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STATE GROUNDWATER QUALITY REPORT OF MEGHALAYA

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES, GANGA REJUVENATION & RIVER DEVELOPMENT
CENTRAL GROUND WATER BOARD,
NORTH EASTERN REGION, GUWAHATI

2023

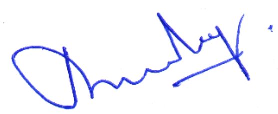
FOREWORD

Groundwater is a vital resource for Meghalaya state, serving as the principal source of public, industrial, rural water supplies, and irrigation. However, concerns are rising about the deterioration of groundwater quality due to both geogenic and anthropogenic activities. It is crucial to have prior information on the quality of groundwater resources available in Meghalaya for judicious management of this resource.

The Central Ground Water Board, North Eastern Region, constantly 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.

This report summarizes various aspects of groundwater quality in the shallow aquifers of Meghalaya, with special reference to sixteen parameters, including pH, EC, TDS, turbidity, carbonate and bicarbonate alkalinity, calcium, magnesium, and total hardness, chloride, sodium, potassium, sulphate, nitrate, and fluoride. Heavy metals, viz., Iron and Arsenic, Manganese, Uranium etc. were also being studied.

The dedicated efforts of the officers of the Board for compiling the trend 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.



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STATE GROUNDWATER QUALITY REPORT OF MEGHALAYA

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Table of Contents

1

GENERAL INTRODUCTION

1. INTRODUCTION

In the overall use and management of water resources groundwater (GW) plays an essential role. The demand for GW for municipal, agricultural and industrial purposes has only grown during the past decades. More than 2.5 billion people across the globe directly depends on GW consumption and approximately 50% of the arable land is irrigated by GW. GW plays a vital role in hydrological cycle as it reacts with other hydrological resources (Alley et al., 2005). The quality of the GW also plays a significant role apart from its quantity. GW pollution has become a global problem with significant effects on environmental security and human health. GW quality depends on the climate, composition of recharge, subsurface medium etc. (Şen, 2015). Partially, changes occur in groundwater quality because of infiltrated particles in the soil (Fitts, 2013). Besides this, the co-occurrence of multifarious organic and inorganic constituents, comprising of heavy metals, pesticides, nitrates, and sulfates culminates in the deterioration of the caliber of the GW in numerous regions. The levels of these contaminants may exceed the permissible limits set by the World Health Organization (WHO) or Bureau of Indian Standards (BIS) in the Indian scenario.

In this study we have elaborately studied the various physicochemical parameters in GW samples collected representatively throughout Meghalaya state in north-eastern part of India where GW is considered a primary source of water. This GW quality report for Meghalaya aims to provide a thorough insight into the current status of GW quality in the state. The chemical data generated from this study would help to determine the suitability of GW for domestic as well as irrigation purposes and draw the attention towards contaminants posing as health hazards for human life. The identification of these sources is crucial for the implementation of effective management strategies to prevent further contamination and improve the GW quality. Fluoride, nitrate, and arsenic, for instance are some of the contaminants that can have severe health consequences, especially for vulnerable populations such as children and pregnant women.

The findings of this report will be essential for policymakers, researchers, and local communities in developing effective GW management strategies and encouraging sustainable GW use. The report will also serve as a reference for future studies and monitoring programs to assess the effectiveness of the implemented measures in improving GW quality in Meghalaya.

1.1. 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 Assam (Goalpara, Kamrup and Nowgong districts) to the north and (Karbi Anglong district and North Cachar Hills) 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, SW Garo Hills, East Khasi Hills, East Jaintia Hills, West Jaintia Hills, SW Khasi Hills, West Khasi Hills, Eastern West Khasi Hills, Ri-Bhoi.

1.2. CLIMATE

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.

1.3. 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 (Barooh and Goswami, 1972) or Mawphalang Formation (Battarcharjee and Rahman, 1985) or Shillong Formation (Ahmed, 1981).

1.4. RIVERS

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 GW in Meghalaya is influenced by the topography, presence of rock fractures, weathering zones. Springs, seepages, wells, and bore wells are some forms in which GW resources are available. Most of the area is occupied by the quartzite and granite rocks having GW 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.

1.5. GROUNDWATER MONITORING & METHODOLOGY

Monitoring of GW quality is an effort to obtain information on chemical quality through representative sampling in different hydrogeological units. GW 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 quality of GW is controlled by geochemical processes dependent upon the nature of lithology, topographical features, recharge and rock weathering associated with mineral dissolution, ion exchange, and evaporation. (Saravanan et al. 2015; Subba Rao et al. 2017) The main objective of GW 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 ground water.

Central Ground Water Board, North Eastern Region, has set up a number of Ground Water Monitoring Wells (GWMW) in different hydrogeological conditions in order to know GW condition and its variation, in both time and space. Figure 1 consists of a map showing the sample points. 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. Thirty-three (33) samples were collected during the pre-monsoon of 2022, i.e. in the month of March 2022. Pre-monsoon being a dry spell just before the arrival of monsoon results in higher elemental concentration as compared to the post-monsoon period. The sample points from which GW samples were collected were marked using their geographical coordinates from GPS. Their latitudes and longitudes were further imported to ArcGIS for spatial distribution analysis.

1.5.1. SAMPLE COLLECTION

The samples were collected in clean, sterile and air-tight high-density polyethylene bottles (HDPE) as per APHA protocol (APHA, 23rd Ed). For basic ions analysis the samples were collected in 1L HDPE bottles while for trace metals samples were collected in 60mL HDPE bottles. The samples in 60mL bottles were filtered with a 0.45-micron membrane using a syringe filtration unit technique. Immediately after filtration 0.5 mL trace elemental grade HNO_3 acid is added as preservatives. If the samples were obtained from wells then it is made sure the wells were pumped before sampling to have a stable water temperature, turbidity and other physical parameters. Also, caution was being taken while filling the bottles to avoid interference from air headspace. Spot analysis of pH, electrical conductivity (EC), dissolved oxygen (DO) and oxidation-reduction potential (ORP) were done using a water test kit. All the sets of samples were labeled and transferred to the laboratory in ice box with ice pads maintaining a temperature of ≤4ºC.

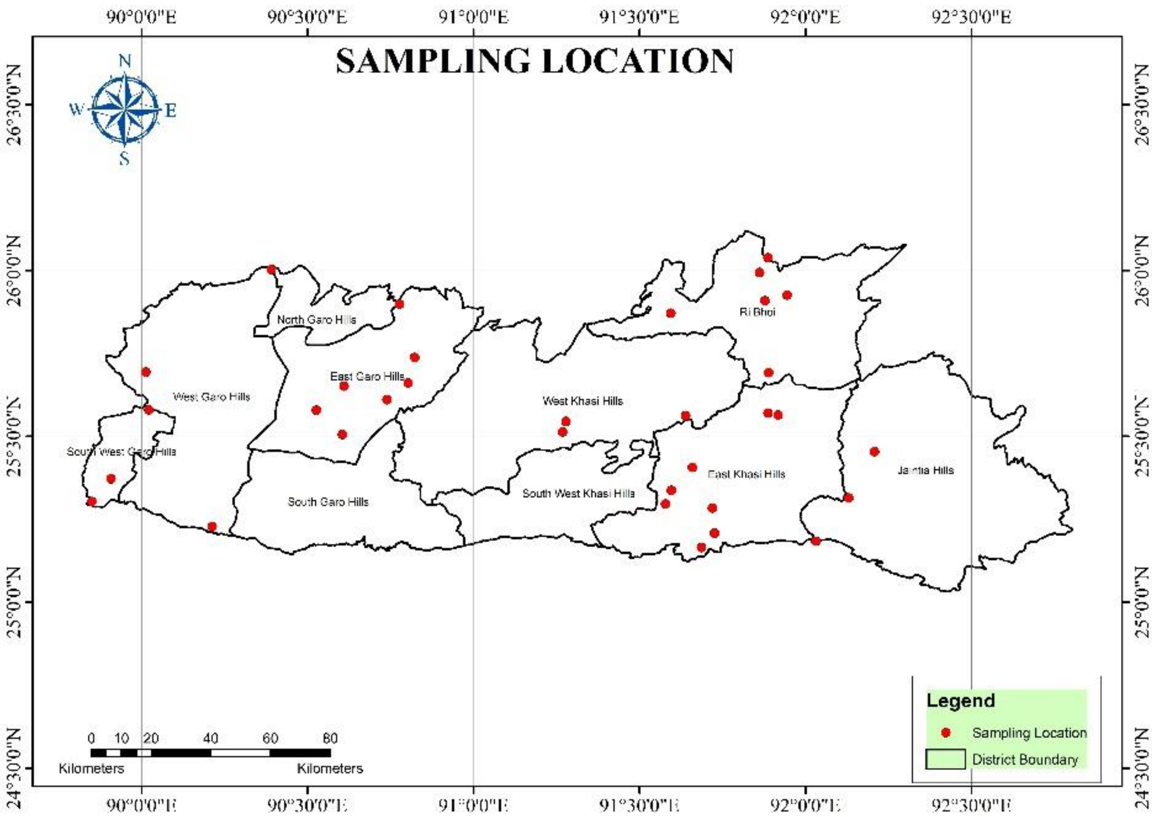

Figure 1: Map of Meghalaya with sampling locations

1.5.2. ANALYTICAL TECHNIQUES & QUALITY CONTROL

Standard analysis procedures described in APHA, 23rd edition was employed for analyzing the GW samples. While analysis, QA/QC protocols were being followed that included blank run, external calibration and standardization by National Institute of Standards and Technology (NIST) certified standard reference materials, retesting, etc. Physical water quality parameters such as pH, EC, TDS, turbidity was measured by pH-meter, conductivity meter and nephalo-turbidity meter respectively. Na and K were analyzed in flame-photometer. NO_3^- and SO_4^{2-} analysis were done in UV-Visible spectrophotometer (Labindia, UV-3200) setting the λ_{max} at 220 nm and 420 nm respectively. Fluoride analysis was done in ion-meter (Oakton Ion 700). Total hardness (TH) as $CaCO_3$, CO_3^{2-}, HCO_3^- and Cl^- were analyzed by volumetric titration method.

All the chemicals used were of analytical grade (Merck). Ultrapure water was used exclusively. For establishing the reliability and quality of the analytical results errors in the ionic balance ought to be < 5% for each analysis. The formula for ionic balance was calculated by $[\{(T^{Z+} - T^{Z-})/(T^{Z+} + T^{Z-})\} \times 100]$ where T^{Z-}/ T^{Z+} are the ions. The ionic balance errors (%IBE) for all GW samples were found to be within the recommended limit of 5% (Burton, R.F., 1983).

The spatial distribution of the GW quality parameters was obtained by using ArcGIS 9.1, a geostatistical software package. Inverse Distance Weighted interpolation technique is adopted to prepare the spatial variations map to assess the GW quality of the study area for drinking purpose.

2

ASSESSMENT OF GROUND WATER QUALITY FOR FEASIBILTY IN IRRIGATION

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 (TDS) in irrigation water (measured in terms of electrical conductance) on crop growth is extremely important. Soil water passes into 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 proper leaching. These effects are visible in plants by their stunted growth, low yield, discoloration and even leaf burns at margin or top. For study of suitability of irrigation various indices are widely used and some of which are as discussed below (Faten et al. 2016; Mukate et al. 2020).

2.1. IRRIGATION WATER QUALITY CRITERIA

2.1.1. SALINITY BASED ON ELECTRICAL CONDUCTIVITY AND CHLORINITY

Electrical conductivity (EC), total dissolved solids (TDS) and chlorinity are used as a measure of salinity of GW. Water with EC<3000 µS/cm at 25ºC and TDS<1000 mg/L is safe to be used for irrigation purpose. Water parameters that exceed these limits can render it unsuitable for irrigation. GW that spends a longer time in the aquifers and has low mobility tends to become more mineralized, which results in higher levels of electrical conductivity (EC) and total dissolved solids (TDS). Chlorinity in ground water should be below 500 mg/L for being suitable to be used in irrigation.

2.1.2. 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. SAR is mathematically calculated as

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

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

Soluble Sodium Percentage (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 are 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. (Kelly WP, 1963)

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

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

2.1.3. EFFECTS OF BICARBONATE ION CONCENTRATION

The residual alkalinity is denoted by Residual Sodium Carbonate (RSC) as developed by Eaton in 1950. 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.

2.1.4. EFFECTS OF BICARBONATE ION CONCENTRATION

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2.1.1. PERMEABILITY

Doneen in 1964 developed Permeability Index (PI). Continuous 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.

2.1.2. MAGNESIUM RATIO

The relative proportion of magnesium in water is calculated as Magnesium Ratio (MR) (Szaboles and Darab, 1964.) It is formulated as below:

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

The MH>50 is considered unsuitable for irrigation purpose.

2.1.3. 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). The diagram is proposed with the assumption that water is used under average conditions with respect to soil texture, filtration rate, and drainage, quantity of water used, climate and tolerance of corps. The diagram takes into consideration the salinity and sodium hazard of irrigation waters.

2.1.4. PIPER DIAGRAM

Hydro-chemical facies are very useful in investigating diagnostic chemical character of water in hydrologic systems. Different types of facies within the same group formations are due to characteristic GW 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.

2.2. GW QUALITY SCENERIO OF MEGHALAYA FOR IRRIGATION PURPOSE

All the irrigation indices as mentioned above were calculated for the 33 locations and tabulated as in Annexure I. The electrical conductivity of the GW samples within the state ranges from 13.12-475.30 µS/cm. Hence the GW of Meghalaya may be categorized being low in salinity. The calculated Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Percentage Sodium for all the samples are reported to be within the safe limits, i.e., SAR<10, RSC<1.25 meq/L and Percentage Sodium<60%. Cherrapunji in East Khasi Hills has shown Soluble Sodium Percentage (SSP) as above 50% and Kelly's Index (KI) greater than 1, thus making it unsuitable for irrigation purpose. While for SSP and KI all other samples are below the safe limits. For Magnesium Ratio (MR) 39% of the samples are above the safe index of 50, indicating unsuitability for irrigation owing to magnesium related concerns pertaining to the soil or soil permeability issues. The Permeability Index (PI) calculation reveals that 69.6% of the samples fall under the Class I category, i.e., they have good soil permeability. Whereas there are locations in East Garo Hills, SW Garo Hills and West Garo Hills where the permeability is not good enough but can be improved by management practices such as soil amendment, irrigation scheduling, or crop selection to maximize their effectiveness for irrigation purposes.

The US salinity diagram for Meghalaya is as shown in Figure 2. It reveals that most of the analyzed GW samples fall in the C1S1 category, which is the lowest level of salinity on the diagram. This means that the water has a low concentration of both sodium and chloride ions, and a low overall TDS. Apart from this there are a few samples from East Garo Hills and Ri Bhoi that falls under C2S1 indicating slightly higher salinity but still below salinity hazard criteria.

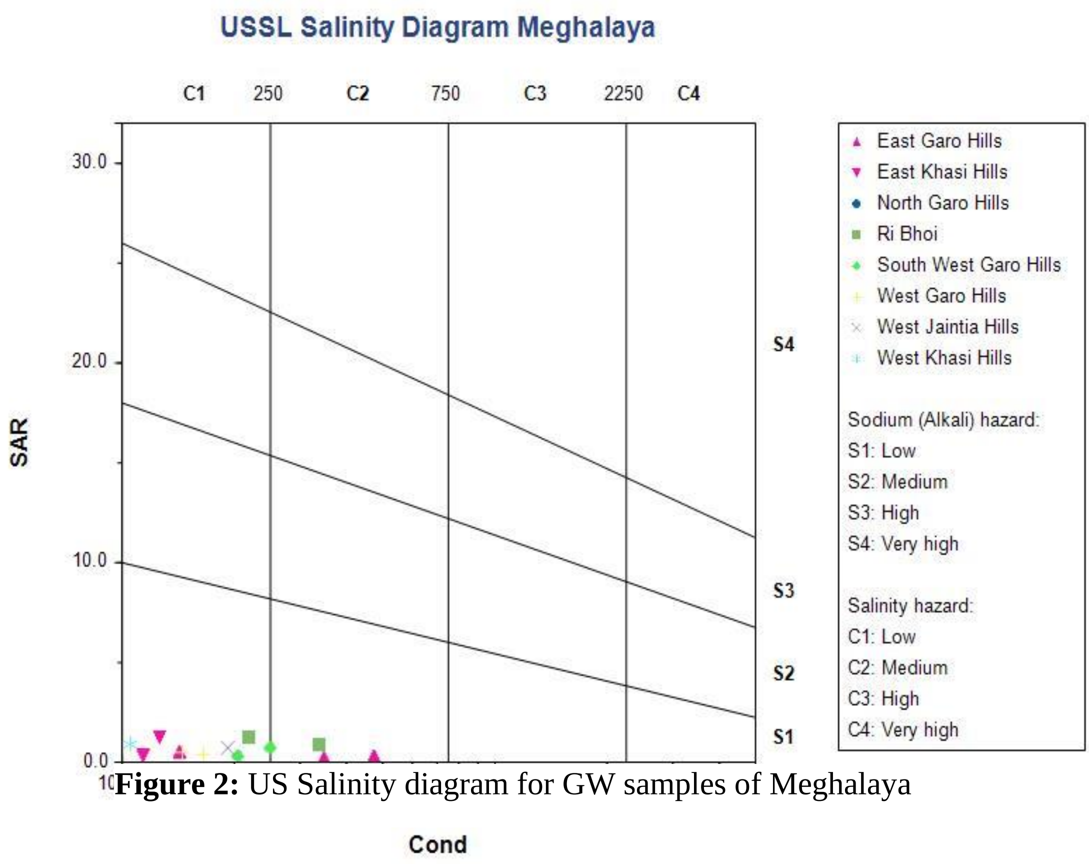

Figure 2: US Salinity diagram for GW samples of Meghalaya

The piper diagram in Figure 3 shows that most of the GW samples fall within the "no dominant type" category, which means that the concentration of the major cations are roughly equal. In the cation triangle though mix type is dominant but has some of the samples under sodium and potassium type. This may indicate that the water is relatively fresh and has not undergone significant mineralization processes. In the anion triangle the water is bicarbonate and chloride type which indicates that the water has a relatively high concentration of these two anions, which may be due to dissolution of minerals or contamination from anthropogenic sources. Subsequently when taking the rhombus into consideration, the water can be widely classified as falling into the mixed type in the piper diagram but also shows to be $Mg(HCO_3)_2$ and $CaCl_2$ type. Moreover, the overall observation indicates the soil is more alkaline than water.

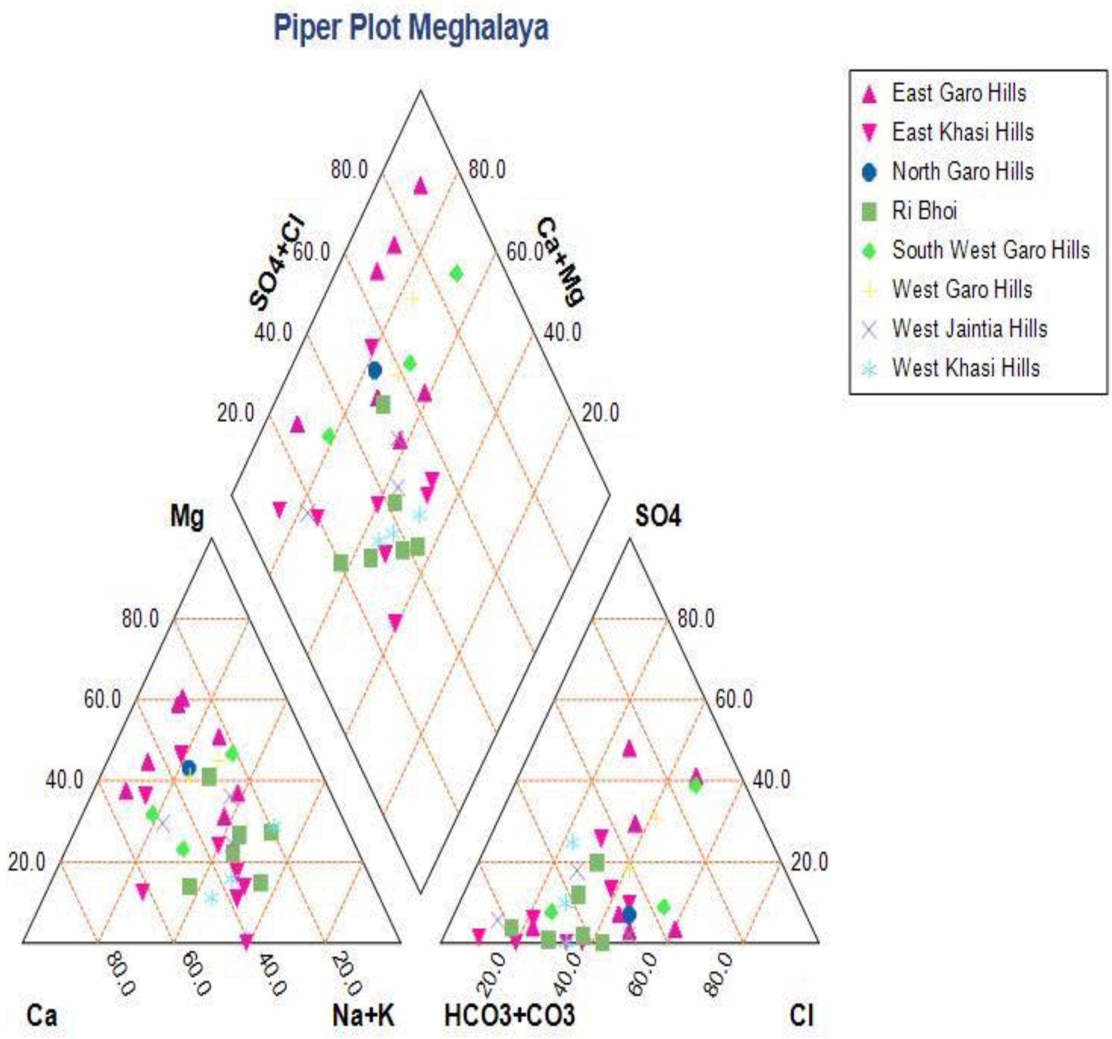

Figure 3: Piper plot for GW samples of Meghalaya

3

ASSESSMENT OF GROUNDWATER QUALITY FOR DRINKING & DOMESTIC PURPOSE

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.

3.1. PHYSIOCHEMICAL PARAMETERS FOR DRINKING WATER & DOMESTIC PURPOSE

3.1.1. HYDROGEN ION CONCENTRATION (pH)

The pH of a sample is the -ve logarithm of H_2 ions ranging from 0 to 14. BIS has set the prescribed range of pH for drinking water to be 6.5-8.5. The pH value in the state ranges from 6.09 to 8.37 both reported from East Garo Hills. The lower range of pH in Meghalaya is below the BIS prescribed limit of drinking water which is 6.5. East Khasi Hills (6.42) and West Garo Hills (6.39) are other districts registering pH lower than BIS range of 6.5-8.5. Except for Ri Bhoi, West Jaintia Hills and West Khasi Hills all other districts have pH below 6.5 rendering the water to be categorized as slightly acidic in nature. This can be attributed to presence of weaker salt in the soil. Figure 4 shows the spatial distribution of pH throughout the state. The acidic pH is concentrated over East Garo Hills while Jaintia Hills, Ri Bhoi and West Garo Hill areas have more of a neutral pH close to 7.

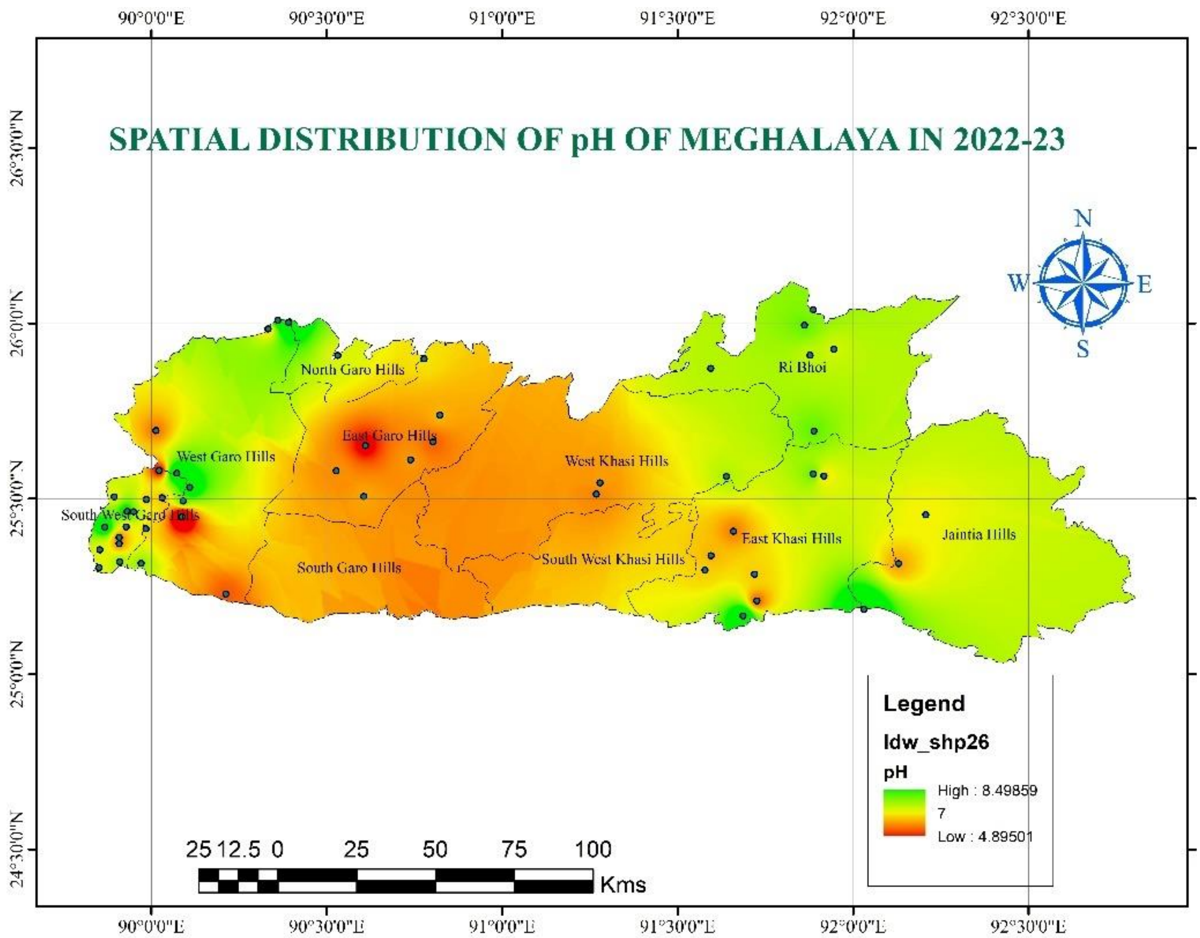

Figure 4: Spatial distribution of pH in GW samples of Meghalaya

3.1.2. ELECTRICAL CONDUCTIVITY (EC) AND TOTAL DISSOLVED SOLIDS (TDS)

Conductivity is the capacity of water to carry an electrical current. This varies both with number and types of ions the sample contains. In contrast, the conductivity of distilled water is less than 1µS/cm. It depends on the presence of ions their total concentration, mobility, valence and relative concentration and on the temperature of the sample. East Khasi Hills records the minimum EC of 13.12 µS/cm and East Garo Hills has the highest EC of 475.30 µS/cm. The lower EC in some parts indicates the water to be softer and lower mineral content while those EC being on comparatively higher part specifies the sample to be more mineral-richer.

TDS is a measure of organic and inorganic salts like carbonates, chlorides, sulphate and phosphates in natural water (Mondal et al. 2005). The TDS ranges from 8.66-313.70 mg/L in the state. The EC values found are far below the BIS permissible limit.

Figure 5 shows the distribution of EC throughout the Meghalaya state where EC recording lower values are concentrated over East Khasi Hills and the surrounding districts and the relatively higher EC are found to be shown over the East Garo Hills and West Garo Hills.

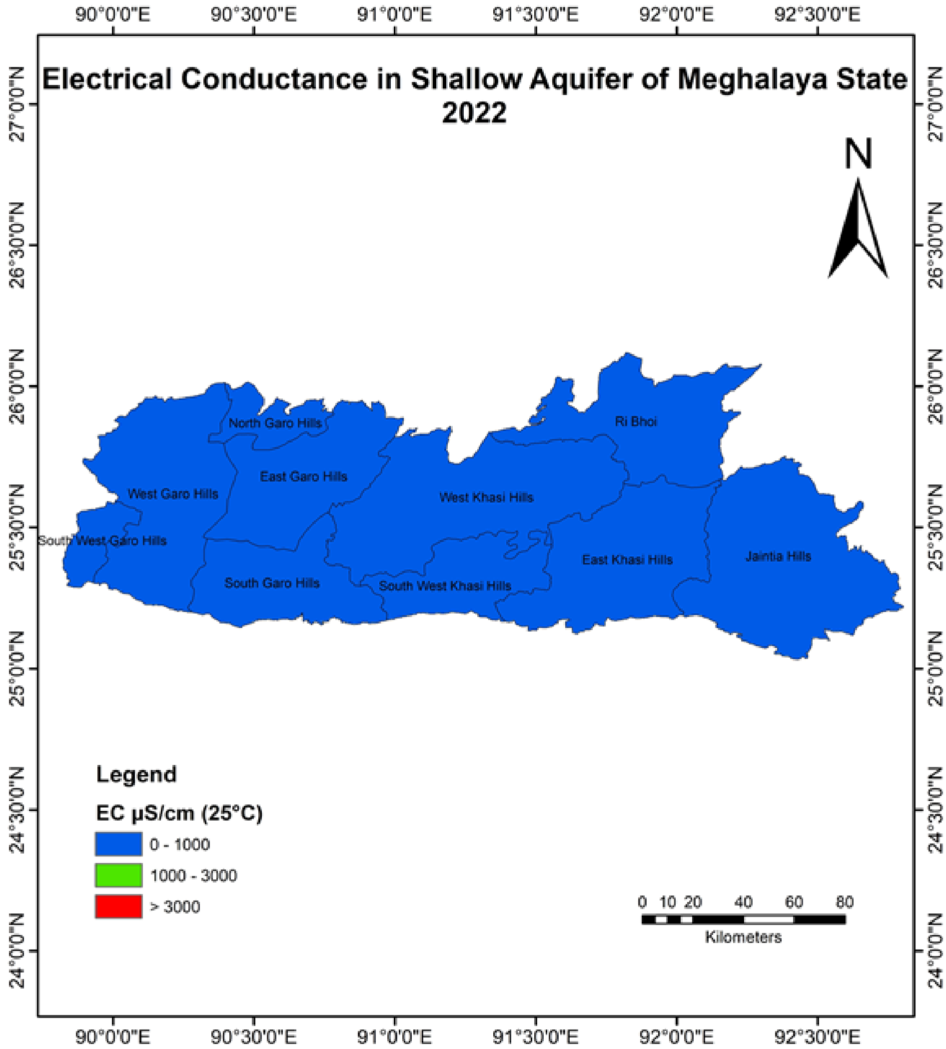

Figure 5: Distribution of EC in GW samples of Meghalaya

3.1.3. MAJOR CATIONS

The major cations present in the GW analyzed within the state are calcium (Ca^{2+}), magnesium (Mg^{2+}), Potassium (K^{+}) and sodium (Na^{+}). Calcium (Ca^{2+}) concentration ranges from 4 to 46 mg/L while magnesium (Mg^{2+}) ranges from 1.21 to 23.04 mg/L, both well below the BIS prescribed limits for drinking water. Likewise Na^{+} and K^{+} concentration are within

2.50-27.86 mg/L and 0.48-11.51 mg/L respectively and within the safe limits prescribed for drinking water.

3.1.4. MAJOR ANIONS

The major anions studied in the GW of Meghalaya state are chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). The ionic concentration is in the order $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^-$. Bicarbonate ion concentration in the GW samples within the state varies from 6.10-213.67 mg/L. The Cl^- ion values range from 7.09-46.09 mg/L, SO_4^{2-} ion ranges from 0.18-45.68 mg/L while NO_3^- ion varies from 0.60 mg/L to 40.15 mg/L. All the values are within the BIS drinking water limits.

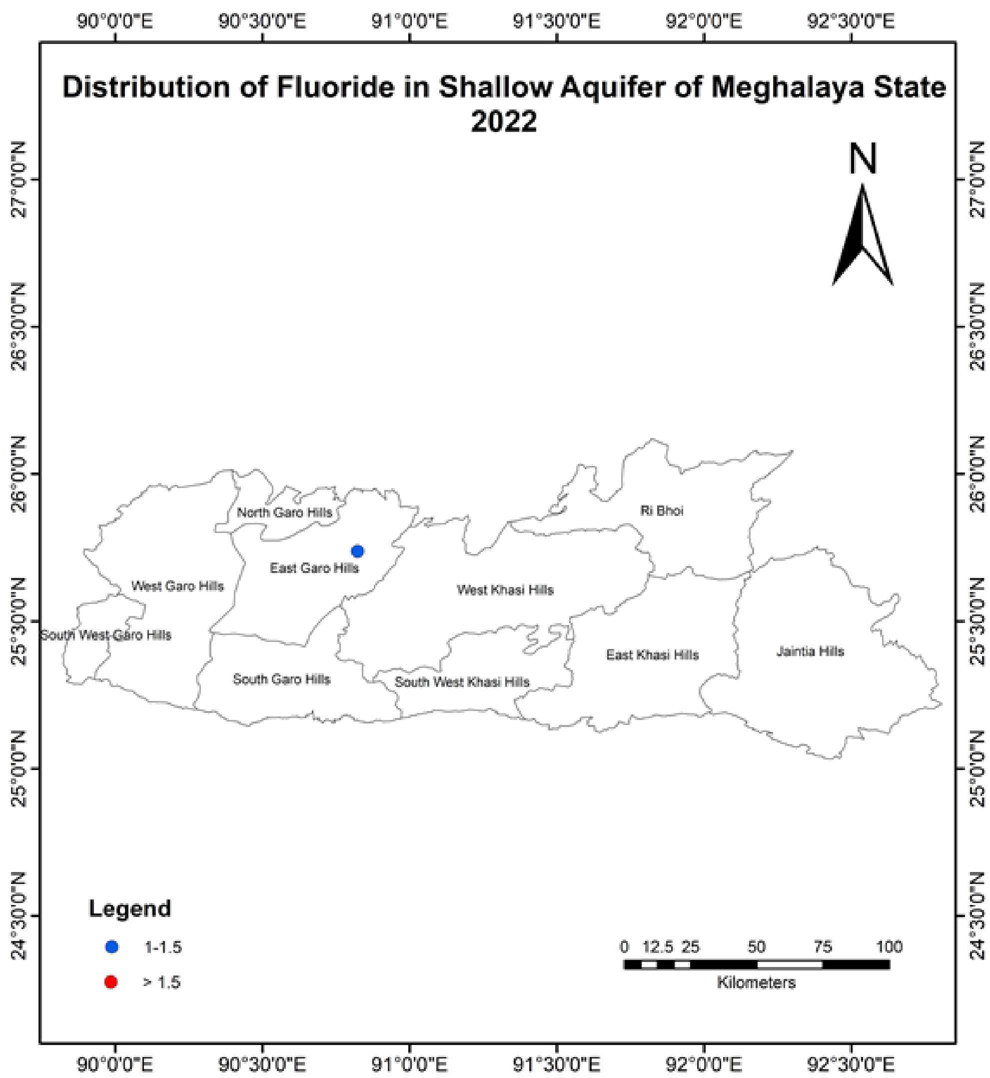

Figure 6 :Distribution of Fluoride in Meghalaya during 2022

The distribution of Fluoride in the state during 2022 is shown in Figure 6. Only one location in East Garo Hills with fluoride concentration of 1.10 mg/L is recorded during this period.

3.1.5. TRACE METALS

The GW samples of Meghalaya were analysed for iron, arsenic and uranium. The concentration of iron ranges from 0.004-20.69 mg/L. Three locations viz., Tyrsad (4.01 mg/L), Pahanmawlier (16.84 mg/L) and Pungsoir (20.69 mg/L) from East Khasi Hills, Ri Bhoi and West Khasi Hills respectively have recorded iron concentration above BIS drinking water limit of 1.0 mg/L. Though these locations do not have much impactful human activities, the iron concentration much above the permissible limit can be attributed to the geogenic factors such as presence of ferruginous rocks and higher organic content in soil. On the other hand, arsenic and uranium in GW samples ranges from 0.01-0.98 µg/L and 0.002 to 1.45 µg/L respectively. Therefore, the GW of the state is safe for drinking water point of view except for iron in some pockets. The GW having iron content above permissible limit can be treated before domestic use by means of local techniques such as filtration through activated carbon, limestone treatment or water softening etc.

The distribution of iron in the GW samples of Meghalaya is shown in Figure 7. As already mentioned the higher concentration of iron in GW is around West Khasi Hills, Ri Bhoi and East Khasi Hills.

The district-wise minimum and minimum values of the chemical parameters of the GW samples collected are tabulated in Annexure II. The statistical findings related to the major cations, major anions and trace metals are shown as below in Table 1.

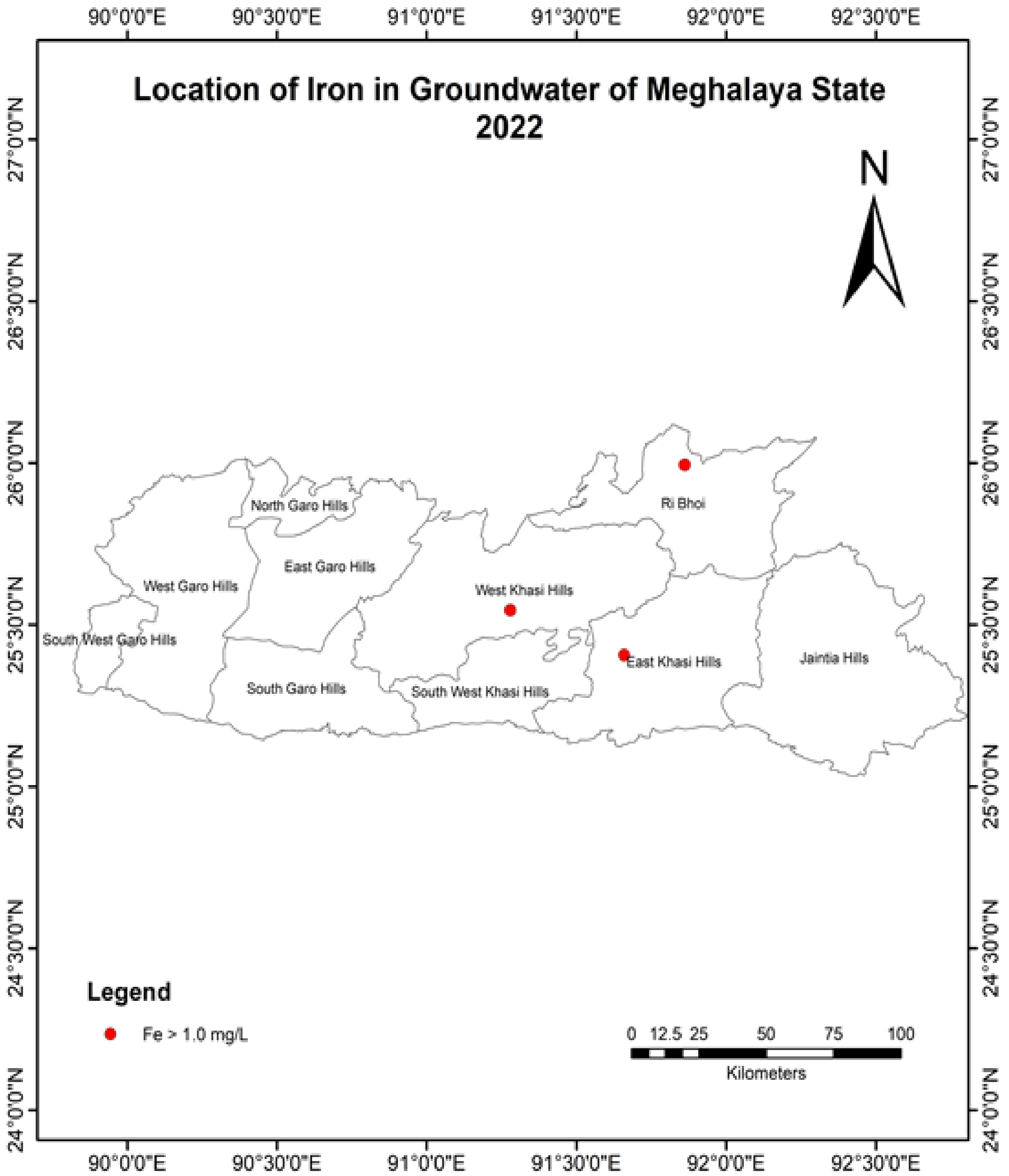

Figure 7: Distribution of iron in GW samples of Meghalaya

Table 1: Statistical information of dataset with BIS and WHO standards

Parameters		Statistical details				Prescribed limits	
		Mean	Minimum	Maximum	Std. deviation	BIS	WHO
pH		6.96	6.09	8.37	0.62	6.5-8.5	6.5-8.5
EC	(µS/cm) 25°C	123.61	13.12	475.30	122.06	–	–
Turbidity	NTU	0.11	0.01	0.64	0.15	1	–
TDS	mg/L	81.58	8.66	313.70	80.56	2000	1000
CO_3^{-2}	mg/L	3.75	BDL	9.00	4.07	–	
HCO_3^{-1}	mg/L	55.27	6.10	152.62	43.24	–	125-130
TA (as CaCO3)	mg/L	54.61	BDL	161.62	45.40	600	–
Cl^-	mg/L	18.59	7.09	46.09	11.10	1000	250
SO_4^{-2}	mg/L	12.88	0.18	45.68	13.66	400	250
NO_3^{-1}	mg/L	13.36	0.60	40.15	12.02	–	50
F^-	mg/L	0.21	0.07	1.10	0.25	1.5	1.5
TH (as $CaCO_3$)	mg/L	65.00	15.00	195.00	54.44	600	–
Ca^{+2}	mg/L	13.79	4.00	46.04	11.76	200	75
Mg^{+2}	mg/L	7.65	1.21	23.04	7.02	100	125
Na	mg/L	9.99	2.50	27.86	6.88	–	200
K	mg/L	4.88	0.48	11.51	2.92	–	12
Fe	µg/L	2.49	0.00	20.69	5.85	1000	300
As	µg/L	0.29	0.01	0.98	0.27	10	10
U	µg/L	0.18	0.00	1.45	0.34	–	30

3.2. TRENDS 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 6 years trend of some significant parameters in GW of Meghalaya. We have plotted graphs with 3 variables with the years 2017 to 2022 on x-axis, followed by number of districts affected and subsequently the percentage of locations affected. The number of locations exceeding the BIS drinking water permissible limits and the graphs depicting the trend analysis of each significant chemical parameters are summed in Figures 8 a-8 h.

Year	Total No. of samples analysed	No. of districts affected by EC	Total No. of locations affected by EC	% of locations affected by EC (EC > 3000 µs/cm)
2017	61	0	0	0
2018	75	0	0	0
2019	39	0	0	0
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

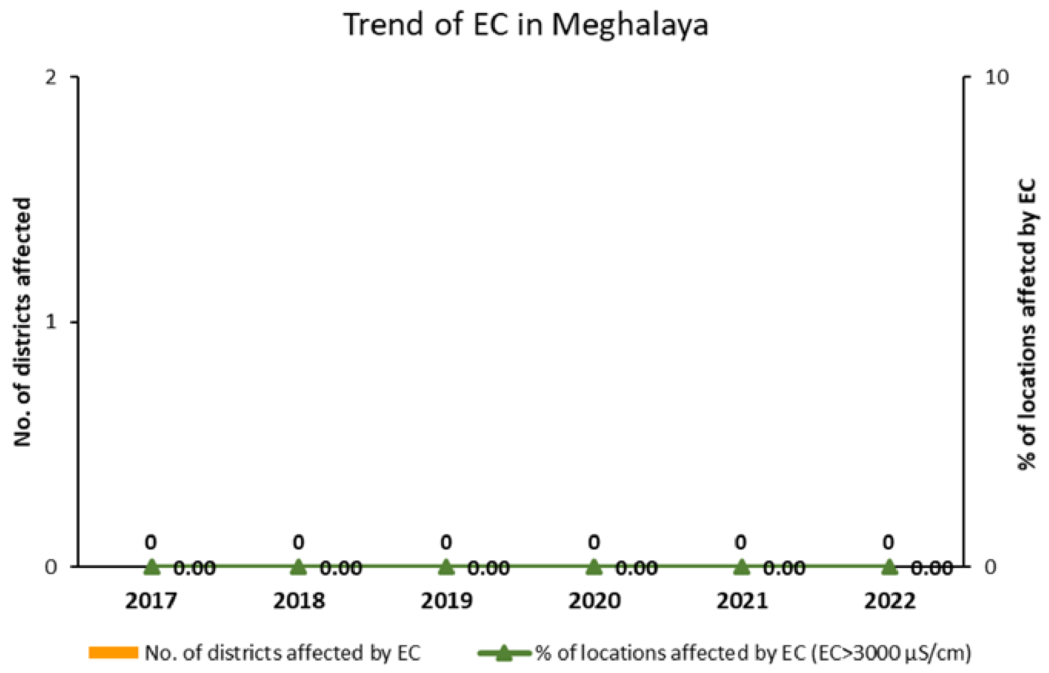

Figure 8 a) Trend analysis of EC from 2017-22

Year	Total Number of samples analysed	No. of districts affected by Cl	Total No of locations affected by Cl	% of locations affected by Cl (Cl >1000 mg/L)
2017	61	0	0	0
2018	75	0	0	0
2019	39	0	0	0
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

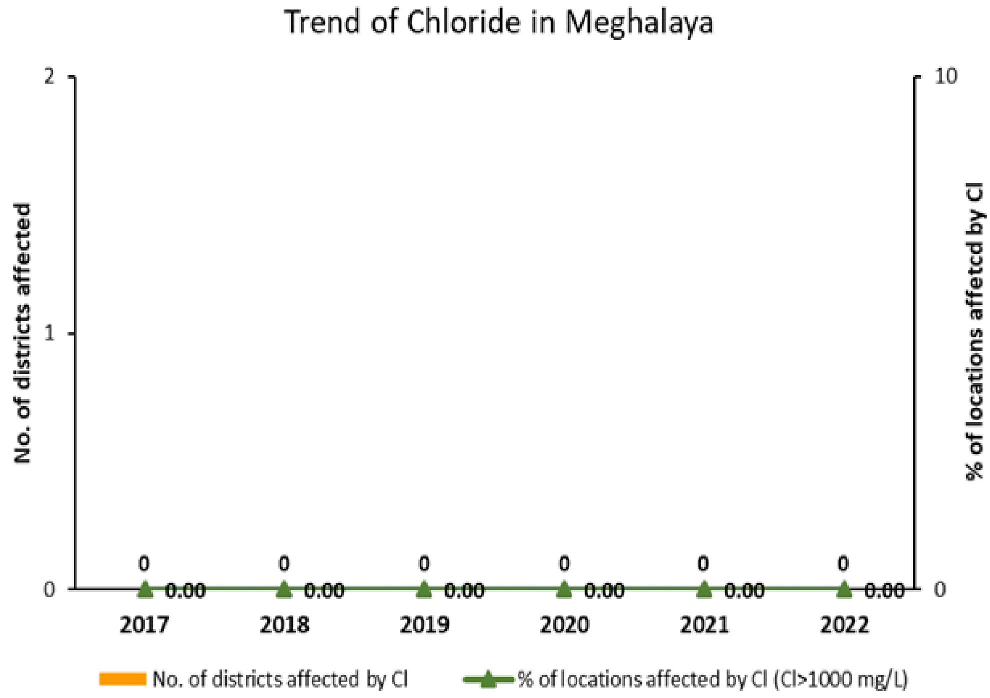

Figure 8 **b) Trend analysis of Chloride from 2017-2022**

Year	Total No. of samples analysed	No. of districts affected by NO_3^-	Total No. of locations affected by NO_3^-	% of locations affected by NO_3^-
2017	61	0	0	0
2018	75	0	0	0
2019	39	0	0	0
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

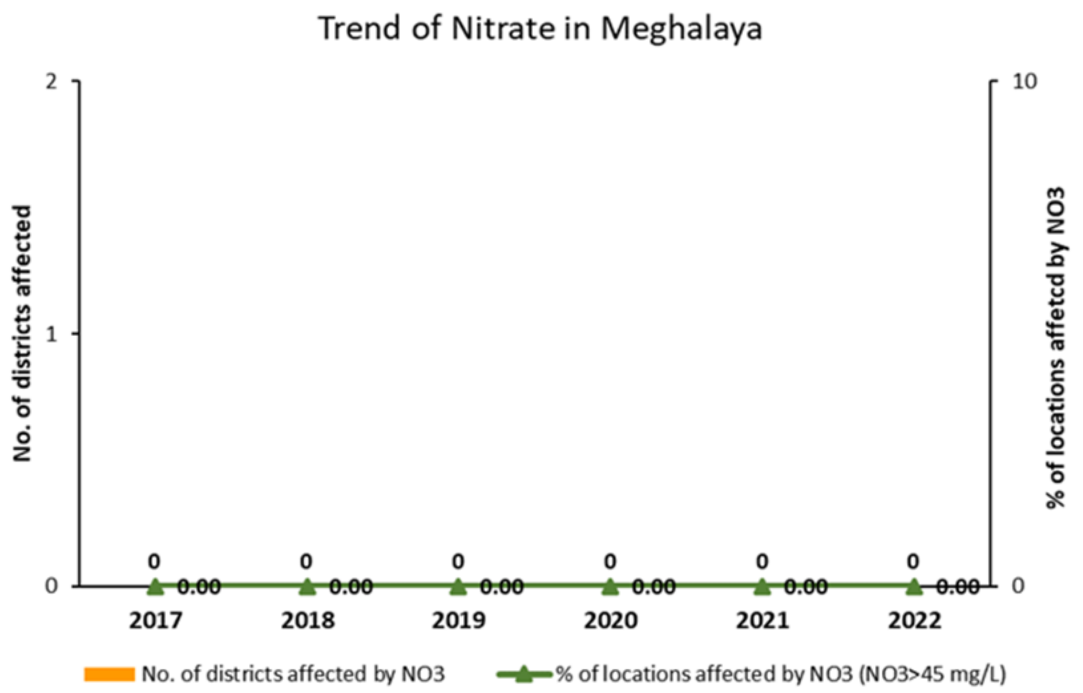

Figure 8 a) Trend analysis of Nitrate from 2017-2022

Year	Total No. of samples analysed	No. of districts affected by F	Total No. of locations affected by F	% of locations affected by F
2017	61	1	3	4.918
2018	75	1	2	2.666
2019	39	1	1	2.564
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

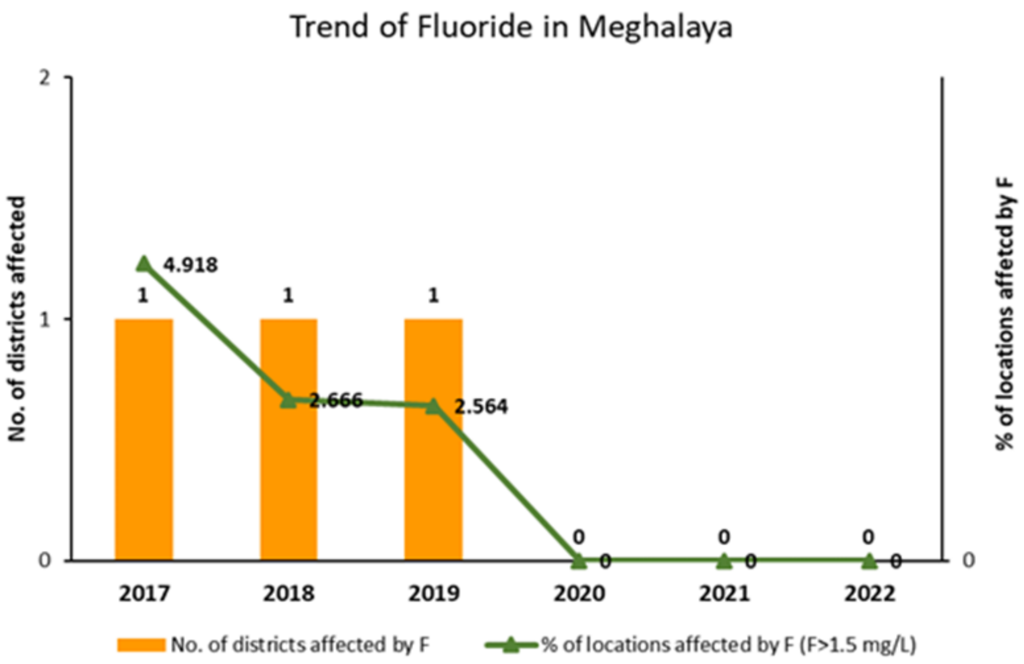

Figure 8 b) Trend analysis of Fluoride from 2017-2022

)

Year	Total Number of samples analysed	No. of districts affected by TH	Total No of locations affected by TH	% of locations affected by TH (TH >600 mg/L)
2017	61	0	0	0
2018	75	0	0	0
2019	39	0	0	0
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

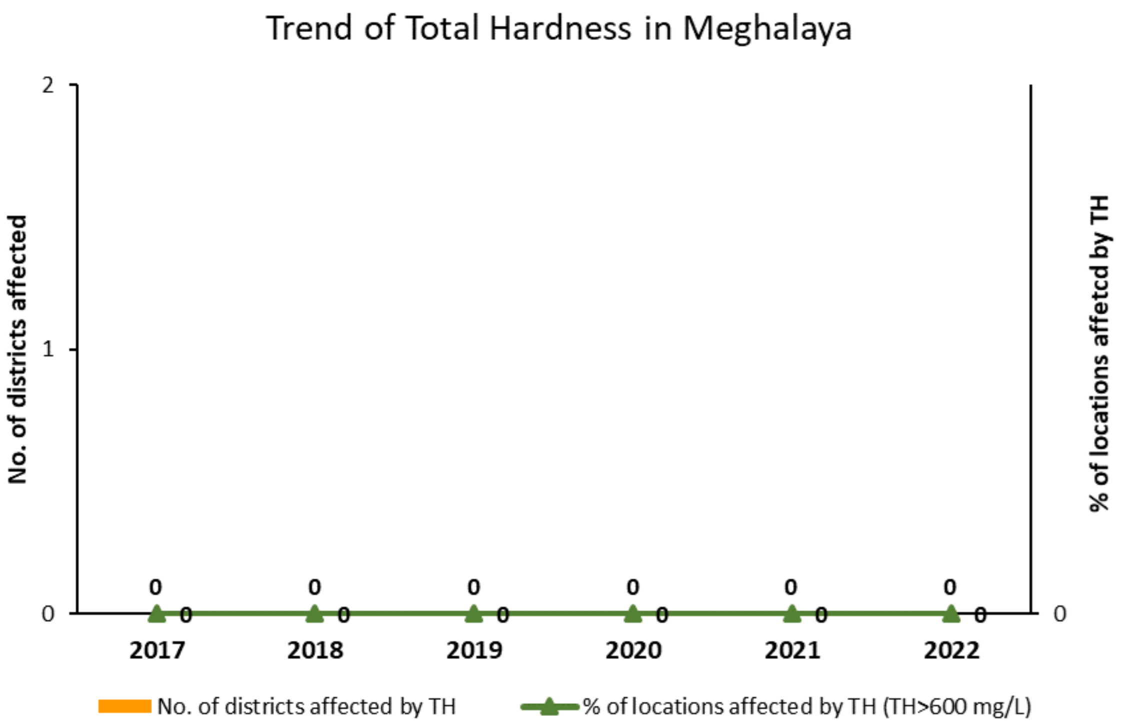

Figure 8 c) Trend analysis of Total Hardness from 2017-2022

Year	Total No. of samples analysed	No. of districts affected by Fe	Total No. of locations affected by Fe	% of locations affected by Fe
2017	61	4	8	13.11
2018	75	4	5	6.66
2019	39	0	0	0.00
2020	27	5	7	25.93
2021	44	5	8	18.18
2022	33	3	3	9.09

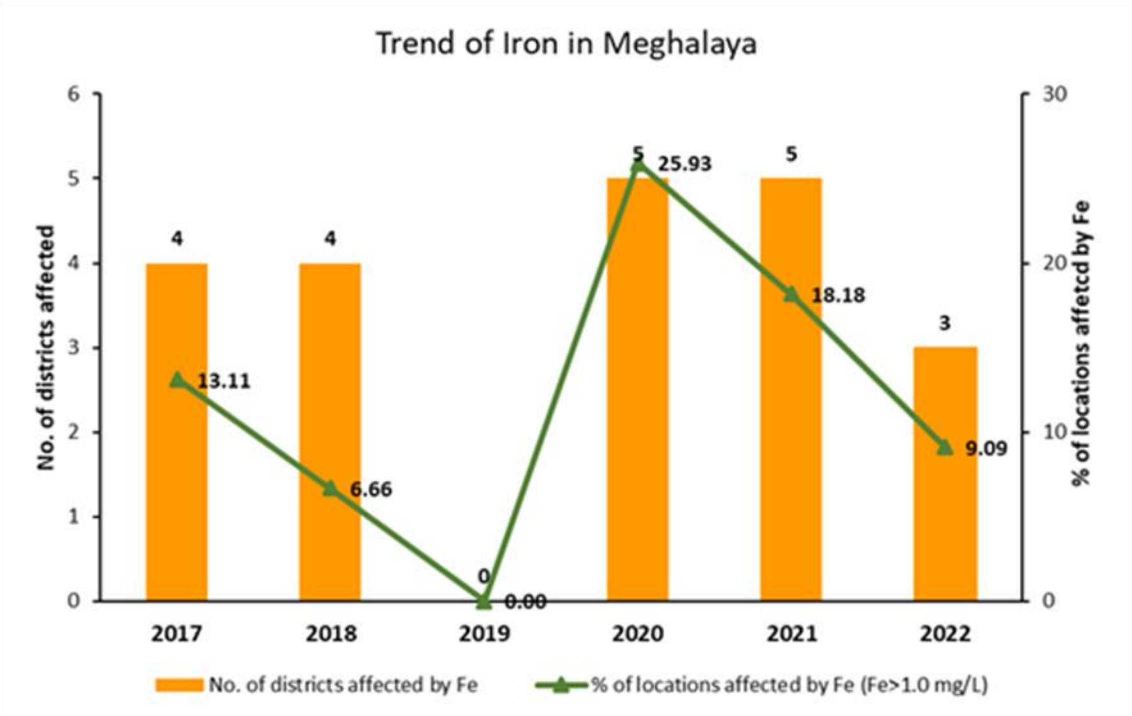

Figure 8 d) Trend analysis of Iron from 2017-2022

Year	Total Number of samples analysed	No. of districts affected by As	Total No of locations affected by As	% of locations affected by As (As >0.01 mg/L)
2017	61	0	0	0
2018	75	0	0	0
2019	39	0	0	0
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

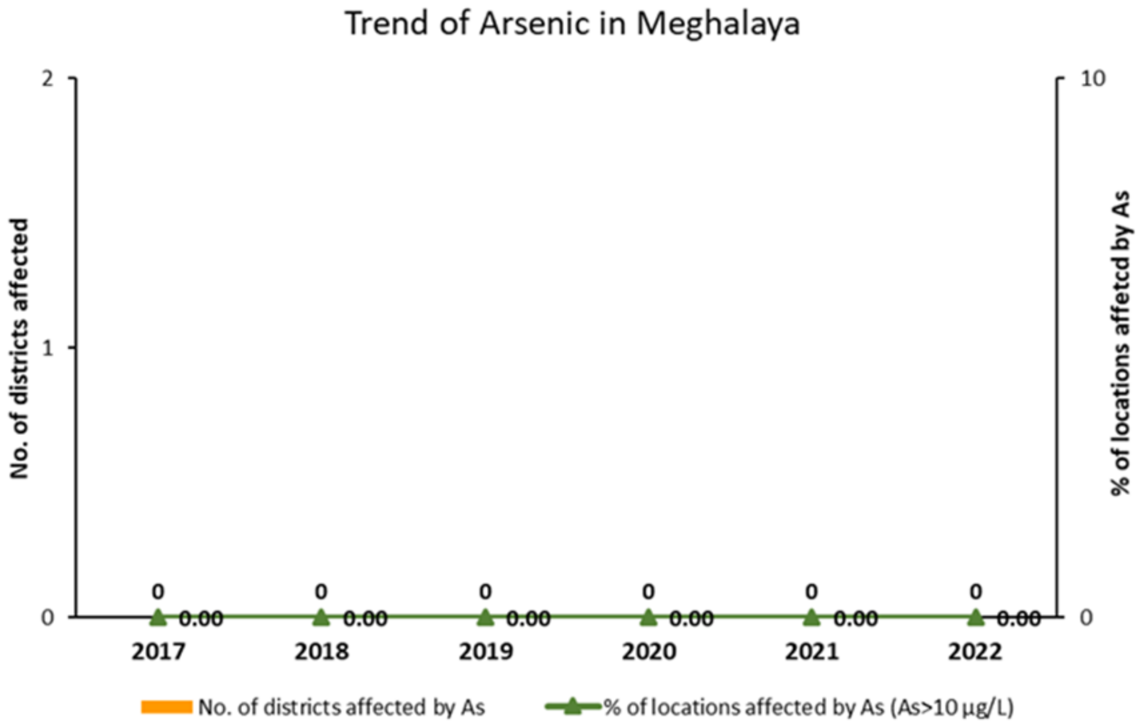

Figure 8 e) Trend analysis of Arsenic from 2017-2022

Year	Total Number of samples analysed	No. of districts affected by U	Total No of locations affected by U	% of locations affected by U (U >0.03 mg/L)
2019	39	0	0	0
2020	27	0	0	0
2021	44	0	0	0
2022	33	0	0	0

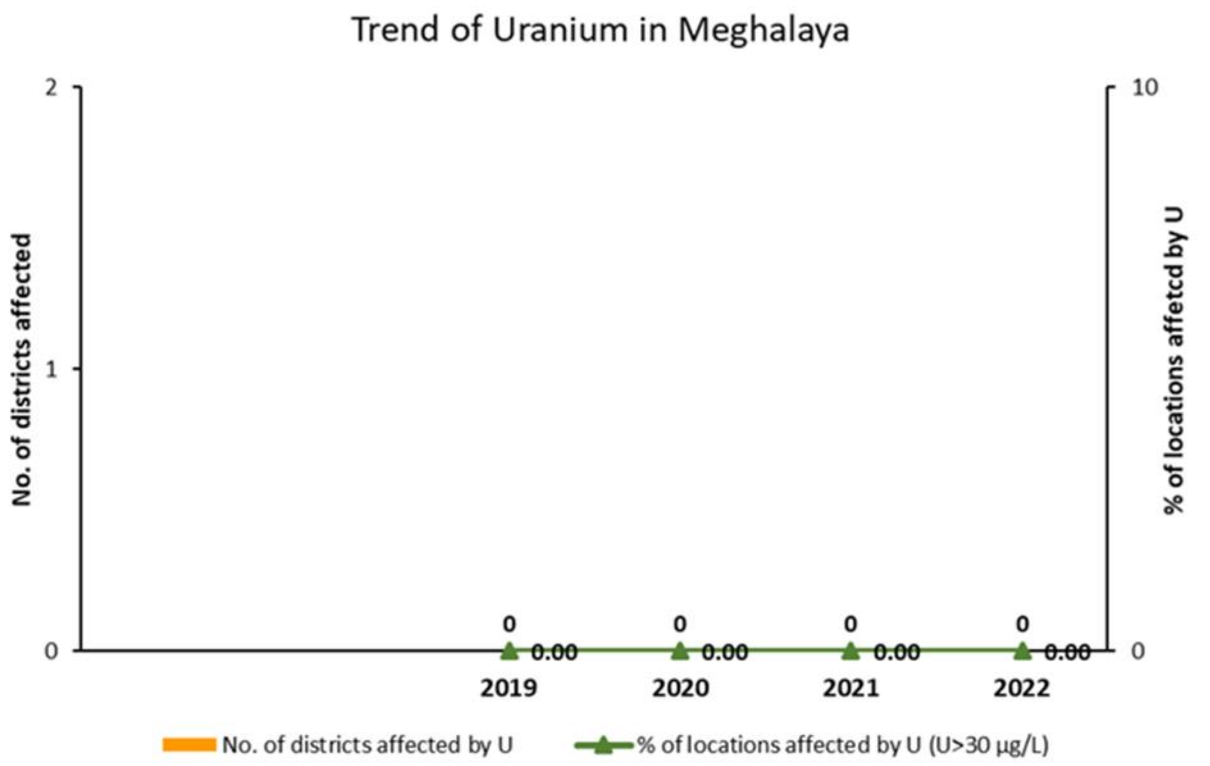

Figure 8 f) Trend analysis of Uranium from 2017-2022

It is observed that fluoride and iron are the two parameters which exhibit a varying trend within the time frame of 6 years, i.e., 2017-2022. Other parameters viz. EC, chloride, nitrate, total hardness and trace metal As and U all do not exceed their respective BIS permissible limits and hence the trend is a steady form at zero baseline. For fluoride analysis in the GW samples within the state the trend line is observed to descend from 2017 to 2019 and then drops to zero baseline at 2020 and continues to do so till 2022. The iron content in GW of Meghalaya descends from 2017 to zero at 2019 and peaks at 2020 before descending till 2022.

3.3. REMEDIAL MEASURES FOR CONTAMINANTS

Out of all the physical and chemical parameters that have been studied iron in 3 out of the 33 samples exceed the BIS permissible limit of 1.0 mg/L. Hence below are some of the suggestions for the mitigation of iron contamination in GW:

a) Oxidation and filtration: Before iron can be filtered, it needs to be oxidized to a state in which it can form insoluble complexes. Ferrous iron (Fe2+) is oxidized to ferric iron (Fe3+), which readily forms the insoluble iron hydroxide complex $Fe(OH)_3$. The common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate and ozone.

b) Combined Photo-Electrochemical (CPE) Method Different processes, such as electrochemical (EC), photo (UV), and combined photo-electrochemical (CPE) methods can be used.

c) Sequestration is the addition of chemicals to GW aimed at controlling problems caused by iron without removing it. These chemicals are added to GW 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 then using polyphosphates followed by chlorination can be an effective and inexpensive method for mitigating iron issue.

4

CONCLUSION

The GW quality of the Meghalaya has been evaluated to find its suitability for drinking and irrigation purposes based on physicochemical parameters. The analysis of GW samples from various districts in Meghalaya shows that most of the samples have low salinity levels and are suitable for irrigation purposes in terms of SAR, RSC and Percentage Sodium. One sample from Cherrapunji have shown high SSP value and Kelly's index indicating a potential for soil salinization. Proper management practices can improve GW quality for irrigation purposes in such areas. Calculation of Magnesium Ratio has revealed that about 39% of the samples are above the safe limit of 50 posing high risk threat to cause magnesium-related issues in soil. Approximately 30% of the samples from East Garo Hills, SW Garo Hills and West Garo Hills have moderate to poor permeability and therefore require appropriate management practices for effective irrigation. The US Salinity laboratory diagram indicates that most samples fall into the C1S1 category, with samples from East Garo Hills and Ri Bhoi classified under C2S1 type indicating slightly higher salinity but still below salinity hazard criteria. The piper diagram shows that the GW is relatively fresh and falls into the $Mg(HCO_3)_2$ and $CaCl_2$ type as well as mixed type. All these three sums up the soil to be more alkaline than the water. In conclusion, regular monitoring of GW quality is necessary, and proper management practices are required to maintain soil health and productivity for effective irrigation in Meghalaya.

The data generated suggests that the pH, electrical conductivity (EC), total dissolved solids (TDS), and ion concentrations vary significantly across the eight districts in Meghalaya. The lowest pH value is reported from SW Garo Hills with 6.03 which falls below the BIS safe range of 6.5-8.5 besides other locations from almost all districts categorizing the GW as slightly acidic in nature. Maximum EC is 475.30 µS/cm which indicates low salinity of GW of Meghalaya. Factors such as soil composition, climate, and water sources are likely contributing to the variation in pH, EC and TDS of the GW. The major cations and anions are within the safe limits as prescribed by BIS. The ionic balance for all the opposite ions are well balanced within ±5%. The Fe concentration ranges from a minimum of 0.004 mg/L to a maximum of 20.69 mg/L detected in West Khasi Hills. Iron content in GW with three districts exceeds BIS permissible limit of 1.0 mg/L. The variation in Fe concentration could be due to the geogenic reasons such as difference in the geological composition of the soil, natural weathering and erosion.

Since 3 locations from 3 states of GW samples showed high iron concentration which exceeds the BIS permissible limits of drinking water. Thus, GW samples from those areas need suitable treatment before drinking or any other domestic use or else there will be adverse effects of iron on the health and material. There is immediate 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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ANNEXURES I: IRRIGATION INDICES OF SAMPLE LOCATIONS

District	Block	Location	SSP	SAR	RSC	% Na	KI	MR	PI
East Garo Hills	Dambo Rongjeng	Darugiri	6.32	0.19	-1.30	8.83	0.07	40.95	43.57
East Garo Hills	Dambo Rongjeng	Narringe	32.33	0.48	-0.20	38.58	0.48	59.94	106.54
East Garo Hills	Dambo Rongjeng	Rongjeng	9.62	0.29	-2.70	11.06	0.11	49.93	34.59
East Garo Hills	Dambo-Ronjeng	Rongmil	10.82	0.16	-0.80	11.89	0.12	66.61	42.19
East Garo Hills	Samanda	Samanda Megapagre	28.39	0.50	-0.20	37.94	0.40	49.93	97.79
East Garo Hills	Samanda	Williamnagar	23.49	0.49	-0.40	26.74	0.31	69.18	79.39
East Garo Hills	Songsak	Songsak	9.25	0.18	-1.20	12.31	0.10	68.70	45.17
East Khasi Hills	Mawsynram	Mawkynep	13.45	0.18	-0.40	18.96	0.16	57.08	81.24
East Khasi Hills	Mawsynram	Mawsynram	19.98	0.39	0.00	25.68	0.25	16.58	93.07
East Khasi Hills	Mawsynram	Tyrsad	35.88	0.43	0.10	48.09	0.56	33.25	171.16
East Khasi Hills	Mylliem	Lapalang	47.87	1.09	-0.20	51.89	0.92	28.49	100.57
East Khasi Hills	Mylliem	Lr.Lachaumiere	48.04	1.24	-0.20	51.41	0.92	22.14	96.37
East Khasi Hills	Shella	Ichamati	11.60	0.30	0.20	14.61	0.13	42.23	65.40
East Khasi Hills	Sohra	Cherrapunji	55.08	1.45	0.30	59.27	1.23	0.00	119.22
East Khasi Hills	Sohra	Wahlong	32.04	0.47	0.00	39.86	0.47	39.92	128.23
North Garo Hills	Resulbelpara	Dainadubi	18.83	0.31	-0.40	22.69	0.23	55.49	82.67
Ri Bhoi	Umling	Tamanpahlong	37.48	0.60	0.00	44.67	0.60	39.92	125.97
Ri Bhoi	Umsning	Sumer	49.90	0.77	0.10	55.73	1.00	33.25	155.60
Ri Bhoi	Jirang	Patharkhamma Barigaon	42.29	0.87	-0.20	52.24	0.73	57.08	100.65
Ri Bhoi	Umling	Byrnihat	25.34	0.87	-1.30	29.11	0.34	57.51	57.37
Ri Bhoi	Umling	Nongpoh	38.95	1.24	-0.40	44.22	0.64	47.30	78.34
Ri Bhoi	Umling	Pahanmawlier	31.80	0.63	0.50	37.41	0.47	22.14	121.52
South West Garo Hills	Zikzak	Mahendraganj	13.19	0.29	-0.50	18.69	0.15	38.81	68.23
South West Garo Hills	Zikzak	Zikzak	25.01	0.45	-0.50	31.12	0.33	33.25	77.75
South West Garo Hills	Betasing	Garobandha	28.25	0.70	-1.30	32.32	0.39	68.70	52.84
West Garo Hills	Dalu	Dalu	19.13	0.38	-0.90	23.79	0.24	53.78	58.52
West Garo Hills	Selsella	Selsella	24.87	0.49	-0.50	29.38	0.33	63.58	77.84
West Jaintia Hills	Amlarem	Dawki	20.00	0.68	0.20	22.64	0.25	37.76	60.49
West Jaintia Hills	Amlarem	Umjarang	34.05	0.61	-0.10	43.39	0.52	42.78	107.09
West jaintia Hills	Thadlaskein	Jowai New	31.82	0.55	-0.30	37.13	0.47	57.08	93.49
West Khasi Hills	Mairang	Mairang	38.77	0.90	0.10	47.48	0.63	29.92	103.04
West Khasi Hills	Nongstoin	Nongstoin	38.41	0.62	0.10	44.65	0.62	19.92	133.89
West Khasi Hills	Nongstoin	Pungsoir	44.25	0.79	0.20	52.20	0.79	59.94	137.64

ANNEXURE II: DISTRICT WISE STATISTICAL DATA

Sl. No.	District		pH	EC (µS/cm) 25°C	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-	Total Hardness	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	As	U
					mg/L												µg/L	
1	East Garo Hills	Min	6.09	42.59	6.00	6.10	14.18	1.28	3.47	0.09	25.00	4.00	3.64	2.51	0.48	0.17	0.03	0.05
		Max	8.37	475.30	6.00	146.52	42.54	45.68	40.15	1.10	195.00	46.04	23.04	9.30	6.72	0.95	0.30	0.27
2	East Khasi Hills	Min	6.42	13.12	9.00	18.31	7.09	1.96	0.60	0.07	15.00	4.00	1.21	2.50	2.15	0.00	0.06	0.00
		Max	8.31	126.40	9.00	152.62	24.82	8.21	21.76	0.18	130.00	30.02	13.33	19.76	6.27	4.01	0.75	0.26
3	North Garo Hills		6.88	99.26	BDL	30.52	17.73	3.44	BDL	0.09	45.00	8.01	6.06	4.80	2.16	0.54	0.22	0.20
4	Ri Bhoi	Min	7.07	16.02	0.00	24.42	7.09	0.18	2.45	0.16	15.00	4.00	1.21	6.87	3.08	0.02	0.11	0.02
		Max	7.48	338.00	0.00	122.10	46.09	38.68	33.57	0.36	165.00	28.02	23.04	27.86	11.51	16.84	0.54	1.45
5	South West Garo Hills	Min	6.03	95.70	0.00	18.31	17.73	4.56	7.75	0.03	45.00	10.01	3.63	6.29	4.16	0.22	0.06	0.01
		Max	6.97	250.50	0.00	79.36	39.00	42.31	8.87	0.18	90.00	22.02	13.34	14.48	5.48	0.81	0.51	0.10
6	West Garo Hills	Min	6.39	145.20	0.00	24.42	21.27	12.67	17.18	0.07	55.00	8.01	8.49	7.07	3.65	0.50	0.01	0.06
		Max	6.49	165.40	0.00	36.63	21.27	21.04	17.18	0.09	65.00	12.01	8.49	8.37	3.84	0.69	0.45	0.10
7	West Jaintia Hills	Min	6.66	42.89	12.00	24.42	10.64	0.67	4.14	0.10	35.00	6.00	3.64	7.51	3.39	0.02	0.06	0.01
		Max	8.32	193.10	12.00	213.67	21.27	12.31	22.79	0.20	185.00	46.04	16.97	21.27	6.84	0.04	0.43	0.04
8	West Khasi Hills	Min	6.53	31.62	0.00	36.63	10.64	8.32	1.18	0.08	25.00	4.00	1.21	7.17	3.58	0.05	0.14	0.00
		Max	7.20	105.50	0.00	67.15	17.73	15.77	13.52	0.13	50.00	14.01	3.64	14.56	10.58	20.69	0.98	0.15

ANNEXURE – III

Chemical Quality of Water Samples Collected from GWMS of Meghalaya during Pre-monsoon Season, 2022 (Basic constituents)

District	Location	Lat DMS	Long DMS	pH	EC	Turbidity	TDS	CO3	HCO3	Total Alkalinity	Cl	SO4	NO3	F	Total Hardness	Ca	Mg	Na	K
					(µS/cm @25°C)	(NTU)	(mg/L)												
East Garo Hills	Darugiri	25.6154	90.7613	8.37	348.90	0.04	230.27	6.00	146.52	152.52	28.36	6.08	23.30	0.27	195.00	46.04	19.40	6.05	4.47
East Garo Hills	Narringirri	25.6103	90.7394	6.61	42.59	0.06	28.11	BDL	18.31	18.31	17.73	1.28	BDL	0.74	25.00	4.00	3.64	5.49	2.94
East Garo Hills	Rongjeng	25.6611	90.8028	6.40	475.30	0.09	313.70	BDL	67.15	67.15	42.54	45.68	40.15	0.25	190.00	38.03	23.04	9.30	2.66
East Garo Hills	Rongmil	25.7378	90.8225	6.70	93.40	0.08	61.64	BDL	6.10	6.10	14.18	16.71	3.47	1.10	45.00	6.00	7.28	2.51	0.48
East Garo Hills	Samanda Megapagre	25.5797	90.5269	6.58	86.74	0.05	57.25	BDL	36.63	36.63	21.27	1.60	BDL	0.16	40.00	8.01	4.85	7.29	6.72
East Garo Hills	Williamnagar	25.5058	90.6053	6.65	143.00	0.05	94.38	BDL	54.94	54.94	28.36	6.08	BDL	0.12	65.00	8.01	10.92	9.17	2.95
East Garo Hills	Songsak	25.6514	90.6103	6.09	58.12	0.04	38.36	BDL	24.42	24.42	14.18	35.30	11.33	0.09	80.00	10.01	13.34	3.75	2.4
East Khasi Hills	Mawkynep	25.3375	91.5960	6.70	28.12	0.13	18.56	BDL	18.31	18.31	7.09	8.21	5.91	0.07	35.00	6.00	4.85	2.50	2.15
East Khasi Hills	Mawsynram	25.2964	91.5784	6.81	72.38	0.10	47.77	BDL	73.26	73.26	10.64	BDL	8.81	0.09	60.00	20.02	2.42	6.89	4.5

District	Location	Lat DMS	Long DMS	pH	EC	Turbidity	TDS	CO3	HCO3	Total Alkalinity	Cl	SO4	NO3	F	Total Hardness	Ca	Mg	Na	K
					(µS/cm @25°C)	(NTU)	(mg/L)												
East Khasi Hills	Tyrsad	25.4066	91.6594	6.53	13.12	0.11	8.66	BDL	24.42	24.42	7.09	BDL	0.60	0.10	15.00	4.00	1.21	3.86	4.3
East Khasi Hills	Lapalang	25.5642	91.9173	6.82	74.68	0.08	49.29	BDL	30.52	30.52	14.18	6.52	21.09	0.07	35.00	10.01	2.42	14.78	4.38
East Khasi Hills	Lr.Lachaumiere	25.5704	91.8871	7.47	126.40	0.01	83.42	BDL	42.73	42.73	24.82	7.13	8.48	0.18	45.00	14.01	2.42	19.13	4.7
East Khasi Hills	Ichamati	25.1650	91.6868	8.31	114.20	BDL	75.37	9.00	152.62	161.62	10.64	1.96	5.38	0.15	130.00	30.02	13.33	7.84	4.06
East Khasi Hills	Cherrapunji	25.2841	91.7195	6.79	73.11	0.01	48.25	BDL	61.05	61.05	10.64	3.72	21.76	0.12	35.00	14.01	BDL	19.76	6.27
East Khasi Hills	Wahlong	25.2084	91.7263	6.42	26.76	0.64	17.66	BDL	30.52	30.52	10.64	BDL	3.50	0.07	25.00	6.00	2.42	5.42	3.74
North Garo Hills	Dainadubi	25.8986	90.7772	6.88	99.26	0.43	65.51	BDL	30.52	30.52	17.73	3.44	BDL	0.09	45.00	8.01	6.06	4.80	2.16
Ri Bhoi	Tamanpahlong	25.9260	91.9447	7.07	36.01	0.11	23.77	BDL	30.52	30.52	7.09	0.18	10.93	0.16	25.00	6.00	2.42	6.89	4.06
Ri Bhoi	Sumer	25.6924	91.8890	7.47	16.02	0.03	10.57	BDL	24.42	24.42	10.63	BDL	2.45	0.17	15.00	4.00	1.21	6.87	3.08
Ri-Bhoi	Patharkhamma Barigaon	25.8714	91.5948	7.18	71.12	0.06	46.94	BDL	30.52	30.52	10.64	0.59	33.57	0.26	35.00	6.00	4.85	11.79	9.88
Ri-Bhoi	Byrnihat	26.0333	91.8867	7.36	338.00	0.06	223.08	BDL	122.10	122.10	46.09	38.68	5.55	0.29	165.00	28.02	23.04	25.75	9.17

District	Location	Lat DMS	Long DMS	pH	EC	Turbidity	TDS	CO3	HCO3	Total Alkalinity	Cl	SO4	NO3	F	Total Hardness	Ca	Mg	Na	K
					(µS/cm @25°C)	(NTU)	(mg/L)												
Ri-Bhoi	Nongpoh	25.0924	91.8776	7.14	219.00	0.05	144.54	BDL	91.57	91.57	28.36	14.48	30.89	0.16	95.00	20.02	10.91	27.86	11.51
Ri-Bhoi	Pahanmawlier	25.9947	91.8618	7.48	77.49	0.04	51.14	BDL	85.47	85.47	10.64	3.04	2.99	0.36	45.00	14.01	2.42	9.65	4.62
South West Garo Hills	Mahendraganj	25.3033	89.8508	6.97	205.10	0.04	135.37	BDL	79.36	79.36	17.73	6.96	8.87	0.18	90.00	22.02	8.48	6.29	5.48
South West Garo Hills	Zikzak	25.3888	89.9086	6.53	95.70	0.07	63.16	BDL	24.42	24.42	21.27	4.56	7.75	0.10	45.00	12.01	3.63	6.90	4.16
South West Garo Hills	Garobandha			6.03	250.50	0.05	165.33	BDL	18.31	18.31	39.00	42.31	BDL	0.03	80.00	10.01	13.34	14.48	5.23
West Garo Hills	Dalu	25.2278	90.2125	6.39	165.40	0.07	109.16	BDL	24.42	24.42	21.27	21.04	17.18	0.07	65.00	12.01	8.49	7.07	3.84
West Garo Hills	Selsella	25.6947	90.0139	6.49	145.20	0.10	95.83	BDL	36.63	36.63	21.27	12.67	BDL	0.09	55.00	8.01	8.49	8.37	3.65
West Jaintia Hills	Dawki	25.1839	92.0309	8.32	193.10	BDL	127.45	12.00	213.67	225.67	21.27	12.31	22.79	0.18	185.00	46.04	16.97	21.27	6.16
West Jaintia Hills	Jowai New	25.4543	92.2076	6.66	42.89	0.21	28.31	BDL	36.63	36.63	10.64	9.21	4.14	0.10	35.00	8.01	3.64	8.31	6.84
West Jaintia Hills	Umjarang	25.3146	92.1304	6.93	51.31	0.04	33.86	BDL	24.42	24.42	14.18	0.67	12.73	0.20	35.00	6.00	4.85	7.51	3.39

District	Location	Lat DMS	Long DMS	pH	EC	Turbidity	TDS	CO3	HCO3	Total Alkalinity	Cl	SO4	NO3	F	Total Hardness	Ca	Mg	Na	K
					(µS/cm @25°C)	(NTU)	(mg/L)												
West Khasi Hills	Mairang	25.5624	91.6394	7.20	105.50	0.01	69.63	BDL	67.15	67.15	17.73	8.32	13.52	0.13	50.00	14.01	3.63	14.56	10.58
West Khasi Hills	Nongstoin	25.5132	91.2684	6.53	31.62	0.09	20.87	BDL	36.63	36.63	10.64	BDL	4.56	0.08	25.00	8.01	1.21	7.17	3.58
West Khasi Hills	Pungsoir	25.5453	91.2788	6.63	32.98	0.10	21.77	BDL	42.73	42.73	10.64	15.77	1.18	0.10	25.00	4.00	3.64	9.12	5.83

ANNEXURE IV: Chemical Quality of Water Samples Collected from GWMS of Meghalaya during Pre-monsoon Season, 2022

(Fe, As, U, Mn, Cu & Zn)

District	Location	Lat DMS	Long DMS	Fe	As	U	Mn	Cu	Zn
				(mg/L)	(µg/L)		(mg/L)		
East Garo Hills	Darugiri	25.6154	90.7613	0.240	0.110	0.272	0.151	0.020	0.325
East Garo Hills	Narringirri	25.6103	90.7394	0.295	0.102	0.077	0.089	0.014	0.352
East Garo Hills	Rongjeng	25.6611	90.8028	0.947	0.303	BDL	0.203	0.025	0.809
East Garo Hills	Rongmil	25.7378	90.8225	0.947	0.113	0.049	0.120	0.017	0.239
East Garo Hills	Samanda Megapagre	25.5797	90.5269	0.277	0.045	0.141	0.057	0.011	0.337
East Garo Hills	Williamnagar	25.5058	90.6053	0.166	0.034	0.098	0.182	0.023	0.306
East Garo Hills	Songsak	25.6514	90.6103	0.351	0.114	0.078	0.047	0.010	0.303
East Khasi Hills	Mawkynep	25.3375	91.5960	0.038	0.232	0.004	0.772	BDL	0.069
East Khasi Hills	Mawsynram	25.2964	91.5784	0.039	0.753	0.154	0.010	BDL	0.042
East Khasi Hills	Tyrsad	25.4066	91.6594	4.006	0.250	BDL	0.048	BDL	0.115
East Khasi Hills	Lapalang	25.5642	91.9173	0.028	0.128	0.008	0.010	BDL	0.027
East Khasi Hills	Lr.Lachaumiere	25.5704	91.8871	0.004	0.120	0.003	0.007	BDL	0.258
East Khasi Hills	Ichamati	25.1650	91.6868	0.031	0.062	0.212	0.045	BDL	0.038
East Khasi Hills	Cherrapunji	25.2841	91.7195	0.038	BDL	0.257	0.009	BDL	0.268
East Khasi Hills	Wahlong	25.2084	91.7263	0.051	0.590	0.003	0.238	0.045	0.049
North Garo Hills	Dainadubi	25.8986	90.7772	0.540	0.224	0.200	0.089	0.014	0.259
Ri Bhoi	Tamanpahlong	25.9260	91.9447	0.221	0.364	0.029	0.001	0.001	0.026
Ri Bhoi	Sumer	25.6924	91.8890	0.019	0.210	0.215	0.010	0.011	0.135
Ri-Bhoi	Patharkhamma Barigaon	25.8714	91.5948	0.349	0.275	0.023	0.367	BDL	0.031
Ri-Bhoi	Byrnihat	26.0333	91.8867	0.028	0.110	0.019	0.002	0.001	0.042
Ri-Bhoi	Nongpoh	25.0924	91.8776	0.018	0.536	1.453	0.006	0.002	0.045
Ri-Bhoi	Pahanmawlier	25.9947	91.8618	16.841	0.130	BDL	0.566	BDL	0.088

District	Location	Lat DMS	Long DMS	Fe	As	U	Mn	Cu	Zn
				(mg/L)	(µg/L)		(mg/L)		
South West Garo Hills	Mahendraganj	25.3033	89.8508	0.809	0.061	0.099	0.057	0.011	0.249
South West Garo Hills	Zikzak	25.3888	89.9086	0.221	0.511	0.014	0.109	0.016	0.291
South West Garo Hills	Garobandha			0.445	0.299	0.039	1.144	0.115	0.183
West Garo Hills	Dalu	25.2278	90.2125	0.693	0.007	0.058	0.036	0.009	0.291
West Garo Hills	Selsella	25.6947	90.0139	0.502	0.454	0.099	0.329	0.037	0.168
West Jaintia Hills	Dawki	25.1839	92.0309	0.021	0.095	0.015	0.001	0.008	0.604
West Jaintia Hills	Jowai New	25.4543	92.2076	0.044	0.063	BDL	0.006	BDL	0.259
West Jaintia Hills	Umjarang	25.3146	92.1304	0.034	0.428	0.039	0.404	BDL	0.015
West Khasi Hills	Mairang	25.5624	91.6394	0.050	0.977	0.002	0.016	BDL	0.116
West Khasi Hills	Nongstoin	25.5132	91.2684	0.728	0.588	0.145	0.224	BDL	0.093
West Khasi Hills	Pungsoir	25.5453	91.2788	20.695	0.141	0.124	0.006	BDL	0.120