	Faridabad	10	5	50.00
4	Fatehabad	14	0	0.00
5	Gurugram	23	4	17.39
6	Hisar	34	2	5.88
7	Jhajjar	14	4	28.57
8	Jind	20	2	10.00
9	Kaithal	29	0	0.00
10	Karnal	41	0	0.00

11	Kurukshetra	24	0	0.00
12	Mahendragarh	8	2	25.00
13	Mewat	11	6	54.55
14	Palwal	21	6	28.57
15	Panchkula	25	0	0.00
16	Panipat	25	0	0.00
17	Rewari	13	3	23.08
18	Rohtak	11	1	9.09
19	Sirsa	36	2	5.56
20	Sonipat	35	1	2.86
21	Yamunanagar	22	0	0.00
	Total (Haryana)	**466**	**40**	**8.58**

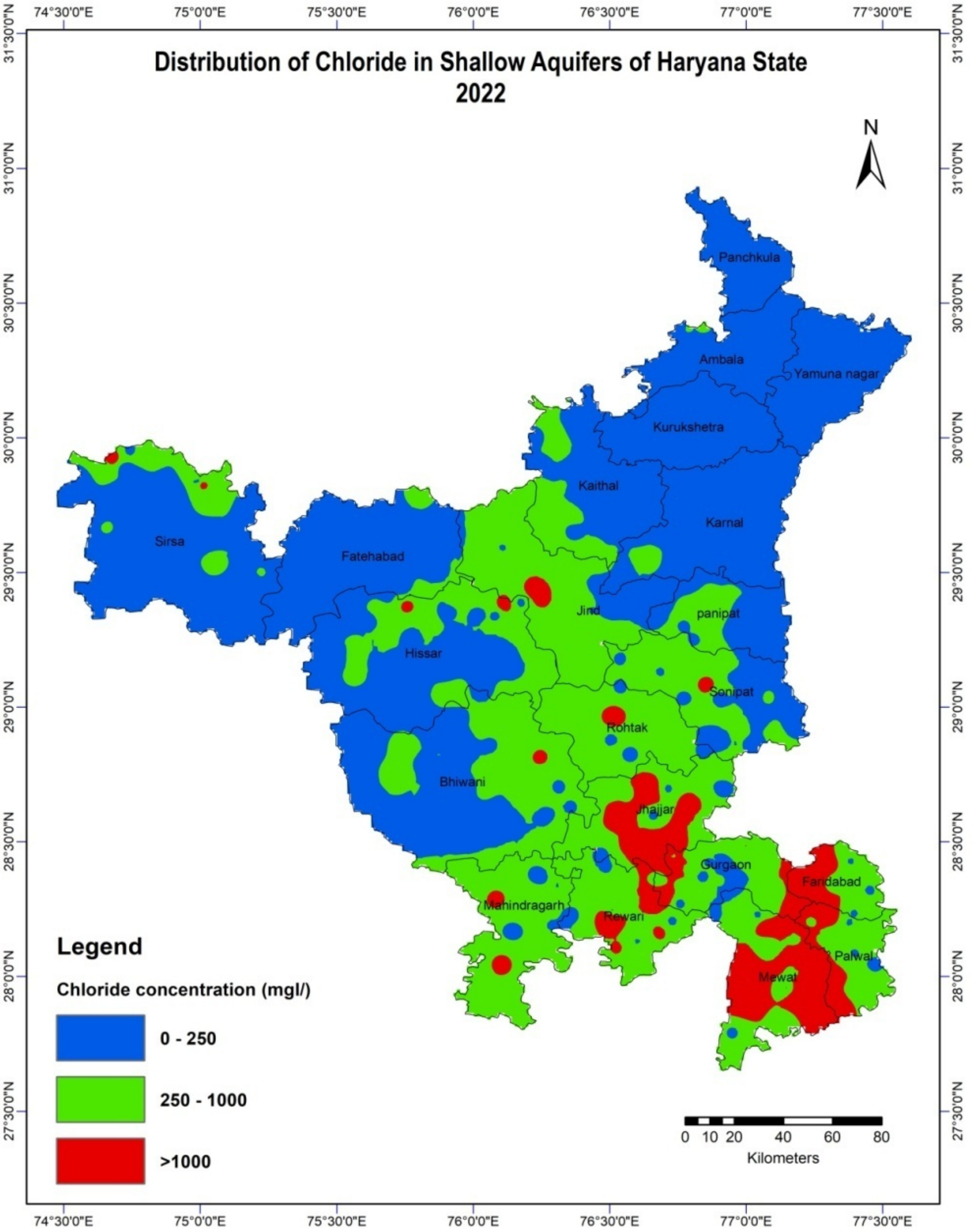


Fig 7.2.1 Spatial Distribution of Chloride during June 2022

Graph: District-wise percentage of well with Chloride>1000 mg/L

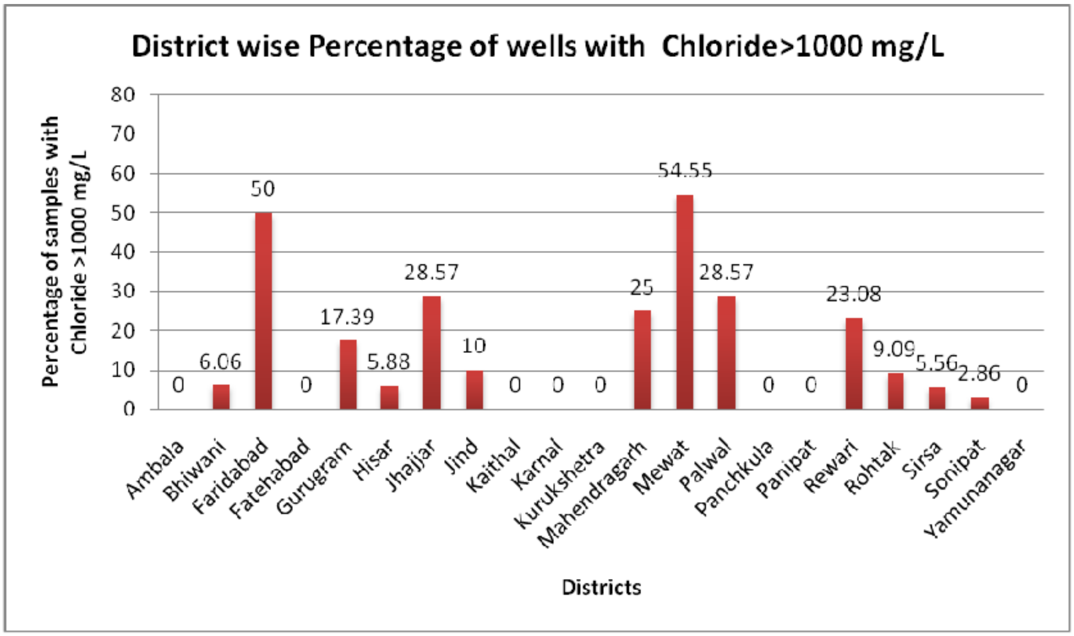


Fig 7.2.2 District-wise percentage of well with Chloride>1000 mg/L

Table-7.2.2: Districts having Chloride concentration (more than 1000 mg/L) in Groundwater in the state of Haryana (NHS 2022-23)

Sr. No	State	Parts of district having Chloride > 1000 mg/L
1.	**Haryana**	Bhiwani
2.	**Haryana**	Faridabad
3.	**Haryana**	Gurugram
4.	**Haryana**	Hisar
5.	**Haryana**	Jhajjar
6.	**Haryana**	Jind
7.	**Haryana**	Mahendragarh
8.	**Haryana**	Mewat
9.	**Haryana**	Palwal
10.	**Haryana**	Rewari
11.	**Haryana**	Rohtak

Sr. No	State	Parts of district having Chloride > 1000 mg/L
12.	**Haryana**	Sirsa
13.	**Haryana**	Sonipat

Table-7.2.3: Comparative Change in number of Districts having Cl > 1000 mg/L in the state of Haryana

S. No.	District	Nos. of locations having Cl > 1000 mg/L		
		2015	2022	Increase/Decrease
1.	Ambala	0	0	0
2.	Bhiwani	2	2	0
3.	Faridabad	0	5	+5
4.	Fatehabad	0	0	0
5.	Gurugram	3	4	+1
6.	Hisar	0	2	+2
7.	Jhajjar	2	4	+2
8.	Jind	0	2	+2
9.	Kaithal	0	0	0
10.	Karnal	0	0	0
11	Kurukshetra	0	0	0
12.	Mahendragarh	1	2	+1
13.	Mewat	4	6	+2
14.	Palwal	1	6	+5
15.	Panchkula	0	0	0
16.	Panipat	0	0	0
17.	Rewari	3	3	0
18.	Rohtak	1	1	0

S. No.	District	Nos. of locations having Cl > 1000 mg/L		
19.	Sirsa	2	2	0
20.	Sonipat	3	1	-2
21.	Yamunanagar	0	0	0
	Total	**22**	**40**	**+18**

In comparison to 2015, it has been observed that the no. of locations having chloride more than 1000 mg/L in various districts has increased in 2022 by 1.75 % (Table 7.2.3 & Fig.7.2.3). In Faridabad and Palwal has the increase in the no. of loactions is a matter of concern. However, in one district it has decreased and in some districts statyed unchanged which may be because of dilution in that particular area.

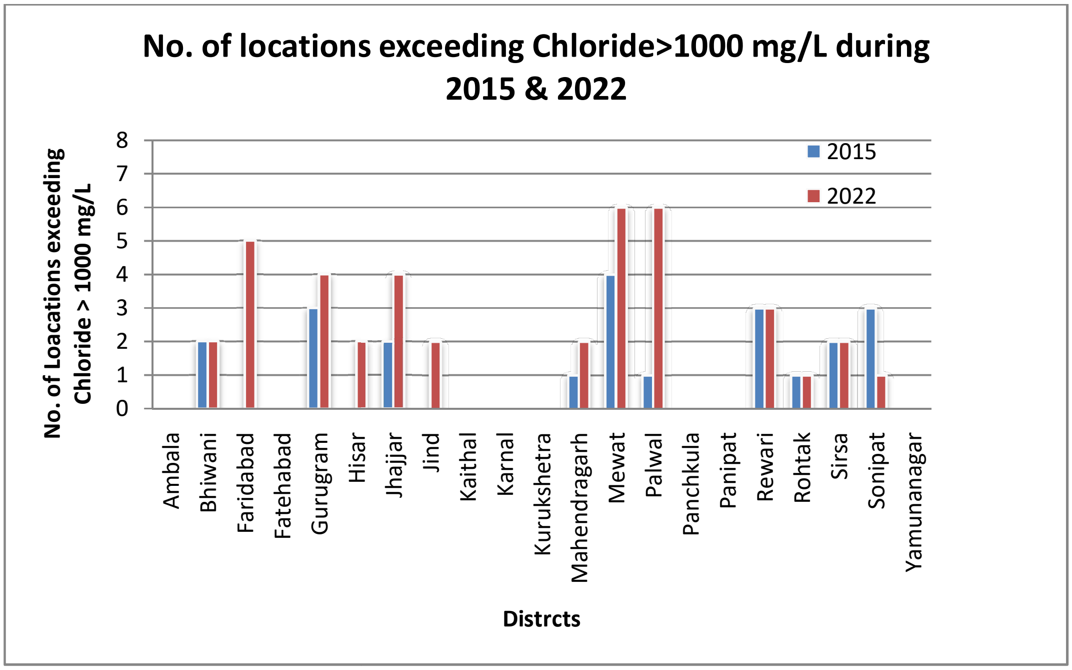


Fig.7.2.3 Comparison on No. of locations exceeding Chloride >1000 mg/L during 2015 and 2022.

Techniques Available for Removal of Salinity

Traditionally, distillation has been the method used for desalting water for human consumption or other use. Membrane methods have emerged through the last 50 years and now predominate among the desalination practices. The following describes each of the various methods used for water desalination treatment.

1. Distillation Methods

There are several variations in distillation technology used in desalination. They are all based on the vapourization of liquid water when brought to its boiling point. The nearly pure water vapour produced is condensed and collected for use, while dissolved salts remain behind in the remaining liquid feed water. Some of the methods by which distillation is practiced are as follows:

- Multi-stage flash;
- Multiple effects;
- Vapour compression;
- Membrane distillation; and
- Solar humidification.

2. Membrane Technologies

Membrane processes involve passing of impaired feed water through a semi-permeable material which can filter out unwanted dissolved or undissolved constituents, depending on the size and treatment of the openings. Membrane technologies identified include:

- Reverse Osmosis;
- Microfiltration/Ultrafiltration/Nanofiltration;
- Electrodialysis Reversal; and
- Forward Osmosis.

3. **Hybrid Technology:** A method of reducing overall costs of desalination can be the use of hybrid systems using both RO and distillation processes. Such a system could provide a more suitable match between power and water development needs.

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 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. 7.3.1. It is observed Ground waters with fluoride above 1.50 mg/L are found mainly in Jind, Sirsa, Fatehabad, Hisar, Bhiwani, Panipat, Rewari, Mahendragarh, Palwal and Jhajjar 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.

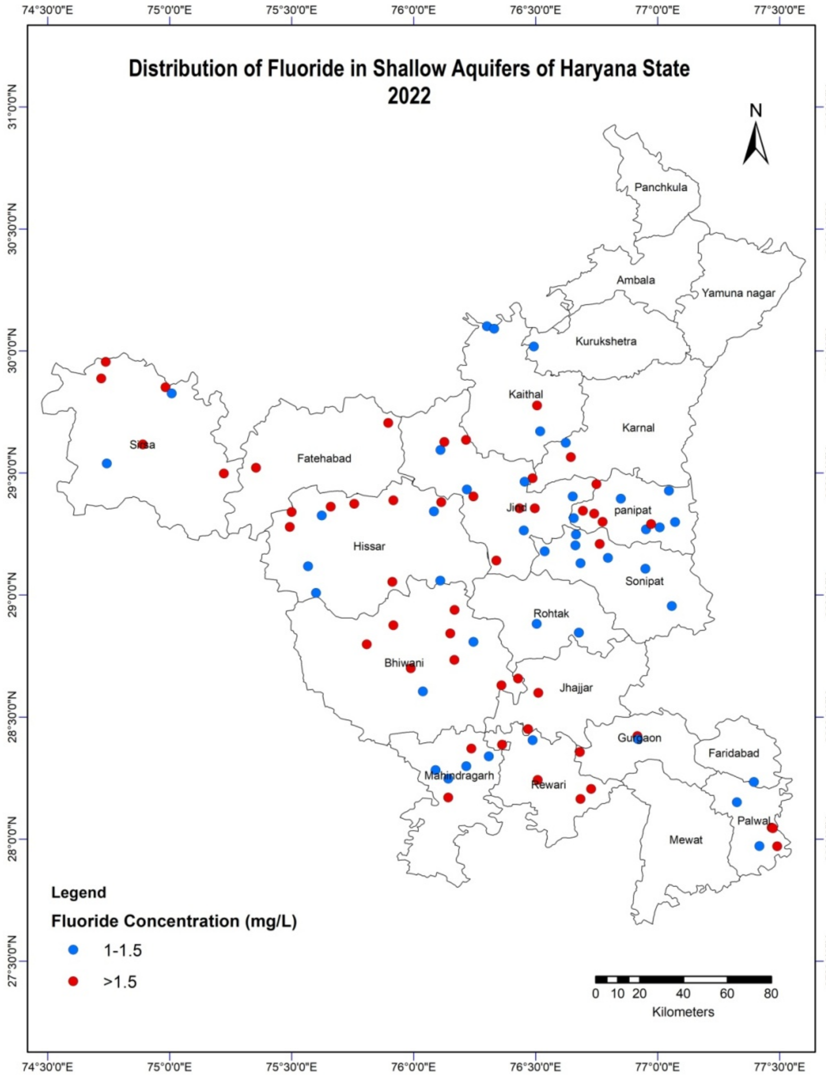


Fig 7.3.1 Locations having Fluoride concentration > 1.5 mg/L during June 2022.

Table 7.3.1 State-wise percentage of wells having Fluoride >1.0 mg/L

S. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (F >1.0 mg/l)	% of Samples (F >1.0 mg/l)
1	Ambala	17	0	0.00
2	Bhiwani	33	9	27.27
3	Faridabad	10	0	0.00
4	Fatehabad	14	3	21.43

5	Gurugram	23	5	21.74
6	Hisar	34	12	35.29
7	Jhajjar	14	4	28.57
8	Jind	20	13	65.00
9	Kaithal	29	5	17.24
10	Karnal	41	0	0.00
11	Kurukshetra	24	1	4.17
12	Mahendragarh	8	6	75.00
13	Mewat	11	0	0.00
14	Palwal	21	8	38.10
15	Panchkula	25	0	0.00
16	Panipat	25	12	48.00
17	Rewari	13	5	38.46
18	Rohtak	11	2	18.18
19	Sirsa	36	8	22.22
20	Sonipat	35	10	28.57
21	Yamunanagar	22	0	0.00
	Total(Haryana)	**466**	**103**	**22.10**

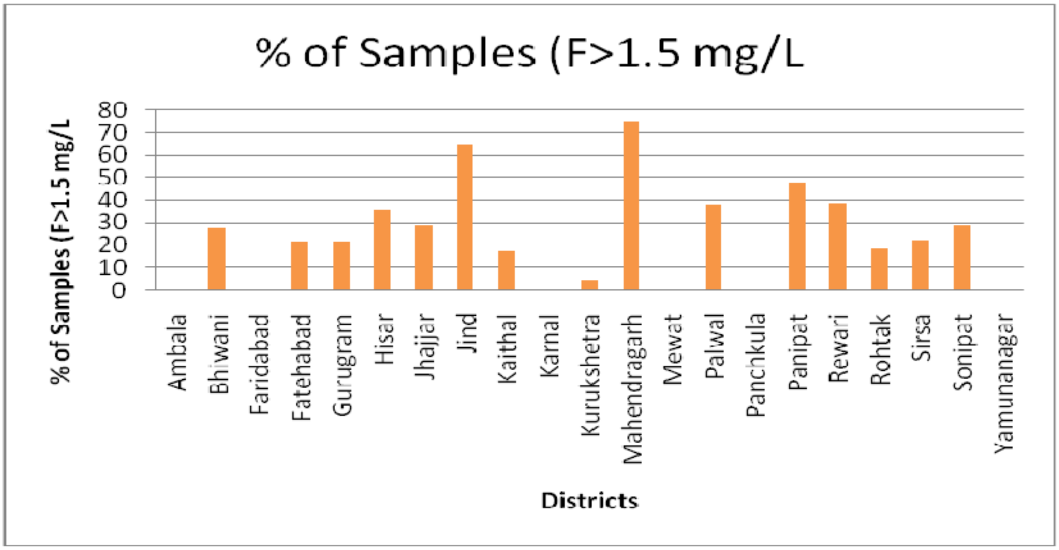


Fig 7.3.2 District-wise percentage of wells having fluoride >1.5 mg/L

Table 7.3.2 Districts showing localized occurrence of Fluoride (>1.5mg/L) in Groundwater in the Haryana State

Sl. No	**State**	**Parts of Districts having F > 1.5mg/L**
1	Haryana	Bhiwani
2	Haryana	Fatehabad
3	Haryana	Gurugram
4	Haryana	Hisar
5	Haryana	Jhajjar
6	Haryana	Jind
7	Haryana	Kaithal
8	Haryana	Kurukshetra
9	Haryana	Mahendragarh
10	Haryana	Palwal
11	Haryana	Panipat
12	Haryana	Rewari
13	Haryana	Sirsa

14	Haryana	Sonipat

Table-7.3.3: Comparative Change in number of locations having F>1.0 mg/L in various districts

S. No.	**District**	**Nos. of locations having F> 1.0 mg/L.**		
		2015	**2022**	**Increase/Decrease**
1.	Ambala	0	0	0
2.	Bhiwani	12	9	-3
3.	Faridabad	0	0	0
4.	Fatehabad	2	3	+1
5.	Gurugram	1	5	+4
6.	Hisar	6	12	+6
7.	Jhajjar	7	4	-3
8.	Jind	5	13	+8
9.	Kaithal	5	5	0
10.	Karnal	0	0	0
11.	Kurukshetra	0	1	+1
12.	Mahendragarh	3	6	+3
13.	Mewat	1	0	-1
14.	Palwal	3	8	+5
15.	Panchkula	0	0	0
16.	Panipat	1	12	+11
17.	Rewari	1	5	+4
18.	Rohtak	4	2	-2
19.	Sirsa	6	8	+2
20.	Sonipat	6	10	+4

S. No.	District	Nos. of locations having F> 1.0 mg/L.		
21.	Yamunanagar	0	0	0
	Total	**63**	**103**	**40**

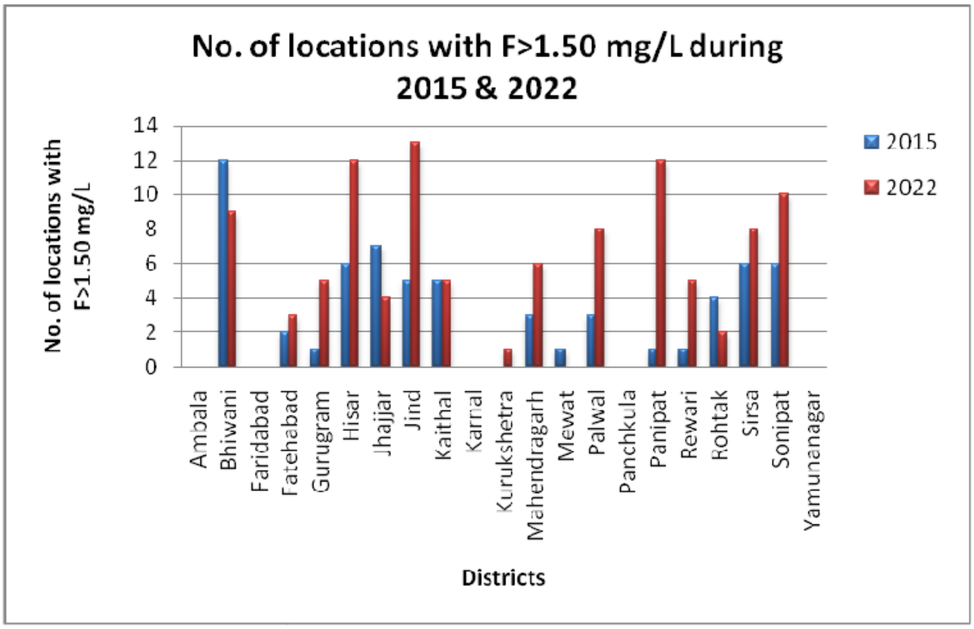


Fig 7.3.3 Comparison on No of districts exceed Fluoride >1.5 during 2015 and 2022

It has been observed (Table 7.3.3) that total number of districts affected by high fluoride in the state has increased by 3.13 % in 2022 as compared to the data available in 2015. In Gururgram Hisar Jind Palwal Panipat Rewari Sonipat has the increase in the no. of locations is a matter of concern.

7.3.1 TREND ON FLUORIDE

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 7.3.4 and Fig 7.3.5 and observed that the percentage of samples exceed the permissible limit of fluoride 1.5 mg/L were ranging between 11 - 22 %. Trend on fluoride in Hisar district of Haryana shows (Fig 7.3.6) an decreasing trend and in Panipat district of Haryana shows (Fig 7.3.7) an increasing trend.

Table 7.3.4: Percentage of wells Exceed fluoride >1.5 mg/L during the period of 2017-2022

Year	Total No. of samples analysed	No. of districts affected by F	Total No. of locations affected by F	% of locations affected by F
2017	420	16	90	21.4
2018	449	15	75	16.7
2019	447	11	68	15.2
2020	420	12	57	13.6
2021	466	15	82	17.6
2022	465	14	51	11

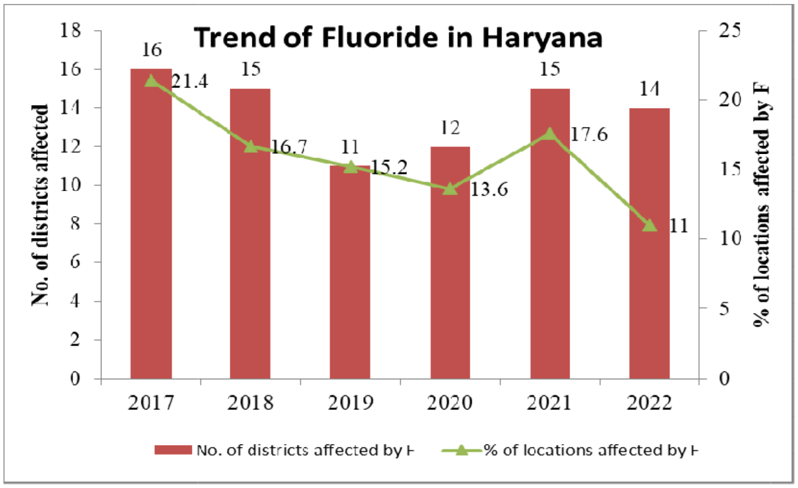


Fig. 7.3.5 Trend of Fluoride occurrence in Haryana

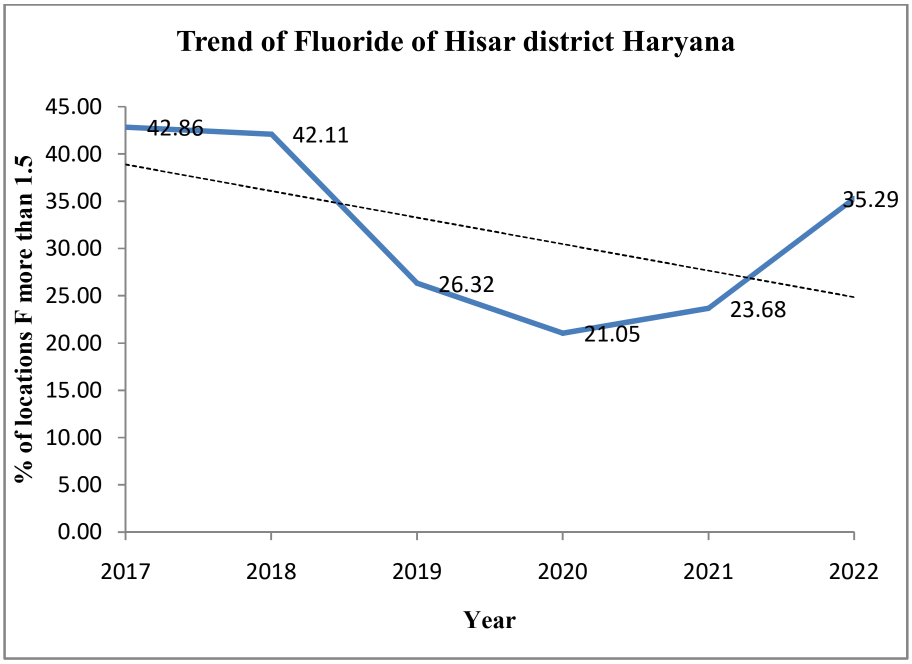


Fig 7.3.6 Trend on Fluoride in Hisar district for the period of 2017-2022

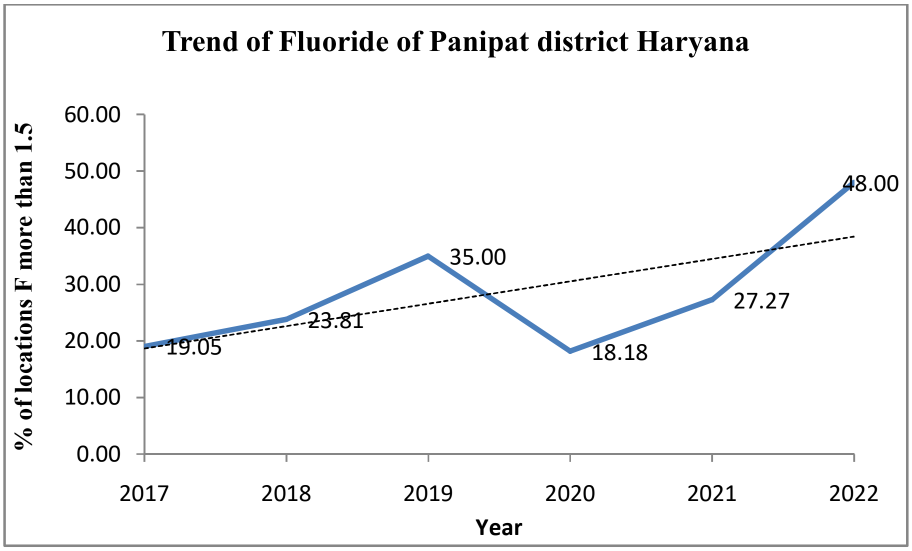


Fig 7.3.7 Trend on Fluoride in Panipat district for the period of 2017-2022

Remedial Measures for Fluoride

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

(a) Adsorption and ion exchange

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

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

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

(b)Coagulation-precipitation

Precipitation methods are based on the addition of chemicals (coagulants and coagulant aids) and the subsequent precipitation of a sparingly soluble fluoride salt as insoluble. Fluoride removal is accomplished with separation of solids from liquid. 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.

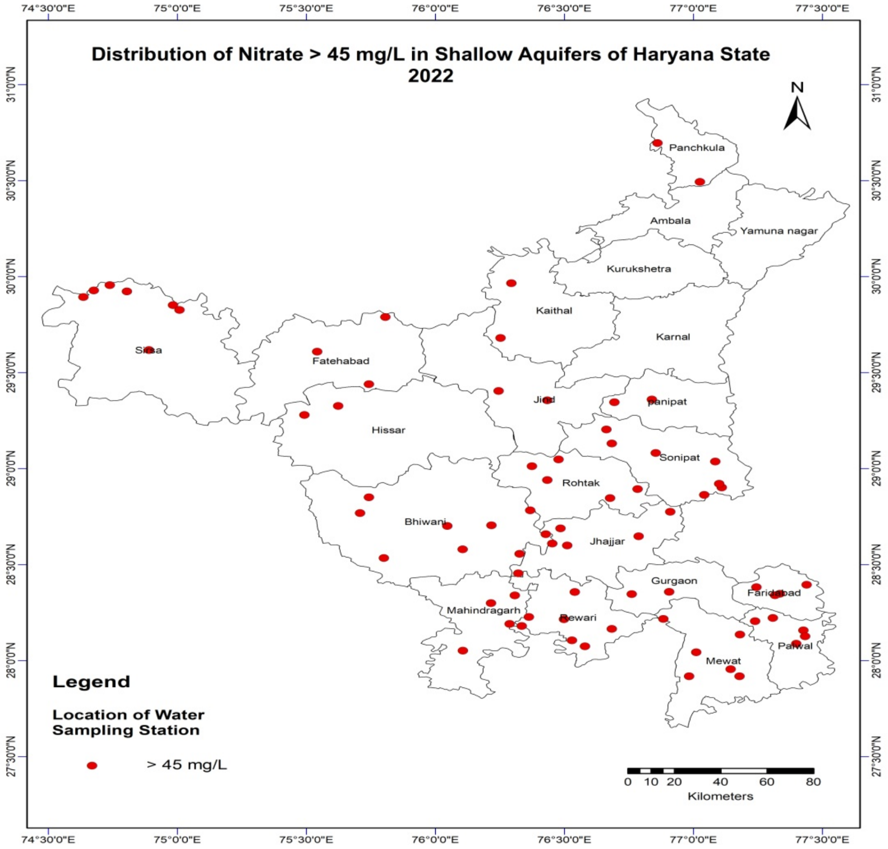


Fig 7.4.1 Locations having Nitrate concentration > 45 mg/L during June 2022

Table 7.4.1: District-wise percentage of wells having Nitrate > 45 mg/L

S. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (NO3 > 45 mg/L)	(%) Samples (NO3 > 45mg/L)
1	Ambala	17	0	0.00
2	Bhiwani	33	9	27.27
3	Faridabad	10	4	40.00
4	Fatehabad	14	3	21.43
5	Gurugram	23	3	13.04
6	Hisar	34	2	5.88
7	Jhajjar	14	5	35.71
8	Jind	20	3	15.00

9	Kaithal	29	1	3.45
10	Karnal	41	0	0.00
11	Kurukshetra	24	0	0.00
12	Mahendragarh	8	4	50.00
13	Mewat	11	4	36.36
14	Palwal	21	6	28.57
15	Panchkula	25	2	8.00
16	Panipat	25	2	8.00
17	Rewari	13	8	61.54
18	Rohtak	11	6	54.55
19	Sirsa	36	7	19.44
20	Sonipat	35	7	20.00
21	Yamunanagar	22	0	0.00
	Total (India)	**466**	**76**	**16.31**

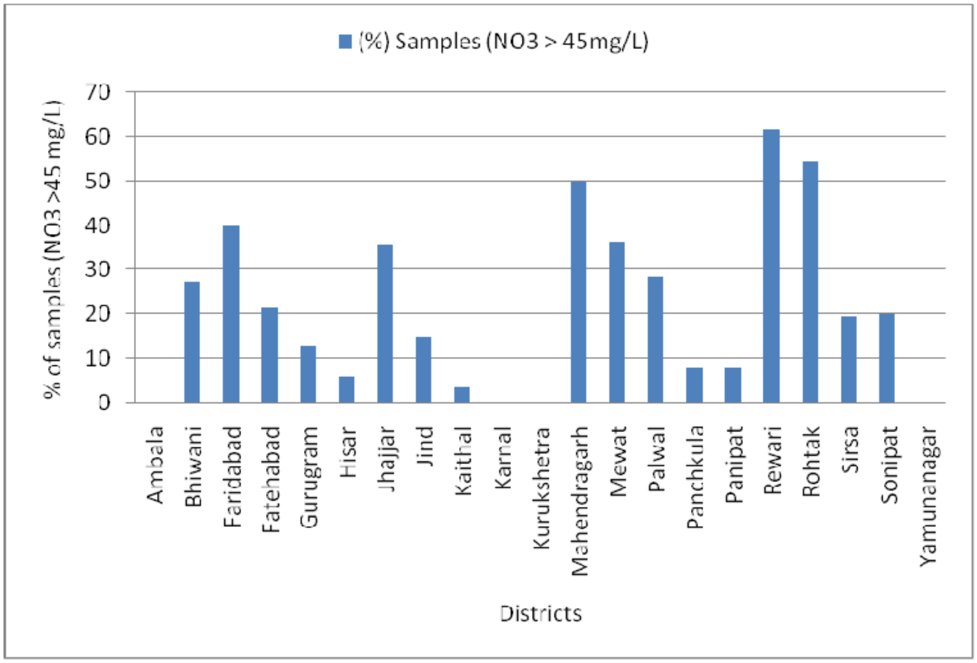


Fig 7.4.2 District-wise samples exceed Nitrate 45 mg/L (NHS 2022-23)

Table 7.4.2: List of Districts Showing Localized Occurrence of Nitrate (>45 mg/L) in Ground Water in the state of Haryana

Sl. No.	State	Parts of Districts having Nitrate > 45 mg/L
1	Haryana	Bhiwani
2	Haryana	Faridabad
3	Haryana	Fatehabad
4	Haryana	Gurugram
5	Haryana	Hisar
6	Haryana	Jhajjar
7	Haryana	Jind
8	Haryana	Kaithal
9	Haryana	Mahendragarh
10	Haryana	Mewat

11	Haryana	Palwal
12	Haryana	Panchkula
13	Haryana	Panipat
14	Haryana	Rewari
15	Haryana	Rohtak
16	Haryana	Sirsa
17	Haryana	Sonipat

Table-7.4.3: Comparative Change in number of Districts having Nitrate > 45 mg/L in the state of Haryana

S. No.	District	Nos. of districts having NO_3> 45 mg/L.		
		2015	2022	Increase/ Decrease
1.	Ambala	4	0	-4
2.	Bhiwani	19	9	-10
3.	Faridabad	3	4	+1
4.	Fatehabad	1	3	+2
5.	Gurugram	9	3	-6
6.	Hisar	8	2	-6
7.	Jhajjar	8	5	-3
8.	Jind	2	3	+1
9.	Kaithal	6	1	-5
10.	Karnal	0	0	0
11.	Kurukshetra	0	0	0
12.	Mahendragarh	4	4	0
13.	Mewat	6	4	-2

S. No.	District	Nos. of districts having NO_3> 45 mg/L.		
14.	Palwal	2	6	+4
15.	Panchkula	6	2	-4
16.	Panipat	1	2	+1
17.	Rewari	4	8	+4
18.	Rohtak	3	6	+3
19.	Sirsa	5	7	+2
20.	Sonipat	4	7	+3
21.	Yamunanagar	1	0	-1
	Total	**96**	**76**	**-20**

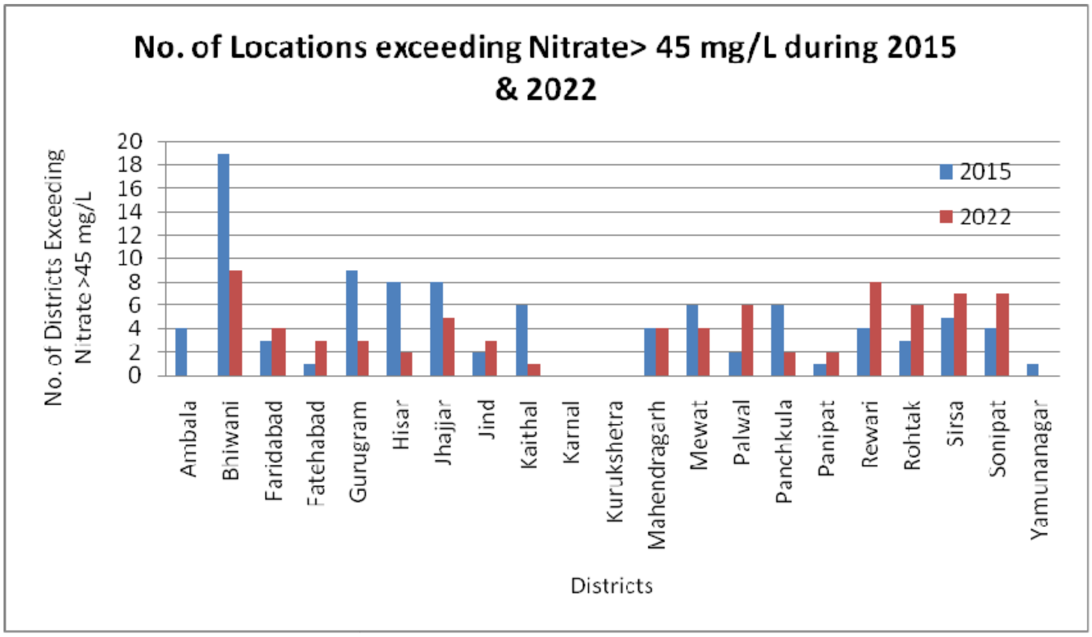


Fig. 7.4.3 Bar diagram comparing no. of Nitrate contaminated (45 mg/L) locations in various districts during year 2015 and 2022

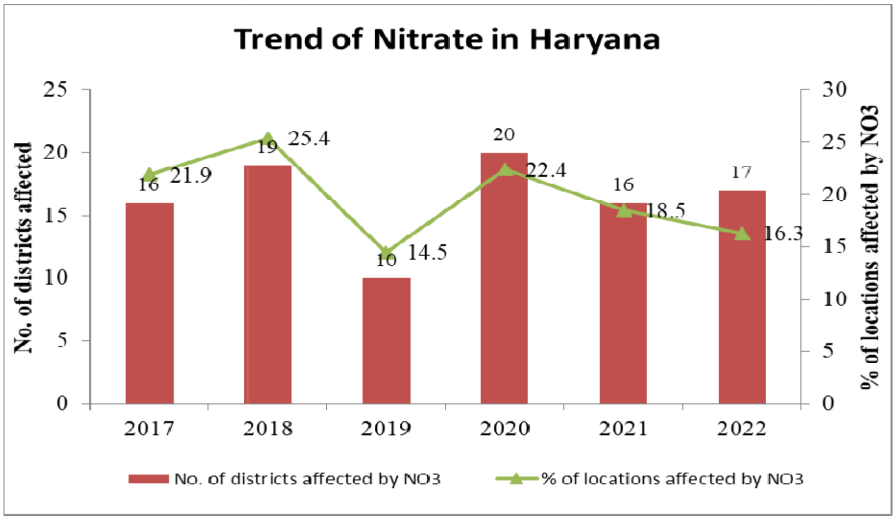
It has been observed (Table 7.4.3) that No. of locations in various districts having high Nitrate (more than 45 mg/l) content in ground water has decreased by 12.60% in year 2022 as compared to the data available in year 2015.

7.4.1 TREND ON NITRATE

Trend analysis determines whether the measured values of the water quality variables increase or decrease during a time period. Nitrate is one of the major indicators of anthropogenic sources of pollution. Nitrate is the ultimate oxidized product of all nitrogen containing matter and its occurrence in groundwater can be fairly attributed to infiltration of water through soil containing domestic waste, animal waste, fertilizer and industrial pollution. As the lithogenic sources of nitrogen are very rare, its presence in ground water is almost due to anthropogenic activity. Hence, nitrate was taken to assess the trend of ground water quality in India due to anthropogenic activity. 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 16 - 28 %. Trend on Nitrate in Bhiwani and Sirsa districts of Haryana are shown (Fig 7.4.6 and 7.4.7) and show decreasing trend.

Table 7.4.5: Percentage of wells Exceed Nitrate >45 mg/L during the period of 2017-2022

Year	Total No. of samples analysed	No. of districts affected by NO3	Total No. of locations affected by NO3	% of locations affected by NO3
2017	420	16	92	21.9
2018	449	19	114	25.4
2019	447	10	65	14.5
2020	420	20	94	22.4
2021	466	16	86	18.5
2022	465	17	76	16.3



. **Fig. 7.4.5** Trend of Nitrate occurrence in Haryana

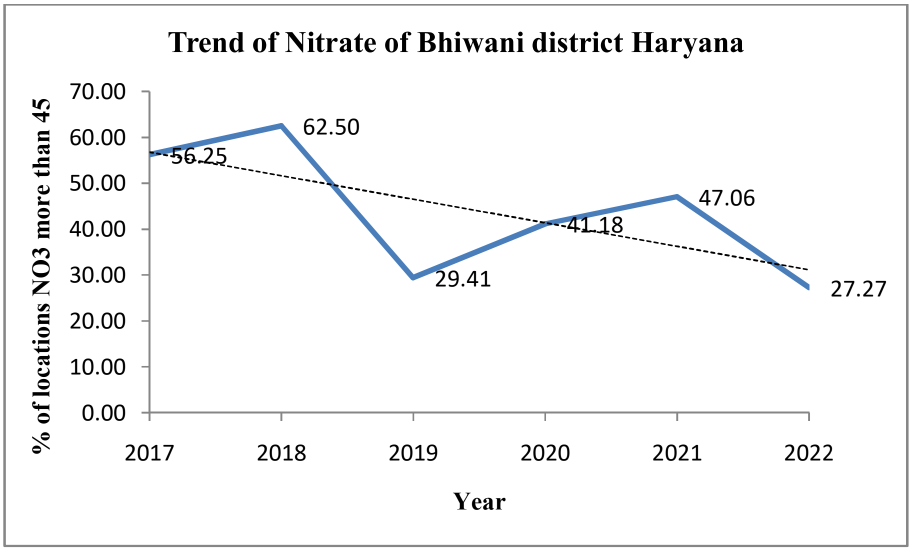


Fig 7.4.6 Trend on Nitrate in Bhiwani district for the period of 2017-2022

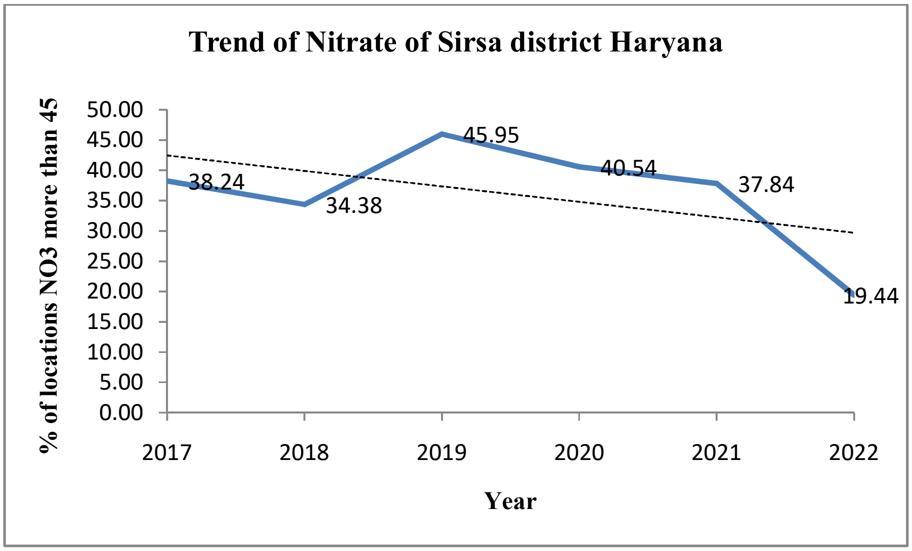


Fig 7.4.7 Trend on Nitrate in Sirsa district for the period of 2017-2022

Remedial Measures for Nitrate

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

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

- Raw water source substitution
- Blending with low nitrate waters

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

b) Methods involving Treatment:

They are as follows

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

The mechanism of nitrate pollution in subsurface porous unconfined/confined aquifer is governed by complex biogeochemical processes. Apart from recharge conditions, groundwater chemistry may be impacted by the mineral kinetics of water-rock interactions. Consequently, suitable nitrate removal technologies should be selected. Nitrate is a very soluble ion with limited potential for co-precipitation or adsorption. This makes it difficult suchaschemicalcoagulation, 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 ofcontaminated 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.

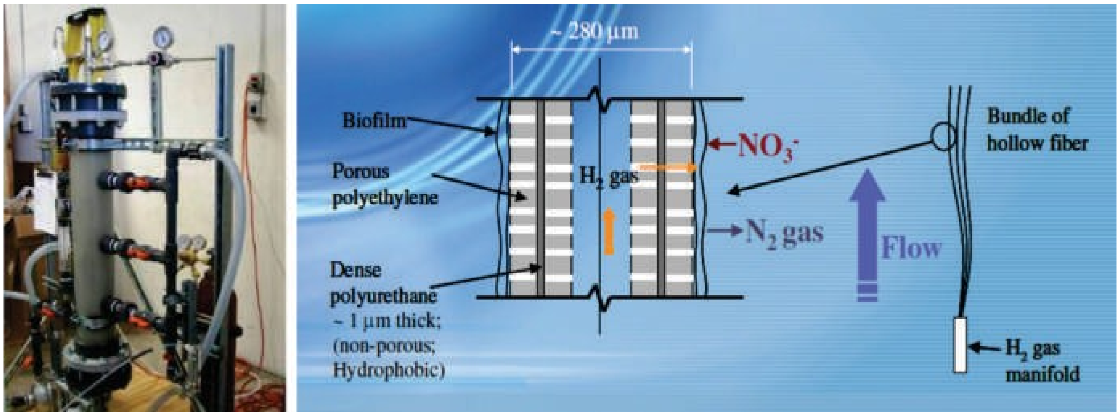


Fig. 7.4.8 Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

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 1.0 mg/L as per the BIS Standard for drinking water. The occurrences of iron in ground water beyond permissible limit (> 1.0 mg /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.

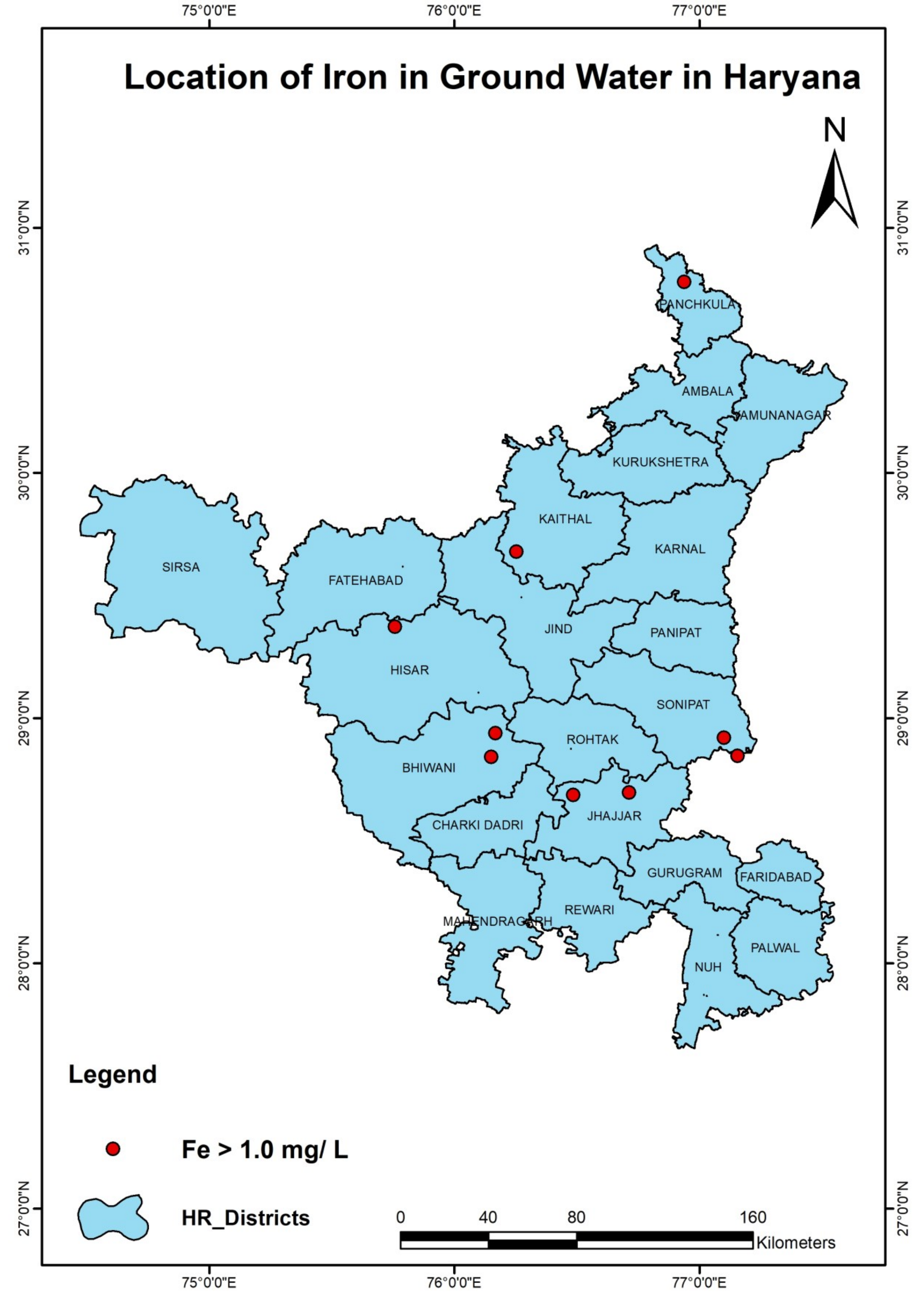


Fig 7.5.1 Map showing areas of Iron contaminated (> 1.0mg/L) groundwater in Haryana (NHS 2022)

Table 7.5.1 Districts Having Localized Occurrence of Iron (>1.0 mg/L) in Ground Water in the state of Haryana

Sl. No	State	Parts of Districts Having Fe > 1.0 mg/L
1	Haryana	Bhiwani
2	Haryana	Hisar
3	Haryana	Jhajjar
4	Haryana	Kaithal
5	Haryana	Panchkula
6	Haryana	Sonipat

Table-7.5.2: Comparative Change in number of locations having Fe > 1.0 mg/L in the state of Haryana

S. No.	State	No of locations having Fe > 1.0 mg/L		
		2015	2022	Increase/Decrease
1	Ambala	2	0	+2
2	Bhiwani	4	2	-2
3	Faridabad	3	0	+3
4	Fatehabad	0	0	0
5	Gurgon	0	0	0
6	Hisar	1	1	0
7	Jhajjar	4	2	-2
8	Jind	2	0	-2
9	Kaithal	4	1	-3
10	Karnal	2	0	-2
11	Kurukshetra	2	0	-2
12	Mahendragarh	0	0	0

S. No.	State	No of locations having Fe > 1.0 mg/L		
13	Mewat	6	0	-6
14	Palwal	8	0	-8
15	Panchkula	0	1	+1
16	Panipat	2	0	-2
17	Rewari	2	0	-2
18	Rohtak	3	0	-3
19	Sirsa	0	0	0
20	Sonepat	7	3	-4
21	Yamunanagar	5	0	-5
	Total	57	10	-47

As compared to the data available in year 2015, the number of locations having Iron more than 1.0 mg/L in ground water samples has decreased (Table 7.5.2) by 15.02 % during the year 2022.

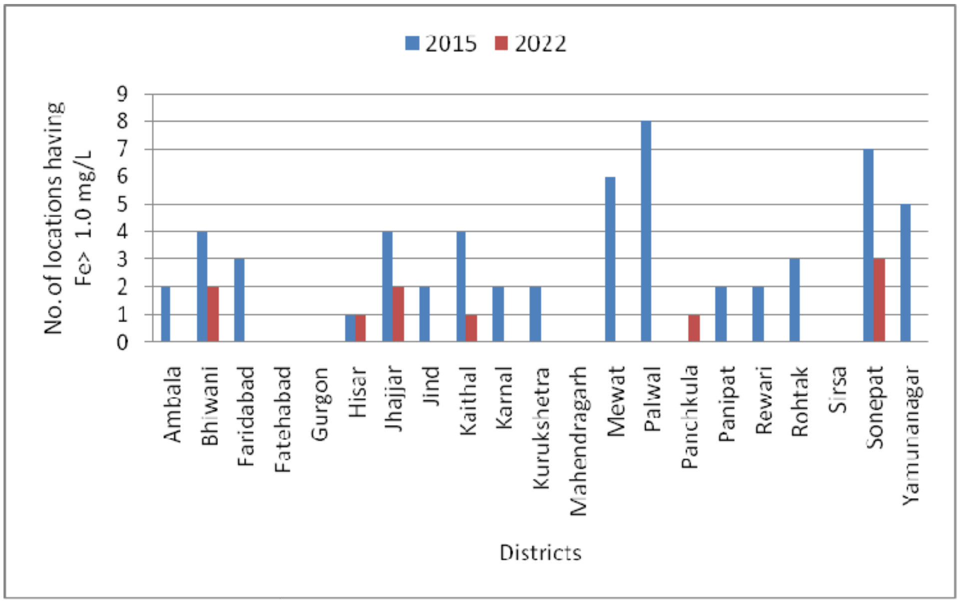


Fig. 7.5.2 Comparison on No. of locations exceed Iron >1.0 mg/L during 2015 and 2022.

Remedial Measures for Iron/Manganese

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

Ozone may be used for iron and manganese oxidation. Ozone may not be effective for oxidation in the presence of humic or fulvic materials. If not dosed carefully, ozone can oxidize reduced manganese to permanganate and result in pink water formation as well. Manganese dioxide particles, also formed by oxidation of reduced manganese, must be carefully coagulated to ensure their removal.

A low-cost method of providing oxidation is to use the oxygen in air as the oxidizing agent. Water is simply passed down a series of porous trays to provide contact between air and water. No chemical dosing is required. This method is not effective for water in which the iron is complexed with humic materials or other large organic molecules.

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

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

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

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

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, Haryana, 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 Haryana (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 details of the locations are given in 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 Haryana are shown in Table-7.6.1.

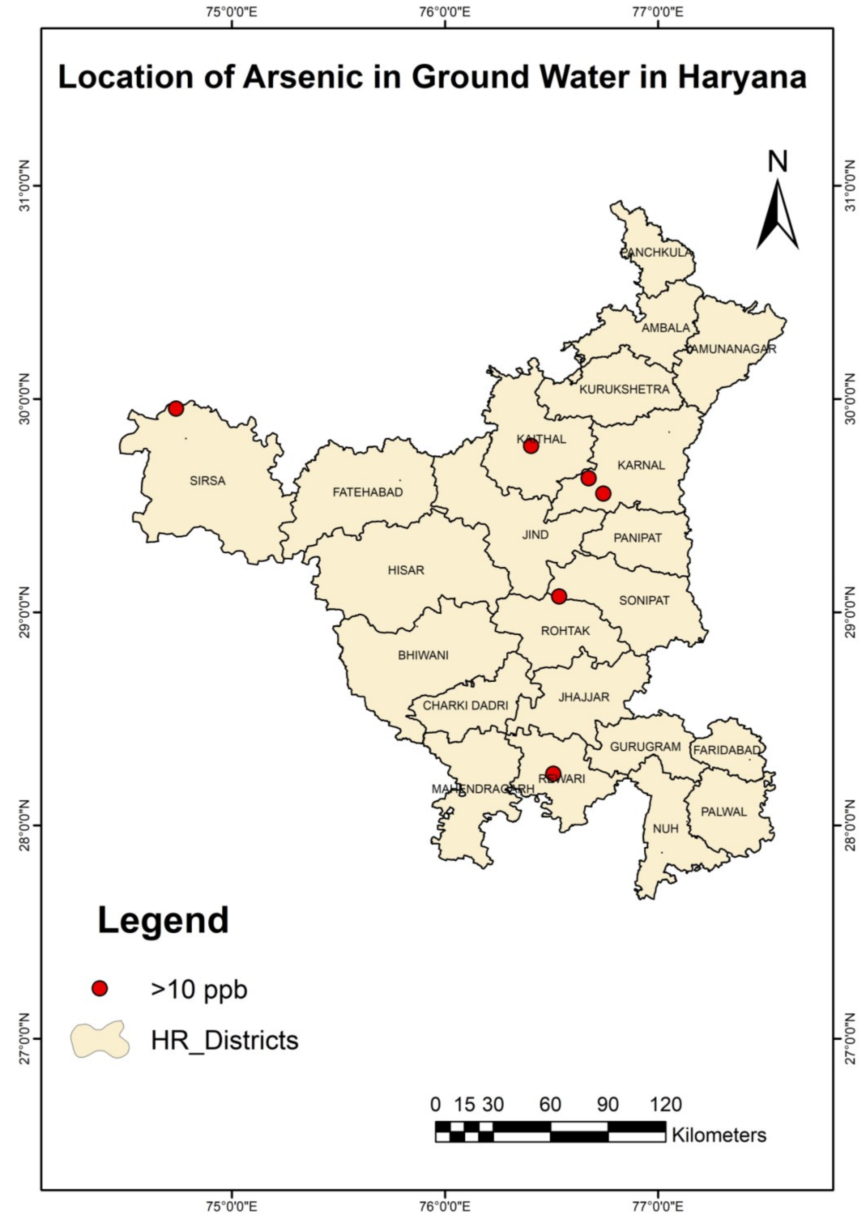


Fig 7.6.1 Map showing areas of Arsenic contaminated (> 10 ppb) groundwater in Haryana (NHS 2022)

Table 7.6.1: Districts having Arsenic >0.01 in Ground Water in the State of Haryana

Sl. No.	State	Parts Of Districts having As > 10 ppb (0.01 mg/L)
1.	Haryana	Kaithal
2.	Haryana	Karnal
3.	Haryana	Rewari
4.	Haryana	Sirsa
5.	Haryana	Sonipat

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 (UO_2^{2+}) and pitchblende ($U_3O_8^{2+}$) 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

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

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

Sl. No	Country / agency	guideline value (µg/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-µm 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 7.7.4.

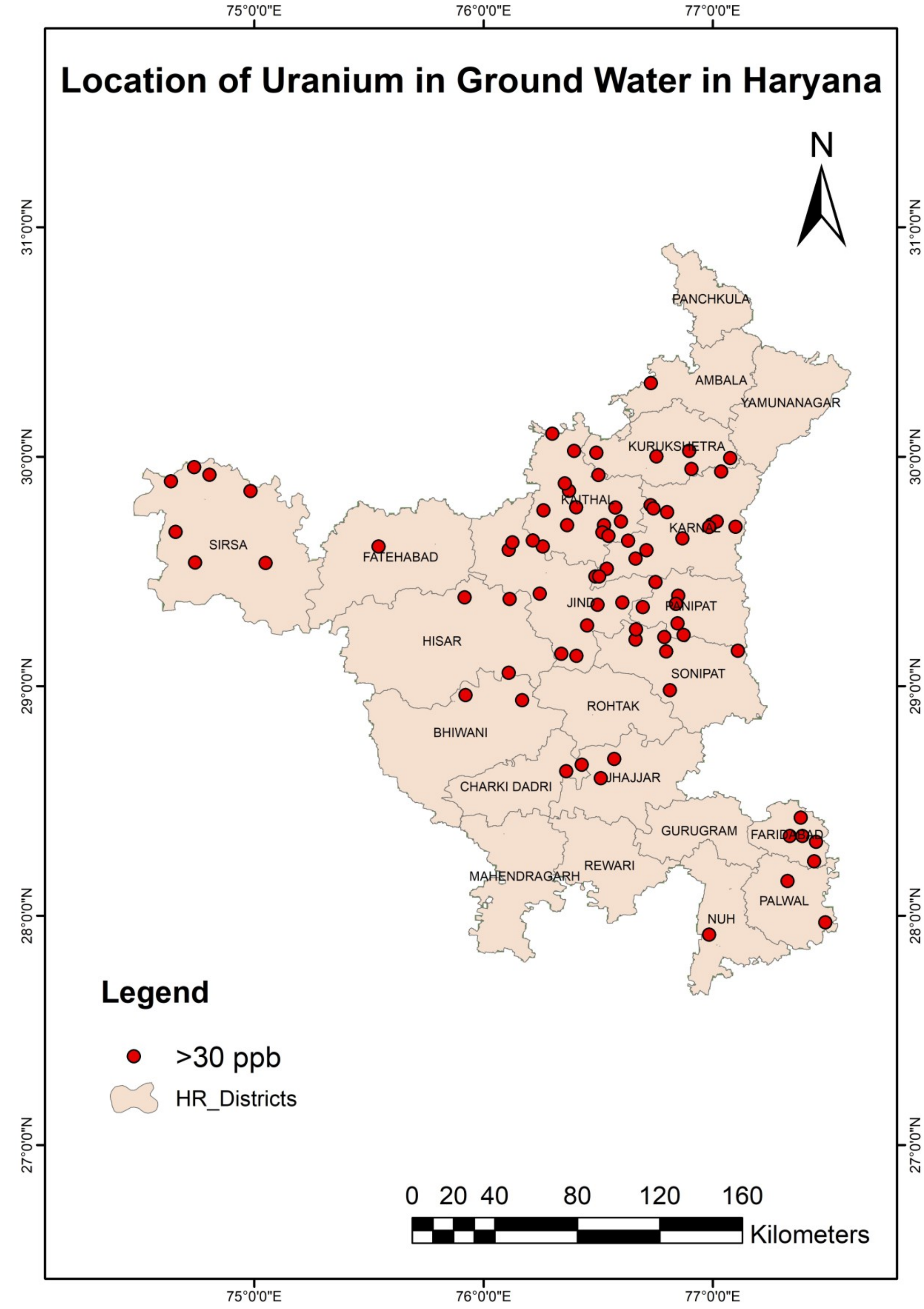


Fig 7.7.1 Map showing areas of Uranium contaminated (> 30 ppb) groundwater in Haryana state (NHS 2022)

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

Sl No	State	Districts Partly affected with Uranium > 30ppb
1	Haryana	Bhiwani
2	Haryana	Faridabad
3	Haryana	Fatehabad
4	Haryana	Hisar
5	Haryana	Jhajjar
6	Haryana	Jind
7	Haryana	Kaithal
8	Haryana	Karnal
9	Haryana	Kurukshetra
10	Haryana	Mahendragarh
11	Haryana	Mewat
12	Haryana	Panipat
13	Haryana	Sirsa
14	Haryana	Sonipat

Table 7.7.4 shows the number of locations partly affected in various districts with maximum values recorded. It is observed that Jind, Kaithal, Karnal, Kurukshetra are mostly affected in terms of percentage of samples observed with U concentration > 30 ppb. Some other districts such as Panipat, Mewat, Jhajjar, Faridabad have also been observed to have Uranium concentration above the permissible level of 30 µg/L in some localized pockets (Annexure VII).

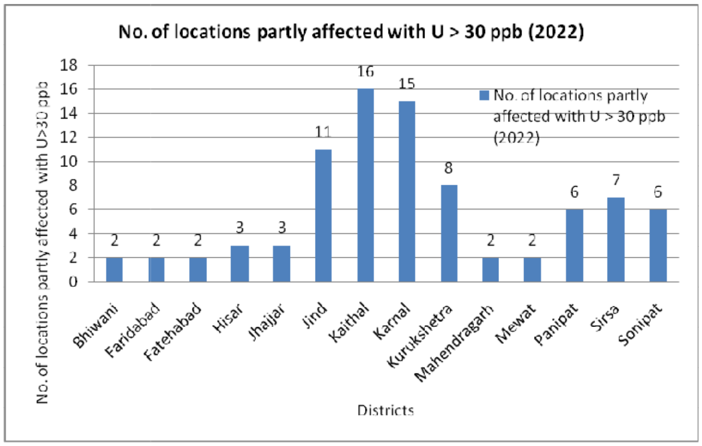


Fig. 7.7.2 Bar diagram displaying no. of partly Uranium contaminated (> 30 ppb) loactions in the state of Haryana during 2022.

Uranium concentration varied from 30.04 to 456.21 ppb in the entire state during Pre-monsoon monitoring (June 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.

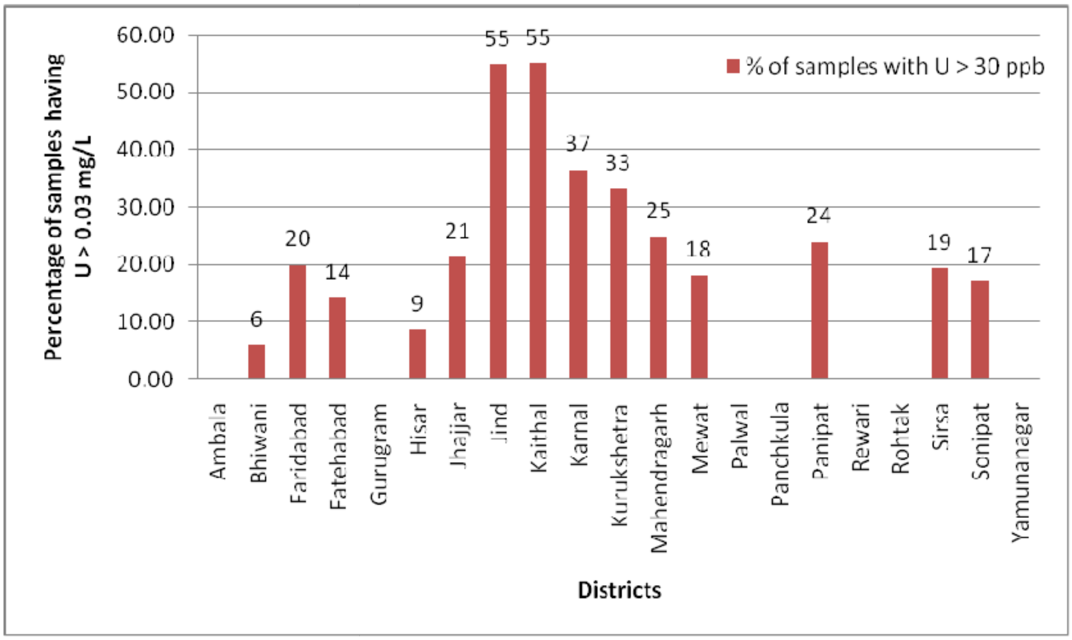


Fig 7.7.3 District-wise percentage of samples exceed Uranium 0.03mg/L (>30ppb)

Table 7.7.4 Details of number of locations partly affected with Uranium > 0.03 mg/L (>30ppb) and the maximum values of Uranium in various districts of Haryana state

Sl. No.	District	No. of locations partly affected with U > 30 ppb (2022)	Maximum value of Uranium observed (in ppb)
1.	Bhiwani	2	47.02
2.	Faridabad	2	53.90
3.	Fatehabad	2	43.46
4.	Hisar	3	231.26
5.	Jhajjar	3	49.10
6.	Jind	11	165.55
7.	Kaithal	16	63.72
8.	Karnal	15	71.77
9.	Kurukshetra	8	64.04
10.	Mahendragarh	2	41.28
11.	Mewat	2	38.91
12.	Panipat	6	456.21
13.	Sirsa	7	127.78
14.	Sonipat	6	76.25

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 such as Hisar, Jind, Panipat and Sirsa 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 Punjab (Tripathi et al.2012), 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. AreviewofvarioustreatmenttechnologiesforUraniumremovalfromwaterandtheirtechnicalachievability as reported by various researchers are given below inTable 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 $CaCO_3$ 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 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 are several locations in the Bhiwani, Hisar, Jind, Jhajjar, Mewat, Rohtak, Palwal, Sonipat where the total hardness in ground water exceeds 600 mg/L.

Table – 7.8.1 Number of location having total hardness > 600 mg/L in the State of Haryana

S. No.	District	No. of locations having TH> 600 mg/L
1	Bhiwani	13
2	Faridabad	5
3	Fatehabad	1
4	Gurugram	4
5	Hisar	9
6	Jhajjar	8
7	Jind	12
8	Kaithal	4
9	Karnal	1
10	Mahendragarh	1
11	Mewat	7

12	Palwal	10
13	Panipat	3
14	Rewari	2
15	Rohtak	6
16	Sirsa	4
17	Sonipat	13
Total		103

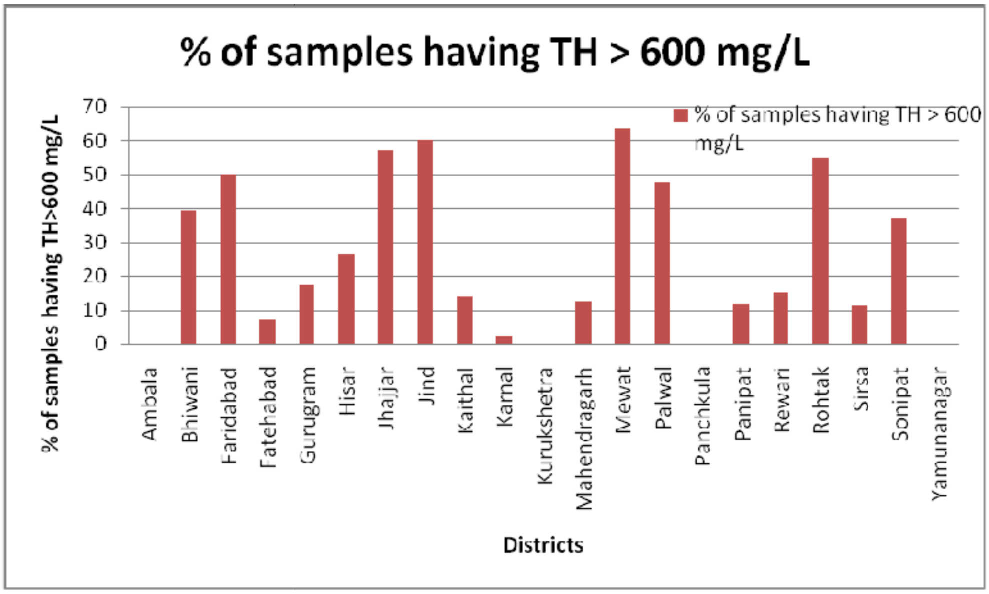


Fig 7.8.1 Bar diagram District-wise percentage of wells having Total hardness > 600 mg/L is shown as a bar diagram in.

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

Table 7.8.4 District-wise percentage of samples having Total Hardness >600 mg/L

S. No	District	No. of Samples collected (NHS 2022-23)	No. of samples having TH > 600 mg/l	% of Samples (TH > 600 mg/L)
1	Ambala	17	0	0.00
2	Bhiwani	33	13	39.39
3	Faridabad	10	5	50.00
4	Fatehabad	14	1	7.14
5	Gurugram	23	4	17.39
6	Hisar	34	9	26.47
7	Jhajjar	14	8	57.14
8	Jind	20	12	60.00
9	Kaithal	29	4	13.79
10	Karnal	41	1	2.44
11	Kurukshetra	24	0	0.00
12	Mahendragarh	8	1	12.50
13	Mewat	11	7	63.64
14	Palwal	21	10	47.62
15	Panchkula	25	0	0.00
16	Panipat	25	3	12.00

17	Rewari	13	2	15.38
18	Rohtak	11	6	54.55
19	Sirsa	36	4	11.11
20	Sonipat	35	13	37.14
21	Yamunanagar	22	0	0.00
	Total(Haryana)	**466**	103	22.10

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_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.

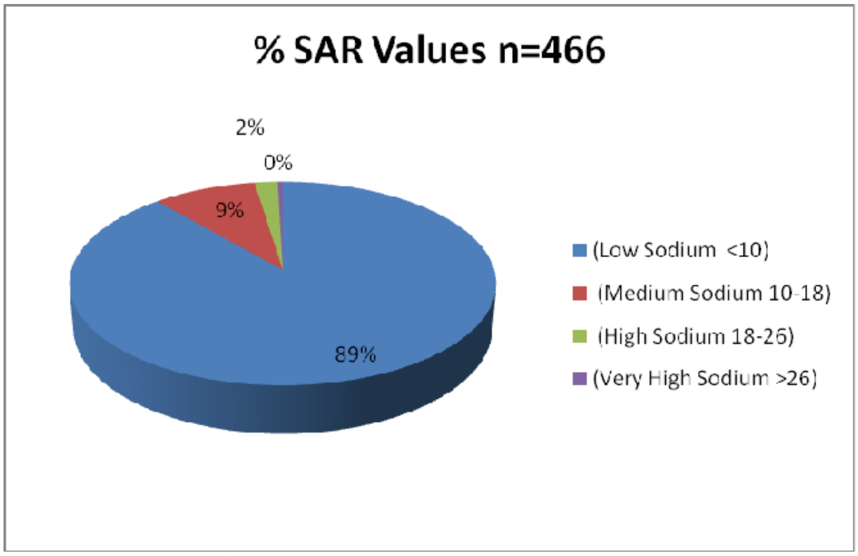


Figure 8.1: Percentage of groundwater samples according to SAR classifications (n=466).

The computed SAR values ranges from 0.13 to 57. The maximum SAR value has been found at Kapro of Hisar district. It is apparent from Fig. 8.1 that 89% samples belong to excellent category (S_1) and only 0.43% (or negligible) water samples are associated with very high sodium category (S_4) and is unsuitable for irrigation.

According to SAR classification, 100% of water samples in Kurukshetra and Yamunanagar fall in excellent category (S_1). While in considerable proportion of samples in different districts are associated with medium sodium hazard and can be classified as good category(S_2) for irrigation use (Table 8.1)

It was found that in Fatehabad and Hisar districts 7.14% and 2.94 % samples respectively fall in Very high sodium range and are unsuitable for use in irrigation practices (Fig. 8.2).

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

District	% of samples in various SAR range			
	(low Sodium <10)	(medium Sodium 10-18)	(high Sodium 18-26)	(very high Sodium >26)
Ambala	94.12	5.88	0.00	0.00
Bhiwani	90.91	9.09	0.00	0.00
Faridabad	60.00	40.00	0.00	0.00
Fatehabad	85.71	0.00	7.14	7.14
Gurugram	73.91	17.39	8.70	0.00
Hisar	85.29	8.82	2.94	2.94
Jhajjar	92.86	7.14	0.00	0.00
Jind	90.00	5.00	5.00	0.00
Kaithal	86.21	13.79	0.00	0.00
Karnal	97.56	0.00	2.44	0.00
Kurukshetra	100.00	0.00	0.00	0.00
Mahendragarh	50.00	50.00	0.00	0.00
Mewat	90.91	9.09	0.00	0.00
Palwal	80.95	19.05	0.00	0.00
Panchkula	96.00	4.00	0.00	0.00
Panipat	88.00	8.00	4.00	0.00

Rewari	69.23	30.77	0.00	0.00
Rohtak	90.91	0.00	9.09	0.00
Sirsa	94.44	5.56	0.00	0.00
Sonipat	94.29	5.71	0.00	0.00
Yamunanagar	100.00	0.00	0.00	0.00

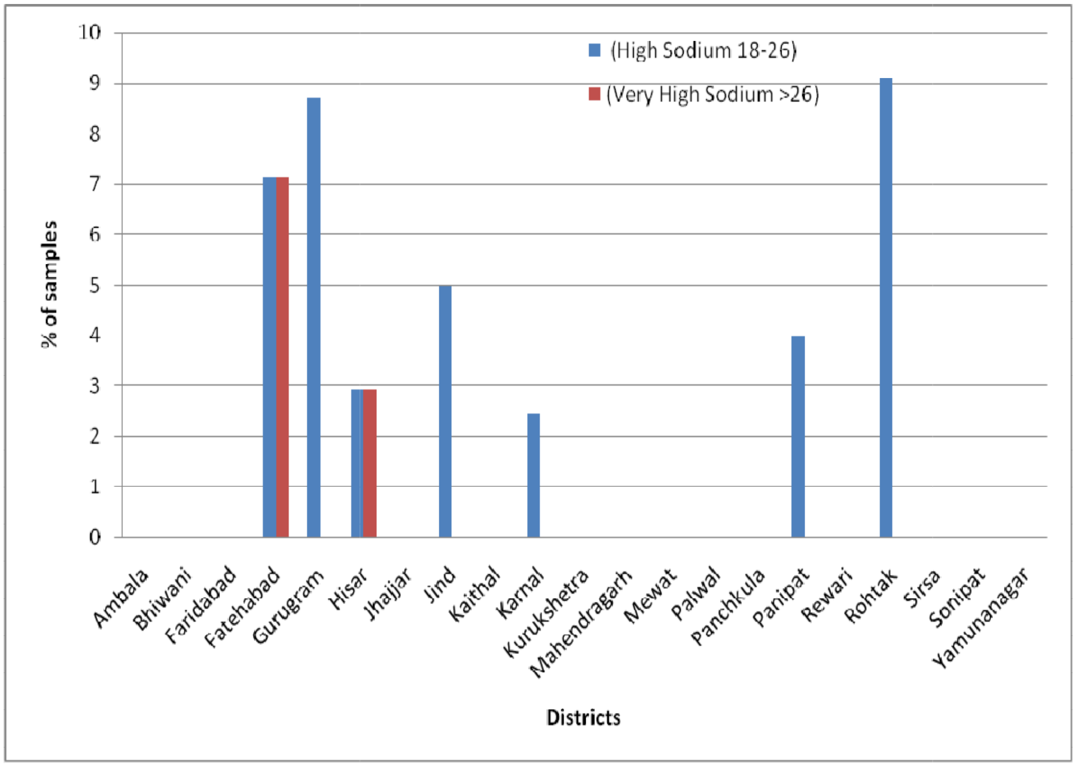


Figure 8.2: Percentage of samples with respect to SAR values.

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;

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

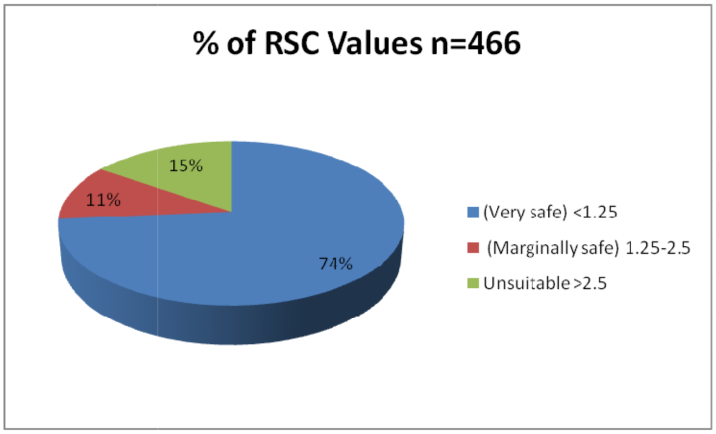


Figure 8.3: Percentage of groundwater samples in various categories according to RSC classifications (n=466) (Wilcox et al.,1954).

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 it can be seen that in India 74% collected water samples are associated with RSC values less than 1.25 and are safe for use in irrigation practices. While 15% water samples are associated with RSC values more than 2.5 and are unsuitable for irrigation. The waterwith 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 disctricts based on RSC values.

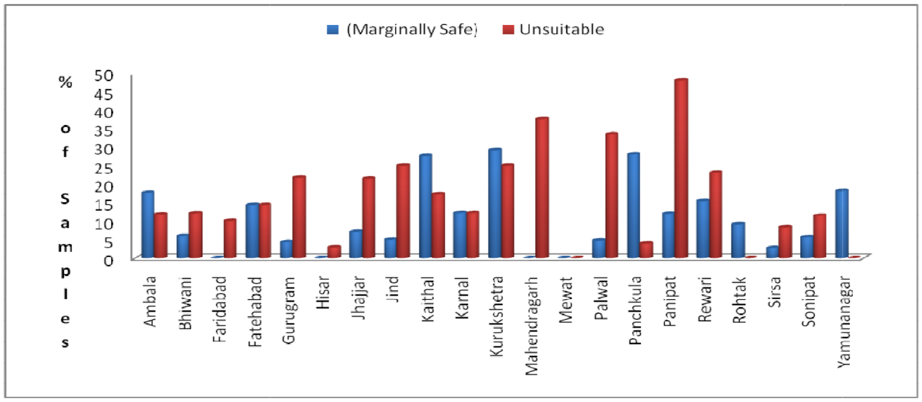


Figure 8.4: Percentage of samples with respect to RSC values.

Most of ground waters from Ambala, Yamunanagar, Sonipat, Panipat, Karnal, Kurukshetra, Panchkula are suitable for irrigation for semi-salt tolerant crops on adequately drained soils. The waters from districts of Bhiwani, Sirsa, Hisar, Kaithal, Jhajjar, Palwal, Rohtak, Jind and Gurugram show wide variability in irrigation rating. According to RSC classification 100% of water samples in Mewat district fall in very safe category with RSC values less than 1.25.

Table 8.2: Summary of irrigation quality of the groundwater samples in various districts based on RSC values.

District	% of samples in various RSC range		
	<1.25	1.25-2.5	>2.5
	(Very safe)	(marginally safe)	Unsuitable
Ambala	70.59	17.65	11.76
Bhiwani	81.82	6.06	12.12
Faridabad	90.00	0.00	10.00
Fatehabad	71.43	14.29	14.29
Gurugram	73.91	4.35	21.74
Hisar	97.06	0.00	2.94
Jhajjar	71.43	7.14	21.43

Jind	70.00	5.00	25.00
Kaithal	55.17	27.59	17.24
Karnal	75.61	12.20	12.20
Kurukshetra	45.83	29.17	25.00
Mahendragarh	62.50	0.00	37.50
Mewat	100.00	0.00	0.00
Palwal	61.90	4.76	33.33
Panchkula	68.00	28.00	4.00
Panipat	40.00	12.00	48.00
Rewari	61.54	15.38	23.08
Rohtak	90.91	9.09	0.00
Sirsa	88.89	2.78	8.33
Sonipat	82.86	5.71	11.43
Yamunanagar	81.82	18.18	0.00

8.1 USSL Diagram

By plotting the values of EC and SAR in USSL diagram, it is observed that ground water occurring in the northern and central parts of the State falls under C_2S_1 and C_3S_1 classes of irrigation waters. It indicates that most of these waters are suitable for irrigating semi-salt tolerant crops on all soils. Ground water mostly from the southern, western and southwestern parts comprising of Bhiwani, Faridabad, Fatehabad, Hisar, Jhajjar, Mahendragarh, Mewat, Palwal, Rewari, Sirsa districts falls under C_3S_2,C_3S_3, C_3S_4, C_4S_1, C_4S_2, C_4S_3 and C_4S_4 classes of irrigation classification. Such waters when used continuously for irrigation, they are likely to cause salinity hazards and lead to reduction in crop yields. They may also cause sodium hazards and lead to hardening of soils when used for irrigation without the addition of adequate quantity of gypsum.

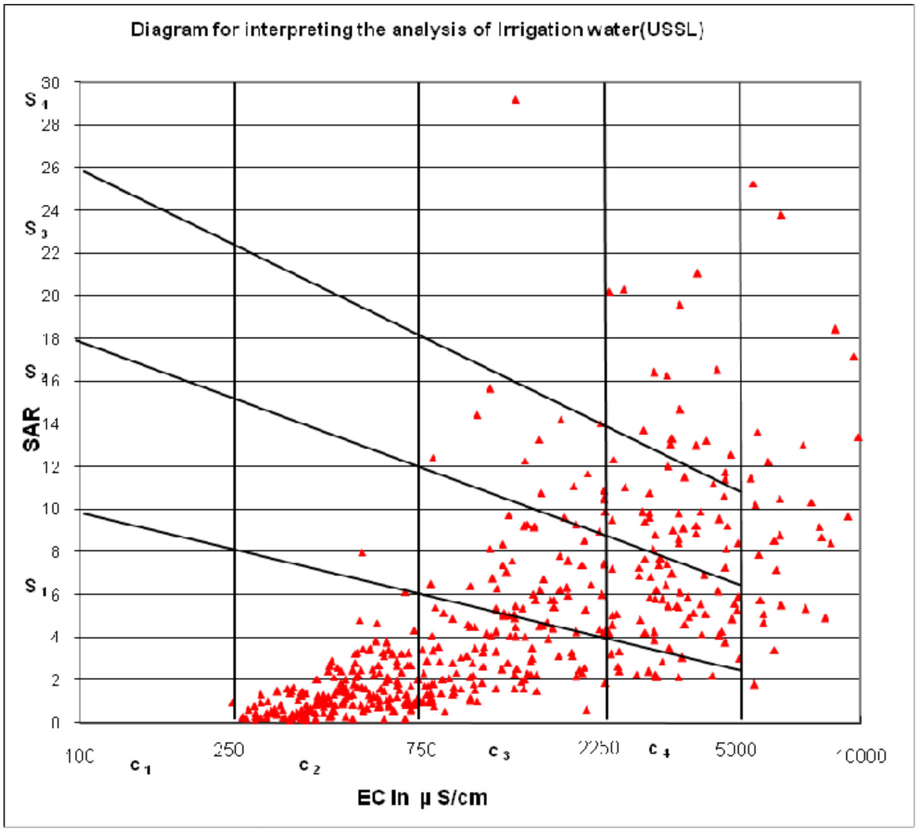


Figure 9.1: Depicting USSL Diagram of Haryana State

Table 9.1: Irrigation Rating of Well Waters of Haryana

(Based on Eaton's index and USSL Classification)

Sl.No.	District	No. of Samples	IRRIGATION SUITABILITY			
			EATON's INDEX (RSC in meq/L)			USSL Classification
			Safe	Marginal	Unsafe	
			<1.25	1.25-2.50	>2.50	
1	Ambala	17	12	3	2	C2S1, C3S1, C3S2, C4S3, C3S3
2	Bhiwani	33	27	2	4	C2S1, C3S1, C4S1, C3S2, C4S2, C3S3, C4S3, C4S4
3	Faridabad	10	9	0	1	C3S1, C4S3, C4S4

4	Fatehabad	14	10	2	2	C2S1, C3S1, C3S2, C3S4
5	Gurugram	23	17	1	5	C2S1, C3S1, C3S2, C4S2, C3S3, C4S3, C4S4
6	Hisar	34	33	0	1	C2S1, C3S1, C4S1, C3S2, C4S2, C4S3, C4S4
7	Jhajjar	14	10	1	3	C2S1, C3S1, C4S2, C4S3,
8	Jind	20	14	1	5	C2S1, C3S1, C4S1, C3S2, C4S2, C3S3, C4S3, C4S4
9	Kaithal	29	16	7	6	C2S1, C3S1, C3S2, C4S2, C3S3, C4S3
10	Karnal	41	31	5	5	C2S1, C3S1, C4S1, C2S2, C3S2, C4S3
11	Kurukshetra	24	11	7	6	C2S1, C3S1
12	Mahendragarh	8	5	0	3	C2S1, C3S2, C3S3, C4S4
13	Mewat	11	11	0	0	C2S1, C31, C3S2, C4S2
14	Palwal	21	13	1	7	C3S1, C3S2, C4S2, C3S3, C4S3
15	Panchkula	25	17	7	1	C2S1, C3S1, C3S3
16	Panipat	25	10	3	12	C2S1, C3S1, C2S2, C3S2, C4S2, C4S3, C4S4
17	Rewari	13	8	2	3	C2S1, C3S1, C3S2, C4S3, C4S4
18	Rohtak	11	10	1	0	C2S1, C3S1, C4S2
19	Sirsa	36	32	1	3	C2S1, C3S1, C4S1, C3S2, C4S2, C3S3, C4S3, C4S4
20	Sonipat	35	29	2	4	C2S1, C3S1, C3S2, C4S2, C3S3, C4S3, C4S4
21	Yamunanagar	22	18	4	0	C1S1, C2S1, C3S1
	Total	**466**	**343**	**50**	**73**	

Most of ground waters from Ambala, Yamunanagar, Sonipat, Panipat, Karnal, Kurukshetra, Panchkula are suitable for irrigation for semi-salt tolerant crops on adequately drained soils.

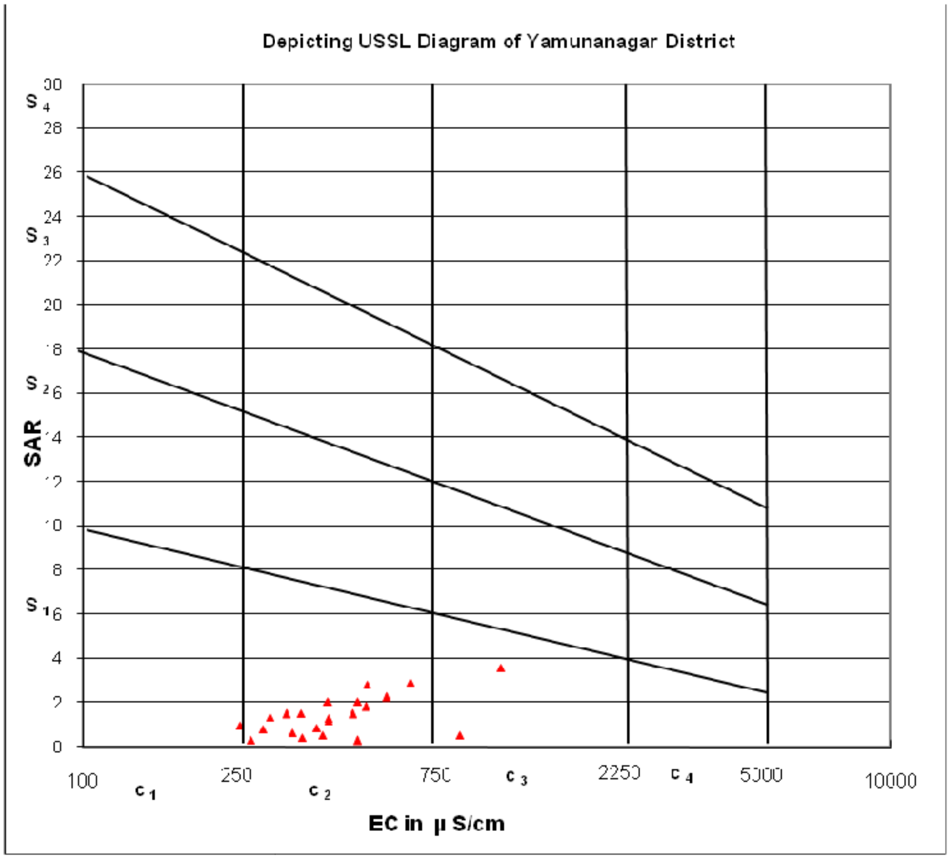


Figure 9.2: Depicting USSL Diagram of Yamunanagar District

The waters from districts of Bhiwani, Sirsa, Hisar, Kaithal, Jhajjar, Palwal, Rohtak, Jind and Gurugram shows wide variability in irrigation rating.

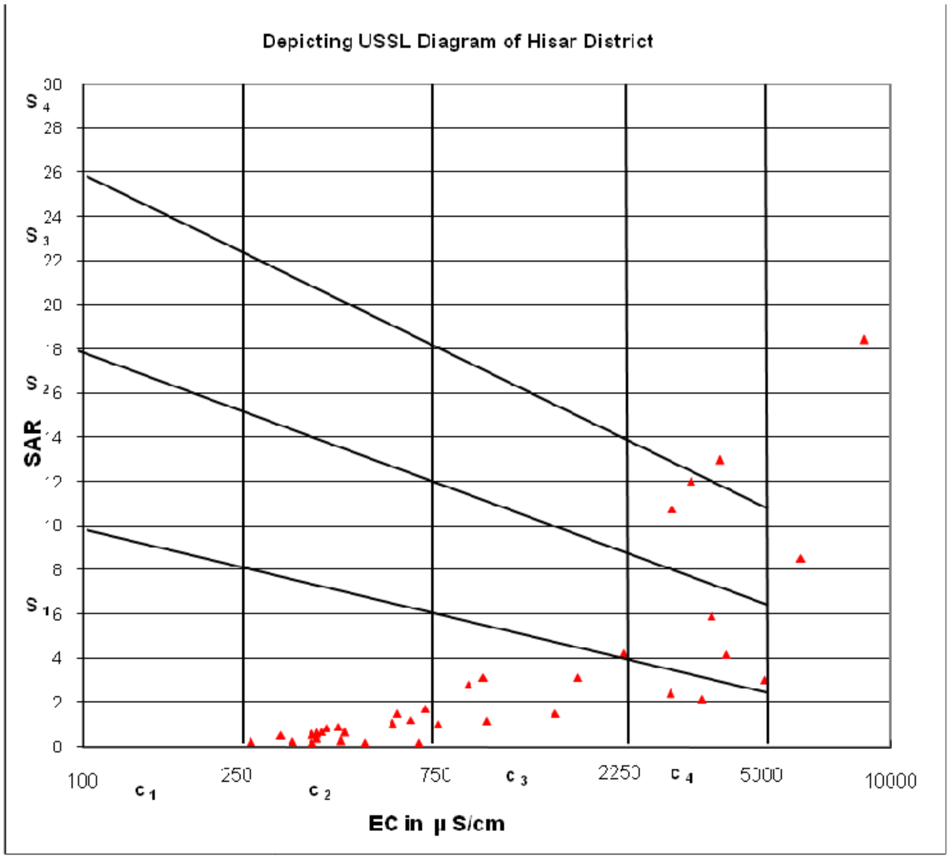


Figure 9.3: Depicting USSL Diagram of Hisar District

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.

In Haryana, 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.9.1) that all type of hydrogeochemical facies i.e. Na-HCO_3, Mg-HCO_3, NaCl, $CaCl_2$ and mixed type are encountered in the state.

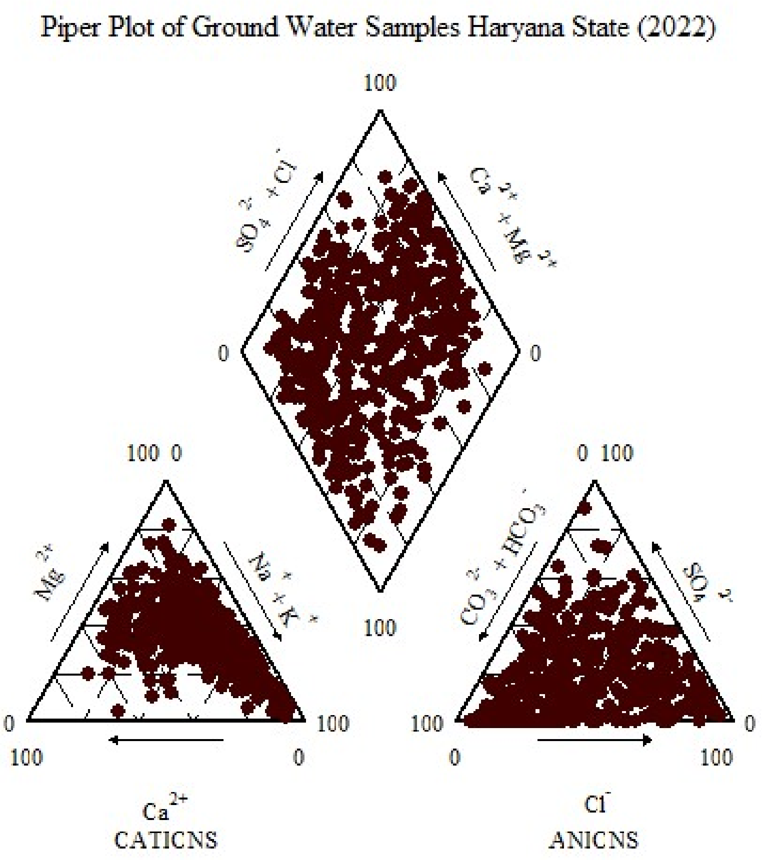


Fig- 9.1 Piper diagram of groundwater of Haryana.

9.0 X-Y Plot:

If halite dissolution is responsible for the sodium, the Na+/Cl- ratio is approximately one, whereas a ratio greater than one, it is typically interpretated as 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 Na+/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).

$$2Na^+ - clay + Ca^{2+} = Ca^{2+} - clay + Na^+$$

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

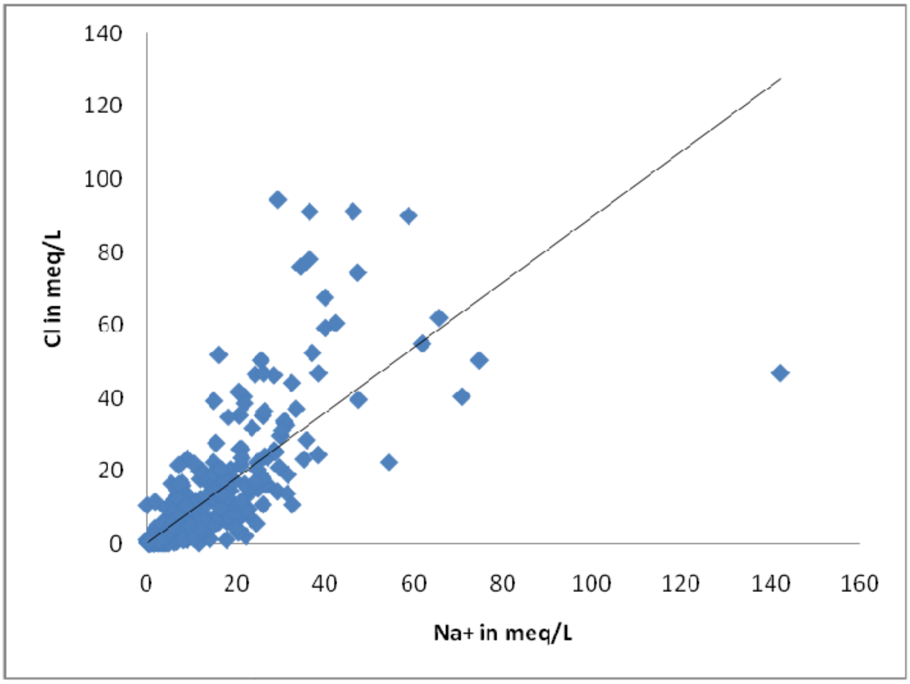


Fig. 9.2: Plot for Na versus Cl in groundwater samples of Haryana

Annexure I

Locations having Electrical Conductivity > 3000 µS/cm in Ground Water in Different Districts of Haryana State

Sr. No.	District	Block	Location	Long	Lat	EC > 3000 µS/cm
1	Bhiwani	Bhawani Khera	Dhanana	76.1680	28.9380	4500
2	Bhiwani	Bhiwani	Bamla	76.2450	28.8070	4800
3	Bhiwani	Bhiwani	Tigrana	76.1500	28.8420	5200
4	Bhiwani	Bhawani Khera	Bhawani Khera	76.0420	28.9360	3300
5	Bhiwani	Dadri - I	Boond Kalan	76.3670	28.7810	4171
6	Bhiwani	Bhiwani	Haluwas	76.1670	28.7330	3440
7	Bhiwani	Kairu	Lohali	76.0460	28.7000	3100
8	Bhiwani	Tosham	Tosham	75.9170	28.8750	4000
9	Faridabad	Ballabgarh	Tigaon	77.3900	28.3470	3282
10	Faridabad	Ballabgarh	Sikri	77.2879	28.2755	6202
11	Faridabad	Ballabgarh	Ferozpur Kalan	77.2380	28.3030	11070
12	Faridabad	Faridabad	CGWB CHQ, NH-IV	77.3140	28.4180	4015
13	Faridabad	Ballabgarh	Ballabgarh	77.3350	28.3470	4461
14	Faridabad	Faridabad	Pali	77.2440	28.3810	10006
15	Fatehabad	Tohana	Talwara	75.8060	29.7880	5300
16	Gurugram	Gurugram	Jhanjrola	77.0040	28.4830	3791
17	Gurugram	Farukhnagar	Kherakhurampur	76.7820	28.4470	3252
18	Gurugram	Farukhnagar	Sewari	76.7230	28.4630	10520
19	Gurugram	Farukhnagar	Machana	76.7500	28.4080	9880
20	Gurugram	Pataudi	Mauzabad	76.6900	28.2970	8362
21	Gurugram	Pataudi	Halley mandi	76.7611	28.3450	3438
22	Hisar	Hansi	Umra	75.9130	29.0530	6000
23	Hisar	Adampur	Kirtan	75.5470	29.2210	3600
24	Hisar	Hisar - I	Dhansu	75.4920	29.2780	4870
25	Hisar	Barwala	Kirori	75.8000	29.3000	3400
26	Hisar	Agroha	Karnoh	75.7570	29.3730	8600
27	Hisar	Barwala	Barwala	75.9170	29.3870	3200
28	Hisar	Barwala	Banbhauri	76.0500	29.4000	3900
29	Hisar	Narnaud	Kapro	76.1130	29.3790	13400
30	Hisar	Hansi	Khanda Kheri	76.2330	29.2090	3780
31	Jhajjar	Bahadurgarh	Kulasi	76.9100	28.7740	3721
32	Jhajjar	Beri	Chamanpura	76.6340	28.6910	10241
33	Jhajjar	Bahadurgarh	Dulhera	76.7880	28.6460	5529
34	Jhajjar	Salahwas	Subnah	76.5710	28.4820	5621
35	Jhajjar	Matanhail	Mudsa	76.4730	28.3450	3400
36	Jhajjar	Beri	Wazirpur	76.5697	28.6830	4331
37	Jhajjar	Matanhail	Chuchakwas	76.5112	28.5980	9636
38	Jhajjar	Beri	Bigoa	76.4280	28.6570	3096
39	Jind	Julana	Rojhala	76.6051	29.365	4546
40	Jind	Uchana	Baroda	76.2184	29.4311	7081
41	Jind	Narwana	Mohal khera	76.1256	29.6262	3414
42	Jind	Jind	Kishanpura	76.3345	29.2953	3065
43	Jind	Jind	Chhabri	76.4510	29.2640	4734

44	Jind	Julana	Julana	76.4049	29.1318	5340
45	Jind	Jind	Dorana	76.4722	29.5276	4836
46	Jind	Uchana	Khatkaran	76.2450	29.4030	4836
47	Kaithal	Kaithal	Jakholi	76.4290	29.6580	3405
48	Kaithal	Rajound	Kithana	76.3930	29.5460	5420
49	Kaithal	kalayat	Kalayat	76.2528	29.6792	3230
50	Kaithal	kalayat	Simla	76.2149	29.6348	3521
51	Kaithal	gulha	Padla	76.3000	30.1000	3432
52	Karnal	Assandh	Khnada Kheri	76.6442	29.5637	6256
53	Mahendragarh	Narnaul	Narnaul(Hot Spot)	76.1066	28.0501	5365
54	Mahendragarh	Mahendragarh	Khatodra	76.0900	28.2820	4269
55	Mewat	Punhana	Gulalta	77.1790	27.9170	6080
56	Mewat	Nagina	Nagina	76.9830	27.9170	10090
57	Mewat	Nuh	Akaira	77.0040	28.0080	5610
58	Mewat	Nuh	Malab	77.0110	28.0420	6190
59	Mewat	Nuh	Indri	77.1003	28.1892	4680
60	Mewat	Nuh	Kheri Kankar	77.0708	28.1874	6250
61	Palwal	Palwal	Baghola	77.3080	28.2210	7184
62	Palwal	Palwal	Lalwa	77.4040	28.1380	3160
63	Palwal	Hathin	Mandkola	77.1801	28.1346	4301
64	Palwal	Hodal	Tumsara	77.3420	28.0080	5798
65	Palwal	Hathin	Lakhnakha	77.1880	28.0350	7941
66	Palwal	Hathin	Kot	77.2290	27.9580	9281
67	Palwal	Hodal	Hodal	77.3500	27.8830	4502
68	Palwal	Hathin	Jaindapur	77.2390	28.2040	3881
69	Palwal	Hathin	Hathin	77.2420	28.0460	7440
70	Palwal	Palwal	Theraka	77.4331	28.1253	4334
71	Panipat	Israna	Israna	76.8454	29.2735	3805
72	Panipat	Israna	puthar	76.8720	29.2230	3480
73	Panipat	Madlauda	Untala	76.8490	29.3940	3406
74	Panipat	Madlauda	Lohari	76.8390	29.3583	5471
75	Rewari	Rewari	Sangwari	76.6836	28.1637	4471
76	Rewari	Bawal	Bawal	76.5794	28.0734	4191
77	Rewari	Bawal	Balawas	76.5290	28.1040	4648
78	Rewari	Khol	Chimnawas	76.4983	28.2143	7820
79	Rewari	Rewari	Guriani	76.5400	28.3560	3182
80	Rewari	Kosli	Lukhi	76.3625	28.3859	3180
81	Rohtak	Maham	Madina	76.4339	28.9390	3961
82	Rohtak	Maham	Maham	76.2946	29.9640	3540
83	Rohtak	Maham	Nidhana	76.3740	29.0114	3198
84	Rohtak	Rohtak	Samargopalpur	76.5130	28.9640	10121
85	Sirsa	Odhan	Taruana	75.0080	29.8250	4500
86	Sirsa	Baragudha	Shergarh	74.6760	29.9260	6000
87	Sonipat	Kathura	Ahulana	76.6400	29.1100	3374
88	Sonipat	Kahtura	Bhunderi	76.6142	29.1001	3034
89	Sonipat	Kharkhoda	Rohat	76.9710	28.9360	3501
90	Sonipat	Kharkhoda	Farmana	76.8125	28.9815	3280
91	Sonipat	Mundlana	Mundlana	76.7628	29.2080	4481
92	Sonipat	Gohana	Khanpur kalan	76.7960	29.1510	3771
93	Sonipat	Sonipat	Barwasni	76.9590	29.4180	4380
94	Sonipat	Sonipat	Bohela	76.8540	29.0800	8080
95	Sonipat	Gohana	Bichpuri	76.6629	29.2024	3881
96	Sonipat	Rai	Janti Khurd	77.1514	28.8491	3623

Annexure II

Locations having Chloride > 1000 mg/L in Ground Water in Different Districts of Haryana State

Sr. No.	District	Block	Location	Long	Lat	Cl > 1000 mg/L
1	Bhiwani	Bhiwani	Bamla	76.2450	28.8070	1250
2	Bhiwani	Bhiwani	Tigrana	76.1500	28.8420	1008
3	Faridabad	Ballabgarh	Sikri	77.2879	28.2755	1858
4	Faridabad	Ballabgarh	Ferozpur Kalan	77.2380	28.3030	3346
5	Faridabad	Faridabad	CGWB CHQ, NH-IV	77.3140	28.4180	1177
6	Faridabad	Ballabgarh	Ballabgarh	77.3350	28.3470	1049
7	Faridabad	Faridabad	Pali	77.2440	28.3810	2694
8	Gurugram	Gurugram	Jhanjrola	77.0040	28.4830	1127
9	Gurugram	Farukhnagar	Sewari	76.7230	28.4630	3230
10	Gurugram	Farukhnagar	Machana	76.7500	28.4080	3190
11	Gurugram	Pataudi	Mauzabad	76.6900	28.2970	2769
12	Hisar	Agroha	Karnoh	75.7570	29.3730	1434
13	Hisar	Narnaud	Kapro	76.1130	29.3790	1661
14	Jhajjar	Beri	Chamanpura	76.6340	28.6910	3233
15	Jhajjar	Bahadurgarh	Dulhera	76.7880	28.6460	1432
16	Jhajjar	Salahwas	Subnah	76.5710	28.4820	1368
17	Jhajjar	Matanhail	Chuchakwas	76.5112	28.5980	2198
18	Jind	Uchana	Baroda	76.2184	29.4311	1404
19	Jind	Uchana	Khatkaran	76.2450	29.4030	1248
20	Mahendragarh	Narnaul	Narnaul(Hot Spot)	76.1066	28.0501	1157
21	Mahendragarh	Mahendragarh	Khatodra	76.0900	28.2820	1314
22	Mewat	Punhana	Gulalta	77.1790	27.9170	1640
23	Mewat	Nagina	Nagina	76.9830	27.9170	1947
24	Mewat	Nuh	Akaira	77.0040	28.0080	1478
25	Mewat	Nuh	Malab	77.0110	28.0420	1564
26	Mewat	Nuh	Indri	77.1003	28.1892	1234
27	Mewat	Nuh	Kheri Kankar	77.0708	28.1874	1648
28	Palwal	Palwal	Baghola	77.3080	28.2210	1787
29	Palwal	Hodal	Tumsara	77.3420	28.0080	1659
30	Palwal	Hathin	Lakhnakha	77.1880	28.0350	2099
31	Palwal	Hathin	Kot	77.2290	27.9580	2637
32	Palwal	Hodal	Hodal	77.3500	27.8830	1290
33	Palwal	Hathin	Hathin	77.2420	28.0460	2145
34	Rewari	Rewari	Sangwari	76.6836	28.1637	1198
35	Rewari	Bawal	Balawas	76.5290	28.1040	1108
36	Rewari	Khol	Chimnawas	76.4983	28.2143	2396
37	Rohtak	Rohtak	Samargopalpur	76.5130	28.9640	1787
38	Sirsa	Odhan	Taruana	75.0080	29.8250	1392
39	Sirsa	Baragudha	Shergarh	74.6760	29.9260	1839
40	Sonipat	Sonipat	Bohela	76.8540	29.0800	1659

Annexure-III

Locations having Fluoride > 1.5 mg/L in Ground Water in Different Districts of Haryana State

Sr. No.	District	Block	Location	Long	Lat	F > 1.5 mg/L
1	Bhiwani	Bhawani Khera	Dhanana	76.1680	28.9380	1.60
2	Bhiwani	Bhiwani	Tigrana	76.1500	28.8420	1.60
3	Bhiwani	Dadri - I	Loharwala	76.3600	28.6290	22.00
4	Bhiwani	Bhiwani	Haluwas	76.1670	28.7330	10.00
5	Bhiwani	Bhiwani	Hetampura	75.9880	28.6990	8.00
6	Bhiwani	Tosham	Pataudi	75.8080	28.7970	6.10
7	Bhiwani	Tosham	Tosham	75.9170	28.8750	2.10
8	Fatehabad	Tohana	Tohana	75.8960	29.7040	1.90
9	Fatehabad	Fatehabad	Dariyapur	75.3539	29.5204	4.90
10	Gurugram	Pataudi	Noorgarh	76.6808	28.3561	1.80
11	Gurugram	Gurugram	Wazirpur	76.9165	28.4210	1.60
12	Hisar	Hansi	Umra	75.9130	29.0530	1.60
13	Hisar	Hisar - II	Balsmand	75.5000	29.3390	2.00
14	Hisar	Agroha	Kuleri	75.6600	29.3610	2.20
15	Hisar	Adampur	Adampur	75.4920	29.2780	5.10
16	Hisar	Agroha	Karnoh	75.7570	29.3730	5.20
17	Hisar	Barwala	Barwala	75.9170	29.3870	5.40
18	Hisar	Narnaud	Kapro	76.1130	29.3790	7.20
19	Jhajjar	Salahwas	Salahwas	76.4693	28.4500	5.50
20	Jhajjar	Matanhail	Chuchakwas	76.5112	28.5980	4.81
21	Jhajjar	Beri	Bigoa	76.4280	28.6570	1.91
22	Jind	Uchana	Uchana	76.4874	29.4774	14.52
23	Jind	Narwana	Mohal khera	76.1256	29.6262	1.68
24	Jind	Pilukhera	Pilukhera	76.4970	29.3540	2.52
25	Jind	Safidon	Lochap	76.4340	29.3540	3.01
26	Jind	Julana	Jhamula	76.3390	29.1404	2.00
27	Jind	Safidon	Bhuslana	76.7494	29.4533	3.51
28	Jind	Uchana	Khatkaran	76.2450	29.4030	1.58
29	Kaithal	kalayat	Simla	76.2149	29.6348	2.17
30	Kaithal	Kaithal	Mundri	76.5060	29.7750	2.69
31	Karnal	Assandh	Khnada Kheri	76.6442	29.5637	2.41
32	Mahendragarh	Mahendragarh	DeroliAhir	76.1417	28.1694	2.70
33	Mahendragarh	Kanina	KheriTalwana	76.2368	28.3700	4.00
34	Palwal	Hodal	Acheja	77.4670	28.0460	1.98
35	Palwal	Hodal	Pirgadi	77.4720	28.0440	1.72
36	Palwal	Hodal	Hassanpur	77.4900	27.9700	1.89
37	Panipat	Madlauda	Urlana Kalan	76.6940	29.3440	2.20
38	Panipat	Samalkha	Patti kalyana	76.6772	28.8450	1.57
39	Panipat	Panipat	Khalila Prahladpur	76.9730	29.2900	2.07
40	Panipat	Madlauda	Atawala	76.7401	29.3321	16.00
41	Panipat	Israna	Khalila Majra	76.7746	29.2985	2.87
42	Rewari	Rewari	Masani	76.7270	28.2050	3.10
43	Rewari	Rewari	Sangwari	76.6836	28.1637	1.80

44	Rewari	Rewari	Rohliwas	76.5080	28.2420	2.60
45	Rewari	Kosli	Lukhi	76.3625	28.3859	3.20
46	Sirsa	Jodhka	Jodhaka	75.2220	29.4970	1.80
47	Sirsa	Odhan	Mithari	74.9830	29.8500	1.70
48	Sirsa	Dabwali	Dabwali	74.7380	29.9540	8.80
49	Sirsa	Dabwali	Masitan	74.7200	29.8860	2.50
50	Sirsa	Rania	Dariya Wala	74.8900	29.6160	7.00
51	Sonipat	Mundlana	Mundlana	76.7628	29.2080	1.52

Annexure-IV

Locations having Nitrate > 45 mg/L in Ground Water in Different Districts of Haryana State

Sr. No.	District	Block	Location	Long	Lat	NO_3 > 45 mg/L
1	Bhiwani	Dadri - I	Boond Kalan	76.3670	28.7810	280
2	Bhiwani	Bhiwani	Manheru	76.2170	28.7030	310
3	Bhiwani	Badhra	Atela	76.1060	28.5780	95
4	Bhiwani	Dadri - I	Mehrana	76.3260	28.5550	56
5	Bhiwani	Dadri - I	Imlota	76.4530	28.6080	68
6	Bhiwani	Kairu	Lohali	76.0460	28.7000	424
7	Bhiwani	Loharu	Singhani	75.8000	28.5330	177
8	Bhiwani	Tosham	Miran	75.7420	28.8490	443
9	Bhiwani	Kairu	Isharwal	75.7080	28.7670	280
10	Faridabad	Ballabgarh	Kabulpur	77.4390	28.3940	108
11	Faridabad	Ballabgarh	Ballabgarh	77.3350	28.3470	161
12	Faridabad	Faridabad	Pali	77.2440	28.3810	307
13	Faridabad	Ballabgarh	Chhainsa	77.3166	28.3393	60
14	Fatehabad	Bhuna	Nahla	75.7420	29.4380	61
15	Fatehabad	Ratia	Aharwan	75.5420	29.6080	99
16	Fatehabad	Tohana	Talwara	75.8060	29.7880	52
17	Gurugram	Pataudhi	Kasan(Hot spot)1	76.9060	28.3570	110
18	Gurugram	Pataudi	Khorikalan	76.8830	28.2160	110
19	Gurugram	Pataudi	Halley mandi	76.7611	28.3450	110
20	Hisar	Agroha	Agroha	75.6230	29.3250	70
21	Hisar	Hisar - I	Dhansu	75.4920	29.2780	915
22	Jhajjar	Bahadurgarh	Kulasi	76.9100	28.7740	215
23	Jhajjar	Bahadurgarh	Dulhera	76.7880	28.6460	57
24	Jhajjar	Matanhail	Chuchakwas	76.5112	28.5980	84
25	Jhajjar	Beri	Majra Dubhaldhan	76.4850	28.6873	114
26	Jhajjar	Beri	Bigoa	76.4280	28.6570	161
27	Jind	Narwana	Dhandoli	0.0000	0.0000	55
28	Jind	Uchana	Ghaso Khurd	76.4340	29.3540	108
29	Jind	Uchana	Khatkaran	76.2450	29.4030	55
30	Kaithal	kalayat	Kalayat	76.2528	29.6792	117
31	Mahendragarh	Kanina	KaninaKhas	76.3080	28.3380	100
32	Mahendragarh	Kanina	RattaKalan	76.2874	28.1894	110
33	Mahendragarh	Narnaul	Narnaul(Hot Spot)	76.1066	28.0501	520
34	Mahendragarh	Mahendragarh	Buchawas	76.2158	28.2982	110
35	Mewat	Punhana	Sikarwa	77.1440	27.9540	48
36	Mewat	Punhana	Gulalta	77.1790	27.9170	231
37	Mewat	Nagina	Nagina	76.9830	27.9170	127
38	Mewat	Nuh	Malab	77.0110	28.0420	109
39	Palwal	Palwal	Baghola	77.3080	28.2210	692
40	Palwal	Hathin	Mandkola	77.1801	28.1346	300
41	Palwal	Palwal	Pelak	77.4260	28.1560	60

42	Palwal	Hathin	Jaindapur	77.2390	28.2040	68
43	Palwal	Palwal	Theraka	77.4331	28.1253	67
44	Palwal	Palwal	Rasulpur	77.3983	28.0867	114
45	Panchkula	Pinjore	Chandi Mandir	76.8610	30.6940	48
46	Panchkula	Raipur Rani	Kakar Majra	77.0250	30.4920	204
47	Panipat	Madlauda	Urlana Kalan	76.6940	29.3440	69
48	Panipat	Madlauda	Lohari	76.8390	29.3583	85
49	Rewari	Rewari	Sangwari	76.6836	28.1637	67
50	Rewari	Bawal	Bawal	76.5794	28.0734	940
51	Rewari	Bawal	Balawas	76.5290	28.1040	450
52	Rewari	Khol	Chimnawas	76.4983	28.2143	170
53	Rewari	Rewari	Guriani	76.5400	28.3560	110
54	Rewari	Khol	Mandola	76.3621	28.2260	90
55	Rewari	Khol	Nangal Jamalpur	76.3350	28.1790	110
56	Rewari	Nahar	Bahu	76.3210	28.4530	150
57	Rohtak	Rohtak	Kansla	76.7837	28.8920	71
58	Rohtak	Maham	Madina	76.4339	28.9390	173
59	Rohtak	Maham	Maham	76.2946	29.9640	194
60	Rohtak	Maham	Nidhana	76.3740	29.0114	68
61	Rohtak	Lakahan Majra	Lakhanmajra	76.4776	29.0460	86
62	Rohtak	Rohtak	Kharawar	76.6772	28.8452	89
63	Sirsa	Odhan	Mithari	74.9830	29.8500	150
64	Sirsa	Dabwali	Dabwali	74.7380	29.9540	109
65	Sirsa	Odhan	Taruana	75.0080	29.8250	54
66	Sirsa	Dabwali	Mangiana	74.8040	29.9210	54
67	Sirsa	Baragudha	Shergarh	74.6760	29.9260	63
68	Sirsa	Dabwali	Sakta Khera	74.6360	29.8920	144
69	Sirsa	Rania	Dariya Wala	74.8900	29.6160	111
70	Sonipat	Gohana	Gohana	76.6834	29.1296	61
71	Sonipat	Murthal	Murthal	77.0846	29.0355	112
72	Sonipat	Rai	Rasoi	77.1100	28.9000	72
73	Sonipat	Rai	Rai	77.1000	28.9200	51
74	Sonipat	Rai	Mahara	77.0420	28.8620	50
75	Sonipat	Sonipat	Bohela	76.8540	29.0800	397
76	Sonipat	Gohana	Bichpuri	76.6629	29.2024	132

Annexure-V

Locations Having Iron > 1.0 mg/L in Ground Water in Different Districts of Haryana State

Sr. No.	District	Block	Location	Long	Lat	F > 1.0 mg/L
1	Bhiwani	Bhawani Khera	Dhanana	76.1680	28.9380	2.290
2	Bhiwani	Bhiwani	Tigrana	76.1500	28.8420	3.420
3	Hisar	Agroha	Kanoh	75.7570	29.3730	1.777
4	Jhajjar	Bahadurgarh	Chhara	76.7130	28.6960	1.044
5	Jhajjar	Beri	Majra Dubaldhan	76.4850	28.6873	12.220
6	Kaithal	kalayat	Kalayat	76.2528	29.6792	1.158
7	Panchkula	Pinjore	Bhoriyan	76.9380	30.7790	1.102
8	Sonipat	Rai	Rai	77.1000	28.9200	1.693
9	Sonipat	Kharkhoda	Rohat-2	76.9695	28.9321	4.196
10	Sonipat		Janti Khurd	77.1549	28.8456	5.990

Annexure-VI

Locations Having Arsenic > 0.01 mg/L (>10 ppb) in Ground Water in Different Districts of Haryana State

S. No	District	Block	Location	Longitude	Latitude	As > 0.01 mg/L (>10ppb)
1	Kaithal		Pyoda	76.4040	29.7794	12.889
2	Karnal	Chorkarsa	Chorkarsa	76.6740	29.6280	10.957
3	Karnal	Assandh	Kurlan	76.7434	29.5554	12.796
4	Rewari	Rewari	Rohliwas	76.5080	28.2420	15.276
5	Sirsa	Dabwali	Dabwali	74.7380	29.9540	148.779
6	Sonipat	Kathura	Kathura	76.5360	29.0730	16.640
7	Sonipat	Gohana	Khanpur Kalan-2	76.8121	29.1464	11.849

Annexure-VII

Locations Having Uranium >0.03 mg/L (>30ppb) in Ground Water in Different Districts of Haryana State

S. No.	District	Block	Location	Longitude	Latitude	U > 0.03 mg/L (>30ppb)
1	Bhiwani	Bhawani Khera	Dhanana	76.1680	28.9380	47.021
2	Bhiwani	Dadri - I	Loharwala	76.3600	28.6290	34.219
3	Bhiwani	Bhiwani	Badala-3	76.2540	28.7570	32.431
4	Faridabad	Ballabgarh	Tigaon	77.3900	28.3470	50.353
5	Faridabad	Ballabgarh	Ballabgarh(Hot spot 1)	77.3350	28.3470	53.902
6	Faridabad	Ballabgarh	Ballabgarh(Hot spot 4)	77.2944	28.3496	32.780
7	Fatehabad	Ratia	Aharwan	75.5420	29.6080	33.860
8	Fatehabad		Dariyapur			43.462
9	Fatehabad	Fatehabad	Badopal-2	75.5500	29.4460	75.444
10	Fatehabad	Tohana	Tohana-1	75.8960	29.7040	234.576
11	Gurgaon	Pataudhi	Kasan(Hot spot)2	76.9110	28.3560	71.425
12	Hisar	Barwala	Barwala	75.9170	29.3870	37.112
13	Hisar	Narnaud	Kapro	76.1130	29.3790	231.263
14	Hisar	Hansi	Sorkhi	76.1090	29.0580	51.145
15	Hisar	Hisar	Balawas-1	75.8220	28.9580	42.312
16	Hisar	Hansi	Khanda Kheri-1	76.2330	29.2090	45.503
17	Hisar	Narnaud	Moth Majra-1	76.0960	29.2080	34.543
18	Hisar	Narnaud	Kheri Jalab-1	76.0830	29.3420	35.918
19	Hisar	Barwala	Gianpura-1	76.0230	29.3500	72.350
20	Hisar	Hisar	Hisar-1	75.7220	29.1400	88.986
21	Jhajjar	Bahadurgarh	Gubana-1	76.8305	28.6233	31.396
22	Jhajjar	Bahadurgarh	Gubana-3	76.8548	28.6002	30.834
23	Jhajjar	Bahadurgarh	Gubana-4	78.8635	28.3201	67.709
24	Jhajjar	Beri	Wazirpur	76.5697	28.6820	30.736
25	Jhajjar	Matanhail	Chhuchhakwas	76.5112	28.5980	39.653
26	Jhajjar	Beri	Bigoa	76.4280	28.6570	49.096
27	Jhajjar	Beri	Bigoa-1	76.4564	28.6670	30.402
28	Jind	Safidon	Rojhla	76.6052	29.3647	52.400
29	Jind	Safidon	Rojhla -1	76.6152	29.3370	52.534
30	Jind	Safidon	Rojhla-2	76.5957	29.3653	34.963
31	Jind	Safidon	Rojhla-3	76.6129	29.3786	35.308
32	Jind	Uchana	Baroda-1	76.2182	29.4366	51.335
33	Jind	Uchana	Baroda-2	76.2120	29.4372	36.264
34	Jind	Uchana	Uchana	76.4875	29.4774	165.548
35	Jind	Jind	Narwana	76.1097	29.5938	30.524
36	Jind	Narwana	Mohal Khera	76.1257	29.6263	44.216
37	Jind	Jind	Kishanpura	76.3345	21.2953	30.744
38	Jind	Jind	Chhabri	76.4510	29.2640	35.274
39	Jind	Pilukhera	Pilukhera	76.4970	29.3540	35.215
40	Jind	Jind	Lochab-1	76.4096	29.3445	46.853
41	Jind	Jind	Lochab-3	76.4462	29.3604	108.025
42	Jind	Jind	Lochab-4	76.4589	29.3606	36.908
43	Jind	Julan	Julana	76.4049	29.1318	42.132
44	Jind	Julan	Julana-2	76.3778	29.1293	33.810
45	Jind	Julana	Jhamula	76.3390	29.1404	30.977
46	Jind	Alewa	Alewa-1	76.4498	29.4891	52.631
47	Jind	Alewa	Alewa-2	76.4601	29.4670	31.967

48	Jind	Alewa	Alewa-3	76.4564	29.4563	30.276
49	Jind	Alewa	Alewa-4	76.4402	29.4591	30.068
50	Jind	Safidon	Bhuslana	76.7494	29.4533	110.469
51	Jind	Safidon	Bhuslana-2	76.7680	29.4390	30.048
52	Jind	Safidon	Bhuslana-3	76.7415	29.4565	34.929
53	Jind	Alewa	Dorana-1	76.4790	29.5210	44.555
54	Jind	Alewa	Dorana-2	76.4749	29.5355	100.685
55	Jind	Alewa	Dorana-3	76.4654	29.8333	46.427
56	Jind	Alewa	Dorana-4	76.4600	29.5254	39.043
57	Jind	Uchana	Khatkaran	76.2450	29.4030	130.149
58	Jind	Uchana	Khatkaran-2	76.2669	29.3833	355.223
59	Jind	Uchana	Khatkaran-3	76.2439	29.4031	48.072
60	Jind	Uchana	Khatkaran-4	76.2266	29.4204	38.322
61	Kaithal	Pundri	Pundri	76.5750	29.7780	30.187
62	Kaithal	Pundri	Pai	76.5256	29.7009	52.029
63	Kaithal	Pundri	Barsana	76.5985	29.7171	48.549
64	Kaithal	Pundri	Sirsal	76.3940	29.805	47.747
65	Kaithal	Pundri	Bhana	76.5180	29.6700	45.361
66	Kaithal		Pyoda	76.4040	29.7794	54.207
67	Kaithal	Kalayat	Matour	76.2580	29.6080	56.256
68	Kaithal	Pundri	Korar	76.5441	29.6547	39.892
69	Kaithal	Kalayat	Simla	76.2149	29.6348	30.311
70	Kaithal	Kaithal	Kelram	76.3645	29.7016	31.045
71	Kaithal	Gulha	Padla	76.3000	30.1000	46.005
72	Kaithal	Kaithal	Guhna	76.2610	29.7660	30.362
73	Kaithal	Gulha	Khanpur	76.3720	29.8510	35.356
74	Kaithal	Kaithal	Siwan	76.3540	29.8830	31.032
75	Kaithal		Balhera	76.3946	30.0248	63.725
76	Kaithal		Keorak			30.873
77	Kaithal	Pundri	Jajanpur			41.132
78	Kaithal	Kalayat	Matour			52.067
79	Kaithal	Kalayat	Matour			101.294
80	Kaithal	Gulha	Padla			34.383
81	Kaithal	Gulha	Padla			49.934
82	Kaithal	Gulha	Padla			39.172
83	Kaithal	Gulha	Padla			31.389
84	Kaithal	kaithal	Manaspatti			92.422
85	Kaithal	Gulha	Khanpur			35.912
86	Kaithal	Gulha	Khanpur			36.276
87	Kaithal	Kaithal	Siwan			32.269
88	Kaithal		Balhera			55.297
89	Kaithal		Balhera			59.192
90	Karnal	Indri	Dhumsi	77.0356	29.9346	32.548
91	Karnal	Gharaunda	Balhera	76.9940	29.7040	39.744
92	Karnal	Nalvi Kalan	Nalvi Kalan	77.0990	29.6940	31.411
93	Karnal	Sheikhpura	Sheikhpura	77.0170	29.7170	71.765
94	Karnal	Sambli	Sambli	76.8000	29.7580	34.427
95	Karnal	Majra Roran	Majra Roran	76.7290	29.7880	63.473
96	Karnal	Amupur Chakda	Amupur Chakda	76.7410	29.7740	33.888
97	Karnal	Chochra	Chochra	76.6303	29.6337	39.158
98	Karnal	Mundh	Mundh	76.5374	29.5112	42.966
99	Karnal		Khanda Kheri			53.786
100	Karnal	Gangatheri	Gangatheri	76.5040	29.4780	51.286
101	Karnal	Assandh	Jabhala	76.6630	29.5559	48.495
102	Karnal	Assandh	Jalwana	76.7099	29.5918	47.069
103	Karnal	Karnal	Jundla	76.8670	29.6430	45.928
104	Karnal	Karnal	Kheri Naru	76.9830	29.6930	39.088
105	Karnal	Mundh	Mundh			39.262

106	Karnal	Mundh	Mundh			70.559
107	Karnal	Mundh	Mundh			68.241
108	Karnal	Gangatheri	Gangatheri			30.681
109	Karnal	Gangatheri	Gangatheri			55.197
110	Karnal	Gangatheri	Gangatheri			32.272
111	Kurukshertra	Pehowa	Bodhni			37.296
112	Kurukshertra	Pehowa	Bodhni			36.287
113	Kurukshertra	Pehowa	Thana			66.627
114	Kurukshertra	Pehowa	Thana			35.762
115	Kurukshertra	Pehowa	Thana			46.115
116	Kurukshertra	Thanesar	Umri			51.103
117	Kurukshertra	Thanesar	Umri			36.165
118	Kurukshetra	Thanesar	Ban	77.0752	29.9940	47.229
119	Kurukshetra	Ladwa	Dabkhera	76.7540	30.0010	42.541
120	Kurukshetra	Thanesar	Umri	76.9061	29.9461	64.043
121	Kurukshetra	Kurukshetra	Kaulapur	76.8960	30.0250	38.377
122	Kurukshetra		Malik Sinhpura			30.055
123	Kurukshetra	Kurukshetra	Buhawa			31.376
124	Kurukshetra	Pehowa	Ishaque	76.4920	30.0170	31.156
125	Kurukshetra	Pehowa	Thana	76.5010	29.9200	42.628
126	Mahendragarh	Narnaul 2	Narnaul(Hot Spot)	76.1141	28.0480	38.015
127	Mewat	Nagina	Nagina	76.9830	27.9170	38.642
128	Mewat	Taoru	Sehsaula	77.4420	28.2359	41.280
129	Palwal	Palwal	Palwal	77.3250	28.1500	31.859
130	Palwal	Hodal	Hassanpur(Hot spot 1)	77.4900	27.9700	38.909
131	Palwal	Hathin	Lakhnakha(Hotspot2)	77.1692	28.0146	32.706
132	Palwal	Hathin	Lakhnakha(Hotspot4)	77.1787	28.0192	47.302
133	Palwal	Hathin	Kot(Hotspot 2)	77.2360	27.9632	39.338
134	Palwal	Hathin	Kot(Hotspot3)	77.2290	27.9580	30.504
135	Palwal	Hathin	Jaindapur(Hot spot)3	77.2105	28.2080	35.052
136	Palwal	Palwal	Jawan (Hotspot) 2	77.3894	28. 2387	106.689
137	Palwal	Palwal	Jawan (Hotspot) 5	77.3901	28.2260	34.768
138	Palwal	Palwal	Rasulpur(Hot spot 5)	77.3982	28.0864	115.848
139	Panipat	Mudlauda	Urlana Kala	76.6940	29.3440	36.406
140	Panipat	Mudlauda	Urlana Kala-2	76.6819	29.3433	45.989
141	Panipat	Israna	Israna	76.8454	29.2735	456.206
142	Panipat	Israna	Israna-1	76.8372	29.2699	103.444
143	Panipat	Israna	Israna-2	76.8488	29.2735	230.578
144	Panipat	Israna	Israna-3	76.8490	29.2635	48.223
145	Panipat	Israna	Israna-4	76.8427	29.2760	37.511
146	Panipat	Israna	Puthar	76.8720	29.2230	43.819
147	Panipat	Panipat	Nimbri	77.034	29.388	41.929
148	Panipat	Panipat	Nimbri-4	77.6210	29.3820	41.641
149	Panipat	Panipat	Khalila Prahladpur-2	76.7856	29.3147	38.348
150	Panipat	Panipat	Khalila Prahladpur-2	76.7533	29.2995	104.312
151	Panipat		Untala	76.8490	29.3940	39.490
152	Panipat		Untala-1	76.8415	29.4279	45.130
153	Panipat		Untala-2	76.8291	29.3922	43.138
154	Panipat		Untala-4	76.8453	29.3909	42.743
155	Panipat	Madlauda	Lohari	76.8390	29.3583	116.510
156	Panipat	Madlauda	Lohari-2	76.8508	29.3584	134.966
157	Panipat	Madlauda	Atawala-1	76.7734	29.3263	43.038
158	Panipat	Madlauda	Atawala-3	76.7316	29.3041	54.236
159	Panipat	Madlauda	Atawala-4	76.7204	29.3314	162.181
160	Rohtak	Rohatk	Kansala-4	76.7919	28.8754	39.264
161	Rohtak	Maham	Mahem-1	76.3126	28.9773	37.515
162	Rohtak	Maham	Mahem-4	76.3278	28.9530	35.440
163	Sirsa	Odhan	Mithari	74.9830	29.8500	127.779

164	Sirsa	Dabwali	Dabwali	74.7380	29.9540	113.708
165	Sirsa	Sirsa	Sirsa	75.0490	29.5360	103.685
166	Sirsa	Dabwali	Mangiana	74.8040	29.9210	42.034
167	Sirsa	Dabwali	Sakta Khera	74.6360	29.8920	95.286
168	Sirsa	Rania	Mamar Khera	74.6570	29.6720	42.185
169	Sirsa	Ellenabad	Srijeevan Nagar	74.7420	29.5380	34.995
170	Sirsa	Sirsa	Sirsa-2	75.0490	29.5360	30.186
171	Sirsa	Dabwali	Chautala-1	74.5170	29.7750	36.785
172	Sirsa	Dabwali	Teja Khera-1	74.5560	29.8440	30.428
173	Sonepat	Gohana	Bichpuri	76.6629	29.2024	76.249
174	Sonipat	Gohana	Jagssi	76.6650	29.2466	30.471
175	Sonipat	Gannaur	Bega	77.1090	29.1540	54.809
176	Sonipat	Kharkhoda	Rohat-4	76.9884	28.9470	202.302
177	Sonipat	Kharkhoda	Farmana	76.8125	28.9815	31.687
178	Sonipat	Gohana	Khanpur Kalan	76.7960	29.1510	35.448
179	Sonipat	Gohana	Khanpur Kalan-1	76.8258	29.1997	34.665
180	Sonipat	Mundlana	Chidana	76.7887	29.2133	39.023

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