A STUDY OF POTABLE WATER SOURCES VIZ-A-VIZ ROCK WATER INTERACTION IN THE SOUTH EASTERN AREA OF KOLASIB DISTRICT, MIZORAM

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A STUDY OF POTABLE WATER SOURCES VIZ-A-VIZ ROCK WATER INTERACTION IN THE SOUTH EASTERN AREA OF KOLASIB DISTRICT, MIZORAM

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CERTIFICATE

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I, M. Lalruatfeli, hereby declare that the subject matter of this thesis is the record work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my Knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

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Dated Aizawl
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CHAPTER-I
INTRODUCTION

1.1 General introduction:

Water is a necessity for agricultural production, for drinking purposes by humans and animals, for municipal and rural homes, commercial and industrial uses. Groundwater is the main source of water supply throughout the world. Where there is no water supply, many villages in India depend primarily on groundwater. Demand for Groundwater is closely related to population, need for food, production of agricultural, industrial items and hydro-energy, and for conservation of ecology and enhancement of living standards.

Groundwater referred to water occupying all voids within a geological stratum. Discharge of groundwater happens when water emerges from underground which usually occurs as flows into surface water bodies, such as streams, lakes, and oceans; flow to the surface forms spring. The high relief and steep topography of the Indo-Myanmar Mobile belt of Northeast India is characterized by high run-off resulting in less chance of rainwater infiltration. Thus, the prevalence of groundwater is limited to intermontane valleys, fractured valleys, and gentle hill slopes.

The availability and chemical composition of natural groundwater is controlled by the geomorphology, rainfall as well as geological Formation with which the water remains in contact. Indian subcontinent encounters diverse climatic conditions, geomorphic units, and geological formations from Archaens to Recent alluvium deposits. Hence, the quality in different parts of the country differs from place to place.

The quality of groundwater become deteriorated with an increase in human activities like rapid urbanization, discharge of domestic and industrial wastewater, agricultural wastes, run-off, and lack of proper waste disposal especially in a developing country, etc. Moreover, naturally occurring pollutants such as oxides of nitrogen, heavy metals, hydrocarbons, and radioactive substances are used to form part of the background concentrations in the environment. Since the status of public health is influenced by the quality of drinking water, monitoring the composition and quality of water is needed.

1.2 Background:

The term quality of drinking water means the composition of water and its relation with the effects of human activities and natural processes (Napacho, 2010). Most of our water demand is satisfied by rainwater, which is deposited in surface and groundwater resources (Goel, 1996). Drinking water is water intended for human consumption for drinking and cooking purposes from any source, which includes water (treated or untreated) supplied by any means for human consumption (BIS,2012). The quality of water is just as significant as its quantity as water is the prime essential component of living things (Todd, 1980). True health requires proper hydration of the body. Thus, deterioration of its quality adversely affects the growth of plants as well as human health (Todd, 1980; WHO1996; Hem, 1991; Karanth, 1997; Singh, *et al.* 2011; Kumar, *et al.*2008).

The evaluation of the physical, chemical, and biological nature of water concerning natural quality, human effects, and domestic purposes that may affect human health and the aquatic system itself are all included in the assessment of water quality (WHO, 1996). Data generated from groundwater quality analysis may instantaneously provide information about the geological history of rocks that indicates the processes of groundwater recharge, movement, and storage (Walton, 1970).

Many current examples of environmental health problems are the result of long-term, low-level exposure to heavy metals, especially the widespread poisoning caused by high Arsenic levels in well waters adversely affects human health in Bangladesh, West Bengal, Manipur, and many regions of Southern & Eastern Asia, China, Vietnam, Taiwan, Thailand, and Nepal (Smedley, 2003). The proposed area lies close to Tripura, Assam, and Manipur states, which have been containing high concentrations of Arsenic in groundwater for a long time. Qualifying the major ion composition of stream waters has also broad implications, i.e., water quality type, hydrogeology characteristics, weathering processes, and rainfall chemistry (Brennan and Lowenstein, 2002; Cruz and Amaral, 2004). The magnitude of the severity of arsenic contamination in Asian countries is given in the order of Bangladesh > India > Mongolia > China > Taiwan. In India, arsenic in groundwater is found in the bordering states of Bangladesh, West Bengal, Assam, Arunachal Pradesh, Manipur, Nagaland, and Tripura (A.K. Singh, 2004). The amount of arsenic concentration exceeding the acceptance limit of 0.01mg/l is obtained from three springs in Lawngtlai district, Mizoram (Blick*et al.*,2016). The presence of a significant amount of arsenic that exceeds permissible limits in groundwater has also been confirmed in the Karimganj and Cachar districts of Assam (Kumar *et al*., 2011). The chemical composition of groundwater is controlled by many factors viz. the composition of precipitation, geologic structure, mineralogy of watershed aquifers, and geological processes within the aquifers.

Considering spatial variation as well as serious aspects of groundwater quality issues, it is essential to use advanced tools such as GIS (Kumar *et al*., 2013). The advent of geospatial technology like the utilization of Remote Sensing and GIS allows fast and cost-effective survey and management of natural resources (Ramakrishna *et al.*, 2013). Hence, this technique has a wide range of applications including groundwater quality mapping (Lalbiakmawia*et al.*, 2015). Satellite remote sensing makes it possible to analyze various ground features such as geological structures, Geomorphic features, and their hydraulic characteristics that may serve as indicators of the presence of groundwater (Raju*et al.*, 2013). In addition, remote sensing and GIS technologies coupled with computer modeling are useful tools in providing solutions for future water resources planning and management to the government, especially in formulating policies related to water quality (Usali& Ismail, 2010).

Groundwater is an essential source of freshwater in rural and urban regions of the world. Lack of proper methods of abstraction and rapidly increasing contamination are posing extreme threats to sustainable water supply worldwide. Contrary to surface water contamination, groundwater contamination is hard to detect due to its hidden nature, and once contaminated, the groundwater can remain so for many decades because of the relatively slow movement. Therefore, there is a compelling requirement to develop efficient management strategies for the sustainable utilization and protection of groundwater resources (Jha*et al*., 2020).

During the last decades, it has been observed that there is a drastic increase in groundwater pollution due to an increase in human activities like the use of chemical fertilizers, pesticides, industrialization, and many other anthropogenic factors that cause pollution of various water sources to at larger extent day by day. Animal and human excrement is also a liable cause of water pollution. Consequently, the consumption of such polluted water directly from the sources led to an increase in the case of waterborne diseases (Deshmukh, 2013). The presence of virus-like human coronavirus (HCoVs) in fecal elimination also suggests the possibility of transmission via water. Furthermore, extensive field studies also confirmed the presence of such viruses in surface water, sewage, slurry, and bio-solids (Carducci *et al*., 2020; Rosa *et al*. 2020). Growth of population and increase in industrial activities exacerbate water demand, which on long practices simultaneously increases the mass of wastewater return to the environment and results in pollution of water bodies and insufficiency of useable water. Thus, the availability of useable water becomes a major obstacle worldwide, particularly in developing countries. Therefore, where there is an extraction of groundwater, systematic monitoring of groundwater quality is a must to ensure a safe and sustainable supply (Al-Jubouri and Holmes 2020; Mohammed *et al.*, 2007).

Mapping of spatial variability of groundwater quality holds significant particularly where groundwater is the main source of potable water. Geographic Information System (GIS) is a powerful tool for the representation and analysis of spatial data related to water resources (Karthikeyan *et al.*, 2013). Laboratory analysis incorporated with spatial technology will be utilized to analyze and represent the conditions and nature of groundwater with geological conditions for the Southern district of Kolasib District, Mizoram.

From the observation of occurrence, spatial distribution, and health risk assessment of heavy metals in groundwater from parts of the KassenaNankana area, Ghana. The water samples were subjected to acid digestion ($HNO_3 + H_2O_2 + H_2SO_4$) and analysis was conducted for Zn, Pb, Ni, Mn, Fe, Cr, Co, and Cu using Atomic Absorption Spectrometer. The concentration of heavy metals showed a complex distribution pattern in space with high concentrations in the northern parts of the study area. It is concluded that the sources of heavy metals in the groundwater were potentially from both the aquifer material and anthropogenic (Zakaria *et al*. 2020).

1.3 Aim and Objectives:

This research work aims to analyze available potable water sources to delineate the relationship between characteristics of each quality of water with the source rock within the study area using modern technology.

The main objectives of the present study are:

1. To characterize physics-chemical and bacteriological parameters of tuikhur (spring)/ hand pump/dug well subject to availability /and water supplied by Public Health Engineering Department (PHED) in the area under study.
2. Assessment of potable water sources in the light of the presence or absence of heavy metals.
3. Monitoring of potable water parameters in respect of three seasons for three consecutive years to comment on rock-water interaction and secondary man-made sources of pollution.

1.4 Outline of thesis:

The thesis is divided into six Chapters. The first Chapter comprises the introductory part of the research work. The background and objectives of the study are also included in this chapter. The second Chapter is mainly a review of the relevant published works of literature, books, and data of concerned departments or bodies including previous work done in the field of groundwater quality assessment regarding groundwater quality, heavy metal concentration, and application of Geoinformatics in groundwater monitoring, minerals and chemical composition of Mizoram, etc. Chapter three presents an overview of the study area such as General geology, location, and extent, geomorphology, structures, demography, rainfall, depth of groundwater, the quantity of water supplied by PHED and drainage system, etc. The materials and methods utilized in the study are shown in Chapter Four. Chapter Five presents the results and discussion of the research. The recommendations, summary, and conclusions are presented in Chapter Six.

CHAPTER-II
LITERATURE REVIEW

2.1 Groundwater quality analysis:

Limited work has been carried out in Mizoram which includes Kumar *et al.*, (2010), Blick *et al.* (2016), and Lalbiakmawia (2019) who described the quality assessment of potable water in the town of Kolasib, Lawngtlai district, and Northern arcuate of Kolasib district, Mizoram, respectively. Kumar *et al.*, (2010), carried out an analysis of potable water sources from the water supply by the PHE department and natural springs water (tuikhur) in Kolasib town and they concluded that the water supply by PHED was better than that of the tuikhurs (springs), though they were all within the tolerance limit. Blick *et al.*, (2016) described the status of arsenic contamination in Lawngtlai district, Mizoram. The two water sources which are of tuikhur (spring) and dug well were found to be exceeding the acceptable limit obtaining a value of 0.5 mg/l. Lalbiakmawia (2019) conducted an assessment of hydrogeological conditions and groundwater quality in the northern arcuate of Mizoram which is located on the northeastern adjacent side of the present study area. He concluded that recent technologies like remote sensing and geographic information systems (GIS) coupled with conventional surveys are indeed reliable for preparing detailed lithological, geomorphological, and structural maps and are found to be very useful in hydrogeological studies. The physical and bacteriological analysis shows that there was no considerable threat till that time. The spatial interpolation technique through Inverse Distance Weighted (IDW) approach has been used to delineate spatial distribution of the groundwater quality for pre-monsoon, monsoon, and post-monsoon seasons in ArcGIS software.

Kumar *et al.,* (2011) studied the status of arsenic contamination in potable waters of the northern part of Mizoram state and its adjoining areas of southern Assam, India. Arsenic contamination exceeding the permissible limit has been found in three locations in the aquifers of alluvial sediments near the Silchar city of southern Assam and its total absence in the neighboring states of Mizoram. Blick (2016) accomplished quality assessment and characterization of potable water sources in the SW Lawngtlai district of Mizoram. He recorded higher concentrations exceeding the permissible limit of Arsenic, Manganese, and Lead. He also noticed an association between contamination of As with the low-lying part of the sluggish area where there was an inhibition of groundwater flow. The presence of a relatively high amount of Arsenic is attributed to the dissolution of rocks, minerals, and ores during rock-water interaction. Sedimentation in the shallow wells causes water to have an elevated concentration of Manganese within the area.

While conducting an application of Geo-Spatial Technology for Ground Water Quality Mapping of Kolasib District, Mizoram, India, Lalbiakmawia (2015b). Water samples were collected from 58 locations and were tested for major water quality parameters such as pH, Electrical Conductivity [EC], Total Dissolved Solids, Total hardness, Iron, Chloride, Nitrate, and Fluoride. Spatial variation of water quality maps was generated in different thematic layers. Each thematic layer was given a rank base on its relative impact. Numerical ratings indicating weightage for each class of the thematic layers were assigned attribute values in the GIS environment. Later, both ranks of thematic layers and attribute values of classes are collectively utilized for the generation of groundwater quality mapping.

Geospatial technology was also applied by Labiakmawia *et al.*, (2019), and Labiakmawia and Vanthangliana (2015a) for mapping groundwater quality of the Aizawl district and northern arcuate of Mizoram, India, respectively.

Spring water quality and discharge assessment in the Basantar watershed of Jammu Himalaya using geographic information system (GIS) and water quality Index(WQI). A total of 60 spring water samples were collected from the three kinds of terrain (mountainous, hilly, and plain) and were analyzed for their major hydrochemistry and hydrochemical evolution in the study area. Gibbs's diagram reveals that the spring water chemistry is indeed controlled by rock-water interaction. The water quality index (WQI) shows that 45% of samples fall in the excellent category and 50% of spring samples fall in the good category for drinking purposes (Taloor *et al.* 2020)

Vespasiano *et al.*, (2021) executed a case study on the characterization of geochemical and geological, and groundwater quality of a complex geological framework in South Italy. They employed statistical methods to investigate the groundwater quality and origin of constituents (anthropogenic or natural). They concluded that the release of harmful Chromium and Nickel was promoted by the presence of ultramafic rocks. Listyani R.A. (2016) described the control of rock minerals on groundwater quality in the Jakarta Quaternary groundwater basin. Samples of rocks and groundwater were analyzed by petrography, XRD, and also the chemical of groundwater. The results showed that the quality of groundwater was indeed controlled by the mineralogical content of the rock and most of the abundant soluble elements in groundwater were known to be derived from weathering of silicate minerals.

Lahkar *et al.*, (2019), while studying heavy metal contamination of groundwater in Guwahati City, Assam, India used Atomic Absorption Spectrophotometer for assessing Cd, Pb, Fe, and As from 27 samples, and their values were compared to that of WHO-specified contaminants level. From the obtained results, they concluded that long-term exposure to these metals even in low quantities can put the health of the population at risk, and almost all groundwater sources are reliable water supply in the area.

Ravindra *et al.*, (2019), utilized ICP-Q-MS to analyze Al, As, Cr, Cu, Fe, Mn, Mo, Ni, Pb, V, and Zn from 80 groundwater samples (21 from hand pump, 59 from bore well) in Chandigarh city, India. Samples were collected following APHA guidelines and areas of poor waste management and industrial pollution were identified from Geospatial interpolation of contaminants. They also came to reveal that water quality assessment of groundwater performed using the Heavy Metal Index is a better convenient method for health risk assessment to Metal Index.

Mahapatra *et al.*, (2021), determined the nature of heavy metal pollution of groundwater in North Chennai during pre-monsoon and post-monsoon seasons. Analysis of metals was performed in Atomic Absorption Spectrometer (Analyst 700 Perkin Elmer) and the DEM map downloaded from the Bhuvan website was processed in ArcGIS 10.3 software using Geo-Hydro Tool to produce a spatial distribution map of each parameter. The determined results of trace elements show wide spatial and temporal variation and spatial variation is attributed mainly to different sources of pollution while the temporal variation is found to be mainly controlled by rainfall and changes in hydrogeochemical conditions.

The rocks exposed in Mizoram are sandstone, siltstone, shale, and clay, and their admixture in various proportions with a few pockets of shell limestone, calcareous sandstone, and intraformational conglomerates. Sequentially, these are grouped into the Barail, the Surma, and the Tipam groups in ascending order. The geologic nomenclature is conducted based on proportions of argillaceous and arenaceous content and topography. The geology of Mizoram exhibits a repetitive succession of Neogene sedimentary rocks of the Surma Group and Tipam Formation, which are extensively folded and faulted and result in the formation of plunging anticlines and synclines.

The whole-rock geochemistry of sandstone in Surma and Barail reveals that A-CN-K (A=Al_2O_3, CN= CaO+Na_2O, K=K_2O) ternary diagram plotted along regular weathering line indicates origins from Granodiorite of Siwalik sediments. The sediments of Mizoram's tertiary foreland basin are found to be probably derived from Himalayan granitoid. Values of various trace elements and REE for the Surma and Barail sandstone also suggest felsic magmatic sources from both Groups. In addition, X-ray Fluorescence Spectrometer (XRF) analysis of major oxide and trace elements and REE analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) suggest that the Surma group is more aluminous but less siliceous as compared to the Barail Group of rock and are having mostly similar content in remaining elements. Chromium concentrations in Surma and Barail sandstone are higher than normal standards. Moreover, Surma sandstone is characterized by higher concentrations of Barium, Strontium, and Chromium as compared to Barail (Hussain *et al*., 2019).

The petrographic analysis of Reiek sandstone of the Middle Bhuban Formation shows the presence of unstable feldspar-like microcline and orthoclase that indicate either plutonic origin or low-grade metamorphic origin, plagioclase of volcanic or hypabyssal as well as unaltered plagioclase indicator of igneous sources. The abundance of muscovite and biotite in detrital minerals indicates micaceous source rock, possibly of mafic igneous rocks or mica schists of high-grade metamorphism and they are known to contribute ferruginous cementation due to the leaching of Fe components as they undergo alteration. Ferruginous cementation is common in buff sandstone as pore fillings whereas siliceous cementation is the most common one in this Formation. The preliminary chemical analysis indicates that sandstone from the Middle Bhuban Formation contains carbonates. The minerals of feldspar like plagioclase, orthoclase, and microcline are well observed in these rocks and are dominating over alkali feldspar. The most abundant mineral in this formation is quartz, followed by lithic fragments and then by feldspar. The main cementing materials are siliceous, carbonate, and ferruginous cementation. Lithic fragments are mainly of metamorphic origin and dominated by aggregates of quartz mineral and silt and shale grains are also uncommonly observed. The tectonic-provenance determination also suggests recycled Orogenic setting and sediments supplied from Himalayan ranges and Indo-Myanmar collision zones (Lalnunmawia *et al.*, 2020). The Study of Middle Bhuban sandstone along Durtlang road also indicates this formation is composed mainly of quartz, mica group of minerals like biotite and muscovite, lithic fragments, and feldspar group of minerals like plagioclase, microcline, and orthoclase (Lalnunmawia e*t al.*, 2014).

Petrographic and heavy minerals study carried out around Aizawl in Upper Bhuban Unit along the Zemabawk-Tuirial road section and Middle Bhuban Unit along the Durtlang-Mualpui road section shows that the Upper Bhuban Unit sandstones are grey, bluish-grey or brown and fine to medium-grained. Brown sandstones are comparatively friable compared to other varieties, which may have been attributed to weak iron-oxide cementation, supplemented by intensive weathering by water seepage. Sedimentary structures observed in the area suggest a pro-gradational process in a deltaic environment. However, the Middle Bhuban Unit exposed along the Durtlang road section comprise mainly of intercalation of shales, siltstones, and sandstones. The siltstone shale is found to be highly micaceous. These sedimentary structures indicate the depositional environment of deltaic to shallow marine environments. Quartz, the dominating mineral in sandstones constitutes about 67.03 to 87.61% of the total sediments in the Upper Bhuban Unit while 54.8 to 82.46% in the Middle Bhuban Unit. The lithic fragments constitute about 5.31 to 23.36% of the Upper Bhuban Unit while 10.96 to 34.23% in the Middle Bhuban Unit. Feldspar minerals, like plagioclase and alkali feldspars, constitute about 4.65 to 14.29% in the Upper Bhuban Unit while 6.58 to 16.03% in the Middle Bhuban Unit, and are the least mineral among quartz-feldspar-lithic. Mica groups of minerals like muscovite and biotite are also observed as detrital minerals. The heavy minerals observed comprise garnet, augite, zircon, rutile, staurolite, sillimanite, kyanite, hypersthene, hornblende, chlorite, tourmaline, apatite, and magnetite (Lalnunmawia e*t al.,* 2016).

Petrographic, granulometric, and heavy mineral analysis of the Upper Bhuban Formation confirmed that the sediments were primarily derived from surrounding orogens and deposited in a shallow marine basin under the influence of fluvial-deltaic conditions from felsic provenance. The lithology of sandstones samples in this Upper Bhuban are lith arenite and wacke type (Bharali *et al*., 2017)

The influence of bedrock on the quality of groundwater in Zango, North-west Nigeria had been carried out on different quality parameters. They concluded that fluoride, major, and trace elements concentration values are the reflection of natural background concentration and are holding landmarks in the geochemical characterization of groundwater in different auriferous units. They also found out that the water could be grossly contaminated by critical elements. The concentration map shows that Flouride concentration is higher in Igneous rocks as compared to the area dominated by sedimentary Formation. (Amadi *et al.* 2015).

Fifty-four groundwater samples were collected representing the hard rock terrain of Madurai district, Tamil Nadu. The samples collected were representative of all the major lithological units of the study area (charnockite -21, fissile hornblende biotite gneiss-21, granite-4, quartzite-3, and 5 samples from floodplain alluvium. The observation reveals that the samples collected from granitic and quartzitic terrains are comparatively better in terms of quality for domestic and drinking purpose due to the presence of resistant minerals to weathering (Thivya *et al.* 2013).

CHAPTER-III
DESCRIPTION OF THE STUDY AREA

3.1 Location and extent:

The Mizoram state is bounded by Myanmar on the East and Southern sides and is neighboring Bangladesh on the West. Its location has significance when considering economics, geography, and politics as it shares an international boundary of about 585 km with the above-mentioned countries. It has a geographical area of 21,081 sq. km. Its maximum dimension from north to south is 285 km. and east to west is 115 km. The Tropic of Cancer i.e., 23º 30'N latitudes cuts across Mizoram in different places such as the southern periphery of Aizawl district, Champhai, Darlung, Chhawrtui, and Phuldungsei, etc. This line divides Mizoram into almost two halves (Pachuau, 2009).

The study area falls under South Eastern Area of Kolasib District, of the Survey of India Toposheet No.83D/12, 83D/16, 84A/9, and 84A/13 lies between latitudes 23˚56'03''N to 24˚05'05''N and longitudes 92˚35' E to 92˚45'0E. Kolasib district is bounded by the Hailakandi district on the Northwest, the Cachar district of Assam on the Northeast, on the South and East by the Aizawl district, and by the Mamit district on the West. The highest elevation (Nisapui) within the study area is 1285m above sea level and the lowest point (Hortoki) is approximately 40m from sea level. It falls under N. Thingdawl rural development block and there is one notified town i.e. Kawnpui and 7 other villages. The total area of the study area is 415.43 sq. km. Lungdai, which is at the southern periphery of the Kolasib district is excluded in the present study as prior studies have existed. Likewise, the southern parts along NH6/NH54 are not taken up as considering geographical boundaries as well as the remote location of villages.

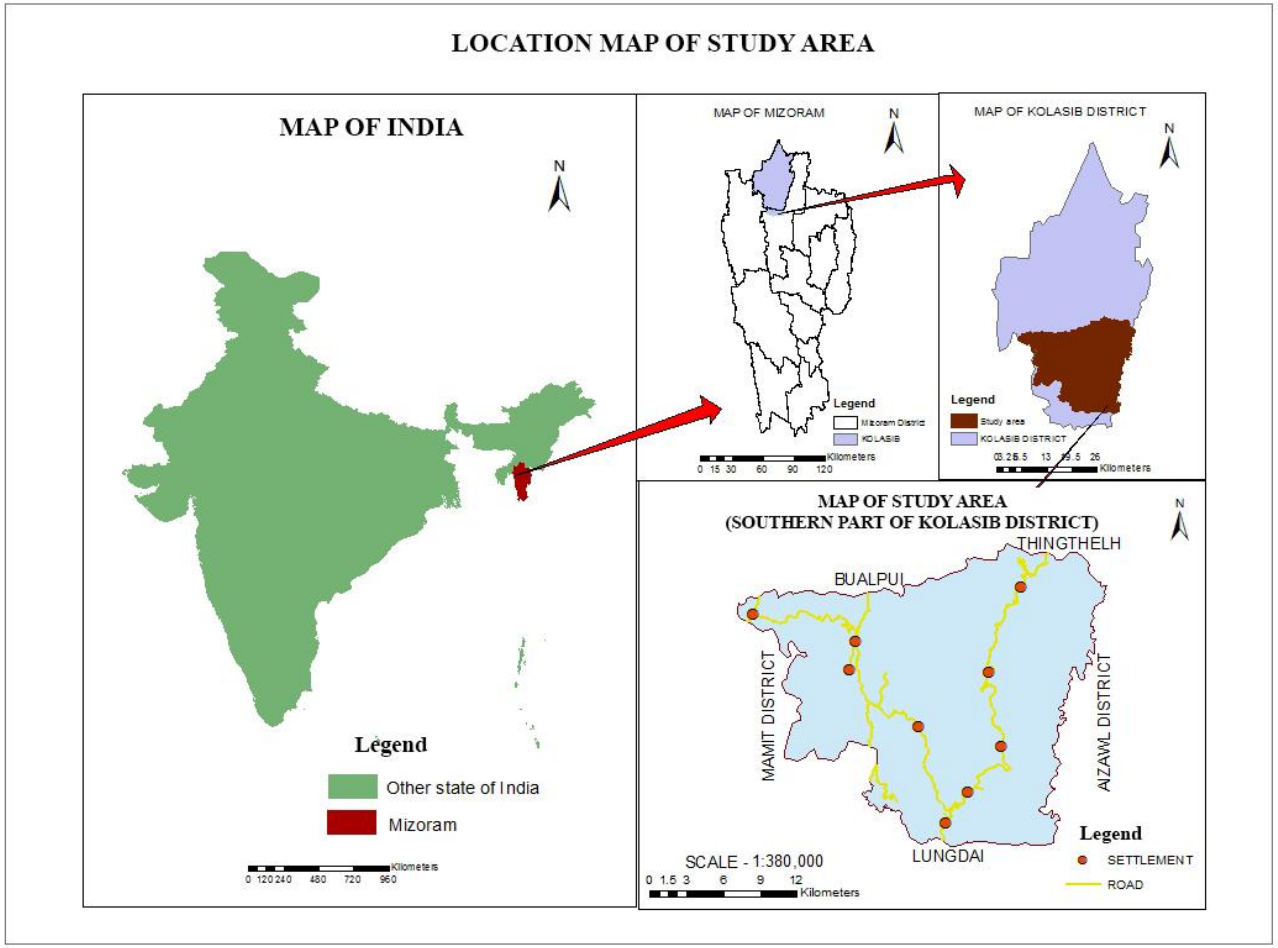


Figure 1: Location map of the study area

3.2 Economic and Administrative set up:

Rapid urbanization is experienced within the study area since it consists of the lifeline of Mizoram connecting to the neighboring state. At several locations along the road commercial hubs are set up as large numbers of passers-by have passed through the study area continuously day and night. It is also found to be escalated by the advancement of the railway in recent years. The majority of the people in the region take part in farming and trading. The study area comprises one rural development block i.e. N.Thingdawl block of the Kolasib district. There is one notified town Kawnpui and 7 other villages. In addition, the core area as well as the eastern part of the study area comprises more than half of the total watershed area of the two biggest Hydel projects in Mizoram viz. Serlui and Tuirial Hydel Project. Considering the establishment of a good transportation network and development activities in the study area, this part of Mizoram will become more and more swarming with automobiles, passers-by, and habitation. Therefore, monitoring and checking potable water quality is indeed a must to sustain the needs of the people in the present and future.

3.3 Demography:

Demography is a statistical study of the population. The general demographic profile of the study area (as per the Base Line Survey conducted by Swatch Bharat Mission, PHED Mizoram in 2012 and Accredited Social Health Activist, ASHA, Community Health Centre, Kawnpui, Mizoram in 2022) is given below:

Table No1: Demographic profile of the study area

DISTRICT	BLOCK	Sl.No	Village	Number of Household	Total Population
Kolasib	N.Thingdawl	1	Hortoki	527	3006
		2	Nisapui	181	905
		3	Zanlawn	228	1140
		4	Serkhan	167	835
		5	N.Chaltlang	218	1090
		6	Lungmuat	160	800
		7	Bukpui	242	1210
		8	Kawnpui	1581	7952
			Total	3304	16938

3.4 Climate:

Despite Mizoram's in tropical, it enjoys a moderate climate. The year may be divided into four seasons. The winter season is relatively short and is experienced from November to February. The extremely cold temperature is felt at places having high altitudes such as Champhai, Zote, Ngur, etc. It is followed by pre-monsoon or summer season of thunderstorms till May and receives a substantial amount of rainfall even in April and May months. The longest season in Mizoram is summer or monsoon season, extending from the beginning of June to late October. The climate of Mizoram is moderate to hot and relatively high in humidity during the summer and monsoon seasons. The hottest season is encountered in May, June, and July. The maximum temperature is encountered in lower valleys such as Kanhmun, Zawlnuam, Bairabi, and Hortoki, etc. in the north and northwestern part; Tlabung, Chawngte, and Tuipuibari, etc. in the south and western part. The state received surplus rainfall in the monsoon season and ultimately lowering the temperature. During pre-monsoon and post-monsoon seasons, the weather mainly prevailed by thundershowers and moderate temperatures. The eastern and central regions of the state are having pleasant weather during these two seasons. The period of mid-October and November is of the post-monsoon season and is characterized by pleasant weather. Most of the central and western parts of Mizoram experience the Subtropical monsoon climatic type with mild and dry winter and hot and humid summer.

The temperatures decrease from west to east with elevation. In general, there is not much temperature fluctuation throughout the year, except in the low-lying topographic landforms. Places at higher elevation experience a lower diurnal range of temperature. The temperature variation depends upon the topography of the state. Typically, the elevated minimum temperature is experienced in western and north-western parts and low hilly terrains of the state.

Summer and southwest monsoon season winds are generally light with occasional slight strengthening. Winds are typically easterly in the mornings while they are westerly in the evenings throughout the year. Westerly and south-westerly components are encountered during the pre-monsoon season and early monsoon season in the mornings. Whereas, a south-westerly wind is experienced in the evening during monsoon season. Convective motion dominating hilly terrains sometimes generates strong winds. The pressure is usually low over plain areas (mostly the western part of the state) and high over hilly terrains during pre-monsoon and southwest monsoon seasons so that winds are moderate to strong.

The highest relative humidity of 85% is observed during the period from June to October. Winter and summer months are characterized by the lowest humidity; it is at around 55% to 75%. Variation of rainfall from place to place is controlled by elevation and topography. The entire state receives a good amount of rainfall. In general, the northeastern part of the state is receiving less precipitation as compared to the remaining state. The average total annual rainfall from 2016 to 2019 is 207.61cm. The average rainfall is least in January and highest during August month during these years. During these four consecutive years, the highest rainfall is recorded in 2017 whereas 2019 has the least amount of rainfall

Table 2: Annual rainfall (2016-2019), Kolasib district, Mizoram

Kolasib District Rainfall (in mm)2016-2019						
Sl.No	**Month**	**Rainfall in mm 2016**	**Rainfall in mm 2017**	**Rainfall in mm 2018**	**Rainfall in mm 2019**	**Average Rainfall in mm 2016-2019**
1	January	0.1	0	0.7	0	0.2
2	February	55	1.9	8.5	59.2	31.15
3	March	107	166.6	14.9	38.5	81.75
4	April	200.4	358.9	107.7	80.4	186.85
5	May	370.8	263.5	241.2	171.9	261.85
6	June	377.7	411.4	371.4	171.1	332.9
7	July	255.1	385.6	318.3	265.2	306.05
8	August	374.3	525.5	339.4	336.6	393.95
9	September	543	256.7	79.9	207.9	271.875
10	October	170.3	243.2	54.4	102.1	142.5
11	November	62.6	0	15.8	56.9	33.825
12	December	0	103.1	3.3	26.4	33.2
	Total	**2516.3**	**2716.4**	**1555.5**	**1516.2**	**2076.1**

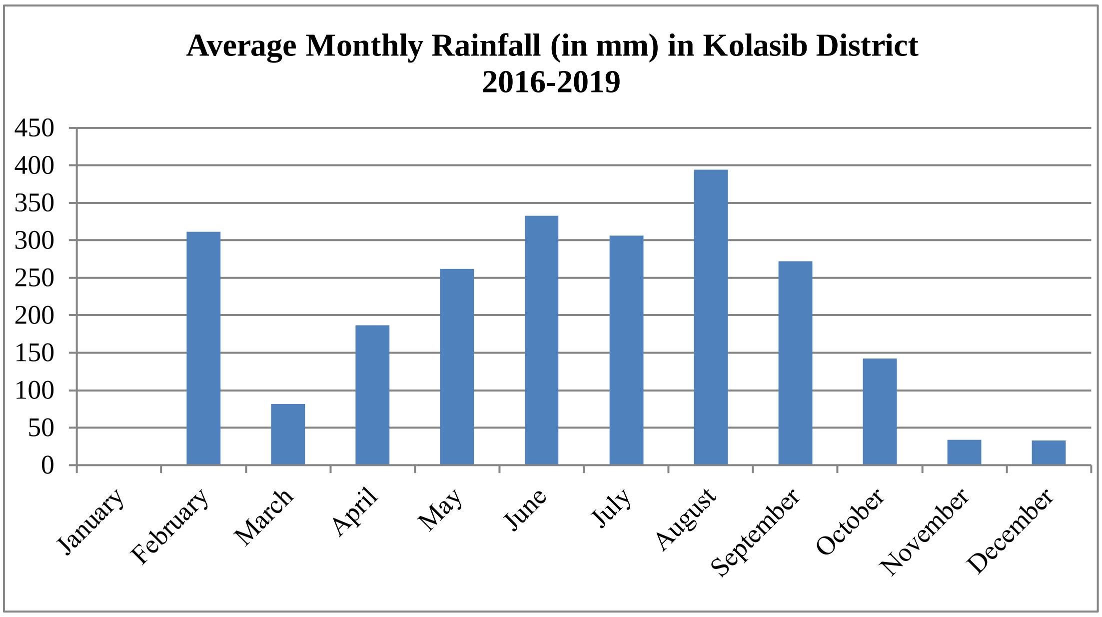


Figure 2: Bar chart of average monthly rainfall in Kolasib district (2016-2017)

3.5 Topography:

The landscape is dominated by mountainous terrain of Tertiary rocks. The mountain ranges are aligned in north to south direction in a parallel series. A narrow, elongated deep river valley that forms Intermontane Valley and Fracture Valley are separating the ranges. Hilly terrain in the eastern and central parts of Mizoram are having prominent relief features with steep slopes. All the hills within the state are of structural origin, associated with folding, faulting, and other tectonic processes. The average height of the hills in Mizoram is about 400 meters. The lowest point within the study area is in Hortoki village, which along Tlawng River has an elevation of ~40m above MSL, while the highest peak Nisapui Khawhlui tlang near Nisapui habitation has an elevation of 1289 meters above MSL.

3.6 General geology of Mizoram:

Geologically, the formation of the Himalayan Mountains over the past 50 million years led to India-Asia plate collision and climate interactions like the development of monsoon conditions over south Asia. During the middle Miocene, the South Asian monsoon condition intensified, the watershed increases north of the Himalayan divide and consequently delivering a large number of sediments to the

Brahmaputra watershed (Betka *et al.*, 2021). Mizoram is a part of this mega depositional depression, which later evolved after the regional uplift of the Barail succession. As continuously being modified by tectonic forces, the mountainous terrain in Mizoram is forming a mobile belt constituted of very tight, elongated asymmetrical, N-S trending anticlines alternating with broad saucer-shaped synclines, which are slightly arcuate and convex westward in sub-meridional trends. The altitude varies between 900m to 1200m from msl with several peaks attaining a height of more than 1800m, the elevation in the state rises towards the east, i.e. towards the China Hills of Myanmar (Karunakaran, 1974). The generalized lithostratigraphic succession (GSI, 2011)is shown below.

Table.3: Lithostratigraphic succession of Mizoram (GSI, 2011)

Group	Formation	Lithology
	Recent	Loose, Friable and unconsolidated pebbles of sandstone and fragments of shale in sandy matrix.
		Unconformity
Tipam Group	Tipam Formation	Mainly arenaceous rocks consisting of medium to coarse, buffed colored loose, friable micaceous sandstone with subordinate shale and siltstone. Fossil wood (drifted) has been reported from this unit.
		Unconformity
Surma Group	Bokabil Formation	Mainly argillaceous rocks represented by shale/siltstone and thinly bedded sandstone alternations with subordinate buff colored, fine to medium grained soft, friable sandstone.
	Upper Bhuban Formation	Mainly arenaceous rocks which includes mainly thickly bedded grey, khaki, buff Formation colored, fine to medium grained, at places friable, kaolinized sandstone with very fine grained sandstone, siltstone, shale (grey, olive green) interbands, with shell limestone as lensoidal bodies, conglomeratic at places, grey, very fine grained to fine grained, hard compact, calcareous sandstones.
	Middle Bhuban Formation	Mainly argillaceous rocks which includes grey, khaki shale, silty shale and siltstone/shale interlaminations with grey, buff colored hard, compact, micaceous, fine to medium grained, thinly to moderately bedded sandstone with a few thick, grey, hard, very fine grained, micaceous bands.
	Contact conformable to transitional	
	Lower Bhuban Formation	Mainly arenaceous rocks which includes fine to very fine grained, compact, blue, ash, green colored, massive, well beded sandstone, exhibiting turbidite features and well laminated siltstone, olive green silty shale/shale interlaminations.
		Unconformity
Barail Group	Barail Formation	Shale and siltstone with bands of weathered and micaceous, medium grained, yellowish greywackes. Locally, a few hard, dark grey, compact, medium to fine grained quartzwackes bands are present

Barail Group: Barail Group occupies the most tectonically uplifted eastern part of the state and comprises the oldest rock formations of the state. The presence of a relative abundance of greywacke and quartz wacke indicates they are deep marine deposits. As made up mainly of argillaceous rocks, their water-bearing capacity is low and hence groundwater resources largely depend on secondary porosity viz., joints, fractures and fissures, etc.

Surma Group: Approximately 5950m thick Neogene argillaceous and arenaceous sediments were deposited in the Surma Basin which is named as Surma Group. It has been further subdivided into upper Bhuban, Middle Bhuban, lower Bhuban unit, and Bokabil formation on the base of the proportion of shale and sandstone and superposition. The rocks of the Tipam group conformably overlie the Bokabil formation.

Bhuban group has been named after the Bhuban range of western Manipur hills which comprises about 5000-meter-thick argillaceous and arenaceous sediments of upper Oligocene to lower Miocene in age. Bhuban Formation is further subdivided into Lower, Middle, and Upper Formations.

Lower Bhuban Formation: Lower Bhuban Formation comprises ~900m thick succession dominated by arenaceous and composed of compact medium to fine-grained less compact sandstone. Thinly bedded, hard and compact, poorly sorted, and fine to very fine-grained, locally calcareous sandstone with interlaminations of well-laminated siltstone and shale is also observed. Since arenaceous rocks dominate this Formation; therefore, capable of storing a good amount of groundwater.

Middle Bhuban Formation: It conformably overlies Lower Bhuban Formation with gradational contact. It comprises the thickest unit of the Bhuban Formation, which is approximately 3000m thick. It is predominantly argillaceous interbedded with thinly bedded shale, siltstone, and mudstone with subordinate sandstone.

Upper Bhuban Formation: It conformably overlies the Middle Bhuban Formation with gradational contact. The thickness is about 1100m. The lithology is dominated by arenaceous thick sandstone beds. They are hard, compact, grey to khaki-colored, and medium to very fine-grained. Locally thinly bedded, micaceous sandstone Interbedded with subordinate siltstone and shale are present.

Bokabil Formation: The Bokabil Formation named after the Bokabil village of Hailakandi valley (Cachar) is well developed in the western part of Mizoram comprising an argillaceous formation of a thickness of more than 950m.This Unit conformably overlies Upper Bhuban Formation and with gradational contact. It mainly occurs on either flank on the anticlinal ridges or in the core of the synclines. Argillaceous are layered with thinly bedded sandstone.

Tipam Group: Tipam Formation of the Tipam Group conformably overlies Bokabil Formation with a gradational contact. Its thickness is found to be more than 900m. The lithology is chiefly of the arenaceous Unit and occurs in northern and western parts of Mizoram. It has distinguished characteristics of friable nature of buff-colored, medium to coarse-grained, massive, loose, micaceous sandstone. It is also interbedded with subordinate laminated grey siltstone/shale intercalations. Fossil wood (drifted) has been recorded from this formation.

3.7 Geology of study area:

3.7.1 Lithology and structure: The Surma (Lower to Middle Miocene), the Bokabil (Late Miocene) Groups, and Unconsolidated sediments (Clay, silt, sand, and gravel) of Recent deposits are the main lithology exposed within the study area. Lower Bhuban Formation is exposing in around Bukpui village and the dip amount in this range is relatively high ranging from ~25° to 60° dipping towards the west direction. Argillaceous-dominated lithology of the Middle Bhuban Formation is found in terrain having higher elevations such as N. Chaltlang village and Serkhan village, it is also encountered in the lower flanks of both the eastern and western sides of the Bukpui anticline. The doubly plunging synclinal basin between the Bukpui anticline range and the Kawnpui mountain range is found to be of Bokabil Formation. Grey to buff-colored sandstone dominant lithology of Upper Bhuban is observed in the remaining part of the study area such as the vicinity of Kawnpui, Zanlawn, Lungmuat, and Nisapui villages. The dip amount of rock beds at the Kawnpui range is very low ranging from 7° to 20° towards the East. However, being structurally more disturbed by folding, faulting, fractures, and joints, the bedrock exposures in the vicinity of Zanlawn, Nisapui, and Lungmuat are characterized by a relatively higher dip amount as compared to Upper Bhuban rocks in the vicinity of Kawnpui range. Sharp and prominent contact is observed between Upper Bhuban rocks exposure and Bokabil Formation at the

western side of Kawnpui along Hortoki road. Unconsolidated narrow elongated alluvium deposits are encountered along major rivers like Tlawng, Serlui, Tuirial, etc. Some pockets of friable sandstone which are unconfirmed to be of Tipam sandstone are also present in the troughs between hillocks in the Intermontane valley unit. It is observed that the rocks within the area are traversed by several Geological features like faults, fractures, joints, etc. of varying magnitude and length (MIRSAC, 2009). The lithological Units and their area covered were given in Table 4.

Table 4: Area coverage of Lithostratigraphic Units of the Study area

Sl.No	**Lithostratigraphy**	**Area in sq. km**	**Percentage**
1	Sandstone (Upper Bhuban) Surma Group	283.23	57.35
2	Shale (Bokabil Formation) Surma Group	65.57	15.78
3	Sandstone (Lower Bhuban) Surma Group	40.80	9.82
4	Gravel, Sand, Silt (Recent)	35.93	8.65
5	Shale (Middle Bhuban) Surma Group	34.90	8.40
	Total	415.43	100

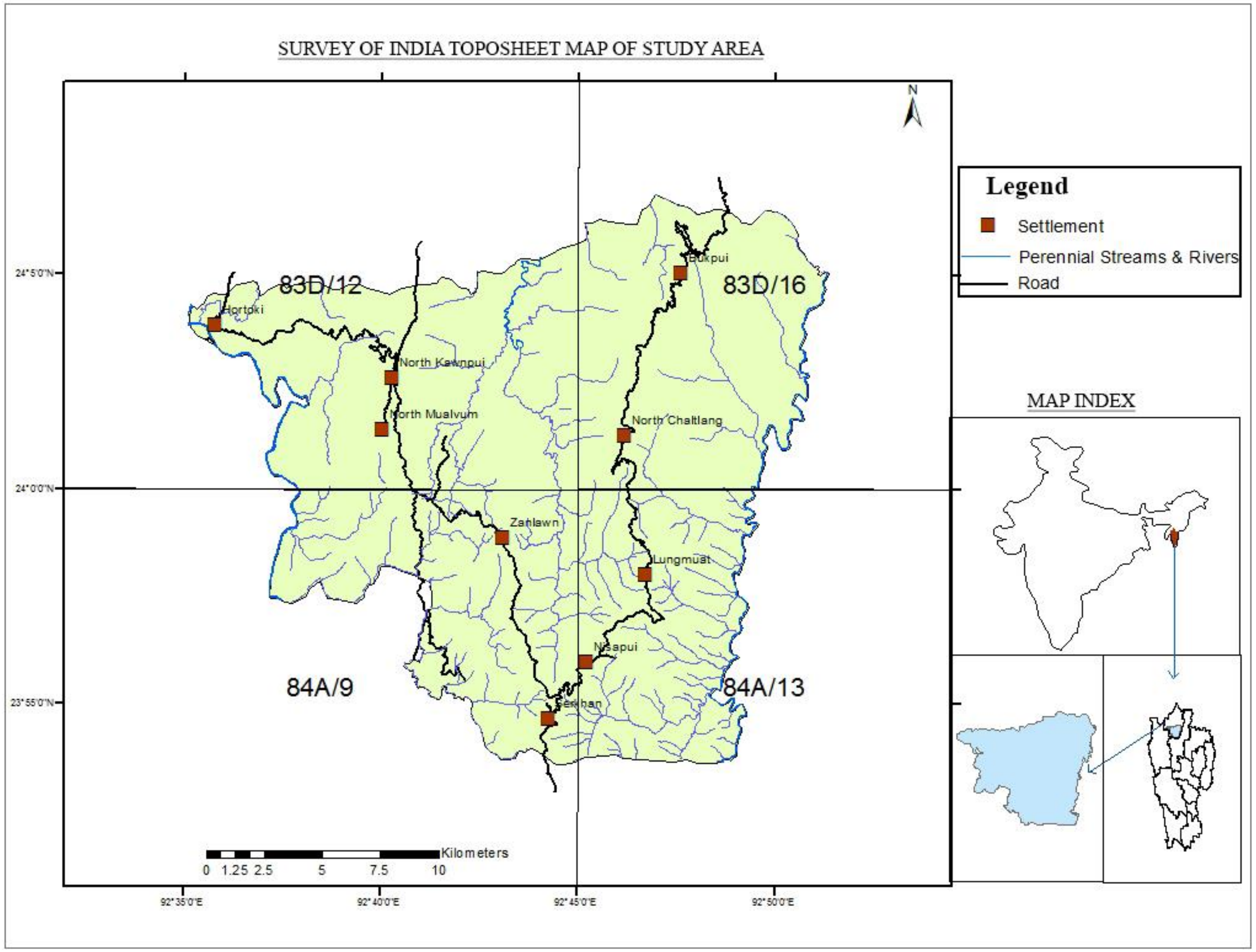


Figure 3: Survey of India Toposheet map of the study area

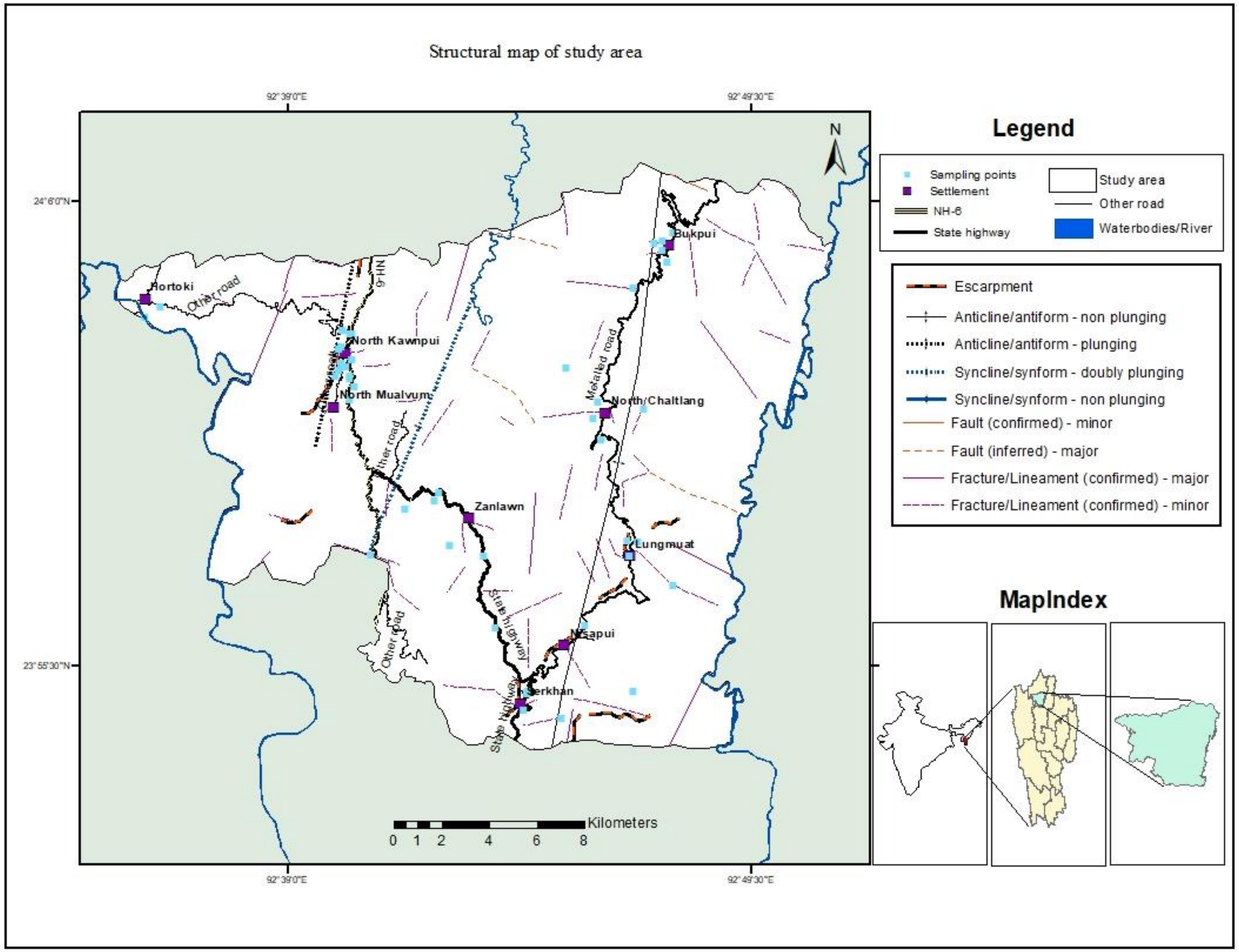


Figure 4: Structural Map of the study area

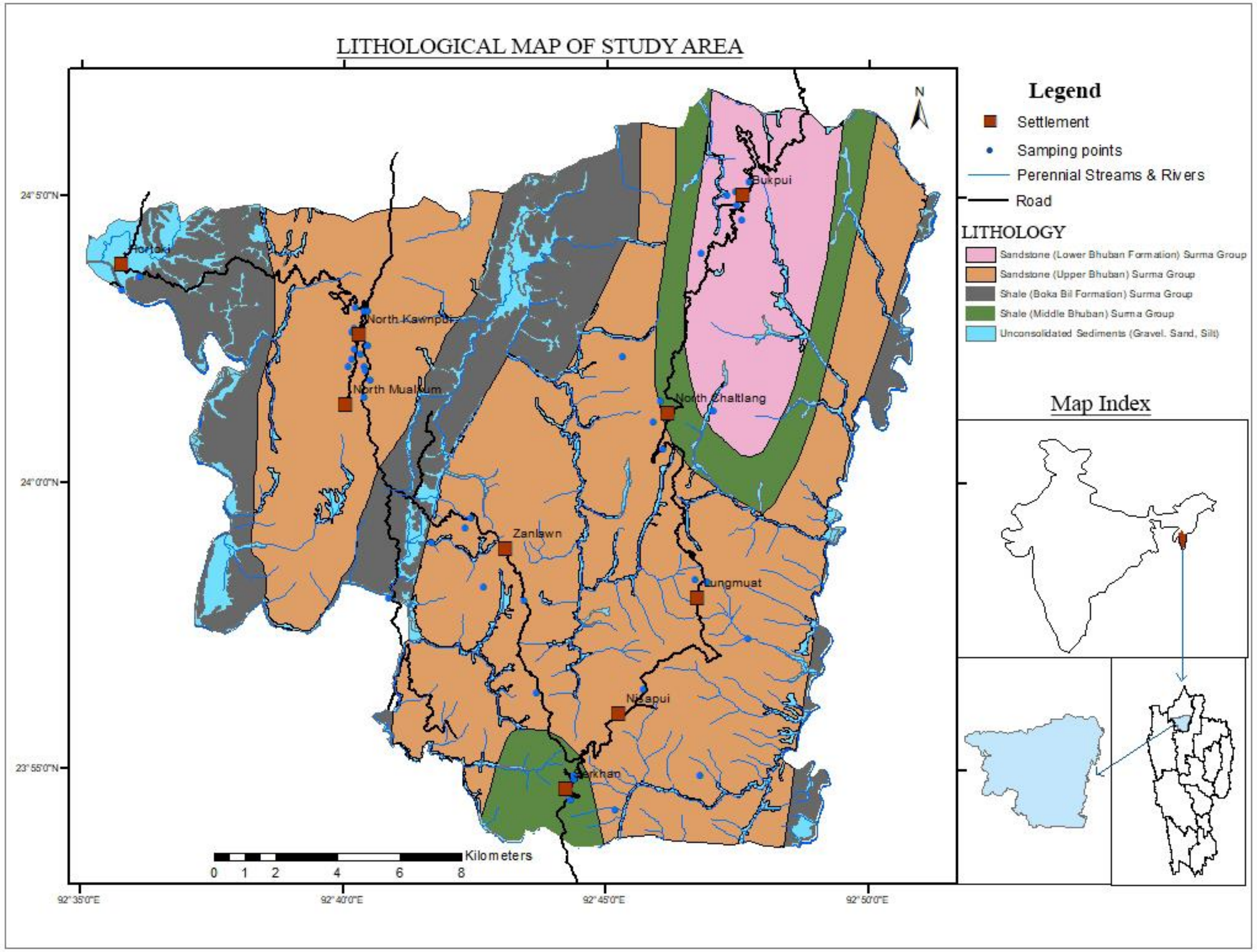


Figure 5: Lithological Map of the study area

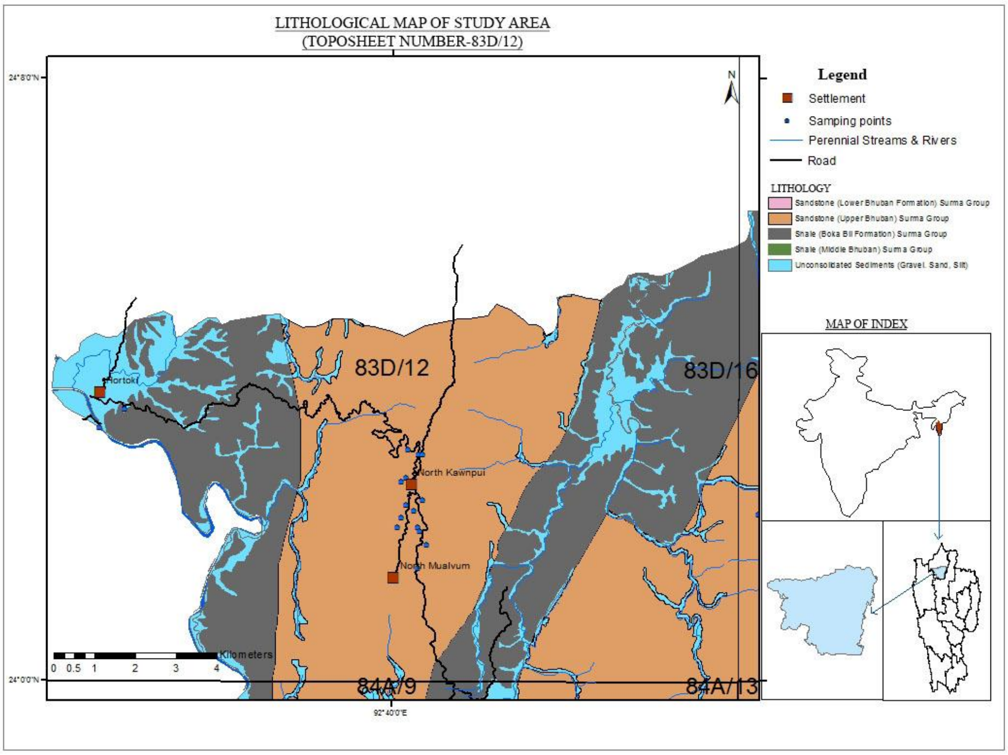


Figure.6 : Lithostratigraphic map of the study area covering 83D/12

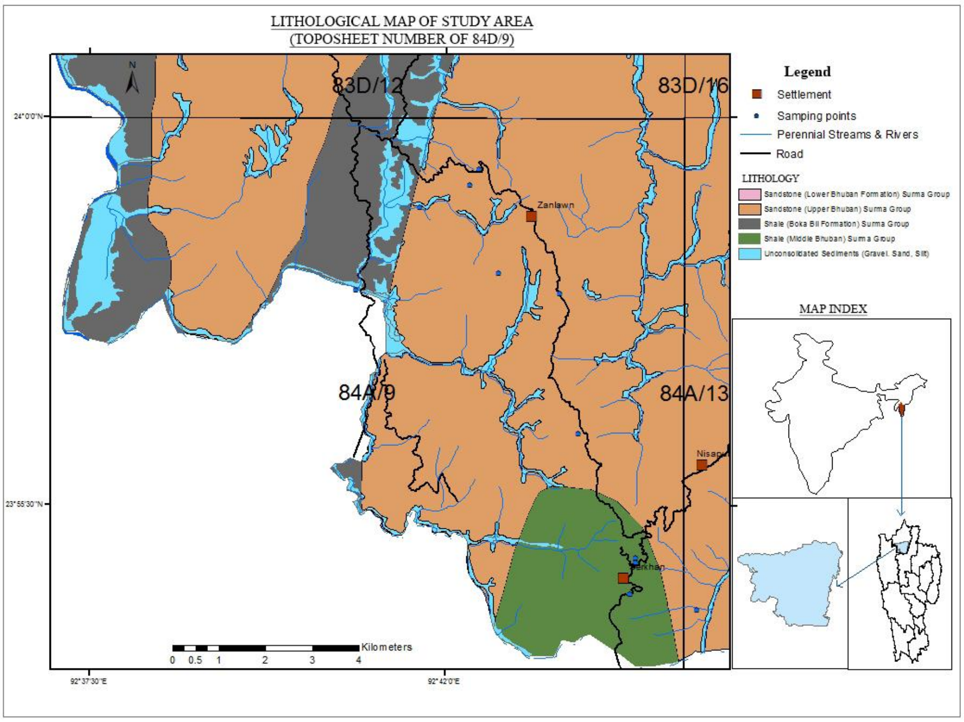


Figure 7: Lithological Map of the study area covering 84A/9

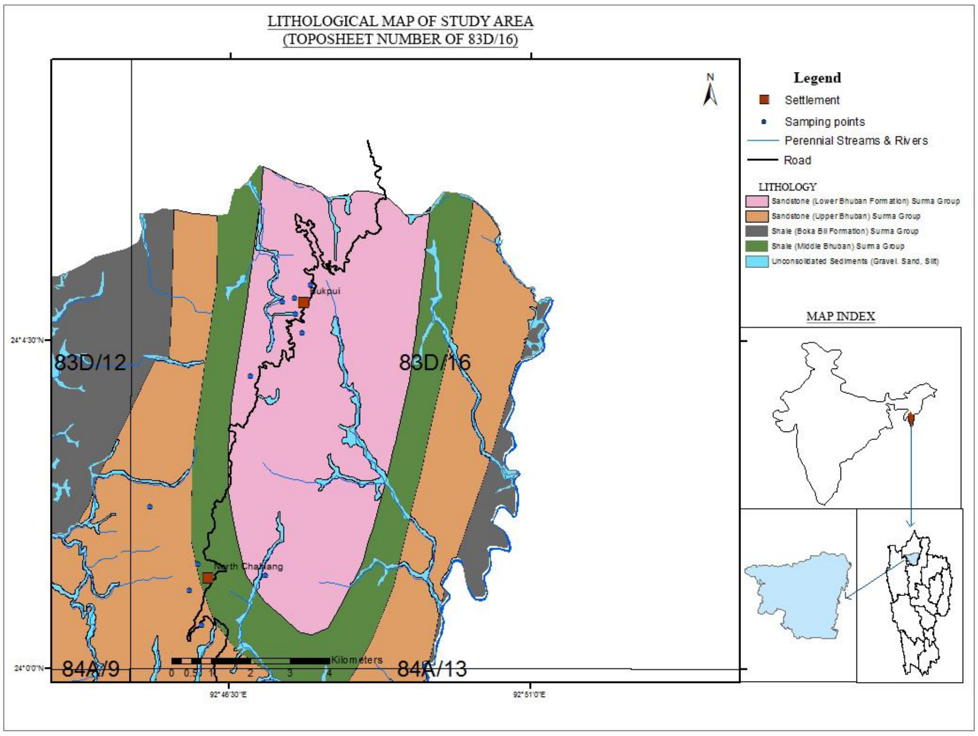


Figure 8: Lithological Map of the study area covering 83D/16

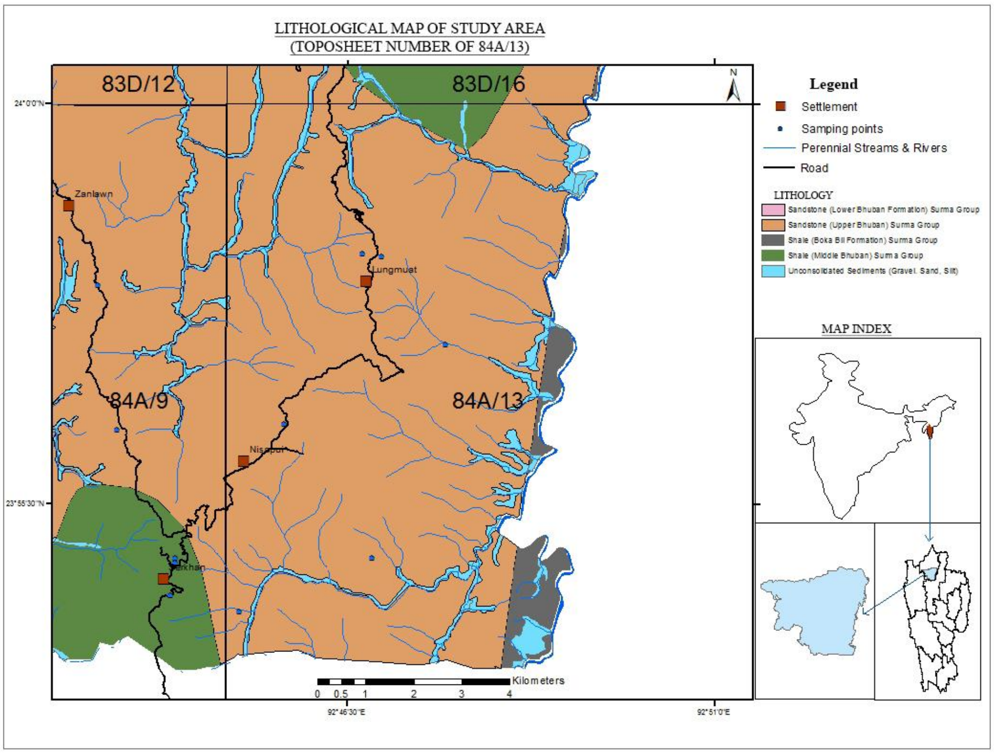


Figure 9: Lithological Map of the study area covering 84A/13

Being continuously modified by tectonic activities and exogenous forces, the terrain of the area is having young and immature topography. All mountainous terrain is of structural origin. Therefore, the topography and physiographic expression within the area is typically N-S trending anticlinal, parallel to the sub-parallel hill ranges and narrow adjoining synclinal valleys with western flanks of the mountain ranges all have a higher degree of slopes. The major Structural trends in the study area correspond with regional tectonic trends. The average strike of the exposing bedding is NNE-SSW. The most dominant exogenic energy is from the action of running water, which has been operating from the Upper Tertiary periods onwards, till today.

3.7.2 Geomorphology: The major Geomorphic Units within the area are Fractured Valley, Intermontane Valley, Less Dissected Structural Hill, Moderately Dissected Structural Hill, and Highly Dissected Structural Hill.

Fractured Valleys are of fluvial origin and are signified by the transporting of unconsolidated sediments mainly boulders and chunks of rock fragments in a narrow fluvial valley. Intermontane Valleys are those which have wider dimensions lying between mountain ranges. Less Dissected Structural Hills include the lower part of the hill slopes either surrounding the valleys or those slopes surrounding the main channel of the stream where numbers of tributaries join the channel and are well distributed within the entire study area. Moderately Dissected Structural Hills include those which are higher than Less Dissected Structural Hills in terms of elevation and drainage density. Highly Dissected Structural Hills include those which rise above Moderately Dissected Structural Hills and are found right below either the weathered hilltop or the crest of the mountain. They are mainly confined to the eastern part of the study area.

The study area is represented by three prominent ridge lines and a vast area of Intermontane valley and Less conspicuous linear ridges mountain terrain. The three ridge lines are along Chawllen tlang–Khawserh tlang, Kawnpui,Serkhan-Lungmuat tlang ridge and N. Chaltlang-Bukpui tlang ridge. The average height of the ridge gradually decreases as we go from south to north except in Kawnpui ridge.

The Less prominent ridge line is observed along Serkhan-Zanlawn, which furcated out from Sakawrhmuituai main ridge at Serkhan village. Fracture valley is observed along Vankeu lui, Tuisen lui, Khuai lui, Keitum lui, Minpui lui, Rahai lui, Sekawi lui, Saikhawh lui and Tuitun lui, etc. Almost all the remaining terrain is of Intermontane Valley and is found near Hortoki habitations.

The area coverage of different Geomorphic classes and the Geomorphological map of the study area is shown below.

Table 5: Area coverage of Geomorphic Units of the study area

Sl.No	**Geomorphic Units**	**Area in sq. km**	**Percent**
1	Moderately Dissected Structural Hill (SHM)	191.88	46.188
2	Less Dissected Structural Hill (SHL)	154.19	37.1165
3	Inter-montane Valley (IV)	35.83	8.625
4	Highly Dissected Structural Hill (SHH)	32.44	7.809
5	Waterbodies	1.08	0.259
	Total	**415.43**	**100**

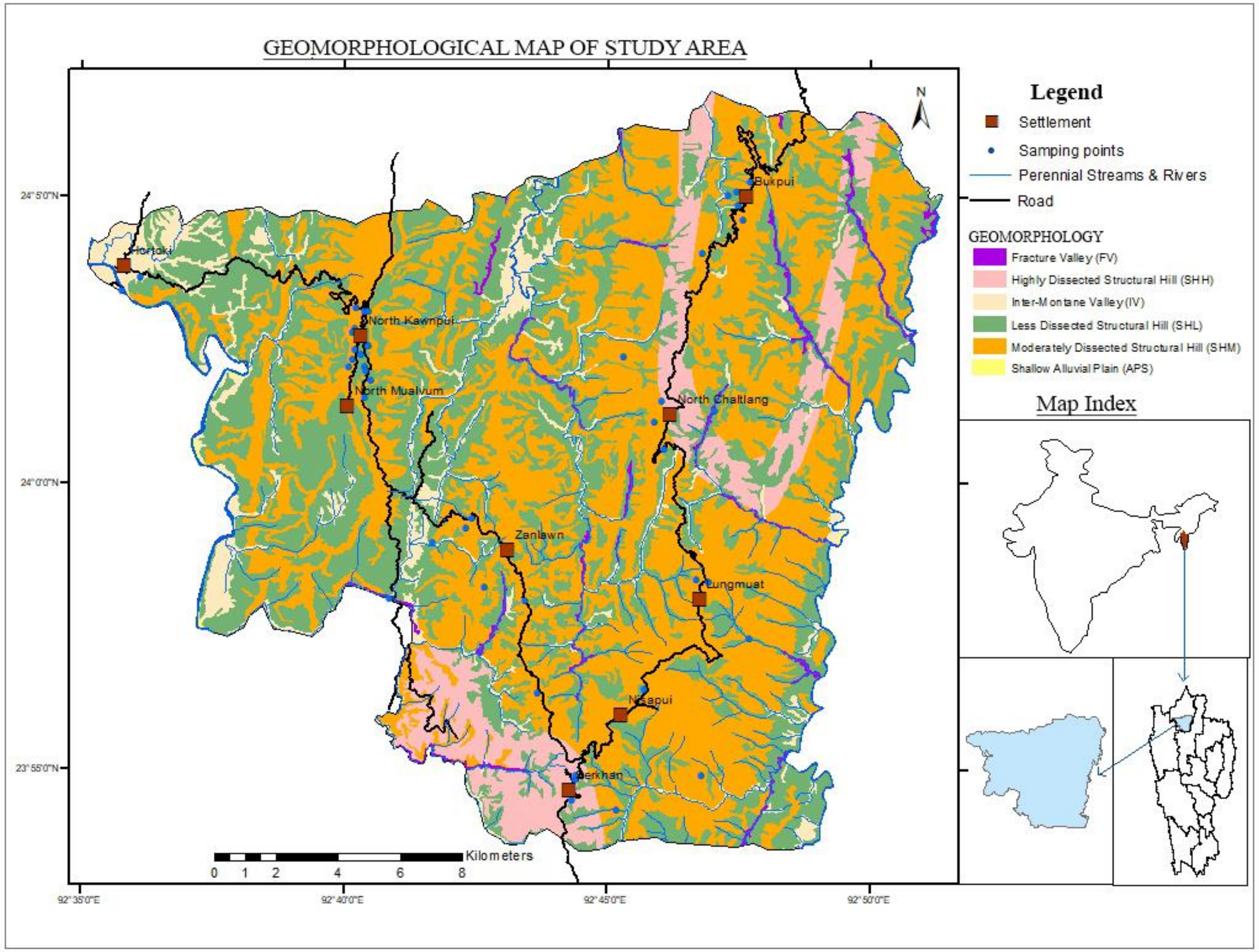


Figure 10: Geomorphological map of the study area

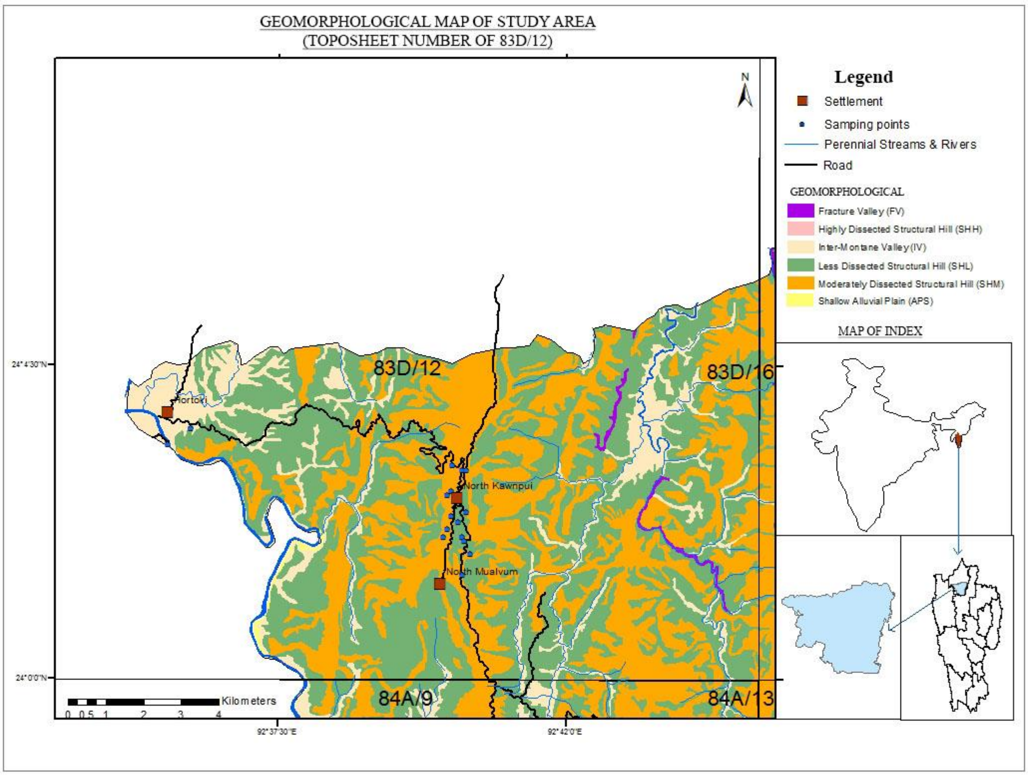


Figure 11: Geomorphic Map of the study are covering 83D/12

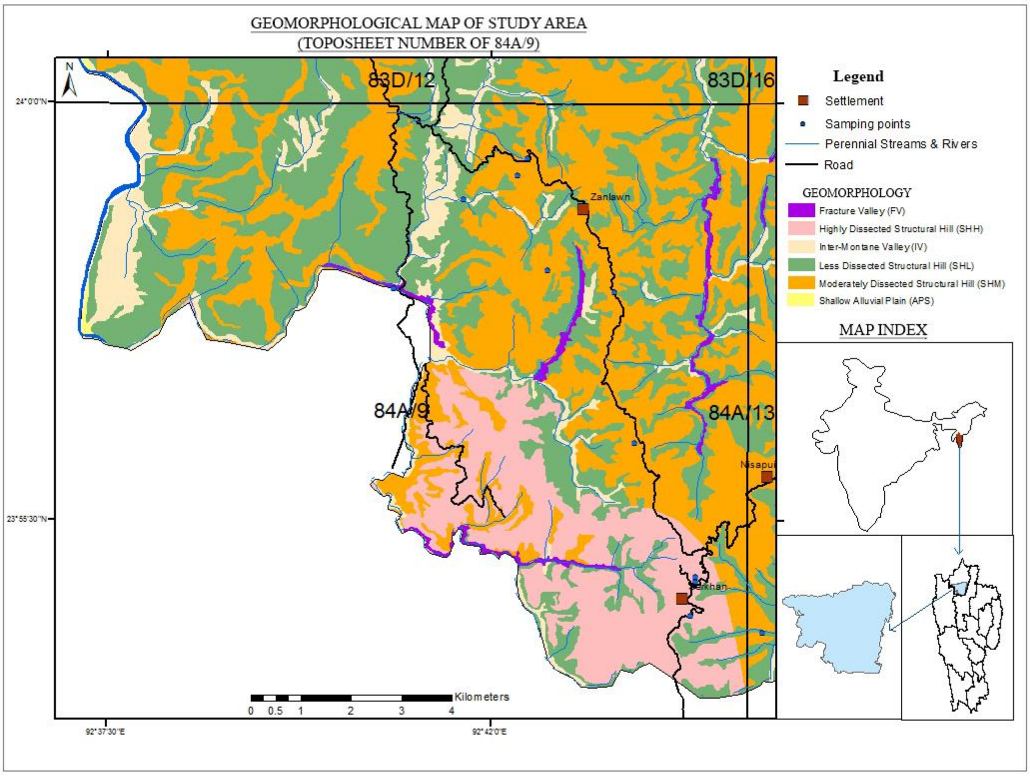


Figure 12: Geomorphic Map of the study area covering 84A/9

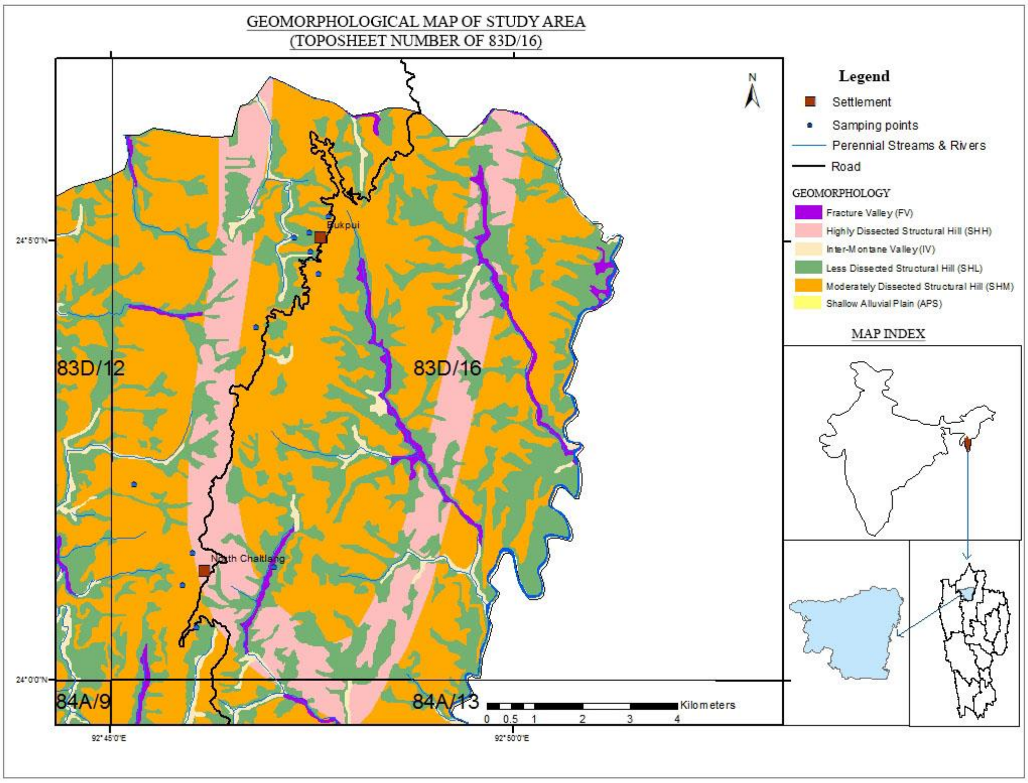


Figure 13: Geomorphic Map of the study area covering 83D/16

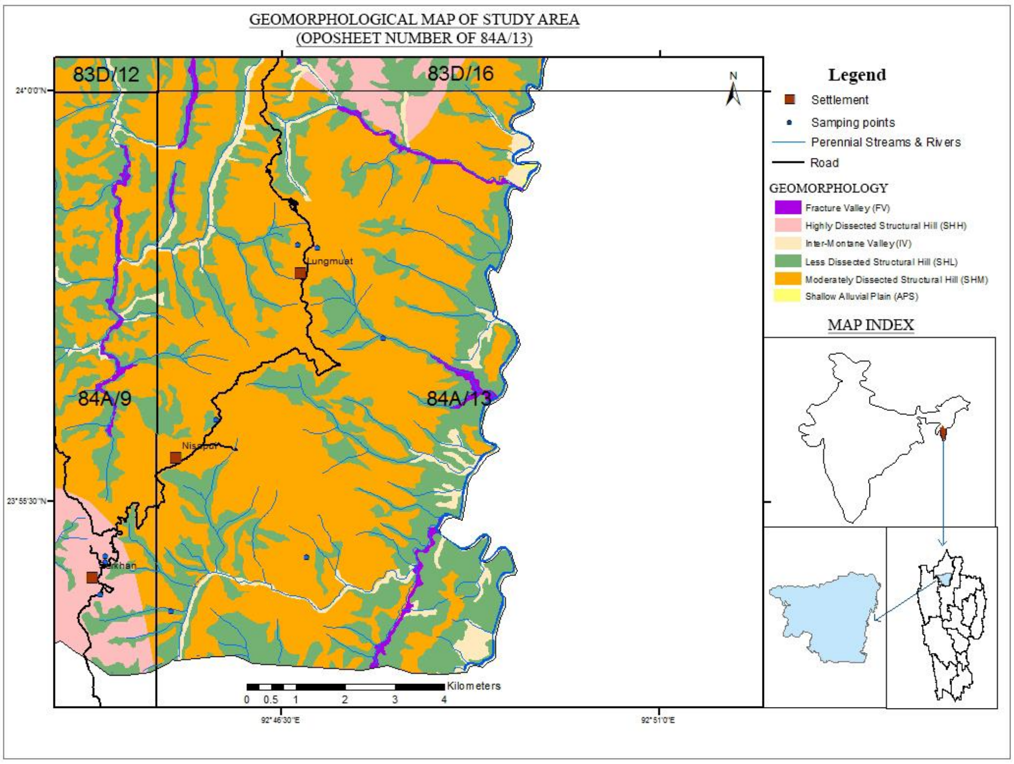


Figure 14: Geomorphic Map of the study area covering 84A/13

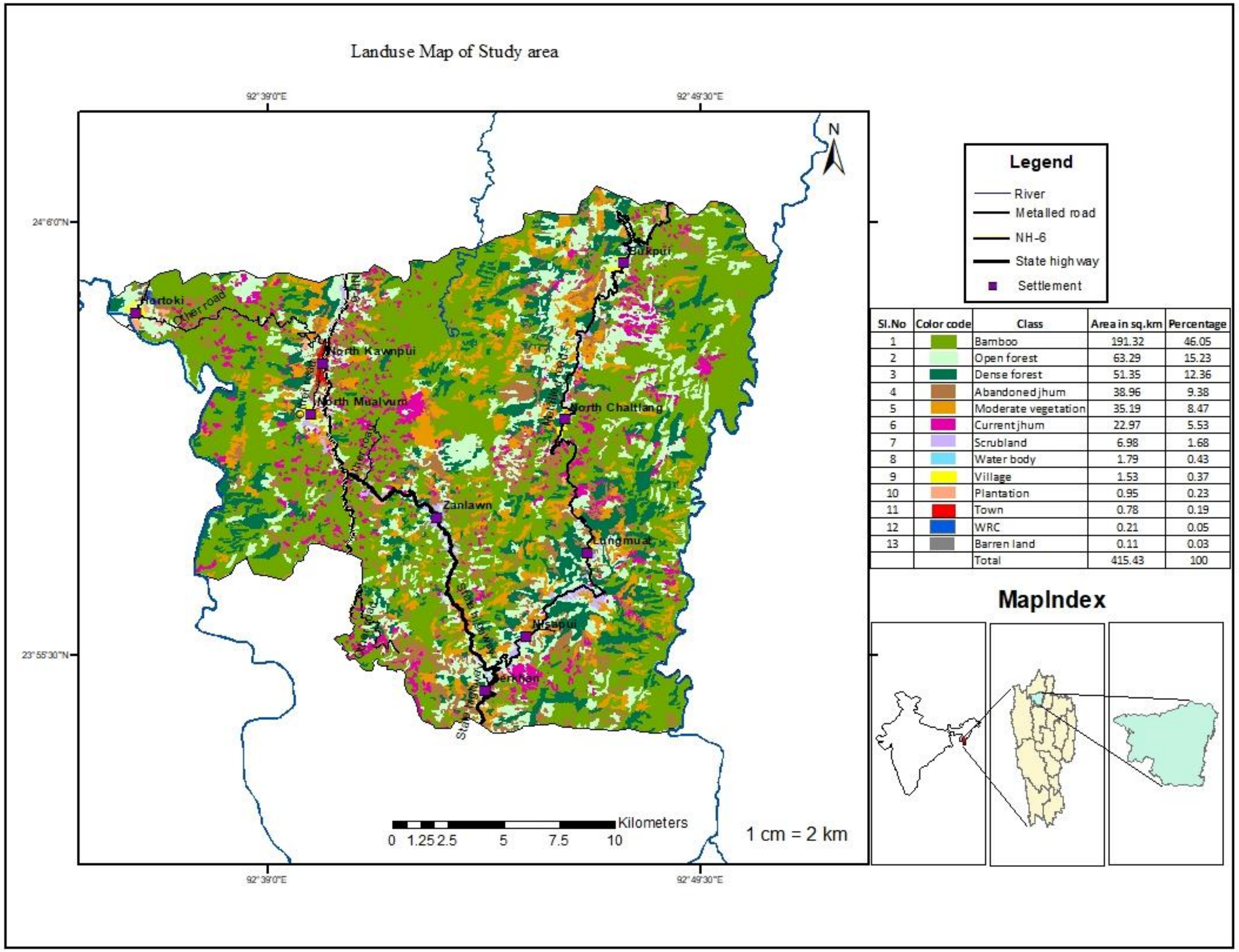
3.8 Land use / Land cover:

Remote sensing and GIS techniques play a vital role in determining land use pattern mapping. Land use and land cover mapping can convey an outline of the nature of groundwater recharge as well as the status of its quality.

Half of the total land use/land cover classes within the study area is covered by Bamboo. Undisturbed heavy vegetation comprises dense forest; it covers 12.56% of the total land cover. Forest plantation area occupied about 0.23%. Stripped forest areas comprising light vegetation like open forest cover 15.28% and moderate forest holds 8.47% of the total area. Abandoned Jhum, Current Jhum, and Wet rice cultivation areas comprise 9.38%, 5.53%, and 0.05% respectively. Abandoned land by shifting cultivation where shrubs, herbs, and grasses grow is classified as Scrubland, it holds 1.68% of the total area. Water bodies and barren land where human activities are limited to some extent are categorized into 0.435% and 0.03% respectively. Habitation areas like villages and towns are covering 0.37% and 0.19% of the total study area. The different land use/land cover classes in the study area are shown in the following table and Figure.

Table 6: Area coverage of Land use and Land cover within the study area

Sl.No	Class	Area in sq. km	Percentage
1	Bamboo	191.32	46.05
2	Open forest	63.29	15.23
3	Dense forest	51.35	12.36
4	Abandoned jhum	38.96	9.38
5	Moderate vegetation	35.19	8.47
6	Current jhum	22.97	5.53
7	Scrubland	6.98	1.68
8	Waterbody	1.79	0.43
9	Village	1.53	0.37
10	Plantation	0.95	0.23
11	Town	0.78	0.19
12	WRC	0.21	0.05
13	Barren land	0.11	0.03
	Total	415.43	100



Sl.No	Color code	Class	Area in sq.km	Percentage
1		Bamboo	191.32	46.05
2		Open forest	63.29	15.23
3		Dense forest	51.35	12.36
4		Abandoned jhum	38.96	9.38
5		Moderate vegetation	35.19	8.47
6		Current jhum	22.97	5.53
7		Scrubland	6.98	1.68
8		Water body	1.79	0.43
9		Village	1.53	0.37
10		Plantation	0.95	0.23
11		Town	0.78	0.19
12		WRC	0.21	0.05
13		Barren land	0.11	0.03
		Total	415.43	100

Figure 15: Land use and Land Cover Map of the study area

3.9 Drainage System:

There are three major drainage systems within the study area, all of them are north-flowing rivers such as Tlawng, Serlui, and Tuirial drainage systems.

Tlawng (Dhaleswari) river passes through five districts of the state and is one of the most important rivers of Mizoram. It forms district boundary lines with Mamit while running along its course in the study area. It is navigable by small boats throughout the year and hence serves as a water transport route for exporting Bamboo and logs to the neighboring Assam state. Dendritic to Sub-dendritic drainage patterns are typical drainage systems in the area. Kutbullui, Tuitun lui, Tuikual lui, Hmarluang lui, Mauchan lui, and Damdiai lui are important tributaries of Tlawng within the study area.

Serlui (Rukni) originates from Serkhan of the southernmost village and flows northward till it meets the Sonai River in the Cachar district of Assam. It is impounded by the Serlui B dam. It has 3 units; each can generate 4MW of power. It is the most important single river within the Kolasib district from the economic point of view as it is developed into a large pisciculture center and tourism site. Its important tributaries within the study area are NNE flowing rivers such as Tialpui, and NNW flowing rivers like Builum lui, Challui, Sekawi lui, and Saikhawh lui. These tributaries highlight dendritic drainage patterns in the region.

Tuirial River starts its journey from north Chawilung Hill in the Aizawl district and flows northward till it enters the Cachar district of Assam. It is an important river for the state of Mizoram since Tuirial dam, the largest power-generating hydroelectric dam that has two units capable of generating 30MW each is situated in this river. It is the largest earthen dam in India.Its important tributaries are Rahai lui, Tuiritai lui, Minpui lui, Keitum lui, Denga lui,Vailokawn lui, Melriat lui, Muallugthu lui, Tuisen lui and Thingsakawr lui. The drainage patterns found in this system are Dendritic to Sub-dendritic drainage patterns (MIRSAC, 2009).

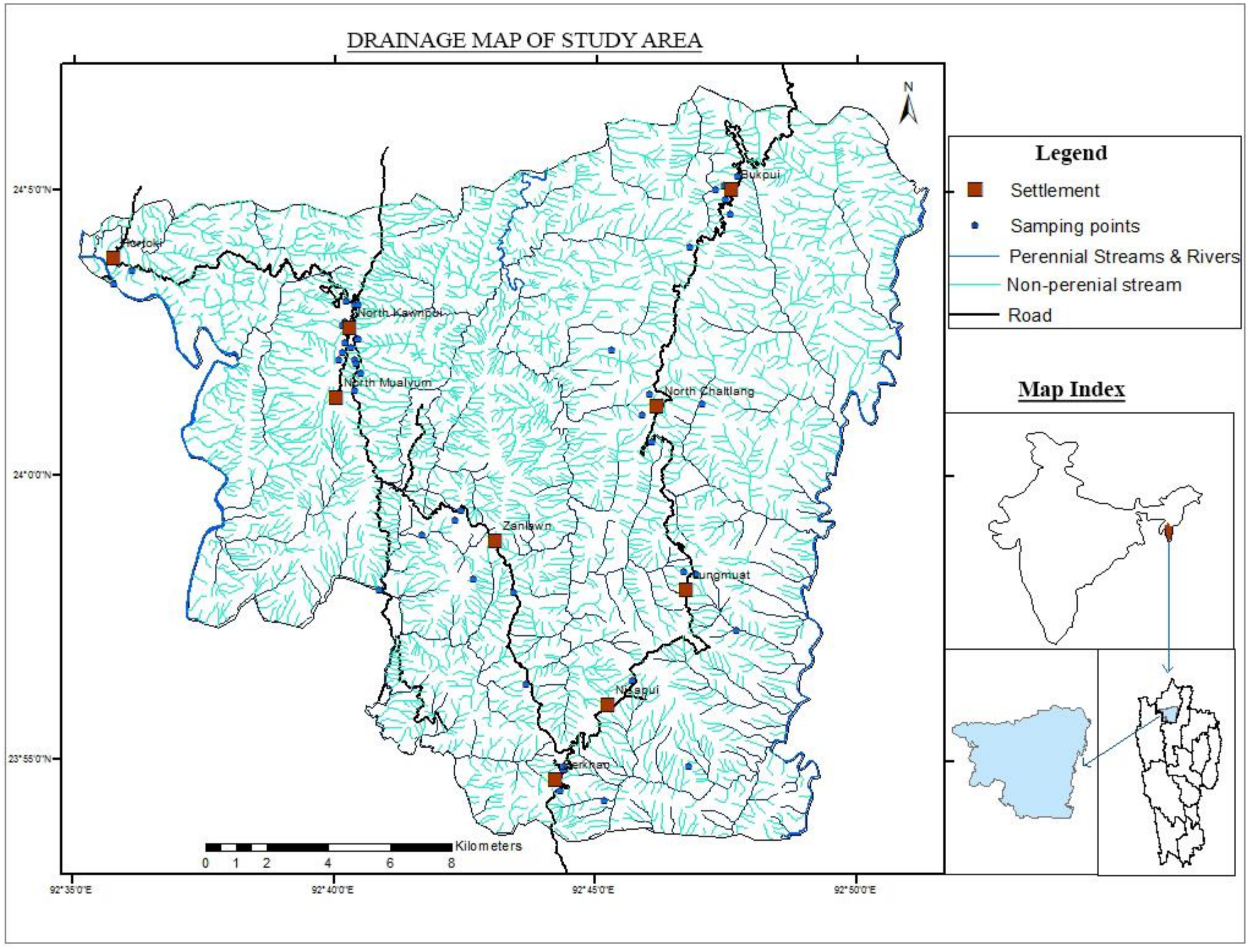


Figure 16: Drainage Map of the study area

3.10 Drainage density:

Drainage density is an indicator of the degree of infiltration and permeability of the drainage basin. It is the ratio of total channel segment lengths within a watershed/basin to the watershed/basin area usually expressed as km/sq.km. It shows the proportion of the total length of all streams and rivers in a drainage basin to the total area of the drainage basin.

The density of the polyline is calculated by the Line density (Spatial Analyst) method to generate a drainage density map. It calculates magnitude per unit area from polyline features that fall within a radius around each cell. Density is calculated in units of length per unit of area.

Drainage density is an inverse function of the permeability of the rock. Less permeable rock is characterized by less infiltration of rainfall, ultimately leading to increased surface runoff. Therefore, high drainage density denotes less infiltration and hence indicates poor recharge of groundwater. Therefore, the Lesser the drainage density, the higher the recharge of groundwater. (Shalu,2013). The drainage density is typically high in Structural hills, whereas, it is low in low-lying areas. (Thapa *et al.,* 2008).

The drainage density is low at the high elevation, and increasing towards the valley. The central part of the area, the Serlui basin has the highest drainage density, it is followed by the eastern part and western part of the study area, the watershed area of Tuirial and Tlawng river respectively.

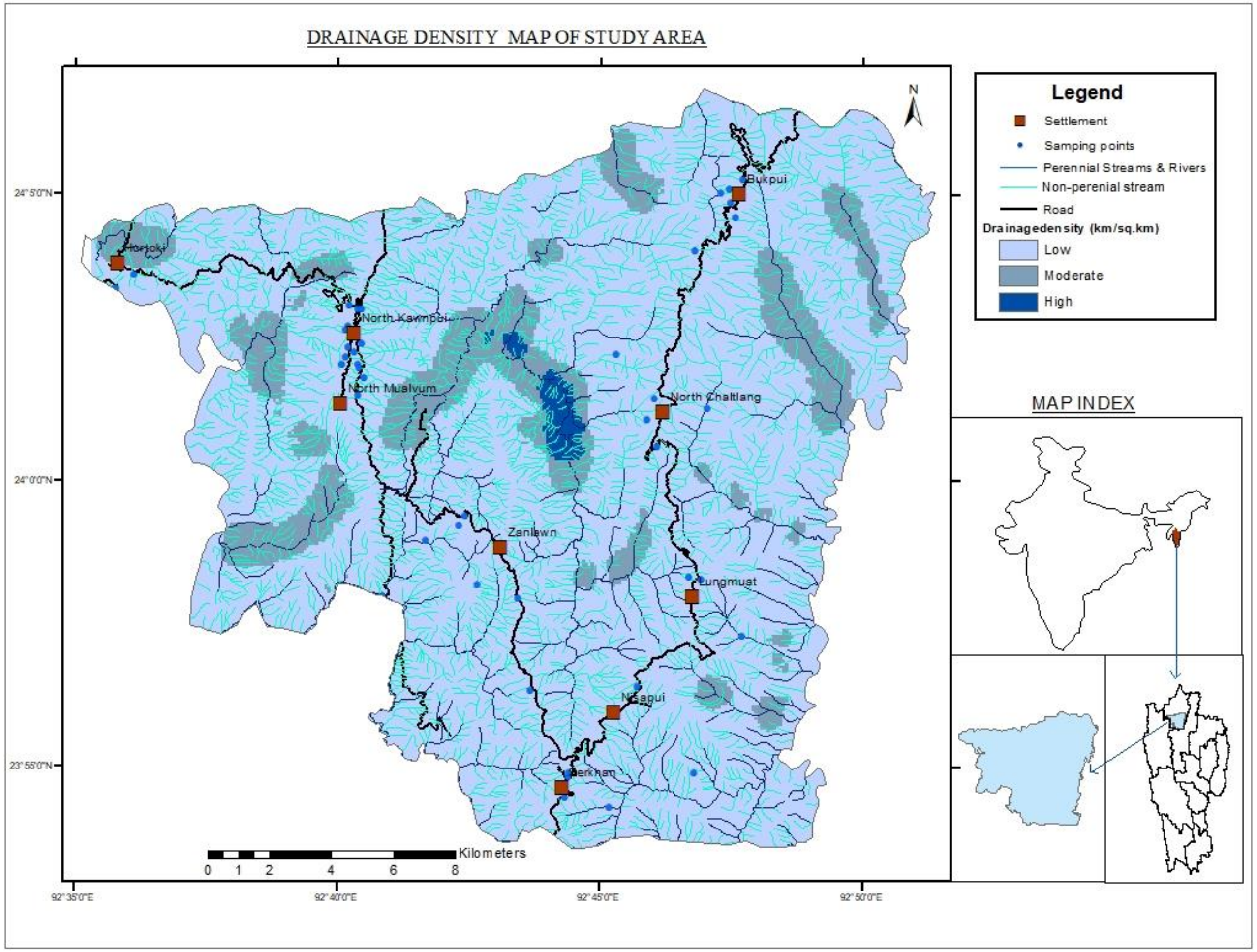


Figure 17: Drainage Density Map of the study area

3.11 Springs and Wells:

A spring is a location where groundwater naturally oozes out from the subsurface forming a defined flow and an amount large enough to form a pool or stream-like flow. Springs can discharge groundwater either to the ground surface or directly into the beds of streams as base flow. Though usually located at the top of hilly terrain, the vicinity of habitation and settlements have an abundant distribution of springs. Out of such spring water in the study area, 41 samples were from springs/Tuikhur which is seepage of groundwater from the subsurface to the surface, and 3 hand pump sources are from aquifers within the ground.

Most of the springs are found to be associated with minor fractures (lineament), therefore having a close connection with the drainage system. We can conclude that the majority of the aquifers within the area are from secondary porosity which has been directly controlled by the geological structures. Therefore, the number of springs is interconnected with the nature of the terrain and topography.

Table 7: Details of monitored Potable water sources in the study area

Sl.No	Source Name	TYPE	Village	Lattitude	Longtitude	GEOMORPHOLOGY	LITHOSTRATIGRAPHY
1	Vankeu	Spring/Tuikhur	Serkhan	23.905	92.753	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
2	Hmarveng Tuikhur	Spring/Tuikhur	Serkhan	23.914	92.74	Highly Dissected Structural Hill (SHH)	Shale (Middle Bhuban) Surma Group
3	Dengalui	Spring/Tuikhur	Serkhan	23.915	92.74	Highly Dissected Structural Hill (SHH)	Shale (Middle Bhuban) Surma Group
4	Bawngpu	Spring/Tuikhur	Serkhan	23.908	92.739	Highly Dissected Structural Hill (SHH)	Shale (Middle Bhuban) Surma Group
5	Vautangbawk	Spring/Tuikhur	Serkhan	23.915	92.78	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
6	Lalthansiama Point	Intake/PHED	Nisapui	24.037	92.755	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
7	Zotui	Stream/PHED	Nisapui	23.94	92.762	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
8	Lalkima Point hand pump	Handpump	North Chaltlang	24.018	92.765	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
9	Challui	Stream	North Chaltlang	24.0214	92.784	Fracture Valley (FV)	Unconsolidated Sediments of Recent(Gravel, Sand, Silt, Clay)
10	Chhimluang	Stream	North Chaltlang	24.01	92.768	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
11	Lengleh	Spring/Tuikhur	North Chaltlang	24.024	92.767	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
12	Vengsang electric GW pump	Electric Pump	North Chaltlang	24.0813	92.7914	Less Dissected Structural Hill (SHL)	Sandstone (Lower Bhuban Formation) Surma Group
13	Lungsum	Spring/Tuikhur	Bukpui	24.084	92.788	Inter-Montane Valley (IV)	Unconsolidated Sediments of Recent(Gravel,Sand, Silt,Clay)
14	Builum	Spring/Tuikhur	Bukpui	24.067	92.78	Moderately Dissected Structural Hill (SHM)	Sandstone (Lower Bhuban Formation) Surma Group
15	Minmawng	Spring/Tuikhur	Bukpui	24.085	92.791	Less Dissected Structural Hill (SHL)	Sandstone (Lower Bhuban Formation) Surma Group
16	Sub-Station Peng hand pump	Handpump	Bukpui	24.088	92.795	Less Dissected Structural Hill (SHL)	Sandstone (Lower Bhuban Formation) Surma Group
17	Nuhliri Point	Intake/PHED	Bukpui	24.077	92.793	Moderately Dissected Structural Hill (SHM)	Sandstone (Lower Bhuban Formation) Surma Group
18	Vandawt	Stream/PHED	Zanlawn	23.984	92.694	Less Dissected Structural Hill (SHL)	Shale (Bokabil Formation)Surma Group
19	Phulraw lui tuikhur	Spring/Tuikhur	Zanlawn	23.939	92.728	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
20	Hiahthar	Spring/Tuikhur	Zanlawn	23.966	92.724	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
21	Fului	Spring/Tuikhur	Zanlawn	23.97	92.711	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
22	Pumpelh	Spring/Tuikhur	Zanlawn	23.99	92.707	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
23	Midum Lui	Spring/Tuikhur	Zanlawn	23.987	92.705	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
24	Phuanberh	Spring/Tuikhur	Kawnpui	24.034	92.673	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
25	Hlitlui	Spring/Tuikhur	Kawnpui	24.05	92.673	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
26	Charpui	Spring/Tuikhur	Kawnpui	24.05	92.674	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
27	Vailui	Spring/Tuikhur	Kawnpui	24.034	92.668	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
28	Thlanmual tuikhur	Spring/Tuikhur	Kawnpui	24.0511	92.6704	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
29	Sentezel	Spring/Tuikhur	Kawnpui	24.04	92.674	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
30	Kuangsei	Spring/Tuikhur	kawnpui	24.0376	92.672	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
31	Sihpui tuikhur	Spring/Tuikhur	Kawnpui	24.045	92.67	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
32	Sakhisih	Spring/Tuikhur	Kawnpui	24.044	92.669	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
33	Bawkkang	Spring/Tuikhur	Kawnpui	24.03	92.675	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
34	Zohrangpa tuikhur	Spring/Tuikhur	Kawnpui	24.033	92.6734	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
35	Kannaan Tuikhur	Spring/Tuikhur	Kawnpui	24.025	92.673	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
36	Tuitun	River	Kawnpui	23.9667	92.681	Fracture Valley (FV)	Unconsolidated Sediments of Recent (Gravel. Sand, Silt,Clay)
37	Khurthuk	Spring/Tuikhur	Kawnpui	24.039	92.67	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
38	Sihpui	Spring/Tuikhur	Kawnpui	24.036	92.669	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
39	Lungpher	Stream	Hortoki	24.06	92.602	Less Dissected Structural Hill (SHL)	Unconsolidated Sediments of Recent (Gravel. Sand, Silt, Clay)
40	Khawzasiaka	Stream	Hortoki	24.056	92.596	Inter-Montane Valley (IV)	Unconsolidated Sediments of Recent (Gravel. Sand, Silt, Clay)
41	Zotui	Spring/Tuikhur	Lungmuat	23.972	92.778	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
42	Luihnai	Stream	Lungmuat	23.966	92.779	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group
43	Thingsakawr	Stream	Lungmuat	23.955	92.795	Less Dissected Structural Hill (SHL)	Sandstone (Upper Bhuban) Surma Group
44	Vengchung	Spring/Tuikhur	Lungmuat	23.9714	92.782	Moderately Dissected Structural Hill (SHM)	Sandstone (Upper Bhuban) Surma Group

3.12 Hydrogeological Units:

The entire area is divided into two Hydrogeological Units such as an Unconsolidated Unit and a Semi-consolidated/Hard rock Unit. The Unconsolidated Formations comprise fluvial deposits mainly of gravel, sand, silt, and clay and are therefore restricted along river valleys. Usually, groundwater within this formation is fed by the base flow. Groundwater is confined only to valley-filled areas. The remaining area of the study area is of Semi-consolidated Unit which constitutes sandstone and shale.

Though having lower pores volume as compared to the unconsolidated formation, Semi-consolidated formations developed secondary porosity due to tectonic disturbances and the groundwater storage is almost limited to secondary porosity as well as structural control in the higher elevation aquifers. As the state is entirely occupied by steep slope hills, most of the rainwater immediately flows as surface runoff into the stream and river. Therefore, water trapped in the porous sandstone and secondary porosity is becoming the main source of springs. Groundwater stored in the aquifer rocks of hill slopes discharge water in the form of springs and stream, which provide a source of water supply.

3.13 Groundwater depletion:

Groundwater depletion occurs when the withdrawal of groundwater exceeds the natural groundwater recharge for extensive areas and long times. The deterioration in groundwater levels can also be due to various reasons like the improper drainage pattern that reduces the rate of infiltration, increasing impermeable strata due to settlement, and lack of rainwater harvesting.

As the depth of groundwater increases, the energy consumption to extract water to the surface increases. Thus, power costs increase as groundwater levels decline. Depending upon the cost of extraction it may not be economical to use ground water for a given purpose. The decline of groundwater may ultimately cause the water unreachable by the bottom of existing pumps, it may require deepening the well or drilling a deeper replacement well. Depletion of groundwater may also lead to land subsidence. The basic cause of land subsidence is a loss of support below ground. The yield of the well may also decline, if there is not enough dilution, it may result in the elevated concentration of some harmful elements in the groundwater.

Table 8: Depth of groundwater in bore wells of Thingdawl Block, Kolasib district

Sl.No	**Borewell location**	**Pre-Monsoon (2021) Depth in meter**	**Post-Monsoon(2021) Depth in meter**	**Elevation (in meters)**
1	Thingdawl Govt. M.E School Thingdawl"	12.10	10.08	605
2	Sethawn(Bualpui) De-Addect Centre bul	17.00	16.00	837
3	N.Chaltlang Lalkima Inbul	21.25	20.20	780
4	Bukpui Lalhlunchhungi Inbul	12.60	12.45	914
5	Thingthelh Lalpianga Inbul	29.70	29.20	713
6	N.Hlimen C.Hall bul	25.40	25.00	721

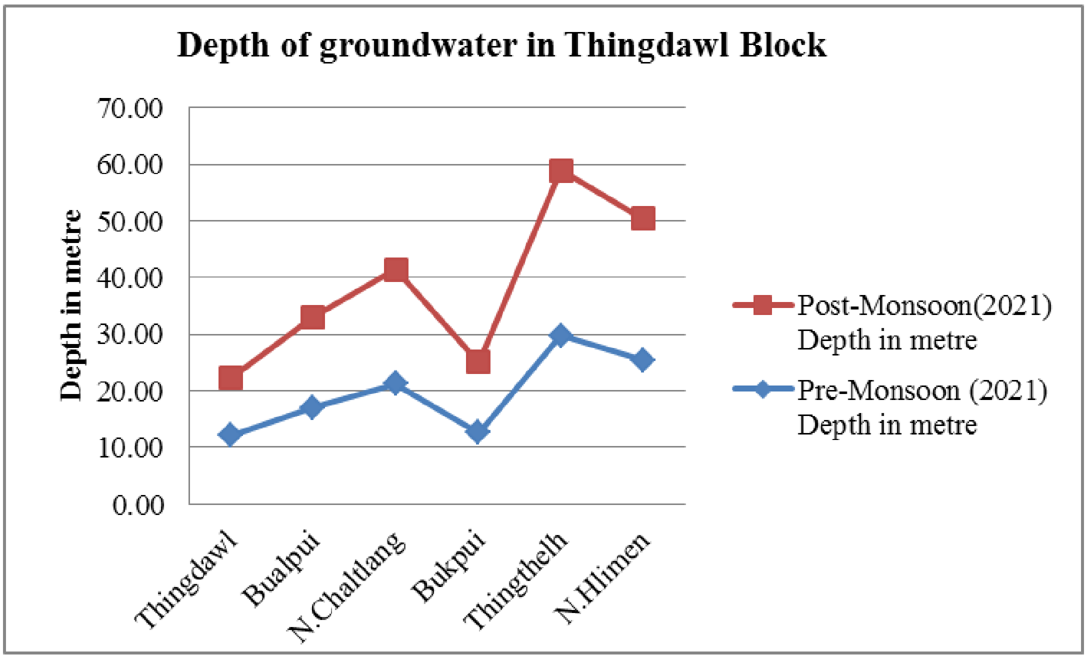


Figure 18: Bar chart showing the depth of groundwater in Thingdawl Block

A groundwater Level Survey has been conducted by PHE Department. Within the study area, the average groundwater level is highest in 2018 and maximum depletion is encountered in 2017. There is no significant change in groundwater from 2019 to 2021. It shows that there is no over-exploitation of groundwater and depletion of groundwater is not an issue in the study area at present status. The average water level of Groundwater in Thingdawl RD block during pre-monsoon and post-monsoon seasons during 2017-2021 are as follows:

Table 9: Average depth of groundwater in Thingdawl Block (2017-2021)

Sl.No	**Average Groundwater level (in meters)**			**Annual average**
	Year	Pre Monsoon	Post Monsoon	
1	**2017**	15.06	13.77	14.41
2	**2018**	20.25	19.27	19.76
3	**2019**	20.25	18.04	19.15
4	**2020**	20.04	18.61	19.33
5	**2021**	19.68	18.82	19.25

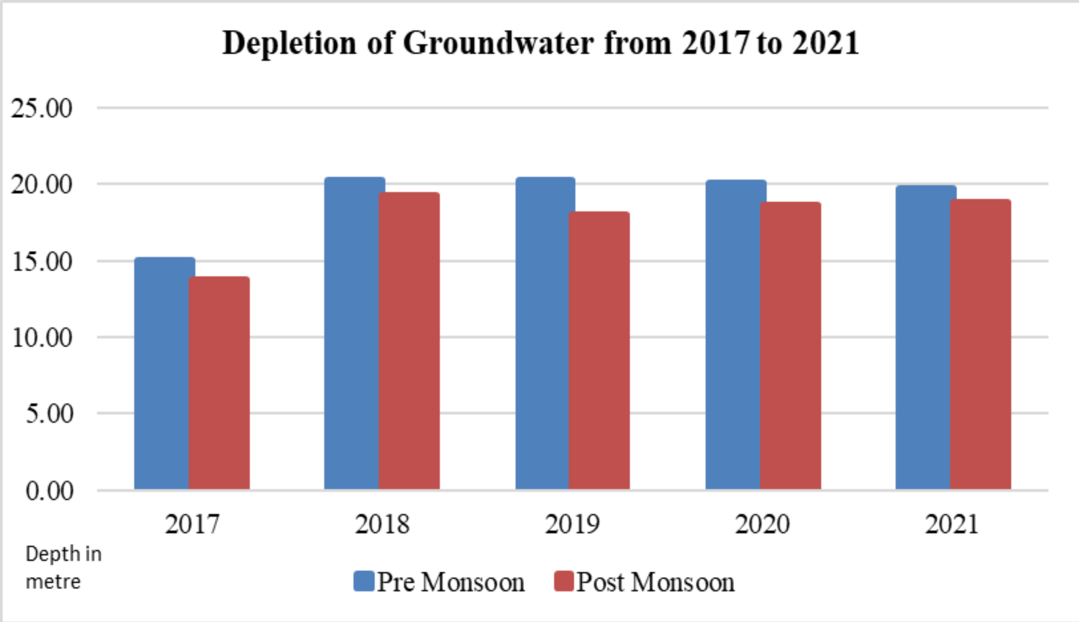


Figure 19. Bar chart showing depletion of groundwater in Thingdawl Block

3.14 Water Supply coverage:

Water availability per person is dependent upon the population of the country. In India, due to over population, this requirement has been reduced. As published by the Ministry of Jal Shakti in The Press Information Bureau (PIB) on 2nd March 2020, 55 LPCD ((liters per capita per day) is considered a benchmark for an individual to meet his/her daily requirement in rural areas. In urban areas, the required LPCD is 135 liters. Thus, when considering the water requirement of an individual suggested by the Ministry of Jal Shakti, all habitations within the area are facing scarcity of water as they do not meet adequate supply by the department. The average water supply for habitations within the study area is listed below:

Table 10: Litre per capita per day (LPCD) of villages in the study area

District	Block	Sl. No.	Habitation	Rural/Urban	Minimum LPCD standard	Liter per capita per day (LPCD)
Kolasib	Bilkhawthlir	1	Bukpui	Rural	55	25.33
		2	Hortoki	Rural	55	38.64
		3	Kawnpui	Urban	135	60.73
		4	Lungmuat	Rural	55	40
		5	Nisapui	Rural	55	56
		6	North Chaltlang	Rural	55	22.18
		7	Serkhan	Rural	55	37.44
		8	Zanlawn	Rural	55	38

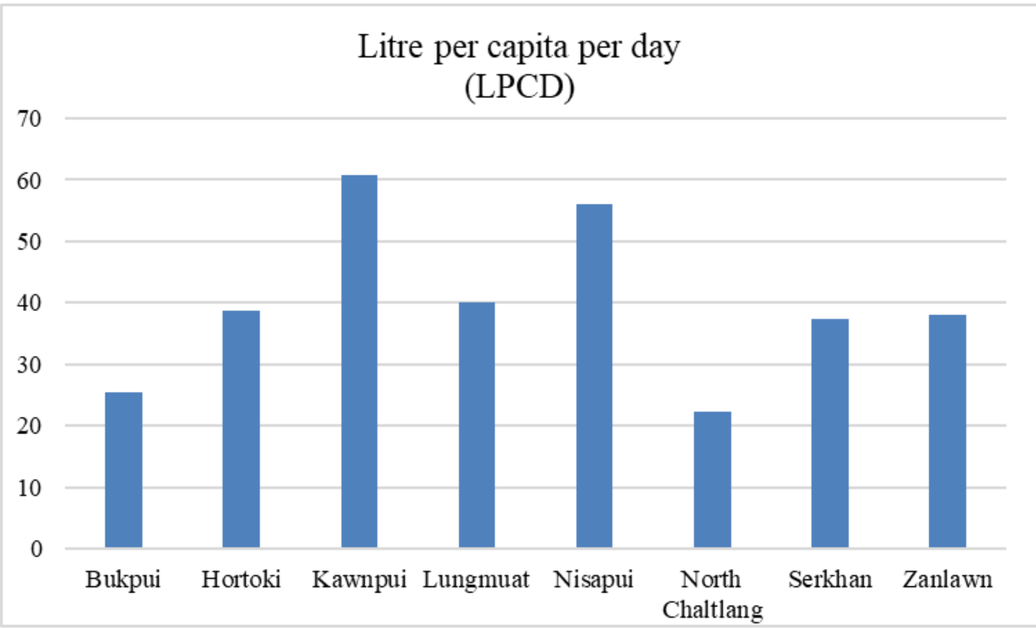


Figure 20: Bar chart showing LPCP of villages in the study area

Chapter IV

MATERIALS AND METHODS

4.1 Materials:

In the present study, various types of data are used to delineate different geospatial data and other relevant information. The materials and data which have been utilized include satellite imagery, legacy/collateral data, and ground truth data.

4.2 Satellite Data

Indian Remote Sensing Satellite LISS III and Cartosat-1 satellite data are utilized for digitization in the study. The details of the satellite imageries are given below:

Table 11: List of satellite data utilized in the present study

Sl.No	Satellite Imagery	Spatial Resolution (m)	Spectral Resolution	Swath (km)
1	IRS-P6 LISS-III	NIR - 23.5 SWIR - 70.5	No. of bands-4, Green, Red, NIR, SWIR	NIR-141 SWIR-148
2	IRS P5 Cartosat-1	2.5X2.78 (Fore camera) 2.2X2.23 (Aft camera)	No. of bands-1, Panchromatic	30

The LISS-III (Linear Imaging Self Scanning Sensor) sensor is an optical sensor working in four spectral bands (green, red, near-infrared, and short-wave infrared). It covers a 141 km-wide swath with a resolution of 23.5m in the NIR spectral band and 148km–wide swath covers with a resolution of 70.5m.

Cartographic Satellite-I (Cartosat-1) data have a spatial resolution of 2.5 meters and cover a swath of 30 km. Two cameras are mounted on the satellite in such a way that near-simultaneous imaging of the same area from two different angles is possible. This facilitates the generation of accurate three-dimensional maps. The data from IRS-P5 strengthen large-scale mapping and amplify its application in urban and rural development, land cover change detection, relief planning and management, environmental impact assessment, and various Geographical Information Systems (GIS) applications.

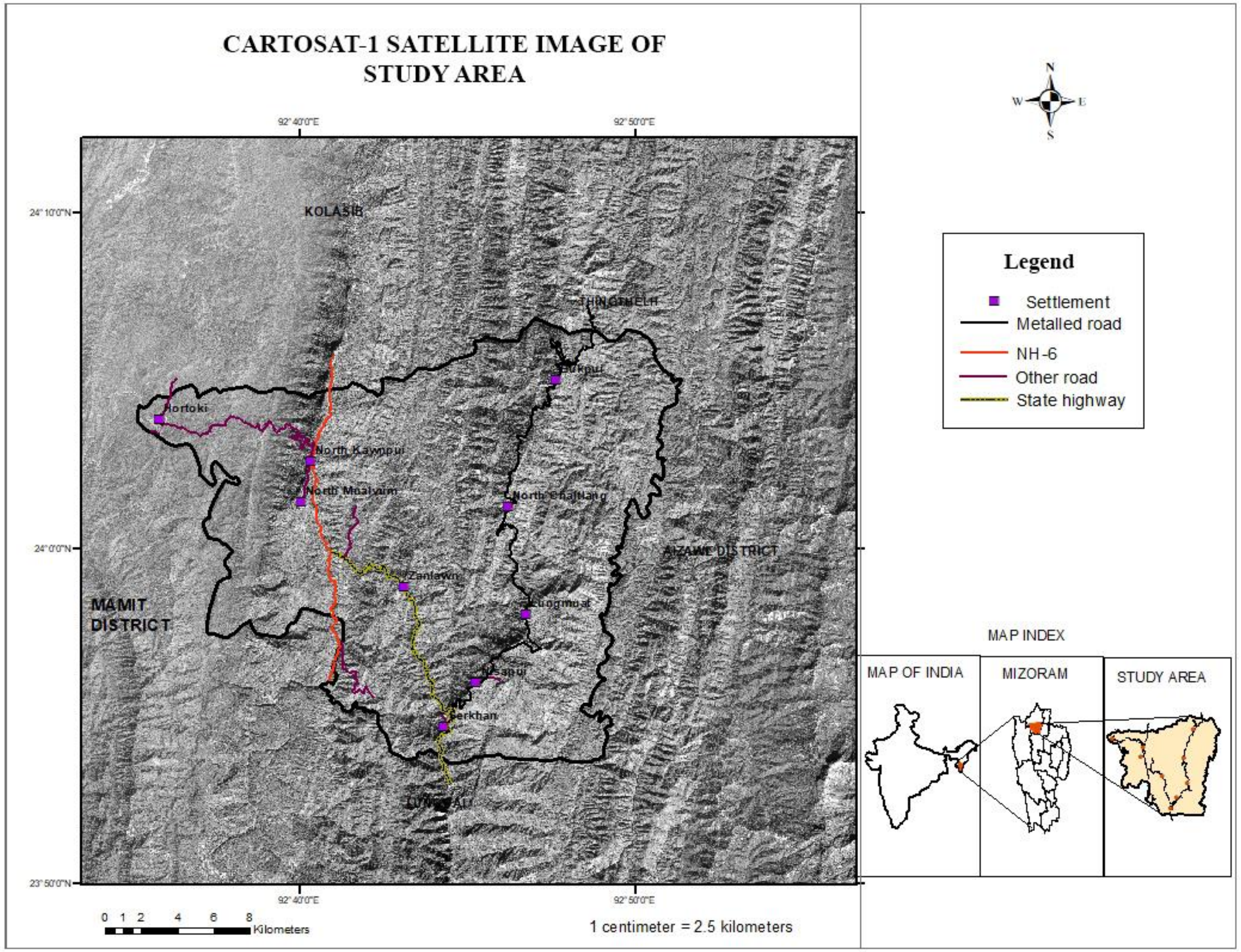


Figure 21: Cartosat-I satellite image of the study area

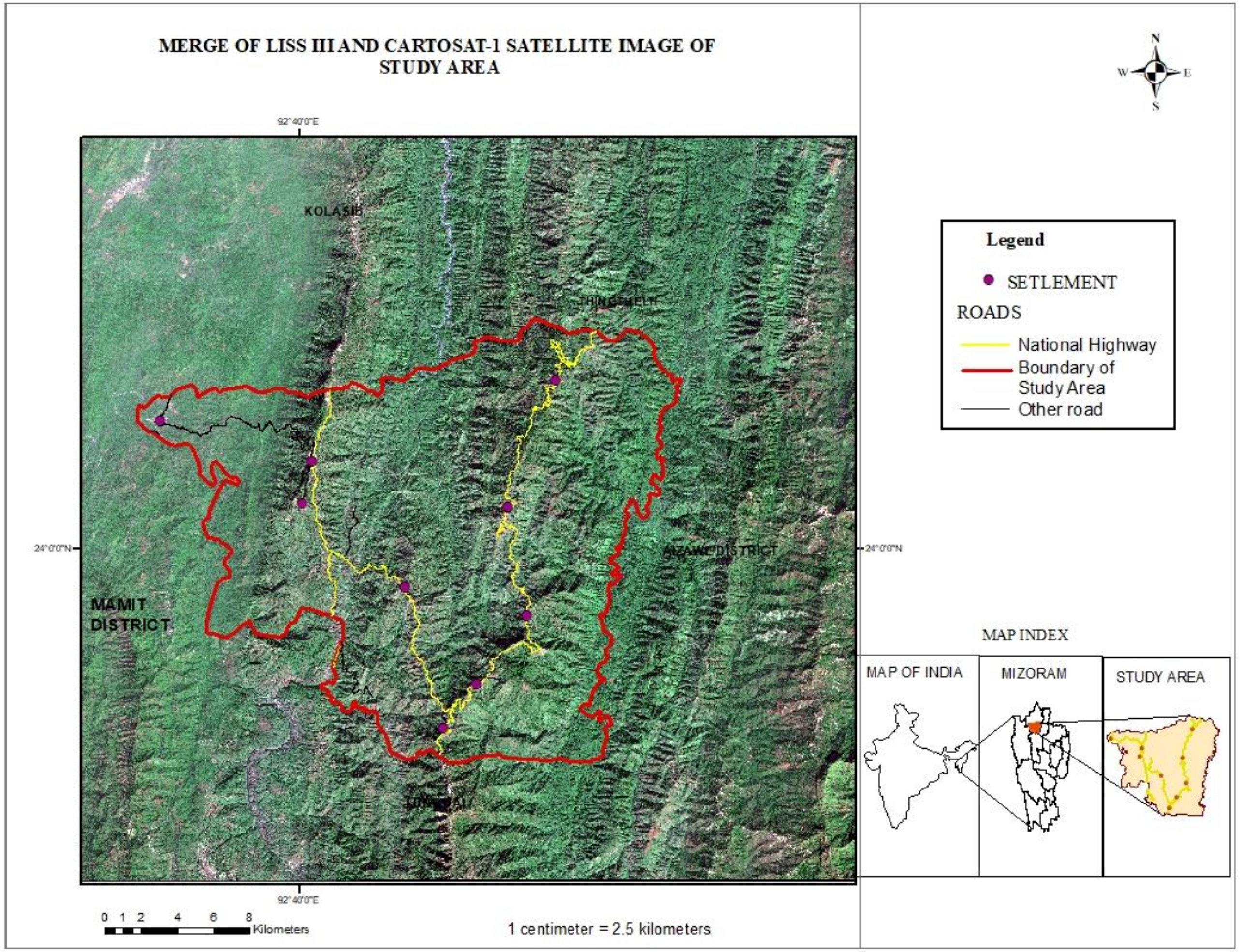


Figure 22: Merge of LISS III and Cartosat-I satellite images of the study area

4.3 Legacy /Collateral Data

The collateral data are gathered from various sources. Demographic data are collected from Base Line Survey conducted by Swatch Bharat Mission, Project Management Unit, PHED Mizoram in 2012 and Accredited Social Health Activist, ASHA, Community Health Centre, Kawnpui, Mizoram in 2022. Meteorological data are collected from IMD, Government of India. Reports and maps from various departments of the state and also from the Geological Society of India, Oil and Natural Gas Corporation (ONGC) and State Remote Sensing Centre, etc.

Forty-seven grids of the Survey of India Toposheet cover Mizoram on a 1:50000 scale. Toposheet No. 83D/6, 83D/12, 84A/9, and 84A/13 are used for preparing base maps and for deriving physiographic information such as altitudes, contours, drainage, geomorphic units, etc.

Data on groundwater quality collected and prepared by the State Referral Institute (SRI), Aizawl Public Health Department, Government of Mizoram, are also utilized.

4.4 Field data

Various field information was collected such as geological data like rock type, faults, joints, dip direction and amount, etc., spring location, spring type, drainage, watershed management, land use, disposal of public waste, and general geomorphology, etc. are also observed and collected during a field visit. Water samples are collected every pre-monsoon, monsoon, and post-monsoon season for three consecutive years

4.5 General methodology

4.5.1 Pre-fieldworkData collection and Analysis: Available information like literature, maps, socio-economic data, and meteorological data are collected from various sources. Toposheet and satellite imageries of the study area are also collected. They were digitized and classified using Geographical Information System (Arc Info)to produce base maps and thematic maps. Preparation of a Lithostratigraphic map, Geomorphological map, drainage map, drainage density map, and Geological structure map is carried out (Geosciences Division, 2012)

4.5.2On-screen interpretation of data: The digitized satellite data, toposheets, and georeferenced GSI& ONGC map, etc. are processed in the Geographical Information System (Arc Info), and the thematic information such as geomorphological, lithostratigraphic, and structural are delineated. All output from this delineation is in vector format, comprising point, line, and polygon features, which supports complex GIS analysis. The on-screen interpretation and mapping enable us zooming and identification of the smaller objects in the image such as minor fractures etc. The distribution and area extent of any spatial objects can be mapped more precisely and details information about each object or feature are incorporated in the GIS system. The vector data are created simultaneously while interpreting the image thereby saving the time of analysis.

Base Map Preparation: At the same time, the base map details are prepared based on on-screen visual interpretation using image interpretation techniques. The interpreted data are crosschecked and corrected with ground truth information from the fieldwork.

The base Map Layer consists of four categories of information. Such are:–

a) Administrative
b) Settlements
c) Road network
d) Rivers

The administrative Units are mapped as polygon shapefile, the settlements are represented as point shapefile, and the road network is mapped by line shapefile.

Thematic mapping: All components capable of affecting the occurrence and movement of groundwater are mapped in the form of thematic layers. Such components are: -

a) Geomorphology layer: During the preparation of the Geomorphic unit, the Geomorphic Map already prepared by Mizoram Remote Sensing Application Centre is used as a reference. All the readable landforms / Geomorphic Units occurring in the image are mapped as polygon features. Each unit is denoted with their respective geomorphic nomenclatures. The Geomorphic Units/landforms are denoted with an alphabetic annotation such as FV for Fractured Valley, IV for Intermontane Valley, SHL for Less Dissected Structural Hill, SHM for Moderately Structural Hill, and SHH for Highly Dissected Structural Hill.

Mainly the toposheet was consulted to comprehend the relief variations and other topographic features. As the deposition of sediments is controlled by the topographic features, consequently co-terminus is established between lithological and Geomorphic boundaries wherever it is possible.

b) Lithostratigraphic layer: For the delineation of the Lithostratigraphic map, Lithological Map prepared by GIS, and ONGC is employed. The classification has been done based on the proportions of argillaceous and arenaceous content and topography (GSI, 2011). Hence, the correlation of the sequence of monotonous rock with topographic features is the main factor for delineating Lithological Unit, each layer is prepared by polygon features and is annotated with respective lithostratigraphic nomenclature in an alphabetical code such as LBh for Lower Bhuban, MBh for Middle Bhuban, UBh for Upper Bhuban, Bkl for Bokabil Formation. Field truth data and consultation with existing maps/literature help in gaining knowledge about the geological setting of the area and different rock types that occur in the watershed area or are likely to occur in the unexplored area.

In addition, prior knowledge of geology is very helpful while observing the satellite image to demarcate tonal variation, color variation, structures, erosional variation, and control of drainage and other image characteristics related to different rock types.

c) Structural layer: The geological structures like faults, fractures/lineaments, bedding, etc., which act as conduits and barriers for the movement of groundwater are delineated as layers consisting of line features. The relation between such structures in the watershed area and the location of springs/ seepage zones are correlated to comment on the control of such discontinuities on groundwater occurrence, flow, and quality.

Prior documented data are consulted during the mapping of Lineaments. They are mapped using the Digital Elevation Model and Satellite imageries. Some lineaments, which are already confirmed by other reports and studies, are classed as Faults, and that show lateral displacements are classed as Inferred Faults, and lineaments with no prominent displacements are classed as Lineaments.

The Structural elements in the area are both primary and secondary. The strike of the beds generally trends N-S to roughly NNW-SSE. The rock beds Serkhan to Lungmuat Ridge, Serkhan to Zanlawn Ridge, and Kawnpui Ridge line are dipping towards East whereas N.Chaltlang to Bukpui Ridge are characterized by rock dipping towards West. However, a variable degree of local variation is observed in shearing areas and the vicinity of faults. Secondary Structures comprise mainly lineaments, which vary in length, and joints, which are either tightly or widely spaced in sandstone. The frequency of joint occurrence and fractures in shale and shale are noticed to be increased in the vicinity of Faults.

4.5.3 Field data collection: Fieldwork was conducted in every Pre-Monsoon (January -April), Monsoon (May-August), and Post-Monsoon(September-December) during three consecutive years, starting from 2017 Monsoon to 2020 Pre-Monsoon. It mainly includes the collection of samples from potable water sources, sample collected were separately marked as Spring/tuikhur or dug well or hand pump or PHED supplied and locations were recorded accordingly with the help of GPS. The method used for the collection of samples is the grab sampling method as per the recommendation of APHA, AWWA (2012).

4.5.4 Laboratory analysis/ Method for analyzing physicochemical properties of groundwater: Laboratory work involves analysis of physical, chemical, and bacteriological parameters. Physio-chemical of water from each season were analyzed thrice a year (Monsoon,2017 – Post-Monsoon,2020)in the District Laboratory of Public Health Engineering Department, Kolasib, and the bacteriological property was tested in August and September 2021 in District PHED Laboratory, Kolasib. The pH of the water samples was measured by using a digital instrument made by "Eutech Instruments" (www.eutechinst.com). Turbidity, total Chlorides (TCl^-), Iron, Total Hardness (TH), and bacteriological test were done by using a water testing kit made by "Transchem Agritech Limited" (www.transchem.in)and total alkalinity (TA) is estimated by a titrimetric method.

In addition, heavy metal analysis is carried out for selected samples and elements in Central Instrumentation Laboratory (CIL), Mizoram University to acquire the concentration of toxic elements in groundwater. The heavy metal test was conducted from samples of Pre-Monsoon 2018, Monsoon 2018, and Post-Monsoon

2019. Analysis of elements that occur as major constituents in potable water like Mg and Cl; minor constituents such as Cu, Mn, Al, Ba, Zn, Cd, Pb, Ni, Cr, Co, and Li as well as trace constituents like Ga, In and Ag were analyzed in Microwave Plasma-Atomic Emission Spectrometer – Agilent 4100 (MP- AES). The arsenic test is conducted with an Eozy water testing kit made by Octopus Inc. Vadodara, Gujarat. Secondary constituents of potable minerals like Mg and Fe were tested by MP-AES and a testing kit made by “Transchem Agritech Limited” (Todd 1980).

4.5.5 Software: Geospatial technology is incorporated for data analysis and interpretation. The results were analyzed by using ArcGIS 10.4.1 software. From the analysis results, vulnerable sources such as springs/tuikhurs or hand pumps are identified. Correlation between physical properties and each element with Geomorphic units as well as with the host rock chemistry and Lithostratigraphic units are depicted. When they are incorporated with geological structures, land use, and watershed conditions provide rock-water interactions.

The term 'Geospatial technology' refers to technology that includes Global Positioning System (GPS), Geographical Information System (GIS), and Remote Sensing (RS). It enables us to acquire data that is referenced with the earth's surface and therefore allows us to do modeling, visualization, measurement, and analysis of the earth's features. All these processes were implemented together in this research for the digitization of data and preparation of various thematic information, which are finally represented in the form of layers such as Structural maps, Geomorphic maps, and Lithological maps. GPS helps in collecting the geographic location of all the spatial objects, which helps interpret rock-water interactions. Remote sensing techniques refer to the utilization and interpretation of data gathered by remote sensory devices like different kinds of satellite imagery. Thus, the valuable information about collected data (non-spatial data) with GPS data (spatial data) and remote sensing data are integrated with the help of the Geographical Information System in this research to generate products that give information about groundwater quality and its relation with the surrounding environment. Area calculation is done to obtain spatial coverage.

In the present study, the distribution of concentration values of various elements present in the groundwater samples collected from different habitations is mapped. During the mapping of groundwater quality, each groundwater sample is considered as a representative of particular areas from which it was taken. The variation of quality of groundwater from recorded spatial location and from pre-monsoon to post-monsoon for each element was mapped out to give recommendation and comment useful to the villager. The spatial interpolation technique through Inverse Distance Weighted (IDW) approach has been employed in the present study for generating spatial distribution of the groundwater quality for pre-monsoon, monsoon, and post-monsoon seasons for 2017-2020 (three years) in ArcGIS 10.4.1 software.

Inverse distance weighting (IDW) is a type of deterministic method for multivariate interpolation with a known location of the scattered set of points. The assigned values to unknown points are calculated with a weighted average of the values available at the known points. The spatial variation maps of major groundwater quality parameters were prepared and a recommendation was made as per BIS guidelines and WHO guidelines. Structural associated with rock formation topography, land use, etc. are further examined in those sources that fall in non-potable to determine the probable source of contamination. Spatial variation maps were prepared for each parameter in season-wise (i.e. Pre-monsoon, Monsoon, and Post monsoon). The concentration of ground water quality parameters in all the Lithostratigraphic unit and Geomorphological classes were also calculated and represented in the form of a bar chart for evaluating the groundwater quality in the study area. A flow chart illustrating the steps and process involved in groundwater quality analysis and mapping has been formulated in Figure 23.

4.5.5 Method for Bacteriological analysis: A Presence- Absence (PA) test of waterborne pathogens, microorganisms, and fecal coliforms, which used sensitive indicators is used. Tests for Total coliform, Fecal coliform, and E. *coli* were carried out using standard laboratory techniques. For bacteriological analysis, water samples were collected and analyzed, the result was given in Most Probable Number (MPN).

Standard laboratory investigation was done for bacteriological analysis for all the groundwater samples at District PHED Laboratory, Kolasib.

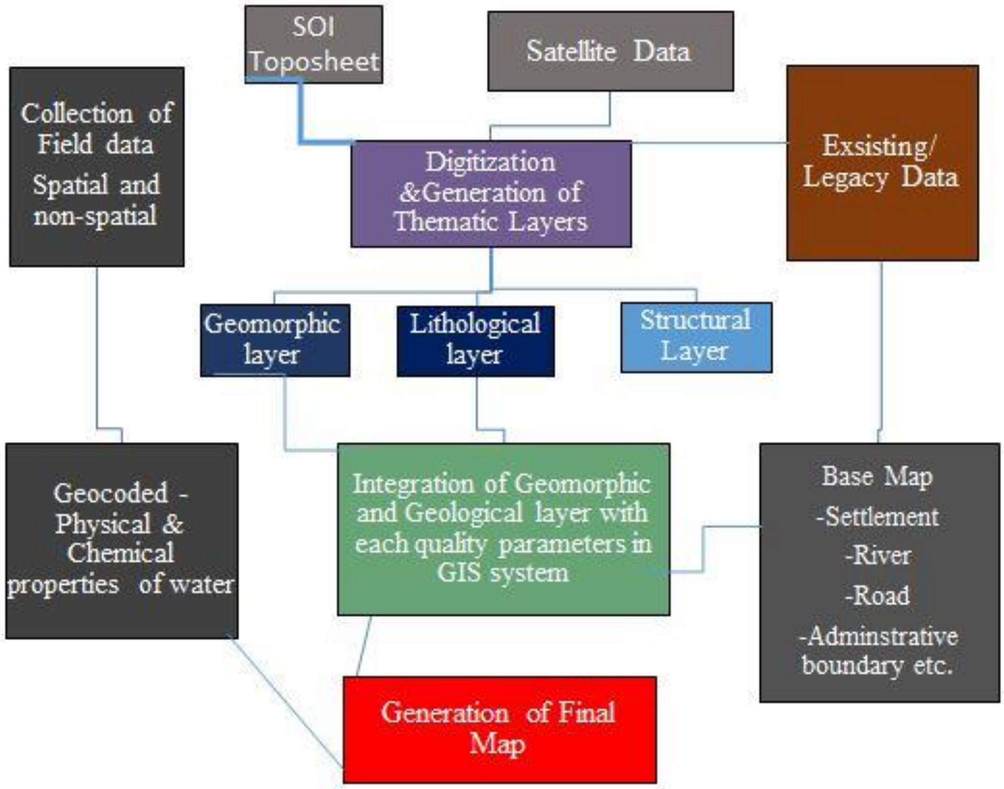


Figure 23: Flow chart of methodology for groundwater quality analysis.

Chapter V
RESULTS AND DISCUSSION

5. Groundwater quality assessment:

Various quality parameters of potable water in the study area are analyzed to determine groundwater quality; each finding is later integrated with the geologic, geomorphic setting, and seasonal variation. The results and discussion for the different parameters are as follows:

5.1 Color:

Pure water is colorless and transparent, allowing light to pass through. However, colored components in water absorb light energy hindering penetration as deeply as in colorless water. Certain wavelengths that get reflected from water allow us to observe the color. The transparency nature of water is affected by its turbidity and color. Water intended for drinking purposes should have Hazen Unit < 1 by BIS guidelines. Coloring of water may result from different sources including natural metallic ions (iron and manganese), organic materials (humus and peat), planktons, industrial wastes, etc., Metallic ions such as iron and manganese usually impart reddish-brown color to water. Some living plants can also release colored organic compounds into the water. Colored water loses its aesthetic value, and is discarded for fishing and swimming, etc. It also hampers oxygen absorption from the atmosphere into water. Such water is also not accepted in the food production industry, pharmaceuticals, and beverages.

Several algal species, especially those with small cells can impart coloration easily in uncovered tanks. The main colors produced by algae include yellow to green, blue to green, red to brown, and black. In addition, the inner surface of pipes and tanks usually possesses a thin membrane of microorganisms such as bacteria, fungi, and actinomycetes. This biological accumulation can gradually start corroding pipes and tanks and the submerged parts of the concrete cements also became pitted and friable due to the growth of green and blue-green algae along with mosses and lichens. The oxygen released from algae can also trigger corrosion and they are also known to cause changes in the normal range of certain physicochemical properties such as pH, CO_2, and $CaCO_3$, which are all responsible for increasing the rate of corrosion (Goel, 2006).

However, the bore well sample of the Lalkima point hand pump, N.Chaltlang, and Sub-station Peng hand pump, Bukpui are turning yellowish to reddish-brown color after putting in a container for 4-7 days. The red, brown, orange, or yellow color of the water is usually caused by corrosion of Iron. Galvanized iron, steel, and iron pipes in water transport facilities or bore well can cause water to have a rusty appearance. As both samples have Fe content exceeding 0.1ppm, they precipitate upon oxidation and cause deterioration in their clarity, consequently resulting in imparting color and stains to the plumbing and utensils (USGS, 1962).

Table 12: Color (2017-2019)

Sl.No	Name	Village	Lattitude	Longtitude	Colour Pre-Monsoon			Colour Monsoon			Colour Postmonsoon		
					2017	2018	2019	2017	2018	2019	2017	2018	2019
1	Vankeu	Serkhan	23.905	92.753	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
3	Dengalui	Serkhan	23.915	92.74	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
4	Bawngpu	Serkhan	23.908	92.739	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
5	Vautangbawk	Serkhan	23.915	92.78	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
6	Lalthansiama Point	Nisapui	24.037	92.755	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
7	Zotui	Nisapui	23.94	92.762	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
8	Challui	North Chaltlang	24.0214	92.784	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
9	Lalkima Point Handpump	North Chaltlang	24.018	92.765	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
10	Chhimluang	North Chaltlang	24.01	92.768	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
11	Lengleh	North Chaltlang	24.024	92.767	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
13	Lungsum	Bukpui	24.084	92.788	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
14	Builum	Bukpui	24.067	92.78	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
15	Minmawng	Bukpui	24.085	92.791	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
17	Nuhliri Point	Bukpui	24.077	92.793	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
18	Phulraw lui tuikhur	Zanlawn	23.939	92.728	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
19	Vandawt	Zanlawn	23.984	92.694	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
20	Hiahthar	Zanlawn	23.966	92.724	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
21	Fului	Zanlawn	23.97	92.711	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
22	Pumpelh	Zanlawn	23.99	92.707	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
23	Midum Lui	Zanlawn	23.987	92.705	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
24	Phuanberh	Kawnpui	24.034	92.673	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
25	Hlitlui	Kawnpui	24.05	92.673	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
26	Charpui	Kawnpui	24.05	92.674	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
27	Vailui	Kawnpui	24.034	92.668	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
29	Kuangsei	Kawnpui	24.0376	92.672	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
30	Sentezel	Kawnpui	24.04	92.674	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
31	Sihpui tuikhur	Kawnpui	24.045	92.67	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
32	Sakhisih	Kawnpui	24.044	92.669	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
33	Bawkkang	Kawnpui	24.03	92.675	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
36	Tuitun	Kawnpui	23.9667	92.681	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
37	Khurthuk	Kawnpui	24.039	92.67	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
38	Sihpui	Kawnpui	24.036	92.669	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
39	Lungpher	Hortoki	24.06	92.602	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
40	Khawzasiaka	Hortoki	24.056	92.596	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
41	Zotui	Lungmuat	23.972	92.778	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
42	Luihnai	Lungmuat	23.966	92.779	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
43	Thingsakawr lui	Lungmuat	23.955	92.795	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
44	Veng Chung Lui	Lungmuat	23.9714	92.782	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless

5.2 Odor:

Tastes and odors are usually the products of certain impurities such as organic matter, and inorganic salts like NaCl, $MgCl_2$, $MgSo_4$, $FeSO_4$, and $MnCl_2$, etc. The odor is naturally produced by decaying organic matter under anaerobic conditions because of accumulation of certain odorous gases like ammonia and hydrogen sulphide. Most of the problems associated with drinking water supplies associated with tastes and odors are due to the presence of algal species and certain microorganisms. Algae secrete oil-type substances, which impart particular tastes and odors to the water. Actinomycetes also produce typical odors such as earthy or musty. Bacteria growing in the drainage system, which later enter into water bodies as well as naturally occurring hydrogen sulphide in the water supply may cause Sulfur or rotten egg odor. Bacteria growing in a sink drain or from the decay of organic matter such as plants, animals, or bacteria that are naturally present in water bodies may cause moldy, earthy, and fishy odors. Due to the presence of metallic ions such as Iron, Copper, and Manganese, the water may sometimes have a metallic odor. Chlorine added to the water or the interaction of chlorine with organic matter in the plumbing system may cause the odor of Chlorine, chemical, or medicine. Water having tastes and odors is not accepted in the food production industry, pharmaceuticals, and beverages. The presence of toxic gases like Hydrogen Sulphide (H_2S) and Methane (CH_4) is a common concern that frequently exists in water. It may cause fatalities among sewage workers (Goel, 2006).

However, all samples from each season during three consecutive years are devoid of any unpleasant smell.

Table 13: Odor (2017-2019)

Sl.No	Name	Village	Lattitude	Longtitude	Odour Pre-Monsoon			Odour Monsoon			Odour Postmonsoon		
					2017	2018	2019	2017	2018	2019	2017	2018	2019
1	Vankeu	Serkhan	23.905	92.753	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
3	Dengalui	Serkhan	23.915	92.74	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
4	Bawngpu	Serkhan	23.908	92.739	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
5	Vautangbawk	Serkhan	23.915	92.78	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
6	Lalthansiama Point	Nisapui	24.037	92.755	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
7	Zotui	Nisapui	23.94	92.762	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
8	Challui	North Chaltlang	24.0214	92.784	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
9	Lalkima Point Handpump	North Chaltlang	24.018	92.765	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
10	Chhimluang	North Chaltlang	24.01	92.768	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
11	Lengleh	North Chaltlang	24.024	92.767	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
13	Lungsum	Bukpui	24.084	92.788	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
14	Builum	Bukpui	24.067	92.78	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
15	Minmawng	Bukpui	24.085	92.791	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
17	Nuhliri Point	Bukpui	24.077	92.793	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
18	Phulraw lui tuikhur	Zanlawn	23.939	92.728	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
19	Vandawt	Zanlawn	23.984	92.694	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
20	Hiahthar	Zanlawn	23.966	92.724	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
21	Fului	Zanlawn	23.97	92.711	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
22	Pumpelh	Zanlawn	23.99	92.707	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
23	Midum Lui	Zanlawn	23.987	92.705	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
24	Phuanberh	Kawnpui	24.034	92.673	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
25	Hlitlui	Kawnpui	24.05	92.673	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
26	Charpui	Kawnpui	24.05	92.674	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
27	Vailui	Kawnpui	24.034	92.668	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
29	Kuangsei	Kawnpui	24.0376	92.672	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
30	Sentezel	Kawnpui	24.04	92.674	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
31	Sihpui tuikhur	Kawnpui	24.045	92.67	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
32	Sakhisih	Kawnpui	24.044	92.669	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
33	Bawkkang	Kawnpui	24.03	92.675	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
36	Tuitun	Kawnpui	23.9667	92.681	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
37	Khurthuk	Kawnpui	24.039	92.67	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
38	Sihpui	Kawnpui	24.036	92.669	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
39	Lungpher	Hortoki	24.06	92.602	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
40	Khawzasiaka	Hortoki	24.056	92.596	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
41	Zotui	Lungmuat	23.972	92.778	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
42	Luihnai	Lungmuat	23.966	92.779	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
43	Thingsakawr lui	Lungmuat	23.955	92.795	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
44	Veng Chung Lui	Lungmuat	23.9714	92.782	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless

5.3 Taste:

Iron, copper, zinc, and manganese may leach into the water from the pipes, this may cause the water to have a metallic taste. Chlorine, chemical, or medicinal taste can occur due to adding of chlorine to the water. The presence of a high amount of naturally occurring sodium, magnesium, or potassium may cause a salty taste, especially in an area where there is a salt-water intrusion. In addition, the presence of several algae and bacteria in water can produce slime or mucilaginous matter. It may hamper the water quality for use in certain food industries. Many members of the blue-green algal group are frequently producing slime (Goel, 2006). Copper and Zinc at a concentration of 3mg/l in water can give an unpleasant taste to the water (Chubaka *et al*., 2018).

Due to the nature of Geological settings and lithology, all samples are free from such unpleasant tastes. However, the presence of saline springs has been known from different regions within the state.

Table 14: Taste (2017-2019)

Sl.No	Name	Village	Lattitude	Longtitude	Taste Pre-Monsoon			Taste Monsoon			Taste Postmonsoon		
					2017	2018	2019	2017	2018	2019	2017	2018	2019
1	Vankeu	Serkhan	23.905	92.753	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
3	Dengalui	Serkhan	23.915	92.74	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
4	Bawngpu	Serkhan	23.908	92.739	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
5	Vautangbawk	Serkhan	23.915	92.78	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
6	Lalthansiama Point	Nisapui	24.037	92.755	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
7	Zotui	Nisapui	23.94	92.762	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
8	Challui	North Chaltlang	24.0214	92.784	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
9	Lalkima Point Handpump	North Chaltlang	24.018	92.765	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
10	Chhimluang	North Chaltlang	24.01	92.768	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
11	Lengleh	North Chaltlang	24.024	92.767	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
13	Lungsum	Bukpui	24.084	92.788	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
14	Builum	Bukpui	24.067	92.78	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
15	Minmawng	Bukpui	24.085	92.791	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
17	Nuhliri Point	Bukpui	24.077	92.793	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
18	Phulraw lui tuikhur	Zanlawn	23.939	92.728	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
19	Vandawt	Zanlawn	23.984	92.694	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
20	Hiahthar	Zanlawn	23.966	92.724	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
21	Fului	Zanlawn	23.97	92.711	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
22	Pumpelh	Zanlawn	23.99	92.707	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
23	Midum Lui	Zanlawn	23.987	92.705	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
24	Phuanberh	Kawnpui	24.034	92.673	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
25	Hlitlui	Kawnpui	24.05	92.673	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
26	Charpui	Kawnpui	24.05	92.674	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
27	Vailui	Kawnpui	24.034	92.668	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
29	Kuangsei	Kawnpui	24.0376	92.672	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
30	Sentezel	Kawnpui	24.04	92.674	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
31	Sihpui tuikhur	Kawnpui	24.045	92.67	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
32	Sakhisih	Kawnpui	24.044	92.669	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
33	Bawkkang	Kawnpui	24.03	92.675	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
36	Tuitun	Kawnpui	23.9667	92.681	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
37	Khurthuk	Kawnpui	24.039	92.67	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
38	Sihpui	Kawnpui	24.036	92.669	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
39	Lungpher	Hortoki	24.06	92.602	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
40	Khawzasiaka	Hortoki	24.056	92.596	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
41	Zotui	Lungmuat	23.972	92.778	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
42	Luihnai	Lungmuat	23.966	92.779	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
43	Thingsakawr lui	Lungmuat	23.955	92.795	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
44	Veng Chung Lui	Lungmuat	23.9714	92.782	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless

5.4 pH:

It is a measure of how acidic or basic the water is. Acidity in natural water is caused by either free carbon dioxide or mineral acids. It can be affected by both natural and man-made factors. The carbon dioxide is known to remain in the water at a pH between 4.5 to 8.5 and gradually decreases with an increase in pH due to the conversion of some carbon dioxide to carbonate and bicarbonate. Acid mine drainage-containing ores of Sulphur or Iron pyrites (FeS_2) in the form of impurities usually cause a decrease in the pH of water. Acidity induced by CO_2 hardly causes health-related problems as compared to that caused by mineral acidity. High sulphuric concentration in water causes corrosion of structures and most biological life is also restricted to a narrow range of pH between 6.5 to 8.5 (Goel, 2006). Naturally, the interaction of groundwater with its surrounding rocks (particularly carbonate rocks) and the geomorphological condition of the source can control pH. It can also fluctuate with the nature of precipitation (especially acid rain) and wastewater discharge. As per BIS guidelines, the Desirable range of pH in groundwater is 6.5 to 8.5. Groundwater having pH below and above this range is too acidic or basic, such are fall into the Non-potable class (BIS, 2012). The average pH during pre-monsoon, monsoon, and post-monsoon is 7.14, 6.63, and 6.69 respectively. It is highest during Pre-Monsoon. The pH values in the Geomorphic Units are shown below:-

Table 15: Average pH in Geomorphic Units

Sl.No	Geomorphology	Average pH Pre-Monsoon	Average pH Monsoon	Average pH Post-Monsoon	Average
1	Fracture Valley (FV)	7.820	7.520	6.650	7.330
2	Highly Dissected Structural Hill (SHH)	7.140	7.180	6.240	6.853
3	Inter-Montane Valley (IV)	7.250	7.260	5.860	6.790
4	Less Dissected Structural Hill (SHL)	7.150	6.650	6.410	6.737
5	Moderately Dissected Structural Hill (SHM)	6.900	6.410	6.180	6.5
	Average	7.252	7.004	6.268	

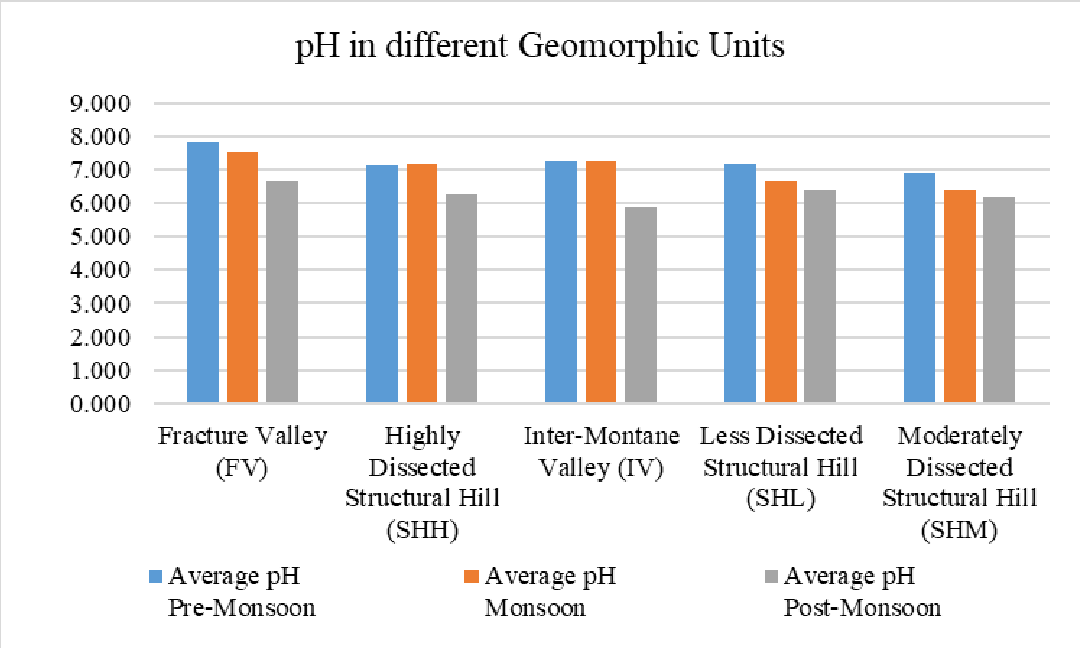


Figure 24: Bar chart of pH in Geomorphic Units

In terms of Geomorphologic Units, the pH of groundwater is lowest in Moderately Dissected Structural hills. Moderately Dissected Structural Hill Unit accounts for 46.188% of the study area and most of the settlements and habitation occur in this Unit, consequently receiving rainwater with higher carbonic acid content. The fractured valley has the highest pH value of 7.33 which is slightly alkaline and groundwater in all other formations is lean towards acidic nature. Water in Fracture Valley has higher alkalinity as the water is coming out from deeper ground fractured. Hence, they are less affected by acidic rainwater and are also richer in dissolved constituents.

Samples from all Units are well within the specified requirement during the Pre-monsoon period, which indicates the lithology and mineral composition are of neutral pH. Then, the average pH of water in Moderately Dissected Hill becomes unfit for human consumption in the Monsoon period; this shows the initial state of diffusion of rainwater with that of water existing in the aquifer. The rainwater gradually recharges the deep aquifer, when the diffused stored groundwater is discharged into the surface the pH value declines and eventually becomes acidic from Pre-Monsoon to Post-Monsoon. It may indicate the neutral water becomes more and more acidic as the rainwater diffuses with pre-existing neutral or alkaline water in the aquifer. So, in the Post-monsoon season, water in all Geomorphic Units except water in Fracture Valley becomes non-potable for drinking. On the other hand, the ground is saturated due to heavy rainfall during monsoon and when post-monsoon arrives, the rain that infiltrates in the shallow ground is discharged into water bodies as interflow and groundwater consequently tends to have relatively low pH.

The pH values in the lithological Units are shown below: -

Table 16: Average pH in Lithological Unit

Sl.No	Lithostratigraphic Unit	Average pH Pre-Monsoon	Average pH Monsoon	Average pH Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	6.97	6.69	6.38	6.68
2	Sandstone dominated (Upper Bhuban Formation)	6.98	6.44	6.24	6.55
3	Shale dominated (Middle Bhuban Formation)	7.02	7.05	6.33	6.80
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	7.7	7.47	5.93	7.03
	Average	7.17	6.91	6.22	

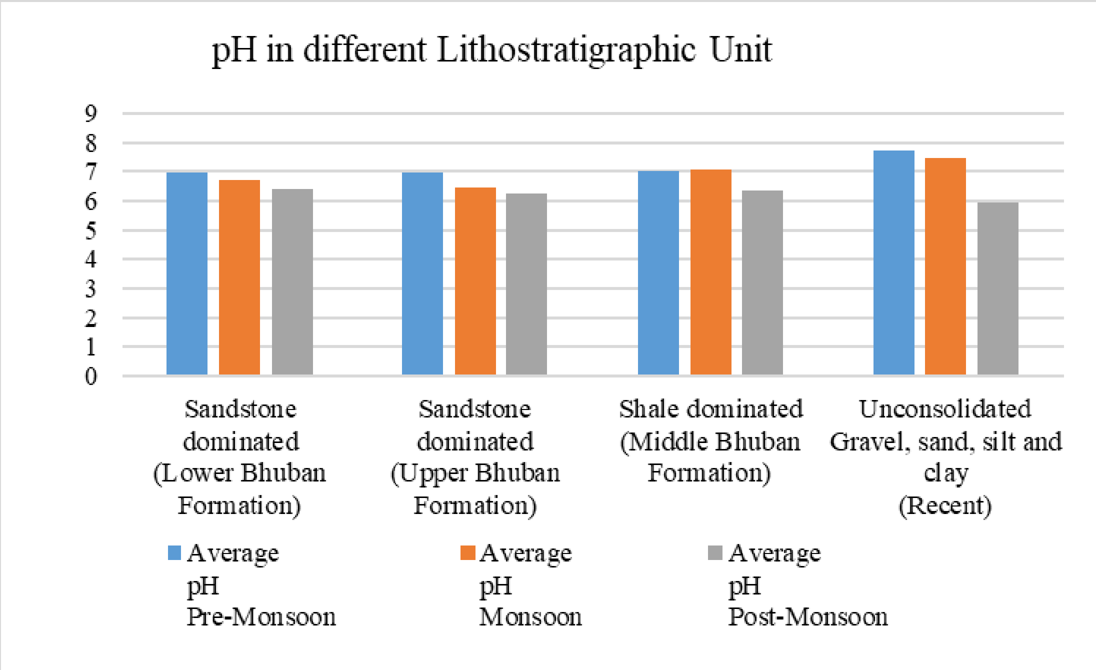


Figure 25: Bar chart of pH in Lithostratigraphic Units

In terms of lithological divisions, the Sandstone of the Upper Bhuban Formation has the lowest pH value. It is also found that the groundwater in sandstone-dominated Formation is of lower pH than shale formations. This may be due to the acidic nature of sandstone as compared to shale. Being rich in clay minerals, the reverse case is observed in Unconsolidated sediment. Clay minerals like kaolinite, smectite, kaolinite, and mica are rich in ions like $Mg2+$, $Ca2+$, and $Na+$. Therefore, the acidic water in Unconsolidated Formation became neutral or alkaline as these ions are dissolved in water.

Throughout these three consecutive years, the vicinity of Kawnpui town is characterized by low pH of 5 to 6.5, which is lower than the desirable range. Most of the remaining areas are having pH within a desirable range of pH 6.5 to 8.5 during Monsoon. During Pre-Monsoon, the broader area around Kawnpui and smaller areas around Bukpui, and Lungmuat are characterized by low pH values. As ground saturation increases, samples of post-monsoon from the southeastern part of the area, Serkhan, Lungmuat, and the southern part of Zanlawn village are having low pH values. However, samples around Nisapui, N.Chaltlang, and Zanlawn villages are having desirable pH. The local variation in the acidity of rainwater is attributed to the main factor for differential pH in the area.

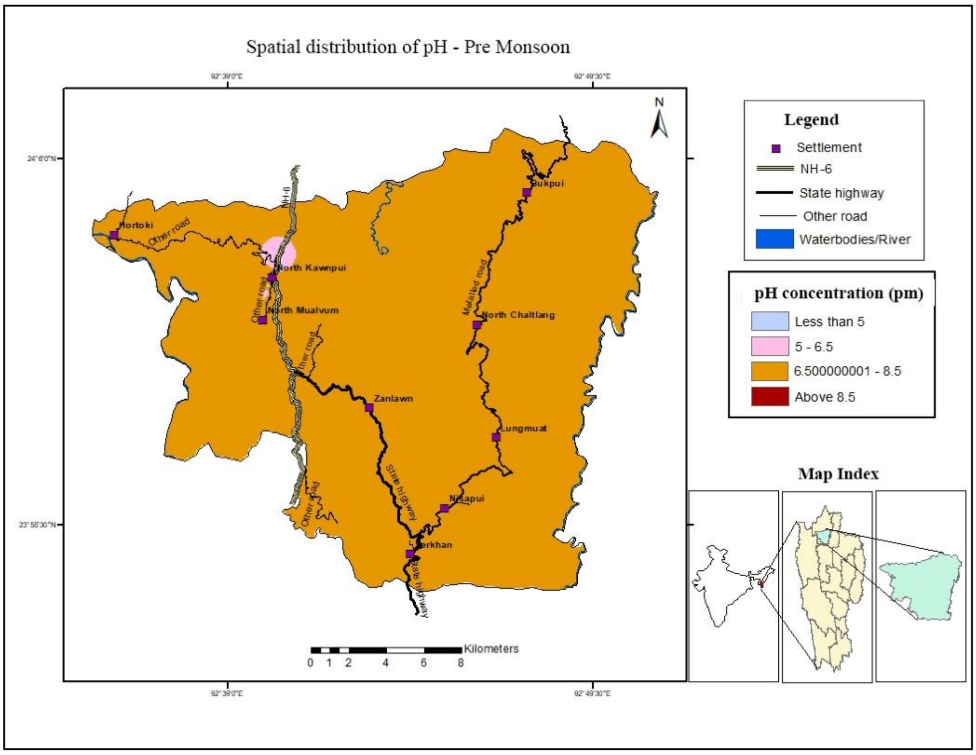


Figure 26: Spatial distribution of pH in Pre-Monsoon

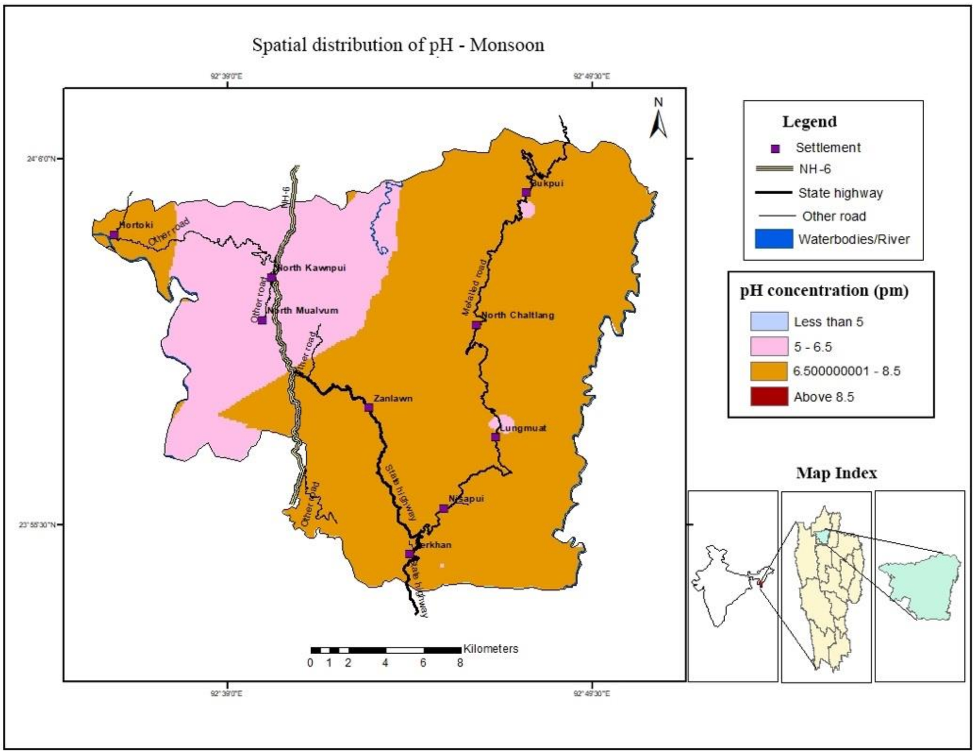


Figure 27: Spatial distribution of pH in Monsoon

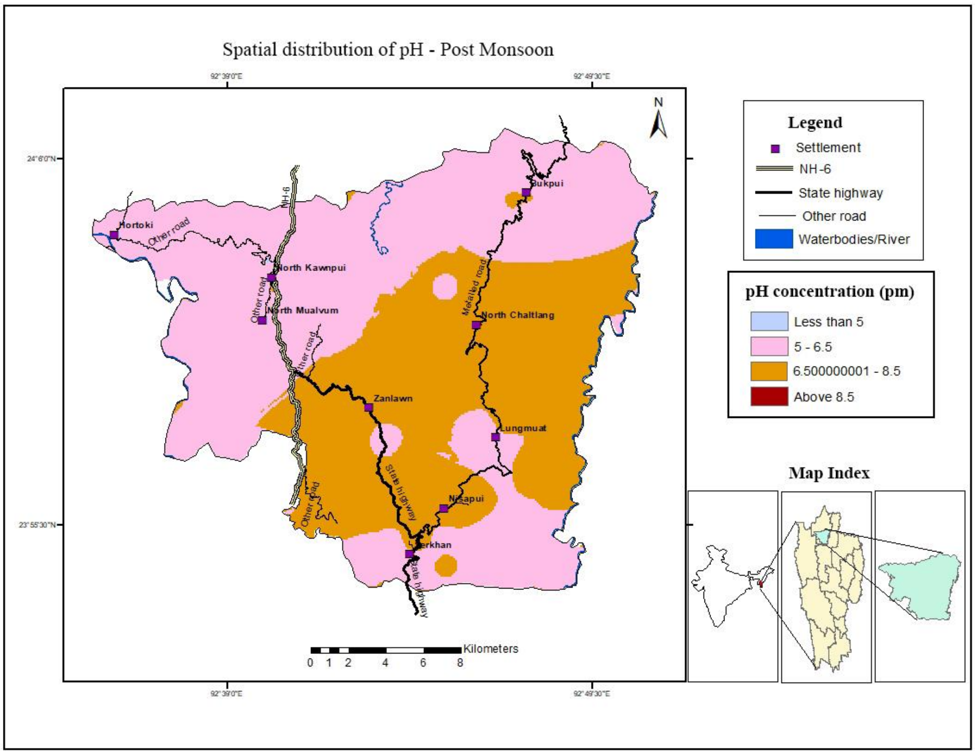


Figure 28: Spatial distribution of pH in Post-Monsoon

Table 17: Value of pH (2017-2019)

Sl.No	Source Name	Village	Lattitude	Longtitude	pH Pre-Monsoon			Ph Pre-Monsoon average	pH Post-Monsoon			Ph Post-Monsoon Average	pH Monsoon			pH Monsoon Average
					2017	2018	2019		2017	2018	2019		2017	2018	2019	
1	Vankeu	Serkhan	23.905	92.753	7.12	7.72	7.33	7.39	5.9	6.11	7.76	6.59	6.05	6.34	7.1	6.49
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	7.18	7.24	7.25	7.22	6.12	5.98	7.61	6.57	7.27	7.23	7.25	7.25
3	Dengalui	Serkhan	23.915	92.74	7.09	7.17	7.21	7.15	6.82	6.84	6.86	6.84	7.21	7.25	7.23	7.23
4	Bawngpu	Serkhan	23.908	92.739	7.03	7.05	7.09	7.05	5.6	5.1	5.4	5.3	7.05	7.07	7.09	7.07
5	Vautangbawk	Serkhan	23.915	92.78	7.61	7.68	7.67	7.65	7.31	6.32	5.61	6.41	7.65	7.69	7.67	7.67
6	Lalthansiama Point	Nisapui	24.037	92.755	7.03	7.06	7.09	7.06	6.47	6.42	6.45	6.44	7.06	7.02	7.04	7.04
7	Zotui	Nisapui	23.94	92.762	7.61	7.62	7.65	7.62	6.74	6.71	6.76	6.73	7.67	7.63	7.65	7.65
8	Challui	North Chaltlang	24.0214	92.784	7.9	6.59	6.56	7.01	5.67	7.23	6.75	6.55	7.1	6.05	6.91	6.68
9	Lalkima Point Handpump	North Chaltlang	24.018	92.765	7.43	7.46	7.48	7.45	6.92	6.94	6.96	6.94	7.48	7.44	7.46	7.46
10	Chhimluang	North Chaltlang	24.01	92.768	6.9	6.9	7	6.93	7.69	6.54	6.67	6.96	7.02	7.06	7.04	7.04
11	Lengleh	North Chaltlang	24.024	92.767	6.63	6.65	6.68	6.65	6.9	6.3	6.6	6.6	6.68	6.66	6.62	6.66
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	6.87	7.75	7.12	7.24	6.87	7.13	7.22	7.073	6.45	6.77	6.23	6.48
13	Lungsum	Bukpui	24.084	92.788	6.73	6.77	6.75	6.75	6.19	6.11	6.17	6.15	6.77	6.79	6.75	6.77
14	Builum	Bukpui	24.067	92.78	6.5	6.5	6.8	6.6	6.14	6.87	6.11	6.37	6.53	6.55	6.57	6.55
15	Minmawng	Bukpui	24.085	92.791	7.31	7.39	7.35	7.35	6.25	6.21	6.27	6.25	7.35	7.33	7.37	7.35
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	6.71	6.74	6.76	6.73	6.03	6.05	6.07	6.05	6.74	6.72	6.76	6.74
17	Nuhliri Point	Bukpui	24.077	92.793	7.11	7.15	7.18	7.14	6.24	6.21	6.25	6.23	6.25	6.27	6.29	6.27
18	Phulraw lui tuikhur	Zanlawn	23.939	92.728	6.82	7.56	7.13	7.17	6.43	6.97	7.23	6.87	6.91	7.01	6.88	6.945
19	Vandawt	Zanlawn	23.984	92.694	7.21	7.34	7.32	7.29	6.29	6.22	7.06	6.53	6.46	6.99	6.78	6.885
20	Hiahthar	Zanlawn	23.966	92.724	6.65	6.63	6.69	6.65	6.33	6.31	6.35	6.33	6.63	6.61	6.65	6.63
21	Fului	Zanlawn	23.97	92.711	7.31	7.38	7.39	7.36	6.83	6.81	6.85	6.83	7.31	7.35	7.33	7.33
22	Pumpelh	Zanlawn	23.99	92.707	6.9	7.1	7.2	7.1	6.92	6.94	6.91	6.92	6.94	6.92	6.96	6.94
23	Midum Lui	Zanlawn	23.987	92.705	7.41	7.01	6.8	7.1	6.75	6.73	6.77	6.75	6.73	6.75	6.77	6.75
24	Phuanberh	Kawnpui	24.034	92.673	6.5	6.25	7.09	6.61	6.02	6.04	6.01	6.01	6.01	6.05	6.03	6.03
25	Hlitlui	Kawnpui	24.05	92.673	6.23	6.21	6.25	6.23	5.7	5.5	5.9	5.7	5.9	5.3	5.6	5.6
26	Charpui	Kawnpui	24.05	92.674	6.11	6.14	6.17	6.14	5.21	5.23	5.25	5.23	5.25	5.21	5.23	5.23
27	Vailui	Kawnpui	24.034	92.668	6.42	6.41	6.46	6.43	5.2	5.3	5.1	5.2	5.3	5.5	5.1	5.3
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	6.43	6.48	6.46	6.45	4.82	4.84	4.85	4.83	5.09	5.01	5.03	5.03
29	Kuangsei	Kawnpui	24.0376	92.672	7.47	6.24	6.73	6.813	7.31	6.46	7.56	7.11	6.87	6.21	6.11	6.39
30	Sentezel	Kawnpui	24.04	92.674	6.78	6.71	6.73	6.74	5.55	5.53	5.57	5.55	6.74	6.76	6.72	6.74
31	Sihpui tuikhur	Kawnpui	24.045	92.67	7.01	7.09	7.06	7.05	5.51	5.53	5.52	5.52	5.53	5.51	5.55	5.53
32	Sakhisih	Kawnpui	24.044	92.669	6.62	6.61	6.65	6.62	6.41	6.43	6.44	6.42	6.41	6.45	6.43	6.43
33	Bawkkang	Kawnpui	24.03	92.675	7.6	7.36	7.61	7.52	6.49	6.47	6.51	6.49	6.47	6.45	6.43	6.45
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	7.81	7.83	7.85	7.83	6.27	6.25	6.29	6.27	6.25	6.27	6.23	6.25
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	7.21	7.24	7.26	7.23	6.04	6.02	6.06	6.04	6.04	6.02	6.06	6.04
36	Tuitun	Kawnpui	23.9667	92.681	7.84	7.82	7.81	7.82	6.38	6.36	6.32	6.65	7.53	7.55	7.51	7.53
37	Khurthuk	Kawnpui	24.039	92.67	6.42	6.48	6.45	6.45	5.4	5.2	5.6	5.4	5.6	5.4	5.8	5.6
38	Sihpui	Kawnpui	24.036	92.669	6.35	6.31	6.37	6.34	5.51	5.53	5.55	5.53	5.51	5.55	5.53	5.53
39	Lungpher	Hortoki	24.06	92.602	7.51	7.54	7.59	7.54	6.11	5.39	5.24	5.58	7.15	7.13	7.11	7.13
40	Khawzasiaka	Hortoki	24.056	92.596	7.72	7.78	7.75	7.75	5.69	5.67	5.34	5.56	7.72	7.76	7.74	7.74
41	Zotui	Lungmuat	23.972	92.778	7.25	7.29	7.21	7.25	6.48	6.46	6.49	6.47	6.49	6.45	6.47	6.47
42	Luihnai	Lungmuat	23.966	92.779	6.74	6.79	6.77	6.76	5.6	5.4	5.8	5.6	6.76	6.74	6.78	6.76
43	Thingsakawr lui	Lungmuat	23.955	92.795	6.91	7.46	6.78	7.05	6.87	6.34	6.78	6.66	6.34	6.44	6.74	6.5
44	Veng Chung Lui	Lungmuat	23.9714	92.782	7.32	6.9	7.11	7.11	7.08	6.77	7.11	6.98	6.55	6.23	6.33	6.37

5.5 Turbidity:

Turbidity is a measure of the cloudiness or clarity of water. The substance that lowers water clarity can arise from natural, developing, and developed areas within a watershed. In all circumstances, sand, silt, clay, and organic particle are removed from the earth's surface by rainwater and transported by surface runoff into water bodies. Suspended and colloidal particles accumulated in this way are the primary causing factor of turbidity. Thus, turbidity in springs is induced by heavy rainfall, flooding, improper drainage, landslides and bank erosion, animals, and anthropogenic activities. However, the clarity of groundwater in deep aquifers is typically inorganic and caused by geological factors.

Turbidity is classified into three standards ($<$1.0 NTU, 1-5NTU, and $>$5NTU) by BIS guidelines (BIS, 2012). The guidelines recommend that water planned for drinking should not exceed 1NTU. During Pre-Monsoon, the average turbidity shows that 10 sources are exceeding the acceptable limit of 1NTU and are not suitable for drinking if there is an alternative source. There are three sources viz. Lalkima hand pump at N.Chaltlang, Vengsang Electric groundwater pump at Bukpui, and Lungpher stream at Hortoki, which exceed the permissible limit of 5NTU. These sources are to be rejected for drinking purposes. The number of water sources that have high turbidity is maximum during Monsoon, 19 samples have exceeded the acceptable limit and 2 sources such as the Lalkima hand pump and Midum Lui at Zanlawn are also found to have turbidity above the permissible limit. The rate of turbidity is slightly decreased during Post-Monsoon, 17 samples are exceeding the acceptable limit, and the turbidity of 3 samples viz. Lalkima hand pump, Midum lui, and Lungpher are above the permissible limit. When comparing the intensity of turbidity, the samples from Pre-Monsoon have a maximum value of NTU, followed by Post-Monsoon. Though there is an increasing number of springs that have high turbidity values, the minimum NTU value is observed during Monsoon.

Table 18: Average Turbidity in Geomorphic Units

Sl.No	Geomorphology	Average Turbidity (NTU) Pre-Monsoon	Average Turbidity (NTU) Monsoon	Average Turbidity (NTU) Post-Monsoon	Average
1	Fracture Valley (FV)	0.470	4.940	4.940	3.450
2	Highly Dissected Structural Hill (SHH)	0.637	0.451	0.607	0.565
3	Inter-Montane Valley (IV)	0.805	1.007	1.385	1.066
4	Less Dissected Structural Hill (SHL)	7.213	1.557	1.984	3.585
5	Moderately Dissected Structural Hill (SHM)	2.952	1.533	1.225	1.903
	Average	2.415	1.898	2.028	

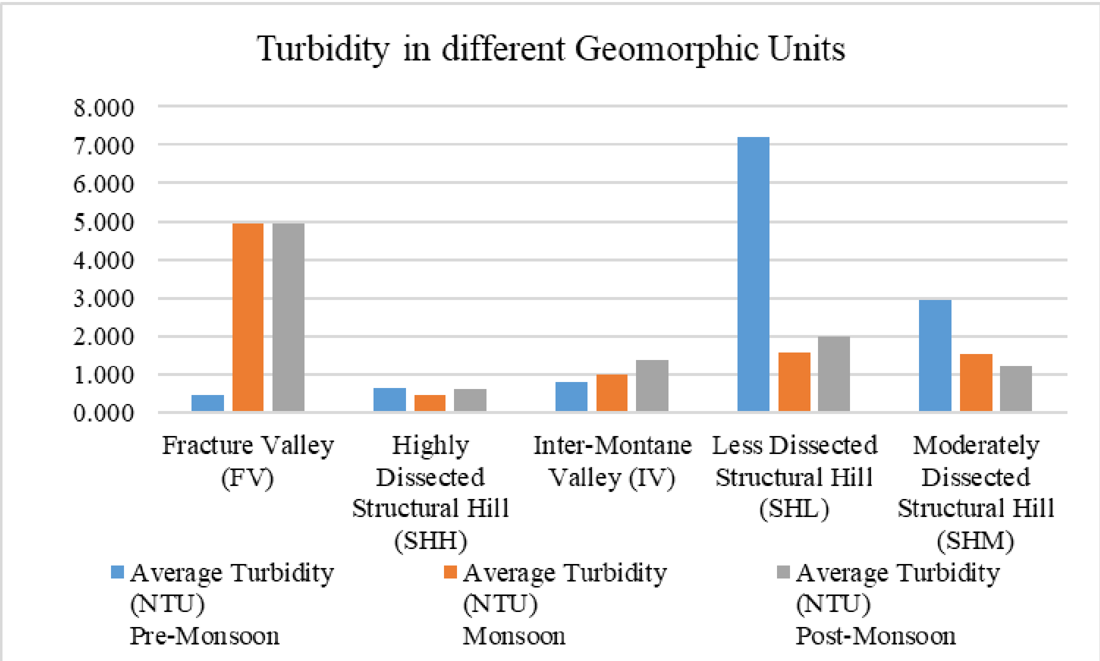


Figure 29: Bar chart of turbidity in Geomorphic Units

In terms of Geomorphic Units, being located in a lower region of the terrain and an inlet to the main basin or perennial stream, Less Dissected Structural Hill probably has received a considerable amount of surface runoff whenever there is precipitation in the uphill areas, consequently making it to have the highest turbidity. Fracture Valley also has high turbidity; it may be due to the influence of the flowing of moving water by its geological setting, the nature of the terrain in the surroundings, dominance of the water basin by boulders and large chunks of rocks that hamper the settling of load sediments.

The speed of runoff is too fast to hold in terrain like a Highly Dissected Structural Hill. Therefore, during monsoon season, sources in Less Dissected Structural Hill have extremely turbid water exceeding the Permissible Limit as receiving most of the runoff in the uphill area. A Moderately Dissected Structural Hill that also crossed Acceptable Limit follows it. However, samples from Fracture Valley, Intermontane Valley, and Highly Dissected Structural Hill remain within the safety side for drinking purposes. It may be attributed to the fact that the surface runoff has enough time to drop off their loaded particles before they reach the lower Geomorphic Unit or the runoff within the Highly dissected terrain does not have enough time for erosion to carry suspended particles. In addition, being located on the top part of hills in the study area, samples from Highly Dissected Structural Hills rarely receive overland flow, consequently, they remain pleasing for drinking purposes throughout the year.

During the Monsoon, water samples of all Geomorphic Units except Highly Dissected Structural Hills are found to have high turbidity exceeding the Acceptable Limit. This condition may have been caused by heavy to very heavy rainfall that prevails during South West Monsoon (June to September). Likewise, during Post-monsoon, water sources in all Geomorphic Units except Highly Dissected Structural Hills are characterized by water exceeding the acceptable limit, which may be attributed to the prolonged rainy season extending to the Post-Monsoon season in the study area. The turbidity of groundwater in the Lithostratigraphic Units is shown below: -

Table 19: Average Turbidity in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Turbidity concentration (NTU) Pre-Monsoon	Average Turbidity concentration (NTU) Monsoon	Average Turbidity concentration (NTU) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	12.0438	1.6767	1.1438	4.955
2	Sandstone dominated (Upper Bhuban Formation)	2.6652	1.5211	1.4267	1.871
3	Shale dominated (Middle Bhuban Formation)	0.5425	0.8958	0.515	0.651
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	3.1256	1.9767	4.6133	3.239
	Average	4.5943	1.5176	1.9247	

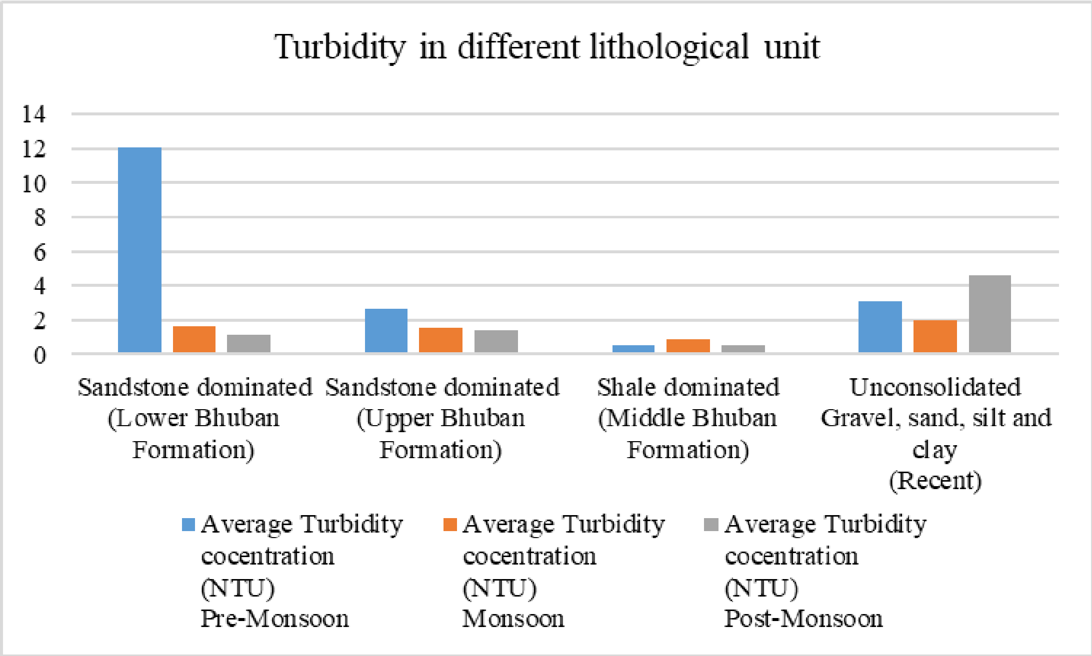


Figure 30: Bar chart of turbidity in Lithostratigraphic Units

In terms of lithological Units, water sources in sandstone-dominated lithology of the Lower Bhuban Unit have the highest turbidity. Lower Bhuban Formation is exposed around Bukpui and N.Chaltlang region, higher turbidity may be attributed to the existence of bore well that have high values of total dissolved solids (TDS) throughout every season and anthropogenic activities like improper disposal of waste, land modification, and rock quarry located in the vicinity. This may also be due to the nature of highly porous and permeable sandstone that consequently letting the transportation of suspended particles to some extent. Both Unconsolidated sediments and Sandstone of Upper Bhuban are characterized by relatively high turbidity, which average has exceeded the acceptable limit.

On the contrary, water sources in impermeable finer grains of shale-dominated lithology of the Middle Bhuban Unit are found to possess the least value of turbidity. After all of the surplus runoff has drained into streams, infiltrating rainwater in the fine-grained aquifer hindered the movement of suspended particles and consequently served as a filtering medium. Therefore, it causes the water in shale-dominant lithology to attain high clarity regardless of the Geomorphic Unit, rainfall, and the season.

Unexpectedly, the average turbidity of water during the Pre-monsoon season is significantly higher as compared to that of the monsoon and post-monsoon seasons. This may be due to the prevalence of surplus downpours during pre-monsoon as a result of the Formation of a cyclonic circulation over Bangladesh and adjoining. It is also intensified by improper drainage, which is especially prevalent during this season, and anthropogenic activities within the watershed area of springs.

During Pre-Monsoon, the limited area around Hortoki and the northeastern area are having high turbidity that exceeds the acceptable limit. The vicinity of Lungmuat and the eastern part of Zanlawn are having turbidity, which exceeds the permissible limit while the remaining part of the study area is characterized by low turbidity. During Monsoon, high turbidity that exceeds the acceptance limit is restricted in smaller areas at Zanlawn and N.Chaltlang villages. However, more than two-thirds of an area is fall in the non-potable class. The northwestern part and southeastern part of the area however characterized by water that is clear enough for drinking purposes. During Post-Monsoon, high turbidity that exceeds the acceptable limit is exhibited as small dots in the eastern part of Hortoki, the northwestern area of Zanlawn, and the southwestern part of N.Chaltlang. Around one-third of the total area like the northern part of Kawnpui village, the vicinity around Serkhan and Nisapui as well as a small area around Lungmuat, N.Chaltlang, and Bukpui are having clear potable water that is well within the desirable range. More than half of the study area however falls within the non-potable class, which exceeds the permissible limit.

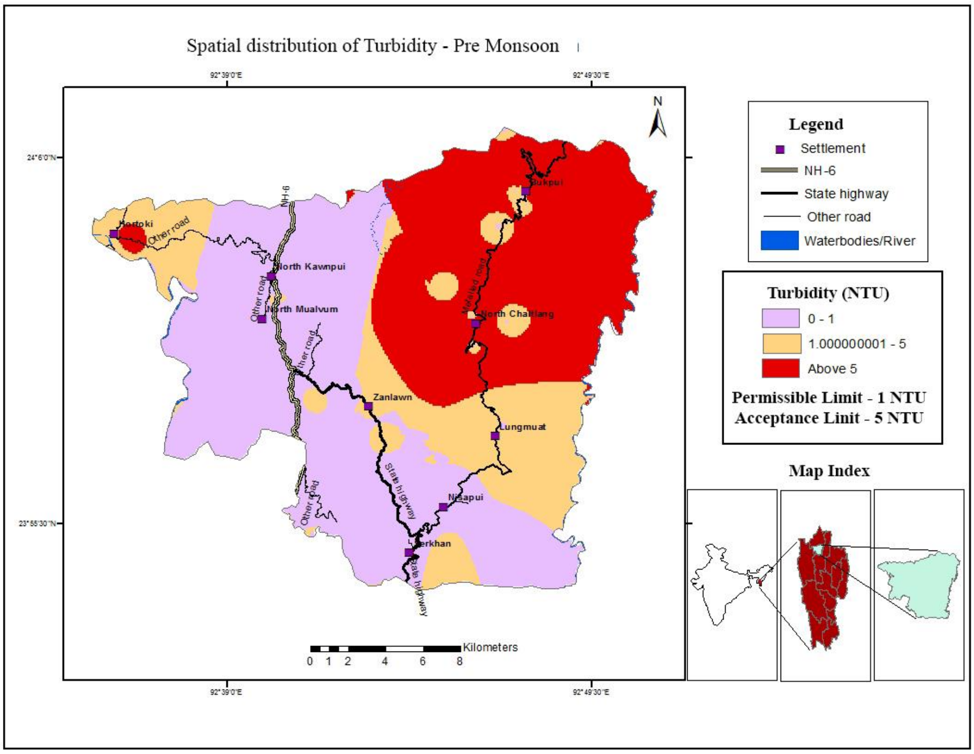


Figure 31: Spatial distribution of Turbidity in Pre-Monsoon

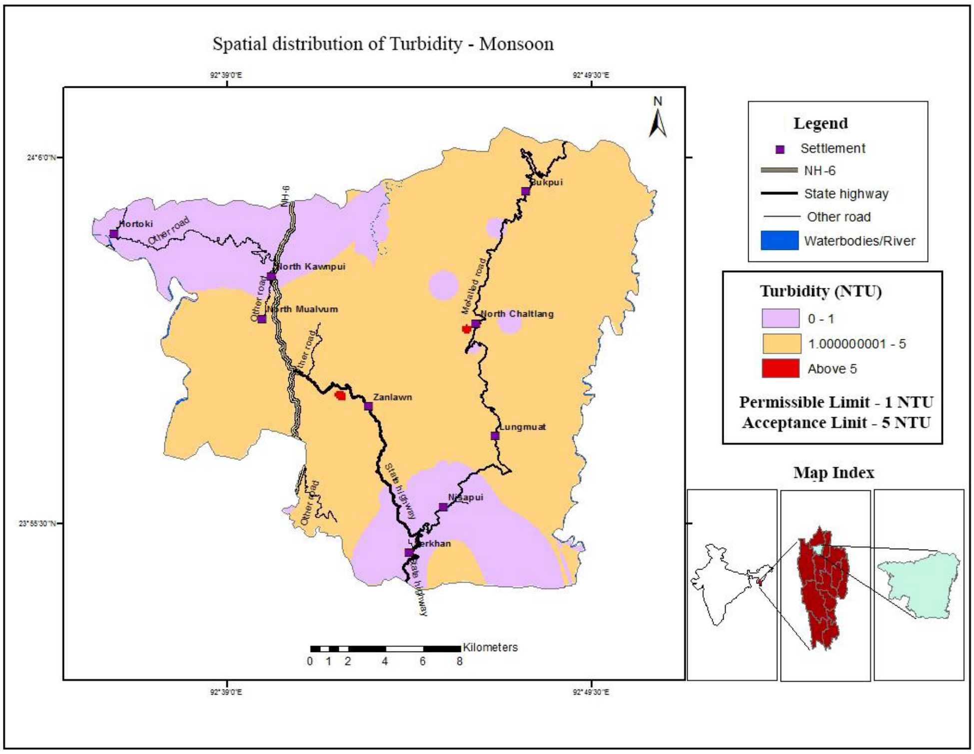


Figure 32: Spatial distribution of Turbidity in Monsoon

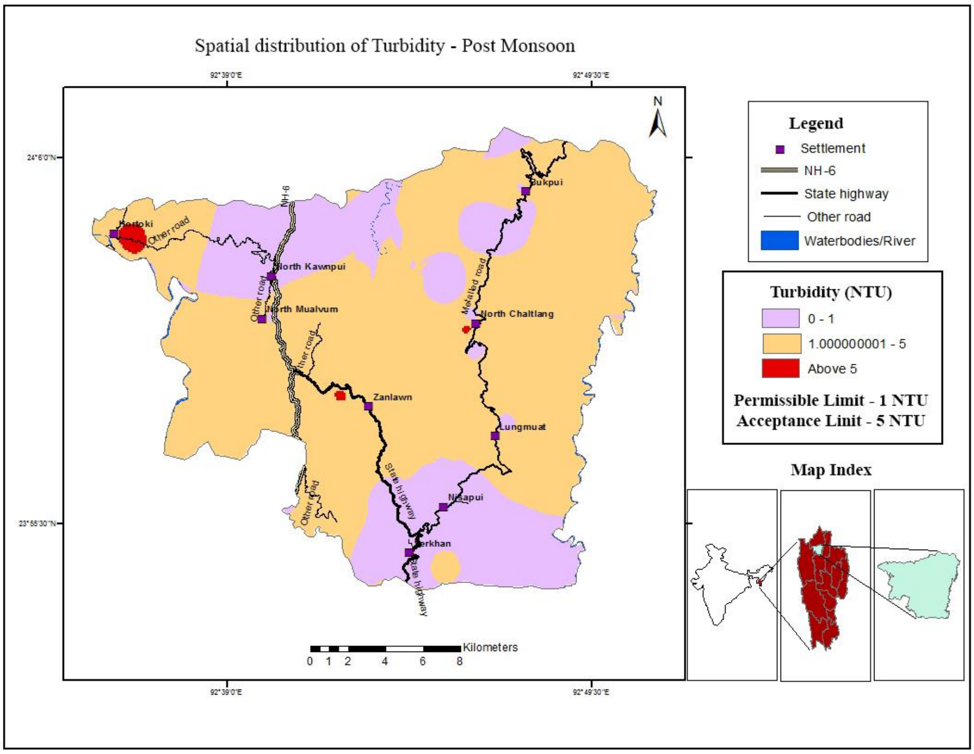


Figure 33: Spatial distribution of Turbidity in Post-Monsoon

Table 20: Turbidity value (2017-2019)

Sl.No	Source Name	Village	Lattitude	Longtitude	Turbidity in Pre-Monsoon			Average Pre-Monsoon	Turbidity in Monsoon			Monsoon Average	Turbidity in Postmonsoon			Average Postmonsoon
					2017	2018	2019	(NTU)	2017	2018	2019	(NTU)	2017	2018	2019	(NTU)
1	Vankeu	Serkhan	23.905	92.753	2.01	2.21	2	2.0733	0.90	3.40	1.40	1.90	3.10	0.80	0.05	1.32
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	1.01	1.02	1.03	1.0200	1.03	0.36	0.36	0.58	1.03	1.07	1.05	1.05
3	Dengalui	Serkhan	23.915	92.74	0.73	0.71	0.75	0.7300	0.63	0.61	0.65	0.63	0.61	0.65	0.63	0.63
4	Bawngpu	Serkhan	23.908	92.739	0.14	0.16	0.18	0.1600	0.12	0.14	0.16	0.14	0.16	0.12	0.14	0.14
5	Vautangbawk	Serkhan	23.915	92.78	0.17	0.19	0.15	0.1700	0.77	0.36	1.05	0.73	0.15	0.13	0.17	0.15
6	Lalthansiama Point	Nisapui	24.037	92.755	1.04	1.06	1.08	1.0600	0.34	0.36	0.32	0.34	0.36	0.32	0.34	0.34
7	Zotui	Nisapui	23.94	92.762	0.74	0.72	0.75	0.7367	0.35	0.37	0.33	0.35	0.33	0.31	0.35	0.33
8	Challui	North Chaltlang	24.0214	92.784	0.91	1	0.8	0.9033	0.09	0.42	1.10	0.54	1.70	1.09	1.77	1.52
9	Lalkima Point Handpump	North Chaltlang	24.018	92.765	56.1	56.3	56.2	56.2000	5.75	5.73	5.77	5.75	5.77	5.73	5.75	5.75
10	Chhimluang	North Chaltlang	24.01	92.768	1.17	0.41	0.33	0.6367	0.59	0.13	0.68	0.47	0.12	0.16	0.14	0.14
11	Lengleh	North Chaltlang	24.024	92.767	0.26	0.28	0.24	0.2600	2.21	2.25	2.23	2.23	0.24	0.22	0.26	0.24
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.23	0.3	0.11	0.2133	2.40	0.40	0.30	1.03	0.80	0.09	2.40	1.10
13	Lungsum	Bukpui	24.084	92.788	0.33	0.35	0.37	0.3500	1.51	1.53	1.55	1.53	1.51	1.55	1.53	1.53
14	Builum	Bukpui	24.067	92.78	0.14	1.06	1.08	0.7600	0.59	1.03	0.14	0.59	0.54	0.52	0.56	0.54
15	Minmawng	Bukpui	24.085	92.791	0.43	0.41	0.45	0.4300	2.46	2.48	2.44	2.46	0.43	0.41	0.45	0.43
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	80	81.1	81.3	80.8000	2.04	2.02	2.06	2.04	2.06	2.04	2.08	2.06
17	Nuhliri Point	Bukpui	24.077	92.793	0.83	0.85	0.87	0.8500	3.55	3.57	3.53	3.55	0.83	0.81	0.85	0.83
18	Phulraw lui tuikhur	Zanlawn	23.939	92.728	1.2	0.6	0.4	0.7333	0.30	1.80	0.70	0.93	0.67	0.45	0.88	0.67
19	Vandawt	Zanlawn	23.984	92.694	0.9	1.1	1.8	1.2667	1.60	1.10	1.80	1.50	1.90	3.70	0.09	1.90
20	Hiahthar	Zanlawn	23.966	92.724	1.13	1.15	1.17	1.1500	1.05	1.07	1.08	1.07	1.15	1.17	1.13	1.15
21	Fului	Zanlawn	23.97	92.711	0.84	0.86	0.88	0.8600	2.81	2.83	2.85	2.83	2.83	2.81	2.85	2.83
22	Pumpelh	Zanlawn	23.99	92.707	0.88	0.03	0.05	0.3200	2.48	2.44	2.46	2.46	2.48	2.46	2.44	2.46
23	Midum Lui	Zanlawn	23.987	92.705	0.72	0.75	0.07	0.5133	6.23	6.21	6.25	6.23	6.25	6.21	6.23	6.23
24	Phuanberh	Kawnpui	24.034	92.673	1.01	0.86	0.03	0.6333	0.79	0.75	0.77	0.77	0.75	0.73	0.71	0.73
25	Hlitlui	Kawnpui	24.05	92.673	0.05	0.07	0.09	0.0700	0.59	0.57	0.55	0.57	0.57	0.55	0.53	0.55
26	Charpui	Kawnpui	24.05	92.674	0.84	0.86	0.88	0.8600	0.11	0.15	0.13	0.13	0.15	0.17	0.19	0.17
27	Vailui	Kawnpui	24.034	92.668	0.16	0.14	0.12	0.1400	0.68	0.64	0.66	0.66	0.64	0.66	0.68	0.66
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0.03	0.05	0.07	0.0500	0.34	0.32	0.36	0.34	0.03	0.01	0.05	0.03
29	Kuangsei	Kawnpui	24.0376	92.672	0.3	0.04	0.09	0.1433	1.20	0.50	0.05	0.58	0.63	0.09	0.80	0.51
30	Sentezel	Kawnpui	24.04	92.674	0.37	0.39	0.35	0.3700	0.45	0.41	0.43	0.43	0.45	0.43	0.47	0.45
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.97	0.95	0.93	0.9500	0.83	0.85	0.81	0.83	0.95	0.91	0.93	0.93
32	Sakhisih	Kawnpui	24.044	92.669	0.44	0.46	0.48	0.4600	0.41	0.45	0.43	0.43	0.46	0.42	0.44	0.44
33	Bawkkang	Kawnpui	24.03	92.675	0.07	1.01	1.36	0.8133	4.32	4.36	4.34	4.34	4.36	4.34	4.38	4.36
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	2.83	2.85	2.87	2.8500	3.74	3.72	3.76	3.74	3.72	3.76	3.74	3.74
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.23	0.21	0.25	0.2300	1.26	1.28	1.24	1.26	0.21	0.25	0.23	0.23
36	Tuitun	Kawnpui	23.9667	92.681	0.47	0.49	0.45	0.4700	4.94	4.92	4.96	4.94	4.92	4.94	4.96	4.94
37	Khurthuk	Kawnpui	24.039	92.67	0.07	0.05	0.03	0.0500	0.04	0.02	0.06	0.04	0.04	0.06	0.02	0.04
38	Sihpui	Kawnpui	24.036	92.669	0.79	0.77	0.75	0.7700	0.83	0.81	0.85	0.83	0.73	0.77	0.75	0.75
39	Lungpher	Hortoki	24.06	92.602	7.64	7.68	7.62	7.6467	0.56	0.55	0.41	0.51	7.64	7.68	7.66	7.66
40	Khawzasiaka	Hortoki	24.056	92.596	1.28	1.26	1.24	1.2600	0.06	0.34	1.05	0.48	1.26	1.22	1.24	1.24
41	Zotui	Lungmuat	23.972	92.778	1.32	1.34	1.36	1.3400	2.52	0.56	0.54	1.21	1.32	1.36	1.34	1.34
42	Luihnai	Lungmuat	23.966	92.779	1.52	1.54	1.56	1.5400	2.41	2.45	2.43	2.43	2.41	2.43	2.45	2.43
43	Thingsakawr lui	Lungmuat	23.955	92.795	1.8	2.2	2.6	2.2000	2.80	0.07	1.60	1.49	0.80	4.10	0.70	1.87
44	Veng Chung Lui	Lungmuat	23.9714	92.782	0	1.4	0.9	0.7667	0.00	1.20	1.80	1.00	0.00	0.09	0.86	0.32

5.6 Iron:

Mostly, Iron is naturally derived from metallic pollutants from their occurrence in soil and rocks. It may also come into the water from corrosion of pipes, pumps, and other structures in the distribution system as well as from steel mills and metal plants. Ferric or ferrous is the dominant form in natural water, but it usually tends to form an insoluble reddish-brown precipitate because of ferric hydroxide formation (Goel, 2006).

As recommended by BIS guidelines, the Iron concentration of <0.3mg/l is specified as a Desirable range, 0.3-1.0mg/l as a Permissible range, and >1.0mg/l as a Non-potable class (BIS, 2012). Fe constituent in groundwater is determined by the chemical composition of the aquifers, it may also have affected by the leaching of rusty Iron used in plumbing pipes and hand pump components in a bore well. Sandstone rocks made up of oxides, carbonates, sulfides and Iron rich clay minerals, ferromagnesian micas¸ pyrite (FeS2), and Magnetite (Fe3O4), etc., are the probable natural sources of Fe constituents in groundwater.

Bore well samples from Lalkima point hand pump, N.Chaltlang, and Sub-station peng, Bukpui are having Iron concentrations exceeding acceptable limits of 0.4 and 0.7 ppm respectively. They indicate the presence of ferric hydroxide by the formation of a reddish-brown precipitate. It is known that more than 0.1 ppm of Iron concentration in water led to the formation of precipitates after exposure to air; causes the water to lose its clarity, stains plumbing fixtures, laundry, and cooking utensils, and imparts objectionable taste and colors to foods and drinks. Hence, samples from these two sources are showing unpleasant colors and tastes, both are not suitable for drinking purposes as well as industrial uses as exceeding 0.2 ppm.

The Iron content in the Geomorphic Units is shown below-

Table 21: Average Total Iron in Geomorphic Units

Sl.No	Geomorphology	Total Iron (mg/l or ppm) Pre-Monsoon	Total Iron (mg/l or ppm) Monsoon	Total Iron (mg/l or ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.010	0.010	0.010	0.010
2	Highly Dissected Structural Hill (SHH)	0.030	0.003	0.003	0.012
3	Inter-Montane Valley (IV)	0.010	0.100	0.005	0.038
4	Less Dissected Structural Hill (SHL)	0.028	0.066	0.017	0.037
5	Moderately Dissected Structural Hill (SHM)	0.020	0.020	0.014	0.018
	Average	0.020	0.040	0.010	

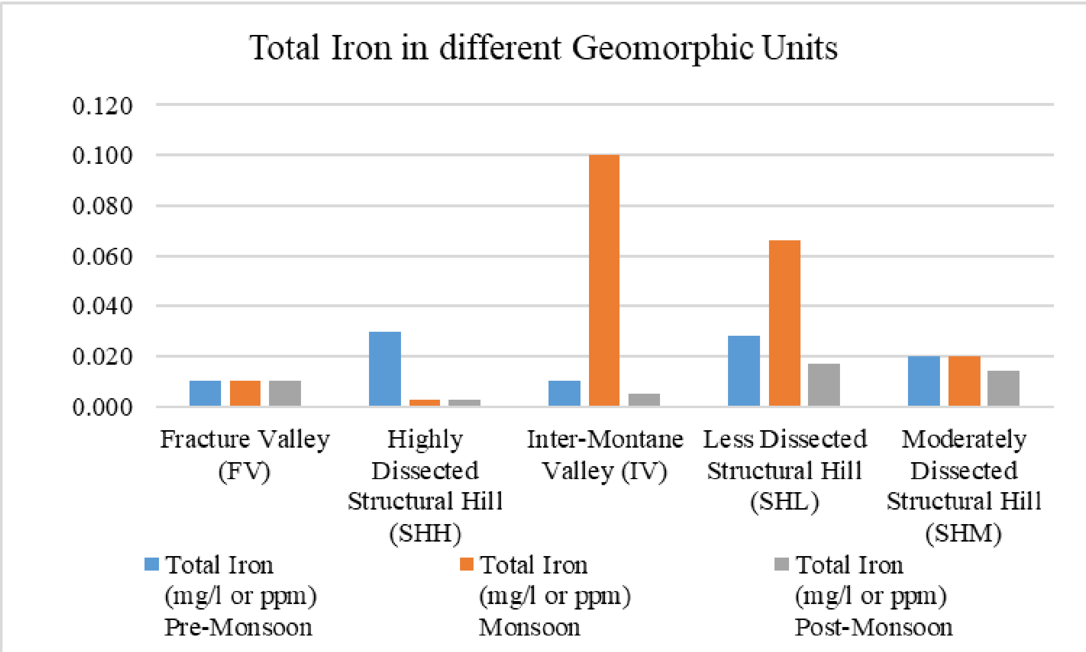


Figure 34: Bar chart of iron concentration in geomorphic unit

In terms of geomorphology, the concentration of iron is highest in Intermontane Valley followed by Less Dissected Structural Hill. The remaining Units are found to have rather the same value as Fe constituents.

The average Total Iron in monsoon is observed to be highest as compared to pre-monsoon and post-monsoon because the iron content of the rocks gets dissolved to a great extent during Monsoon as the aquifer gets recharged by a substantial amount of infiltrating rainwater.

The Iron content in the lithological Units is shown below: -

Table 22: Average Total Iron in Lithostratigraphic Units

Sl.No	**Lithostratigraphic Unit**	**Average Total Iron concentration (ppm) Pre-Monsoon**	**Average Total Iron concentration (ppm) Monsoon**	**Average Total Iron concentration (ppm) Post-Monsoon**	**Average**
1	Sandstone dominated (Lower Bhuban Formation)	0.0357	0.16	0.033	0.0762
2	Sandstone dominated (Upper Bhuban Formation)	0.021	0.015	0.012	0.0160
3	Shale dominated (Middle Bhuban Formation)	0.0275	0.003	0	0.0102
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0.01	0.007	0.003	0.0067
	Average	0.024	0.046	0.012	

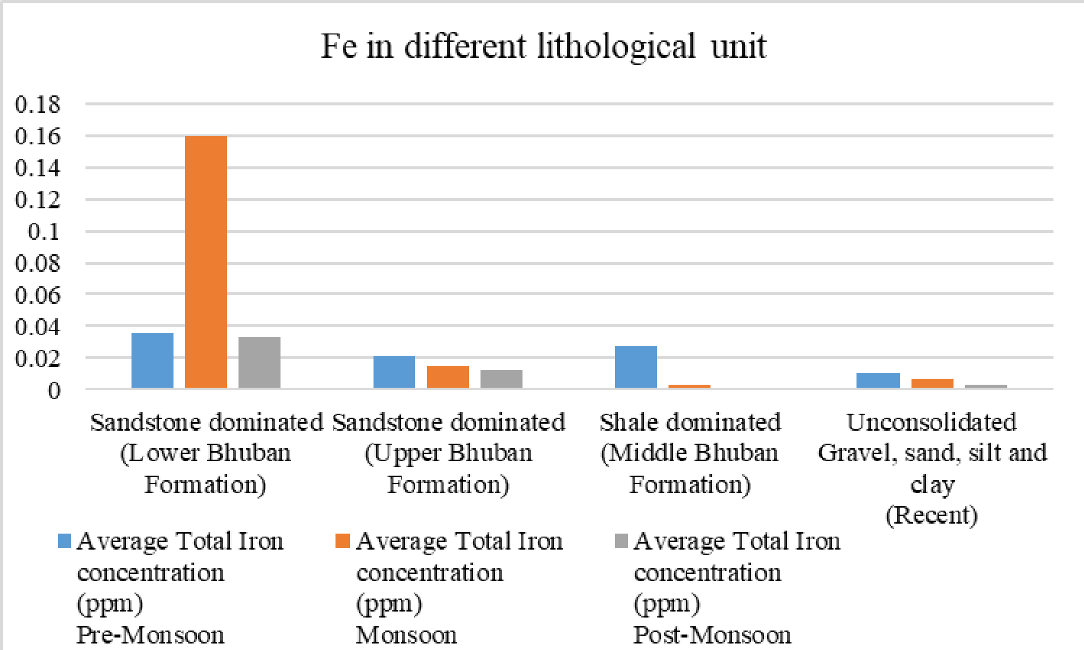


Figure 35: Bar chart of iron concentration in Lithostratigraphic unit

In terms of lithology, the sandstone-dominated lithology of the Lower Bhuban Formation has the highest iron concentration. A petrographic and heavy minerals study carried out at Aizawl in Upper Bhuban Unit along the Zemabawk-Tuirial road section shows that the Upper Bhuban Brown sandstones are comparatively friable compared to Middle Bhuban sandstone. It was attributed to weak iron-oxide cementation, supplemented by intensive weathering by water seepage (Lalnunmawia *et al.*, 2016). However, the Fe concentration in groundwater of Middle and Upper Bhuban Formations are almost equivalent with a slightly higher value in Upper Bhuban Unit. The abundance of both muscovite and Biotite as a detrital mineral is recorded from the Petrographic Analysis of the Middle Bhuban sandstone of Reiek. They are known to contribute ferruginous cementation due to the leaching of their Fe components as a result of alterations (Lalnunmawia *et al.*, 2020). It is evident that the lithological Formation of the Lower Bhuban Formation has a higher concentration of Fe-bearing minerals than that of the Upper Bhuban Formation and Middle Bhuban Formations. Unconsolidated sediments have groundwater with the lowest iron concentration indicating the lithology comprising this Formation is highly depleted in Fe. Iron is continuously supplied to groundwater by the reduction of hydrous ferric oxides (HFO) and other Iron bearing minerals. In addition, the unconsolidated sediments usually deposit as exceedingly long and narrow shapes in the basin of streams and rivers as alluvial deposits and they have undergone extensive weathering and transportation. Moreover, based on the nature of sorting, the porosity is typically very high, ranging from 1% to 90% of the materials; it enhances infiltration and water movements, ultimately capable of storing high amounts of rainwater, so making them highly depleted in Iron content.

Although has iron-rich mineral composition, impermeable shale has obstructed its iron content from dissolving into the water due to its interlocking-grains structure that inhibits the transportation of solvent in the aquifer.

Seasonal-wise, the iron content is lowest during the post-monsoon period, while the monsoon season has the highest iron concentration. An increasing amount of water during monsoon may have dissolved a substantial amount of iron composition of minerals forming the aquifers whereas the amount of water in the aquifer is deficient during pre-monsoon and post-monsoon.

During Pre-Monsoon, all samples are well within the desirable range. However, about one-fourth of the study area such as the area around Bukpui, N.Chaltlang, and Serkhan are having moderate Iron content of 0.05 to 0.3 ppm. The remaining parts of the area are having Iron content between 0 to 0.05 ppm. A limited small area at Bukpui and N.Chaltlang has Iron concentrations exceeding permissible limits during Monsoon season. Bukpui and N.Chaltlang area has moderate Iron concentration, the rest of the study area falls within Iron content ranging between 0 to 0.05 ppm. Even during Post-Monsoon, the vicinity of Bukpui and N.Chaltlang show moderate concentrations of Fe.

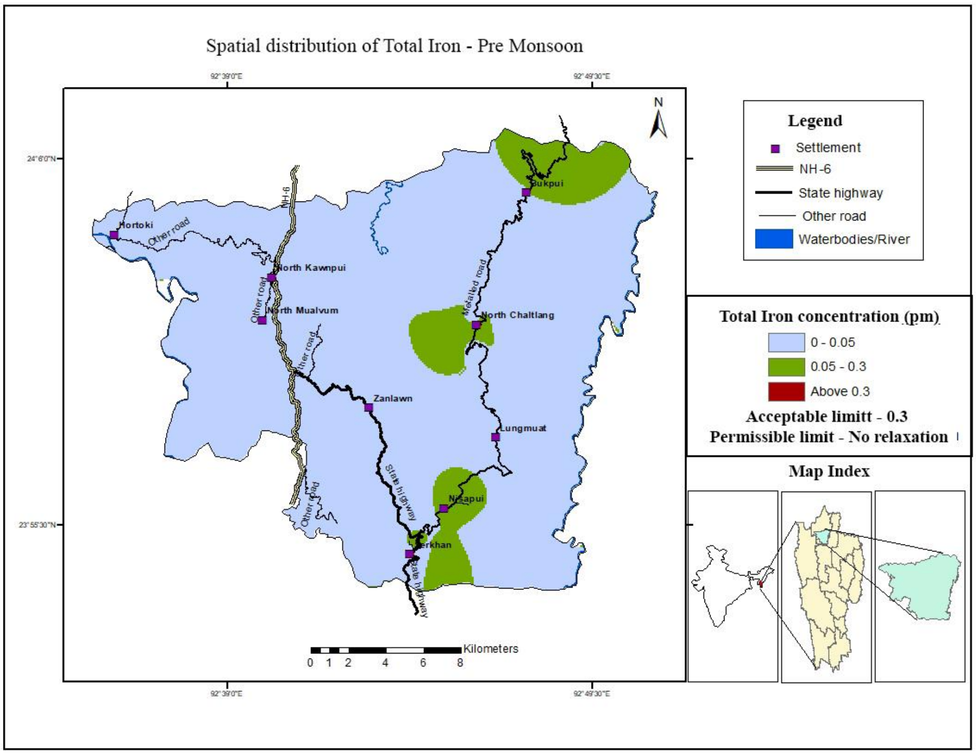


Figure 36: Spatial distribution map of Iron during pre-monsoon

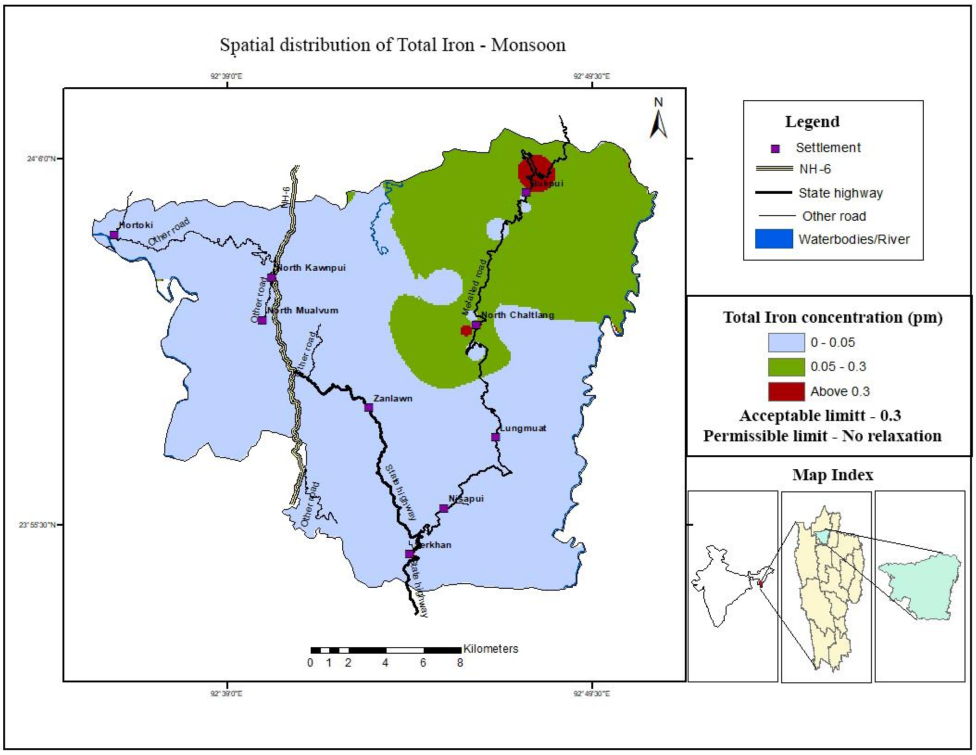


Figure 37: Spatial distribution map of Iron during monsoon

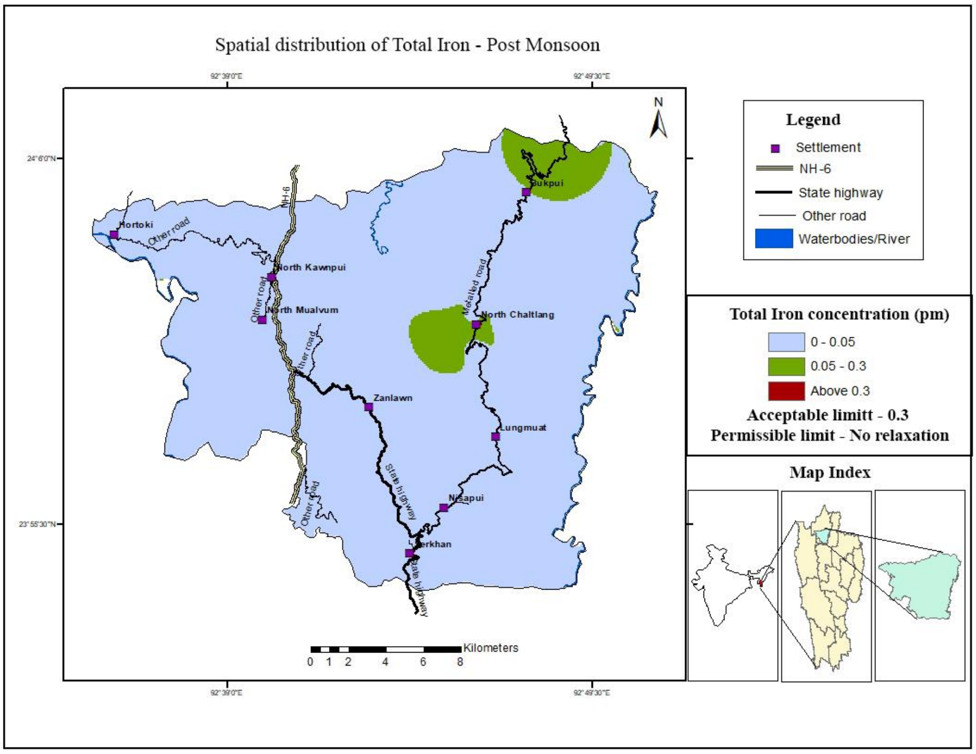


Figure 38: Spatial distribution map of Iron during post-monsoon

Table 23: Total Iron value (2017-2019)

Sl.No	Source Name	Village	Lattitude	Longtitude	Total Iron Pre-Monsoon 2017	2018	2019	Pre-Monsoon Average (mg/l)	Total Iron Monsoon 2017	2018	2019	Monsoon Average (mg/l)	Total Iron Postmonsoon 2017	2018	2019	Postmonsoon Average (mg/l)
1	Vankeu	Serkhan	23.905	92.753	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Dengalui	Serkhan	23.915	92.74	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Bawngpu	Serkhan	23.908	92.739	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Vautangbawk	Serkhan	23.915	92.78	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
6	Lalthansiama Point	Nisapui	24.037	92.755	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Zotui	Nisapui	23.94	92.762	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Challui	North Chaltlang	24.0214	92.784	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Lalkima Point handpump	North Chaltlang	24.018	92.765	0.30	0.30	0.30	0.30	0.40	0.40	0.40	0.40	0.30	0.30	0.30	0.30
10	Chhimluang	North Chaltlang	24.01	92.768	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Lengleh	North Chaltlang	24.024	92.767	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Lungsum	Bukpui	24.084	92.788	0.01	0.01	0.01	0.01	0.20	0.20	0.20	0.20	0.01	0.01	0.01	0.01
14	Builum	Bukpui	24.067	92.78	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
15	Minmawng	Bukpui	24.085	92.791	0.01	0.01	0.01	0.01	0.20	0.20	0.20	0.20	0.01	0.01	0.01	0.01
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	0.20	0.20	0.20	0.20	0.70	0.70	0.70	0.70	0.20	0.20	0.20	0.20
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
18	Vandawt	Zanlawn	23.984	92.694	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Hiahthar	Zanlawn	23.966	92.724	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
21	Fului	Zanlawn	23.97	92.711	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
22	Pumpelh	Zanlawn	23.99	92.707	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
23	Midum Lui	Zanlawn	23.987	92.705	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Phuanberh	Kawnpui	24.034	92.673	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Hlitlui	Kawnpui	24.05	92.673	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Charpui	Kawnpui	24.05	92.674	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Vailui	Kawnpui	24.034	92.668	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Kuangsei	Kawnpui	24.0376	92.672	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
30	Sentezel	Kawnpui	24.04	92.674	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	Sakhisih	Kawnpui	24.044	92.669	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	Bawkkang	Kawnpui	24.03	92.675	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	Tuitun	Kawnpui	23.9667	92.681	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
37	Khurthuk	Kawnpui	24.039	92.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	Sihpui	Kawnpui	24.036	92.669	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	Lungpher	Hortoki	24.06	92.602	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
40	Khawzasiaka	Hortoki	24.056	92.596	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	Zotui	Lungmuat	23.972	92.778	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	Luihnai	Lungmuat	23.966	92.779	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	thingsakawrlui	Lungmuat	23.955	92.795	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	Vengchung lui	Lungmuat	23.9714	92.782	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5.7 Total Alkalinity:

The ability of water to neutralize acid is alkalinity. Alkalinity is usually imparted by bicarbonate and to a lesser extent by chemical species such as carbonates, borates, silicates, phosphate, and the salts of humic and fulvic acids. Organically, salts of weak acids like acetic acid, propionic acid, and hydro-sulphuric acid can also induce alkalinity. Ammonia and hydroxides may also cause alkalinity (Goel, 2020).

Based on BIS guidelines (BIS, 2012), total alkalinity is categorized into three classes (0-200 mg/l, 200-600 mg/l, and >600 mg/l) representing Desirable, acceptable limit, and Permissible limits respectively. Water having high alkalinity is said to be "hard." The main causing mineral compound of alkalinity is calcium carbonate. High alkalinity may impart a bitter taste to water.

Samples from bore wells like Lalkima point hand pump, N.Chaltlang, and Vengsang electric groundwater pump, Bukpui have average total alkalinity of 390mg/l and 325mg/l respectively, which are exceeding the permissible limit. It seems that samples from deep groundwater mineral constituents are richer in mineral content and are characterized by high alkalinity value compared to shallow sources springs.

The Total alkalinity in the Geomorphic Units is shown below:-

Table 24: Average Total Alkalinity in Geomorphic Units

Sl.No	Geomorphology	Total alkalinity (mg/l or ppm) Pre-Monsoon	Total alkalinity (mg/l or ppm) Monsoon	Total alkalinity (mg/l or ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	92.000	48.000	46.000	186.000
2	Highly Dissected Structural Hill (SHH)	50.000	20.220	52.000	122.220
3	Inter-Montane Valley (IV)	69.000	39.000	70.000	178.000
4	Less Dissected Structural Hill (SHL)	61.780	36.310	52.560	150.650
5	Moderately Dissected Structural Hill (SHM)	83.540	53.540	67.670	204.750
	Average	71.264	39.414	57.646	

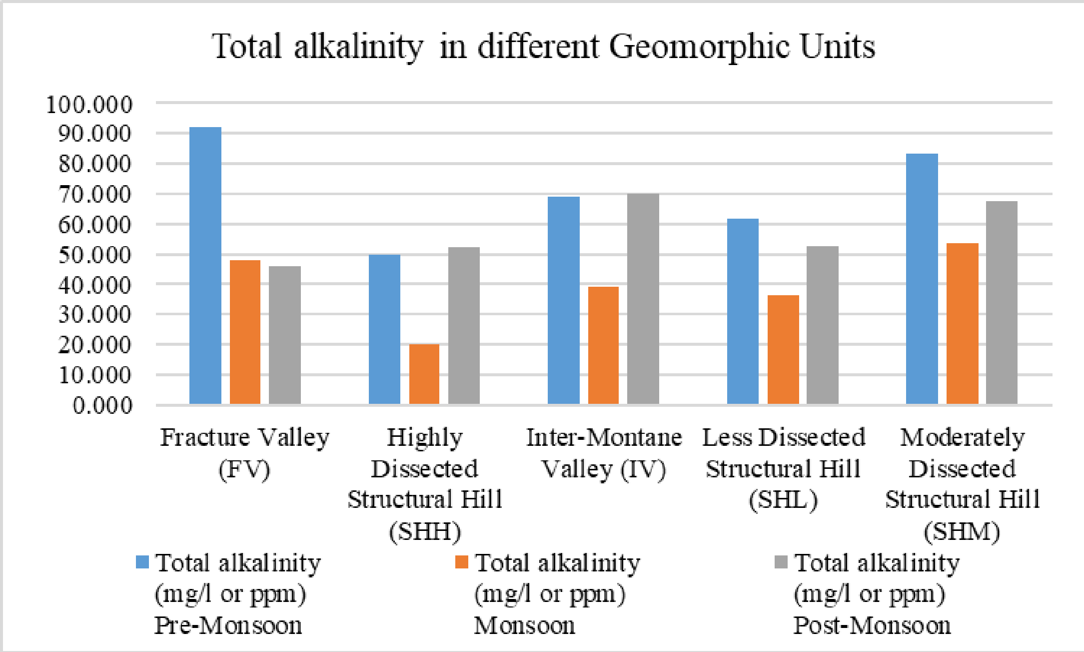


Figure 39: Bar chart of Total Alkalinity in Geomorphic Units

The Total Alkalinity is evenly distributed in the different Geomorphic Units of the study area with the highest concentration in Fracture Valley. It is that the dissolved solids concentration of groundwater increases towards the interior of the continent. Fracture Valley is at the lowest elevation (8 -10m from sea level) and therefore water is seeping out from older, deeper aquifers as compared to other Geomorphic Units. This may define the nature of high alkalinity in Fracture Valley. The Less Dissected Structural Hill has the least Total Alkalinity value.

The highest alkalinity value is observed during Pre-monsoon, followed by post-monsoon, and then, monsoon. It indicates the chemical constituents of groundwater are extensively diluted by infiltrated acidic rainwater during monsoon.

The Total alkalinity in the Lithostratigraphic Units is shown below: -

Table 25: Average Total Alkalinity in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Total alkalinity concentration (mg/l or ppm) Pre-Monsoon	Average Total alkalinity concentration (mg/l or ppm) Monsoon	Average Total alkalinity concentration (mg/l or ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	69.89	40.39	62.5	57.59
2	Sandstone dominated (Upper Bhuban Formation)	72.38	41.48	53.74	55.87
3	Shale dominated (Middle Bhuban Formation)	115.47	88.53	116.67	106.89
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	54	33.6	53.8	47.13
	Average	77.94	51.00	71.68	

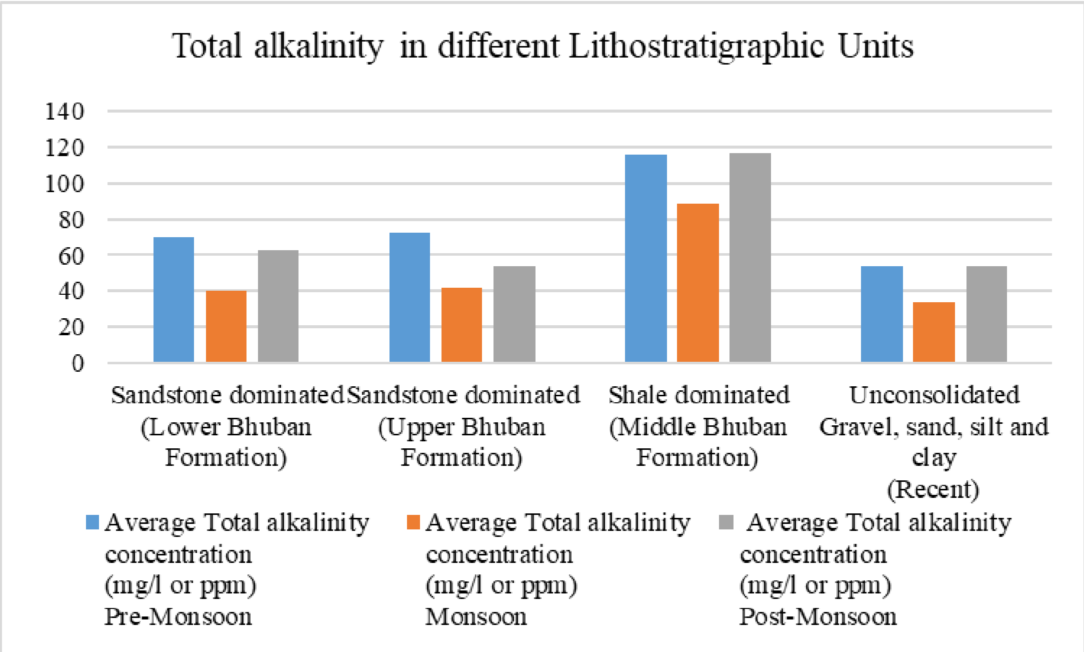


Figure 40: Bar chart of Total alkalinity in Lithostratigraphic Units

In terms of lithology, the total alkalinity in groundwater of shale-dominated rocks is found to be twice higher than that of sandstone and unconsolidated rocks of the area. Groundwater in unconsolidated Formation has the lowest Alkalinity as being most porous, shallowest, and easily depleted by rainwater. Sample from sandstone-dominated rock are also characterized by relatively lower total alkalinity, this coincides with the acidic nature of the groundwater from its lithological Unit.

The total alkalinity is lower during the monsoon season than during the pre-monsoon and post-monsoon periods. Pre-monsoon has the highest total alkalinity. This may be due to the acidification of groundwater by slightly acidic rainwater during the monsoon period.

The western part of N.Chaltlang is characterized by total alkalinity of 200 to 600ppm during Pre-Monsoon, exceeding the acceptable limit of 200ppm. Small patch areas at Kawnpui, the southern part of Serkhan, the eastern part of Lungmuat, and the southern part of Bukpui are having alkalinity of less than 50 ppm. The remaining area are having values ranging between 50 -200 ppm. During Monsoon, small patches at N.Chaltlang village are having alkalinity exceeding 200 ppm. About one-third of an area has alkalinity ranging between 50-200 ppm. The northern and western half of the area is having an alkalinity value of less than 50 ppm.N.Chaltlang area has high alkalinity throughout the season. The western tip around Hortoki and the eastern half except Lungmuat and the southern part of Serkhan are having alkalinity values ranging from 50 to 200 ppm during Post-Monsoon. The remaining parts are having alkalinity of less than 50 ppm.

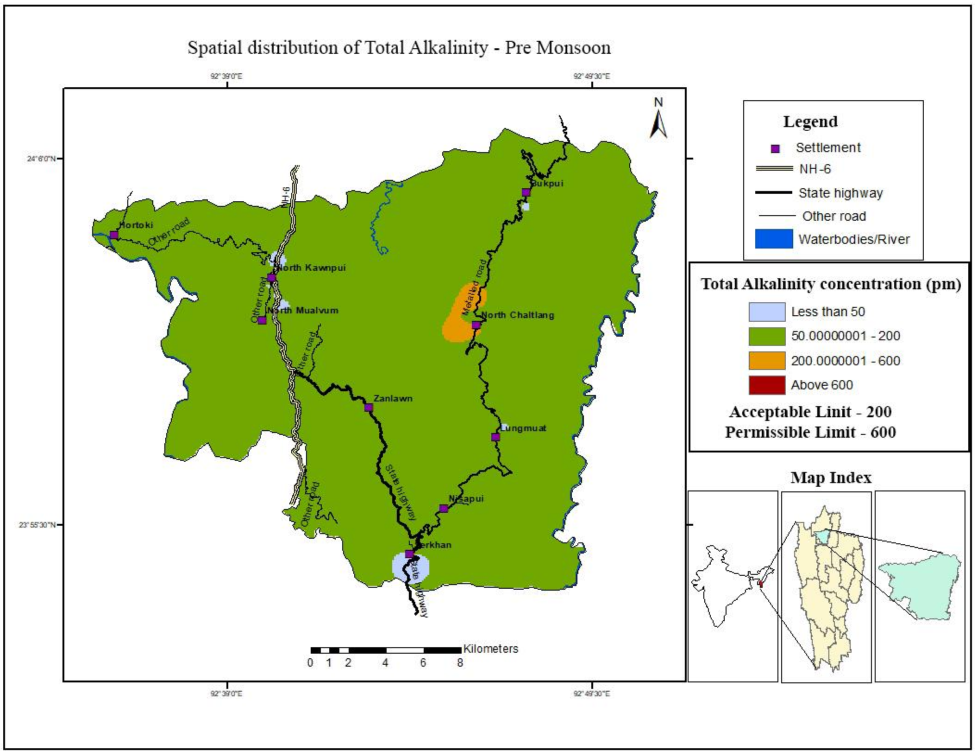


Figure 41: Spatial distribution map of Total alkalinity during Pre-monsoon

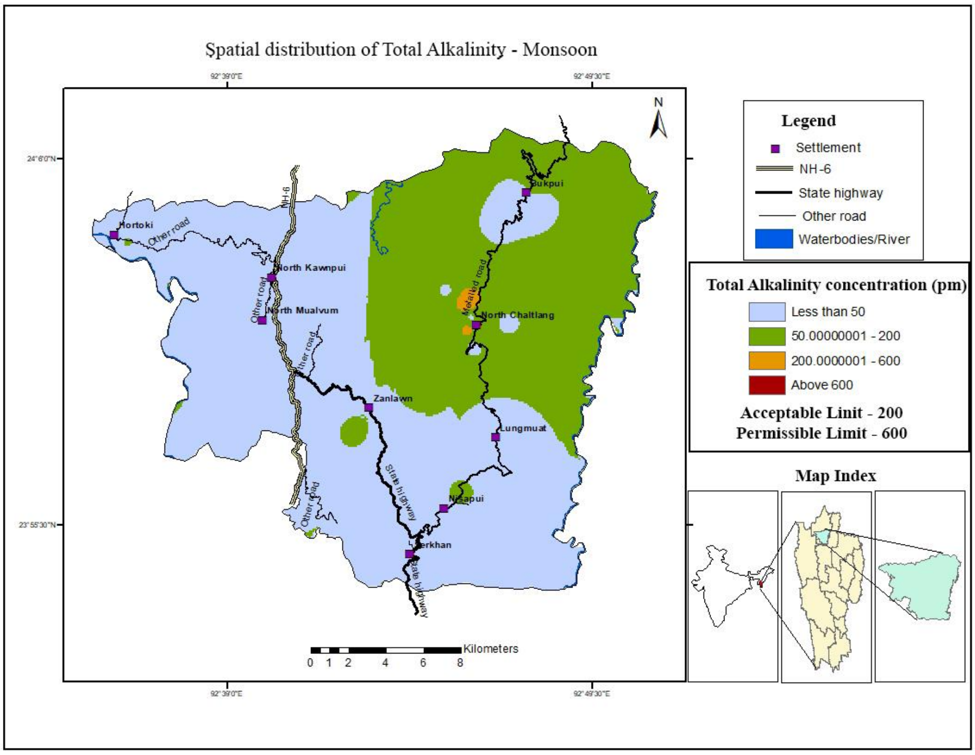


Figure 42: Spatial distribution map Total alkalinity during monsoon

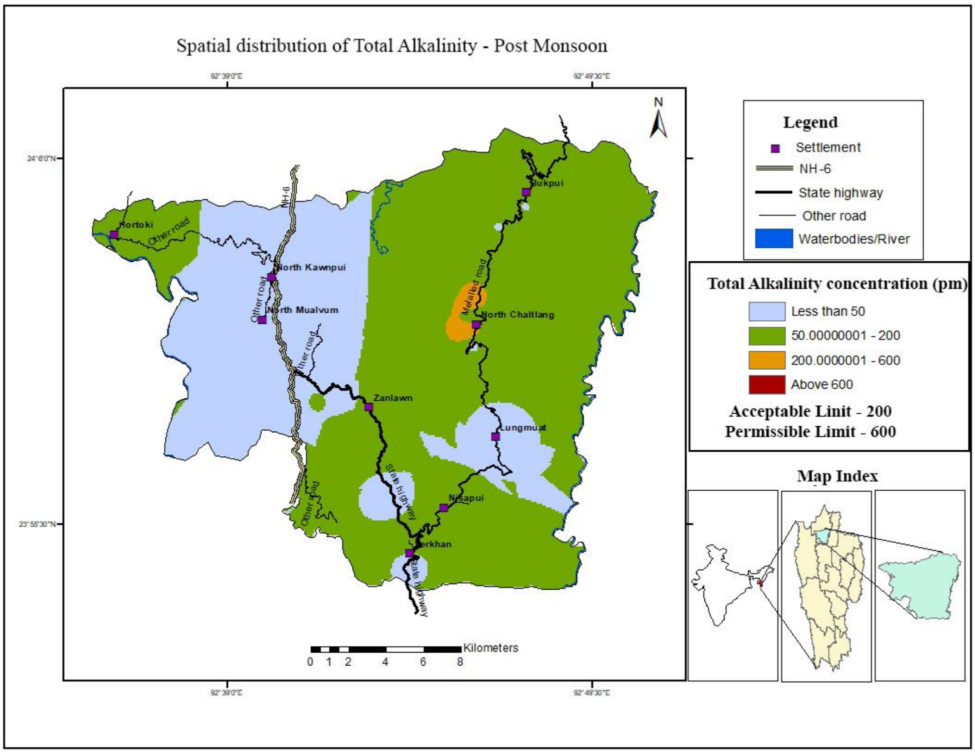


Figure 43: Spatial distribution map of Total alkalinity during Post-monsoon

Table 26: Total alkalinity (2017-2019)

Sl.No	Source Name	Village	Lattitude	Longtitude	Total Alkalinity Pre-Monsoon			Pre-Monsoon Average mg/l	Total Alkalinity Monsoon			Monsoon Average mg/l	Total Alkalinity Postmonsoon		
					2017	2018	2019		2017	2018	2019		2017	2018	2019
1	Vankeu	Serkhan	23.905	92.753	51	44	58	51	23	16	31	23.33	44	52	44
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	56.0	58.0	60.0	58.0	17.0	33.0	24.0	24.7	60.0	62.0	64.0
3	Dengalui	Serkhan	23.915	92.74	50.0	52.0	54.0	52.0	8.0	10.0	6.0	8.0	54.0	50.0	52.0
4	Bawngpu	Serkhan	23.908	92.739	38.0	40.0	42.0	40.0	28.0	26.0	30.0	28.0	42.0	44.0	40.0
5	Vautangbawk	Serkhan	23.915	92.78	72.0	76.0	74.0	74.0	11.0	18.0	31.0	20.0	72.0	74.0	70.0
6	Lalthansiama Point	Nisapui	24.037	92.755	64.0	66.0	68.0	66.0	34.0	36.0	32.0	34.0	66.0	64.0	68.0
7	Zotui	Nisapui	23.94	92.762	68.0	70.0	72.0	70.0	56.0	54.0	58.0	56.0	70.0	68.0	72.0
8	Challui	North Chaltlang	24.0214	92.784	71.0	67.0	59.0	65.7	32.0	31.0	26.0	29.7	34.0	65.0	66.0
9	Lalkima point handpump	North Chaltlang	24.018	92.765	392.0	394.00	396.0	394.0	235.0	237.0	233.0	235.0	392.0	394.0	390.0
10	Chhimluang	North Chaltlang	24.01	92.768	68.0	57.0	34.0	53.0	21.0	28.0	21.0	23.3	28.0	26.0	30.0
11	Lengleh	North Chaltlang	24.024	92.767	67.0	62.0	80.0	69.7	34.0	32.0	36.0	34.0	68.0	43.0	67.0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7194	321.0	367.0	385.0	357.7	348.0	346.0	350.0	348.0	390.0	389.0	325.0
13	Lungsum	Bukpui	24.084	92.788	58.0	60.0	62.0	60.0	24.0	55.0	66.0	48.3	60.0	58.0	62.0
14	Builum	Bukpui	24.067	92.78	56.0	72.0	53.0	60.3	26.0	34.0	37.0	32.3	48.0	46.0	50.0
15	Minmawng	Bukpui	24.085	92.791	80.0	78.0	76.0	78.0	46.0	44.0	48.0	46.0	76.0	78.0	74.0
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	112.0	110.0	108.0	110.0	64.0	66.0	62.0	64.0	89.0	87.0	91.0
17	Nuhliri Point	Bukpui	24.077	92.793	42.0	46.0	48.0	45.3	22.0	20.0	24.0	22.0	47.0	45.0	49.0
18	Hiahthar	Zanlawn	23.966	92.724	66.0	64.0	62.0	64.0	44.0	46.0	42.0	44.0	64.0	62.0	68.0
19	Phulraw Lui Tuikhur	Zanlawn	23.939	92.728	51.0	45.0	54.0	50.0	22.0	20.0	30.0	24.0	45.0	50.0	31.0
20	Vandawt	Zanlawn	23.984	92.694	57.0	47.0	58.0	54.0	12.0	17.0	16.0	15.0	53.0	51.0	50.0
21	Fului	Zanlawn	23.97	92.711	86.0	88.0	90.0	88.0	60.0	58.0	62.0	60.0	62.0	64.0	60.0
22	Pumpelh	Zanlawn	23.99	92.707	45.0	66.0	45.0	52.0	48.0	46.0	50.0	48.0	50.0	48.0	52.0
23	Midum Lui	Zanlawn	23.987	92.705	35.0	65.0	57.0	52.3	42.0	44.0	40.0	42.0	40.0	42.0	38.0
24	Phuanberh	Kawnpui	24.034	92.673	36.0	32.0	28.0	32.0	32.0	28.0	30.0	30.0	30.0	28.0	32.0
25	Hlitlui	Kawnpui	24.05	92.673	38.0	40.0	42.0	40.0	28.0	30.0	26.0	28.0	26.0	24.0	28.0
26	Charpui	Kawnpui	24.05	92.674	44.0	46.0	48.0	46.0	18.0	20.0	16.0	18.0	16.0	14.0	18.0
27	Vailui	Kawnpui	24.034	92.668	62.0	60.0	58.0	60.0	22.0	20.0	24.0	22.0	24.0	26.0	22.0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.753	22.0	24.0	26.0	24.0	40.0	38.0	42.0	40.0	42.0	44.0	40.0
29	Kuangsei	Kawnpui	24.0376	92.672	45.0	46.0	61.0	50.7	41.0	32.0	11.0	28.0	35.0	56.0	57.0
30	Sentezel	Kawnpui	24.04	92.674	62.0	60.0	58.0	60.0	50.0	48.0	52.0	50.0	52.0	50.0	54.0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	78.0	80.0	82.0	80.0	38.0	40.0	36.0	38.0	36.0	34.0	38.0
32	Sakhisih	Kawnpui	24.044	92.669	70.0	68.0	66.0	68.0	42.0	40.0	44.0	42.0	44.0	42.0	46.0
33	Bawkkang	Kawnpui	24.03	92.675	0.0	0.0	0.0	0.0	28.0	30.0	26.0	28.0	26.0	24.0	28.0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	112.0	114.0	116.0	114.0	30.0	28.0	32.0	30.0	32.0	30.0	34.0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	106.0	104.0	102.0	104.0	44.0	46.0	42.0	44.0	42.0	40.0	44.0
36	Tuitun	Kawnpui	23.9667	92.681	90.0	92.0	94.0	92.0	48.0	50.0	46.0	48.0	46.0	44.0	48.0
37	Khurthuk	Kawnpui	24.039	92.67	50.0	48.0	46.0	48.0	28.0	26.0	30.0	28.0	30.0	28.0	32.0
38	Sihpui	Kawnpui	24.036	92.669	58.0	60.0	62.0	60.0	38.0	40.0	36.0	38.0	36.0	34.0	38.0
39	Lungpher	Hortoki	24.06	92.602	98.0	100.0	102.0	100.0	45.0	53.0	57.0	51.7	100.0	102	98.0
40	Khawzasiaka	Hortoki	24.056	92.596	76.0	78.0	80.0	78.0	26.0	28.0	35.0	29.7	80.0	78.0	82.0
41	Zotui	Lungmuat	23.972	92.778	102.0	104.0	106.0	104.0	28.0	30.0	26.0	28.0	26.0	28.0	23.0
42	Luihnai	Lungmuat	23.966	92.779	80.0	82.0	84.0	82.0	22.0	24.0	20.0	22.0	20.0	18.0	22.0
43	Thingsakawr lui	Lungmuat	23.955	92.672	0.0	0.0	0.0	0.0	33.0	32.0	51.0	38.7	46.0	41.0	42.0
44	Vengchung Lui	Lungmuat	23.9714	92.782	43.0	32.0	35.0	36.7	42.0	36.0	60.0	46.0	31.0	36.0	40.0

5.8 Total Hardness:

Natural water always variable quantity of dissolved inorganic salts. The Total hardness is a measure of Ca^{+2}, Mg^{+2}, Cl^{-}, SO_4^{-2}, CO_4^{-2}, and HCO_3^{-} in water. They are differing from other sources of pollutants as they are usually derived from natural sources rather than anthropogenic sources. Thus, it mainly depends upon the composition and nature of the bedrock (Goel, 2020).

It is categorized into three ranges (0-200 mg/l, 200-600 mg/l, and >600 mg/l) as Desirable, Permissible, and Non-potable classes as per BIS guidelines (BIS, 2012). The value of Total hardness in groundwater is controlled by the chemical composition of rocks in the aquifers. Hardness depends upon the amount of dissolved calcium and magnesium in the water. Being tapping out from a deep aquifer, the highest Total hardness value recorded at the bore well of the Lalkima point hand pump, N. Chaltlang has a value of 366mg/l exceeding the acceptable limit. The rest of the ground water sources are within the desirable limit.

The Total hardness in the GeomorphicUnits is shown below-

Table 27: Average Total Hardness in Geomorphic Units

Sl.No	Geomorphology	Hardness (mg/l or ppm) Pre-Monsoon	Hardness (mg/l or ppm) Monsoon	Hardness (mg/l or ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	50.000	32.000	50.000	132.000
2	Highly Dissected Structural Hill (SHH)	33.500	29.500	33.500	96.500
3	Inter-Montane Valley (IV)	39.000	42,50	39.000	78.000
4	Less Dissected Structural Hill (SHL)	42.810	35.400	49.240	127.450
5	Moderately Dissected Structural Hill (SHM)	56.760	62.430	49.240	168.430
	Average	44.414	39.833	44.196	

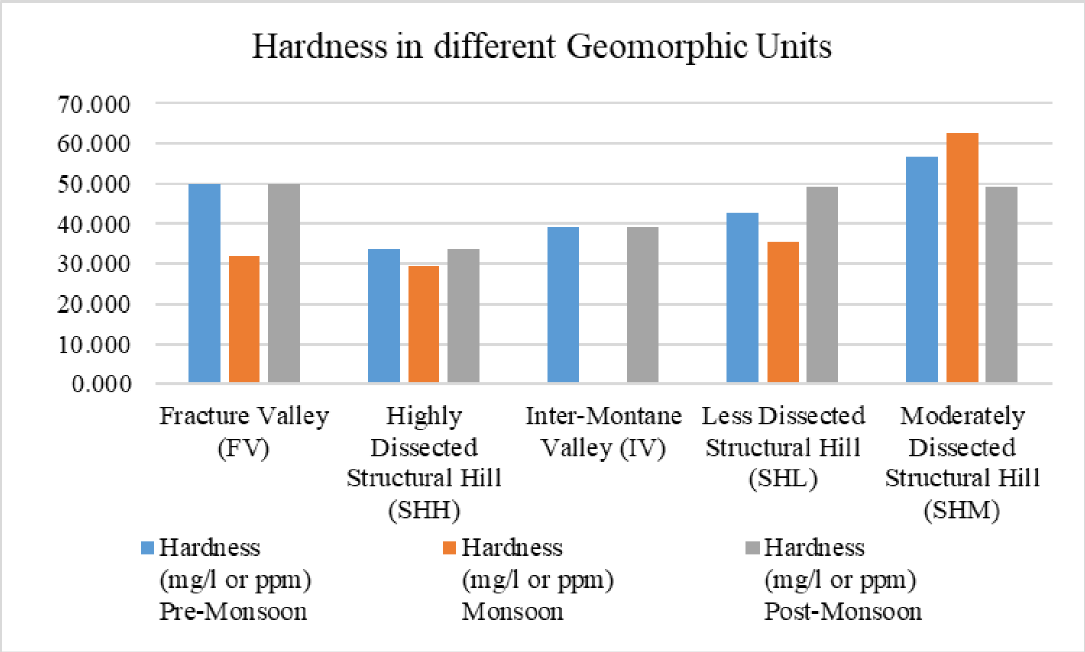


Figure 44. Bar chart of Total Iron in Geomorphic Units

In terms of geomorphology, groundwater within the Less Dissected Structural Hill, Fractured Valley, and Intermontane Valley have almost the same Total Hardness ranging from 40 to 44mg/l. The highest and lowest total hardness value is found in the Moderately Dissected Hill and Highly Dissected Structural Hill respectively. As characterized by high elevation, narrow hogback, steep slope, high rate of erosion, and transportation of surface runoff, groundwater in the Highly Dissected Structural Hill does not have enough time to dissolve the Calcium and Magnesium content of the rock or the rock forming aquifer are highly depleted in Calcium and Magnesium. On the other hand, Moderately Dissected Structural Hills have the highest hardness value. It may be due to slightly dropping down transporting current and depositional phenomenon as they are on a gently sloping portion of the mountain flank, which makes it ultimately richer in mineral composition.

In terms of season-wise, groundwater in each Unit is highly depleted in Ca and Mg ions during Monsoon rainy season. The post-monsoon has the highest alkalinity, followed by the pre-monsoon season.

The Total hardness in the Lithostratigraphic Units is shown below: -

Table 28: Average Hardness in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Hardness (mg/l or ppm) Pre-Monsoon	Average Hardness (mg/l or ppm) Monsoon	Average Hardness (mg/l or ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	44.48	45.38	48.29	46.05
2	Sandstone dominated (Upper Bhuban Formation)	52.18	54.01	55.71	53.97
3	Shale dominated (Middle Bhuban Formation)	37.25	39.33	42	39.53
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	50	32	50	44.00
	Average	45.98	42.68	49.00	

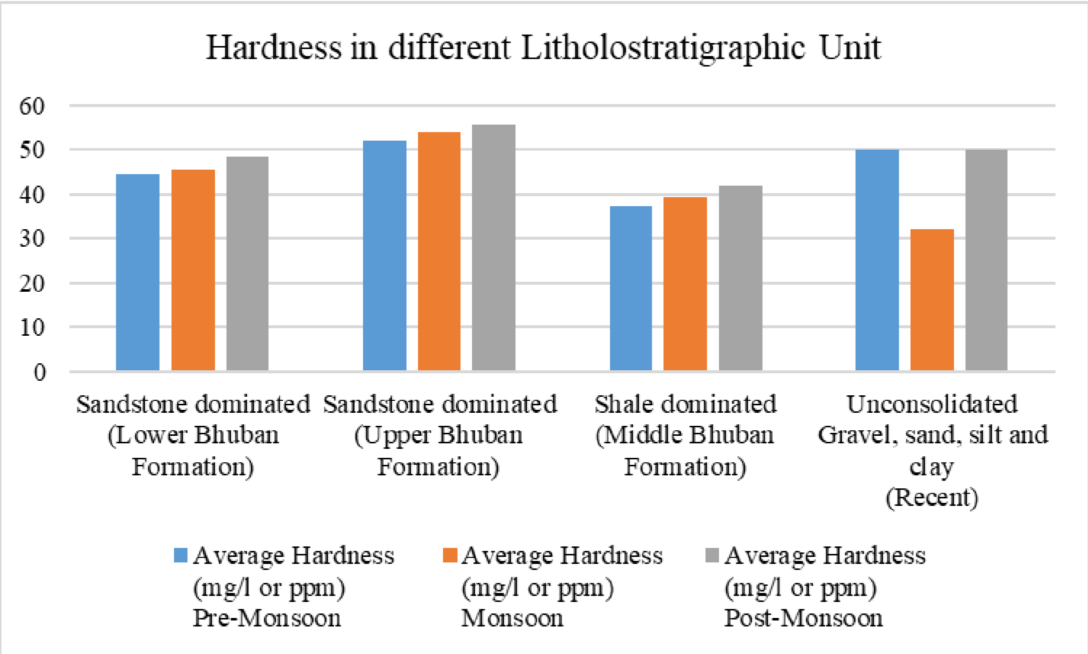


Figure 45: Bar chart of Hardness in Lithostratigraphic Units

The total Hardness of groundwater in the shale Formation is the lowest. This may be due to its impermeability though having a higher content of Calcium and Magnesium in its chemical composition. The unconsolidated sedimentary Formation and Sandstone of the Lower Bhuban Formation are having groundwater with almost the same value of Total hardness. Sandstones of the Upper Bhuban Formation have a high value of sodic and alkalic oxides indicating the abundant presents of feldspar minerals, the alteration of such minerals will result in the release of Ca, K, and Na affecting the chemistry of groundwater. The water-rock interaction concerning the alteration of such minerals present in the sandstones will be minimum during pre-monsoon which in turn will affect less hardness characteristic of groundwater; thus making the total hardness to be at its lowest during the pre-monsoon period. It became slightly higher during the monsoon period, which may likely be due to the onset of dissolution activities with subsequent increase in alkali concentration in the groundwater, and then finally with continued dissolution processes, the groundwater will attain more hardness during the post-monsoon period.

The small locality at N.Chaltlang is characterized by a total hardness value of 100 to 300ppm during Pre-Monsoon. The remaining areas are having values ranging from less than 100 ppm. During the Monsoon, hardness exceeding the permissible limit of 300 ppm is found in a confined area at N.Chaltlang village, and that range between 100-300 ppm is found in this vicinity. The remaining area is having a hardness value of less than 100ppm. N.Chaltlang areas have hardness values between 100 to 300 ppm during the Post-Monsoon season. The high value of hardness of this area in every season may be attributed to the presence of bore well-tapping water from readily soluble formation. The remaining areas are having hardness values of less than 100ppm.

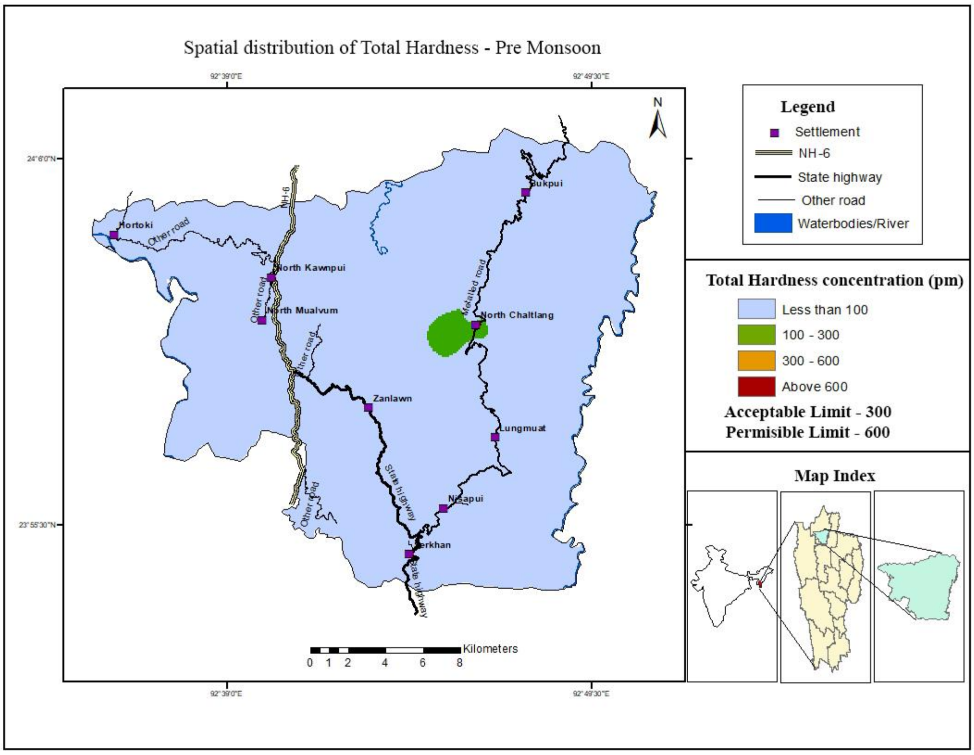


Figure 46: Spatial distribution map of Total hardness during Pre-Monsoon

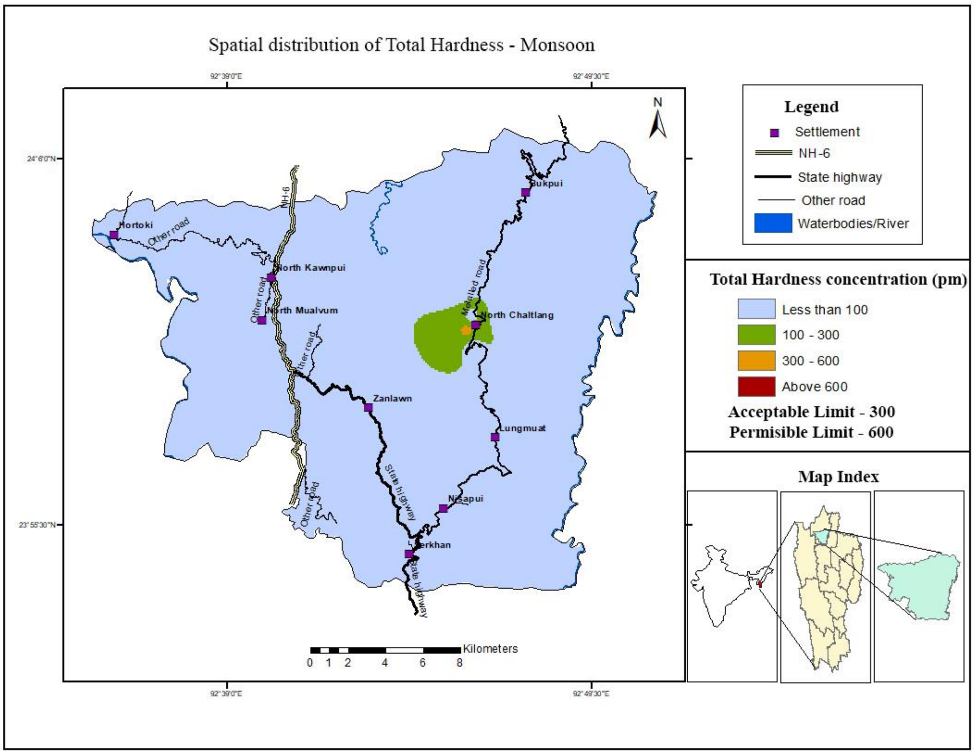


Figure 47: Spatial distribution map of Total hardness during Monsoon

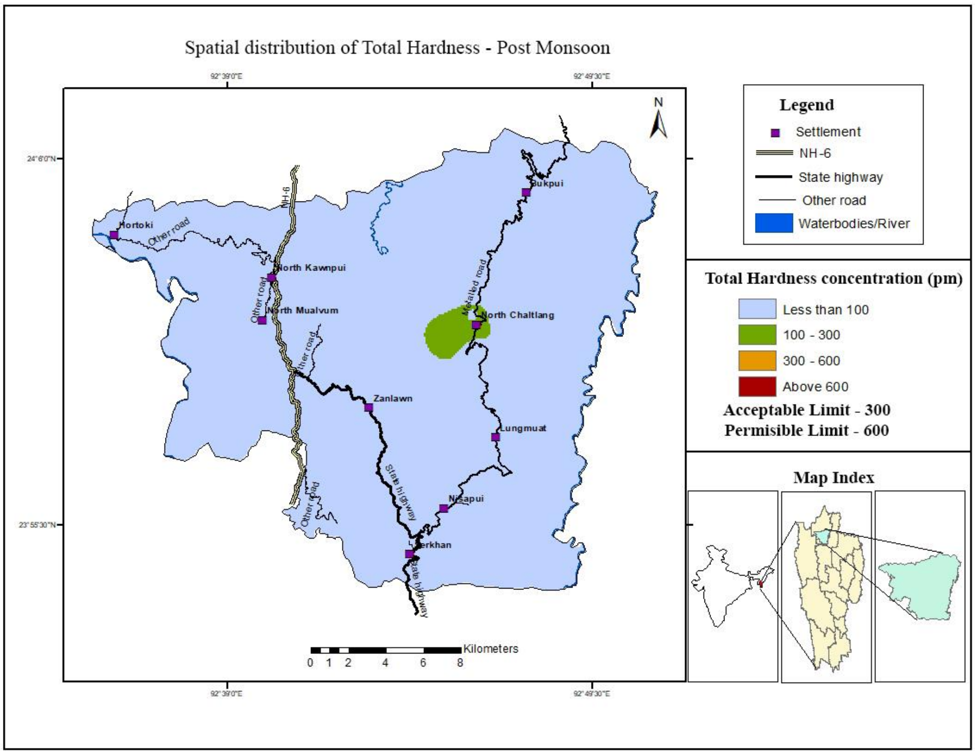


Figure 48: Spatial distribution map of Total hardness during Post-Monsoon

Table 29: Total Hardness (2017-2019)

Sl.No	Source Name	Village	Lattitude	Longtitude	Total Hardness in Pre-Monsoon 2017	2018	2019	Pre-Monsoon Average (mg/l)	Total Hardness Monsoon 2017	2018	2019	Monsoon Average (mg/l)	Total Hardness Post-monsoon 2017	2018	2019	Post-monsoon Average (mg/l)
1	Vankeu	Serkhan	23.905	92.753	24.0	26.0	24.0	24.7	22.0	32.0	31.0	28.3	45.0	44.0	31.0	40.0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	32.0	36.0	34.0	34.0	21.0	25.0	20.0	22.0	34.0	36.0	32.0	34.0
3	Dengalui	Serkhan	23.915	92.74	26.0	28.0	30.0	28.0	28.0	26.0	30.0	28.0	30.0	26.0	28.0	28.0
4	Bawngpu	Serkhan	23.908	92.739	24.0	20.0	22.0	22.0	36.0	34.0	38.0	36.0	20.0	22.0	24.0	22.0
5	Vautangbawk	Serkhan	23.915	92.78	46.0	48.0	50.0	48.0	33.0	48.0	44.0	41.7	50.0	48.0	46.0	48.0
6	Lalthansiama Point	Nisapui	24.037	92.755	26.0	28.0	30.0	28.0	34.0	32.0	36.0	34.0	28.0	30.0	26.0	28.0
7	Zotui	Nisapui	23.94	92.762	52.0	54.0	56.0	54.0	34.0	32.0	36.0	34.0	54.0	52.0	56.0	54.0
8	Challui	North Chaltlang	24.0214	92.784	36.0	33.0	31.0	33.3	31.0	37.0	40.0	36.0	34.0	45.0	47.0	42.0
9	Lalkima Point handpump	North Chaltlang	24.018	92.765	294.0	296.0	298.0	296.0	364.0	362.0	366.0	364.0	296.0	294.0	298.0	296.0
10	Chhimluang	North Chaltlang	24.01	92.768	27.0	27.0	21.0	25.0	32.0	52.0	34.0	39.3	28.0	24.0	26.0	26.0
11	Lengleh	North Chaltlang	24.024	92.767	82.0	84.0	29.0	65.0	68.0	76.0	70.0	71.3	86.0	84.0	82.0	84.0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	44.0	41.0	37.0	40.7	49.0	22.0	39.0	36.7	66.0	67.0	59.0	64.0
13	Lungsum	Bukpui	24.084	92.788	14.0	16.0	18.0	16.0	54.0	52.0	56.0	54.0	18.0	14.0	16.0	16.0
14	Builum	Bukpui	24.067	92.78	45.0	44.0	41.0	43.3	41.0	40.0	54.0	45.0	36.0	38.0	40.0	38.0
15	Minmawng	Bukpui	24.085	92.791	54.0	56.0	58.0	56.0	24.0	22.0	26.0	24.0	56.0	58.0	54.0	56.0
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	78.0	80.0	82.0	80.0	46.0	44.0	48.0	46.0	80.0	82.0	78.0	80.0
17	Nuhliri Point	Bukpui	24.077	92.793	40.0	42.0	44.0	42.0	76.0	78.0	74.0	76.0	42.0	44.0	40.0	42.0
18	Vandawt	Zanlawn	23.984	92.694	33.0	39.0	36.0	36.0	47.0	42.0	41.0	43.3	49.0	44.0	42.0	45.0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	11.0	19.0	23.0	17.7	20.0	32.0	33.0	28.3	53.0	55.0	49.0	52.3
20	Hiahthar	Zanlawn	23.966	92.724	32.0	34.0	36.0	34.0	26.0	24.0	28.0	26.0	34.0	32.0	36.0	34.0
21	Fului	Zanlawn	23.97	92.711	36.0	38.0	40.0	38.0	56.0	58.0	54.0	56.0	40.0	36.0	38.0	38.0
22	Pumpelh	Zanlawn	23.99	92.707	27.0	33.0	31.0	30.3	26.0	24.0	28.0	26.0	24.0	26.0	28.0	26.0
23	Midum Lui	Zanlawn	23.987	92.705	20.0	20.0	23.0	21.0	30.0	28.0	32.0	30.0	32.0	36.0	34.0	34.0
24	Phuanberh	Kawnpui	24.034	92.673	28.0	25.0	25.0	26.0	28.0	26.0	30.0	28.0	26.0	30.0	28.0	28.0
25	Hlitlui	Kawnpui	24.05	92.673	32.0	34.0	36.0	34.0	44.0	46.0	42.0	44.0	34.0	36.0	32.0	34.0
26	Charpui	Kawnpui	24.05	92.674	44.0	46.0	48.0	46.0	78.0	76.0	80.0	78.0	46.0	48.0	44.0	46.0
27	Vailui	Kawnpui	24.034	92.668	58.0	60.0	62.0	60.0	60.0	58.0	62.0	60.0	60.0	62.0	58.0	60.0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	82.0	84.0	86.0	84.0	94.0	96.0	92.0	94.0	84.0	86.0	82.0	84.0
29	Kuangsei	Kawnpui	24.0376	92.672	41.0	44.0	37.0	40.7	19.0	26.0	31.0	25.3	61.0	61.0	66.0	62.7
30	Sentezel	Kawnpui	24.04	92.674	42.0	44.0	46.0	44.0	44.0	42.0	46.0	44.0	46.0	44.0	42.0	44.0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	42.0	44.0	46.0	44.0	28.0	26.0	30.0	28.0	46.0	44.0	42.0	44.0
32	Sakhisih	Kawnpui	24.044	92.669	40.0	42.0	44.0	42.0	38.0	36.0	40.0	38.0	42.0	44.0	46.0	44.0
33	Bawkkang	Kawnpui	24.03	92.675	38.0	33.0	38.0	36.3	26.0	24.0	28.0	26.0	28.0	24.0	26.0	26.0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	66.0	68.0	70.0	68.0	24.0	22.0	26.0	24.0	70.0	68.0	66.0	68.0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	72.0	74.0	76.0	74.0	56.0	54.0	58.0	56.0	74.0	76.0	72.0	74.0
36	Tuitun	Kawnpui	23.9667	92.681	48.0	50.0	52.0	50.0	32.0	30.0	34.0	32.0	52.0	48.0	50.0	50.0
37	Khurthuk	Kawnpui	24.039	92.67	42.0	40.0	44.0	42.0	64.0	66.0	62.0	64.0	44.0	40.0	42.0	42.0
38	Sihpui	Kawnpui	24.036	92.669	32.0	30.0	34.0	32.0	28.0	26.0	30.0	28.0	34.0	32.0	30.0	32.0
39	Lungpher	Hortoki	24.06	92.602	34.0	36.0	38.0	36.0	34.0	42.0	40.0	38.7	38.0	36.0	34.0	36.0
40	Khawzasiaka	Hortoki	24.056	92.596	62.0	60.0	64.0	62.0	28.0	32.0	33.0	31.0	62.0	64.0	60.0	62.0
41	Zotui	Lungmuat	23.972	92.778	82.0	80.0	84.0	82.0	58.0	60.0	56.0	58.0	80.0	84.0	82.0	82.0
42	Luihnai	Lungmuat	23.966	92.779	64.0	66.0	62.0	64.0	74.0	72.0	76.0	74.0	62.0	66.0	64.0	64.0
43	thingsakawrlui	Lungmuat	23.955	92.795	52.0	56.0	50.0	52.7	56.0	53.0	59.0	56.0	63.0	75.0	77.0	71.7
44	Vengchung lui	Lungmuat	23.9714	92.782	0.0	62.0	61.0	41.0	0	66.0	66.0	44.0	0.0	68.0	63.0	43.7

5.9 Chloride:

The chief source of Chlorides is sedimentary rocks mainly evaporites such as halite, gypsum, anhydrite, etc., Igneous rocks may also serve as minor sources. Chloride concentration is categorized into three classes (0-250 mg/l, 250-1000 mg/l, and >1000 mg/l) by BIS guidelines as Desirable (BIS, 2012). Chlorides may also enter into Groundwater due to anthropogenic activities. However, water samples from various locations within the study area are well within the Desirable range.

Chlorides concentration in the Geomorphic Units is shown below-

Table 30: Average Total Chloride in Geomorphic Units

Sl.No	Geomorphology	The concentration of Total Chloride (ppm) Pre-Monsoon	The concentration of Total Chloride (ppm) Monsoon	The concentration of Total Chloride (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	37.000	13.000	13.000	63.000
2	Highly Dissected Structural Hill (SHH)	39.250	13.830	21.000	74.080
3	Inter-Montane Valley (IV)	38.000	23.500	14.500	76.000
4	Less Dissected Structural Hill (SHL)	39.480	18.070	17.690	75.240
5	Moderately Dissected Structural Hill (SHM)	44.360	20.680	20.710	85.750
	Average	39.618	17.816	17.380	

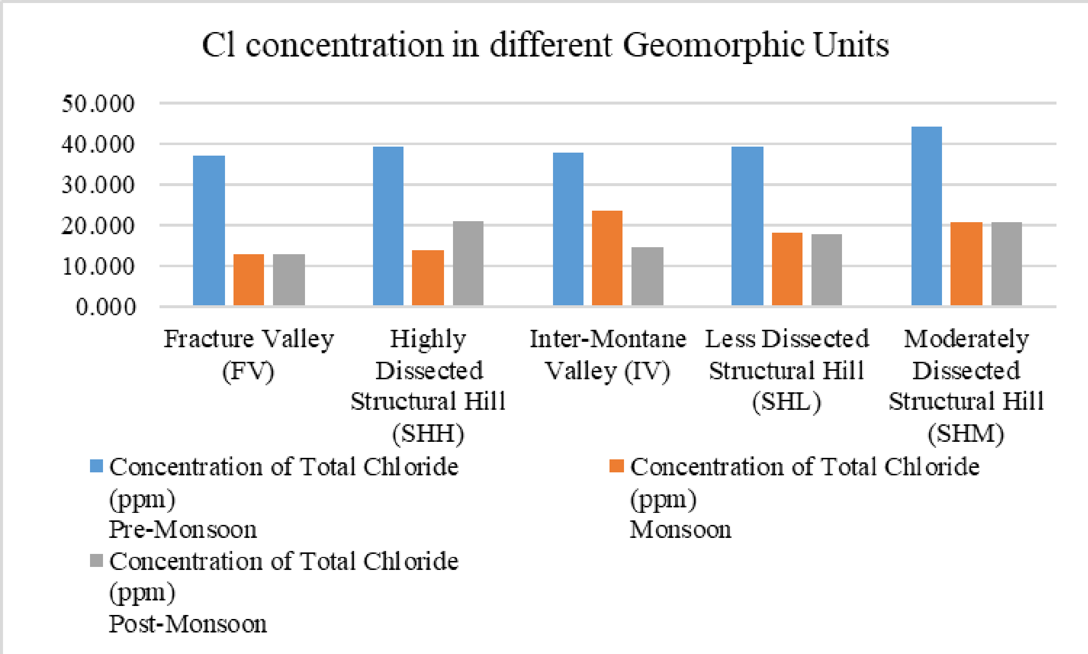


Figure 49: Bar chart of Total chloride in Geomorphic Units

In terms of Geomorphic Units, the Moderately Dissected Structural Hill has the highest Chlorides concentration, while the Fractured Valley has the lowest Chlorides concentration. Its nature of highly fracture rock consequently makes it highly porous therefore amplifying the depletion rate of readily dissolvable mineral constituents of the rocks, resulting in lower Cl content in comparison to other Units.

Chlorides concentration in the lithological Units is shown below: -

Table 31: Average Chloride Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Chloride concentration (mg/l or ppm) Pre-Monsoon	Average Chloride concentration (mg/l or ppm) Monsoon	Average Chloride concentration (mg/l or ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	42.38	17.67	16.1	25.38
2	Sandstone dominated (Upper Bhuban Formation)	43.02	20.41	20.73	28.05
3	Shale dominated (Middle Bhuban Formation)	38.5	13.83	21	24.44
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	36.33	20.11	13	23.15
	Average	40.058	18.005	17.708	

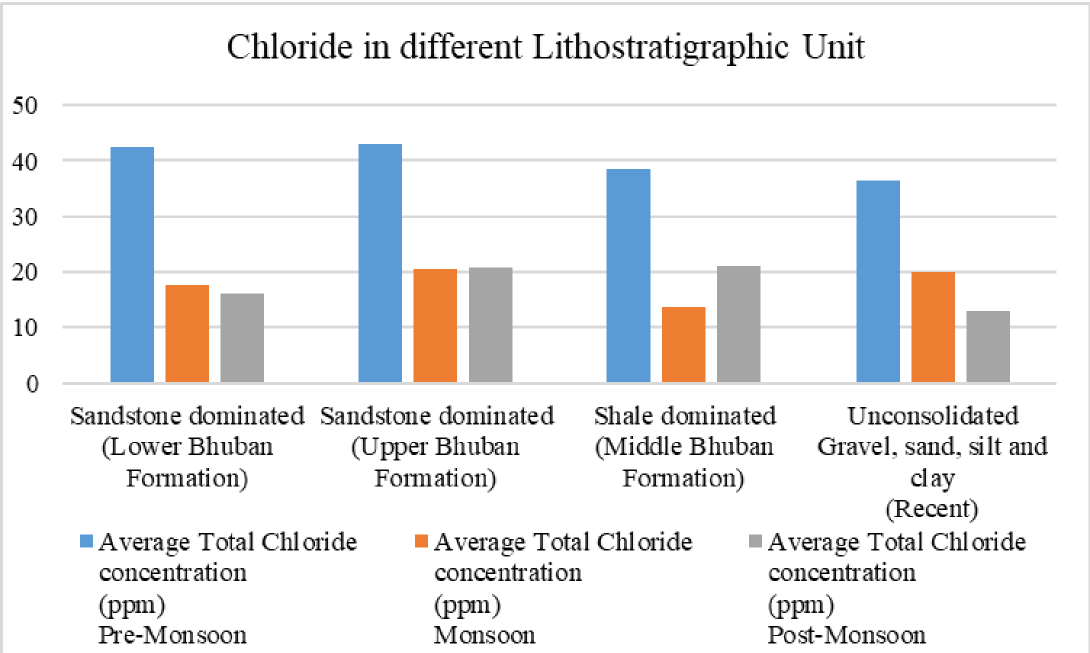


Figure 50: Bar chart of Chloride in Lithostratigraphic Units

Sandstone rock Formations have groundwater with the highest chloride concentration. Upper Bhuban has higher Cl content than Lower Bhuban Formation. This may be due to the presence of higher chloride minerals in this rock Unit. The chloride concentration is more or less the same in Shale and Unconsolidated sedimentary rock.

The concentration of Chlorides is twice higher during the pre-monsoon season than during the monsoon and post-monsoon periods. This may be due to the increasing amount of solvent that dilutes minerals during the monsoon rain.

The average concentration of chloride in all over the study area except a small area in Lungmuat and Hortoki during Pre-Monsoon is between 30-250 ppm. The two-mentioned area are having concentrations of less than 30 ppm. The western part of Hortoki and the northern part of Kawnpui are having concentrations of 30-250ppm during Monsoon and the remaining areas are characterized by less than 30ppm concentration. During Post-Monsoon, the northern part of Kawnpui has a slightly higher Cl value of 30-250ppm.

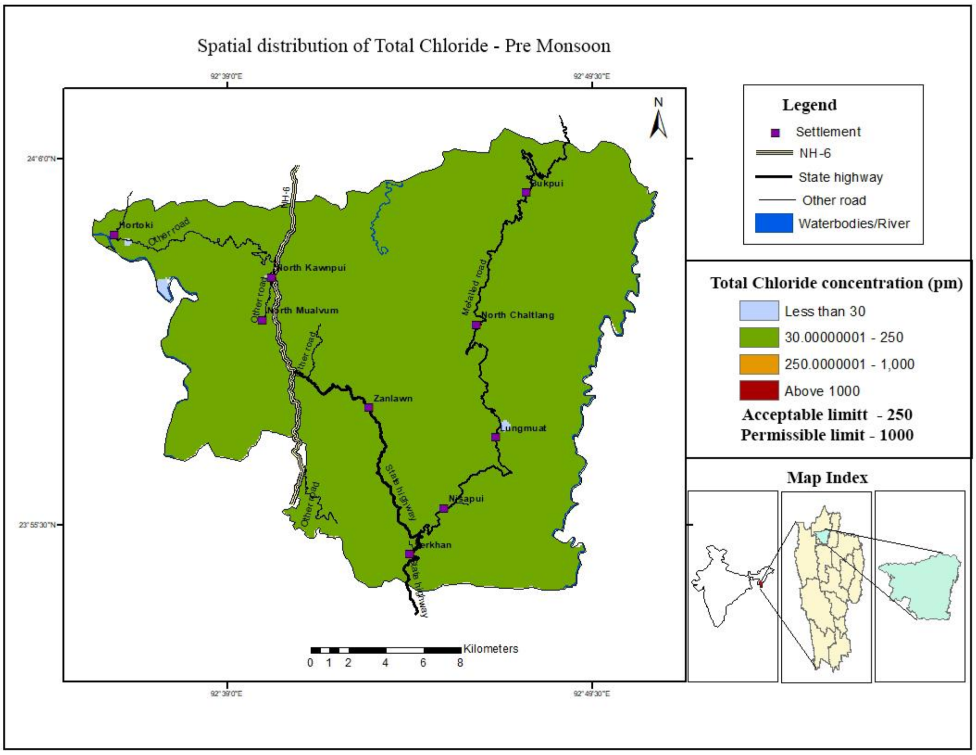


Figure 51: Spatial distribution map of Total chloride during Pre-Monsoon

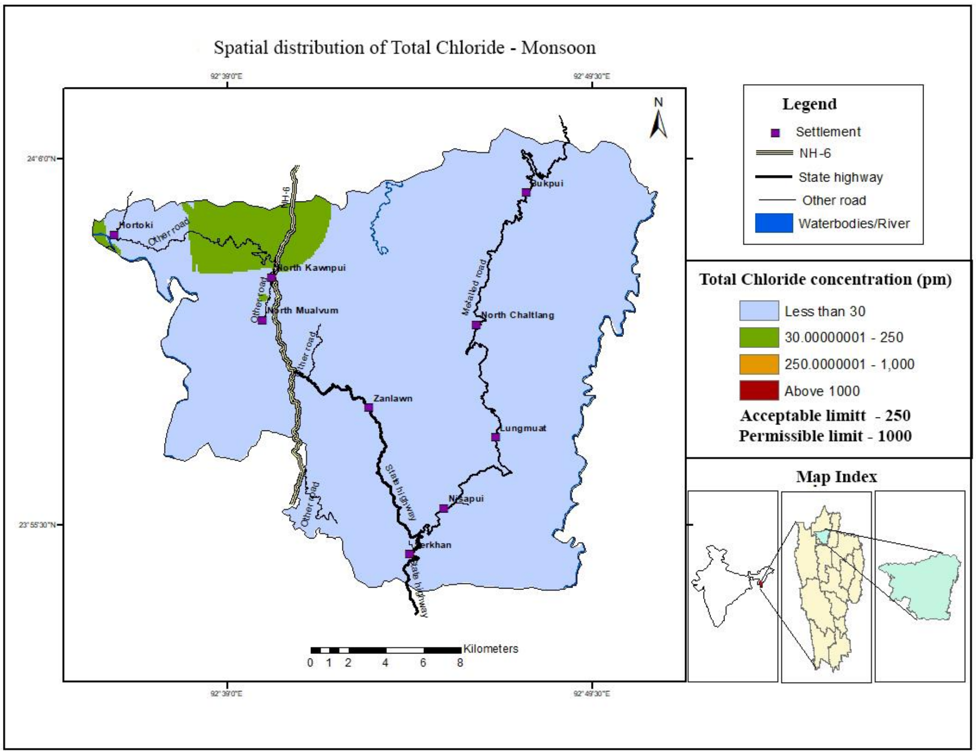


Figure 52: Spatial distribution map of Total chloride during Monsoon

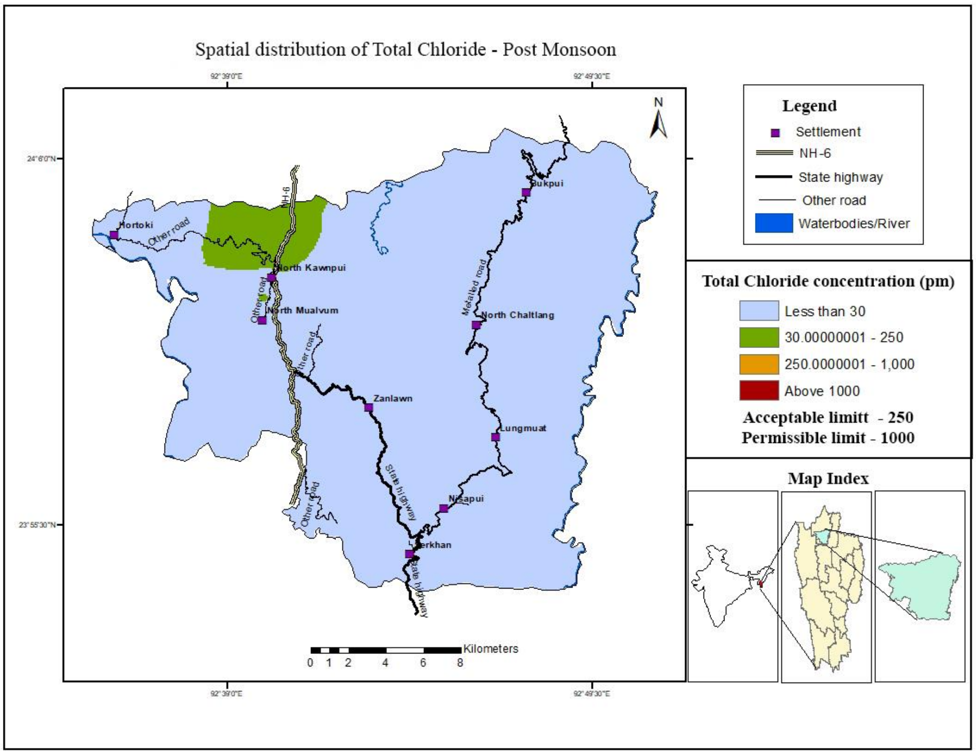


Figure 53: Spatial distribution map of Total chloride during Post-Monsoon

Table 32: Chloride value (2017-2019)

Sl.No	Source Name	Village	Lattitude	Longtitude	Total Chloride Pre-Monsoon			Pre-Monsoon Average (mg/l)	Total Chloride in Monsoon			Monsoon Average (mg/l)	Total Chloride Postmonsoon			Postmonsoon Average (mg/l)
					2017.0	2018.0	2019.0		2017.0	2018.0	2019.0		2017	2018	2019	
1	Vankeu	Serkhan	23.905	92.753	32.0	27.0	41.0	33.33	21.0	18.0	19.0	19.333	12.0	16.0	18.0	15.3
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	40.0	42.0	44.0	42.00	15.0	11.0	14.0	13.333	40.0	42.0	44.0	42.0
3	Dengalui	Serkhan	23.915	92.74	36.0	38.0	40.0	38.00	12.0	10.0	14.0	12.000	12.0	14.0	10.0	12.0
4	Bawngpu	Serkhan	23.908	92.739	38.0	40.0	42.0	40.00	19.0	15.0	17.0	17.000	19.0	15.0	17.0	17.0
5	Vautangbawk	Serkhan	23.915	92.78	35.0	37.0	39.0	37.00	14.0	13.0	11.0	12.667	10.0	12.0	14.0	12.0
6	Lalthansiama Point	Nisapui	24.037	92.755	39.0	37.0	35.0	37.00	12.0	14.0	10.0	12.000	14.0	12.0	10.0	12.0
7	Zotui	Nisapui	23.94	92.762	46.0	48.0	50.0	48.00	14.0	12.0	16.0	14.000	16.0	12.0	14.0	14.0
8	Challui	North Chaltlang	24.0214	92.784	34.0	51.0	45.0	43.33	22.0	24.0	26.0	24.000	10.0	12.0	11.0	11.0
9	Lalkima Point handpump	North Chaltlang	24.018	92.765	41.0	43.0	45.0	43.00	21.0	23.0	25.0	23.000	23.0	21.0	25.0	23.0
10	Chhimluang	North Chaltlang	24.01	92.768	39.0	41.0	40.0	40.00	15.0	11.0	18.0	14.667	12.0	16.0	14.0	14.0
11	Lengleh	North Chaltlang	24.024	92.767	32.0	34.0	36.0	34.00	13.0	11.0	15.0	13.000	15.0	11.0	13.0	13.0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	33.0	39.0	37.0	36.33	25.0	19.0	21.0	21.667	17.0	21.0	27.0	21.7
13	Lungsum	Bukpui	24.084	92.788	33.0	31.0	35.0	33.00	13.0	11.0	15.0	13.000	15.0	11.0	13.0	13.0
14	Builum	Bukpui	24.067	92.78	51.0	44.0	49.0	48.00	10.0	16.0	16.0	14.000	16.0	14.0	18.0	16.0
15	Minmawng	Bukpui	24.085	92.791	45.0	41.0	43.0	43.00	16.0	14.0	18.0	16.000	14.0	16.0	18.0	16.0
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	47.0	49.0	51.0	49.00	21.0	23.0	25.0	23.000	25.0	23.0	21.0	23.0
17	Nuhliri Point	Bukpui	24.077	92.793	42.0	44.0	46.0	44.00	12.0	10.0	14.0	12.000	10.0	14.0	12.0	12.0
18	Vandawt	Zanlawn	23.984	92.694	41.0	43.0	47.0	43.67	13.0	21.0	14.0	16.000	21.0	22.0	27.0	23.3
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	34.0	36.0	38.0	36.00	12.0	16.0	18.0	15.333	19.0	16.0	12.0	15.7
20	Hiahthar	Zanlawn	23.966	92.724	44.0	46.0	48.0	46.00	13.0	11.0	15.0	13.000	11.0	13.0	15.0	13.0
21	Fului	Zanlawn	23.97	92.711	37.0	39.0	41.0	39.00	18.0	16.0	14.0	16.000	16.0	14.0	18.0	16.0
22	Pumpelh	Zanlawn	23.99	92.707	55.0	54.0	58.0	55.67	18.0	16.0	14.0	16.000	16.0	14.0	18.0	16.0
23	Midum Lui	Zanlawn	23.987	92.705	44.0	36.0	36.0	38.67	18.0	16.0	14.0	16.000	16.0	14.0	18.0	16.0
24	Phuanberh	Kawnpui	24.034	92.673	55.0	43.0	59.0	52.33	29.0	25.0	31.0	28.333	31.0	29.0	25.0	28.3
25	Hlitlui	Kawnpui	24.05	92.673	40.0	42.0	44.0	42.00	24.0	22.0	26.0	24.000	26.0	22.0	24.0	24.0
26	Charpui	Kawnpui	24.05	92.674	55.0	57.0	59.0	57.00	33.0	31.0	35.0	33.000	31.0	35.0	33.0	33.0
27	Vailui	Kawnpui	24.034	92.668	58.0	60.0	62.0	60.00	40.0	42.0	44.0	42.000	42.0	40.0	44.0	42.0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	105.0	107.0	109.0	107.00	91.0	93.0	95.0	93.000	93.0	95.0	91.0	93.0
29	Kuangsei	Kawnpui	24.0376	92.672	52.0	36.0	35.0	41.00	21.0	20.0	24.0	21.667	15.0	16.0	16.0	15.7
30	Sentezel	Kawnpui	24.04	92.674	40.0	42.0	44.0	42.00	30.0	28.0	32.0	30.000	28.0	32.0	30.0	30.0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	34.0	36.0	38.0	36.00	16.0	14.0	12.0	14.000	12.0	14.0	16.0	14.0
32	Sakhisih	Kawnpui	24.044	92.669	25.0	27.0	29.0	27.00	13.0	11.0	15.0	13.000	11.0	15.0	13.0	13.0
33	Bawkkang	Kawnpui	24.03	92.675	32.0	42.0	44.0	39.33	12.0	10.0	14.0	12.000	14.0	10.0	12.0	12.0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	28.0	30.0	32.0	30.00	13.0	11.0	15.0	13.000	11.0	13.0	15.0	13.0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	32.0	30.0	28.0	30.00	10.0	8.0	12.0	10.000	8.0	10.0	12.0	10.0
36	Tuitun	Kawnpui	23.9667	92.681	35.0	37.0	39.0	37.00	11.0	13.0	15.0	13.000	13.0	15.0	11.0	13.0
37	Khurthuk	Kawnpui	24.039	92.67	47.0	49.0	51.0	49.00	30.0	28.0	32.0	30.000	28.0	32.0	30.0	30.0
38	Sihpui	Kawnpui	24.036	92.669	31.0	33.0	35.0	33.00	16.0	14.0	18.0	16.000	18.0	14.0	16.0	16.0
39	Lungpher	Hortoki	24.06	92.602	27.0	29.0	31.0	29.00	11.0	14.0	15.0	13.333	12.0	10.0	8.0	10.0
40	Khawzasiaka	Hortoki	24.056	92.596	41.0	43.0	45.0	43.00	31.0	33.0	38.0	34.000	18.0	16.0	14.0	16.0
41	Zotui	Lungmuat	23.972	92.778	35.0	37.0	39.0	37.00	13.0	11.0	15.0	13.000	11.0	15.0	13.0	13.0
42	Luihnai	Lungmuat	23.966	92.779	55.0	57.0	59.0	57.00	12.0	10.0	14.0	12.000	10.0	14.0	12.0	12.0
43	Thingsakawrlui	Lungmuat	23.955	92.795	0.0	44.0	47.0	30.33	0.0	0.0	0.0	0.000	11.0	15.0	17.0	14.3
44	Vengchung lui	Lungmuat	23.9714	92.782	0.0	37.0	33.0	23.33	0.0	33.0	25.0	19.333	0.0	27.0	28.0	18.3

5.10 Silver (Ag):

Minerals of Ag include argentite (Ag_2S), chlorargyrite (AgCl), polybasite $(Ag, Cu)_{16}Sb_2S_{11}$), and proustite (Ag_3AsS_3). Silver also occurs as a contaminant in chalcopyrite, galena, and ores of copper and lead. Silver occurs as trace constituents in potable water (generally <0.01 mg/l). Silver nitrate, which is soluble and silver chloride, relatively insoluble are the most important forms of silver for drinking water. Disinfecting devices that contain silver may release silver in its ionic or nanoparticle (AgNP) form into drinking water. It may also release from fabrics coated with AgNPs. Nano-silver is increasingly used in washing machines textiles and façade coatings, and personal care products. Silver and its salts, oxides, and halides are used in alkaline batteries, electrical equipment, hard alloys, mirrors, chemical catalysts, coins, table silver, and jewelry. A majority of the nano-silver and silver released during the use of devices or after the disposal of products ultimately finds its way, through the drain and stream, and eventually reaches water bodies used as drinking water sources (Tugulea *et al.* 2014).

Silver concentration exceeding 0.1 ppm is classified as non-potable sources by BIS guidelines (BIS, 2012). Groundwater from various locations of the study area is well within the Desirable class during Pre-Monsoon, Monsoon, and Post-Monsoon as per BIS classification. Its concentration value decreases from Pre-Monsoon to Post-Monsoon, this indicates that Ag concentration in aquifer rock is diluted and depleted by rainwater.

Silver concentration in the Geomorphic Units is shown below: -

Table 33: Average Silver Concentration in Geomorphic Units

Sl.No	Geomorphology	Concentration of Ag (ppm) Pre-Monsoon	Concentration of Ag (ppm) Monsoon	Concentration of Ag (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.010	0.000	0.000	0.003
2	Highly Dissected Structural Hill (SHH)	0.013	0.003	0.000	0.006
3	Inter-Montane Valley (IV)	0.000	0.000	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.012	0.002	0.000	0.004
5	Moderately Dissected Structural Hill (SHM)	0.013	0.001	0.000	0.005
	Average	0.010	0.001	0.000	

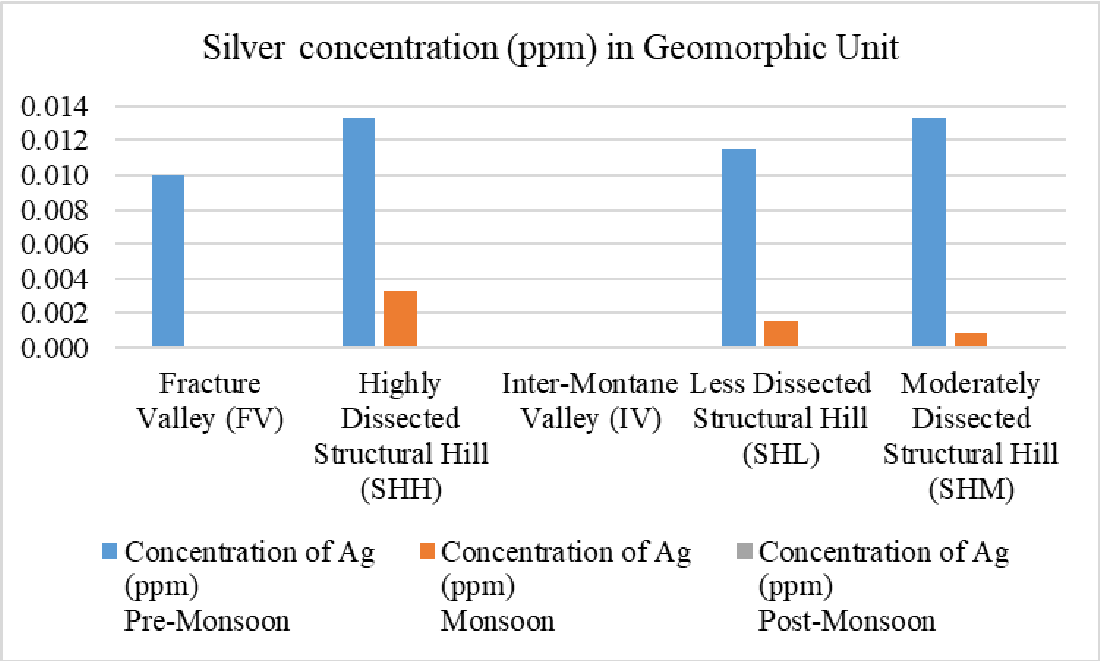


Figure 54: Bar chart of Silver in Geomorphic Units

In terms of geomorphology, Ag concentration is lower in the low-lying Units whereas it is uniformly distributed in Highly Dissected, Moderately Dissected, and Less Dissected Units.

Silver concentration in the Lithostratigraphic Units is shown below-

Sl.No	Lithostratigraphic Unit	Average Silver concentration (ppm) Pre-Monsoon	Average Silver concentration (ppm) Monsoon	Average Silver concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.0167	0	0	0.006
2	Sandstone dominated (Upper Bhuban Formation)	0.013	0.0007	0	0.005
3	Shale dominated (Middle Bhuban Formation)	0.0133	0.0033	0	0.006
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0.004	0	0.001
	Average	0.0108	0.0020	0.0000	

Table 34: Average Silver in Lithostratigraphic Units

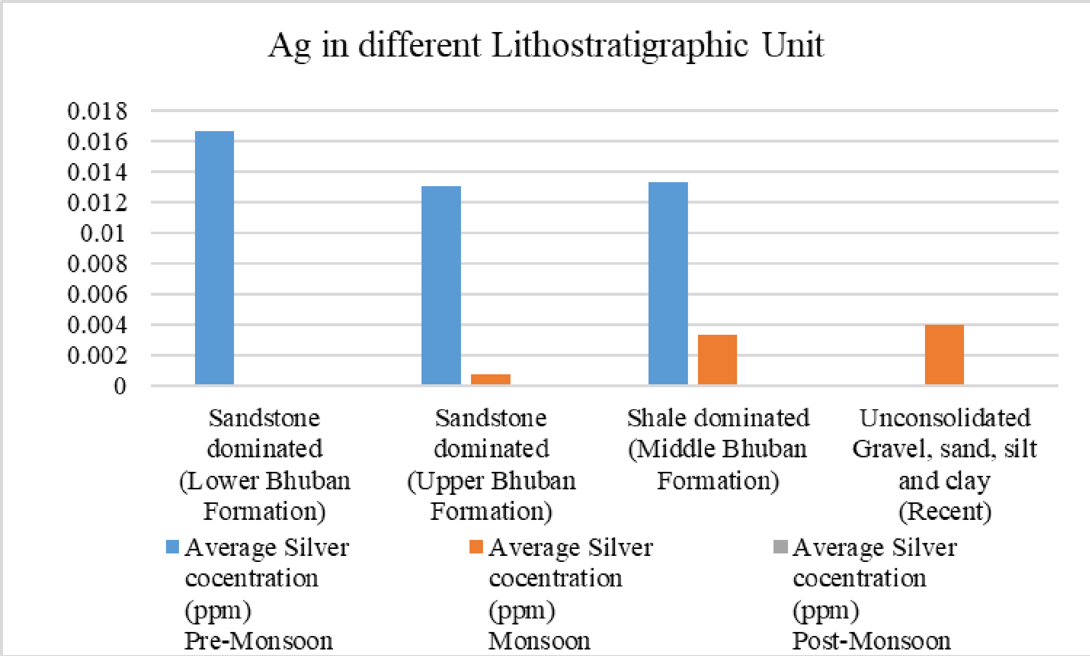


Figure 55: Bar chart of Silver in Lithostratigraphic Units

The unconsolidated sedimentary formation has a lower Ag concentration than the semi-consolidated rocks. This may be because the unconsolidated materials were found in low-lying areas like alluvial plains and valleys where there is an active exchange zone between stream flow and the aquifer. However, all other Lithological Formations are characterized by even distribution of Ag (Moraru, 2016).

The northern part of Serkhan is characterized by Silver concentrations of 0.02 to 0.04 ppm during Pre-Monsoon. The area around Kawnpui, N.Chaltlang, Bukpui, Lungmuat, N.Chaltlang, and the southern part of Serkhan are having Ag between 0.005 to 0.02ppm. A small area around Hortoki village, Zanlawn, and Nisapui has an Ag value of less than 0.005ppm. During Monsoon, an area around Hortoki and Nisapui villages are having Ag concentration between 0.005 – 0.02 ppm. The remaining area shows a concentration of less than 0.005 ppm. All samples in the study area are characterized by Ag concentration below the detectable limit during Post-Monsoon.

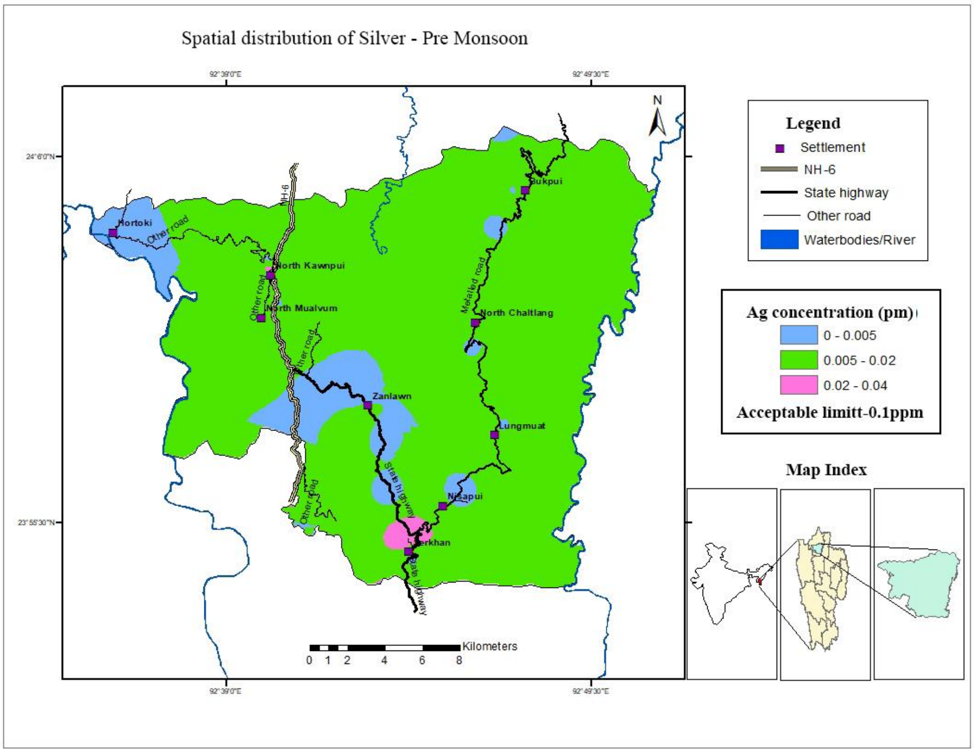


Figure 56: Spatial distribution map of Silver during Pre-Monsoon

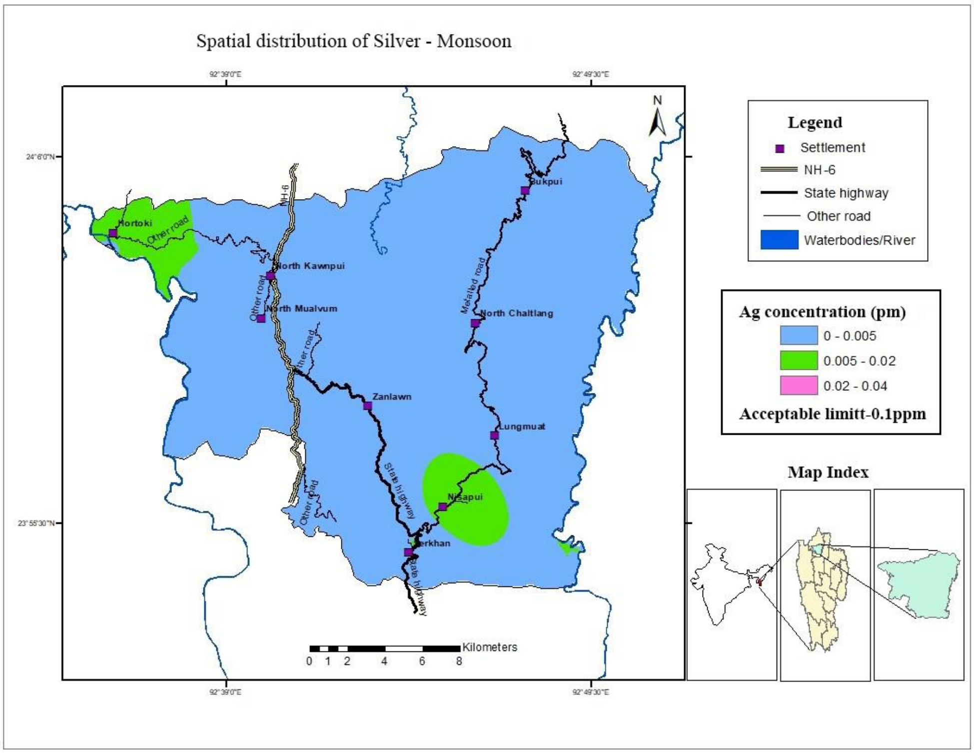


Figure 57: Spatial distribution map of Silver during Monsoon

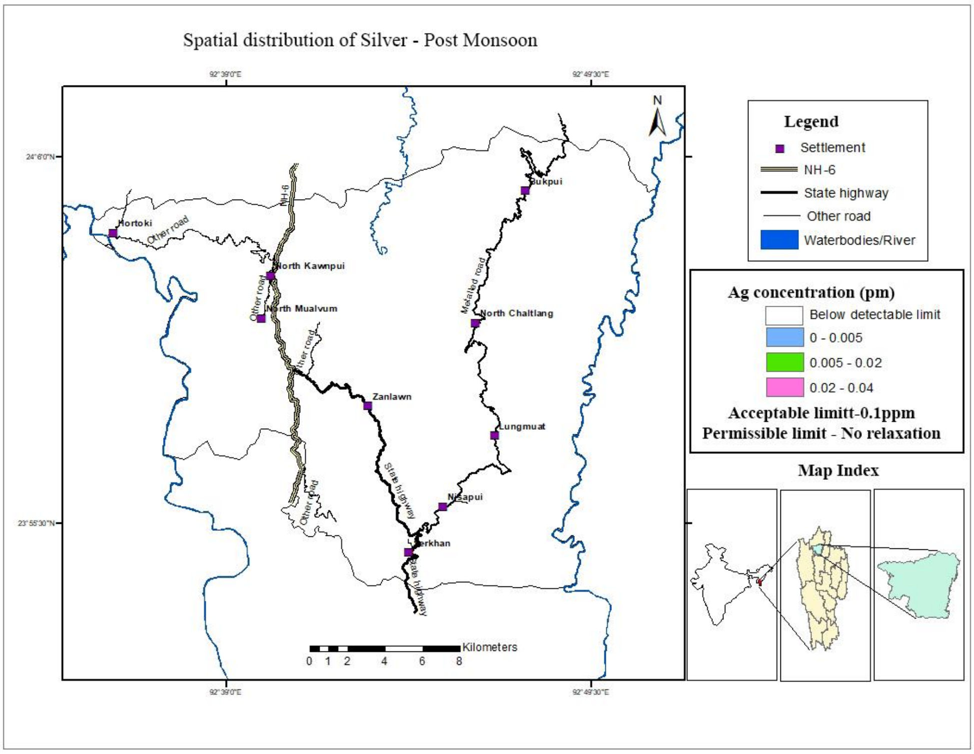


Figure 58: Spatial distribution map of Total chloride during Post-Monsoon

Table 35: Silver (in ppm) during Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Silver (ppm) Pre-Monsoon 2018	Silver (ppm) Monsoon 2018	Silver (ppm) Post-Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.02	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.04	0.01	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.04	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.02	0	0
7	Zotui	Nisapui	23.94	92.762	0	0.02	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0.02	0	0
9	Challui	North Chaltlang	24.0214	92.784	0.02	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.02	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.02	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.02	0	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.02	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0.02	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.02	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.02	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.02	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0	0
27	Vailui	Kawnpui	24.034	92.668	0.02	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.01	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.02	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.04	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.02	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0.02	0	0
38	Sihpui	Kawnpui	24.036	92.669	0.02	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0.02	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0.02	0	0
42	Luihnai	Lungmuat	23.966	92.779	0.01	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.02	0	0
44	Vengchung	Lungmuat	23.9714	92.782	0	0	0

5.11 Copper (Cu):

Copper metal is widely distributed in nature. It is found in minerals such as Copper pyrite ($CuFeS_2$), Charcocite (Cu_2S), Bornite (Cu_5FeS_4), etc. Anthropogenic sources of contamination include the use of copper as a fungicide, alloys and steels, electroplating, mining effluents, industrial wastes, etc.

Copper concentration is classified into three ranges (0-0.05 mg/l, 0.05-1.5 mg/l, and >1.5 mg/l) as maximum desirable concentration or acceptance limit, permissible limit, and non-potable classes by BIS guideline (BIS, 2012). Thlanmual spring from Kawnpui is observed to be exceeding the acceptable limit during Pre-Monsoon. Sihpui stream from Kawnpui is also found to be at a desirable margin during the same season. A relatively high amount of Cu concentration is observed during Pre-Monsoon, Pre-Monsoon is also found to have a minute concentration. However, it is completely depleted during the Monsoon season.

Copper concentration in the Geomorphic Units is shown below: -

Table 36: Average Cu in Geomorphic Units

Sl.No	Geomorphic Units	Average concentration Cu (ppm) Pre-Monsoon	Average concentration Cu (ppm) Monsoon	Average concentration Cu (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.000	0.000	0.000	0.000
3	Intermontane Valley (IV)	0.000	0.000	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.016	0.000	0.001	0.006
5	Moderately Dissected Structural Hill (SHM)	0.015	0.000	0.000	0.005
	Average	0.0064	0.0000	0.0001	

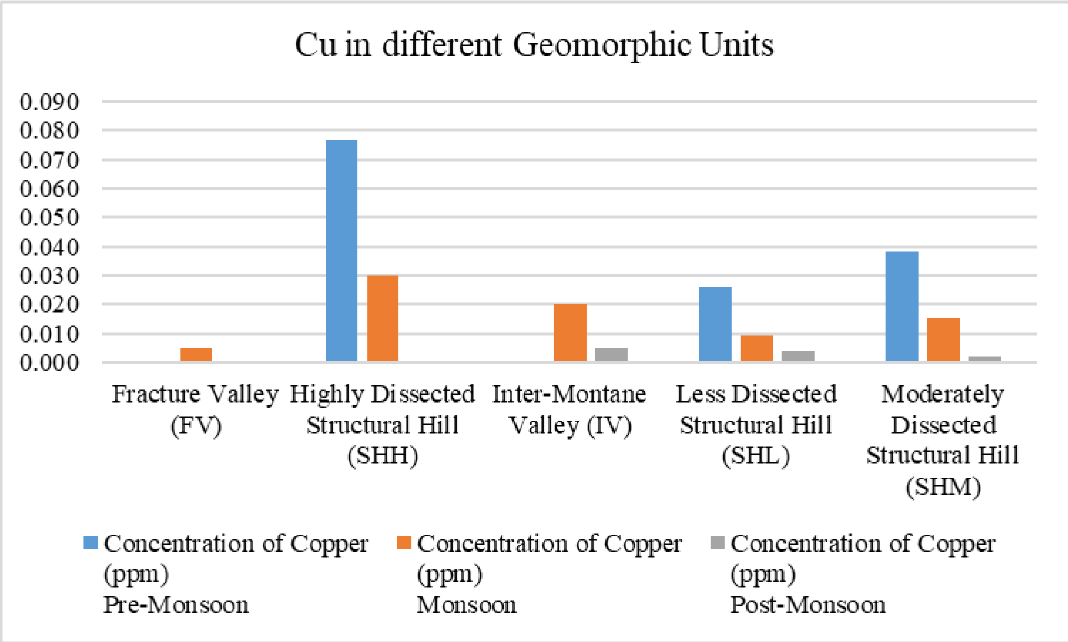


Figure 59: Bar chart of Cu in Geomorphic Units

In terms of Geomorphic Units, the value of Copper concentration in groundwater is highest in Less Dissected Structural Hill, followed by Moderately Dissected and then Less Dissected Structural Hill. The concentrations in the water samples of other units are negligible. Copper value is lowest in samples of low-lying terrain and top of terrain, this indicates that either the water in low terrain is depleting in Cu or the Cu ions in Highly Dissected Terrain are carried away by infiltrating rainwater and deposited in Moderately dissected and Less Dissected Structural Hill Units.

The Copper concentration is highest during Pre-Monsoon, then rapidly diluted by rainwater and became insignificant constituents of groundwater in Monsoon and then began to accumulate at a detectable amount in the Post-Monsoon season as a consequence of the retreating rainy season.

Copper concentration in the Lithostratigraphic Units is shown below: -

Table 37: Average Cu Concentration in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Copper concentration (ppm) Pre-Monsoon	Average Copper concentration (ppm) Monsoon	Average Copper concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.0133	0	0	0.00
2	Sandstone dominated (Upper Bhuban Formation)	0.0173	0	0	0.01
3	Shale dominated (Middle Bhuban Formation)	0	0	0	0.00
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0	0	0.00
	Average	0.008	0	0.000	

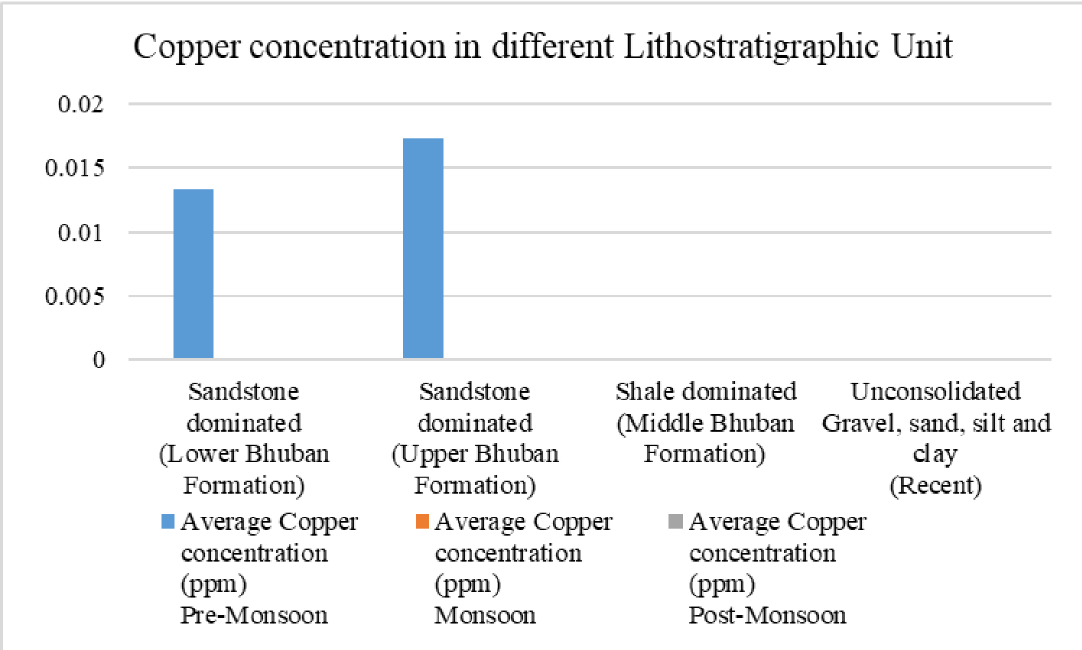


Figure 60: Bar chart of Cu in Lithostratigraphic Units

A considerable amount of copper is distributed only in sources of Sandstone formation of the Upper and Lower Bhuban Formation. Ground water in shale-dominant rock and unconsolidated sediments however has negligible value.

Seasonal-wise, in each Lithostratigraphic Unit, the Pre-Monsoon season is slightly enriched in Cu in comparison to Monsoon and Post-Monsoon.

A copper concentration of 0.05-1.5ppm is observed in a confined area in the southern part of Kawnpui. The rest of the area has a concentration of Cu less than 0.05 ppm. The monsoon samples are characterized by Cu concentration below the detectable limit. All samples taken during post-monsoon are having concentrations ranging between 0 to 0.005 ppm.

The groundwater in the small area of Kawnpui exhibits Cu concentration exceeding the acceptable limit of 0.05ppm during Pre-Monsoon. The whole area shows a concentration value of less than 0.05ppm during Post-Monsoon and the quantity of Cu in groundwater became completely depleting during Monsoon. As the amount of water within the aquifer receded, there is not enough water to dilute the Cu content; hence, it became detectable again during the Post-Monsoon season.

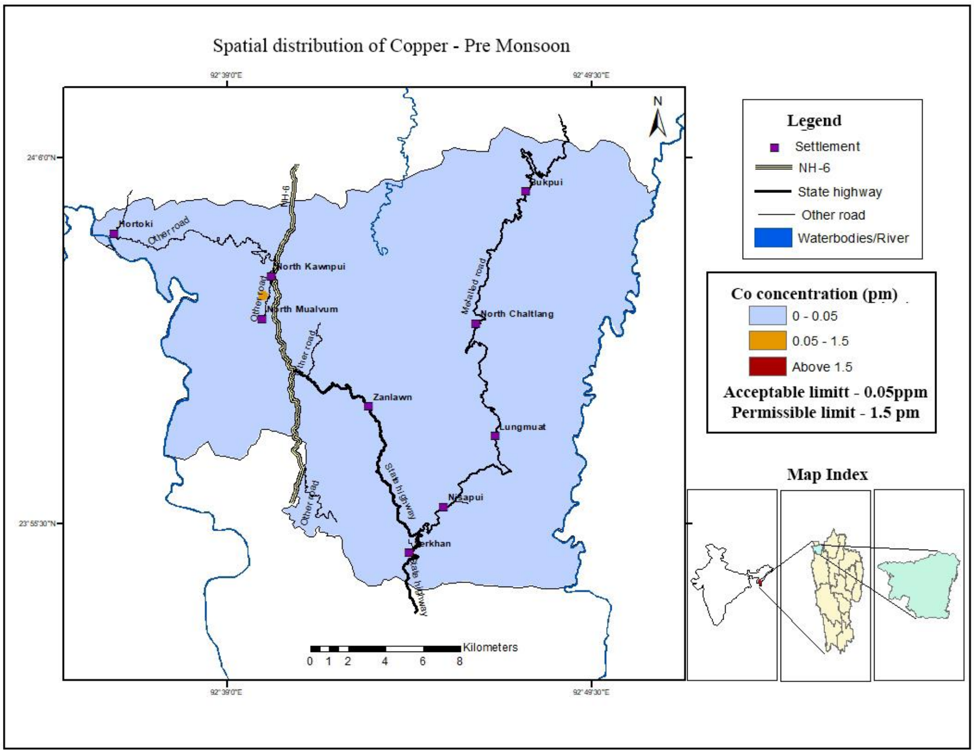


Figure 61: Spatial distribution map of Cu during Pre-Monsoon

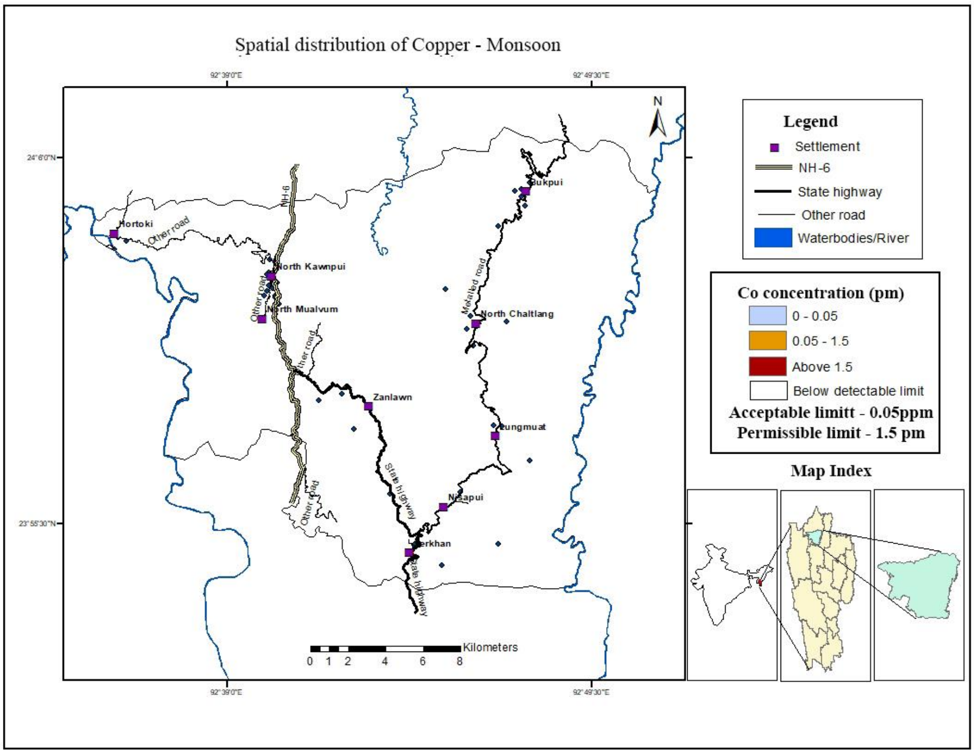


Figure 62: Spatial distribution map of Cu during Monsoon

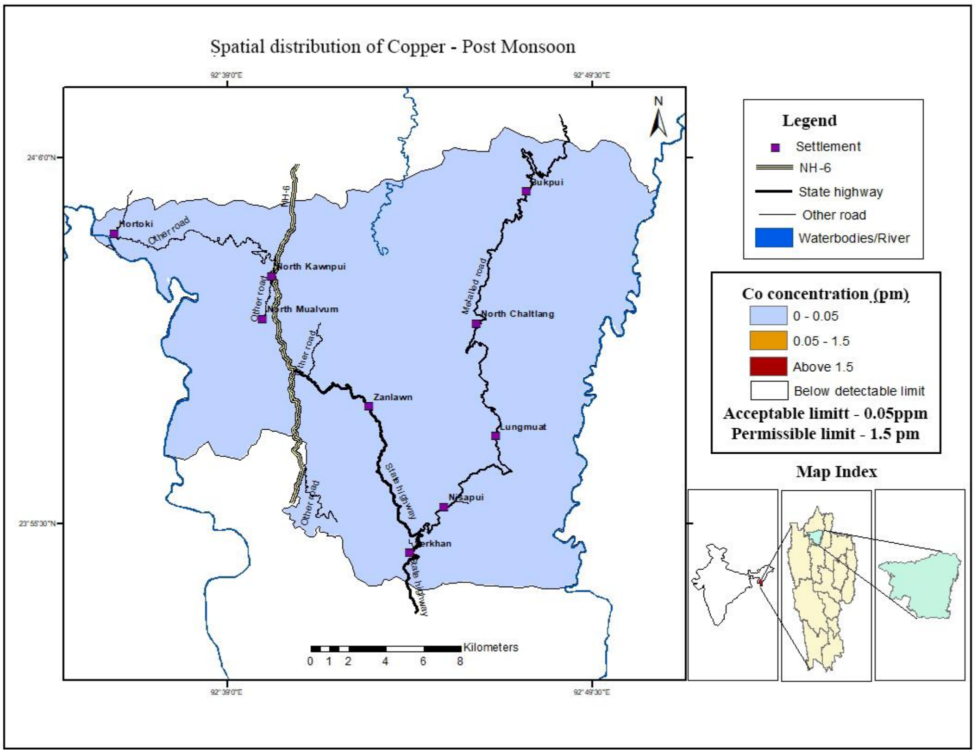


Figure 63: Spatial distribution map of Cu during Post-Monsoon

Table 38: Copper concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Copper (ppm) Pre-Monsoon 2018	Copper (ppm) Monsoon 2018	Copper (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.04	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0	0	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point handpump	North Chaltlang	24.018	92.765	0.01	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.01	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.03	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.03	0	0
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	0.01	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.03	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.03	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.03	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0	0
27	Vailui	Kawnpui	24.034	92.668	0.08	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.01	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.04	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.01	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.04	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0.03	0	0
38	Sihpui	Kawnpui	24.036	92.669	0.05	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0.01
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0.04	0	0
42	Luihnai	Lungmuat	23.966	92.779	0.01	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.04	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.12 Manganese (Mn):

Manganese concentration in water is generally a naturally derived metallic pollutant like Iron. Soil and rocks usually contain manganese-bearing minerals, other sources like fertilizers and fuel oils may impart Mn into water in certain areas. The concentration of Mn in water is affected by pH, it may even exceed 10mg per liter in acidic water (Goel, 2006).

The concentration of Mn is categorized into three classes (0-0.1mg/l, 0.1-0.3mg/l, and >0.3 mg/l) by BIS guidelines (BIS, 2012). Manganese mainly comes from sediments and soils, when erosion occurs; Mn ions are transported into water bodies. Mica, Biotite, Amphibole and Hornblende minerals in Metamorphic and Sedimentary rocks contain large amounts of manganese. However, human activities are also responsible for much of the manganese contamination in water in some areas.

One source of Lalkima hand pump, N.Chaltlang has exceeded the acceptable limit during Pre-Monsoon and two sources each have surpassed recommended limits of acceptable and permissible during Monsoon. Two sources with high values of Manganese concentration that are above permissible limits are observed in Post-Monsoon. Manganese concentration in the Geomorphic Units is shown below: -

Table 39: Average Manganese Concentration in Geomorphic Units

Sl.No	Geomorphology	Concentration of Manganese (ppm) Pre-Monsoon	Concentration of Manganese (ppm) Monsoon	Concentration of Manganese (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.003	0.017	0.000	0.020
3	Inter-Montane Valley (IV)	0.000	0.005	0.000	0.005
4	Less Dissected Structural Hill (SHL)	0.002	0.005	0.005	0.012
5	Moderately Dissected Structural Hill (SHM)	0.001	0.011	0.004	0.015
	Average	0.001	0.007	0.002	

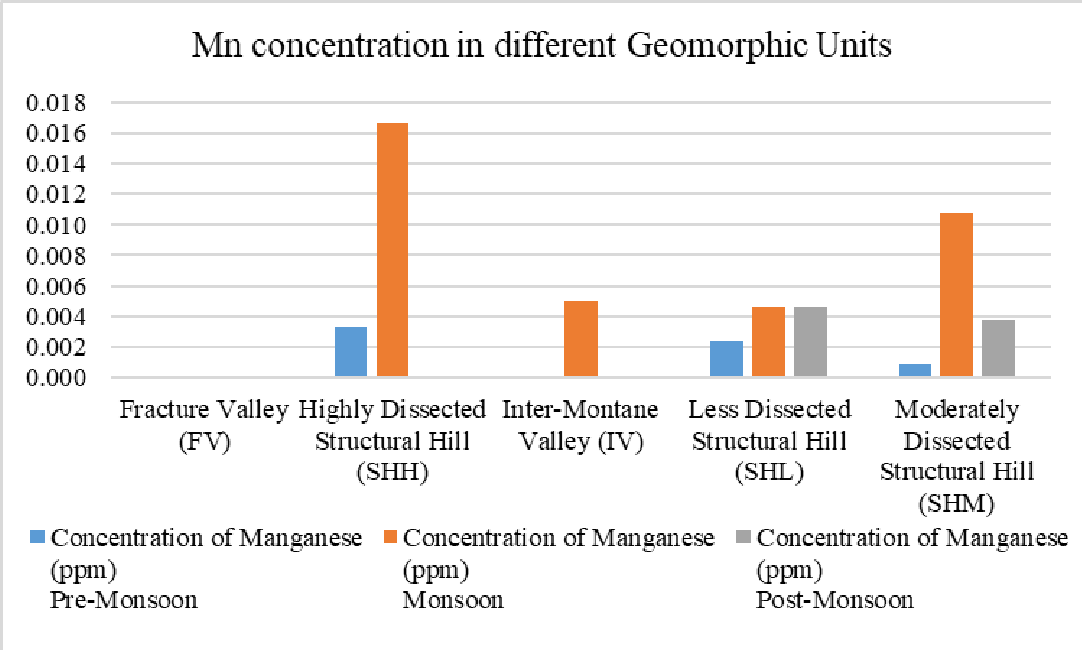


Figure 64: Bar chart of Manganese concentration in Geomorphic Units

In terms of Geomorphic Units, Highly Dissected Structural hill have the highest Manganese concentration of 0.007ppm, and is followed by Moderately Dissected Structural hill. Intermontane Valley has the lowest Manganese concentration of 0.002 ppm. Less Dissected Structural Hill and Fracture Valley have Mn concentrations of 0.004 and 0.005ppm respectively.

Manganese concentration in the Lithostratigraphic Units is shown below: -

Table 40: Average Manganese Concentration in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Manganese concentration (ppm) Pre-Monsoon	Average Manganese concentration (ppm) Monsoon	Average Manganese concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.002	0.01	0.012	0.008
2	Sandstone dominated (Upper Bhuban Formation)	0.0013	0.0057	0.003	0.003
3	Shale dominated (Middle Bhuban Formation)	0.0033	0.0167	0	0.007
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0.002	0	0.001
	Average	0.0017	0.008	0.0038	

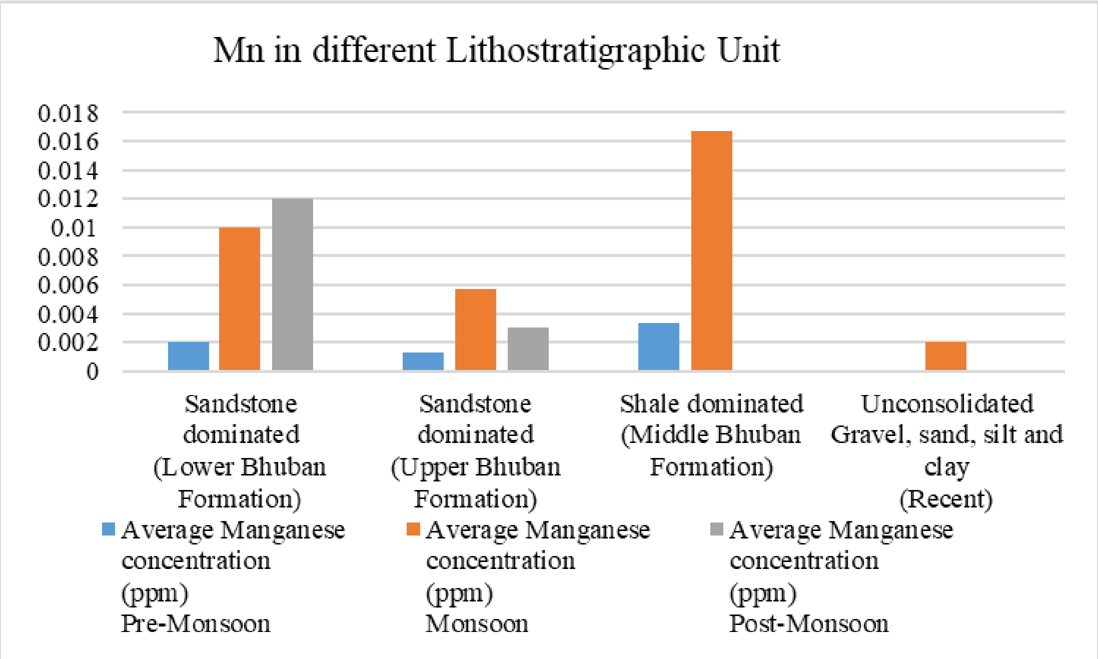


Figure 65: Bar chart of Manganese concentration in Lithostratigraphic Units

In terms of lithological Units, the Manganese concentration is highest in sandstone of the Lower Bhuban Formation, while the unconsolidated sedimentary Unit has the lowest Manganese concentration. Middle Bhuban Shale Formation has the second highest Mn concentration and is followed by Upper Bhuban sandstone.

Manganese usually occurs with iron in the earth's crust; here also the concentration of Manganese is high within sandstone where there is a high iron concentration. The Manganese concentration is highest during the Monsoon season and gradually decreases in Post-Monsoon and Pre-Monsoon. It shows how the Manganese abundantly present in the shallow earth crust are carried and transported along with rainwater.

The groundwater in the vicinity of N.Chaltlang and Bukpui has a slightly higher concentration of Manganese in every season. During the Monsoon, samples from the northern part of Kawnpui and the northeastern part of the study area are characterized by Mn concentrations of 0.005 to 0.1 ppm. During the Monsoon, the eastern part of Zanlawn, Hortoki, and Lungmuat, and the northern part of Kawnpui are characterized by a lower value of Mn, which is lower than 0.005ppm. During Post-Monsoon, all areas except the northeastern part and northern parts of Kawnpui are characterized by low concentrations of Mn. The groundwater near Bukpui, N.Chaltlang, and the southwestern part of Kawnpui exhibit slightly higher concentrations of Mg during Pre and Post-Monsoon season. The interpolation map of Mg in Monsoon however shows a slightly higher concentration of Mg in all villages except in the northeastern part of Zanlawn and the southern region of Kawnpui. This may indicate that the dissolution of Mg-bearing minerals is higher in Monsoons as a consequence of greater infiltration of the lithological column by rainwater.

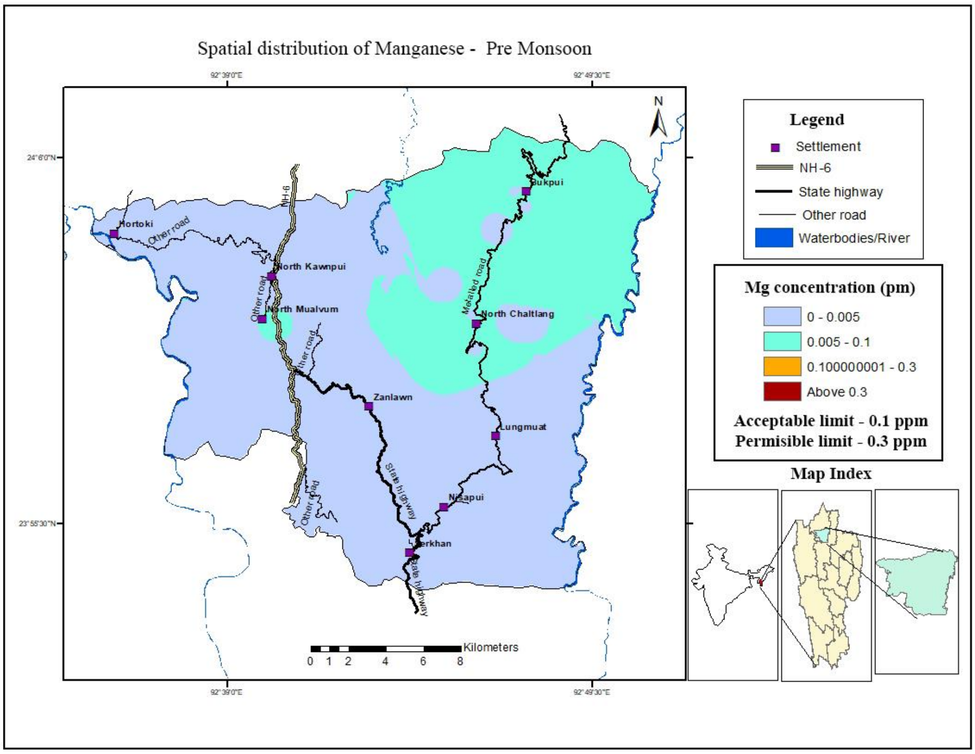


Figure 66: Spatial distribution map of Mn during Pre-Monsoon

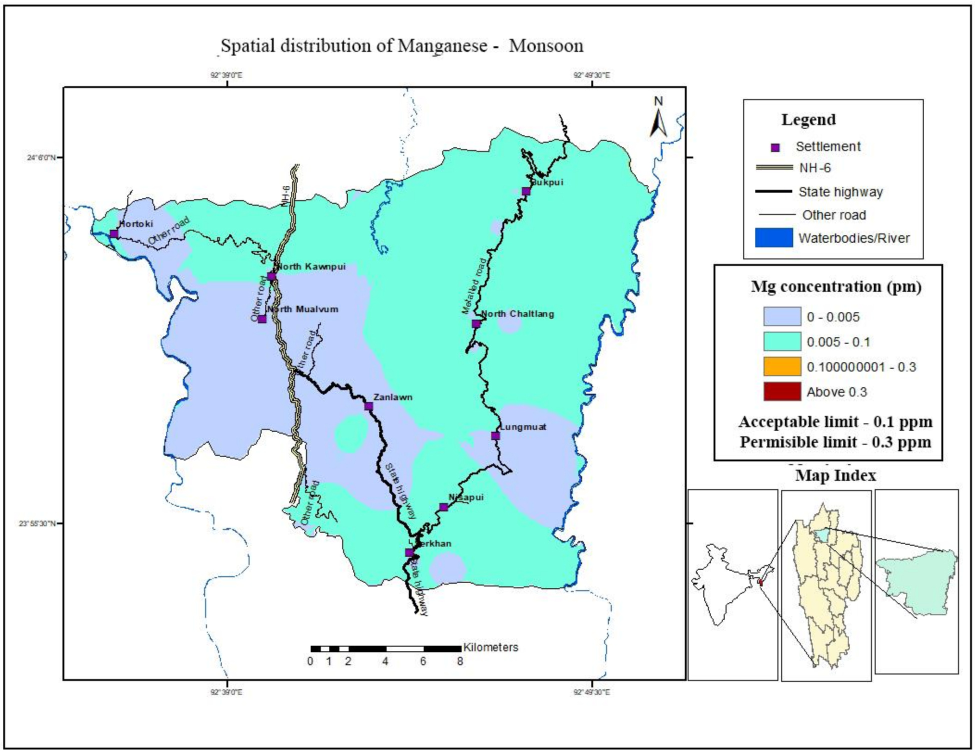


Figure 67: Spatial distribution map of Mn during Monsoon

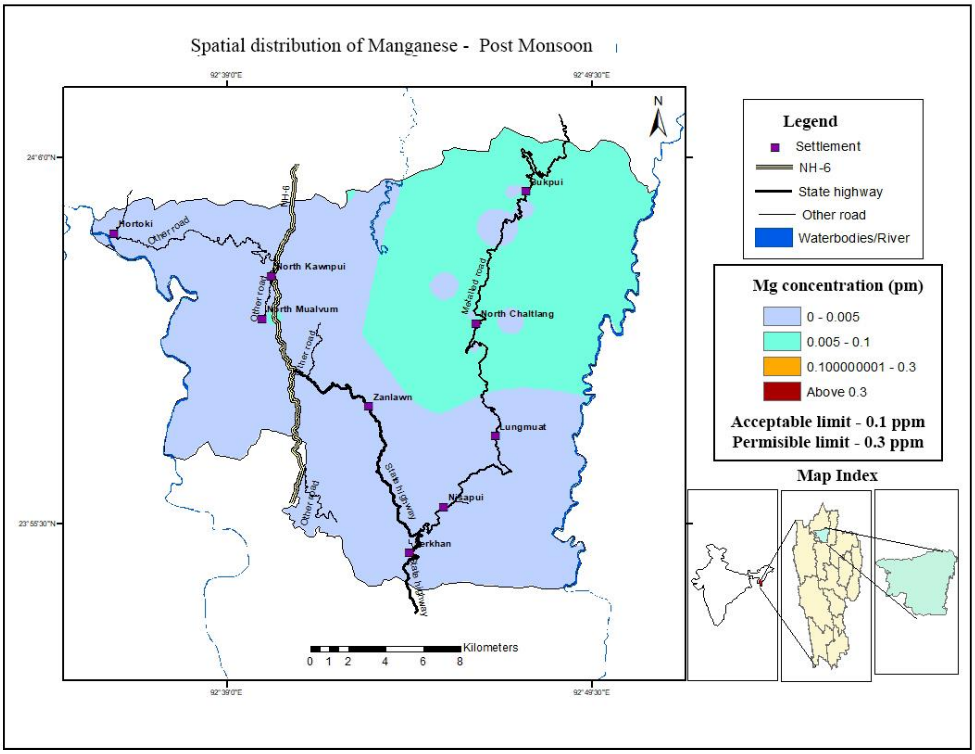


Figure 68: Spatial distribution map of Mn during Post-Monsoon

Table 41: Mn (in ppm) during Pre-Monsoon, Monsoon, and Post-Monsoon)

Sl.No	Source Name	Village	Lattitude	Longtitude	Manganese (ppm) Pre-Monsoon 2018	Manganese (ppm) Monsoon 2018	Manganese (ppm) Post-Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.01	0.05	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0	0.01	0
7	Zotui	Nisapui	23.94	92.762	0	0.01	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0.02	0.07	0.08
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0	0	0.01
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0	0.02	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.01	0.03	0.05
17	Nuhliri Point	Bukpui	24.077	92.793	0	0.1	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0	0.01	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0	0.01	0
27	Vailui	Kawnpui	24.034	92.668	0	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0.02	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0	0.01	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0.01	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0.01	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0	0	0.01
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0	0.01	0
38	Sihpui	Kawnpui	24.036	92.669	0	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0.01	0
41	Zotui	Lungmuat	23.972	92.778	0	0.01	0
42	Luihnai	Lungmuat	23.966	92.779	0	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung	Lungmuat	23.9714	92.782	0	0	0

5.13 Magnesium:

Magnesium is classified into three categories (0-30mg/l, 30-100mg/l, and >100mg/l) by BIS guidelines (BIS, 2012). Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals are major natural sources of Magnesium. The high amount of Magnesium and Calcium ions in water causes hard water. However, the groundwater samples from the study area contain relatively low Magnesium concentrations and are well within Desirable as per BIS norms. Magnesium concentration in the Lithostratigraphic Units is shown below: -

Table 42: Average Magnesium concentration in Geomorphic Units

Sl.No	Geomorphology	Concentration of Magnesium (ppm) Pre-Monsoon	Concentration of Magnesium (ppm) Monsoon	Concentration of Magnesium (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.101	0.000	0.167	0.089
2	Highly Dissected Structural Hill (SHH)	0.053	0.000	0.243	0.099
3	Inter-Montane Valley (IV)	0.021	0.000	0.305	0.109
4	Less Dissected Structural Hill (SHL)	0.636	0.056	0.784	0.492
5	Moderately Dissected Structural Hill (SHM)	4.301	0.888	4.738	3.309
	Average	1.022	0.189	1.247	

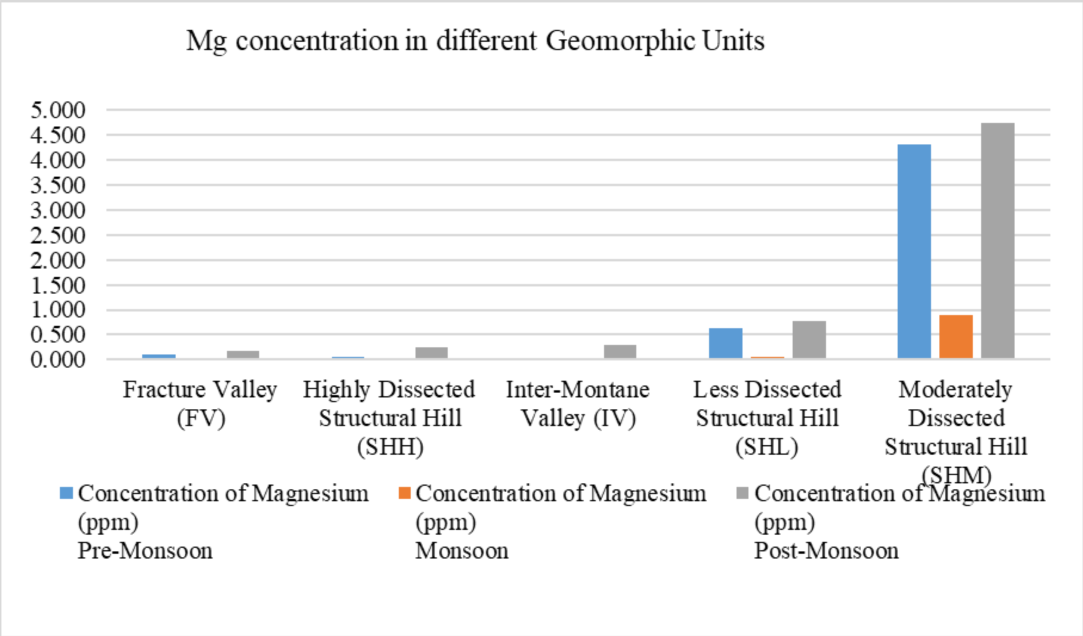


Figure 69: Bar chart of Magnesium in Geomorphic Units

In terms of Geomorphic Units, groundwater in the Moderately Dissected Structural Hill contains a relatively higher Magnesium value of 3.309ppm. However, the Magnesium concentration in Fracture Valley is lowest after Highly Dissected Structural Hill with Mg values 0.089ppm and 0.0986ppm respectively. Less Dissected Structural Hill and Intermontane Valley have Mg values of 0.492ppm and 0.108ppm.

Magnesium concentration in the Lithostratigraphic Units is shown below: -

Table 43: Average Magnesium in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Magnesium concentration (ppm) Pre-Monsoon	Average Magnesium concentration (ppm) Monsoon	Average Magnesium concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.382	0.103	0.59	0.358
2	Sandstone dominated (Upper Bhuban Formation)	3.646	0.714	4.02	2.793
3	Shale dominated (Middle Bhuban Formation)	0.053	0	0.24	0.098
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0.013	0	0.14	0.051
	Average	1.024	0.204	1.248	

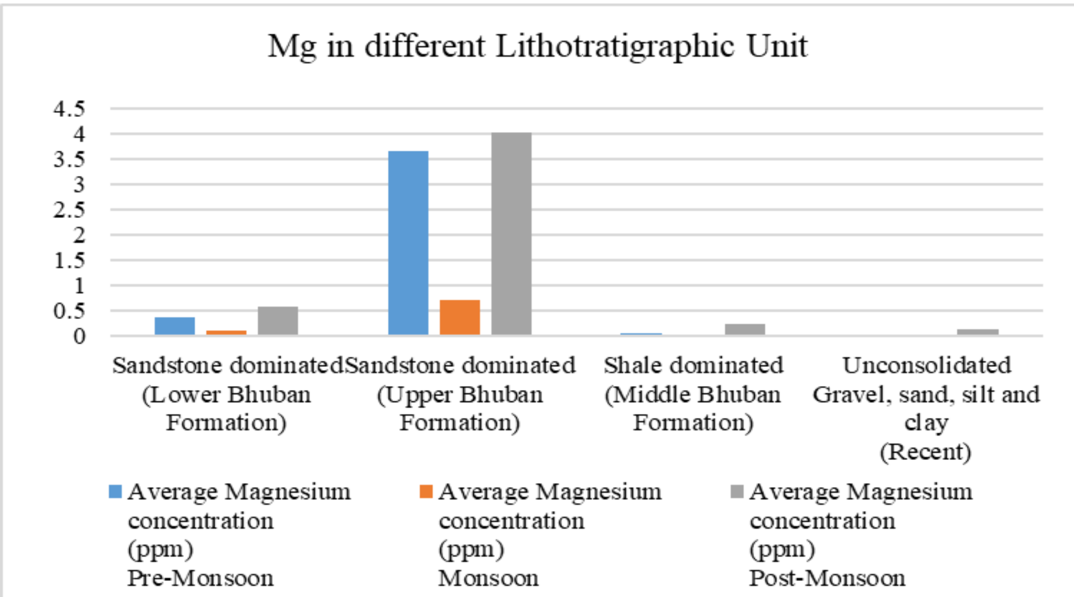


Figure 70: Bar chart of Magnesium in Lithostratigraphic Units

In terms of different rock types present in the study area, the Magnesium concentration in the groundwater is highest in the sandstone-dominated rock of the Lower Bhuban Formation, followed by Upper Bhuban Formation. Semi-consolidated rock has a higher Mg value compared to Unconsolidated sediments. This may be due to the usual presence of thicker soil upon sandstone bedrock in comparison to Shale formation.

Seasonal variation of Magnesium concentration shows that it is comparatively lower during the monsoon season than during the pre-monsoon and post-monsoon periods within the study area.

During Pre-Monsoon and Post-Monsoon, water in the vicinity of N. Chaltlang has a slightly higher value of Mg concentration ranging from 30-100ppm. During Monsoon, it is reduced to 15-30ppm. The remaining part of the study area has a concentration value of 0.001-15ppm.

The interpolation map of Mg concentration in the study area shows that the region of N.Chaltlang has a slightly higher concentration of 30-100ppm in comparison to the rest of the area during Pre-Monsoon and Post-Monsoon. During Monsoon, only small dots in N.Chaltlang village show Al concentration ranging between 15-30 ppm. The rest part of the study area has a concentration of less than 15 ppm.

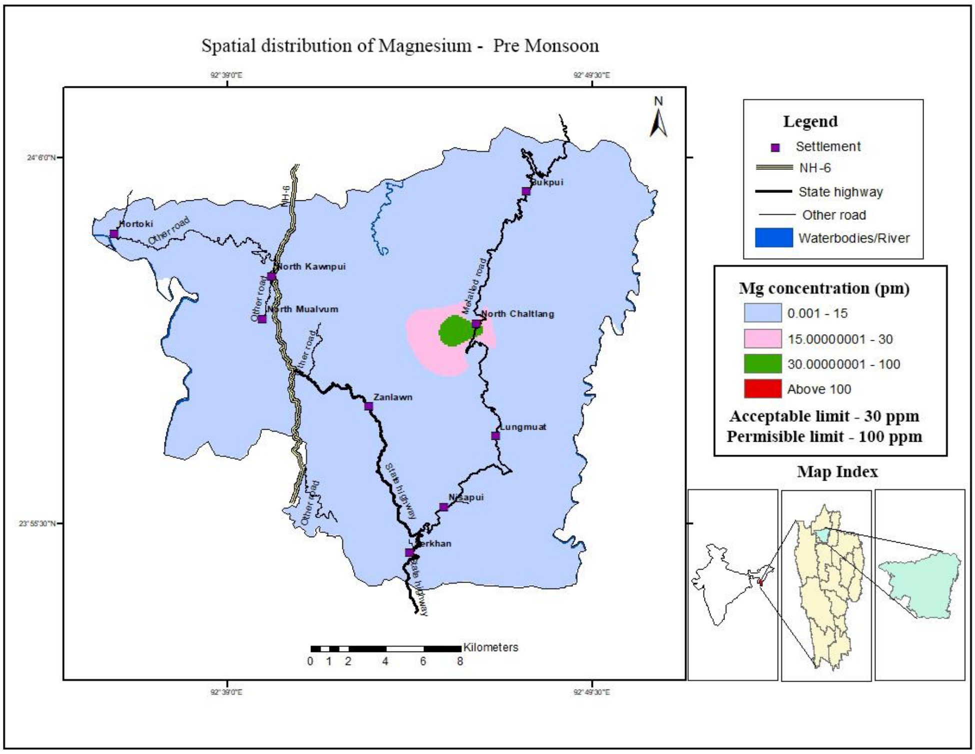


Figure 71: Spatial distribution map of Mg during Pre-Monsoon

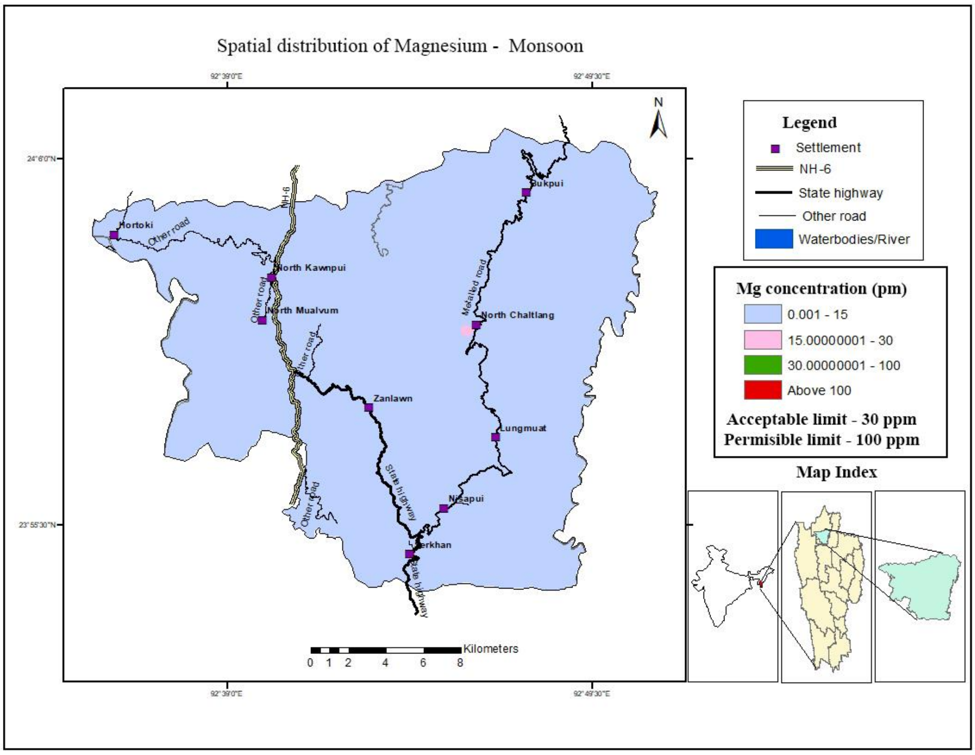


Figure 72: Spatial distribution map of Mg during Monsoon

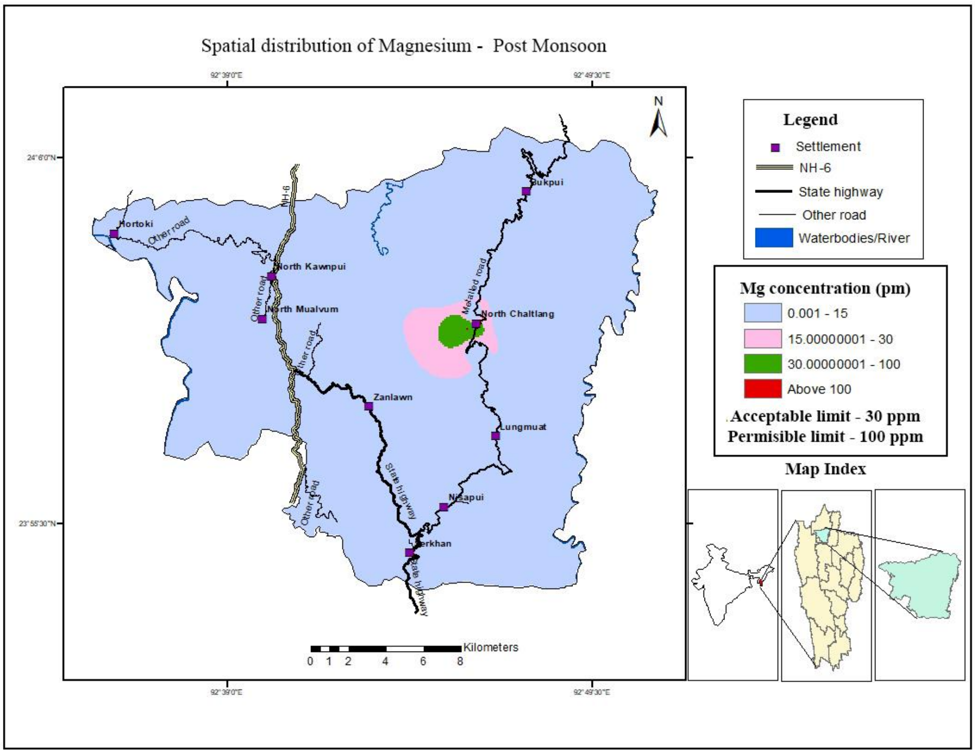


Figure 73: Spatial distribution map of Mg during Post-Monsoon

Table 44: Mg (in ppm) during Pre-Monsoon, Monsoon, and Post-Monsoon.

Sl.No	Name	Village	Lattitude	Longtitude	Magnesium (ppm) Pre-Monsoon 2018	Magnesium (ppm) Monsoon 2018	Magnesium (ppm) Post-Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0	0	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	96.8	20.5	100.65
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.38	0.21	0.41
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	1.5	0.2	1.7
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	1.5	0.21	1.6
17	Nuhliri Point	Bukpui	24.077	92.793	0	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0	0	0
27	Vailui	Kawnpui	24.034	92.668	0	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0376	92.672	5	0.3	4.56
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	5.1	0.5	6.49
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0	0	0
38	Sihpui	Kawnpui	24.036	92.669	1.1	0.11	1.22
39	Lungpher	Hortoki	24.06	92.602	1.2	0.8	1.21
40	Khawzasiaka	Hortoki	24.056	92.596	1.9	0.7	2.09
41	Zotui	Lungmuat	23.972	92.778	2	0.5	3.92
42	Luihnai	Lungmuat	23.966	92.779	0	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.14 Aluminium (Al):

Aluminum occurs as a minor constituent in potable water, it became undesirable when present in excessive amounts. Aluminum is often found in silicate minerals like feldspar (KAlSi3O8). The oxide of aluminum known as bauxite (Al2O3.nH2O) is a source of uncontaminated ore. Generally, the leaching of Aluminium from rock and soil that enter into water sources results in contamination. Aluminum solubility is known to be pH-dependent and aluminum is insoluble in the pH range 5-9 that includes most natural waters. Therefore, it is soluble only at very low and high pH (Li 2016). Above 7pH, the solubility of Al decreases and causes a decrease in the concentration of toxic Al^{3+} form. Below pH 7, Al^{3+} started dominating again (Frankowski, 2011). It explains why the Al concentration is higher in Pre-Monsoon as the rain acidity is at its extremes due to the prevalence of forest firing during this season.

Al is classified into three classes (<0.03 mg/l, 0.03-0.2 mg/l, and >0.2 mg/l) by BIS guidelines (BIS, 2012). Al concentration in most springs within the study area is satisfactory for drinking. However, four samples during Pre-Monsoon and two samples during Monsoon fall in the non-potable class.

Aluminium concentration in the Geomorphic Units is shown below: -

Table 45: Average Aluminium in Geomorphic Units

Sl.No	Geomorphology	Concentration of Aluminium (ppm) Pre-Monsoon	Concentration of Aluminium (ppm) Monsoon	Concentration of Aluminium (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.010	0.000	0.003
2	Highly Dissected Structural Hill (SHH)	0.010	0.027	0.000	0.012
3	Inter-Montane Valley (IV)	0.000	0.000	0.005	0.002
4	Less Dissected Structural Hill (SHL)	0.011	0.005	0.005	0.007
5	Moderately Dissected Structural Hill (SHM)	0.029	0.003	0.001	0.011
	Average	0.010	0.009	0.002	

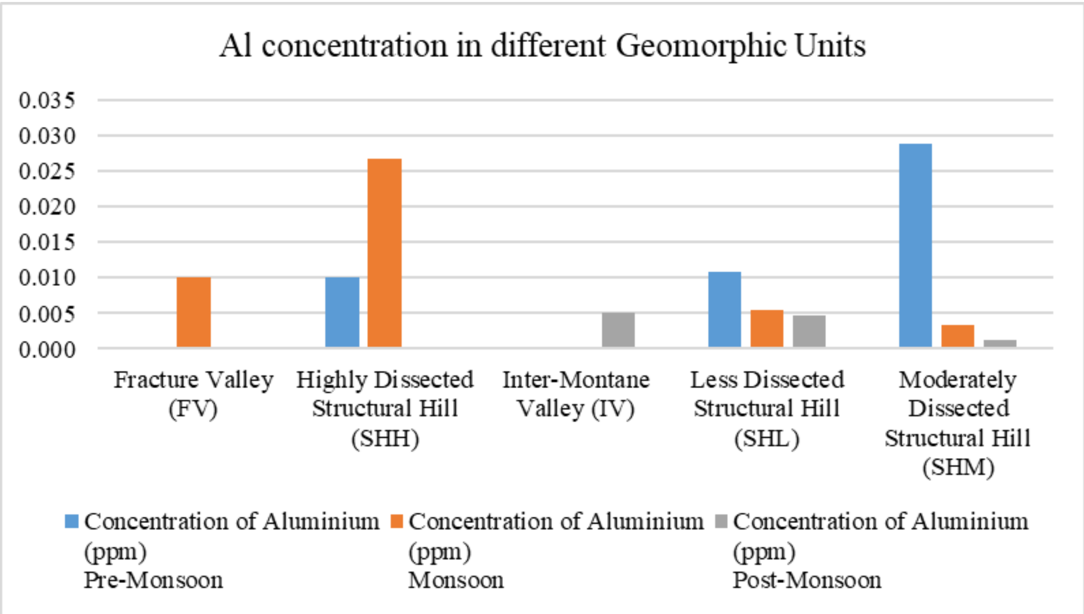


Figure 74: Bar chart of Aluminium in Geomorphic Units

It is observed that the higher the elevation of the terrain higher the aluminium value in the water. It may be due to the reason that Al-bearing feldspar is not stable and the dissolved ions are carried away immediately by stream water. Fracture Valley and Intermontane Valley are characterized by almost the same value of 0.003 and 0.002 ppm. Aluminium concentration in the Lithostratigraphic Units is shown below:-

Table 46: Average Aluminium in Lithostratigraphic Units

Sl.No	**Lithostratigraphic Unit**	**Average Aluminium concentration (ppm) Pre-Monsoon**	**Average Aluminium concentration (ppm) Monsoon**	**Average Aluminium concentration (ppm) Post-Monsoon**	**Average**
1	Sandstone dominated (Lower Bhuban Formation)	0.0133	0.0067	0.005	0.008
2	Sandstone dominated (Upper Bhuban Formation)	0.025	0.0023	0.0013	0.010
3	Shale dominated (Middle Bhuban Formation)	0.01	0.0267	0	0.012
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0.012	0.005	0.006
	Average	0.0121	0.0119	0.0028	

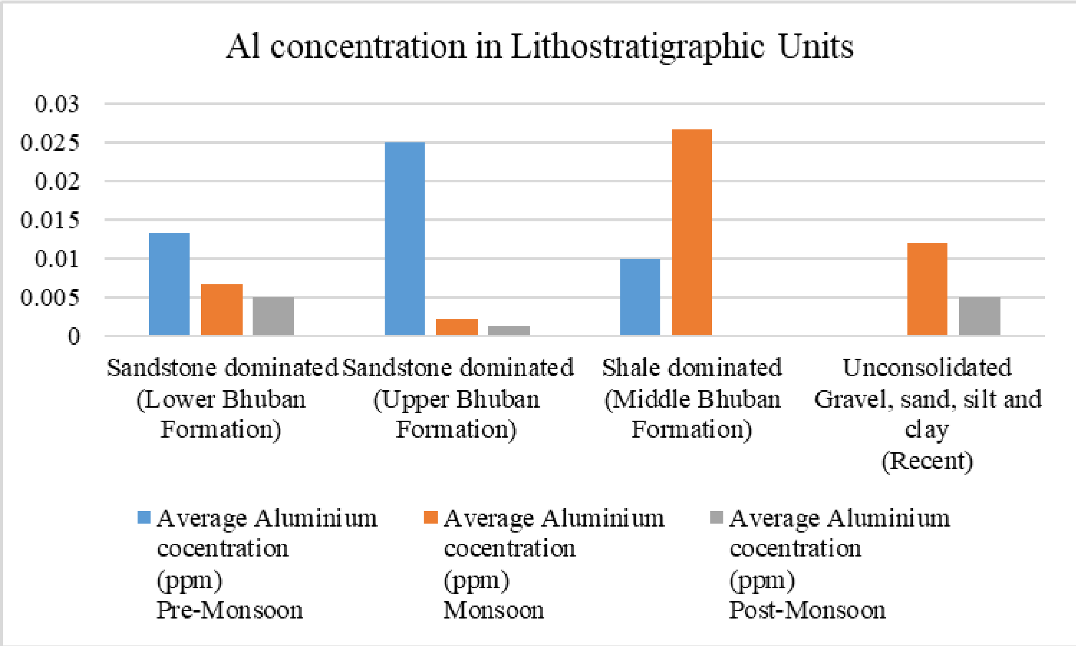


Figure 75: Bar chart of Aluminium in Lithostratigraphic Units

In terms of the Lithostratigraphic Unit, the groundwater within the study area has the highest Al concentration in the shale-dominated unit. This may be due to the higher amount of Al minerals like mica and feldspar within the shale. Unconsolidated sediment has groundwater with the lowest Al concentration. The upper Bhuban Unit has twice as much concentration in comparison to the Lower Bhuban which may indicate shale content of this formation is richer in Al-bearing mica and feldspar minerals.

The vicinity of Kawnpui and N.Chaltlang have Al concentration exceeding the acceptable limit of 0.03ppm during Monsoon and only small areas at Hortoki and Serkhan show Al concentration above 0.03ppm in Post-Monsoon. The whole study area shows Al concentration below 0.03ppm during Monsoon indicating that dilution of Al unaltered from its mineral.

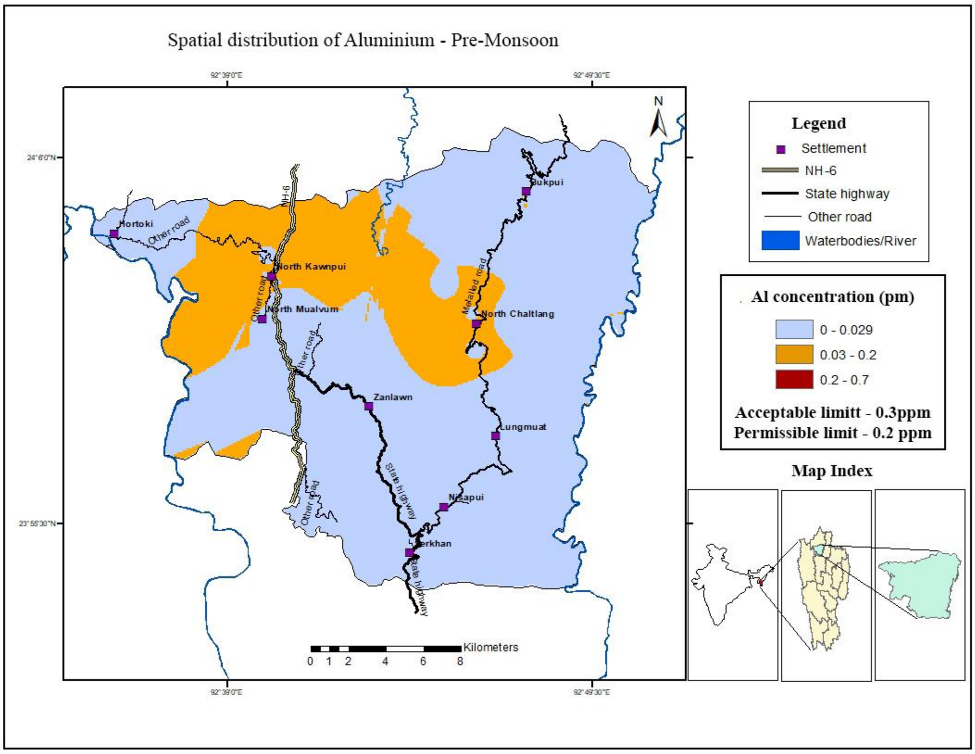


Figure 76: Spatial distribution map of Al during Pre-Monsoon

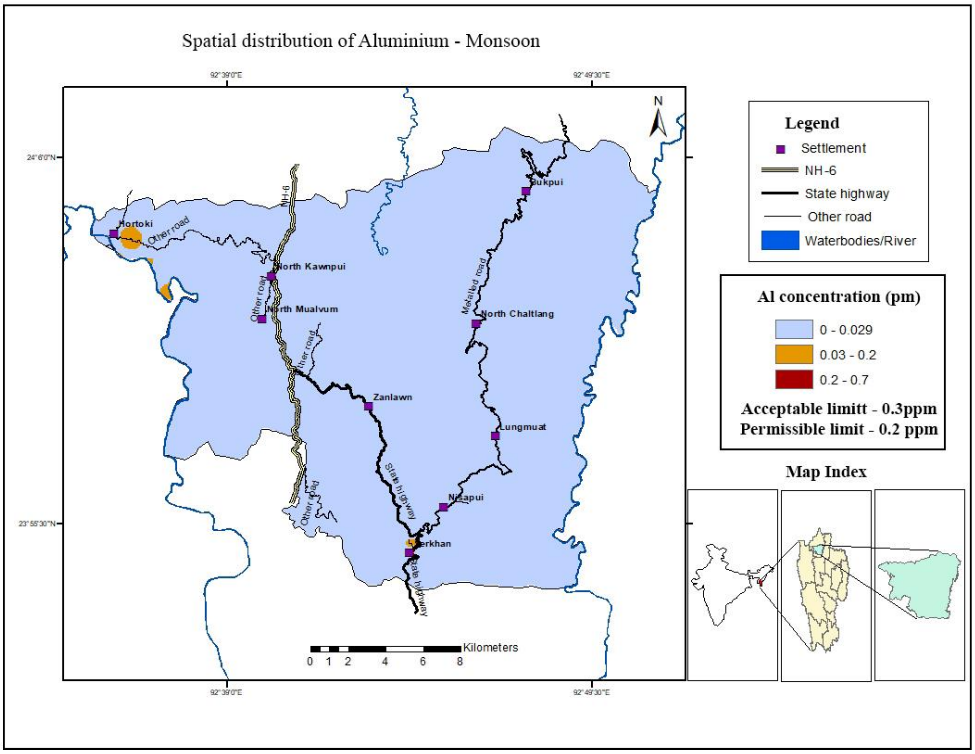


Figure 77: Spatial distribution map of Al during Monsoon

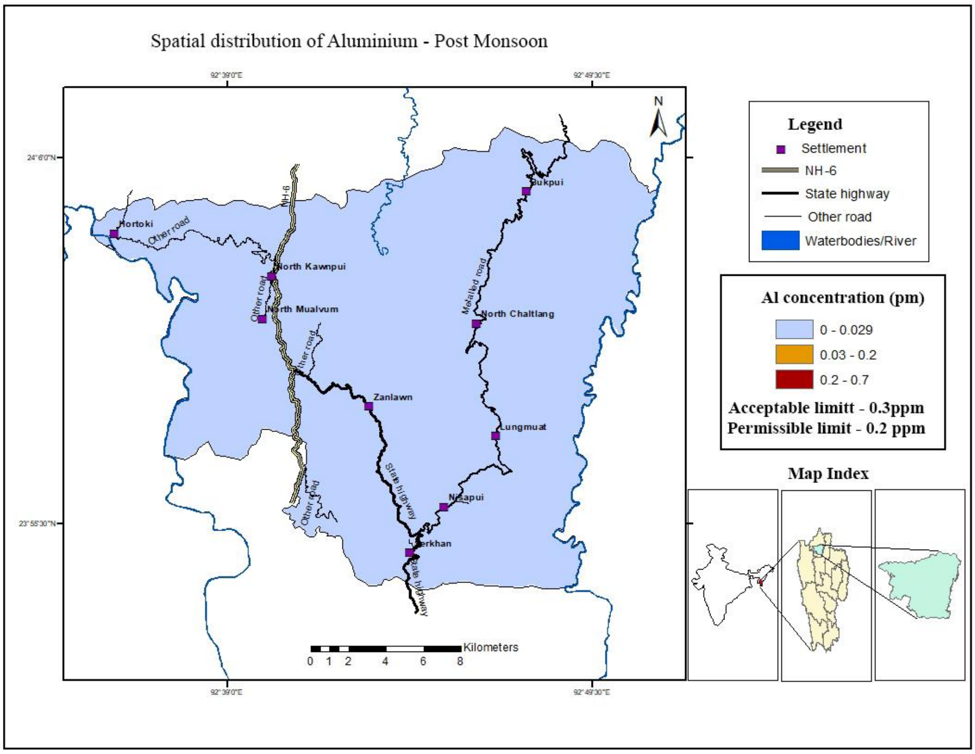


Figure 78: Spatial distribution map of Al during Post-Monsoon

Table 47: Al (in ppm) during Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Aluminium (ppm) Pre-Monsoon 2018	Aluminium (ppm) Monsoon 2018	Aluminium (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.01	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.03	0.08	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.03	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.02	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0.23	0	0.01
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.03	0	0.01
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0.02	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.01	0	0.02
17	Nuhliri Point	Bukpui	24.077	92.793	0.03	0.02	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0.02	0
21	Fului	Zanlawn	23.97	92.711	0.01	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.01	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.05	0	0
26	Charpui	Kawnpui	24.05	92.674	0.03	0	0
27	Vailui	Kawnpui	24.034	92.668	0.05	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0.01	0
29	Sentezel	Kawnpui	24.04	92.674	0.02	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.04	0	0.01
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.07	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0.01	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.01	0.01	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0.02	0
37	Khurthuk	Kawnpui	24.039	92.67	0.13	0	0
38	Sihpui	Kawnpui	24.036	92.669	0.03	0	0.01
39	Lungpher	Hortoki	24.06	92.602	0	0.04	0.02
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0.01
41	Zotui	Lungmuat	23.972	92.778	0	0	0.01
42	Luihnai	Lungmuat	23.966	92.779	0	0.02	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung	Lungmuat	23.9714	92.782	0	0	0

5.15 Barium (Ba):

Naturally occurring barium is found in igneous, metamorphic, and sedimentary rocks. Leaching and eroding of nearby sedimentary rocks can be a substantial source of barium in surface and groundwater. Anthropogenic activities such as the use of barium-rich fertilizers and insecticides, drilling mud, and shale gas development can also increase its concentration. The mobility of barium in the soil is usually low, and it adsorbs easily to clay minerals and organic matter; it tends to form insoluble salts and not soluble humic complexes. However, under the environment of acidic, anaerobic, and high chloride/low Sulphate conditions, as well as conditions of reduced reduction–oxidation potential, barium mobility is increased and therefore supporting its movement into groundwater (Health Canada, 2019).

Barium occurs as a minor constituent in potable water, ranging between 0.0001 to 0.1 ppm. The Ba concentration of water was classified into two classes (below 0.7 ppm as potable and above 0.7 ppm as non-potable) by BIS guidelines. All samples within the study area are well within the permissible limit.

In terms of Geomorphology, Ba concentration in groundwater is highest in Highly Dissected Structural Hill and is followed by water samples of Moderately Dissected Structural Hills. Its concentration value has dropped to almost half at Less Dissected Structural Hill and becomes negligible at Fracture and Intermontane Valley. The concentration value is highest during Pre-Monsoon and gradually decreases to Pre-Monsoon.

The barium concentration of groundwater in the Geomorphic Units is shown below-

Table 48: Average Barium in Geomorphic Units

Sl.No	Geomorphology	Concentration of Barium (ppm) Pre-Monsoon	Concentration of Barium (ppm) Monsoon	Concentration of Barium (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.027	0.013	0.000	0.013
3	InterMontane Valley (IV)	0.000	0.000	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.016	0.002	0.002	0.006
5	Moderately Dissected Structural Hill (SHM)	0.021	0.005	0.005	0.010
	Average	0.013	0.004	0.001	

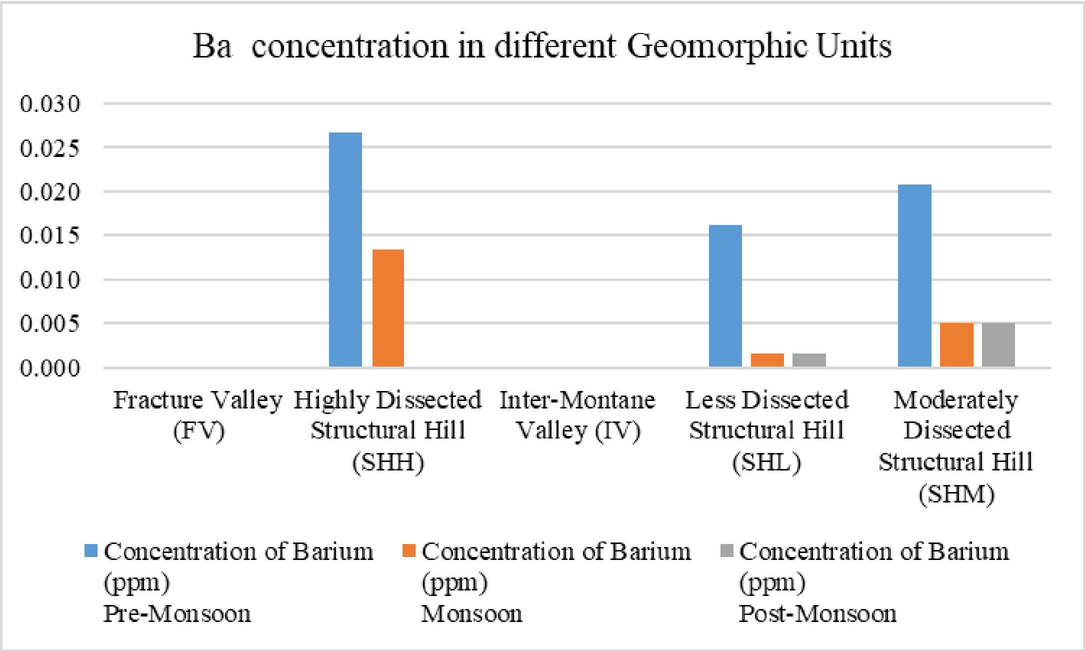


Figure 79: Bar chart of Barium in Geomorphic Units

The barium concentration of groundwater in the Lithostratigraphic Units is shown below-

Table 49: Average Barium Concentration in Geomorphic Units

Sl.No	Lithostratigraphic Unit	Average Barium concentration (ppm) Pre-Monsoon	Average Barium concentration (ppm) Monsoon	Average Barium concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.0183	0.0033	0.0017	0.008
2	Sandstone dominated (Upper Bhuban Formation)	0.02	0.004	0.0043	0.009
3	Shale dominated (Middle Bhuban Formation)	0.0267	0.0133	0	0.013
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0	0	0.000
	Average	0.016	0.00515	0.002	

In terms of Lithostratigraphic Units, the groundwater in shale-dominated Units has the highest Barium concentration. Upper and Lower Bhuban Formation has Ba concentration of 0.09 and 0.08ppm respectively. Unconsolidated sediment has a negligible concentration of Barium.

The vicinity of Kawnpui, Bukpui, Lungmuat, Nisapui, Serkhan, and the western part of Zanlawn shows a moderate concentration of Ba during Monsoon and the remaining part has less than 0.02ppm concentration. During Monsoon, as dilution by rainwater increases only small patches at N.Chaltlang exhibits moderate concentration while the rest are having Ba concentration of less than 0.02ppm. The area of moderate concentration of Ba at N. Chaltlang became wider during the Post-

Monsoon season indicating that the groundwater is less diluted because of the retreating Monsoon.

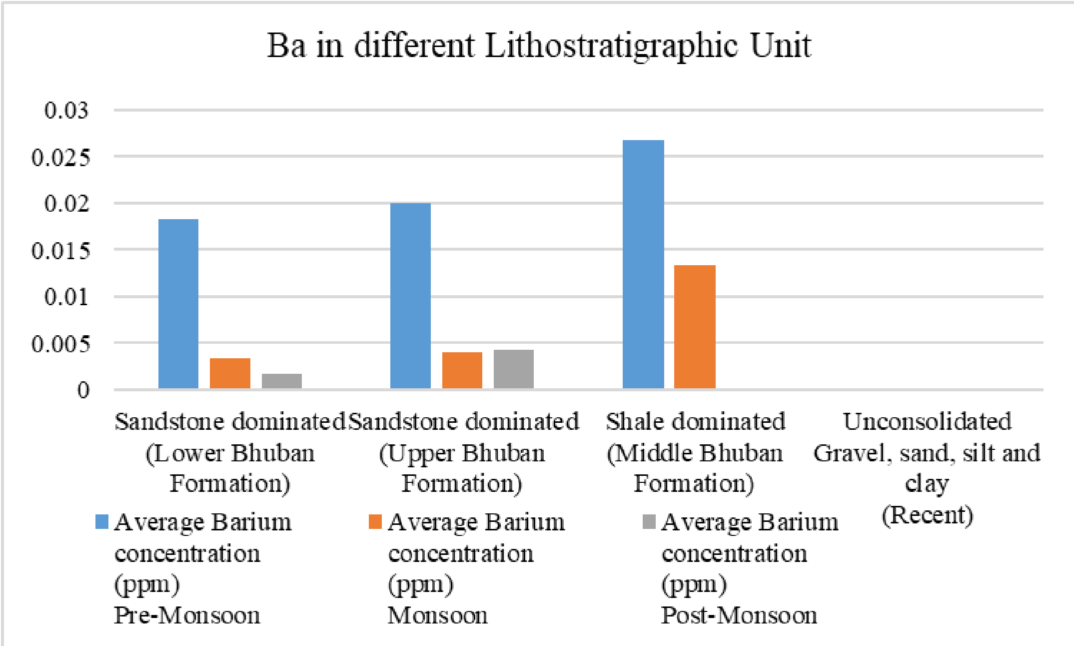


Figure 80: Bar chart of Barium in Lithostratigraphic Units

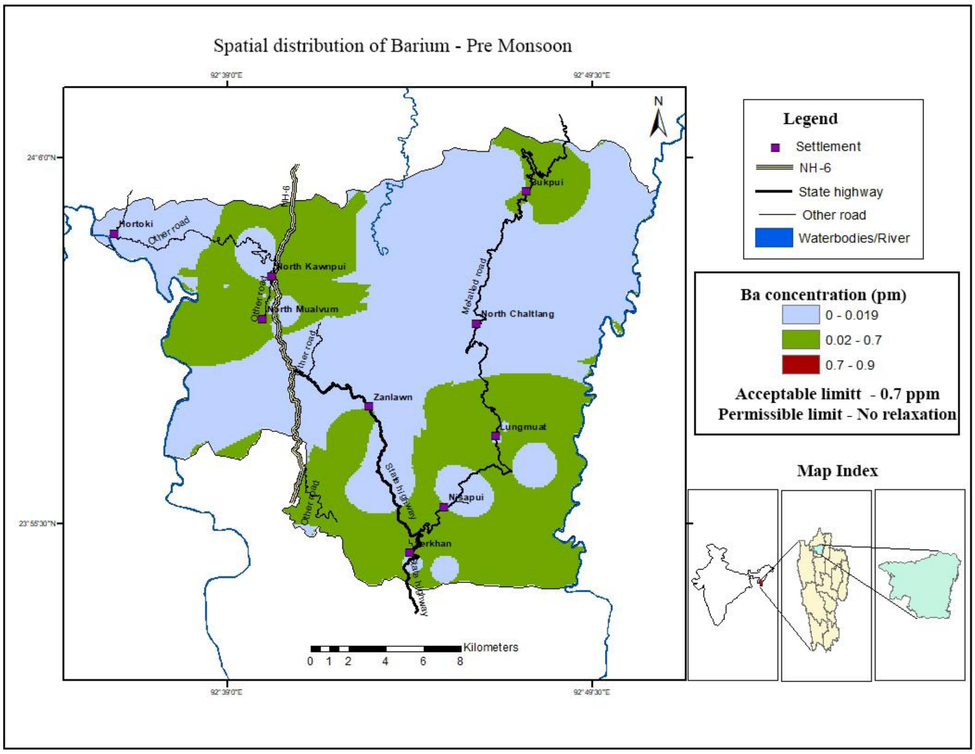


Figure 81: Spatial distribution map of Ba during Pre-Monsoon

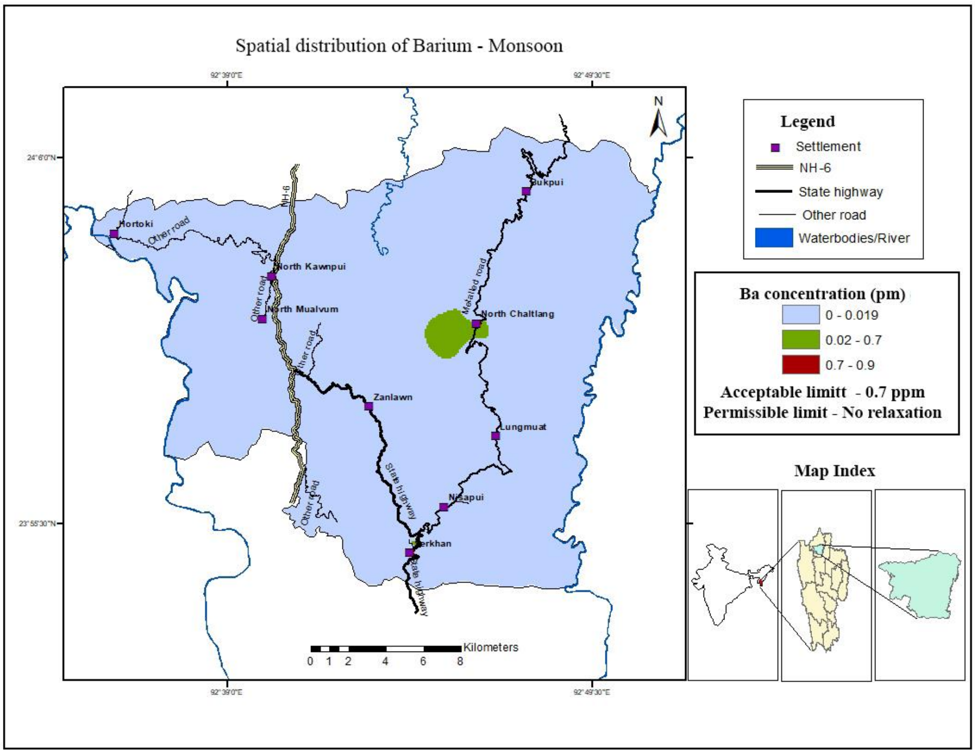


Figure 82: Spatial distribution map of Ba during Monsoon

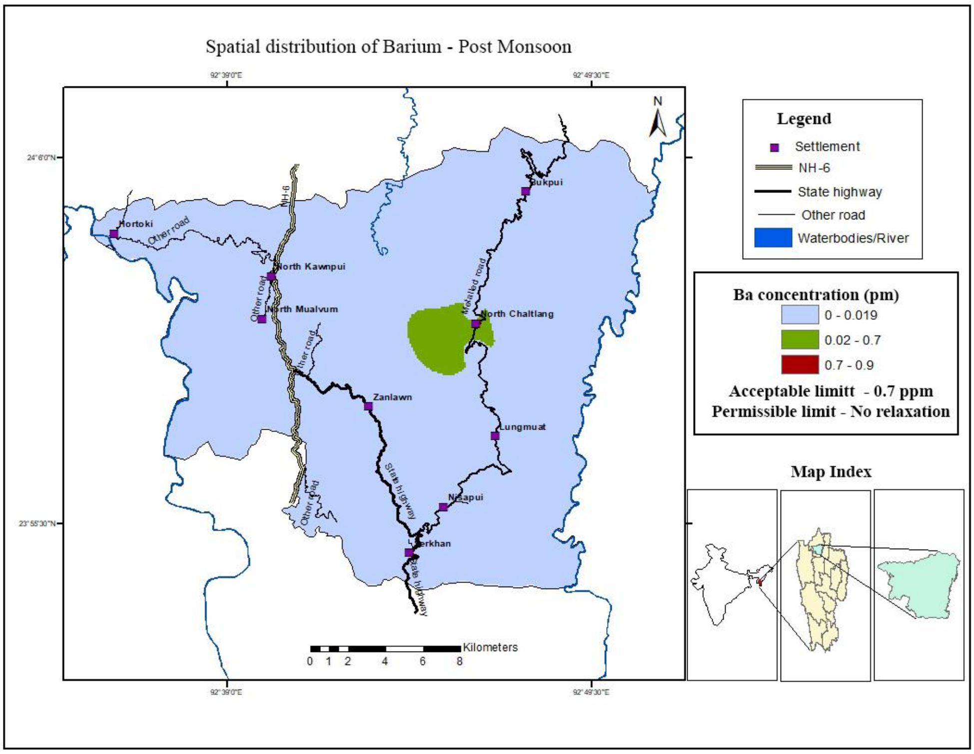


Figure 83: Spatial distribution map of Ba during Post-Monsoon

Table 50: Ba (in ppm) during Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Name	Village	Lattitude	Longtitude	Barium (ppm) Pre-Monsoon 2018	Barium (ppm) Monsoon 2018	Barium (ppm) Post-Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.01	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.08	0.04	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.08	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0	0
7	Zotui	Nisapui	23.94	92.762	0	0.01	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0.01	0.09	0.12
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.01	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.07	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0.02	0.01
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.02	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.06	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.04	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.01	0	0
26	Charpui	Kawnpui	24.05	92.674	0.05	0	0
27	Vailui	Kawnpui	24.034	92.668	0.01	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0.01	0
29	Sentezel	Kawnpui	24.04	92.674	0.04	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.01	0	0.01
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.01	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.02	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0.01	0.01	0
38	Sihpui	Kawnpui	24.036	92.669	0.08	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0.12	0	0
42	Luihnai	Lungmuat	23.966	92.779	0.01	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung	Lungmuat	23.9714	92.782	0	0	0

5.16 Zinc (Zn):

Zinc is also occurring as a minor constituent in groundwater (0.0001 to 0.1 ppm). The most important zinc ores are sphalerite (ZnS) and smithsonite ($ZnCO_3$). The presence of Zinc metal in water could be from weathering of soil and rock (Batayneh,2012). It could also be from anthropogenic activities, Zinc is used in paints and catalyzers, as fertilizer, and as a growth stimulant in animal husbandry. Leakage from pipes, car tires containing zinc, and motor oil from zinc tanks can introduce a substantial amount of zinc compounds on roads. Zinc compounds are present in fungicides and insecticides, and consequently end up in water. Significant differences in Zn contents were found based on the depth of seepage (infiltration vs. deep seepage) and geology. At the city level, significant differences in Zn were found for soil and land use (Stein, 1995). The occurrence of zinc in Groundwater and its diverse mobility in the environment make these metals a precise indicator of industrial and municipal pollution of freshwaters. The highest Zinc concentration is found in soils and anthropogenic deposits; the vertical section of the sand layer also shows a constant decline in Zinc content (Malecki *et al*., 2016).

From prior studies, it is observed that in the weathering zone and under oxidizing conditions, an increase in the solubility of zinc sulfates facilitates the migration of this metal. This causes Zn to be one of the most mobile water migrants. It is recognized that the atmospheric input of heavy metals is probably responsible for the concentration of Heavy metals in groundwater. Prior studies show that a high value of Zinc (>15mg/l) is found to be associated with acidic groundwater recharge where there is atmospheric deposition from a zinc smelter. The concentration of micro constituents of copper and zinc in the groundwater tends to decline with depth. Relatively high concentrations of these two elements in rainwater are introduced into the soils and rocks, which ultimately decrease with depth (Bas, 1990).

Zinc concentration is classified into three ranges (<5 ppm, 1-15 ppm, and >15 ppm) by BIS guidelines (BIS, 2012). Sub-station peng hand pump, Bukpui is characterized by Zinc concentration exceeding the permissible limit of 15 ppm during Post-Monsoon season. It is thought to be leaching from the bore well facilities of a hand pump.

The zinc concentration of groundwater in the Geomorphic Units is shown below-

Table 51: Average Zinc in Geomorphic Units

Sl.No	Geomorphology	Concentration of Zinc (ppm) Pre-Monsoon	Concentration of Zinc (ppm) Monsoon	Concentration of Zinc (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0	0	0
2	Highly Dissected Structural Hill (SHH)	0.007	0	0	0
3	Inter-Montane Valley (IV)	0.000	0	0	0
4	Less Dissected Structural Hill (SHL)	0.192	0	2	1
5	Moderately Dissected Structural Hill (SHM)	0.005	0	0	0
	Average	0.041	0	0	

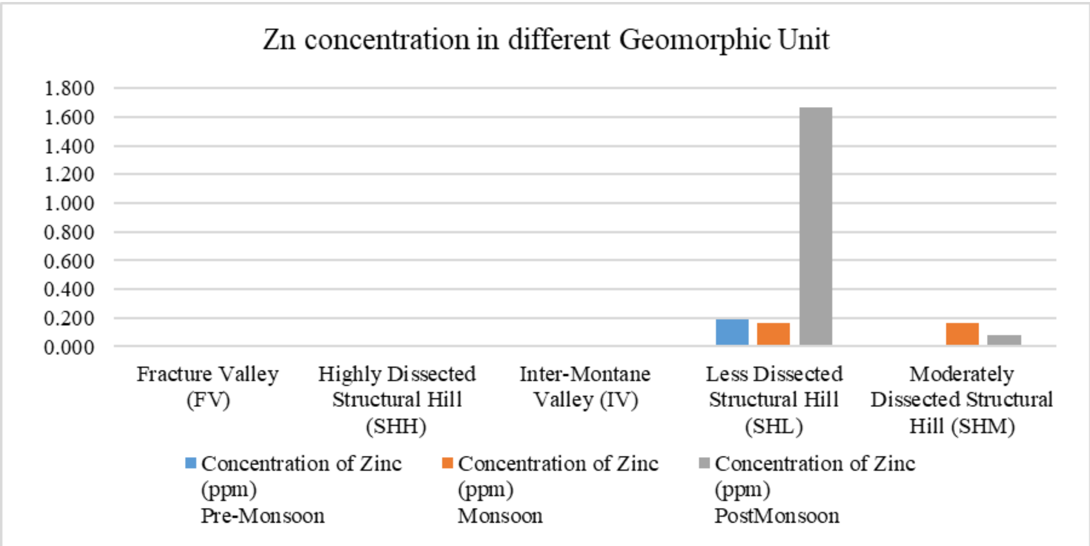


Figure 84: Bar chart of Zinc in Geomorphic Units

In terms of Geomorphology, less dissected terrain has the highest Zinc concentration; Highly Dissected and Moderately Dissected Structural Hill follow it. Average Zinc concentration is negligible at the lowest elevation terrain of both Fracture and Intermontane Valley. All dissected structural terrain are enriched in zinc constituents during Pre-Monsoon in comparison to Monsoon and Post-Monsoon seasons.

Samples from sandstone-dominant lithology of the Upper Bhuban Formation have the highest concentration value of Zinc, and the next one is sources of sandstone-dominated Lower Bhuban. Groundwater samples from the shale-dominated Middle Bhuban Formation are having least concentration. It may be due to the reason that either porosity or permeability of rock formation plays an important role in carrying dissolved zinc particles, as infiltrate down to the aquifer or sandstone rock are richer in Zinc bearing minerals. The concentration of Zinc in water samples of each Lithology is highest in Post-Monsoon and lowest in Pre-Monsoon indicating Zn is entered into the aquifer by infiltration during recharge of groundwater.

During Pre-Monsoon, all of the study areas show concentration values less than 1ppm. Elevated zinc content is observed from small patches area of Bukpui and N.Chaltlang village during Monsoon. The maximum concentration exceeding the acceptable limit of 5ppm is observed in the northern part of Bukpui during Post-Monsoon, its surrounding areas with a small area in N.Chaltlang have shown a moderate concentration of 1-5ppm. The remaining parts exhibit a Zn concentration of less than 1ppm.

The zinc concentration of groundwater in the lithological Units is shown below-

Table 52: Average Zinc Concentration in Lithostratigraphic Units

Sl.No	**Lithostratigraphy**	**Average Zinc concentration in Pre Monsoon (in ppm)**	**Average Zinc concentration in Monsoon (in ppm)**	**Average Zinc concentration in Post-Monsoon (in ppm)**	**Average**
1	Sandstone (Lower Bhuban Formation)	0.3817	0.02	0	0.1339
2	Sandstone (Upper Bhuban)	0.0033	0.209	0.7517	0.321333
3	Shale (Middle Bhuban)	0	0.0167	0.0167	0.011133
4	UnconsolidatedGravel, Sand, Silt, Clay (Recent)	0.012	0.058	0.018	0.029333
5	Average	0.09925	0.075925	0.1966	

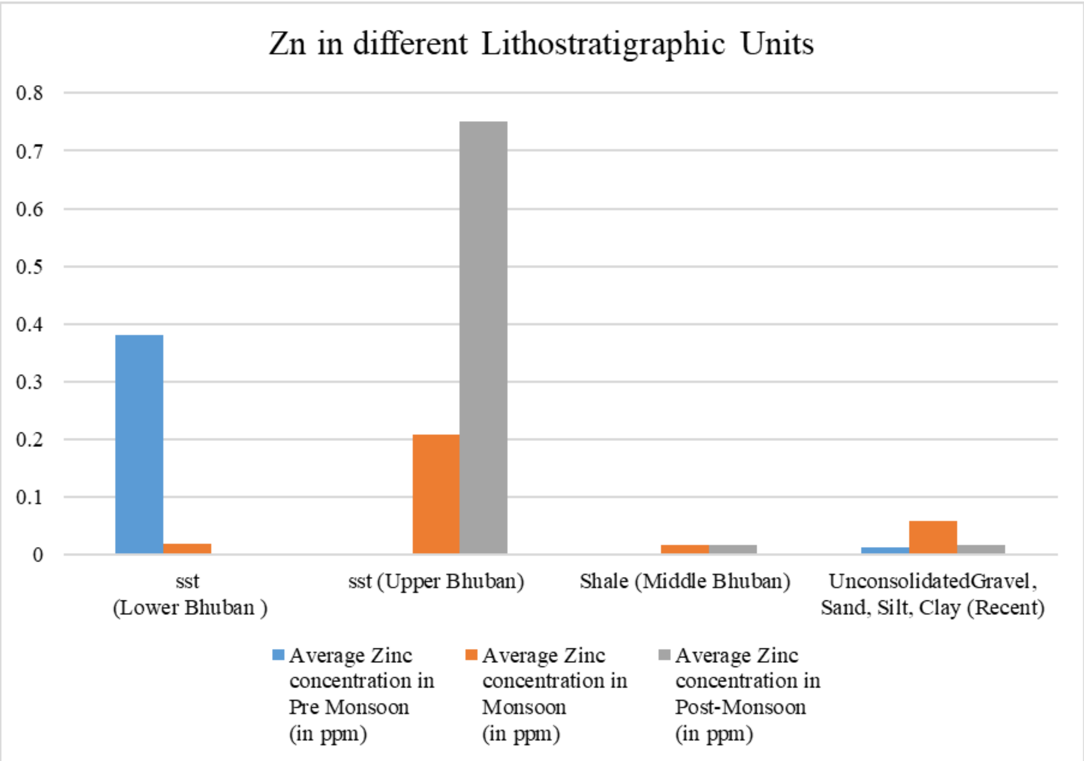


Figure 85: Bar chart of Zinc in Lithostratigraphic Units

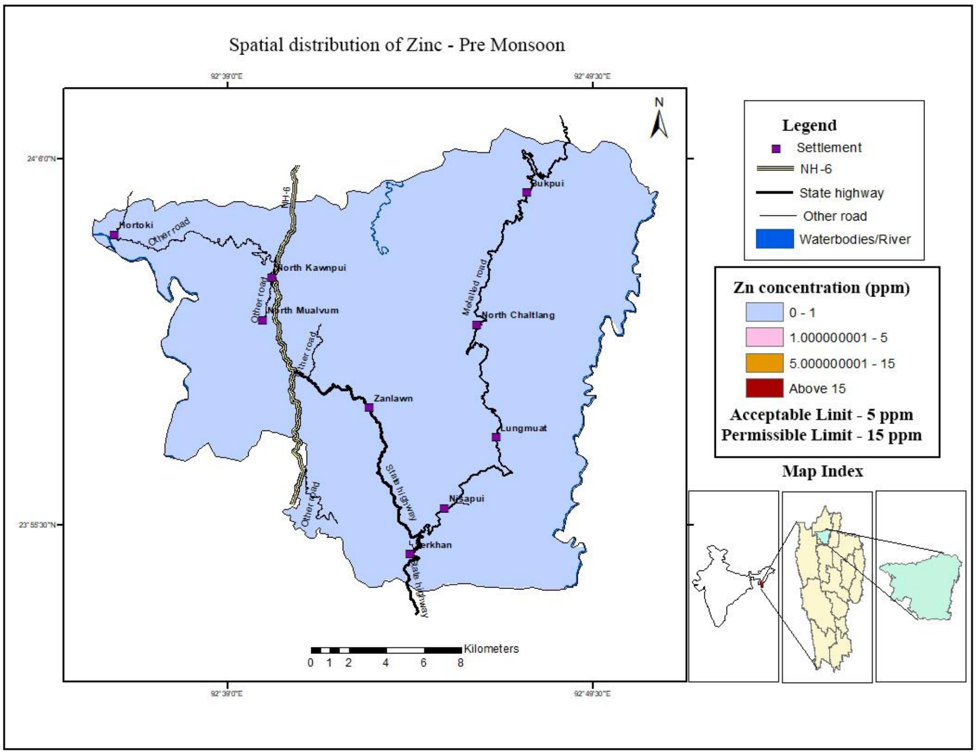


Figure 86: Spatial distribution map of Zn during Pre-Monsoon

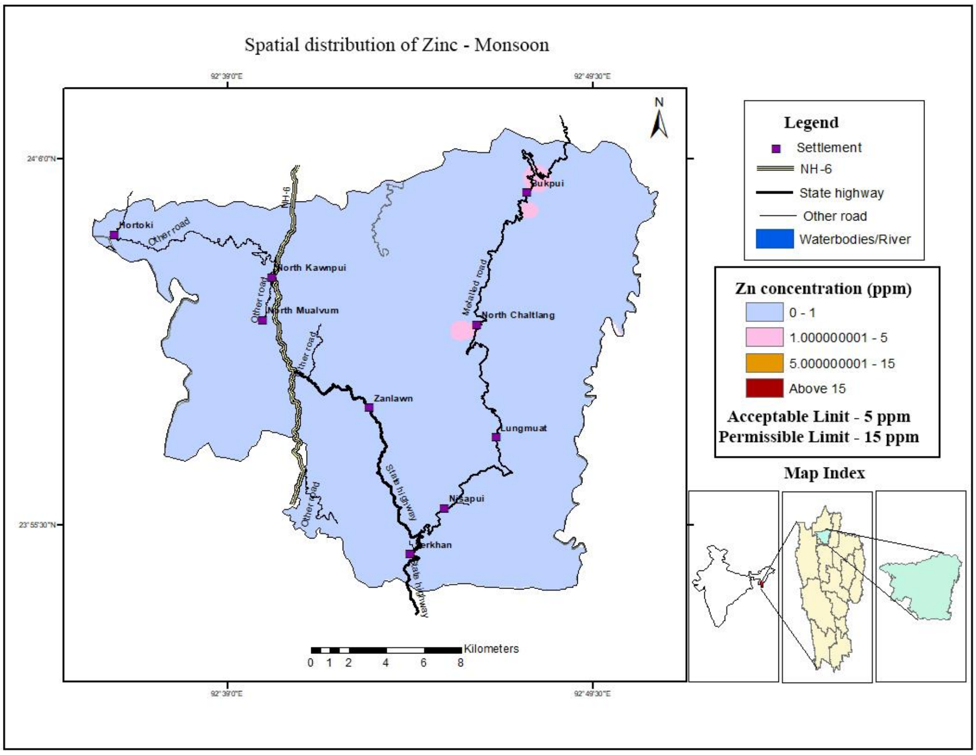


Figure 87: Spatial distribution map of Zn during Monsoon

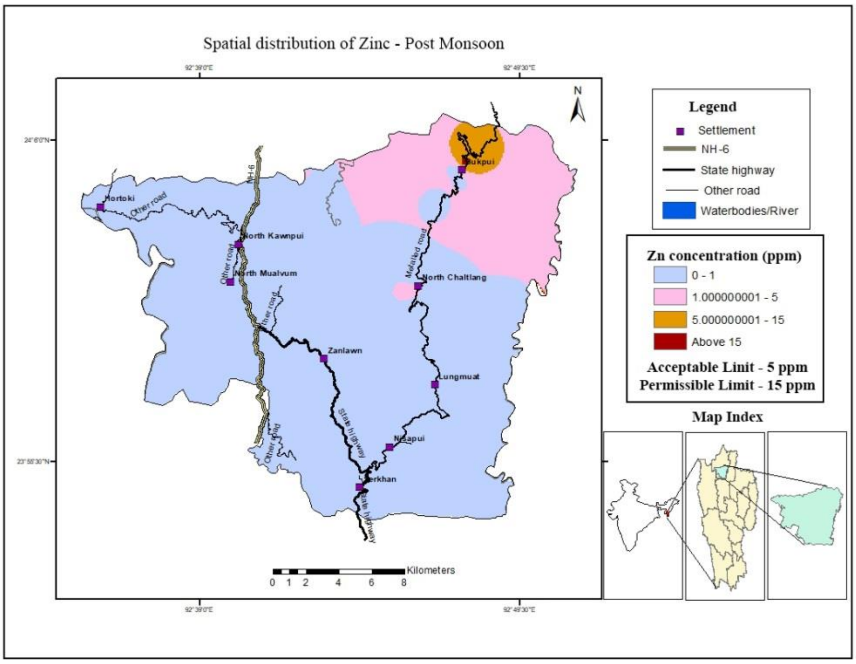


Figure 88: Spatial distribution map of Zn during Post-Monsoon

Table 53: Zn (in ppm) during Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Zinc (ppm) Pre Monsoon 2018	Zinc (ppm) Monsoon 2018	Zinc (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	2.25	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.02	0.12	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.01	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima handpump	North Chaltlang	24.018	92.765	0.01	2.25	2.45
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.01	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.02	0	0.02
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.02	0.02	0
16	Sub-Station Peng Handpump	Bukpui	24.088	92.795	0	2.06	19.91
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	1.71	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0.18	0
21	Fului	Zanlawn	23.97	92.711	0	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0	0
27	Vailui	Kawnpui	24.034	92.668	0.01	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0	0	0.02
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.01	0	0.02
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0.02	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0	0.03	0.13
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0	0.02	0
38	Sihpui	Kawnpui	24.036	92.669	0	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0.03	0.05
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0.08
41	Zotui	Lungmuat	23.972	92.778	0.05	0	0.01
42	Luihnai	Lungmuat	23.966	92.779	0	0.04	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0.25	0

5.17 Cadmium (Cd):

Cadmium in nature occurs typically in the form of sulphide, large quantities are found to be associated with the ores of zinc, copper, and lead in the form of impurities. It may also be present in crude oil and gasoline. Cadmium salts are also used in insecticides, fluorescent tubes, television tubes, and batteries.

As per BIS recommendation, Cadmium concentrations exceeding 0.003ppm are unfit for drinking purposes. During Pre-Monsoon, one source from the groundwater of Serkhan and Zanlawn villages are having a Cd value exceeding the permissible limit, and two sources from Zanlawn are also exceeding the permissible limit. Eight sources of spring water from Kawnpui village and three samples from Lungmuat villages fall into non-potable classes. All samples from Hortoki, Nisapui, and N. Chaltlang villages are confined within the desirable limit. During Monsoon, Dengalui spring water of Serkhan has exceeded the permissible limit.

In terms of Geomorphic Units, samples collected from Less Dissected Structural Hill have a higher concentration of Cadmium in comparison to Moderately Dissected Structural Hills. On the other hand, groundwater from Fracture Valley, Intermontane Valley, and Highly Dissected Structural Hill have insignificant amounts of Cd concentration.

Table 54: Average Cadmium Concentration in Geomorphic Units

Sl.No	Geomorphology	Concentration of Cadmium (ppm) Pre-Monsoon	Concentration of Cadmium (ppm) Monsoon	Concentration of Cadmium (ppm) Post-Monsoon
1	Fracture Valley (FV)	0.000	0	0
2	Highly Dissected Structural Hill (SHH)	0.000	0	0
3	Inter-Montane Valley (IV)	0.000	0	0
4	Less Dissected Structural Hill (SHL)	0.005	0	0
5	Moderately Dissected Structural Hill (SHM)	0.004	0	0

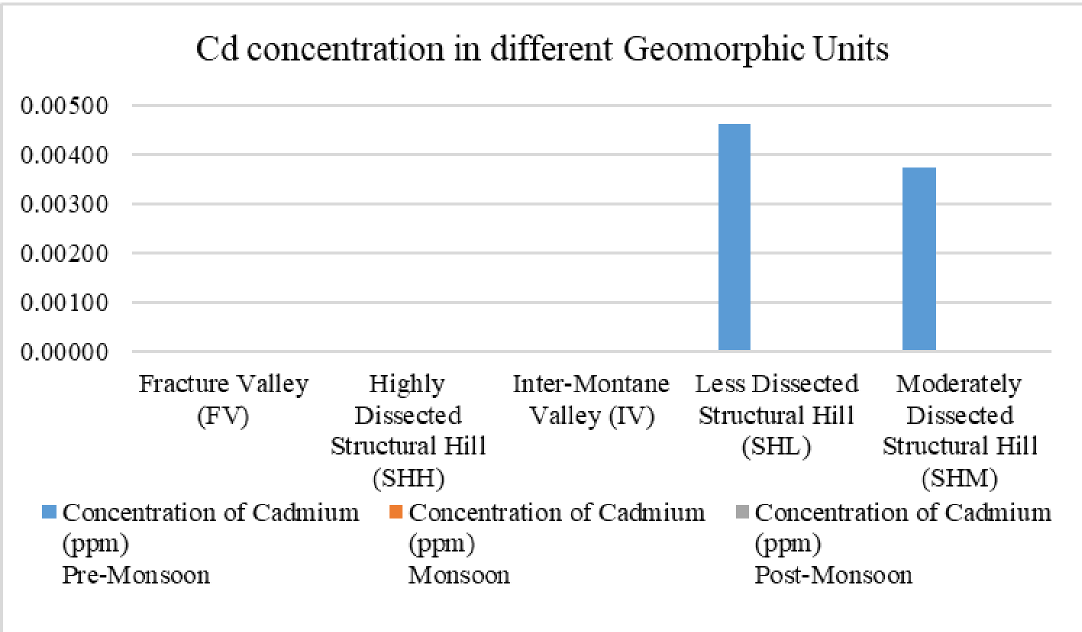


Figure 89: Bar chart of Cadmium in Geomorphic Units

In each Geomorphic and Lithological Unit, Cd concentration is highest in Pre-Monsoon and is gradually depleted by rainwater, eventually, its concentration is below the detectable limit in the post-monsoon season.

The relatively high amount of Cadmium concentration is found only in groundwater of sandstone-dominated rock Formation of Upper and Lower Bhuban Formation. However, Middle Bhuban shale-dominated Formation and Unconsolidated sediments have negligible amounts of Cd concentration.

During Pre-Monsoon, the vicinity of Bukpui, Kawnpui, Lungmuat, and the western part of Zanlawn has shown Cd concentration, which exceeds the permissible limit. The remaining parts have a concentration lower than 0.003 ppm.

Table 55: Average Cadmium in Lithostratigraphic Units

Sl.No	**Lithostratigraphy**	**Average Cadmium concentration in Pre Monsoon (in ppm)**	**Average Cadmium concentration in Monsoon (in ppm)**	**Average Cadmium concentration in Post Monsoon (in ppm)**
1	Sandstone (Lower Bhuban Formation)	0.0033	0	0
2	Sandstone (Upper Bhuban)	0.0043	0	0
3	Shale (Middle Bhuban)	0.0000	0	0
4	Unconsolidated Gravel, Sand, Silt, and Clay (Recent)	0.0000	0	0

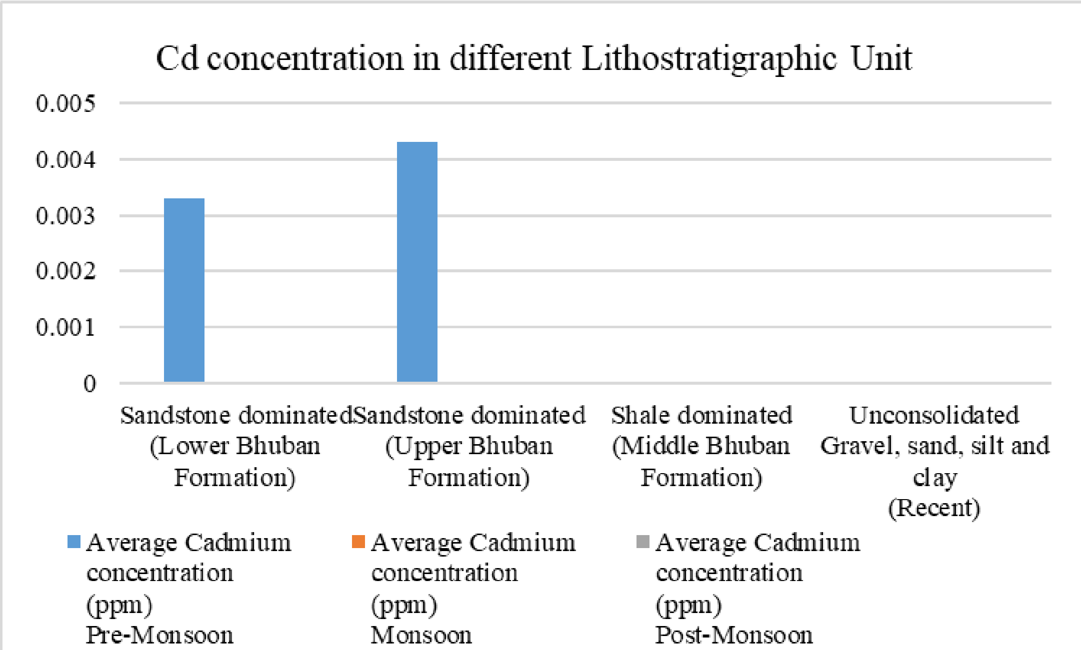


Figure 90: Bar chart of Cadmium in Lithostratigraphic Units

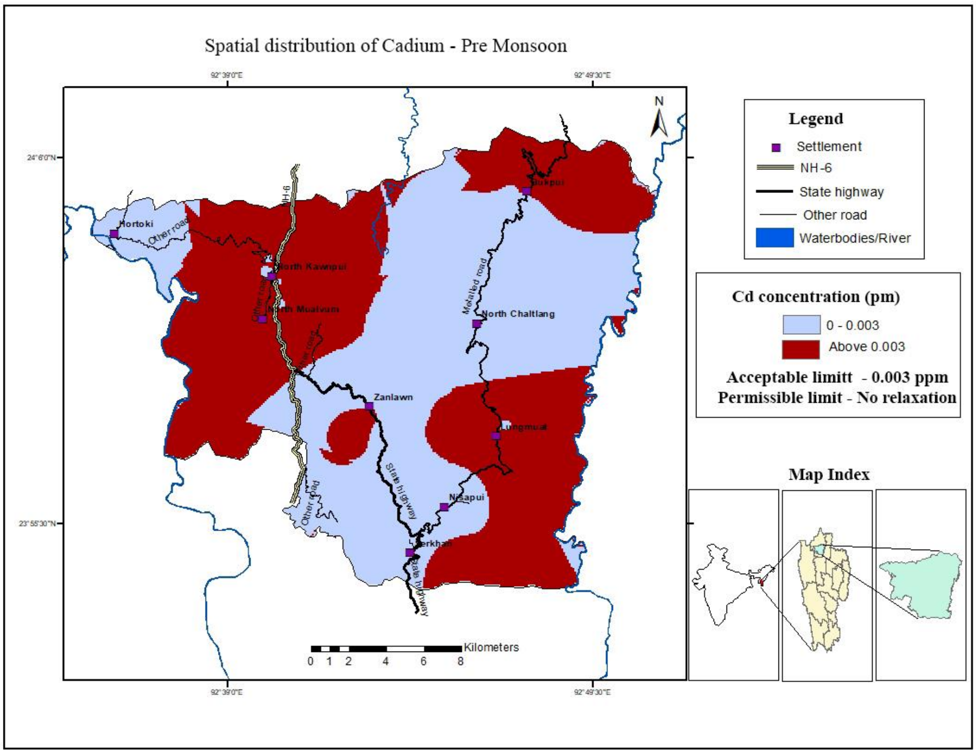


Figure 91: Spatial distribution map of Cd during Pre-Monsoon

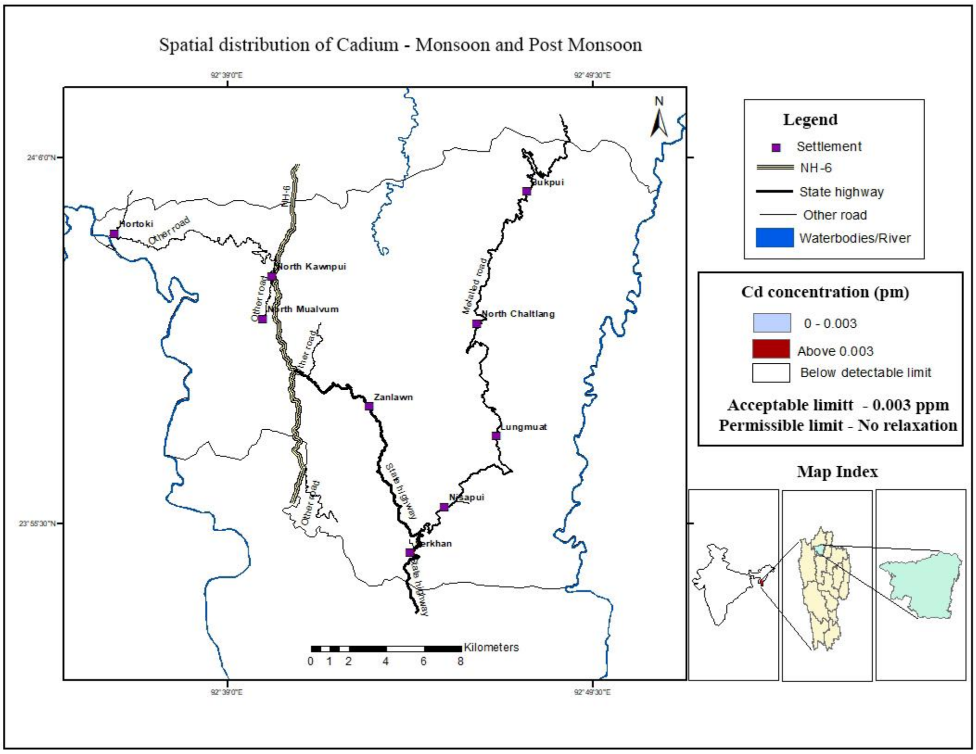


Figure 92: Spatial distribution map of Cd during Monsoon and Post-Monsoon

Table 56: Cadmium concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Cadmium (ppm) Pre-Monsoon 2018	Cadmium (ppm) Monsoon 2018	Cadmium (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.01	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0	0.01	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point	North Chaltlang	24.018	92.765	0	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0	0
16	Sub-Station Peng	Bukpui	24.088	92.795	0.01	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.01	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.01	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.01	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0	0
27	Vailui	Kawnpui	24.034	92.668	0.01	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.01	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.01	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0.01	0	0
38	Sihpui	Kawnpui	24.036	92.669	0.01	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0.01	0	0
42	Luihnai	Lungmuat	23.966	92.779	0.01	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.18 Lead (Pb):

Galena (PbS) is the most prevalent mineral where Lead exists in nature. Lead-containing minerals are sparingly soluble, which is evident by their acutely low concentration in natural water. Anthropogenic activities like the use of pesticides, burning of coal and gasoline that ultimately deposits Pb in the atmosphere with exhaust gas, dumping of solid waste and industrial waste, etc., mainly increase the concentration of Pb in natural water.

According to BIS specification, water samples with a Pb concentration surpassing 0.01(ppm) are categorized as non-potable classes. Out of 44 sample sources, 21 samples are contaminated by Pb. Sihpui stream water at Kawnpui has a Pb concentration higher than the acceptable limit throughout each season.

Lead pollution is found to be very high in almost all Geomorphic Units; Water samples from Moderately Dissected Structural Hill, Less Dissected Structural Hill, and Intermontane Valley have almost the same value of Pb concentration. Lead concentration in potable water is highest in Moderately Dissected Structural Hill whereas lowest in Fracture Valley Unit.

Season-wise, Pb pollution of water sources is found to be extensively high in the Pre-monsoon season, and its concentration is gradually decreased during Monsoon in each Geomorphic Unit. This may be due to the increasing amount of water that enhances the dilution of Pb in groundwater as aquifers get recharged.

Cadmium concentration of groundwater in the Geomorphic Units is shown below: -

Table 57: Average Lead in Geomorphic Units

Sl.No	Geomorphology	Concentration of Lead (ppm) Pre-Monsoon	Concentration of Lead (ppm) Monsoon	Concentration of Lead (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.015	0.000	0.01
2	Highly Dissected Structural Hill (SHH)	0.160	0.030	0.000	0.06
3	Inter-Montane Valley (IV)	0.000	0.030	0.425	0.15
4	Less Dissected Structural Hill (SHL)	0.028	0.007	0.431	0.16
5	Moderately Dissected Structural Hill (SHM)	0.054	0.018	0.502	0.19
	Average	0.05	0.02	0.27	

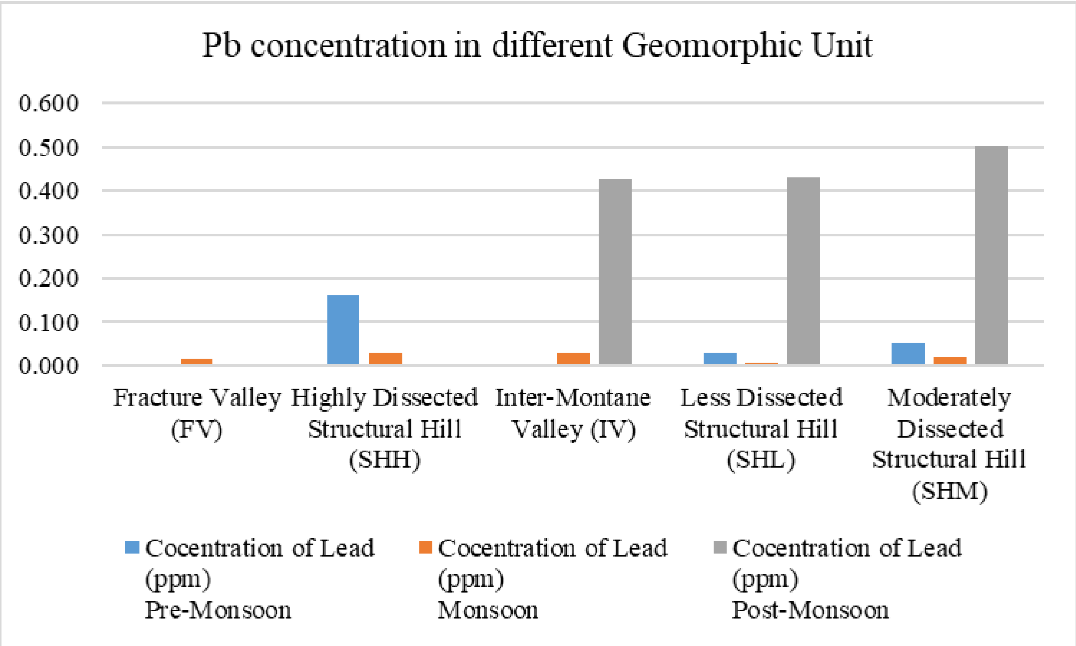


Figure 93: Bar chart of Lead in Geomorphic Units

The lead concentration of groundwater in the Lithostratigraphic Units is shown below: -

Table 67: Average Lead in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Lead concentration (ppm) Pre-Monsoon	Average Lead concentration (ppm) Monsoon	Average Lead concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.1683	0.025	0	0.06
2	Sandstone dominated (Upper Bhuban Formation)	0.0183	0.0123	0.49	0.17
3	Shale dominated (Middle Bhuban Formation)	0.18	0.0233	0.65	0.28
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0.006	0.024	0.37	0.13
	Average	0.093	0.02115	0.378	

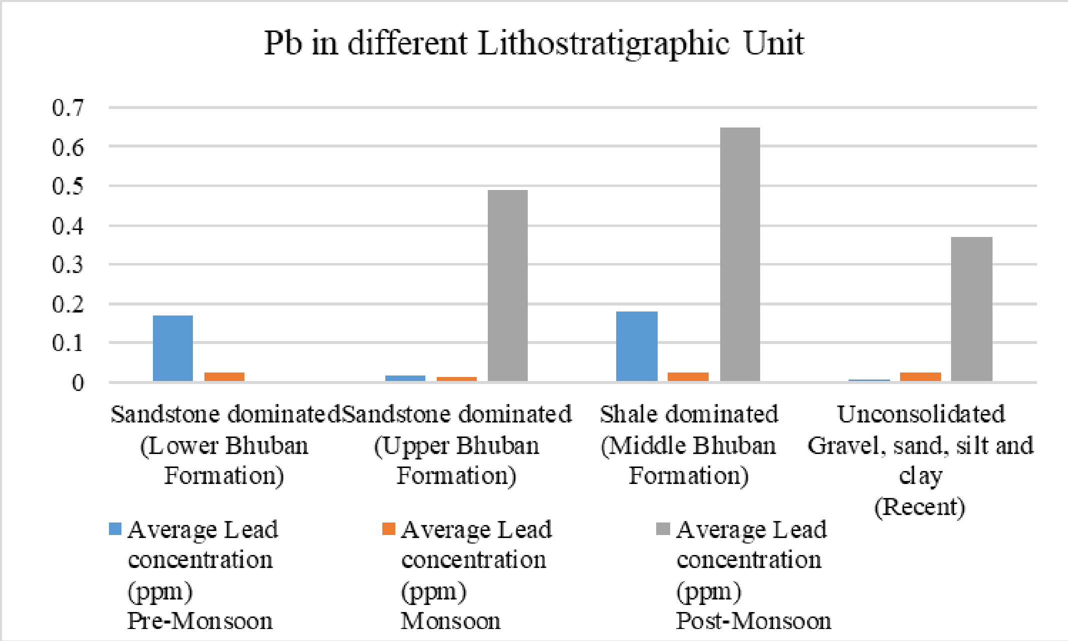


Figure 94: Bar chart of Lead in Lithostratigraphic Units

In terms of the Lithological Unit, groundwater from shale dominant rock of the Middle Bhuban Formation has the highest Pb pollution, followed by Upper Bhuban Formation. Samples from Unconsolidated Formation have the lowest record of Pb concentration value.

The lead concentration value of groundwater from each lithological Unit shows that it is minimum during the Monsoon season, and is slightly higher during Pre-monsoon and Post-monsoon.

During Pre-Monsoon, samples from almost every region of the study area exceed the permissible limit of 0.01ppm. However, the vicinity of Hortoki, N.Chaltlang, and small patches at Zanlawn, Nisapui, and Bukpui show a Pb concentration of less than 0.01 ppm. The concentration of Pb in groundwater is slightly reduced in the Monsoon season, the northwestern part of the study area, and small dots at Lungmuat, Serkhan, Zanlawn, Kawnpui, and Hortoki have Pb concentrations of desirable characteristics. During Post-Monsoon, an extremely high concentration of Pb in groundwater is observed in the study area except in the northern villages and small dots at Bukpui, N. Chaltlang, Kawnpui, and Lungmuat.

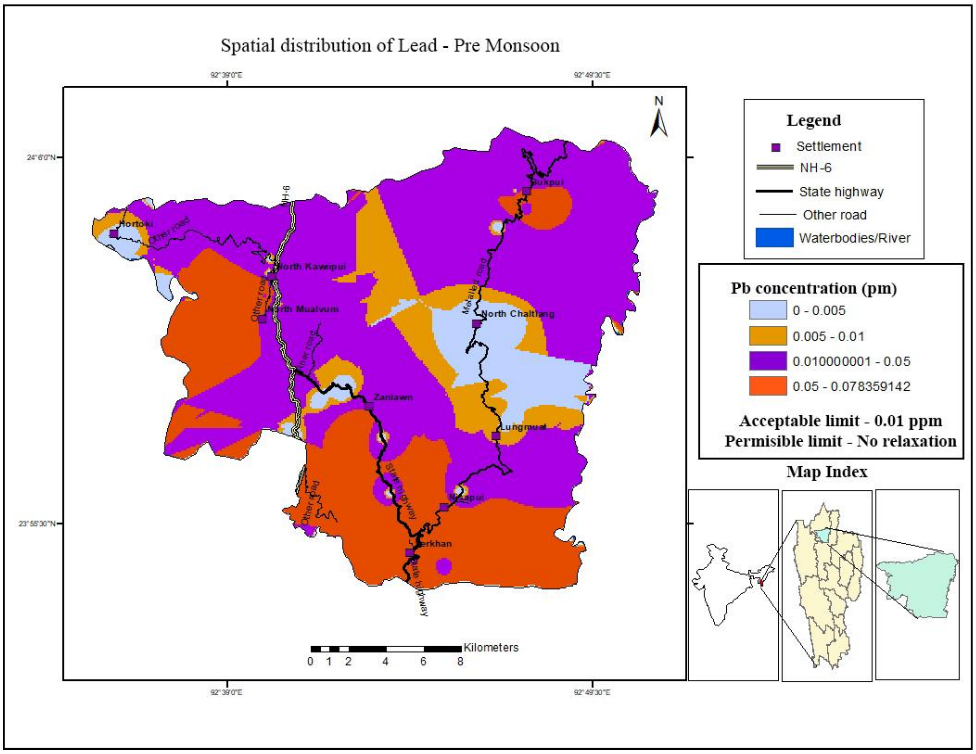


Figure 95: Spatial distribution map of Pb during Pre-Monsoon

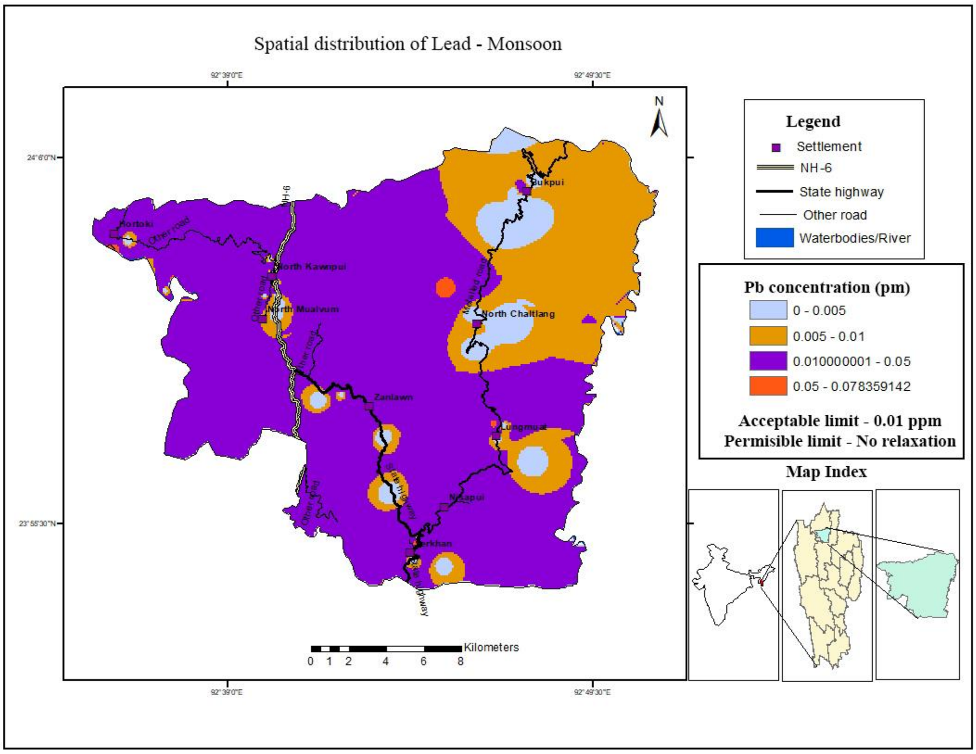


Figure 96: Spatial distribution map of Pb during Monsoon

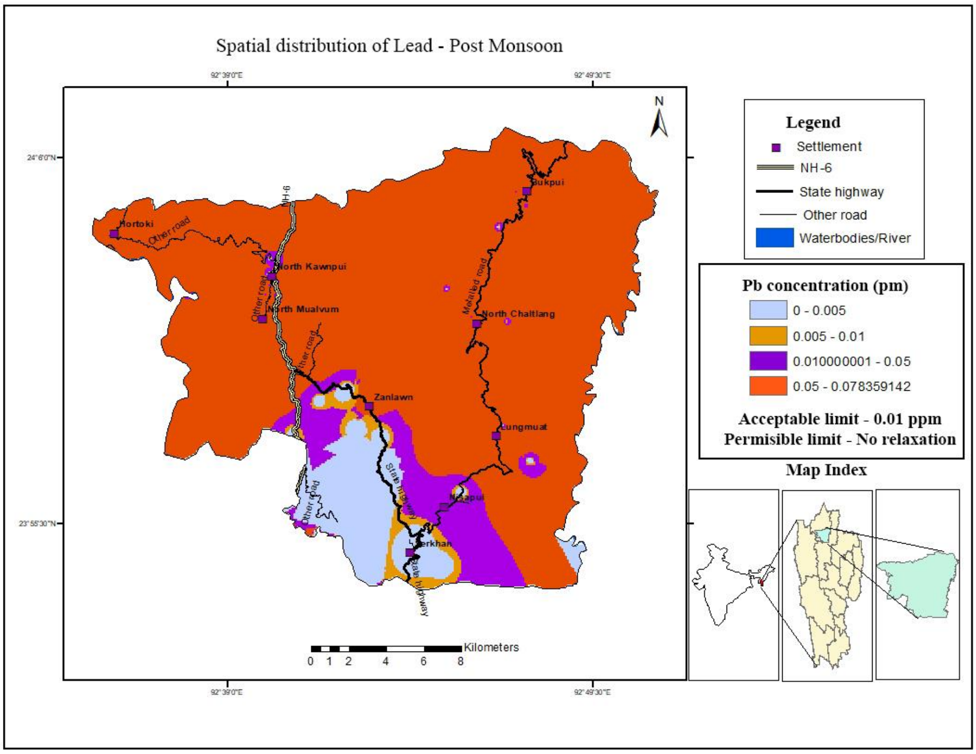


Figure 97: Spatial distribution map of Pb during Post-Monsoon

Table 59: Lead concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Lead (ppm) Pre-Monsoon 2018	Lead (ppm) Monsoon 2018	Lead (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.01		0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.48	0.09	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.51	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0.06	0
7	Zotui	Nisapui	23.94	92.762	0	0.03	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0	0.01	8.66
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.26	0	1.06
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0.03	1.36
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.01	0	0.45
17	Nuhliri Point	Bukpui	24.077	92.793	0.02	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.15	0.05	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0.05	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.01	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0.02	0.06	0
27	Vailui	Kawnpui	24.034	92.668	0.01	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.04	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.01	0.06	1.75
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0.05	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.01	0	1.42
36	Tuitun	Kawnpui	23.9667	92.681	0	0.03	0
37	Khurthuk	Kawnpui	24.039	92.67	0.02	0.03	0
38	Sihpui	Kawnpui	24.036	92.669	0.52	0.04	0.97
39	Lungpher	Hortoki	24.06	92.602	0	0	0.98
40	Khawzasiaka	Hortoki	24.056	92.596	0	0.06	0.85
41	Zotui	Lungmuat	23.972	92.778	0.01	0.06	1
42	Luihnai	Lungmuat	23.966	92.779	0.01	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung	Lungmuat	23.9714	92.782	0	0	0

5.19 Nickel (Ni):

Nickel is used in the production of stainless steel and alloys. It is also used in electroplating, as catalysts, in nickel–cadmium batteries, in coins, in welding products, and certain pigments and electronic products. Nickel is also incorporated into some food supplements. Nickel enters into water bodies primarily as nickel-containing particulate matter carried by rainwater, through the degradation or dissolution and mobilization of nickel-containing rocks and soils, combustion and incineration of fossil fuels, and discharges of industrial and municipal wastes, it can also be leached from metal alloys which are in contact with water, such as in pipes and fittings.

Ni concentrations exceeding 0.02ppm are classed as non-potable sources as per BIS recommendation. 24 sampling sources are found to be polluted during the Pre-monsoon season, and 1 source during Monsoon. Then, its concentration becomes below the detectable limit during Post-monsoon.

In terms of Geomorphic Units, Groundwater from Less Dissected Structural Hills has the highest concentration. Samples from Highly and Moderately Dissected Structural Hill are found to have more or less equal concentration, 0.027ppm and 0.0026ppm respectively. An insignificant amount of Nickel concentration is observed in samples from Intermontane Valley and Fracture Valley so that their average concentration remains zero throughout each season.

The nickel concentration of groundwater in the Geomorphic Units is shown below: -

Table 60: Average Nickel in Geomorphic Units

Sl.No	Geomorphology	Concentration of Nickel (ppm) Pre-Monsoon	Concentration of Nickel (ppm) Monsoon	Concentration of Nickel (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.043	0.037	0.000	0.027
3	Inter-Montane Valley (IV)	0.000	0.000	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.091	0.002	0.000	0.031
5	Moderately Dissected Structural Hill (SHM)	0.075	0.002	0.000	0.026
	Average	0.042	0.008	0.000	

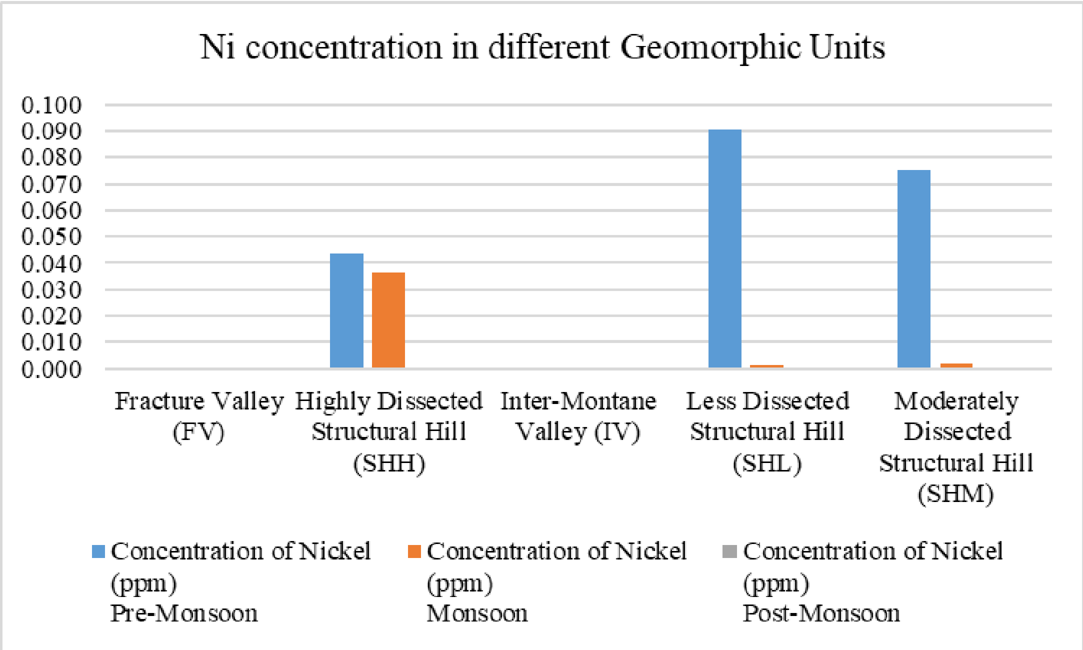


Figure 98: Bar chart of Nickel in Geomorphic Units

In terms of the Lithostratigraphic Unit, samples collected from Upper, Lower, and Middle Bhuban have almost the same value of Nickel concentration of 0.028ppm, 0.025ppm, and 0.027ppm respectively. Water samples from Unconsolidated sediment have the lowest concentration of 0.011 ppm.

During Post-Monsoon, most of the study area excluding small patches at Hortoki, Zanlawn, Nisapui, Lungmuat, N. Chaltlang, and Bukpui are characterized by Ni concentration exceeding the permissible limit. The nickel concentration of groundwater in the Lithostratigraphic Units is shown below: -

Table 61: Average Ni in Lithostratigraphic Units

Sl.No	**Lithostratigraphic Unit**	**Average Nickel concentration (ppm) Pre-Monsoon**	**Average Nickel concentration (ppm) Monsoon**	**Average Nickel concentration (ppm) Post-Monsoon**	**Average**
1	Sandstone dominated (Lower Bhuban Formation)	0.0717	0.003	0	0.025
2	Sandstone dominated (Upper Bhuban Formation)	0.081	0.002	0	0.028
3	Shale dominated (Middle Bhuban Formation)	0.0433	0.037	0	0.027
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0.0325	0	0	0.011
	Average	0.057	0	0.000	

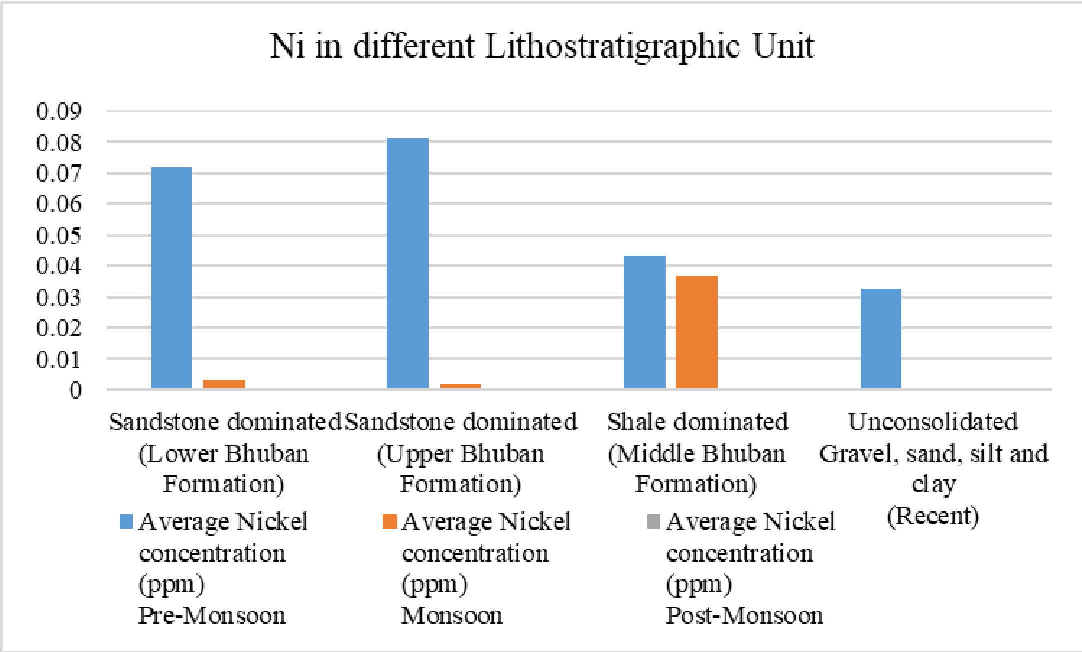


Figure 99: Bar chart of Nickel in Lithostratigraphic Units

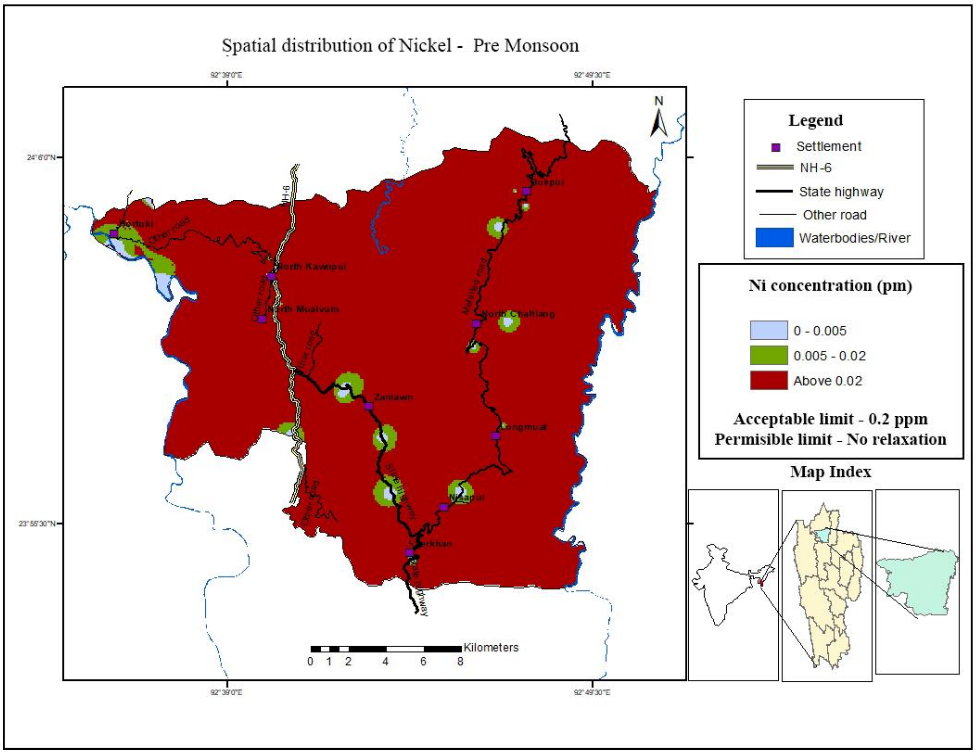


Figure 100: Spatial distribution map of Nickel during Pre-Monsoon

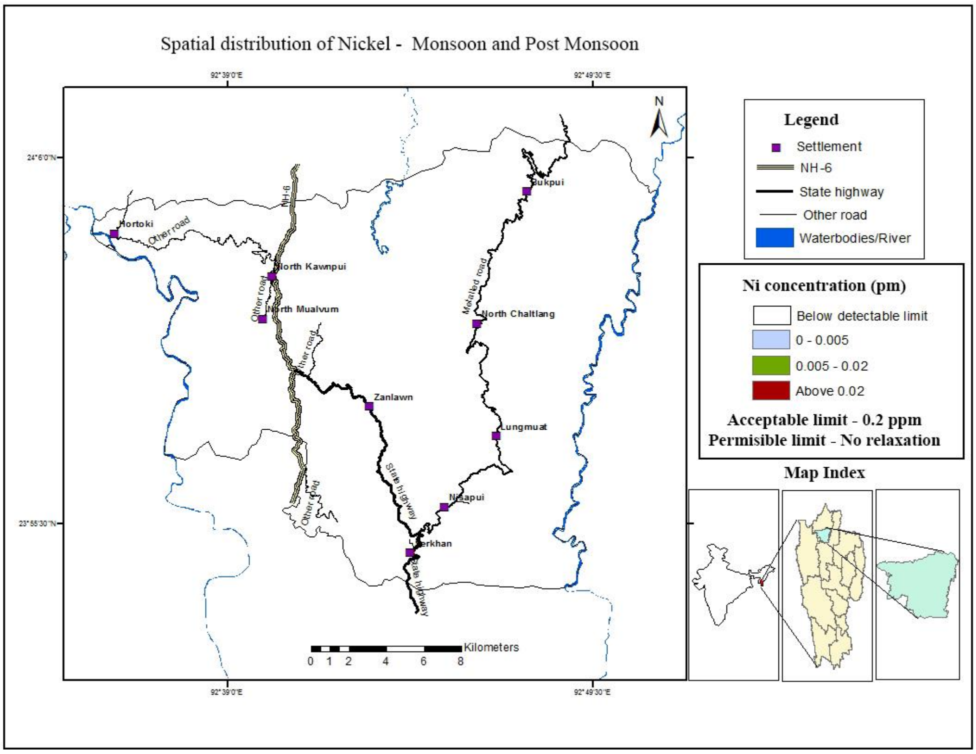


Figure 101: Spatial distribution map of Ni during Monsoon and Post-Monsoon

Table 62: Nickel concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Nickel (ppm) Pre-Monsoon 2018	Nickel (ppm) Monsoon 2018	Nickel (ppm) Post-Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.12	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.13	0.11	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.13	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.14	0	0
7	Zotui	Nisapui	23.94	92.762	0	0.01	0
8	Lalkima Point handpump	North Chaltlang	24.018	92.765	0.13	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.14	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.12	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.12	0.02	0
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	0.19	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0	0	0
18	Vandawt	Zanlawn	23.984	92.694	0.13	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.12	0.01	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.12	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.12	0	0
26	Charpui	Kawnpui	24.05	92.674	0.13	0.01	0
27	Vailui	Kawnpui	24.034	92.668	0.12	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.14	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.12	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.12	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0.01	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.12	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0.12	0	0
38	Sihpui	Kawnpui	24.036	92.669	0.13	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0.12	0.01	0
42	Luihnai	Lungmuat	23.966	92.779	0.17	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.12	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.20 Arsenic:

It is considered that semi-metal impartially shows the properties of true metals. It is widely distributed in the crust in the form of sulphides, such as orpinent (As_2S_3), arsenopyrite (FeAsS), and in naturally occurring minerals of Ag, Pb, Cu, Ni, Co, and Fe. It may enter into water bodies from man-made sources like uses of pesticides, burning of coal, and hide preservatives, etc., Arsenic pollution of water is found to have undergone biological magnification from low ambient concentrations.

Water sources whose arsenic concentration exceeds 0.01ppm are considered non-potable as per BIS recommendation. The detectable limit of an instrument is one part per billion and all samples from the study area are characterized by arsenic concentration below the detectable limit.

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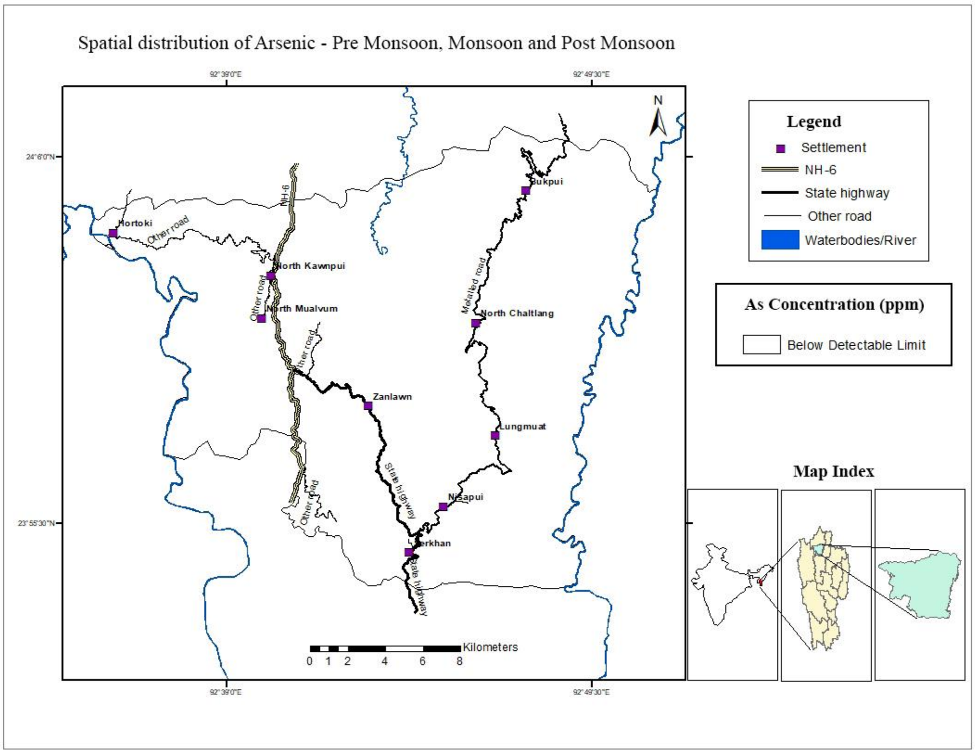

Figure 102: Spatial distribution map of Arsenic during Pre-Monsoon, Monsoon, and Post-Monsoon

Table 63: Arsenic concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Name	Village	Lattitude	Longtitude	Arsenic (ppm) Pre-Monsoon 2018	Arsenic (ppm) Monsoon 2018	Arsenic (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0	0	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0	0	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0	0	0
27	Vailui	Kawnpui	24.034	92.668	0	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0367	92.672	0	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0	0	0
38	Sihpui	Kawnpui	24.036	92.669	0	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0	0	0
42	Luihnai	Lungmuat	23.966	92.779	0	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0	0	0
44	Vengchung Lui	Lungmuat	23.9714	92.782	0	0	0

5.21 Chromium (Cr):

It is a heavy metal that is widely distributed in the earth's crust. The main ore of chromium metal is Chromate. It gives characteristic color to many precious stones when present as impurities. Higher concentrations of Chromium are generally associated with phosphorites, igneous rocks, shales, and clays. Chromium is extensively used for the manufacturing of alloys, steels, and refractory materials like bricks. It is also used in electroplating, tanneries, pigments, fertilizers, corrosion inhibitors, etc. Its wide range of applications makes it a source of contamination of air, soil, and water.

BIS classifies chromium concentration exceeding 0.01ppm as unfit for human consumption. However, all samples within the area are lacking such Chromium contamination.

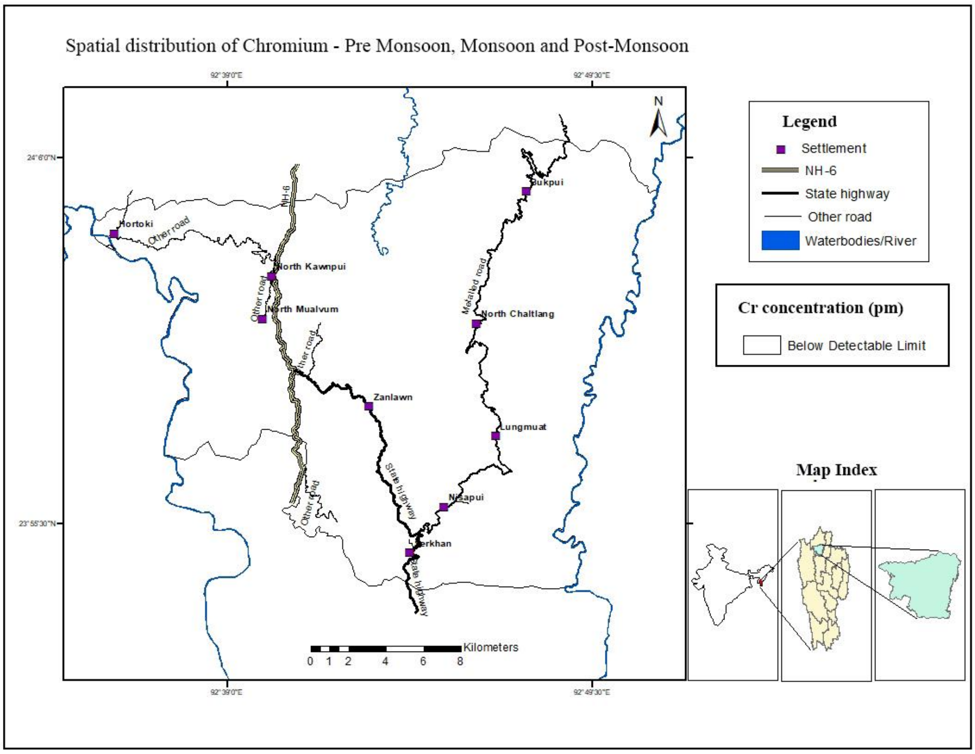

Figure 103: Spatial distribution map of Arsenic during Pre-Monsoon, Monsoon, and Post-Monsoon

Table73: Chromium concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Name	Village	Lattitude	Longtitude	Chromium (ppm) Pre-Monsoon 2018	Chromium (ppm) Monsoon 2018	Chromium (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0	0	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0	0	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0	0	0
27	Vailui	Kawnpui	24.034	92.668	0	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0367	92.672	0	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0	0	0
38	Sihpui	Kawnpui	24.036	92.669	0	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0	0	0
42	Luihnai	Lungmuat	23.966	92.779	0	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0	0	0
44	Vengchung Lui	Lungmuat	23.9714	92.782	0	0	0

5.22 Cobalt (Co):

Cobalt occurs as a minor constituent in potable water ranging between 0.0001 to 0.1ppm. Naturally, small amounts of cobalt are occurring in rock, making up approximately 0.0025% of the earth's crust. It is often present in association with nickel, silver, lead, copper, and iron ores. Cobalt occurs in mineral form as arsenides, sulfides, and oxides, such as linnaeite (Co3S4), carrolite (CuCo2S4), safflorite (CoAs2), skutterudite (CoAs3), erythrite (Co3(AsO4)2*8H2O), and glaucodot (CoAsS). The absorption of cobalt in water samples is observed to be increased with the pH of the aqueous phase. In a fixed pH value, the measured *Cobalt distribution coefficient* values are observed to be strongly correlated to the surface area of materials and minerals, but not to the number of individual clay minerals like illite, kaolinite, or smectite (Payne *et al.*, 2009).

Natural sources of elevated cobalt concentration in the environment include volcanic eruptions, seawater spray, and forest fires. Anthropogenic sources of cobalt in the atmosphere and aquatic environment include coal-fired power plants and incinerators, exhaust from vehicles, sewage effluents, urban run-off, and agricultural run-off.

As recommended by BIS, water exceeding Co concentrations of 0.005 ppm is non-potable for drinking. Out of 44 sample sources, 21 potable sources and 24 samples during Pre-Monsoon and Monsoon fall in the potable class. But, in Post-Monsoon, only 10 sources are found to be contaminated by Co. It may be due to either contamination caused by urban runoff or by forest fire practices as a result of Jhum cultivation during Pre-Monsoon.

Moderately Dissected and Less Dissected Structural Hills, the major site of practicing settlement and cultivation are characterized by nearly the same and highest value of cobalt concentration. It is followed by Intermontane Valley Unit, where settlement is still established. However, Highly Dissected terrain and Fracture Valley that are less suitable for inhabitation are characterized by zero value of average concentration.

The cobalt concentration of groundwater in the Geomorphic Units is shown below: -

Table 65: Average Cobalt in Geomorphic Units

Sl.No	**Geomorphology**	**Concentration of Cobalt (ppm) Pre-Monsoon**	**Concentration of Cobalt (ppm) Monsoon**	**Concentration of Cobalt (ppm) Post-Monsoon**	**Average**
1	Fracture Valley (FV)	0.000	0.005	0.000	0.002
2	Highly Dissected Structural Hill (SHH)	0.077	0.030	0.000	0.036
3	Inter-Montane Valley (IV)	0.000	0.020	0.005	0.008
4	Less Dissected Structural Hill (SHL)	0.026	0.009	0.004	0.013
5	Moderately Dissected Structural Hill (SHM)	0.038	0.015	0.002	0.018
	Average	0.028	0.016	0.002	

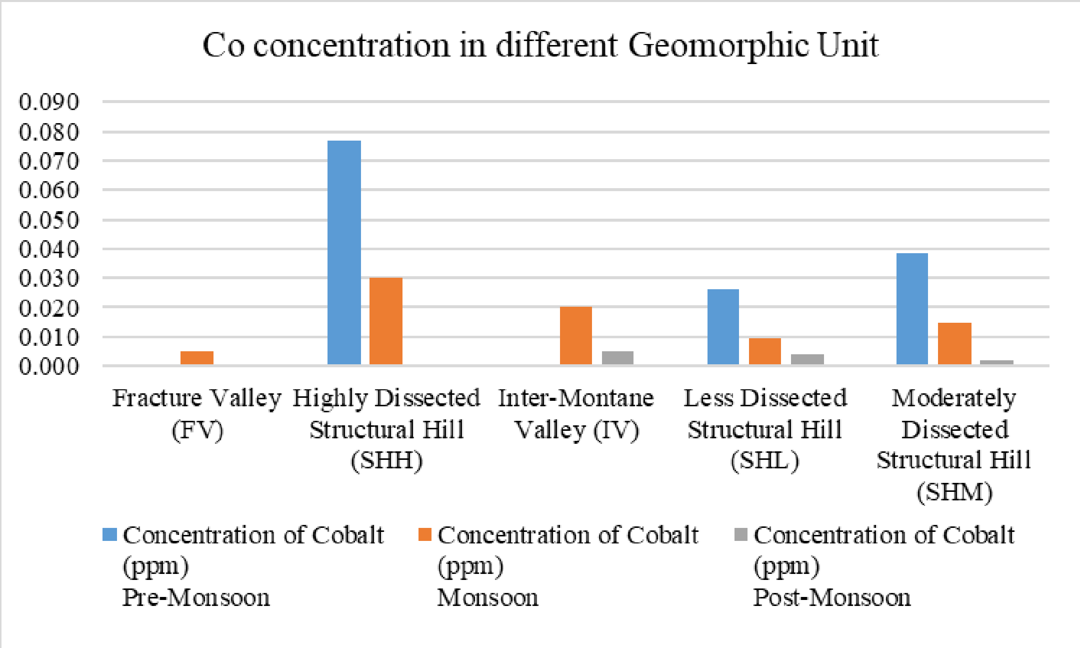

Figure 104: Bar chart of Cobalt in Geomorphic Units

In terms of Lithostratigraphy, groundwater in shale-dominated lithology where surface run-off has moved at maximum speed with little or no infiltration is characterized by the highest value of Co. It is followed by the sandstone lithology of Upper and Lower Bhuban. Unconsolidated sediments are found to have the least concentration of Co.

During Pre-Monsoon, the concentration of Co in almost every part of the study area exceeds the permissible limit of 0.005ppm. Small areas of Zanlawn, Hortoki, Lungmuat, Nisapui, and N. Chaltlang are characterized by desirable concentrations of Co. Though there is a slight reduction of Cobalt contaminated areas during Monsoon, its concentration is relatively high in the majority of the area except in small patches of Hortoki, Zanlawn, N. Chaltlang, Lungmuat, and Nisapui. During Monsoon, the Cobalt concentration became depleted in most of the area excluding the vicinity of N.Chaltlang, Bukpui, Hortoki, and a small area of Kawnpui and Lungmuat.

The cobalt concentration of groundwater in the Lithostratigraphic Units is shown below: -

Table 66: Average Cobalt in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Cobalt concentration (ppm) Pre-Monsoon	Average Cobalt concentration (ppm) Monsoon	Average Cobalt concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.037	0.01	0.005	0.017
2	Sandstone dominated (Upper Bhuban Formation)	0.035	0.014	0.002	0.017
3	Shale dominated (Middle Bhuban Formation)	0.077	0.03	0	0.036
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0.012	0.004	0.005
	Average	0.037	0.017	0.003	

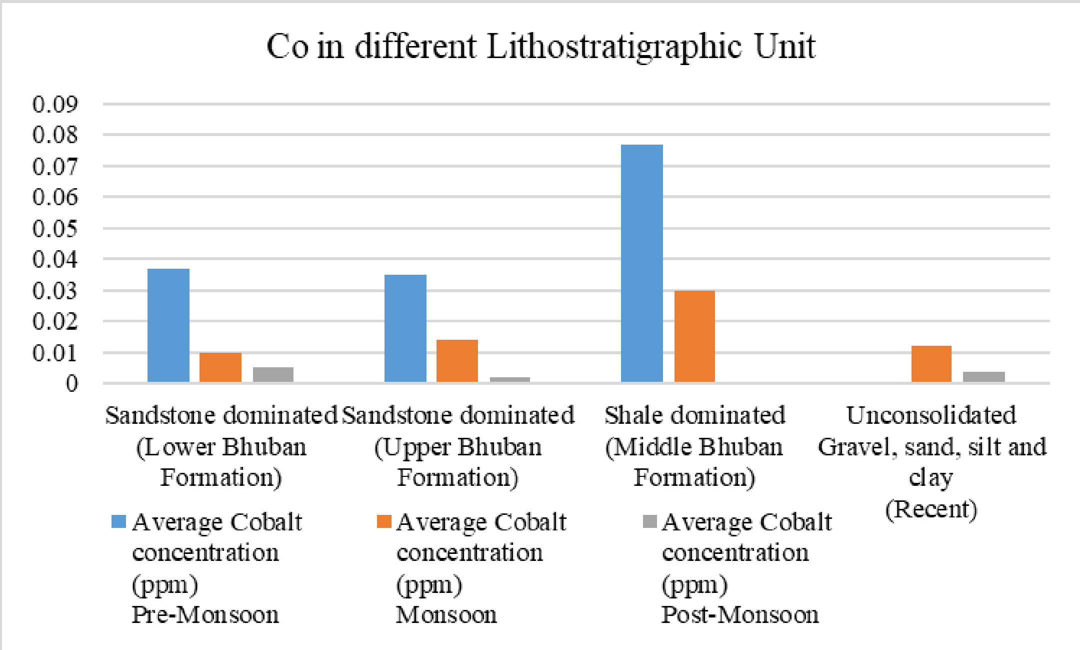

Figure 105: Bar chart of Cobalt in Lithostratigraphic Units

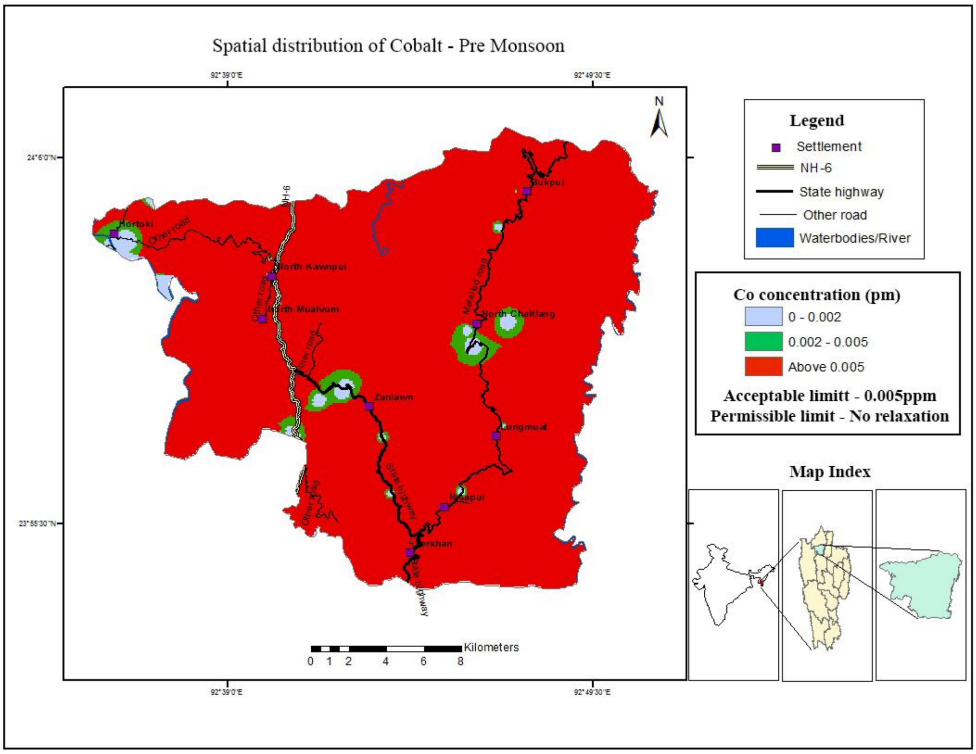

Figure 106: Spatial distribution map of Co during Pre-Monsoon

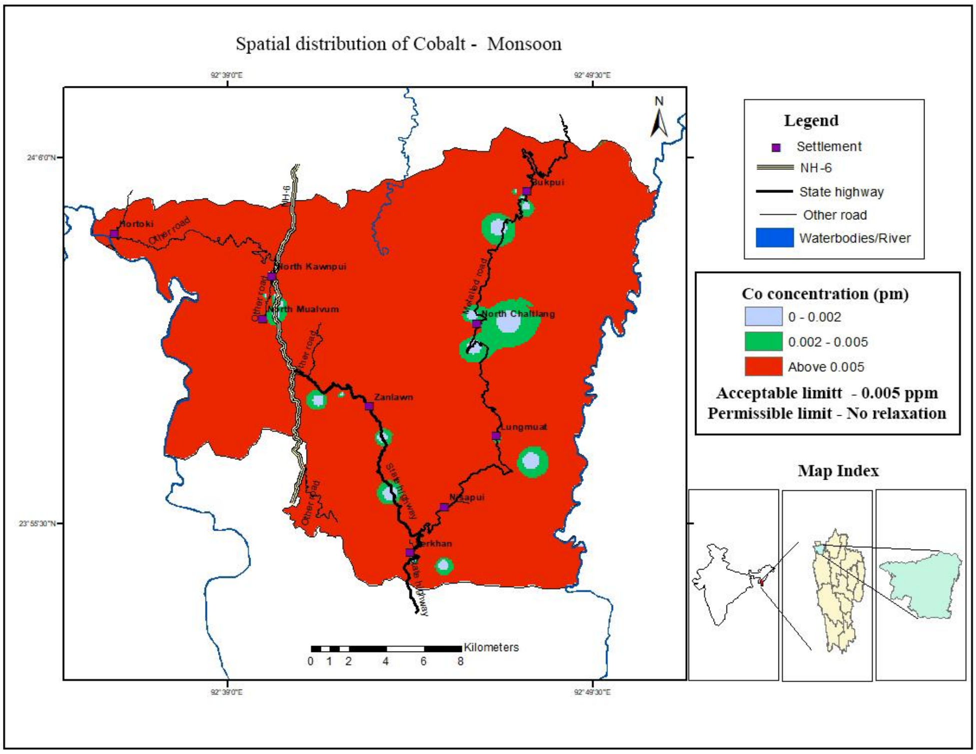

Figure 107: Spatial distribution map of Co during Monsoon

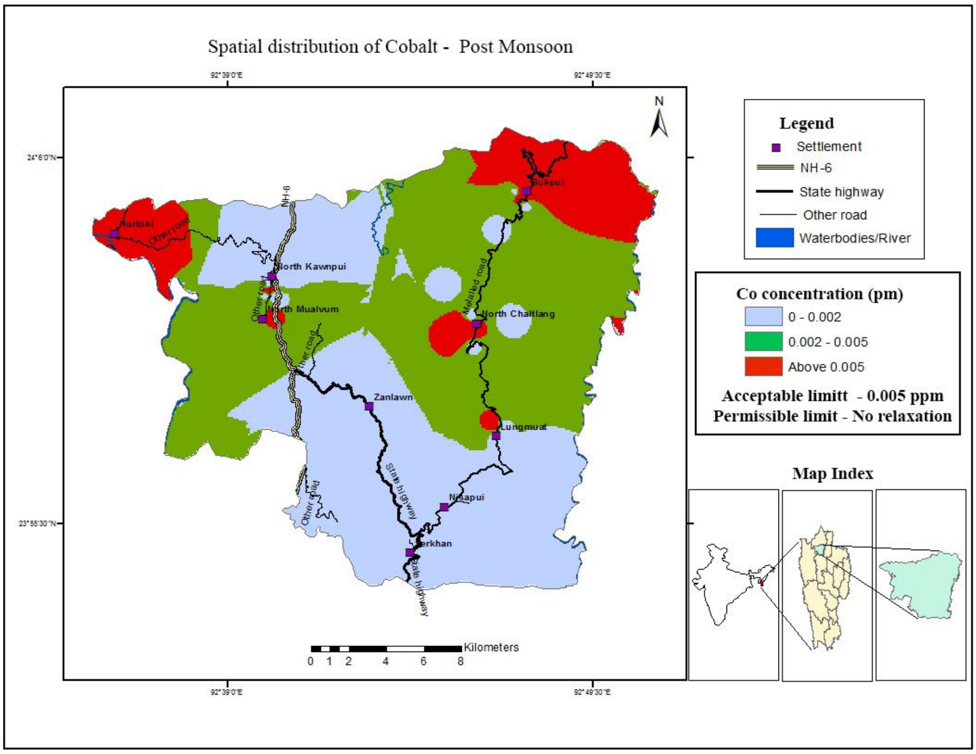

Figure 108: Spatial distribution map of Co during Pre-Monsoo

Table 67: Cobalt concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Cobalt (ppm) Pre-Monsoon 2018	Cobalt (ppm) Monsoon 2018	Cobalt (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.02	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.23	0.09	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.29	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.02	0.04	0
7	Zotui	Nisapui	23.94	92.762	0	0.02	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0	0.01	0.02
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.02	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.17	0	0.01
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.02	0.05	0.01
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.02	0.01	0.01
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.08	0.05	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0.04	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.02	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.02	0	0
26	Charpui	Kawnpui	24.05	92.674	0.03	0.04	0
27	Vailui	Kawnpui	24.034	92.668	0.02	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0.01	0
29	Sentezel	Kawnpui	24.04	92.674	0.04	0.01	0
30	Kuangsei	kawnpui	24.0376	92.672	0.03	0.04	0.01
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.02	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0.05	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.03	0	0.01
36	Tuitun	Kawnpui	23.9667	92.681	0	0.01	0
37	Khurthuk	Kawnpui	24.039	92.67	0.02	0.02	0
38	Sihpui	Kawnpui	24.036	92.669	0.3	0.02	0.01
39	Lungpher	Hortoki	24.06	92.602	0	0.01	0.01
40	Khawzasiaka	Hortoki	24.056	92.596	0	0.04	0.01
41	Zotui	Lungmuat	23.972	92.778	0.03	0.05	0.01
42	Luihnai	Lungmuat	23.966	92.779	0.03	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.02	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0.01	0

5.23 Strontium (Sr):

Strontium is found as a trace element in the lithosphere and is widely associated with Calcium in the rocks. Therefore, occurs naturally in some minerals like calcium carbonate, and the most common mineral is Celestite ($SrSO_4$). Celestite is also present in the shells of certain marine organisms. The upper zone of Carbonate rock, which are in contact with Gypsum, have typically enriched with Celestite. If such strontium-containing minerals are present in soils and rocks, strontium is released to groundwater as those minerals dissolve. During weathering, Sr is dissolved and transported typically as Bicarbonate, and sometimes as sulphate and chloride (Horr, 1946). Natural Strontium is not toxic to human health, but artificially produced radioactive isotopes are highly toxic. Elevated strontium concentrations can adversely affect bone development and mineralization. A maximum acceptable concentration (MAC) of 7.0 mg/L is proposed for strontium in drinking water, based on bone effects in rats and using currently available scientific studies and approaches.

There is no specification for Sr concentration by BIS. However, a maximum acceptable concentration of 7ppm is proposed for drinking water in a country like Canada. Sr concentration is highest in Less Dissected Structural Hill, followed by Moderately Dissected Structural Hill. Highly Dissected Structural Hill and Intermontane Valley have more or less the same value of 0.016ppm and 0.013ppm respectively. However, its average concentration in Fracture Valley remains insignificant amount in every season.

The concentration of Strontium in different Geomorphic Units is shown below:-

Table 68: Average Strontium in Geomorphic Units

Sl.No	Geomorphology	Concentration of Strontium (ppm) Pre-Monsoon	Concentration of Strontium (ppm) Monsoon	Concentration of Strontium (ppm) Post-Monsoon	Average
1	Fracture Valley (FV)	0.000	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.007	0.040	0.000	0.016
3	Inter-Montane Valley (IV)	0.000	0.000	0.040	0.013
4	Less Dissected Structural Hill (SHL)	0.177	0.164	1.538	0.626
5	Moderately Dissected Structural Hill (SHM)	0.005	0.187	0.109	0.100
	Average	0.038	0.078	0.337	

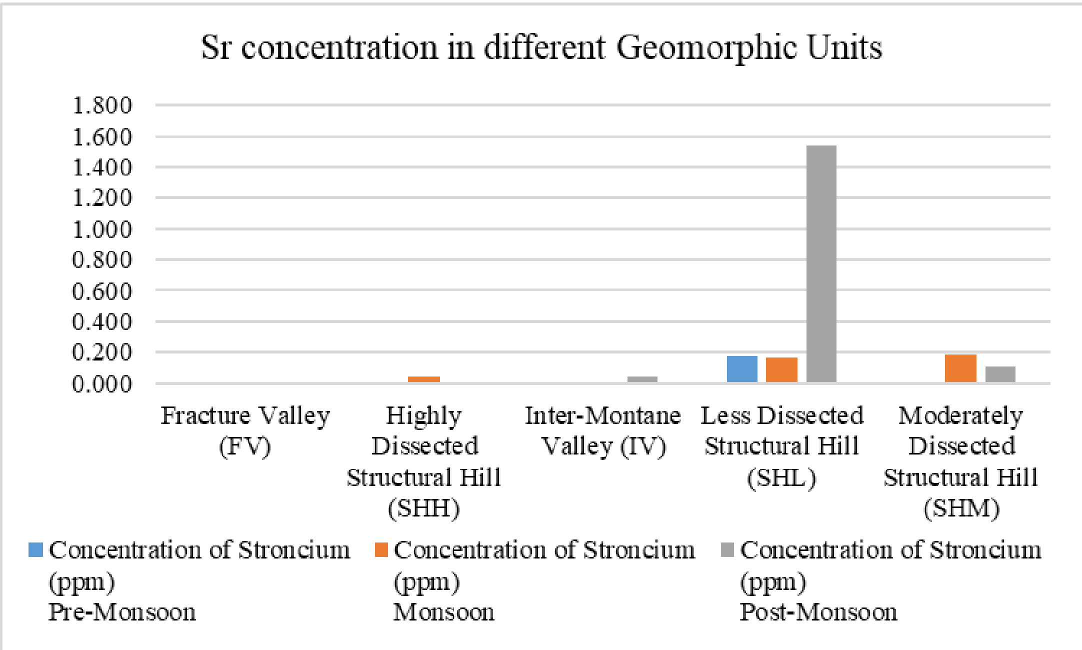

Figure 109: Bar chart of Strontium in Geomorphic Units

In terms of the Lithostratigraphic Unit, it is highest in the Sandstone of the Upper Bhuban Formation and followed by the shale-dominated Middle Bhuban Formation. Unconsolidated sediments and Lower Bhuban Formation has the lowest concentration of Strontium.

Seasonal-wise, the concentration of Sr is highest during Pre-Monsoon in comparison to Monsoon and Post-monsoon. It reflects that Sr in the aquifer is highly diluted and carried away by overland flow during the rainy season.

During Pre-Monsoon, Sr concentration in groundwater is highest in the vicinity of Kawnpui, Zanlawn, and Lungmuat. The remaining portion has less than 0.02ppm of Sr. The concentration of Sr in different Lithostratigraphic Units is shown below: -

Table 69: Average Strontium in Lithostratigraphic Units

Sl.No	**Lithostratigraphic Unit**	**Average Strontium concentration (ppm) Pre-Monsoon**	**Average Strontium concentration (ppm) Monsoon**	**Average Strontium concentration (ppm) Post-Monsoon**	**Average**
1	Sandstone dominated (Lower Bhuban Formation)	0.005	0.000	0.005	0.003
2	Sandstone dominated (Upper Bhuban Formation)	0.065	0.011	0.013	0.030
3	Shale dominated (Middle Bhuban Formation)	0.010	0.017	0.000	0.009
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0.000	0.004	0.006	0.003
	Average	0.020	0	0.006	

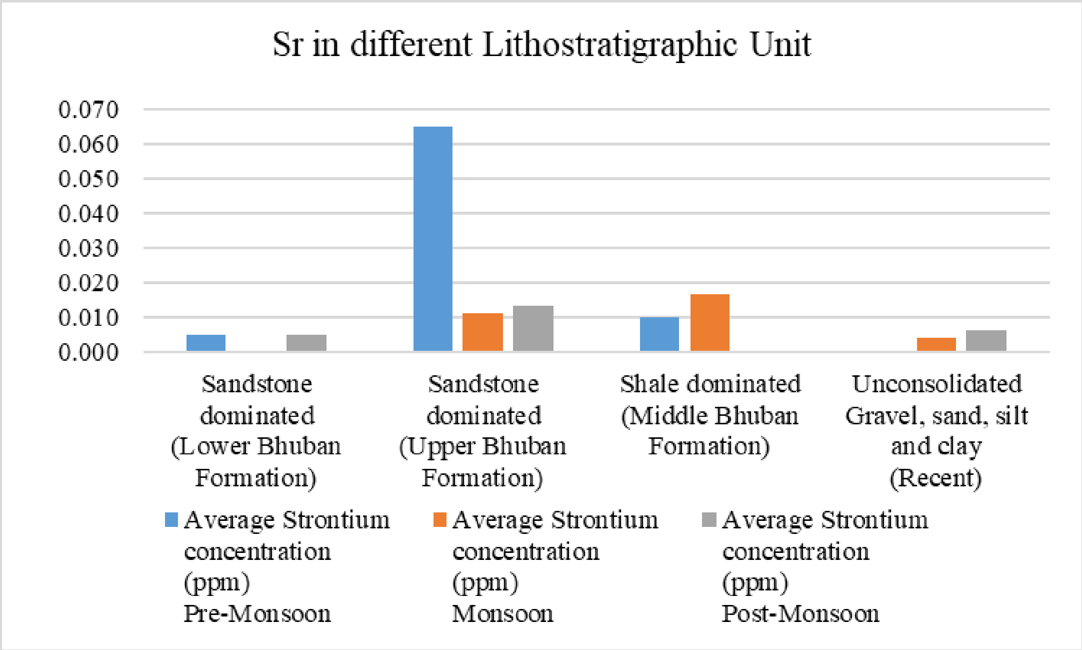

Figure 110: Bar chart of Strontium in Lithostratigraphic Units

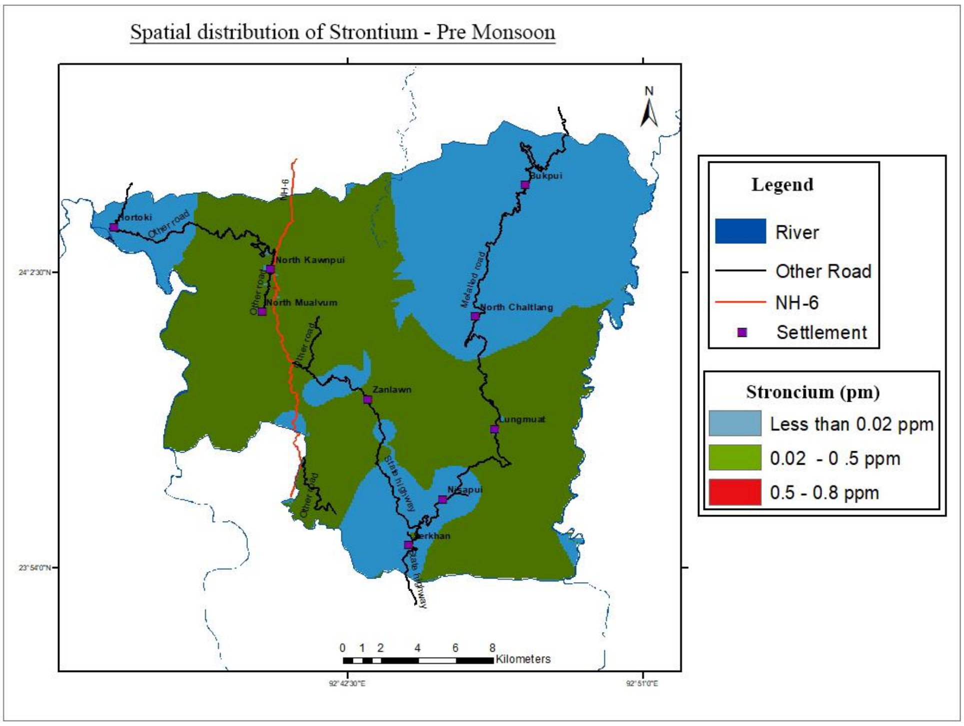

Figure 111: Spatial distribution map of Sr during Pre-Monsoon

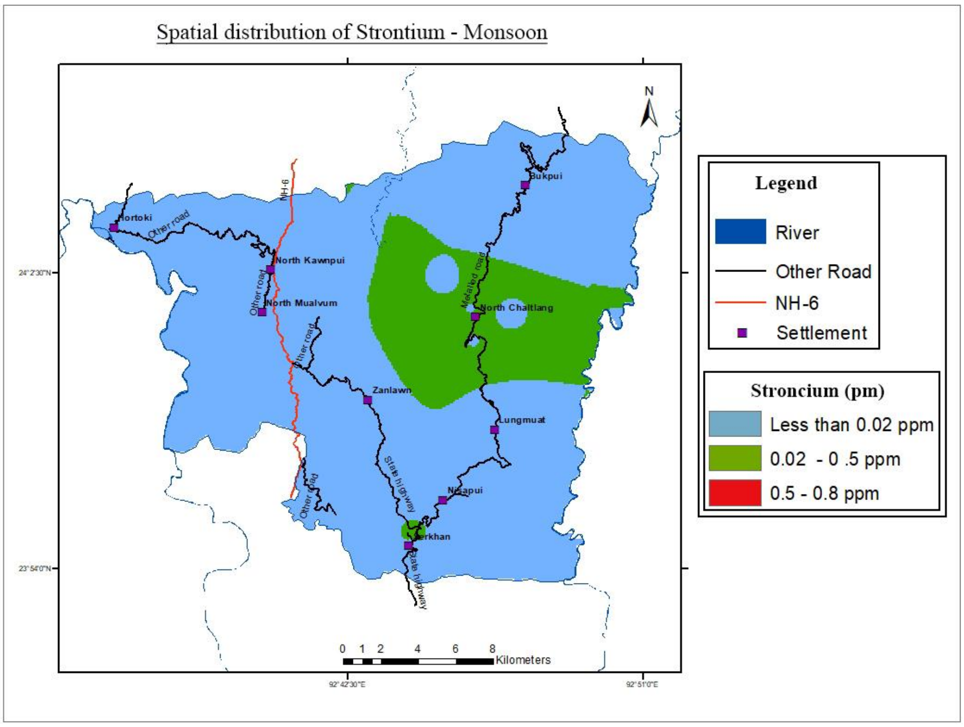

Figure 112: Spatial distribution map of Sr during Monsoon

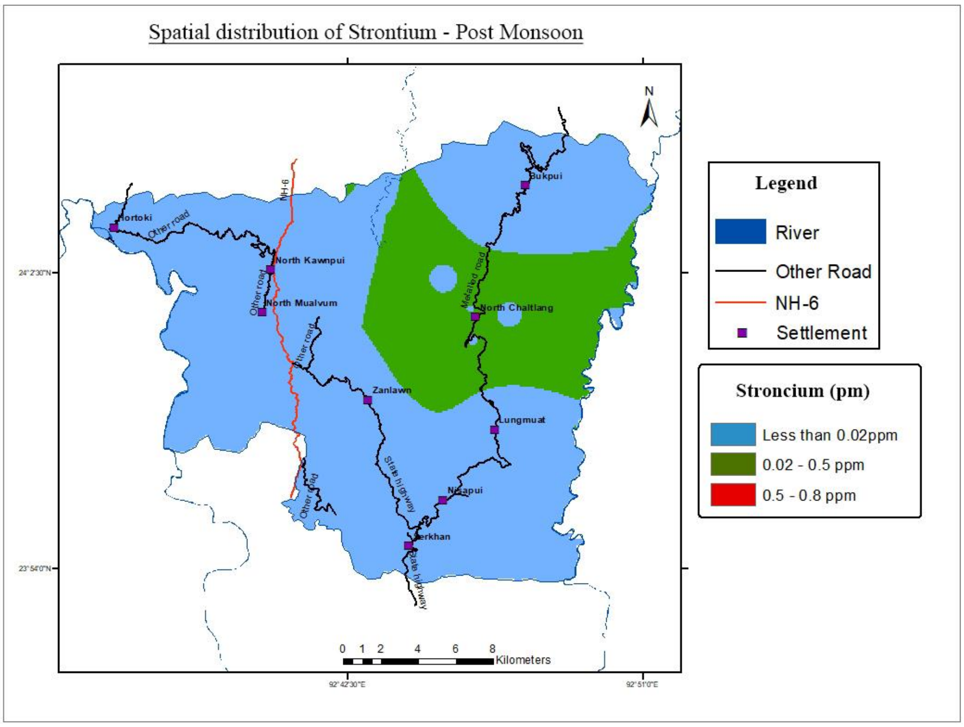

Figure 113: Spatial distribution map of Sr during Post-Monsoo

Table 70: Strontium concentration in Pre-Monsoon, Monsoon and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Strontium (ppm) Pre-Monsoon 2018	Strontium (ppm) Monsoon 2018	Strontium (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.04	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.03	0.05	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.02	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0	0
7	Zotui	Nisapui	23.94	92.762	0	0.02	0
8	Lalkima Point handpump	North Chaltlang	24.018	92.765	0.01	0.28	0.35
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.01	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.01	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0	0.02
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	0	0	0.01
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0.01	0
21	Fului	Zanlawn	23.97	92.711	0.18	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.8	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.07	0	0
26	Charpui	Kawnpui	24.05	92.674	0.12	0	0
27	Vailui	Kawnpui	24.034	92.668	0.04	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.01	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.1	0	0.02
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.02	0.01	0.01
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.15	0	0.01
36	Tuitun	Kawnpui	23.9667	92.681	0	0.01	0
37	Khurthuk	Kawnpui	24.039	92.67	0.04	0.01	0
38	Sihpui	Kawnpui	24.036	92.669	0	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0.01	0.01
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0.02
41	Zotui	Lungmuat	23.972	92.778	0.29	0	0.01
42	Luihnai	Lungmuat	23.966	92.779	0	0.01	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.04	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.24 Indium (In):

Indium occur as trace constituents in natural groundwater, Indium has an average crustal abundance of about 49 ppb and are of very low abundance metal in the earth crust. Indium is primarily produced as a by-product from zinc ore mineral Sphalerite. Soluble Indium is used effectively as tracers for surface and ground water movement (Chrysikopoulos, 1987). Indium arsenide (InAs) is widely used semiconductor materials and it becomes an emerging form of environmental pollution (Cheah, 2022). Ga and In ion in water can cause immune system disease and reduced blood leukocyte count. The concentration of Indium in different Geomorphic Units is: -

Table 71: Average Indium in Geomorphic Units

Sl.No	Geomorphology	Concentration of Indium (ppm) Pre-Monsoon	Concentration of Indium (ppm) Monsoon	Concentration of Indium (ppm) Post-Monsoon
1	Fracture Valley (FV)	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.003	0.000	0.000
3	Inter-Montane Valley (IV)	0.005	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.006	0.000	0.000
5	Moderately Dissected Structural Hill (SHM)	0.005	0.000	0.000

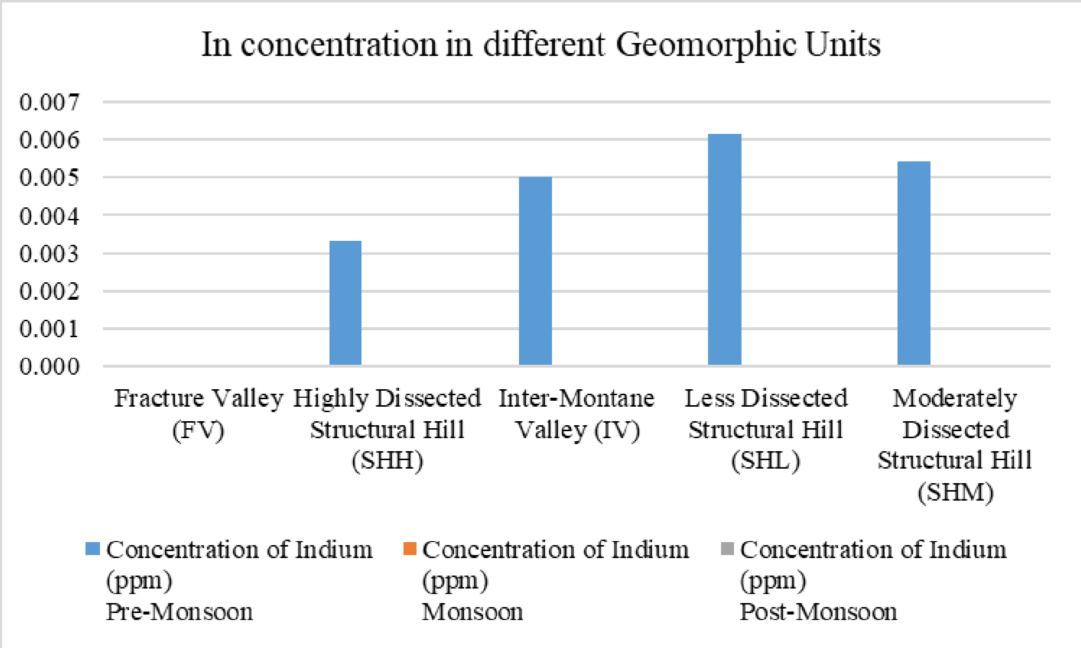

Figure 114: Bar chart of Indium in Geomorphic Units

When comparing Indium concentration of ground water in each Geomorphic Unit, all Geomorphic Unit except Fracture valley are characterized by almost equivalent value of Indium. However, average concentration in Fracture Valley is remain zero in each season indicating ground water of deep aquifer has low or negligible concentration of In. This shows that the contamination of sources could probably from shallow surface like anthropogenic activities. Concentration of Indium is detectable only in samples from Pre-Monsoon season, indicating they are readily carried away by runoff and hence depleted by rainwater.

In terms of Lithological Unit, Indium concentration in ground water is uniformly distributed in each unit indicating that there is little or no influence of lithology. Its concentration is gradually decline from Pre-Monsoon and became imperceptible in Post-Monsoon samples.

Western part of Kawnpui and northern part of Bukpui village have shown higher concentration of Indium. The outer edge of these region and the vicinity of Serkhan have moderate concentration. The middle portion of the area and small spot in Hortoki has shown least value. The concentration of Lithium in different Lithostratigraphic Units is shown below:-

Table 72: Average Indium in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Indium concentration (ppm) Pre-Monsoon	Average Indium concentration (ppm) Monsoon	Average Indium concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.00667	0	0	0.0022
2	Sandstone dominated (Upper Bhuban Formation)	0.004	0.003	0	0.0023
3	Shale dominated (Middle Bhuban Formation)	0.00333	0.003	0	0.0021
4	Unconsolidated Gravel, sand, silt and clay (Recent)	0	0.006	0	0.0020
	Average	0.0035	0.0030	0.0000	

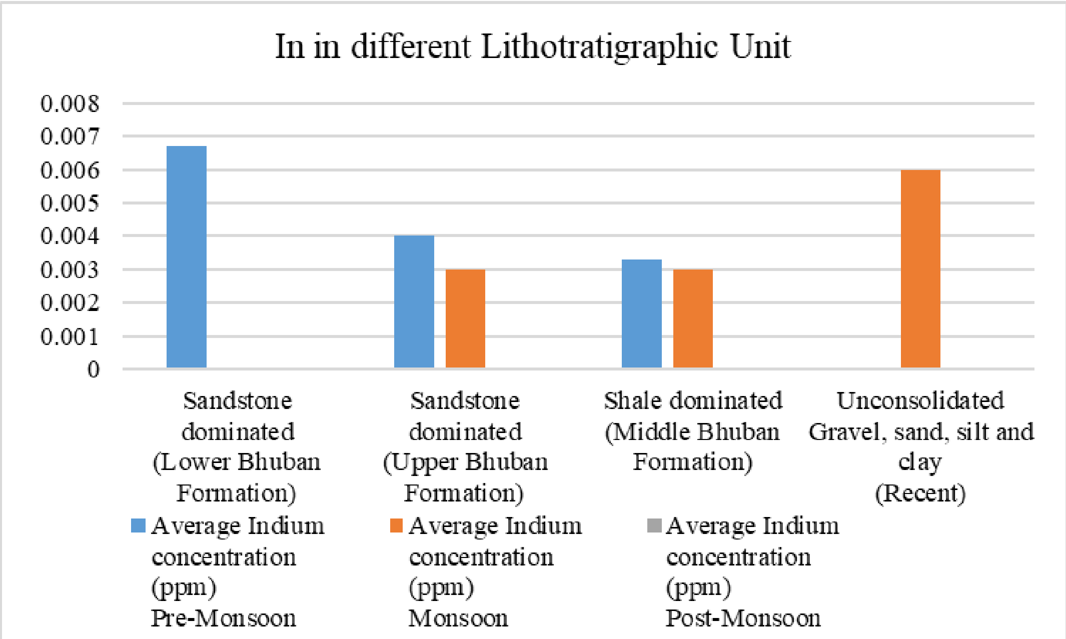

Figure 115: Bar chart of Indium in Lithostratigraphic Units

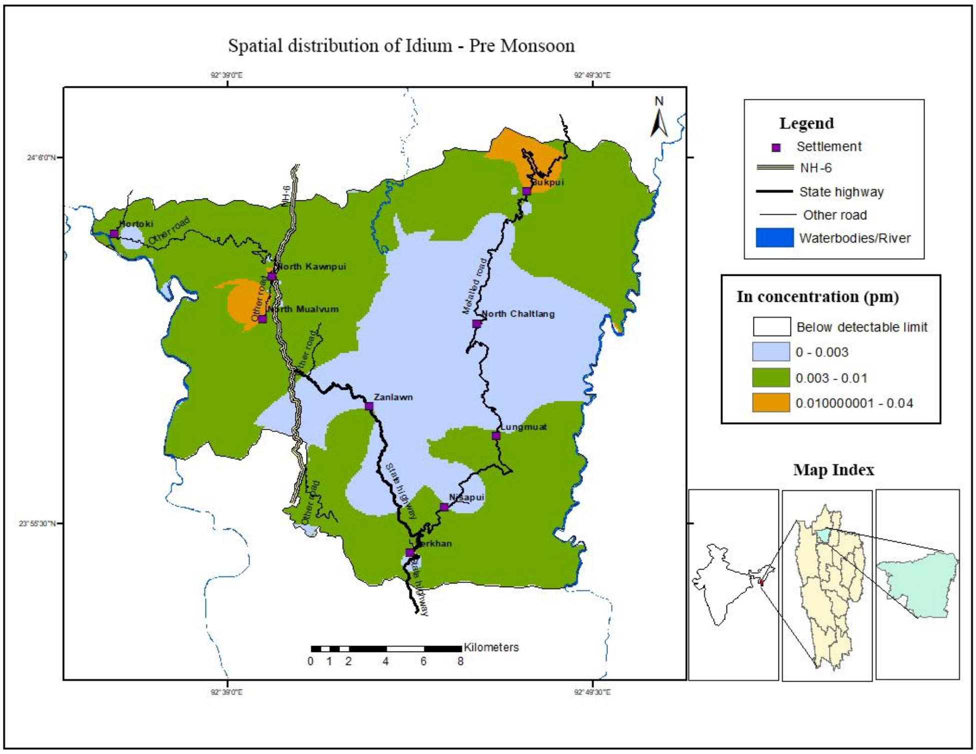

Figure 116: Spatial distribution map of In during Pre-Monsoon

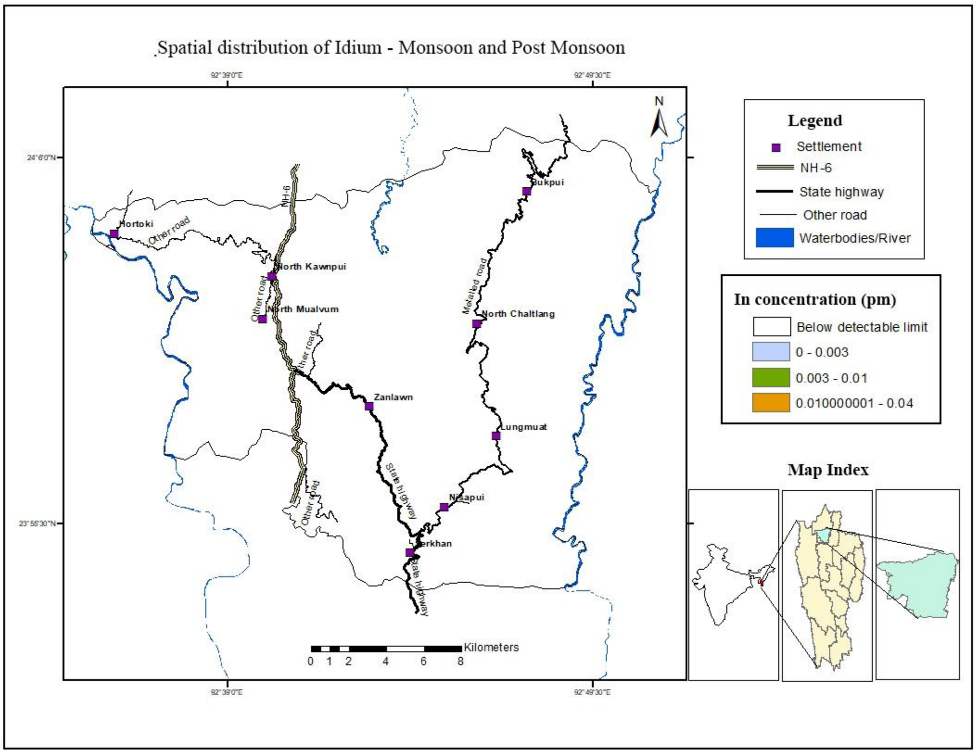

Figure 117: Spatial distribution map of In during Monsoon and Post-Monsoon

Table 73: Concentration of Indium in Pre-Monsoon, Monsoon and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Indium (ppm) Pre-Monsoon 2018	Indium (ppm) Monsoon 2018	Indium (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.01	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.01	0	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.01	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point handpump	North Chaltlang	24.018	92.765	0	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.01	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0	0
16	Sub-Station Peng handpump	Bukpui	24.088	92.795	0.02	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.01	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.01	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0.01	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0	0
27	Vailui	Kawnpui	24.034	92.668	0.04	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.01	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.02	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.01	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0.01	0	0
38	Sihpui	Kawnpui	24.036	92.669	0	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0.01	0	0
41	Zotui	Lungmuat	23.972	92.778	0	0	0
42	Luihnai	Lungmuat	23.966	92.779	0.01	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.25 Lithium (Li):

Lithium is an alkali metal that occurs naturally in some groundwater as minor constituents (0.0001 to 0.1 ppm) where groundwater interacts with lithium-containing minerals or saline water (Todd, 1980). Groundwaters in sedimentary basins have been recognized for carrying appreciable amounts of Lithium metals in their dissolved load. Peralkaline and peraluminous pegmatite, hectorite clay from volcanic and salar and evaporites deposits are the three broad types of economic Li deposits. However, it is able to extract only from spodumene, lepidolite, petalite, amblygonite and eucriptite (Peiro *etal.,* 2013).

In small quantities, it is also widespread in clay minerals as impurities, inclusions, in lattice cavities, adsorbed on the surface, or by isomorphous substitution. Isomorphous substitution is the most common occurrence. The largest amount of lithium is contained by clay mineral of swinefordite, Hectorite, a trioctahedral smectite, kaolinite can contain a large amount of lithium. It is also generally distributed in micas and the degradation of the micas by weathering, causes transformation of mica-like illite to mixed-layer clays and then to smectites. During this transformation, mica is considered as Li carrier minerals in clay mixtures. However, the lithium is not shift to the montmorillonites during this transformation because of its highly mobile nature. During such processes, it is shortly weathered out of the mica and either remains in ground water or carried off in streams or remains to be integrated into the structure of newly formed clay minerals. The water carried off by streams will eventually reach the oceans or it may accumulate in closed basins (Starkey 1982).

Brines, which are accumulations of saline groundwater that occur in continental sedimentary basin are common source of dissolved trace metals, including Li. A systematic analysis of lithium concentration in about 3000 samples of groundwater from 48 sedimentary basins worldwide indicates the highest lithium concentrations of > 102mg/ l are primarily found in high salinity waters at Total Dissolved Solids >105mg/ l and are in the same range as brines from the most productive salars (Dugamin, 2021). Lithium concentrations show a positive correlation with Salinity and Total Dissolved Solids values. Therefore, Saline springs in Mizoram are also assumed to have higher Li concentration in compare to freshwater spring. Prior studies in sedimentary basin reveal that Li concentration is higher in deeper horizon. Lithium sources in the Cambro-Ordovician freshwater aquifer of Manitoba USA are found to be deposited from weathering of Pegmatite and Carbonate rock (Nicolas, 2017). Li is particularly use in batteries of hybrid cars and portable electronic devices. Multiple studies indicate natural sources for the lithium concentrations; however, anthropogenic sources play an important role because of the rapid increase of lithium battery use and their subsequent disposal. Geochemical models show that extensive evaporation, mineral dissolution, an exchange of cations, and mixing with geothermal waters or brines justify the observed lithium and associated constituent concentrations in ground water, with the latter two processes being as major contributing factors.

In India, there is no standardization of Lithium concentration in ground water by BIS. However, The United States Geological Survey (USGS), in collaboration with the United States Environmental Protection Agency (EPA), calculated a non-regulatory Health-Based Screening Level (HBSL) for drinking water of 10 micrograms per litre (µg/L) or 0.01 ppm to provide factor for assessing lithium concentrations in groundwater (Lindsey, 2021). Li concentrations that exceed 0.01 are observed from Dengalui and Vautangbawk springs water at Serkhan, Vengsang erlectric groundwater pump at Bukpui, Fului stream water at Zanlawn and Lungpher stream at Hortoki. Samples taken during Monsoon and Post-Monsoon are having Li concentration below detectable limit indicating that Li are competely depleted by rainwater.

In term of Geomorphology, highest Li value is found in Highly Dissected Structural Hill, which undergone enormous cut up and break down by exogenous forces are characterized by extensive weathering and ultimately micas and clay minerals in these terrain acts as Li sources. Being having highest terrain in the area, as the dissolved Li are transported down the hill they are found to be continuously depleted and finally its average value become zero in Fracture and Intermontane Valley. The concentration of Lithium in different Geomorphic Units are shown in the following table: -

Table 74: Average Lithium in Geomorphic Units

Sl.No	Geomorphology	Concentration of Lithium (ppm) Pre-Monsoon	Concentration of Lithium (ppm) Monsoon	Concentration of Lithium (ppm) Post-Monsoon
1	Fracture Valley (FV)	0.000	0.000	0.000
2	Highly Dissected Structural Hill (SHH)	0.013	0.000	0.000
3	Inter-Montane Valley (IV)	0.000	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.005	0.000	0.000
5	Moderately Dissected Structural Hill (SHM)	0.006	0.000	0.000

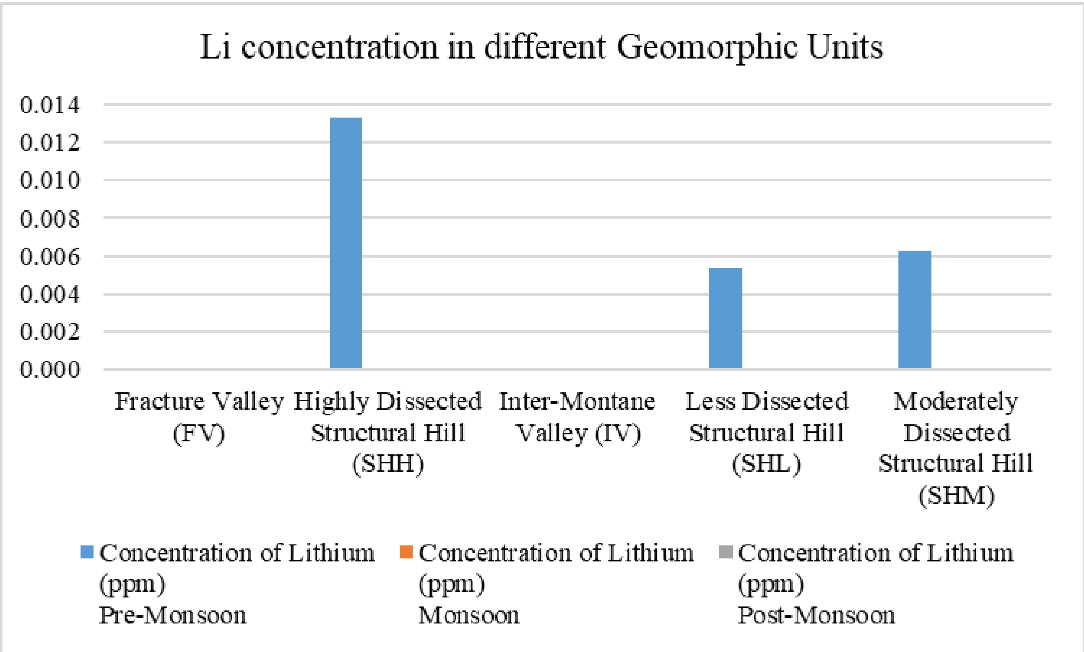

Figure 118: Bar chart of Lithium in Geomorphic Units

In terms of the Lithostratigraphic unit, its concentration is twice higher in the shale-dominated lithology of the Middle Formation as compared to that of sandstone dominated Formation of Upper Bhuban. However, the Sandstone of the Lower Bhuban Formation has nearly the same concentration as Shale-dominated Middle Bhuban Formation, it may be due to either this Formation being related to Li-rich Igneous rocks or salar deposits that make the spring higher in TDS and ultimately elevated Li concentration.

A detectable amount of Li is observed only from samples of Pre-Monsoon, the vicinity around Serkhan and Bukpui, and a small portion of the western part of Zanlawn and Kawnpui have Li concentrations above 0.01 ppm. The outer edge region of the above area shows concentrations ranging between 0.005 and 0.01 ppm. The remaining portion has a value of less than 0.005 ppm.

The average concentration of Lithium in groundwater of different Lithostratigraphic Units are: -

Table 85: Average Lithium in Lithostratigraphic Units

Sl.No	**Lithostratigraphic Unit**	**Average Lithium concentration (ppm) Pre-Monsoon**	**Average Lithium concentration (ppm) Monsoon**	**Average Lithium concentration (ppm) Post-Monsoon**	**Average**
1	Sandstone dominated (Lower Bhuban Formation)	0.01	0	0	0.003
2	Sandstone dominated (Upper Bhuban Formation)	0.006	0	0	0.002
3	Shale dominated (Middle Bhuban Formation)	0.013	0	0	0.004
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0.013	0	0	0.004
	Average	0.0105	0	0	

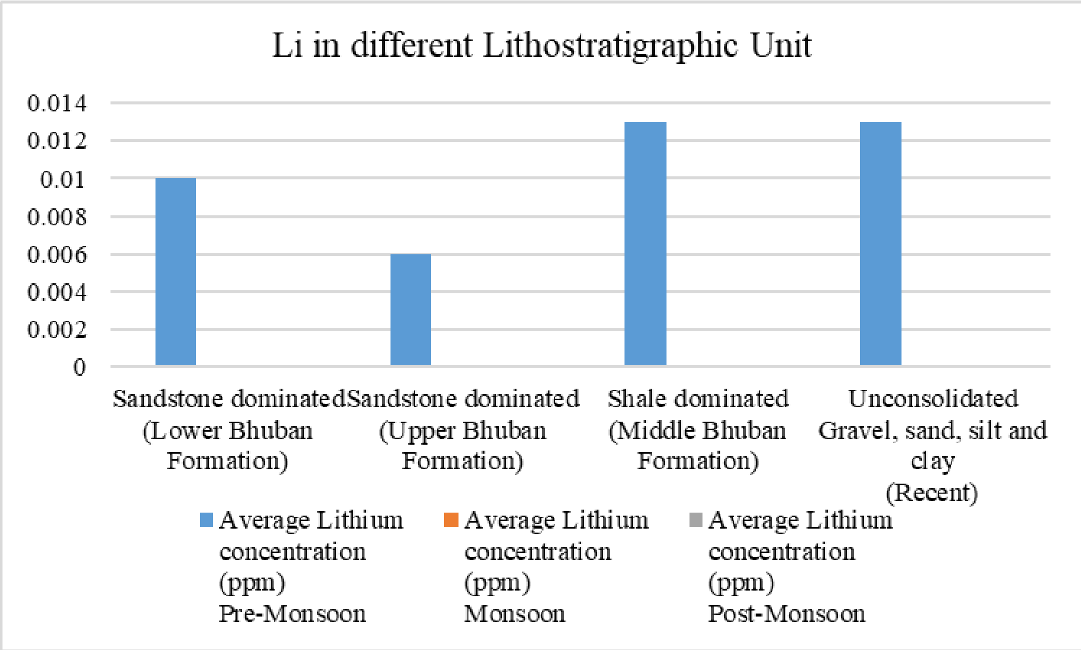

Figure 119: Bar chart of Lithium in Lithostratigraphic Units

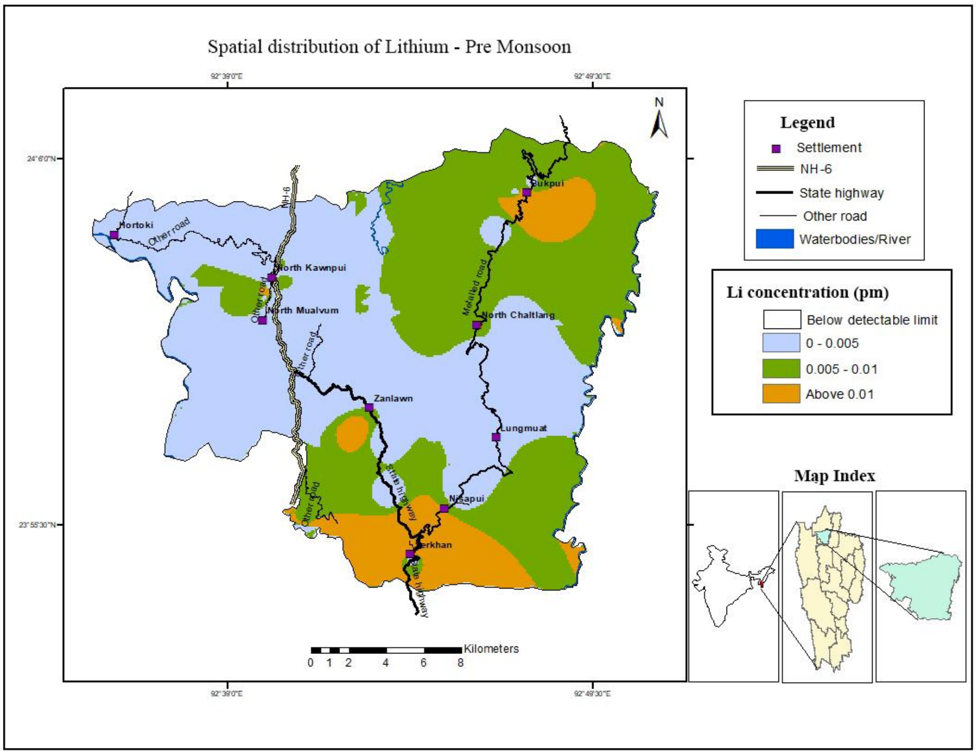

Figure 120: Spatial distribution map of Li during Pre-Monsoon

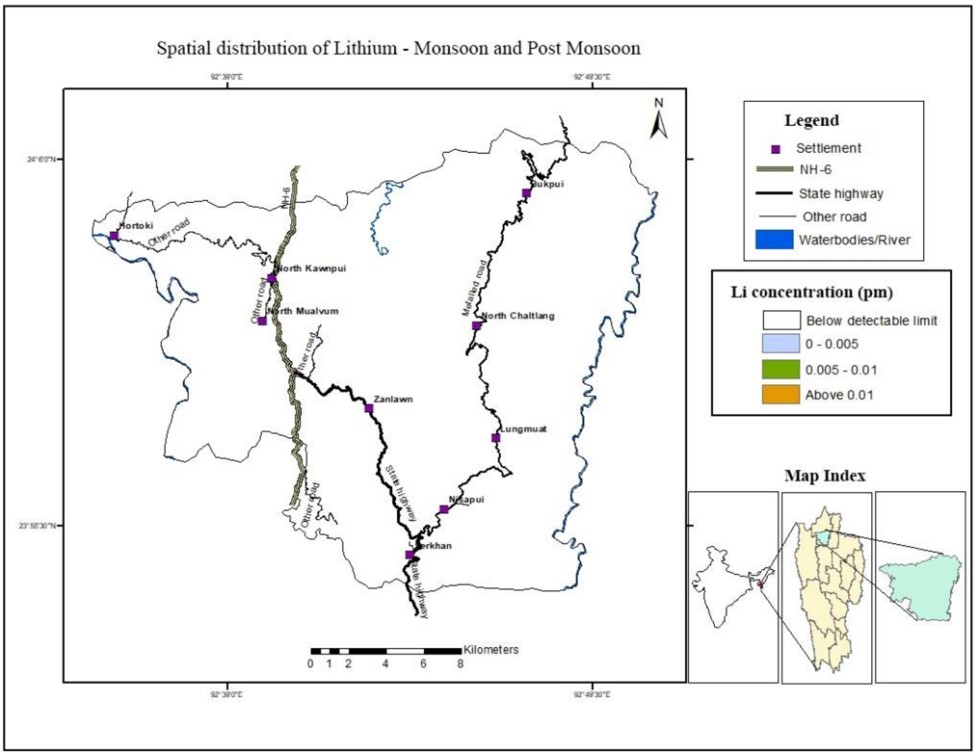

Figure 121: Spatial distribution map of Li during Monsoon and Post-Monsoon

Table 76: Concentration of Lithium in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Lithium (ppm) Pre-Monsoon 2018	Lithium (ppm) Monsoon 2018	Lithium (ppm) Post-Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0.01	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.04	0	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.04	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0.01	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.01	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.04	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.02	0	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0	0
27	Vailui	Kawnpui	24.034	92.668	0	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.01	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0	0	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0	0
37	Khurthuk	Kawnpui	24.039	92.67	0	0	0
38	Sihpui	Kawnpui	24.036	92.669	0.04	0	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0	0
41	Zotui	Lungmuat	23.972	92.778	0	0	0
42	Luihnai	Lungmuat	23.966	92.779	0	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0.01	0	0
44	Vengchung	Lungmuat	23.9714	92.782	0	0	0

5.26 Gallium (Ga):

It is generally found in association with zinc, germanium, and aluminum. It is also found primarily in germanite minerals (Gad, 2014). Gallium alloy is used as Mercury-free dental amalgam. It is widely used in the technology Industry. Like Indium, with the increasing use of Gallium arsenide (GaAs) as semiconductor materials, and became an emerging form of environmental pollution. Because of its relatively low volume, Ga is not recycled from electronic devices (Korla *et al.*, 2020). In an aqueous solution Ga, In, and As occur as organic ions. As mentioned before, Ga and In ions in water are known to cause immune system disease and reduced blood leukocyte count. Ga and its associated wastes may pollute air and water (Chen, 2006).

From previous research work, it was summarized that the solubility of solid gallium (as GaO(OH)) is highest (approximately 10^{-6} M) at pH 7.4 and 25 °C and is lowest ($10^{-7.2}$ M) at pH 5.2. Both high and low pH values increase the solubility of gallium. At pH 2, the solubility is 10^{-2} M, and at pH 10 it is $10^{-3.3}$ M. The dissolved gallium mostly exists as $Ga(OH)_4$ or $Ga(OH)_3$ (Yu, 2014). Since gallium is geologically widely dispersed and its solubility is low, the background concentration of gallium in the aquatic environment is low. The average concentrations of gallium are 0.03 ppb in seawater, 0.15 ppb in stream water, and lower than 1 ppb in groundwater. The chemical solubility of pure solid Ga in the aqueous solution is strongly affected by the presence of Cl^- ions in a solution (Horasawa *et al.*, 1997). Gallium concentration and its effect on the quality of air and water are not yet standardized at present.

When comparing relations between pH and Ga dissolving rate; out of 19 total samples where Ga presence was found, 8 samples were characterized by pH values ranging from 6.23 to 6.93 during Pre- Monsoon, and the remaining 11 samples were having pH 7.05 to 7.65., which is coinciding with the previous study that states that the nature of solubility of Ga is highest at around pH 7.4? During Monsoon, out of 12 samples where Ga concentration was encountered, 7 samples were found to have pH value ranging between 6.42 to 6.92, and 5 samples were characterized by pH value of 5.52 to 5.56 indicating solubility is much more prevalent at pH value around 6.42 to 6.92.

When referring to the Ga concentration of groundwater indifferent Geomorphic unit, sources in Moderately Dissected Structural Hills have a slightly higher value to sources in Fracture Valley, Highly Dissected, and Less Dissected Structural Hill. Groundwater in Intermontane Valley has a negligible amount of Ga concentration. The highest value of Ga in Moderately Dissected Structural Hill may be probably due to the prevalence of settlement in this unit, which causes the sources to be more contaminated from anthropogenic waste disposal. The pollution of groundwater is maximum during Monsoon when there is excess runoff. The concentration of Gallium in different Geomorphic Units is shown below: -

Table 77: Average Gallium Concentration in Geomorphic Units

Sl.No	**Geomorphology**	**Concentration of Gallium (ppm) Pre-Monsoon**	**Concentration of Gallium (ppm) Monsoon**	**Concentration of Gallium (ppm) Post-Monsoon**	**Average**
1	Fracture Valley (FV)	0.000	0.005	0.000	0.002
2	Highly Dissected Structural Hill (SHH)	0.003	0.003	0.000	0.002
3	Inter-Montane Valley (IV)	0.000	0.000	0.000	0.000
4	Less Dissected Structural Hill (SHL)	0.004	0.002	0.000	0.002
5	Moderately Dissected Structural Hill (SHM)	0.004	0.004	0.000	0.003
	Average	0.002	0.003	0.000	

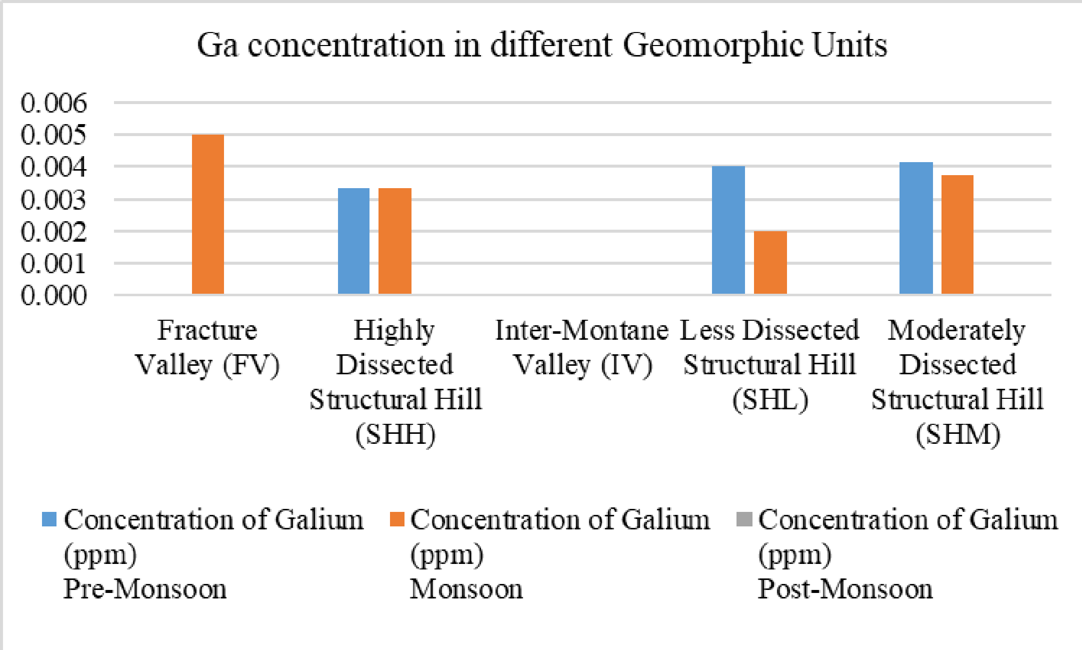

Figure 122: Bar chart of Gallium in Geomorphic Units

In terms of the Lithostratigraphic Unit, all lithological formation is characterized by the same value of concentration indicating there is not much lithological control in the composition of groundwater in the study area.

During Pre-Monsoon, Gallium concentration in groundwater is highest in the vicinity of Kawnpui, Bukpui, and small patches of Zanlawn and Serkhan. The outer rim of this area has moderate concentration and the residual portion such as Lungmuat, Nisapui, Hortoki, and the eastern part of Nisapui and Zanlawn show the lowest value of Gallium. During the Monsoon, samples from Hortoki, Zanlawn, the northern part of Kawnpui, a small area on the western part of Bukpui, and Lungmuat have shown the maximum concentration of Gallium.

The concentration of Gallium in different Lithostratigraphic Units is shown below:-

Table 78: Average Gallium concentration in Lithostratigraphic Units

Sl.No	Lithostratigraphic Unit	Average Gallium concentration (ppm) Pre-Monsoon	Average Gallium concentration (ppm) Monsoon	Average Gallium concentration (ppm) Post-Monsoon	Average
1	Sandstone dominated (Lower Bhuban Formation)	0.00667	0	0	0.002
2	Sandstone dominated (Upper Bhuban Formation)	0.004	0.0033	0	0.002
3	Shale dominated (Middle Bhuban Formation)	0.00333	0.0033	0	0.002
4	Unconsolidated Gravel, sand, silt, and clay (Recent)	0	0.006	0	0.002
	Average	0.0035	0.0032	0.0000	

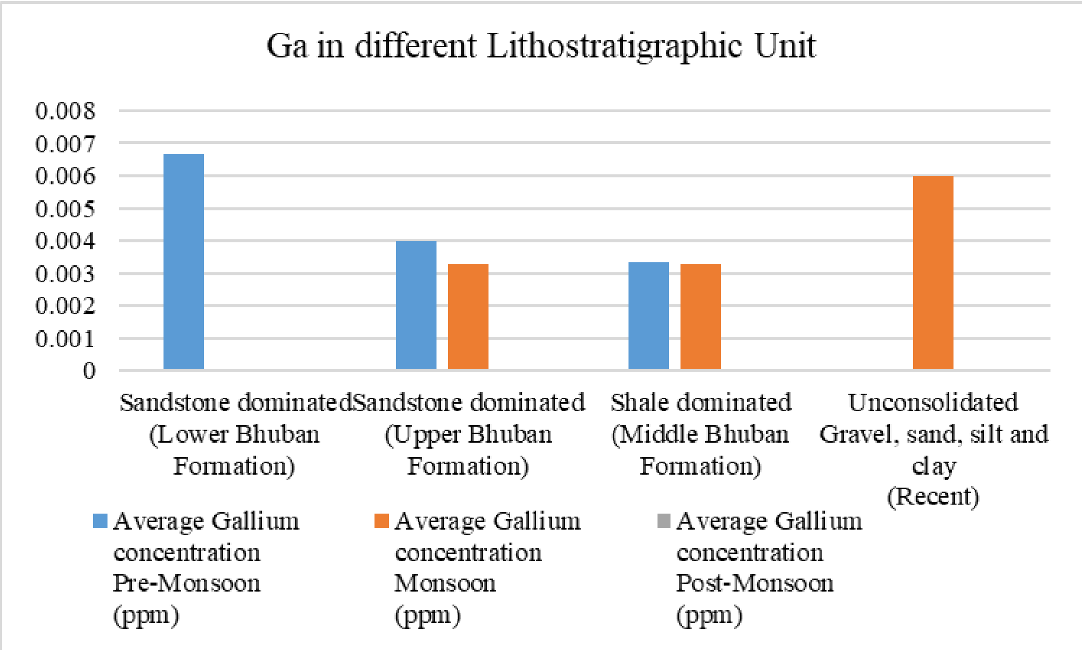

Figure 123: Bar chart of Gallium in Lithostratigraphic Units

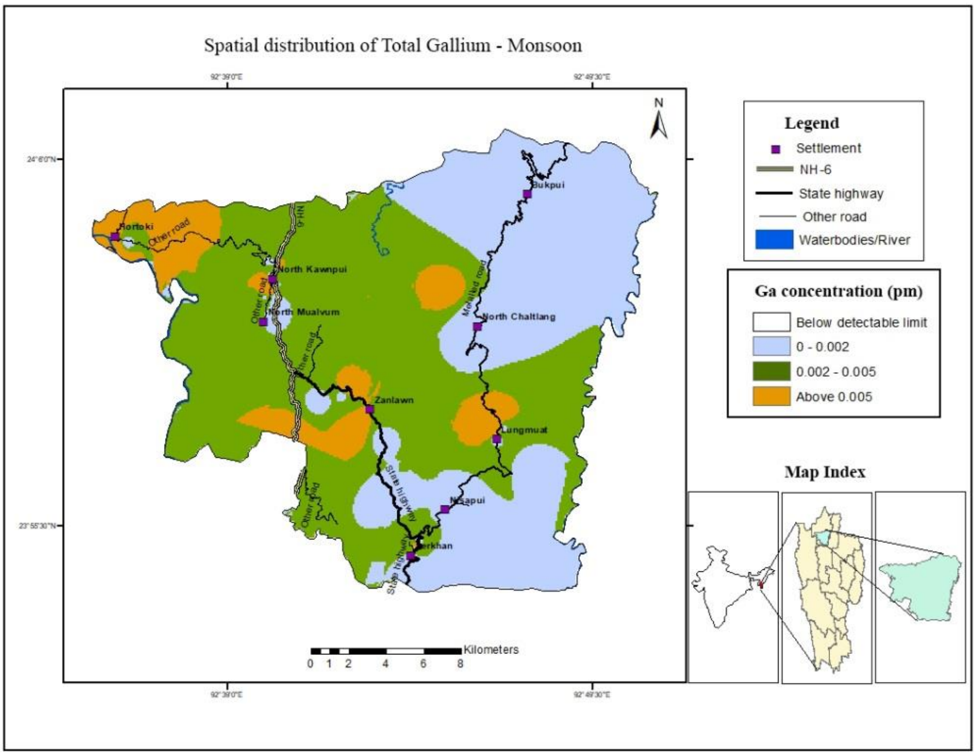

Figure 124: Spatial distribution map of Ga during Pre-Monsoon

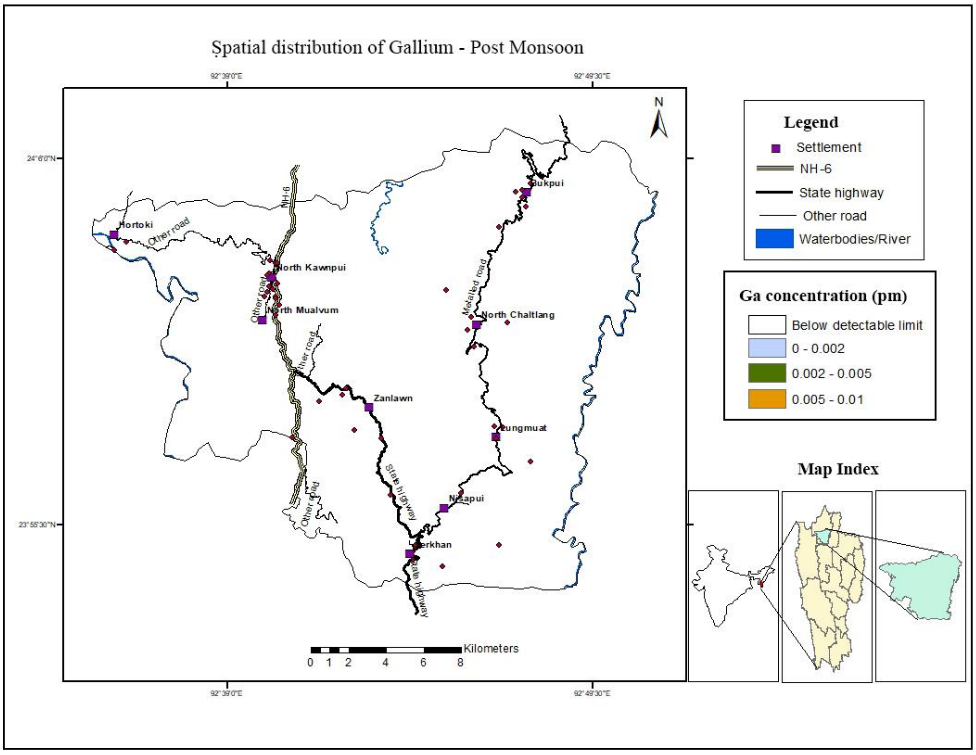

Figure 125: Spatial distribution map of Ga during Monsoon and Post-Monsoon

Table 79: Value of Gallium and pH in Pre-Monsoon and Monsoon Season

Sl.No	Source Name	Village	Lattitude	Longtitude	Concentration of Gallium (ppm) Pre-Monsoon 2018	Average pH Pre-Monsoon	Concentration of Gallium (ppm) Monsoon 2018	Average pH Monsoon
1	Vankeu	Serkhan	23.905	92.753	0	**7.39**	0	**6.49**
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	**7.22**	0	**7.25**
3	Dengalui	Serkhan	23.915	92.74	0.01	**7.15**	0.01	**7.23**
4	Bawngpu	Serkhan	23.908	92.739	0	**7.05**	0	**7.07**
5	Vautangbawk	Serkhan	23.915	92.78	0.01	**7.65**	0	**7.67**
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	**7.06**	0.01	**7.04**
7	Zotui	Nisapui	23.94	92.762	0	**7.62**	0	**7.65**
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0	**7.01**	0	**6.68**
9	Challui	North Chaltlang	24.0214	92.784	0	**7.45**	0	**7.46**
10	Chhimluang	North Chaltlang	24.01	92.768	0	**6.93**	0	**7.04**
11	Lengleh	North Chaltlang	24.024	92.767	0.01	**6.65**	0	**6.66**
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.01	**7.24**	0	**6.48**
13	Lungsum	Bukpui	24.084	92.788	0	**6.75**	0	**6.77**
14	Builum	Bukpui	24.067	92.78	0	**6.6**	0	**6.55**
15	Minmawng	Bukpui	24.085	92.791	0.01	**7.35**	0	**7.35**
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.01	**6.73**	0	**6.74**
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	**7.14**	0	**6.27**
18	Vandawt	Zanlawn	23.984	92.694	0	**7.17**	0	**6.945**
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	**7.29**	0	**6.885**
20	Hiahthar	Zanlawn	23.966	92.724	0	**6.65**	0	**6.63**
21	Fului	Zanlawn	23.97	92.711	0.01	**7.36**	0.01	**7.33**
22	Pumpelh	Zanlawn	23.99	92.707	0	**7.1**	0.01	**6.94**
23	Midum Lui	Zanlawn	23.987	92.705	0	**7.1**	0	**6.75**
24	Phuanberh	Kawnpui	24.034	92.673	0.01	**6.61**	0	**6.03**
25	Hlitlui	Kawnpui	24.05	92.673	0	**6.23**	0	**5.6**
26	Charpui	Kawnpui	24.05	92.674	0.01	**6.14**	0.01	**5.23**
27	Vailui	Kawnpui	24.034	92.668	0.01	**6.43**	0	**5.3**
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	**6.45**	0	**5.03**
29	Sentezel	Kawnpui	24.04	92.674	0.01	**6.813**	0	**6.39**
30	Kuangsei	kawnpui	24.0376	92.672	0.01	**6.74**	0.01	**6.74**
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.01	**7.05**	0	**5.53**
32	Sakhisih	Kawnpui	24.044	92.669	0	**6.62**	0.01	**6.43**
33	Bawkkang	Kawnpui	24.03	92.675	0	**7.52**	0	**6.45**
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	**7.83**	0	**6.25**
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.01	**7.23**	0	**6.04**
36	Tuitun	Kawnpui	23.9667	92.681	0	**7.82**	0.01	**7.53**
37	Khurthuk	Kawnpui	24.039	92.67	0.01	**6.45**	0.01	**5.6**
38	Sihpui	Kawnpui	24.036	92.669	0	**6.34**	0.01	**5.53**
39	Lungpher	Hortoki	24.06	92.602	0	**7.54**	0	**7.13**
40	Khawzasiaka	Hortoki	24.056	92.596	0	**7.75**	0.02	**7.74**
41	Zotui	Lungmuat	23.972	92.778	0	**7.25**	0.02	**6.47**
42	Luihnai	Lungmuat	23.966	92.779	0	**6.76**	0	**6.76**
43	Thingsakawr	Lungmuat	23.955	92.795	0	**7.05**	0	**6.5**
44	Vengchung lui	Lungmuat	23.9714	92.782	0	**7.11**	0	**6.37**

Table 80: Gallium concentration in Pre-Monsoon, Monsoon, and Post-Monsoon

Sl.No	Source Name	Village	Lattitude	Longtitude	Concentration of Gallium (ppm) Pre-Monsoon 2018	Concentration of Gallium (ppm) Monsoon 2018	Concentration of Gallium (ppm) Post Monsoon 2019
1	Vankeu	Serkhan	23.905	92.753	0	0	0
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	0	0
3	Dengalui	Serkhan	23.915	92.74	0.01	0.01	0
4	Bawngpu	Serkhan	23.908	92.739	0	0	0
5	Vautangbawk	Serkhan	23.915	92.78	0.01	0	0
6	Lalthansiama Point	Nisapui	24.037	92.755	0.01	0.01	0
7	Zotui	Nisapui	23.94	92.762	0	0	0
8	Lalkima Point hand pump	North Chaltlang	24.018	92.765	0	0	0
9	Challui	North Chaltlang	24.0214	92.784	0	0	0
10	Chhimluang	North Chaltlang	24.01	92.768	0	0	0
11	Lengleh	North Chaltlang	24.024	92.767	0.01	0	0
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0.01	0	0
13	Lungsum	Bukpui	24.084	92.788	0	0	0
14	Builum	Bukpui	24.067	92.78	0	0	0
15	Minmawng	Bukpui	24.085	92.791	0.01	0	0
16	Sub-Station Peng hand pump	Bukpui	24.088	92.795	0.01	0	0
17	Nuhliri Point	Bukpui	24.077	92.793	0.01	0	0
18	Vandawt	Zanlawn	23.984	92.694	0	0	0
19	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	0	0
20	Hiahthar	Zanlawn	23.966	92.724	0	0	0
21	Fului	Zanlawn	23.97	92.711	0.01	0.01	0
22	Pumpelh	Zanlawn	23.99	92.707	0	0.01	0
23	Midum Lui	Zanlawn	23.987	92.705	0	0	0
24	Phuanberh	Kawnpui	24.034	92.673	0.01	0	0
25	Hlitlui	Kawnpui	24.05	92.673	0	0	0
26	Charpui	Kawnpui	24.05	92.674	0.01	0.01	0
27	Vailui	Kawnpui	24.034	92.668	0.01	0	0
28	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	0	0
29	Sentezel	Kawnpui	24.04	92.674	0.01	0	0
30	Kuangsei	kawnpui	24.0376	92.672	0.01	0.01	0
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0.01	0	0
32	Sakhisih	Kawnpui	24.044	92.669	0	0.01	0
33	Bawkkang	Kawnpui	24.03	92.675	0	0	0
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	0	0
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0.01	0	0
36	Tuitun	Kawnpui	23.9667	92.681	0	0.01	0
37	Khurthuk	Kawnpui	24.039	92.67	0.01	0.01	0
38	Sihpui	Kawnpui	24.036	92.669	0	0.01	0
39	Lungpher	Hortoki	24.06	92.602	0	0	0
40	Khawzasiaka	Hortoki	24.056	92.596	0	0.02	0
41	Zotui	Lungmuat	23.972	92.778	0	0.02	0
42	Luihnai	Lungmuat	23.966	92.779	0	0	0
43	Thingsakawr	Lungmuat	23.955	92.795	0	0	0
44	Vengchung lui	Lungmuat	23.9714	92.782	0	0	0

5.27 Bacteriological properties:

The analysis conducted for bacteriological analysis includes the Presence – Absence (PA) test and test of Total coliforms content.

Potable or drinking water is water that is free from pathogenic microorganisms and chemicals that are harmful to human health. Surface or ground waters, which are polluted by fecal material, became a carrier of pathogenic, causing diseases such as typhoid, dysentery, cholera, and viral diseases like polio and hepatitis. Besides pathogens, water also contains *Escherichia coli (E. coli)*and Enterobacteriaceae, as well as Faecal Streptococci and various species of intestinal Clostridium. Soil Saprophytes such as *Spirillum, Vibrio, Sarcina, Micrococcus, Mycobacterium, Bacillus, Beggiatoa, Sphaerotilus,* and members of Streptomyceteceae and Spirochetes are also usually present in polluted water (Goel, 2006).

The bacteriological quality of drinking water can be described and the recommendation as per BIS specification (BIS, 2012) as follows:-

i) In all water intended for drinking *E. coli* or thermo-tolerant coliform bacteria shall not be detectable in any 100 ml sample.

ii) In treated water entering the distribution system *E. coli* or thermotolerant coliform bacteria shall not be detectable in any 100 ml sample and Total coliform bacteria shall not be detectable in any 100 ml sample.

iii) In treated water in the distribution system *E. coli* or thermotolerant coliform bacteria shall not be detectable in any 100 ml sample and Total coliform bacteria shall not be detectable in any 100 ml sample.

There has been an improvement in the use of a presence-absence (PA) procedure as an alternative method for detecting coliform bacteria in drinking water or small water systems to determine compliance with a regulation based on the presence-absence concept. PA test is rather qualitative than a quantity test. The PA test shows that 7 samples within the are characterized by the presence of coliform bacteria.

Few sources of water in the study area are polluted by the coliforms. These include Zotui (spring) of Nisapui, Bawngpu (spring) of Serkhan village, Lengleh spring from N. Chaltlang village, Lungsumtuikhur and Minmawng tuikhur of

Bilkhawthlir, Phuanberh tuikhur of Kawnpui village and Luihnai stream of Lungmuat. All these sources contain high Total coliform. The coliform content of these springs is considered to be accumulated from surface runoff into the springs as most of these springs are located in the drainage. Therefore, washing pollutants, trash, and improper dumping of human and animal waste and other materials into the spring catchment area.

Table 81: Total coliform and PA test value in the study area (2021)

Sl.No	Name	Village	Lattitude	Longtitude	Total Coliform MPN/100ml Monsoon 2021	P.A Test 19.08.2021 Monsoon
1	Vankeu	Serkhan	23.905	92.753	0	ABSENT
2	Hmarveng Tuikhur	Serkhan	23.914	92.74	0	ABSENT
3	Dengalui	Serkhan	23.915	92.74	0	ABSENT
4	Bawngpu	Serkhan	23.908	92.739	-	PRESENT
5	Vautangbawk	Serkhan	23.915	92.78	0	ABSENT
6	Lalthansiama Point	Nisapui	24.037	92.755	0	ABSENT
7	Zotui	Nisapui	23.94	92.762	32	PRESENT
8	Lalkima Point	North Chaltlang	24.018	92.765	0	ABSENT
9	Challui	North Chaltlang	24.0214	92.784	0	ABSENT
10	Chhimluang	North Chaltlang	24.01	92.768	0	ABSENT
11	Lengleh	North Chaltlang	24.024	92.767	-	PRESENT
12	Vengsang electric GW pump	Bukpui	24.0813	92.7914	0	ABSENT
13	Lungsum	Bukpui	24.084	92.788	32	PRESENT
14	Builum	Bukpui	24.067	92.78	0	ABSENT
15	Minmawng	Bukpui	24.085	92.791	32	PRESENT
16	Sub-Station Peng	Bukpui	24.088	92.795	0	ABSENT
17	Nuhliri Point	Bukpui	24.077	92.793	0	ABSENT
18	Phulraw lui tuikhur	Zanlawn	23.939	92.728	0	ABSENT
19	Vandawt	Zanlawn	23.984	92.694	0	ABSENT
20	Hiahthar	Zanlawn	23.966	92.724	0	ABSENT
21	Fului	Zanlawn	23.97	92.711	0	ABSENT
22	Pumpelh	Zanlawn	23.99	92.707	0	ABSENT
23	Midum Lui	Zanlawn	23.987	92.705	0	ABSENT
24	Phuanberh	Kawnpui	24.034	92.673	-	PRESENT
25	Hlitlui	Kawnpui	24.05	92.673	0	ABSENT
26	Charpui	Kawnpui	24.05	92.674	0	ABSENT
27	Vailui	Kawnpui	24.034	92.668	0	ABSENT
28	Kuangsei	kawnpui	24.338	92.672	0	ABSENT
29	Thlanmual tuikhur	Kawnpui	24.0511	92.6704	0	ABSENT
30	Sentezel	Kawnpui	24.04	92.674	0	ABSENT
31	Sihpui tuikhur	Kawnpui	24.045	92.67	0	ABSENT
32	Sakhisih	Kawnpui	24.044	92.669	0	ABSENT
33	Bawkkang	Kawnpui	24.03	92.675	0	ABSENT
34	Zohrangpa tuikhur	Kawnpui	24.033	92.6734	0	ABSENT
35	Kannaan Tuikhur	Kawnpui	24.025	92.673	0	ABSENT
36	Tuitun	Kawnpui	23.9667	92.681	0	ABSENT
37	Khurthuk	Kawnpui	24.039	92.67	0	ABSENT
38	Sihpui	Kawnpui	24.036	92.669	0	ABSENT
39	Lungpher	Hortoki	24.06	92.602	0	ABSENT
40	Khawzasiaka	Hortoki	24.056	92.596	0	ABSENT
41	Zotui	Lungmuat	23.972	92.778	0	ABSENT
42	Luihnai	Lungmuat	23.966	92.779	32	PRESENT
43	Thingsakawr	Lungmuat	23.955	92.795	0	ABSENT

CHAPTER-VI

SUMMARY AND CONCLUSION

6.1 Summary:

The study of potable water and the relation between rock and water in the southern area of Kolasib district, Mizoram is implemented based on mainly lithostratigraphy, geomorphology, and geological structures. This particular area is selected since it has geomorphic variation as well as a sequential arrangement of varying geological formations in a traverse section from East to West. In addition, the central part of the area is a basin that served as a catchment area for the Serlui dam and the eastern part of the study area also constitutes a fragment of the catchment area of the Tuirial Hydel Project. The western part of the area also drained into the Tlawng River, and this area has witnessed deforestation and land modification due to railway setup during the past years. Even though groundwater depletion is not an issue in the study area when considering the water requirement of an individual suggested by the Ministry of Jal Shakti, all habitations within the area do not meet an adequate water supply by the concerned department. Therefore, considering environmental changes caused by transport network establishment, impoundment of water in the surroundings as well as increasing anthropogenic activities in the study area, a systematic study of groundwater quality, data, and knowledge acquired from this research would have beneficial to the community and interesting person in the future.

Geospatial technology comprising GPS, Remote Sensing, and GIS acts as a medium for articulating research findings. Satellite data such as Indian Remote Sensing LISS-III, CARTOSAT-I images, and Survey of India topographic maps along with maps prepared by Geological Survey of India and Oil and Natural Gas Corporation are used for preparing maps. Lineament and structural mapping were carried out with the help of LISS III and Toposheet. By using contour, digital elevation models are prepared for delineating various Geomorphic Units. Other reliable legacy data like Geological maps, geomorphic maps, structural maps, demography, current water supply status, land use/land cover, etc. are either collected from the concerned department or generated using remote sensing and geospatial technologies. The analyzed data of water samples and reliable references

are converted into a compatible format for geospatial technology in a GIS environment to convey the nature of groundwater quality in different geological and geomorphological settings.

Following the objectives of the study, the following summaries can be made:-

1) Preparation of geomorphic, structural map, location map and lithological maps of the study area: Various data such as information and map from GSI reports, ONGC reports, satellite data, toposheet, and ground truth data from field surveys utilized for the preparation and generations of different kinds of the map.

2) Collection of samples: a collection of samples from selected potable water sources viz. Tuikhurs (spring), hand pump and dug well, etc. within the study area for their physicochemical and bacteriological analysis, demarcation of GPS location of44 sampling points, and analysis of selected samples during pre-monsoon, monsoon, and post-monsoon seasons for three consecutive years from 2017 to 2020. Groundwater samples were analyzed in the District laboratory, and Public Health DepartmentKolasiband heavy metal analysis was conducted in Microwave Plasma-Atomic Emission Spectrometer – Agilent 4100 (MP- AES) MP-AES, in Central Instrumentation Laboratory, Mizoram. In physical properties and element-wise, the groundwater quality is correlated with the geomorphic and lithostratigraphic classes of the study area to evaluate the rock-water interaction to assess the controlling factors of groundwater quality.

3) Generation of a comprehensible spatial database using ArcGIS for potable water sources to demarcate the contaminated water sources, the origin of pollutants in the watershed, and requisite remedial measures: All the information and data acquired during the study are digitized in a GIS-compatible format (shapefile format) with comprehensive attribute information (non-spatial data) of each particular object. Spatial variation of groundwater quality is also created using spatial analyst tools. From the interpretation of these entire generated data, the physical and chemical status of potable water sources with their environments like lithology, geomorphology, and geological structures are also rationalized. Under these interpretations, remedial measures for protecting the potable water sources in the study area are suggested.

6.2 Conclusion about groundwater quality assessment:

GIS technique has great potential in resource inventory, baseline data creation, planning, and management of resources. With satellite data from a high-resolution sensor and high-end computer technology, Geoinformatics enables us to map all types of terrain ranging from deep valleys to rugged mountains within the study area that are not accessible by humans owing to their large aerial extents. Therefore spatial variation of groundwater quality in a regional pattern can assess through remote sensing and the connection of potable sources with its geology and geomorphology can also be established. From the study of the terrain and geological structures of the watershed area remedial measures for groundwater quality safekeeping are also proposed.

Groundwater has moved slowly through a lithological column to the water table and recharges the aquifer. As more and more water is entering into the aquifer, older water in the aquifer is pushed deeper by the newly recharged water and then trends of increasing age are observed with depth. The groundwater can take tens to thousands of years in the aquifer. However, groundwater usually is young, often only a few decades old in shallow, unconfined aquifers with high rates of recharge. So that the age of groundwater is an important factor in predicting which contaminants it might contain (USGS, 2019). Therefore, the quality of groundwater in the study area is also found to have contrasting behavior in different rock types. It is also controlled by the duration of water percolates in the aquifers, the chemical composition of the rocks, permeability, and porosity of Lithological Units, and geological structures of the rocks. In addition, it also reveals the interconnection between anthropogenic activities, geological structures, and rainwater with groundwater quality. As of now, the location of springs with respect to Land use indicates there is a limited effect of anthropogenic activities on water quality, thus guaranteeing the direct correlation between water with Lithology and Geomorphology is established.

Rocks are slow to weather, and rainwater infiltrated through secondary porosity is depleted in terms of mineral content. However, the retention time within the fractures and aquifers can influence the water chemistry (Nwanko*et al.,* 2020). Physico-chemical properties of groundwater also show variation in different landforms which may be due to the flowing of groundwater from higher to lower elevations and that must have controlled even the retention period of different elements in groundwater. During the time of travel accumulation of particular elements in different units may change from lower to higher or Vice versa.

The taste and odor of all water samples are free from any form of degradation of quality. Though all the fresh samples of potable water sources are colorless, one source of Lalkima bore well from Zanlawn has developed a stain of reddish-brown color after putting it in a container for a long time.

In terms of pH, 6 samples from Kawnpui town are acidic during Pre-Monsoon. During Monsoon, 26 sources have exceeded the permissible limit, out of these sources, 13 samples are from Kawnpui. The deterioration pH of water sources is slightly reduced to 18 sources in the Post-Monsoon season and out of these polluted sources, 13 samples are from Kawnpui. So, we can conclude that Kawnpui town has encountered intense degradation of the pH quality of groundwater yearlong in comparison to other villages within the study area.

The turbidity during Pre-Monsoon shows that 10 sources are exceeding the acceptable limit and 3 sources viz. Lalkima hand pump at N.Chaltlang, Vengsang Electric groundwater pump at Bukpui, and Lungpher stream at Hortoki are to be rejected for drinking purposes. During Monsoon, the number of sources that have high NTU is increasing to 19 samples that have exceeded the acceptable limit and 2 sources such as the Lalkima hand pump and MidumLui at Zanlawn have surpassed the permissible limit. During Post-Monsoon, 17 samples and 3 samples viz. Lalkima hand pump, Midumlui, and Lungpher are above acceptable and permissible limits respectively. When comparing the intensity of turbidity, the samples from Pre-Monsoon have a maximum value of NTU, followed by Post-Monsoon. Though there is a large number of springs that have high turbidity, a minimum NTU value is observed during Monsoon when compared to other seasons.

The content of BariumandCopper, in the groundwater of the study area, is within the Desirable limit. Arsenic and Chromium constituents of potable sources are below detectable limits.

According to Central Ground Water Board (CGWB, 2014), Arsenic is found in all natural environments in abundance in the earth's crust and in small quantities in

rock, soil, water, and air. In sedimentary rock, it ranges from 1.7-400 mg/kg. It frequently occurs in the earth's crust along with pyrites. Pieces of pyrites are usually found in some shale formations and then make semi-consolidated sedimentary rock as a probable source of Arsenic contamination. The evaluation work on the geochemical dataset from Bangladesh sedimentary aquifer shows that the mineral concentration in regards to dietary needs showed that the sedimentary aquifers represented by 731 tube wells in Bangladesh have almost double the concentration of salubrious minerals such as calcium, magnesium, and iron relative to the basement aquifers (Ghana and Tanzania). Moreover, the groundwater of sedimentary aquifers was also found to contain excessive levels of arsenic; levels at which elements pose a serious public health threat (Nwanko*et al*., 2020). Arsenic was detected at Chawngte, Lawngtlai District of Mizoram (Blick*et al.,* 2016) in southwestern low-lying terrain. However, the absence of Arsenic in all samples within the study area indicates the groundwater in relatively high slope and mountainous terrain are depleted in arsenic content as compared to low-lying valleys areas.

In terms of Total Alkalinity, samples from the Lalkima hand pump (bore well) and Vengsang Electric GW pump (bore well) from N.Chaltlang and Bukpui village of geological formation belonging to sandstone-dominated Upper Bhuban and Lower Bhuban Formation is not potable for drinking purposes throughout the year in the presence an alternative sources (BIS 2012).

The Total Hardness Lalkima hand pump, Bukpui has exceeded the acceptable limit. Therefore this source is unfit for consumption if there is an alternative source (BIS 2012). Shale-dominated Formation of Middle Bhuban has a minimum hardness value whereas the Upper Bhuban Formation has a maximum value of hardness, which conveys that Upper Bhuban sandstone has a high value of sodic and alkali oxides like feldspar minerals.

The Magnesium content of the Lalkima hand pump has exceeded the acceptable limit during Pre-Monsoon and the permissible limit during Post-Monsoon. Hence, given the Mg concentration, it is not suitable for drinking purposes except in the Monsoon season (BIS 2012).

Concerning Total Iron concentration, bore well samples from Lalkima point hand pump, N.Chaltlang, and Sub-station peng, Bukpui are having Iron

concentrations exceeding acceptable limits of 0.4 and 0.7 ppm respectively and are not suitable for drinking purposes (BIS 2012). Iron concentration is highest in the sandstone-dominated Lower Bhuban Formation and lowest in the Unconsolidated Formation.

In terms of Magnesium concentration, one source of Lalkima hand pump, N. Chaltlang has exceeded the acceptable limit during Pre-Monsoon and two sources such as Dengalui, Serkhan of Middle Bhuban shale and Lalkima hand pump have surpassed the permissible limit and Thlanmual Tuikhur, Kawnpui at soil-rich Colluvium deposits of Upper Bhuban Formation and Vengsang Electric GW pump have exceeded acceptable limit during Monsoon.

Lalkima hand pump and Vengsang electric GW pump have a high value of Manganese concentration that is above the permissible limit is observed in Post-Monsoon.

The Aluminium concentration, four spring samples such as Phuanberh, Sihpui Tuikhur, Thlanmual tukhur and Khurthuk of Kawnpui town, which geologically belongs to sandstone-dominated Upper Bhuban Formation has elevated Aluminium concentration that exceeds acceptable limit during Pre-Monsoon. In addition, two samples from Dengalui of spring sources at Serkhan and stream water of Khawzasiakalui, Hortoki have surpassed the acceptable limit during Monsoon are fall into the non-potable class in the presence of an alternative source (BIS 2012).

Zinc concentration exceeding the permissible limit is observed from the Substation Peng hand pump, Bukpui, and is thought to be leaching from the bore well facilities of the hand pump. All other samples are well within the permissible limit.

Cadmium concentration is highest from Pre-Monsoon samples, Vankeu spring water of Serkhan and Fului spring of Zanlawn villages are having Cd values exceeding the permissible limit, and Sub-station peng hand pump and Minmawng spring water are also exceeding the permissible limit. Eight sources of spring water from Kawnpui village and three samples from Lungmuat villages fall into non-potable classes. All samples from Hortoki, Nisapui, and N.Chaltlang villages are confined within the desirable limit. During Monsoon, Dengalui spring water of Serkhan has exceeded the permissible limit.

In terms of Lead concentration in potable sources, 8 samples such as Dengalui and Vautangbawk (spring) at Serkhan, Vengsang electric GW pump, and Nuhliri point (PHED supplied water) at Bukpui, Fului (spring) at Zanlawn and Hlitlui, Charpui, Sentezel, Khurthuk, and Sihpui springs at Kawnpui are not qualified for consumption during Pre-Monsoon. During Monsoon, 14 sources such as Dengalui (Spring) at Serkhan, Lalthansiama point (PHED supplied water) and Zotui(source) at Nisapui, Minmawng at Bukpui, Fului, and Pumpelh spring sources at Zanlawn and 6 sources from Kawnpui namely Charpui, Kuangsei, Sakhisih, Kuangsei, Khurthuk, and Sihpui spring sources, Tuitun stream water do exceed the permissible limit. Ten sources such as the Lalkima handpump, Vengsang electric GW pump, Sub-station peng handpump, and Minmawng sources at Bukpui, Kuangsei, Kannan, and Sihpui spring sources at Kawnpui, Khawzasiaka and Lungpher stream at Hortoki and Zotui at Lungmuat are not potable during Post-Monsoon.

The Nickel contamination is relatively high in the Pre-Monsoon season, 24 sampling sources and 1 sample from Monsoon are not suitable for drinking purposes. 3 sources each from Bukpui and Serkhan, 1 source each from Lungmuat and Nisapui, 2 sources each from N.Chaltlang and Zanlawn, and 10 sources from Kawnpui exceed permissible limits. Dengalui source of Serkhan falls in the non-potable class during Pre-Monsoon and Monsoon seasons.

In terms of Cobalt concentration, 23 sources, 20 sources and 10 sources of water during Pre-Monsoon, Monsoon, and Post-Monsoon respectively fall in the non-potable class. Cobalt pollution is found to be widespread in the area within the area throughout the year.

The concentration of Strontium within the study area is relatively low. Sandstone-dominant lithology of Upper Bhuban Formation and followed by shale-dominated Middle Bhuban Formation. Unconsolidated sediments and Lower Bhuban Formation has the lowest concentration of Strontium.

Indium concentration in groundwater is uniformly distributed in all units of Lithostratigraphy and Geomorphic indicating that there is little or no influence of lithology as well as the topography of the terrain. The concentration of Indium is detectable only in samples from the Pre-Monsoon season, indicating accumulated

contaminants by anthropogenic activities are readily carried away by runoff and completely diluted by rainwater.

Li concentrations from Dengalui and Vautangbawk springs water at Serkhan, Vengsang electric groundwater pump at Bukpui, Fului stream water at Zanlawn, and Lungpher stream at Hortoki have exceeded 0.01 (Health Based Screening level of Li in groundwater by USGS) are observed. Samples taken during Monsoon and Post-Monsoon are having Li concentrations below the detectable limit indicating that Li is completely depleted by rainwater.

The trend between pH and Gallium dissolving rate is rationalized and was found to be following prior studies, which concludes that the nature of solubility of Ga is highest at around pH 7.4 and lowest at pH 5.2; from the analyzed sources, out of 19 total samples where Ga concentration was detected, 8 samples were characterized by pH value ranging 6.23 to 6.93 during Pre- Monsoon and the remaining 11 samples were having pH 7.05 to 7.65. Out of 12 samples where Ga concentration was encountered, 7 samples were found to have pH value ranging between 6.42 to 6.92, and 5 samples were characterized by pH value of 5.52 to 5.56 indicating solubility of Gallium is much prevalent at pH value around 6.42 to 6.92.

Hand pump usually has high Iron content, hardness, and alkalinity and sources from bore wells exceed the Permissible limit in these parameters. It is also noticed that hand pump samples have slightly higher values of Magnesium and Zinc concentration. Lalkima hand pump, N.Chaltlang is characterized by high turbidity, Mn, Fe, etc., it is also found to be located in association with minor fracture(lineament), hence the dumping site on the eastern side along the escarpment slope which is coupled by the dip direction and dip amount may contaminate the groundwater in the deep aquifer by percolation of rainwater.

The PA test shows that 7 samples within the are characterized by the presence of coliform bacteria. These include Zotui (spring) of Nisapui, Bawngpu (spring) of Serkhan village, Lengleh spring from N. Chaltlang village, Lungsumtuikhur and Minmawngtuikhurof Bilkhawthlir, Phuanberhtuikhur of Kawnpui village and Luihnai stream of Lungmuat. They are not potable for drinking purposes.

6.3 Recommendations:

The area of Mizoram is 21081sq km. Systematic and detailed groundwater quality studies for geospatial variation had been carried out at the northern arcuate of Mizoram, which covers about 395sq. km only. The present study covers an area of 415.43sq.km. Moreover, heavy metal and trace element concentration in groundwater and its correlation with Lithostratigraphy, Geomorphology and geospatial variation has been justified only in the present studies. The remaining areas of 20270.5 sq. km are still in need of exploration in this regards.

In addition, the present study comprises Geological Formation like Recent, Upper Bhuban, Middle Bhuban, and Lower Bhuban Formations, other Formations like Bokabil, Tipam, and Barail exposed in the remaining part of Mizoram are excluded. Therefore, further studies are needed to rationalize the complete correlation between Lithostratigraphy and groundwater in Mizoram. Furthermore, major oxide, petrographic, traces element and heavy metals, etc., studies in different Lithostratigraphic Units are also limited, and consequently, scarcity of lithological data to refer to may hamper justification made during correlation between rock chemistry and groundwater chemical composition. Therefore, obtaining detailed Lithological data from such different Lithological Units, especially in Lower Bhuban Formation and Bokabil Formation is indeed a must to facilitate the study of rock and water interaction.

Considering the quantity of water supplied by the concerned department, springs are still the most important sources of potable water in Mizoram. The elevated concentrations of lead, cadmium, etc. are observed in watershed areas that have domestic sewage, livestock wastes, solid waste dumping site, and road transport. Protection of the catchment area by shifting piggery activities and toilets located extremely near the water sources is highly recommended for remedial measures. Treatment of water at least by boiling is highly crucial for drinking purposes in such sources.

Moreover, concentration exceeding the normal range of zinc, iron, manganese, nickel, etc. is found to be higher in water-supplied facilities and bore

wells that have used Iron pipes. Hence, constant monitoring and assessment of springs, further inventory, and watershed management are also recommended.

Given the public health and the groundwater system, intensive monitoring of groundwater geochemistry to demarcate contamination sources that reflect the background concentration of aquifers as well as anthropogenic sources is indeed a need. Moreover, being located in one of the most studied geological area with good information on geology and a very little information about groundwater, deeper analysis of groundwater and further research work in hydrology is strongly required and is highly recommended.

REFERENCES

Al-Jubouri, S. M., and Holmes, S. M. (2020). Immobilisation of cobalt ions using hierarchically porous 4A zeolite-based carbon 497 composites: Ion-exchange and solidification. Journal of Water Process Engineering, 33:101059.

Amadi A.N., Aminu, T., Okunlola I.A., olasehinde P.I., Jimoh M.O. (2015). Lithologic Influence on the Hydrogeochemical Characteristics of Groundwater in Zango, North-west Nigeria. Natural Resources and Conservation, 3(1):11-18.

APHA, AWWA (2012). Standard Methods for Examination of Water and Waste Water. 22nd Edition, American Public Health Association, Washington DC.

Batayneh, A.T. (2012). Toxic (aluminium, beryllium, borom, chromium and zinc) in groundwater: health risk assessment. Environ. Sci. Technol., 9: 153-162.

Bas M.G., Pedroli, Wilfried A.C., Maasdam and. Verstraten, J.M. (1990). Zinc in poor sandy soils and associated groundwater. A case study. The Science of the Total Environment, 91: 59-77.

Betka, P.M., Thomson, S.N., Sincavage, R., Zoramthara, C., Lalremruatfela C., Lang, K.A., Steckler, M.S., Bezbaruah, D., Borgohain, P., and Seeber, L. (2021). Geochemistry, Geophysics, Geosystems. Advancing Earth and space Science, 10(1029):1-30.

Bharali, B., Borgohain, P., Bezbaruah, D., Vanthangliana, V., Phukan, P.P., Rakshit, R. (2017). A geological study on Upper Bhuban Formation in parts of Surma Basin, Aizawl, Mizoram. Science Vision, 7(3):128-147.

BIS. (2012). Indian Standard, Drinking Water — Specification (Second Revision). Bureau of Indian Standards: 4.

Blick, J., Kumar, S., Bharati, V.K. and Kumar, S. (2016). Status of arsenic contamination in potable water in Chawngte, Lawngtlai district, Mizoram. Science Vision, 6(2):74-81.

Blick J.(2016). Quality assessment and characterisation of potable water sources in SW Lawngtlai District in Mizoram,India. (PhD thesis), Mizoram University.

Blick J. and Kumar S. and Bharat B K. and Kumar S. (2016). Status of Arsenic contamination in potable water in Chawngte, Lawngtlai, Mizoram, Science vision,116(2):74-81.

Brennan, S.K. and Lowenstein, T.K. (2002). The major ion composition of Silurian sea water. Geochim Acta., 66: 2683-2700.

Carducci, A., Federigi, I., Liu, D., Thompson, J.R., Verani, M. (2020). Making Waves: Coronavirus detection, presence and persistence in the water environment: State of the art knowledge needs for public health. Water Research, 179(115907):1-9.

CGWB. (2014). Concept Note on Geogenic Contamination of Ground Water in India. Central Ground Water Board, Ministry of Water Resources, 17-28.

Cheah, B.H., Liao, P.C., Lo, J.C., Wang, Y.T., Tang, I.C., Yeh, K.C., Lee, D.Y., Lin, Y.F. (2022). Oryza sativa, groundwater, homeostasis, indium, industry, leaves, magnesium, metal tolerance, necrosis, phenotype, phosphates, phosphorus, pollution, rice, root growth, sclerenchyma, soil, starvation, toxicity. Journal of hazardous materials, 429: 128265.

Chen, H.W. (2006). Gallium, Indium, and Arsenic Pollution of Ground Water from a Semiconductor Manufacturing Area of Taiwan. Environmental Contamination and Toxicology, 77:289-296.

Chrysikopoulos, C.V., Kruger, P. (1987). Investigation of soluble indium chelates for groundwater and hydrothermal fluid tracing. Applied Geochemistry, 2(3): 329-335.

Chubaka, C.E., Whiley, H., Edwards, J.W. and Ross, K.E. (2018). Lead, Zinc, Copper and Cadmium content of water from South Australian rainwater tanks. International Journal of Environmental Research and Public Health,15(1551):1-12.

Cruz, J.V. and Amaral, C.S. (2004). Major ion chemistry of ground water from perched water

Deshmukh, K.K. (2013). Impact of Human Activities on the Quality of Ground water from Sangamner Area, Ahmednagar District, Maharashtra, India. International Research Journal of Environment Sciences, 2(8): 66-74.

Dugamin, E.J.M., Richard, A., Cathelineau, M., Boiron, M.C., Despinois, F. & Brisset, A. (2021). Groundwater in sedimentary basins as potential lithium resource: a global prospective study. Scientific Reports,11:21091.

Frankowski, M., Ziola-Frankowska, A., Kurzyca, I., Novotny,K., Vaculovic, T., Kanicky, V., Siepak, M., Siepak, J. (2011). Determination of aluminium in groundwater samples by GF-AAS, ICP-AES, ICP-MS and modelling of inorgannic aluminium complexes. Environ Monit Assess., 182:71-84.

Gad, S.C. (2014). Gallium. Encyclopedia of Toxicology (Third Edition):691-692.

Geosciences Division. (2012). Manual for Geomorphology and Lineament Mapping (Web Version), 1-28

Goel, P.K. (2006). Water pollution. Causes, effects and control. 139-157, 221- 234, 245, 247-256,

GSI (2011). Geology and Mineral resources of Manipur, Mizoram, Nagaland and Tripura. Geological Survey of India, Miscellaneous Publication No. 30 Part IV, 1 (2): 36-39.

Horasawa, N., Nakajima, H., Takahashi, S. and Okabe, T. (1997). Behavior of Pure Gallium in Water and Various Saline Solutions. Dental Materials Journal, 16(2):200-208

Horr, C.A. (1946). A survey of analytical methods for the determination of strontium in natural water. Chemistry of Strontium in natural water. Geological Survey Water-Supply: 1-18.

Health Canada (2019) Barium in drinking water, Guideline technical document for public consultation. Health Canada, 1-7.

Hem, J.D. (1991). Study and interpretation of the chemical characteristics of natural water, Book 2254. Scientific Publishers, Jodhpur, 3rd edn.

Hussain, M.F., Bharali, B. (2019). Whole-rock geochemistry of Tertiary sediments of Mizoram Foreland Basin, NE India: implications for source composition tectonic setting and sedimentary processes. Acta Geochim, 38(6):897-914.

Jagadish Kumar, J.M., Sunitha. V., Reddy, R.M. (2013). Determination of an optimal interpolation technique to represent the spatial distribution of groundwater quality at urban and peri-urban areas of Proddatur, Y.S.R district, Andhra Pradesh, India. International Journal of Geomatics and Geosciences, 4(2):417-426.

Jha, M.K., Shekhar, A., Jenifer, M.A. (2020). Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index. Water Research, 179: 1-16.

Karanth, K.R. (1997). Groundwater assessment development and management. Tata McGraw-Hill New Delhi.

Karunakaran, 1974. Geology and Mineral Resources of the North Eastern States of India. Misc. Publ. Geol. Surv. India, 30: 93-101.

Karthikeyan, N., Saranya, A., and Sashikkumar, M.C. (2013). Spatial Analysis of Ground water Quality for Virudhunagar District, Tamil Nadu using GIS. International Journal of Remote Sensing & Geoscience, 2(4): 23-30.

Korla, C.K., Mitra, C.K. (2020). Biochemical hazards associated with unsafe disposal of electrical and electronic items. Handbook of Electronic Waste Management,55-80.

Kumar, S., Bharti, V.K., Singh, K.B., Singh, T.N. (2010). Quality assessment of potable water in the town of Kolasib, Mizoram (India). Environment Earth Sciences, 61(1):115-121.

Kumar, B. and Kumar, U. (2011). Ground water recharges zonation mapping and modeling using Geomatics techniques. International Journal of Environmental Sciences, 1 (7): 1671.

Kumar, S. and Sing, K.B. and Bharati, V.K. (2009). assessment of spring water quality in Aizawl City, Mizoram. JAH XXII: 3-4.

Kumar, Shikhar. and Baier, Klaus. and Jha, Ramakar. and Azzam, Rafig. (2011). Status of Arsenic contamination in potable water of Northern areas of Mizoram State and its adjoining areas of Southern Assam, India. Arab J Geosci DOI 10.1007/s12517-011-0373-9.

Lahkar, M., Bhattacharyya, K.G. (2019). Heavy metal contamination of Groundwater in Guwahati City, Assam, India. International Research Journal of Engineering and Technology, 6(6):1520-1525.

Lalbiakmawia, F. and Vanthangliana, V. (2015a). Application of geo-spatial technologies for ground water quality mapping of Aizawl district, Mizoram, India. Science Vision, 15(3): 115-123.

Lalbiakmawia, F., Bharati, V.K., Kumar, S. (2019). Application of geo-spatial technology for mapping seasonal variation of ground water quality in the northern arcuate of Mizoram, India. International Journal of Research and Analytical Reviews, 6(2):51-58.

Lalbiakmawia, F. (2015b). Ground Water Quality Mapping of Kolasib District, Mizoram, India using Geo-Spatial Technology. SSRG International Journal of Geo informatics and Geological Science, 2(2):1-7.

Lalbiakmawia, F. (2016). Assessment of Hydrogeological conditions and groundwater quality in northern arcuate of Mizoram. (Ph.D. thesis), Department of Geology, Mizoram University.

Lalnunmawia, J., Vabeihmo, C., and Lalremruatsanga, H. (2016). Petrography and heavy minerals as tools for reconstruction of provenance and depositional environment of Bhuban sandstones in Aizawl, Mizoram. Science Vision, 16(1):1-9.

Lalnunmawia, J., Hauhnar, M., Laltluanpuii, Dawngliana, O.M.S., Lalrochani, T. (2020). Petrographic analysis of Surma sandstones in Reiek Hill area, Mizoram, India. Advances in Environmental Research of Northeast India, 242-254.

Lalnunmawia, J., Lalhlimpuii, J. (2014). Classification and provenance studies of the sandstones exposed along Durtlang road section, Aizawl, Mizoram. Science Vision, 14(3):158-167.

Lindsey, B.D., Belitz, K., Cravotta III C.A., Toccalino, P.L., Dubrovsky, N.M. (2020). Lithium in groundwater used for drinking-water supply in the United States. Science of The Total Environment, 1(767): 144691.

Listyani R.A.T. (2016). Rock's Mineral Control on Groundwater Quality in Jakarta Groundwater Basin. Geological Engineering Department, 13-19.

Mahapatra, S.R., Nimmy P.M. (2021). Groundwater contamination with heavy metals in Chennai city, India –A threat to the human population. Earth and Environmental Science, 889:1-16.

Malecki, J.J., Kadzikiewicz-Schoeneich, M., Szostakiewicz-Holownia, M. (2016). Concentration and mobility of copper and zinc in the hypergenic zone of a highly urbanized area. Environ Earth Sci., 75(24):1-13.

MIRSAC (2009). Natural Resources Atlas of Mizoram. Mizoram Remote Sensing Application Centre, Aizawl, Mizoram, S&T, Planning Dept. Mizoram, A project report. 10-13.

Mohammed, L. N., Aboh, H. O. & Emenike, E. A. (2007). A regional geoelectric investigation for groundwater exploration in Minna area, north west Nigeria. Science World Journal, 2 (NO3):15-19.

Moraru, C.Y. (2016). Contemporary approaches to studying and mapping of active water exchange zone of groundwater IOP Conference Series: Earth and Environmental Science, 33:1-4.

Napacho Z.A. and Manyele S.V. (2010).Quality asssesment of drinking water in Temeke District (part ii):Characterisation of chemical parameters. African Journal of Environmental Science and Technology,4(11):7775-789.

Nicolas, M.P.B. (2017). Preliminary investigation of the potential for lithium in groundwater in sedimentary rocks in southwestern Manitoba. Report of Activities, Manitoba Geological Survey, 183-190.

Nwanko, C.B., Hoque, M.A., Islam, M.A. & Dewan, A. (2020). Groundwater Constituents and Trace Elements in the Basement Aquifers of Africa and Sedimentary Aquifers of Asia: Medical Hydrogeology of Drinking Water Minerals and Toxicants. Earth System and Environment, 6: 369-384.

Pachuau, R. (2009). Mizoram A Study of Comprehensive Geography. 24-43.

Payne, T.E., Itakura, T., Comarmond, M.J., Harrison, J.J. (2009). Environmental mobility of cobalt – Influence of solid phase characteristics and groundwater chemistry. Applied Radiation and Isotopes, 67(7-8): 1269-1276.

Peiro, L.T., Mendez, G.V. and Ayres, R.U. (2013). Lithium: Sources, Production, Uses, and Recovery Outlook. JOM, 65(8):986-996.

Ramakrishna, Nagaraju, D., Mohammad, S.B., Siddalingamurthy, S. and Sumithra, S. (2013). Ground water prospect studies of Tattekere watershed, Mysore district, Karnataka, India using Remote Sensing and GIS. International Journal of Remote Sensing & Geoscience, 3(1): 6-10.

Raju, G.S., Babul, K.R., Siva, Kumar, K.N., and Kumar, P.L.K. (2013). Application of remote sensing data for identification of ground water potential zones in and around Kadapa area, Andhra Pradesh, India. International Journal of Remote Sensing & Geoscience, 2(1): 58.

Ravindra, K., Mor, S (2019). Distribution and health risk assessment of arsenic and selected heavy metals in Groundwater of Chandigarh, India. Environmental Pollution, 250:820-830.

Rosa, G.L., Bonadonna, L., Lucentini, L., Kenmoe, S., Suffredini, E. (2020). Coronavirus in water environments: occurrence, persistence and concentration methods – A scoping review. Water Research, 179(115899):1-11.

Shalu, M. (2013). Spatial analysis of drainage network for Ground water exploration in river basin Using GIS and remote sensing techniques: A case study of Tons river In Allahabad, India. Journal of Environmental Research and Development, 7(3):1316-1319.

Smedley, P.L. (2003). Arsenic in groundwater-south and east Asia. Arsenic in groundwater. Kluwer Acadamic Publishers, NY.

Starkey, H.C. (1982). The Role of Clays in Fixing Lithium. Geological Survey Bulletin 1278-F.F1-F8.

Stein, A., Varekamp, C., Egmond, C.V., Zoest R.V. (1995). Zinc Concentrations in Groundwater at Different Scales. Environmental Quality, 24(6): 1205-1214.

Taloor, A.K., Pir, R.A., Adimalla, N., Ali, S., Manhas, D.S., Roy, S., Singh, A.K. (2020). Spring water quality and discharge assessment in the Basantar watershed of Jammu Himalaya using geographic information system (GIS) and water quality Index(WQI). Groundwater for Sustainable Development, 10: 100364.

Thapa, R., Kumar, R. and Sood, R.K. (2008). Study of Morphotectonics and Hydrogeology for Ground water Prospecting using Remote Sensing and GIS in the North West Himalaya, District Sirmour, Himachal Pradesh, India. The International

Archives of the Photogrammetry, Remote Sensing and Spatial InFormation Sciences, XXXVII (B4): 227-231.

Thivya, C., Chidambaram, S., Singaraja, C., Thiagavathi, R., Prasanna, M.V., Anandhan, P, Jainab, I. (2013). A study on the significance of lithology in groundwater quality of Madurai district, Tamil Nadu (India). Environmental Development sustainability, 15:1365-1387.

Todd, D.K. (1980). Groundwater Hydrogeology. Wiley, New York.

Tugulea, A.M., Berube, D., Giddings, M., Lemieux, F., Hnatiw, J., Priem, J., and Avramescu, M.L. (2014). Nano-silver in drinking water and drinking water sources: stability and influences on disinfection by-product formation. Environmental Science and Pollution, 21(20): 11823-11831.

Usali, N. & Ismail, M.H. (2010). Use of Remote Sensing and GIS in Monitoring Water Quality. Journal of Sustainable Development, 3(3):228-238.

U.S. Geological Survey (1962). Chemistry of iron in natural water. Washington, U.S. Govt. Print. Off.

USGS (2019). Groudwater age – Insight of ground water quality. Headquarters, 12201 Sunrise Valley Drive Reston, VA 20192.

Vespasiano, V., Muto, F., Apollaro, C. (2021). Geochemical, Geological and Groundwater Quality Characterization of a Complex Geological Framework: The Case Study of the Coreca Area (Calabria, South Italy). Geosciences, 11(121):1-22.

Walton, W.C. (1970). Groundwater resources evaluation. McGraw-Hill, New York.

World Health Organisation (WHO)(1996) Health criteria and other supporting information. In: (2nd ed.), Guidelines for drinking-water quality 2, WHO, Geneva, pp. 940–949.

Yu, H.S., Liao, W.T. (2014). Gallium: Environmental Pollution and Health Effects: 829-833.

Zakaria, N., Gibrilla, A., Owusu-Nimo, F., Adomako, D., Anornu, G. (2022). Occurrence, spatial distribution, and health risk assessment of heavy metals in groundwater from parts of the Kassena Nankana area, Ghana. Sustainable Water Resources Management, 8(77): 1-14.

ABSTRACT

A STUDY OF POTABLE WATER SOURCES VIZ-A-VIZ ROCK WATER INTERACTION IN THE SOUTH EASTERN AREA OF KOLASIB DISTRICT, MIZORAM

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A STUDY OF POTABLE WATER SOURCES VIZ-A-VIZ ROCK WATER INTERACTION IN THE SOUTH EASTERN AREA OF KOLASIB DISTRICT, MIZORAM

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The Surma (Lower to Middle Miocene), the Bokabil (Late Miocene) Groups, and Unconsolidated sediments (Clay, silt, sand, and gravel) of Recent deposits are the main lithology exposed within the study area. Lower Bhuban Formation is exposing in around Bukpui village and the dip amount in this range is relatively high ranging from ~25° to 60° dipping towards the west direction. Argillaceous-dominated lithology of the Middle Bhuban Formation is found in terrain having higher elevations such as N. Chaltlang village and Serkhan village, it is also encountered in the lower flanks of both the eastern and western sides of the Bukpui anticline. The doubly plunging synclinal basin between the Bukpui anticline range and the Kawnpui mountain range is found to be of Bokabil Formation. Grey to buff-colored sandstone dominant lithology of Upper Bhuban is observed in the remaining part of the study area such as the vicinity of Kawnpui, Zanlawn, Lungmuat, and Nisapui villages. The dip amount of rock beds at the Kawnpui range is very low ranging from 7° to 20° towards the East. However, being structurally more disturbed by folding, faulting, fractures, and joints, the bedrock exposures in the vicinity of Zanlawn, Nisapui, Lungmuat, and the Southern area along the national highway are characterized by relatively higher dip amount as compared to Upper Bhuban rocks in the vicinity of Kawnpui range. Unconsolidated narrow elongated alluvium deposits are encountered along major rivers like Tlawng, Serlui, Tuirial, etc. It is observed that the rocks within the area are traversed by several Geological features like faults, fractures, joints, etc. of varying magnitude and length.

Fieldwork was conducted in every Pre-Monsoon (January -April), Monsoon (May-August), and Post-Monsoon(September-December) during three consecutive years, starting from the 2017 Monsoon to the 2020 Pre-Monsoon. It mainly includes a collection of samples from potable water sources, sample collected were separately marked as Spring/tuikhur or dug well or hand pump or PHED supplied and locations were recorded accordingly with the help of GPS. Laboratory work involves the analysis of physical, chemical, and bacteriological parameters. Physio-chemical of water from each season were analyzed thrice a year (Monsoon,2017 – Post-Monsoon,2020)in the District Laboratory of Public Health Engineering Department, Kolasib, and the bacteriological property was tested in August and September 2021 in District PHED Laboratory, Kolasib. In addition, heavy metal analysis is carried out for selected samples and elements in Central Instrumentation Laboratory (CIL), Mizoram University to acquire the concentration of toxic elements in groundwater. The heavy metal test was conducted from samples of Pre-Monsoon 2018, Monsoon 2018, and Post-Monsoon 2019. Analysis of elements that occur as major constituents in potable water like Mg and Cl; minor constituents such as Cu, Mn, Al, Ba, Zn, Cd, Pb, Ni, Cr, Co, and Li as well as trace constituents like Ga, In and Ag were analyzed in Microwave Plasma-Atomic Emission Spectrometer – Agilent 4100 (MP- AES). The arsenic test is conducted with an Eozy water testing kit made by Octopus Inc. Vadodara, Gujarat. Secondary constituents of potable minerals like Mg and Fe were tested by MP-AES and a testing kit made by "Transchem Agritech Limited".

Geospatial technology is incorporated for data analysis and interpretation. The results were analyzed by using ArcGIS 10.4.1 software. From the analysis results, vulnerable sources such as springs/tuikhurs or hand pumps are identified. Correlation between physical properties and each element with Geomorphic units as well as with the host rock chemistry and Lithostratigraphic units are depicted.

The taste and odor of all water samples are free from any form of degradation of quality. Though all the fresh samples of potable water sources are colorless, one source of Lalkima bore well from Zanlawn has developed a reddish brown coloring stain after putting it in a container for a long time.

In terms of pH, 6 samples from Kawnpui town are acidic during Pre-Monsoon. During Monsoon, 26 sources have exceeded the permissible limit, out of these sources, 13 samples are from Kawnpui. The deterioration pH of water sources is slightly reduced to 18 sources in the Post-Monsoon season and out of these polluted sources, 13 samples are from Kawnpui. So, we can conclude that Kawnpui town has encountered intense degradation of the pH quality of groundwater yearlong in comparison to other villages within the study area.

The turbidity during Pre-Monsoon shows that 10 sources are exceeding the acceptable limit and 3 sources viz. Lalkima hand pump at N.Chaltlang, Vengsang Electric groundwater pump at Bukpui, and Lungpher stream at Hortoki are to be rejected for drinking purposes. During Monsoon, the number of sources that have high NTU is increasing to 19 samples that have exceeded the acceptable limit and 2 sources such as the Lalkima hand pump and MidumLui at Zanlawn have surpassed the permissible limit. During Post-Monsoon, 17 samples and 3 samples viz. Lalkima hand pump, Midumlui, and Lungpher are above acceptable and permissible limits respectively. When comparing the intensity of turbidity, the samples from Pre-Monsoon have a maximum value of NTU, followed by Post-Monsoon. Though there is a large number of springs that have high turbidity, a minimum NTU value is observed during Monsoon when compared to other seasons.

The content of BariumandCopper, in the groundwater of the study area, is within the Desirable limit. Arsenic and Chromium constituents of potable sources are below detectable limits.

In terms of Total Alkalinity, samples from the Lalkima hand pump (bore well) and Vengsang Electric GW pump (bore well) from N.Chaltlang and Bukpui village of geological formation belonging to sandstone-dominated Upper Bhuban and Lower Bhuban Formation is not potable for drinking purposes throughout the year in the presence an alternative sources (BIS 2012).

The Total Hardness Lalkima hand pump, Bukpui has exceeded the acceptable limit. Therefore this source is unfit for consumption if there is an alternative source (BIS 2012). Shale-dominated Formation of Middle Bhuban has a minimum hardness value whereas the Upper Bhuban Formation has a maximum value of hardness, which conveys that Upper Bhuban sandstone has a high value of sodic and alkali oxides like feldspar minerals.

The Magnesium content of the Lalkima hand pump has exceeded the acceptable limit during Pre-Monsoon and the permissible limit during Post-Monsoon. Hence, given the Mg concentration, it is not suitable for drinking purposes except in the Monsoon season (BIS 2012).

Concerning Total Iron concentration, bore well samples from Lalkima point hand pump, N.Chaltlang, and Sub-station peng, Bukpui are having Iron concentrations exceeding acceptable limits of 0.4 and 0.7 ppm respectively and are not suitable for drinking purposes (BIS 2012). Iron concentration is highest in the sandstone-dominated Upper Bhuban Formation and lowest in the Unconsolidated Formation.

In terms of Magnesium concentration, one source of Lalkima hand pump, N.Chaltlang has exceeded the acceptable limit during Pre-Monsoon and two sources such as Dengalui, Serkhan of Middle Bhuban shale and Lalkima hand pump have surpassed the permissible limit and ThlanmualTuikhur, Kawnpui at soil-rich Colluvium deposits of Upper Bhuban Formation and Vengsang Electric GW pump have exceeded acceptable limit during Monsoon. Lalkima hand pump and Vengsang electric GW pump have high values of Manganese concentration that are above the permissible limit observed in Post-Monsoon.

The Aluminium concentration, four spring samples such as Phuanberh, SihpuiTuikhur, Thlanmualtukhur and Khurthuk of Kawnpui town, which geologically belongs to sandstone-dominated Upper Bhuban Formation has elevated Aluminium concentration that exceeds acceptable limit during Pre-Monsoon. In addition, two samples from Dengalui of spring sources at Serkhan and stream water of Khawzasiakalui, Hortoki have surpassed the acceptable limit during Monsoon are fall into the non-potable class in the presence of an alternative source (BIS 2012).

Zinc concentration exceeding the permissible limit is observed from the Substation Peng hand pump, Bukpui, and is thought to be leaching from the bore well facilities of a hand pump. All other samples are well within the permissible limit.

Cadmium concentration is highest from Pre-Monsoon samples, Vankeu spring water of Serkhan and Fului spring of Zanlawn villages are having Cd values exceeding the permissible limit, and Sub-station peng hand pump and Minmawng spring water are also exceeding the permissible limit. Eight sources of spring water from Kawnpui village and three samples from Lungmuat villages fall into non-potable classes. All samples from Hortoki, Nisapui, and N.Chaltlang villages are confined within the desirable limit. During Monsoon, Dengalui spring water of Serkhan has exceeded the permissible limit.

In terms of Lead concentration in potable sources, 8 samples such as Dengalui and Vautangbawk (spring) at Serkhan, Vengsang electric GW pump and Nuhliri point (PHED supplied water) at Bukpui, Fului (spring) at Zanlawn and Hlitlui, Charpui, Sentezel, Khurthuk, and Sihpui springs at Kawnpui are not qualified for consumption during Pre-Monsoon. During Monsoon, 14 sources such as Dengalui (Spring) at Serkhan, Lalthansiama point (PHED supplied water) and Zotui(source) at Nisapui, Minmawng at Bukpui, Fului, and Pumpelh spring sources at Zanlawn and 6 sources from Kawnpui namely Charpui, Kuangsei, Sakhisih, Kuangsei, Khurthuk, and Sihpui spring sources, Tuitun stream water do exceed the permissible limit. Ten sources such as the Lalkima handpump, Vengsang electric GW pump, Sub-station peng handpump, and Minmawng sources at Bukpui, Kuangsei, Kannan, and Sihpui spring sources at Kawnpui, Khawzasiaka and Lungpher stream at Hortoki and Zotui at Lungmuat are not potable during Post-Monsoon.

The Nickel contamination is relatively high in the Pre-Monsoon season, 24 sampling sources and 1 sample from Monsoon are not suitable for drinking purposes. 3 sources each from Bukpui and Serkhan, 1 source each from Lungmuat and Nisapui, 2 sources each from N.Chaltlang and Zanlawn, and 10 sources from Kawnpui exceed permissible limits. Dengalui source of Serkhan falls in the non-potable class during Pre-Monsoon and Monsoon seasons.

In terms of Cobalt concentration, 23 sources, 20 sources and 10 sources of water during Pre-Monsoon, Monsoon, and Post-Monsoon respectively fall in the non-potable class.

The concentration of Strontium within the study area is relatively low. Sandstone-dominant lithology of Upper Bhuban Formation and followed by shale-dominated Middle Bhuban Formation. Unconsolidated sediments and Lower Bhuban Formation has the lowest concentration of Strontium.

Indium concentration in groundwater is uniformly distributed in all units of Lithostratigraphy and Geomorphic indicating that there is little or no influence of lithology as well as the topography of the terrain. The concentration of Indium is detectable only in samples from the Pre-Monsoon season, indicating accumulation of contaminants by anthropogenic activities is readily carried away by runoff or completely diluted by rainwater.

Li concentrations from Dengalui and Vautangbawk springs water at Serkhan, Vengsang electric groundwater pump at Bukpui, Fului stream water at Zanlawn, and Lungpher stream at Hortoki have exceeded 0.01 (Health Based Screening level of Li in groundwater by USGS) are observed. Samples taken during Monsoon and Post-Monsoon are having Li concentrations below the detectable limit indicating that Li is completely depleted by rainwater.

The trend between pH and Gallium dissolving rate is rationalized and was found to be following prior studies, which concludes that the nature of solubility of Ga is highest at around pH 7.4 and lowest at pH 5.2; from the analyzed sources, out of 19 total samples where Gaconcentration was detected, 8 samples were characterized by pH value ranging 6.23 to 6.93 during Pre- Monsoon and the remaining 11 samples were having pH 7.05 to 7.65. Out of 12 samples where Ga concentration was encountered, 7 samples were found to have pH value ranging between 6.42 to 6.92, and 5 samples were characterized by pH value of 5.52 to 5.56 indicating solubility of Gallium is much prevalent at pH value around 6.42 to 6.92.

Hand pump usually has high Iron content, hardness, and alkalinity and sources from bore wells exceeds the Permissible limit in these parameters. It is also noticed that hand pump samples have slightly higher values of Magnesium and Zinc concentration. Lalkima hand pump, N.Chaltlang is characterized by high turbidity, Mn, Fe, etc., it is also found to be located in association with minor fracture(lineament), hence the dumping site on the eastern side along the escarpment slope which is coupled by the dip direction and dip amount may contaminate the groundwater in the deep aquifer.

According to Central Ground Water Board (CGWB, 2014), Arsenic is found in all natural environments in abundance in the earth's crust and in small quantities in rock, soil, water, and air. In sedimentary rock, it ranges from 1.7-400 mg/kg. It frequently occurs in the earth's crust along with pyrites. Pieces of pyrites are usually found in some shale formations and then make semi-consolidated sedimentary rock as a probable source of Arsenic contamination. The evaluation work on a geochemical dataset from Bangladesh sedimentary aquifer shows that the mineral concentration in regards to dietary needs showed that the sedimentary aquifers represented by 731 tubewells in Bangladesh have almost double the concentration of salubrious minerals such as calcium, magnesium, and iron relative to the basement aquifers (Ghana and Tanzania). Moreover, the groundwater of sedimentary aquifers was also found to contain excessive levels of arsenic; levels at which elements pose a serious public health threat (Nwanko*et al.,* 2020). Arsenic was detected at Chawngte, Lawngtlai District of Mizoram (Blick*et al.,* 2016) in southwestern low-lying terrain.

However, Arsenic is absent in all the water samples collected from the relatively high slope and mountainous terrain of the study area.

The PA test shows that 7 samples within the are characterized by the presence of coliform bacteria. These include Zotui (spring) of Nisapui, Bawngpu (spring) of Serkhan village, Lengleh spring from N. Chaltlang village, Lungsumtuikhur and Minmawngtuikhurof Bilkhawthlir, Phuanberhtuikhur of Kawnpui village and Luihnai stream of Lungmuat.