Evaluation of Ground Water Quality in Shillong: The Capital City of Meghalaya

NATIONAL INSTITUTE OF HYDROLOGY
CENTRE FOR FLOOD MANAGEMENT STUDIES
DISPUR, GUWAHATI - 781 006

2018-19

PREFACE

Ground water forms the major source of water supply for drinking purposes in most part of the country. For proper utilization of water for various purposes, understanding of geo-chemical controls and study of the extent of ground water contamination are of prime importance. The quality of ground water is particularly important to humans when the water is used for drinking water supply. The quality of ground water varies from place to place along with the depth of water table. It also varies with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it.

There has been heavy dependence on ground water in recent decades due to growth in agriculture, population and industries in many parts of our country. The situation is not so alarming at present in the North-Eastern Region of the country. However, scientific and sustainable approach is important in managing ground water resources and its quality.

Shillong is the district headquarters of East Khasi Hills and capital of Meghalaya. Shillong is well connected by road with other places in the district as well as with the rest of the Meghalaya and Assam. Shillong is connected by road with all major north eastern states. Two major National Highways pass through East Khasi Hills District - National Highway 40 connects Shillong to Jorabat, Assam in the north and extends southwards to Dauki, at Bangladesh border and National Highway 44 connects Shillong to States of Tripura and Mizoram. As per 2011 census (provisional), the total population of the district is about 824,059 with male population of 410,360 and female population of 413,699 (a sex ratio of about 1008 females per thousand males), with rural population of 458,010 and urban population of 366,049. The main occupation of the population in the district is agriculture.

In this report, an attempt has been made to bring out the ground water quality status in Shillong – the Capital City of Meghalaya. The report will be of immense use to the planners, administrators, scientists and engineers concerned with the management and protection of ground water quality in Shillong.

The report has been prepared by Dr. C. K. Jain, Sc. 'G' & Head, Environmental Hydrology Division, NIH, Roorkee. Other officers/scientists/staff involved in the study include Mrs. M. B. Ritshong, SE, Water Resources Department, Govt. of Meghalaya, Shillong; Dr. S. K. Sharma, Sc. 'C' of NIH-Centre for Flood Management Studies, Guwahati and Smt. Babita Sharma, RA, Environmental Hydrology Division, NIH, Roorkee, under the work programme of 2017-18 and 2018-19. Sri. Biren Das, MTS (M) was involved in field investigations.

(S. K. JAIN)
DIRECTOR

CONTENTS

				Page No.
	PREFACE			i
	LIST OF TABLES			iii
	LIST OF FIGURES			iv
	ABSTRACT			v
1.0	INTRODUCTION			1
2.0	SHILLONG – THE CAPITAL CITY OF MEGHALAYA			3
	2.1	Land Use		3
	2.2	Drainage		4
	2.3	Rainfall and Climate		4
	2.4	Geomorphology and Soil Type		5
	2.5	Geological Set-up		5
	2.6	Hydrogeology		6
3.0	EXPERIMENTAL METHODOLOGY			8
	3.1	Sampling and Preservation		8
	3.2	Chemicals and Reagents		8
	3.3	Physico-chemical Analysis		8
	3.4	Metal Ion Analysis		8
4.0	RESULTS AND DISCUSSION			11
	4.1	Drinking Water Quality		11
		4.1.1	General Characteristics	38
		4.1.2	Heavy Metals	40
	4.2	Irrigation Water Quality		51
		4.2.1	Salinity	53
		4.2.2	Relative Proportion of Sodium to other Cations (SAR)	54
		4.2.3	Residual Sodium Carbonate (RSC)	54
		4.2.4	Boron	55
	4.3	Classification of Ground Water		55
		4.3.1	Piper Trilinear Classification	57
		4.3.2	Chadha's Diagram	57
		4.3.4	U.S. Salinity Laboratory Classification	59
5.0	CONCLUSIONS AND RECOMMENDATIONS			64
6.0	REFERENCES			65

LIST OF TABLES

Table No.	Description	Page No.
3.1	Details of Sampling Locations in Shillong City	9
3.2	Source and Depth Wise Distribution of Sampling Sites in Shillong City	10
3.3	Analytical Methods and Equipment Used in the Analysis	10
4.1a	Hydro-chemical Data of Ground Water Samples of Shillong City (Pre-monsoon 2018)	11
4.1b	Hydro-chemical Data of Ground Water Samples of Shillong City (Post-monsoon 2018)	12
4.2	pH Distribution in Ground Water of Shillong City	13
4.3	TDS Distribution in Ground Water of Shillong City	13
4.4	Alkalinity Distribution in Ground Water of Shillong City	14
4.5	Hardness Distribution in Ground Water of Shillong City	14
4.6	Calcium Distribution in Ground Water of Shillong City	15
4.7	Magnesium Distribution in Ground Water of Shillong City	15
4.8	Chloride Distribution in Ground Water of Shillong City	16
4.9	Sulphate Distribution in Ground Water of Shillong City	16
4.10	Nitrate Distribution in Ground Water of Shillong City	17
4.11	Fluoride Distribution in Ground Water of Shillong City	17
4.12	Iron Distribution in Ground Water of Shillong City	41
4.13	Manganese Distribution in Ground Water of Shillong City	41
4.14	Copper Distribution in Ground Water of Shillong City	41
4.15	Nickel Distribution in Ground Water of Shillong City	42
4.16	Chromium Distribution in Ground Water of Shillong City	42
4.17	Lead Distribution in Ground Water of Shillong City	42
4.18	Cadmium Distribution in Ground Water of Shillong City	43
4.19	Zinc Distribution in Ground Water of Shillong City	43
4.20	Arsenic Distribution in Ground Water of Shillong City	43
4.21	Safe Limits of Electrical Conductivity for Irrigation Water	52
4.22	Guidelines for Evaluation of Irrigation Water Quality	52
4.23	SAR, Na% and RSC Values in Ground Water of Shillong	53
4.24	Summarized Results of Water Classification for Shillong	56
4.25	U.S. Salinity Laboratory Classification	59

LIST OF FIGURES

Fig. No.	Description	Page No.
2.1	Shillong City in Mylliem Block Showing Location of Sampling Points	4
4.1(a)	pH Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	18
4.1(b)	pH Distribution in Ground Water of Shillong City (Post-monsoon 2018)	19
4.2(a)	TDS Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	20
4.2(b)	TDS Distribution in Ground Water of Shillong City (Post-monsoon 2018)	21
4.3(a)	Alkalinity Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	22
4.3(b)	Alkalinity Distribution in Ground Water of Shillong City (Post-monsoon 2018)	23
4.4(a)	Hardness Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	24
4.4(b)	Hardness Distribution in Ground Water of Shillong City (Post-monsoon 2018)	25
4.5(a)	Calcium Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	26
4.5(b)	Calcium Distribution in Ground Water of Shillong City (Post-monsoon 2018)	27
4.6(a)	Magnesium Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	28
4.6(b)	Magnesium Distribution in Ground Water of Shillong City (Post-monsoon 2018)	29
4.7(a)	Chloride Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	30
4.7(b)	Chloride Distribution in Ground Water of Shillong City (Post-monsoon 2018)	31
4.8(a)	Sulphate Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	32
4.8(b)	Sulphate Distribution in Ground Water of Shillong City (Post-monsoon 2018)	33
4.9(a)	Nitrate Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	34
4.9(b)	Nitrate Distribution in Ground Water of Shillong City (Post-monsoon 2018)	35
4.10(a)	Fluoride Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	36
4.10(b)	Fluoride Distribution in Ground Water of Shillong City (Pre-monsoon 2018)	37
4.11	Distribution of Iron at Different Sampling Sites City	44
4.12	Distribution of Manganese at Different Sampling Sites	44
4.13	Distribution of Copper at Different Sampling Sites	45
4.14	Distribution of Nickel at Different Sampling Sites	45
4.15	Distribution of Chromium at Different Sampling Sites	46
4.16	Distribution of Lead at Different Sampling Sites	46
4.17	Distribution of Cadmium at Different Sampling Sites	47
4.18	Distribution of Zinc at Different Sampling Sites	47
4.19	Distribution of Arsenic at Different Sampling Sites	48
4.20	Piper Trilinear Diagram Showing Chemical Character of Ground Water	61
4.21	Chadha's Diagram Showing Chemical Character of Ground Water	62
4.22	U.S. Salinity Laboratory Classification	63

ABSTRACT

The ground water quality of Shillong has been assessed to see the suitability of ground water for domestic and irrigation applications. Twenty ground water samples from various abstraction sources were collected each during pre- and post-monsoon seasons of 2018 and analysed for various water quality constituents. The hydro-chemical data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified. The analysis of data clearly indicated that the concentrations of various water quality constituents except pH in more than 50% of the samples and nitrate at few locations are within the acceptable limits for drinking water.

The presence of heavy metals in ground water though recorded in almost all the samples but these were not significantly higher except iron, manganese, nickel and cadmium. The water quality standards have been violated for iron and manganese in 30% and 25% of the samples respectively. The concentration of iron varies from 47 to 6342 μg/L during pre-monsoon season as against the acceptable limit of 300 μg/L while that of manganese vary from 10 to 464 μg/L as against the acceptable limit of 100 μg/L. High concentrations of iron generally cause inky flavour, bitter and astringent taste. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration also promotes bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity. The concentration of copper, chromium, lead, zinc and arsenic were found well within the permissible limits in almost all the samples of Shillong.

An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear, Chadha's diagram and U.S. Salinity Laboratory classifications. The grouping of samples according to their hydrochemical facies indicates that majority of the samples fall under Ca-Mg-Cl-SO_4 hydrochemical facies followed by Ca-Mg-HCO_3 and Na-K-Cl-SO_4 hydrochemical facies. The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR), Residual Sodium Carbonate (RSC) and boron content. In general the ground water of Shillong is safe for irrigation purpose. According to U.S. Salinity Laboratory classification of irrigation water, majority of the samples fall under water type C1-S1 followed by C2-S1 type.

1.0 INTRODUCTION

The quality of ground water is of great importance in determining the suitability of particular ground water for a certain use (public water supply, irrigation, industrial applications, power generation etc.). The quality of ground water is the resultant of all the processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well. Therefore, the quality of ground water varies from place to place, with the depth of water table, and from season to season and is primarily governed by the extent and composition of dissolved solids present in it.

In recent years, an increasing threat to ground water quality due to human activities has become of great importance. The adverse effects on ground water quality are the results of man's activity at ground surface, unintentionally by agriculture, domestic and industrial effluents, unexpectedly by sub-surface or surface disposal of sewage and industrial wastes.

A vast majority of ground water quality problems are caused by contamination, over-exploitation, or combination of the two. Most ground water quality problems are difficult to detect and hard to resolve. The solutions are usually very expensive, time consuming and not always effective. Ground water quality is slowly but surely declining everywhere. Ground water pollution is intrinsically difficult to detect, since problem may well be concealed below the surface and monitoring is costly, time consuming and somewhat hit-or-miss by nature.

The wide range of contamination sources is one of the many factors contributing to the complexity of ground water assessment. It is important to know the geochemistry of the chemical-soil-groundwater interactions in order to assess the fate and impact of pollutant discharged on to the ground. Pollutants move through several different hydrologic zones as they migrate through the soil to the water table. The serious implications of this problem necessitate an integrated approach in explicit terms to undertake ground water pollution monitoring and abatement programmes.

The intensive use of natural resources and the large production of wastes in modern society often pose a threat to ground water quality and have already resulted in many incidents of ground water contamination. Pollutants are being added to the ground water system through human activities and natural processes. Solid waste from industrial units is being dumped near the factories, which is subjected to reaction with percolating rain water and reaches the ground water level. The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the ground water. The problem of ground water pollution in several parts of the country has become so acute that unless urgent steps for detailed identification and abatement are taken, extensive ground water resources may be damaged.

The quality of ground water depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportions of dissolved constituents are found in ground water than in surface water because of greater interaction of ground water with various materials in geologic strata. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders.

The contamination of ground water by heavy metals and pesticides has also assumed great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The determination of the concentration levels of heavy metals and pesticides in these waters, as well as the elucidation of the chemical forms in which they appear is a prime target in environmental research today.

There has been heavy dependence on ground water in recent decades due to growth in agriculture, population and industries in many parts of our country. The situation is not so alarming at present in the North-Eastern Region of the country. However, scientific and sustainable approach is important in managing ground water resources and its quality.

Shillong is the district headquarters of East Khasi Hills which is also the capital of Meghalaya. East Khasi Hills is one of the seven districts of Meghalaya covering an area of 2748 km^2. Shillong is well connected by road with other places in the district as well as with the rest of the Meghalaya and Assam. Shillong is connected by road with all major north eastern states. Two major National Highways pass through East Khasi Hills District - National Highway 40 connects Shillong to Jorabat, Assam in the north and extends southwards to Dauki, at Bangladesh border and National Highway 44 connects Shillong to States of Tripura and Mizoram. As per 2011 census (provisional), the total population of the district is about 824,059 with male population of 410,360 and female population of 413,699 (a sex ratio of about 1008 females per thousand males), with rural population of 458,010 and urban population of 366,049. The main occupation of the population in the district is agriculture.

In this report, an attempt has been made to bring out the ground water quality status in Shillong, the Capital City of Meghalaya. The report will be of immense use to the planners, administrators, scientists and engineers concerned with the management and protection of ground water quality in Shillong.

2.0 SHILLONG – THE CAPITAL CITY OF MEGHALAYA

Shillong is the district headquarters of East Khasi Hills and capital city of Meghalaya. East Khasi Hills is one of the seven districts of Meghalaya covering an area of 2748 km^2. Shillong is well connected by road with other places in the district as well as with the rest of the Meghalaya and Assam. Shillong is connected by road with all major north eastern states. Two major National Highways pass through East Khasi Hills District - National Highway 40 connects Shillong to Jorabat, Assam in the north and extends southwards to Dauki, at Bangladesh border and National Highway 44 connects Shillong to States of Tripura and Mizoram. As per 2011 census (provisional), the total population of the district is about 824,059 with male population of 410,360 and female population of 413,699 (a sex ratio of about 1008 females per thousand males), with rural population of 458,010 and urban population of 366,049. The main occupation of the population in the district is agriculture. The district has been divided into eight blocks as shown below:

Name of Block	Inhabited villages
Mawphlang	184
MyIliem	97
Mawrynkneng	36
Mawkynrew	71
Mawsynram	166
Shella Bholaganj	139
Pynursla	156
Khatarshnong-Laitkroh	98

2.1 Land Use

The land utilization statistics of East Khasi District (2010-11) is presented below:

Land Classification	**Area (km^2)**
Geographical area	2748
Forest area	1067.52
Non-Agricultural area	206.69
Cultivable Waste Land and groves	544.76
Fallow Land	105.41
Net Area Sown	377.85
Area Sown more than once	78.41
Gross cropped area	456.26

The district has a forest area of 1068 km^2, i.e. about 39% of the total geographical area. The net area sown is 377.85 km^2 and the total cropped area is 456.26 km^2. Fallow land covers about 4%, net area sown is about 14%, while the total cropped area is about 17%.

Principal crops grown in the district are rice, maize, millets, oilseeds and pulses. Horticulture products include orange, pineapple, pears, peaches, plums, sohiong, sophi, betel nut and many local fruits. Vegetables like potato, sweet potato, ginger, garlic etc. are also grown.

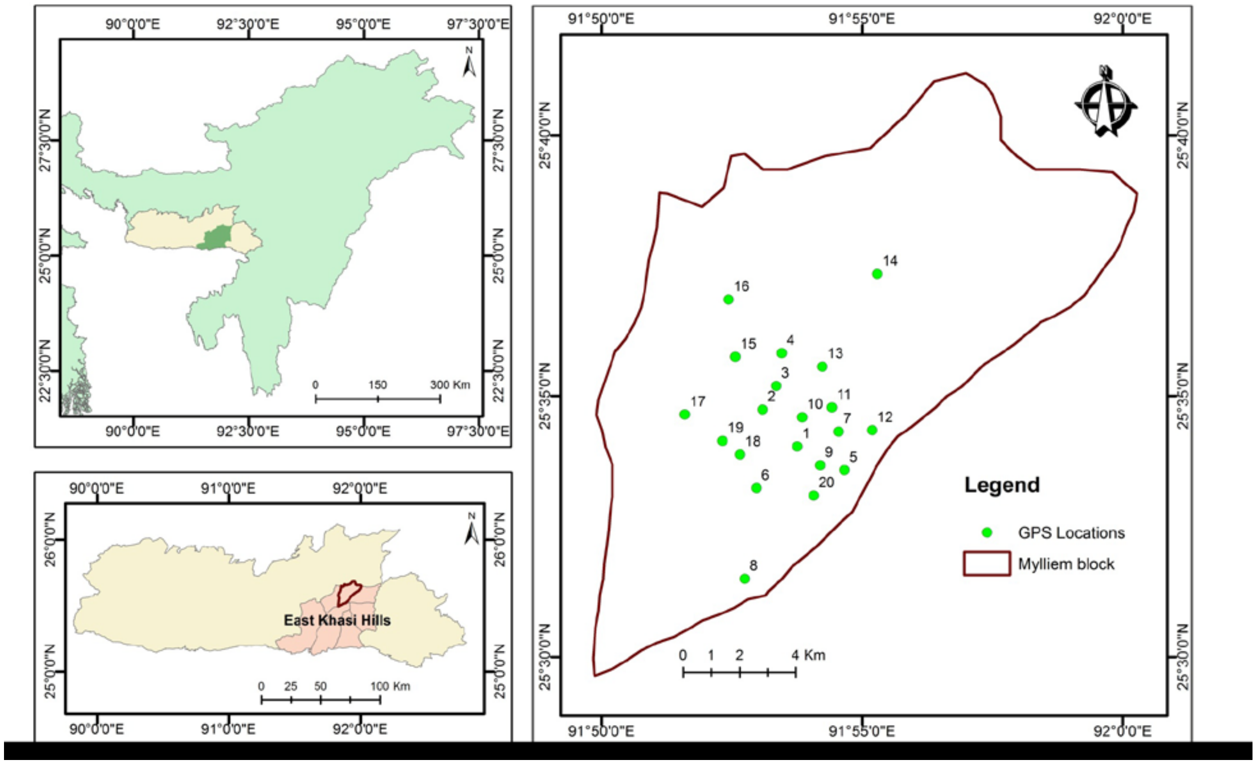

Fig. 2.1 Shillong City in Mylliem Block Showing Location of Sampling Points

2.2 Drainage

The topography controls the drainage system as it divides the state into two watersheds namely the Brahmaputra system in the North and Meghna /Surma system in the South. Drainage of the district in the north flows toward the Brahmaputra River and in the south, the rivers flow towards the Bangladesh plains into Surma river. The important rivers in the northern part are Umtrew, Umiam and Umkhen. The Umtrew (or Digaru) River originates from the west of the Sohpetbneng range in East Khasi Hills District, near Lum Raitong. It flows towards the west till it meets the waters from the Umiam River which is being diverted by the Umiam Hydel Project. In the southern part, rivers Umiew (or Shella, also known as Bagra), Umngot, Umngi (Balat), etc. all tributaries of the Surma, originating from southern slopes of Khasi Hills, drain one of the world's heaviest rainfall areas and flow southwards into Bangladesh, have violent flows. The drainage pattern is structurally controlled and parallel to sub-parallel in nature.

2.3 Rainfall and Climate

The district has the unique distinction of having the wettest place on earth i.e. Mawsynram with an average annual rainfall of about 12,270 mm. This is followed by Cherrapunjee with an average annual rainfall of 11,600 mm. Southwest monsoon originating from the Bay of Bengal and the Arabian Sea directly influences this high rainfall. The high altitude areas of the district experience temperate humid climate and low altitude areas experience tropical to sub-tropical humid climate. The whole year can be divided into four seasons namely summer, rainy, autumn and winter. The temperature varies from 1.7 to 24°C.

2.4 Geomorphology and Soil Type

Geomorphologically, the East Khasi hills is an undulatory one. It comprises of denudational high and low hills with deep gorges. The district represents a remnant of ancient plateau of Indian Peninsular Shield which is deeply dissected suggesting several geotectonic and structural deformities that the plateau has undergone. The northern portion of the district is a dissected Shillong plateau gradually rising southwards to the rolling grasslands with gentle river valleys, then falls sharply in the Southern portion forming deep gorges and ravines in Mawsynram and Shella-Bholaganj, bordering Bangladesh. In the southern border areas, there are fringes of alluvial plains that are localized in nature.

Soil type of an area is dependent on factors like geology, relief, climate and vegetation. Red Loamy soil is a product of weathering of rocks like granites, gneisses etc which are relatively rich in clay forming minerals. This soil type are rich in organic matter, nitrogen and acidic in nature. They are found exposed in the central part of the district. Laterite soil is a weathering product of rocks like quartzite, schist, conglomerate etc, which are found exposed in the northern area of East Khasi Hills. The soils are rich in iron and aluminium. Alluvial soils are found exposed in the southern part of the district that are rich in potash but poor in phosphate content. They are acidic in nature.

2.5 Geological Set-up

The district area falls mainly within the Shillong or Meghalaya Plateau which is constituted mainly of Precambrian rocks of gneissic composition in which granites, schists, amphibolits, calc-silicate rocks occur as inclusions of various dimensions.

The gneisses form the Basement Complex for the overlying Shillong Group of rocks and is separated from the later by an unconformity indicated at places by the occurrence of a conglomerate bed. The presence of primary structures like current bedding, ripple marks etc. indicated that quartzites of the Shillong Group are of sedimentary derivative later metamorphosed to quartzites. These occur mostly as thick layers. The Khasi basic ultrabasic Intusives comprising basic intusive like epidiorite, metagabro, metadoleraite etc occur mostly as sills, dykes in the various sub-facies of Shillong Group. In the study area one such exposure noticed in the North-Western part of the district where it intruded the Basement Gneissic Complex.The rocks are generally dark green, medium to coarse graines and massive.In weathered outcrops, the basic rocks give a reddish brown colour. Grainite Plutons occur as isolated patches in the district and cover an area next to area covered by Basement Gneissic complex.The South Khasi Granites occur as intrusive body in the Basement Gneissic complex. Both Porphyritic and fine-grained pink granite form the South Khasi Granite.

The Sylhet Traps are of the nature of plateau basalts exposed in a narrow E-W strip along the southern border of the area and their anticipated thickness is 550-680 m. The Sylhet traps comprise predominantly basalts, rhyolites and acid tuffs.

The Cretaceous sediments exposed in the Meghalaya Plateau are classified as Khasi Group. The Mahadek Formation, the top unit of the Khasi Group, consisting of coarse arkosic sandstone, often gluconitic, are found exposed in the extreme southern part of the district. The Shella Formation of Jaintia Group consists of alteration of sandstone and limestone occurs in the south-central and south-western part of the district. The Quaternary fluvial sediments occur in the extreme northern part of the district bordering Assam.

2.6 Hydrogeology

The district of East Khasi Hills is covered mainly by crystalline rocks with Tertiary sedimentary rocks. The secondary porosity in consolidated formation e.g. fractures; joints, etc developed due to major, minor tectonic movements, prolonged physicochemical weathering, form the conduits as well as reservoirs of ground water. The weathered mantle varies from 10 to 30 m bgl. Ground water occurs under water table condition in the top weathered quartzite and in semi-confined condition in the fractured and jointed rocks. At hydrogeologically feasible locations, well drilled down to the depth of about 80 -150 m below ground level may yield a moderate discharge of 5-15 m3/hr in Archaean and Pre-Cambrian Group of rocks. Depth to water level is found to occur between 2 and 15 m bgl. The valley areas are found to be favourable for the construction of dug wells and bore wells in other steep areas. It should be borne in mind that the zones are not uniform in characteristics as the aquifer material, fracture density and distribution and hydrogeological characteristics vary widely over short distances. Consequently, their water yielding capabilities vary considerably.

Ground water development in the district is mainly through dug /open well tapping the water in the weathered zone and bore wells are constructed to tap ground water from the fractures/joints in the hard rocks. In the shallow aquifer, the depth to water level ranges from less than 2 m bgl to 6 m bgl.

Springs play a major role to cater water requirement of the people throughout the year. Most of the springs are gravity springs. It is observed that discharge of most of the springs lie within the range of 5000-25000 lpd in pre- and post-monsoon period.

Groundwater resources in Shillong area are highly variable, it being mountainous terrain and are mainly dependent on topography, zone of weathering, fracturing and interstices present in country rocks. The availability of ground water in hilly region is manifested in the form of springs, seepages, wells and bore well of limited/ nominal yield.

Ground water occurs in the area under water table conditions in the top weathered and fractured zone of quartzite. Further below, semi-confined to confined condition exist in the interconnected joints, fractures etc of the underlying hard quartzite. The weathered quartzites have poor to moderate yields. The depth of this weathered zone varies up to about 30 m below ground level. The underlying second zone is fissured and jointed which is the zone of saturation. The distribution and disposition of these joints and fractures are of complex nature due to the various tectonic and structural disturbances to which country rocks are subjected to. Groundwater occurs under semi-confined condition in this zone. Such zones saturated with water are likely to extend down to 60 to 180 m below ground level.

Quartzite and recent valley fills (in Polo area) constitute the major aquifer system in the area. Ground water occurs under unconfined condition in the weathered rock and residuum. Ground water development in the urban agglomeration is both by dug wells generally confining to the weathered zone & bore wells, which mainly tap, fractured zone in the hard rocks. These fractures sometime extend very deep occurring even beyond 60mbgl, but otherwise generally close before 60m depth. From the well inventory data, it has been found during the dry period that in dug wells depth to water level varies from 0.50mbgl (at Polo) to 5.56mbgl (at Pynther). In post monsoon period it is from 0.15mbgl to 5.10 mbgl at the same locations respectively. The average seasonal water level fluctuation is 1.19m with minimum fluctuation of 0.35 m at Polo and maximum 2.95m at Mawlai- Mawroh.

3.0 EXPERIMENTAL METHODOLOGY

3.1 Sampling and Preservation

Twenty ground water samples were collected each during pre- and post-monsoon seasons of 2018 from various abstraction sources in clean polyethylene bottles and preserved by adding an appropriate reagent (Jain and Bhatia, 1988; APHA, 1992). The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (5 mL/lit.). All the samples were stored in sampling kits maintained at 4^oC and brought to the laboratory for detailed physico-chemical analysis. The details of sampling locations and source and depth wise distribution are given in Table 3.1 and 3.2 respectively.

3.2 Chemicals and Reagents

All general chemicals and reagents used in the study were of analytical reagent grade (Merck/BDH). Standard solutions of metal ions were procured from Merck, Germany. De-ionized water was used throughout the study. All glassware and other containers used for trace element analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with de-ionized water several times prior to use.

3.3 Physico-chemical Analysis

The physico-chemical analysis was performed following standard methods (Jain and Bhatia, 1988; APHA, 1992). The brief details of analytical methods and equipment used in the study are given in Table 3.3. Ionic balance was determined, the error in the ionic balance for all the samples was within 5%.

3.4 Metal Ion Analysis

Metal ion concentrations were determined using Inductively Coupled Plasma – Mass Spectrometer (ICP-MS). Operational conditions were adjusted in accordance with the manufacturer's guidelines to yield optimal determination. Quantification of metals was based upon calibration curves of standard solutions of respective metals. These calibration curves were determined several times during the period of analysis.

Table 3.1 Details of Sampling Locations in Shillong City

Sample ID	Name of Owner of the Borewell / Tubewell	Location	Lat	Long	Source	Depth (m)	Use of Water
1.	Smt. Delis Mary Suja	Gordon Road, Bhagyakul Laitumkhrah	25°34’2”	91°53’45.1”	BW	198.25	Domestic
2.	Shri. Samir Ghosh	Jail Road	25°34’44.6’’	91°53’5.1’’	BW	50.02	Domestic
3.	Smt. Priya Warbah	Forest Colony	25°35’11.6’’	91°53’20.9’’	BW	61.00	Domestic
4.	Smt. Tralincy Khardewsaw	Mawlaidatbaki Pata Blk A	25°35.821’	91°53.457’	BW	84.18	Domestic
5.	Rev. Lallienvel Pakhuongte	Evangelical Free Church of India, Demthring	25°33’34.9’’	91°54’39.3’’	BW	45.75	Domestic
6.	Doris Khriam	Happy Valley	25°33’14.1”	91°52’58.3”	BW	68.63	Domestic
7.	Smt. Laltingzo Hmar	Law U Sib, Divine Grace Cottage	25°33’47.0”	91°54’46.7”	BW	96.99	Domestic
8.	Woodland Institute of Nurning	Laitkor Lumheh Mawrie	25°31’04.20”	91°52’46.78”	BW	100.04	Commercial
9.	Bethany Hospital	Nomgrim Hills	25°33’58.1’’	91°54’3.8’’	BW	245.22	Commercial
10.	Hotel Poinisuk	Laitumkhrah	25°34’16.8”	91°53’48.2”	BW	198.25	Commercial
11.	Office of the CE (WR)	Fruit Garden	25°33’56.2”	91°53’45.9”	BW	143.05	Domestic
12.	Evangelical Baptist Church	Lapalang Dong Parmaw	25°34’16.6’’	91°55’37.7’’	BW	125.05	Domestic
13.	Mary our Help Training Centre	Bellefonte Lumshyiap	25°35’33.9’’	91°54’14.0’’	BW	36.60	Domestic
14.	Smt. Donboklin Lyngdoh	Mawtawar Lummawsing	25°37’20.5”	91°55’17.2”	BW	183.00	Domestic
15.	G.C. Wanchand	Mawlai Syllaikariah	25°35’45.1”	91°52’33.9”	BW	100.04	Domestic
16.	G. C. Wanchand	Mawiong Umjapung Block Nongneng- A	25°36’51.1”	91°52’25.9”	BW	132.07	Domestic
17.	Persha Kharlyngdoh	3rd Mile Upper Shillong	25°34’38.7”	91°51’35.6”	BW	91.50	Domestic
18.	Smt. Rupa Jubilee Saiborne	Howell Road near Shiv Mandir, laban	25°33’52.7”	91°52’39.1”	BW	42.70	Domestic
19.	Smt. Krialtina Wahlang	Behind Shillong Times	25°34’8.6’’	91°52’19.1’’	BW	85.40	Domestic
20.	Smt. Phildarose Lyngdoh	Nongthymmai, Dum Dum, PO Nongthymmai	25°33’48.5’’	91°54’36.8’’	BW	10.37	Domestic

Table 3.2 Source and Depth Wise Distribution of Sampling Sites in Shillong City

Source structure	Depth range			Total number
	<20 m	21-40 m	>40 m	
Hand Pumps	-	-	-	-
Bore Wells/ Tube Wells	20	13	1,2,3,4,5,6,7,8,9, 10,11,12,14,15,1 6,17,18,19	20
Open Wells	-	-	-	-
Total	1	1	18	20

Table 3.3 Analytical Methods and Equipment Used in the Analysis

S.No.	**Parameter**	**Method**	**Equipment**
A.	**Physico-chemical**		
1.	pH	Electrometric	pH Meter
2.	Conductivity	Electrometric	Conductivity Meter
3.	TDS	Electrometric	Conductivity/TDS Meter
4.	Alkalinity	Titration by H_2SO_4	-
5.	Hardness	Titration by EDTA	-
6.	Chloride	Titration by $AgNO_3$	-
7.	Sulphate	Turbidimetric	Turbidity Meter
8.	Nitrate	Ultraviolet screening	UV-VIS Spectrophotometer
9.	Fluoride	SPADNS	UV-VIS Spectrophotometer
10.	Sodium	Flame emission	Flame Photometer
11.	Potassium	Flame emission	Flame Photometer
12.	Calcium	Titration by EDTA	-
13.	Magnesium	Titration by EDTA	-
14.	Boron	Carmine	UV-VIS Spectrophotometer
B.	**Heavy Metals**		
15.	Iron	Digestion followed by Atomic Spectrometry	Inductively Coupled Plasma Mass Spectrometer (ICP-MS)
16.	Manganese		
17.	Copper		
18.	Nickel		
19.	Chromium		
20.	Lead		
21.	Cadmium		
22.	Zinc		
23.	Mercury		
24.	Arsenic		

4.0 RESULTS AND DISCUSSIONS

4.1 Drinking Water Quality

The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institution (ISI) has laid down the standard specifications for drinking water (BIS, 2012). In order to enable the users, exercise their discretion towards water quality criteria, the permissible limit has been prescribed especially where no alternate source is available. The national water quality standards describe acceptable and permissible characteristics required to be evaluated to assess suitability of water for drinking purpose.

The hydro-chemical data of the samples collected from the Shillong during pre- and post-monsoon seasons are presented in Table 4.1 (a&b). Distribution of different water quality constituents with depth and season are given in Table 4.2-4.11 and distribution maps are presented in Figs. 4.1 (a&b) to 4.10 (a&b).

Table 4.1(a). Hydro-chemical Data of Ground Water Samples in Shillong City (Pre-monsoon 2018)

Characteristics	Min	Max	Average
pH	3.5	8.0	5.95
Conductivity, µS/cm	12.2	759	214
TDS, mg/L	7.8	486	137
Alkalinity, mg/L	Nil	96	21
Hardness, mg/L	6.3	156	53
Sodium, mg/L	0.5	59	13
Potassium, mg/L	0.3	27	4.2
Calcium, mg/L	1.99	44	15
Magnesium, mg/L	0.20	16	3.6
Chloride, mg/L	0.43	81	21
Sulphate, mg/L	0.09	39	9.9
Nitrate, mg/L	0.14	186	31
Fluoride, mg/L	0.02	0.42	0.09
Boron, mg/L	0.01	0.03	0.02
Iron, µg/L	47	6342	986
Manganese, µg/L	10	464	178
Copper, µg/L	3	311	52
Nickel, µg/L	1.5	54	7.6
Chromium, µg/L	0.2	4.7	1.0
Lead, µg/L	0.3	10	3.2
Cadmium, µg/L	0.3	10	3.2
Zinc, µg/L	19	3356	552
Arsenic, µg/L	0.06	4.89	0.9
Mercury, µg/L	0.07	9.45	0.9

N=20

Table 4.1(b). Hydro-chemical Data of Ground Water Samples in Shillong City (Post-monsoon 2018)

Characteristics	Min	Max	Average
pH	4.1	7.8	6.1
Conductivity, µS/cm	20.9	710	183
TDS, mg/L	13.4	454	117
Alkalinity, mg/L	Nil	108	21
Hardness, mg/L	9.3	144	43
Sodium, mg/L	0.57	55	12
Potassium, mg/L	0.36	24	3.55
Calcium, mg/L	2.59	33	12
Magnesium, mg/L	0.40	16	3.17
Chloride, mg/L	0.46	75	17
Sulphate, mg/L	0.11	31	7.35
Nitrate, mg/L	0.03	165	25
Fluoride, mg/L	0.01	0.34	0.07
Boron, mg/L	0.01	0.03	0.02

N=20

Table 4.2 pH Distribution in Ground Water of Shillong City

S. No	TDS range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-6.5	0-20	20	-	60	45
		20-40	-	-		
		>40	1,2,5,7,9,10,12,14, 17,18,19	2,4,5,7,9,10,12, 15,18		
2.	6.5-8.5	0-20	-	20	40	55
		20-40	13	13		
		>40	3,4,6,8,11,15,16	1,3,6,8,11,14, 16,17,19		
3.	>8.5	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.3 TDS Distribution in Ground Water of Shillong City

S. No.	TDS range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-500	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	501-2000	0-20	-	-	-	-
		20-40	-	-		
		>40		-		
3.	>2000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.4 Alkalinity Distribution in Ground Water of Shillong City

S. No.	Alkalinity, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	201-600	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>600	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.5 Hardness Distribution in Ground Water of Shillong City

S. No.	Hardness range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-300	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	301-600	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>600	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.6 Calcium Distribution in Ground Water of Shillong City

S. No.	Calcium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-75	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	76-200	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>200	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.7 Magnesium Distribution in Ground Water of Shillong City

S. No.	Magnesium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-30	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9, 10,11,12,14,15,161 7,18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	31-100	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>100	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.8 Chloride Distribution in Ground Water of Shillong City

S. No.	Chloride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-250	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	251-1000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>1000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.9 Sulphate Distribution in Ground Water of Shillong City

S. No.	Sulphate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	201-400	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>400	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

Table 4.10 Nitrate Distribution in Ground Water of Shillong City

S. No.	Nitrate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-45	0-20	-	20	75	90
		20-40	13	13		
		>40	1,2,3,4,6,8,9,10,11, 14,16,17,18,19	1,2,3,4,6,8,9,10,11, 12,14,15,16,17,18, 19		
2.	46-100	0-20	-	-	20	5
		20-40	-	-		
		>40	5,12,15,20	5		
3.	>100	0-20	-	-	5	5
		20-40	-	-		
		>40	7	7		
Total number of samples			20	20	100	100

Table 4.11 Fluoride Distribution in Ground Water of Shillong City

S. No.	Fluoride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-1.0	0-20	20	20	100	100
		20-40	13	13		
		>40	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19	1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17, 18,19		
2.	1.1-1.5	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>1.5	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			20	20	100	100

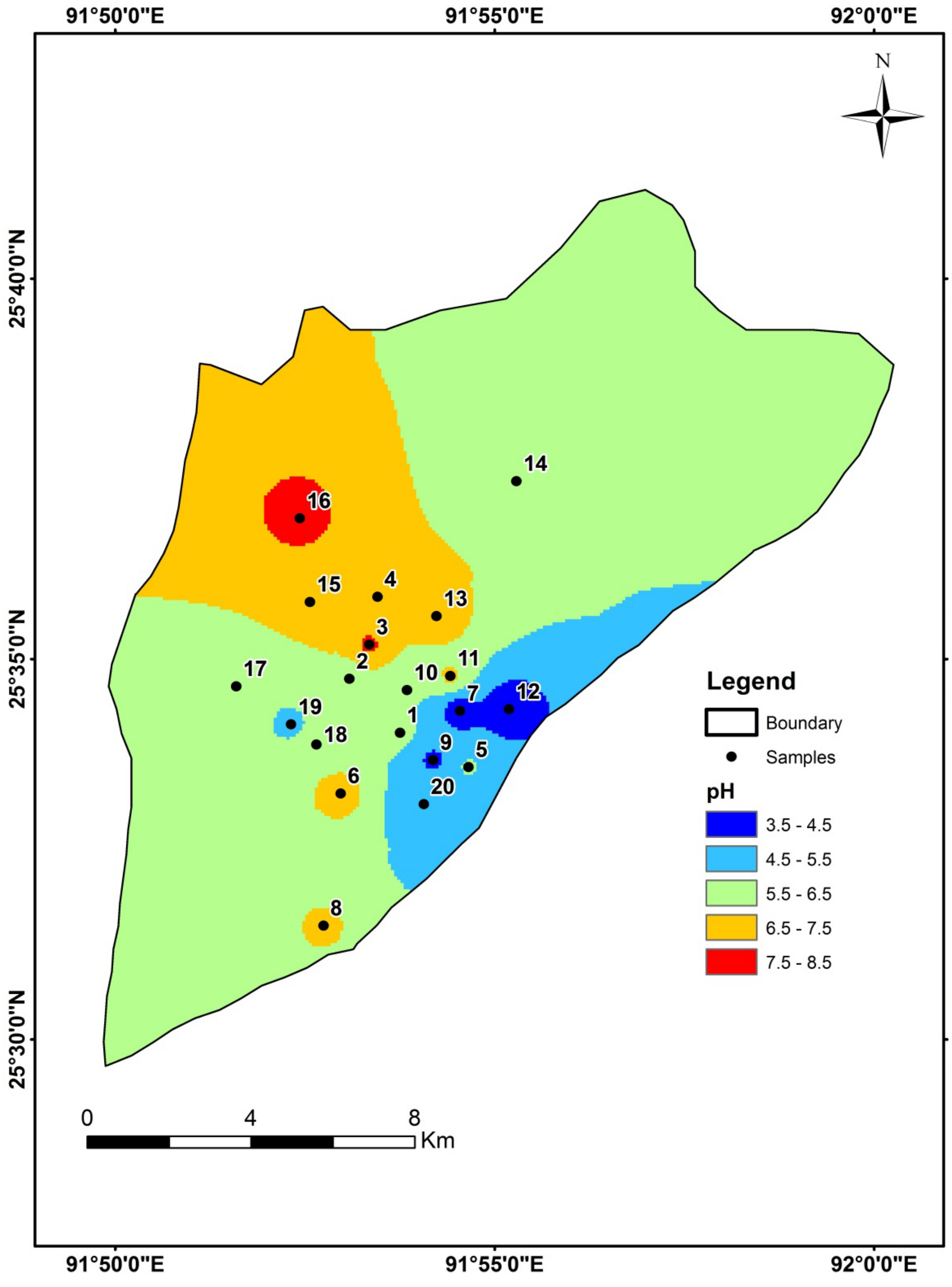

Fig. 4.1(a). pH Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

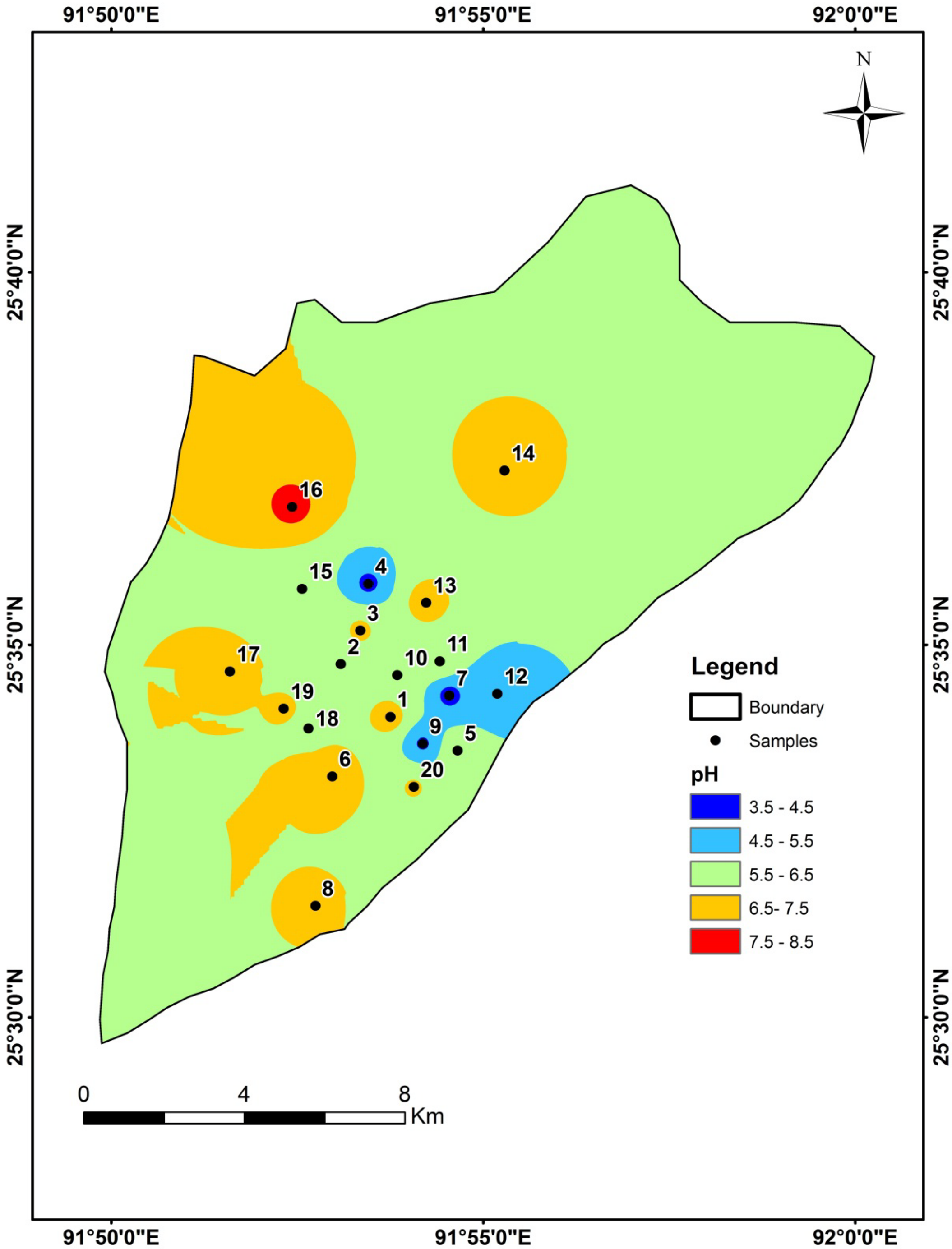

Fig. 4.1(b). pH Distribution in Ground Water of Shillong City (Post-monsoon 2018)

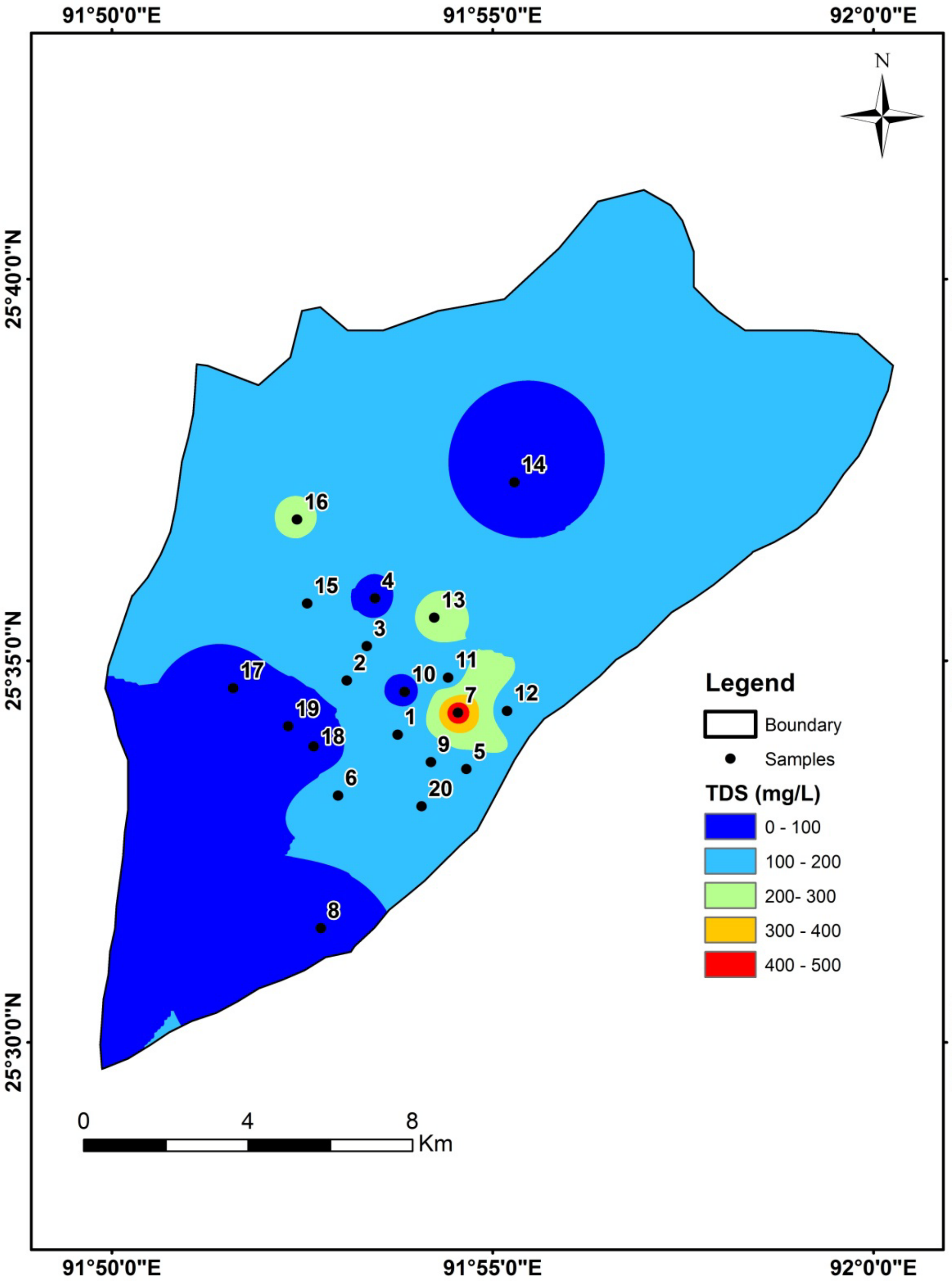

Fig. 4.2(a). TDS Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

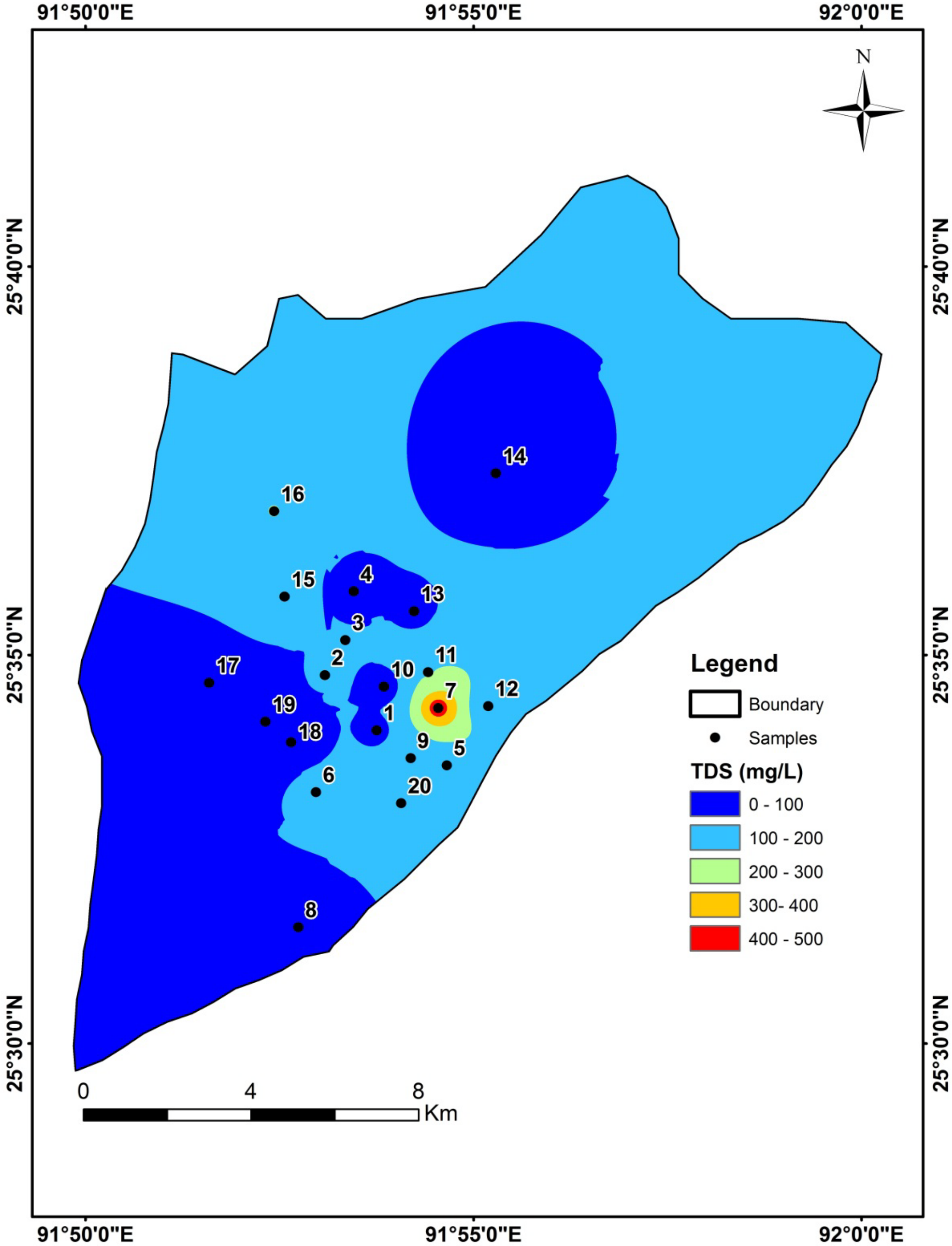

Fig. 4.2(b). TDS Distribution in Ground Water of Shillong City in (Post-monsoon 2018)

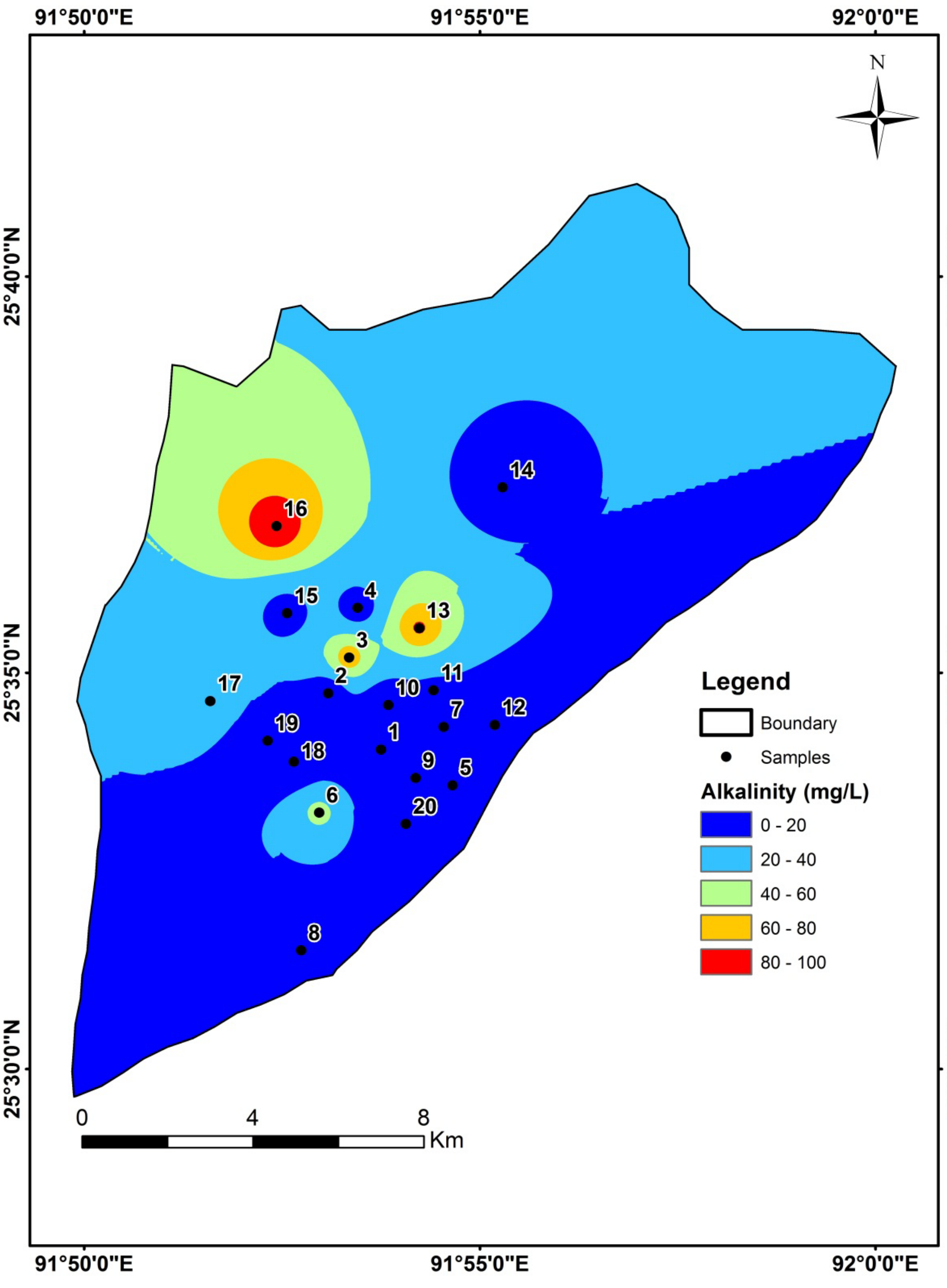

Fig. 4.3(a). Alkalinity Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

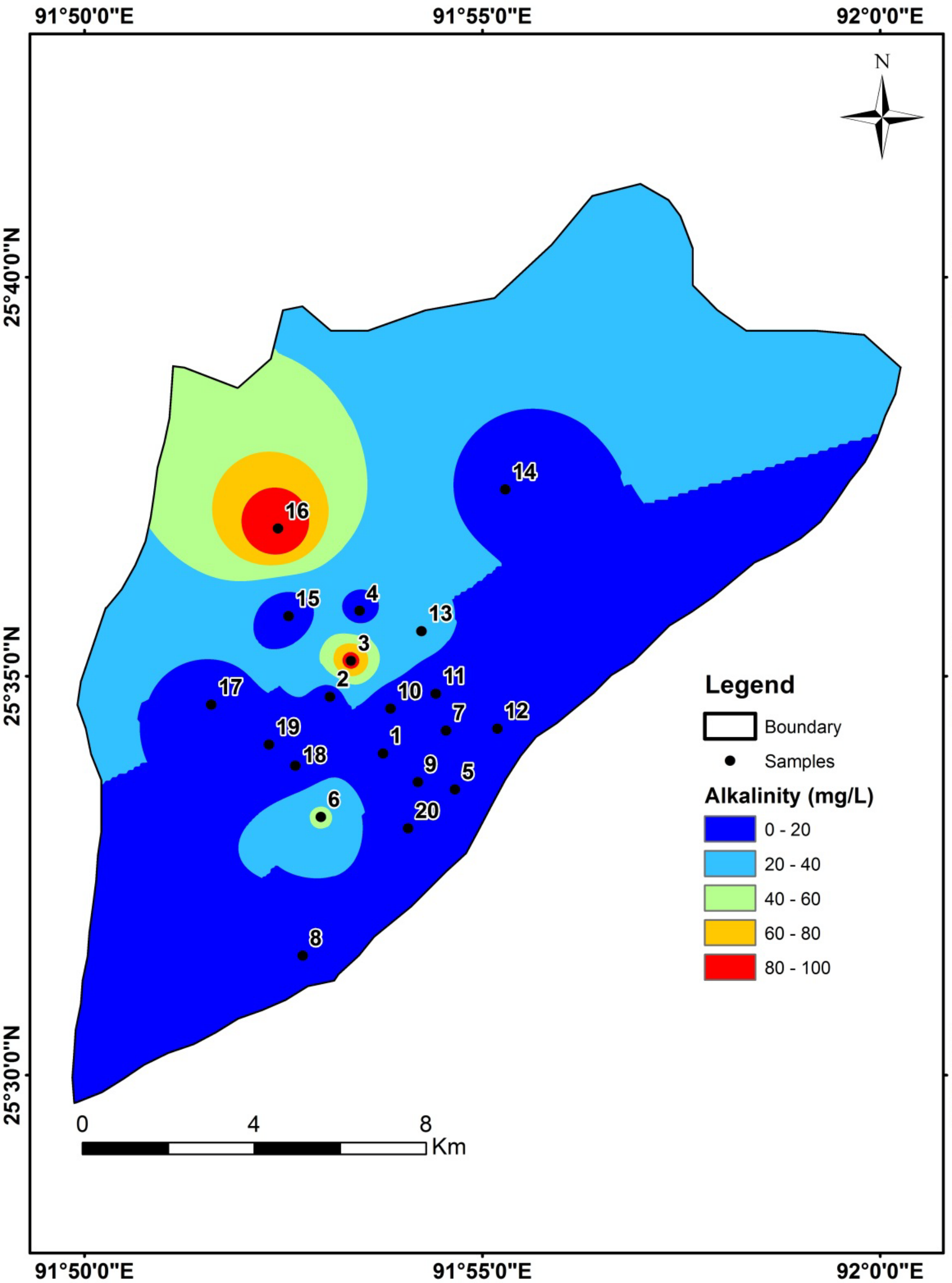

Fig. 4.3(b). Alkalinity Distribution in Ground Water of Shillong City (Post-monsoon 2018)

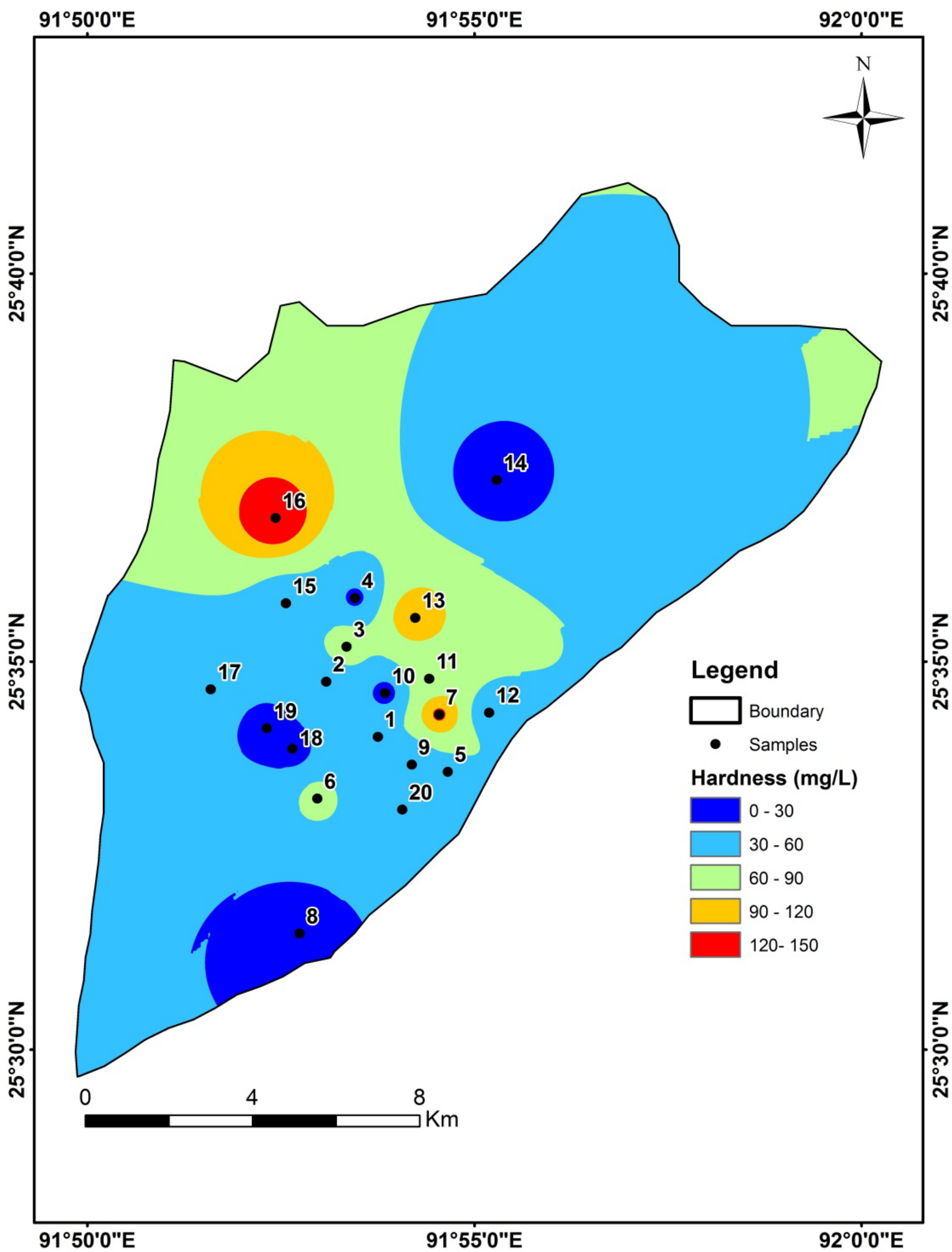

Fig. 4.4(a). Hardness Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

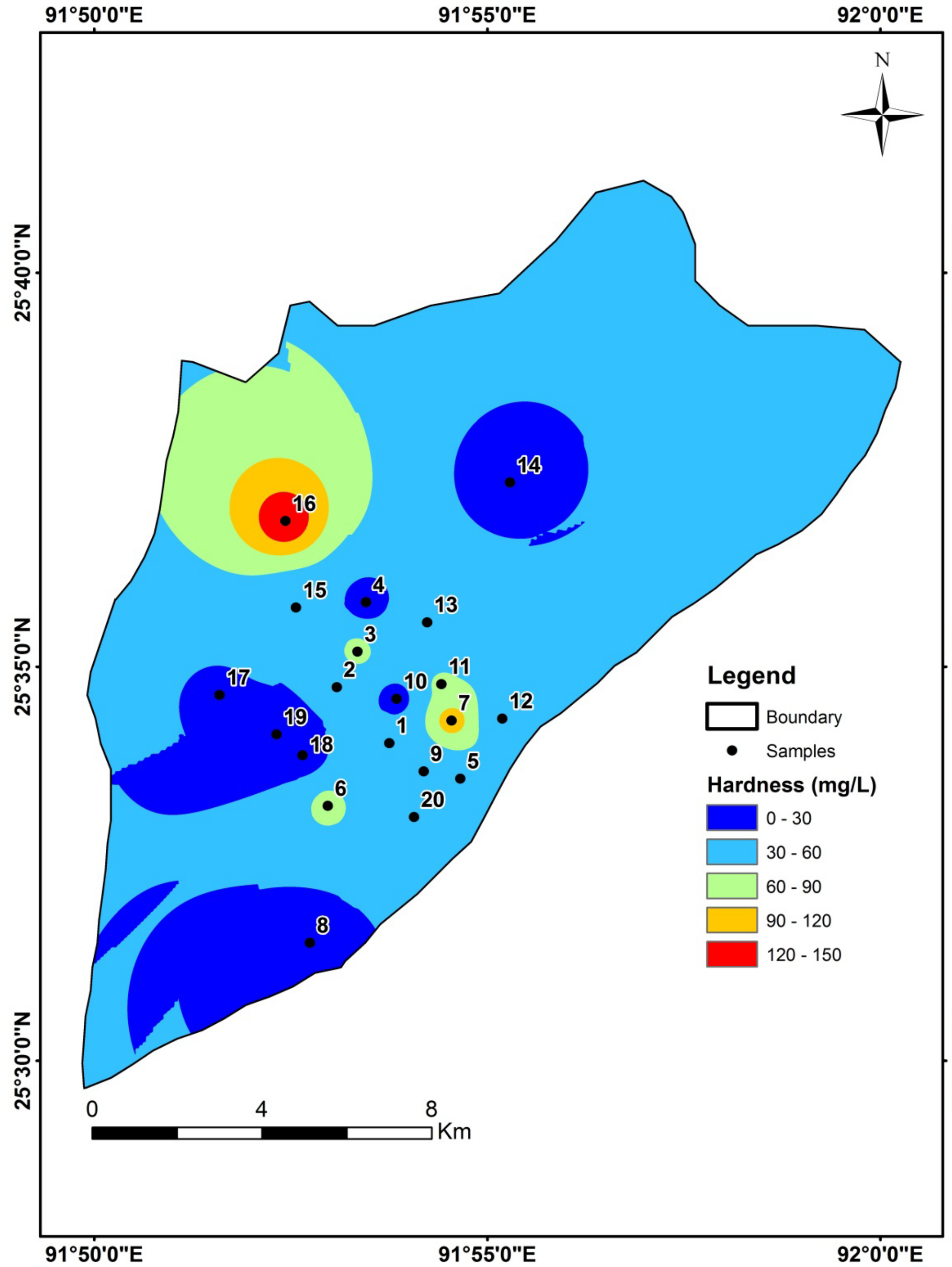

Fig. 4.4(b). Hardness Distribution in Ground Water of Shillong City (Post-monsoon 2018)

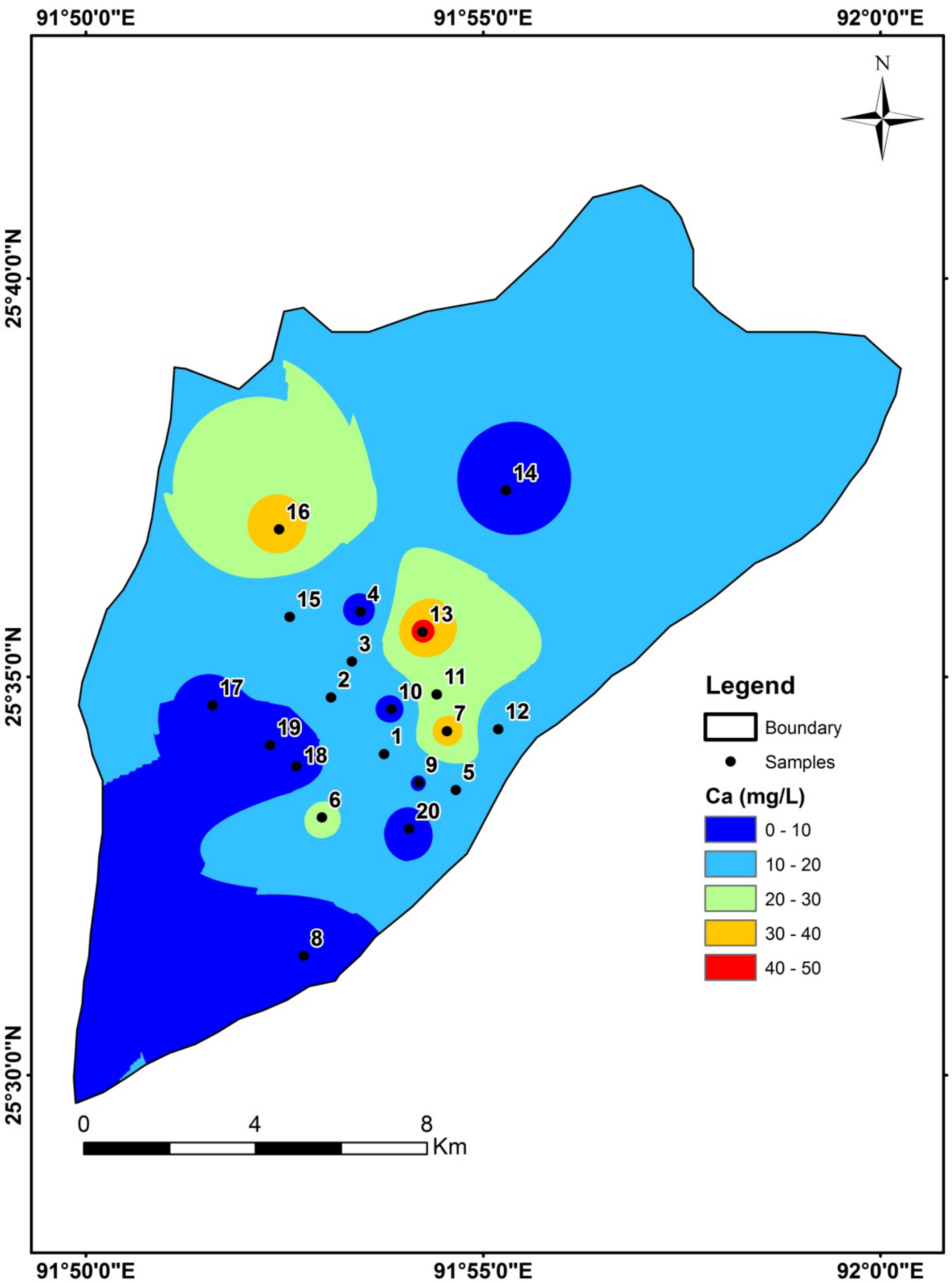

Fig. 4.5(a). Calcium Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

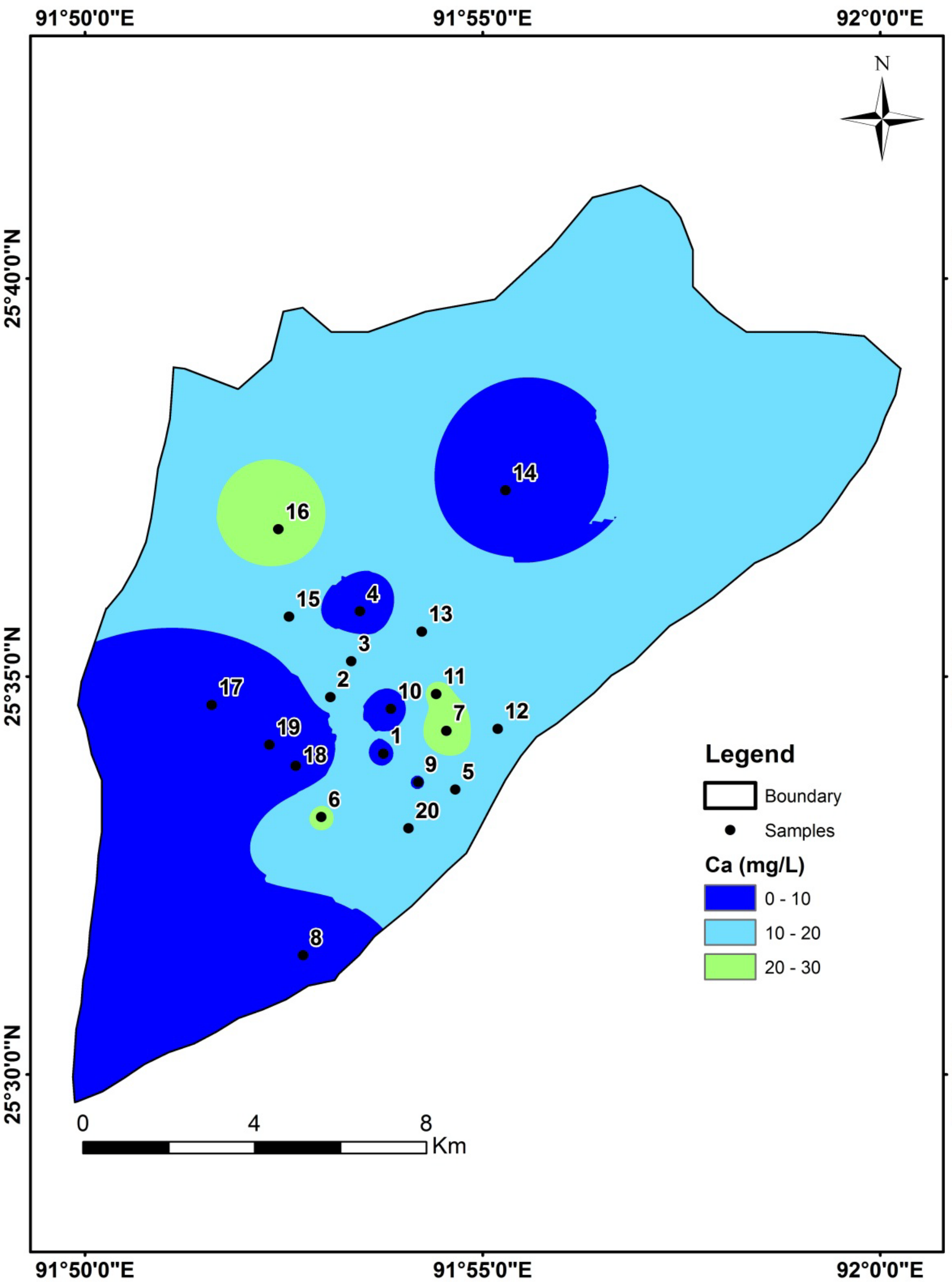

Fig. 4.5(b). Calcium Distribution in Ground Water of Shillong City (Post-monsoon 2018)

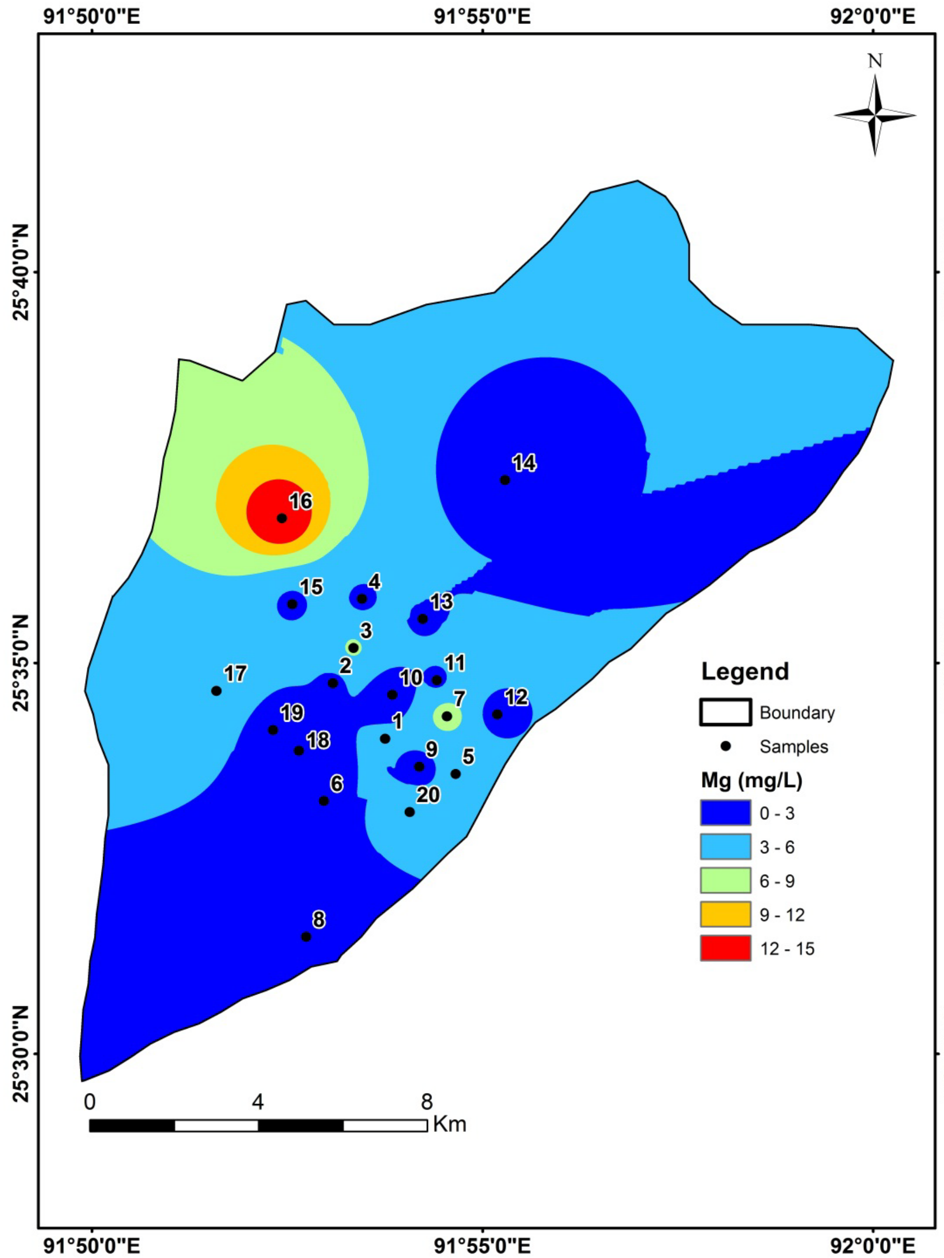

Fig. 4.6(a). Magnesium Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

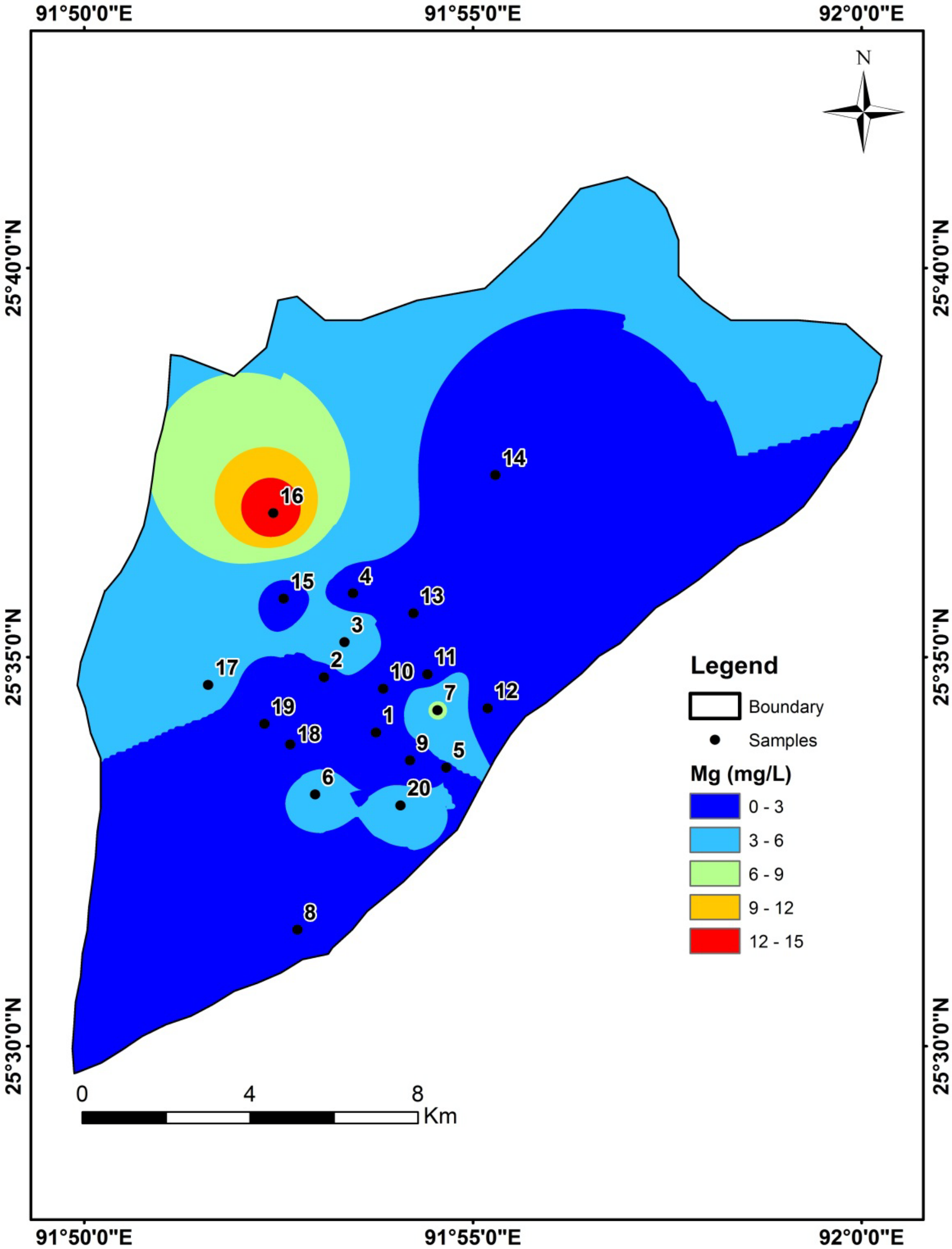

Fig. 4.6(b). Magnesium Distribution in Ground Water of Shillong City (Post-monsoon 2018)

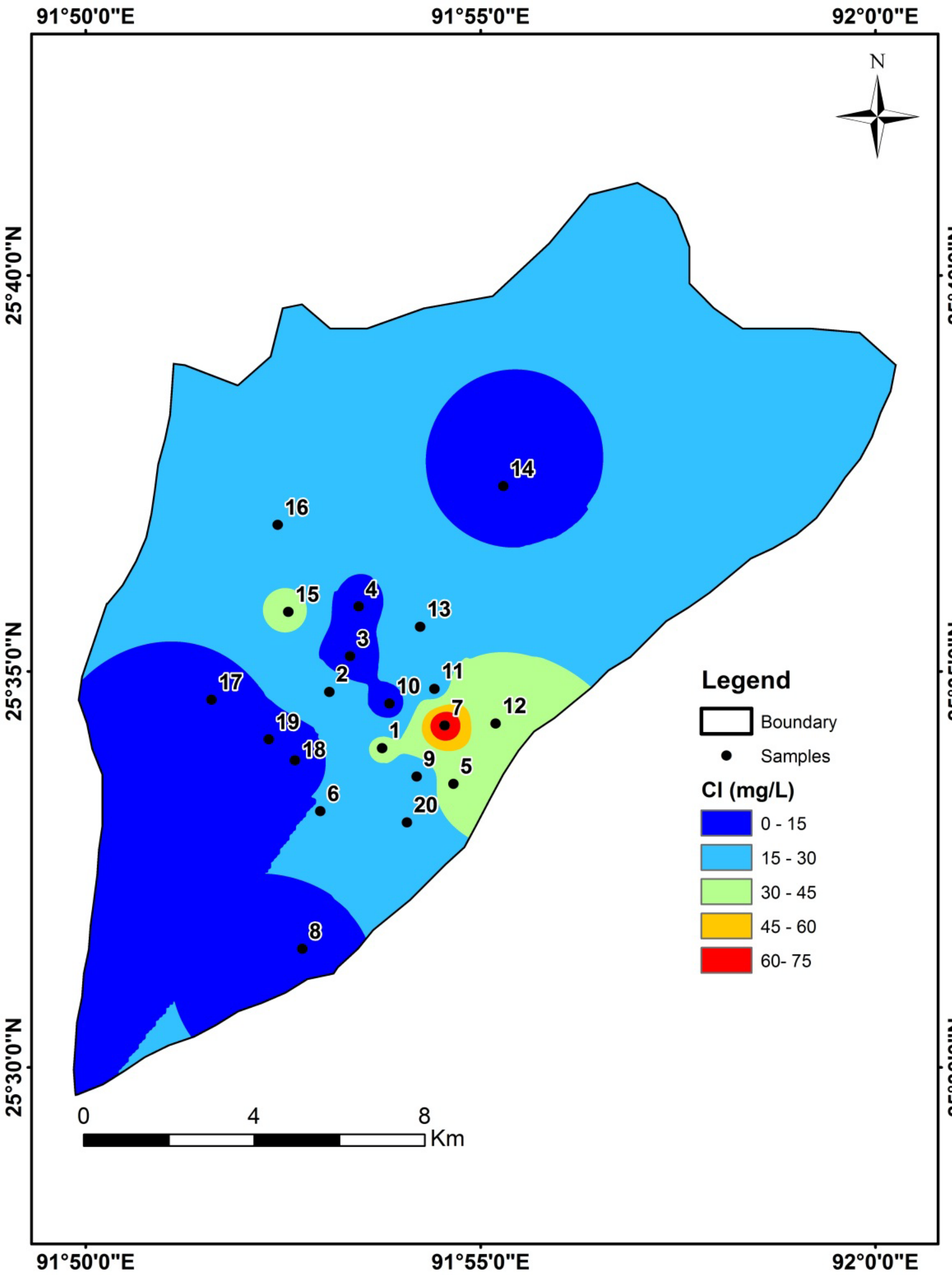

Fig. 4.7(a). Chloride Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

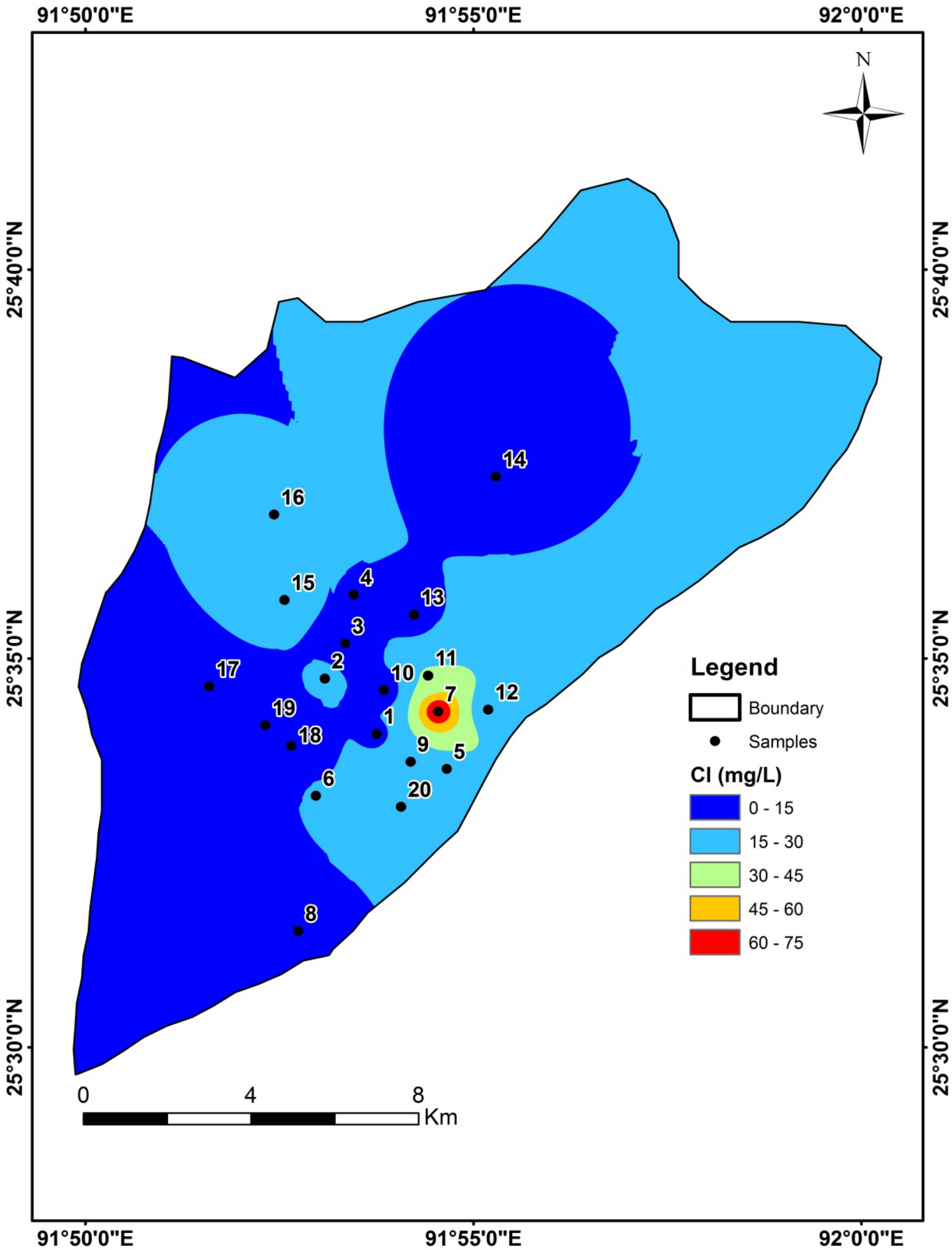

Fig. 4.7(b). Chloride Distribution in Ground Water of Shillong City (Post-monsoon 2018)

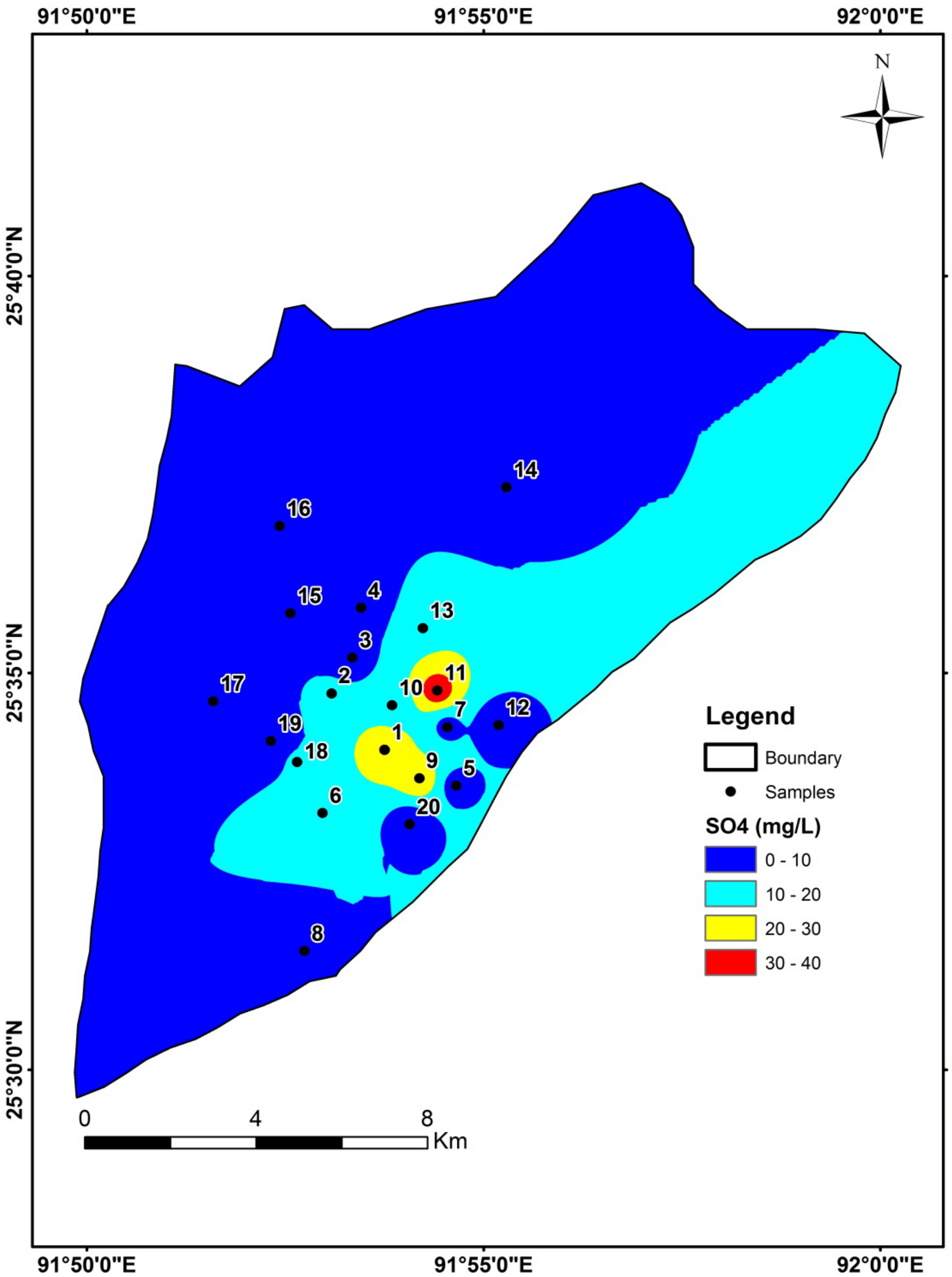

Fig. 4.8(a). Sulphate Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

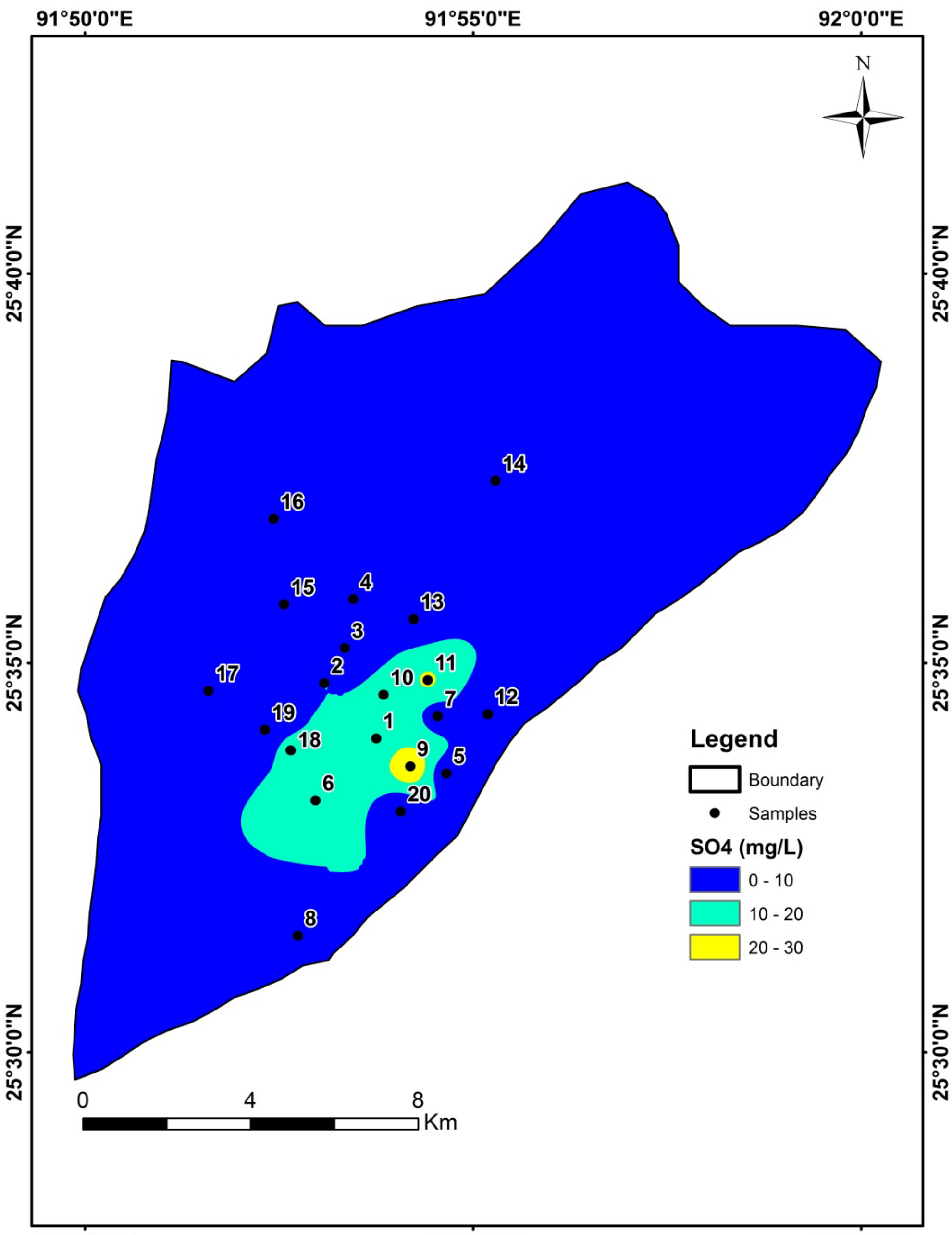

Fig. 4.8(b). Sulphate Distribution in Ground Water of Shillong City (Post-monsoon 2018)

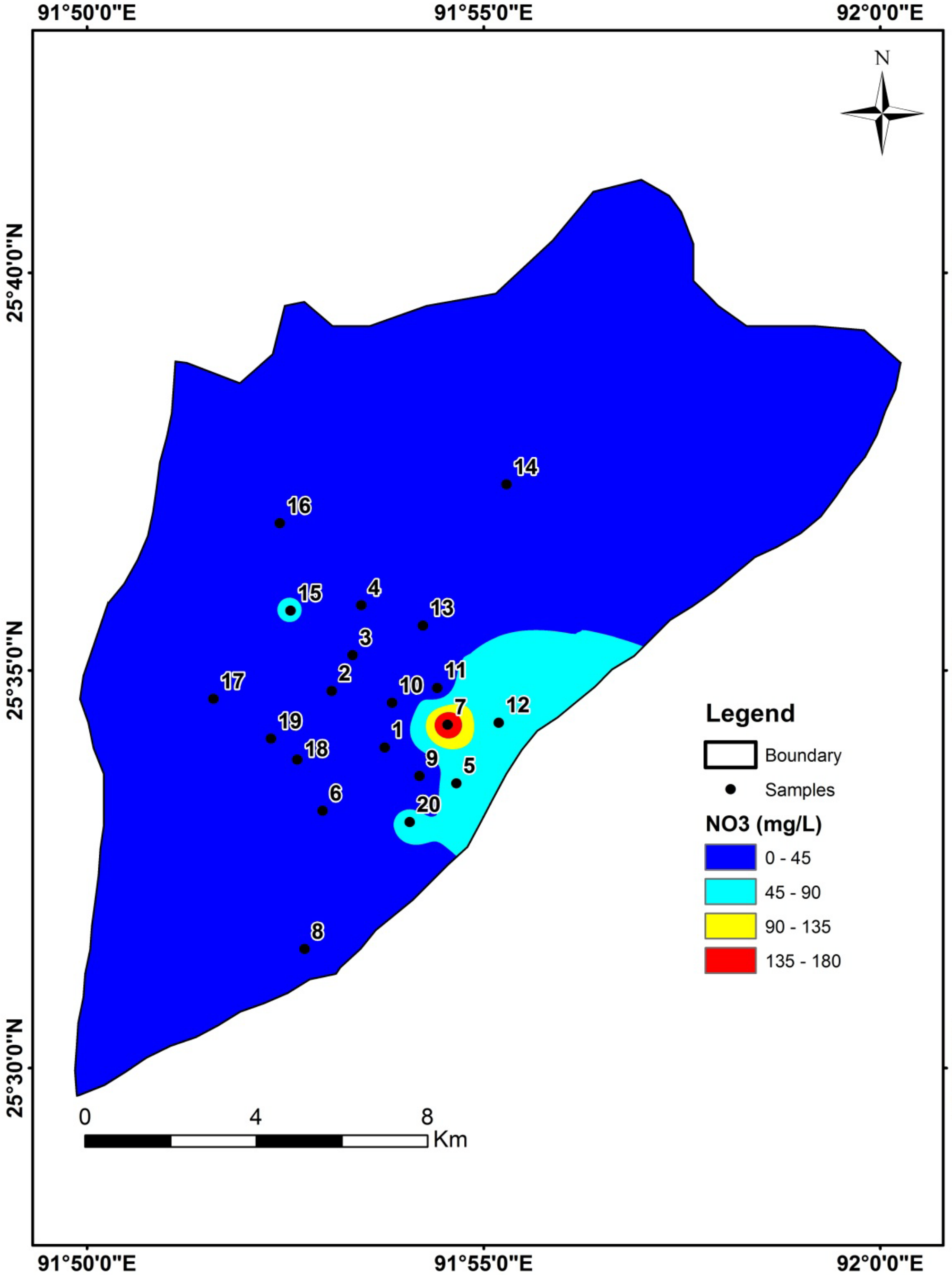

Fig. 4.9(a). Nitrate Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

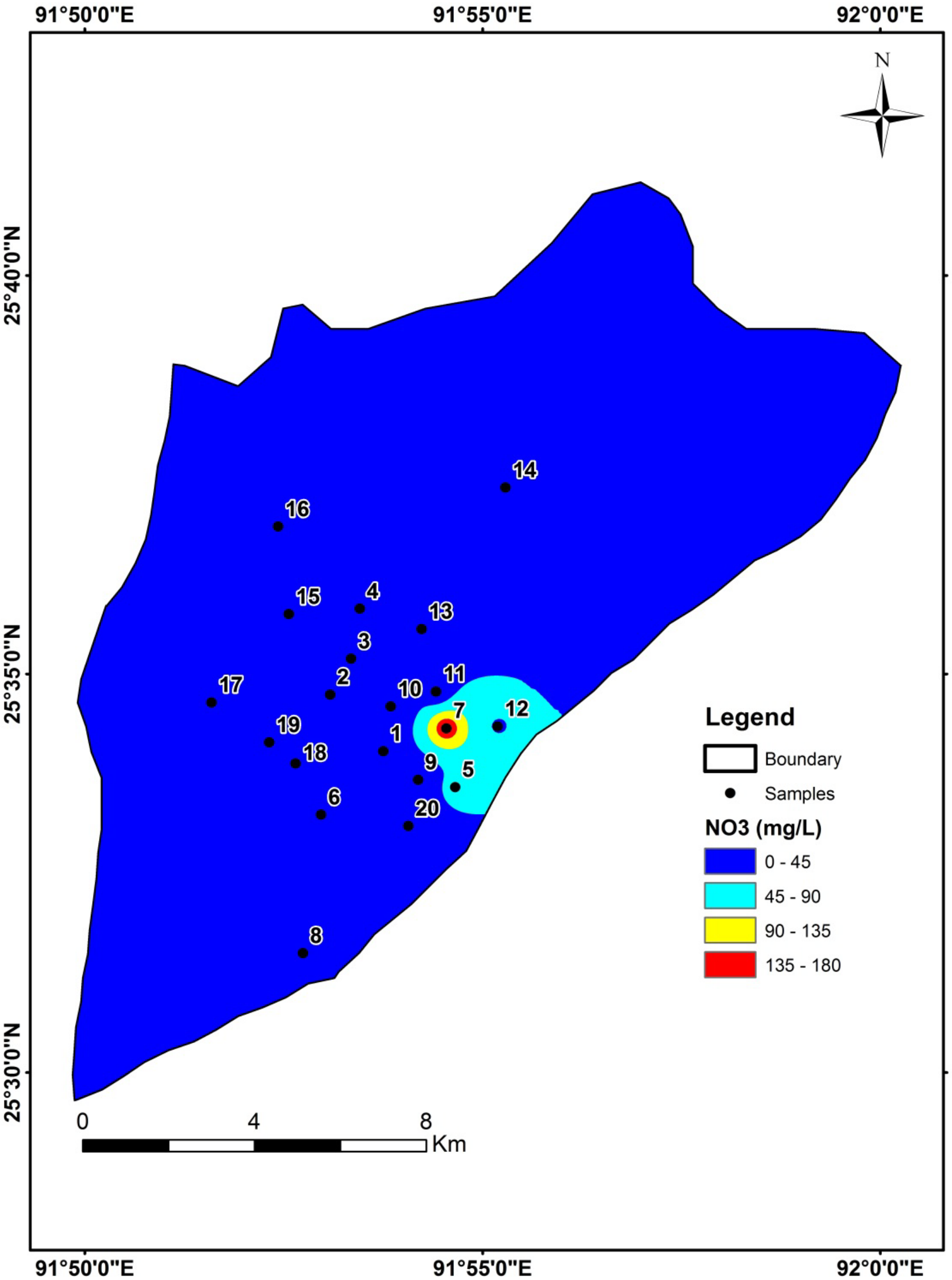

Fig. 4.9(b). Nitrate Distribution in Ground Water of Shillong City (Post-monsoon 2018)

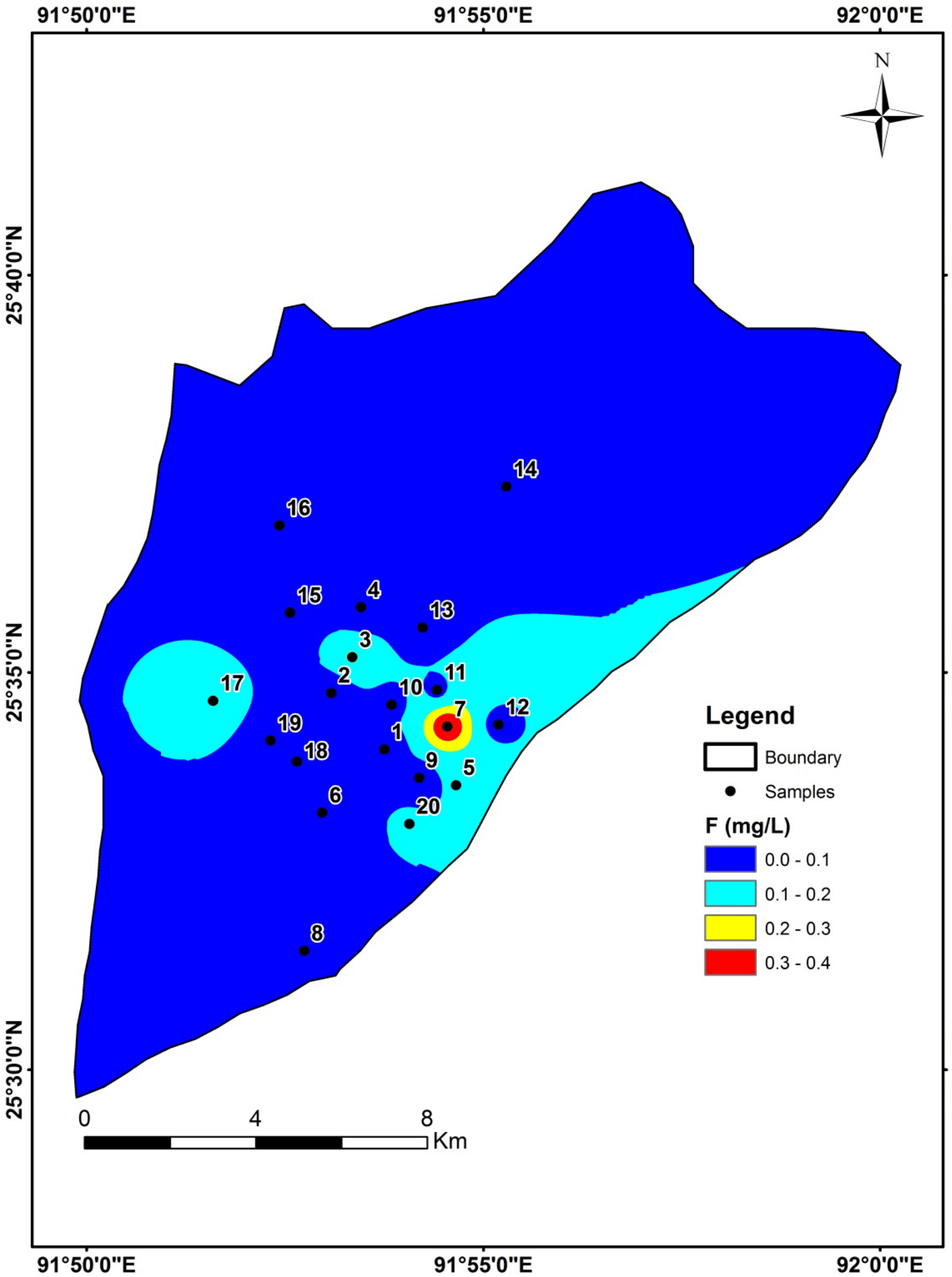

Fig. 4.10(a). Fluoride Distribution in Ground Water of Shillong City (Pre-monsoon 2018)

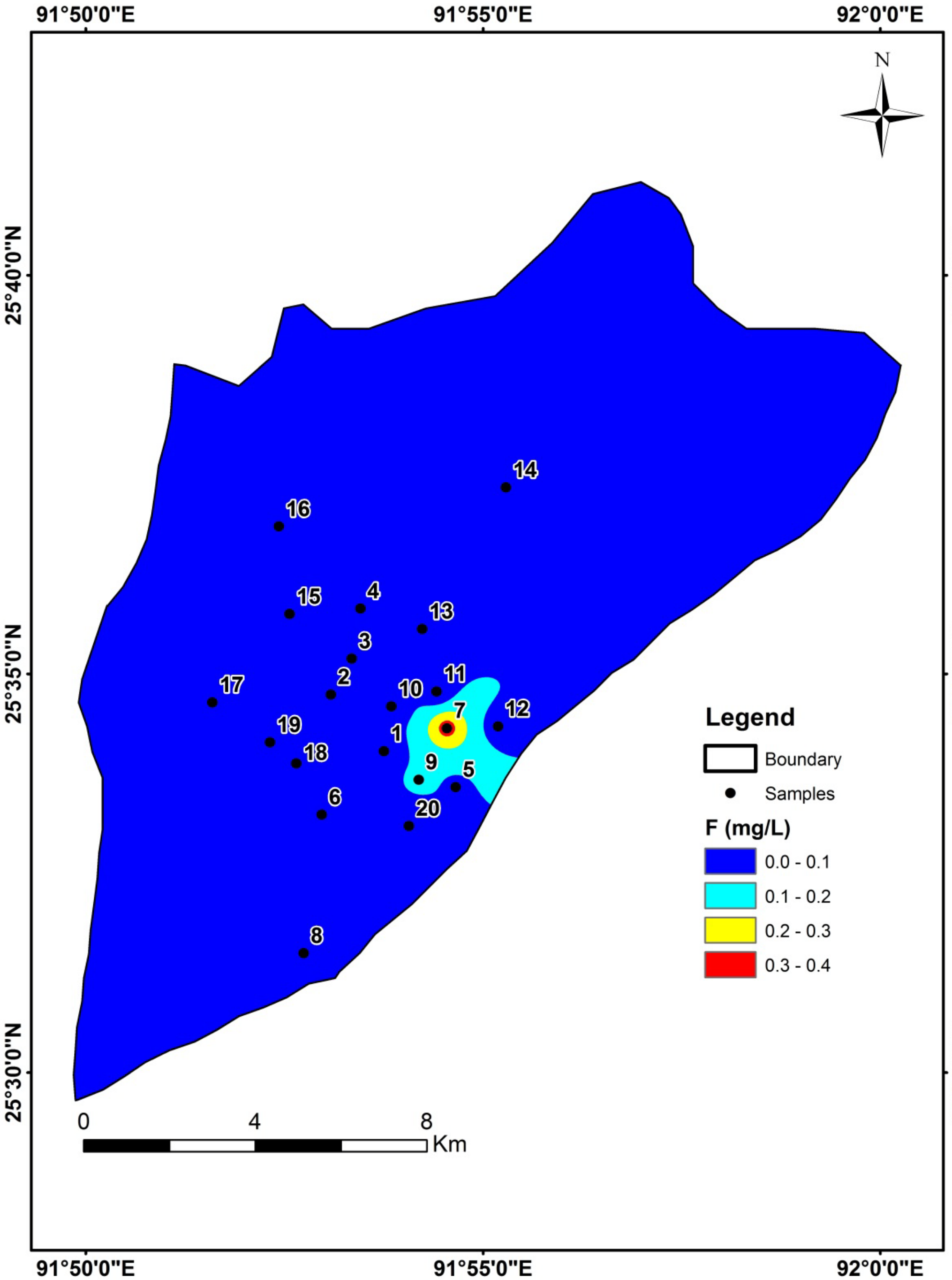

Fig. 4.10(b). Fluoride Distribution in Ground Water of Shillong City (Post-monsoon 2018)

4.1.1 General Characteristics

The pH values in the ground water of Shillong are mostly confined within the range 3.5 to 8.0 with more than 50% of the samples having pH less than 6.5 during pre-monsoon season and are not suitable for drinking purpose (BIS, 2012). The pH distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.1(a&b).

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the Shillong vary from 12.2 to 759 μS/cm during pre-monsoon season and 20.9 to 710 μS/cm during post-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 7.8 to 486 mg/L during pre-monsoon season and 13.4 to 454 mg/L during post-monsoon season indicating low mineralization in the area. All the samples of the study area were found within the acceptable limit of 500 mg/L. It may be concluded that there is low mineralization of ground water. The TDS distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 2012). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 2012).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from nil to 96 mg/L during pre-monsoon season and nil to 108 mg/L during post-monsoon season. All the samples of the study area were found within the acceptable limit of 200 mg/L during both pre- and post-monsoon seasons. The alkalinity distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.3(a&b).

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 200 mg/L as acceptable limit and 600 mg/L as permissible limit for total hardness has been recommended for drinking water (BIS, 2012). The total hardness values in the study area range from 6.3 to 156 mg/L during pre-monsoon season and 9.3 to 144 mg/L during post-monsoon seasons. All the samples of the study area were found within the acceptable limit of 300 mg/L during both pre- and post-monsoon seasons. The hardness distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.4(a&b).

The acceptable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 2012). In ground water of the Shillong, the values of calcium and magnesium range from 1.99 to 44 mg/L and 0.20 to 16 mg/L respectively during pre-monsoon season. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in pre-monsoon season. The calcium and magnesium distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.5(a&b) and 4.6(a&b) respectively.

The concentration of sodium in the study area varies from 0.5 to 59 mg/L during pre-monsoon season and 0.57 to 55 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The concentration of potassium in ground water of the Shillong varies from 0.3 to 27 mg/L during pre-monsoon season and 0.36 to 24 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, all but two samples fall within the prescribed limit of 10 mg/L.

The concentration of chloride varies from 0.43 to 81 mg/L during pre-monsoon season and 0.46 to 75 mg/L during post-monsoon season with all the samples falling within the acceptable limit of 250 mg/L. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as acceptable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 2012). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 0.09 to 39 mg/L during pre-monsoon season and 0.11 to 31 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the acceptable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, all the samples analysed fall well within the acceptable limit of 200 mg/L both during pre- and post-monsoon seasons. The sulphate distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the Shillong varies from 0.14 to 186 mg/L during pre-monsoon seasons and 0.03 to 165 mg/L during post-monsoon season indicating that except few samples, majority of the samples of the study area falls within the acceptable limit of 45mg/L. At few locations water is not suitable from nitrate perspective and should be treated before using for drinking purpose. The nitrate distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (2012) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The fluoride content in the ground water of the study area varies from 0.02 to 0.42 mg/L during pre-monsoon season and 0.01 to 0.34 mg/L with all the samples falling within the acceptable limit of 1.0 mg/L. The fluoride distribution maps for pre- and post-monsoon seasons are shown in Fig. 4.10(a&b). The presence of small amount of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentrations of almost all the water quality constituents except pH in more than 50% of the samples and nitrate in few samples are well within the acceptable limits for drinking water.

4.1.2 Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre-monsoon season is given in Tables 4.1. The distribution of different metals with depth is presented in Tables 4.12 to 4.20 and graphically shown in Fig. 4.11 to 4.19. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

Table 4.12 Iron Distribution in Ground Water of Shillong

S. No.	Fe range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-300	< 20	20	65
		20-40	13	
		> 40	2,3,4,6,7,8,12,14,16,17,19	
2.	> 300	< 20	-	35
		20-40	-	
		> 40	1,5,9,10,11,15,18,	
Total number of samples			20	100

Table 4.13 Manganese Distribution in Ground Water of Shillong

S. No.	Mn range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-100	< 20	20	40
		20-40	-	
		> 40	3,4,6,8,14,16,19	
2.	101-300	< 20	-	35
		20-40	13	
		> 40	1,2,5,12,17,18	
3.	> 300	< 20	-	25
		20-40	-	
		> 40	7,9,10,11,15	
Total number of samples			20	100

Table 4.14 Copper Distribution in Ground Water of Shillong

S. No.	Cu range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-50	< 20	20	70
		20-40	13	
		> 40	1,3,4,5,7,8,9,11,12,16,17,19	
2.	51-1500	< 20	-	30
		20-40	-	
		> 40	2,6,10,14,15,18	
3.	> 1500	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			20	100

Table 4.15 Nickel Distribution in Ground Water of Shillong

S. No.	Ni range, μg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-20	< 20	20	95
		20-40	13	
		> 40	1,2,3,4,5,6,7,8,9,11,12,14,15,16,17,18,19	
2.	> 20	< 20	-	5
		20-40	-	
		> 40	10	
Total number of samples			20	100

Table 4.16 Chromium Distribution in Ground Water of Shillong

S. No.	Cr range, μg/L	Depth Range, M	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-50	< 20	20	100
		20-40	13	
		> 40	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19	
2.	>50	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			20	100

Table 4.17 Lead Distribution in Ground Water of Shillong

S. No.	Pb range, μg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-10	< 20	20	100
		20-40	13	
		> 40	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19	
2.	>10	< 20	-	0
		20-40	-	
		> 40	-	
Total number of samples			20	100

Table 4.18 Cadmium Distribution in Ground Water of Shillong

S. No.	Cd range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-3	< 20	-	60
		20-40	-	
		> 40	1,2,3,4,6,8,10,11,12,16,17,19	
2.	> 3	< 20	20	40
		20-40	13	
		> 40	5,7,9,14,15,18	
Total number of samples			20	100

Table 4.19 Zinc Distribution in Ground Water of Shillong

S. No.	Zn range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-5000	< 20	20	100
		20-40	13	
		> 40	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19	
2.	5001-15000	< 20	-	-
		20-40	-	
		> 40	-	
3.	> 15000	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			20	100

Table 4.20 Arsenic Distribution in Ground Water of Shillong

S. No.	An range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-10	< 20	20	100
		20-40	13	
		> 40	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19	
2.	11-50	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			20	100

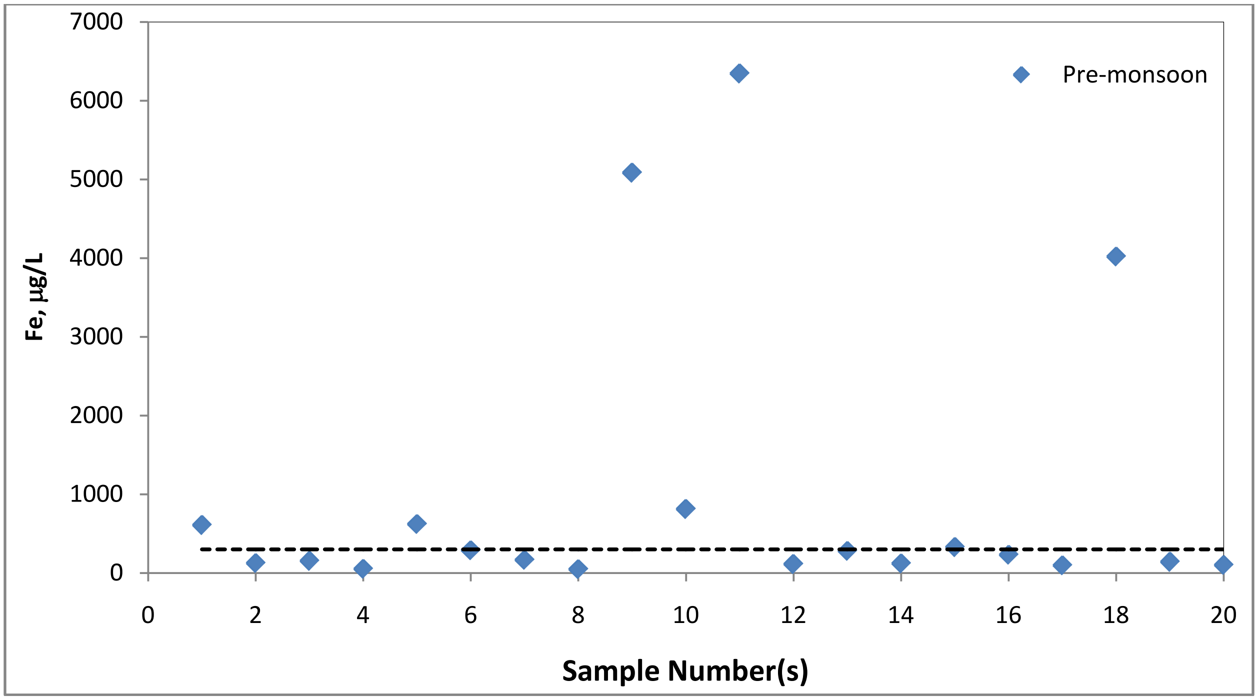

Fig. 4.11 Distribution of Iron at Different Sampling Sites

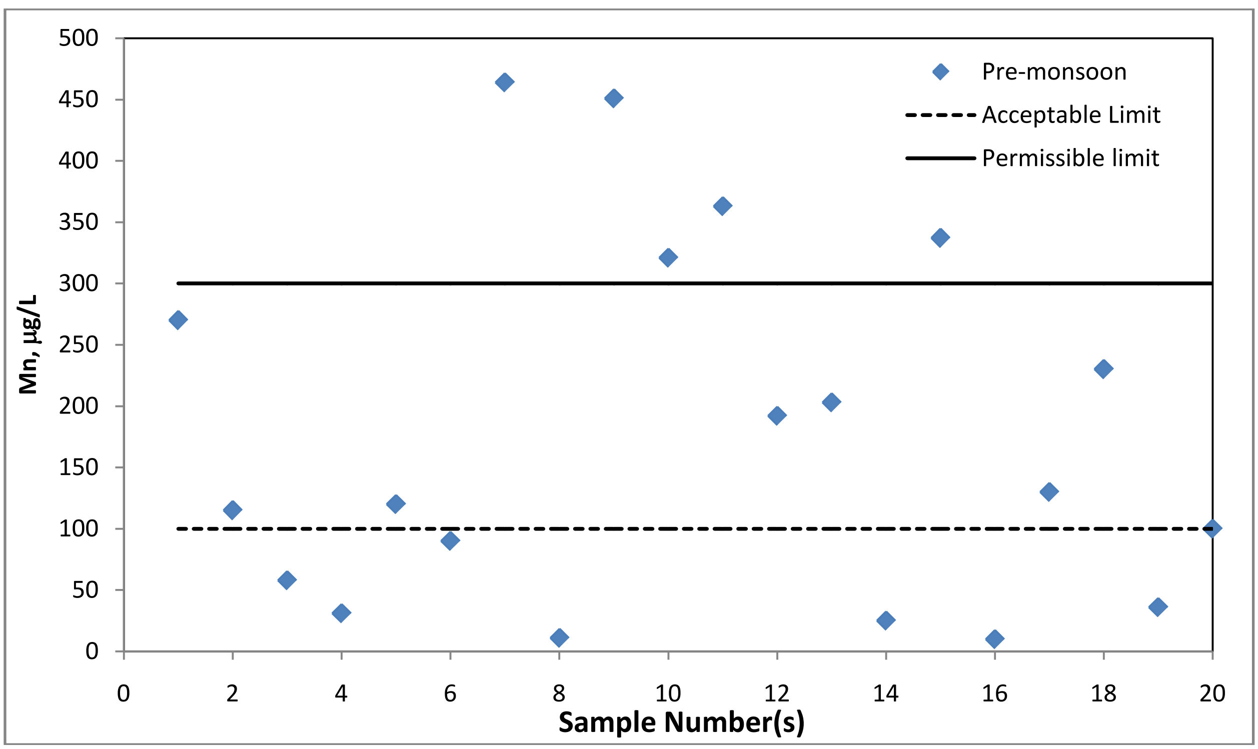

Fig. 4.12 Distribution of Manganese at Different Sampling Sites

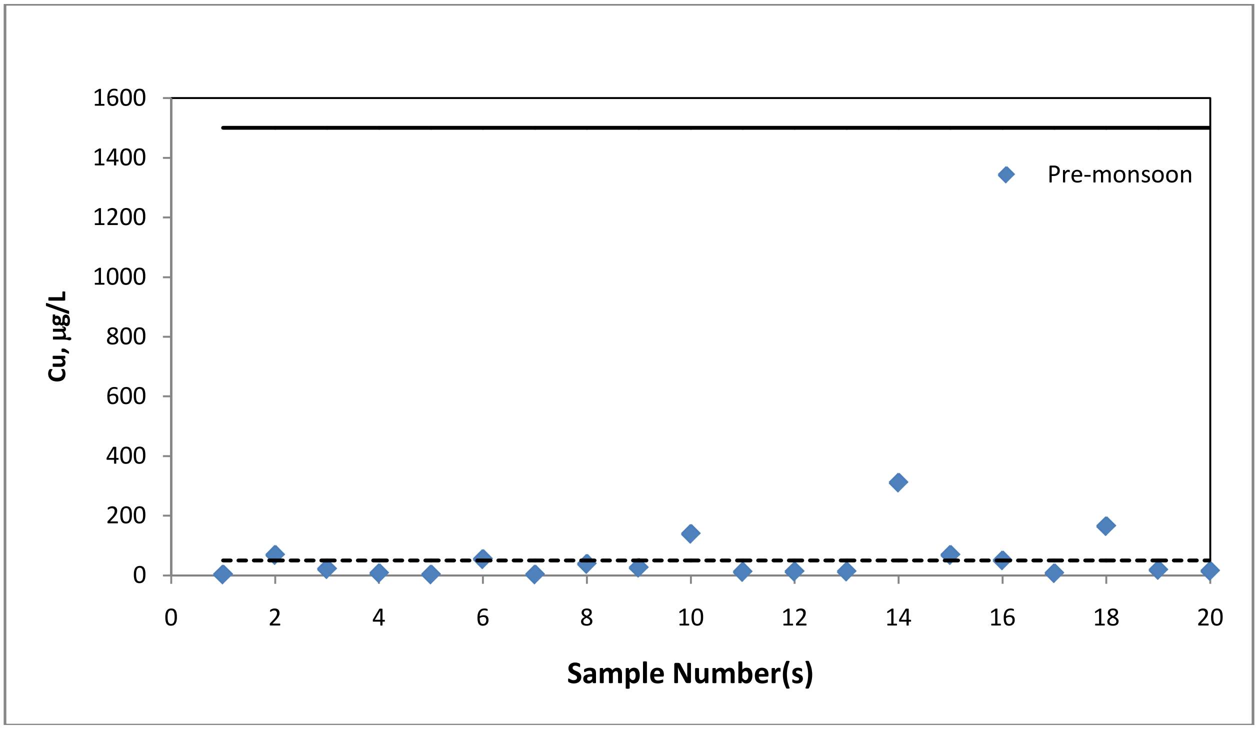

Fig. 4.13 Distribution of Copper at Different Sampling Sites

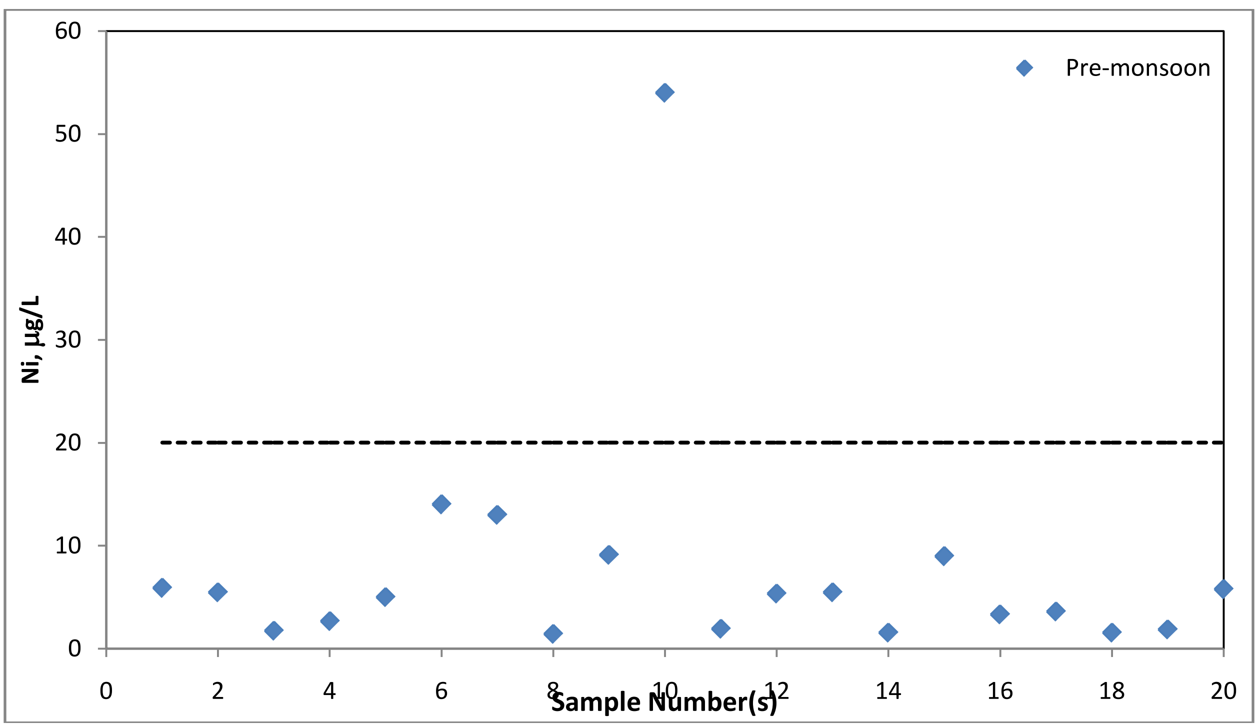

Fig. 4.14 Distribution of Nickel at Different Sampling Sites

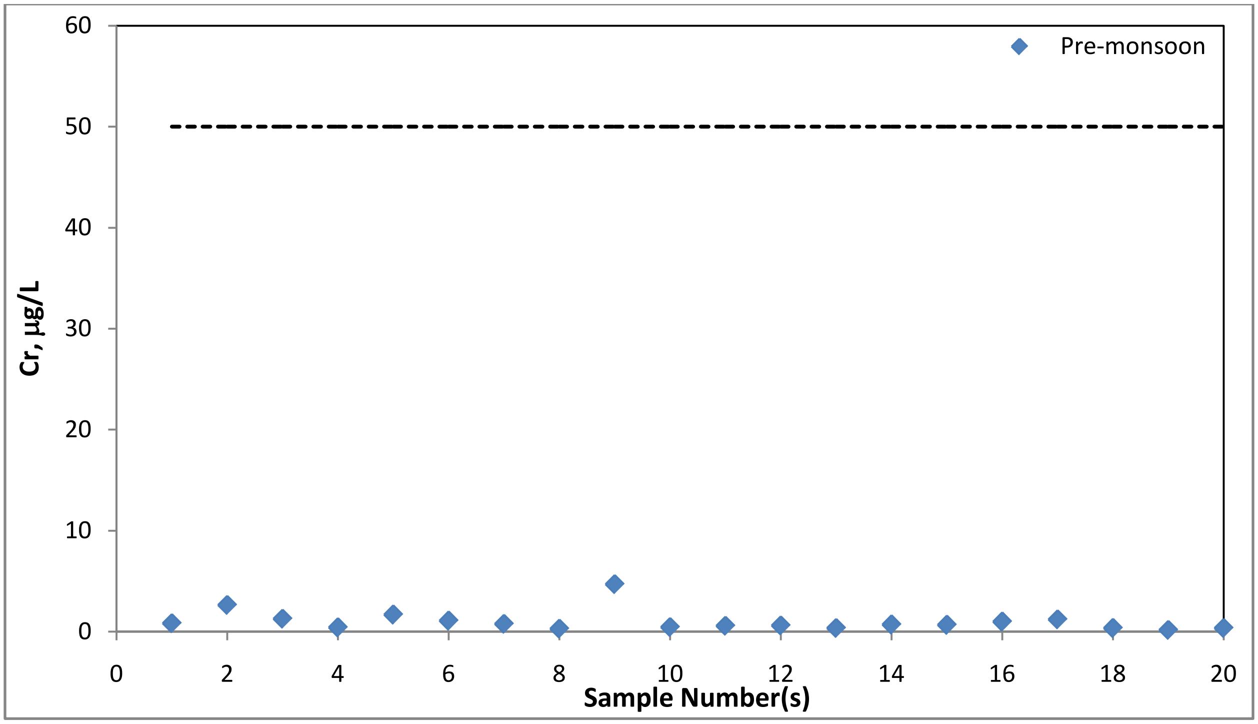

Fig. 4.15 Distribution of Chromium at Different Sampling Sites

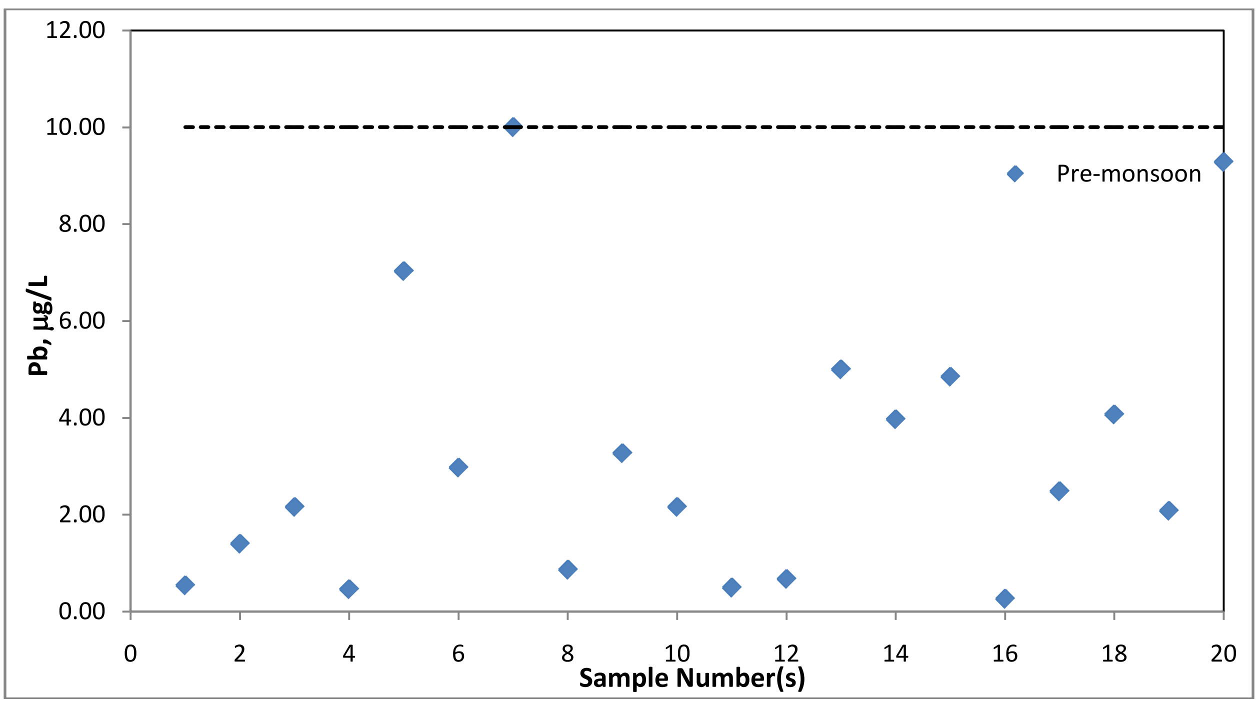

Fig. 4.16 Distribution of Lead at Different Sampling Sites

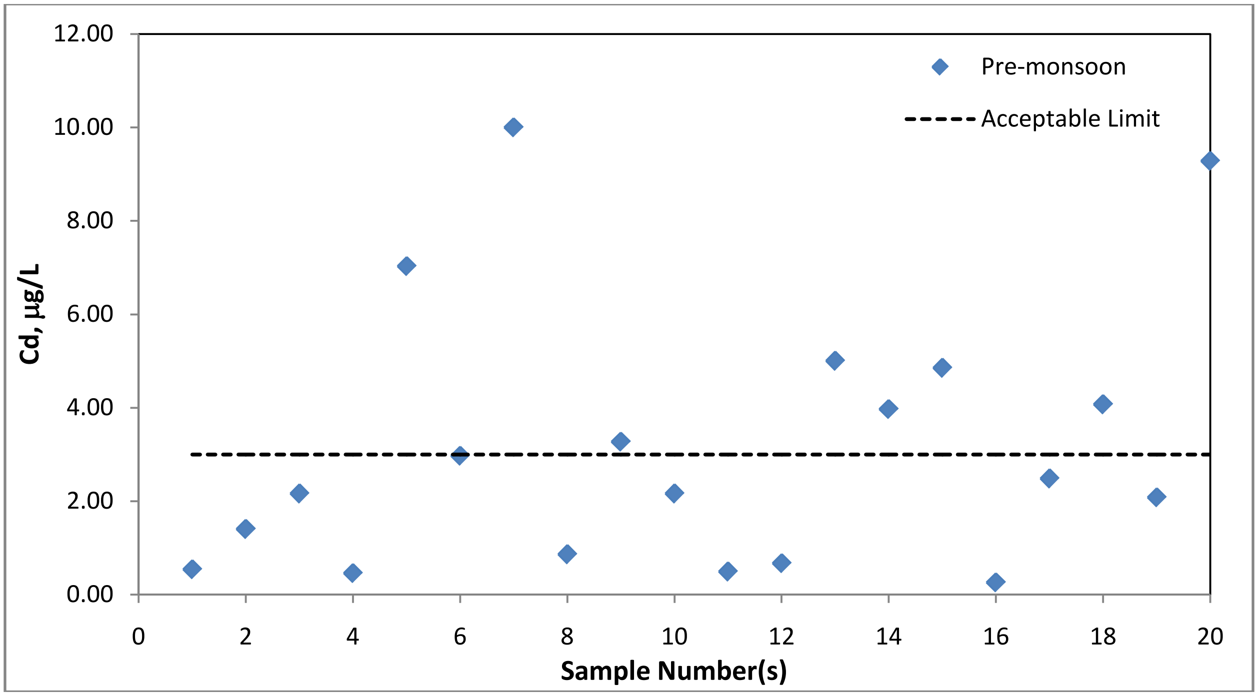

Fig. 4.17 Distribution of Cadmium at Different Sampling Sites

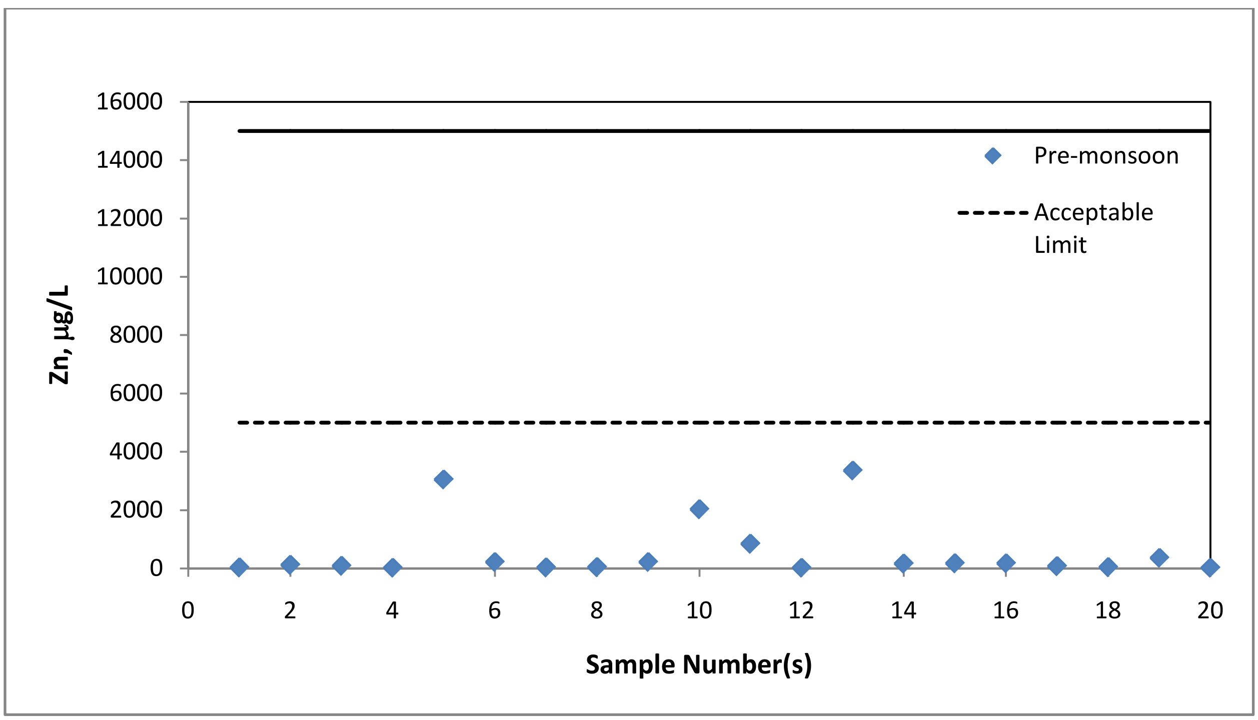

Fig. 4.18 Distribution of Zinc at Different Sampling Sites

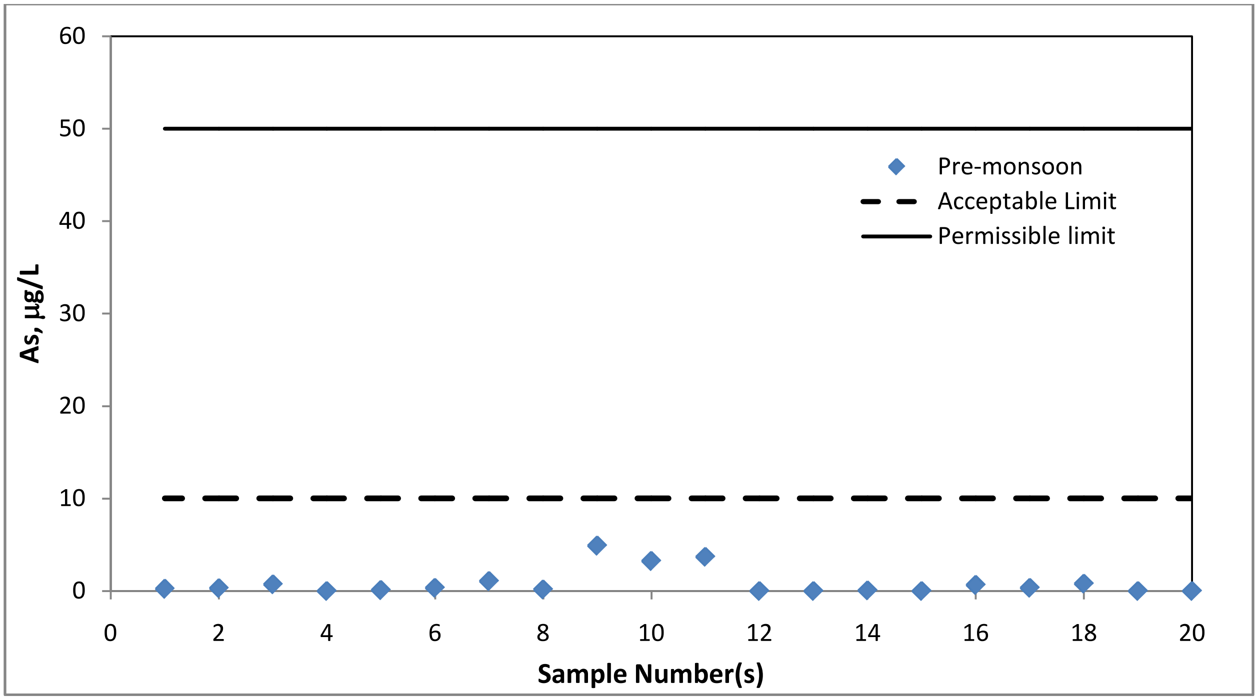

Fig. 4.19 Distribution of Arsenic at Different Sampling Sites

Iron (Fe): The concentration of iron in the ground water of Shillong ranges from 47 to 6342 μg/L. The distribution of iron at different sites is shown in Fig. 4.11. The Bureau of Indian Standards has recommended 300 μg/L as the acceptable limit for drinking water (BIS, 2012). It is evident from the results that more than 30% of the samples exceed the acceptable limit of 300 μg/L during pre-monsoon seasons. High concentrations of iron generally cause inky flavour, bitter and astringent taste. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. The weathering of rock and discharge of waste effluents on land are generally considered the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous (Fe^{2+}) and Ferric (Fe^{3+}) forms.

Manganese (Mn): The concentration of manganese varies from 10 to 464μg/L during pre-monsoon season. The distribution of manganese at different sites during pre-monsoon season is shown in Fig. 4.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general, concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a acceptable limit and 300 μg/L as the permissible limit in the absence of alternate source for drinking water (BIS, 2012). WHO has prescribed 500 μg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 40% of the samples of Shillong fall within the acceptable limit of 100 μg/L, 35% of the samples crosses the acceptable limit but are within the permissible limits and about 25% of the samples even exceeds the permissible limit of 300 μg/L and are not suitable for drinking purpose. High concentration of manganese at many locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

Copper (Cu): The concentration of copper varies from 3.1 to 311 μg/L during pre-monsoon season. The distribution of copper at different sites during pre-monsoon season is shown in Fig. 4.13. The Bureau of Indian Standards has recommended 50 μg/L as the acceptable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 2012). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In Shillong, about 70% of the samples fall below the acceptable limit of 50 μg/L during pre-monsoon season, such water is safe as a source of drinking water supplies. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

Nickel (Ni): The concentration of nickel in the study area varies from 1.44 to 54 μg/L during pre-monsoon season. The distribution of nickel at different sites during pre-monsoon season is shown in Fig. 4.14. The Bureau of Indian Standards has recommended 20 μg/L as the acceptable limit for drinking water (BIS, 2012). World Health Organization has also recommended 20 μg/L as the guideline value for drinking water (WHO, 1996).

In Shillong, almost all the samples fall within the acceptable limit as prescribed by BIS and WHO for drinking water. Nickel at trace level is essential to human nutrition and no systemic poisoning from nickel is known in this range. The level of nickel usually found in food and water is not considered a serious health hazard. Some of the important nickel minerals include Garnierite, nickeliferous limonite and pentiandite. Certain nickel compounds have carcinogenic effects on animals, however, soluble compounds are not currently regarded as human or animal carcinogens.

Chromium (Cr): The concentration of chromium in the study area recorded a maximum level of 4.71μg/L during pre-monsoon season. The distribution of chromium at different sites during pre-monsoon season is shown in Fig. 4.15. A concentration of 50 μg/L has been recommended as a acceptable limit for drinking water (BIS, 2012). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the study area, all the samples fall well within the acceptable limit as prescribed by BIS (2012) and WHO (1996) for drinking water.

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

Lead (Pb): The concentration of lead in the study area varies from 0.26 to 10 μg/L during pre-monsoon season. The distribution of lead at different sites during pre-monsoon season is shown in Fig. 4.16. The Bureau of Indian Standards has prescribed 10 μg/L lead as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In Shillong, all the samples were found within the acceptable limits as prescribed by BIS (2012) for drinking water. It is obvious, therefore, that the ground water of Shillong does not present any lead hazard to humans. The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

Cadmium (Cd): Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 0.26 to 10 μg/L during pre-monsoon season. The distribution of cadmium at different sites during pre- monsoon season is shown in Fig. 4.17. The Bureau of Indian Standards has prescribed 3 μg/L cadmium as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In Shillong, about 60% of the samples were found within the acceptable limit of 3 μg/L as prescribed by BIS for drinking purpose and 40% samples exceed the acceptable limit. The levels of cadmium in public water supplies are normally very low since generally only small amounts exist in raw water and many conventional water treatment processes remove much of the cadmium. The drinking water having more than 10 µg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

Zinc (Zn): The concentration of zinc in the study area ranges from 10 to 3356 µg/L during pre-monsoon season. The distribution of zinc at different sites during pre-monsoon season is shown in Fig. 4.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the acceptable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the study area, all the samples analysed were found within the acceptable limit prescribed by BIS (2012) and WHO (1996) for drinking water.

Arsenic (As): The concentration of arsenic in the study area varies from 0.06 to 4.89 µg/L during pre-monsoon season. The distribution of arsenic at different sites is shown in Fig. 4.19. The Bureau of Indian Standards has prescribed 10 µg/L arsenic as the acceptable limit and 50 µg/L as the maximum permissible limit for drinking water (BIS, 2012). WHO has prescribed 10 µg/L as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found within the acceptable of 10 µg/L and such water is safe for drinking purpose.

The heavy metals in ground water except iron, manganese, nickel and cadmium, which are present in appreciable concentration in ground water, have been below the prescribed acceptable / permissible limits. The concentration of iron varies from 47 to 6342 µg/L during pre-monsoon season as against the acceptable limit of 300 µg/L while that of manganese vary from 10 to 464 µg/L as against the acceptable limit of 100 µg/L. The concentration of nickel varies from 1.44 to 54 µg/L as against the acceptable limit of 20 µg/L for drinking water (BIS, 2012). The concentration of copper, chromium, lead, zinc and arsenic were found well within the permissible limits in almost all the samples of the study area.

4.2 Irrigation Water Quality

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 4.21. The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to electrical conductivity, sodium content, Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are given in Table 4.22. The values of sodium percentage (Na%), SAR and RSC in ground water of Shillong are given in Table 4.23.

Table 4.21 Safe Limits of Electrical Conductivity for Irrigation Water

S.No.	Nature of soil	Crop growth	Upper permissible safe limit of EC, µS/cm
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.	Having 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% soil that have excellent internally and surface drainage system	Semi-tolerant	6000
		Tolerant	8000

Source: CGWB and CPCB (2000).

Table 4.22 Guidelines for Evaluation of Irrigation Water Quality

Water class	Na, %	EC, µS/cm	SAR	RSC, meq/l
Excellent	< 20	< 250	< 10	< 1.25
Good	20-40	250-750	10-18	1.25-2.0
Medium	40-60	750-2250	18-26	2.0-2.5
Bad	60-80	2250-4000	> 26	2.5-3.0
Very bad	> 80	> 4000	> 26	> 3.0

Source: CGWB and CPCB (2000).

Table 4.23 SAR, Na% and RSC Values in Ground Water in Shillong

S.No.	Location	Source	Depth m	Pre-monsoon 2018			Post-monsoon 2018		
				SAR	Na (%)	RSC	SAR	Na (%)	RSC
1	Gordon Road, Bhagyakul Laitumkhrah	BW	198.25	0.97	41.6	-1.04	0.59	38.5	-0.29
2	Jail Road	BW	50.02	1.02	48.6	-0.66	0.99	49.1	-0.47
3	Forest Colony	BW	61.00	0.27	14.6	-0.09	0.28	15.4	0.40
4	Mawlaidatbaki Pata Blk A	BW	84.18	0.62	39.5	-0.30	1.21	61.0	-0.06
5	Evangelical Free Church, Demthring, PO Madanryting	BW	45.75	1.17	48.1	-0.99	1.10	47.9	-0.70
6	Happy Valley	BW	68.63	0.44	32.3	-0.53	0.42	32.0	-0.53
7	Law U Sib, Divine Grace Cottage	BW	96.99	2.27	56.1	-2.55	2.27	57.6	-2.22
8	Laitkor Lumheh Mawrie	BW	100.04	0.11	24.6	-0.01	0.08	15.7	-0.01
9	Nomgrim Hills	BW	245.22	0.92	46.6	-0.64	0.92	46.4	-0.64
10	Laitumkhrah	BW	198.25	0.28	27.5	-0.31	0.37	32.9	-0.28
11	Fruit Garden	BW	143.05	0.61	30.9	-1.09	0.97	41.7	-0.90
12	Lapalang Dong Parmaw	BW	125.05	1.28	51.7	-0.83	1.02	49.2	-0.64
13	Bellefonte Lumshyiap	BW	36.60	0.71	27.9	-0.77	0.42	30.0	-0.24
14	Mawtawar Lummawsing	BW	183.00	0.09	18.9	0.02	0.16	23.7	0.06
15	MawlaiSyllaikariah	BW	100.04	1.60	57.2	-0.61	1.73	61.7	-0.58
16	MawiongUmjapung Block Nongneng-A	BW	132.07	0.18	7.7	-1.19	0.19	8.4	-0.71
17	3rd Mile Upper Shillong	BW	91.50	0.41	25.8	-0.16	0.98	50.2	-0.27
18	Howell Road near Shiv Mandir, laban	BW	42.70	0.17	21.0	-0.26	0.13	17.1	-0.20
19	Behind Shillong Times	BW	85.40	1.06	56.2	-0.38	0.50	46.1	0.02
20	Nongthymmai, Dum Dum	BW	10.37	1.53	60.6	-0.49	1.10	48.7	-0.49

HP – Hand Pump; BW – Bore Well

4.2.1 Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top. The electrical conductivity values in Shillong are well within the prescribed limits and therefore safe for irrigation purpose.

4.2.2 Relative Proportion of Sodium to other Cations (SAR)

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

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

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of Shillong vary from 0.09 to 2.27 during pre-monsoon season and 0.08 to 2.27 during post-monsoon season. As evident from the SAR values, the ground water of the study area falls under the category of low sodium hazard, which reveals that ground water of the study area is free from any sodium hazard. The sodium percentage in the study area was found to vary from 7.7 to 60.6% during pre-monsoon season 8.4 to 61.7 during post-monsoon season indicating that almost all the samples are well within the permissible limit of irrigation water and does not create any sodium hazard.

4.2.3 Residual Sodium Carbonate (RSC)

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

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

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of Shillong is not having any residual sodium carbonate hazard.

4.2.4 Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant.

4.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram and U.S. Salinity Laboratory classification have been used in the present study to classify the ground water. Piper trilinear (Piper, 1944) and Chadha's diagrams (1999) are used to express similarity and dissimilarity in the chemistry of water based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955) is used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage characteristics, quantity of water used, climate and salt tolerance of crop. The results of all the aforesaid classifications are compiled in Table 4.24 and discussed in the following sections.

Table 4.24 Summarized Results of Water Classification in Shillong

Classification/Type	Sample Numbers	
	Pre-monsoon 2018	Post-monsoon 2018
Piper Trilinear Classification		
Ca-Mg-HCO_3 (Group 5)	3,6,8,13,14,16,17	3,6,8,13,14,16,19
Ca-Mg-Cl-SO_4 (Group 6)	1,2,4,5,9,10,11,18	1,2,5,9,10,11,12,18,20
Na-K-Cl-SO_4 (Group 7)	7,12,15,19,20	4,7,15,17
Na-K-HCO_3 (Group 8)	-	-
Chadha's Diagram		
Ca-Mg-HCO_3 (Group 5)	3,6,8,13,14,16,17	3,6,8,13,14,16,19
Ca-Mg-Cl-SO_4 (Group 6)	1,2,4,5,9,10,11,18	1,2,5,9,10,11,12,18,20
Na-K-Cl-SO_4 (Group 7)	7,12,15,19,20	4,7,15,17
Na-K-HCO_3 (Group 8)	-	-
U.S. Salinity Laboratory Classification		
C1-S1	1,2,3,4,6,8,9,10,14,15,17,18,19,20	1,2,3,4,6,8,9,10,12,13, 14,15,17,18,19,20
C2-S1	5,11,12,13,16,	5,7,11,16
C3-S1	7	-
C4-S1	-	-

4.3.1 Piper Trilinear Classification

Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot.

The diagram combine three distinct fields by plotting two triangular fields at the lower left and lower right respectively and an intervening diamond-shaped field. All three fields have scales reading in 100 parts. In the triangular fields at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na+K) are plotted as a single point according to conventional trilinear coordinates. The three anion groups (HCO_3, SO_4, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a ground water. The central diamond-shaped field is used to show the overall chemical character of the ground water by a third single point plotting, which is at the intersection of rays projected from the plotting of cations and anions. The position of this plotting indicates the relative composition of a ground water in terms of cation-anion pairs that correspond to the four vertices of the field. The three areas of plotting show the essential chemical character of ground water according to the relative concentrations of its constituents.

The chemical analysis data of all the samples collected from Shillong have been plotted on trilinear diagram (Fig. 4.20) and results have been summarized in Table 4.24. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-Cl-SO_4 hydrochemical facies followed by Ca-Mg-HCO_3 and Na-K-Cl-SO_4 hydrochemical facies.

4.3.2 Chadha's Diagram

The diagram is a somewhat modified version of the piper trilinear diagram. In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plottings from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms, so the diagram lacks certain logic. This method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the Piper diagram in the representation of some geochemical processes.

In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydrochemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

1. Alkaline earth exceeds alkali metals.
2. Alkali metals exceed alkaline earth.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness. The position of data points in the diagram represent Ca^{2+} -Mg^{2+}-HCO_3^- type, Ca^{2+} -Mg^{2+}- dominant HCO_3^- type, or HCO_3^- - dominant Ca^{2+} -Mg^{2+}- type waters.
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The position of data points in the diagram represents Ca^{2+} -Mg^{2+}-Cl^- type, Ca^{2+} -Mg^{2+}- dominant Cl^- - type or Cl^- - dominant Ca^{2+} -Mg^{2+}- type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The position of data points in the diagram represent Na^+-Cl^-- type, Na_2SO_4- type, Na^+-dominant Cl^--type, or Cl^--dominant Na^+-type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the diagram represent Na^+- HCO_3^- -type, Na^+-dominant HCO_3^- -type, or HCO_3^- -dominant Na^+-type waters.

The Chadha's diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The chemical analysis data of all the samples collected from Shillong have been plotted on Chadha's diagram (Fig. 4.21) and results have been summarized in Table 4.24. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-Cl-SO_4 hydrochemical facies followed by Ca-Mg-HCO_3 and Na-K-Cl-SO_4 hydrochemical facies. The Chadha's diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

4.3.3 U. S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). The diagram for use in studying the suitability of ground water for irrigation purposes is based on the sodium adsorption ratio (SAR) and electrical conductivity of water expressed in μS/cm (Table 4.25).

Table 4.25 U.S. Salinity Laboratory Classification

Salinity	
Low Salinity (C1)	Low salinity water (C1) can be used for irrigation with most crops on most soils.
Medium Salinity (C2)	Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
High Salinity (C3)	High salinity water (C3) can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected.
Very High Salinity (C4)	Very high salinity water (C4) is not suitable for irrigation water under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate and irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected.
SAR	
Low SAR (S1)	Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.
Medium SAR (S2)	Medium sodium water will present an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. This water may be used on coarse-textural or organic soils with good permeability.
High SAR (S3)	High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions.
Very High SAR (S4)	Very high sodium water is generally unsatisfactory for irrigation purposes.

The chemical analysis data of ground water samples of Shillong has been processed as per U.S. Salinity Laboratory classification (Fig. 4.22) and the results have been summarized in Table 4.23.

It is evident from the results that majority of water samples fall under water type C1-S1 (low salinity and low SAR) during both pre- and post-monsoon seasons, such water can be used for irrigation with most crops on most soils. Few samples fall under water type C2-S1 (medium salinity and low SAR), such water can be used if a moderate amount of leaching occurs and plants with moderate salt tolerance can be grown in most cases without special practices for salinity control. Almost similar behavior was observed during post-monsoon season.

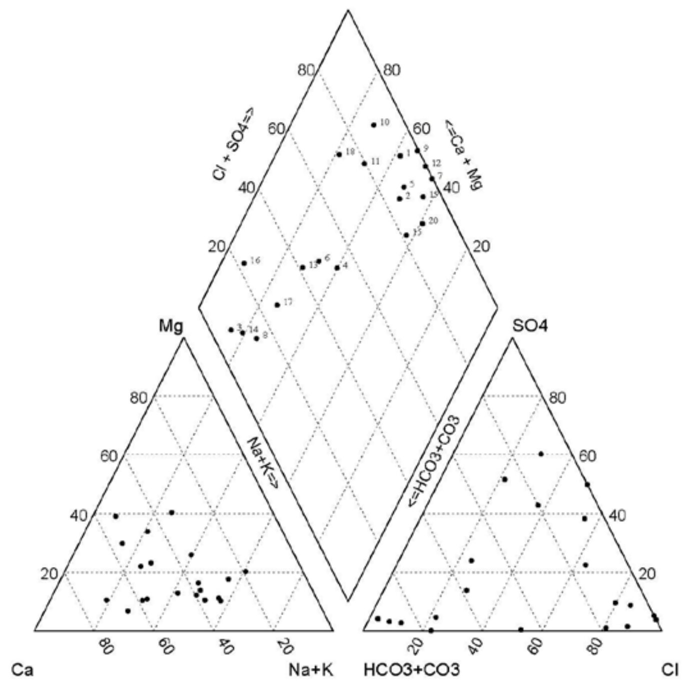

Fig. 4.20a Piper Trilinear Diagram Showing Chemical Character of Ground Water (Pre-monsoon 2018)

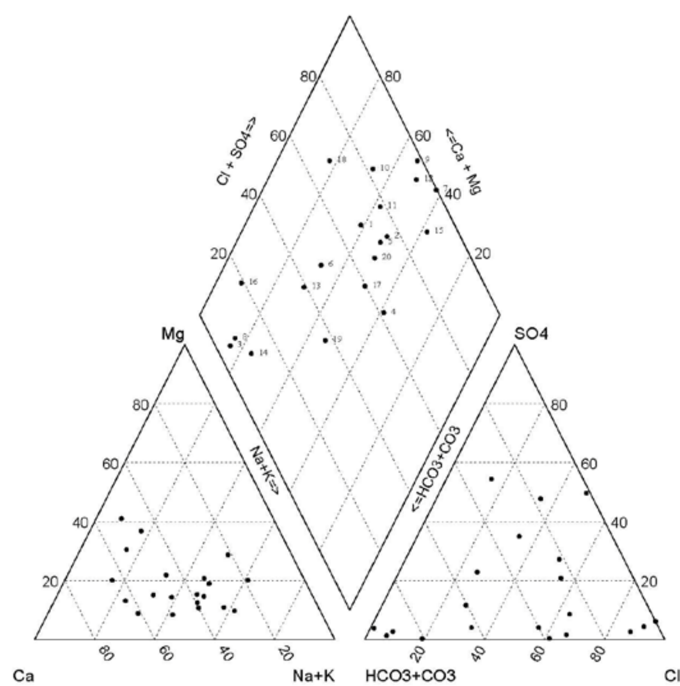

Fig. 4.20b Piper Trilinear Diagram Showing Chemical Character of Ground Water (Post-monsoon 2018)

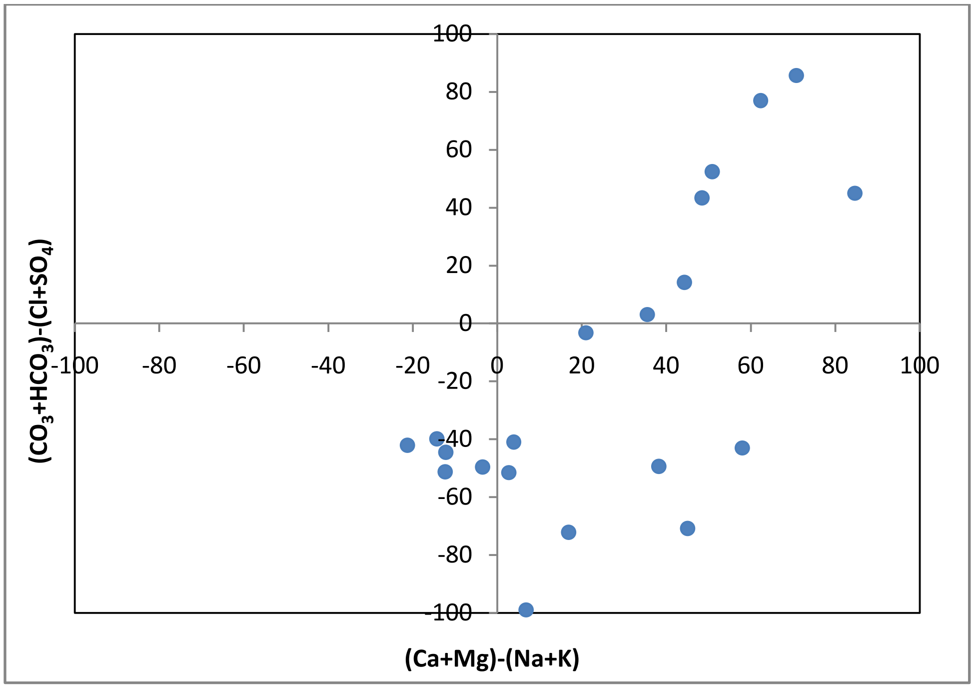

Fig. 4.21a Chadha's Diagram Showing Chemical Character of Ground Water in Shillong (Pre-monsoon 2018)

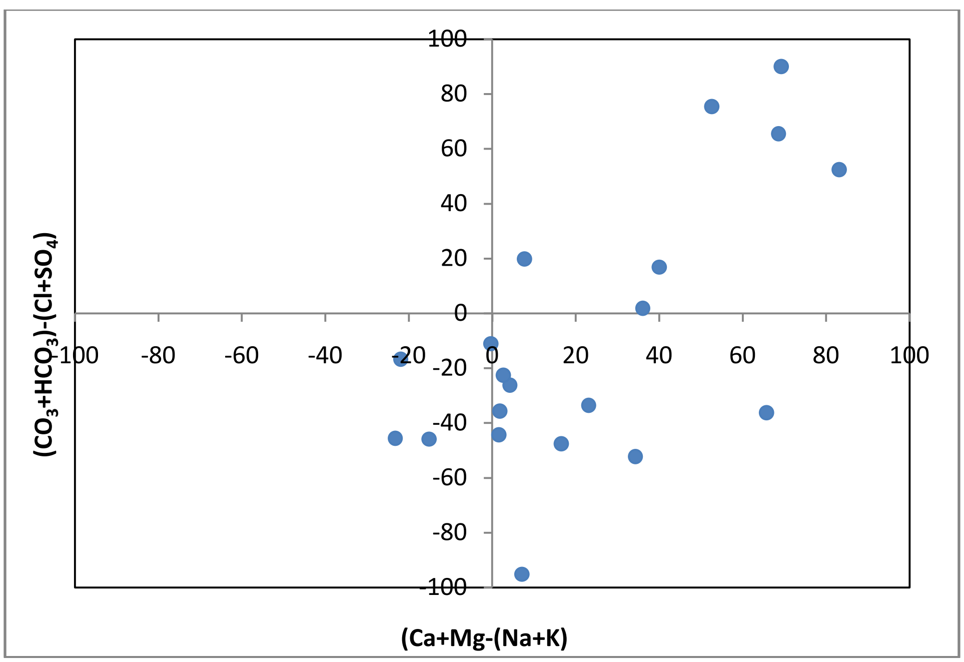

Fig. 4.21b Chadha's Diagram Showing Chemical Character of Ground Water in Shillong (Post-monsoon 2018)

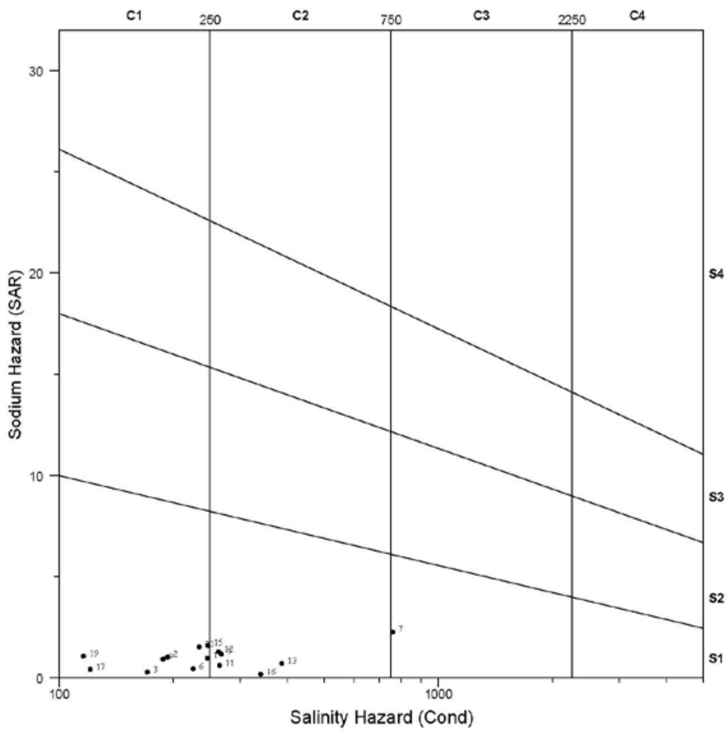

Fig. 4.22a U.S. Salinity Laboratory Classification (Pre-monsoon 2018)

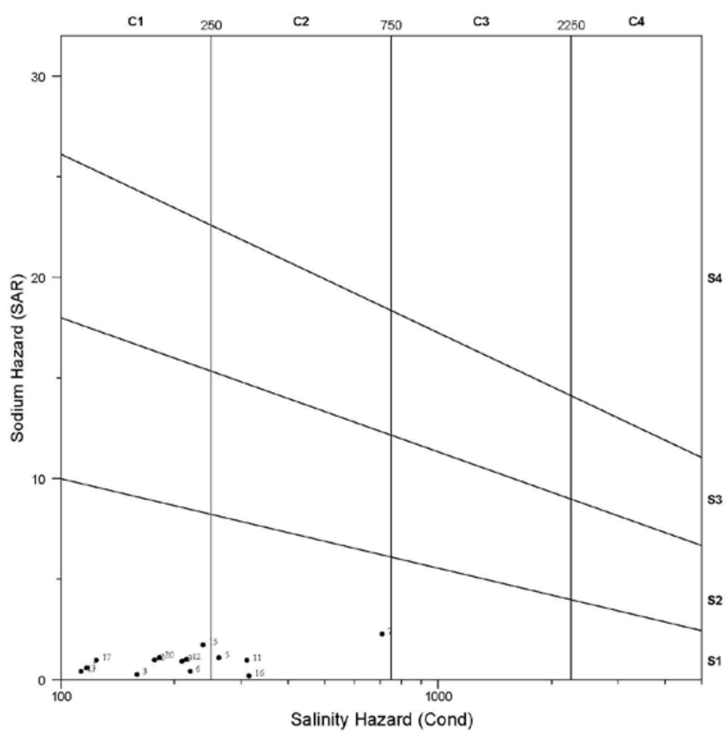

Fig. 4.22b U.S. Salinity Laboratory Classification (Post-monsoon 2018)

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. The ground water quality in Shillong varies from place to place and with the depth of water table. The analysis of data clearly indicated that the concentrations of almost all the general water quality constituents (except pH in more than 50% of the samples and nitrate at few locations) are within the acceptable limits for drinking water.
2. The ground water of Shillong recorded very high concentration of iron and manganese during pre-monsoon season. The concentration of iron varies from 47 to 6342 μg/L during pre-monsoon season as against the acceptable limit of 300 μg/L while that of manganese vary from 10 to 464 μg/L as against the acceptable limit of 100 μg/L. The water from such sources should be treated before being used for drinking purpose.
3. The interpretation of the results of the analysis shows that ground water is fresh and suitable for both domestic and irrigation purposes except higher content of iron, manganese, nickel and cadmium, which requires treatment before being used for drinking purposes.
4. The hand pumps and wells, which have been identified as having suspected water quality should be painted red to indicate and warn the public that the water drawn from the source is not fit for human consumption.
5. In the absence of alternate safe source of water, the water with excessive undesirable constituents must be treated with specific treatment process before its use for human consumption.
6. In general the ground water of Shillong is safe for irrigation purpose.
7. Major programmes should be launched for comprehensive assessment of surface and ground water quality mapping, its relative vulnerability for pollution and identification of degraded water quality zones for identifying the source of pollution and taking remedial measures.
8. State of the art Water Quality Laboratories are required to be established at different locations in NE region. Capacity building programme should be taken up for having the trained man power to carry out the water quality monitoring and testing.
9. The mass awareness programmes should be launched in a big way in NE region to create awareness among the people about the quality of water for different uses and its present status, the effect on human health and responsibilities of public to safeguard water resources.

6.0 REFERENCES

1. APHA (1992), Standard Methods for the Examination of Water and Waste Waters, American Public Health Association, 18th Edition, Washington, DC.
2. BIS (2012), Drinking Water Specifications, IS:10500:2012, Bureau of Indian Standards, New Delhi.
3. CGWB (2013), Ground Water Information Booklet, Shillong, Assam, Central Ground Water Board, North Eastern Region, Guwahati, November 2013.
4. CGWB and CPCB (2000), Status of Ground Water Quality and Pollution Aspects in NCT-Delhi, January 2000.
5. Chadha, D. K. (1999), A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data, Hydrogeology Journal, 7(5), 431-439.
6. Jain, C. K. and Bhatia, K. K. S. (1988), Physico-chemical Analysis of Water and Wastewater, User's Manual, UM-26, National Institute of Hydrology, Roorkee.
7. Piper, A. M. (1944), A Graphical Procedure in the Geochemical Interpretation of Water Analysis, Trans. Am. Geophysical Union, Vol. 25, 914-923.
8. Richards, L. A. (ed.) (1954), Diagnosis and improvement of saline and alkali soils, Agricultural Handbook 60, U.S. Dept. Agric., Washington, D.C., 160 p.
9. Wilcox, L. V. (1955), Classification and Use of Irrigation Water, U.S. Dept. of Agr. Circular 969, Washington, D.C., 19 p.