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मेघालय के सतही जलभृत में भूजल की गुणवत्ता

GROUNDWATER QUALITY IN SHALLOW AQUIFER OF MEGHALAYA

केंद्रीय भूजल बोर्ड

Central Groundwater Board

जल संसाधन, नदी विकास और गंगा संरक्षण विभाग

Department of Water Resources, River Development and Ganga Rejuvenation

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FOREWORD

Groundwater serves as an important source for drinking water and irrigation in Meghalaya. Of late, owing to increased anthropogenic activities as well as geogenic actions groundwater quality issues have posed a threat in the state. Hence it is crucial to have prior information on the groundwater quality available in Meghalaya for judicious management of this resource.

The Central Ground Water Board, North Eastern Region, regularly monitors the quality, quantity, availability, and non-availability of groundwater in the state through a network of various Groundwater Monitoring Stations (GWMS), mainly representing dug wells. Samples are collected during the month of March/April every year, following standard practice of collection and analysis.

Sixteen physico-chemical parameters including pH, EC, TDS, turbidity, carbonate and bicarbonate alkalinity, total alkalinity, calcium, magnesium, total hardness, chloride, sodium, potassium, sulphate, nitrate, and fluoride were analyzed for the samples collected within the state. Heavy metals, viz., Iron and Arsenic and radioactive Uranium content of the samples were also being considered for a holistic approach in characterizing the groundwater quality of Meghalaya.

The dedicated efforts of the officers of the Board for compiling the data and preparing the report deserve appreciation. This report will help in better understanding the quality aspects of groundwater resources in Meghalaya and will be a valuable guide for planners, policymakers, administrators, and all other stakeholders to optimize the development and management of this precious resource in the state.

Regional Director
Central Ground Water Board
North Eastern Region

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Groundwater is a primary source of water supply for irrigation, domestic and industrial. It is a crucial factor in India's socioeconomic growth. Despite possessing only 4% of the world's fresh water resources, India sustains over 16% of the global population and presently faces an acute water crisis. According to the safe water index survey, India ranks second to last among 123 countries. Though groundwater is less susceptible to pollution compared to surface water, reckless exploitation and overuse of groundwater resources may result in declining groundwater levels and diminished water quality.

In addition, there is mounting concern about the degradation of groundwater quality caused by both geogenic processes and human activities. The potential contamination of groundwater used for public and rural domestic purposes is of particular concern. Furthermore, atmospheric precipitation, inland surface water, recharge water quality, and geochemical processes also impact groundwater quality. Groundwater contamination can have a significant impact on human health, economic development, and social well-being. In Northeast, as in other parts of India, anthropogenic activities can negatively impact groundwater quality. To effectively manage groundwater, it is necessary to have comprehensive data on its current and potential quality. Therefore, a thorough understanding of water resource quality in the State of Meghalaya is paramount for prudent groundwater management.

Natural and anthropogenic processes shape the character of groundwater. Among the natural factors that affect initial water quality are:

1. Precipitation chemistry.
2. Leaching of organic and mineral materials from soil, rocks, and vegetation as water infiltrates the earth's surface and passes through geological materials.
3. Duration of contact with soil and rocks.

Groundwater contains a variety of dissolved inorganic chemical constituents in different concentrations, which result from chemical and biochemical interactions between water and geological formations. These factors establish the levels of dissolved minerals in groundwater. Groundwater quality is also affected by contributions from the atmosphere, surface water bodies, and anthropogenic factors. Human activities alter water quality by drawing water from the groundwater system or introducing chemicals and pollutants directly into aquifers. Waste discharges from agricultural, industrial, and urban sources typically introduce contaminants into groundwater. The sources of waste and associated types of pollutants that are most likely to impact groundwater quality in the North Eastern Region are itemized in **Table 1.1.**

Table 1.1: Natural and human factors affecting quality of groundwater.

Natural factors		Human factors	
Source	**Types of contaminant**	**Sources**	**Types of contaminant**
Precipitation	Dissolved gases, dust and emission products	Agricultural	Fertilizers, pesticides and herbicides
Infiltration	Organic material, mineral, biochemical products etc.	Urban activities	Solids, organic matter, nitrates, metallic trace elements, detergents, chloride etc.
Aquifer rocks	Mineral contents	Mining	Metallic trace elements and phosphates
		Industrial facilities	Biochemical Oxygen Demand, sodium, chloride, suspended solids

Thus, investigating the quality of groundwater is crucial in groundwater research. The variability of groundwater quality in a region is a function of physicochemical parameters that are greatly influenced by geological formations and anthropogenic activities. The current document proffers detailed insight into the quality of groundwater in all districts of Meghalaya.

This report has been compiled in order to give insight of mounting concerns regarding the degradation of groundwater quality. Accordingly, an attempt has been made to provide a comprehensive overview of various facets of groundwater quality in the shallow aquifers of Meghalaya, with particular emphasis on diverse parameters such as pH, electrical conductivity, total dissolved solids (TDS), turbidity, carbonate and bicarbonate alkalinity, calcium, magnesium, total hardness, chloride, sodium, potassium, sulphate, nitrate, fluoride, various trace metals and radioactive uranium.

1.2 STUDY AREA

Meghalaya—in Sanskrit is *alaya* ("abode") and *megha* ("of the clouds")— is a state located in northeastern part of India. It is geographically termed the Shillong Plateau or the Meghalaya Plateau. It is bounded by the Indian state of Meghalaya (Goalpara, Kamrup and Nowgong districts of Assam) to the north and (Karbi Anglong district and North Cachar Hills of Assam) to the northeast and by Bangladesh to the south and southwest. The state capital is Shillong, situated in east-central Meghalaya. It is located between Latitude 20°1'N & 26°5'N and Longitude 85°49'E & 92°52'E. Meghalaya occupies a total land area of 22,429 square kms. The total population is reported to be 1,774,778. The whole state has been divided into twelve districts namely East Garo Hills, North Garo Hills, South Garo Hills, West Garo Hills, South West Garo Hills, East Khasi Hills, East Jaintia Hills, West Jaintia Hills, SW Khasi Hills, West Khasi Hills, Eastern West Khasi Hills, Ri Bhoi.

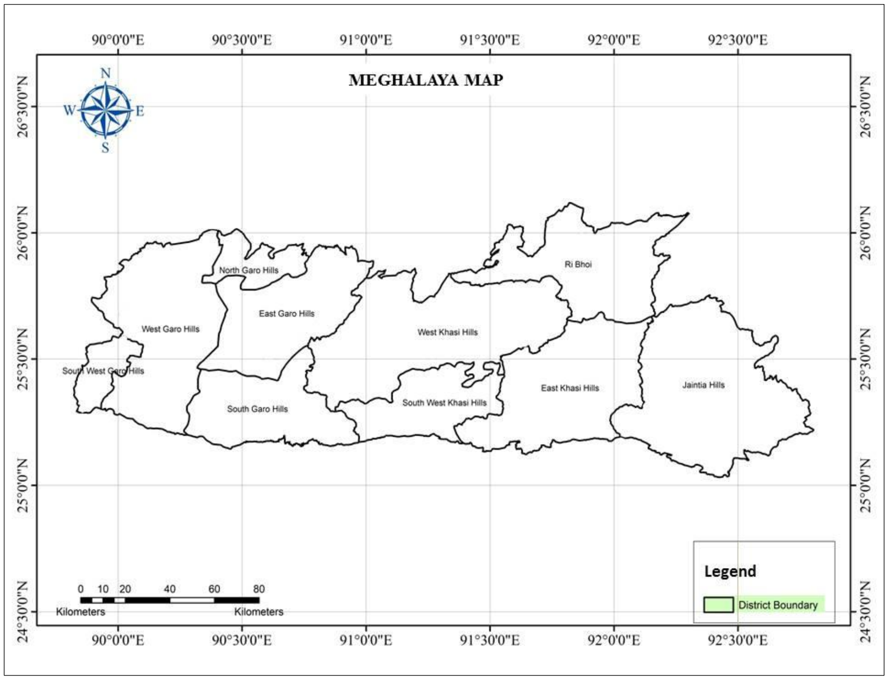

Figure 1. 1: Study area map

1.3 CLIMATE & RAINFALL

Meghalaya climate varies with altitude. Higher the altitude, cooler the climate. This is the reason why Khasi and Jaintia Hills have more soothing climate than Garo Hills. Between November and April, the climate is mostly dry while from May to October it rains heavily. This is then followed by winter from December to February.

The northern Meghalaya receives an average yearly rainfall between 2500 to 3000 mm and the annual shower is around 2600 mm in the western part of the north eastern state while the south eastern Meghalaya gets yearly rainfall above 4000 millimeters. It is Cherrapunji that receives the highest rainfall somewhere around 12000 millimeters annually. With such high amount of rainfall, Mawsynram, near Sohra (Cherrapunji), holds the record for the wettest place on Earth with 12,270 mm of rainfall. This place has the world record for receiving the longest duration of rainfall in a calendar year.

1.4. GEOLOGY

The Shillong Plateau or the Meghalaya Plateau has a length of about 300 kilometers from east to west and a width of 100 kilometers. An important aspect of the geography in Meghalaya is its rock formations; some of which are the oldest. Geologically the Meghalaya Plateau is comprised of rocks from the oldest Precambrian gneissic complex to the recent alluvium formations. Meghalaya represents the extension of peninsular India towards the north-east. The height of the dissected Meghalaya Plateau is 150 meters - 1961 meters above sea level. The stratrigraphic sequence is as below:

1. Cretaceous –Tertiary sediments occupy southern part of the Meghalaya plateau comprises of the Khasi Group, the Jaintia Group and the youngest formation the Garo Group.
2. The Sylhet trap is exposed in a narrow E-W strip along the southern border of Khasi Hills.
3. Lower Gondwana rocks are recognized at the western part of Garo Hills.
4. Shillong Group of rocks exposed in the central, eastern and northern parts of the Meghalaya plateau.
5. Precambrian gneissic complex (Basement gneiss).

The Dupi Tilla group of mid-Pliocene age occurs in the west of Garo Hills and towards southern part of Khasi Hills. Along the southern and western borders of the state isolated patches of older alluvium is found. Shillong Group was classified into Upper Shillong Formation (mid-Proterozoic) and Lower Shillong Formation (early Proterozoic) by CGWB (2012). Upper Shillong Group is also known as Shillong Formation or Upper Quartzite Formation (Barooah and Goswami, 1972) or Mawphalang Formation (Battarcharjee and Rahman, 1985) or Shillong Formation (Ahmed, 1981).

1.5 RIVERS & VEGETATION

The drainage pattern in the state reveals straight courses of rivers as well as streams markedly along the joints and faults. Rivers in the southern Khasi and Jaintia Hills scooped out magnificent gorges. Towards the west of the Garo Hills the subsequent streams are typically controlled by the structures, faults and monoclines in the sedimentary rock. A number of rivers, such as Umtrew, Umiam, Umkhen in the northern parts and Umiew (Shella), Umngot, Umngi (Balat) in the southern part flow through the Shillong pleateau. The rivers present in the northern part of the state drain into the Brahmaputra River (India), while southern rivers drain into the Surma River (Bangladesh).

Shillong plateau being mountainous and undulating, the groundwater in Meghalaya is influenced by the topography, presence of rock fractures, weathering zones. Springs, seepages, wells, and bore wells are some forms in which groundwater resources are available. Most of the area is occupied by the quartzite and granite rocks having groundwater potential of 5–15 m^3/hr.

Meghalaya has diverse natural vegetation - the Garo hills tropical mixed forests to the high-altitude pine forests. Unplanned cutting and grazing have destroyed the natural vegetation of the place. Some forests are destroyed, while some other inaccessible ones are unaffected. Pine, sal, bamboo, etc are rampant in the region.

1.6 HYDROGEOLOGY

Meghalaya's general hydrogeological framework can be classified as follows:

1. Unconsolidated sediments like sand, silt and clay, that have thick, continuous aquifer are found in western, northern and southern fringes of Meghalaya. There groundwater occurs under unconfined to semi-confined conditions with depth to water level at 3-5 mbgl.
2. Another formation with Garo group comprised of coarse sandstone, siltstone, clay, conglomerate, silty clay and fossiliferous limestone alongwith Barail group having shale, minor coal lenses carbonaceous shale are in West Garo Hills area. There thick, discontinuous aquifer is encountered down to 250 mbgl. Depth to water level rests at 4-9 mbgl.
3. Jaintia group and Khasi group are comprised of shale, sandstone, marble, calcareous shale, Arkosic sandstone. They have discontinuous aquifer in the

cavernous limestones and sandstones area with groundwater occurring under unconfined to semi-confined conditions while depth to water level at 2-4 mbgl.

4. Shillong group with quarzite, phyllite, quartzsericite schist, conglomerate and Meghalaya Archaean gneissic complex formed of granite gneiss, biotite gneiss, mica schist, silliminite- quartz schist, pyroxene granulite, etc. both have groundwater under unconfined to semi-confined conditions. There the aquifer formed by weathered and fractured zones extends to 150 mbgl. In this formation has depth to water level rests at 7-17 mbgl.

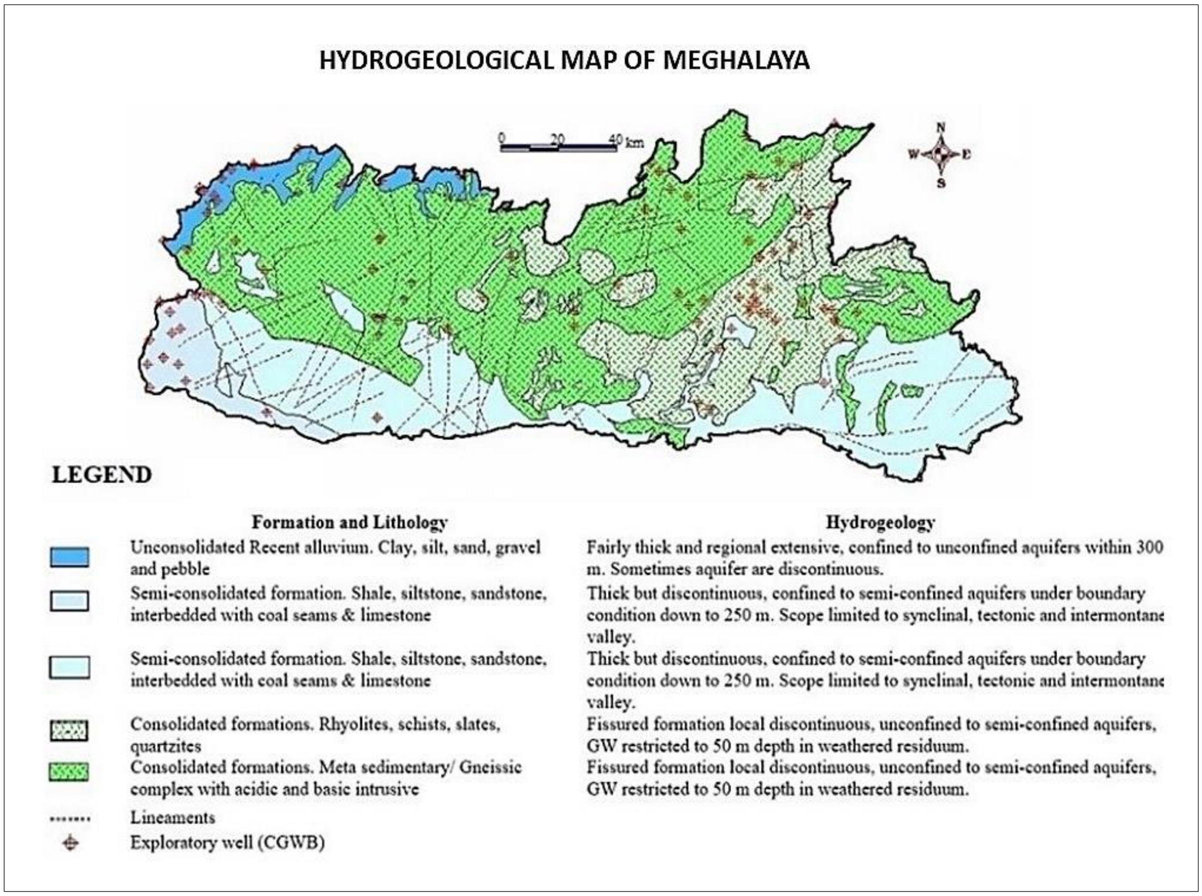

Figure 1.2: Hydrogeological map of Meghalaya

1.7 HYDROCHEMISTRY

Hydrochemistry is an interdisciplinary field that focuses on the chemical properties of water in the natural environment. To fully understand hydrochemistry and its effects on pollution, it is necessary to study atmospheric water (i.e. rainwater), surface water, and groundwater simultaneously. The atmosphere contains various gaseous components, such as N_2,

O_2, CO_2, CH_4, CO, SO_x, NO_x as well as water vapours and dust particles. The wind can transport these pollutants over long distances, and are typically deposited onto the earth's surface as precipitation or dry fallout. The chemical composition of rainwater is influenced by the source of water vapours and the ions that are picked up during transport through the atmosphere.

The chemical composition of surface water is highly variable due to the relative contributions of groundwater and surface water sources. Typically, the mineral content in river water has an inverse relationship with its discharge. The mineral content of river water generally increases from the source to the mouth, although this increase may not be consistent or uniform. Additionally, the discharge of city wastewater, industrial waste, and mixing of waters can also impact the concentration and nature of minerals present in surface water. Bicarbonates are the most significant anions present, constituting over 50% of the total anions in terms of milliequivalent per liter (meq/L). In terms of cations, calcium is typically the most prevalent alkaline earth present.

The downward movement of water through soil is not a passive process; as it moves, it becomes enriched in CO_2. This can make it a powerful agent of weathering and its general solution effects. Therefore, groundwater's chemical makeup is influenced by various factors, including the frequency of rainfall, which leaches out salts; the time that rainwater spends in the root zone and intermediate zone; and organic matter. Additionally, the groundwater front does not move uniformly, as the soil strata are usually heterogeneous. The flow of percolating water through larger pores is much faster than through finer pores. The net result of all these factors is that the composition of groundwater can vary from place to place and over time. Before reaching the saturated zone, percolating water is charged with oxygen and CO_2, and is particularly aggressive in the initial stages. However, as free CO_2 associated with the percolating water is gradually consumed through interaction with minerals, the water becomes less aggressive.

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

$$H^+ + Feldspar + H_2O \rightarrow Clay + H_4SiO_4 + Cation$$

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.

$$CH_2O + O_2 = CO_2 + H_2O$$

(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.

1.8 GROUNDWATER MONITORING & METHODOLOGY

Monitoring of groundwater quality is an effort to obtain information on chemical quality through representative sampling in different hydrogeological units. Groundwater is commonly tapped from phreatic aquifers through dug wells in a major part of the region and through springs and hand pumps in hilly areas. The main objective of groundwater quality monitoring programme is to get information on the distribution of water quality on a regional scale as well as create a background data bank of different chemical constituents in groundwater.

Central Groundwater Board, North Eastern Region, has set up a number of Groundwater Monitoring Wells (GWMW) in different hydrogeological conditions in order to know groundwater condition and its variation, in both time and space. Monitoring of water levels and collections of water samples are being carried out periodically to observe any change in water level and its quality consequent to changes in inputs and outputs. To establish the groundwater chemistry of the state, samples from different corners of the state have been collected during the month of March/April (Pre-monsoon) which is generally a dry period, leading to maximum concentration of elements in the water samples and Post monsoon samples are collected during the month of November. For the state of Meghalaya 39 samples were collected for pre-monsoon and 74 were collected for post-monsoon analysis.

Standard procedures and guidelines of sampling, storing, and transferring were strictly followed as prescribed by American Public Health Association (APHA 2017). 1000 mL of samples were collected in high-density polyethylene bottles (HDPE) without preservatives for physical and major solutes analysis. On-site sampling and sample filtration using 0.45 µm membrane by syringe filtration technique in 60 mL HDPE bottles were carried out to analyze uranium and heavy metals. Immediately after filtration, 0.5 mL trace elemental grade HNO_3 acid is added as preservatives. Caution was being taken while bottling the samples to avoid interference from the air headspace. Standard analysis procedures (APHA, 2017) were employed for analyzing the groundwater samples as shown in **Table 1.2**.

Table 1.2: Analytical methods/equipment for Groundwater quality analysis.

Parameters	Method adopted	Instrument/technique used
PHYSICO-CHEMICAL		
pH	Electrometric method	pH meter
Conductivity	Electrometric method	Conductivity meter
Turbidity	Turbidimetric method	Nephalo-turbidity meter
TDS	Electrometric	Conductivity/TDS Meter
Alkalinity	Titrimetric method	(Titration by H_2SO_4)
Chloride (Cl)	Argentometric /Chromatographic method	(Titration by $AgNO_3$)/Ion Chromatograph
Sodium (Na)	Flame Emission Spectroscopy/ Chromatographic method	Flame photometer/ Ion Chromatograph
Potassium (K)	Flame Emission Spectroscopy/ Chromatographic method	Flame photometer / Ion Chromatograph
Total Harness	Titrimetric method	(Titration by EDTA)
Calcium (Ca)	Titrimetric method/ Chromatographic method	(Titration by EDTA)/ Ion Chromatograph
Fluoride (F^-)	Electrometric method/ Chromatographic method	Ion Meter/ Ion Chromatograph
Sulphate (SO_4^{-2})	Turbidimetric method/ Chromatographic method	UV-visible Spectrophotometer/ Ion Chromatograph
Nitrate (NO_3^-)	Ultraviolet screening/ Chromatographic method	UV-visible Spectrophotometer/ Ion Chromatograph
Phosphate	Molybdophosphoric acid/ Chromatographic method	UV-VIS Spectrophotometer / Ion Chromatograph
Dissolved Oxygen (DO)	Electrometric	DO meter
HEAVY METALS AND RADIOACTIVE URANIUM		
Uranium (U)	Plasma Spectroscopy/Fluorescence Spectrometry	ICP-MS/Uranium analyzer
Iron (Fe)	Colorimetric method/Atomic absorption spectroscopy/Palsma Spectroscopy	UV-visible Spectrophotometer/AAS
Arsenic	Hydride generation/ Plasma Spectroscopy	AAS/ICPMS
Cr, Mn, Fe, Ni, Cu, Zn, Se, Ag, Cd and Pb	Atomic Spectroscopy/ Plasma Spectroscopy	AAS/ICPMS
Mercury	Cold Vapour Generation followed by tomic Spectroscopy/ Plasma Spectroscopy	Mercury Analyser/AAS
Arsenic (+3 & +5)	Ion chromatography	Ion chromatograph

During the analysis, QA/QC protocols were followed, including blank run, external calibration, and standardization by NIST certified standard reference materials, retesting, etc. Physical water quality parameters pH, EC, TDS, and turbidity were measured by pH-meter, conductivity meter, and nephalo-turbidity meter. Na and K were analyzed in a flame-photometer. NO_3^- and SO_4^{2-} analyses were done in UV-Visible spectrophotometer (Labindia, UV-3200), setting the λ_{max} at 220 nm and 420 nm, respectively. For fluoride analysis ion-meter (Oakton Ion 700) was used. Total hardness (TH) as $CaCO_3$, CO_3^{2-}, HCO_3^- and Cl^- were analyzed using the volumetric titration method. The ionic balance errors (%IBE) for all groundwater samples were found to be within the recommended limit of 5% (Wu et al., 2014; Burton, 1983). During Pre-monsoon Fe and As were analysed by Atomic Absorption Spectophotometer (PG Instruments AA8000) using flame and hydride mode respectively. Whereas U was analysed in LED Fluorimeter (Quantalase LF-2) using measurement of green fluorescence. For Post-monsoon analysis the heavy metals, viz., U, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Ag, Cd and Pb in groundwater were analyzed in Inductively coupled plasma mass spectrometry, ICP-MS (Agilent 8900 series). The calibration curves were linear with a correlation coefficient of (R2) ~ 0.993-1.000 for U and metals.

CHAPTER 2

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 groundwater 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 groundwater 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 us"'. 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 (**Table 2.1**).

Table 2.1: Water quality criteria parameters for various uses

Public Water supply	Industrial Water supply	Agricultural Water supply	Aquatic life & Wild life Water supply	Recreation and Aesthetics
Coliform bacteria, Turbidity, colour, Taste, Odour, TDS, CI, F, SO4, NO3, 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	Farmstead Same as for public supply Live-stock Same as for public supply Irrigation TDS, EC, Na, Ca, Mg, K, B, Cl and Trace metals	Temp, DO, pH, Alkalinity, Acidity,TDS Salinity, pH, DCOs, Turbidity, Colour, Settleablem aterials, Toxic substances, Nutrients, Floating materials	Recreations, Turbidity, Colour, Odour, Floating Materials, Settable Materials Nutrients, Coliforms. Aesthetics Same as for Recreation and Substances adversely affecting wild life

2.1 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 downby 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 assesssuitability of water for drinking purposes.The important water quality characteristics as laid down in BIS standard (IS 10500: 2012) are summarized in **Table 2.2.**

Table 2.2: 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.

2.2 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 represented in **Table 2.3.**

Table 2.3: Safe Limits for electrical conductivity for irrigation water (IS:11624-1986)

S. No.	Nature of soil	Crop Growth	Upper permissible safe limit of electrical conductivity in water µS/cm at 25°C
1	Deep black soil and alluvial soils having clay content more than 30%; soils that are fairly to moderately well drained	Semi-tolerant	1500
		Tolerant	2000
2	Textured soils having clay contents of 20-30%; soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3	Medium textured soils having clay 10-20%; internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4	Light textured soils having clay less than 10%; soils that have excellent internal and surface drainage system.	Semi-tolerant	6000
		Tolerant	8000

In addition to problems caused by total amount of salts, some of the specific ions like sodium, boron and trace elements, if present in water in excess, also render it unsuitable for agricultural use.

2.3 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 2.4**). 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 2.4: 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 (Hazen unit)	5	15	Makes water aesthetically undesirable
2	Odour	Essentially free from objectionable odour		Makes water aesthetically undesirable
3	Taste	Agreeable		Makes water aesthetically undesirable
4	Turbidity (NTU)	1	5	High turbidity indicates contamination/Pollution.
5	pH	6.5	8.5	Indicative of acidic or alkaline waters, affect staste, corrosivity and the water supply system
6	Hardness as $CaCO_3$ (mg/L)	200	600	Affects water supply system (Scaling), Excessive soap consumption, and calcification of arteries. There is no conclusive proof but it may cause urinary concretions, diseases of kidney or bladder and stomach disorder.
7	Iron (mg/L)	1.0	No relaxation	Gives bitter sweet a stringent taste, causes staining of laundry and porcelain. In traces it is essential for nutrition.

S. No.	Parameters	Prescribed limits IS:10500, 2012 Desirable Limit	Permissible Limit	Probable Effects
8	Chloride (mg/L)	250	1000	May be injurious to some people suffering from diseases of heart or kidneys. Taste, indigestion, corrosion and palatability are affected.
9	Residual Chlorine (mg/L) Only when water is Chlorinated	0.20	-	Excessive chlorination of drinking water may cause asthma, colitis and eczema.
10	Total Dissolved Solids- TDS (mg/L)	500	2000	Palatability decreases and may cause gastro intestinal irritation inhuman, may have laxative effect particularly upon transits and corrosion may damage water system.
11	Calcium (Ca) (mg/L)	75	200	Causes encrustation in water supply system. While insufficiency causes a severe type of rickets, excess causes concretions in the body such as kidney or bladder stones and irritation in urinary passages.
12	Magnesium (Mg) (mg/L)	30	100	Its salts are cathartics and diuretic. High concentration may have laxative effect particularly on new users. Magnesium deficiency is associated with structural and functional changes. It is essential as an activator of many enzyme systems.
13	Copper (Cu) (mg/L)	0.5	1.50	A stringent 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 enhances corrosion of aluminum in particular.
14	Sulphate (SO_4) (mg/L)	200	400	Causes gastro intestinal irritation along with Mg or Na, can have acathartic effect on users, concentration more than 750mg/L may have laxative effect along with Magnesium.

S. No.	Parameters	Prescribed limits IS:10500, 2012		Probable Effects
		Desirable Limit	Permissible Limit	
15	Nitrate (NO_3) (mg/L)	45	No relaxation	Cause infant methaemoglobin aemia (blue babies) at very high concentration, causes gastric cancer and affects adversely Central nervous system and cardiovascular 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.
18	Lead (Pb) (mg/L)	0.01	No relaxation	Toxic in both acute and chronic exposures. Burning in the mouth, severe inflammation of the gastro-intestinal tract with vomiting and diarrhoea, chronic toxicity produces nausea, severe abdominal pain, paralysis, mental confusion, visual disturbances, anaemia etc.
19	Zinc (Zn) (mg/L)	5	15	An essential and beneficial element in human metabolism.Taste threshold for Zn occurs at about 5 mg/L imparts a stringent taste to water.
20	Chromium (Cr) (mg/L)	0.05	No relaxation	Hexa valent state of Chromium produces lung tumors can produce cutaneous and nasal mucous membrane ulcers and Dermatitis.
21	Boron (B) (mg/L)	0.5	2.4	Affects central nervous system its salt may cause nausea, cramps, convulsions, coma etc.
22	Alkalinity (mg/L) as $CaCO_3$	200	600	Impart distinctly unpleasant taste may be deleterious to human being in presence of high pH, hardness and total dissolved solids.

S. No.	Parameters	Prescribed limits IS:10500, 2012 Desirable Limit	Permissible Limit	Probable Effects
23	Pesticides: (mg/l)	Absent	0.001	Imparts toxicity and accumulated in different organs of human body affecting immune and nervous systems may be carcinogenic.
24	Phosphate (PO_4) (mg/L)	No guideline		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 are 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.
29	Pathogens (a)Total coliform (per 100mL) (b) Faecal Coliform (per 100mL)	nil		Cause water borne diseases like coliform Jaundice, Typhoid, Cholera etc. produce infections involving skin mucous membrane of eyes, ears and throat.
30	Arsenic (As) (mg/L)	0.01	No relaxation	Various skin diseases, Carcinogenic
31	Uranium (U) (mg/L)	0.03	No relaxation	Kidney disease, Carcinogenic

CHAPTER 3

GROUNDWATER QUALITY SCENERIO IN MEGHALAYA FOR DRINKING PURPOSES

Different physical parameters studied are appearance, colour, odour, taste, turbidity, electrical conductivity and total dissolved solids. Different chemical parameters studied are pH, alkalinity, total hardness, calcium, magnesium, iron, sodium, potassium, nitrate, chloride, fluoride, sulphate, trace metals and uranium. The values were compared with the values of drinking water standard of BIS (IS 10500:2012) and WHO (2017) for uranium. The overall chemical quality of Meghalaya is provided in **Annexure I to VIII**.

3.1 Drinking water specification as per 10500:2012

Values of drinking water standard of BIS (IS 10500:2012) are given in **Table 3.1 to Table 3.4**.

Table 3.1: Organoleptic and Physical Parameters [BIS, IS 10500]

(*Foreword* and *Clause 4*)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the absence of Alternate Source	Method of Test
i)	Odour	Agreeable	Agreeable	Part 5
ii)	pH value	6.5-8.5	No relaxation	Part 11
iii)	Taste	Agreeable	Agreeable	Parts 7 and 8
iv)	Turbidity, NTU, *Max*	1	5	Part 10
v)	Total dissolved solids, mg/l, *Max*	500	2000	Part 16

NOTE — It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

Table 3.2: General Parameters Concerning Substances Undesirable in Excessive amounts [BIS, IS 10500]

(*Foreword* and *Clause* 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the absence of Alternate Source	Method of Test
i)	Aluminium (as Al), mg/L, *Max*	0.03	0.2	IS 3025 (Part 55)
ii)	Ammonia (as total ammonia-N), mg/L, *Max*	0.5	No relaxation	IS 3025 (Part 34)
iii)	Anionic detergents (as MBAS), mg/L, Max	0.2	1.0	Annex K of IS 13428
iv)	Barium (as Ba), mg/L, *Max*	0.7	No relaxation	Annex F of IS 13428* or IS 15302
v)	Boron (as B), mg/L, *Max*	0.5	1.0	IS 3025 (Part 57)
vi)	Calcium (as Ca), mg/L, *Max*	75	200	IS 3025 (Part 40)
vii)	Chloramines (as Cl_2), mg/L, *Max*	4.0	No relaxation	IS 3025 (Part 26)* or APHA 4500-Cl G
viii)	Chloride (as Cl), mg/L, *Max*	250	1 000	IS 3025 (Part 32)
ix)	Copper (as Cu), mg/L, *Max*	0.05	1.5	IS 3025 (Part 42)
x)	Fluoride (as F) mg/L, *Max*	1.0	1.5	IS 3025 (Part 60)
xi)	Free residual chlorine, mg/L, *Min*	0.2	1	IS 3025 (Part 26)
xii)	Iron (as Fe), mg/L, *Max*	1.0	No relaxation	IS 3025 (Part 53)
xiii)	Magnesium (as Mg), mg/L, *Max*	30	100	IS 3025 (Part 46)
xiv)	Manganese (as Mn), mg/L, *Max*	0.1	0.3	IS 3025 (Part 59)
xv)	Mineral oil, mg/L, *Max*	0.5	No relaxation	Clause 6 of IS 3025 (Part 39) Infrared partition method
xvi)	Nitrate (as NO_3^-), mg/L, *Max*	45	No relaxation	IS 3025 (Part 34)
xvii)	Phenolic compounds (as C_6H_5OH), mg/L, *Max*	0.001	0.002	IS 3025 (Part 43)
xviii)	Selenium (as Se), mg/L, *Max*	0.01	No relaxation	IS 3025 (Part 56) or IS 15303*
xix)	Silver (as Ag), mg/L, *Max*	0.1	No relaxation	Annex J of IS 13428
xx)	Sulphate (as SO_4^{2-}) mg/L, *Max*	200	400	IS 3025 (Part 24)
xxi)	Sulphide (as H_2S), mg/L, *Max*	0.05	No relaxation	IS 3025 (Part 29)
xxii)	Total alkalinity as calcium carbonate, mg/L, *Max*	200	600	IS 3025 (Part 23)
xxiii)	Total hardness (as $CaCO_3$), mg/L, *Max*	200	600	IS 3025 (Part 21)
xxiv)	Zinc (as Zn), mg/L, *Max*	5	15	IS 3025 (Part 49)

NOTES

1 In case of dispute, the method indicated by '*' shall be the referee method.

2 It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

Table 3.3: Parameters Concerning Toxic Substances [BIS, IS 10500]

(Foreword and Clause 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the absence of Alternate Source	Method of Test
i.	Cadmium (as Cd), mg/L, *Max*	0.003	No relaxation	IS 3025 (Part 41)
ii.	Cyanide (as CN), mg/L, *Max*	0.05	No relaxation	IS 3025 (Part 27)
iii.	Lead (as Pb), mg/L, *Max*	0.01	No relaxation	IS 3025 (Part 47)
iv.	Mercury (as Hg), mg/L, *Max*	0.001	No relaxation	IS 3025 (Part 48)/ Mercury analyser
v.	Molybdenum (as Mo), mg/L, *Max*	0.07	No relaxation	IS 3025 (Part 2)
vi.	Nickel (as Ni), mg/L, *Max*	0.02	No relaxation	IS 3025 (Part 54)
vii.	Polychlorinated biphenyls, mg/L, *Max*	0.0005	No relaxation	ASTM 5175* or APHA 6630
viii.	Polynuclear aromatic hydro-carbons (as PAH), mg/L, *Max*	0.0001	No relaxation	APHA 6440
ix.	Total arsenic (as As), mg/L, *Max*	0.01	No	IS 3025 (Part 37)
x.	Total chromium (as Cr), mg/L, *Max*	0.05	No relaxation	IS 3025 (Part 52)
xi.	Trihalomethanes:			
	a) Bromoform, mg/L, *Max*	0.1	No relaxation	ASTM D 3973-85*or APHA 6232
	b) Dibromochloromethane, mg/L, *Max*	0.1	No relaxation	ASTM D 3973-85*or APHA 6232
	c) Bromodichloromethane, mg/L, *Max*	0.06	No relaxation	ASTM D 3973-85*or APHA 6232
	d) Chloroform, mg/L, *Max*	0.2	No relaxation	ASTM D 3973-85* or APHA 6232

NOTES

1. In case of dispute, the method indicated by '*' shall be the referee method.
2. It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under ‘acceptable’ render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source’ in col 4, above which the sources will have to be rejected.

Table 3.4: Parameters Concerning Radioactive Substances [BIS, IS 10500]

(Foreword and Clause 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the absence of Alternate Source	Method of Test
	Radioactive materials:			
	a) Alpha emitters Bq/L, Max	0.1	No relaxation	Part 2
	b) Beta emitters Bq/L, Max	1.0	No relaxation	Part 1

NOTE — It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

3.2 Groundwater quality for drinking purposes in Meghalaya

To assess the suitability of groundwater samples for the drinking purpose, results of the physico-chemical analysis of groundwater samples were compared with Bureau of Indian Standards prescribed for drinking water. The summary of the physico-chemical of groundwater samples collected from Meghalaya during pre-monsoon and post-monsoon season are presented in **Table 3.5 and 3.6**. The mean, minimum and maximum values of the physicochemical parameters of groundwater samples collected during pre-monsoon and post-monsoon samples are depicted in the tables. The summary of the samples exceeding desirable and permissible limits are given alongside.

3.2.1. Pre-monsoon groundwater quality for drinking purposes in Meghalaya

For the pre-monsoon season pH values of ~70% of the samples are within the BIS limit of 6.5 to 8.5 while 30.7% have pH less than 6.5 with the minimum pH being recored at 5.72. All the samples have EC are less than 3000 µS/cm and subsequently TDS values are also below the BIS permissible limit of 2000 mg/L. Turbidity of all the samples are below desirable limit of 1 NTU except for 1 sample from Ri Bhoi district is having 1.3 NTU. From the mean concentration (mg/L) of cations the order of the cations is Ca^{2+}> Na^{+}> Mg^{2+}> K^{+} while that of the anions varies as HCO_3^{-}> Cl^{-}> SO_4^{2-}> NO_3^{-} >F^{-}. Concentration of all the ionic species analysed are within the BIS drinking water permissible limits. Heavy metals analysed during pre-monsoon are Iron

($Fe^{+2/+3}$) and Arsenic ($As^{+2/+3}$) along with radioactive Uranium. Almost 85% of the samples state-wide are showing iron level below BIS permissible limit of 1.0 mg/L while 15%, i.e a total of 6 samples from East Khasi, North Garo Hills, South West Garo Hills, West Garo Hills and West Khasi Hills have iron beyond the prescribed limit. The maximum iron concentration being recored is 18.4 mg/L. Arsenic in the groundwater samples is far below the permissible limit of 0.01 mg/L with the maximum value as 0.001 mg/L. Likeswise Uranium values are also within the safe limits laid by WHO guidelines. The summarized results of chemical analysis of water samples collected from different districts of Meghalaya during pre-monsoon 2023 is represented in **Annexure I to Annexure IV**.

Some of the parameters of significance for the region are depicted pictorially from **Figure 3a.1** to **Figure 3a.9.**

Table 3.5: Statistical data set and summary of physicochemical parameters of groundwater samples collected from Meghalaya during pre-monsoon 2023

Parameters	Unit	Statistical Data			IS 10500:2012		No. of Samples beyond Desirable Limit	Samples beyond Desirable Limit (%)	No of Samples beyond Permissible Limit	Samples beyond Permissible limit (%)
		Mean	Minimum	Maximum	Desirable Limit	Permissible Limit				
pH		6.85	**5.721**	7.71	6.5-8.5	No relaxation	12	30.76	-	-
EC	(µS/cm) 25°C	108.12	11.5	367.00	-	-	-	-	-	-
TDS	mg/L	70.28	7.475	238.55	500	2000	0	0	0	0
Turbidity	NTU	0.17	0.01	**1.30**	1	5	1	2.56	0	0
CO_3^{-2}	mg/L	-	-	-	-	-	-	-	-	-
HCO_3^{-1}	mg/L	42.58	6.10	140.41	-	-	-	-	-	-
TA (as CaCO3)	mg/L	42.58	6.10	140.41	200	600	0	0	0	0
Cl^-	mg/L	17.85	6.63	39.77	250	1000	0	0	0	0
SO_4^{-2}	mg/L	8.73	0.06	37.77	200	400	0	0	0	0
NO_3^{-1}	mg/L	8.49	0.25	27.22	45	No relaxation	0	0	-	-
F^-	mg/L	0.04	0.01	0.12	1	1.5	0	0	0	0
Ca^{+2}	mg/L	11.19	2.00	40.03	-	-	-	-	-	-
Mg^{+2}	mg/L	4.20	1.20	9.71	-	-	-	-	-	-
TH (as $CaCO_3$)	mg/L	45.26	10	140.00	200	600	0	0	0	0
Na	mg/L	9.41	1.33	26.70	-	-	-	-	-	-
K	mg/L	3.86	0.07	18.30	-	-	-	-	-	-
Fe	mg/L	1.10	0.02	**18.40**	1	No relaxation	6	15.38	-	-
As	mg/L	0.0003	0.000002	0.0019	0.01	No relaxation	0	0	-	-
U	mg/L	0.0006	0.000002	0.0163	0.03*	No relaxation	0	0	-	-

*****_Uranium limit according to WHO (2017) Guidelines for drinking water quality._

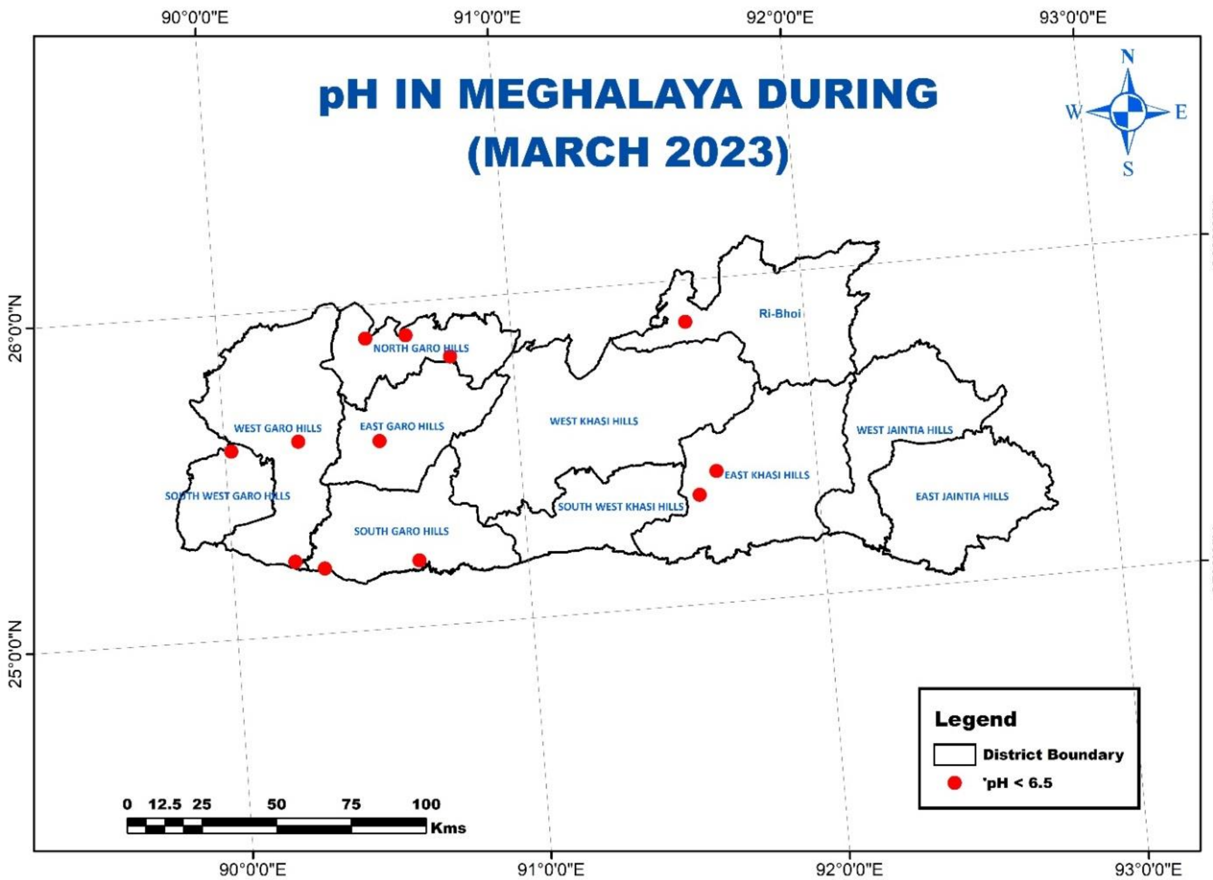

Figure 3a.1: pH distributions in groundwater of Meghalaya during pre-monsoon, 2023.

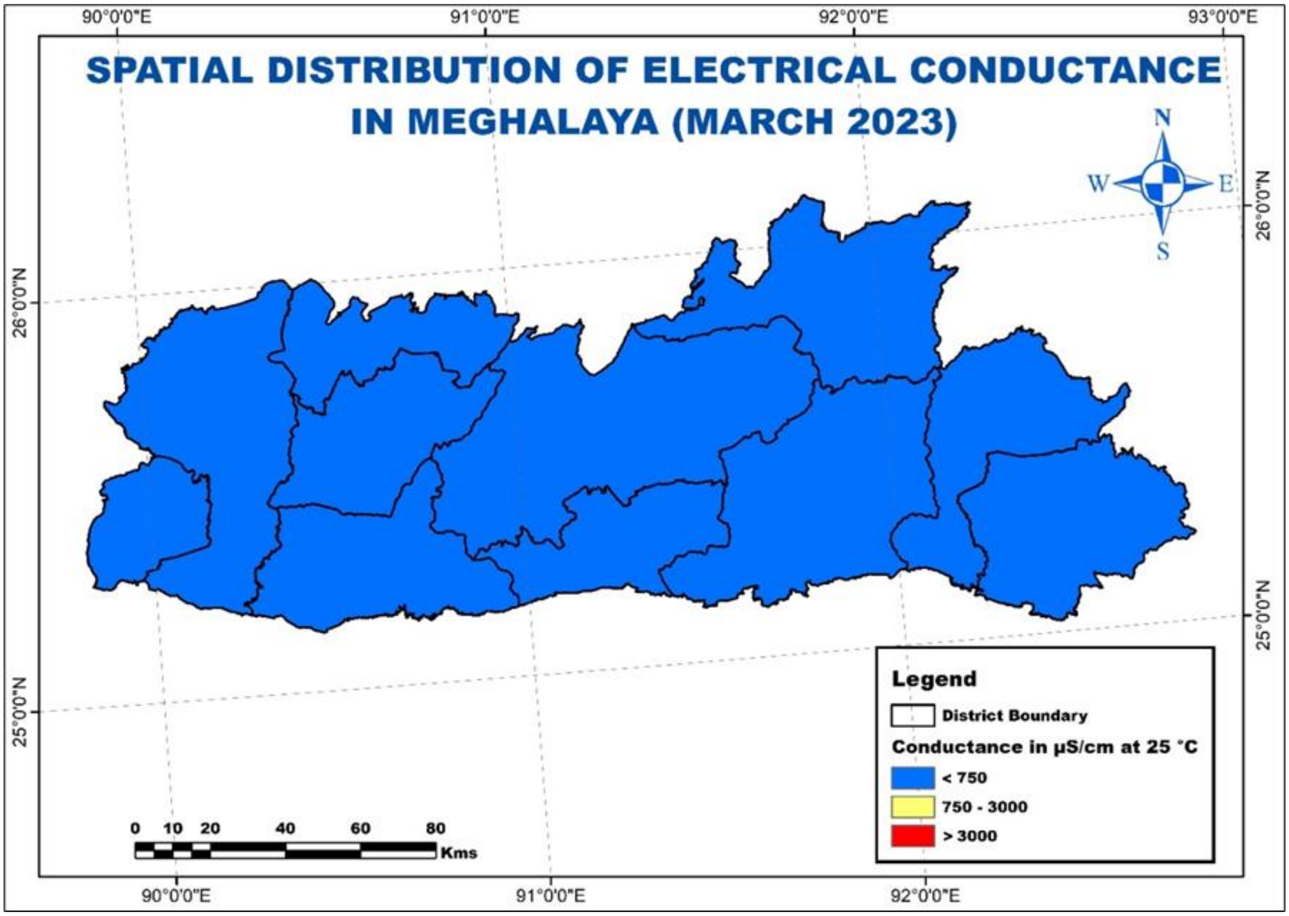

Figure 3a.2: Map showing the spatial distribution of EC in groundwater of Meghalaya during pre-monsoon, 2023.

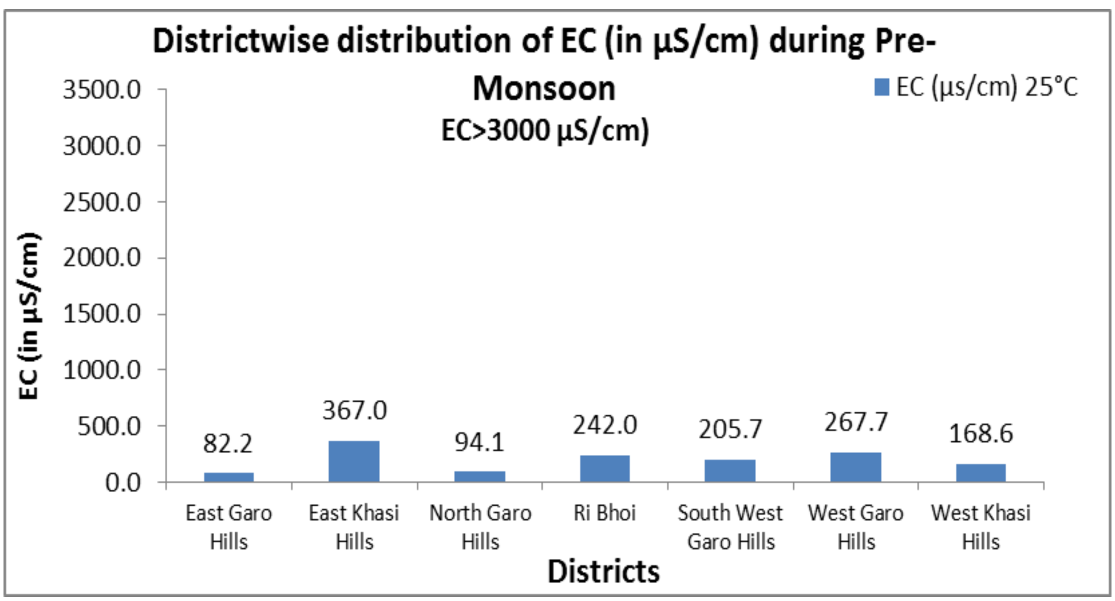

Figure 3a.3: EC distributions in groundwater of Meghalaya during pre-monsoon, 2023.

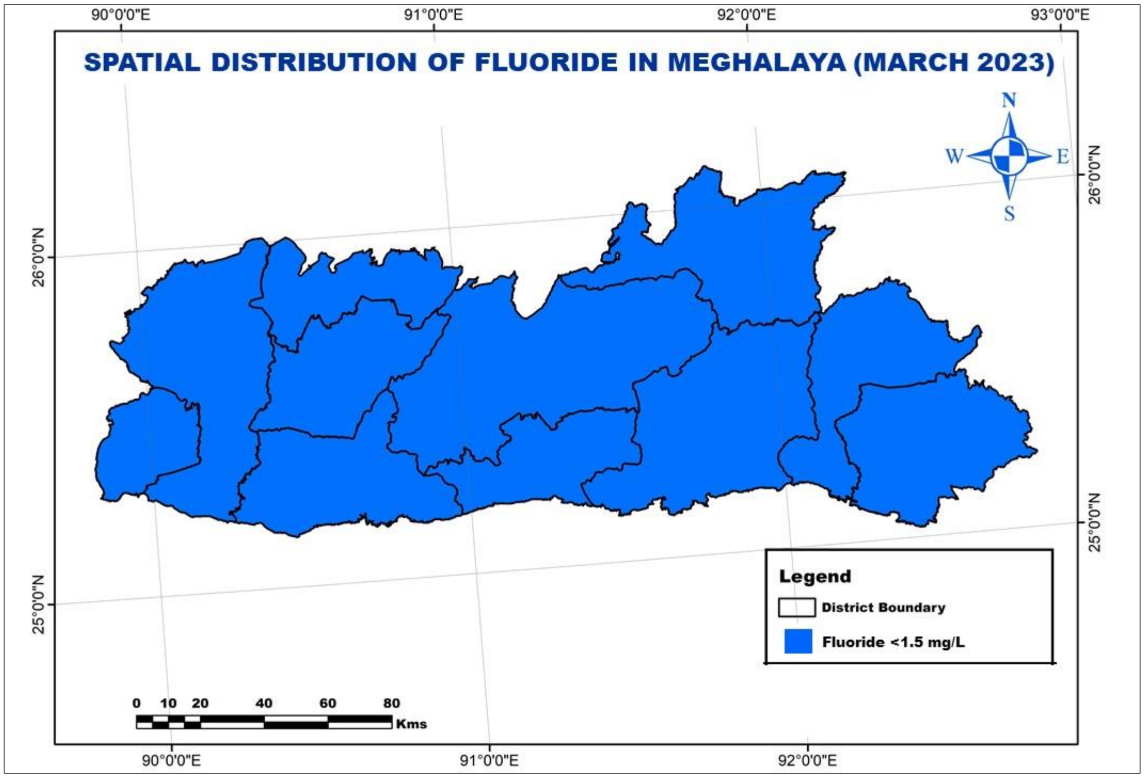

Figure 3a.4: Map showing the spatial distribution of Fluoride in groundwater of Meghalaya during pre-monsoon, 2023.

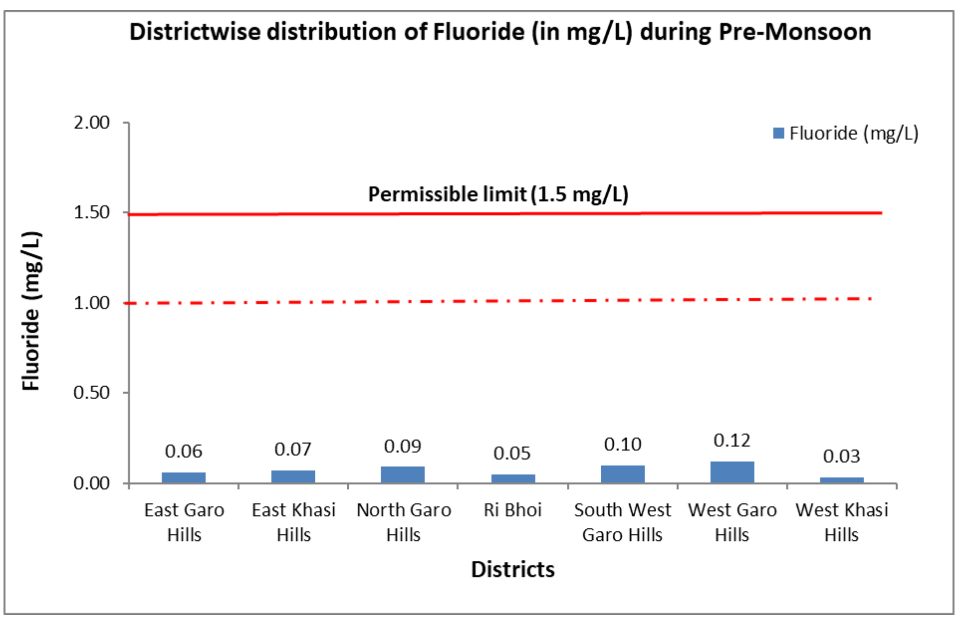

Figure 3a.5: Fluoride distributions in groundwater of Meghalaya during pre-monsoon, 2023.

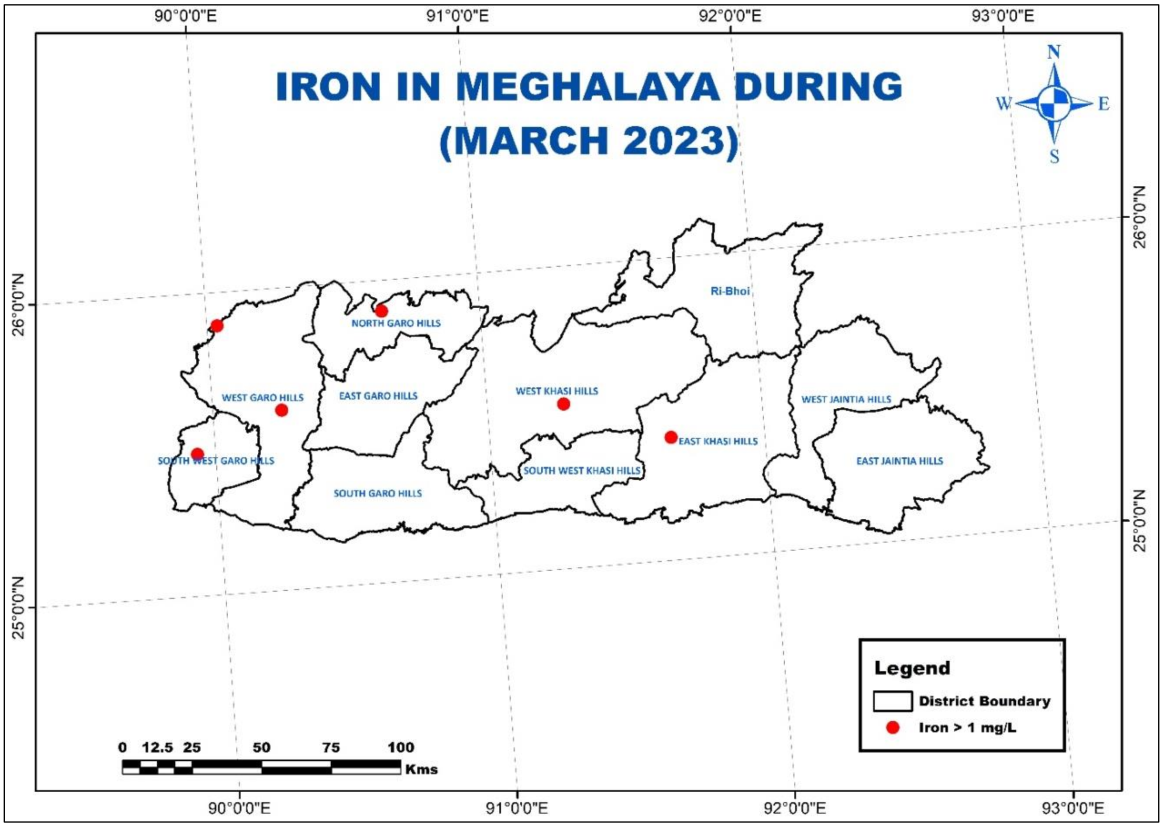

Figure 3a.6: Map showing groundwater samples of Iron concentration above permissible limit in Meghalaya during pre-monsoon season, 2023.

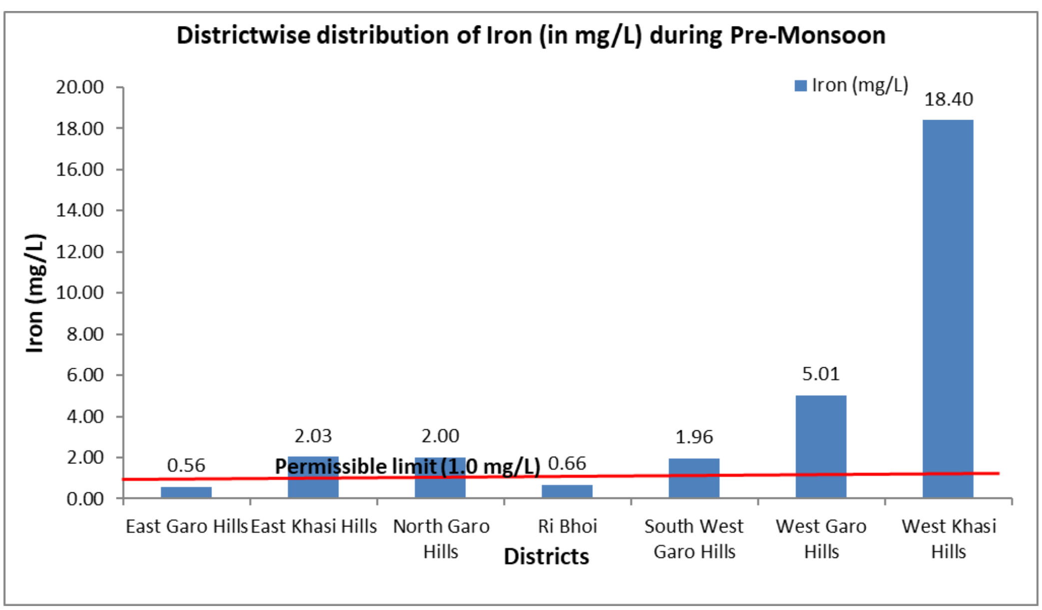

Figure 3a.7: Iron distributions in groundwater of Meghalaya during pre-monsoon, 2023.

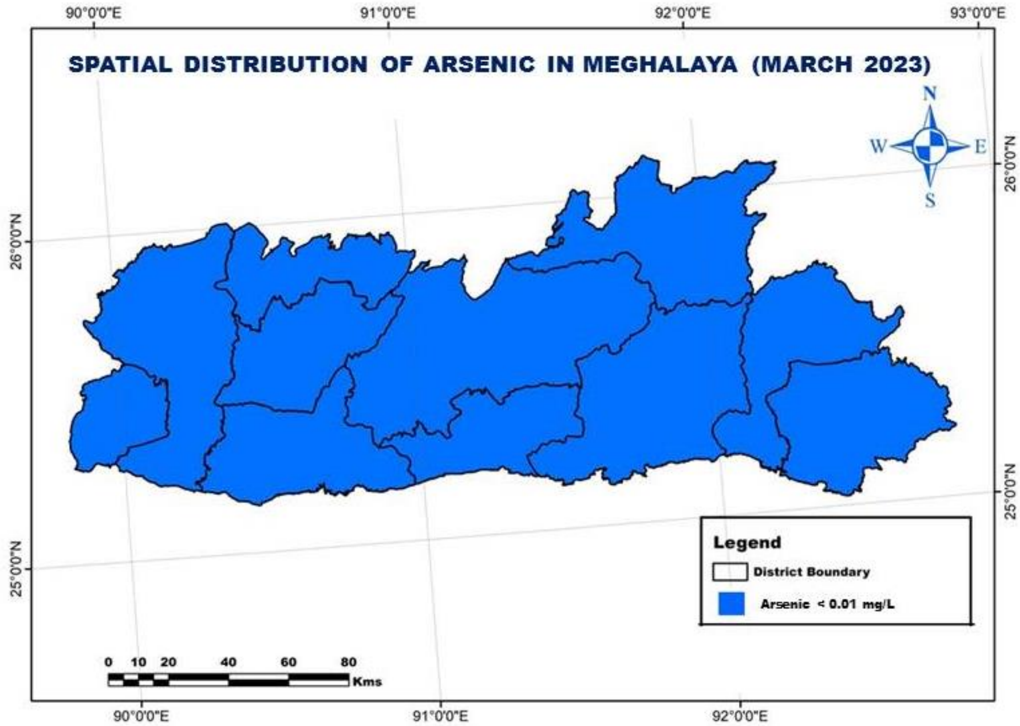

Figure 3a.8: Map showing groundwater samples of Arsenic concentration above permissible limit in Meghalaya during pre-monsoon season, 2023.

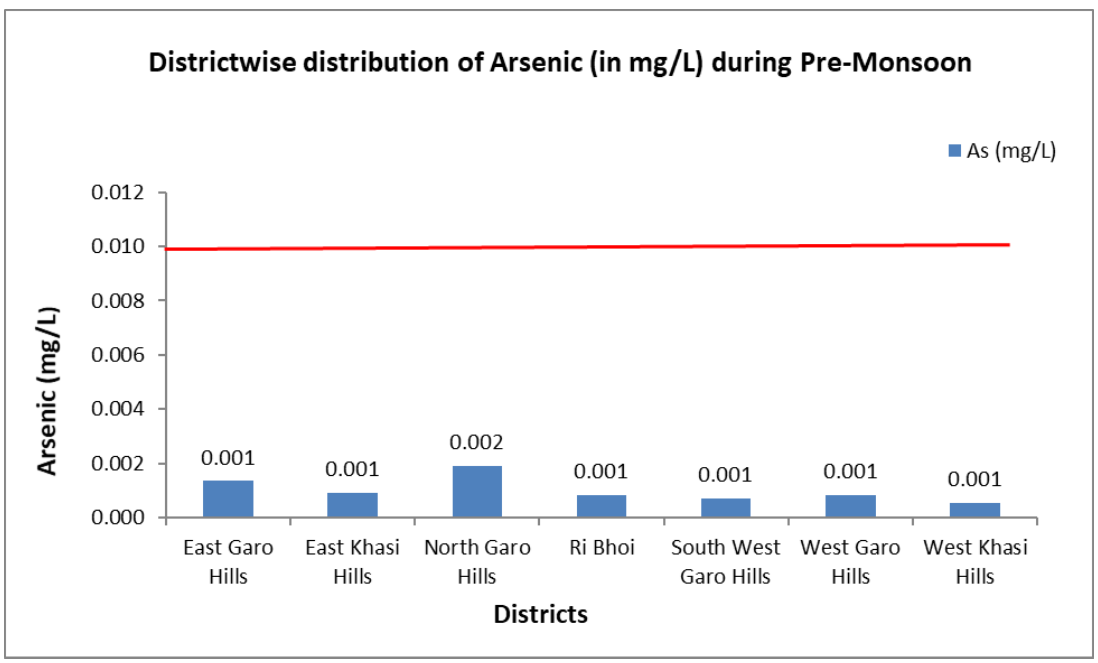

Figure 3a.9: Arsenic distributions in groundwater of Meghalaya during pre-monsoon, 2023.

3.2.2. Post-Monsoon groundwater quality for drinking purposes in Meghalaya

For the post-monsoon samples some locations have pH values below the lower range of BIS value of 6.5. The minimum value being recored from North Garo Hills with a pH of 5.64. The EC of the samples are less than 3000 µS/cm. Though all the samples have TDS within safe limits but the desirable limit of TDS is exceeded in a location from South Garo Hills and recorded a TDS of 989.3 mg/L. Turbidity of the samples show excellent property except for 2 locations where it exceeds the desirable turbidity limit of 1 NTU but safely well below the permissible limit of 5 NTU. From the mean concentration (mg/L) of cations the order of the cations is Ca^{2+}> Mg^{2+}> Na^{+}>> K^{+} while that of the anions varies as Cl^{-}> HCO_3^{-}> SO_4^{2-}> NO_3^{-} >F^{-}. Concentration of all the ionic species are within the permissible limits. Heavy metals analysed during pre-monsoon are Fe, As, Mn, Cu, Pb, Zn, Ni, Cd, Cr, Se, Hg along with radioactive Uranium. 6 of the samples state-wide are showing iron level beyond BIS permissible limit of 1.0 mg/L. A total of 9 samples from various districts have Manganese concentration beyond permissible limit of 0.3 mg/L indicating Manganese contamination to be of major concern. In addition to this, there are 6 samples whose Manganese concentration are beyond the desirable limit of 0.1 mg/L. The summarized results of chemical analysis of water samples collected from different districts of Meghalaya during post-monsoon 2023 is represented in **Annexure V to Annexure VIII.**

Some of the parameters of significance for the region are depicted pictorially from **Figure 3b.1** to **Figure 3b.11.**

Table 3.6: Statistical data set and summary of physicochemical parameters of groundwater samples collected from Meghalaya during post-monsoon 2023

Parameters		Post-monsoon			IS 10500:2012		No. of Samples beyond Desirable Limit	Samples beyond Desirable Limit (%)	No of Samples beyond Permissible Limit	Samples beyond Permissible limit (%)
		Mean	Minimum	Maximum	Desirable Limit	Permissible Limit				
pH		7.09	**5.64**	8.27	6.5-8.5	No relaxation	19	25.67	-	-
EC	(µS/cm) 25°C	144.69	12.67	1522.00	-	-	-	-	-	-
TDS	mg/L	94.05	8.24	**989.30**	500	2000	1	1.35	0	0
Turbidity	NTU)	0.59	0.10	**3.50**	1	5	2	2.72	0	0
CO_3^{-2}	mg/L	-	-	-	-	-	-	-	-	-
HCO_3^{-1}	mg/L	14.93	6.10	36.63	-	-	-	-	-	-
TA (as CaCO3)	mg/L	14.93	6.10	36.63	200	600	0	0	0	0
Cl^-	mg/L	39.47	10.64	127.62	250	1000	0	0	0	0
SO_4^{-2}	mg/L	10.95	0.03	74.82	200	400	0	0	0	0
NO_3^{-1}	mg/L	6.65	0.05	42.38	45	No relaxation	0	0	-	-
F^-	mg/L	0.20	0.01	0.75	1	1.5	0	0	0	0
Ca^{+2}	mg/L	14.69	2.00	70.06	-	-	-	-	-	-
Mg^{+2}	mg/L	7.16	1.20	50.97	-	-	-	-	-	-
TH (as $CaCO_3$)	mg/L	66.22	15.00	215.00	200	600	0	0	0	0
Na	mg/L	9.90	0.92	50.69	-	-	-	-	-	-
K	mg/L	4.51	0.26	32.08	-	-	-	-	-	-
Fe	mg/L	0.48	0.00112	**2.91**	1	No relaxation	6	8.10	-	-
As	mg/L	0.0003	0.000007	0.002	0.01	No relaxation	0	0	-	-
U	mg/L	0.00003	0.0000002	0.0001	0.03*	No relaxation	0	0	-	-
Mn	mg/L	0.23	0.00138	**1.56**	0.1	0.3	6	8.10	9	12.16
Cu	mg/L	0.001	0.00002	0.006	0.05	1.5	0	0	0	0
Pb	mg/L	0.001	0.000003	0.005	0.01	No relaxation	0	0	-	-

Parameters		Post-monsoon			IS 10500:2012		No. of Samples beyond Desirable Limit	Samples beyond Desirable Limit (%)	No of Samples beyond Permissible Limit	Samples beyond Permissible limit (%)
		Mean	Minimum	Maximum	Desirable Limit	Permissible Limit				
Zn	mg/L	0.06	0.00047	0.266	5	15	0	0	0	0
Ni	mg/L	0.0001	0.00006	0.0001	0.02	No relaxation	0	0	-	-
Cd	mg/L	0.00003	0.0000029	0.00006	0.003	No relaxation	0	0	-	-
Cr	mg/L	-	-	-	0.05	No relaxation	0	0	-	-
Se	mg/L	0.0001	0.000002	0.0010	0.01	No relaxation	0	0	-	-
Hg	mg/L	0.00001	0.000000161	0.000026	0.001	No relaxation	0	0	-	-

**Uranium limit according to WHO (2017) Guidelines for drinking water*

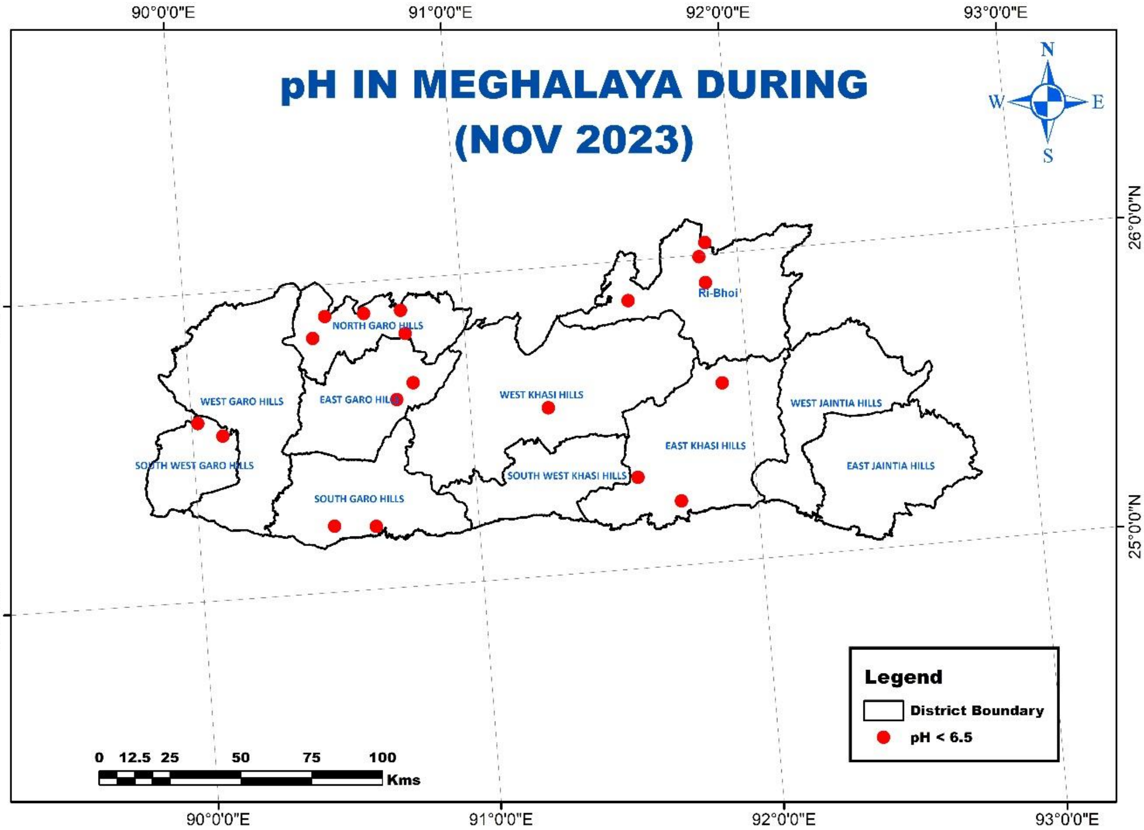

Figure 3b.1: pH distributions in groundwater of Meghalaya during post-monsoon, 2023.

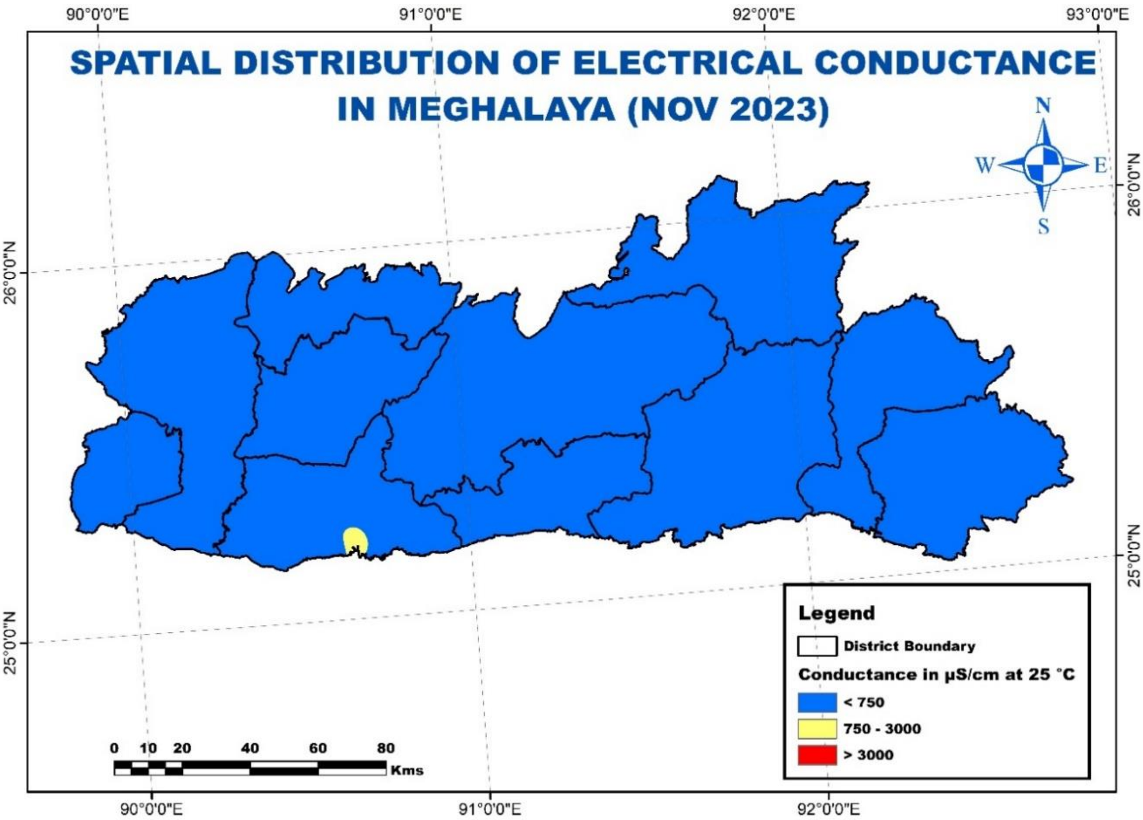

Figure 3b.2: Map showing the spatial distribution of EC in groundwater of Meghalaya during post-monsoon, 2023.

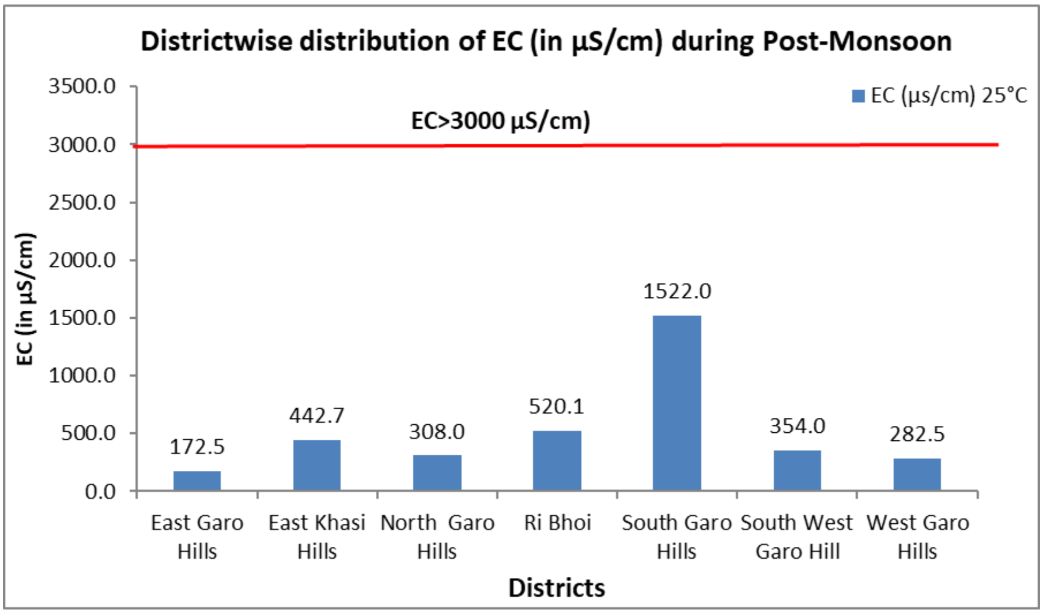

Figure 3b.3: EC distributions in groundwater of Meghalaya during post-monsoon, 2023.

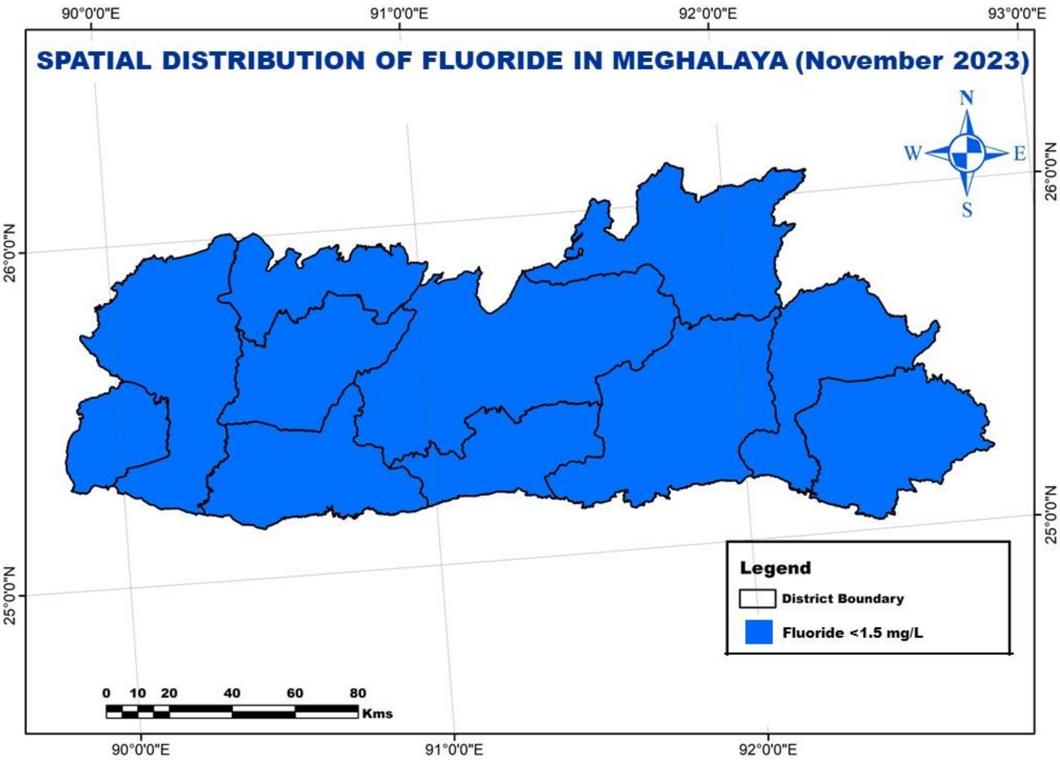

Figure 3b.4: Map showing the spatial distribution of Fluoride in groundwater of Meghalaya during post-monsoon, 2023

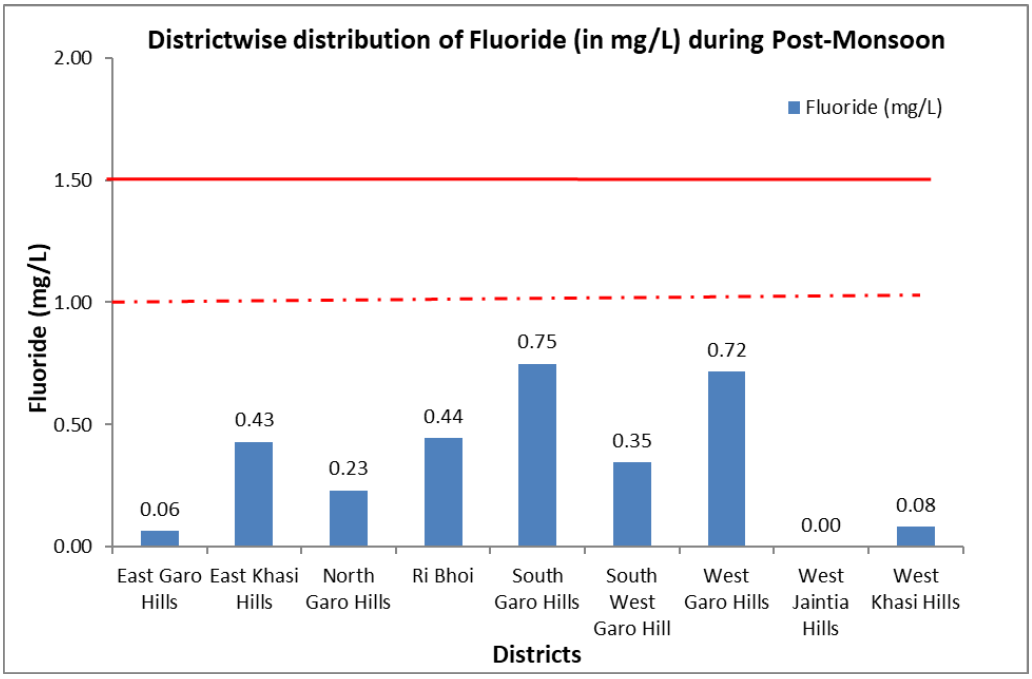

Figure 3b.5: Fluoride distributions in groundwater of Meghalaya during post-monsoon, 2023.

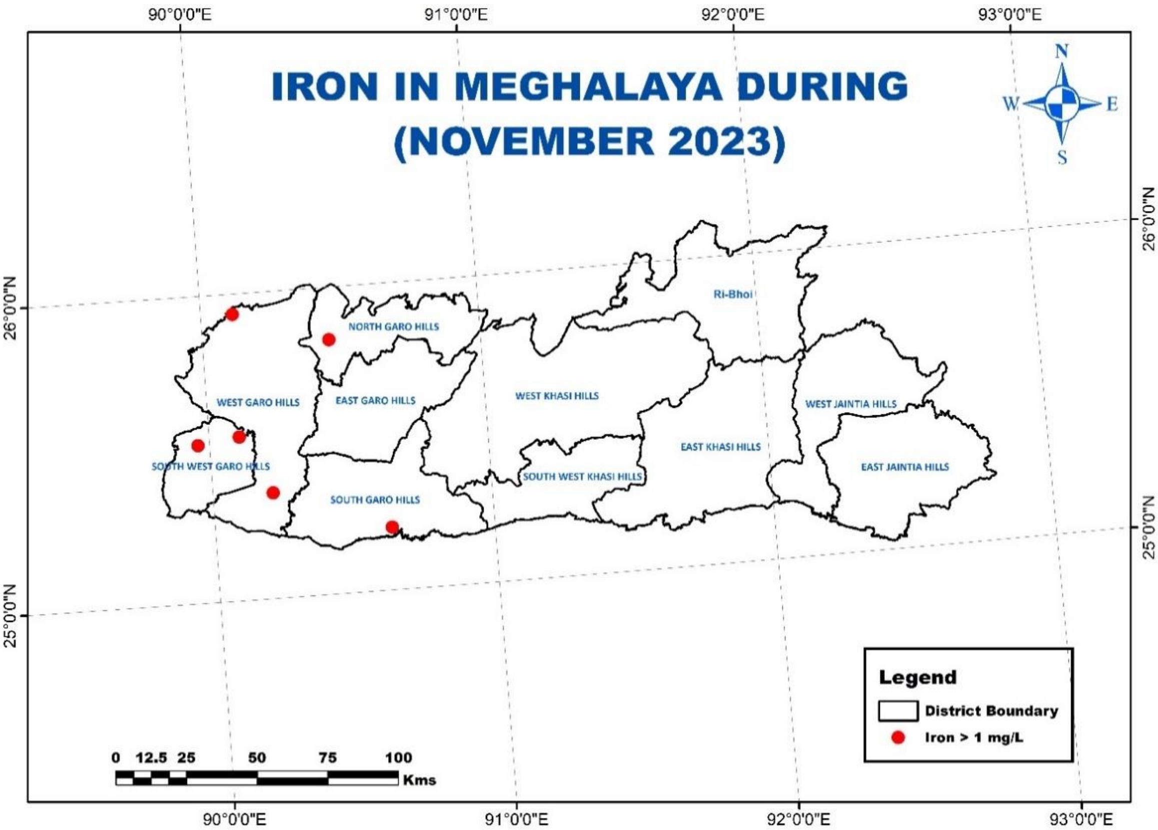

Figure 3b.6: Map showing the spatial distribution of Iron in groundwater of Meghalaya during post-monsoon, 2023

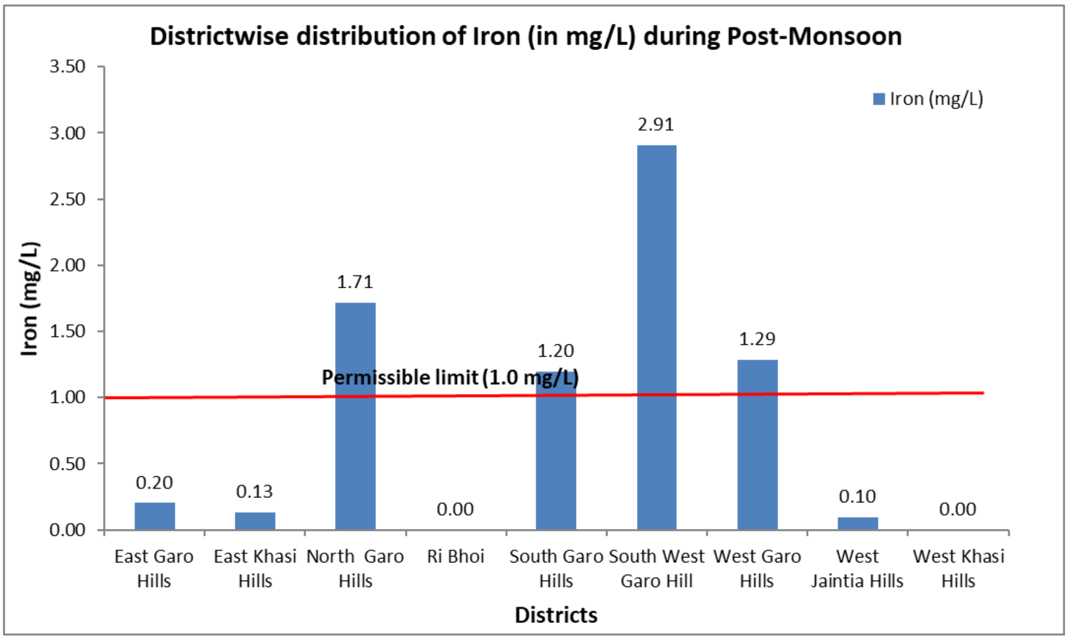

Figure 3b.7: Iron distributions in groundwater of Meghalaya during post-monsoon, 2023.

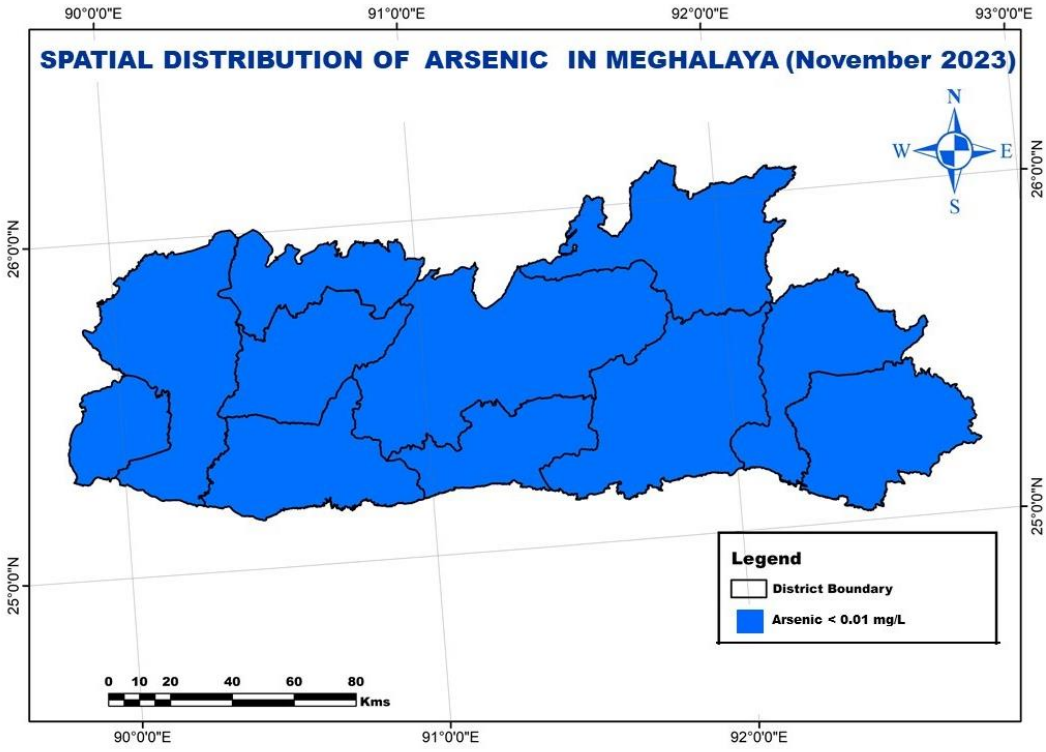

Figure 3b.8: Map showing the spatial distribution of Arsenic in groundwater of Meghalaya during post-monsoon, 2023

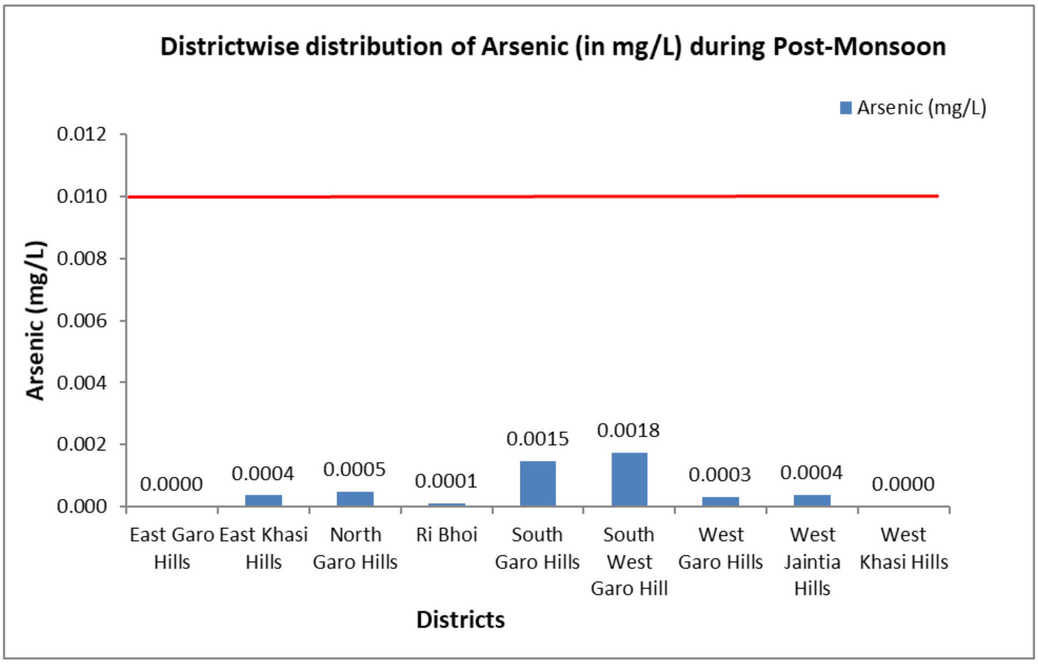

Figure 3b.9: Arsenic distributions in groundwater of Meghalaya during post-monsoon, 2023.

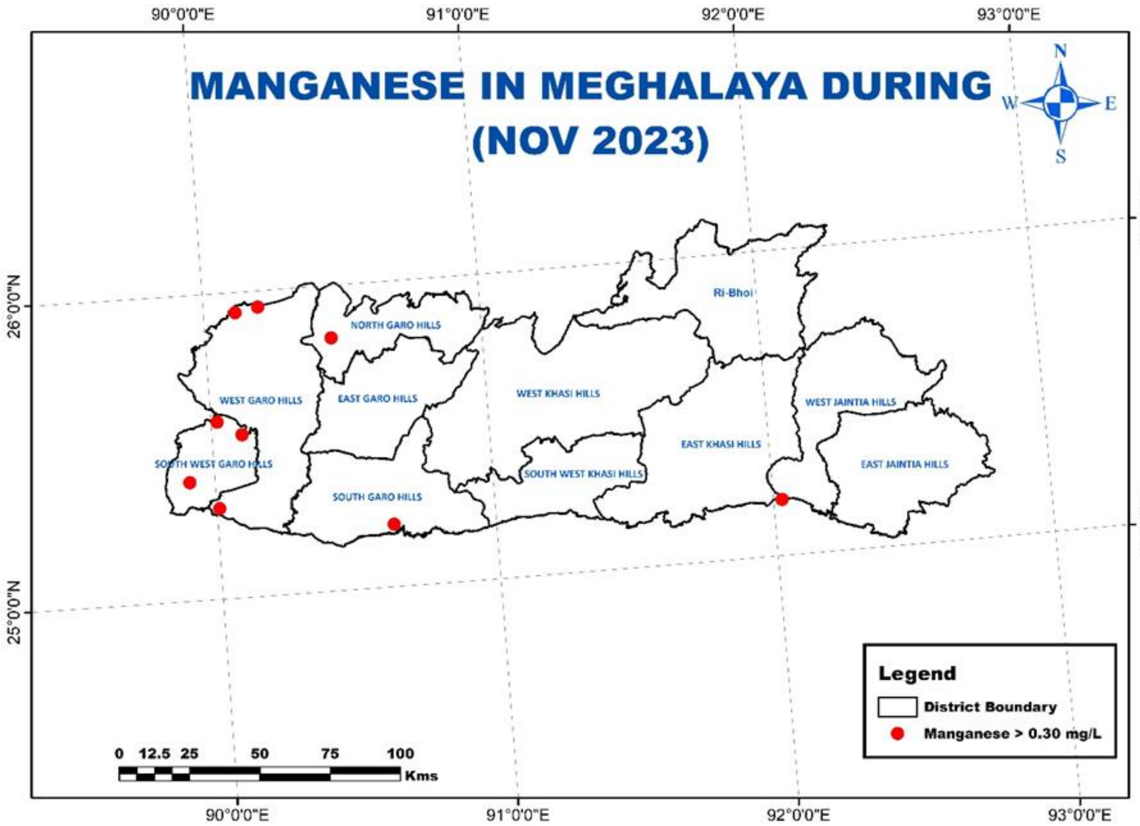

Figure 3b.10: Map showing the spatial distribution of Manganese in groundwater of Meghalaya during post-monsoon, 2023

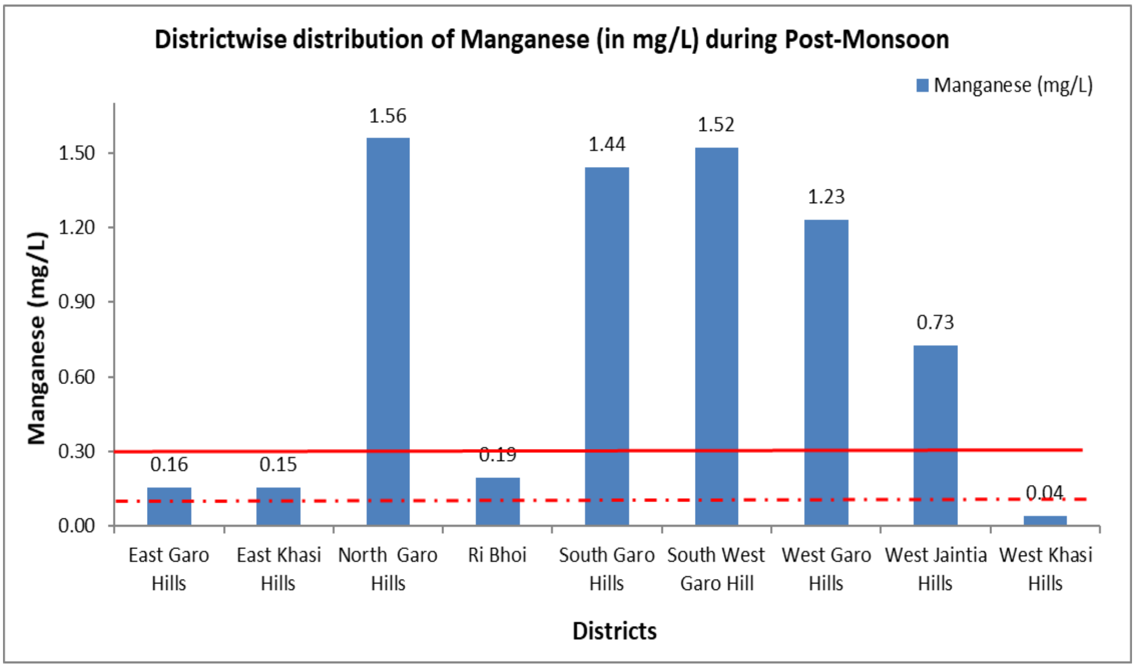

Figure 3b.11: Manganese distributions in groundwater of Meghalaya during post-monsoon, 2023.

3.3 Trend analysis of significant parameters

Trend analysis is necessary in order to determine whether the measured values of the water quality variables increase or decrease during a time period. In this case we have studied 7 years trend of some significant parameters in groundwater of Meghalaya. We have plotted graphs with 3 variables with the years 2017 to 2023 on X-axis, followed by number of districts affected and lastly the percentage of locations affected. **Figure 3c.1, 3c.2 and 3c.3 and Table 3a (1-6)** depict the trend analysis graphs of EC, Fluoride and Iron. For trend analysis these three parameters are considered to be of viral importance since other parameters in the state are well within the safe limits. Trend in EC is of critical importance due to its interpretation in suitability for drinking, irrigitaion and other domestic purposes considering its salinity viewpoint.

DISTRIBUTION OF ELECTRICAL CONDUCTIVITY (EC)

- From the trend analysis over 7 years of time frame it is seen that no sample in the state has exceeded the safe limit of 3000 µS/cm in case of EC thereby showing absolutely no periodic variation from 2017 to 2023. The same is shown in the pictorial representation in **Figure 3c-1.**
- **Table 3a-2** shows the districtwise details of EC within the samples collected statewide.
- Grouping water samples based on EC values, it is found that none of them have EC above 3000µS/cm and all samples are in between 11.5 to 367.0 µS/cm in pre-monsoon and 12.67 to 1522.0 µS/cm during post-monsoon.
- The maps showing spatial distribution of EC in pre and post monsoon signifies that EC of all samples are within the safe limits in both the seasons.
- The **Table 3a-3** provides the number of samples analyzed per district, along with their minimum, maximum, and mean EC values based on pre and post monsoon NHS 2023 Data.

Table 3a.1: Comparative change in number of locations having EC > 3000 µS/cm in various districts of Meghalaya from 2017-2023

Sl. No.	District	No. of locations having Electrical Conductivity>3000 µS/cm @25°C							
		2017	2018	2019	2020	2021	2022	2023	
								Pre-monsoon	Post-monsoon
1	East Garo Hills	0	0	0	0	0	0	0	0
2	East Jantia Hills	0	0	0	0	0	0	0	0
3	East Khasi Hills	0	0	0	0	0	0	0	0
4	North Garo Hills	0	0	0	0	0	0	0	0
5	Ri-Bhoi	0	0	0	0	0	0	0	0
6	South Garo Hills	0	0	0	0	0	0	0	0
7	South West Garo Hills	0	0	0	0	0	0	0	0
8	West Garo Hills	0	0	0	0	0	0	0	0
9	West Jaintia Hills	0	0	0	0	0	0	0	0
10	West Khasi Hills	0	0	0	0	0	0	0	0
Total		0	0	0	0	0	0	0	0

Table 3a.2: District wise Range and distribution of EC in shallow groundwater of Meghalaya in 2023

Sl. No.	District	EC (Pre-monsoon)				% of samples with EC < 3000 µS/cm	% of samples with EC > 3000 µS/cm
		No. of samples analyzed	Min	Max	Mean		
			(in µS/cm @25°C)				
1	East Garo Hills	4	27.80	82.20	55.28	100	0
2	East Khasi Hills	10	30.70	367.00	138.13	100	0
3	North Garo Hills	4	55.06	94.10	78.19	100	0
4	Ri-Bhoi	5	11.50	242.00	84.10	100	0
5	South West Garo Hills	7	37.30	205.70	104.59	100	0
6	West Garo Hills	6	68.20	267.70	148.97	100	0
7	West Khasi Hills	3	26.80	168.60	114.10	100	0

Sl. No.	District	EC (Post-monsoon)				% of samples with EC < 3000 µS/cm @25°C	% of samples with EC > 3000 µS/cm @25°C
		No. of samples analyzed	Min	Max	Mean		
			(in µS/cm @25°C)				
1	East Garo Hills	8	44.28	172.50	96.81	100	0
2	East Khasi Hills	12	17.10	442.70	121.54	100	0
3	North Garo Hills	6	68.30	308.00	132.17	100	0
4	Ri Bhoi	9	18.76	520.10	150.51	100	0
5	South Garo Hills	10	33.94	1522.00	246.64	100	0
6	South West Garo Hills	6	91.19	354.00	218.58	100	0
7	West Garo Hills	16	21.40	282.50	117.51	100	0
8	West Jaintia Hills	3	12.67	335.50	136.15	100	0
9	West Khasi Hills	4	15.75	149.20	65.05	100	0

Periodic variation in suitability classes of Salinity in groundwater of Meghalaya									
Parameter	Class	Percentage of samples							Periodic Variation 2017-2023
		2017	2018	2019	2020	2021	2022	2023	
		(n=17)	(n=20)	(n=14)	(n=13)	(n=31)	(n=34)	(n=113)	
Salinity as EC	EC < 3000 µS/cm @25°C	100	100	100	100	100	100	100	0
	EC > 3000 µS/cm @25°C	0	0	0	0	0	0	0	0

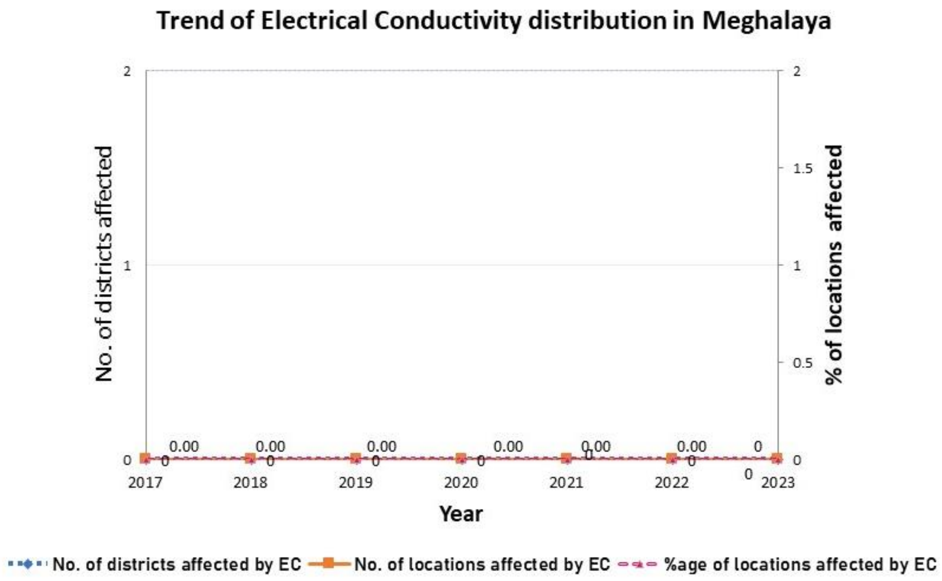

Figure 3c.1: 7 years EC data comparison (up) and trend analysis graph of EC (down).

DISTRIBUTION OF FLUORIDE (F)

- From the trend analysis over 7 years of time frame it is seen that no sample in the state has exceeded the BIS permissible limit of 1.5 mg/L in case of Fluoride except for 1 sample in 2021 from West Garo Hills. The same is shown in the pictorial representation in **Figure 3c-2.**
- **Table 3a-2** shows the districtwise details of Fluoride within the samples collected statewide.
- Grouping water samples based on Fluoride values, it is found that in both the season of pre and post monsoon none of the samples have Fluoride above 1.5 mg/L and all samples are in between 0.01 to 0.12 mg/L in pre-monsoon and 0.01 to 0.75 mg/L during post-monsoon.
- The maps showing spatial distribution of Fluoride in pre and post monsoon signifies that Fluoride concentration of all samples are within the safe limits in both the seasons.

- The **Table 3a-3** provides the number of samples analyzed per district, along with their minimum, maximum, and mean Fluoride values based on pre and post monsoon NHS 2023 Data.

Table 3a.3: Comparative change in number of locations having Fluoride > 1.5 mg/L in various districts of Meghalaya from 2017-2023

Sl. No.	District	No. of locations having Fluoride>1.5 mg/L							
		2017	2018	2019	2020	2021	2022	2023	
								Pre-monsoon	Post-monsoon
1	East Garo Hills	0	0	0	0	0	0	0	0
2	East Jantia Hills	0	0	0	0	0	0	0	0
3	East Khasi Hills	0	0	0	0	0	0	0	0
4	North Garo Hills	0	0	0	0	0	0	0	0
5	Ri-Bhoi	0	0	0	0	0	0	0	0
6	South Garo Hills	0	0	0	0	0	0	0	0
7	South West Garo Hills	0	0	0	0	0	0	0	0
8	West Garo Hills	0	0	0	0	1	0	0	0
9	West Jaintia Hills	0	0	0	0	0	0	0	0
10	West Khasi Hills	0	0	0	0	0	0	0	0
Total		0	0	0	0	1	0	0	0

Table 3a.4: District wise Range and distribution of Fluoride in shallow groundwater of Meghalaya in 2023

Sl. No.	District	Fluoride (Pre-monsoon)				% of samples with Fluoride <1.5 mg/L	% of samples with Fluoride >1.5 mg/L
		No. of samples analyzed	Min	Max	Mean		
			(in mg/L)				
1	East Garo Hills	4	0.01	0.06	0.03	100	0
2	East Khasi Hills	10	0.01	0.07	0.02	100	0
3	North Garo Hills	4	0.04	0.09	0.06	100	0
4	Ri-Bhoi	5	0.01	0.05	0.03	100	0
5	South West Garo Hills	7	0.01	0.10	0.04	100	0
6	West Garo Hills	6	0.01	0.12	0.05	100	0
7	West Khasi Hills	3	0.01	0.03	0.01	100	0

Sl. No.	District	Fluoride (Post-monsoon)				% of samples with Fluoride <1.5 mg/L	% of samples with Fluoride >1.5 mg/L
		No. of samples analyzed	Min	Max	Mean		
			(in mg/L)				
1	East Garo Hills	8	0.02	0.06	0.04	100	0
2	East Khasi Hills	12	0.08	0.43	0.22	100	0
3	North Garo Hills	6	0.12	0.23	0.17	100	0
4	Ri Bhoi	9	0.02	0.44	0.23	100	0
5	South Garo Hills	10	0.01	0.75	0.20	100	0
6	South West Garo Hills	6	0.02	0.35	0.18	100	0
7	West Garo Hills	16	0.05	0.72	0.26	100	0
8	West Jaintia Hills	3	0.00	0.00	0.00	100	0
9	West Khasi Hills	4	0.08	0.08	0.08	100	0

Periodic variation in suitability classes of Fluoride in groundwater of Meghalaya									
Parameter	Class	Percentage of samples							Periodic Variation 2017-2023
		2017 (n=17)	2018 (n=20)	2019 (n=14)	2020 (n=13)	2021 (n=31)	2022 (n=34)	2023 (n=113)	
Fluoride	F^- < 1.5 mg/L	100	100	100	100	96.78	100	100	0
	F^- > 1.5 mg/L	0	0	0	0	3.22	0	0	0

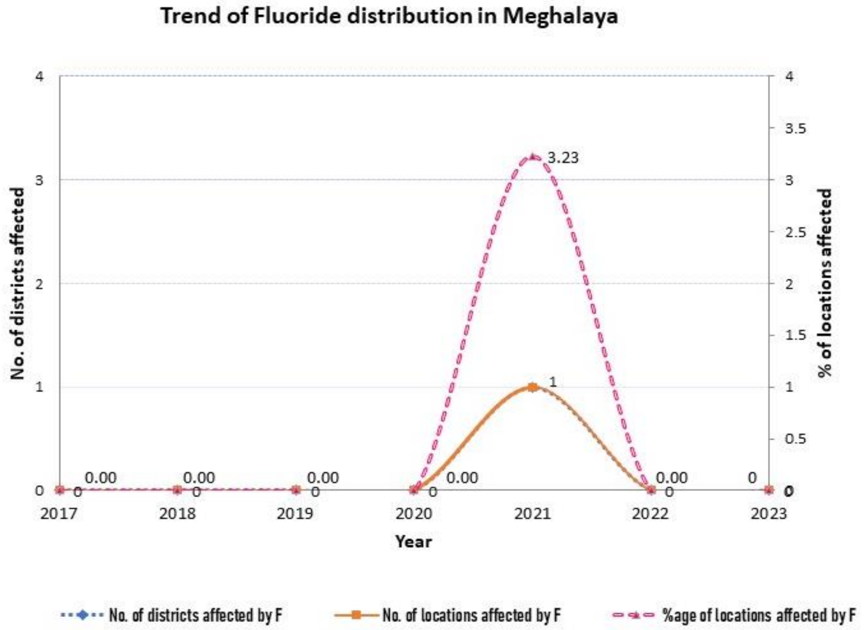

Figure 3c.2: 7 years Fluoride data comparison (up) and trend analysis graph of Fluoride (down).

DISTRIBUTION OF IRON (Fe)

- From the trend analysis over 7 years of time frame it is seen that there are few samples in each year which exceeded the BIS permissible limit of 1.0 mg/L in case of Iron. The same is shown in the pictorial representation in **Figure 3c-2.** The trend is zigzag from 2017 to 2020 then there is a sharp increase in 2021 then decreases in 2022 and eventually in the current year of 2023 (both pre and post-monsoon combined) it is again at increasing trend.
- **Table 3a-2** shows the districtwise details of Iron within the samples collected statewide.
- Grouping water samples based on Iron values, it is found that in both the seasons of pre and post monsoon except for East Garo Hills and Ri Bhoi all other districts have shown Iron in groundwater above permissible drinking limit of 1.0 mg/L.

During pre-monsoon Iron concentration ranges from 0.02 to as high as 18.4 mg/L while during post-monsoon samples is between 0.001 to 2.91 mg/L.

- The maps showing the contaminated locations of Iron in pre and post monsoon signifies that Iron concentration in South Garo Hills, East Garo Hills, South West Khasi Hills, West Jaintia Hills, East Jaintia Hills and Ri Bhoi are the districts that have Iron within safe limits during pre-monsoon. During post-monsoon iron contaminated samples are more concentrated towards the western districts like South West Garo Hills, West Garo Hills, North Garo Hills and South Garo Hills.
- The **Table 3a-3** provides the number of samples analyzed per district, along with their minimum, maximum, and mean Iron values based on pre and post monsoon NHS 2023 Data.

Table 3a.5: Comparative change in number of locations having Iron > 1.0 mg/L in various districts of Meghalaya from 2017-2023

Sl. No.	District	No. of locations having Iron>1.0 mg/L							
		2017	2018	2019	2020	2021	2022	2023	
								Pre-monsoon	Post-monsoon
1	East Garo Hills	1	0	0	0	0	0	0	0
2	East Jantia Hills	0	0	0	0	0	0	0	0
3	East Khasi Hills	0	1	1	2	0	1	1	0
4	North Garo Hills	1	0	1	0	1	0	1	1
5	Ri-Bhoi	0	0	0	1	1	1	0	0
6	South Garo Hills	0	0	0	0	0	0	0	1
7	South West Garo Hills	0	0	0	0	1	0	1	2
8	West Garo Hills	0	0	0	0	4	0	2	2
9	West Jaintia Hills	0	0	0	0	0	0	1	0
10	West Khasi Hills	0	0	0	0	0	1	0	0
	Total	2	1	2	3	7	3	6	6

Table 3a.6: District wise Range and distribution of Iron in shallow groundwater of Meghalaya in 2023

Sl. No.	District	Iron (Pre-monsoon)				% of samples with Iron <1.0 mg/L	% of samples with Iron >1.0 mg/L
		No. of samples analyzed	Min	Max	Mean		
			(in mg/L)				
1	East Garo Hills	4	0.03	0.56	0.31	0	0
2	East Khasi Hills	10	0.06	2.03	0.28	90	10
3	North Garo Hills	4	0.05	2.00	0.78	75	25
4	Ri-Bhoi	5	0.02	0.66	0.23	0.00	0
5	South West Garo Hills	7	0.33	1.96	0.81	85.72	14.28
6	West Garo Hills	6	0.42	5.01	1.67	66.67	33.33
7	West Khasi Hills	3	0.07	18.40	0.32	66.67	33.33

Sl. No.	District	Iron (Post-monsoon) No. of samples analyzed	Min (in mg/L)	Max (in mg/L)	Mean (in mg/L)	% of samples with Iron <1.0 mg/L	% of samples with Iron >1.0 mg/L
1	East Garo Hills	8	0.01	0.20	0.09	100	0
2	East Khasi Hills	12	0.03	0.13	0.08	100	0
3	North Garo Hills	6	0.05	1.71	0.48	83.34	16.66
4	Ri Bhoi	9	0.00	0.00	0.00	100	0
5	South Garo Hills	10	0.01	1.20	0.45	90	10
6	South West Garo Hills	6	0.78	2.91	1.67	67.67	33.33
7	West Garo Hills	16	0.03	1.29	0.43	87.5	12.5
8	West Jaintia Hills	3	0.002	0.10	0.05	100	0
9	West Khasi Hills	4	0.00	0.001	0.001	100	0

Periodic variation in suitability classes of Iron in groundwater of Meghalaya									
Parameter	Class	Percentage of samples 2017 (n=17)	2018 (n=20)	2019 (n=14)	2020 (n=13)	2021 (n=31)	2022 (n=34)	2023 (n=113)	Periodic Variation 2017-2023
Iron	Fe < 1.0 mg/L	88.24	95	85.72	76.93	77.42	91.18	89.39	1.15
	Fe > 1.0 mg/L	11.76	5	14.28	23.07	22.58	8.82	10.61	-1.15

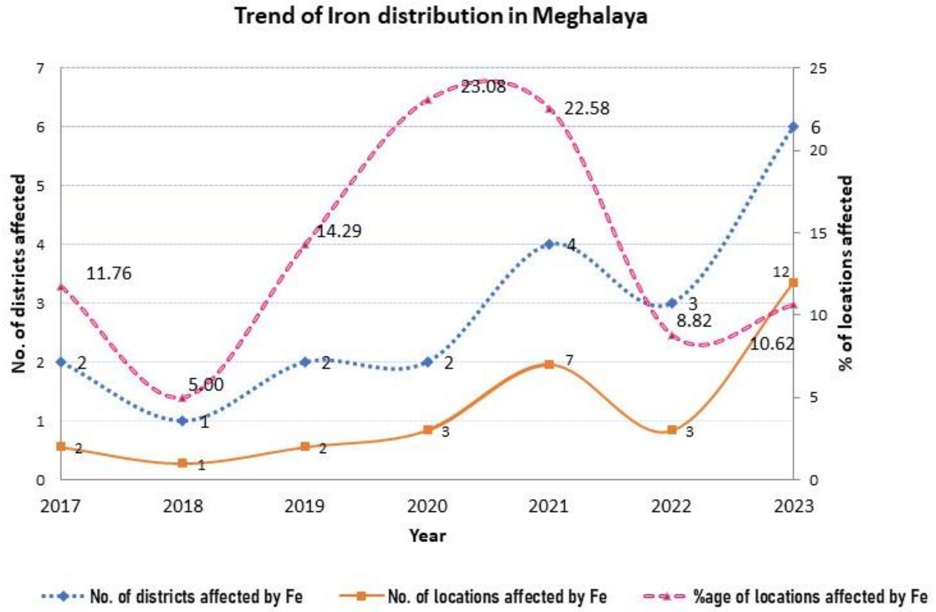

Figure 3c.3: 7 years Iron data comparison (up) and trend analysis graph of Iron (down).

CHAPTER 4

ASSESSMENT OF GROUNDWATER QUALITY OF MEGHALAYA FOR IRRIGATION FEASIBILTY

When there is excessive accumulation of soluble salts in soil the crop production is reduced. Plants growing under osmotically produced water stresses are one of the major causes for reduction in crop production. The primary sources of soluble salts in agriculture soils are:

- Irrigation water,
- Salt deposits in soil,
- Drainage water, draining from upper lying to lower lying lands,
- Capillary flow of water-especially in shallow water table, areas,
- Soil reclamation practices and use of fertilizers,
- Weathering of soil minerals and Precipitation.

Suitability of groundwater for irrigation purpose is evaluated based on chemical characteristics indicative of their potential to create soil condition hazardous to crop growth and yield. Various indices are used for assessment and classification of groundwater into different categories. Some of the widely used criteria are discussed below.

4.1. IRRIGATION WATER QUALITY CRITERIA

4.1.1. Salinity based on Electrical conductivity and chlorinity

Electrical conductivity (EC), total dissolved solids (TDS) and chlorinity are used as a measure of salinity of groundwater. Water with EC<3000 µS/cm at 25ºC and TDS<1000 mg/L is safe to be used for irrigation purpose. The parameters with values greater than these limits renders water unfit for irrigation. Higher residency time in the aquifers and low mobility of groundwater resulted in more mineralization and leads to higher EC and TDS. Chlorinity in groundwater should be below 500 mg/L for being suitable to be used in irrigation.

4.1.2. Sodium hazards

The absolute and relative concentration of sodium and also calcium and magnesium determine the sodium hazard in water used for irrigation purpose. Accumulation of exchangeable sodium results in alkali soil and it is associated with poor tilt and low permeability. Sodium Absorption Ratio (SAR) is recommended by the U. S. Salinity Laboratory since it more accurately depicts the sodium absorbed by the soil. Mathematically SAR is calculated as

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

As per Richards classification water with SAR<10 makes it suitable for irrigation.

Soluble Sodium Pecentage (SSP) is another criterion that represents the sodium in water exchanged by calcium by Base Exchange process that decreases the soil permeability.

$$SSP = \frac{Na*100}{Ca + Mg + Na}$$

Water with SSP<50 is of good quality for irrigation. Besides these two indices, percent sodium (%Na) is another factor in assessing the suitability of irrigation water.

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

Kelly's Index (KI) developed in 1951 is another index included in sodium hazard.

$$KI = \frac{Na}{Ca + Mg}$$

Water with KI>1 is considered of poor quality for irrigation.

4.1.3. Effects of bicarbonate ion concentration

The residual alkalinity is denoted by Residual Sodium Carbonate (RSC) as developed by Eaton in 1950. Water containing high concentration of bicarbonate ions, the calcium and magnesium may precipitate as carbonates in the soil. When the Ca and Mg precipitates out, the relative proportion of sodium in that water increases. RSC is calculated as shown below:

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

RSC<1.25 is suitable for irrigation, 1.25<RSC>2.50 is marginally suitable and that >2.50 is unsuitable for irrigation.

4.1.4. Permeability

Doneen in 1964 developed Permeability Index (PI). Continuos application of water may affect soil permeability by precipitation of certain elements in the top soil that reduces void space hindering water dynamics. In such case PI of that water gives an idea of the permeability of the top soil.

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} * 100$$

Water with PI>75% is suitable for irrigation.

4.1.5. Magnesium Ratio

The relative proportion of magnesium in water is calculated as Magnesium Ratio (MR) and it was developed by Llyod and Heathcote in 1985. It is formulated as below:

$$MR = \frac{(Mg * 100)}{(Ca + Mg)}$$

The MR>50 is considered unsuitable for irrigation purpose.

4.1.6 US Salinity Laboratory Diagram/Wilcox plot and Piper Diagram

US SALINITY Laboratory Diagram: One of the most important procedures which have been in use for considerable period of time till date is the one recommended by the U.S. Salinity Laboratory (U. S. S. L. 1954) and is briefly out lined below (Wilcox, 1955). The diagram is proposed with the assumption that water is used under average conditions with respect to soil texture, filtration rate, drainage, quantity of water used, climate and tolerance of corps. The diagram takes into consideration the salinity and sodium hazard of irrigation waters.

Piper Diagram: Hydro-chemical facies are very useful in investigating diagnostic chemical character of water in hydrologic systems (Piper, 1944). Different types of facies within the same group formations are due to characteristic groundwater 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.

4.2. GROUNDWATER QUALITY SCENARIO FOR IRRIGATION IN MEGHALAYA

Quality of groundwater, soil types and cropping practices play an important role for a suitable irrigation practice. Salinity and alkalinity of groundwater are two main problems for irrigation. Hence, it is important to check the chemical constituents that affect the suitability of water for irrigation in terms of total concentration of dissolved salts, relative proportion of bicarbonate to calcium, magnesium and relative proportion of sodium to calcium.

4.2.1. Pre-Monsoon Groundwater Quality Scenario for Irrigation in Meghalaya

Table 4a indicates the various categories of the water samples analysed during pre-monsoon based on the various irrigation indices.

Table 4a: Classification of pre-monsoon groundwater samples of Meghalaya for irrigation purposes.

Parameters	Range	Classification	Number of samples
Salinity hazard (EC) (µS/cm)	<250	Excellent	37
	250-750	Good	2
	750-2000	Permissible	0
	2000-3000	Doubtful	0
	>3000	Unsuitable	0
Alkalinity hazard (SAR)	<10	Excellent	39
	10--18	Good	0
	18-26	Doubtful	0
	>26	Unsuitable	0
Percent Sodium (%Na)	<20	Excellent	8
	20-40	Good	16
	40-60	Permissible	10
	60-80	Doubtful	5
	>80	Unsuitable	0
Kelly's Index (KI)	<1	Suitable	32
	>1	Unsuitable	7
Residual sodium carbonate (RSC)	<1.25	Suitable	39
	1.25-2.5	Marginally suitable	0
	>2.5	Unsuitable	0
Soluble	<50	Suitable	32

Parameters	Range	Classification	Number of samples
Sodium Percentage (SSP)	>50	Unsuitable	7

Different inidces indicate the water quality for irrigation purposes. The salinity hazard is absent for most of the pre-monsoon samples. The alkalinity hazard (SAR) for all the samples is categorized as excellent. The Na% indicates that the groundwater is excellent to permissible for irrigation except a few samples which falls under doubtful category. 12.8% of the samples in pre-monsoon are under doubtful category according to Na% index. High concentration of sodium tends to be absorbed by clay particles, displacing Ca^{2+} and Mg^{2+} ions thereby reducing the permeability resulting in poor internal drainage in soil making the soil dry (Faten, 2016). Similarly, based on calculated value of Kelly's ratio, KR (Kelly, 1963), more than 82.06% samples of pre-monsoon season are suitable for irrigation purpose with value of KR < 1 and same in case of SSP with SSP < 50. As per the RSC value-based classification of irrigation water given by Lloyd and Heathcote, 100% samples in pre-monsoon season are suitable for irrigation with RSC value less than 1.25.

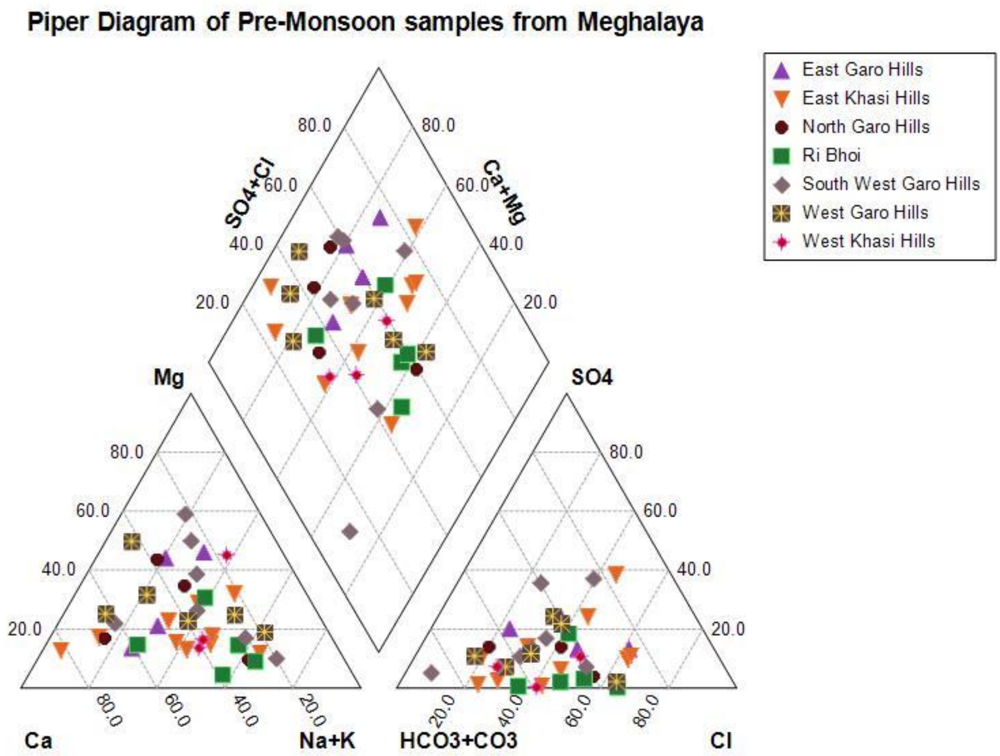

Figure 4a.1: Piper plot for classification of groundwater of Meghalaya during pre-monsoon 2023.

Water can be classified into different hydrochemical facies using Piper diagram. The above Figure is the Piper plot of Meghalaya during the pre-monsoon. Considering the cation triangle there is no dominant type while there are samples equally distributed in Ca-type and Na and K-type. The anion triangle shows mainly HCO_3-type of samples. Thus, on combining the results in the diamond plot most of the samples fall under Mg-HCO_3 type and mixed type. In Mg-HCO_3 type, samples from West Garo Hills and East Khasi Hills are primarily predominant. One sample from South West Garo Hills is identified dominantly as HCO_3-type.

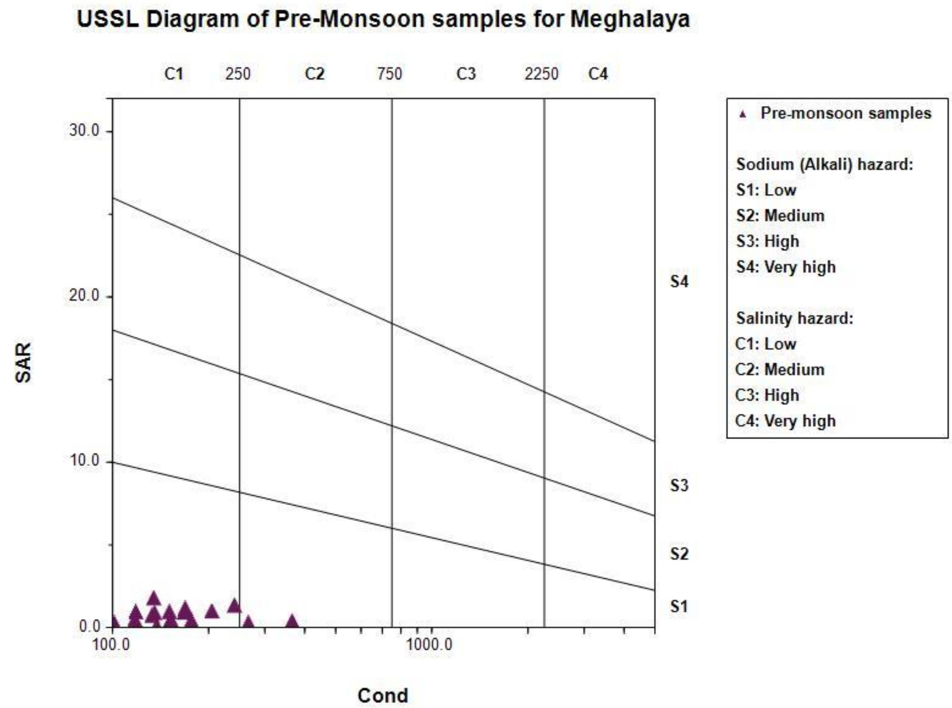

Figure 4a.2: USSL salinity diagram for classification of groundwater in Meghalaya during pre-monsoon 2023.

The data plotted on the US salinity diagram reveals that most of the groundwater samples from Meghalaya fall in the field C1S1 indicating low salinity-low sodium water. Two of the samples from East Khasi Hills and West Garo Hills are in C2S1 signifying low sodium and medium salinity hazard. Hence the samples across the state can be used for irrigation for almost all types of soil with little danger of exchangeable sodium. This diagram is in accordance with irrigation indices calculations as shown earlier. The irrigation parameters viz. Salinity hazard (EC), Alkalinity hazard (SAR), Percent Sodium (%Na), Kelly's index (KI) and Residual Sodium Carbonate (RSC) are shown in **Annexure XI and X.**

4.2.2. Post-Monsoon samples

The categories of water quality for post-monsoon samples for irrigational use are shown in **Table 4b.**

Table 4b: Classification of post-monsoon groundwater samples of Meghalaya for irrigation purposes.

Parameters	Range	Classification	Number of samples
Salinity hazard (EC) (µS/cm)	<250	Excellent	63
	250-750	Good	10
	750-2000	Permissible	1
	2000-3000	Doubtful	0
	>3000	Unsuitable	0
Alkalinity hazard (SAR)	<10	Excellent	74
	10--18	Good	0
	18-26	Doubtful	0
	>26	Unsuitable	0
Percent Sodium (%Na)	<20	Excellent	21
	20-40	Good	33
	40-60	Permissible	15
	60-80	Doubtful	5
	>80	Unsuitable	0
Kelly's Index (KI)	<1	Suitable	64
	>1	Unsuitable	10
Residual sodium carbonate (RSC)	<1.25	Suitable	74
	1.25-2.5	Marginally suitable	0
	>2.5	Unsuitable	0
Soluble Sodium Percentage (SSP)	<50	Suitable	64
	>50	Unsuitable	10

According to the irrigation indices the salinity hazard for 85.13% is excellent category while 13.51% are good and 1.36% are permissible. The samples are safe from alkalinity hazard (SAR). %Na calculated shows that 6.75% of the samples are doubtful to be used for irrigation. The Kelly's Index and SSP index yield same results when calucated with 86.48% of the samples categorized as suitable for irrigation. 100.0% of the samples are safe from

RSC point of view. Thus, most of the samples are within safe limits for irrigation purpose with light treatments necessary in some regions.

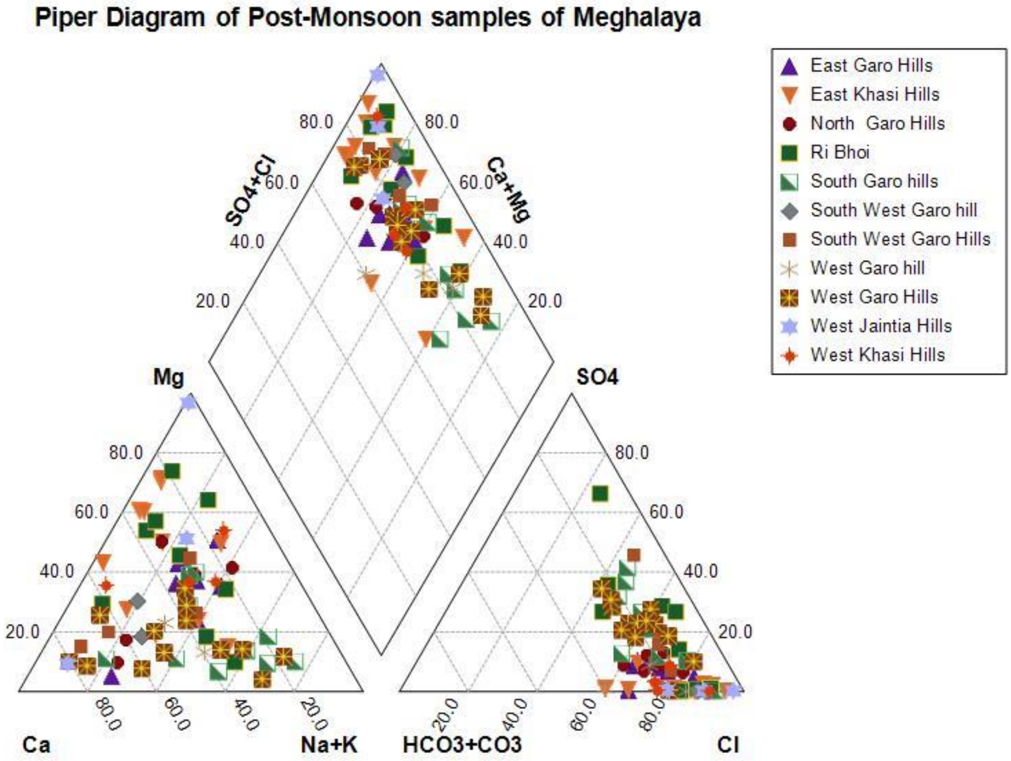

Figure 4b.1: Piper plot for classification of groundwater of Meghalaya during post-monsoon 2023.

The cation triangle shows the samples to be of a combination of no dominant type, Ca-type, Na and K-type as well as Mg-type. The anion triangle is plotted to be Cl type with one sample from Ri Bhoi to be SO_4 -type. Therefore, in the combined plot most of the samples are shown to be dominantly Ca-Cl and Na-Cl type alongwith some mixed type. It is also earlier discussed that from the mean concentration Cl^- from anion and Ca^{2+} are among the cations are dominant types of ionic species.

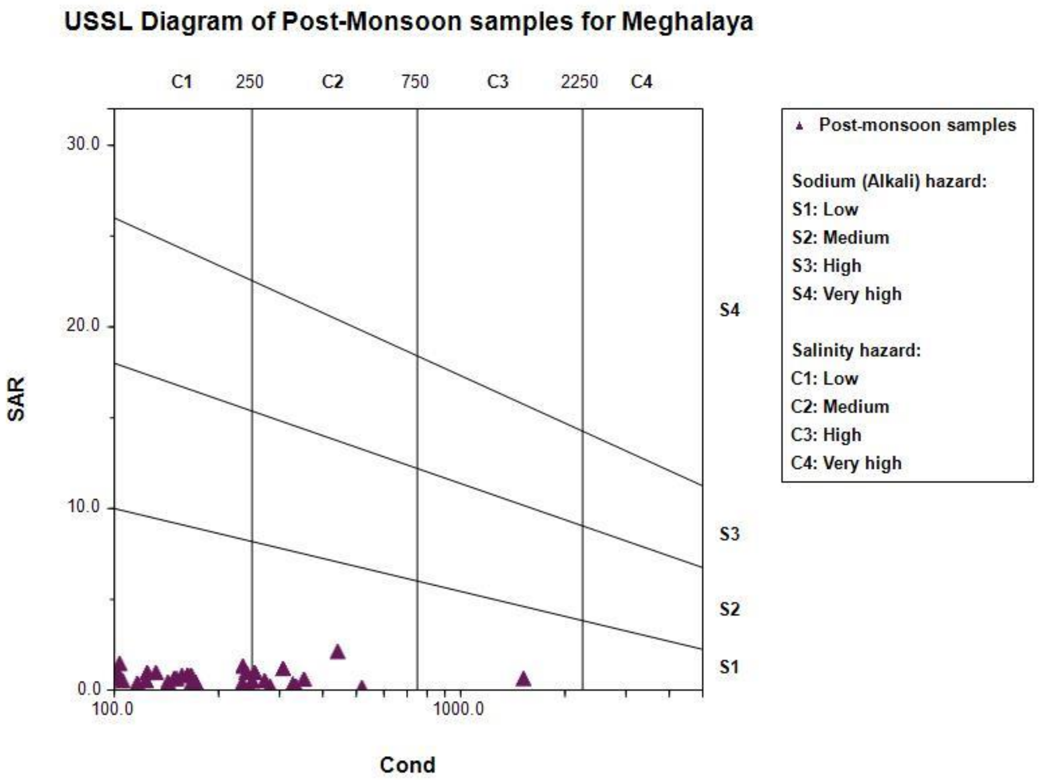

Figure 4b.2: USSL salinity diagram for classification of groundwater in Meghalaya during post-monsoon 2023.

Most of the post-monsoon samples are classified as C1S1 and C2S1 type indicating low sodium hazard with low and medium salinity hazard. One sample from South Garo Hills which has EC of 1522 µS/cm is C3S1 type showing low sodium and high salinity hazard.

Chapter 5

ASSESSMENT OF GROUNDWATER USING WATER QUALITY INDEXING TECHNIQUES

In order to assess the level of pollution in the water resources several indices have been developed and subsequently classifying the quality based on the degree of pollution (Sahu and Sikdar, 2008; Bouderbala A, 2017). For the suitability of drinking purpose Water Quality Index (WQI) is being calculated for the major cations and anions, viz. HCO_3^{-1}, Cl^-, SO_4^{-2}, NO_3^{-1}, F^-, Ca^{+2}, Mg^{+2}, TH (as $CaCO_3$), Na and K together with pH, EC and TDS. The equations for the calculation of WQI are as shown below:

Equations	Details
$q_i = \left(\frac{M_i}{S_i}\right) \times 100$	M_i = *M*easured reading of ith parameter
	Wi=Relative weight of ithparameter
$W_i = w_i / \sum_{i=1}^{n} w_i$	*Wi*=weight of each parameter
$SI_i = W_i \times q_i$	*Si*=recommended standard for each parameter
$WQI = \sum_{i=1}^{n} SI_i$	*qi*=quality rating scale
	SIi=sub-index of each parameter.

The first step is weight assigning for each of the 13 parameters based on their relative significance to the overall quality of drinking water. The second step is a calculation of relative weight (W_i) followed by calculation of quality rating scale (q_i) and finally the sub-index (SI_i) for each parameter where "i" is the individual parameter. The relative weights of the basic parameters used for WQI calculation are as shown in **Table 5a**.

Table 5a: Relative weights of basic parameters for WQI

Chemical Weight (w_i) parameters		W_i	S_i
pH	4	0.08889	8.5
EC	3	0.06667	1500
TDS	2	0.04444	500
HCO_3^-	4	0.08889	300
Cl^-	3	0.06667	200
SO_4^{2-}	5	0.11111	200
NO_3^-	5	0.11111	45
F^-	5	0.11111	1.5
Ca^{2+}	3	0.06667	75
Mg^{2+}	3	0.06667	30
Total Hardness	2	0.04444	300
Na	3	0.06667	200
K	3	0.06667	10
	45	**1.0**	

WQI is being calculated for all the samples collected during pre-monsoon as well as post-monsoon. The samples were classified accordingly as shown in the **Table 5b**. The table shows the data about both pre and post-monsoon samples collected from all over the state based on the classification.

Table 5 b: Classification of pre-monsoon and post-monsoon samples based on WQI

Classification range of WQI	Water quality status	Pre-monsoon		Post-monsoon		Classification based on
		No. of sample	% of sample	No. of sample	% of sample	
<50	Excellent	39	100	74	100	Yenugu et. al. 2020
50-100	Good	0	0	0	0	
101-200	Poor water	0	0	0	0	
201-300	Very poor	0	0	0	0	
>300	Water unsuitable for drinking	0	0	0	0	

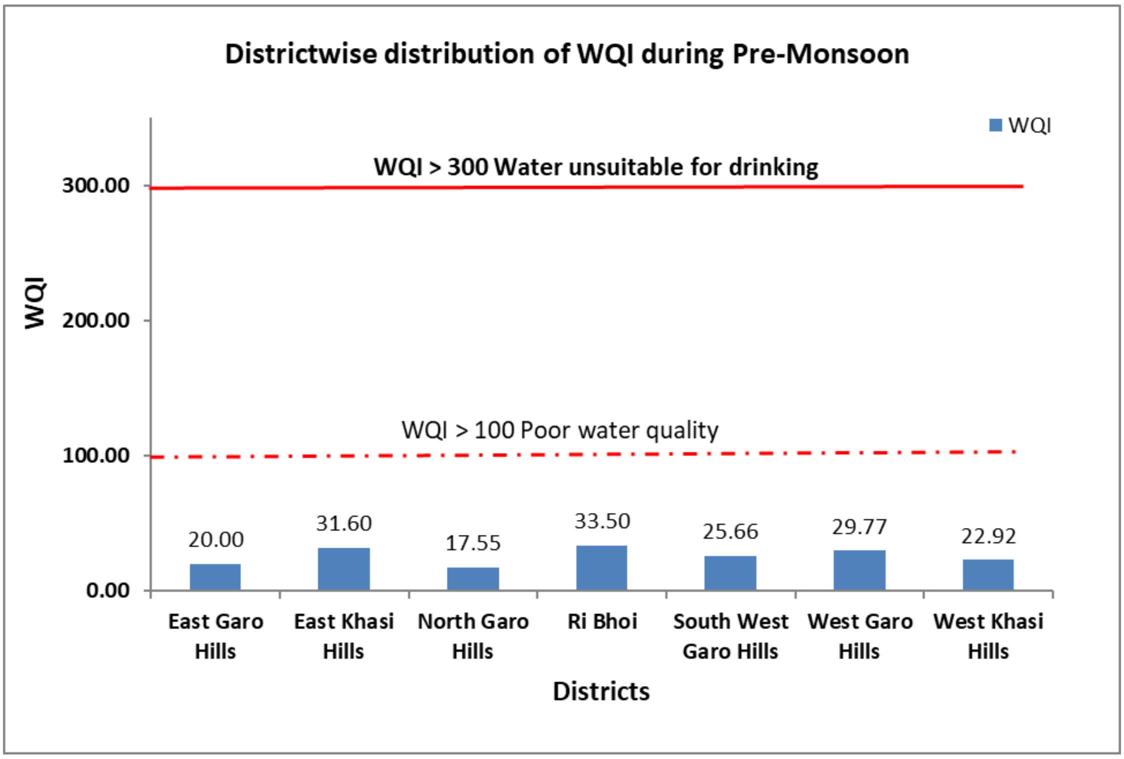

Figure 5 a: Districtwise distribution of WQI during pre-monsoon

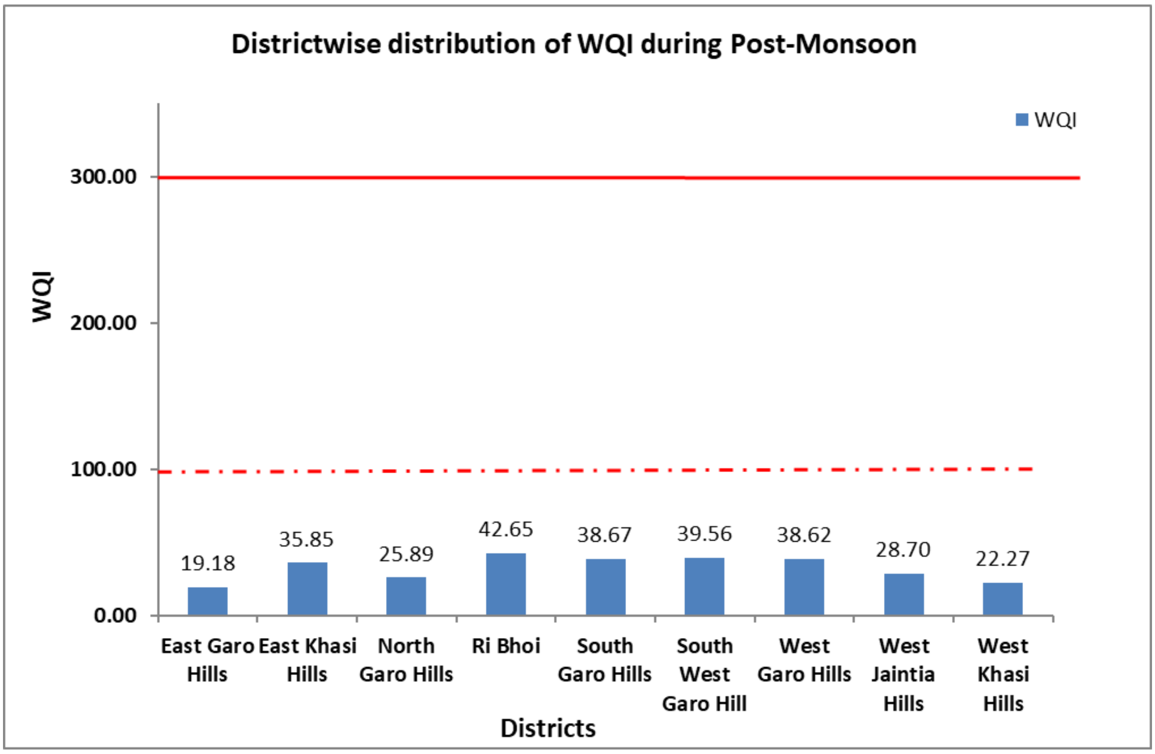

Figure 5 b: Districtwise distribution of WQI during post-monsoon

The WQI of both the pre and post-monsoon samples are classified as excellent. **Figure 5a and 5b** shows the district-wise graph for pre and post-monsoon samples. In addition to this, district-wise dataset of the classification of pre and post-monsoon samples are given in **Annexure XI and XII** for respectively.

CHAPTER 6

REMEDIAL MEASURES

Though most of the physicochemical parameters in the state are well within the safe limits the analysis of trace metals has revealed an alternate scenario. Sporadic occurrence of Iron and Manganese are found to be prevalent in the groundwater of Meghalaya. Hence remdial measures are necessary to be taken up for mitigation of the said hazards.

6.1. Remedial Measures of 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 Groundwater 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**: It 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.

CHAPTER 7

CONCLUSIONS

The groundwater quality of Meghalaya has been evaluated to find its suitability for drinking and irrigation purposes based on physicochemical parameters. Almost all the groundwater samples studied statewide during both pre and post-monsoon are safe with few exceptions. pH and turbidity being the physical parameters where some anomalies are being reported. A number of groundwater samples showed chemical parameters like Iron and Manganese levels which exceed their BIS permissible limits of drinking water. Iron and Mnaganese emerged as the predominant contaminants, with average 8.10% and 12.16% their respective samples have crossed the permissible limits of 1.0 mg/L and 0.3 mg/L in post-monsoon. Sporadic occurrences of Iron and Managnese are highly confined to the western districts like South West Garo Hills, West Garo Hills, North Garo Hills and South Garo Hills. The concentration of other heavy metals viz., Cadmium, Chromium, Zinc, Copper, Mercury, Selenium etc. and radioactive Uranium are found out to be within the permissible limit of BIS.

In terms of irrigation, the water in the region is suitable for irrigation with respect to irrigation indices such as SAR, Percentage Sodium (%Na), RSC, etc. Study of the hydrochemical facies it is revealed that in case of groundwater of the study area during pre-monsoon most of the samples were of mixed-type of water. Besides we can fairly conclude that majority of samples were of Mg-HCO_3, Ca-Cl and Na-Cl type. Bicarbonate type of water is typical of shallow and fresh groundwater which is truly complying in case of Meghalaya. Bicarbonate released through dissolution of carbonate minerals also contributes to alkalinity. Besides, deep ancient groundwater attributing to Na-Cl type, major contaminant sources of alkalinity including landfills and other alkaline dumping sites contribute to this category of hydrochemcial facies. Regarding sodium hazards affecting soil permeability as per U. S. Salinity Laboratory, most of the samples fall in S_1 (low sodium water) category. As such it should not create any sodium hazard. It is evident from the diagram that groundwater falls in the low range of sodium hazard and low to medium range of salinity hazard. Overall most of the samples are suitable for irrigation on almost all soils type.

Trend analysis of EC is shown to be same within 7 years from 2017 to 2023, i.e. no sample has exceeded 3000 µS/cm. However, for Fluoride the trend is increased due to contamination of one sample in 2021 which again re-analysed and found to be within safe criteria thereby decreasing the trend in subsequent years. For Iron level in groundwater, from 2017 increasing trend is observed which then peakes in 2021, again drops in 2022 and in 2023 it increases again.

Water Quality Index (WQI) is being calculated for all the samples collected during pre-monsoon as well as post-monsoon. The WQI of all the samples are classified as excellent category.

In view of long-term adverse effects of Iron and Managnese on the health and material, there is necessity for developing sustainable low-cost effective treatment technologies for such contaminant's remediation for sustainable access to safe drinking water. These findings may help in developing sustainable low-cost effective treatment technologies/strategies for contaminants remediation for sustainable access to safe drinking water.

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