CGWB, NWR, CHANDIGARH

Ground Water Quality in Shallow Aquifer of Punjab

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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 PUNJAB

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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

Geologically, the area in Punjab State is covered by Siwaliks and Alluvium deposits of Middle Miocene to Recent age. The Siwaliks (Middle Miocene to Pleistocene) form hilly tract running in northern and north-eastern part of the State and the alluvial deposits (Pleistocene to Recent) constitute the plains of Punjab. The Siwaliks are divided into three parts i.e lower, middle and upper Siwaliks on the basis of lithology and vertebrate fossils. The Siwalik formations have been folded and faulted due to tectonic activities.

Hydrogeologically the State can be divided into four units i.e.(i) Piedmont deposits occurring along a narrow belt along the Siwaliks, commonly known as “Kandi”; (ii) Alluvial plains; (iii) Aeolian deposits occurring in the south-western part of the State and (iv) an intermontanevalley at Anandpur Sahib of Ropar district. The alluvium is divided into newer alluvium occurring along active flood plains of rivers and older alluvium confined to abandoned flood plains.

These aquifers are laterally and vertically extensive and persistent in nature. However, in south western parts, the thickness of fresh water aquifer is much less as compared to the other parts because area is underlain by brackish / saline water. At places, the thickness of fresh water bearing aquifer is even less than 10 m.

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 PUNJAB

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 Punjab 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 **338** Groundwater Monitoring wells were monitored for water quality during June 2022 representing pre-monsoon water quality.

The summarized results of groundwater quality ranges are given in **Table - 6.1.**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 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	163	48.22
		Moderate	750- 2250	130	38.46
		Slightly mineralized	2251- 3000	19	5.62
		Highly mineralized	> 3000	26	7.70
2	Chloride mg/L	Desirable limit	< 250	301	89.05
		Permissible limit	251-1000	34	10.06
		Beyond permissible limit	> 1000	3	0.89

S. No	Parameters		Range	No. of sample	Percentage
3	Fluoride mg/L	Desirable limit	< 1.0	287	84.91
		Permissible limit	1.0 - 1.5	22	6.51
		Beyond permissible limit	>1.5	29	8.58
4	Nitrate mg/L	Permissible limit	< 45	273	80.77
		Beyond permissible limit	> 45	65	19.23

The groundwater samples collected from dug wells and hand pumps tapping phreatic aquifers are analyzed for all the major inorganic parameters. Based on the results, it is found that ground water of the state is mostly of calcium bicarbonate ($Ca\text{-}HCO_3$) type when the total dissolved solids of water is below 500 mg/L (corresponding to electrical conductance of 750 µS/cm at 25^0C). They are of mixed cations and mixed anion type when the electrical conductance is between 750 and 3000 µS/cm and waters with electrical conductance above 3000 µS/cm are of sodium chloride (Na-Cl) type. However, other types of water are also found among these general classifications, which may be due to the local variations in hydro-chemical environments due to anthropogenic activities. Nevertheless, occurrence of high concentrations of some water quality parameters such as salinity, chloride, fluoride, iron, arsenic and nitrate have been observed in some pockets in the state.

7.0 GROUND WATER QUALITY HOT SPOTS IN UNCONFINED AQUIFERS OF PUNJAB

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)

ELECTRICAL CONDUCTIVITY

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

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

Salinity always exists in ground water but in variable amounts. It is mostly influenced by aquifer material, solubility of minerals, duration of contact and factors such as the permeability of soil, drainage facilities, and quantity of rainfall and above all, the climate of the area. The salinity of groundwater in coastal areas in addition to the above may be due to air borne salts originating from air water interface over the sea and also due to over pumping of fresh water which overlays saline water in coastal aquifer systems.

BIS has recommended a drinking water standard for total dissolved solids a limit of 500 mg/L (corresponding to EC of about 750 µS/cm at 25^{0}C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000 µS/cm at 25^{0}C) in case of no alternate source. Water having TDS more than 2000 mg/L is not suitable for drinking purpose. In Fig 7.1.1, the EC values (in µS/cm at 25^{0}C) of ground water from observation/monitoring wells have been used to show distribution patterns of electrical conductivity in different ranges of suitability for drinking purposes

7.1 The EC value of ground waters in the State varies from 115 µS/cm to 8768 µS/cm at 25°C. Grouping water samples based on EC values, it is found that 48.2 % of them have EC less than 750, 44.1% have between 750 and 3000 and the remaining 7.7% of the samples have EC above 3000µS/cm.(Annexure-I) The Plate 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 in northern and central area of the State. Districts falling in different EC ranges are given in Table 2. The ground water occurring in the southern and southwestern parts comprising of mainly of Mukatsar and parts of Bhatinda, Faridkot, Fazilka, and Mansa districts is mostly saline and not suitable for drinking uses (Fig-2).

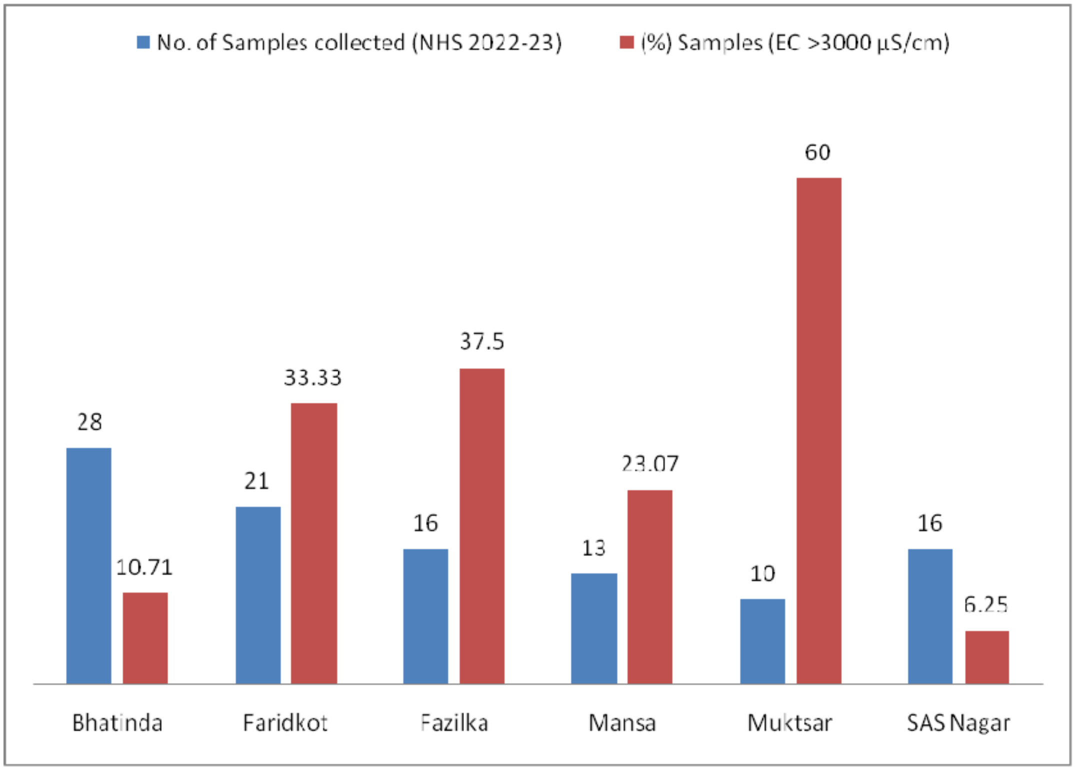
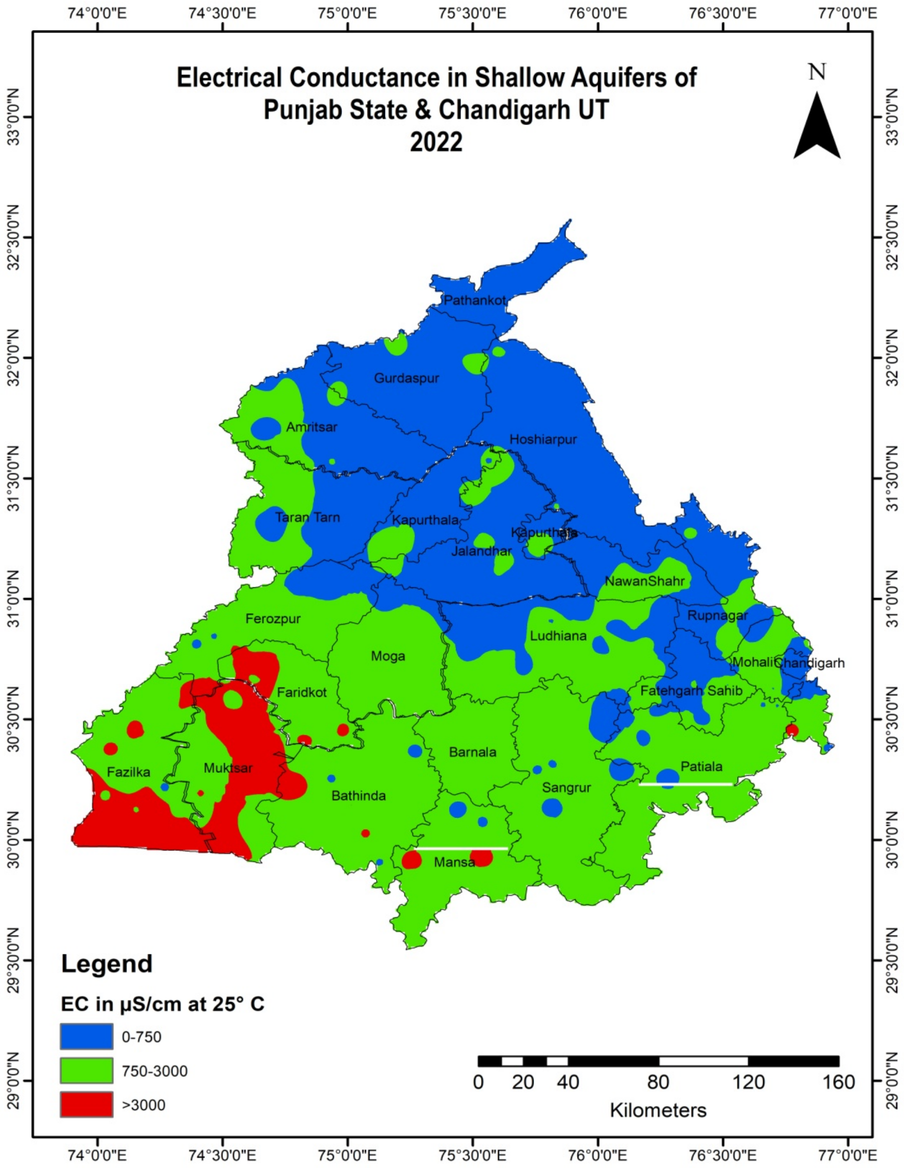


Fig 7.1.1 District-wise percentage of wells having EC >3000 µS/cm.

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

Sr. No	State and UT	No. of Samples collected (NHS 2022-23)	No. of Samples (EC >3000 µS/cm)	(%) Samples (EC >3000 µS/cm)
1	**Bhatinda**	28	3	10.71
2	**Faridkot**	21	7	33.33
3	**Fazilka**	16	6	37.50
4	**Mansa**	13	3	23.07
5	**Muktsar**	10	6	60
6	**SAS Nagar**	16	1	6.25
7	**Total**	104	26	25

Fig 7.1.2 Spatial distribution of Electrical Conductivity during June- 2022.



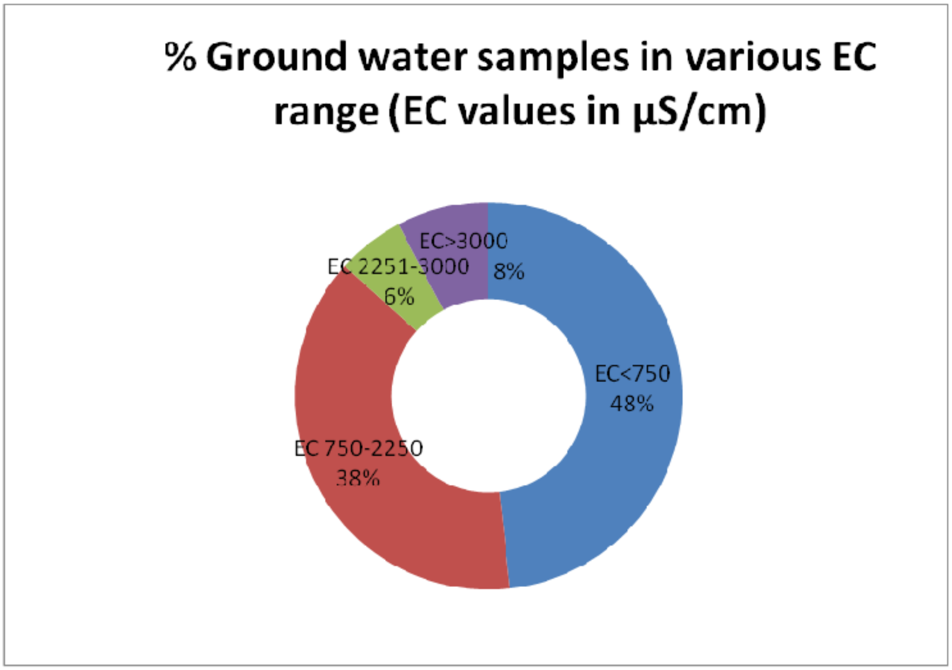


Fig 7.1.3 Percentage groundwater samples in various EC range of Punjab state

Table 7.1.2: Districts Affected by Salinity (High EC) in Groundwater in Punjab States of India.

S. No.	State	Parts of districts having EC > 3000 µS/cm.
1.	**Punjab**	**Bhatinda**
2.	**Punjab**	**Faridkot**
3.	**Punjab**	**Fazilka**
4.	**Punjab**	**Mansa**
5.	**Punjab**	**Muktsar**
6.	**Punjab**	**SAS Nagar**

Table 7.1.3: Comparative change in number of districts having EC > 3000 µS/cm in Punjab states.

S. No.	District	Nos. of districts having EC > 3000 µS/cm.		
		2015	**2022**	**Increase/Decrease**
1	**Amritsar**	0	0	0
2	**Barnala**	0	0	0
3	**Bhathinda**	3	3	0
4	**Faridkot**	4	7	+3
5	**Fatehgarh Sahib**	0	0	0
6	**Fazilka**	0	6	+6
7	**Firozepur**	7	0	-7
8	**Gurdaspur**	0	0	0
9	**Hoshiarpur**	0	0	0
10	**Jalandhar**	0	0	0
11	**Kapurthala**	0	0	0
12	**Ludhiana**	1	0	-1
13	**Mansa**	1	3	+2
14	**Moga**	1	0	-1
15	**Muktsar**	2	6	+4
16	**Nawanshahr**	0	0	0
17	**Pathankot**	0	0	0
18	**Patiala**	0	0	0
19	**Ropar**	0	0	0
20	**Sangrur**	1	0	-1
21	**SAS Nagar**	1	1	0
22	**Tarantaran**	0	0	0
	TOTAL	**21**	**26**	**+5**

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

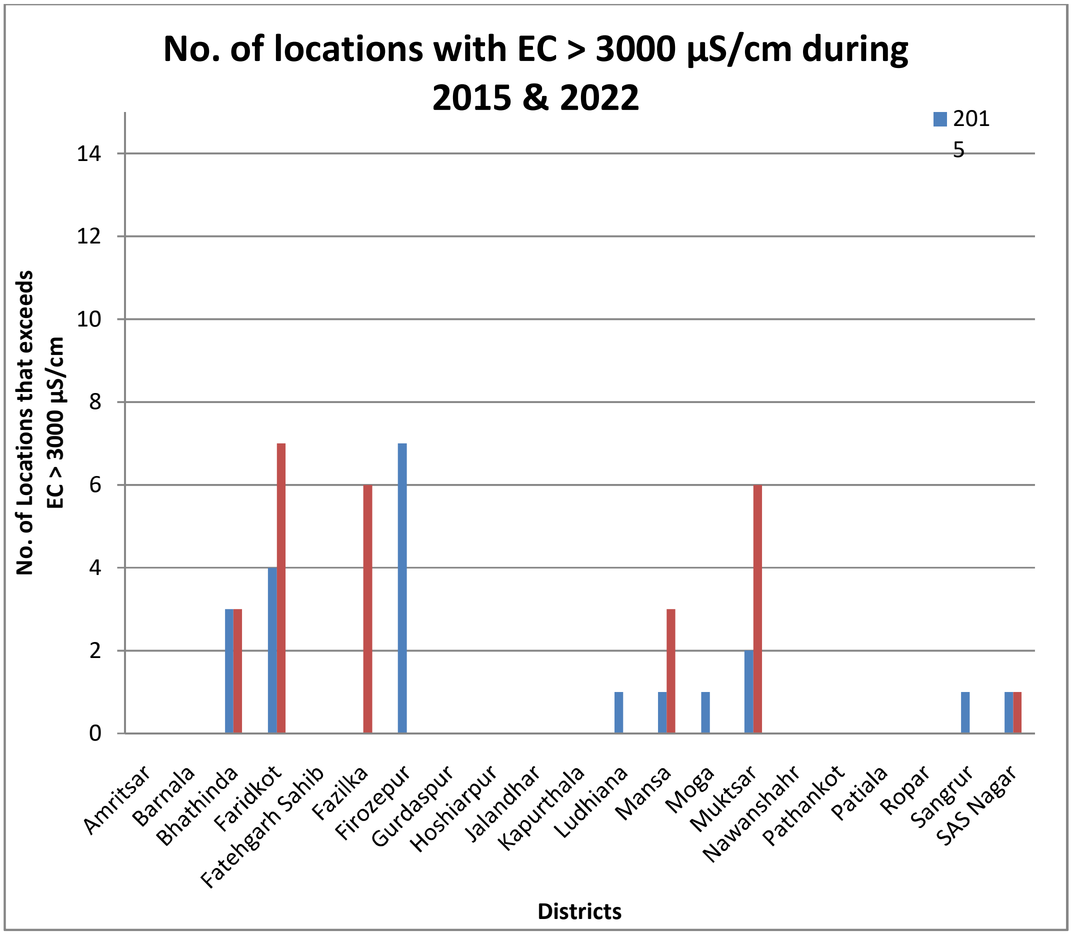


Fig. 7.1.4 Comparison on No of Locations exceed EC >3000 µS/cm during 2015 and 2022.

In comparison to 2015 (Table 7.1.3), it has been observed that the no. of districts having EC more than 3000 µS/cm in Punjab States has increased in 2022 by 0.30%.

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 Punjab is showing a slightly decreasing trend (Fig. 7.1.5). Trend on Electrical Conductivity in Faridkot district of Punjab shows (Fig 7.1.6 & 7.1.7) decreasing trend and of Muktsar district shows increasing 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
2017	281	7	32	11.4
2018	278	6	24	8.6
2019	302	7	24	7.9
2020	323	7	29	9.0
2021	330	6	26	7.9
2022	338	6	26	7.7

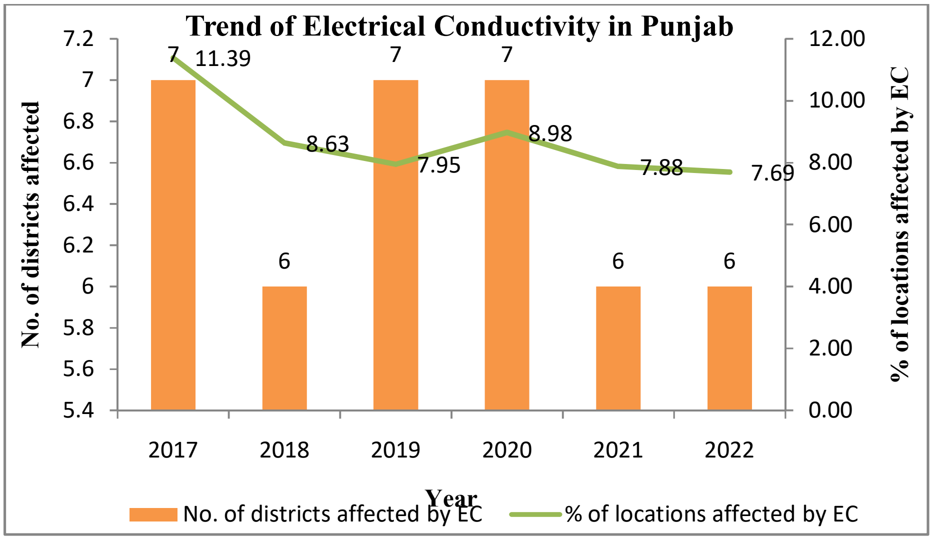


Fig. 7.1.5 Trend of Electrical Conductivity in Punjab

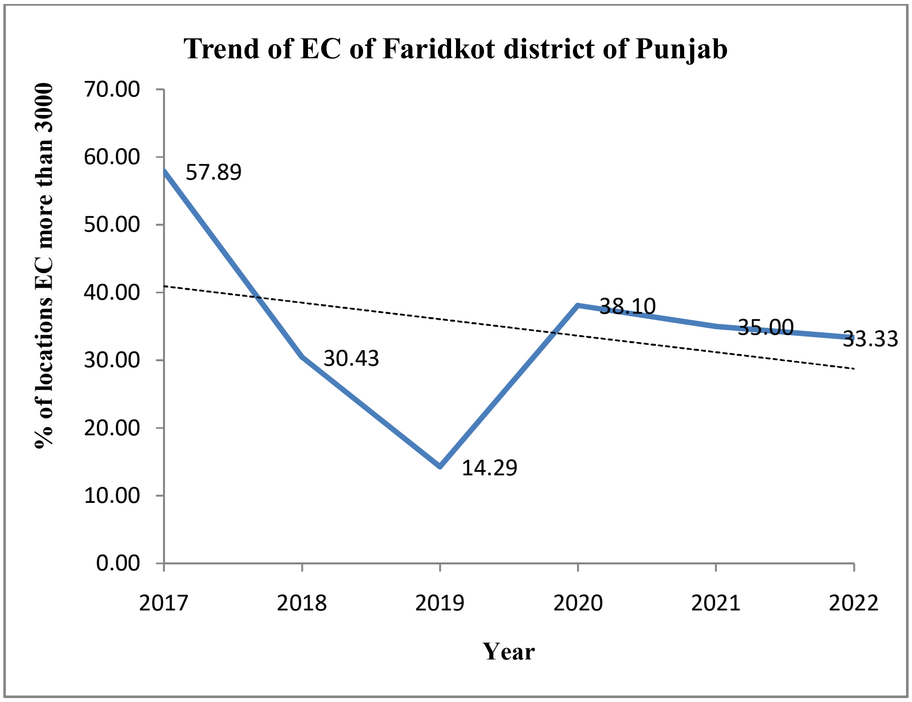


Fig. 7.1.6 Trend on Electrical Conductivity in Faridkot district for the period of 2017-2022

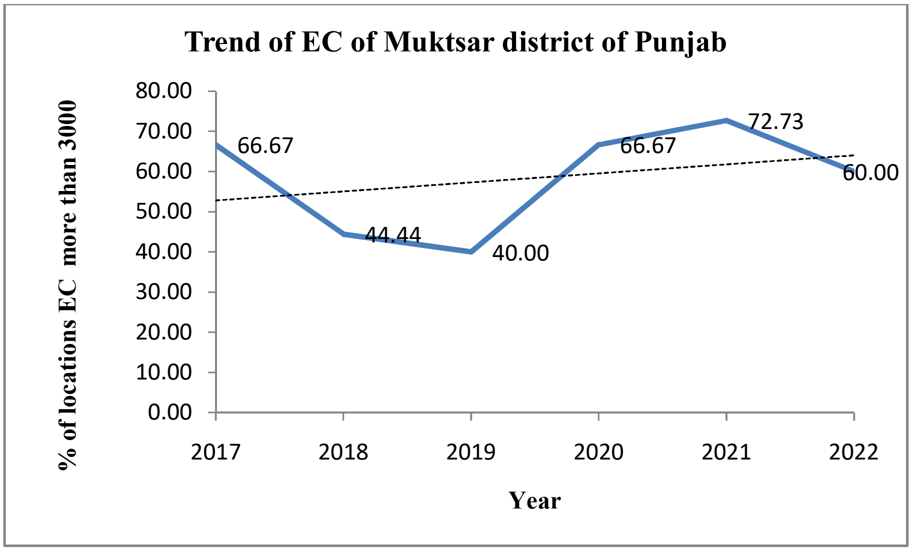


Fig. 7.1.7 Trend on Electrical Conductivity in Muktsar district for the period of 2017-2022

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.

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. It is apparent from the map that majority of the samples having chloride values less than 250 mg/L are found mostly in the states

Water with chloride ranging between 250 and 1000 mg/L falling under 'permissible' range are confined mostly to parts of Patiala,SAS Nagar,Fazilka,& Muktsar district of the State

Relatively high values of Chloride (>1000 mg/L) are observed in the. Mukatsar, , Fazilka, district. Table 7.2.1 shows the District wise list of districts affected by high chloride water (>1000 mg/L) and these areas are water quality hot spots from high chloride point of view.

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, State-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 State-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	Fazilka	16	1	6.25
2	Muktsar	10	2	20
	Total (India)	**26**	**3**	**11.54**

Fig 7.2.1 Spatial Distribution of Chloride during May 2022

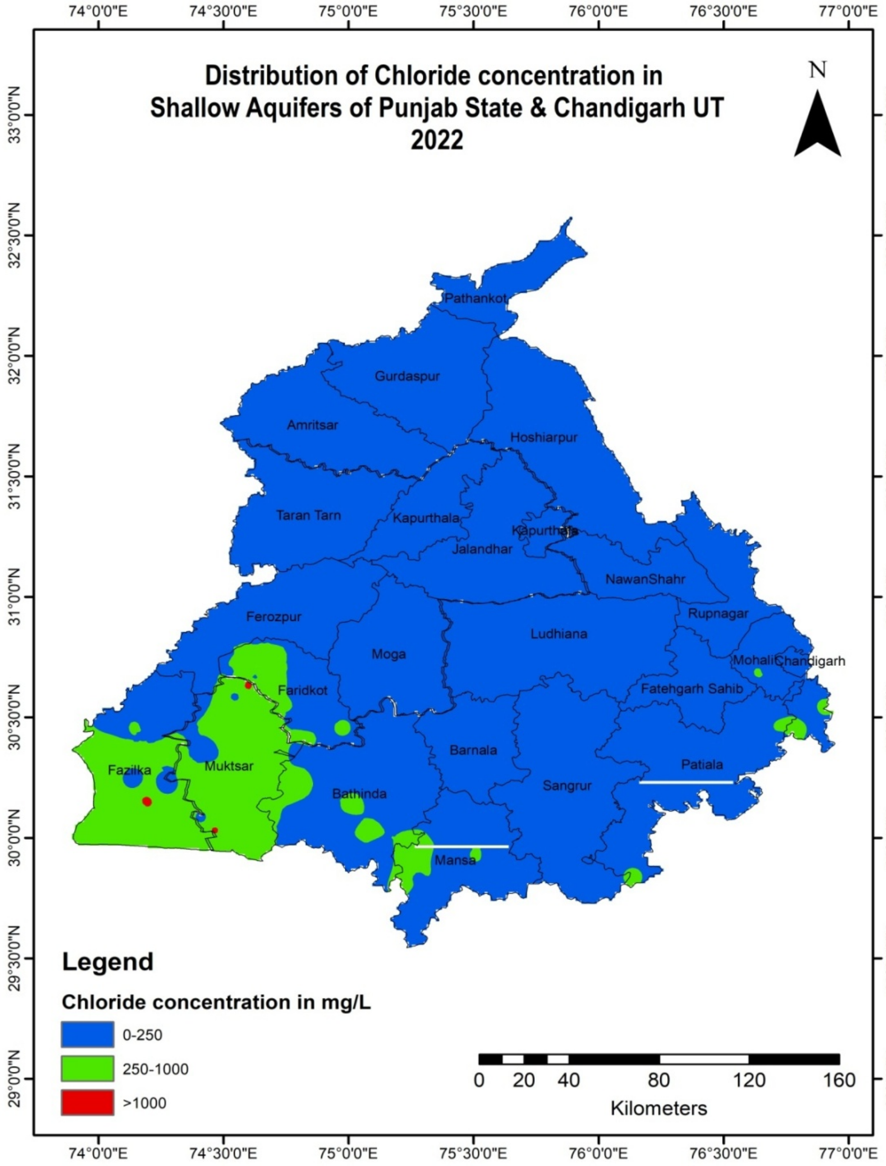


Table-7.2.2: Districts having Chloride concentration (more than 1000 mg/L) in Groundwater in India (NHS 2022-23)

S. No.	State	Parts of districts having Chloride > 1000 mg/L.
1.	**Punjab**	**Fazilka**
2.	**Punjab**	**Muktsar**

Table 7.1.3: Comparative change in number of districts having Chloride > 1000 mg/Lin Punjab states.

S. No.	District	Nos. of districts having Chloride > 1000mg/L.		
		2015	**2022**	**Increase/Decrease**
1	**Amritsar**	0	0	0
2	**Barnala**	0	0	0
3	**Bhathinda**	0	0	0
4	**Faridkot**	1	1	0
5	**Fatehgarh Sahib**	0	0	0
6	**Fazilka**	0	0	0
7	**Firozepur**	1	0	-1
8	**Gurdaspur**	0	0	0
9	**Hoshiarpur**	0	0	0
10	**Jalandhar**	0	0	0
11	**Kapurthala**	0	0	0
12	**Ludhiana**	0	0	0
13	**Mansa**	0	0	0
14	**Moga**	0	0	0
15	**Muktsar**	1	2	+1
16	**Nawanshahr**	0	0	0
17	**Pathankot**	0	0	0
18	**Patiala**	0	0	0
19	**Ropar**	0	0	0
20	**Sangrur**	0	0	0
21	**SAS Nagar**	1	0	-1

S. No.	**District**	**Nos. of districts having Chloride > 1000mg/L.**		
22	**Tarantaran**	0	0	0
	TOTAL	**4**	**3**	-1

In comparison to 2015, it has been observed that the no. of districts having chloride more than 1000 mg/L in various States has decreased in 2022 by 0.51 % (Table 7.2.3 & Fig.7.2.3). Which may be because of dilution in that particular area.

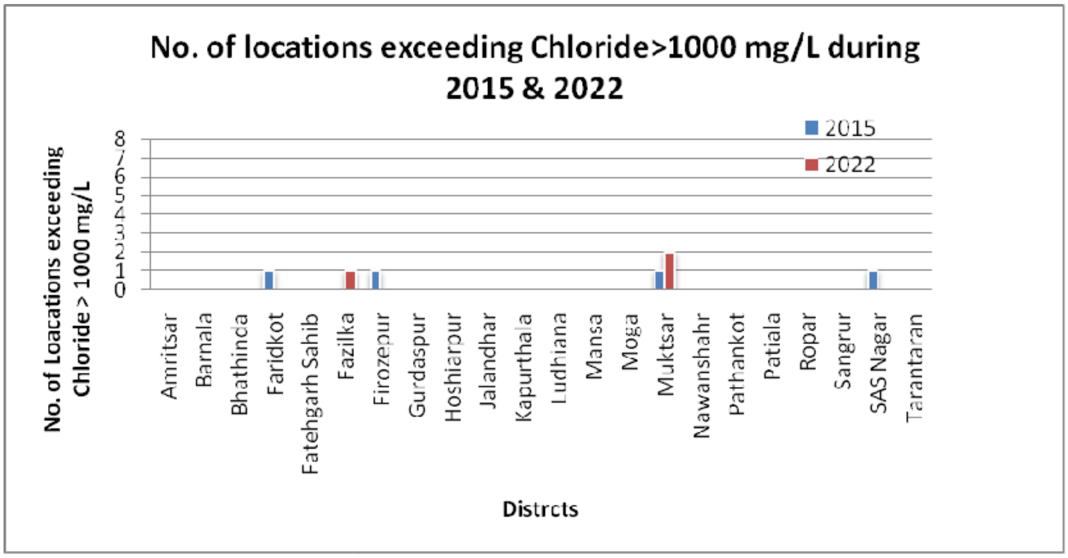


Fig. 7.2.3 Comparison on No of districts exceed Chloride >1000 mg/L during 2015 and 2022.

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 effect;
- 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. Water having fluoride concentration of more than 1.5 mg/L are not suitable for drinking purposes.

Fluoride in small amounts in drinking water is beneficial while in large amounts it is injurious. The fluoride content in ground water ranges from 0 to 9.00 mg/L. based on this recommendation, it is found that 84.9 % samples have fluoride in desirable range, 6.5 % in the permissible and the remaining 8.6% have fluoride above 1.50 mg/L. Map showing spatial distribution of fluoride contents in ground water (Fig-5) indicates that ground water in most parts of the State has desirable concentration of fluoride. Ground waters with fluoride above 1.50 mg/L are found mainly in Bathinda, Faridkot, Fazilka, Muktsar ,Mansa and Taran Taran districts It is worth mentioning that high fluoride waters are encountered in areas where agriculture activities are predominant. It indicates the possibility that fluoride has come from the phosphatic fertilizers, which have fluoride as impurity.

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 contour 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.

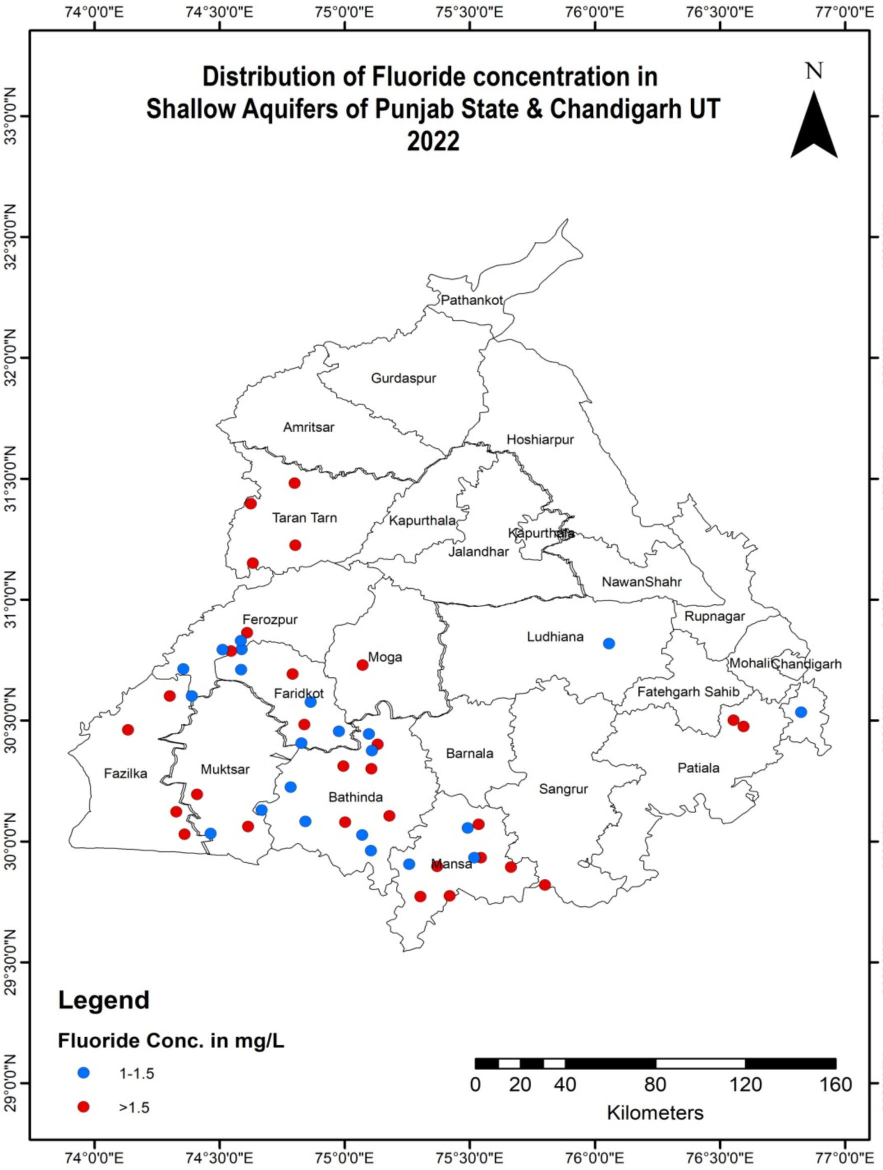


Fig 7.3.1 Locations having Fluoride concentration > 1.5 mg/L during May 2022.

Table 7.3.1 District wise percentage of wells having Fluoride >1.50mg/L

S. No	State and UT	No. of Samples collected (NHS 2022-23)	No. of Samples (F >1.50 mg/l)	% of Samples (F >1.50 mg/l)
1	**Bhathinda**	28	5	17.86
2	**Faridkot**	21	3	14.29
3	**Fazilka**	16	4	25.00
4	**Firozepur**	9	1	11.11
5	**Mansa**	13	6	46.15
6	**Moga**	8	1	12.50
7	**Muktsar**	10	2	20.00
8	**Patiala**	28	2	7.14
9	**Sangrur**	15	1	6.67
10	**Tarantaran**	14	4	28.57
	Total(India)	**162**	**29**	17.90

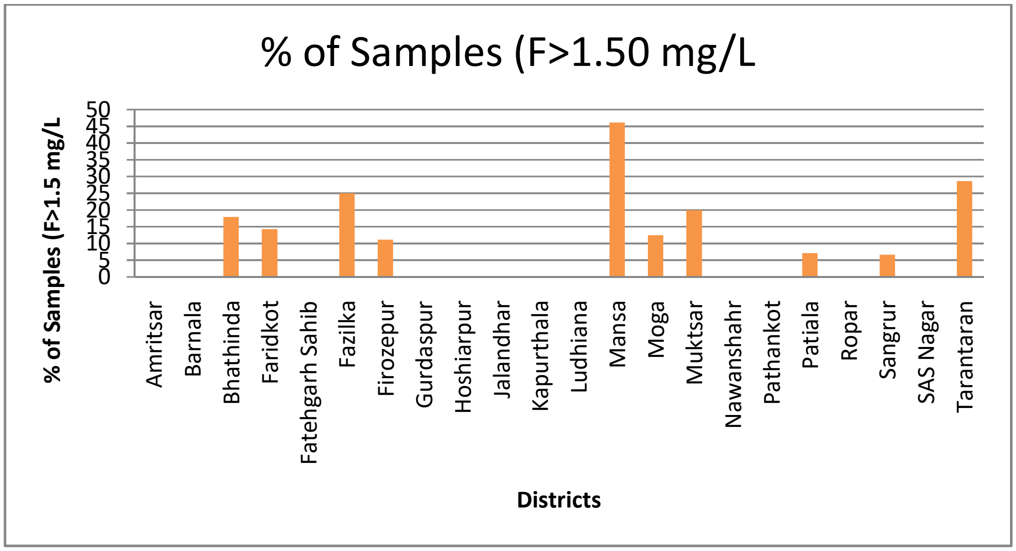


Fig 7.3.2 District-wise percentage of wells having fluoride >1.50 mg/L

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

Sl. No	State	Parts of Districts having F > 1.5mg/L
1.	**Punjab**	Bhathinda
2.	**Punjab**	Faridkot
3.	**Punjab**	Fazilka
4.	**Punjab**	Firozepur
5.	**Punjab**	Mansa
6.	**Punjab**	Moga
7.	**Punjab**	Muktsar
8.	**Punjab**	Patiala
9.	**Punjab**	Sangrur
10	**Punjab**	Tarantaran

Table-7.3.3: Comparative Change in number of Districts having F > 1.5 mg/L in various states.

S. No.	State	Nos. of districts having F> 1.50 mg/L.		
		2015	2022	Increase/Decrease
1	**Amritsar**	0	0	0
2	**Barnala**	0	0	0
3	**Bhathinda**	3	5	+2
4	**Faridkot**	2	3	+1
5	**Fatehgarh Sahib**	0	0	0
6	**Fazilka**	0	4	+4
7	**Firozepur**	8	1	-7
8	**Gurdaspur**	0	0	0
9	**Hoshiarpur**	0	0	0
10	**Jalandhar**	0	0	0
11	**Kapurthala**	0	0	0
12	**Ludhiana**	0	0	0
13	**Mansa**	3	6	+3
14	**Moga**	1	1	0
15	**Muktsar**	2	2	0

S. No.	State	Nos. of districts having F> 1.50 mg/L.		
16	**Nawanshahr**	0	0	0
17	**Pathankot**	0	0	0
18	**Patiala**	2	2	0
19	**Ropar**	0	0	0
20	**Sangrur**	3	1	-2
21	**SAS Nagar**	1	0	-1
22	**Tarantaran**	2	4	+2
	Total	**27**	**29**	**+2**

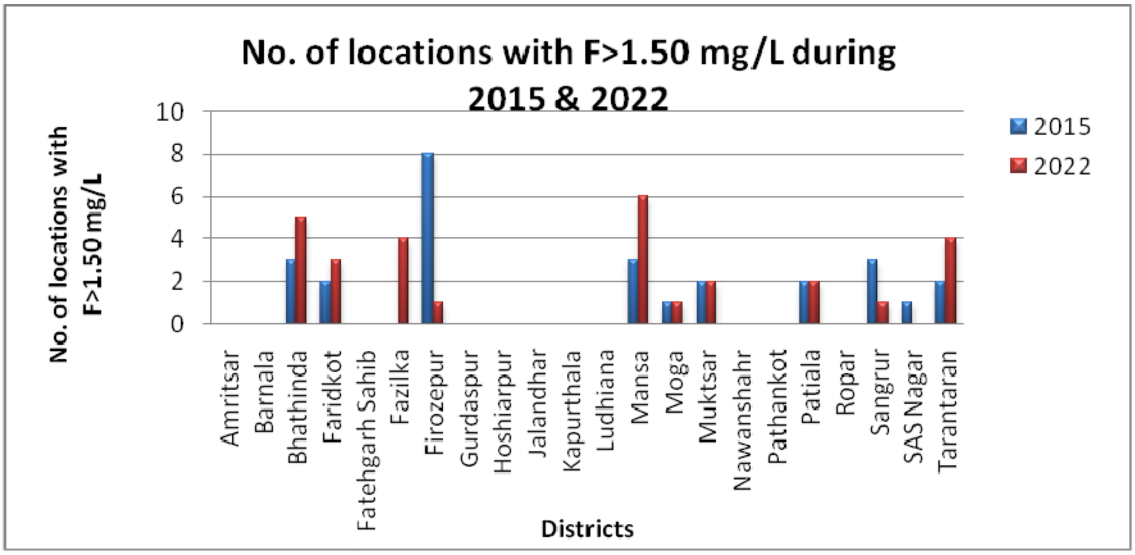


Fig 7.3.3 Comparison on No of districts exceed Fluoride >1.50 during 2015 and 2022

It has been observed (Table 7.3.3) that total number of districts affected by high fluoride in different States has increased by 0.93 % in 2022 as compared to the data available in 2015.

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 Mansa and Firozepur districts of Punjab Fig 7.3.6) & (Fig 7.3.7) show (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	281	9	30	10.7
2018	278	5	20	7.2
2019	302	11	31	10.3
2020	323	10	27	8.4
2021	330	12	29	8.8
2022	338	10	29	8.6

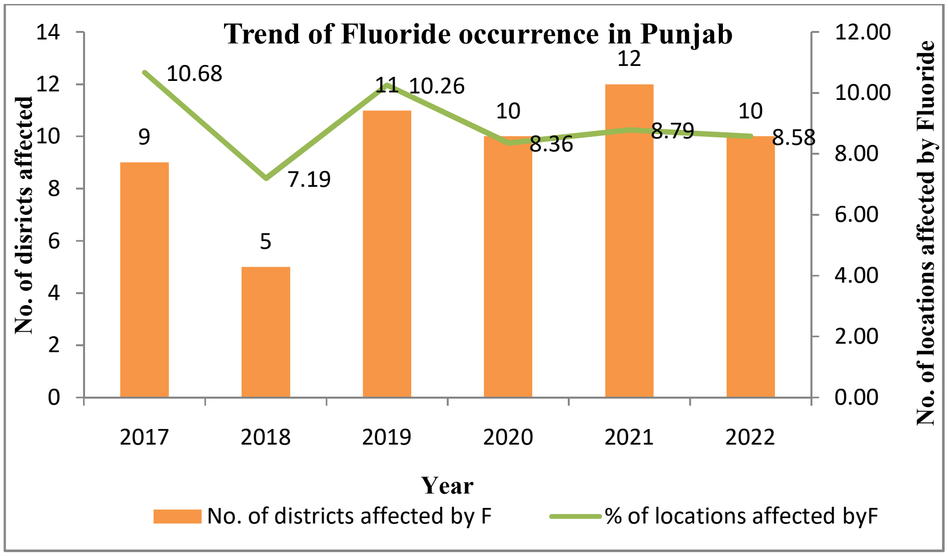


Fig. 7.3.4 Trend of Fluoride occurrence in Punjab

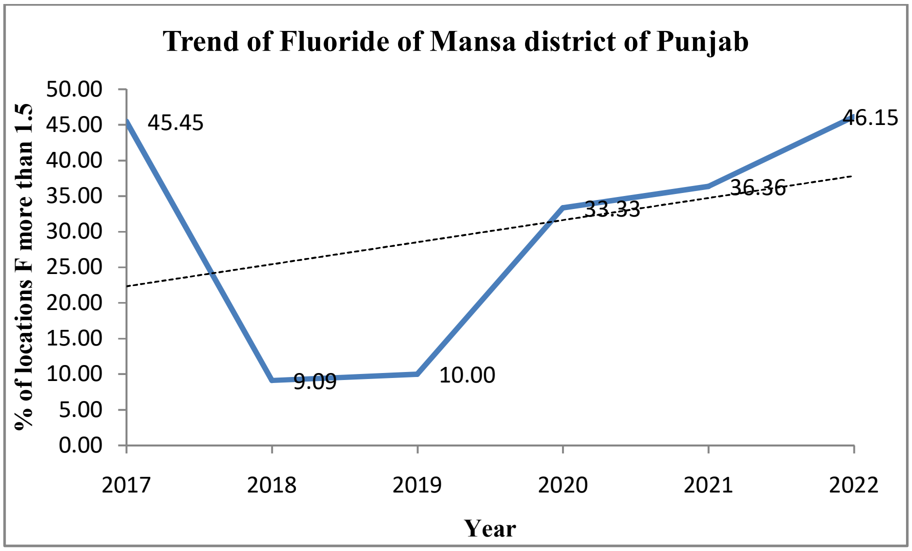


Fig 7.3.5 Trend on Fluoride Mansa district for the period of 2017-2022

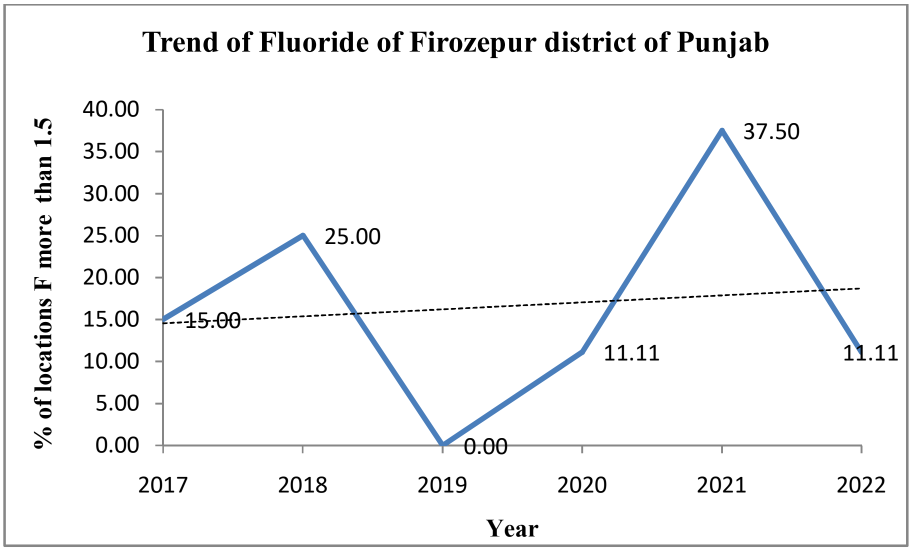


Fig 7.3.6 Trend on Fluoride in Firozepur district for the period of 2017-2022

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. Aluminium salts (eg. Alum), lime, Poly Aluminium Chloride, Poly Aluminium 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 Aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. It is opined that this technique is preferable at all levels because of the low price and ease of handling, is highly versatile and can be used in various scales from household level to community scale water supply.

The Nalgonda technique can be used for raw water having fluoride concentration between 1.5 and 20 mg/L and the total dissolved solids should be <1500 mg/L, and total hardness < 600 mg/L. The alkalinity of the water to be treated must be sufficient to ensure complete hydrolysis of alum added to it and to retain a minimum residual alkalinity of 1 - 2 meq/L in the treated water to achieve a pH of 6.5 - 8.5 in treated water. Several researchers have attempted to improve the technique by increasing the removal efficiency of fluoride using Poly Aluminium Chloride (PAC) and Poly Aluminium Hydroxy Sulphate (PAHS).

(c)Membrane techniques

Reverse osmosis, nanofiltration, dialysis and electro dialysis are physical methods that have been tested for 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 districts where nitrate has been found in excess of 45 mg/L in groundwater.

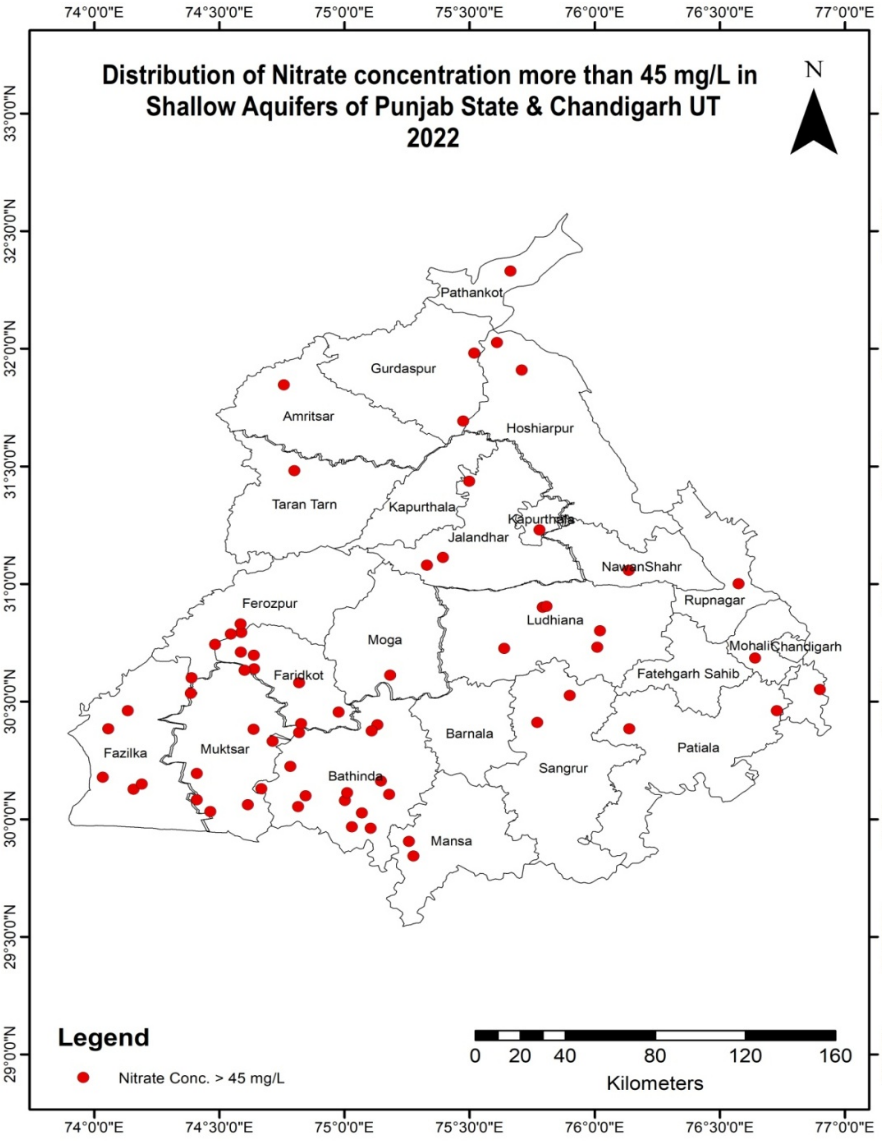


Fig 7.4.1 Locations having Nitrate concentration > 45 mg/L during 2022-23

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

S. No	State and UT	No. of Samples collected (NHS 2022-23)	No. of Samples (NO3 > 45 mg/L)	(%) Samples (NO3 > 45mg/L)
1	**Amritsar**	12	1	8.33
2	**Barnala**	3	0	0.00
3	**Bhathinda**	28	14	50.00
4	**Faridkot**	21	9	42.86
5	**Fatehgarh Sahib**	12	0	0.00
6	**Fazilka**	16	6	37.50
7	**Firozepur**	9	2	22.22
8	**Gurdaspur**	22	2	9.09
9	**Hoshiarpur**	30	2	6.67
10	**Jalandhar**	20	3	15.00
11	**Kapurthala**	8	1	12.50
12	**Ludhiana**	22	5	22.73
13	**Mansa**	13	2	15.38
14	**Moga**	8	1	12.50
15	**Muktsar**	10	7	70.00
16	**Nawanshahr**	6	1	16.67
17	**Pathankot**	14	1	7.14
18	**Patiala**	28	2	7.14
19	**Ropar**	11	1	9.09
20	**Sangrur**	15	2	13.33
21	**SAS Nagar**	16	2	12.50
22	**Tarantaran**	14	1	7.14
	Total (India)	**338**	**65**	**19.23**

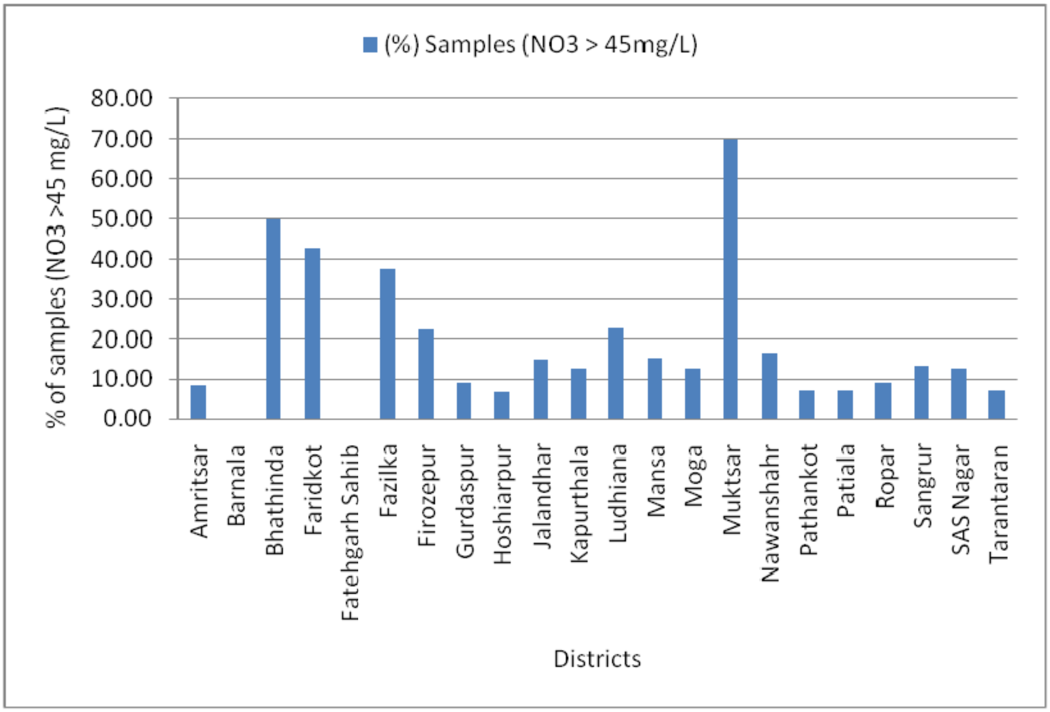


Fig 7.4.2 State-wise samples exceed Nitrate 45 mg/L (NHS 2022-23)

Table 7.4.2: List of Districts Showing Localized Occurrence of Nitrate (>45 mg/L) in Ground Water in Different States of India

Sl. No.	State	Parts of Districts having Nitrate > 45 mg/L
1.	Punjab	Amritsar
2.	Punjab	Bhatinda
3.	Punjab	Faridkot
4.	Punjab	Fazilka
5.	Punjab	Firozpur
6.	Punjab	Gurdaspur
7.	Punjab	Hoshiarpur
8.	Punjab	Jalandhar
9.	Punjab	Kapurthala
10.	Punjab	Ludhiana
11.	Punjab	Mansa
12.	Punjab	Moga
13.	Punjab	Muktsar

14.	Punjab	Nawanshahar
15.	Punjab	Pathankot
16.	Punjab	Patiala
17.	Punjab	Roper
18.	Punjab	Sangrur
19.	Punjab	SAS Nagar
20.	Punjab	Taran Taran

Table-7.4.3: Comparative Change in number of Districts having Nitrate > 45 mg/L in various states

S. No.	State	Nos. of districts having NO_3> 45 mg/L.		
		2015	2022	Increase/ Decrease
1	**Amritsar**	3	1	-2
2	**Barnala**	0	0	0
3	**Bhathinda**	16	14	-2
4	**Faridkot**	8	9	+1
5	**Fatehgarh Sahib**	1	0	-1
6	**Fazilka**	0	6	+6
7	**Firozepur**	13	2	-11
8	**Gurdaspur**	4	2	-2
9	**Hoshiarpur**	5	2	-3
10	**Jalandhar**	1	3	+2
11	**Kapurthala**	2	1	-1
12	**Ludhiana**	8	5	-3
13	**Mansa**	4	2	-2
14	**Moga**	2	1	-1
15	**Muktsar**	5	7	+2
16	**Nawanshahr**	1	1	0
17	**Pathankot**	1	1	0
18	**Patiala**	2	2	0
19	**Ropar**	3	1	-2
20	**Sangrur**	3	2	-1
21	**SAS Nagar**	4	2	-2
22	**Tarantaran**	1	1	0

S. No.	State	Nos. of districts having NO_3> 45 mg/L.		
	Total	**87**	**65**	**-22**

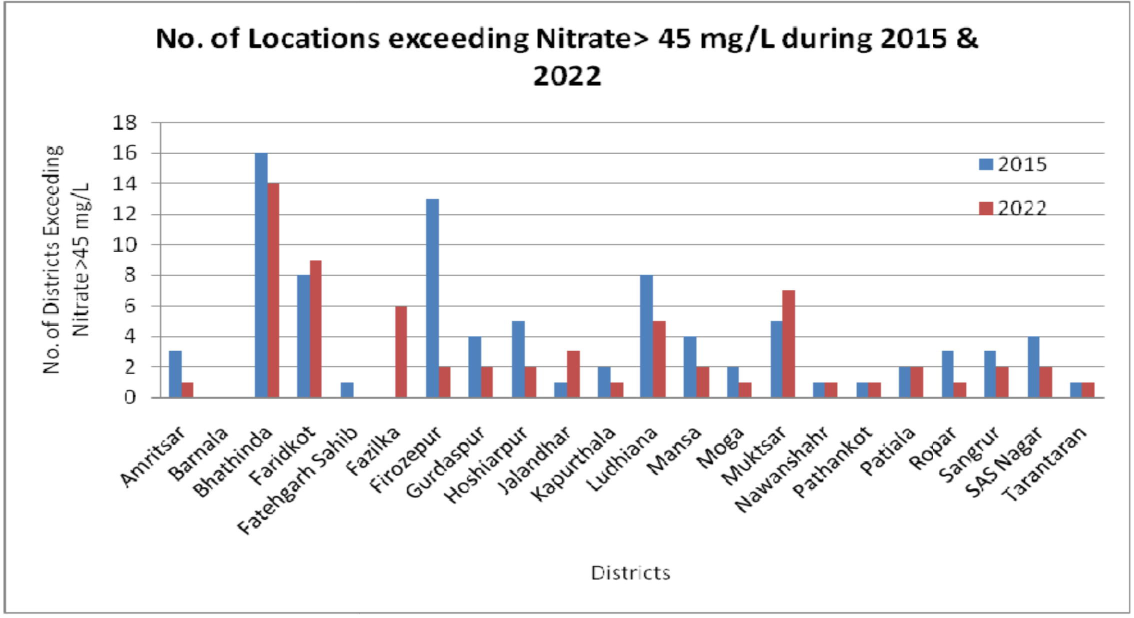


Fig. 7.4.3 Bar diagram comparing no. of Nitrate contaminated (45 mg/L) districts in various state during year 2015 and 2022

It has been observed (Table 7.4.3) that No. of districts in various States having high Nitrate (more than 45 mg/l) content in ground water has decreased by 7.18% 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 Bhatinda and Jalandhar districts of Punjab are shown (Fig 7.4.6 and 7.4.7) and show increasing 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	281	18	37	13.2
2018	278	7	16	5.8
2019	302	21	45	14.9
2020	323	19	100	31.0
2021	330	18	74	22.4
2022	338	20	65	19.2

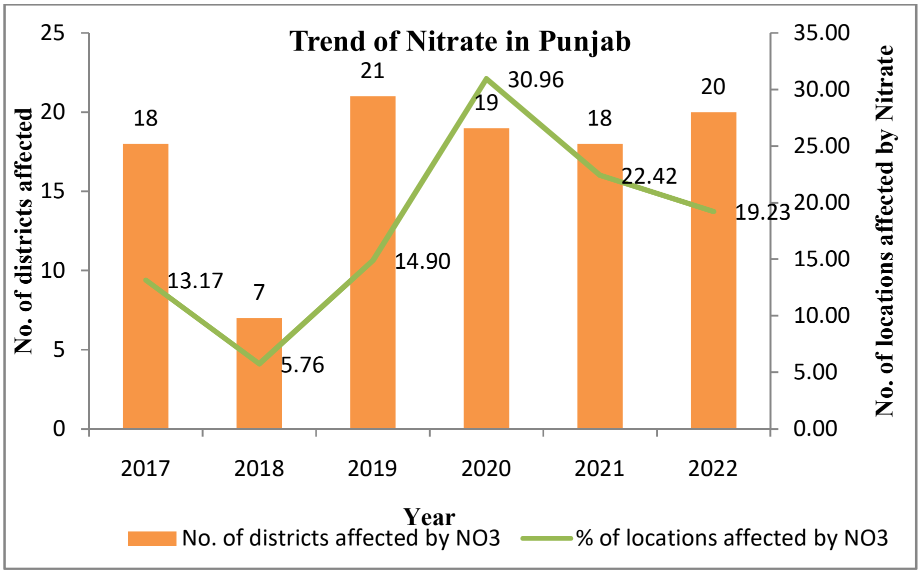


Fig. 7.4.4 Trend of Nitrate occurrence in Punjab

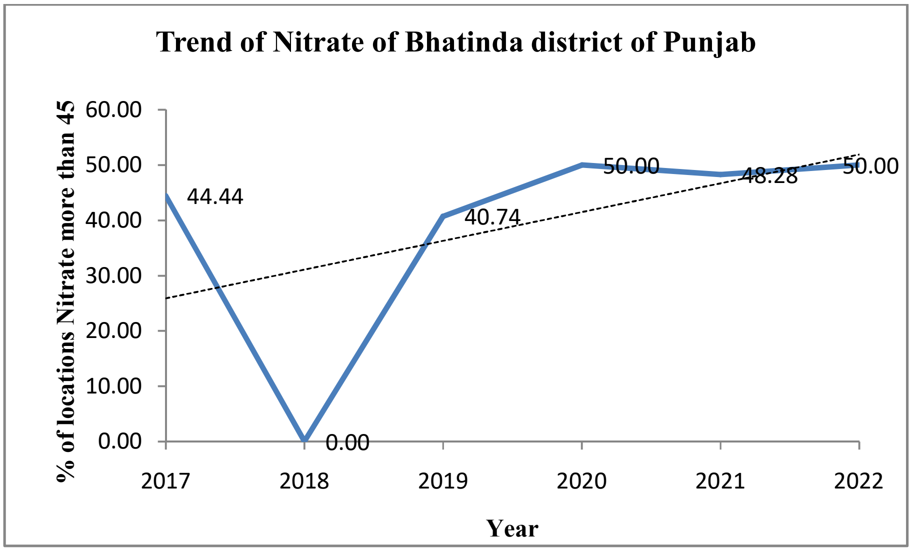


Fig 7.4.6 Trend on Nitrate in Bhatinda district for the period of 2017-2022

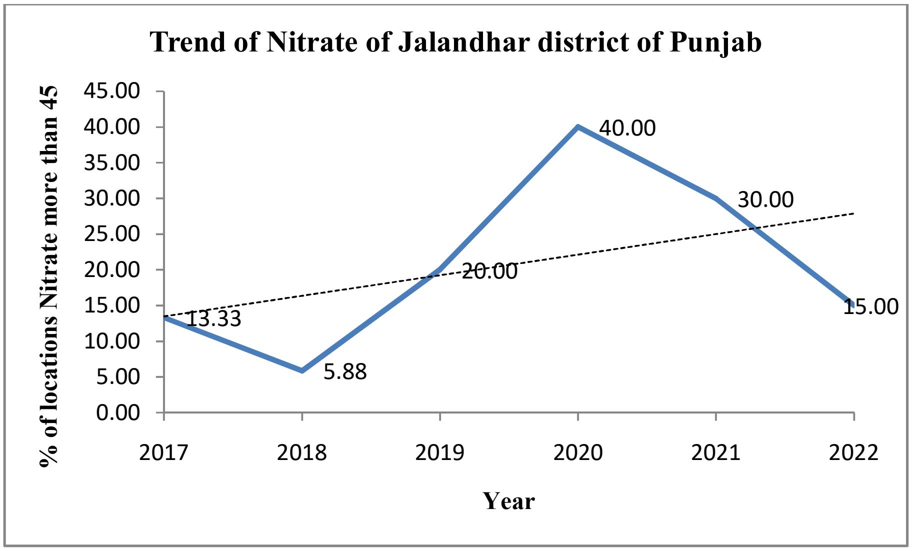


Fig 7.4.7 Trend on Nitrate in Jalandhar district for the period of 2017-2022

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 filtration which are commonly used forremovingmostofthe chemical pollutants such as fluoride, arsenic and heavy metals. According to King et al., 2012 nitrate treatment technologies can be classified in two categories in two categories, i.e. nitrate reduction and nitrate removal options. Nitrate removal technologies involve physical processes that does not necessarily involve any alteration of the chemical state of nitrate ions. Bio-chemical reduction options aim to reduce nitrate ions to other states of nitrogen, e.g. ammonia, or a more innocuous form as nitrogen gas. In-situ bioremediation is also effectively used in used in nitrate treatment 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.

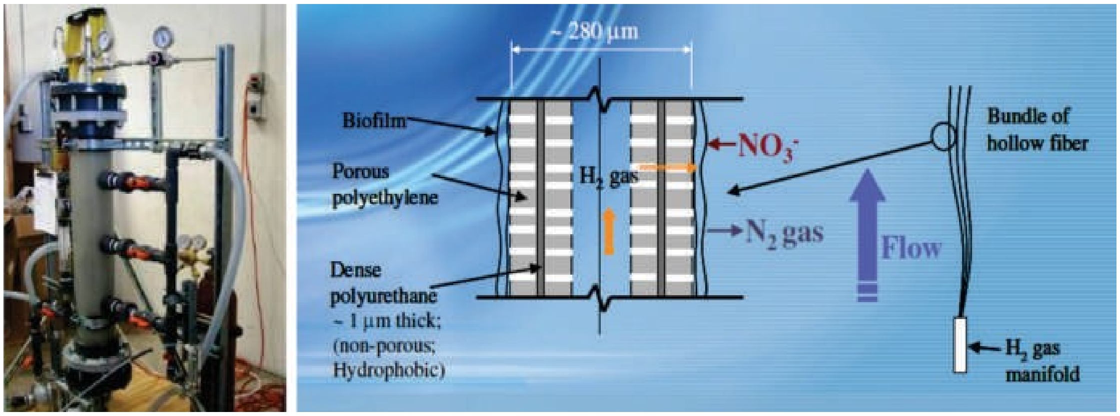


Fig. 7.4.8 Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

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 maps as point sources (Fig 7.5.1). It is based on the chemical analysis of water samples mostly collected from the groundwater observation wells/ springs/ 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.

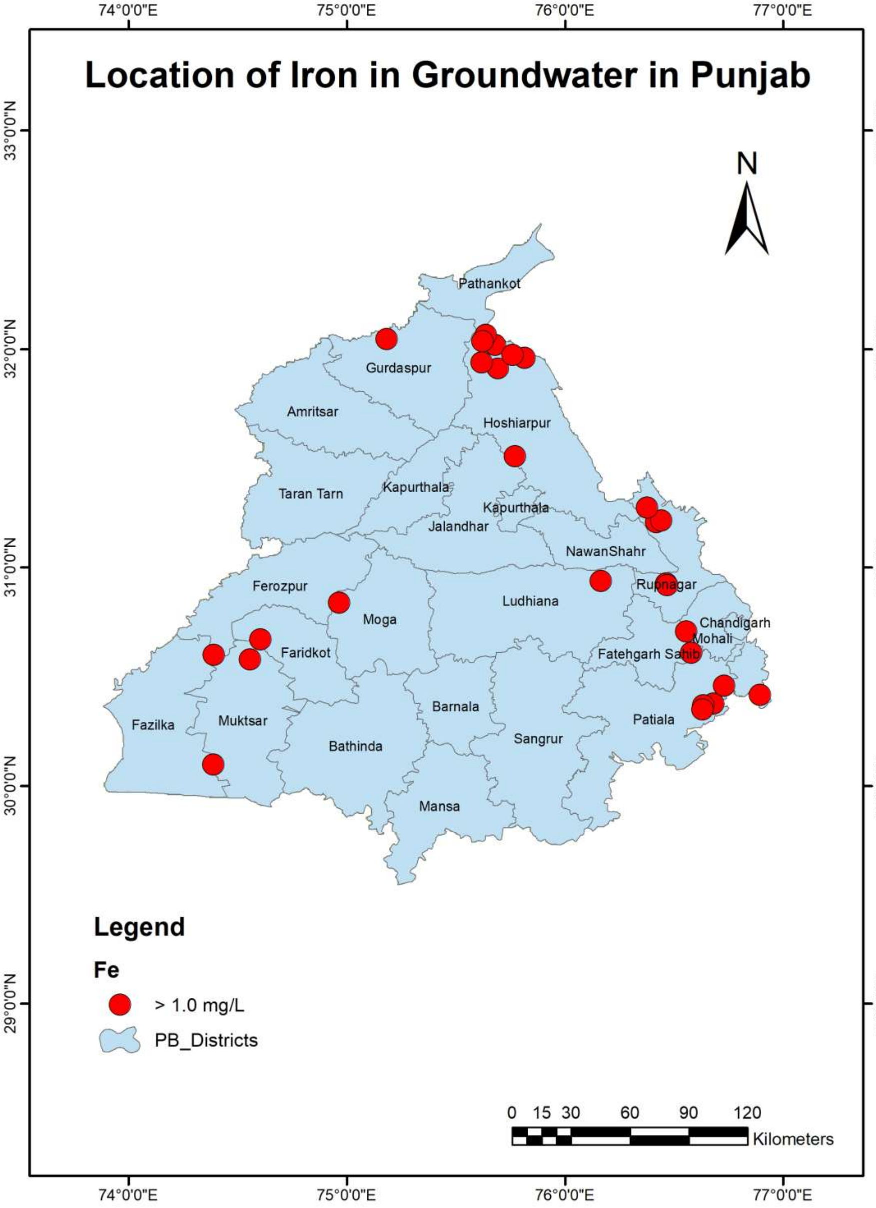


Fig 7.5.1 Map showing areas of Iron contaminated (> 1.0mg/L) groundwater in Punjab State (NHS 2022)

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

Sl. No	State	Parts of Districts Having Fe > 1.0 mg/L
1	**Punjab**	Faridkot
2	**Punjab**	Fatehgarh Sahib
3	**Punjab**	Fazilka
4	**Punjab**	Gurdaspur
5	**Punjab**	Hoshiarpur
6	**Punjab**	Ludhiana
7	**Punjab**	Moga
8	**Punjab**	Muktsar
9	**Punjab**	Patiala
10	**Punjab**	Roper
11	**Punjab**	SAS Nagar

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

S. No.	State	No of Districts having Fe > 1.0 mg/L		
		2015	2022	Increase/Decrease
1	**Amritsar**	3	0	-3
2	**Barnala**	0	0	0
3	**Bhathinda**	5	0	-5
4	**Faridkot**	3	1	-2
5	**Fatehgarh Sahib**	3	1	-2
6	**Fazilka**	0	1	+1
7	**Firozepur**	2	0	-2
8	**Gurdaspur**	6	1	-5
9	**Hoshiarpur**	6	8	+2
10	**Jalandhar**	4	0	-4
11	**Kapurthala**	1	0	-1
12	**Ludhiana**	3	1	-2

S. No.	State	No of Districts having Fe > 1.0 mg/L		
13	**Mansa**	0	0	0
14	**Moga**	0	1	+1
15	**Muktsar**	0	2	+2
16	**Nawanshahr**	1	0	-1
17	**Pathankot**	1	0	-1
18	**Patiala**	0	4	+4
19	**Ropar**	2	5	+3
20	**Sangrur**	0	0	0
21	**SAS Nagar**	4	2	-2
22	**Tarantaran**	2	0	-2
	Grand total	**46**	**27**	**-19**

As compared to the data available in year 2015, the number of districts having Iron more than 1.0 mg/L in ground water samples has decreased (Table 7.5.2) by 11.47 % during the year 2022.

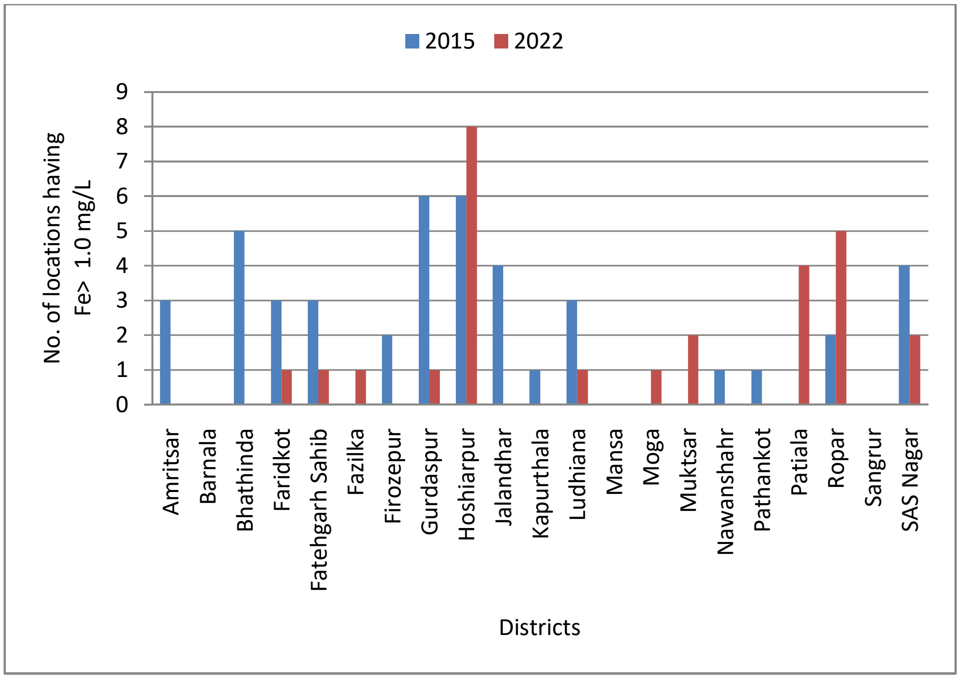


Fig. 7.5.2 Comparison on No of districts exceed Iron >1.0 mg/L during 2015 and 2012.

Remedial Measures for Iron/Manganese

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

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

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

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

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

Electromedia is a proprietary multi-media formulation which uses a naturally occurring zeolite and does not require potassium permanganate regeneration. Finally, macrolite, is a manufactured ceramic material with a spherical shape and a rough, textured surface. The principal removal mechanism is physical straining rather than contact oxidation or adsorption. Each medium has its advantages and disadvantages. Selection of a medium and oxidant should be based on pilot testing in which all necessary design criteria can be determined.

b)Ion Exchange Ion exchange should be considered only for the removal of small quantities of iron and manganese because there is a risk of rapid clogging. Ion exchange involves the use of synthetic resins where a pre-saturate ion on the solid phase (the “adsorbent,” usually sodium) is exchanged for the unwanted ions in water. One of the major difficulties in using this method for controlling iron and manganese is that if any oxidation occurs during the process, the resulting precipitate can coat and foul the media. Cleaning would then be required using acid or sodium 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 map showing distribution of Arsenic in ground water of Punjab (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 Annexure-VIII and locations exceed the limit of 0.01mg/L (10 ppb) are given in Annexure VI. The point sources are plotted on the map (Fig 7.6.1). Districts having Arsenic > 0.01 mg/L in Ground Water in the State of Punjab are shown in Table-7.6.1.

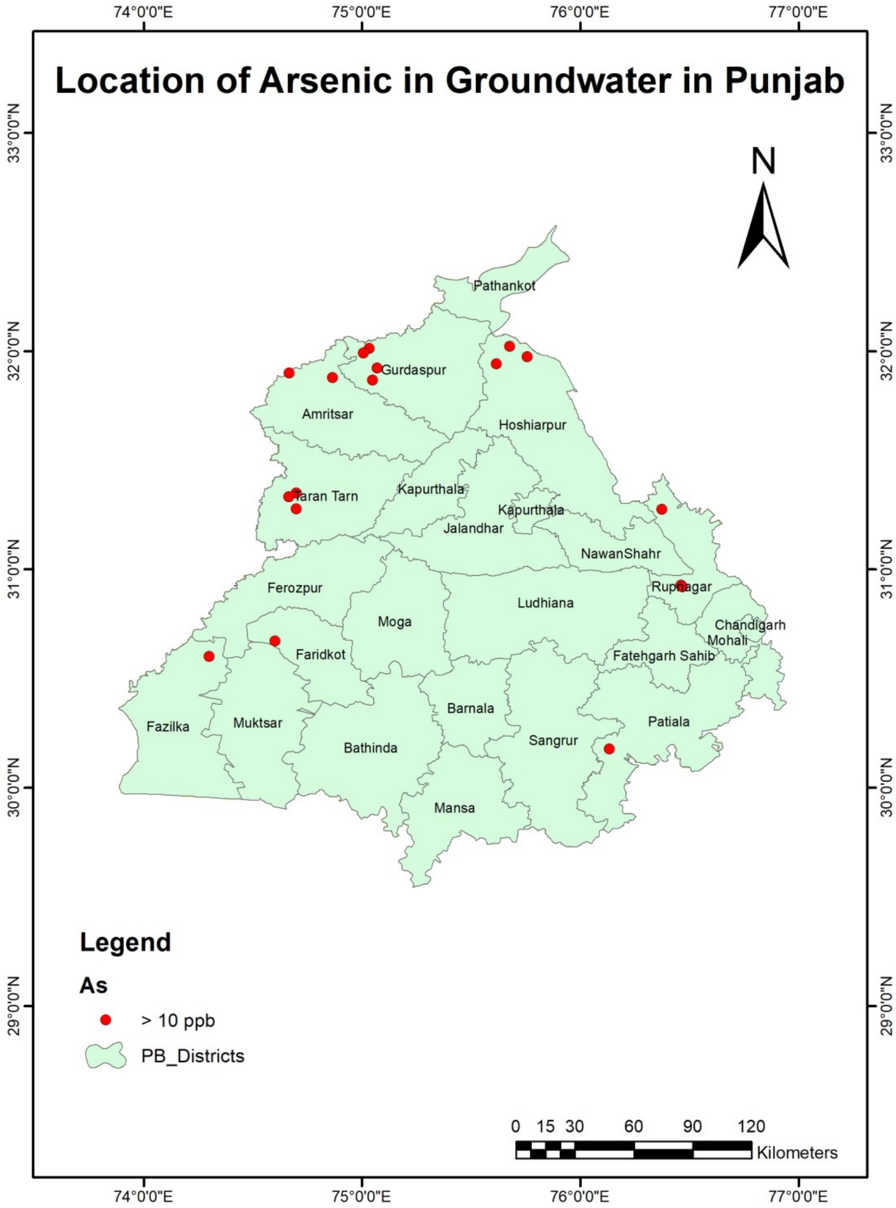


Table 7.6.1: Districts having Arsenic >0.01 in Ground Water in the State of Punjab

Sl. No.	State	Parts Of Districts having As > 10 ppb (0.01 mg/L)
1.	**Punjab**	Amritsar
2.	**Punjab**	Faridkot
3.	**Punjab**	Gurdaspur
4.	**Punjab**	Hoshiarprur
5.	**Punjab**	Nawashehar
6.	**Punjab**	Roper
7.	**Punjab**	Sangrur
8.	**Punjab**	Taran Taran

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 (June-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. State wise no. of districts affected by Uranium (>30 ppb) and maximum value observed is given in Table 7.7.4.

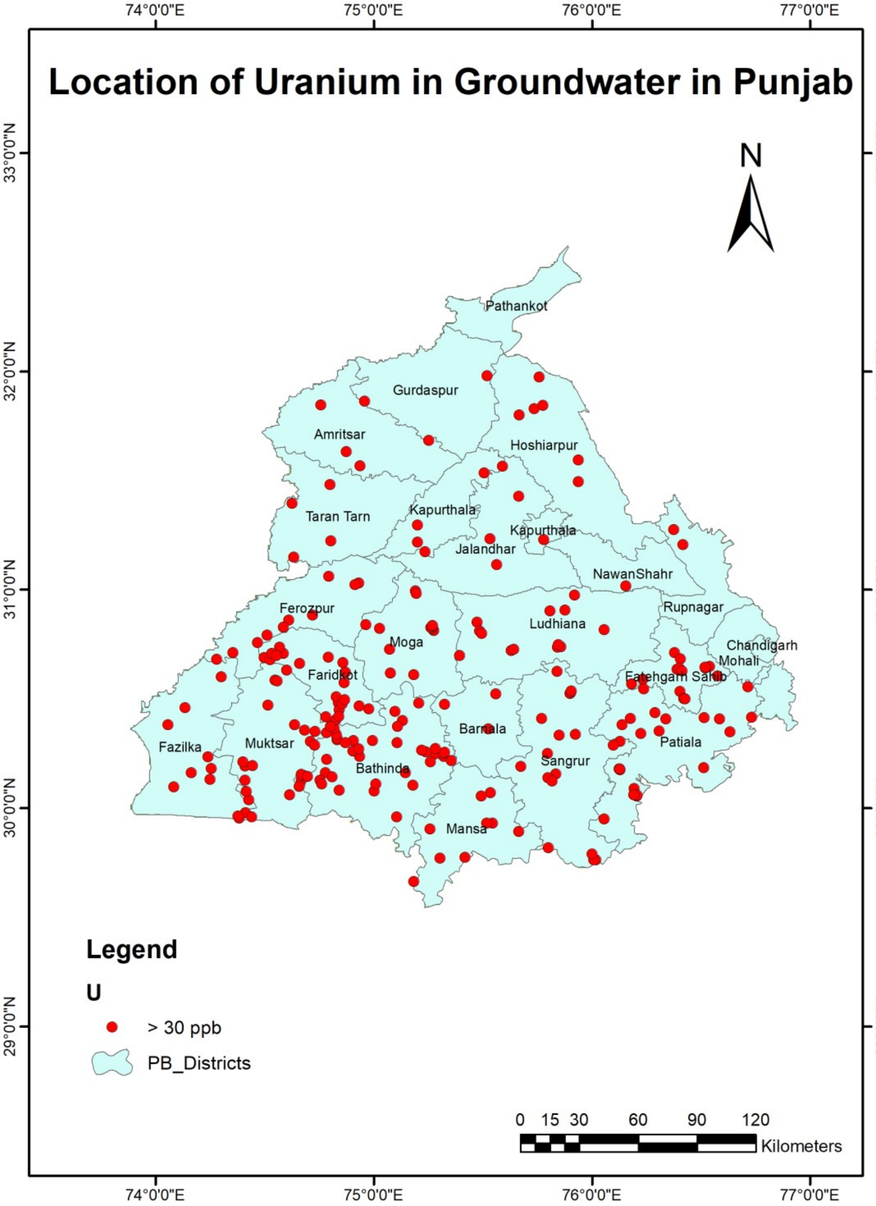

Location of Uranium in Groundwater in Punjab
74°0'0"E
75°0'0"E
76°0'0"E
77°0'0"E
33°0'0"N
32°0'0"N
31°0'0"N
30°0'0"N
29°0'0"N
N
Pathankot
Gurdaspur
Amritsar
Hoshiarpur
Taran Tarn
Kapurthala
Jalandhar
Kapurthala
NawanShahr
Rupnagar
Ferozpur
Moga
Ludhiana
Chandigarh
Mohali
Faridkot
Fatehgarh Sahib
Fazilka
Muktsar
Barnala
Patiala
Bathinda
Sangrur
Mansa
Legend
U
● > 30 ppb
PB_Districts
0 15 30 60 90 120
Kilometers

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

Sl No	State	Districts Partly affected with Uranium > 30ppb
1	**Punjab**	Amritsar
2	**Punjab**	Barnala
3	**Punjab**	Bhathinda
4	**Punjab**	Faridkot
5	**Punjab**	Fatehgarh Sahib
6	**Punjab**	Fazilka
7	**Punjab**	Firozepur
8	**Punjab**	Gurdaspur
9	**Punjab**	Hoshiarpur
10	**Punjab**	Jalandhar
11	**Punjab**	Kapurthala
12	**Punjab**	Ludhiana
13	**Punjab**	Mansa
14	**Punjab**	Moga
15	**Punjab**	Muktsar
16	**Punjab**	Nawanshahr
17	**Punjab**	Patiala
18	**Punjab**	Ropar
19	**Punjab**	Sangrur
20	**Punjab**	Tarantaran

Table 7.7.4 shows the number of districts partly affected in various states with maximum values recorded.

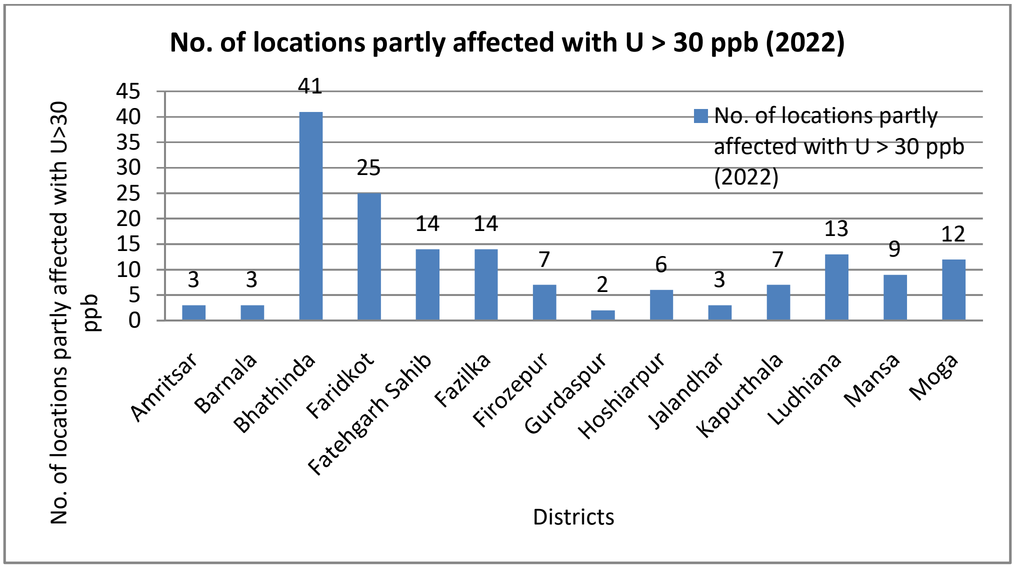


Fig. 7.7.2 Bar diagram displaying no. of partly Uranium contaminated (> 30 ppb) Districts in various state during 2022.

It is observed that Punjab Uranium concentration varied from 0.0 15to 551.191 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 hydro geochemical characteristics of groundwater.

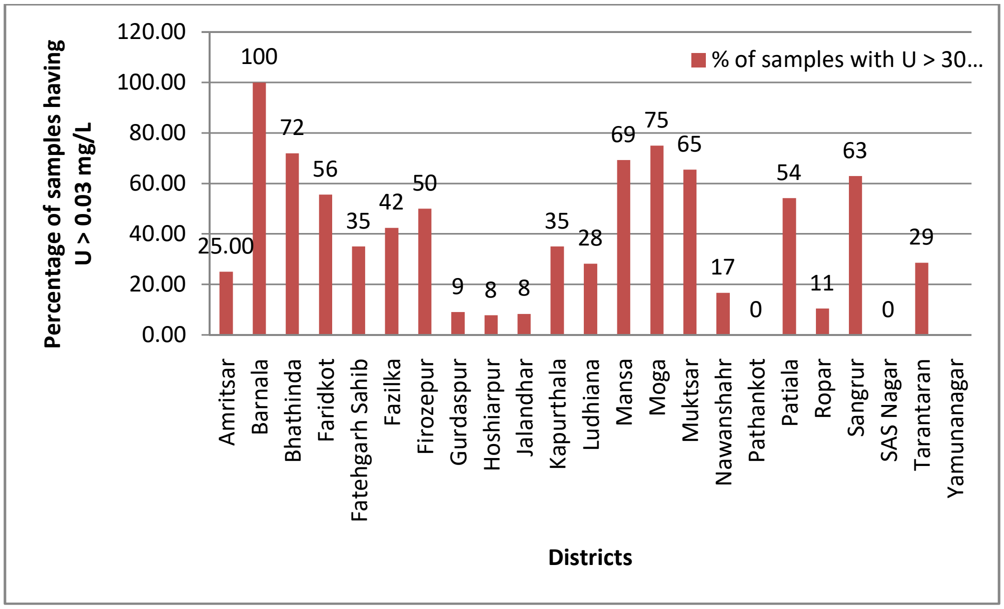


Fig 7.7.3 State-wise percentage of samples exceed Uranium 0.03mg/L (>30ppb)

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 Punjab state

Sl. No.	District	No. of Locations partly affected with U > 30 ppb (2022)	Maximum value of Uranium observed (in ppb)
1.	Amritsar	3	74.247
2.	Barnala	3	50.087
3.	Bhathinda	41	549.958
4.	Faridkot	25	313.736
5.	Fatehgarh Sahib	14	50.236
6.	Fazilka	14	131.976
7.	Firozepur	7	73.499
8.	Gurdaspur	2	68.405
9.	Hoshiarpur	6	112.977
10.	Jalandhar	3	43.159
11.	Kapurthala	7	101.566
12.	Ludhiana	13	95.443
13.	Mansa	9	479.375
14.	Moga	12	97.793
15.	Muktsar	17	551.191
16.	Nawanshahr	1	63.173
17.	Patiala	26	89.789
18.	Ropar	2	112.977
19	Sangrur	17	393.989
20	Tarantaran	4	202.713

The occurrences of Uranium in groundwater beyond permissible limit (30 ppb) have been displayed on the map (Fig.7.7.1).The high Uranium concentrationin states such as Punjab may be due to leaching through soil by heavy use of fertilizers in the agriculture lands. Since 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 a 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 can not 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. Areviewofvarioustreatmenttechnologiesfor Uraniumremovalfromwaterandtheirtechnicalachievability as reported by various researchers are given below in Table 7.7.4

7.7.5 Comparison of treatment methods for removal of Uranium.

Treatment Method	**Technical Achievability (%)**
Coagulation/filtrationathighpH (10+)	> 95
Limesoftening	85-99
Anionexchange	99
Reverseosmosis	>95
Activatedalumina	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 CaC03 mg/l. 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 country. It is observed that there are several locations in the States of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Rajasthan, Chhattisgarh, Punjab, Orissa, Punjab, Tamilnadu, kerala, Telangana, Punjab, Uttar Pradesh West Bengal, Bihar, Delhi, Jharkhand, Maharashtra, and West Bengal where the total hardness in ground water exceeds 600 mg/L. The details of locations where total hardness concentration more than 600 mg/l is given in table 7.8.1.

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

S. No.	District	No. of locations having TH> 600 mg/L
1	Bhatinda	2
2	Faridkot	2
3	Fazilka	5
4	Mansa	2
5	Muktsar	5
6	Patiala	1
7	SAS Nagar	1
Total		18

Table 7.8.2 Districts having total hardness > 600 mg/L in Ground Water in Different States of unjab

S.No.	State	Parts of District having Total Hardness > 600 mg/L as $CaCO_3$
1	Punjab	Bhatinda
2	Punjab	Faridkot
3	Punjab	Fazilka
4	Punjab	Mansa
5	Punjab	Muktsar
6	Punjab	Patiala
7	Punjab	SAS Nagar

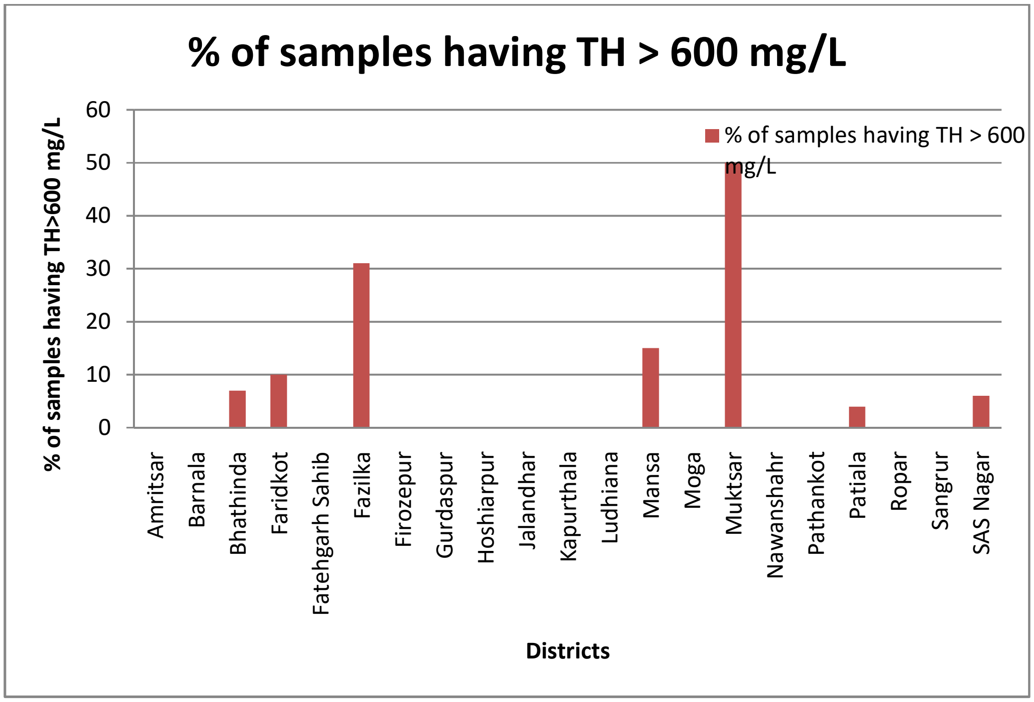


Fig 7.8.1 Bar diagram District-wise percentage of wells having Total hardness > 600 mg/L is shown as a bar diagram in.

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 State-wise percentage of samples having Total hardness >600 mg/L

S. No	State and UT	No. of Samples collected (NHS 2022)	No. of samples having TH > 600 mg/l	% of Samples (TH > 600 mg/L)
1	Amritsar	12	0	0.0
2	Barnala	3	0	0.0
3	Bhathinda	28	2	7.14
4	Faridkot	21	2	9.52
5	Fatehgarh Sahib	12	0	0.0
6	Fazilka	16	5	31.25
7	Firozepur	9	0	0.0
8	Gurdaspur	22	0	0.0
9	Hoshiarpur	30	0	0.0
10	Jalandhar	20	0	0.0
11	Kapurthala	8	0	0.0
12	Ludhiana	22	0	0.0
13	Mansa	13	2	15.38
14	Moga	8	0	0.0
15	Muktsar	10	5	50
16	Nawanshahr	6	0	0.0
17	Pathankot	14	0	0.0
18	Patiala	28	1	3.57
19	Ropar	11	0	0.0
20	Sangrur	15	0	0.0
21	SAS Nagar	16	1	6.25
22	Tarantaran	14	0	0.0
	Total(India)	**338**	18	5.32

8.0 SUITABILITY OF GROUNDWATER FOR IRRIGATION PURPOSE

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation purposes. Plants grown by irrigation absorb and transpire water but leave nearly all the salts behind in the soil, where they accumulate and eventually prevent plant growth. Excessive concentrations of solute interfere with the osmotic process by which plant root membranes are able to assimilate water and nutrients. In areas where natural drainage is inadequate, the irrigation water infiltrating the root zone will cause water table to rise excessively. In addition to problems caused by excessive concentration of dissolved solids, certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations. Irrigation indices viz. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) have been evaluated to assess the suitability of ground water for irrigation purposes.

Alkali Hazard

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

SAR is derived by the following equation:

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

The water with regard to SAR is classified into four categories

- **S_1 – Low Sodium Water** (SAR <10)

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

- **S_2 – Medium Sodium Water** (SAR 10-18)

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

- **S_3 – High Sodium Water** (SAR >18-26)

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

- **S_4 – Very High Sodium Waters** (SAR >26)

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

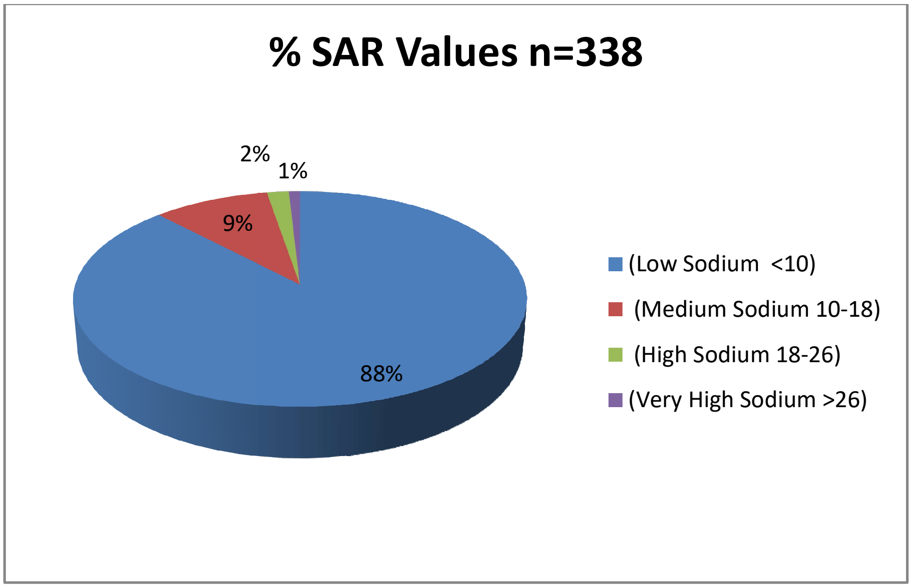


Figure 8.1: Percentage of groundwater samples according to SAR classifications (n=15507).

The computed SAR values ranges from 0.12 to 32.87. The maximum SAR value has been found at Shahwala of Fazilka district in Pujab State. It is apparent from Fig. 8.1 that 88% samples belong to excellent category (S_1) and only 1% 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 Amritsar,Barnala,Fatehgarh Sahib,Gurdaspur,Hoshiarpur,Jalandhar,Kapurthala,Ludhiana,Nawashehar,Pathankot,and SAS Nagar 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 Faridkot, Fazika and Mansa district 7.76% , 6.25% and 7.69% 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 states based on SAR classifications.

State	%. of samples in various SAR range			
	(low Sodium <10)	(medium Sodium 10-18)	(high Sodium 18-26)	(very high Sodium >26)
Amritsar	100.00	0.00	0.00	0.00
Barnala	100.00	0.00	0.00	0.00
Bhathinda	85.71	10.71	3.57	0.00
Faridkot	47.62	38.10	9.52	4.76
Fatehgarh Sahib	100.00	0.00	0.00	0.00
Fazilka	56.25	18.75	18.75	6.25
Firozepur	88.89	11.11	0.00	0.00
Gurdaspur	100.00	0.00	0.00	0.00
Hoshiarpur	100.00	0.00	0.00	0.00
Jalandhar	100.00	0.00	0.00	0.00
Kapurthala	100.00	0.00	0.00	0.00
Ludhiana	100.00	0.00	0.00	0.00
Mansa	61.54	30.77	0.00	7.69
Moga	75.00	25.00	0.00	0.00
Muktsar	60.00	40.00	0.00	0.00
Nawanshahr	100.00	0.00	0.00	0.00
Pathankot	100.00	0.00	0.00	0.00
Patiala	89.29	10.71	0.00	0.00
Ropar	100.00	0.00	0.00	0.00
Sangrur	80.00	20.00	0.00	0.00
SAS Nagar	100.00	0.00	0.00	0.00
Tarantaran	92.86	7.14	0.00	0.00
Total	**87.87**	**9.47**	**1.78**	**0.89**

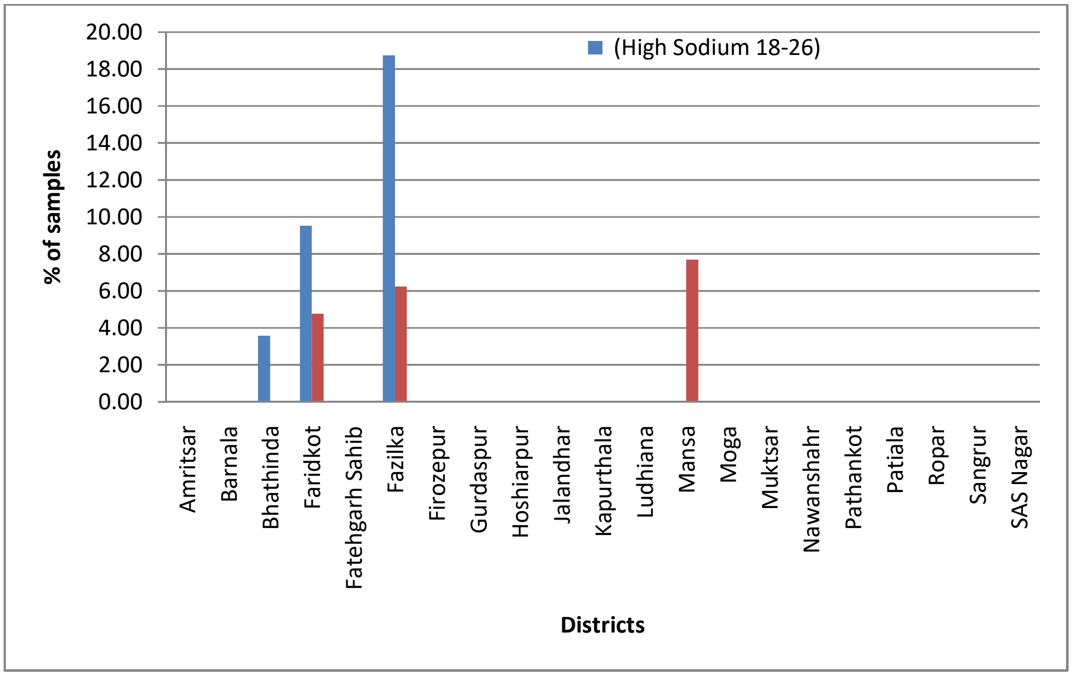


Figure 8.2: percentage of samples with respect to SAR values.

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;

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

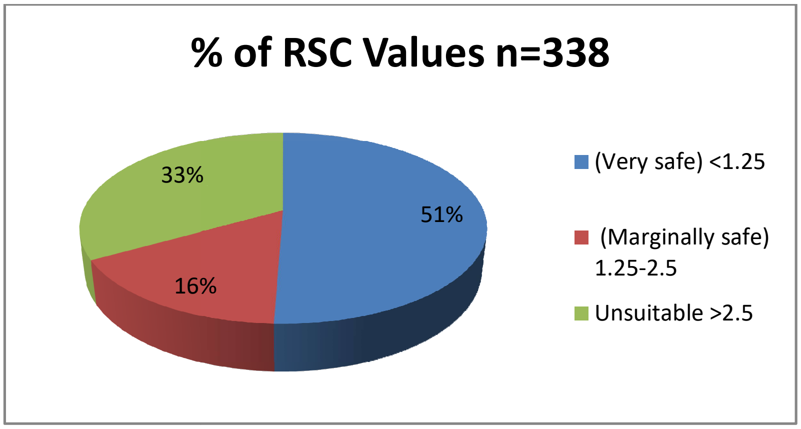


Figure 8.3: Percentage of groundwater samples in various categories according to RSC classifications (n=338) (Wilcox et al., 1954).

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. it can be seen that in India 51 % collected water samples are associated with RSC values less than 1.25 and are safe for use in irrigation practices. Only 16 % 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 8.4summarizes the irrigation quality of the groundwater samples in various states based on RSC values.

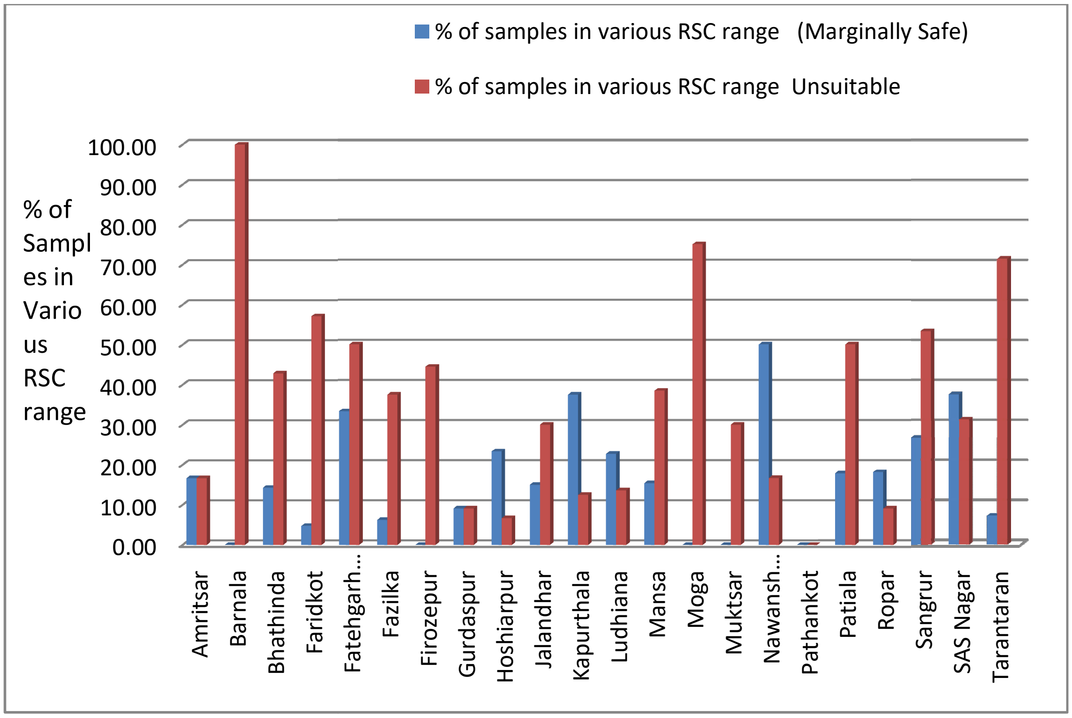


Figure 8.4: Percentage of samples with respect to RSC values.

According to RSC classification 100% of water samples in Pathankot 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 states based on RSC values.

State	%. of samples in various RSC range		
	<1.25	**1.25-2.5**	**>2.5**
	(Very safe)	**(marginally safe)**	**Unsuitable**
Amritsar	66.67	16.67	16.67
Barnala	0.00	0.00	100.00
Bhatinda	42.86	14.29	42.86
Faridkot	38.10	4.76	57.14
Fatehgarh Sahib	16.67	33.33	50.00
Fazilka	56.25	6.25	37.50
Firozpur	55.56	0.00	44.44
Gurdaspur	81.82	9.09	9.09
Hoshiarpur	70.00	23.33	6.67
Jalandhar	55.00	15.00	30.00
Kapurthala	50.00	37.50	12.50
Ludhiana	63.64	22.73	13.64
Mansa	46.15	15.38	38.46
Moga	25.00	0.00	75.00
Muktsar	70.00	0.00	30.00
Nawanshahar	33.33	50.00	16.67
Pathankot	100.00	0.00	0.00
Patiala	32.14	17.86	50.00
Roper	72.73	18.18	9.09
Sangrur	20.00	26.67	53.33
SAS Nagar	31.25	37.50	31.25
Taran Taran	21.43	7.14	71.43

9.0 USSL

Plot of USSL diagram based on EC and SAR, 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 and southwestern parts comprising of Bhatinda, Faridkot, Fazilka, Mansa, Muktsar , 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.

RSC: Alkali hazards of irrigation ground waters are estimated through the computation of Residual Sodium Carbonate (RSC), also known as Eaton's Index. Waters with RSC value <1.25 meq/L are safe for irrigational uses, RSC between 1.25 and 2.5 are marginal and waters with RSC value >2.5 meq/L are unsafe. Based on RSC values of ground waters, it is found that 50.60% of the waters are safe, 16.26% marginal and the remaining 33.14 % are unfit for irrigational uses. RSC of ground waters are found to vary from below 0 to 50.20meq/l (Sohangarh, Fazilka district). The district wise distribution of ground waters in different categories of suitability for irrigational uses based on USSL and RSC considerations is given in

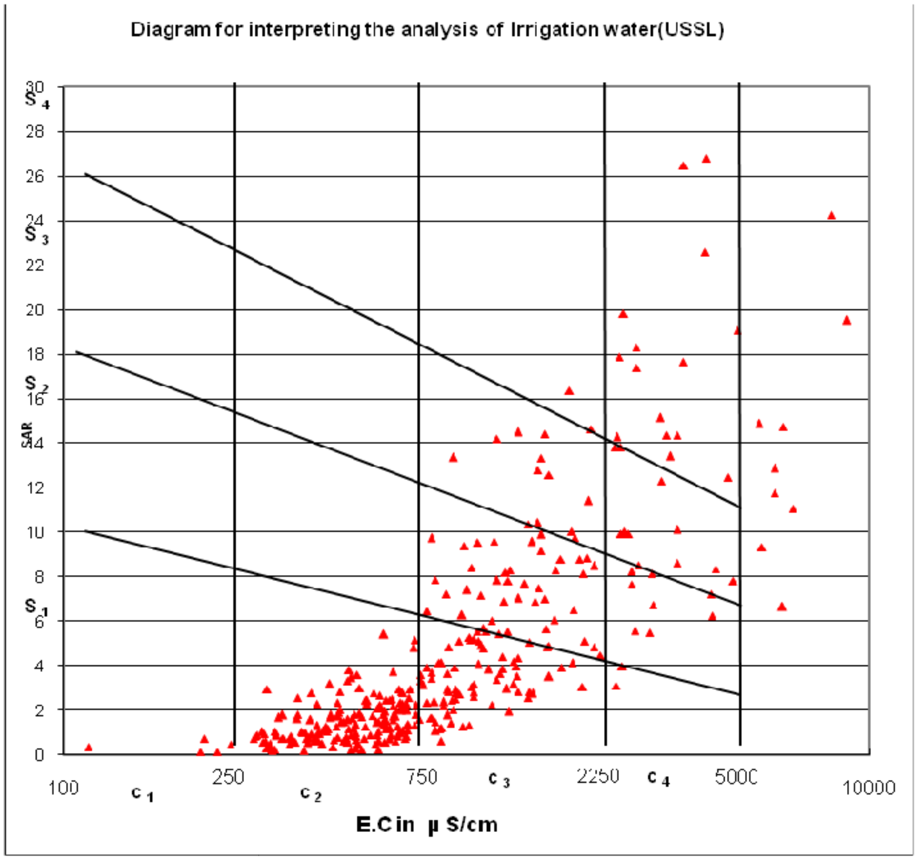
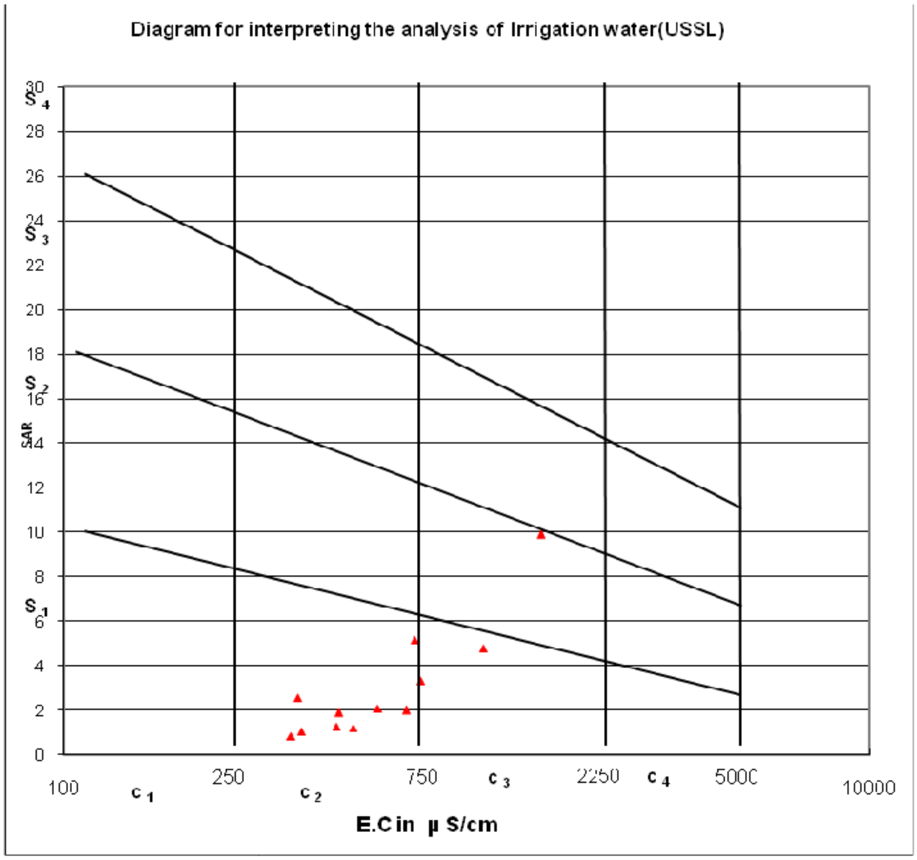
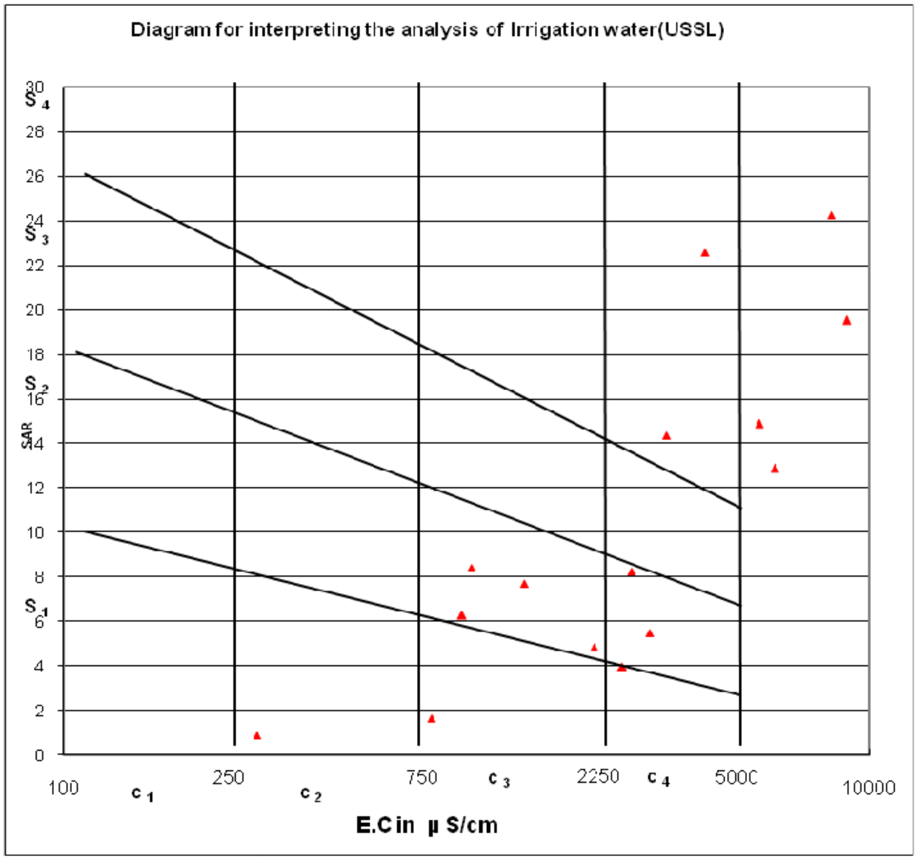


Diagram for interpreting the analysis of Irrigation water(USSL)
SAR
S 4
S 3
S 2
S 1
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
100
c 1
250
c 2
750
c 3
2250
c 4
5000
10000
E.C in µ S/cm



USSL Diagramme of Amritsar District of Punjab state-2022



USSL Diagramme of Fazilka District of Punjab state-2022

9.0 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 Punjab, cation chemistry is dominated by calcium and Magnesium is followed by sodium and Potassium. In anion side bicarbonate is dominated 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, and mixed type are encountered in the state.

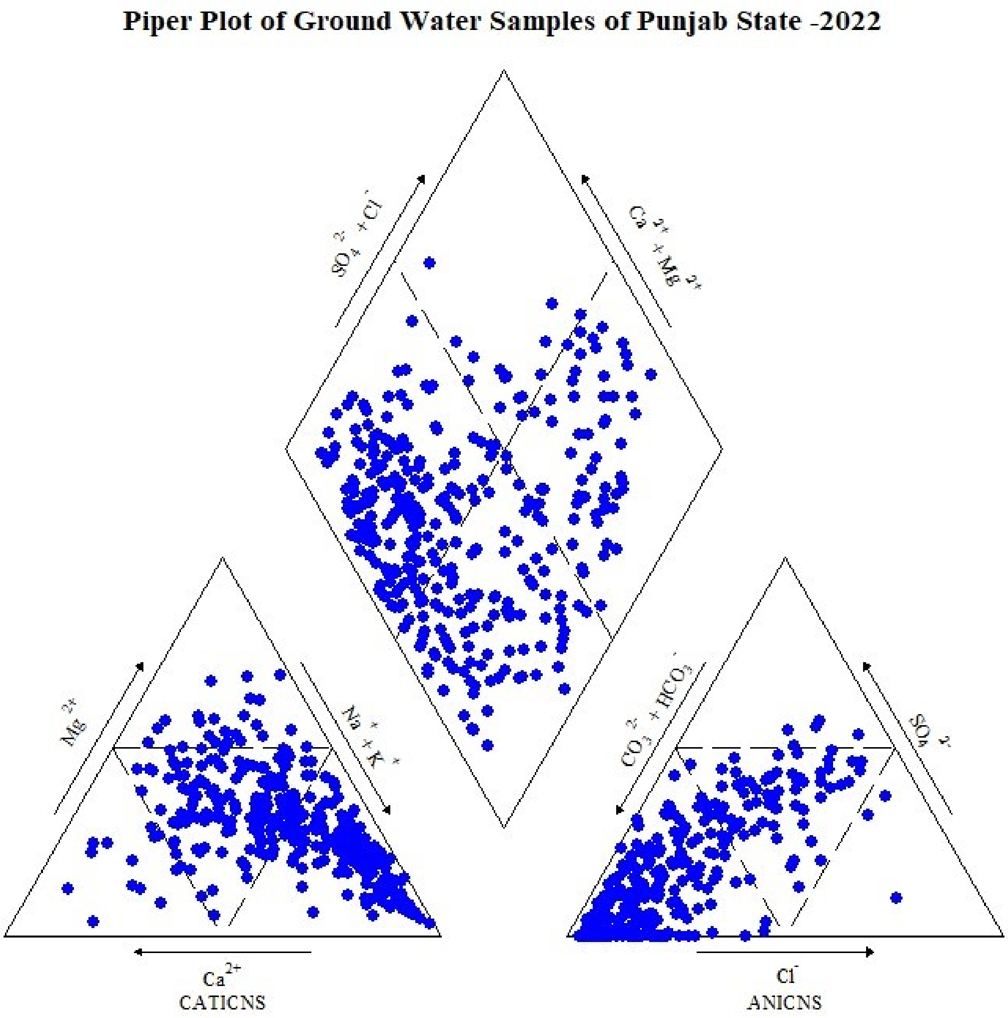


Fig- 9.1 Piper diagram of groundwater of Punjab State.

9.2 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).

$$\mathbf{2Na^{+} - clay + Ca^{2+} \;=\; Ca^{2+} - clay + Na^{+}}$$

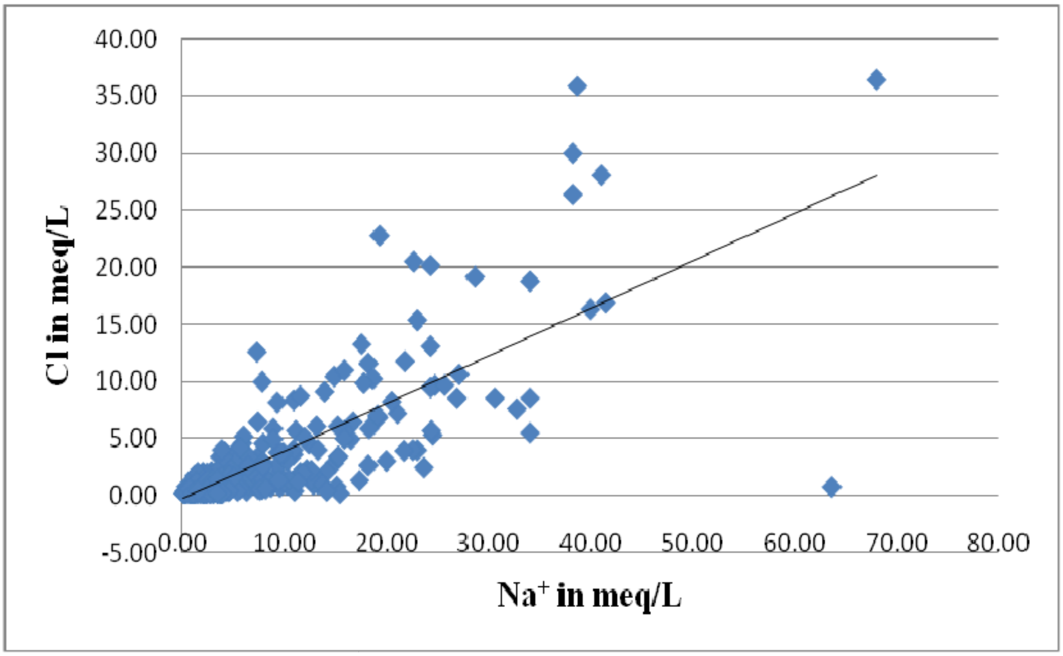


Fig. 9.2: The plot for Na versus Cl in groundwater samples of Punjab State.

10.0 *Annexure- I*

Locations having Electrical Conductivity > 3000 µS/cm in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	EC > 3000 µS/cm
1	Bhatinda	Bhatinda	Balluana	74.7839	30.2237	5405
2	Bhatinda	Bathinda	Gulabgarh	75.0106	30.1443	3040
3	Bhatinda	Talwandi Saboo	Bhagi Bandar	75.0697	30.0251	3325
4	Faridkot	Faridkot	Mehmunna Sadiq	74.6381	30.6957	5812
5	Faridkot	Faridkot	Sukhanwala	74.6394	30.6382	3327
6	Faridkot	Faridkot	Sadiq	74.5856	30.7088	4686
7	Faridkot	Ferozepur	Mumara	74.5885	30.7935	3200
8	Faridkot	Faridkot	Killi	74.5461	30.7861	3923
9	Faridkot	Kotkapura	Baja Khana	74.9772	30.4547	3450
10	Faridkot	Kotkapura	Karir Wali	74.8273	30.4056	4155
11	Fazilka	Jalalabad	Sohangarh(Coloured Samples)	74.3892	30.6003	8022
12	Fazilka	Fazilka	Deepulana	74.1346	30.4607	3910
13	Fazilka	Fazilka	Kauranwali	74.0561	30.3829	3130
14	Fazilka	Khuiyan Serovar	Khuyan sarwar	74.0805	30.1129	5817
15	Fazilka	Abohar	Abohar	74.1901	30.1480	8768
16	Fazilka	Abohar	Sitogano	74.3602	30.0290	5320
17	Mansa	Jhunir	Raipur	75.2573	29.9041	4455
18	Mansa	Budhwala	Budhlanda	75.5444	29.9317	3455
19	Mansa	Budhwala	Budhlanda	75.5176	29.9317	3327
20	Muktsar	Muktsar	Dohak	74.6009	30.6324	6434
21	Muktsar	Muktsar	Muktsar	74.5149	30.4714	4060
22	Muktsar	Lambi	Sheranwali	74.4644	30.0318	6098
23	Muktsar	Malout	Kabarwala	74.4097	30.1931	3027
24	Muktsar	Muktsar	Doda	74.6370	30.3816	4042
25	Muktsar	Muktsar	Bhalaiana	74.7133	30.3301	6078
26	SAS Nagar	Dera Bassi	Sirsini	76.7710	30.4540	4586

Annexure II

Locations having Chloride >1000 mg/L in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	Cl > 1000 mg/L
1	Fazilka	Abohar	Abohar	74.1901	30.1480	1293
2	Muktsar	Muktsar	Dohak	74.6009	30.6324	1273
3	Muktsar	Lambi	Sheranwali	74.4644	30.0318	1064

Annexure III

Locations having Fluoride >1.50 mg/L in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	Fluoride > 1.50 mg/L
1	Bhatinda	Rampura Phul	Dyalpur Mirja	75.1318	30.4002	2.10
2	Bhatinda	Bhatinda	Khialiwala	74.9948	30.3101	2.00
3	Bhatinda	Nathana	Phulla	75.1070	30.2993	3.10
4	Bhatinda	Maur	Maiser Khanna	75.1791	30.1047	2.00
5	Bhatinda	Talwandi Saboo	Kale Bandar	75.0023	30.0789	4.80
6	Faridkot	Faridkot	Tehna	74.7916	30.6909	2.30
7	Faridkot	Faridkot	Killi	74.5461	30.7861	4.00
8	Faridkot	Kotkapura	Matta	74.8384	30.4827	2.00
9	Fazilka	Jalalabad	Swahwala	74.3009	30.6007	4.70
10	Fazilka	Fazilka	Deepulana	74.1346	30.4607	3.60
11	Fazilka	Abohar	Dhaban Kokaryan	74.3272	30.1219	2.20
12	Fazilka	Abohar	Sitogano	74.3602	30.0290	1.90
13	Firozpur	Firozpur	Jhok harihar	74.6105	30.8616	1.80
14	Mansa	Bhikhi	Bhikhi	75.5354	30.0699	2.10
15	Mansa	Sardulgarh	Fatta Maluka	75.3031	29.7710	1.70
16	Mansa	Budhwala	Mofar	75.4193	29.774	6.80
17	Mansa	Budhwala	Kot Dharmu	75.3696	29.8956	1.60
18	Mansa	Budhwala	Budhlanda	75.5444	29.9317	5.80
19	Mansa	Budhwala	Dialpura	75.6642	29.8929	2.50
20	Moga	Moga-II	Jaisinghwala	75.0720	30.7280	7.10
21	Muktsar	Malout	Kabarwala	74.4097	30.1931	2.10
22	Muktsar	Lambi	Lambi	74.6136	30.0610	2.00
23	Patiala	Rajpura	Thua	76.5540	30.5000	2.00
24	Patiala	Rajpura	Rajpura	76.5940	30.4740	2.40
25	Sangrur	Lehra Gaga	Chural Kalan	75.8000	29.8190	4.90
26	Taran Taran	Tarn Taran	Chabal	74.8000	31.4810	2.20
27	Taran Taran	Patti	Barwala	74.8030	31.2240	4.50
28	Taran Taran	Patti	Rattoke	74.6330	31.1500	1.60
29	Taran Taran	Bhikhiwind	Aminsha Khalra	74.6250	31.3960	9.00

Annexure IV

Locations having Nitrate >45 mg/L in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	Nitrate > 45 mg/L
1	Amritsar	Ajnlala	Ajnala	74.7580	31.8460	55
2	Bhatinda	Sangat	Raike Kalan	74.6682	30.1282	120
3	Bhatinda	Sangat	Jassi Bhagwali	74.8145	30.0522	101
4	Bhatinda	Sangat	Phullo Mithi	74.8450	30.0980	46
5	Bhatinda	Rampura Phul	Dyalpur Mirja	75.1318	30.4002	47
6	Bhatinda	Bhatinda	Ganga	74.8187	30.3676	121
7	Bhatinda	Nathana	Kalyan sukha	75.1087	30.3743	293
8	Bhatinda	Bhatinda	Balluana	74.7839	30.2237	425
9	Bhatinda	Rampura	Jhanduke	75.1453	30.1616	48
10	Bhatinda	Maur	Maiser Khanna	75.1791	30.1047	94
11	Bhatinda	Talwandi Saboo	Bhagi Bandar	75.0697	30.0251	56
12	Bhatinda	Talwandi Saboo	Kale Bandar	75.0023	30.0789	56
13	Bhatinda	Bhatinda	Kot Shamir	75.0104	30.1113	284
14	Bhatinda	Talwandi Saboo	Jajal	75.0298	29.9665	99
15	Bhatinda	Talwandi Saboo	Gurusar	75.1052	29.9608	112
16	Faridkot	Faridkot	Mehmunna Sadiq	74.6381	30.6957	110
17	Faridkot	Faridkot	Sukhanwala	74.6394	30.6382	125
18	Faridkot	Faridkot	Sadiq	74.5856	30.7088	200
19	Faridkot	Kotkapura	Deep singwala	74.4829	30.7426	100
20	Faridkot	Ferozepur	Mumara	74.5885	30.7935	150
21	Faridkot	Faridkot	Killi	74.5461	30.7861	144
22	Faridkot	Kotkapura	Kot Kapura	74.8192	30.5789	82
23	Faridkot	Kotkapura	Baja Khana	74.9772	30.4547	81
24	Faridkot	Kotkapura	Karir Wali	74.8273	30.4056	106
25	Fazilka	Jalalabad	Sohangarh(Coloured Samples)	74.3892	30.6003	158
26	Fazilka	Fazilka	Deepulana	74.1346	30.4607	89
27	Fazilka	Fazilka	Kauranwali	74.0561	30.3829	62
28	Fazilka	Khuiyan Serovar	Danewal Satkosi	74.0341	30.1773	130
29	Fazilka	Khuiyan Serovar	Alamgarh	74.1576	30.1269	98
30	Fazilka	Abohar	Abohar	74.1901	30.1480	160
31	Firozpur	Ferozepur	Moharewala	74.5849	30.8287	180
32	Firozpur	Jalalabad	Ladhewala	74.3863	30.5347	90
33	Gurdaspur	Har Govindpur	SriHargobindpur	75.4750	31.6920	46
34	Gurdaspur	Dinanagar	Saidowal	75.5190	31.9800	145
35	Hoshiarpur	Mukerian	Bhangala	75.6090	32.0250	70
36	Hoshiarpur	Hajipur	Nangal Bhaiala	75.7080	31.9080	90
37	Jalandhar	Shahkot	Billi Charmi	75.3940	31.1120	57

38	Jalandhar	Shahkot	Shahkot	75.3300	31.0790	70
39	Jalandhar	Jalandhar west	Kartarpur	75.4990	31.4360	85
40	Kapurthala	Phagwara	phagwara	75.7790	31.2290	64
41	Ludhiana	Dehlon	Doraha	76.0210	30.8000	55
42	Ludhiana	Khanna	Maksudra	76.0100	30.7300	60
43	Ludhiana	Sudhar	Hallwara	75.6380	30.7250	50
44	Ludhiana	Ludhiana I	Chattar Singh Park	75.7920	30.9000	88
45	Ludhiana	Ludhiana	P.A.U.Ludhiana	75.8070	30.9040	60
46	Mansa	Jhunir	Raipur	75.2573	29.9041	150
47	Mansa	Jhunir	Burj Bhalaika	75.2754	29.8426	50
48	Moga	Nihal singh wala	Nihalsinghwala	75.1830	30.6110	47
49	Muktsar	Muktsar	Dohak	74.6009	30.6324	75
50	Muktsar	Lambi	Sheranwali	74.4644	30.0318	87
51	Muktsar	Muktsar	Balochkhera	74.4104	30.0816	53
52	Muktsar	Malout	Kabarwala	74.4097	30.1931	61
53	Muktsar	Lambi	Lambi	74.6136	30.0610	52
54	Muktsar	Muktsar	Doda	74.6370	30.3816	500
55	Muktsar	Muktsar	Bhalaiana	74.7133	30.3301	1000
56	Nawanshahar	Nawanshahar	Rahon	76.1360	31.0570	140
57	Pathankot	Pathankot	Ghoh	75.6630	32.3290	50
58	Patiala	Rajpura	Bassma Pipla	76.7280	30.4600	100
59	Patiala	Nabha	Dulladi	76.1380	30.3830	65
60	Ropar	Rup Nagar	Ahemadpur	76.5750	31.0000	68
61	Sangrur	Amargarh	Maler Kotla	75.9000	30.5250	84
62	Sangrur	Dhuri	Ghanauri Kalan	75.7700	30.4100	49
63	SAS Nagar	Dera Bassi	Sawara	76.6410	30.6840	180
64	SAS Nagar	Dera Bassi	Joli	76.9000	30.5500	91
65	Taran Taran	Tarn Taran	Chabal	74.8000	31.4810	48

Annexure V

Locations having Iron >1.00 mg/L in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	Iron >1.00 mg/L
1	Faridkot	Faridkot	Bihle wala	74.603	30.672	1.382
2	Fatehgarh Sahib	Khera	Bhangrana	76.578	30.611	4.943
3	Fazilka	Jalalabad	Sohangarh	74.389	30.600	29.150
4	Gurdaspur	Kalanaur	Saleh Chak	75.181	32.049	2.040
5	Hoshiarpur	Mukerian	Pankhuh-U-III	75.678	32.022	3.081
6	Hoshiarpur	Mukerian	Chak Sheru-U-III	75.636	32.068	7.936
7	Hoshiarpur	Mukerian	Bhangala-U-IV	75.620	32.039	2.284
8	Hoshiarpur	Hajipur	Nangal Bhaiala-U-III	75.691	31.913	4.943
9	Hoshiarpur	Hoshiarpur I	Sham Chaurassi-U-IV	75.769	31.510	1.014
10	Hoshiarpur	Mukerian	Jhir Di Khui	75.813	31.963	1.850
11	Hoshiarpur	Hajipuur	Hajipur	75.758	31.975	3.330
12	Hoshiarpur	Mukerian	Mukeriya	75.617	31.942	1.599
13	Ludhiana	Macchiwara	Manewal	76.162	30.938	5.193
14	Moga	Moga-I	Chogawan	74.963	30.840	1.618
15	Muktsar	Muktsar	Lubaniawali	74.554	30.579	2.485
16	Muktsar	Muktsar	Mahni Khera	74.387	30.098	1.073
17	Patiala	Ghanaur	Kami Kalan	76.679	30.378	1.481
18	Patiala	Ghanaur	Kami Kalan	76.632	30.370	5.130
19	Patiala	Ghanaur	Lacharu Kalan	76.628	30.351	20.662
20	Patiala	Rajpura	Bassma Pipla	76.728	30.460	1.131
21	Roper	Nurpur Bedi	Dumewal	76.417	31.208	1.850
22	Roper	Nurpur Bedi	Dumewal U1	76.439	31.216	1.014
23	Roper	Rup Nagar	Bara Chauta	76.463	30.928	3.081
24	Roper	Rup Nagar	Bara Chauta U3	76.467	30.919	1.599
25	Roper	Anandpur Sahib	Bhalan	76.375	31.275	3.330
26	SAS Nagar	Kharar	Goga	76.554	30.708	7.936
27	SAS Nagar	Dera Bassi	Handesra	76.892	30.417	2.284

Annexure VI

Locations having Arsenic >0.01 mg/L(10ppb) in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	Arsenic >10 µg/L
1	Amritsar	Ajnlala	Urdhan	31.879	74.866	52.692
2	Amritsar	Ajnlala	Gaggo Mahal	31.900	74.667	36.939
3	Faridkot	Faridkot	Bihle wala	30.672	74.603	86.048
4	Fazilka	Jalalabad	Swahwala	30.601	74.301	19.041
5	Gurdaspur	Dera Baba Nanak	Dera Baba Nanak	32.013	75.033	17.511
6	Gurdaspur	Dera Baba Nanak	Mullanwali	31.992	75.008	26.374
7	Gurdaspur	Fatehgarh Churian	Ghaniye Ke Bangar	31.867	75.050	19.344
8	Gurdaspur	Dera Baba Nanak	Dhianpur	31.922	75.070	32.997
9	Hoshiarpur	Mukerian	Pankhuh-U-III	32.022	75.678	103.343
10	Hoshiarpur	Hajipuur	Hajipur	31.975	75.758	10.011
11	Hoshiarpur	Mukerian	Mukeriya	31.942	75.617	28.807
12	Patiala	Samana	Behmana	30.178	76.134	11.905
13	Roper	Rup Nagar	Bara Chauta	30.928	76.463	103.343
14	Roper	Rup Nagar	Bara Chauta U3	30.919	76.467	28.807
15	Roper	Anandpur Sahib	Bhalan	31.275	76.375	10.011
16	Taran Taran	Bhikhiwind	Bhikhiwind	31.350	74.700	17.143
17	Tarn Taran	Bhikhiwind	Kalsian Kalan	31.278	74.700	10.952
18	Tarn Taran	Bhikiwind	Maarhi Nav Abaad	31.332	74.666	17.920

Annexure VII

Locations having Uranium >0.03 mg/L(30ppb) in Ground Water in Punjab State

S.No.	District	Block	Location	Long	Lat	Uranium >30 µg/L
1	Amritsar	Chogawan	Mohawa	31.567	74.938	51.514
2	Amritsar	Ajnlala	Ajnala	31.846	74.758	42.468
3	Amritsar	Verka	Amritsar	31.633	74.875	74.247
4	Barnala	Sehna	Bhadaur	30.475	75.324	50.087
5	Barnala	Barnala	Barnala	30.363	75.525	35.054
6	Barnala	Mahal Kalan	Mahal Kalan	30.523	75.559	31.906
7	Bhatinda	Sangat	Raike Kalan	30.128	74.668	47.542
8	Bhatinda	Sangat	Mann	30.100	74.658	41.468
9	Bhatinda	Sangat	Bhadurgarh jandian	30.149	74.679	76.799
10	Bhatinda	Sangat	Lool bai	30.155	74.668	45.077
11	Bhatinda	Sangat	Chak daneka	30.145	74.697	100.581
12	Bhatinda	Bhatinda	Mehma sarkari	30.314	74.832	104.766
13	Bhatinda	Bhatinda	Mehma Sawai	30.320	74.832	99.634
14	Bhatinda	Bhatinda	Dan singh wala	30.338	74.829	191.919
15	Bhatinda	Bhatinda	Kotli	30.347	74.785	46.136
16	Bhatinda	Bhatinda	Nehian wala	30.309	74.906	86.240
17	Bhatinda	Bhatinda	Lakhi jungle	30.301	74.870	37.746
18	Bhatinda	Bhatinda	Bhai ghaniya chowk	30.236	74.935	66.218
19	Bhatinda	Bhatinda	Sivian	30.263	74.905	80.262
20	Bhatinda	Bhatinda	Gill Patti	30.271	74.931	60.996
21	Bhatinda	Rampura	Badiala	30.236	75.321	75.777
22	Bhatinda	Rampura	Pitho	30.249	75.281	74.658
23	Bhatinda	Rampura	Jaid	30.251	75.318	34.772
24	Bhatinda	Rampura	Jeond	30.257	75.325	42.903
25	Bhatinda	Rampura	Balloh	30.218	75.355	41.793
26	Bhatinda	Rampur phul	Rampuraphul	30.258	75.239	96.481
27	Bhatinda	Rampur phul	Gill kalan	30.274	75.282	43.209
28	Bhatinda	Rampur phul	Mandi Kalan	30.212	75.259	58.551
29	Bhatinda	Rampur phul	Rampura phul	30.266	75.220	45.998
30	Bhatinda	Sangat	jhumba	30.162	74.778	39.578
31	Bhatinda	Sangat	Bajak	30.128	74.754	47.174
32	Bhatinda	Sangat	Nandgarh	30.111	74.762	549.958
33	Bhatinda	Sangat	Baho Jattri	30.144	74.810	96.070
34	Bhatinda	Sangat	Sangat Kalan	30.082	74.843	83.757
35	Bhatinda	Bhagta Bhaika	Dialpur Bhai ke	30.481	75.206	111.193
36	Bhatinda	Bhagta Bhaika	Kotha guru ka	30.443	75.097	150.443
37	Bhatinda	Rampura Phul	Dyalpur Mirja	30.400	75.132	128.926
38	Bhatinda	Bhatinda	Ganga	30.368	74.819	76.552
39	Bhatinda	Bhatinda	Khialiwala	30.310	74.995	66.906
40	Bhatinda	Nathana	Phulla	30.299	75.107	62.730
41	Bhatinda	Nathana	Kalyan sukha	30.374	75.109	133.480
42	Bhatinda	Bhatinda	Balluana	30.224	74.784	47.458
43	Bhatinda	Rampura	Jhanduke	30.162	75.145	40.062
44	Bhatinda	Maur	Maiser Khanna	30.105	75.179	103.732
45	Bhatinda	Talwandi	Kale Bandar	30.079	75.002	71.966

		Saboo				
46	Bhatinda	Bhatinda	Kot Shamir	30.111	75.010	75.173
47	Bhatinda	Talwandi Saboo	Gurusar	29.961	75.105	197.671
48	Faridkot	Faridkot	Chet Singh Wala	30.663	74.661	40.941
49	Faridkot	Faridkot	Sadiq	30.709	74.586	304.552
50	Faridkot	Faridkot	Sadhu wala	30.718		46.846
51	Faridkot	Faridkot	Rupianwala	30.737	74.568	32.082
52	Faridkot	Faridkot	Jand Sahib	30.689	74.527	44.967
53	Faridkot	Faridkot	Pind Balocha	30.689	74.498	47.900
54	Faridkot	Faridkot	Veere Wala Kalan	30.680	74.525	120.726
55	Faridkot	Faridkot	Maan Marahar	30.709	74.532	56.958
56	Faridkot	Faridkot	Gadhuwala	30.699	74.554	313.736
57	Faridkot	Kotkapura	Chak Jamait Singh (Mishri wala)	30.758	74.468	39.562
58	Faridkot	Kotkapura	Matta	30.483	74.838	33.414
59	Faridkot	Kotkapura	Dhaipai	30.510	74.829	81.500
60	Faridkot	Kotkapura	Ramuwala	30.451	74.842	100.032
61	Faridkot	Kotkapura	Ajit Gill	30.477	74.856	137.949
62	Faridkot	Kotkapura	Guru ki Dhab	30.496	74.866	138.602
63	Faridkot	Kotkapura	Karir Wali	30.406	74.827	127.202
64	Faridkot	Kotkapura	Kothekotli (Kotliablu)	30.374	74.802	41.755
65	Faridkot	Kotkapura	Chaina	30.420	74.840	40.711
66	Faridkot	Kotkapura	Ramiana	30.418	74.781	96.724
67	Faridkot	Faridkot	Tehna	30.691	74.792	49.169
68	Faridkot	Kotkapura	Nagal	30.666	74.859	43.785
69	Faridkot	Kotkapura	Daviwala	30.623	74.871	88.738
70	Faridkot	Kotkapura	Dhilwan Kalan	30.575	74.864	109.435
71	Faridkot		Dal Singhwala	30.467	74.933	36.770
72	Faridkot	Kotkapura	Baja Khana	30.455	74.977	93.673
73	Fatehgarh Sahib	Chunni Kalan	Chunni Kalan U4	30.649	76.538	31.793
74	Fatehgarh Sahib	Khera	Bhangrana U4	30.605	76.576	35.233
75	Fatehgarh Sahib	Khera	Badli Ala singh U2	30.643	76.520	31.667
76	Fatehgarh Sahib	Khera	Badli Ala singh U3	30.646	76.518	36.437
77	Fatehgarh Sahib	Bassi Pathana	Bassi pathana	30.713	76.378	32.236
78	Fatehgarh Sahib	Bassi pathana	Bassi pathana	30.683	76.405	45.188
79	Fatehgarh Sahib	Bassi pathana	Fatehgarh Sahib U1	30.637	76.390	49.264
80	Fatehgarh Sahib	Bassi pathana	Fatehgarh Sahib U3	30.643	76.400	50.236
81	Fatehgarh Sahib	Sarhind	Innayatpur U2	30.629	76.413	30.479
82	Fatehgarh Sahib	Sirhind	Nalini	30.500	76.425	39.215
83	Fatehgarh	Sirhind	Nalini U2	30.534	76.403	34.315

	Sahib					
84	Fatehgarh Sahib	Sirhind	Nalini U3	30.503	76.421	47.694
85	Fatehgarh Sahib	Sirhind	Nalini U4	30.500	76.428	48.934
86	Fatehgarh Sahib	Sirhind	Bhaddal Thuha	30.591	76.233	45.023
87	Fazilka	Khuiyan Serovar	Sappanwali	30.097	74.083	43.040
88	Fazilka	Abohar	Dharangwala	30.235	74.240	118.815
89	Fazilka	Abohar	Gobindgarh	30.182	74.256	131.976
90	Fazilka	Abohar	Masir Dhani	30.163	74.163	76.806
91	Fazilka	Abohar	Dhani Sucha Singh	30.132	74.250	75.653
92	Fazilka	Abohar	Bazipur Bhoma	29.954	74.383	37.391
93	Fazilka	Abohar	Chak Radhewala	29.980	74.412	87.238
94	Fazilka	Abohar	Bazidpur Bhoma	29.964	74.378	46.780
95	Fazilka	Abohar	Telia ki Dhani	29.961	74.441	111.675
96	Fazilka	Jalalabad	Noore ke Uttar	30.681	74.280	99.488
97	Fazilka	Jalalabad	Mottiwala	30.713	74.356	37.525
98	Fazilka	Jalalabad	Swahwala	30.601	74.301	60.782
99	Fazilka	Fazilka	Deepulana	30.461	74.135	111.296
100	Fazilka	Fazilka	Kauranwali	30.383	74.056	31.254
101	Firozpur	Makhu	Chabba	31.031	74.932	34.052
102	Firozpur	Makhu	Thatha	31.025	74.915	32.383
103	Firozpur	Ferozepur	Jaimal Singh Wala	31.061	74.795	38.748
104	Firozpur	Gahll Khurd	Piyarana	30.884	74.720	73.499
105	Firozpur	Firozpur	Jhok harihar	30.862	74.611	35.232
106	Firozpur	Ferozepur	Moharewala	30.829	74.585	30.282
107	Firozpur	Mamdot	Sham Singhwala	30.792	74.512	38.834
108	Gurdaspur	Fatehgarh Churian	Madipur (Fatehgarh Churian)	31.864	74.958	68.405
109	Gurdaspur	Dinanagar	Saidowal	31.980	75.519	37.890
110	Hoshiarpur	Hoshiarpur II	Chohal-U-IV	31.594	75.937	63.173
111	Hoshiarpur	Dasuya	Dulmiwal-U-I	31.829	75.735	32.236
112	Hoshiarpur	Dasuya	Dulmiwal-U-IV	31.844	75.775	39.215
113	Hoshiarpur	Hoshiarpur II	Rampur Camp colony-**U-II**	31.495	75.939	37.330
114	Hoshiarpur	Hajipuur	Hajipur	31.975	75.758	112.977
115	Hoshiarpur	Dasuya	Dasuya	31.800	75.667	45.023
116	Jalandhar	Nur Mahal	Rampura	31.115	75.564	30.673
117	Jalandhar	Rurka Kalan	Goraya	31.233	75.533	35.252
118	Jalandhar	Adampur	Allawalpur	31.429	75.664	43.159
119	Kapurthala	Phagwara	phagwara	31.229	75.779	32.230
120	Kapurthala	Sultanpur Lodhi	Taspur	31.685	75.253	38.790
121	Kapurthala	Sultanpur Lodhi	Dalla	31.174	75.235	35.436
122	Kapurthala	Sultanpur Lodhi	Sultanpur Lodhi	31.219	75.200	57.834
123	Kapurthala	Sultanpur Lodhi	Talwandi Choudhurian	31.296	75.200	32.704

124	Kapurthala	Dhilwan	Bhatnura Khurd	31.566	75.591	101.566
125	Kapurthala	Dhilwan	Bholath	31.535	75.506	44.066
126	Ludhiana	Ludhiana II	Mangat	30.976	75.920	39.176
127	Ludhiana	Dehlon	Gopalpur	30.738	75.842	86.313
128	Ludhiana	Dehlon	Gopalpur	30.739	75.857	95.443
129	Ludhiana	Dehlon	Gopalpur	30.723	75.631	37.424
130	Ludhiana	Dehlon	Gopalpur	30.748	75.846	47.051
131	Ludhiana	Sudhar	Hallwara	30.728	75.642	40.341
132	Ludhiana	Ludhiana I	Chattar Singh Park	30.907	75.877	32.463
133	Ludhiana	Jagraon	Jagraon	30.852	75.474	31.466
134	Ludhiana	Jagraon	Jagraon	30.811	75.486	30.119
135	Ludhiana	Jagraon	Jagraon	30.800	75.495	46.066
136	Ludhiana	Ludhiana	P.A.U.Ludhiana	30.904	75.807	33.831
137	Ludhiana	Samrala	Begowal	30.817	76.056	37.310
138	Ludhiana	Jagraon	Rasulpur	30.699	75.394	50.095
139	Mansa	Bhikhi	Bhikhi	30.070	75.535	43.411
140	Mansa	Bhikhi	Kotra Kalan	30.055	75.492	84.911
141	Mansa	Jhunir	Raipur	29.904	75.257	45.052
142	Mansa	Sardulgarh	Fatta Maluka	29.771	75.303	103.746
143	Mansa	Sardulgarh	Jhanda Khurd	29.664	75.184	37.520
144	Mansa	Budhwala	Mofar	29.774	75.419	305.084
145	Mansa	Budhwala	Budhlanda	29.932	75.544	479.375
146	Mansa	Budhwala	Dialpura	29.893	75.664	101.225
147	Mansa	Budhwala	Budhlanda	29.932	75.518	71.086
148	Moga	Kote Ishe Khan	Baje Ke	30.824	75.026	33.840
149	Moga	Kote Ishe Khan	Baje Ke	30.996	75.192	34.262
150	Moga	Kote Ishe Khan	Baje Ke	30.984	75.194	66.409
151	Moga	Moga-I	Chogawan	30.840	74.963	42.299
152	Moga	Moga-I	Chogawan	30.813	75.275	43.375
153	Moga	Moga-I	Chogawan	30.824	75.268	49.446
154	Moga	Moga-I	Chogawan	30.826	75.261	43.707
155	Moga	Moga-I	Chogawan	30.833	75.267	34.191
156	Moga	Bagha Purana	Budh Singh Wala	30.836	75.269	41.304
157	Moga	Moga-I	Darapur	30.618	75.077	37.518
158	Moga	Moga-II	Jaisinghwala	30.728	75.072	97.793
159	Moga	Nihal singh wala	Nihalsinghwala	30.611	75.183	82.032
160	Muktsar	Muktsar	Labanianwali	30.586	74.548	32.255
161	Muktsar	Muktsar	Labanianwali	30.582	74.558	551.191
162	Muktsar	Muktsar	Khema Khera	30.039	74.428	37.940
163	Muktsar	Muktsar	Bhai ka Kher	30.077	74.416	74.397
164	Muktsar	Muktsar	Sham Khera	30.129	74.411	38.065
165	Muktsar	Malout	Kabarwala	30.193	74.410	35.995
166	Muktsar	Malout	Karamgarh	30.195	74.445	39.658
167	Muktsar	Malout	Sarawan	30.212	74.401	33.595
168	Muktsar	Malout	Pakki Tibbi	30.167		47.958
169	Muktsar	Muktsar	Buttar sarihn	30.357	74.683	89.956
170	Muktsar	Muktsar	Kothe sahib chand	30.306	74.711	221.532

171	Muktsar	Muktsar	chotian	30.288	74.728	48.407
172	Muktsar	Muktsar	Kothe kaur singh wale	30.352	74.730	173.201
173	Muktsar	Muktsar	Dohak	30.632	74.601	300.437
174	Muktsar	Muktsar	Muktsar	30.471	74.515	36.763
175	Muktsar	Lambi	Lambi	30.061	74.614	30.622
176	Muktsar	Muktsar	Doda	30.382	74.637	41.643
177	Nawanshahar	Nawanshahar	Behloor Kalan	31.018	76.156	63.173
178	Patiala	Ghanaur	Lacharu Kalan	30.350	76.632	43.313
179	Patiala	Sanour	Mardanheri	30.056	76.205	89.789
180	Patiala	Bagha Purana	Mardanheri	30.091	76.194	63.565
181	Patiala	Bagha Purana	Mardanheri	30.059	76.207	47.816
182	Patiala	Bagha Purana	Mardanheri	30.061	76.192	54.094
183	Patiala	Bagha Purana	Mardanheri	30.570	76.183	31.689
184	Patiala	Samana	Behmana	30.177	76.128	65.903
185	Patiala	Samana	Behmana	30.180	76.124	45.335
186	Patiala	Samana	Behmana	30.179	76.126	73.255
187	Patiala	Sangrur	Majji	30.306	76.128	30.490
188	Patiala	Sangrur	Majji	30.289	76.098	49.246
189	Patiala	Bhuner Heri	Devigarh	30.185	76.513	33.427
190	Patiala	Patiala	Lachkani	30.408	76.338	38.876
191	Patiala	Nabha	Allowal	30.438	76.290	34.914
192	Patiala	Patiala	Birkauli	30.414	76.514	49.372
193	Patiala	Ghanaur	LohaKheri	30.409	76.586	44.909
194	Patiala	Nabha	Chehal	30.546	76.238	46.451
195	Patiala	Nabha	Rajgarh	30.416	76.732	48.274
196	Patiala	Nabha	Dulladi	30.383	76.138	40.760
197	Patiala	Nabha	Ramgarh	30.555	76.715	33.880
198	Patiala	Nabha	Kalyan	30.353	76.308	46.717
199	Patiala	Patrah	Patran	29.950	76.056	58.504
200	Patiala	Rajpura	Rajpura	30.474	70.594	30.794
201	Patiala	Nabha	Bhojo majri	30.410	76.177	37.033
202	Patiala	Nabha	Sangatpura	30.342	76.225	47.953
203	Patiala	Sanaur	Balbhera			45.152
204	Roper	Nurpur Bedi	Dumewal U4	31.207	76.416	37.330
205	Roper	Anandpur Sahib	Bhalan	31.275	76.375	112.977
206	Sangrur	Amargarh	Maler Kotla	30.525	75.900	44.792
207	Sangrur	Amargarh	Maler Kotla	30.531	75.904	54.009
208	Sangrur	Amargarh	Maler Kotla	30.537	75.905	55.226
209	Sangrur	Sunam	sunam	30.157	75.836	50.041
210	Sangrur	Sunam	sunam	30.139	75.798	35.134
211	Sangrur	Sunam	sunam	30.124	75.817	32.847
212	Sangrur	Andana	Bhulan	29.763	76.010	33.031
213	Sangrur	Andana	Bhulan	29.763	76.018	49.880
214	Sangrur	Andana	Bhulan	29.763	76.009	63.565
215	Sangrur	Andana	Bhulan	29.790	76.000	49.934
216	Sangrur	Malerkotla-II	Baurhai Khurd	30.626	75.840	65.746
217	Sangrur	Dhuri	Bhojowali-	30.338	75.925	108.170
218	Sangrur	Dhuri	Benra	30.334	75.849	46.468
219	Sangrur	Dhuri	Ghanauri Kalan	30.410	75.770	46.017
220	Sangrur	Sangrur	Longowal	30.192	75.675	83.477
221	Sangrur	Sangrur	Badrukhan	30.251	75.797	89.191
222	Sangrur	Lehra Gaga	Chural Kalan	29.819	75.800	393.989

223	Taran Taran	Tarn Taran	Chabal	31.481	74.800	83.975
224	Tarn Taran	Patti	Barwala	31.224	74.803	106.244
225	Tarn Taran	Patti	Rattoke	31.150	74.633	43.079
226	Tarn Taran	Bhikhiwind	Aminsha Khalra	31.396	74.625	202.713

10.0 Bibliography

- APHA (2017), "Standard Methods for the Examination of Water and Wastewater (22th Ed.)".Washington, Dc: American Public Association.
- CGWB (2018), "Ground Water Quality In Shallow Aquifers of India". Faridabad: Central Ground Water Board, Ministry of water Resources, Government of India.
- Drinking water standards of BIS 10500: 2012.
- Karanth K.R. (1997), „Groundwater Assessment, Development and Management. New Delhi, India‟: Tata Mcgraw-Hill Publishing Company Limited.
- Todd D.K., Groundwater Hydrology. John Wiley and sons Inc. Newyork, 1976
- USSL (1954), Diagnosis and improvement of saline and alkali soils. USDA Agr. Handbook No. 60,Washington DC.
- Freeze, R.A., and Cherry, J.A., 1979, Groundwater: New Jersey, Prentice Hall.
- Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey, Water Supply Paper.2254.
- L.V. Wilcox, (1955), "Classification and Use of Irrigation Waters", U.S. Department of Agriculture Circle, Amer. J. of Science, Vol,8, No.3, pp. 123128.
- N. Manivasagam (1984), Physico-Chemical Examination of Water, Sewage And Industrial Effluents, PragatiPrakashan, Meerut.
- Piper, A.M., 1944, A graphical procedure in the geochemical interpretation of water analysis: American Geophysical Union Trans., v. 25, p. 914-923.