GROUNDWATER POTENTIAL MAPPING AND WATER QUALITY ASSESSMENT IN ZAWLNUAM RD BLOCK, MAMIT DISTRICT, MIZORAM, INDIA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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OCTOBER, 2025

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This is to certify that the thesis entitled "***Groundwater potential mapping and water quality assessment in Zawlnuam RD Block, Mamit district, Mizoram, India***" written by Teresa Lalrinengi Reg No. MZU/ Ph. D/ 1788 of 08.09.2021in the Department of Geology, Mizoram Univeristy for the award of her Doctor of Philosophy in Geology has been written under our supervision.

She has fulfilled all the required norms laid down under the Ph.D Regulations of Mizoram University. The thesis incorporates the student's bonafide research and that these have not been submitted for award of any degree in this or any other University or Institute of learning.

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DECLARATION
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I Teresa Lalrinengi, hereby declare that the subject matter of this thesis is the record of 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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ACKNOWLEDGEMENT

First and foremost, I am thankful to the Almighty GOD for giving me the strength, knowledge, ability and opportunity to undertake this study and complete it satisfactorily.

Secondly, I would like to express my sincere gratitude to my respected supervisor, Dr. Malsawmtluanga, Assistant Professor, Department of Geology, Lunglei Government College, and respected joint supervisor, Dr. Tanvi Arora, Senior Scientist, NGRI, Uppal Road, Hyderabad for their worthy guidance and professional attitude which is appreciable in completing this thesis.

I am deeply grateful to my Grandparents K. Thanpara and F. Thanmawii, parents P.C. Lalhmingmawia and K. Thannghilhlovi, brother Newton Lalrinhlua, sister Ruthi Lalrindiki, sister- in – law Lalnunpuii, nieces Hadasi Lalrinfeli and Rakil Lalrinpuii and cousin brother Timothy Lalrinpuia for their support, appreciation, encouragement and keen interest in my academic achievements and their moral support throughout the research work. My special thanks to my friends Dr. Marina Lalruatfeli, Dr F. Lalbiakmawia, Er. Eliza Vanlalpeka, Lalrinhlua, Vanlalchhanhima and Zonunmawii for their invaluable guidance, feedback, and support throughout my research. Their extensive knowledge and experience were instrumental in the completion of this thesis.

My appreciation also goes to the teaching and non- teaching staff of Department of Geology, Mizoram University for their support and whose resources and assistance have been invaluable. I would also like to acknowledge my peers for their camaraderie and the stimulating discussions that inspired me throughout my academic journey. Their collective wisdom and encouragement have been a cornerstone of my research experience.

Finally, I dedicate this thesis to my family, who instilled in me from a young age the value of education and supported me every step of the way. Their unwavering belief in my abilities inspired me to set high goals and work diligently towards achieving them.

Teresa

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CHAPTER-I

INTRODUCTION

1.1 General introduction:

Water the essence of life, has played a pivotal role in shaping the history of the Earth and its inhabitants. All life forms, including humans are dependent on water for their existence. The evolution of the first known organism began in the ancient oceans and over the course of millions of years, mankind evolved with water continuing to be an indispensable element in the development and sustenance of humankind and life in general.

Throughout history, water has been revered and considered holy in various cultures, and its significance has been the subject of extensive study. It is widely acknowledged that the presence of water has been a driving force behind the establishment and growth of civilizations, with human settlements predominantly thriving in close proximity to water bodies due to the vital resources they provide.

In the context of India, groundwater serves as the primary strategic resource for meeting the country's water requirements. Understanding the characteristics and potential of groundwater is crucial for effective water resource management. The distribution, occurrence, and movement of groundwater in India are influenced by diverse factors such as rainfall patterns, geological features, hydrogeological conditions, and the morphology of the study area. India's vast expanse encompasses distinct geological formations, topographic variations, and climatic conditions, contributing to a wide range of groundwater dynamics.

The geological diversity of India results in variations in groundwater occurrence, with different rock formations giving rise to diverse types of pores and openings that influence the movement and distribution of groundwater. For instance, the high relief areas in the north-eastern region, characterized by the Himalayan ranges and steep topographic slopes, exhibit limited potential for rainwater infiltration and high run-off. Groundwater potential in these terrains is predominantly confined to intermontane valleys, fractured valleys, and gentle hill slopes.

Groundwater plays a critical role in meeting domestic, agricultural, and industrial water demands in both urban and rural areas, making it a valuable resource for sustainable groundwater management. Its relatively lower susceptibility to contamination compared to surface water makes it a preferred water source. The development of groundwater potential maps is instrumental in identifying areas with high potential for groundwater utilization, thereby contributing to improved community livelihood and sustainable water resource management.

In hilly terrains, groundwater occurrences are primarily restricted to weak zones such as fractures, lineaments, and weathered residuum, which serve as conduits for seepage and are a source of springs. These springs are vital for providing water supply to the local population. The discharge of these springs tends to be meager at higher altitudes but increases gradually downstream. Additionally, linear ridges with low permeability and infiltration capacity act as run-off zones, while moderate linear ridges characterized by hard and compact geological formations further limit groundwater potential.

Water scarcity, particularly in rural areas, poses a significant challenge, with water resources predominantly sourced from streams, lakes, rivers, ponds, and wells. However, the quality of water from these sources is susceptible to contamination from various point and non-point sources, including industrial and sewage discharge, urban and agricultural runoff, and excessive use of fertilizers and pesticides. Geographic information system-based studies have emerged as valuable tools for groundwater research, offering rapid and comprehensive insights into groundwater resources for informed decision-making and future development planning.

Despite the critical importance of groundwater, its development is often undertaken without adequate knowledge of its spatial and temporal occurrence. Random drilling of wells based on immediate requirements has led to instances of unproductive wells, resulting in financial losses for users. Over-exploitation of groundwater resources has further exacerbated the situation, leading to decreased water tables and the drying up of wells in several regions. Artificial recharge of groundwater has been proposed to mitigate this issue, as natural recharge alone is insufficient in many areas.

In addition to quantity, the quality of groundwater is of utmost importance, as poor water quality can have detrimental effects on human health and the broader ecosystem. Contaminated groundwater can give rise to chronic diseases and various ailments, underscoring the critical need for comprehensive management and protection of this vital resource.

The comprehensive analysis and computation of groundwater quality is imperative for determining the requisite methods of treatment, development, and management programs. Groundwater stands as one of the most vital natural resources and represents the primary accessible source of fresh water to meet the escalating demand. Typically, groundwater in natural systems contains dissolved solids, minerals, and salts. The chemical composition of groundwater in an aquifer is primarily determined by aquifer gases, the soil zone, soluble minerals, and salts present in the aquifer. An in-depth understanding of the natural groundwater quality can significantly contribute to our comprehension of the nature of this invaluable resource.

The assessment of the natural chemical composition of groundwater can furnish insights into the reactions that produce natural water chemistry, the recharge, movement, mixing, and discharge of groundwater. Notably, rocks in Mizoram exhibit high solubility and contribute a substantial portion of the soluble constituents of groundwater. The prevalent cations include calcium and sodium, while sulphate and bicarbonate are the predominant connate anions. Additionally, a limited amount of chloride is present, attributed to sources such as sewage, connate water, and intruded sewage. Although nitrate is typically a natural constituent, elevated concentrations may indicate past or present pollution.

In the context of evaluating the water quality of the Zawlnuam R.D. Block during the pre-monsoonal season, various physico-chemical analyses, such as pH, alkalinity, iron content, total dissolved solids (TDS), chloride levels, turbidity, and water hardness, are conducted. These analyses are performed using water samples collected from diverse sources, including springs, traditional springs, and groundwater. This meticulous approach to assessing groundwater quality is crucial for ensuring the sustainable utilization and management of this vital resource.

Studies by Arulbalaji (2019), Bhuyan & Deka (2022), Borah & Bora (2025), and Deb & Kenye (2024) demonstrate that integrating GIS, AHP, and thematic layers effectively delineates groundwater potential zones, supporting sustainable groundwater management across diverse regions in India, especially in data-scarce and geologically complex areas.

Sunmin Lee et al. (2020) developed an ensemble FR-BCT model combining remote sensing data and machine learning to effectively map groundwater potential, showing high accuracy and suitability for data-scarce regions.

Studies using GIS and MIF techniques, including those by Borah & Deka (2022), Lalbiakmawia & Vanthangliana (2015), and Roy et al. (2021), effectively identified groundwater potential and quality zones, highlighting issues like poor recharge in the Jamuna watershed, substandard urban groundwater in Aizawl, and potability concerns in West Tripura—emphasizing the need for region-specific planning, monitoring, and treatment.

Ahmed & Rao (2019) and Barman & Biswas (2022) utilized DEM and GIS for terrain and watershed analysis, revealing tectonic influences in the Tuirini River Basin and classifying groundwater potential in the Vanvate Lui Basin to address seasonal water scarcity and improve resource management in Mizoram.

Biswas et al. (2023) used AHP-TOPSIS and AHP-VIKOR models to map spring water suitability and watershed vulnerability in Aizawl District, identifying central areas as both highly suitable and heavily impacted by human activities, with ROC analysis validating model accuracy.

Ritse et al. (2020) analysed long-term LULC changes in Nagaland, revealing rapid urbanization with loss of forest and agricultural lands, increased aquaculture in Dimapur, and waterbody shrinkage in Kohima linked to poor urban planning.

Aherwar et al. (2023) reviewed RS-GIS integration for groundwater mapping, highlighting its cost-effectiveness in data-scarce areas but noting challenges like non-standardized methods, subjective layer weighting, and the need for field validation.

1.2 Aim and Objectives:

This research work aims to evaluate the current status of the ground water resources of the district and identifying potential zones of ground water recharge for rejuvenation of ground water resources.

The main objectives of the present study are:

1) To prepare geological, geomorphological, lithological, structural, rainfall, land use/land cover, slope, soil and drainage thematic maps.

2) To prepare a groundwater potential map for Zawlnuam RD Block in Mamit district.

3) To identify zones of potential ground water recharge areas to augment artificial recharge.

4) To assess the physico-chemical groundwater quality of different water sources.

5) To assess the geological impact of rock-water interaction on the quality of potable water.

6) To demarcate vulnerable water sources in the area along with potable remedial measures.

1.3 Outline of thesis:

The current thesis is structured into eight comprehensive and intricate chapters, each contributing to the holistic understanding of the research work. Chapter I meticulously delineates the fundamental introductory aspects, setting the stage for the extensive exploration to follow. Additionally, this chapter succinctly outlines the aims and objectives of the study, providing a clear roadmap for the ensuing chapters. Moving forward, Chapter II delves into the intricate regional geology and stratigraphy of Mizoram, meticulously unraveling the geological intricacies specific to the region.

Chapter III assumes a comprehensive stance, presenting a meticulous review of the extensive body of relevant published literature. This inclusive review encapsulates previous research efforts within the domain of groundwater assessment, enriching the thesis with a deep historical and theoretical context. The diligent detailing of the materials and methods utilized in the study is meticulously curated within Chapter IV, providing an invaluable resource for researchers and practitioners in the field.

Chapter V takes on the responsibility of presenting a comprehensive overview of the study area, enriching the reader's understanding of the contextual factors shaping the research. Furthermore, Chapter VI meticulously reviews water quality analyses by employing diverse methods, enriching the thesis with a multifaceted perspective.

Chapter VII meticulously presents the culmination of the research efforts, offering a detailed exposition of the results and fostering an in-depth discussion around their implications. This chapter serves as a testament to the exhaustive nature of the research, providing valuable insights for further exploration and practical applications.

Finally, Chapter VIII serves as the intellectual culmination of the thesis, encapsulating the summary and conclusions drawn from the extensive research. This chapter offers a reflective space for the synthesis of key findings, paving the way for future research endeavors and practical implications.

1.4 Background:

The escalating demand for water supply is attributable to the rapid increase in population, urbanization, and extensive usage in agricultural and industrial sectors (Choudhary et al., 1996; Majumder and Sivaramakrishnan, 2014). Groundwater, as one of the most crucial natural resources and the primary source of fresh water, is facing significant pressure due to these factors (Sharma and Kujur, 2012; Neelakantan and Yuvaraj, 2012). Consequently, the identification of potential groundwater areas, along with the monitoring and conservation of this invaluable resource, has emerged as a critical concern for modern civilization (Kumar and Kumar, 2011).

Mizoram, a region that historically benefitted from abundant rainfall and a substantial number of perennial streams, now grapples with water shortages in the post-monsoon season. This scarcity is mainly a result of the considerable loss of rainwater as surface runoff (CGWB, 2007). Geologically, the area is characterized by ridges with steep slopes and narrow intervening synclinal valleys (GSI, 2011), contributing to a general shortage of groundwater due to rapid surface runoff of monsoon rainfall.

The ever-increasing demand for water supply necessitates the use of advanced and scientific techniques to identify potential groundwater areas in a time and cost-

effective manner. The emergence of geospatial technology, such as Remote Sensing and GIS, enables rapid and cost-effective survey and management of natural resources (Ramakrishna et al., 2013). These techniques find wide-ranging applications in the field of geosciences, particularly in groundwater prospecting (Anirudh, 2013). Satellite remote sensing offers the capability to analyze various ground features, such as geological structures and geomorphic features, which may serve as indicators of the presence of groundwater (Raju et al., 2013). GIS techniques can be employed to delineate groundwater prospect zones by overlaying various geospatial data (Dey, 2014). Many researchers have successfully utilized these techniques in groundwater studies (Sinha et al., 2012; Krishnamurthy et al., 2000), demonstrating their potential value in hydrogeology and the development of surface water resources (Sharma and Kujur, 2012).

Furthermore, the poor quality of water negatively impacts crop productivity and industrial processes. Industrial effluents and agricultural wastes often contaminate water bodies, limiting their use for recreational purposes and causing adverse effects on aquatic ecosystems and groundwater systems (Lee et al., 2002). Contamination of underlying soil, surface water, and groundwater may also occur due to petrochemical leaks from underground petroleum storage tanks and leachates from landfill soil (Wagh et al., 2014). Additionally, the concentration of carbon dioxide in the air and the type of rocks in an area can influence groundwater quality (Laldintluanga et al., 2016).

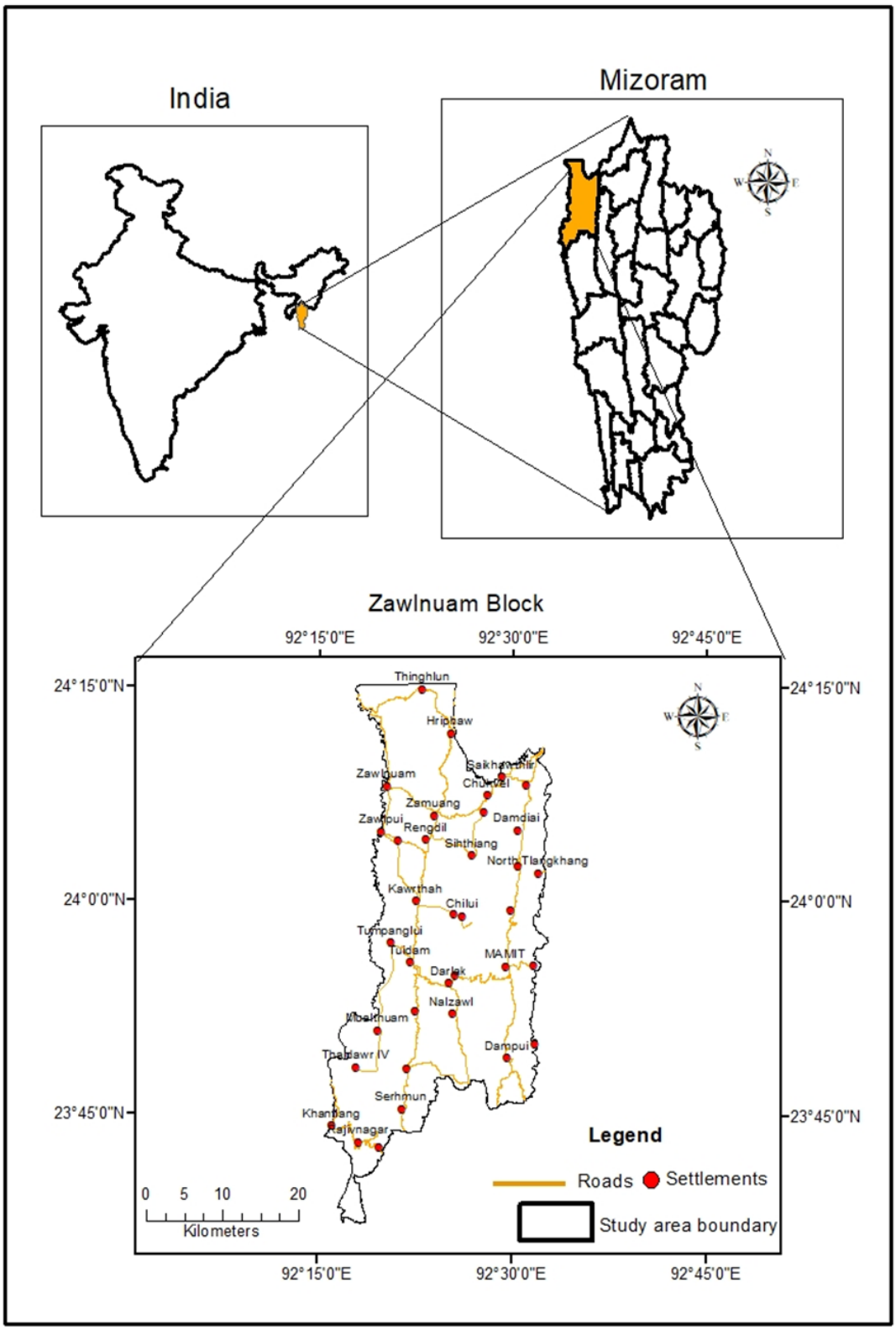
In North East India, arsenic contamination has been detected in several districts of Assam, Tripura, Arunachal Pradesh, Manipur, and Nagaland. The recent detection of arsenic in the Cachar and Karimganj districts of Barak Valley, Assam, underscores the severity of this issue (Saikia and Gupta, 2012). Anthropogenic factors, such as the use of chemical fertilizers, pesticides, and industrialization, contribute significantly to the pollution of various water sources. Moreover, animal and human excrement further exacerbate water pollution, leading to the prevalence of waterborne diseases. Extensive research has been conducted on the quality of groundwater with respect to various anthropogenic activities (Deshmukh, 2013; Nandwana and Chhipa, 2014).

The advent of geospatial technology has facilitated fast and cost-effective survey and management of natural resources, particularly in geo-scientific research. Many researchers have successfully utilized these techniques in groundwater quality studies, further highlighting their potential for assessing and analyzing the conditions of groundwater in various regions (Karthikeyan et al., 2013). Hence, spatial technology, combined with laboratory analysis, will be crucial in assessing and analyzing the groundwater conditions in the northern arcuate of Mizoram, India.

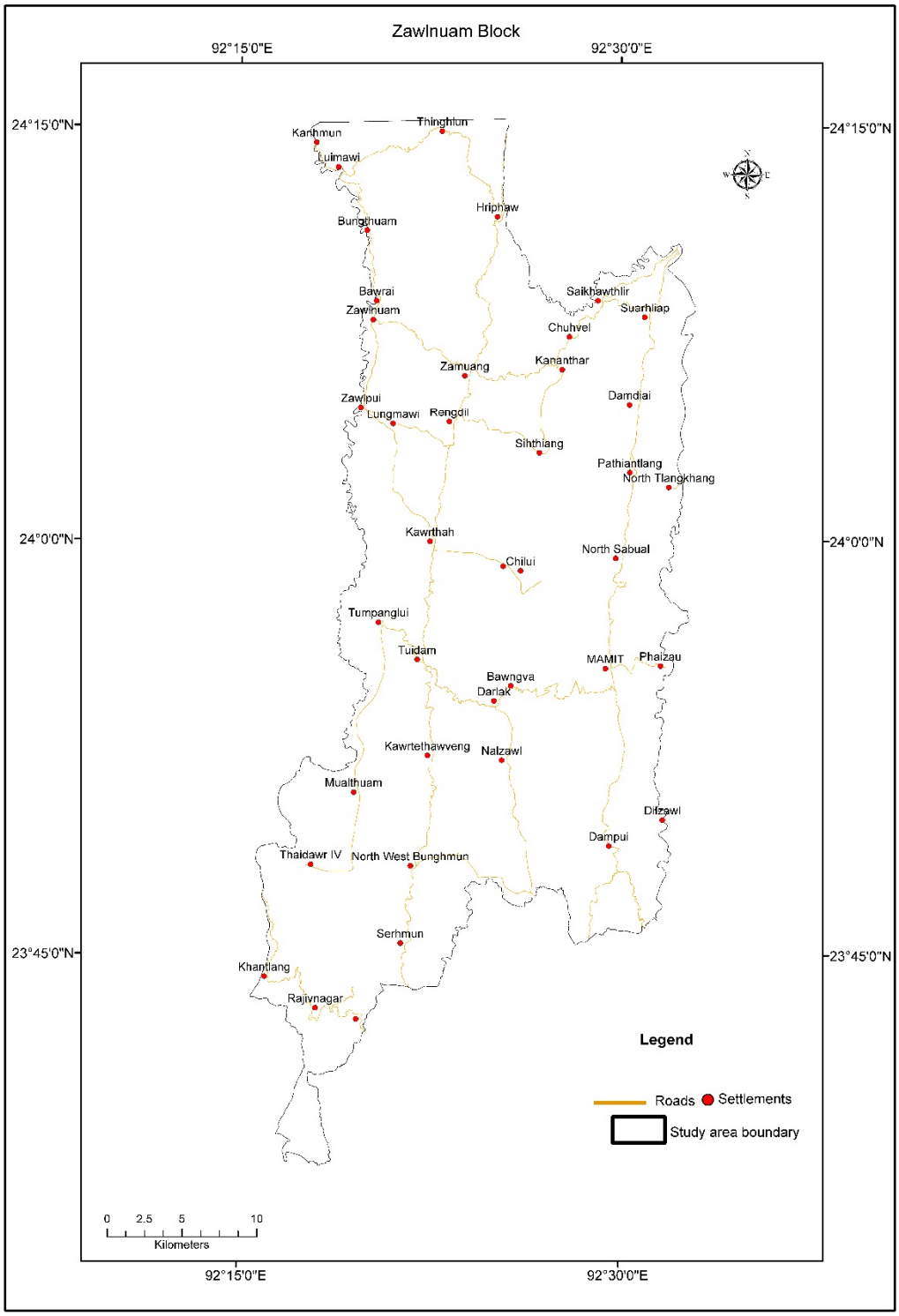
1.5. Location of the study area

The study area of Zawlnuam RD block is situated in the northwestern section of the Mamit district, located in the northwestern part of Mizoram. It shares its borders with Tripura to the west. Geographically, the study area spans from 23º 40’ 38.88” N to 24º 15’ 12.60’ N latitudes and 92º 15’ 13.18’E to 92º33’ 00” E longitudes, covering an approximate area of 1170 sq. km. Zawlnuam RD block is surrounded by Assam to the north, Mamit RD block to the south, Kolasib district to the east, and Bangladesh to the west. The area falls within the Survey of India Topo sheet numbers 83 D/7, 83 D/8, 83 D/11, 83 D/12, 84 A/5, 84 A/6, and 84 A/9.

The study area experiences a moderate climate due to its tropical location, characterized by neither extreme heat nor cold throughout the year. Furthermore, the area is well-connected by road transportation, facilitating easy accessibility from various parts of the state. These geographical and climatic features make the study area of Zawlnuam RD block an interesting subject for further academic exploration and research.The propose study area of Zawlnuam RD block is located in the north western sectionofMamit district in the north western part of Mizoram which borders Tripura to the west. Location of study area is shown in Map 1.



Map 1: Location of the study area



Map 2: Study area Map

CHAPTER – II

REGIONAL GEOLOGY AND STRATIGRAPHY OF MIZORAM

2.1. REGIONAL GEOLOGY

Geologically, the north-eastern region of India showcases a diverse stratigraphic sequence encompassing the Pre-Cambrian era through to the Quaternary period with notable intervals in between. The Indo-Burma mountains and north-eastern India contain various tectonic units and geological structures: the Himalayan Arc in the north-eastern Himalaya, the Indo-Burma mountains, the Burmese Arc, the Eastern Himalaya Syntaxis, the Shillong-Mikir Massif, the Assam Valley and the Bengal Basin. The oldest geological formation in the region is the pre-Cambrian gneissic complex of the Meghalaya plateau and the Karbi-Anglong plateau which are both part of Gondwanaland. The Himalayas located on the northern border of the region ranges in height from 1,500 – 8,800 meters above mean sea level (MSL) and consist of formations ranging in age from Protozoic to early Palaeozoic. The southern part of the mountains contains low-grade metamorphic rocks, while the higher sections consist of high-grade schists. The foothills of the Himalayas are made up of Tertiary rocks primarily Mio-Pliocene deposits formed after the major orogenic mountain-building phase. The remaining area comprises of Tertiary rocks with various marine characteristics, spanning from the Eocene to the Pliocene period. The Indian plate northward, northeastward and eastward movement has resulted in multiple thrusts. The Himalayan Main Boundary Thrust (MBT) and the Naga–Naga–Disang Thrust separate the Himalayas and the eastern hilly region from the Brahmaputra valley. The significant fault of the area is the Dauki fault, which runs from west to east and divides the Meghalaya plateau from Bangladesh with a vertical displacement of over 1,000 m. This fault along with some Cretaceous deposits at 1,200 m above mean sea level (MSL) indicating an uplift of the plateau after the Cretaceous period. The north-south ridges and valleys of Mizoram, formed by Neogene sediments represent the upward and downward folds caused by compressional movement from the east. The Indo-Myanmar plate

boundary is characterised by hills resulting from the Indian plate being pushed underneath and the presence of ophiolite in the region (GSI 2011).

2.2 GEOLOGY OF MIZORAM

The Cenozoic rocks are extensively found in the north-eastern region of India, covering around 70% of the area. This area is home to the Surma basin which is a sedimentary succession reaching approximately 13 kilometers in thickness. The sedimentary column in Mizoram is predominantly made up of repetitive layers of sandstone, siltstone, shale, mudstone and various mixtures along with pockets of limestone, calcareous sandstone and conglomerates. The Tertiary succession in Mizoram is categorised into three groups: the Barail (Oligocene), the Surma, and the Tipam Groups (Upper Oligocene to early Pliocene) in ascending order. For detailed information on the stratigraphic succession of Mizoram and the characteristics of each litho unit, please refer to Table 1.

Group	Formation	Lithology
	Recent	Loose, friable and unconsolidated pebbles of sandstone and fragments of shale in sandy matrix.
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interlaminated with siltstone which exhibit weathering of pink, violet, greenish, grey and white colorations. Weathered micaceous, feldspathic, soft and medium grained sandstone are mostly confined and one important feature which set Barail Group of rocks apart from Bhuban Formation is that it consists of sedimentary structure like flute casts.

Surma Group: Surma group is divided into two main sub-groups of rocks, which are (a) Bhuban and (b) Bokabil.

Bhuban Formation: Bhuban sub-group is sub divided into three formations, which are:

1. Upper Bhuban formation

2. Lower Bhuban formation

3. Middle Bhuban formation

a) Upper Bhuban Formation: The Upper Bhuban formation underlies conformably the Bokabil Formation and in most cases the contact is gradational, and a faulted. This formation covers the whole area; and rather covers the whole hill ranges of central and western parts of the state. The whole hill ranges comprise mostly of massive, brownish, comparatively soft friable, to some degree it is weathered, medium grained sandstone usually containing garment and patches of shale, in the eastern parts of the state there are mainly hard grained grayish sandstone. The upper Bhuban is predominantly argillaceous and comprises mostly of shale, mud stone, siltstone, thin interlamination of varying amount of shale, silt and sand and massive to well bedded with argillaceous sequences of varying thickness.

b) Middle Bhuban Formation: This rock formation conformably overlies the upper Bhuban is predominantly argillaceous and comprises mostly of shale,siltstone, thin interlamination of varying amount of shale, silt and sand and massive to well bedded with argillaceous sequences of varying thickness.

c) Lower Bhuban Formation: Lower Bhuban formation comprises mainly grained massive sandstone. This rock formation is found mostly in part of the district bordering Myanmar. At some places there are well compact, fine to very fine-

grained sandstone bands inter bedded with comparatively thinner bands of siltstone and shale.

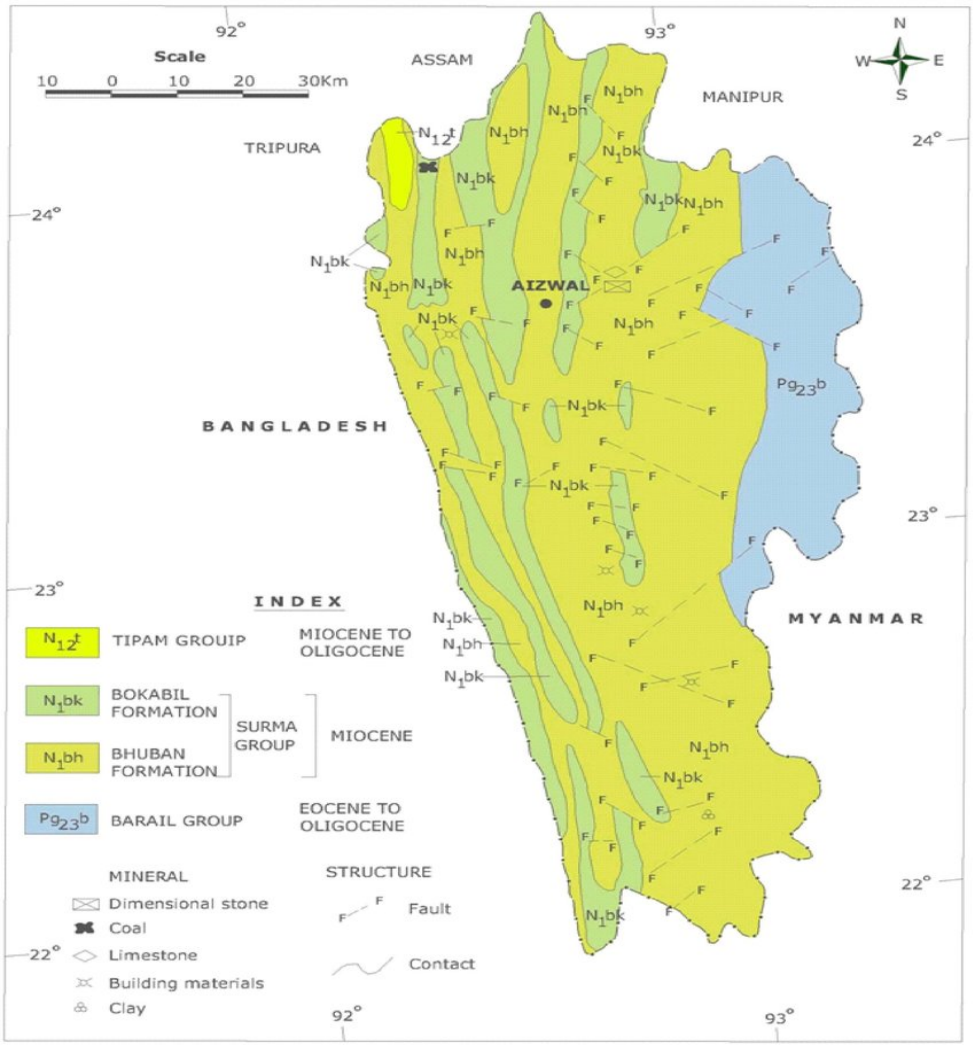
Bokabil Formation: The rocks belong to this formation occurs conformably over the upper Bhuban and is represented by soft, friable, loosely packed medium to fine felspathic sandy grey wacke, sandy shale with interlaminated silt or shale alternation. The rocks of this formation exposed typical turbidity features with multiple grading and ripple drift cross lamination, cross bedding and large current bedding are also present. The shale is generally grey and brownish yellow colour which is widely exposed in the western part.

Tipam Group: The Tipam Group is exposed in the extreme northwestern part of Mizoram comprising of grey to ash grey massive friable coarse-grained sandstone with minor lenticular buff and bluish plastic clay bands (Ganju, 1975). Tipam Group in Mizoram extends about 900 meters in thickness consisting of medium to coarse ferruginous with plenty of molluscan fossil and petrified wood occurs only on the northern and western part of Mizoram.

2.3. STRUCTURE OF MIZORAM

Structurally, the hills of Mizoram are considered to be forming an integral part of the mobile belt constituted of very tight, elongated, double plunging folds. The folds are sub-meridionally trending anticlines alternating or en-echleon with broad saucer shaped synclines in which the belt slightly accurate in with western convexity (*Shrivastava et al.,* 1979). The intensity of deformation becomes progressively lesser from east to west across the fold belt and the succession also becomes younger in the same direction. Thus, the western flank of the state along with the neighbouring areas i.e., Tripura and Cachar district of Assam are typified by younger rock formations folded into narrow, box like anticlines in alternation with wide and flat synclines, while the eastern part of the state is characterized by relatively older rock formations folded into tight, linear anticlines and synclines (Ganguly, 1974). There are around fifteen major long and arcuate anticlines and corresponding synclines in the region (Nandy et al., 1973) in which the anticlines and synclines are commonly dislocated by numerous longitudinal faults and thrusts. The magnitude of the faulting

generally increases with an increase in the intensity of folding to the east. The hill ranges mainly comprise of compact and resistant older unit exposed in the anticlinal crests, whereas the valleys are composed of younger and softer formation exposed in the synclinal troughs (Ganguly, 1974). Tectonically, Mizoram forms a part of the Indo-Myanmar fold belt. The arcuate shape of this fold belt is the result of the eastward subduction of the Indian plate along the Arakan-Yoma saucer during Eocene time (Nandy, 1983). Neogene succession deposited in the mobile belt is deformed into a series of sub-parallel folds by both horizontal compressions as well as by vertical motion (Nandy and Sarkar, 1973). The geological map of Mizoram is shown in Map 3.



Map 3: Geological map of Mizoram (Behra et. al., 2011)

2.4. GEOLOGICAL HISTORY OF MIZORAM

The geology of Mizoram is completely comprises of Tertiary sediments and is considered as part of the Surma Valley. It is formed by the collision of Indo-Burmese plates. The Surma Basin was estimated to be evolved during late Oligocene period with depositional environment of shallow marine environment which are deformed into fold and fault. The Surma Basin was subjected to transverse faults and thrusts which trend towards NE-SW, ENE-WSW and NW-SE direction. The most prominent transverse fault found in Mizoram, 'Mat River Fault' is located between Aizawl and Lunglei district and trends along the NE-SW direction. The strike direction of the rock formation is N-S with dip amount varying from almost horizontal to vertical dipping either towards east or west.

2.5. CLIMATE AND RAINFALL IN MIZORAM

Mizoram enjoys a moderate climate due to its tropical location and is neither very hot nor too cold throughout the year. The climate is usually humid tropical, characterized by short winter and long summer with heavy rainfall. The climate of Mizoram is pleasant. It is generally cool in summer, the temperature ranging from 8°C to 29°C whereas during the winter the temperature varies from 11°C to 24°C. The average annual rainfall is about 254 cm. There are dense forests in the valleys and hill slopes. Bamboo is the most important forest produce. Wild animals include elephants, tigers, leopard, bears, Mithun, deer, etc. The climatic condition of Mizoram in general is cool and wet and the Western part is warmer than the Eastern part. During last two decades, rapid increase in temperature has been noticeable, mainly due to the large-scale degradation of vegetation and mismanagement of environment. During winter, the lower temperature is felt at places having higher altitudes usually at the eastern parts and maximum temperature in summer is observed at relatively lower places of western side. The whole region falls under the direct influence of the South-West Monsoon. As such, the region receives an adequate amount of rainfall every year. The region receives heavy rainfall during May to September and increases southward with the increase in humidity. In the year 2010-2001, the total rainfall was 9,876 mm. and in 2001-2002 the total annual rainfall was 88,018 mm. The average annual rainfall in Mizoram during the year

2000-2001 was 8,230.08 mm; while during 2001-2002 it reduced to the average of about 7,334.83 mm. The maximum rainfall is between the month of May and September. The average rainfall received is estimated to be around 275 cms per annum and the north western part of the state receives the highest rainfall i.e., more than 350 cms per annum. The rainfall also increases southward with the increase in humidity thus receiving an average amount of 250 cms rainfall. Despite its tropical location Mizoram enjoys a moderate climate which is mainly due to its high elevation. The temperature does not fluctuate much throughout the year except in the low-lying valleys and the temperature is usually between 18℃ to 25℃ in autumn, 11℃ to 23℃ in winter and 25℃ to 34℃ in summer.

2.6. FLORA AND FAUNA OF MIZORAM

Mizoram is bounded by Bangladesh on the west and Myanmar on the east and south and in terms of biodiversity habitat it falls within the Indo- Malayan bio- geographic region. Mizoram has a very wide range of flora and fauna in which the Himalayan Maple and Bamboo are one of the most important trees. The state is also the home for various rare species of orchids and home to a large family of birds and animals and many reptiles, amphibians, fish and inverterbrates are also present. Various species of moths and butterflies re also found in the hills of Mizoram. There are 1 Tiger reserve, 7 wildlife sanctuaries and 2 national parks in Mizoram.Mizoram is a land of rolling hills, rivers and lakes and is characterized by its physical set up which mainly composed of its hilly and mountainous terrain of tertiary rocks. It shows prominent relief features with steep slopes with average elevation of about 900m from mean sea level. The elevation of the mountains ranges from 21 meters at Tlabung to 2,157 meters at Phawngpui (the Blue Mountain).

The hills tend to trend in NNW-SSE to NNE-SSW direction in parallel series in which the central part of the state is higher and tapper towards north and south. The relief is low on the western part and higher towards the east. A distinctive feature of Mizoram is that the mountain ranges in the western part all have higher degrees of slope and the ridges are characterized by relatively compact and resistant older rock units, whereas the valleys and the synclinal trough are composed of younger and softer formations (Ganguly, 1983). The geographical area covered by Mizoram is

21,087 square kilometers, which constitutes 0.64 per cent of the total geographical area of India and length from North to South is about 277 kilometers and width from East to West is about 121 kilometers. The longitudinal and latitudinal extent of Mizoram falls between 92°16‟E to 93°26‟E and 21°56‟N to 24°31‟N and has an international boundary with Bangladesh and Myanmar. The exact length of this international boundary in the west with Bangladesh is ≈404 Km and in the east with Myanmar is ≈318 Km. And the state has inter-state boundary with Assam on the North (≈123 Km), Tripura on the North West (≈66 Km.) and Manipur on the North East (≈95 Km.). Being sand-witched between Bangladesh and Myanmar, location of Mizoram has strategic significance geographically and politically. The tropic of cancer, i.e., 23° 30' North latitude cuts across the region through Champhai district, Kolasib district and Mamit district of Mizoram.

The ranges in this region are running from North to South direction, which tends to be higher in the east than the west and the highest elevation is 2,157metres above mean sea level. There are a number of parallel hill ranges running in North South direction separated each other by deep and narrow valleys occupied by sedimentary rocks of conglomerates, sandstones, shales, etc. and various inter-mixture of the different types. The general geology is represented by a repetitive succession of arenaceous and argillaceous sediments and the first geological studied of Mizoram was made by La Tauche (1891). According to La Tauche, the area consists of a great flyschfacies of rock comprising monotonous sequences of shale and sandstone, which are thrown into N-S trending folds and is believed that the rock is in fact, the southernly continuation of those rocks forming the Cachar hills and were probably laid down in a delta or estuary of a large river during the Late Tertiary period.

2.7. DRAINAGE SYSTEM OF MIZORAM

The terrain of Mizoram is very young and immature and shows prominent features with steep slopes and it still undergoes denudation in response to various exogenetic (isostatic gravity) processes. Since the terrain is very young the land does not show much diversity in its landform formation. The most prominent cause of the present landform is running water and the physiographic expression of the running water is inclined north to south direction, mostly anticlinal, longitudinal, and parallel to sub-

parallel hill ranges and synclinal narrow valleys with a series of parallel hummock or topographic high. The degrees of slopes are higher in the western mountain ranges and thus the eastern mountain ranges have gentler slopes. The flat lands are mostly of inter-valley plains and are in the middle of hills and narrow valleys.

The drainage patterns are of mainly dendritic, rectangular and parallel and its bifurcation ratios follow the N-S trending depression and gorges in the low-level topography. Large scale structural control is evident and due to its high relief and high receive of rainfall, the dissection is very prominent. The widths of valleys increase towards the north and south and other geomorphic elements such as gorges, cols, keels, spurs are developed due to intensive erosion mostly by water. A number of rivers, streams, etc. of various patterns and length actively drain Mizoram. Surface configuration like slope, relief and dissection are important factors, which affect the development and patterns of drainage system of the area. Mizoram has six important drainage systems; which are Tlawng Drainage system, Tuirial drainage system, Tuivawl drainage system, Tiau drainage system, Chhimtuipui drainage system and Khawthlangtuipui Drainage system. River Tlawng is the longest river in Mizoram, which measures 102 Km inside the state and originates from Zopui hill, some 8 km east of Lunglei Town, at the height of 1395m which flows towards north and is navigable by small boats throughout the year and is regarded as the most important channel of water transport in Mizoram. It cuts the region into two almost equal parts and after confluence with other smaller rivers, it enters into Cachar hills. Tuirial river is also navigable by small boat to a considerable length and originates from Chawilung hill which flow Northward to join Barak River in Assam. The Eastern fringe of the state is drained by |iau drainage system. It is a demarcating line between India and Myanmar; it flows Southward direction to join river Tuipui and again join river Chhimtuipui on the southeast. Meanwhile river Chhimtuipui drains the south-eastern part of Mizoram. The main river Chhimtuipui is the biggest river in Mizoram by volume which originates from the western part of Myanmar, and flow southward direction.

2.8. SOIL OF MIZORAM

Northeastern Indian state of Mizoram has a varied topography and climate that are ideal for the growth of a wide range of crops. Hills, valleys, plateaus, and plains make up the state's topography, which has resulted in a variety of soil types in Mizoram. The six main types of soil found in Mizoram are red soil, laterite soil, alluvial soil, mountain soil, peat soil, and clay soil, according to the Soil Survey of India (SSI). A noteworthy fact regarding the soils of Mizoram is that hills make up nearly 70% of the state's entire land. This indicates that over time, weathering and erosion processes have carved out the majority of the soils found in Mizoram from parent rocks like granite and gneiss. Recognizing the features and attributes of every kind of soil it is essential for farmers in Mizoram to choose crops and farming techniques that will optimize output while protecting the environment.

1. Red soil: Because of their unique qualities and potential for increased agricultural output, Mizoram's red soil properties and characteristics are significant. Igneous rocks like granite, gneiss, and basalt weather and produce red soil, a type of lateritic soil. Its color varies from deep red to yellowish-red because iron oxide minerals are present. Red soil has various textures, ranging from sandy to clayey, with excellent drainage characteristics. Red soil has special qualities that make it important for agriculture. It is appropriate for producing crops including tea, coffee, rubber, legumes, oilseeds, and tea because of its high concentration of aluminum, calcium, magnesium, and potassium. While holding moisture during dry intervals, the excellent drainage qualities shield against waterlogging during the rainy season. As a result, farmers don't have to worry about crop failure during the entire growing season. Because red soil may filter contaminants out of water before they reach rivers or groundwater sources, it also serves a crucial role in preserving ecological equilibrium. Additionally, by retaining nutrients inside its layers, it serves as a natural reservoir for these essential elements for plant growth. The composition and applications of laterite soil are crucial to Mizoram's agricultural sector. Because of its unique qualities, this kind of soil is ideal for growing a variety of crops in the area.

2. Laterite soil: Due to its excellent load-bearing capacity, laterite soil, which is made up of iron and aluminum oxides, is frequently utilized in road construction projects. In tropical areas with a lot of rainfall, weathering and leaching processes create this kind of soil. Because of its high acidity and nutrient shortage, laterite soil has very low fertility when compared to other soil types. To increase its fertility, it can be supplemented with minerals and organic matter. Road construction is not the only application for laterite soil, despite its low fertility. Because of its strength and longevity, it is frequently utilized as a building material for houses and other structures. It can also be combined with lime or cement to make a solid foundation for buildings. A more crucial application of Agriculture makes use of laterite soil. This kind of soil can be made more productive by adding organic matter and fertilizers, even though it is not naturally fertile. In hilly regions where other types of soils are less suited, farmers have in certain circumstances even employed laterite soils for terrace farming. The manufacturing sector might benefit from laterite soil due to its distinct qualities. Because of its durability and erosion resistance, it's perfect for making weather-resistant ceramics, tiles, and bricks. Although laterite soil has many applications in a variety of industries, it's vital to remember that it might not always be the greatest option for certain tasks, including gardening or landscaping projects where more rich soils might produce better results. Shifting now turn our attention to alluvial soils, their formation process, and how they differ from the two previously stated types of soils prevalent in Mizoram's terrain. This leads us from the study of the composition and applications of laterite soil.

3. Alluvial soil: Alluvial soil is a dynamic soil type that is created by the constant movement of water, resulting from the deposition of sediments transported by rivers and streams. The weathering and erosion of rocks, minerals, and organic matter—which are carried downstream by flowing water—begins the formation process. Over time, these materials settle and create layers of sedimentary deposits in riverbeds, floodplains, deltas, and estuaries. Because of the range of nutrients that make up alluvial soils, including calcium, magnesium, phosphorus, potassium, and nitrogen, these soils have high fertility levels. These nutrients are capable of supporting a wide range of plant life, including crops like rice paddies, which are typically found in low-

lying regions of Mizoram with alluvial soil has made it one of the most sought-after soils for farming globally, but maintaining its vital characteristics—such as its nutrient content and drainage capacity—requires appropriate land management techniques. Mountain soil, in contrast to the dynamic qualities of alluvial soil, has various characteristics that make it unsuitable for crop development, including steep slopes and shallow depth.

4. Mountain soil: Like a difficult jigsaw, mountain soil poses a number of challenges to crop development because of its shallow depth and steep slopes, which can restrict the amount of water retained and nutrients available. Because of Mizoram's hilly terrain, which ranges in elevation from 200 to 2,500 meters above sea level, mountain agriculture is the most common type of farming in the area. The main components of mountain soil are minerals and worn rocks, with varied amounts of organic stuff. These soils have a high inclination, which makes erosion a typical occurrence and causes topsoil and nutrient loss. It is impossible to overestimate the influence of topography on soil fertility in mountain agriculture in Mizoram. Terracing is one of the soil conservation techniques that has been brought to the area, although growing in them because crop plants and tree roots compete for the same nutrients. Because of this, farmers need to apply fertilizers sparingly and choose planting strategies that maximize nutrient uptake. It's crucial to remember that, despite their limits, mountain soils continue to be essential resources for maintaining agricultural productivity in the region as we proceed into our discussion of peat soil development and conservation in Mizoram. Although their shallow depth and limited capacity to retain nutrients may present some difficulties, enhancing soil quality through sustainable land management techniques may significantly increase agricultural productivity on these soils and protect natural resources for future generations.

5. Peat Soil: A special kind of organic soil known as peat is created when partially decomposing plant matter builds up under damp conditions. It is acidic due to its low pH and high carbon content. Bogs, swamps, and wetlands all contain peat soil. Its creation is a gradual process that involves the accumulation of layers of biological debris over thousands of years. The following are some fascinating facts regarding peat soil: Throughout the world, peat soil is a major source of fuel. Peatlands store a

lot of carbon dioxide and function as carbon sinks. Nevertheless, they release this stored carbon into the atmosphere when they are disturbed or drained for development or agricultural reasons. methods of conservation including replenishing peatlands and minimizing human interference can aid in protecting these priceless ecosystems. Certain plant and animal species that have evolved to survive in wet conditions can be found in peat soils. Peatlands are important ecologically, yet human activities like mining and draining pose a threat to them globally. Peat soils are crucial for regulating the global climate and have a substantial impact on the local environment. Thus, conservation measures are needed to keep them from degrading any more. We shall talk about the benefits and drawbacks of clay soil, another form of soil, for agriculture without sacrificing environmental integrity, in the next part.

6. Clay soil: One of the most prevalent forms of soil, clay soil, has benefits and drawbacks in terms of agricultural productivity. Holding water and nutrients properly is one of its key advantages. This makes it perfect for crops like rice, wheat, and soybeans that need a steady supply of nutrients and moisture. Furthermore, clay soils may hold onto positively charged ions like calcium, magnesium, and potassium that are necessary for plant growth because of their high cation exchange capacity (CEC). Nevertheless, there are several drawbacks to farming in clay soil. One significant disadvantage is that because of its high density and small particle size, it compacts quickly. Root growth is impeded by compacted soil, which lowers crop output overall. Another issue with clay soil is drainage; because it retains water so well, excess water can accumulate in low-lying areas leading to waterlogging or even flooding. This can be detrimental for many crops that do not thrive in excessively wet conditions. Overall, the choice to use clay soil for farming should take into consideration both its advantages and disadvantages. While it can provide ideal growing conditions for certain crops if managed properly through techniques like tillage practices or cover cropping systems that improve soil structure and drainage over time without harming beneficial microorganisms living within the soil ecosystem – farmers need to carefully weigh these benefits against potential challenges before making a final decision on using this type of soil in their fields.

CHAPTER-III

LITERATURE REVIEW

Saaty (1980) introduced the Analytic Hierarchy Process (AHP) as a decision-making tool designed to facilitate the selection of optimal solutions from a set of alternatives based on a predefined set of evaluation criteria. This method has seen widespread application in the generation of groundwater potential maps through the integration of remote sensing techniques.

Shah et al. (2001) projected a looming crisis of groundwater overexploitation, underscoring the necessity not only for innovative supply-side interventions but also for the implementation of diverse corrective measures that necessitate a shift from resource development to resource conservation.

In a study conducted by Kumar et al. (2009), an analysis of water samples from the Tuichhuahen river in Kolasib district was carried out to assess the physico-chemical and bacteriological characteristics, aiming to determine the potable water's quality. The results indicated that water supplied by the PHED exhibited better quality compared to that from the tuikhurs. However, both sources, utilized for drinking and domestic purposes, were found to generally adhere to the tolerance limits.

Subsequently, Kumar et al. (2011) conducted research on arsenic pollution levels in potable water within the northern region of Mizoram state and southern Assam state in India. The study revealed that certain locations in the alluvial sediment aquifers in southern Assam exceeded the permissible arsenic levels, while no detectable arsenic contamination was found in Mizoram.

In another study, Blick (2017) characterized and assessed the quality of drinkable water sources in Mizoram's SW Lawngtlai district. Elevated concentrations of lead, manganese, and arsenic were observed, surpassing permissible levels. Moreover, a correlation was noted between low-lying areas and the obstruction of groundwater movement, with rock-water interaction being suggested as the cause of the high arsenic concentrations, and sedimentation in shallow wells leading to elevated manganese levels.

In their more recent work, Kumar et al. (2020) emphasized the importance of integrating indigenous knowledge and active participation of native communities in disaster risk reduction and management, particularly in addressing water scarcity in Mizoram.

Furthermore, Kumar et al. (2013) utilized GIS-based techniques to map groundwater quality in the central portion of Proddatur town, Y.S.R. Kadapa district, Andhra Pradesh, India. Water samples from forty-three wells were collected, and various parameters including pH, total hardness, calcium, magnesium, chloride, fluoride, and alkalinity were analyzed using Arc GIS 9.3 and GPS technology.

In a separate study by Lalchhingpuii et al. (2011) the analysis of Sulphate, phosphate-P, and nitrate-N contents of Tlawng river near Aizawl City, India revealed that sulphate levels remained within the approved range established by WHO and BIS. The study also found that sulphate readings were lower during the monsoon season and higher post-monsoon, potentially due to increased biological activity and decreased river flow. Additionally, the study highlighted the impact of sulphate on sewage corrosion, odor, and phytoplankton growth. Phosphate levels observed during the study period were within the permissible limits set by BIS and WHO, with higher values in the pre-monsoon and monsoon seasons attributed to anthropogenic sources. The study emphasized the role of phosphate as a necessary plant nutrient and its influence on phytoplankton growth in aquatic environments.Furthermore, the study found that nitrate values remained within the allowable range provided by BIS and WHO, with low nitrate amounts in winter and higher values during the rainy season. The study emphasized the diverse uses of nitrates in the chemical industry and highlighted its significance as an essential nutrient for aquatic life. The Royal Commission further affirmed the high-quality nitrate levels in River Tlawng.

Vaux (2011) illuminated the array of options offered by groundwater storage for augmenting storage capacity and enhancing overall water supply. Notably, the author underscored the increasing value of groundwater amid shortages, underscoring the imperative of sound groundwater management in realizing its full potential, which hinges on adherence to established economic principles.

Bhatnagar et al. (2014) investigated the impact of open-pit limestone mining on groundwater in the Katni River watershed in Madhya Pradesh, India. Their methodology involved using Survey of India Topographical maps and Indian Remote Sensing Satellite (IRS) images from the LISS III sensor. They also collected village-level water quality data and utilized satellite images for lithology and geomorphology analysis.

Similarly, Kumaravel et al. (2014) conducted a study along the east coast of Tamil Nadu state and Pondicherry union territory, analyzing thirteen groundwater samples from bore wells for pH, TDS, calcium, magnesium, sodium, potassium, HCO3, SO4, and fluoride. The study involved the use of geospatial technology and GIS to map the groundwater quality, with measurements of electrical conductivity and pH being made in the field.

Moreover, Lalbiakmawia and R. Lalruatkima (2014) utilized geospatial technology to map groundwater potential zones in Serchhip District, Mizoram, and concluded that parameters such as land use/land cover, slope, geomorphology, lithology, and geological structure directly influence groundwater availability. They highlighted the significance of remote sensing and GIS in groundwater management and delineation.

Against the backdrop of population growth and climate change, Sharma et al. (2015) conducted a study revealing that groundwater scarcity in Bihar could plummet to levels significantly below the minimum thresholds set by the Government of India and the World Health Organization unless immediate corrective measures are taken.

Kulkarni et al. (2015) emphasized the significance of hydrogeological features and socioeconomic factors in determining groundwater typology and dependency.

In a study by Lalbiakmawia (2015), the use of Remote Sensing and GIS techniques for groundwater potential zones mapping in Mamit district, Mizoram revealed the direct association of geo-environmental factors such as land use/land cover, slope, geomorphology, lithology, and geological structure with the occurrence of groundwater. These factors were identified as crucial parameters for selecting suitable areas for groundwater exploitation.

Building on this, Saha et al. (2015) underscored the insensitivity of mean monthly rainfall trends to altitude, emphasizing the urgent need for the development of effective water management strategies to address water scarcity issues and enhance the resilience of rabi agriculture in Mizoram. Hence, the creation of groundwater potential maps emerges as a vital priority in this context.

H. Laldintluanga et al. (2016) conducted an assessment of rural water quality in Aizawl, Mamit, and Serchhip Districts of Mizoram, India. They observed acceptable pH levels in spring water but noted low pH levels in water samples from reservoirs and tube wells, potentially due to prevalent sandstone and shale, and highlighted the impact of forest fires and rainfall on water quality.

Anbazhagan and Jothibasu (2016) conducted a study on groundwater mapping in southern India, specifically in the Uppar Odai sub-basin of the Amaravati River basin. Their research involved assigning weights and rankings to thematic layers based on their influence on groundwater occurrence, and they utilized ArcGIS 9.3 for spatial integration.

In a comprehensive review, Mechlem (2016) emphasized the critical issues that warrant attention in water law, particularly in the effective management and preservation of groundwater resources. The author provided an extensive overview of prevailing groundwater legislation practices while delving into recent trends and advancements in response to contemporary concerns.

Listyani R.A. (2016) delved into the impact of rock minerals on groundwater quality in the Jakarta Quaternary groundwater basin, leveraging petrographic analysis, XRD, and chemical analysis of groundwater and rock samples. Their investigation revealed the profound influence of the mineralogical composition of rock on groundwater quality, attributing the majority of abundant soluble elements in groundwater to silicate mineral weathering. Moreover, the proliferation of issues relating to potable water quality deterioration stemming from pollution, overexploitation, population growth, rapid industrialization, and mismanagement of water resources necessitates concerted efforts to assess and monitor water bodies across mainland India,

particularly given the heavy reliance of rural populations on groundwater for various needs.

Andualem and Demeke (2019) focused on the Upper Blue Nile Basin in Ethiopia, aiming to develop a groundwater potential map using GIS and remote sensing. They assigned weights to various thematic layers such as land cover, drainage density, lineament density, soil, geology, slope, and geomorphology to create groundwater potential maps.

Moreover, Shimpi et al. (2019) harnessed remote sensing and GIS techniques to delineate groundwater potential zones in Boro-Chikli, Maharashtra, India. Their approach involved the amalgamation and overlay of various thematic layers and data, such as lithology, geomorphology, land use and land cover, slope, and drainage, to generate a comprehensive groundwater potential map.

Tolche (2020) explored the potential applications of weighted index overlay analysis in assessing groundwater potential using GIS techniques. The resulting groundwater map proved instrumental in identifying suitable sites for groundwater resource exploitation.

Biswas and Azyu (2021) studied 12 villages in the Phullen RD Block and identified tuikhur or village springsource (VSS) and piped water supply as the main sources of water, along with rainwater harvesting and water from streams or rivers. They noted a decline in the perennial status of springs due to inadequate spring shed management.

In a related study, Lalbiakmawia et al. (2023) conducted ground water exploration using Remote Sensing and GIS in Zawlnuam RD Block, Mizoram. Their findings concluded that the overlay analysis of lithological, geomorphological and structural layers in a GIS environment facilitated the delineation of aquifers. Different types of aquifers were identified based on their geomorphic classes and lithological units.

GIS and AHP Techniques Based Delineation of Groundwater Potential Zones: a case study from Southern Western Ghats, India. P. Arulbalaji, D. Padmalal & K Sreelash (2019). The current study aims to identify the groundwater potential zones in the Vamanapuram river basin, a small, humid tropical river basin in South India situated

on the western side of the southern Western Ghats, an elevated continental margin, by combining AHP and GIS techniques. The groundwater potential zones were defined in this study using a total of 12 thematic layers, including Geology, Geomorphology, LULC, Soil, Rainfall, Lineament Density, Drainage Density, Slope gradient, TPI, TWI, Roughness, and Curvature. The study area may be divided into five different ground water potential zones, including extremely high, high, moderate, low, and poor, based on the final output map. The middle reaches of the river basin and lower catchment areas are mostly home to very high and high groundwater potential zones. The river basin's migmatite complex deposit contains low and very low groundwater potential zones. 59% of the study area is in the moderate groundwater potential zone, which extends throughout the catchment region. Zones with high and poor groundwater potential make up 11% and 29% of the total area, respectively. Together, the study area's extremely high and very low groundwater potential zones make up less than 1%. The research area's groundwater flow and prospects data were used to evaluate the map of designated groundwater potential zones. The current study's groundwater potential zone map gives decision-makers information on how to properly plan and manage groundwater for both agricultural and urban uses. Since the majority of the study area is made up of agricultural land, this research will contribute to the development of irrigation infrastructure and the enhancement of the region's agricultural output.

A review of integrated RS and GIS technique in groundwater potential zone mapping, Pushplata Aherwar, YK Tiwari, S Nema, MK Awasthi and PM Dhage (2023). The thorough evaluations in this study emphasize the application of combined GIS and RS technologies to groundwater research and evaluation. The points listed below were emphasized in the current research: A viable and economical groundwater exploration plan can be prepared for any location with the use of RS and GIS techniques, which are effective instruments for assessing groundwater potential. In developing and low-income nations, where sufficient and high-quality hydro-geologic data are frequently missing for groundwater evaluation by data-intensive techniques, the methodology is more cost-effective and appropriate. The kind and quantity of thematic layers that researchers employ differ from study to study, and their choice is also subjective.

Weights have been assigned to different thematic levels and their attributes based on personal opinion in the majority of the investigations. Another essential component for fully utilizing the potential of RS and GIS technologies is field research. There is typically no standard methodology for mapping groundwater potential using integrated RS and GIS. We will undoubtedly be able to develop and manage this valuable groundwater resource if we use a standard model.

Groundwater Potential Mapping Using Remote Sensing and GIS-Based Machine Learning Techniques (2020). Sunmin Lee,Yunjung Hyun, Saro Lee and Moung-JinLee. Effective water management and planning are necessary in light of the current worldwide water deficit. Inadequate water management and careless use of water resources can interrupt a steady and consistent supply of water. The first step in effectively planning the use of water resources is to make an accurate prediction and react to the critical resources' current state. Particularly in areas with limited water supplies, groundwater is a great source of water. But since there is a lot of uncertainty about groundwater availability, estimating groundwater potential is crucial. Effective groundwater resource management and conservation planning face the crucial task of mapping groundwater potential. There are several approaches to mapping groundwater potential. One way to estimate the uncertainty of a groundwater model is to improve the groundwater potential model. Even though the predictive performance of new machine learning technologies is constantly improving. Since it would not be feasible to generalize from a tiny, labeled dataset, all strategies can be employed effectively in areas where data is scarce. Thus, the proposed FR-BCT model, an ensemble model combining these two machine learning methods, was applied in conjunction with FR analysis and the BCT model.16 groundwater control factors—nine topographic, two hydrological factors, forest type, soil material, land use, and two geological factors—based on remote sensing data were incorporated to the models for this purpose. Groundwater well data was used to test and constrain the model; 53 wells were divided into training (70%) and testing (30%) datasets. Existing probability models and the machine learning approach of the BCT model were contrasted with the new FR-BCT model. These findings are helpful in promoting thorough management of groundwater recharge and exploration. This study's

methodology can be adapted to other groundwater-dependent areas. Groundwater potential modeling can be effectively analyzed by managers and policymakers. Outcomes to optimize management's benefits. However, more research is needed in other fields to ascertain how accurately the suggested ensemble model represents groundwater potential.

Application of geo-spatial technologies for ground water quality mapping of Aizawl district, Mizoram, India. F. Lalbiakmawia and V. Vanthangliana (2015). Understanding the current state of the ground water in the research area is made easier by the ground water quality map. The results of this investigation showed that certain urban areas' groundwater quality is subpar according to BSI standards. The research area's good, moderate, and poor ground water quality zones are depicted in general on the integrated map. It is possible to use the prediction of ground water quality zones for ground water management, development, and exploration programs. Groundwater quality mapping has been demonstrated to benefit from the use of GIS techniques. The map of ground water quality created by this study will be helpful in organizing further ground water development initiatives.

Application of DEM and GIS in Terrain Analysis: A Case Study of Tuirini River Basin, NE India. Fuzal Ahmed and K. Srinivasa Rao (2019). According to the study, the majority of tributaries begin at high elevations (>800 m) and have roughly straight courses as a result of the structural effect. Based on the graded character of the curves as shown in the longitudinal profiles, the terrain reached a mature stage of landscape evolution with a balance between erosion and deposition. Furthermore, the profiles contain a number of tiny knickpoints that show the ongoing tectonic processes and differences in the lithology. The high lineament density in the basin's northern region may be the result of extensive rock faulting and fracture. The presence of numerous lineaments, fractures, and faults supports the idea that the landscape is tectonically active overall. Thus, it can be inferred from the study that the combination of GIS techniques with remotely sensed and DEM data acknowledged as a capable instrument for terrain study that would support a range of development initiatives and the preservation of the basin's natural resources.

Application of e-TOPSIS for Ground Water Potentiality Zonation using Morphometric Parameters and Geospatial Technology of Vanvate Lui Basin, Mizoram, NE India. Jonmenjoy Barman and Brototi Biswas (2022). Depletion of groundwater is a serious environmental issue. In India and around the world, it is a vital resource. The Earth and most of our bodies are composed of water. Groundwater encounters numerous requirements of people worldwide in areas with little or inaccessible surface water, such as lakes and rivers. Although human activity is mostly to blame for groundwater depletion, climatic changes can accelerate the process. In terms of integrated water resource management methods, the northeastern Indian states—Mizoram in particular—lag behind their fellow Himalayan states. In addition to promoting sustainable resource management, efficient water resource management in the northeast will also help to resolve a number of environmental and financial issues. Because Mizo people choose to construct their communities atop hills and ridges, water supply has always been an issue for Mizoram's villages. The state has severe water shortages.In Mizoram, the dry season, which lasts from October to April, is characterized by a scarcity of rainfall and the drying and depletion of surface water supplies. In order to determine the groundwater potentiality of the Vanvate Lui basin, the current study was carried out utilizing the e- TOPSIS model, which was validated in the Donor River basin. The study region was divided into three groundwater potentiality zones based on geological factors and the basin's areal, linear, and relief aspects — "more potentiality," "low potentiality," and "moderate potentiality." The project is intended to inspire similar initiatives in northeastern India, an area with abundant water shortages, and to motivate government representatives and planners to take the required actions toward sustainable water management.

Evaluation of groundwater quality in West Tripura, Northeast India, through combined application of water quality index and multivariate statistical techniques. Biplab Roy & Stabak Roy & Saptarshi Mitra & Ajay Kumar Manna (2021). Several research methods, including WQI, correlation analysis, CA, and PCA, have been used to determine the current state of groundwater fitness for drinking successfully based on data analysis of 38 groundwater samples. Higher Fe and turbidity readings

significantly contribute to groundwater being non-potable, according to WQI results. Because the EWWQI approach consistently avoids personal judgments (that assume weighting factor to each water quality parameter), which are carried over for the WAWQI method, it produces more accurate and dependable results than the WAWQI method when two WQI methods are compared. The WAWQI method does not offer comprehensive data regarding the true state of groundwater because exaggerating phenomena. In order to differentiate water quality decline, the PCA approach in this work reduces 11 parameters into 3 underlying variables (PC1, PC2, and PC3). The contribution of metallic ion concentration, turbidity, and DO for PC3; pH and alkalinity for PC2; and the other parameters accountable for PC1 causes this technique to represent deteriorating water quality. The WQI results are satisfactorily validated by CA results. Accordingly, based on the investigation above, groundwater quality should be regularly monitored, and treatment should only be implemented when the sample is unfit for human consumption.

Spring water suitable and vulnerable watershed demarcation using AHP-TOPSIS and AHP-VIKOR models: study on Aizawl district of North-Eastern hilly state of Mizoram, India. Brototi Biswas, Abhishek Ghosh & Benjamin Lalengliana Sailo (2023). In the Mizoram area in India's northeastern highland state, springs are one of the most important water sources. The literature on spring water serviceability, recharge potentiality, and spring watershed management is, nevertheless, scarce. Thus, the current study uses the AHP-TOPSIS and AHP-VIKOR models to create a watershed map of the Aizawl district that is suited for spring water and vulnerable. The main elements that were thought to induce spring suitability were the highest relief, mean slope, mean annual rainfall, mean annual temperature, spring distribution, geomorphic units, geological formations, stream order, concentration of lineaments, and epicenter. In addition, the percentage of agricultural land, degraded land, open space, water body, built-up area, stone mining sites, landslide, forest fire, and forest cover area were measured to gauge susceptibility across watersheds. AHP-TOPSIS (0–0.60) and AHP-VIKOR (0.04–1.00) relative analyses indicate that the district's core region is suitable for spring water. The study also shows that, in comparison to other regions, the center part has very high levels of anthropogenic interventions and

hazard intensity (AHP-VIKOR—0.0–1.00 and AHP-TOPSIS—0.0–0.85). Thus, the maps of watersheds that are suitable and vulnerable that were created for this study may serve as a guide for spring management. Finally, the ROC curve indicates that AHP-TOPSIS (0.816) predicts somewhat better than AHP-VIKOR (0.743).

Monitoring land use land cover changes in the Eastern Himalayan landscape of Nagaland, Northeast India Vimha Ritse & Himolin Basumatary & Amenuo Susan, Kulnu & Gitamani Dutta & Mayur Mausoom Phukan & Nabajit Hazarik (2020). This study demonstrated the importance of long-term geospatial evaluation of LULC changes and associated trends in a fast growing and data-poor area of India. Our work sheds insight on the changing terrain features and their effects in the hilly areas of Nagaland, which is important in an expanding economy like India where population growth and development are accelerating. It appears that the built-up areas in the capital city of Kohima and the commercial center of Dimapur are growing quickly. Large tracts of forest and agricultural lands are being occupied by urbanization and development projects, which is causing the loss of agricultural fields and forest cover across the studied periods. Urban migration, the expansion of fisheries ponds, and the marginalization of shifting farming were all important auxiliary factors in the LULC dynamics of the research area. While the two districts' Built Up, Agricultural Land, and Forest Land classes all displayed comparable patterns of change over the course of two decades, the Water Body class produced contradictory findings that highlighted the significance of aquaculture activity in Dimapur's expanding waterbodies. Waterbodies' accumulation (in Dimapur) and shrinkage (in Kohima) can also be linked to poor urban area management and planning, which are negative consequences of rapidly unplanned development. This study offers firsthand data on the monitoring of LULC changes in Nagaland's two emerging districts. It will help authorities and interested parties in the future when planning land use and carrying out development projects.

Exploration of Potential Zones of Groundwater in Jamuna Watershed, Assam, by Applying Multi-influencing Factor Technique. Himadree Borah and Sujit Deka (2022). Because it saves time and effort, the use of GIS, MIF, and remote sensing techniques to identify possible groundwater availability zones is proven to be quite

beneficial and cost, which facilitates quicker decision-making for the management of sustainable water resources. The MIF technique in GIS has been used in the current work to delineate possible groundwater zones in the Jamuna watershed. The Jamuna watershed is categorized into four classes based on the groundwater potential zone map: "very good, "good," "moderate," and "poor" groundwater potential. Nearly 70% of the research region (the Jamuna watershed) is classified as having moderate-to-poor groundwater potential, while the remaining 30% is classified as having good and very good groundwater potential. Due to the flat alluvial plains and agricultural lands with high infiltration capacity, the watershed's western and southwest regions have the majority of its good groundwater potentiality, while the northeastern region has the majority of its poor potential zones because of the steep slopes and hilly terrain. Planners and other agencies involved in the groundwater management of the Jamuna watershed are anticipated to find this study useful. The several impacting factors when combined with remote sensing and GIS, the technique effectively yields a significant outcome in terms of identifying possible groundwater zones. Additionally, this approach can be repeated in other Assamese regions for groundwater investigation and watershed management.

Delineation of groundwater potential zones at micro-spatial units of Nagaon district in Assam, India, using GIS-based MCDA and AHP techniques. Manash Jyoti Bhuyan and Nityananda Deka (2022). Thus, the current study uses GIS-based MCDA and AHP technology to identify and generate groundwater potential zones in the Nagaon district. Several ground water potential-influencing parameters are carefully chosen in order to achieve this goal, taking into account the opinions of experts, field research, and the assessment of pertinent literature. The AHP technique is used to carry out the multi-criteria decision-making process between the characteristics controlling the district's groundwater availability and spatial distribution. According to the findings, roughly 2.15% of the district's total villages are in the low GWPZ, whereas 32.33%, 23.42%, and 42.11% are in the moderate, high, and very-high GWPZs, respectively. For a range of household, agricultural, livestock, and industrial uses, groundwater must be managed and used responsibly, especially in regions with high groundwater extraction rates. Furthermore, in order to reduce the strain on groundwater, rainwater

gathering methods should be applied scientifically. In the end, the results of this study will aid in the sustainable use and management of groundwater resources by assisting the local population and the relevant government bodies in tackling the water hazards, such as water stress and security. Additionally, the study's approach will assist hydrologists, specialists, professionals, and interested researchers in tracking and evaluating the groundwater recharge potential locally, regionally, and internationally.

Comprehensive groundwater potential mapping in Nagaland, India using integrated geo-spatial techniques. Subhrajyoti Deb and Azeri Kenye (2024). For a thorough groundwater analysis, this study used an integrated methodology that blends GIS, remote sensing, and AHP. This method enables the effective identification of new groundwater potential zones, which is especially significant in light of growing freshwater demands. The research revealed a number of management approaches for Nagaland's focused groundwater management and water harvesting. The Geological Survey of India (GSI), the Environmental Systems Research Institute (ESRI), the Food and Agriculture Organization (FAO), the Climatic Research Unit (CRU), the Landsat 8 and Sentinel-2 satellite imagery, and other data sources were used to generate a number of attributes, including geomorphology, geology, slope, soil, rainfall, drainage density, and land use/land cover (LU/LC). Using Arc-GIS (Arc-GIS Desktop 10.8.1), these datasets are extracted, weighted using Saaty's scale, and then normalized using the AHP. According to the results, 14% (2240 km2) of the state has very good groundwater potential, 42% (6720 km2) has good groundwater potential, 9% (1440 km2) has moderate groundwater potential, 27% (4320 km2) has bad groundwater potential, and 8% (1280 km2) has very poor groundwater potential. These observations are important for areas that need immediate attention, such as Mokokchung, Longleng, and Wokha. On the other hand, the analysis finds that Dimapur and Chumoukedima have a lot of groundwater potential and can supply the growing need for water. These conclusions are supported by the confirmation of these results using well discharge data from 12 monitoring wells.

Unleashing the Untapped Potential: Groundwater Exploration in a Watershed Environment of North-East India Using MCDA-AHP Techniques. Debashree Borah, Ashok Kumar Bora (2025). This study uses the Analytical Hierarchy Process (AHP)

technique and the GIS-based multi-criteria decision analysis (MCDA) approach to try and define the groundwater potential zones (GWPZs) in a vulnerable and agriculturally dominated watershed of North-East India. Geomorphology, geology, land use/land cover (LU/LC), drainage density, rainfall, soil texture, slope, lineament density, topographic wetness index (TWI), and normalized difference water index (NDWI) are the ten influencing factors that have been examined in this study. A pairwise comparison matrix (PCM) is used to determine appropriate weights for the characteristics based on their respective importance and relationship to groundwater storage. Four GWPZs are identified, each with a coverage category: poor (3.39%), moderate (24.98%), good (33.36%), and excellent (38.27%). High groundwater potentiality is indicated by the porous geological settings and floodplains found in the center and southern regions of the research area, which includes sections of the Assamese districts of Udalguri, Sonitpur, and Darrang. In contrast, there is no groundwater storage in the northern region due to its rough and harsh terrain. The study's usefulness is greatly increased by including the socioeconomic component, specifically the number of communities with or without access to adequate groundwater. With an accuracy of 72.9%, the results are cross-checked with field data and well data from the Central Groundwater Board (CGWB), which are verified using the receiver operating characteristics (ROC) curve. As a result, this investigation has both regional and worldwide consequences and will help authorities and stakeholders develop a plan for efficient and sustainable water use.

CHAPTER IV

METHODOLOGY

The study area primary research inputs will be derived from remote sensing data, geological maps and geological field studies. These sources will be integrated and analyzed using Geographic Information System (GIS) technology. Remote sensing and GIS techniques have revolutionized natural resource surveys due to their efficiency and cost-effectiveness. These techniques find extensive applications in geo-sciences, particularly in ground water studies. By combining satellite data with ground truth information, researchers can identify and delineate geological structures, geomorphic features, and hydraulic characteristics that serve as indicators of ground water presence.

GIS is a computer-based tool used for collecting, managing, and displaying spatially referenced data. It supports decision-making in various contexts, such as planning and environmental management. GIS is essentially a database management system that stores spatial information along with its attributes, enabling retrieval, processing, and analysis to address geographical queries.

The integration of common database operations with unique visualization and geographic analysis capabilities sets GIS apart from other information systems. This makes GIS valuable for explaining events, predicting outcomes, and planning strategies across public and private enterprises.

The term "Geographic Information System" reflects its nature as an information system containing a database of spatially distributed objects, activities, or events. These can be represented by points, lines, or surfaces, which can be superimposed to create meaningful maps. Each GIS layer consists of a map view and a data view, allowing for the visual representation of data and the display of specific attributes. Moreover, GIS provides a comprehensive set of tools for capturing, storing, retrieving, transforming, and visualizing real-world spatial data for specialized applications.

Remote sensing involves obtaining information about the Earth's surface without direct contact. This is achieved through the collection and analysis of reflected or emitted energy. Remote sensing data is typically obtained through the sensing of electromagnetic radiation, with sensors such as cameras being commonly used for this purpose. Parameters such as tone, color, size, shape, pattern, association, and location are analyzed to interpret satellite remote sensing data, allowing for the description of lithology, drainage patterns, and subsurface structures. Geologists can utilize remote sensing imagery to identify potential exploration sites by delineating structures and identifying associated lithologies.

The applications of remote sensing imagery are diverse and include mapping land use and cover, agricultural monitoring, soil mapping, urban planning, and surveying of geomorphological features. The methodology for remote sensing and GIS technology is typically divided into three phases: pre-field, field, and post-field work.

During the pre-field phase, satellite data of the study area is acquired, and various information such as literature, maps, socio-economic data, and meteorological data are collected from multiple sources. The satellite imagery is then aligned with Survey of India toposheets, and base maps for different themes are prepared. Contour and slope maps are also generated, and printed pre-field maps are used for field verification.

The field phase involves ground confirmation and data collection, which is crucial for remote sensing technology. Ground information is collected during field visits to verify doubtful areas on the pre-field interpreted maps. Information that cannot be obtained from satellite data, such as the location of springs and groundwater samples, is collected during fieldwork, often using GPS for recording geographical locations.

In the post-field phase, the finalized maps are adjusted as necessary, and the collected field data is studied and analyzed. Water samples are analyzed in the laboratory, and derived data is prepared using primary layers. Area calculations are performed to determine spatial coverage, and a report is generated, including a description, a map of ground water prospects and quality, and an action plan for ground water resources development.

The methodology involves the analysis of various groundwater controlling factors including geomorphology, lithology, geological structures, slope, land use/land cover and rainfall

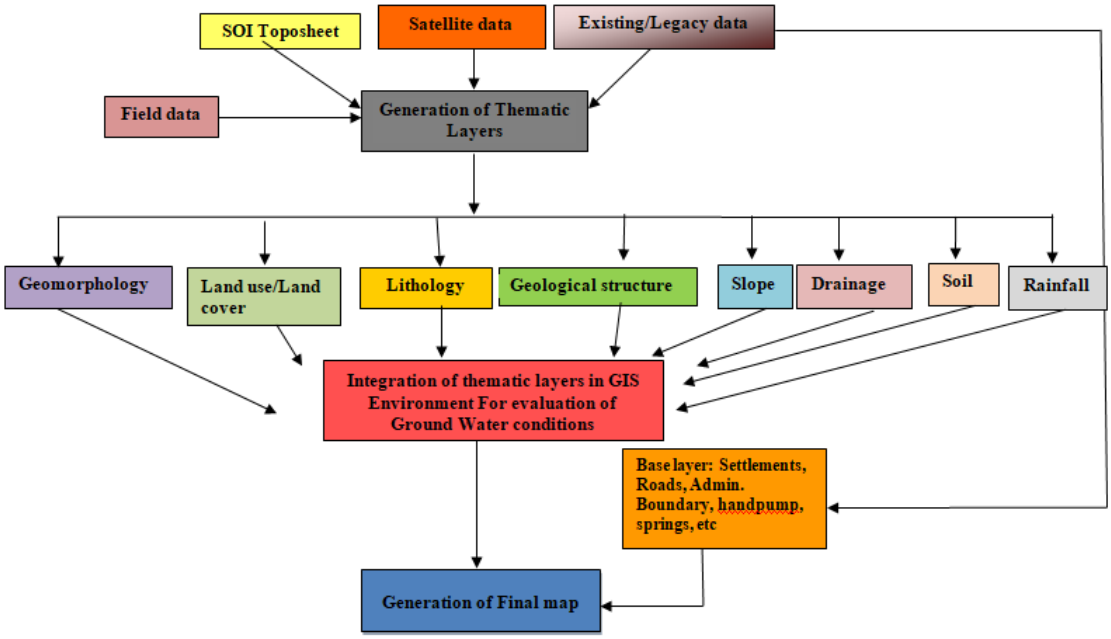


Figure 1: Flow Chart of methodology

Geomorphology plays a crucial role in the assessment of groundwater potential and prospect, as well as in the management of groundwater resources. It also aids in the identification of suitable artificial recharge sites. Valleys are particularly favorable areas in this regard. When considering lithological parameters, factors such as geological boundaries and porosity should be taken into account. Unconsolidated material units are perceived to offer greater potential for groundwater occurrence.

In terms of geological structures, lineaments are significant features from a groundwater perspective. High yielding wells and springs are often associated with large lineaments and corresponding structural features. Fractures that are hydraulically connected with alluvium and weathered bedrock constitute optimal aquifers. Lineaments serve as pathways for groundwater movement and contribute to groundwater recharge potential.

Aspect data and maps are derived from Digital Elevation Models (DEM) generated from elevation (contour) data of the study area. The aspects of an area may impact the physico-chemical properties of water quality.

The slope angle plays a crucial role in groundwater availability and replenishment. However, anthropogenic activities can lead to dynamic changes in the slope angles of landforms, thereby reducing the accuracy of the maps.

Land use/land cover significantly influences natural groundwater recharge to aquifers. Impermeable pavements and urban structures hinder the natural recharge process. It is well-established that recharge is higher in cultivable and irrigated land compared to wasteland and settlements.

Rainfall data collected from various sources is the primary source for recharging groundwater. Therefore, incorporating rainfall data is essential in the methodology.

All geo-environmental factors that influence the quantity and quality of groundwater are represented in layers. Each layer is assigned a rank and weightage, and then integrated in a GIS environment to generate the final groundwater potential map and groundwater quality map of the study area.

Groundwater chemistry is influenced by various factors such as geological conditions, the extent of chemical weathering of different types of rocks, the quality of recharged water, and inputs from sources other than water interaction. These factors and their interactions contribute to the complexity of groundwater quality. Therefore, the assessment of groundwater quality involves the methodology of groundwater quality mapping, which can be divided into three main parts.

The first part involves organizing the raw-input data into a GIS database, specifically as a layer of groundwater samples.

The second part entails creating groundwater quality layers for each chemical element from the GIS database.

The third part involves analyzing the groundwater quality element-wise in relation to rock types and geomorphological classes and presenting the results in charts and maps. Ground water samples were collected to determine the concentration of trace elements like iron, chloride, nitrate, sulphate, chromium, arsenic, cadmium, nickel, manganese, mercury and zinc. All the samples were acidified with 5% nitric acid and preserved at 4°C temperature before testing. The testing equipment include iCE Series 3000 Atomic Absorption Spectrophotometer.2.6 (9th May 2023). A flow chart illustrating the steps and process involved in ground water quality analysis and mapping has been formulated as below.

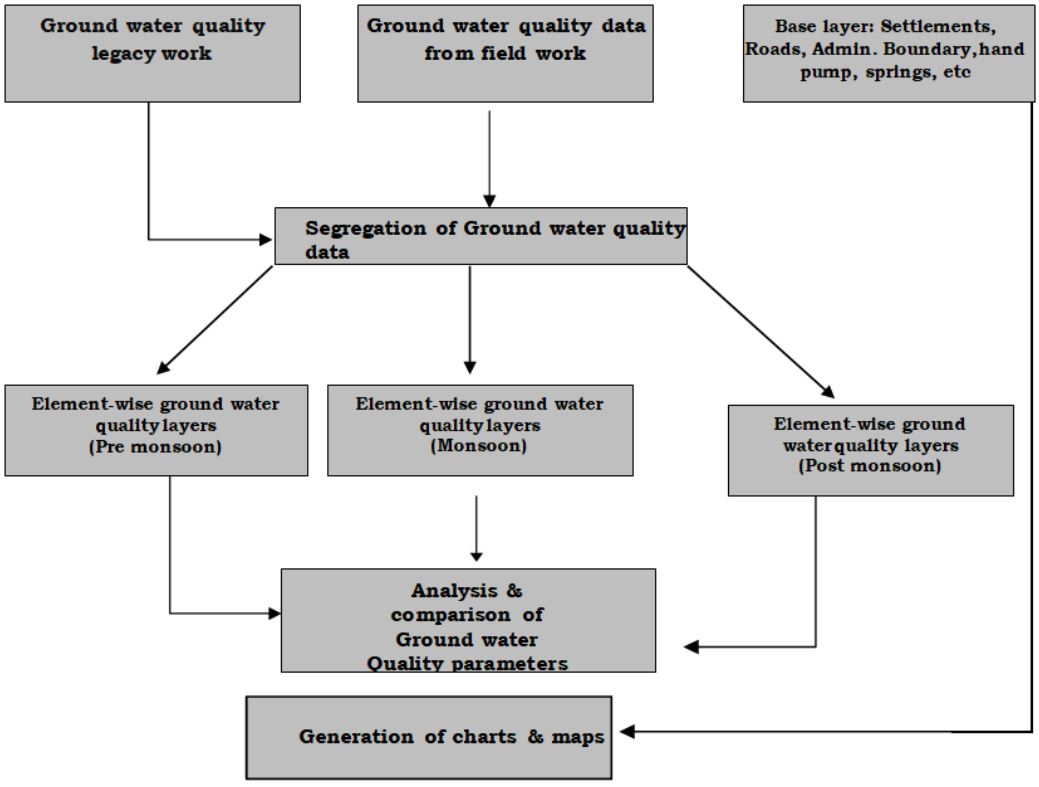


Figure 2: Flow chart of methodology for ground water quality assessment

4.1. Field Methods

Understanding rocks and water in their natural surroundings and their natural interaction to one another requires geological field and laboratory studies. Therefore, rigorous geological fieldworks were carried out during the study to complete the objectives. Field work include sample collections during pre-monsoon, monsoon and post-monsoon seasons and accordingly the GPS readings was recorded from the selected locations. The sampling was done according to the recommendations of the APHA and AWWA by following the grab sampling method.

4.2. Laboratory methods

4.2.1. Data consisting of satellite Landsat-8, SRTM DEM (30m resolution) from United States Geological Survey, toposheet from Survey of India (1:50,000) and georeferenced maps was used.

4.2.2. The interpreted data was cross checked and correlated with ground validations.

4.2.3. GIS analysis of the resultant output.

4.2.4. DEM of 10 m accuracy was used for the preparation of thematic maps using hydrology tools in ArcMap 10.4 software.

4.2.5. Mapping of geomorphology, lithology, structural layers with the inclusion of base map generated from administrative, settlements, road networks, railway lines etc. from existing/ legacy data such as Survey of India, Geological Survey of India, Statistical Handbook of Mizoram editions.

In order to gain a comprehensive understanding of the natural interactions between rocks and water, it was essential to conduct extensive geological fieldwork and laboratory studies. The fieldwork involved the collection of samples during pre-monsoon, monsoon, and post-monsoon seasons, with GPS readings recorded at

specific locations. These sampling procedures adhered to the guidelines set forth by the APHA and AWWA, utilizing the grab sampling method.

In the laboratory, a variety of data sources were employed, including satellite imagery such as Landsat-8, SRTM DEM from the United States Geological Survey, and georeferenced maps. The interpreted data was meticulously cross-checked and correlated with ground validations. Furthermore, GIS analysis was instrumental in processing the resultant output, with a focus on utilizing a 10m accuracy DEM for the creation of thematic maps using hydrology tools in ArcMap 10.4 software. This mapping included the depiction of geomorphology, lithology, and structural layers, integrating base maps generated from existing data sources such as Survey of India, Geological Survey of India, and Statistical Handbook of Mizoram editions. The integration of different thematic maps for the generation of a groundwater potential map was achieved through the application of the Analytic Hierarchy Process (AHP).

The chemical analysis of water samples involved the use of various instruments and methods. The pH of the water samples was measured using a digital instrument, while the Total Dissolved Solids were determined through a gravimetric method. Turbidity was assessed using a turbidity meter, and bacteriological tests were conducted using a water testing kit. Additionally, total Chlorides, total alkalinity, Total Hardness, Magnesium, Calcium, and Chloride were estimated using titrimetric methods, while Sulphate and nitrate were measured utilizing a UV Visible Spectrophotometer. Alkali metals such as Na and K were detected using a Flame Photometer, and heavy metals (e.g., Arsenic, Nickel, etc.) were identified through the iCE Series 3000 Atomic Absorption Spectrophotometer.2.6. Analytic Hierarchy Process (AHP) was used for the integration of the different thematic maps for generation of groundwater potential map.

The pH of the water samples was measured by using digital instrument and Total Dissolved Solids was measured by gravimetric method, Turbidity by turbidity meter, and bacteriological test is done by using water testing kit, total Chlorides, total alkalinity, Total Hardness, Magnesium, Calcium, Chloride were estimated by titrimetric method. Sulphate and nitrate were estimated by UV Visible

Spectrophotometer. Alkali metals like Na and K are detected by Flame Photometer and heavy metals (e.g., Arsenic, Nickel etc.) were detected by iCE Series 3000 Atomic Absorption Spectrophotometer.

CHAPTER V
GROUND WATER MAPPING FOR ZAWLNUAM RD BLOCK

The geological formations in Mizoram mainly consist of rocks from the Surma group, spanning from the Upper Oligocene to Miocene Age, as well as rocks from the Barail group (Oligocene) to the Holocene Age. Predominantly, Mizoram is characterized by arenaceous and argillaceous rocks, often accompanied by siltstone, clay, and gravel. The stratigraphy is defined by folded sediments and distinct conformable and transition contacts, with the landscape featuring steep slopes, extensive rock folding, troughs, ridges, crests, valleys, and hills. The lithology is marked by a thick soil cover, and intercalated sandstone and shale are commonly found. Furthermore, weathering, erosional features, joint sets, and the presence of weak zones such as local faults and fractures contribute to the defining characteristics of the lithology.

The distribution of groundwater in Mizoram varies based on lithology, geomorphology, and rainfall patterns. In high relief areas like the Zawlnuam RD block, characterized by steep topographic slopes and specific geological features, the groundwater potential is limited to intermontane and fractured valleys due to high run-off and limited rainwater infiltration. Unfortunately, the exploitation of groundwater often occurs without comprehensive knowledge of its distribution in both temporal and spatial dimensions, leading to the drilling of unproductive wells and subsequent financial losses for users. Over-exploitation has also resulted in wells gradually drying up over time, necessitating artificial recharge in regions where natural recharge is insufficient. Despite this, there are still areas in the state where the full potential of groundwater remains untapped.

Efforts to map the groundwater potential involve gathering data on geology, hydrology, topography, land use, and climate, as well as identifying key features such as fractures, lineaments, and drainage patterns through fieldwork and remote sensing techniques. The integration and validation of these datasets are crucial in the creation of groundwater potential maps, which aid in identifying suitable areas for well drilling, managing water resources, and understanding groundwater systems.

5.1 Lithology:

Detailed knowledge of lithology is an important factor in groundwater exploration and in particular, the features to be considered are geological boundaries, porosity, etc (CGWB 2000; Al-Bakri1 and Al-Jahmany, 2013). All the rock formations occurring in the study area are mapped as a layer. Existing geological and literature are consulted which helps in knowing the general geological setting of the area and different rock types that occur or are likely to occur in the area (RGNDWM, 2008).

The lithology of Mizoram comprises great flysch facies of rocks made up of monotonous sequences of shale and sandstone (La Touche, 1891). The study area lies over rocks of Middle Bhuban, Upper Bhuban and Bokabil formations of the Surma Group along with the Tipam group of Tertiary age. Recent unconsolidated sedimentary materials are also found in the low-lying areas. Middle Bhuban and Bokabil formations consist mainly of argillaceous rocks while the Upper Bhuban formation and Tipam group are comprised mainly of arenaceous rocks (GSI, 2011).

Understanding the lithology of an area is essential for groundwater prospecting as it helps in identifying the types of rocks and their properties, which in turn influence the occurrence, movement, and quality of groundwater. Different types of rocks have varying abilities to store and transmit water. For instance, sandstone often serves as a good aquifer, while shale may not be as effective. The permeability of rocks influenced by their lithology plays a significant role in controlling the flow of groundwater. It is important to have detailed knowledge of lithology when exploring groundwater considering factors such as geological boundaries and porosity.

In our study, we conducted detailed lithological mapping using existing maps prepared by MIRSAC (Mizoram Remote Sensing Application Centre) and verified the information through field checks. We also referred to data from the Indian Remote Sensing Satellite (IRS-1D) LISS III, Cartosat-1 and Survey of India Topographic maps. The study area was divided into three lithology: Sandstone, Shale and unconsolidated rocks comprising gravel, sand, silt and clayey sand. Sandstone, being a harder rock formation, is primarily found along the ridgeline due to its resistance to erosion. On the other hand, Shale covers a smaller part of the total area, and unconsolidated rocks are predominantly located in low-lying areas such as floodplains and valleys.

The sandstone units in the area are primarily from the Upper Bhuban and Tipam Formations, while shale units consist of rock from the Middle Bhuban and Bokabil Formations. This detailed understanding of lithology is crucial for effective groundwater exploration and management.

Indian Remote Sensing Satellite (IRS-1D) LISS III and Cartosat-1 data are used for cross-checking Lithology map.

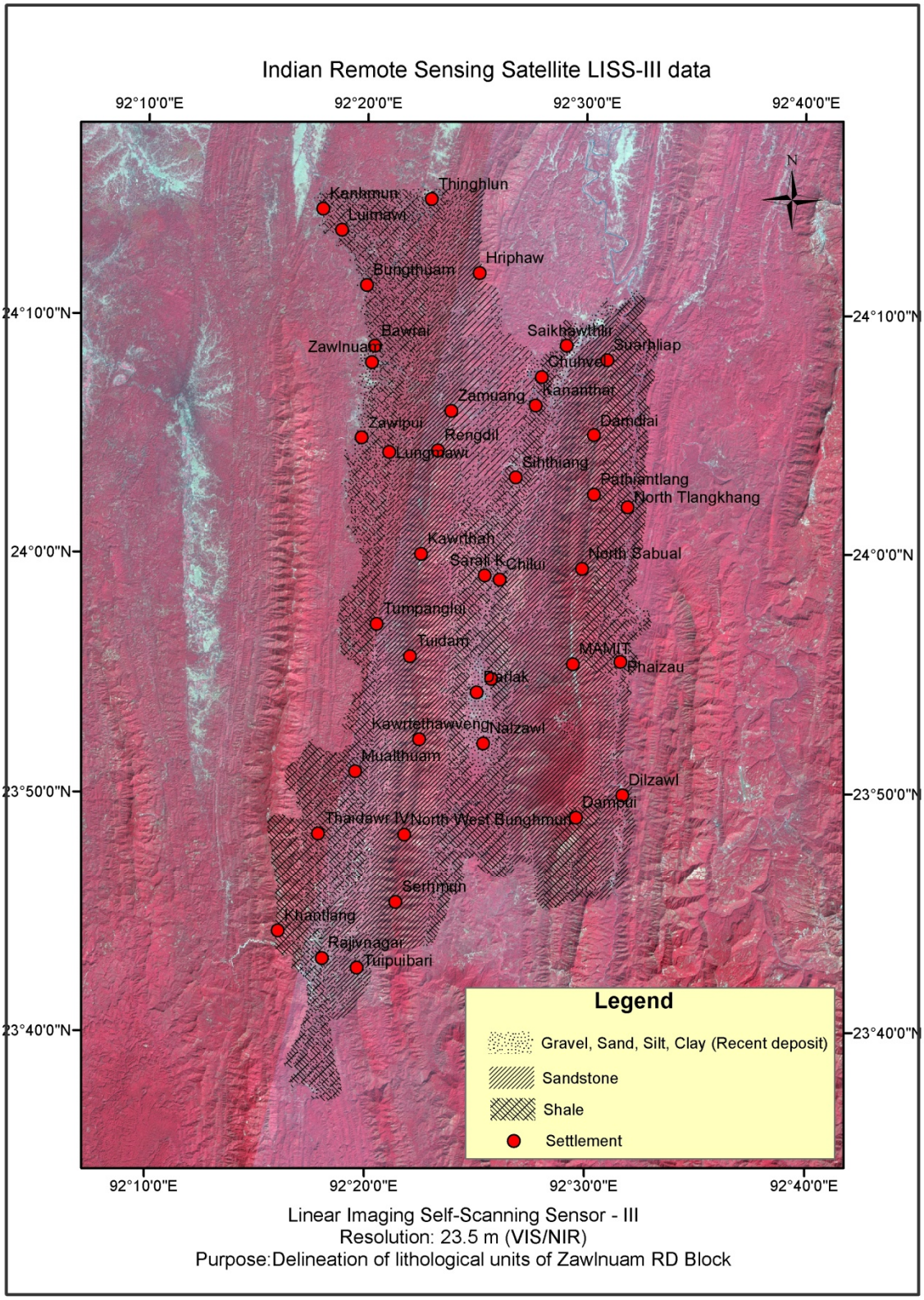


Figure 3: Indian Remote Sensing satellite LIS- III data

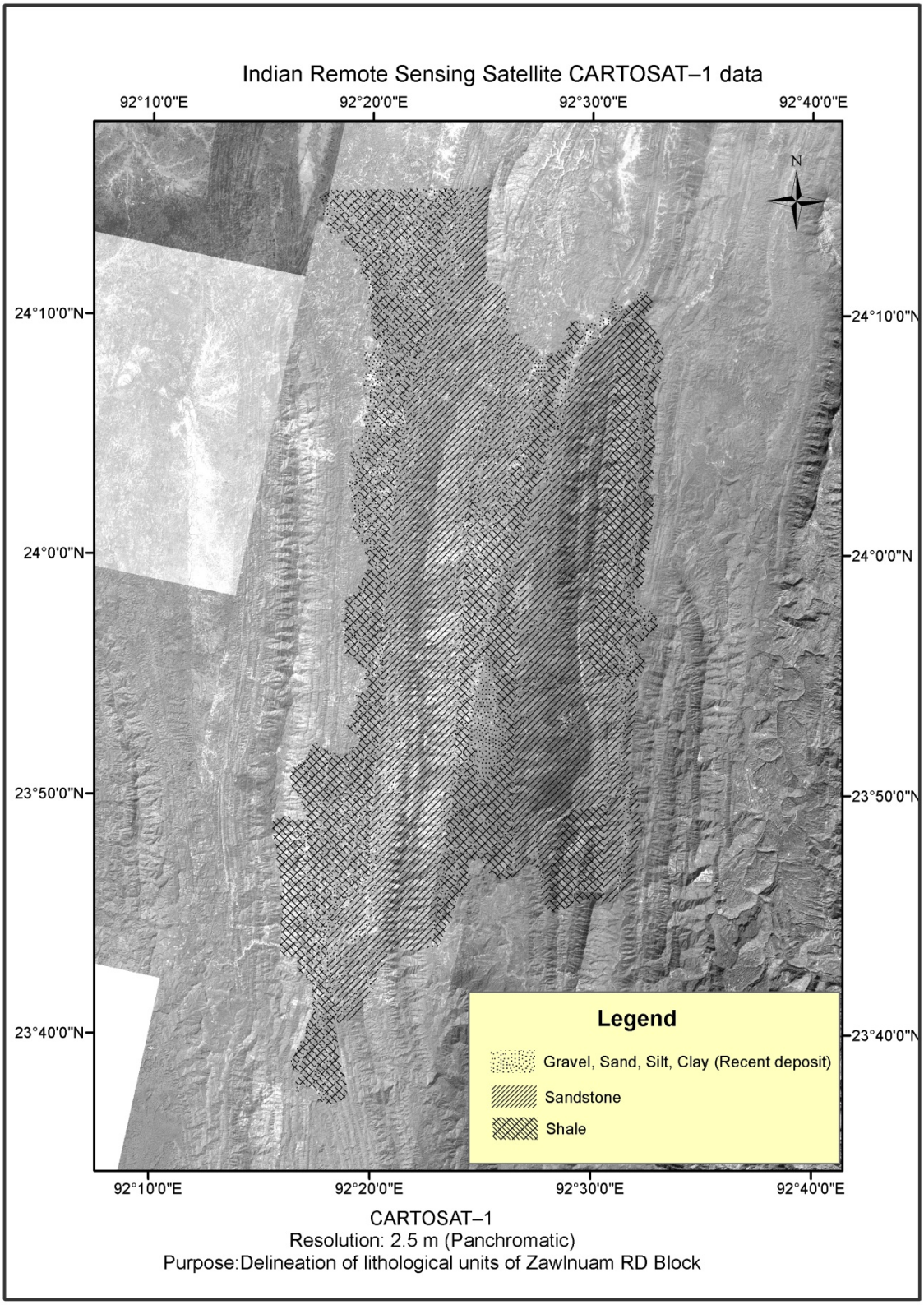
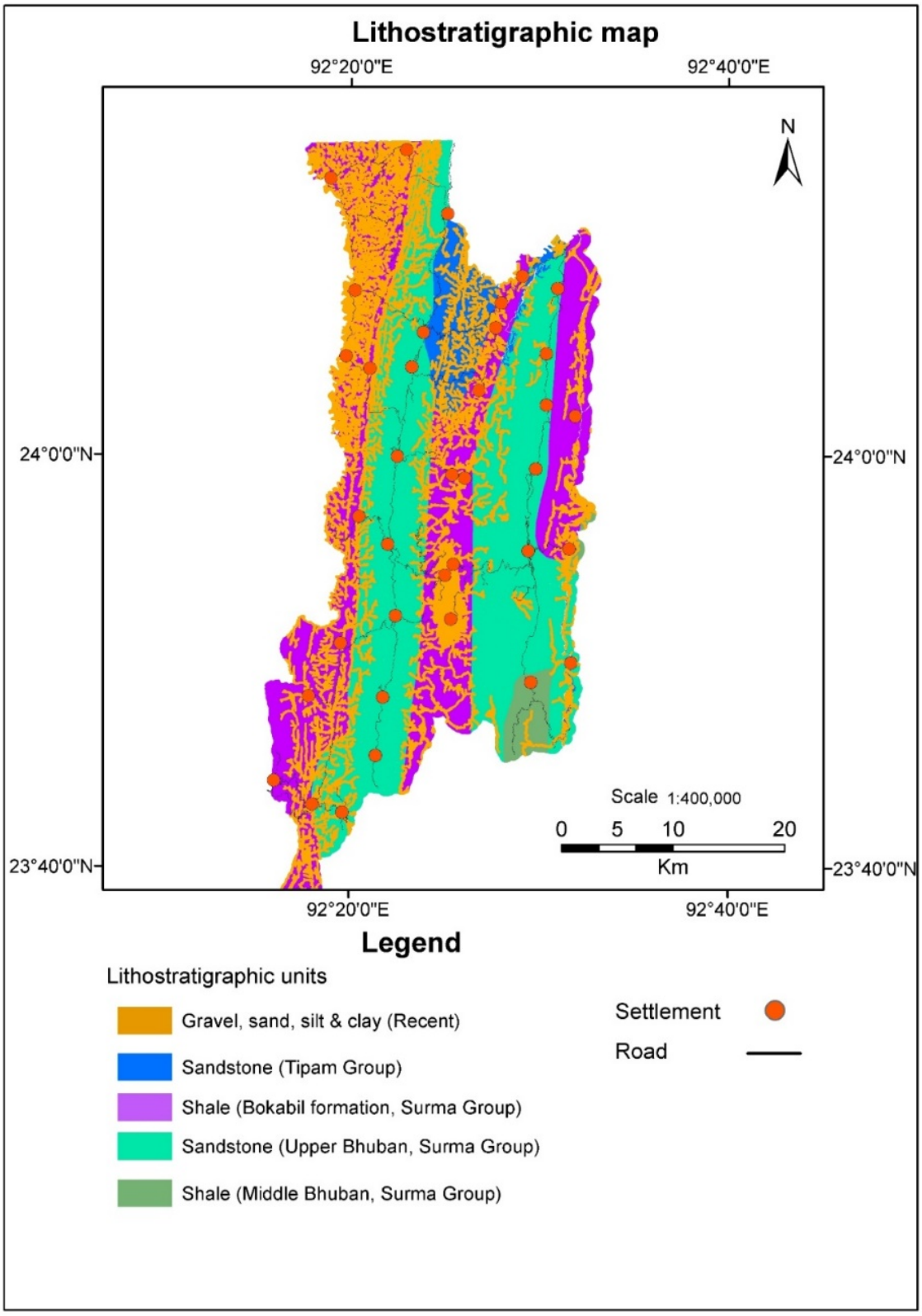


Figure 4: Indian Remote Sensing satellite Cartosat- 1 data

Sl. No	Litho units	Area (in Sq Km)
1	Unconsolidated sediments-Gravel, Sand, Silt, Clay (Recent)	220.93
2	Sandstone (Tipam Group)	50.56
3	Sandstone (Upper Bhuban Formation) Surma Group	503.56
4	Shale (Boka Bil Formation) Surma Group	366.82
5	Shale (Middle Bhuban Formation) Surma Group	28.13
	Total area	1170.00

Table 2: Litho units



Map 4: Lithostratigraphic map

5.2 Geomorphology

Geomorphology plays a crucial role in evaluating the potential of groundwater resources due to its close association with key features such as slope, drainage density, and water infiltration into the subsurface (Kumar and Kumar, 2011; Valliammai et al., 2013; Raju et al., 2013; Ghayoumian et al., 2007). It directly impacts groundwater recharge and water chemistry, and is therefore fundamental in assessing groundwater potential and prospects. Moreover, it is instrumental in the management of groundwater resources and in the selection of artificial recharge sites.

Different geomorphological units are integral in groundwater mapping as they aid in identifying areas with similar hydrogeological characteristics, often corresponding with hydrogeological boundaries and influencing aquifer properties and groundwater flow patterns. Various landforms such as valleys, hills, and plains exhibit distinct relationships with underlying aquifers, affecting groundwater occurrence and flow. Geomorphological features like valleys and ridges have the ability to control groundwater flow paths and directions.

Furthermore, these units assist in characterizing aquifer properties, including thickness, permeability, and storage capacity. By understanding geomorphological units, groundwater maps can predict areas with similar hydrogeological conditions, guiding exploration and management efforts. In the study area, various geomorphic units such as intermontane valley, alluvial plain, fractured valley, less dissected structural hill, moderately dissected structural hill, and highly dissected structural hill have been mapped as polygon features using toposheets to comprehend relief variations and other topographic features. The geomorphological map is prepared based on the lithological map, classifying each rock type into different geomorphic units. Additionally, slope form also plays a crucial role in groundwater occurrence and flow in hilly/mountainous terrain.

The geomorphic data of the study area was obtained from the map prepared by MIRSAC (Mizoram Remote Sensing Application Centre) as the base. Additionally, field validation was conducted using Indian Remote Sensing Satellite (IRS-1D) LISS-III data and Survey of India Topographic maps to prepare the geomorphological map.

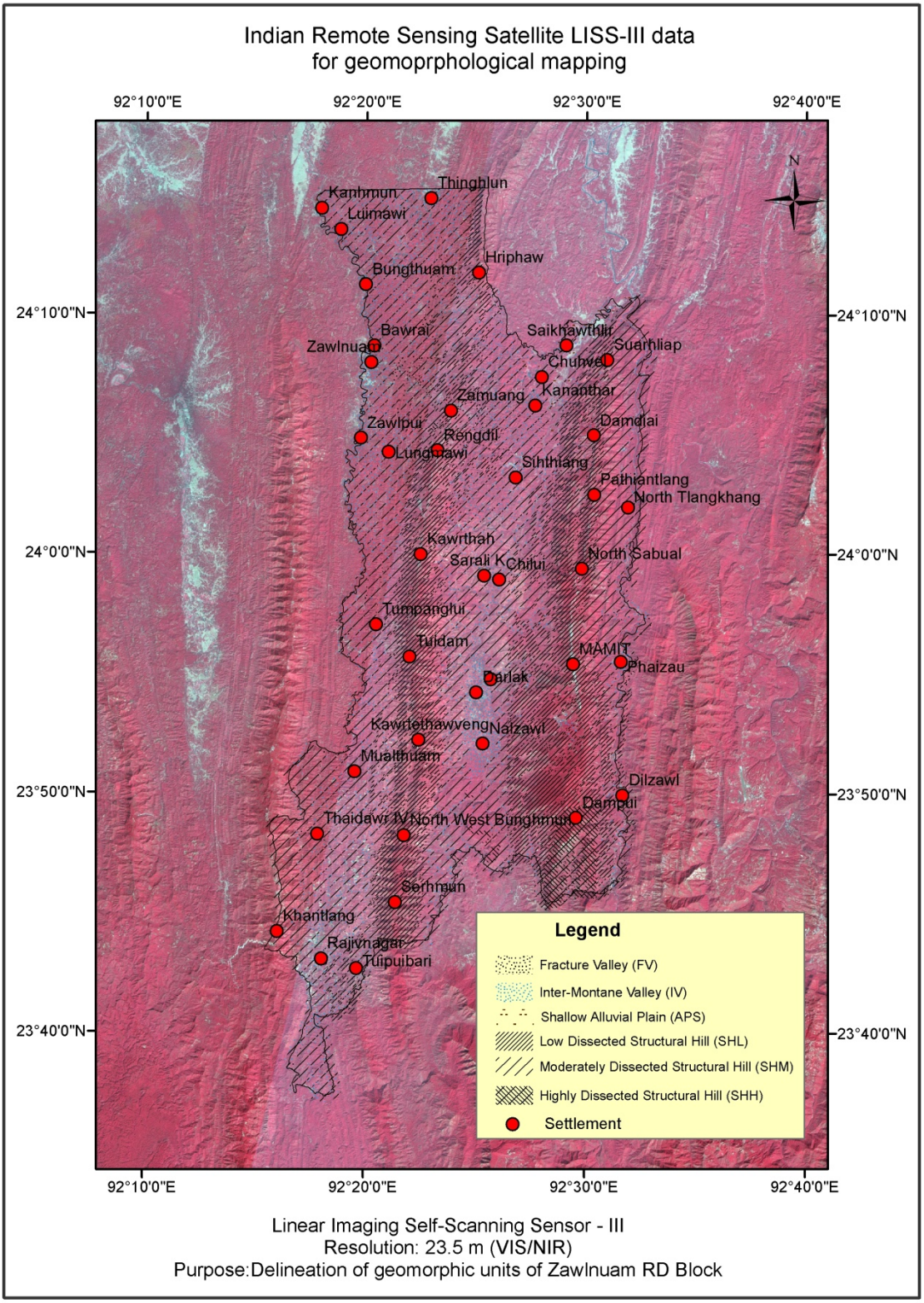


Figure 5: Indian Remote Sensing satellite LIS- III data for geomorphological mapping

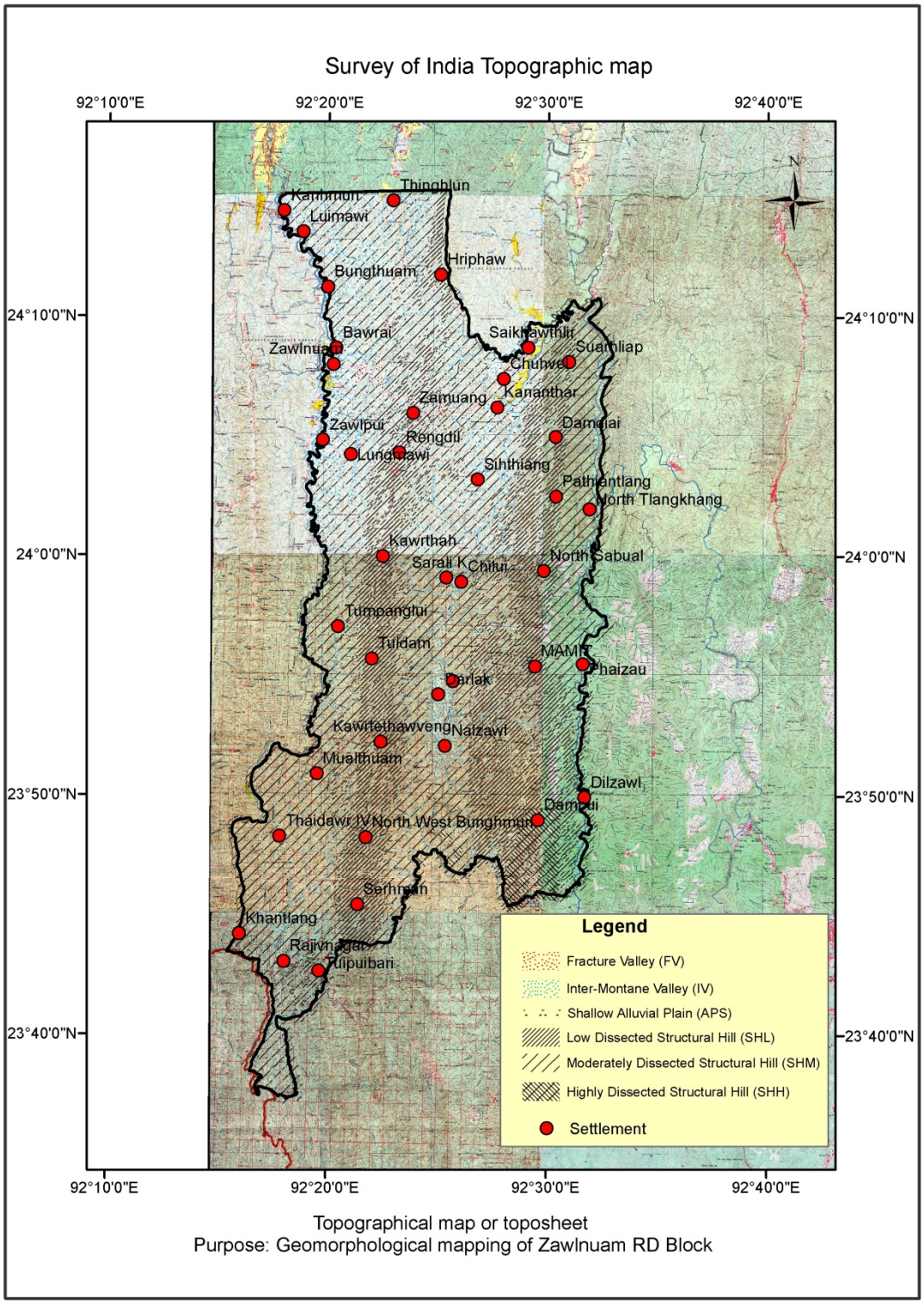
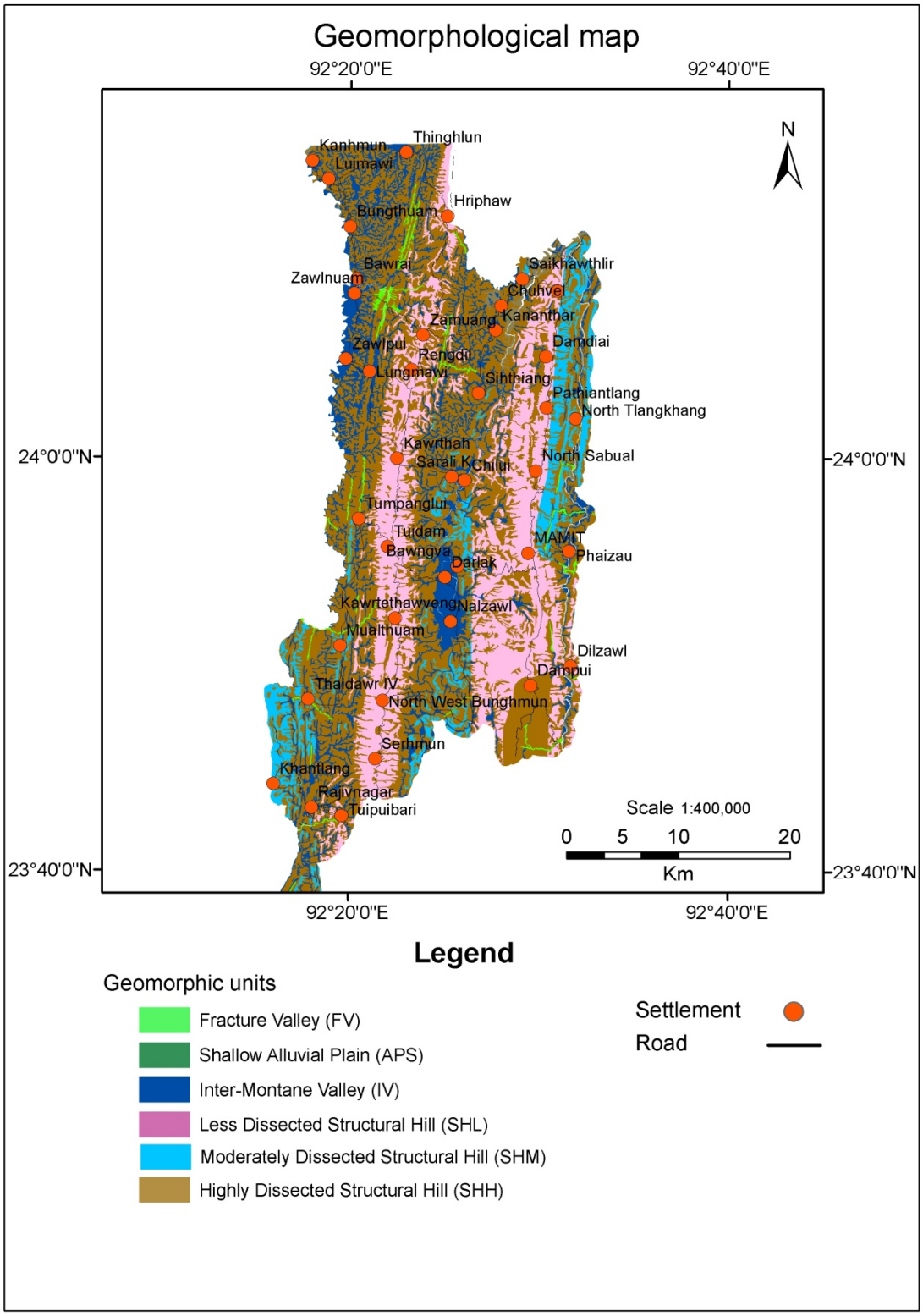


Figure 6: Survey of India Topographic map for geomorphological mapping

Sl. No	Geomorphic Units	Area (in Sq km)
1	Shallow Alluvial Plain (APS)	14.27
2	Fracture Valley (FV)	14.12
3	Inter-Montane Valley (IV)	192.53
4	Moderately Dissected Structural Hill (SHM)	653.05
5	Highly Dissected Structural Hill (SHH)	22.95
6	Low Dissected Structural Hill (SHL)	273.07
	Total area	**1170.00**

Table 3: Geomorphic units



Map 5: Geomorphological map

5.3 Geological structure:

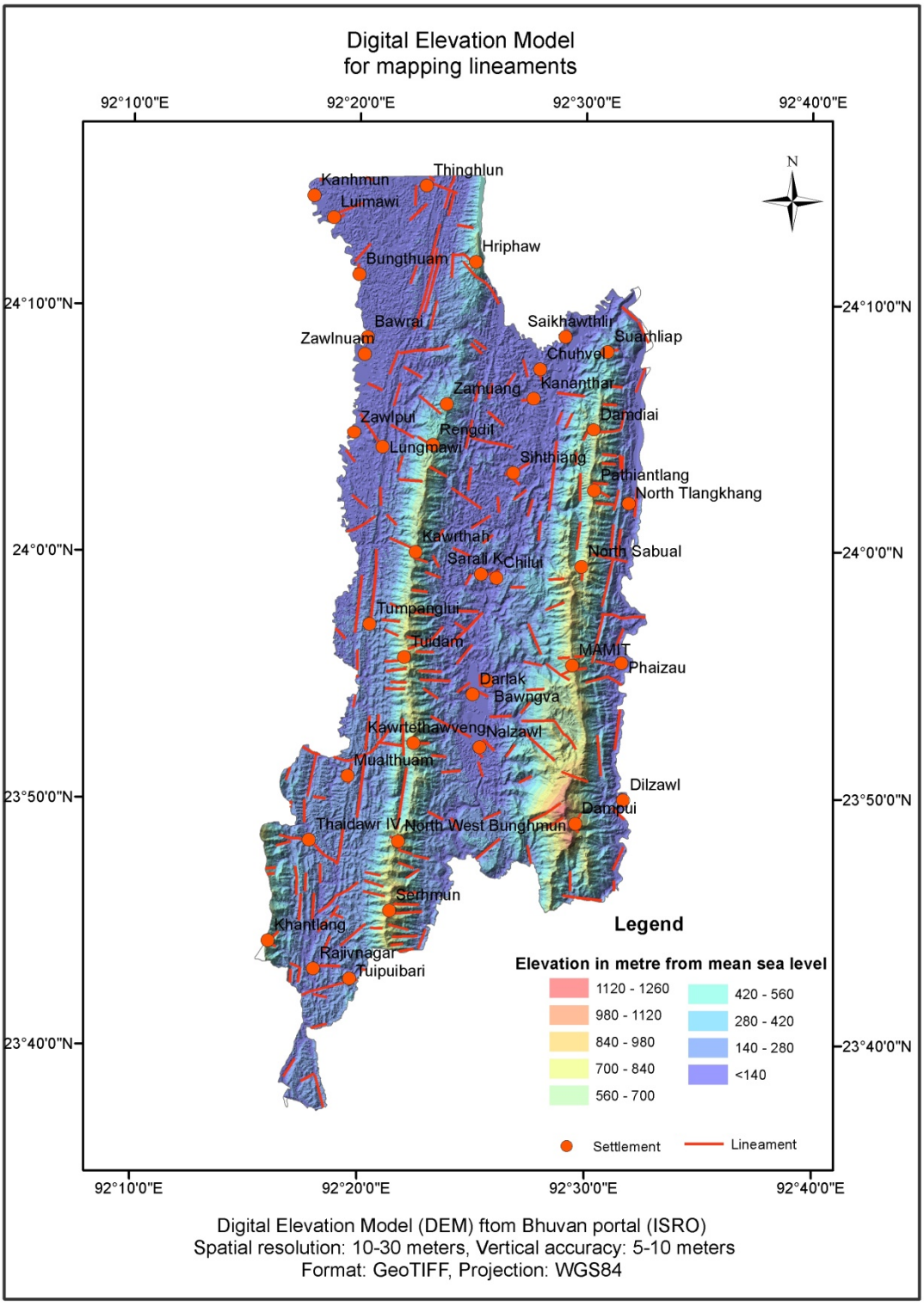
Geological structures such as lineaments, including fractures, fissures, joints, and faults, play a crucial role in mapping potential groundwater areas. These structures can serve as conduits, facilitating the movement of groundwater and creating pathways for flow. Additionally, fractures, fissures, and joints have the capacity to store groundwater, thereby increasing local storage capacity. From a groundwater perspective, these are the most prominent structural features (Bhatnagar et al, 2014). Furthermore, faults and fractures can enhance permeability, allowing groundwater to flow more freely.

Geological structures can also influence the direction of groundwater flow, aiding in the identification of areas with high groundwater potential. Lineaments and fractures can indicate regions with high recharge potential. The geological structures present in a given area are considered conduits for groundwater movement and provide potential for groundwater recharge (CGWB, 2000; Sharma and Kujur, 2012).

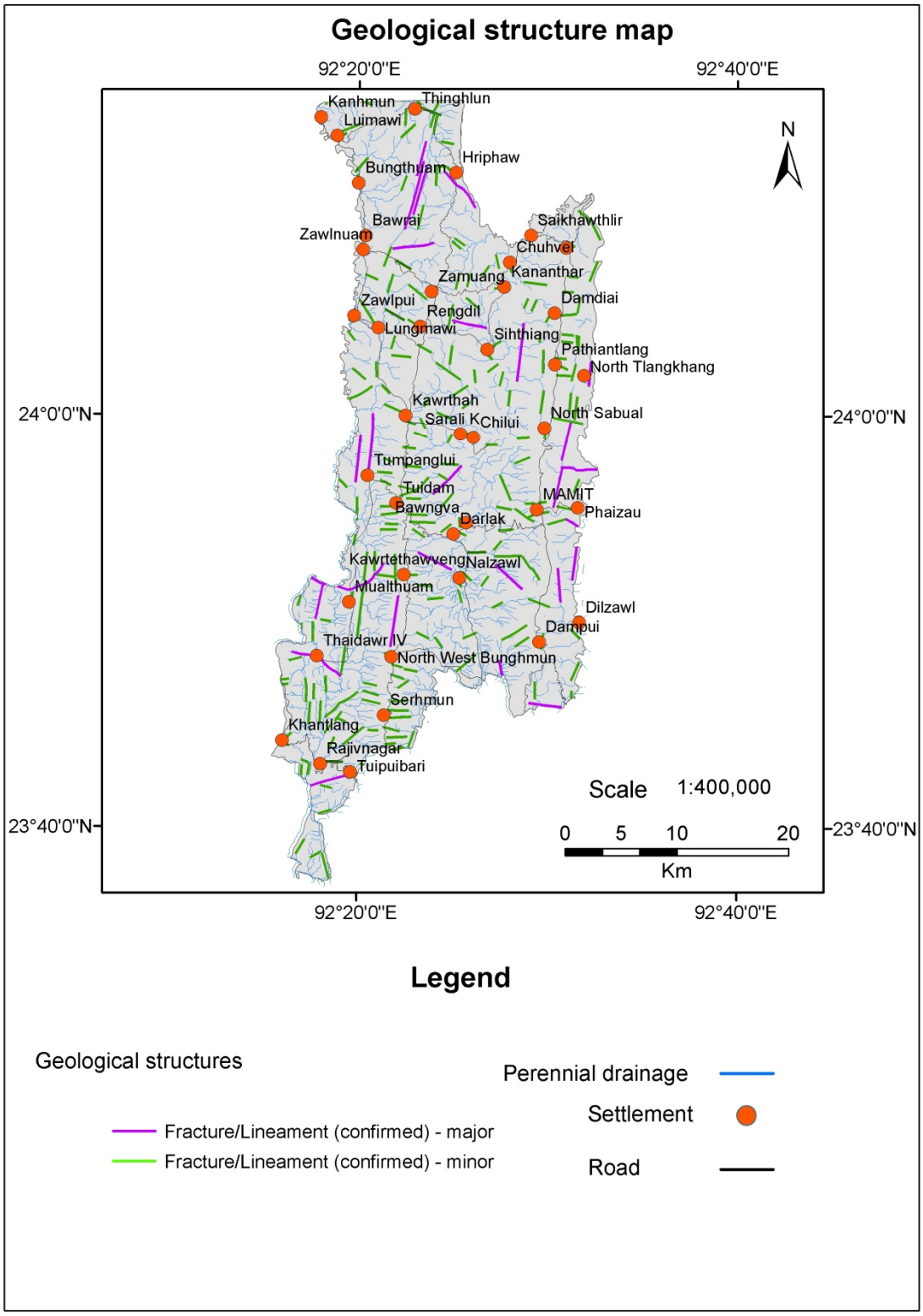
The use of remote sensing and GIS techniques can assist in identifying and mapping these geological structures, which can then be validated through fieldwork and hydrogeological investigations. Lineaments such as faults, fractures, and joints can be delineated and analyzed using remote sensing data (Kanungo et al., 1995). Remote sensing satellite images are visually studied to identify different lineaments and interpret the tectonics. The identified lineaments from imagery are validated by field data.

A Digital Elevation Model (DEM) from the Bhuvan portal serves as one of the sources for lineament mapping. DEM is a digital representation of the Earth's surface topography, showcasing the elevation of various points on the Earth's surface. It provides a 3D model of the terrain, created from a grid of elevation values, each representing the height of a point on the Earth's surface. The Bhuvan portal, developed by the Indian Space Research Organisation (ISRO), offers free DEM data for India and surrounding regions. The DEM data available on Bhuvan has a spatial resolution of 10-30 meters, vertical accuracy of 5-10 meters, and a projection with WGS84 matching the ongoing research work.

The study area revealed numerous faults and fractures of varying magnitude and length within the exposed rocks (MIRSAC, 2006). These geological structures are mapped as line features. All lineaments within the study area are classified into minor (less than km in length) and major (> 5km) lineaments.



Map 6: Digital elevation model for mapping lineaments



Map 7: Geological structure Map

Lineament Type	Nos.	Total Length (in km)
Major Lineament	26	306.35
Minor Lineament	212	983.85

Table 4 : Lineament Type

5.4. Land Use/Land Cover (LULC):

The role of land use/land cover (LULC) in the mapping of groundwater potential cannot be overstated, as it directly impacts the recharge and discharge of groundwater. The varying infiltration rates of different LULC types influence the amount of rainfall that reaches the aquifer. Additionally, LULC affects surface runoff, which can either recharge groundwater or flow into surface water bodies.

The identification of LULC types that facilitate recharge, such as forests and grasslands, is crucial for pinpointing potential groundwater recharge areas. LULC also affects hydrological processes like interception, infiltration, and percolation, which in turn control groundwater flow.

Integrating LULC data with other factors such as geology, topography, and hydrology enhances the accuracy of groundwater potential mapping, thereby enabling better management and sustainable use of this vital resource.

Within the research region, wet rice cultivation (WRC) and other cultivated areas fall under the principal land use/land cover classes, categorized as agricultural land. Playgrounds and other recreational areas are primarily included in the definition of built-up land. Additionally, heavy vegetation includes not only deep forests unaffected by human activity but also forest plantations.

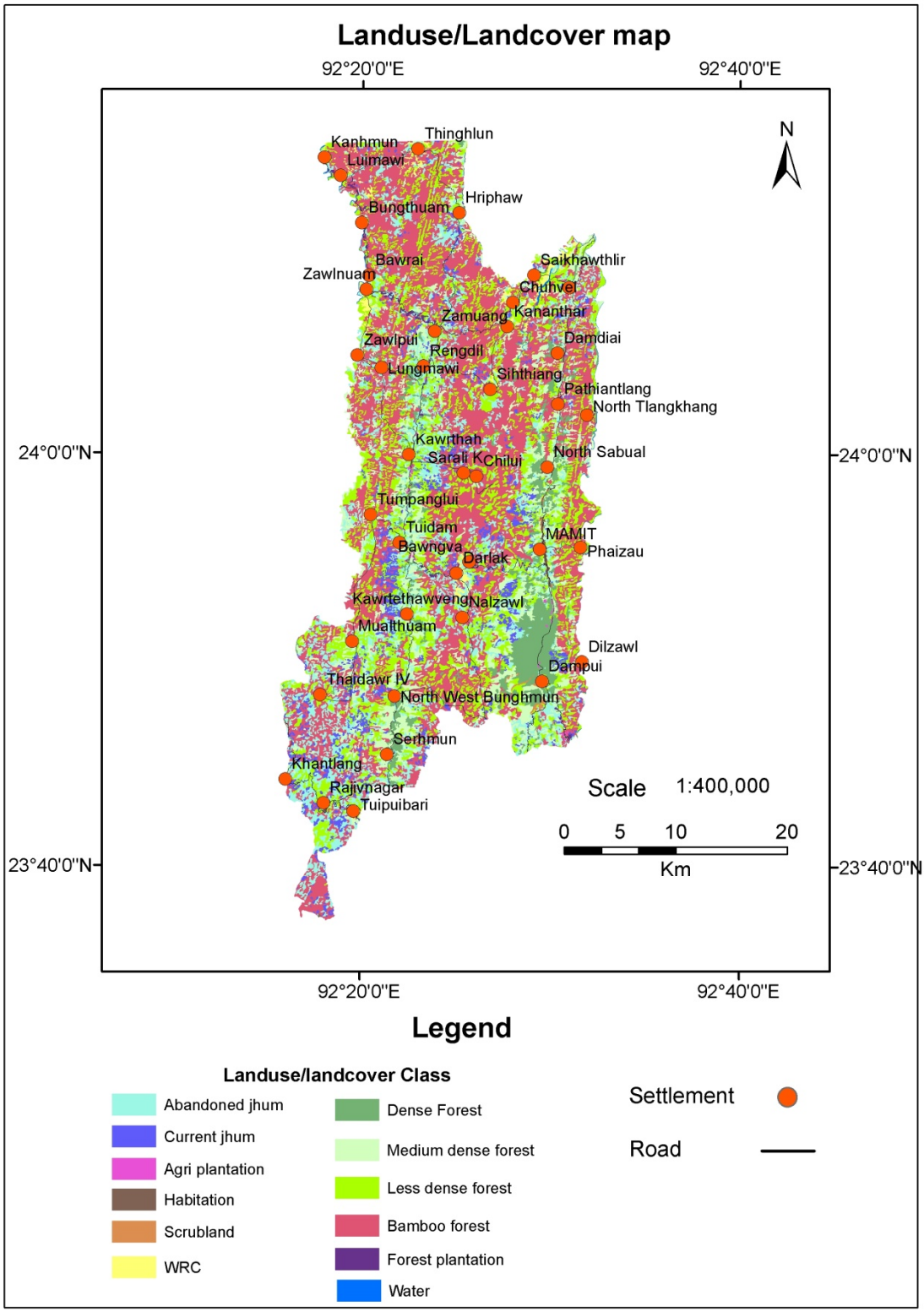
Light vegetation, primarily open forests, has been affected and disturbed by biotic factors such as human activity and shifting agricultural practices. Areas with patches of grasses, shrubs, herbs, and abandoned land used for sporadic farming are referred to as scrubland.

The use of remote sensing and GIS techniques can provide valuable information for land use mapping, which is essential in identifying patterns of land use. The land use and land cover of aquifers significantly contribute to natural groundwater recharge (Anirudh, 2013; Sharma and Kujur, 2012). Urbanization-related infrastructure, such as impermeable pavements, hampers the natural recharging process. It is well documented that irrigated and cultivable land have higher recharge rates than wasteland and populated areas (NRAA, 2011; Valliammai et al., 2013).

The land use/land cover data of the study area was prepared using the base layer map generated by MIRSAC (Mizoram Remote Sensing Application Centre). Additionally, field validation using Quickbird satellite data was also referenced in preparing the land use/land cover map.

Sl No	Land use_Class	Area (in Sq km)
1	Abandoned jhum	180.97
2	Agri plantation	2.12
3	Bamboo forest	455.74
4	Current jhum	56.86
5	Dense Forest	66.73
6	Forest plantation	3.08
7	Habitation	6.10
8	Less dense forest	247.17
9	Medium dense forest	133.13
10	Scrubland	2.38
11	WRC	12.65
12	Water	3.07
	Total	**1170.00**

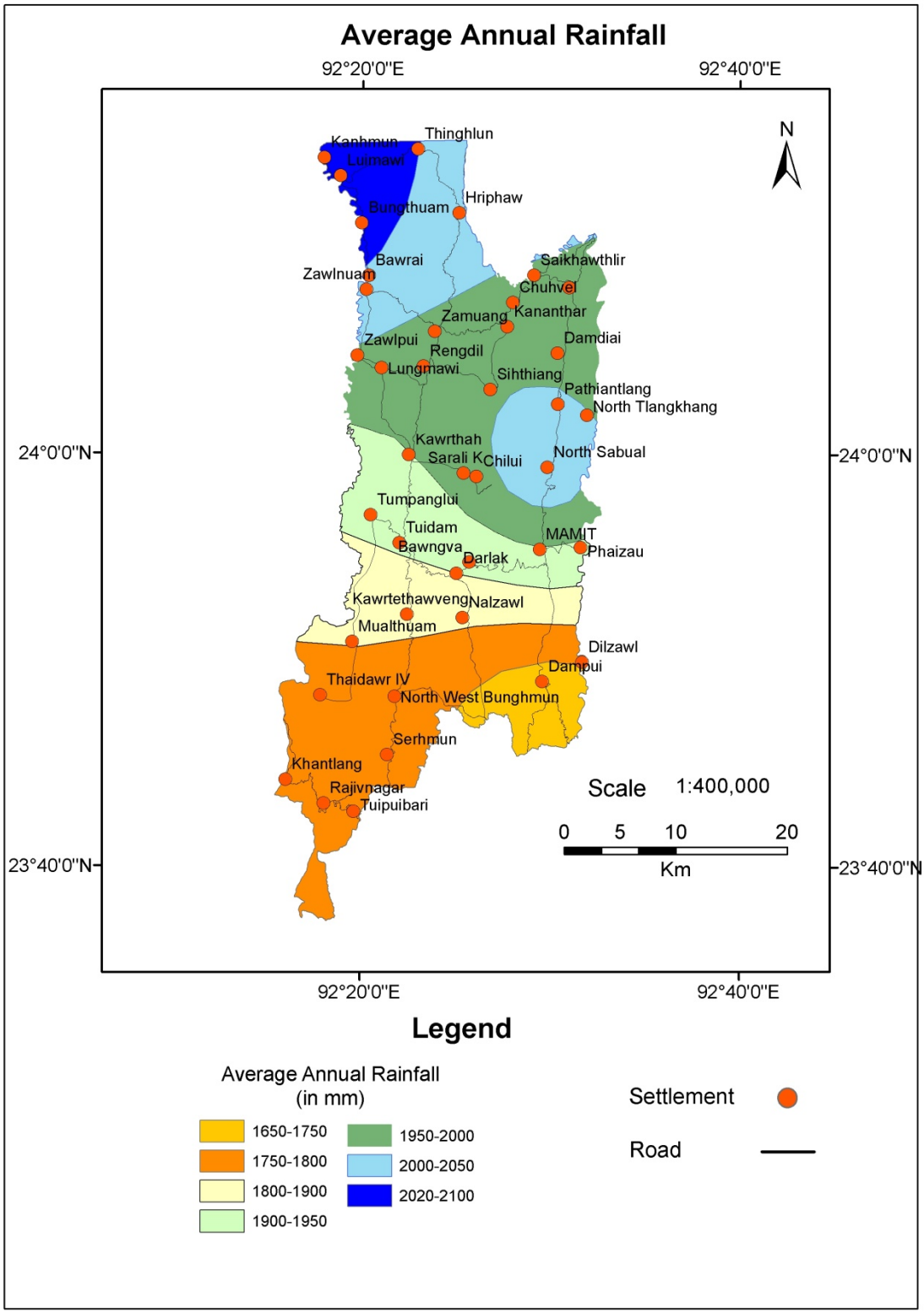
Table 5: Land use class



Map 8: Land use/ land cover map of Zawlnuam R.D. Block

5.5. Rainfall

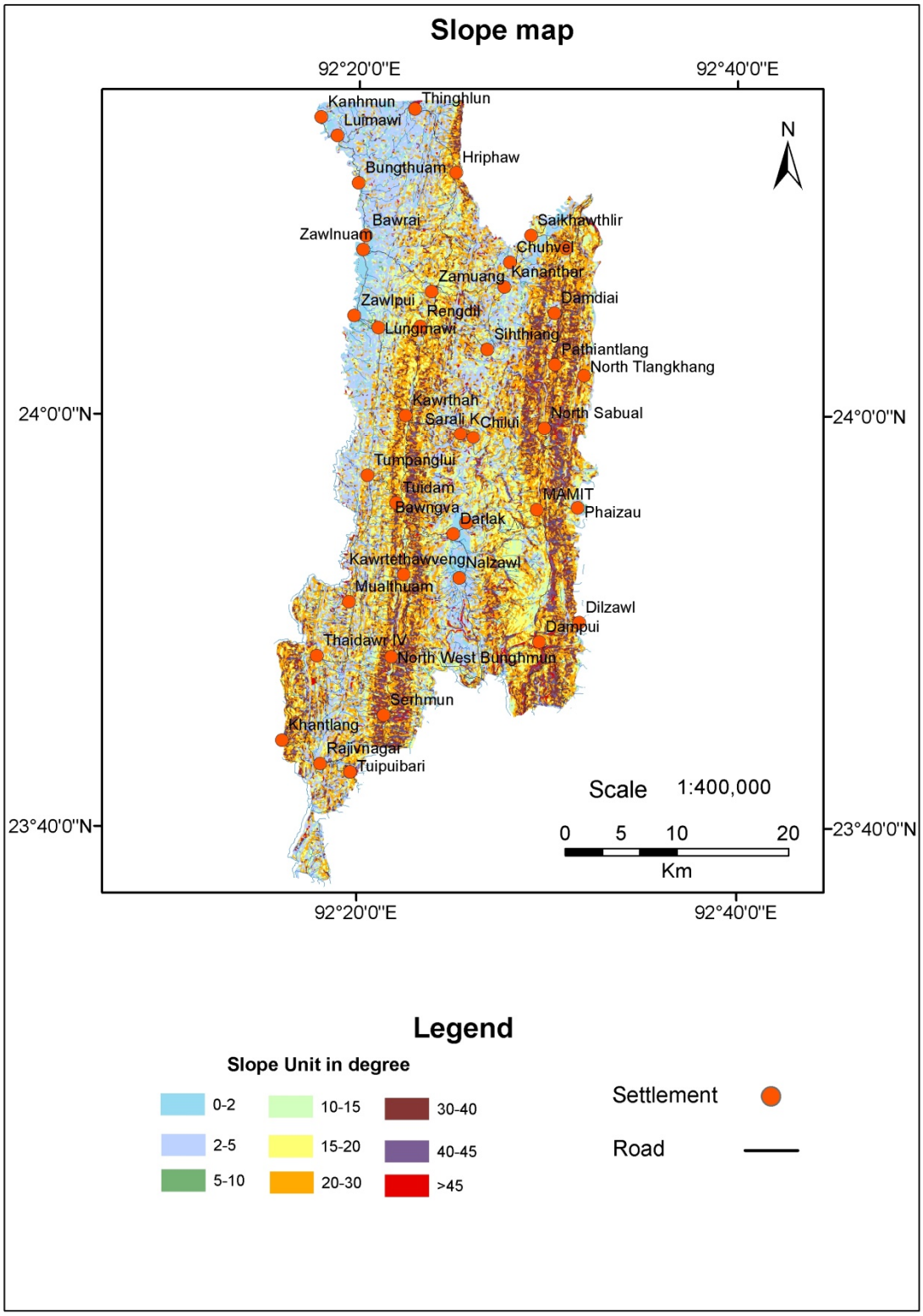
Rainfall maps play a crucial role in groundwater prospect mapping as they aid in identifying areas with high recharge potential. These maps utilize rainfall data to pinpoint regions with high groundwater potential and infiltration rates, where rainfall is likely to recharge groundwater. They also illustrate seasonal patterns, helping to identify periods of high recharge and potential fluctuations in groundwater levels. Integrating rainfall data with other datasets such as geology, land use, and hydrology is essential for delineating groundwater prospect mapping. This comprehensive approach ensures sustainable groundwater use and management. Rainfall serves as the primary source for replenishing groundwater recharge, and it is measured in millimeters using a rain gauge. The water cycle on Earth, crucial for all life, relies on rainfall to replenish subterranean aquifers, fill lakes and rivers, and provide water for plants and animals. Understanding the recharge process and its relation to rainfall is vital for managing groundwater systems. IMD (India Meteorological Department) operates several stations in the North East region of India, including Mizoram, Tripura (Agartala), and Assam (Silchar). Rainfall data from these stations is interpolated to generate an isohyetal map of the study area (Sangita Dey, et.al., 2020; Jinquan Wu et.al., 1996).



Map 9: Rainfall map of Zawlnuam R.D. Block

5.6. Slope

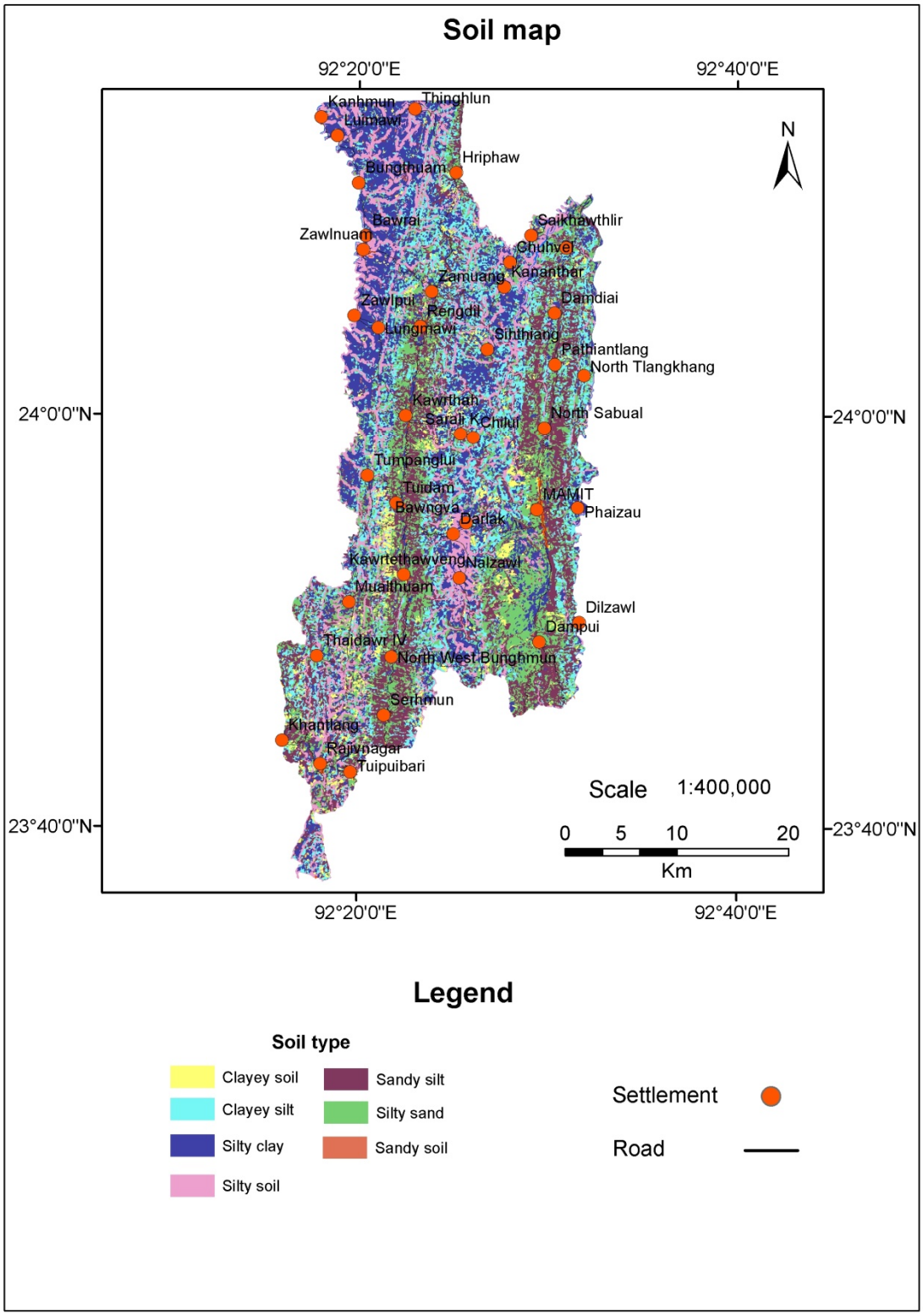
Different slope angles play a crucial role in ground water prospect mapping. According to various sources (CGWB, 2000; Kumar et al, 2013; Al-Bakri1 and Al-Jahmany, 2013; Siddalingamurthy et. al., 2013), gentle slopes facilitate water infiltration and ground water recharge, while steep slopes act as high runoff zones. Areas with gentle slopes are indicative of recharge zones where water can infiltrate and recharge ground water. Conversely, steeper slopes indicate runoff zones where water flows over the surface, reducing infiltration and recharge. Slope angles can help identify areas where ground water flows. Flat slopes may indicate a shallow water table, while gentle to steep slopes may indicate a deeper water table. Valleys and basins (low slopes) indicate areas of ground water accumulation, whereas ridges and hills (steeper slopes) indicate runoff zones. By analyzing slope angles in conjunction with other geological, hydrological, and geophysical data, ground water prospect mapping can identify areas with favorable conditions for ground water occurrence and flow. Based on this concept, weightage values were assigned according to the steepness of the slope, with gentle slopes being given high weightage and steep slopes being given less weightage. The slope map was generated from Digital Elevation Model (DEM) using Cartosat-I stereo-paired data in a GIS environment. The slopes of the area are represented in terms of degrees and are divided into eight slope classes, ranging from 0-15 degrees to above 60 degrees.



Map 10: Slope map of Zawlnuam R.D. Block

5.7. Soil

The earth's surface is covered by a thin layer of material known as soil, which is formed through the gradual weathering of rock into sediments. Soil filtration is a crucial ecological service for the preservation of surface and groundwater. Research aims to identify information gaps about the processes affecting how pollutants behave in soils and their potential to reach ground water. Soil has a significant impact on groundwater potential mapping, affecting movement, storage, and quality of groundwater. It also controls the rate of infiltration, recharge, and groundwater potential based on its texture, structure, water holding capacity, permeability, porosity, hydraulic conductivity, salinity and chemistry. Soil-geology interactions, such as soil-mantled bedrock, also influence groundwater flow and potential. (SD Keesstra et.al., 2012).



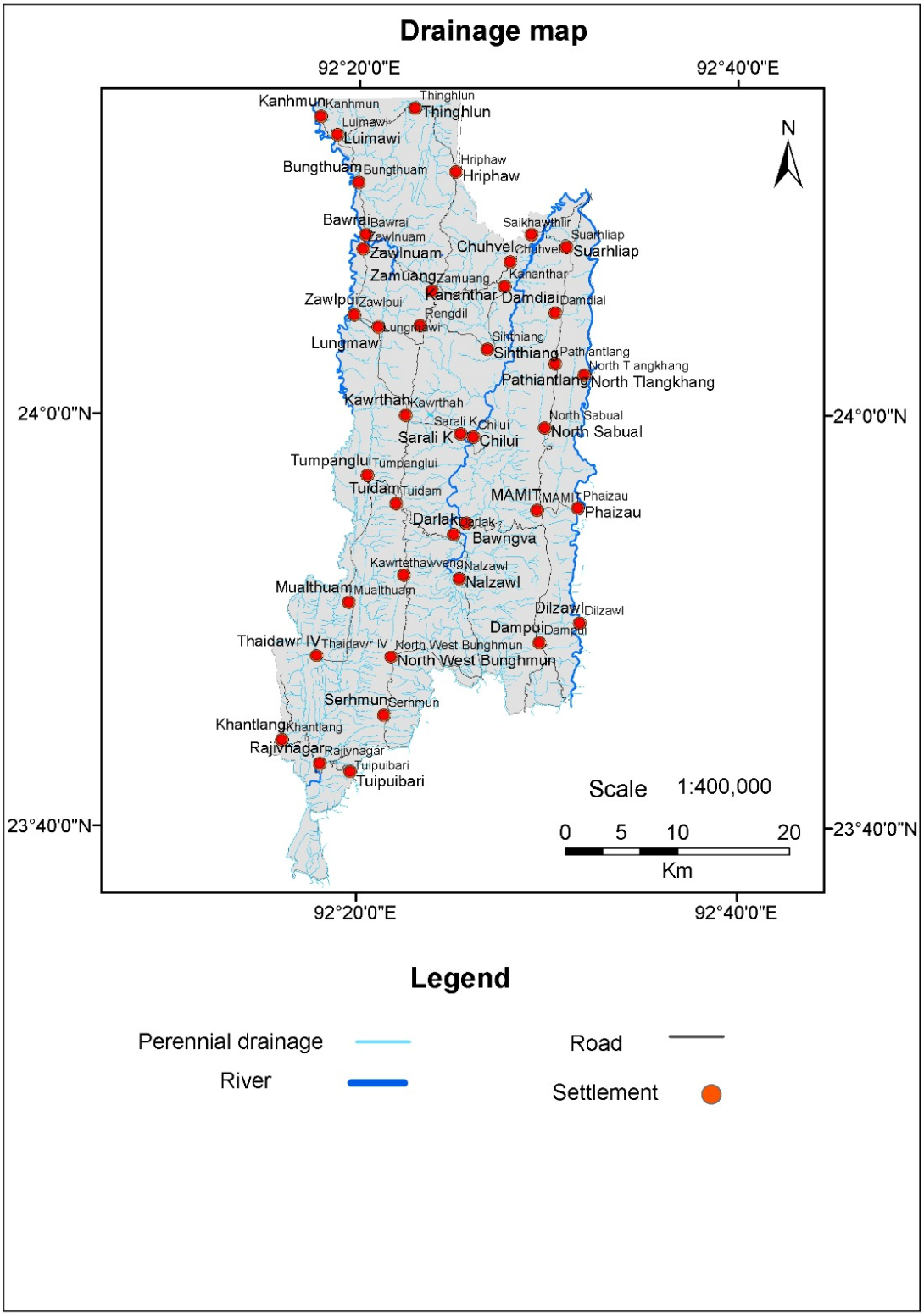
Map 11: Soil map of Zawlnuam Block

5.8. Drainage

The role of drainage systems in ground water potential mapping is crucial. They show where surface water flows and infiltrates, recharging ground water. Drainage patterns can reveal underlying geological structures, such as faults and fractures, and indicate the orientation and extent of underlying aquifers. Additionally, drainage systems impact ground water availability by controlling recharge and discharge. Incorporating drainage patterns and systems improves the accuracy of ground water potential maps.

Furthermore, drainage density also plays a significant role in ground water potential mapping. It can indicate the permeability and transmissivity of underlying aquifers, as well as the permeability of the terrain, affecting ground water infiltration and availability. Analyzing drainage density helps to understand the relationships between surface and ground water, leading to more accurate groundwater potential mapping and informed decision-making.

In the research area, there are three major drainage systems, all of which are major rivers in the state flowing northward. These include the drainage systems in Teirei, Tlawng, Tut, and Langkaih. The Tlawng River is one of the most significant rivers in Mizoram, forming district boundaries as it flows through five different districts in the state. It serves as a water transportation route with Assam, a neighboring state. The Teirei River and Tut River are tributaries of the Tlawng River, while the Langkaih River is located in western Mizoram and empties into the Barak River in the Assamese Cachar plain after flowing northward.



Map 12: Drainage Map of Zawlnuam RD Block

5.9. Hydrogeological units

Muhammad Salik Javaid and Shaukat Ali Khan (2017) categorized the rock types in the research region into semi-consolidated formations and unconsolidated formations from a hydrogeological perspective. The region was divided into two hydrogeological units: the semi-consolidated/hard rock unit and the unconsolidated unit. Unconsolidated rocks with minimal alluvial thickness were found in intermontane valleys, broken valleys, and shallow alluvial plain, with shallow groundwater conditions. The semi-consolidated unit mainly comprised shale and sandstone, with tectonic disruptions causing secondary porosity. Due to the hilly terrain with slopes of more than 20%, surface runoff was the primary source of precipitation, and ground water storage options included secondary porosity and structural control in aquifers at higher elevations. The primary source of springs was aquifers in valley-filled locations. According to the Central Ground Water Board ground water investigation, deep tube wells with a depth range of 200 m tapping into Tertiary sandstone had varying production potential. Overlay analysis in a GIS setting integrated geomorphological, lithological, land use/land cover, rainfall, drainage, slope, soil, and structural layers to define aquifers, considering primary and secondary porosity and permeability. Aquifers were defined as cohesive units of geomorphology, lithology, and structure, capable of supporting wells and springs. Aquifers, as geological formations containing enough water to support wells and streams, were discussed along with their significance and characteristics. The mapping of combined lithological-structural-geomorphic units involved the use of polygon and line features to represent units derived from geological structures and overlay analysis. The resulting polygon features are then labeled with alphabetic codes such as Fracture Valley, Shallow Alluvial Plain, Inter-Montane Valley, Less Dissected Structural Hill, Moderately Dissected Structural Hill and Highly Dissected Structural Hill.

5.10 Classification of aquifer materials:

Based on their material content, the aquifer material is divided into the following groups taking into account the porosity and permeability of the geological strata placed in the subsurface at different levels.

Unconsolidated Soils: Mostly Quarternary structure rocks with semi-consolidated sediments that have primary porosity and permeability are known as permeable rocks with alluvial flood plains representing the unconsolidated sediments.

Broken Rock: These are hard rock areas that are broken and typically serve as channels for groundwater flow.

Impermeable Rocks (IR): These are rocks, such as vast shale, that act as a barrier to the movement of groundwater because they lack significant porosity and permeability to the movement of groundwater because they lack significant porosity and permeability.

5.11. Types of aquifers:

Confined aquifers, also known as artesian aquifers, are water bodies found in permeable rock surrounded by impermeable rock layers or bodies. These aquifers are covered by a layer of restricting rock, often composed of clay, which provides some protection against surface contamination. The water in confined aquifers is under high pressure due to the non-permeable geological barriers. In areas with fractures or cracks in the bedrock, such as karst counties like Augusta and Bath in Virginia, water can flow through large openings created by the dissolution of rock, resulting in significant well yields. Aquifers allow groundwater to flow vertically or horizontally, with flow rates influenced by local geological formations and gravity. Water levels in wells that tap into artesian aquifers fluctuate due to changes in pressure rather than the amount of water stored. These perforated wells primarily serve as conduits for transferring water from recharge areas to natural or man-made outlets. Confined aquifers have very low storativity values, typically ranging from 0.01 to 0.0001.

Unconfined aquifers

Unconfined aquifers are typically located near the ground surface and lack impermeable layers above the water table, making them more susceptible to surface pollution. The level of groundwater fluctuates based on the amount of water held in the aquifer, affecting water levels in wells. These aquifers have a storative value higher than 0.01. Perched aquifers are unique instances of unconfined aquifers that have limited water accessible for short periods, separated from their primary groundwater source by impermeable rock layers.

5.12. Ground water potential classification of the study area

In the legend, the final map is divided into "Very good," "Good," "Moderate," and "Poor" prospect areas based on the combination of ground water governing criteria such as geomorphology, lithology, and geological structures. Here's a brief description of each class:

5.12.1. Very-good prospect area: This area is characterized by low-lying regions, fracture valleys, and intermontane valleys. It also encompasses the convergence of lineaments and the presence of unconsolidated sediments, such as clayey sand, gravel, sand, and silt. These sediments, due to their larger pore spaces between grains, exhibit high percolation rates, thereby enhancing their capacity to retain water. Promising prospective sites can be identified in and around the areas of Luimawi, Zawlnuam, Zawlpui, Lungmawi, Bawngva, Darlak, Nalzawl, Bawrai and Phaizau.

5.12.2 Good prospect area. This area includes all remaining areas restricted by geological structure, as well as additional low-lying places with gentle slopes. Sandstones are considered suitable aquifers due to their ability to store and transfer water through pore spaces and interstices between grains. This zone also encompasses areas where exposed sandstones are present.

5.12.3 Moderate Prospect Area: This refers to locations where the water-yielding capabilities and recharging condition of the underlying materials are neither inadequate nor optimal. Topographically, this area includes the gently sloping slopes of the hills. Even though the lithology may contain good water-bearing rock formations like sandstone, the sloping topography with high run-off reduces the potential. The moderate zone is typically found in poor water-bearing rock formations

such as silty shale, which are further characterized by the presence of secondary structures. The moderate zone in the study area is evenly distributed and can be found in and around Mamit.

5.12.4 Area of poor prospect: This area is primarily found in higher elevations. A larger portion of precipitation in high relief areas runs off as surface runoff, making it difficult for it to penetrate below the ground's surface. Therefore, it is typically considered that the groundwater output is modest. The groundwater yield of elevated places is often poor unless they are accompanied by geological structures, have a high drainage density, and have a suitable rock formation that can hold water. The poor zone is primarily found around ridgelines. This zone, which makes up a small portion of the study region, is primarily high in terms of aerial extent and includes Dampui, N. Tlangkhang, Khantlang, Thaidawr, and Mualthuam.

Map 13: Ground water prospect map of Zawlnuam Block, Mizoram, India.

5.13. Identifying areas for recharging ground water:

In rapidly urbanizing areas with a growing population, the demand for water supply is on the rise. This surge in demand often leads to the depletion of both surface and ground water resources. The fluctuation of ground water levels during periods of abundance and scarcity in hilly regions like Mizoram highlights the urgent need for the construction of recharge structures. The primary aim is to establish a comprehensive geo-database to identify suitable sites for the construction of ground water recharge structures within the study area. This involves conducting thorough analyses of the hydrogeological conditions and creating detailed maps using GIS techniques. The process begins with the generation of geo-spatial data, including base layers such as road, habitation, tube well, spring, and drainage layers. Subsequently, suitable sites for constructing recharge structures near springs and wells will be mapped. The resulting database will be invaluable for administrators, decision makers, and developmental planners, ensuring an adequate water supply for all households in the area.

As urbanization accelerates and populations grow, the demand for water supply increases proportionally. In many cases, the available surface water resources are insufficient to meet the escalating demand for water supply. Consequently, extensive development of ground water resources has occurred, with significant tapping and utilization. In areas plagued by persistent drought and water scarcity, ground water resources have emerged as a viable solution to the problem. Thus, ground water resources are now utilized not only for domestic purposes but also for irrigation and agricultural activities.

Currently, ground water is predominantly used for domestic purposes and, to a lesser extent, for agricultural activities within the area. The extraction of water from springs for domestic use remains a common practice in many villages in the region. This underscores the importance of sustainable management and conservation of ground water resources to ensure continued access to water for both domestic and agricultural needs.

Cutting-edge research has been conducted by various experts in India to address the critical issue of ground water development and recharge in hard-rock terrains. By utilizing advanced technologies such as remote sensing and GIS, these studies have successfully identified potential sites for artificial recharge structures in drought-prone areas. The integration of thematic information layers and geomatics techniques has allowed for the precise mapping and modeling of ground water recharge zones, leading to the identification of suitable locations for rainwater harvesting and artificial recharge structures. These efforts have not only contributed to the development of innovative methodologies for ground water recharge studies but also provided valuable insights for implementing artificial recharge schemes in specific regions. The use of GIS-based models has further enhanced the accuracy of site selection and suitability analysis, taking into account various local environmental and hydrogeological conditions. Overall, these studies represent a significant step forward in the field of ground water management and have the potential to make a meaningful impact on water resource sustainability in hard-rock terrains.

The research conducted by various scholars from different institutes in India focused on using GIS and remote sensing techniques for identifying suitable sites for artificial recharge and water harvesting structures. The studies involved the integration of various thematic layers such as geomorphology, geology, land use, and drainage patterns into GIS for accurate site selection. The aim was to apply these techniques to establish basic information for rainwater harvesting and artificial recharge structures in different regions of India, ensuring the optimal and judicious use of groundwater resources.

The identification of potential recharge zones in the selected watershed was conducted by A. Valliammai, K. Balathanduytham, D. Tamilmani, and C. Mayilswami from Tamil Nadu Agricultural University, Coimbatore, India. The study utilized remote sensing data and GIS techniques. Using ARC/INFO GIS software, thematic layers such as soil, land use, geology, geomorphology, lineament, and drainage were prepared and integrated to identify areas suitable for artificial recharge.

Methods for selecting recharge areas:

The project will utilize standard Geographic Information System (GIS) techniques, such as data processing, digitization and geo-referencing. The resulting data will be used to create a base map featuring essential elements like roads, drainage, and administrative boundaries. Additionally, thematic maps will be generated using various sources including Survey of India Topographic maps, literature, and field surveys. These thematic layers will be used to identify suitable sites for recharge structures, with each parameter categorized and assigned weightage values based on their importance. The methodology will adhere to the guidelines provided by the Central Ground Water Board, Ministry of Water Resources. Finally, the thematic layers will be integrated and analyzed in a GIS environment to determine suitable areas for the construction of ground water recharge structures. The final maps will be produced in print format and stored in a computer system for monitoring and updates.

Flowchart for Methodology of standard GIS techniques is given below:

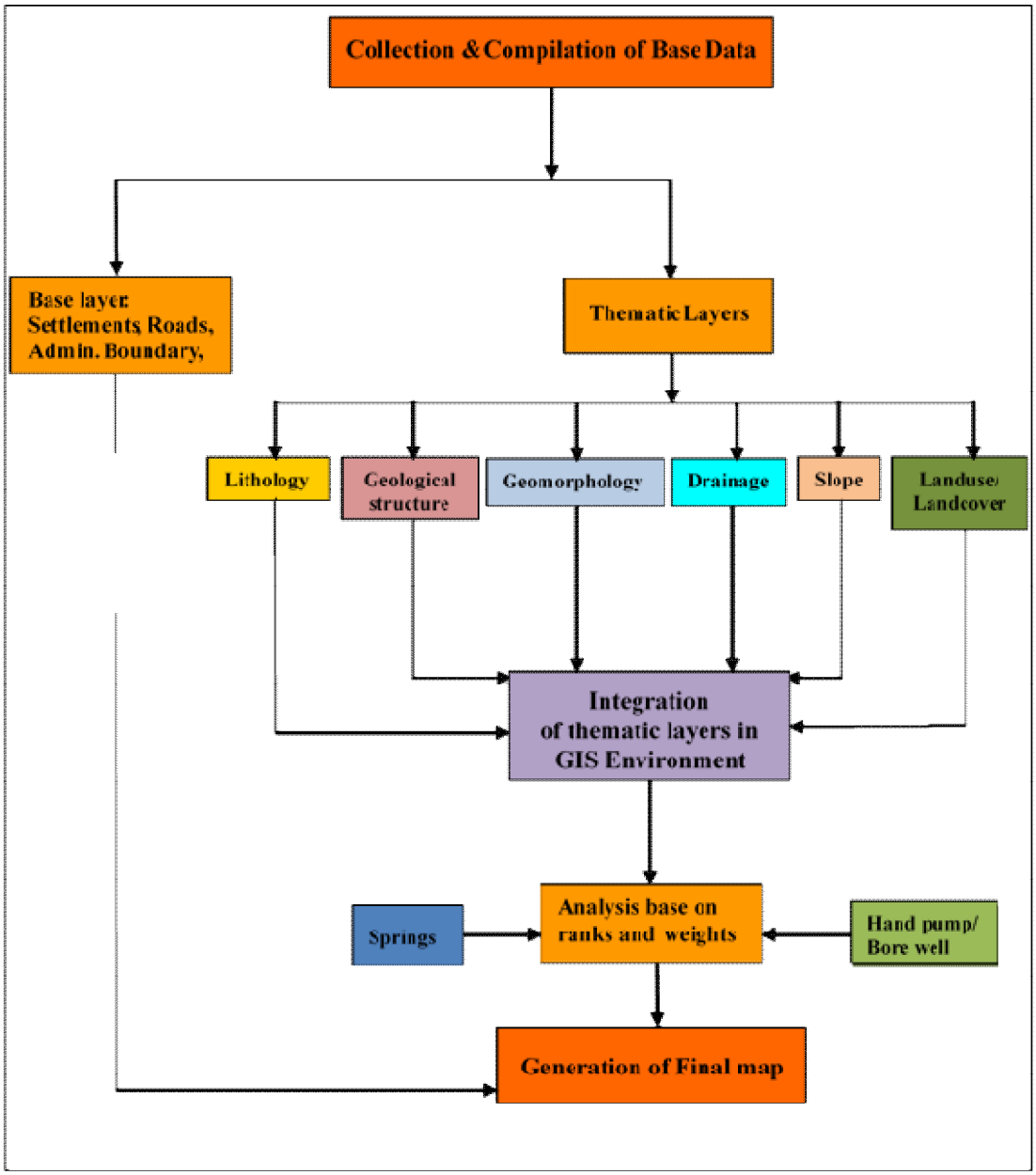


Figure 7: Flowchart of methodology for identifying areas for recharging ground water

5.14. NEED FOR ARTIFICIAL RECHARGE

Natural replenishment of ground water reservoir is a slow process and is often unable to keep pace with the exploitation of ground water resources. This has resulted in declining ground water levels and depletion of ground water resources. Artificial recharge efforts are basically aimed at augmentation of the natural movement of surface water into ground water reservoir through suitable civil construction techniques. Such techniques interrelate and integrate the source water to ground water reservoir and are dependent on the hydrogeological situation of the area concerned.

Occurrence of rainfall in Mizoram is mostly limited to about three months in a year. The natural recharge to ground water reservoir is restricted to this period only in a major part of the state. Artificial recharge techniques aim at extending the recharge period in the post-monsoon season for about three or more months, resulting in enhanced sustainability of ground water sources during the lean season.

In areas where climatic conditions are not favourable for creating surface storage, artificial recharge techniques have to be adopted for diverting most of the surface storage to the ground water reservoirs within the shortest possible time.

In hilly states like Mizoram, even though the rainfall is comparatively high, scarcity of water is often felt in the post-monsoon season, as most of the water available is lost as surface runoff. Springs, the major source of water in such terrains, are also depleted during the post monsoon period. In such areas, rainwater harnessing and small surface storages at strategic locations in the recharge areas of the springs can provide sustainable yields to the springs as well as enhance the recharge of ground water during and after the rainy season.

Artificial recharge techniques play a significant role in mitigating the impacts of water scarcity by effectively managing the surface water and enhancing the sustainability of ground water sources.

5.15. SCOPE FOR ARTIFICIAL RECHARGE:

Artificial recharge of groundwater in Mizoram can be accomplished using check dams, gabion structures, and weirs. This method is typically employed in the following scenarios:

1. Areas where groundwater levels are continuously declining

2. Areas where a significant volume of the aquifer has been desaturated

3. Areas where groundwater availability is insufficient during dry months

4. Areas where there is potential for improving the quality of groundwater or addressing salinity ingress into fresh water aquifers.

In our study area, the relevant point would be number 3, as there is significant fluctuation in groundwater levels and quantity. Constructing artificial recharge structures aims to produce economically viable filtered water and store enough water during the operating season to meet the year-round demand. These structures will replenish springs and wells in the area, catering to domestic and agricultural water needs.

Natural recharge can range from minimal to almost all of the runoff from a drainage area. Artificial recharge can be used to supplement naturally recharged water where available. Recharge methods must be customized to suit specific situations.

5.16. IDENTIFICATION OF AREA

The identification of suitable areas for artificial recharge was carried out using the Geographical Information System (GIS) technique. Geological factors such as lithology, lineaments, and geomorphology were mapped and analyzed. Additionally, important factors like drainage pattern, drainage density, land use/land cover, slope morphometry, groundwater level, and rainfall were taken into consideration.

5.17. SOURCE WATER AVAILABILITY:

The availability of source water, a key requirement for recharging groundwater, is primarily assessed in terms of surplus monsoon runoff that is currently not being utilized. This assessment is based on the pattern, frequency, and spatial and temporal

variations of monsoon rainfall. These variations, along with the drainage pattern and density, determine the availability of source water. The physical, chemical, and biological quality of the recharge water also plays a role in planning and selecting recharge methods.

In our study area, there is abundant source water due to ample rainfall and perennial streams.

5.18. AQUIFERS/HYDROGEOLOGICAL ASPECTS:

The state is geologically comprised of unconsolidated sediments such as gravel, sand, silt and clay, as well as semi-consolidated rocks like sandstone, siltstone, shale, and limestone. From a hydrogeological perspective, these unconsolidated and semi-consolidated rocks are considered ideal. The area is intersected by numerous lineaments as part of a linear belt of folds that includes Mizoram and its surrounding areas. The area shows signs of tectonic folding and faulting, resulting in linear structural features. The prominent directions are NNW – SSE and E-W, with less prominent ones in almost all directions, such as NNE – SSW. Lineaments vary in length.

Digital Elevation Models, satellite imagery and ground checks can be used to delineate these lineaments. These lineament zones are highly productive for constructing bore wells, offering good potential for recharge through suitable techniques.

Water storage within the earth's crust depends on geological processes that have created voids capable of absorbing, transmitting, storing and yielding water. Earth materials contain numerous voids, some of which are large enough to transmit water freely while others are too small preventing the transmission of water due to surface tension exceeding hydrostatic pressures.

The useful storage capacity of ground water is not determined by the porosity of the reservoir, but rather by the amount of water that the reservoir can yield through gravity drainage, known as specific yield. It's the difference between porosity and field moisture capacity. Potential aquifers below the zone of soil moisture are already

at field capacity, so most of the recharged water can either be recovered or will move to natural discharge areas.

The following conditions indicate possibilities for artificial recharge:

1. Formations of sand, gravel, or highly fractured rocks, either underground or exposed over a large area or in stream channels.

2. The presence of fractured or faulted zones, or numerous small cavities in rock formations, either underground or exposed on the land surface or in stream channels.

3. The absence of barriers to the horizontal or vertical movement of ground water.

4. Feasible locations for the installation of recharge structures, such as check dams, gabions, and weirs.

However, the above conditions do not necessarily indicate possibilities for beneficial recharge. The water may emerge in nearby springs or channels, or may recharge an aquifer that is so deep that recovery is impractical. These conditions should be carefully studied to determine whether recharge is feasible.

Geological reports, ground-water reports, well logs and descriptions of stratigraphic sections can indicate the possibility of groundwater recharge, storage and recovery. This preliminary information may warrant a detailed groundwater investigation.

Groundwater recharge can be influenced by factors such as the season of the year, intensity and duration of precipitation, topography, vegetative cover, soils, land use, evapotranspiration, and availability of storage. The rates and amounts of recharge may be improved by:

1. Increasing opportunity time by regulating the flow of water over the intake area

2. Desilting and removing materials or debris that might seal the intake area

3. Planting or improving the growth of deep-rooted vegetation

4. Diversions from less to more suitable intake areas

When selecting the proper location of sites for artificial recharge, the following factors must be considered:

1. Water availability, source, turbidity, quality etc.

2. Surface soils

3. Depth to aquifer

4. Geologic structure and capacity of the groundwater reservoir

5. The presence of aquicludes

6. Movement of groundwater

7. Location of withdrawal area

An investigation to determine the location, extent, permeability and other physical characteristics of the surface and the various underlying strata is necessary to select the site best adapted to artificial recharge. The greatest volumes and rates of recharge are possible in thick formations of pervious sands and gravels or porous rocks.

The Controlling Stratum:

It is important to identify the stratum that will control the infiltration rate if injection wells are not used. This is typically the least permeable stratum between the aquifer and the recharge surface, taking into account its thickness. The recharge rates are determined by the stratum with the lowest quotient of permeability divided by thickness, assuming a constant water head. Identifying the controlling stratum may require drilling, testing, and sampling, as small drill cores may not provide an accurate picture of the fracturing and jointing in a rock formation.

The water table's proximity to the ground surface significantly affects recharge. When the water table is close to the surface, there is limited opportunity for recharge. Some water may be stored shallowly, but once this space is filled, any excess infiltration will flow back to the stream channel or other discharge area. The impact of a shallow water table may be partly mitigated if the groundwater gradient is steep. In an aquifer with good permeability, this will rapidly remove water from the recharge area.

In Mizoram, all these factors and conditions were taken into consideration when selecting suitable areas for artificial recharge of groundwater.

5.19. ADVANTAGES OF ARTIFICIAL RECHARGE:

The advantages of artificially recharging groundwater aquifers are as follows:

a) No need for large storage structures to store water; required structures are small and cost-effective.

b) Enhances the dependable yield of wells and hand pumps.

c) Negligible losses compared to losses in surface storages.

d) Improved water quality due to dilution of harmful chemicals/salts.

e) No adverse effects such as inundation of large surface areas and loss of crops.

f) No displacement of local population and loss of scarce agricultural land, etc.

g) Reduction in the cost of energy for lifting water, especially where the rise in groundwater level is substantial.

h) Utilizes surplus surface runoff which would otherwise drain off.

i) Biological purity is very high.

j) Minimum temperature variation.

k) It is environmentally friendly, controls soil erosion and flood, and provides sufficient soil moisture even during summer months.

l) Water stored underground is relatively immune to natural and man-made catastrophes.

m) It provides a natural distribution system between recharge and discharge points.

5.19. PROPOSED STRUCTURES:

Artificial recharge structures such as check dams, gabion structures, and weirs are all suitable in different parts of the state. The maps below show the areas suitable for artificial recharge. However, due to space limitations, the scale of the maps may not allow for a detailed representation of all suitable areas.

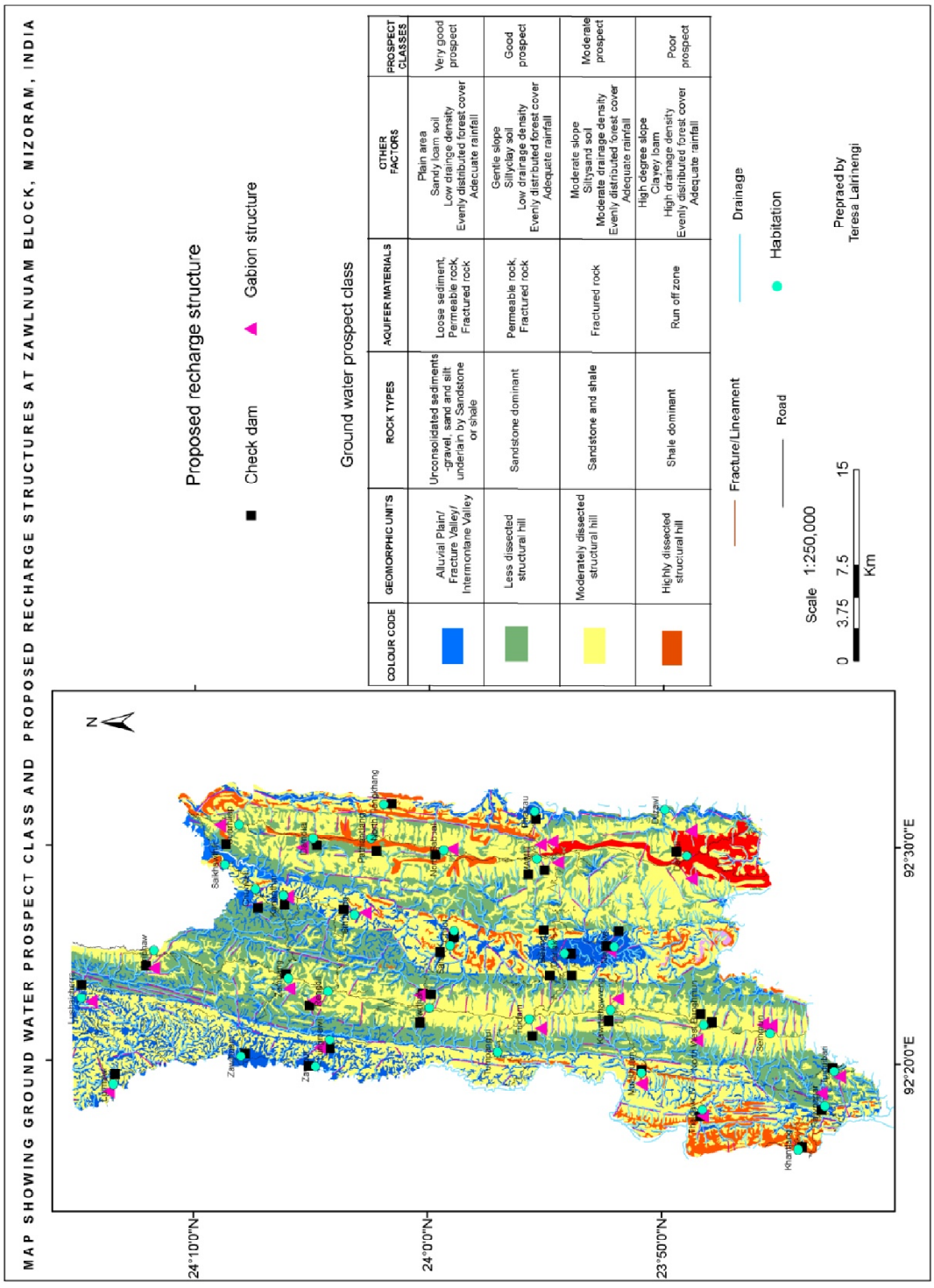
5.19.1. Check Dam

A check dam is a permanent structure built across natural drainage to recharge or replenish the groundwater of an area. It can also be used to reduce the speed of concentrated flows. Check dams are typically installed on first and second order streams in foothill zones and on slopes with a gradient of 3:1 or less, or in areas with a slope of 0-5%. Constructing check dams across rivers is a method to retain surface runoff and increase groundwater recharge. In regions like Mizoram and many parts of India, where rivers flow for only a few days during the monsoon, check dams can help capture and store the surface runoff, reducing flooding and allowing more time for water to infiltrate the river bed and recharge the groundwater. This can also improve groundwater quality if the impounded water is protected from contamination. Researchers have studied the impact of check dams on groundwater potential and have identified several suitable sites for check dam construction in Mizoram.

5.19.2. Gabion Structure

A gabion structure is a semi-permeable barrier made of boulders encased in a steel wire mesh and anchored to the stream bank. Its purpose is to slow down the flow of storm water in a small watercourse, allowing water to infiltrate the ground and preventing soil erosion.

Gabions are commonly used across small streams to conserve stream flows without causing significant submergence beyond the stream course. Local boulders are enclosed in a steel wire mesh and placed across the stream to create a small dam, anchored to the streamside. These structures are typically around 0.5 meters high and are used in streams with widths of about 10 to 15 meters. When there is excess water, it overflows the structure, storing some water for recharge purposes. Over time, the silt content of the stream water is deposited in the gaps between the boulders, making the structure more impermeable. Gabion structures are commonly employed in many parts of the country, and Mizoram, a state in India, has great potential for implementing these structures.



Map 14: Map showing ground water prospect class and proposed recharge structure at Zawlnuam Block, Mizoram, India.

CHAPTER – VI

PHYSICO-CHEMICAL ASSESSMENT OF WATER SOURCES

The study utilized GIS software to develop base maps for spatial analysis, incorporating layers such as settlements, road types, administrative boundaries, drainage, and water bodies. Groundwater quality was assessed using physico-chemical characteristics gathered from various sites within the research region. To create element-wise groundwater quality layers, point features from the GIS data source were interpolated using the Inverse Distance Weighted method, which considers the concentration values of a single element as the Z value. This method is commonly used for interpolating scatter points and is widely applied in mapping groundwater quality. It operates on the principle that closer points exert a greater influence on the interpolating surface, with weights decreasing as distance increases. The region of influence for each sampled location is determined by the value of the inverse-distance weighting power. Groundwater samples were collected from 16-point sources, including 3 tubewells with depth ranging from 50 feet- 200 feet and 13 springs (Tuikhur), primarily used for domestic and agricultural purposes. Samples were collected during the pre-monsoon, monsoon, and post-monsoon seasons and underwent laboratory analysis to assess significant factors related to groundwater quality. The data from all three seasons were compared to evaluate rock-water interaction based on lithological and geomorphological origins (Ambica et al., 2017; Khadri and Pande, 2015; Kumar et al., 2015; Mishra, 2014; Mahalingam et al, 2014; Narsimha et al., 2013; Boominathan et al., 2015; Rani and Chaudhary, 2015; Shyamala and Jeyanthi, 2017; Singh and Khan, 2011; Teli et al., 2014; RGNDWM, 2011; Tikle et al., 2012; Arif et al., 2014; Gnanachandrasamy et al., 2015).

The study utilized the Inverse Distance Weighted (IDW) approach to create spatial distributions of groundwater quality for different seasons using ArcGIS software. IDW is a deterministic technique that uses a weighted average of known point values to estimate values at unknown points. The analysis considered the geo-coordinates and concentration of each parameter to assess groundwater quality according to BIS guidelines. Comparison of BIS and WHO standard for water quality is shown below. Spatial variation maps were created for each parameter, divided into desirable,

permissible, and non-potable classes. Additionally, the study computed the concentration of groundwater quality parameters in various rock types and geomorphological classes and presented the findings in bar charts.

BIS Guidelines				
Sl.No	Element	Potable		Non-Potable
		Desirable limit	Permissible limit	
1	pH	6.5 to 8.5	-	<6.5 to >8.5
2	Total Hardness (as $CaCo_3$)	< 300	300-600	> 600
3	Iron (as Fe) mg/L	< 0.3	0.3-1.0	> 1.0
4	Chlorides (as Cl) mg/L	< 250	250-1000	> 1000
5	Total Dissolves solids mg/L	< 500	500-2000	> 2000
6	Bicarbonate (as MG) mg/L	< 500	-	> 500
7	Calcium (as Ca) mg/L	< 75	75-200	> 200
8	Magnesium (as Mg) mg/L	< 30	30-100	> 100
9	Nitrate (as NO3) mg/L	< 45	45-100	> 100
10	Sulphate (as SO_4) mg/L	< 200	200-400	> 400
11	Fluoride (as F) mg/L	< 1.0	1.0-1.5	> 1.5
12	Manganese (as Mn) mg/L	< 0.10	0.10-0.3	> 0.3
13	Sodium (as Na) mg/L	-	-	-
14	Potassium (as K) mg/L	-	-	-
15	Arsenic (as As) mg/L	< 0.05	-	< 0.05
16	Mercury (as Hg) mg/L	< 0.001	-	< 0.001
17	Cadmium (as Cd) mg/L	< 0.01	-	< 0.01
18	Lead (as Pb) mg/L	< 0.05	-	< 0.05
19	Zinc (as Zn) mg/L	< 5	5-15	> 15
20	Chromium (as Cr^{6+}) mg/L	< 0.05	-	> 0.05
21	Alkalinity mg/L	< 200	200-600	> 600
22	Nickel mg/L	-	0.02	-

Table 6: BIS Guidelines of water quality

WHO Guidelines		
Sl.No	**Element**	**Permissible limit**
1	pH	6.5 to 8.5
2	Total Hardness (as $CaCo_3$)	500
3	Iron (as Fe) mg/L	0.3
4	Chlorides (as Cl) mg/L	200- 300
5	Total Dissolves solids mg/L	1000
6	Bicarbonate (as MG) mg/L	400
7	Calcium (as Ca) mg/L	500
8	Magnesium (as Mg) mg/L	150
9	Nitrate (as NO3) mg/L	10
10	Sulphate (as SO_4) mg/L	400
11	Fluoride (as F) mg/L	1.5
12	Manganese (as Mn) mg/L	0.1
13	Sodium (as Na) mg/L	200
14	Potassium (as K) mg/L	1.2
15	Arsenic (as As) mg/L	0.05
16	Mercury (as Hg) mg/L	0.001
17	Cadmium (as Cd) mg/L	0.005
18	Lead (as Pb) mg/L	0.05
19	Zinc (as Zn) mg/L	5
20	Chromium (as Cr^{6}+) mg/L	0.05
21	Alkalinity mg/L	20- 200
22	Nickel mg/L	0.07

Table 7: WHO Guidelines of water quality

6.1. pH: The pH of groundwater can be affected by the chemical makeup of the rocks and the geomorphological condition of the water source. According to BIS IS 10500: 2012, the recommended pH range for groundwater is 6.5 to 8.5. Groundwater with a pH above or below this range is considered unsuitable for drinking.

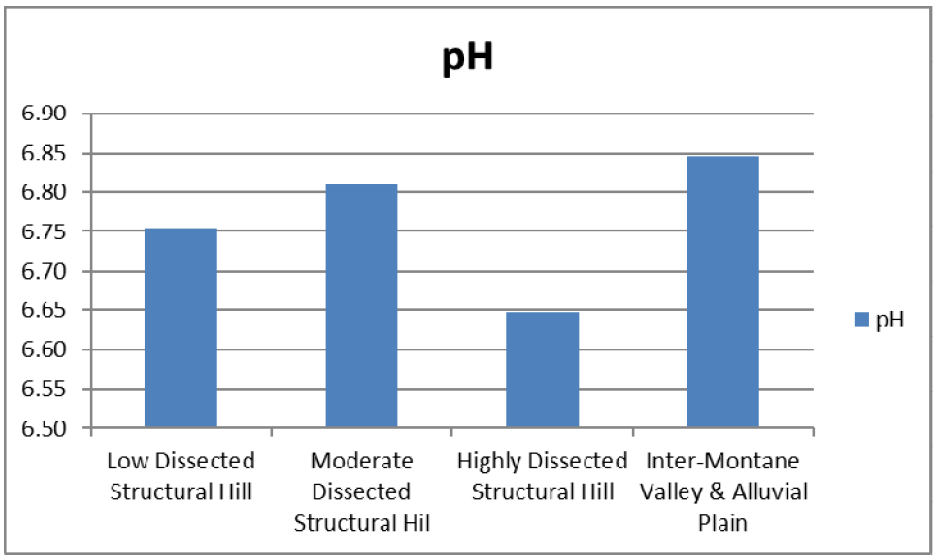


Figure 8: pH in terms of geomorphic units

In terms of geomorphological units, the pH of groundwater collected is lowest in the highly dissected structural hill and highest in inter-montane valleys and alluvial plains.

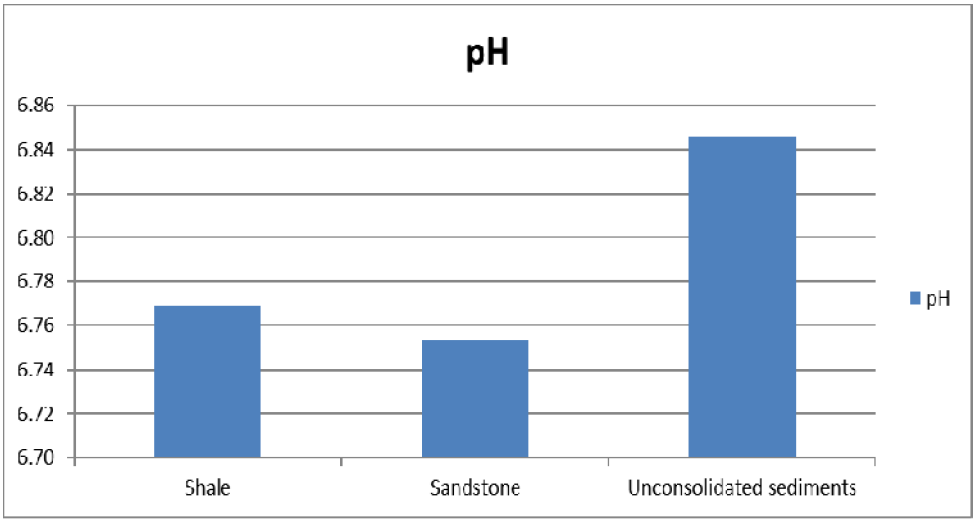
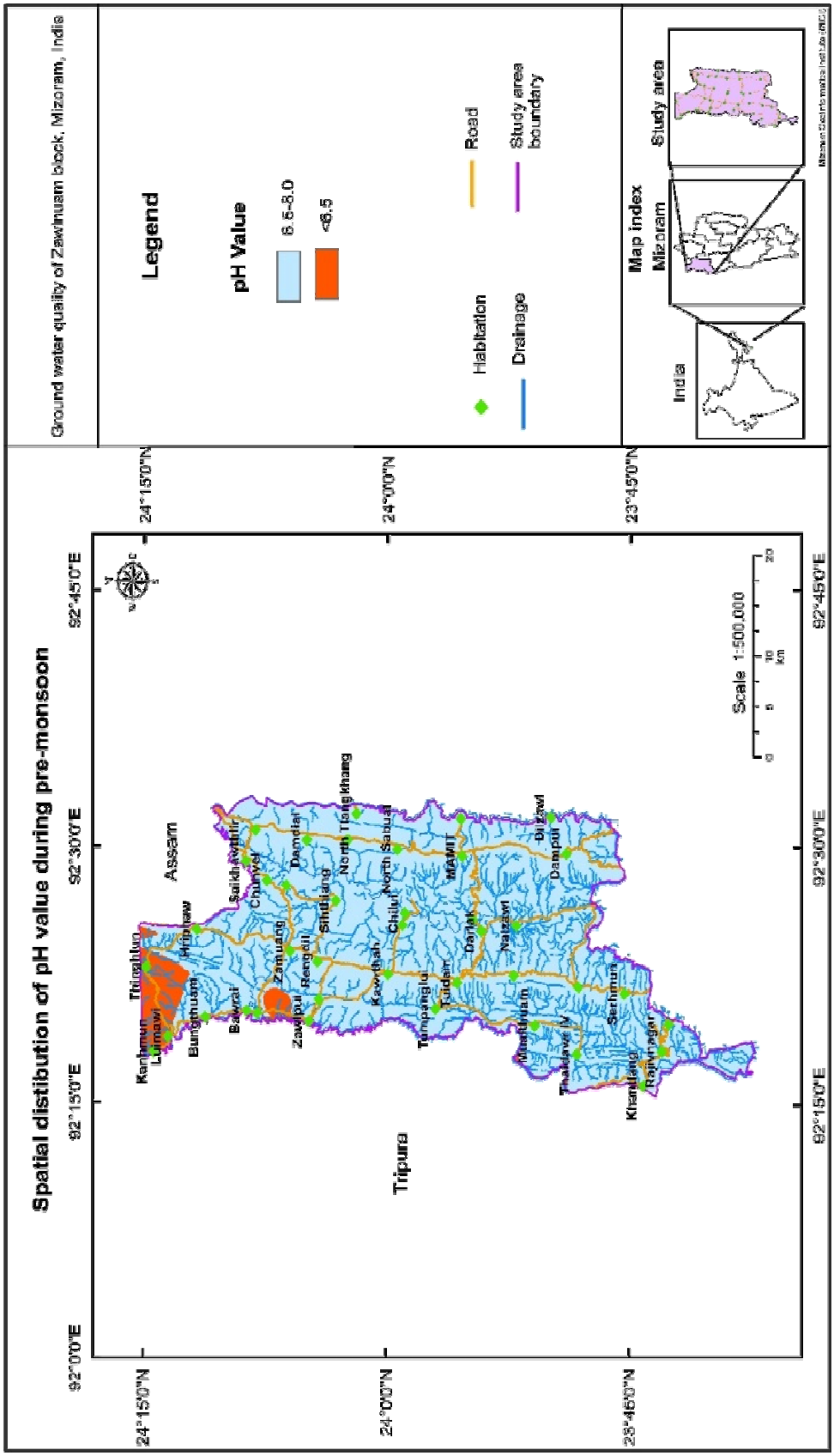
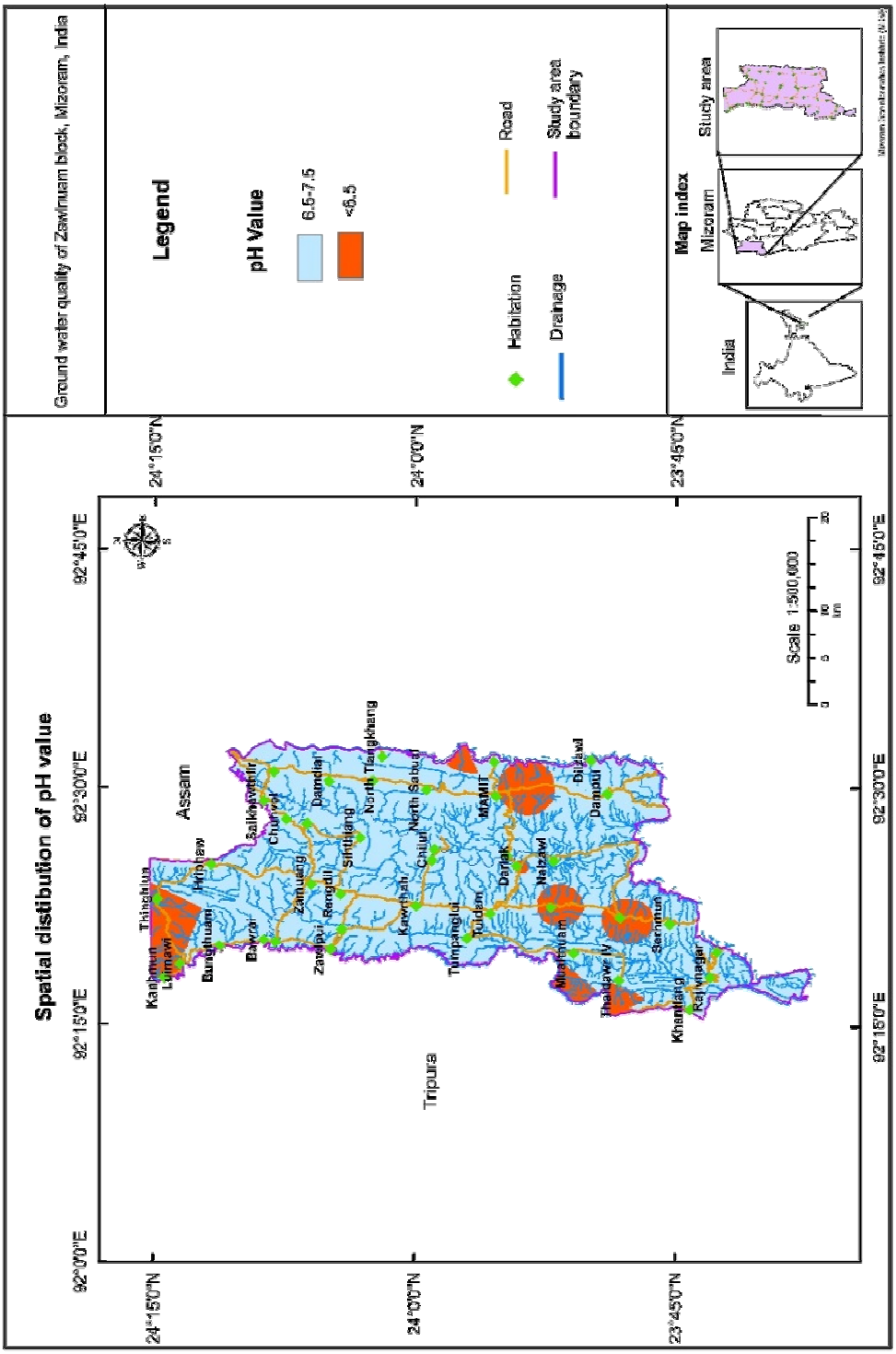


Figure 9: pH in terms of lithological units

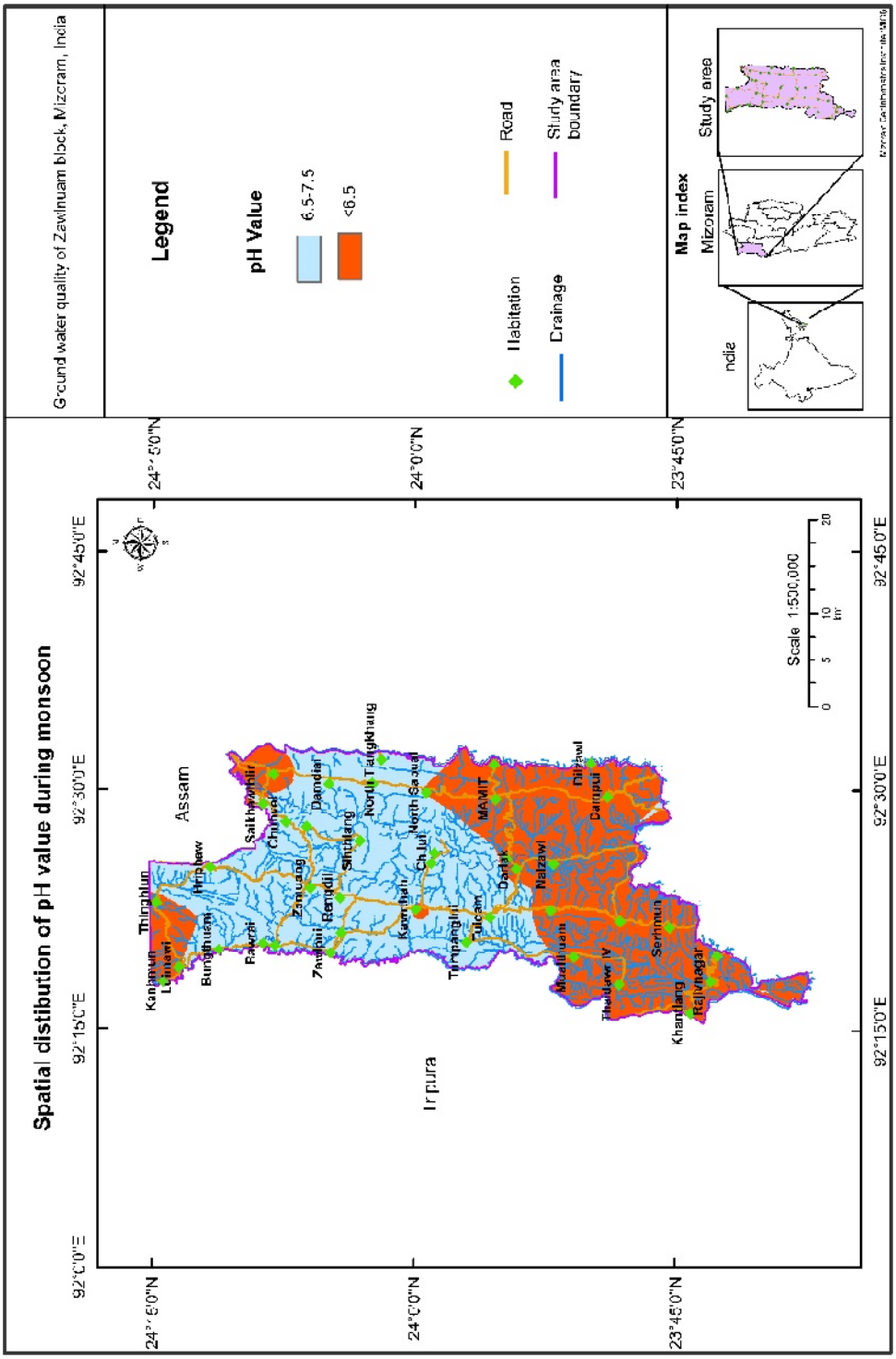
The pH level is highest in unconsolidated sediments due to the dissolution of carbonate minerals, which makes the liquid more alkaline. Additionally, the process of photosynthetic activity also raises the pH by removing carbon dioxide from water. On the other hand, the pH level is lowest in sandstone because sandstones, which are high in silica, result in neutral or slightly acidic soils.



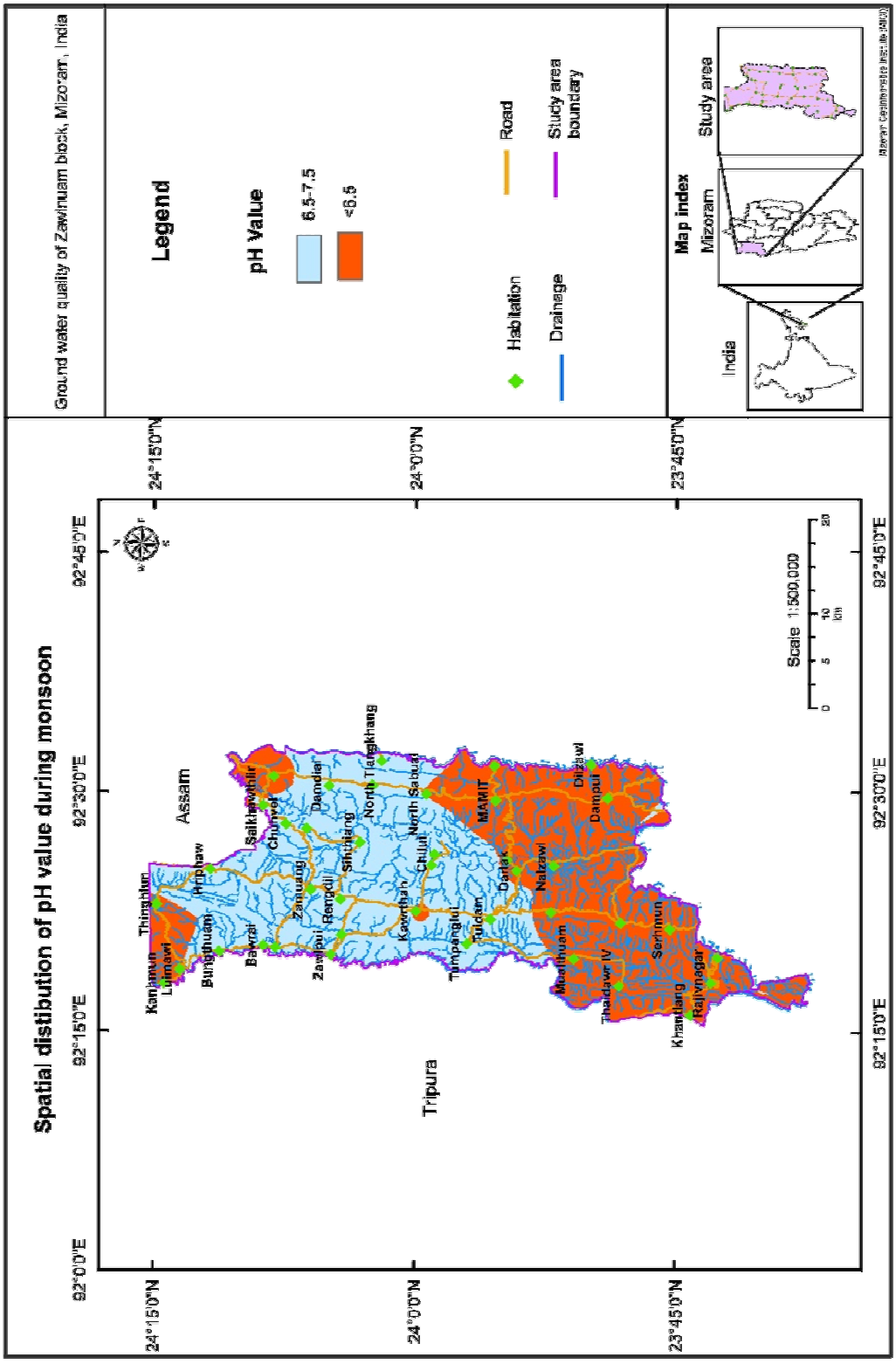
Map 15: Spatial distribution of pH During pre- monsoon



Map 16: Spatial distribution of pH



Map 17: Spatial distribution of pH during monsoon



Map 18: Spatial distribution of pH during post monsoon

6.2. Total Dissolved Solids(TDS): The concentration of minerals in water is commonly known as total dissolved solids (TDS). The dissolution of solids in water primarily arises from the weathering of rocks. The TDS concentration is influenced by the geological characteristics of the area and the composition of the rocks. According to BIS IS 10500: 2012, TDS levels below 500 mg/L are considered desirable, while those ranging from 500–2000 mg/L are permissible. TDS levels exceeding 2000 mg/L are classified as non-potable. All the samples analyzed fall within the acceptable and desirable TDS ranges.

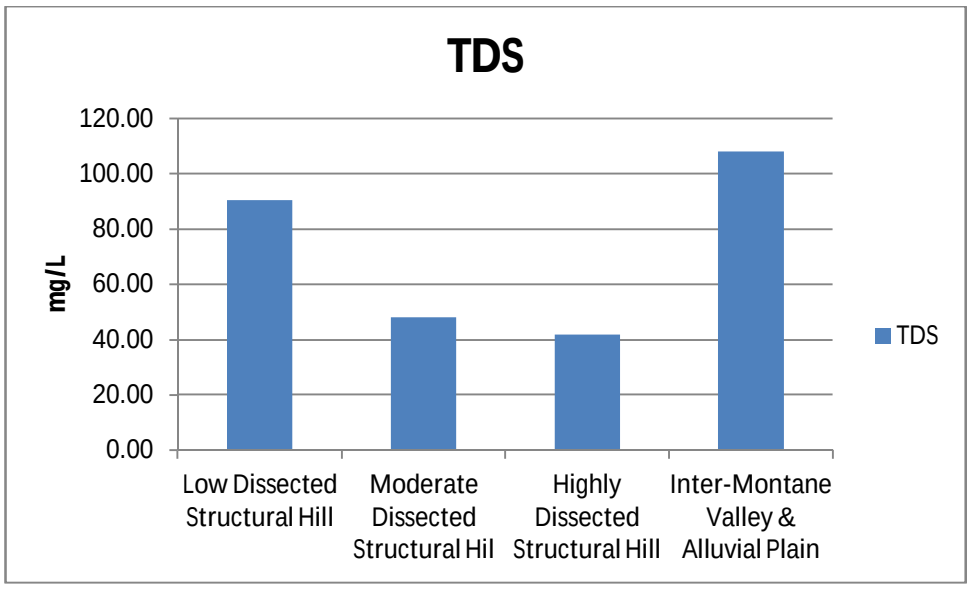


Figure 10: TDS in terms of geomorphic units

TDS levels are high in inter-montane valleys and alluvial plains due to runoff from residential and commercial buildings, clay-rich mountain streams, leaching of contaminated soil, and discharge of point source water pollution from sewage treatment plants or industries clustered in the area. Conversely, TDS levels are low in highly dissected structural hills due to high runoff.

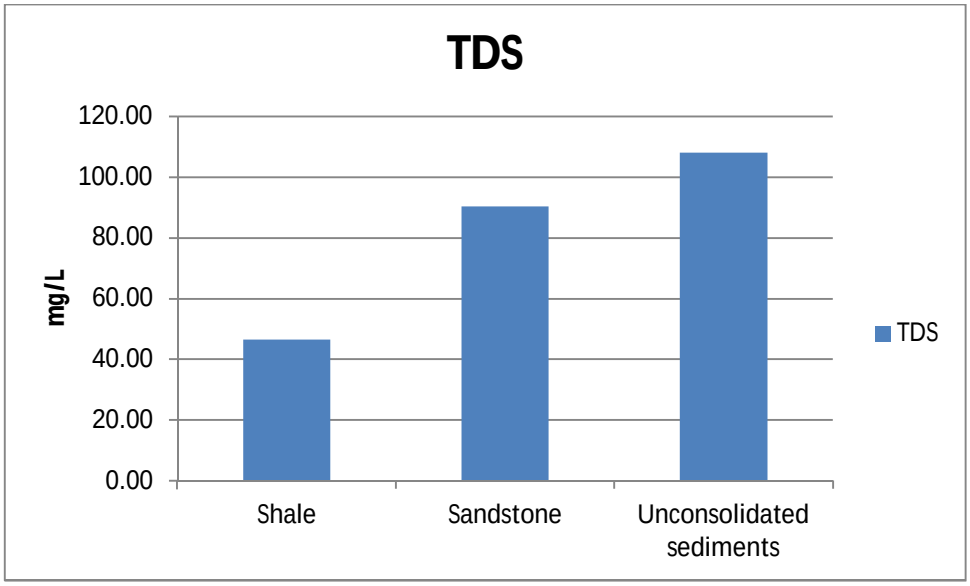
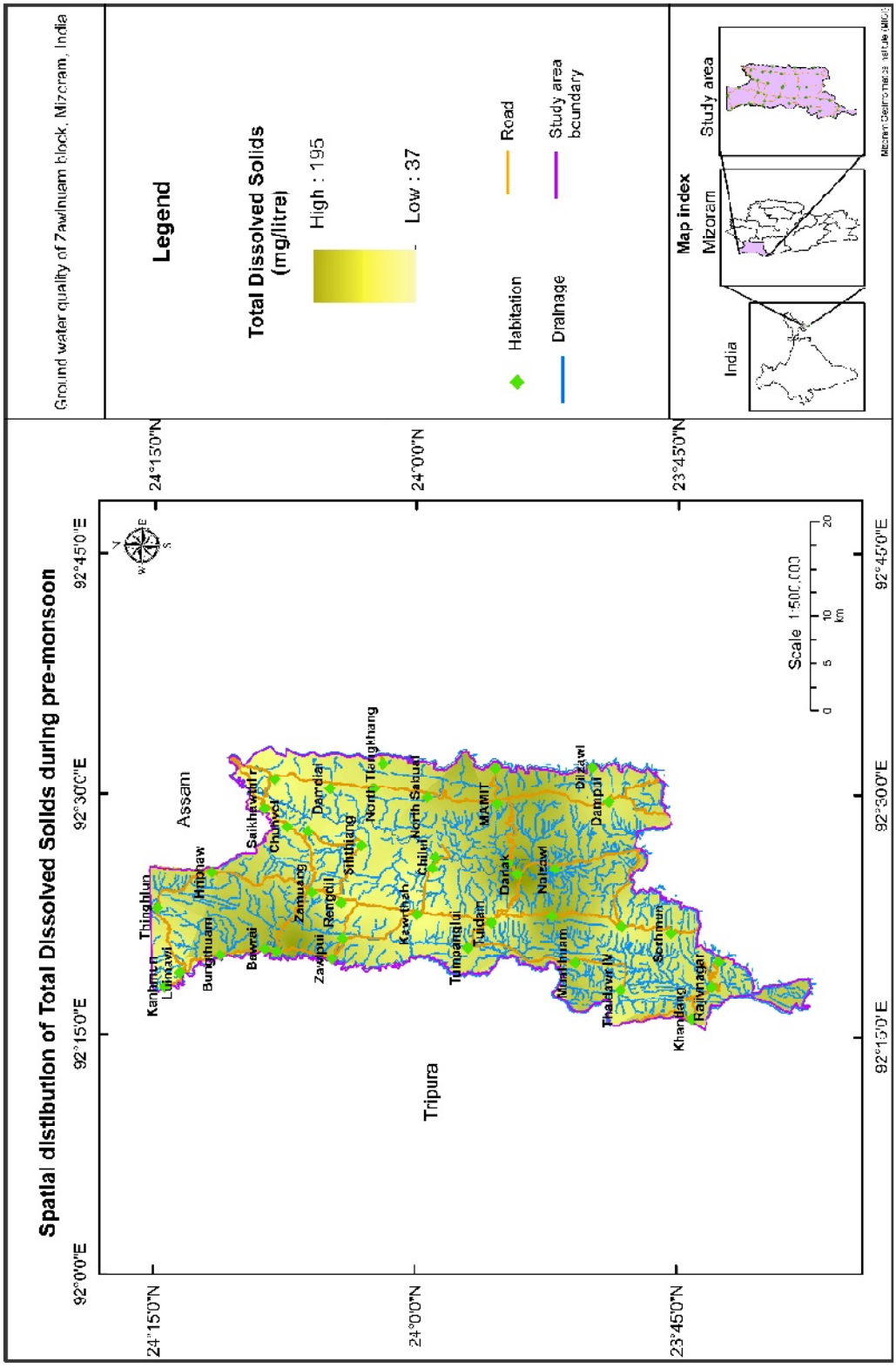
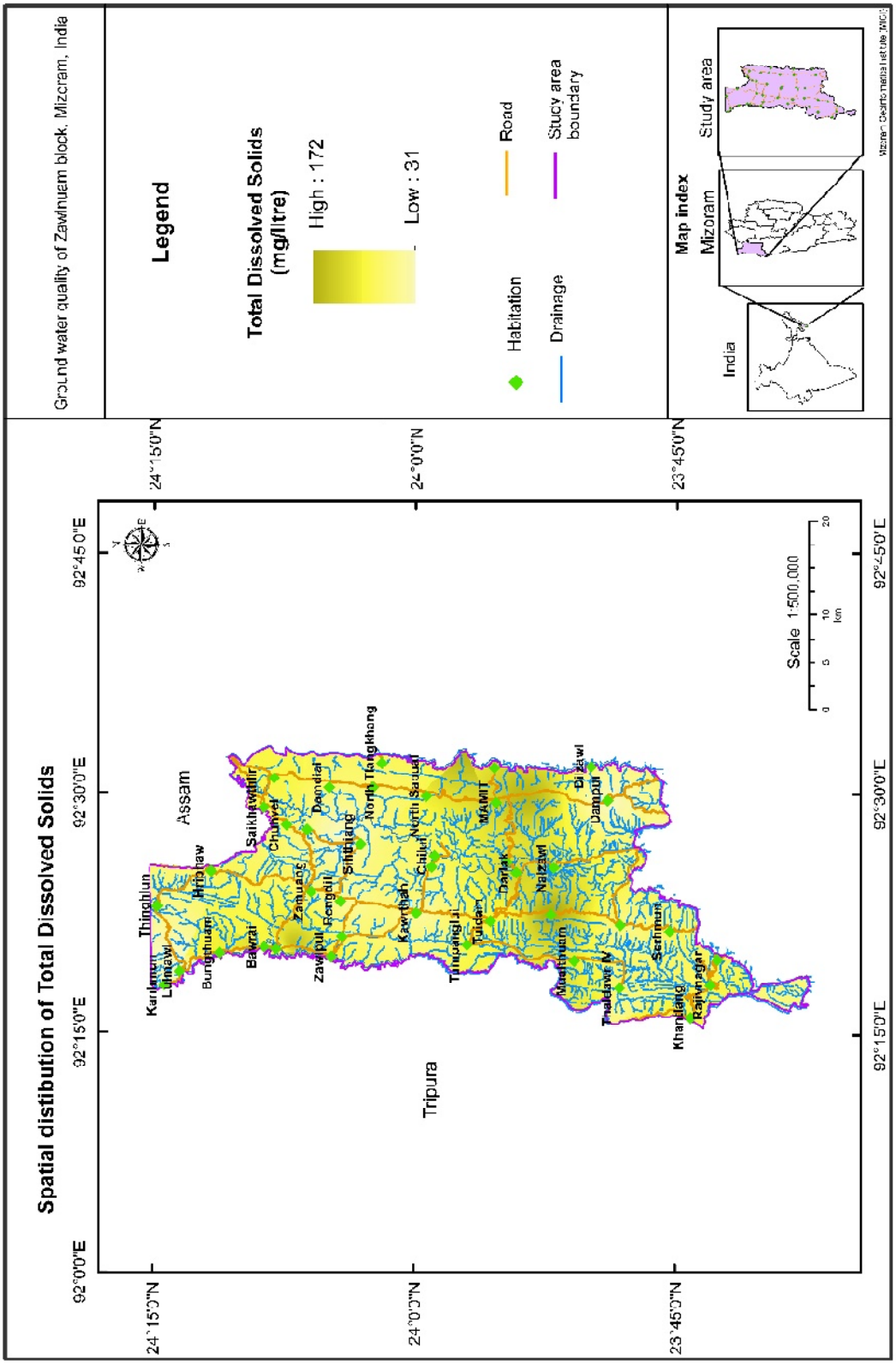


Figure 11: TDS in terms of lithological units

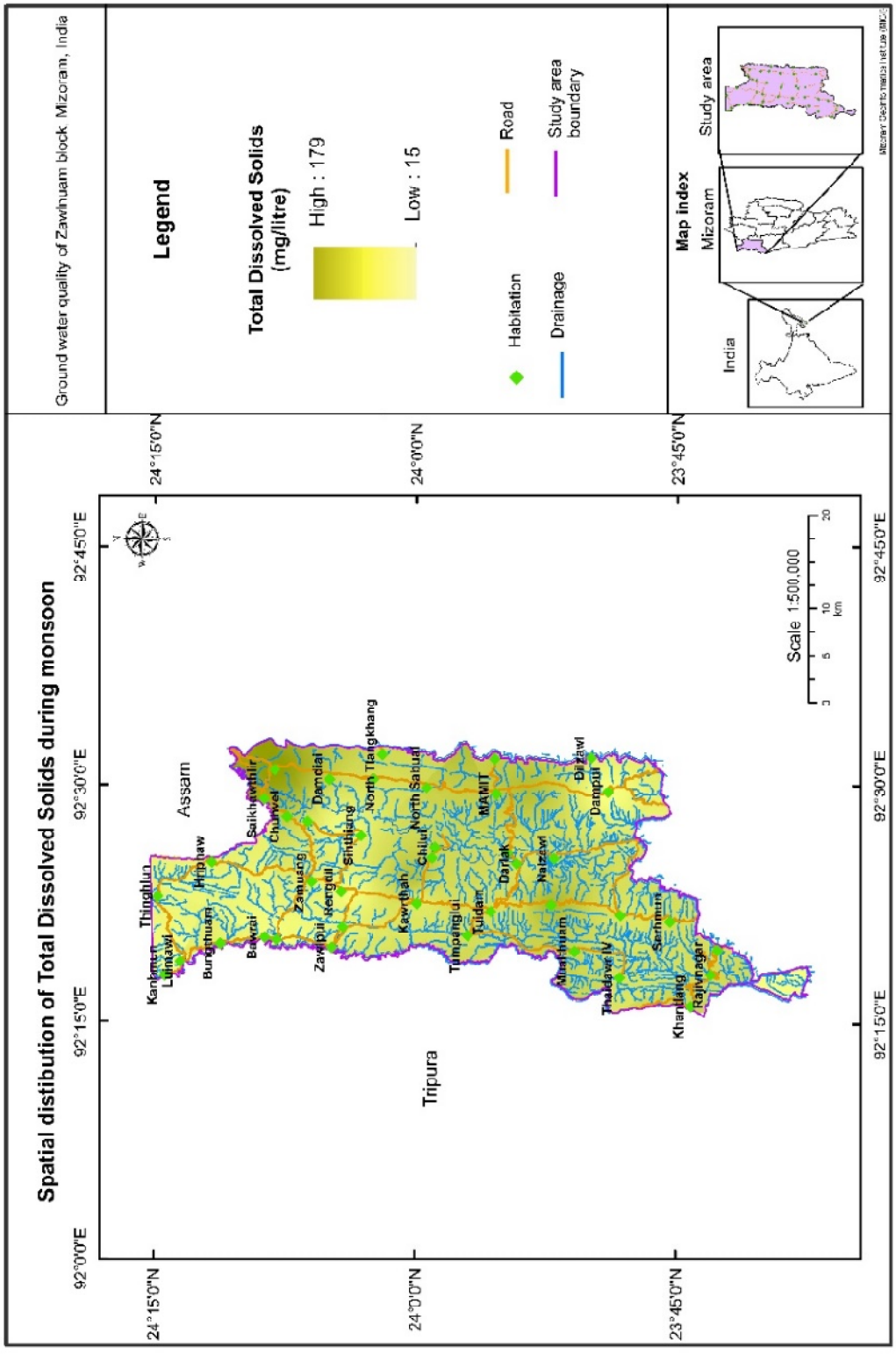
In terms of lithology, the Total Dissolved Solids (TDS) is high in unconsolidated sediments because it is a mixture of different types of rocks, where elements and minerals occur in a dissolved state. Conversely, TDS is lowest in shale because the minerals are not in a dissolved state.



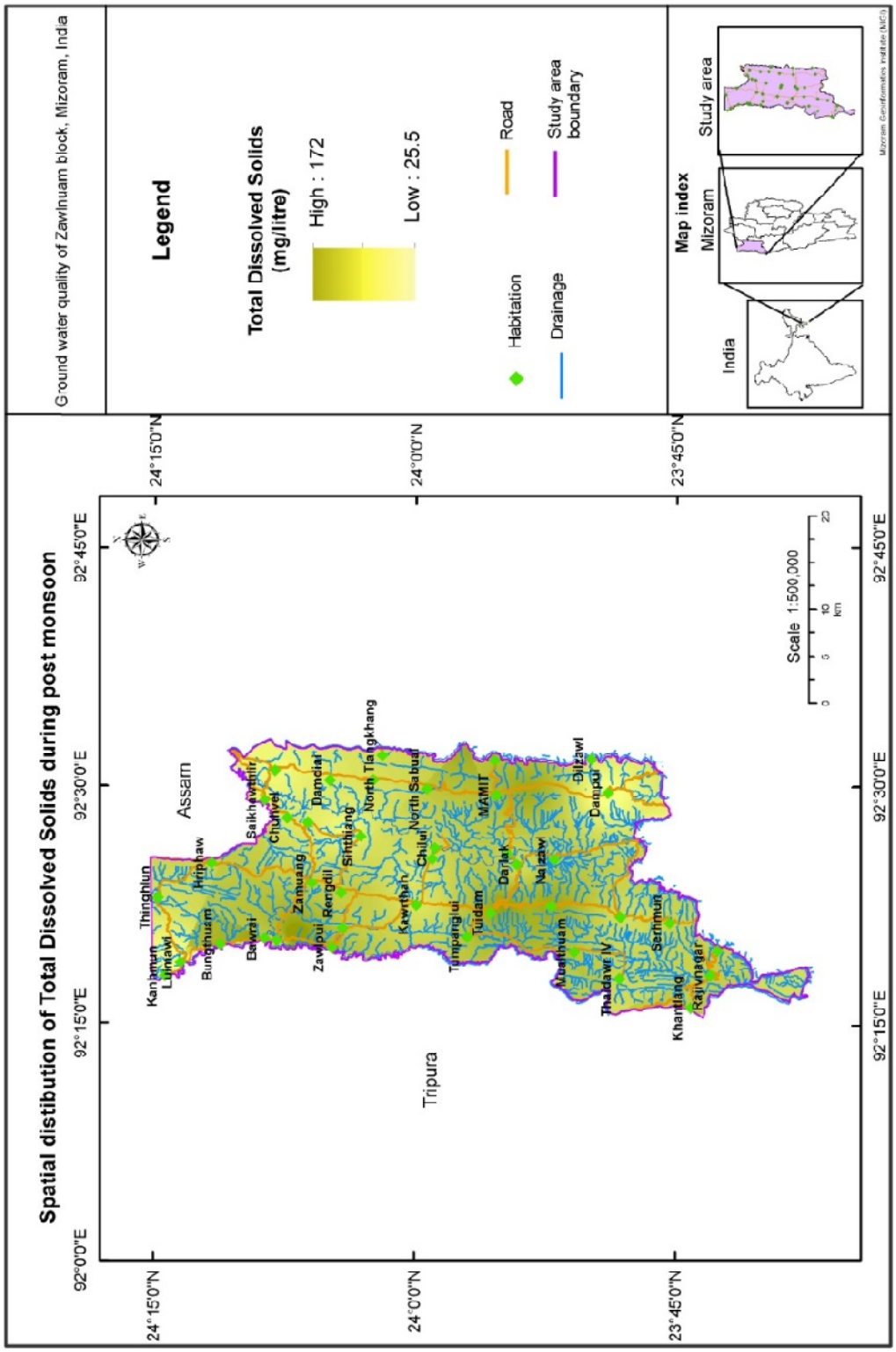
Map 19: Spatial distribution of TDS during pre- monsoon



Map 20: Spatial distribution of TDS



Map 21: Spatial distribution of TDS during monsoon



Map 22: Spatial distribution of TDS during post- monsoon

6.3. Total Alkalinity:

As per BIS IS 10500: 2012, total alkalinity is categorized into three ranges: 0-200 mg/L, 200-600 mg/L, and >600 mg/L. Water with high alkalinity is often called "hard" water, and it is primarily due to the presence of calcium carbonate. High alkalinity water tends to have a harsh taste. However, all the samples from various sources in the research area are well below the recommended limit for total alkalinity.

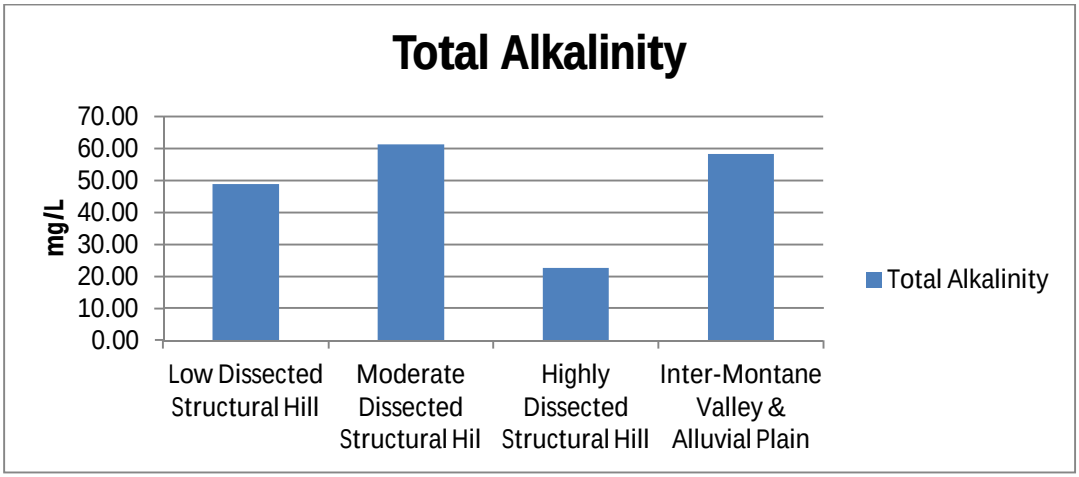


Figure 12: Total alkalinity in terms of geomorphic units

When it comes to total alkalinity in various geomorphic units, it is high in moderately dissected structural hills and low in highly dissected structural hills.

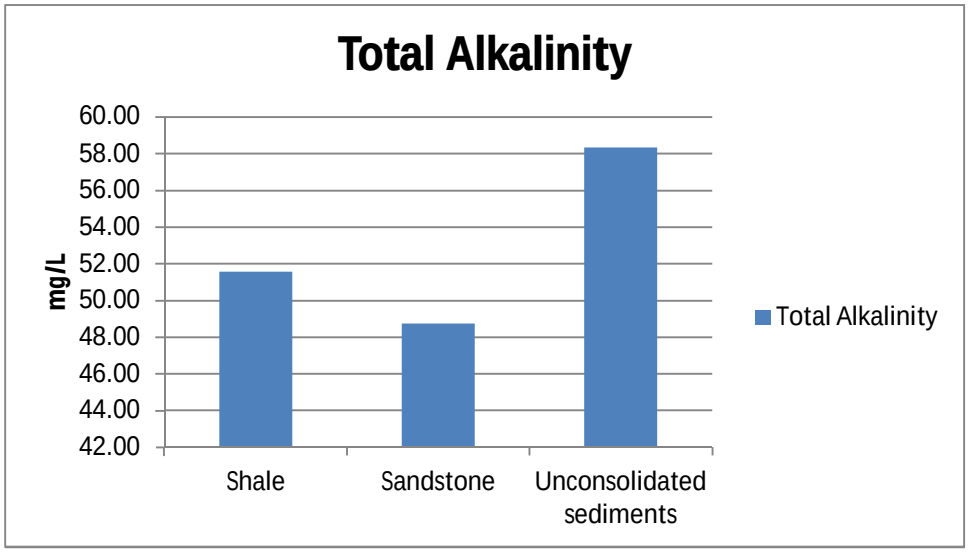
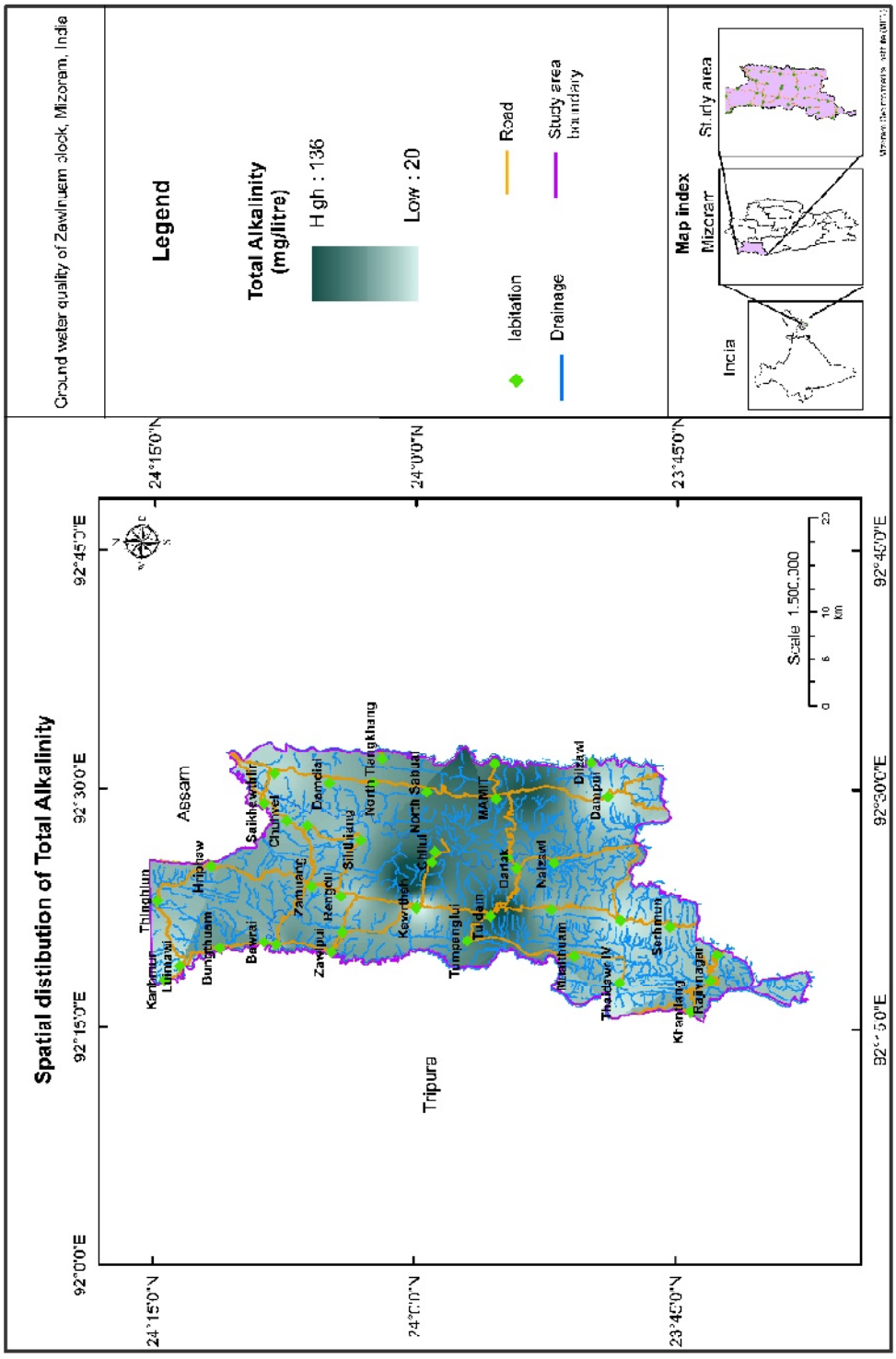
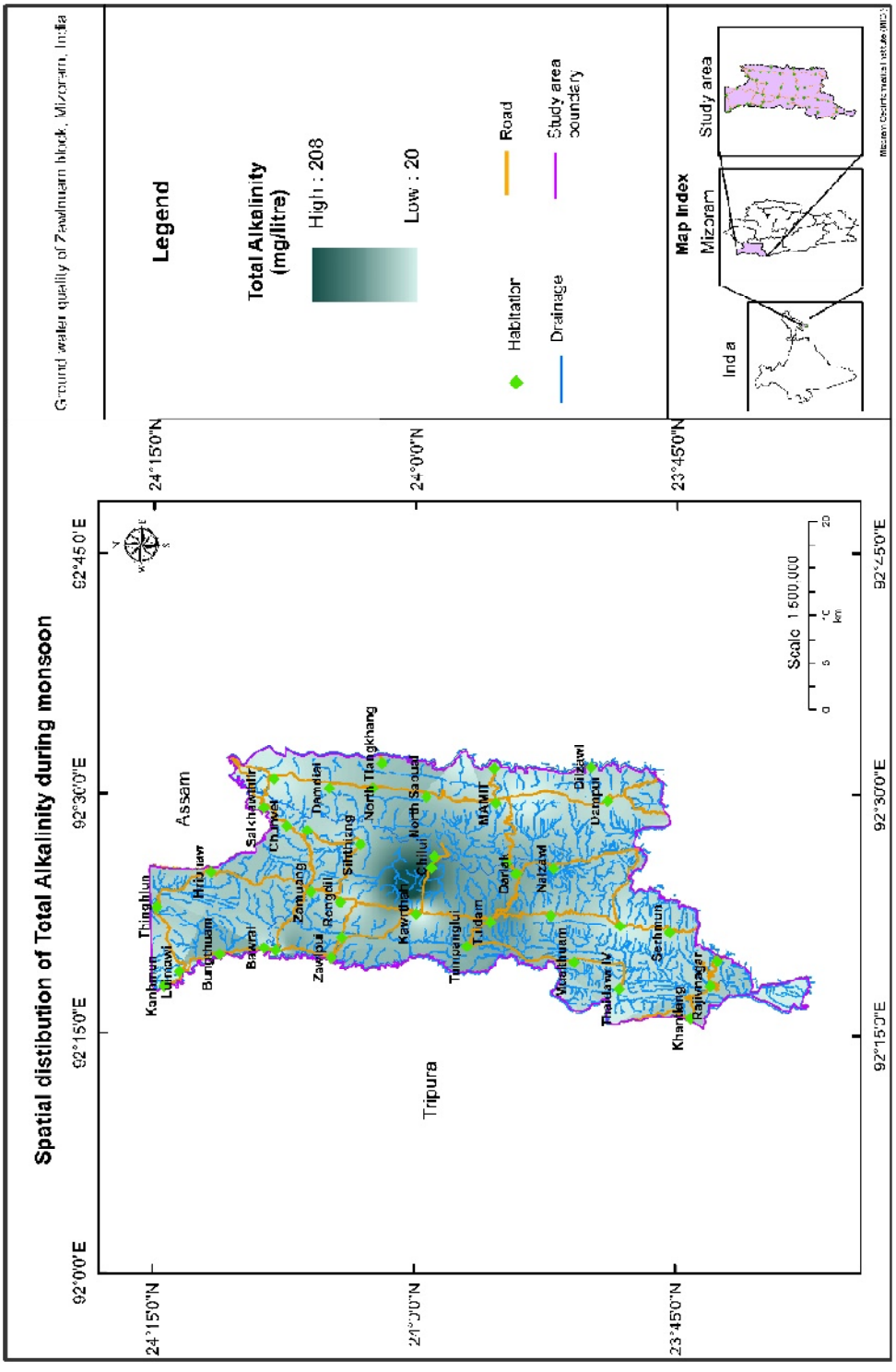


Figure 13: Total alkalinity in terms of lithological units

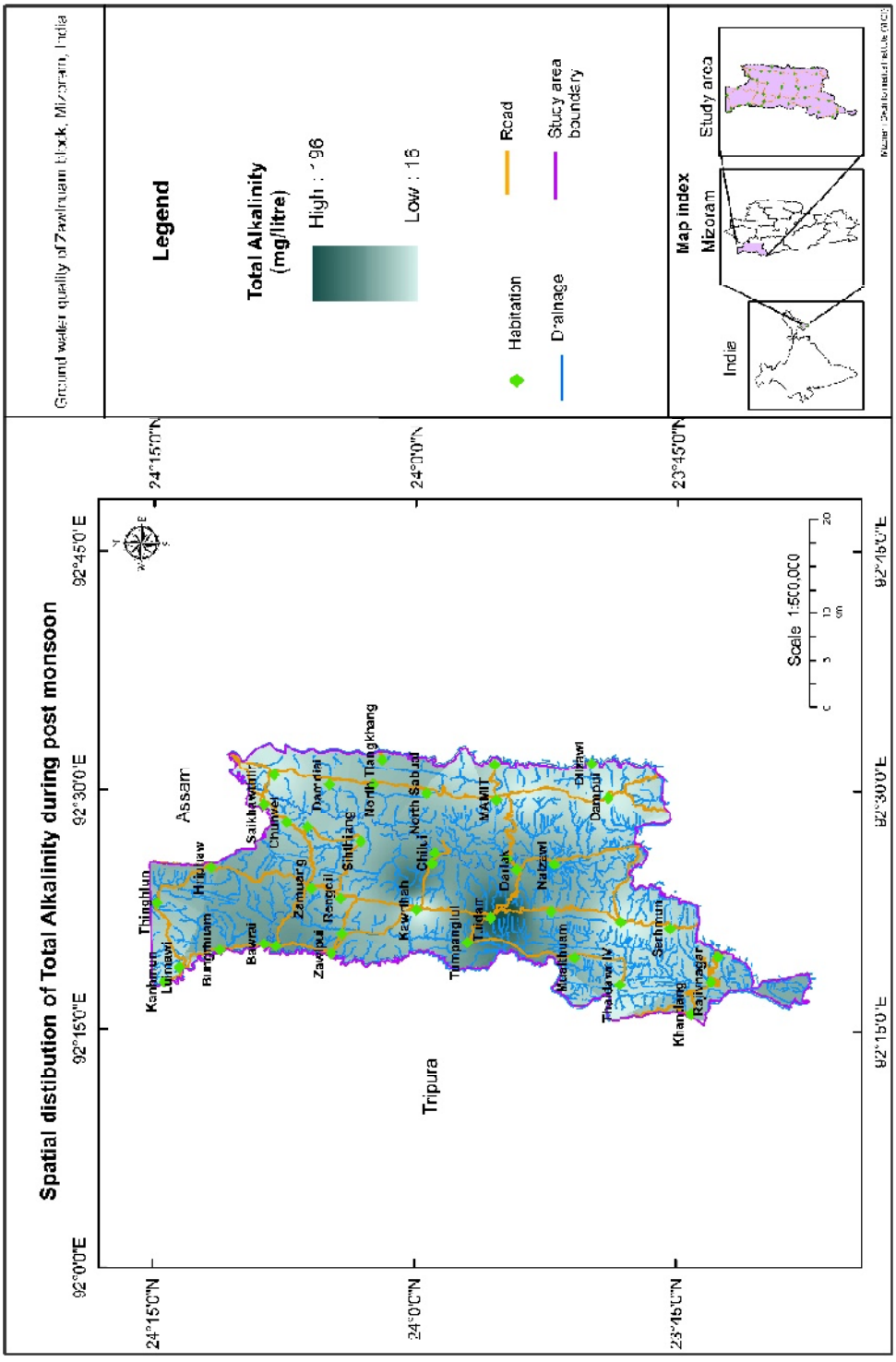
Total alkalinity is elevated in loose sediments due to dissolved carbonate minerals, leading to more alkaline liquids. In contrast, alkalinity is reduced in sandstone because silica, a component of sandstone, can make water less alkaline.



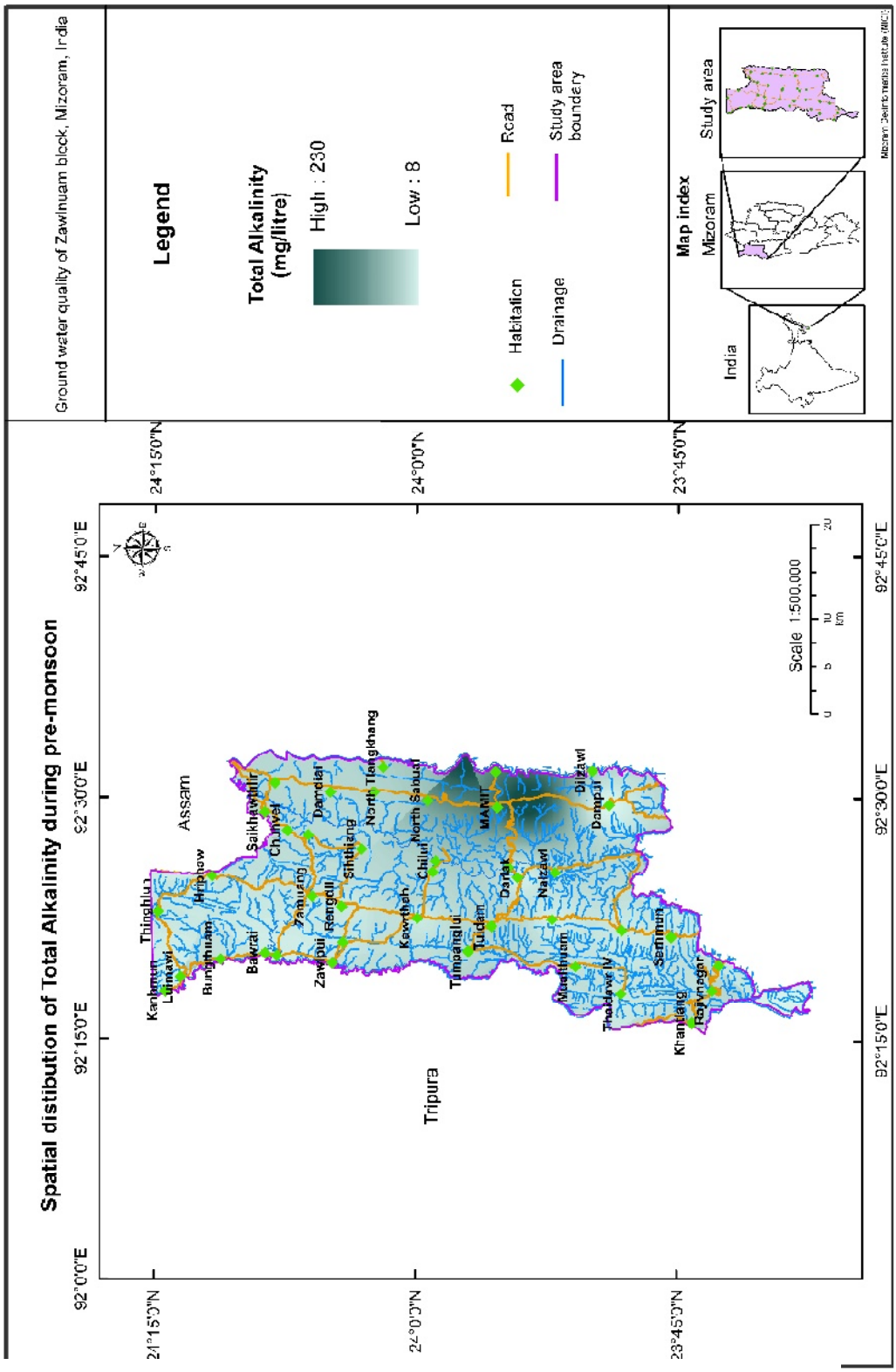
Map 23: Spatial distribution of Total alkalinity



Map 24: Spatial distribution of Total alkalinity during monsoon



Map 25: Spatial distribution of Total alkalinity during post- monsoon


Ground water quality of Zawlnuam block, Mizoram, India
Legend
Total Alkalinity (mg/litre)
High : 230
Low : 8
Habitation
Road
Drainage
Study area boundary
Map index
Mizoram
India
Study area
Spatial distibution of Total Alkalinity during pre-monsoon
Assam
Tripura
Scale 1:500,000
92°0'0"E
92°15'0"E
92°30'0"E
92°45'0"E
24°15'0"N
24°0'0"N
23°45'0"N
Thingdawl
Hnahthial
Saitlawpui
Chawngte
Darlak
Lawngtlai
Sangau
Chawngte
Saiha
Tuipang
Tuipui
Tuidam
Lungsen
Bunghmun
Bawngkawn
Zawlnuam
Rengdil
Sihthiang
Kawrthah
Chhimluang
North Tlangkhang
North Vanlaiphai
Chhumkeu
Tlungvel
MAHIT
Darlak
Natchhip
Dilkhawdar
Dampui
Dilzawl
Thingsai
Lungsen
Lungleng
Lungsen
Lungsen
Lungsen

6.4. Total Chloride: The amount of chlorides found in groundwater depends on the chemical composition of the rocks. According to BIS IS 10500: 2012, chlorides are categorized as desirable, permitted, and non-potable, with concentration ranges of 0–250 mg/L, 250–1000 mg/L, and >1000 mg/L, respectively. Generally, the chloride content increases with the mineral content. Human activities can also introduce chlorides into groundwater. However, the groundwater in different locations within the research area has chloride concentrations well within the desirable range.

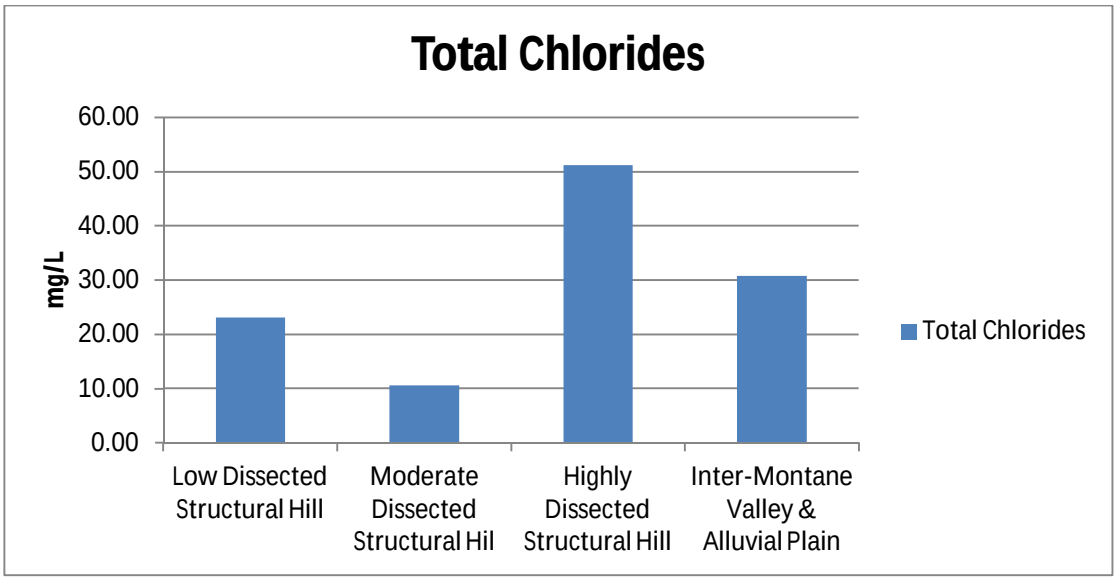


Figure 14: Total Chlorides in terms of geomorphic units

Considering the geomorphic units, the highest total chlorides are found in the highly dissected structural hills, while the lowest are found in the moderately structural hills.

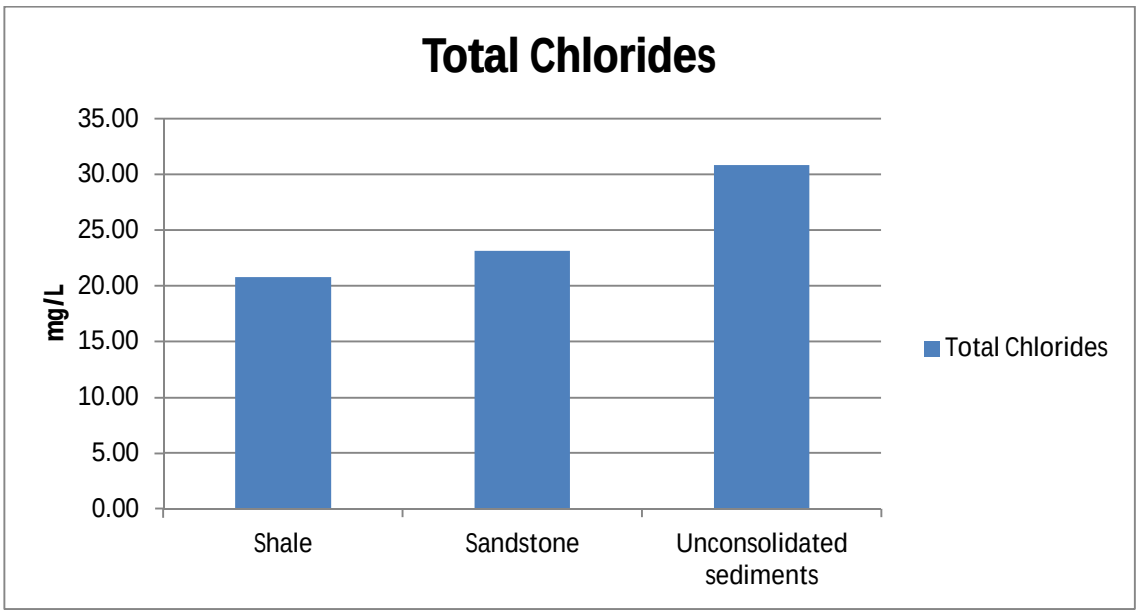
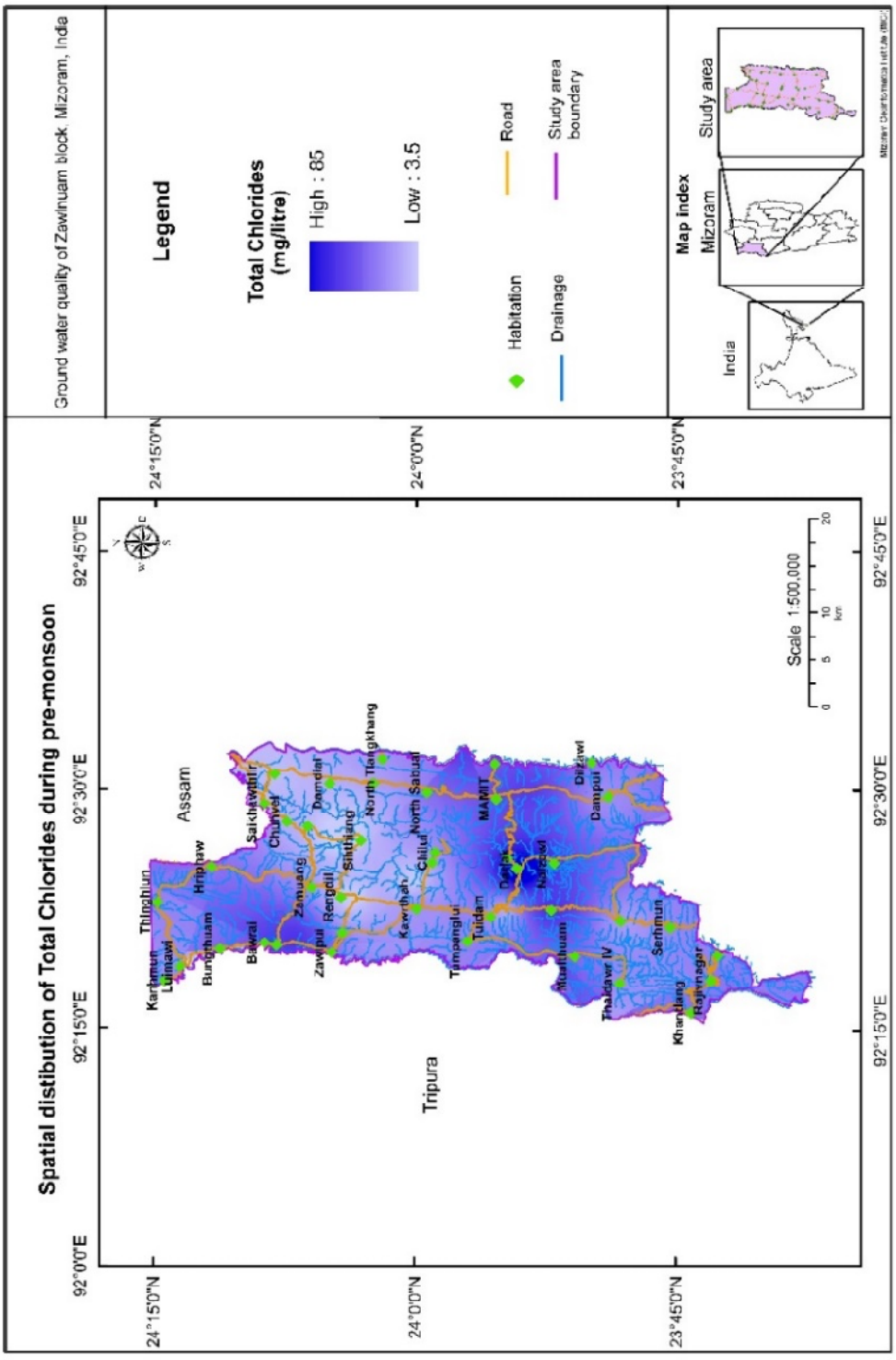
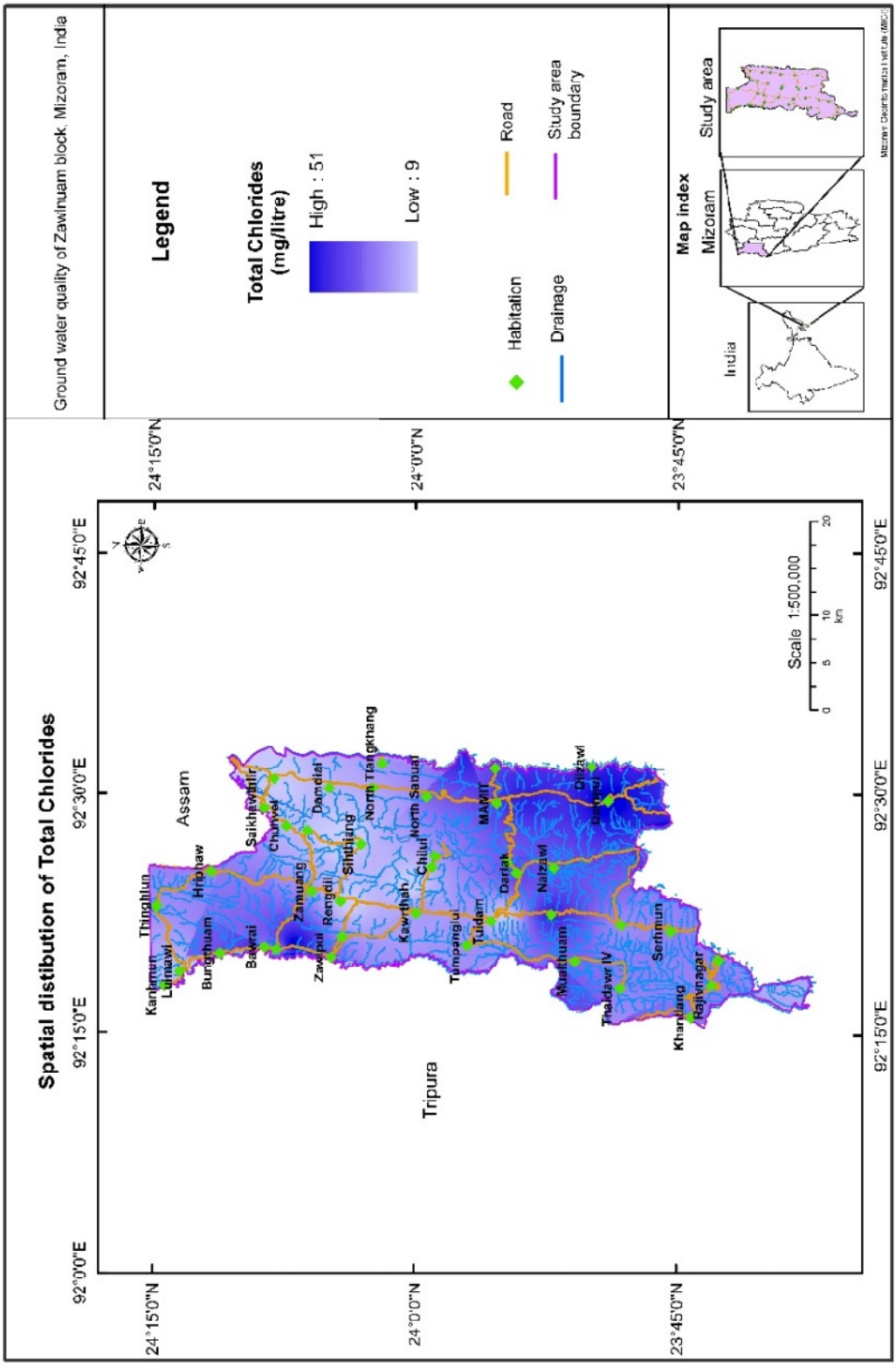


Figure 15: Total Chlorides in terms of lithological units

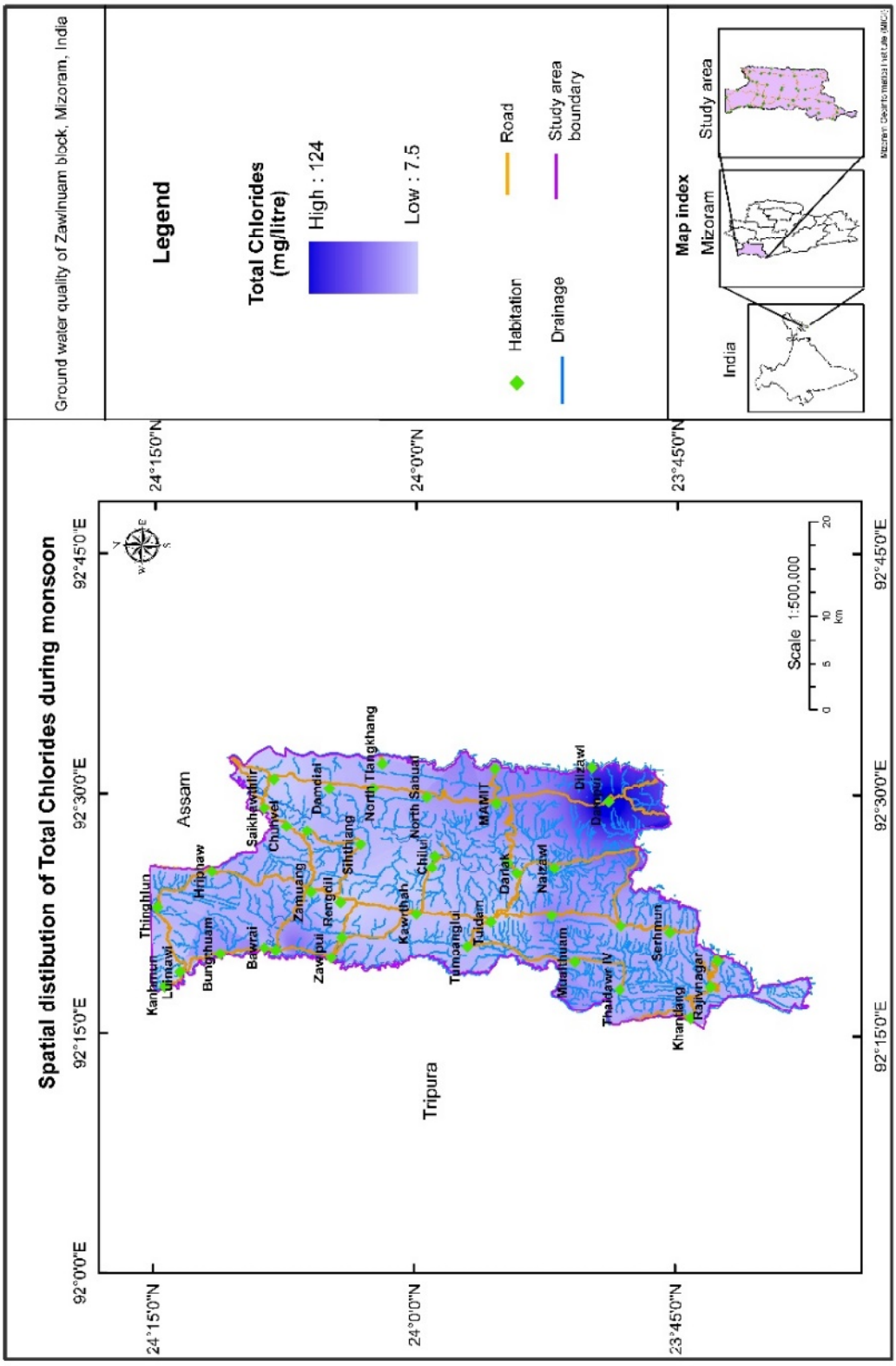
From a lithological perspective, the highest concentration of chlorides is found in unconsolidated sediments, while the lowest concentration is found in sandstone.



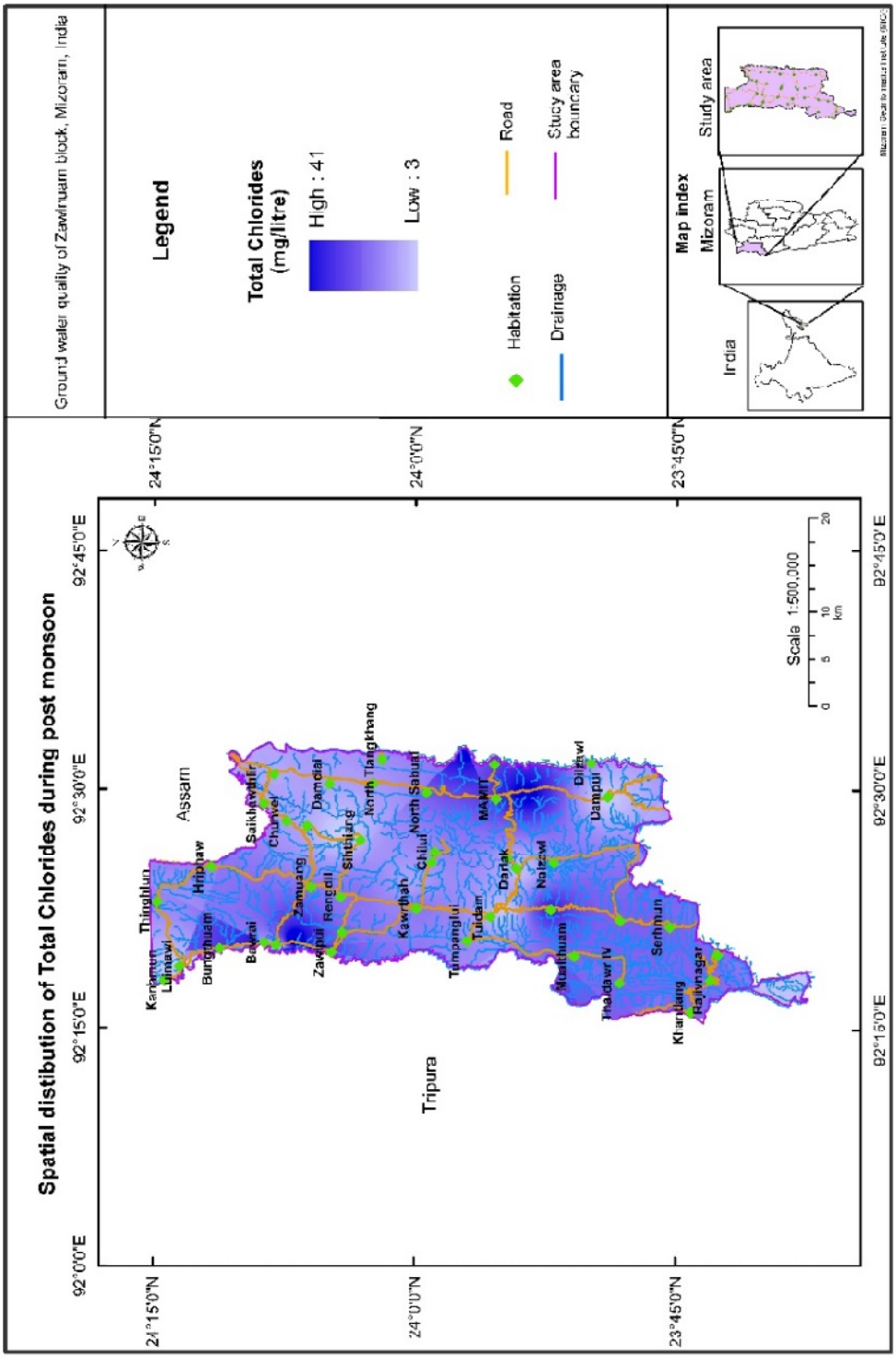
Map 27 : Spatial distribution of Total Chlorides during pre- monsoon



Map 28: Spatial distribution of Total Chlorides



Map 29: Spatial distribution of Total Chlorides during monsoon



Map 30: Spatial distribution of Total Chlorides during post- monsoon

6.5. Total Hardness: As per BIS IS 10500: 2012, the total hardness is classified into three ranges: 0-300 mg/L, 300-600 mg/L, and >600 mg/L, which correspond to desirable, permissible, and non-potable categories. The composition of aquifers can influence the total hardness of groundwater. Hardness of water is determined by the presence of dissolved calcium and magnesium. This suggests that the groundwater quality in the study area falls within the desirable category.

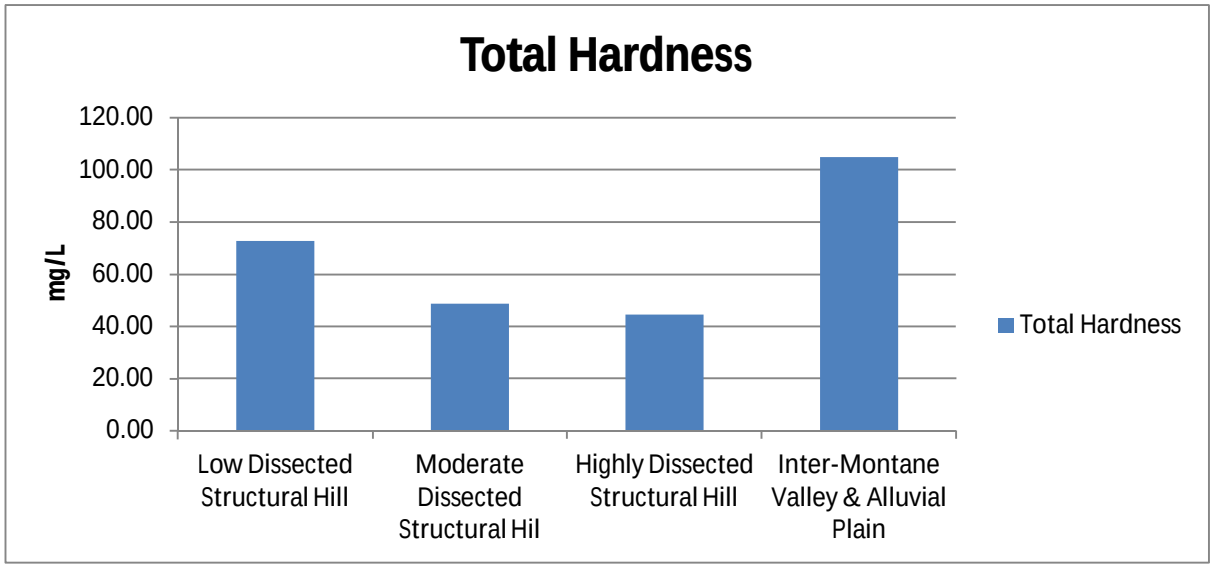


Figure 16: Total hardness in terms of geomorphic units

In terms of geomorphic units, the highest total hardness is found in inter-montane valleys and alluvial plains, while the lowest is in highly dissected structural hills.

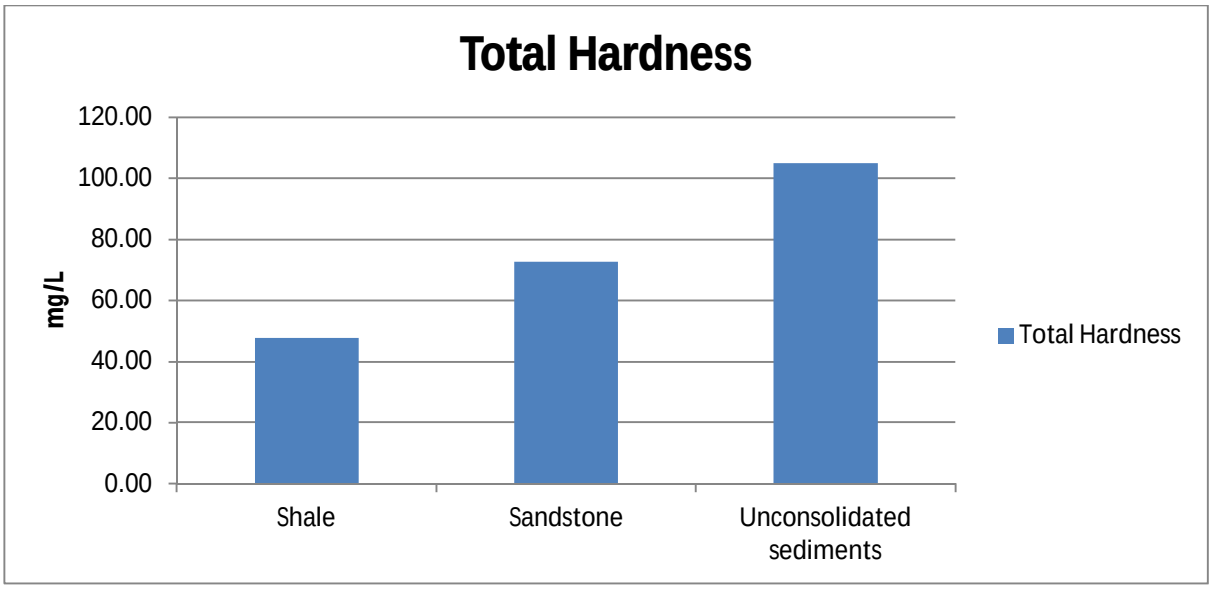
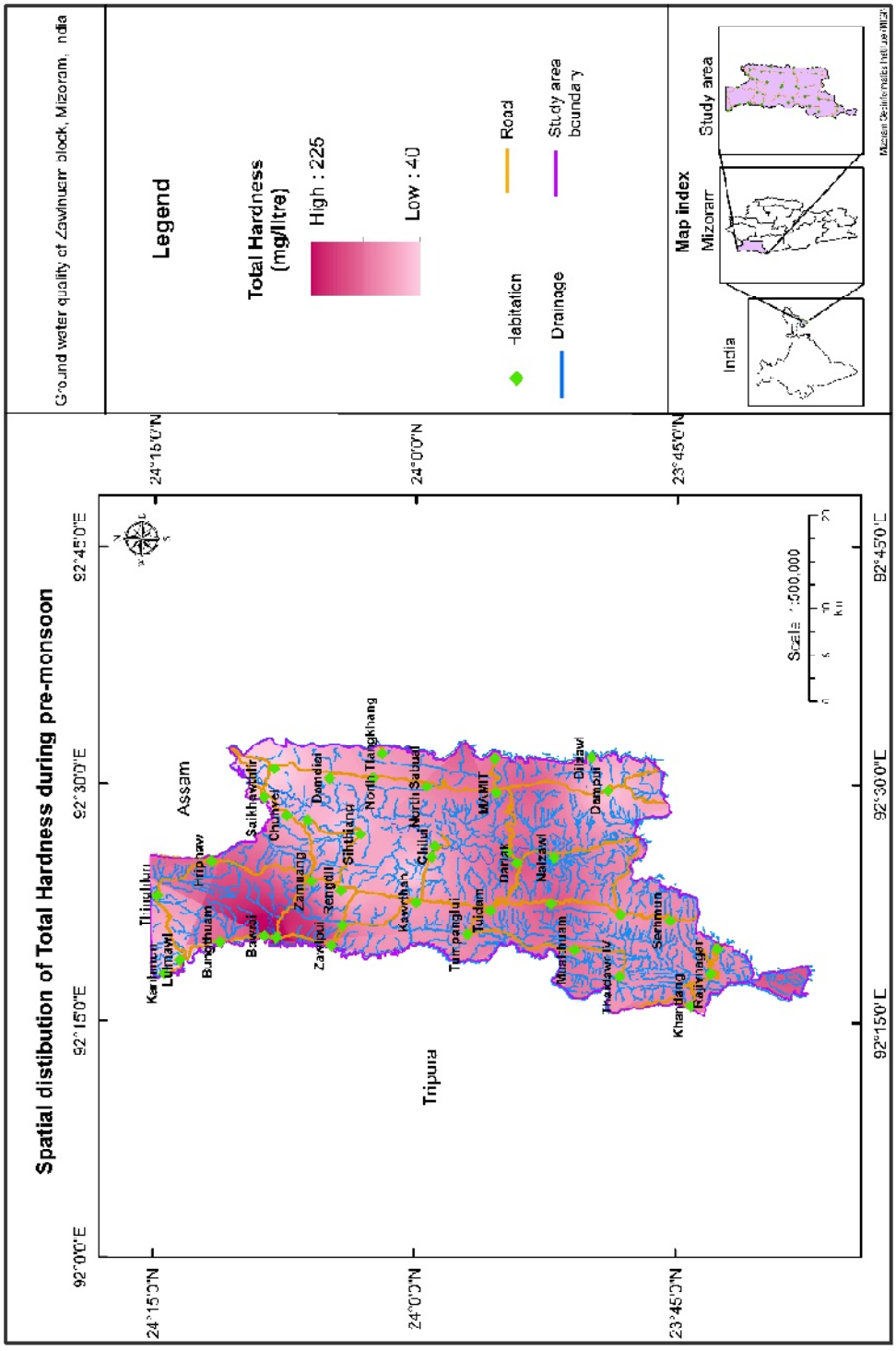
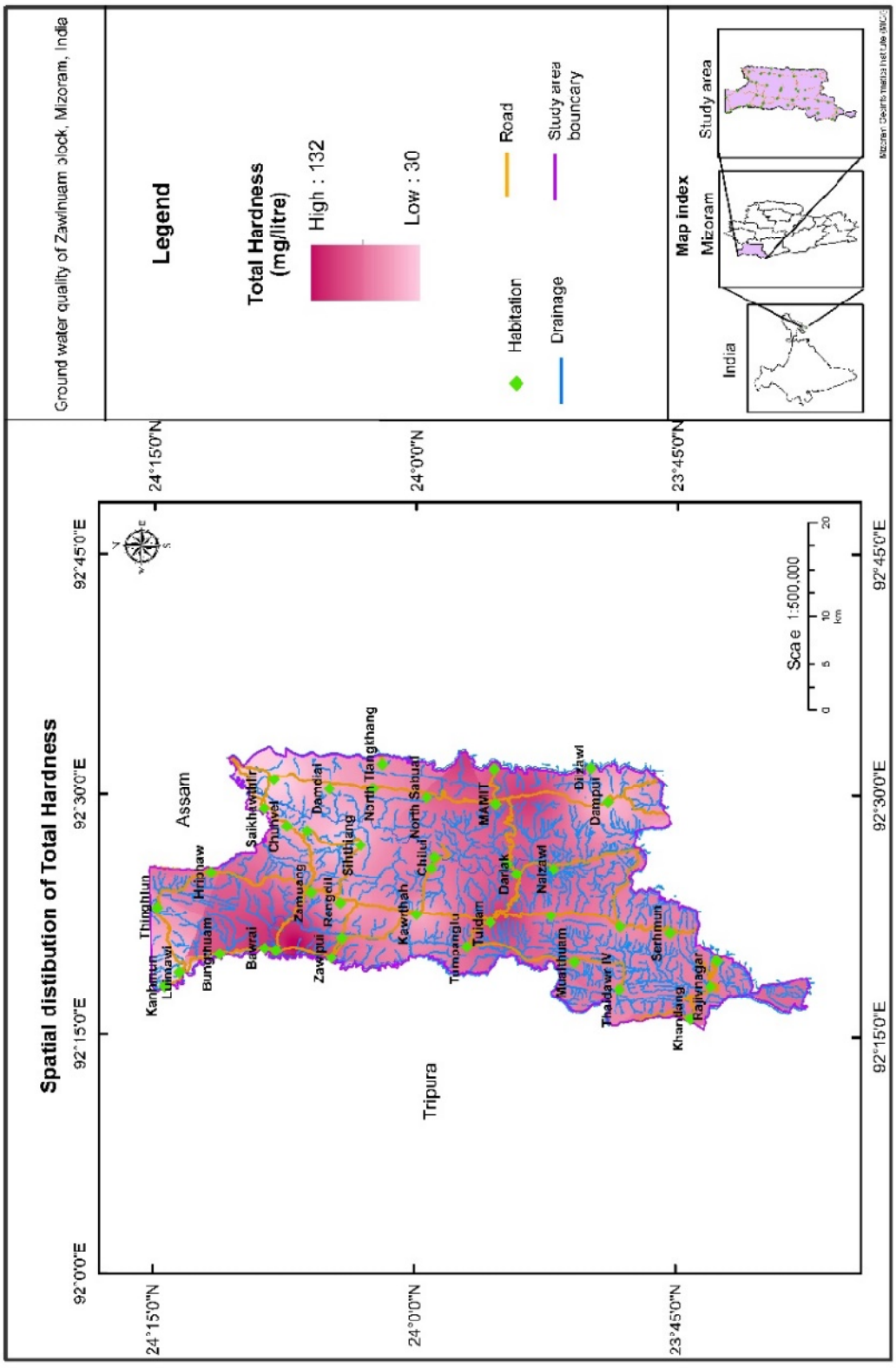


Figure 17: Total hardness in terms of lithological units

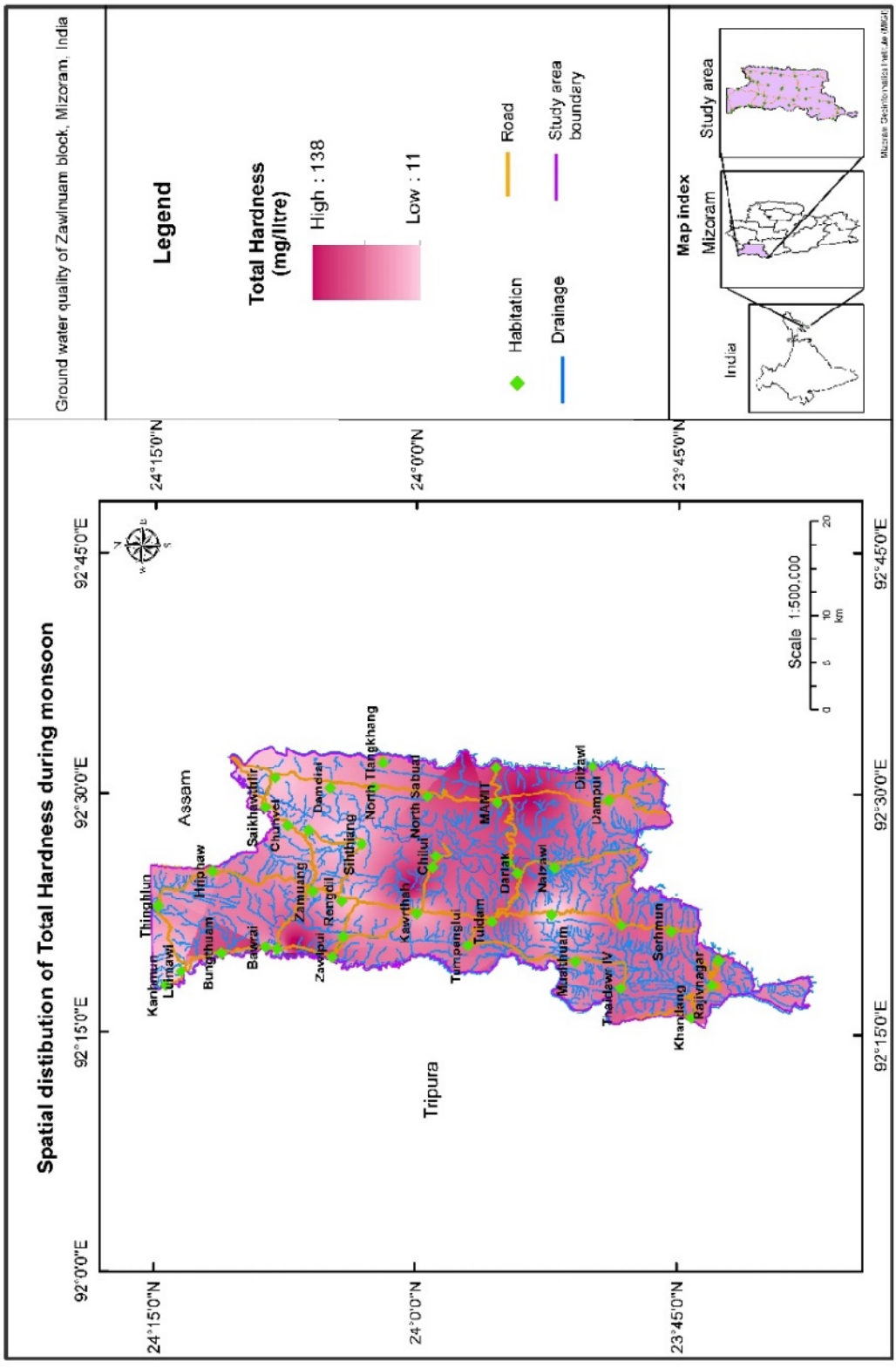
Regarding lithology, total hardness is highest in unconsolidated sediments and lowest in shale.



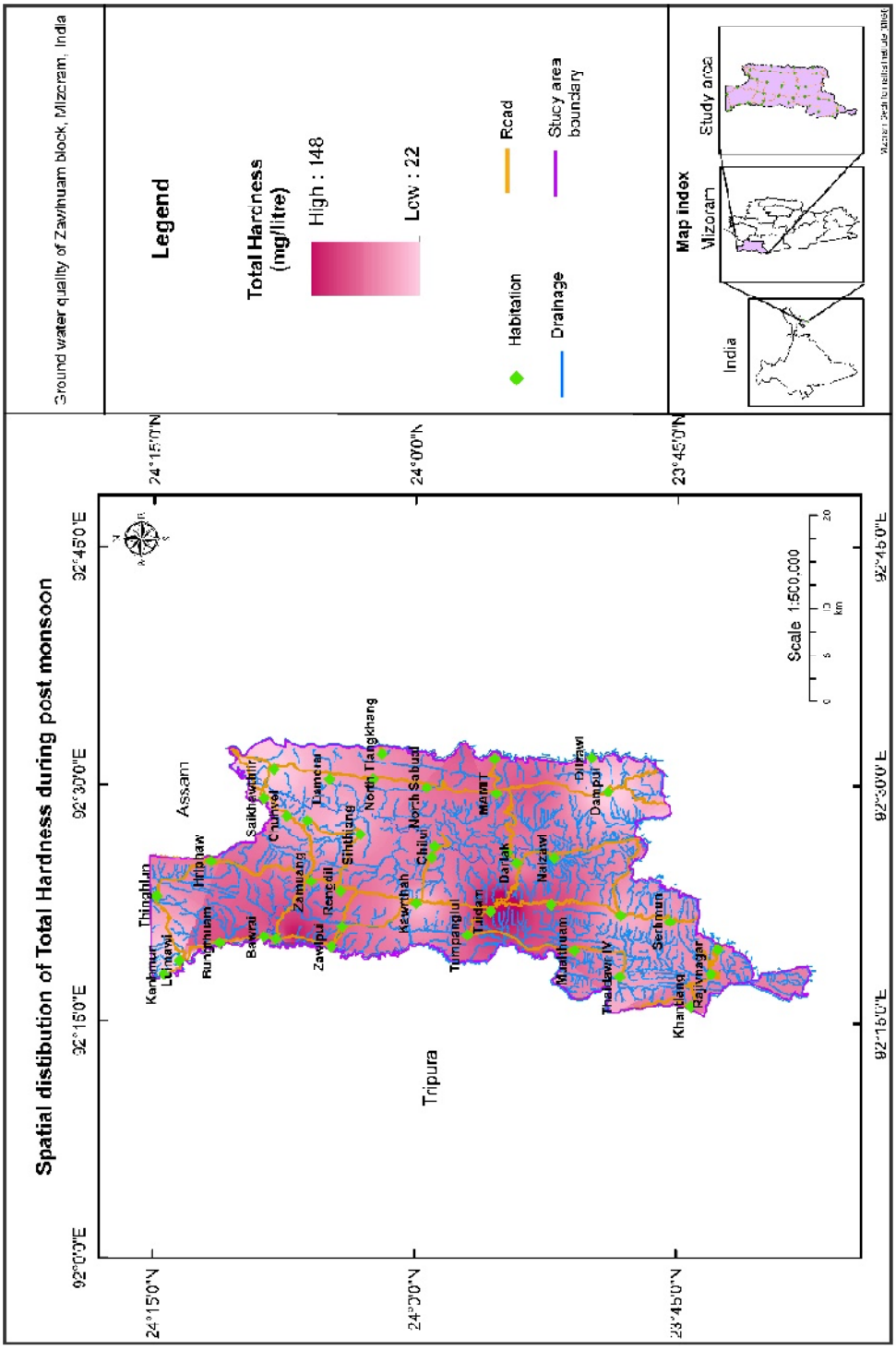
Map 31 : Spatial distribution of Total Hardness during pre- monsoon



Map 32: Spatial distribution of Total Hardness



Map 33: Spatial distribution of Total Hardness during monsoon



Map 34: Spatial distribution of Total Hardness during post- monsoon

6.6. Turbidity: The cloudiness or murkiness of water caused by suspended particles is known as turbidity. According to BIS IS 10500: 2012, turbidity is categorized into three ranges: <1.0 NTU, 1-5 NTU, and >5 NTU. Both inorganic and organic particles can contribute to turbidity. During spring, various factors such as human activities, animal movements, landslides, flooding, and heavy rainfall can result in turbidity. In deep subsurface water, the majority of turbidity is inorganic and is a result of natural geological processes.

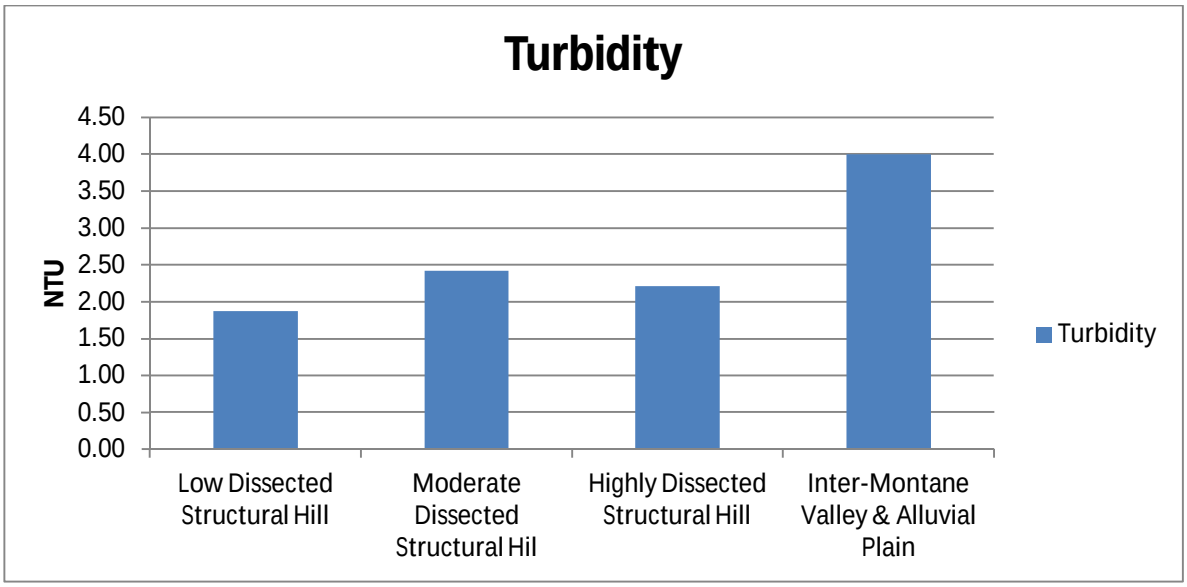


Figure 18: Turbidity in terms of geomorphic units

With regard to geomorphic units, turbidity is highest in intermontane valleys and alluvial plains and lowest in low dissected structural hills.

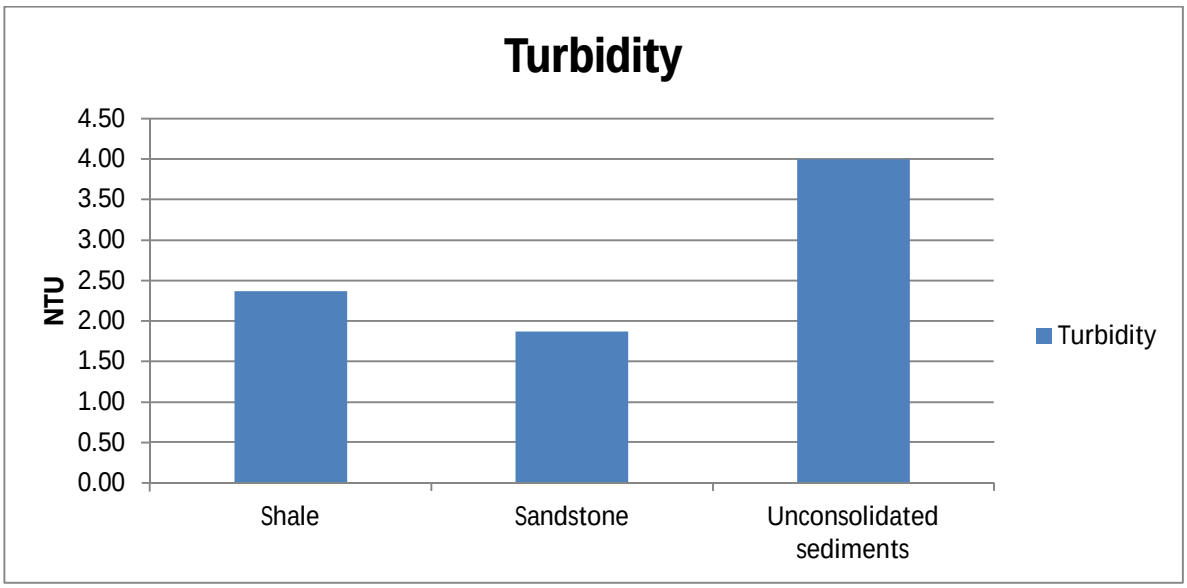
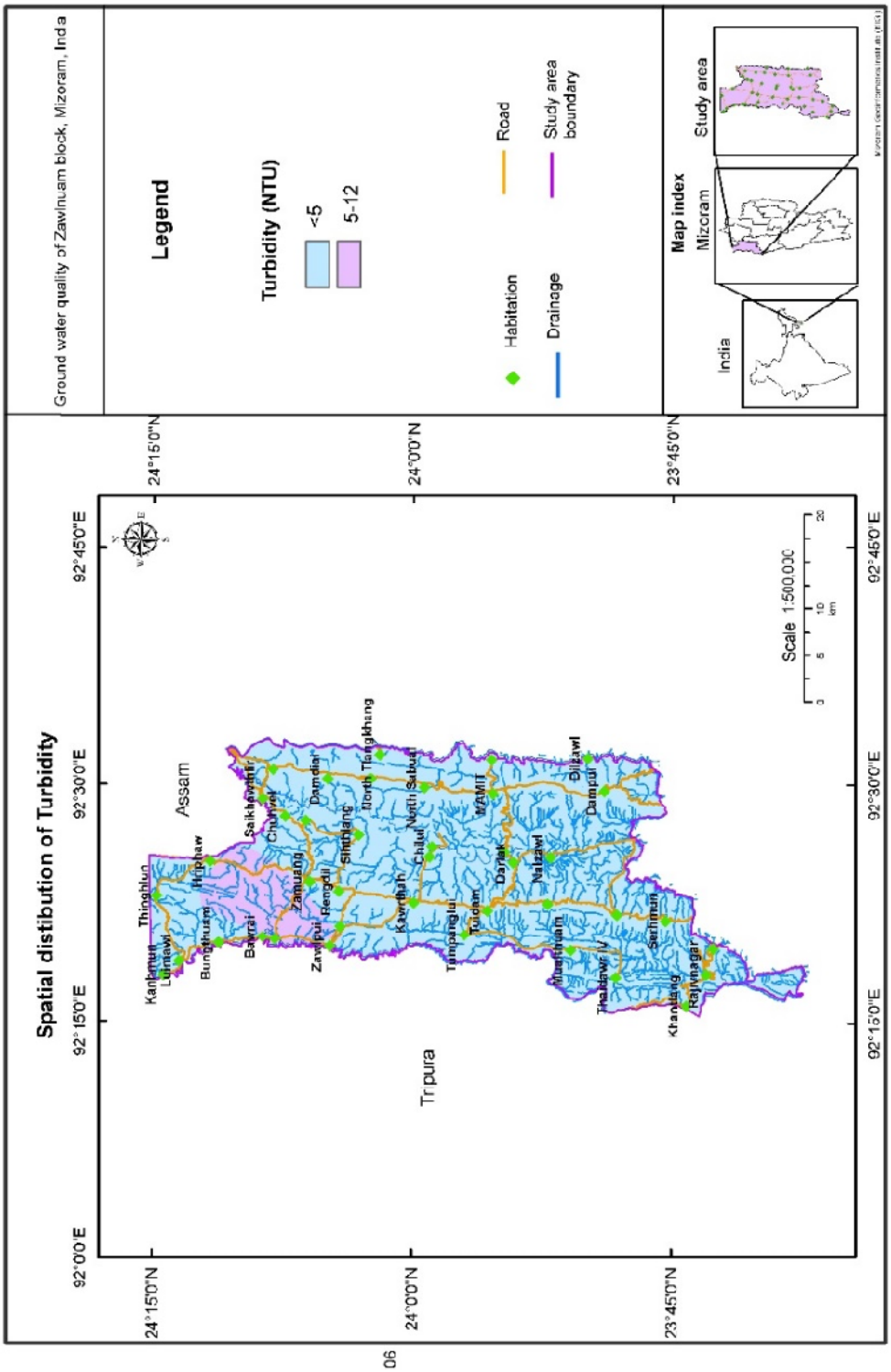
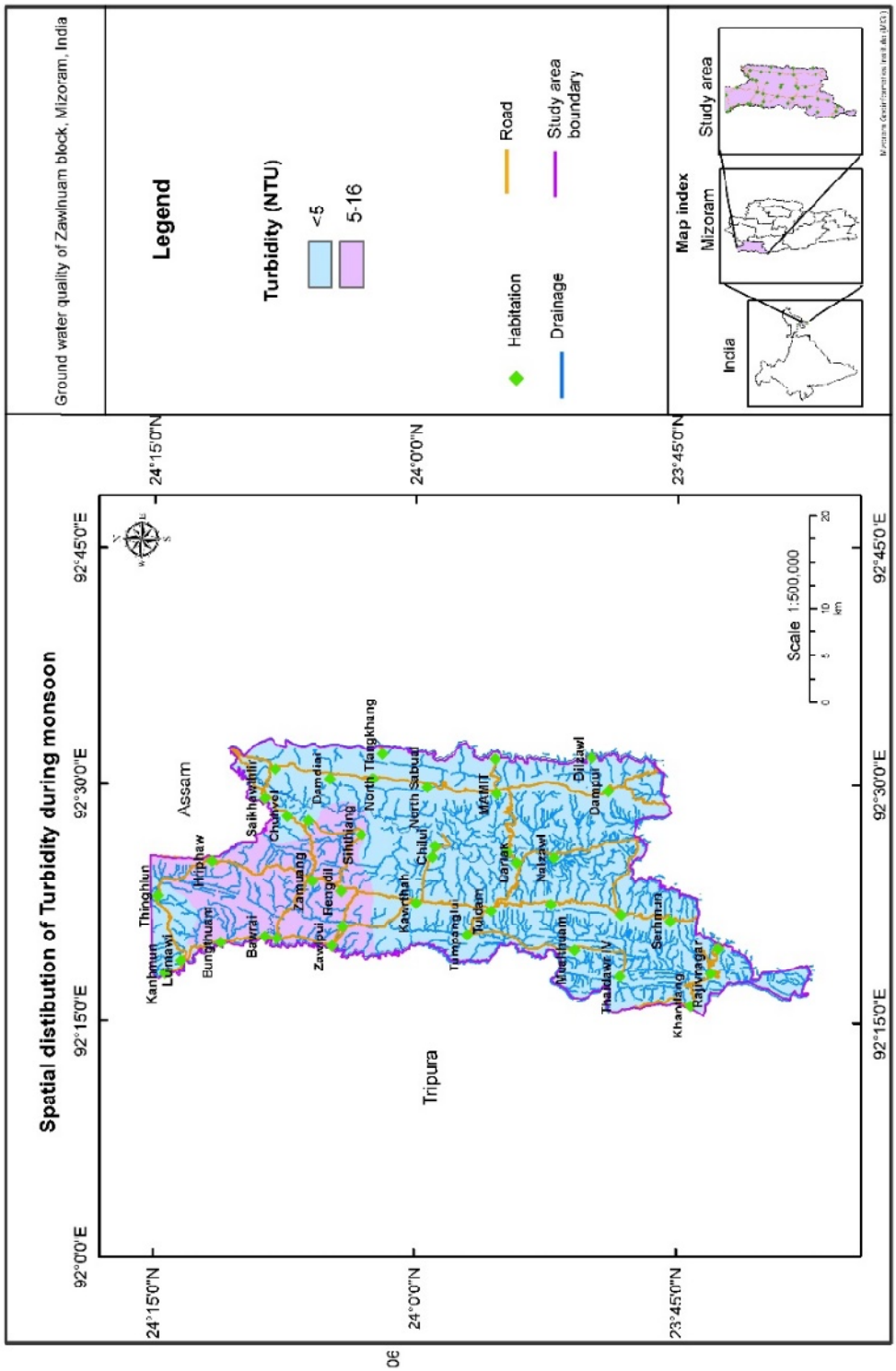


Figure 19: Turbidity in terms of lithological units

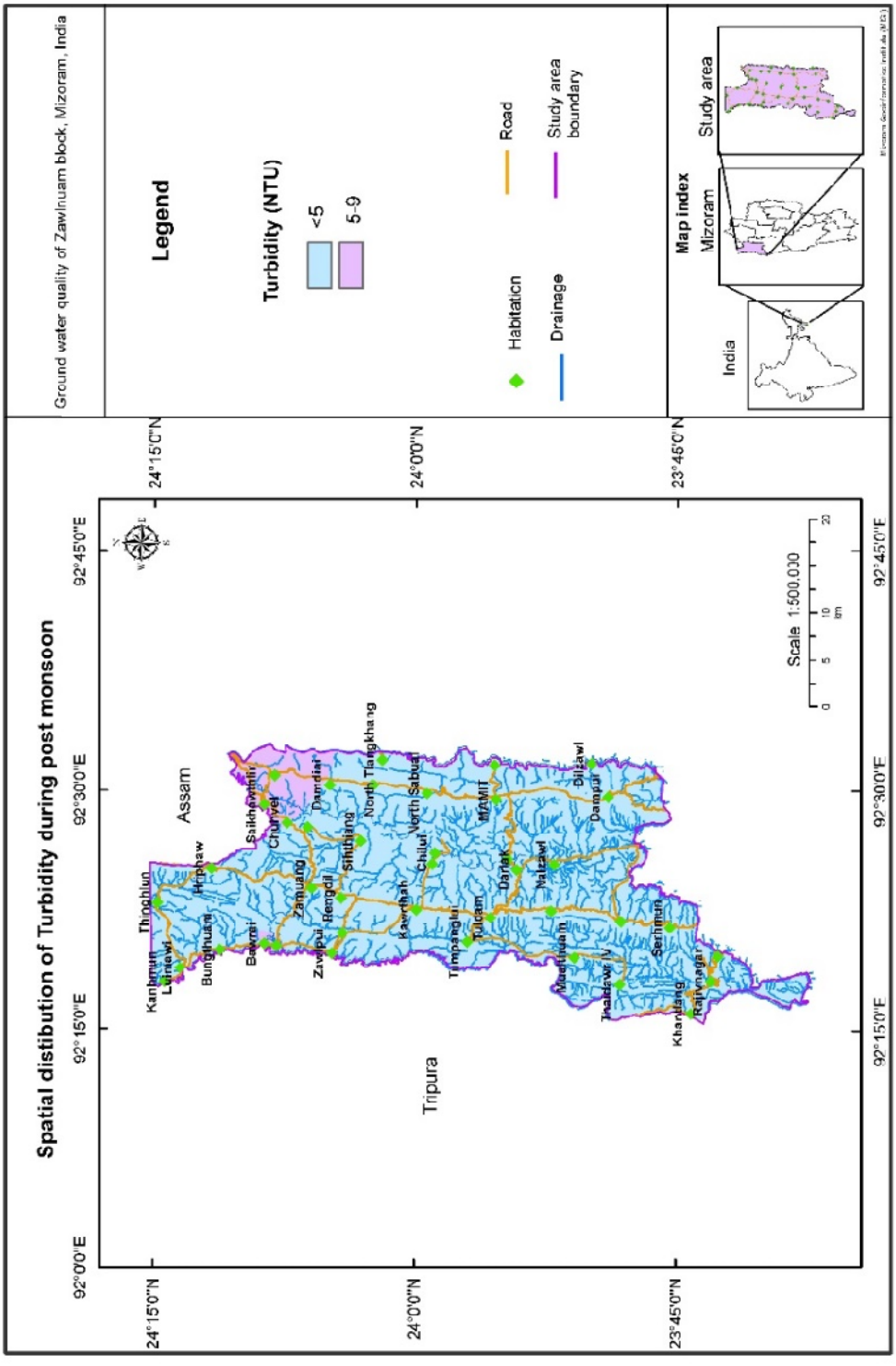
In terms of lithology, turbidity is highest in unconsolidated sediments and lowest in sandstone.



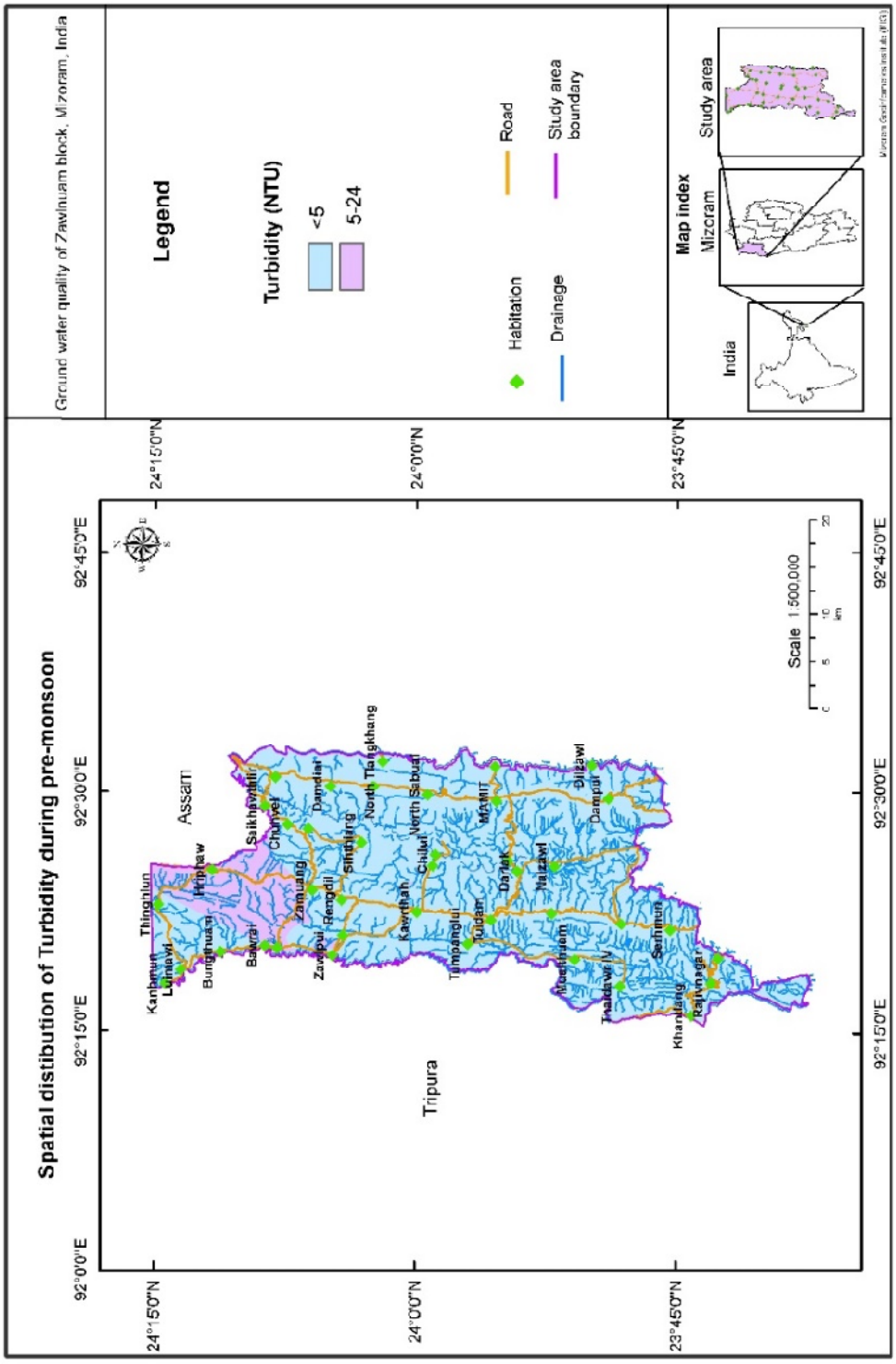
Map 35: Spatial distribution of turbidity



Map 36: Spatial distribution of turbidity during monsoon



Map 37: Spatial distribution of turbidity during post- monsoon



Map 38: Spatial distribution of turbidity during pre- monsoon

6.7. Iron: The BIS IS 10500: 2012 sets the acceptable iron concentration range at 0.3–1.0 mg/L, with less than 0.3 mg/L being the desirable limit and greater than 1.0 mg/L falling into the non-potable class. The iron content in groundwater is primarily determined by the chemical composition of the aquifers and is often linked to the components of handpumps in bore wells.

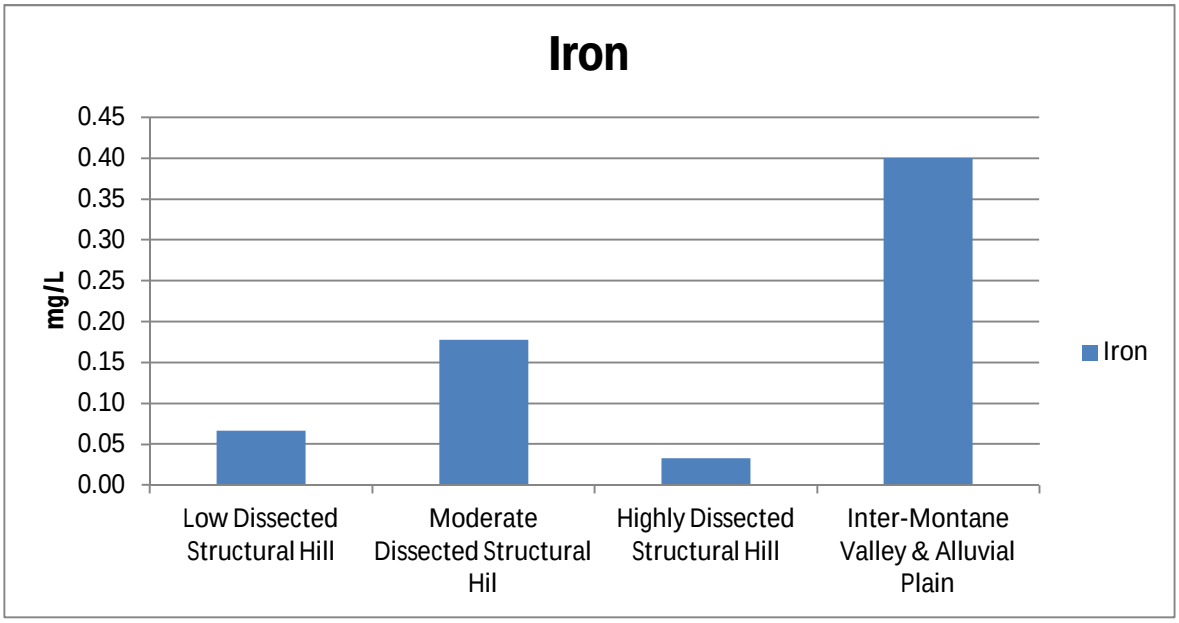


Figure 20: Iron in terms of geomorphic units

From a geomorphic point of view, iron content is highest in inter-montane valleys and alluvial plains, and lowest in highly dissected structural hills.

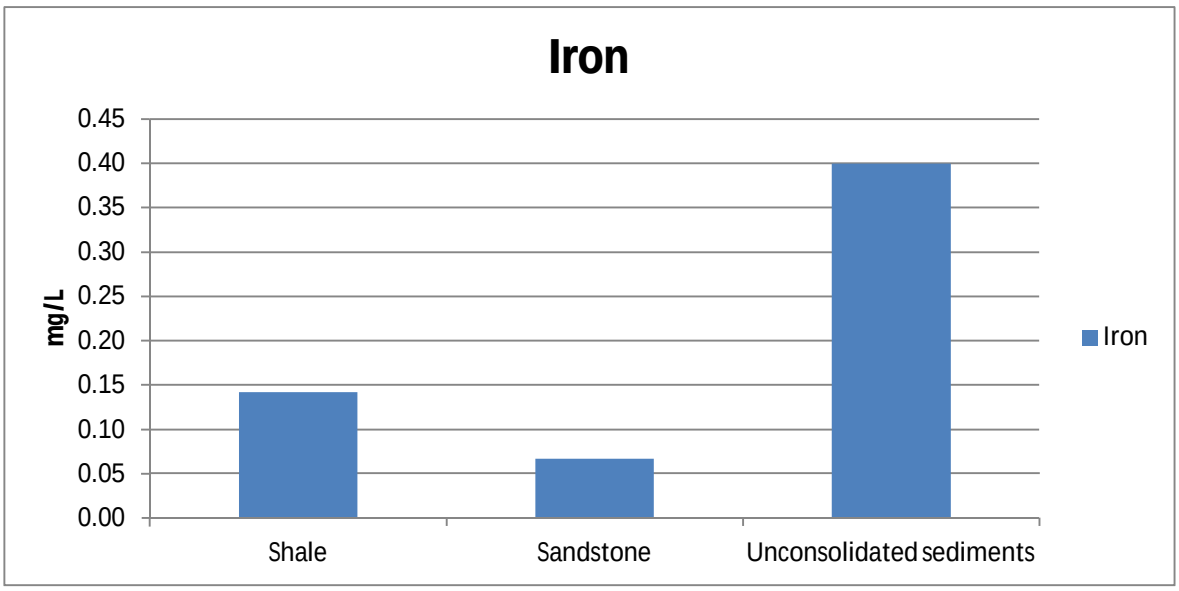
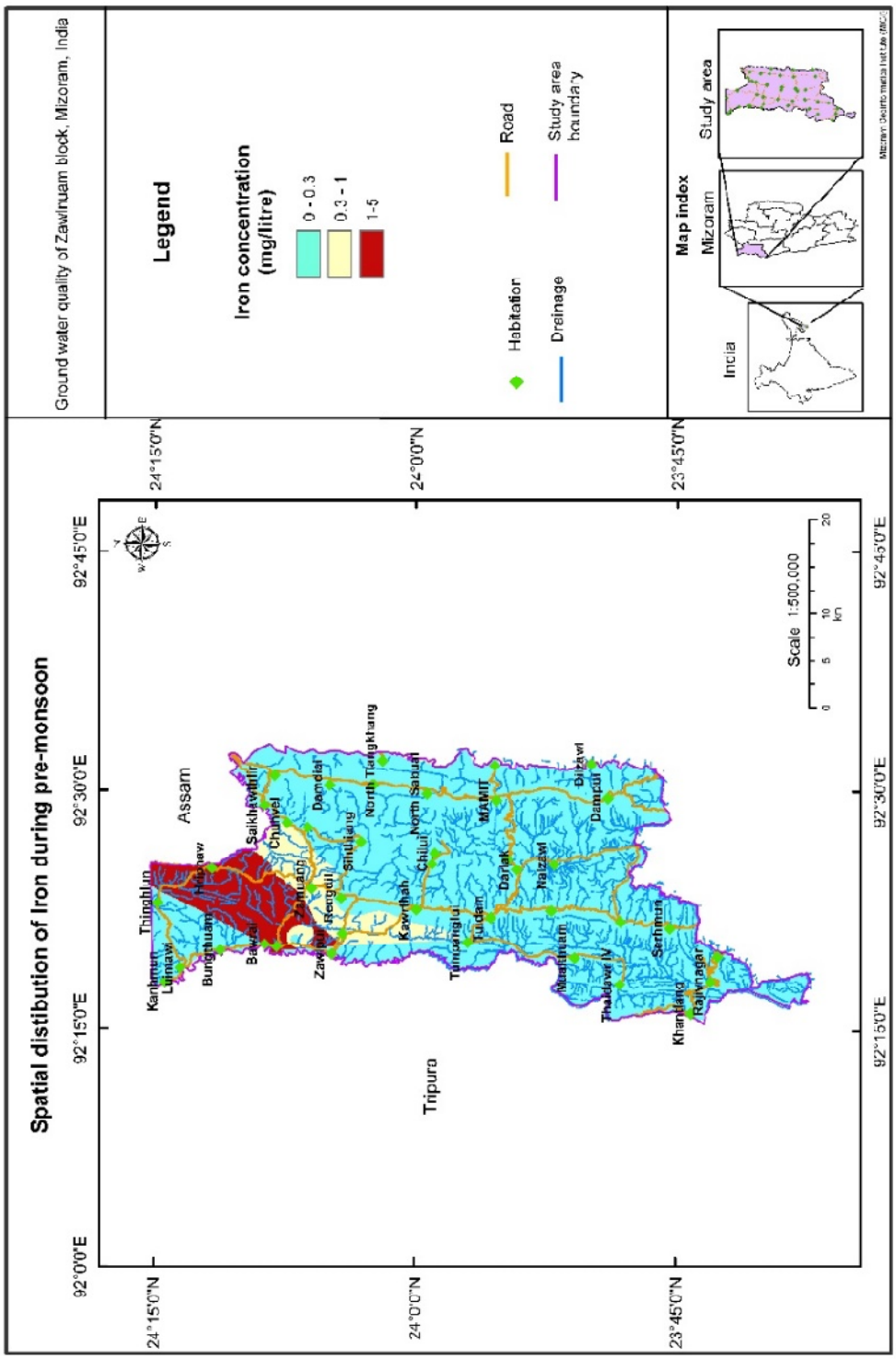
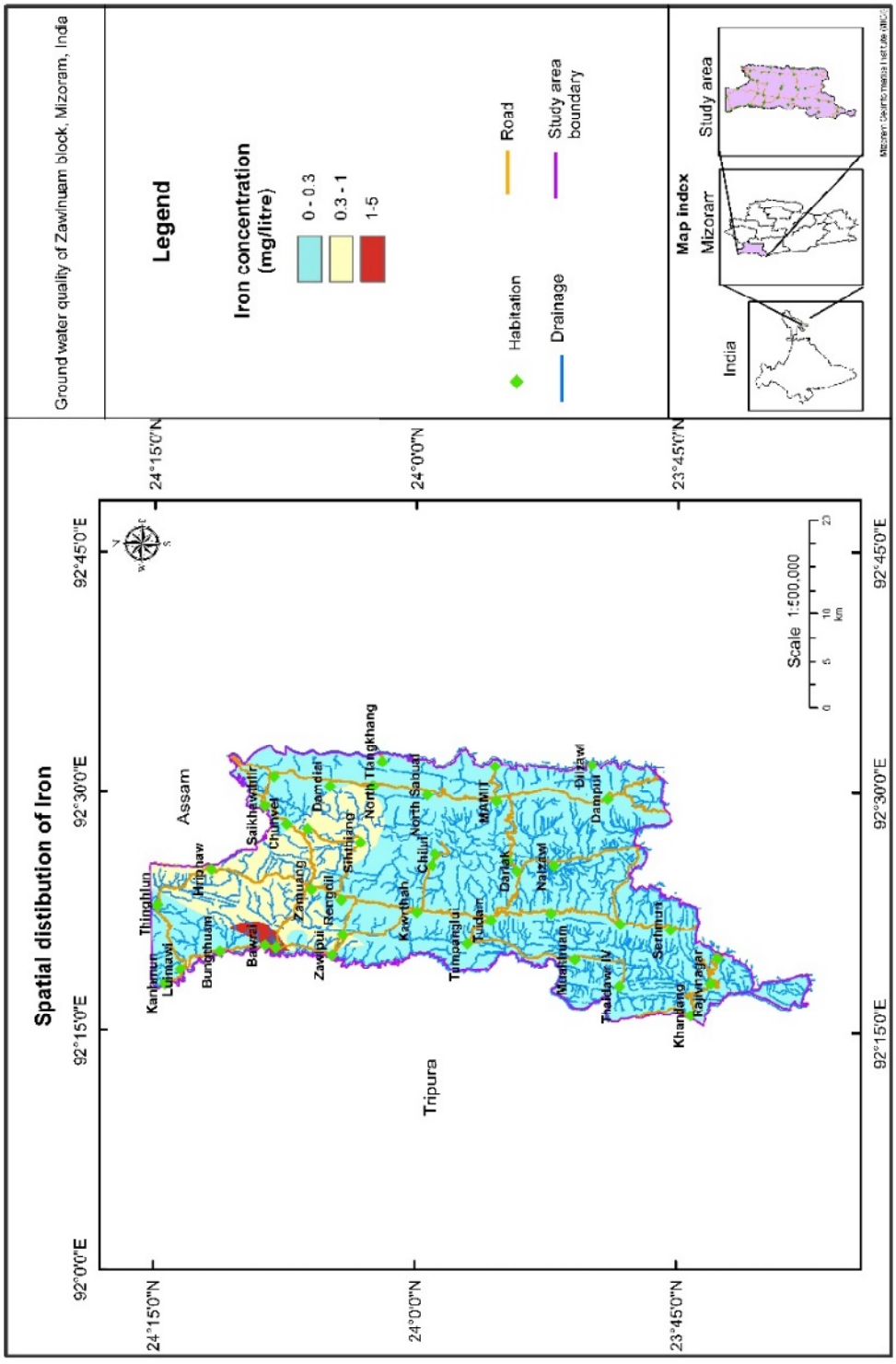


Figure 21: Iron in terms of lithological units

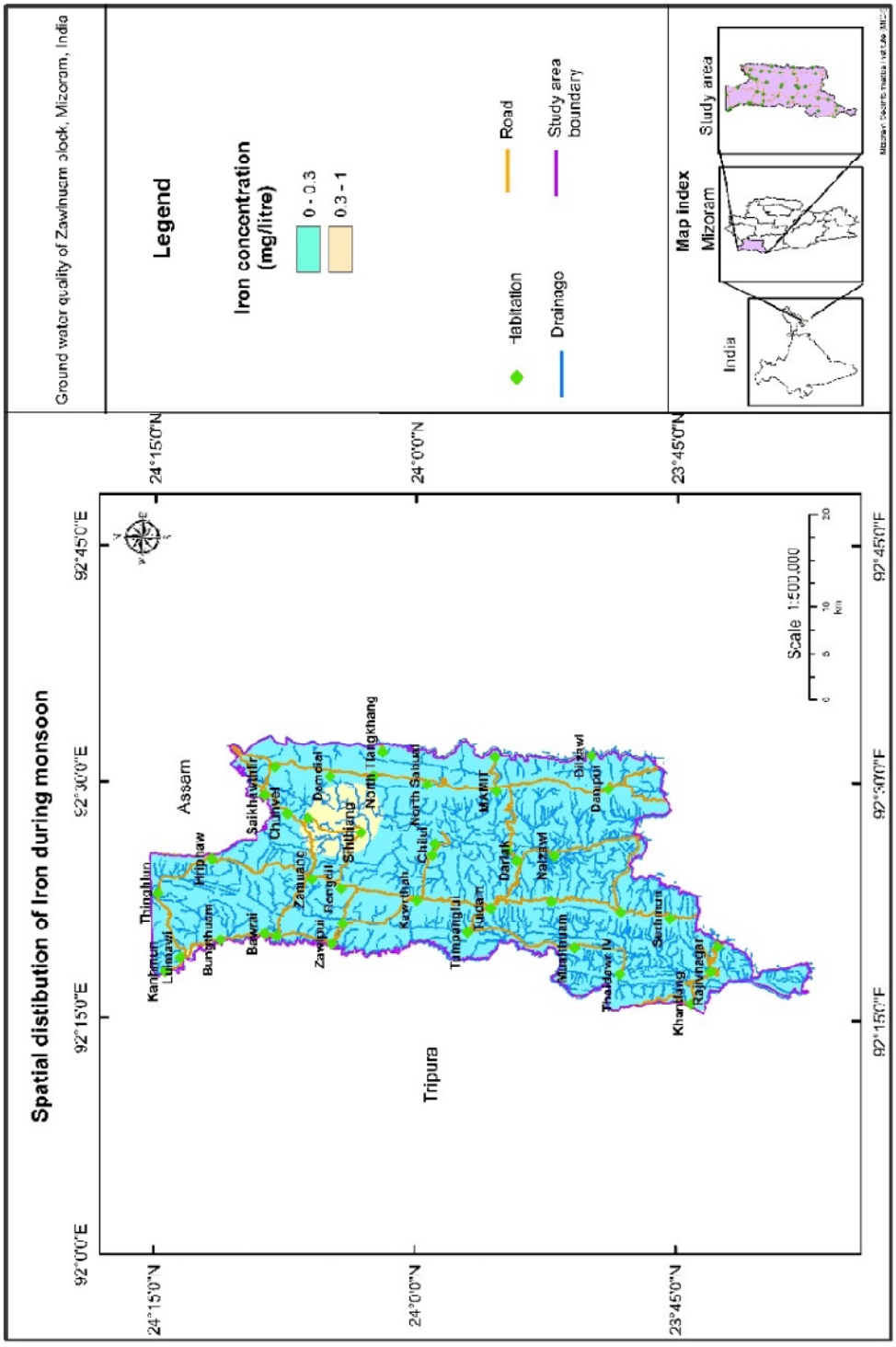
Regarding lithology, iron is highest in unconsolidated sediments and lowest in sandstone.



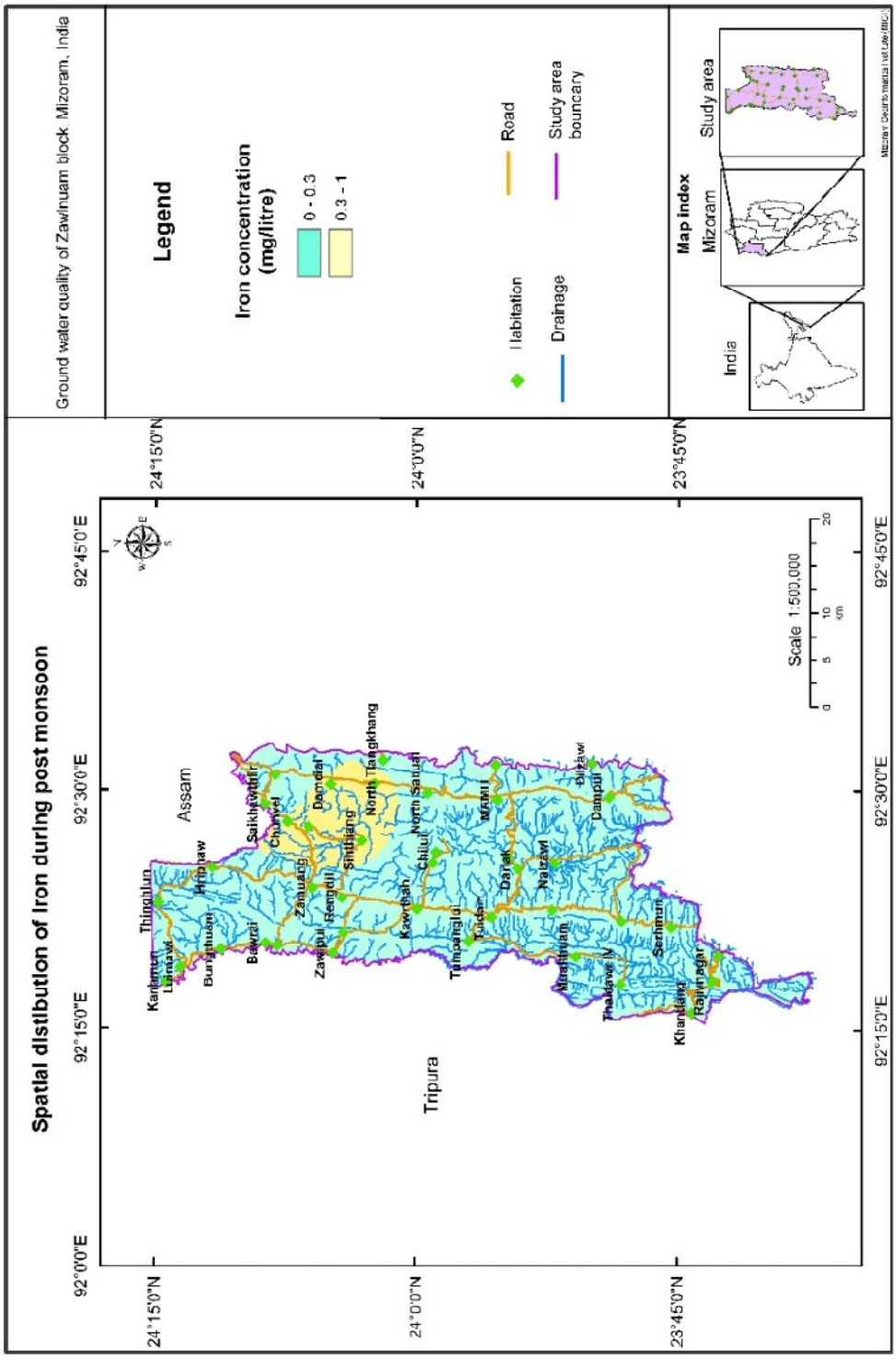
Map 39: Spatial Distribution of Iron during pre- monsoon



Map 40: Spatial Distribution of Iron



Map 41: Spatial Distribution of Iron during monsoon



Map 42: Spatial Distribution of Iron during post- monsoon

6.8. Conductivity: The quality of groundwater is often assessed using a key measure known as conductivity. As per BIS IS 10500: 2012, water's electrical conductivity is categorized into three ranges: 0–2250 µmhos/cm, 2250–3000 µmhos/cm, and >3000 µmhos/cm. The level of dissolved minerals in water influences its Conductivity, which is linked to the specific geological characteristics of the area.

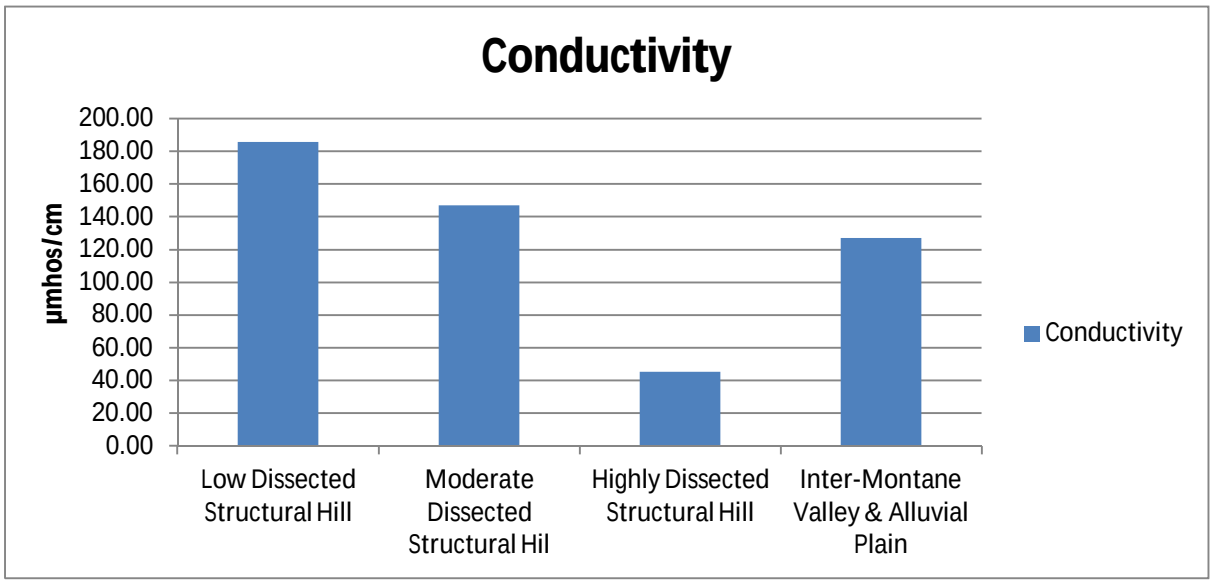


Figure 22 : Conductivity in terms of geomorphic units

In terms of geomorphic units, conductivity is highest in low dissected structural hills and lowest in highly dissected structural hills.

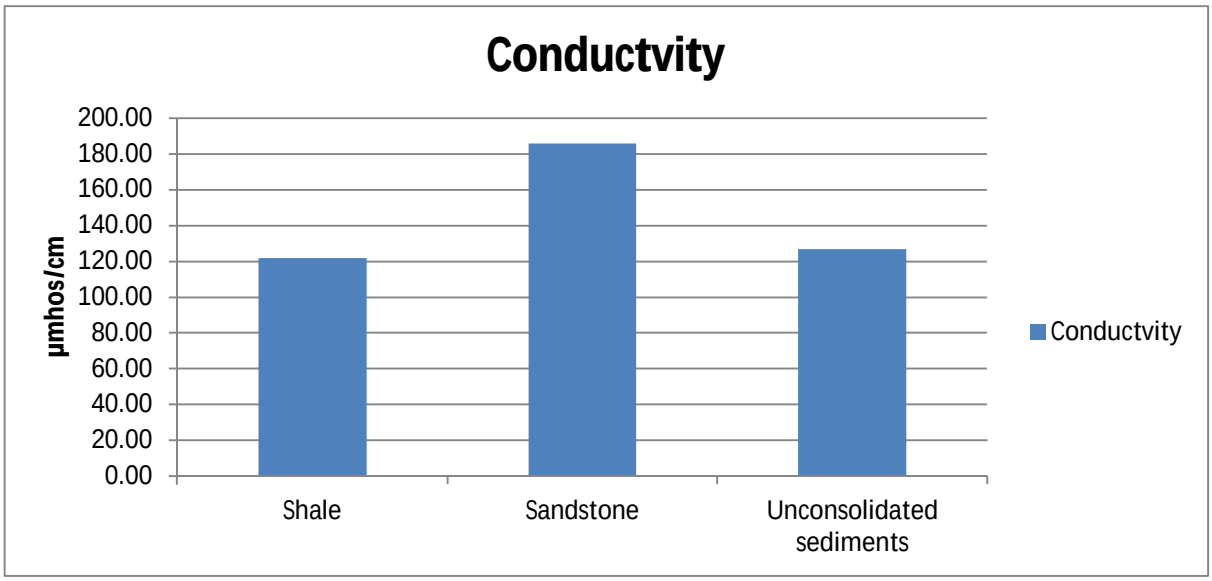


Figure 23 : Conductivity in terms of lithological units

When considering lithology, the conductivity is highest in sandstone and lowest in shale.

6.9. Calcium: According to BIS IS 10500: 2012, the calcium concentration was categorized into three ranges: 0-75 mg/L, 75-200 mg/L, and >200 mg/L. Groundwater that has come into contact with specific rocks and minerals contains calcium.

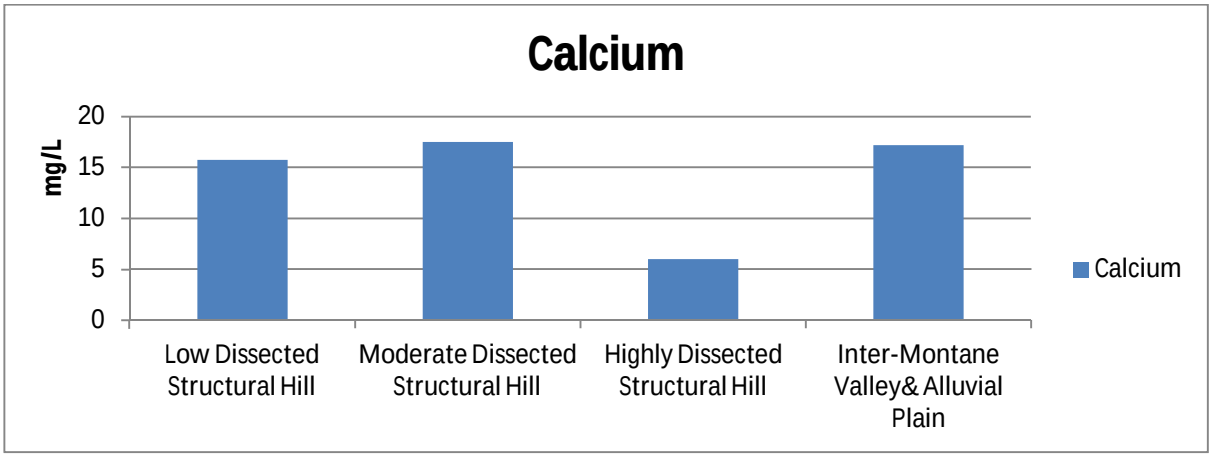


Figure 24 Calcium in terms of geomorphic units

In the study area, calcium concentration is high in intermontane valleys and alluvial plains, moderate in dissected structural hills, and low in highly dissected structural hills.

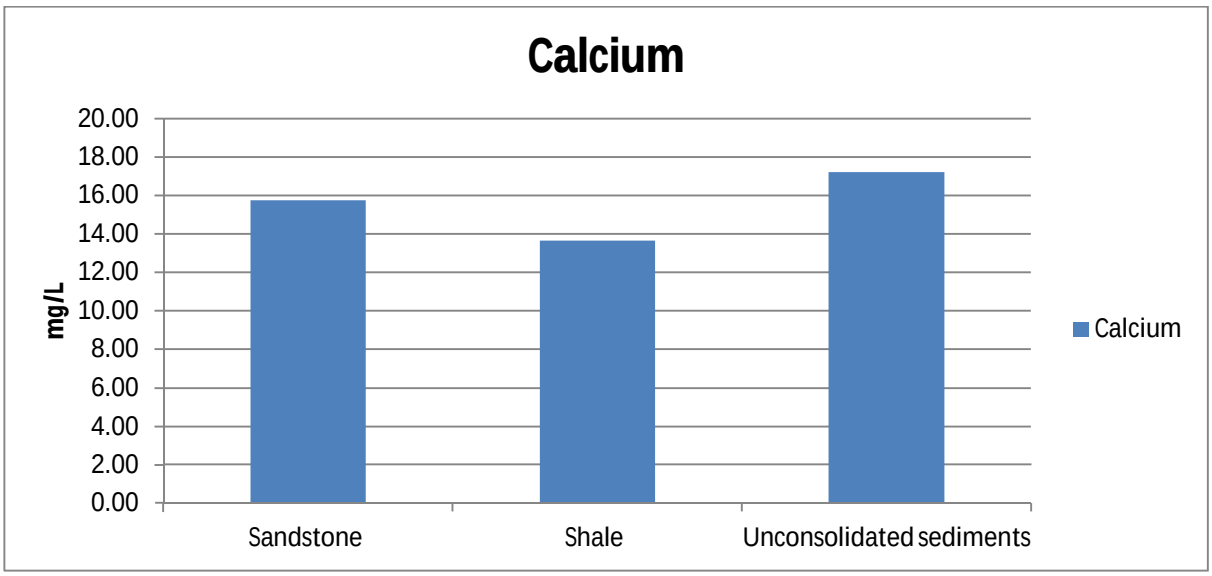
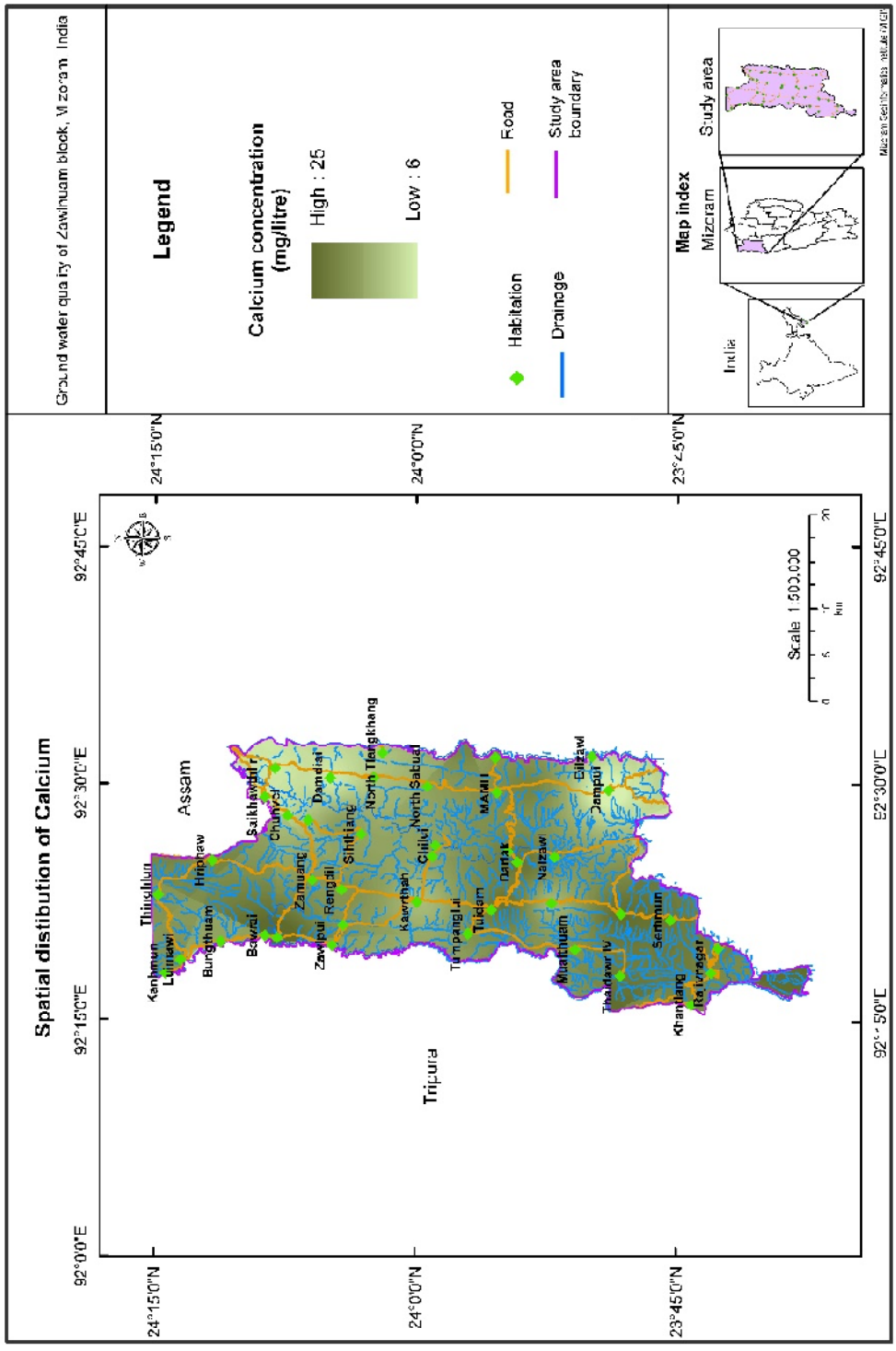


Figure 25 : Calcium in terms of lithological units

In terms of lithology, calcium is highest in unconsolidated sediments and lowest in shale



Map 43: Spatial distribution of Calcium

6.10. Magnesium: According to BIS IS 10500: 2012, magnesium is categorized into three ranges: 0–30 mg/L, 30-100 mg/L, and >100 mg/L. Hard water is caused by a high magnesium content in the water. As per BIS IS 10500: 2012, the magnesium concentration in the ground waters from the study region is within the desirable and permissible limits.

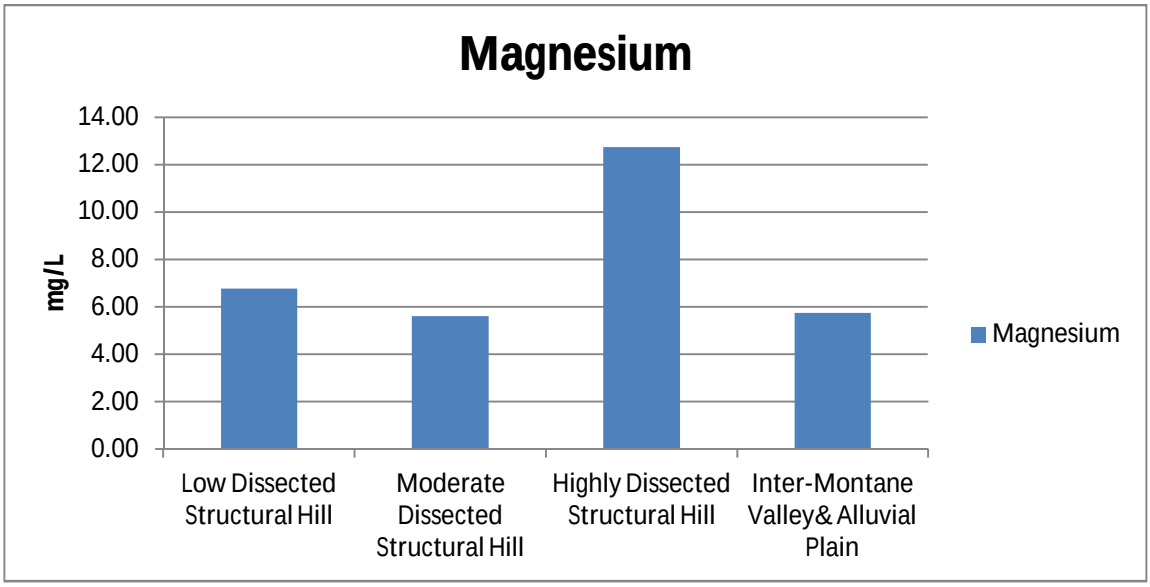


Figure 26 : Magnesium in terms of geomorphic units

With regards to geomorphic units, magnesium is highest in highly dissected structural hills and lowest in moderately dissected structural hills.

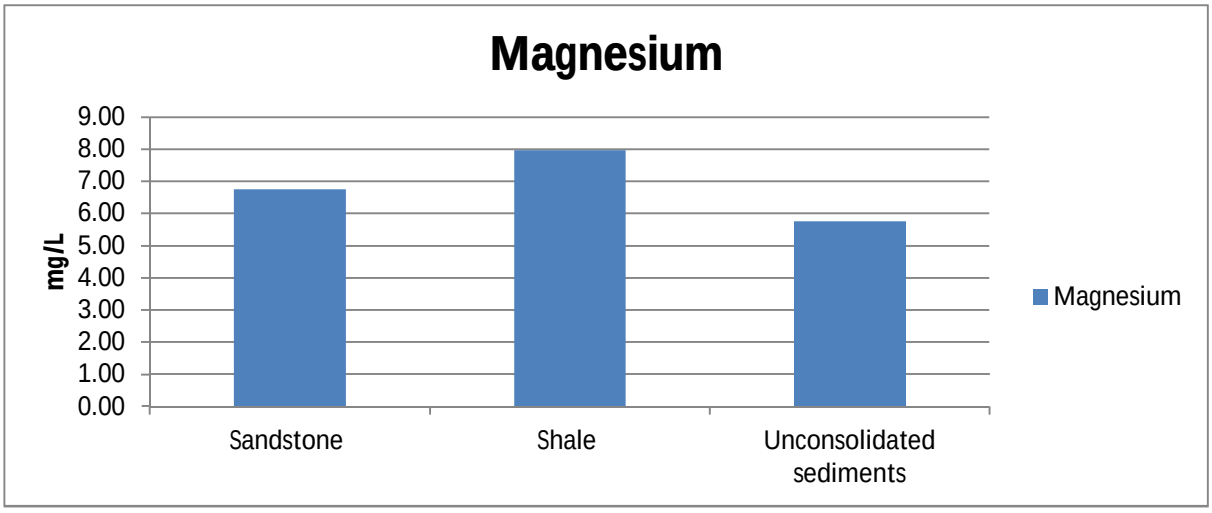
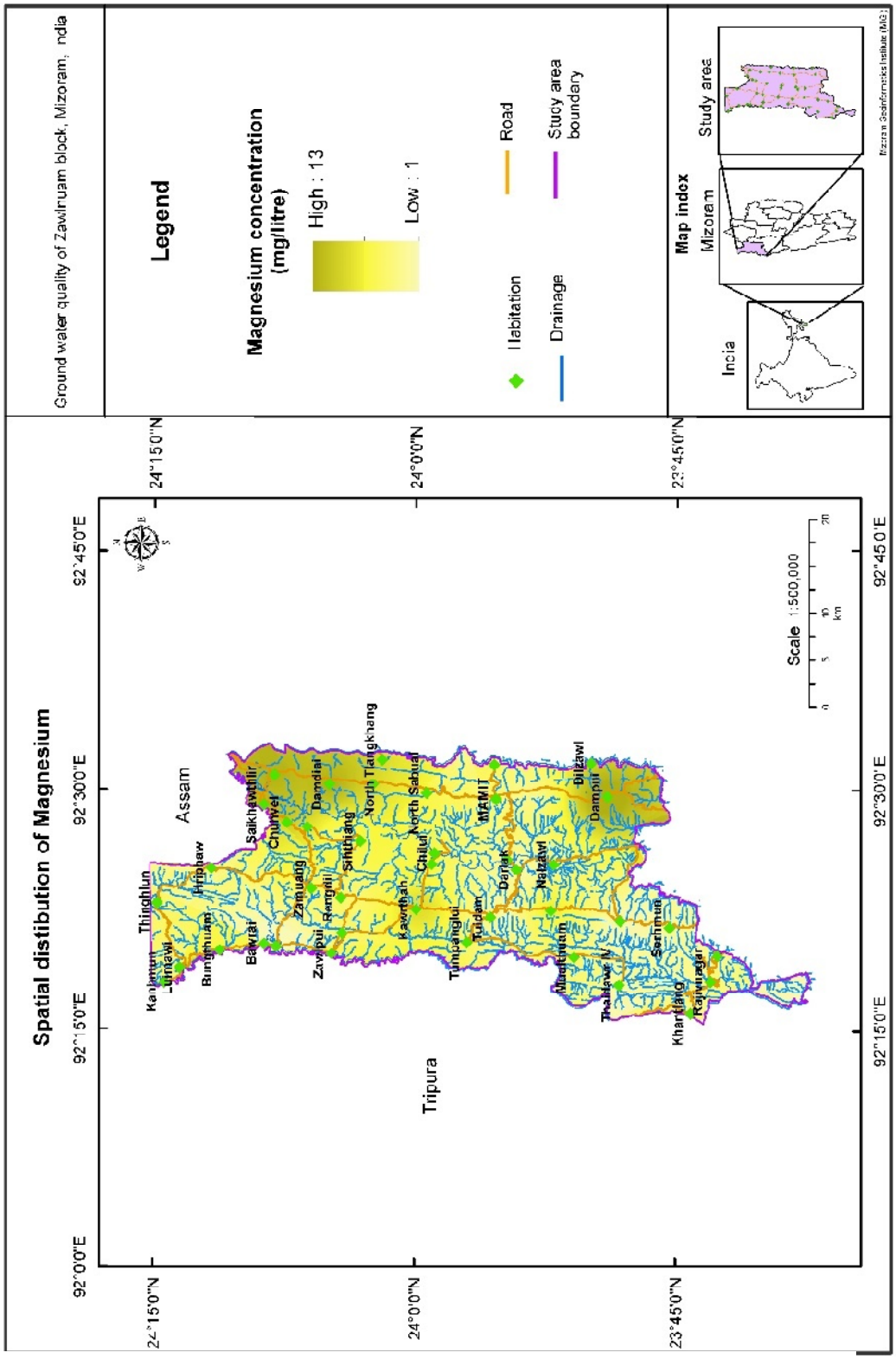


Figure 27 : Magnesium in terms of lithological units

Regarding lithology, concentration magnesium is highest in shale and lowest in unconsolidated sediments.



Map 44: Spatial distribution of Magnesium

6.11. Sodium: According to BIS IS 10500: 2012, Sodium desirable limit is 200 mg/L.

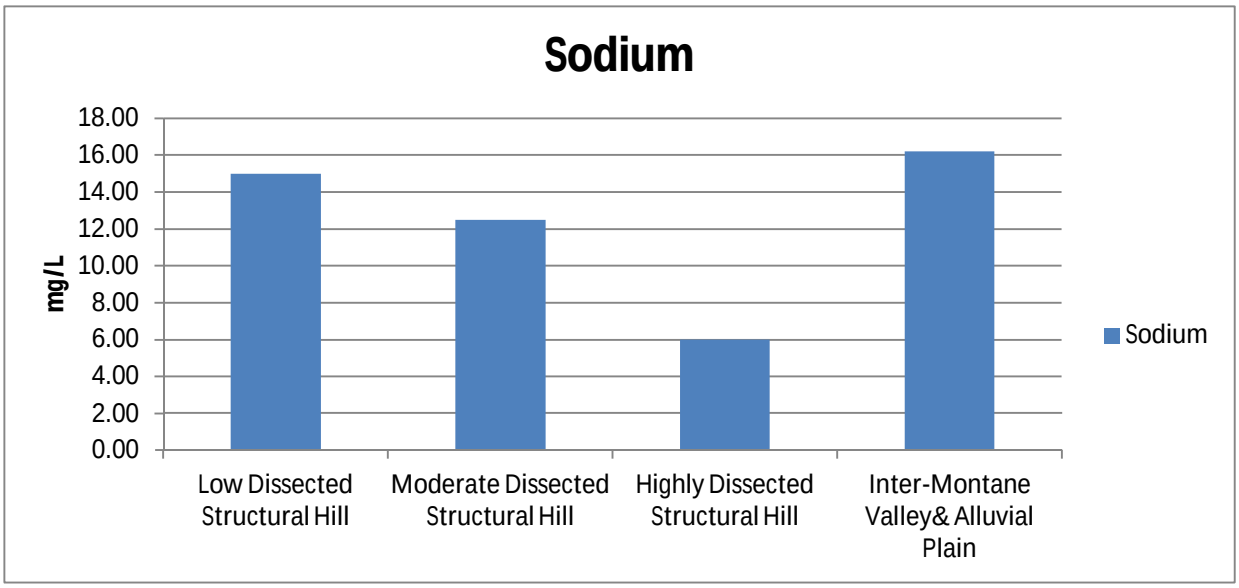


Figure 28 : Sodium in terms of geomorphic units

Pertaining to geomorphic units, sodium levels are highest in intermontane valleys and alluvial plains, and lowest in highly dissected structural hills.

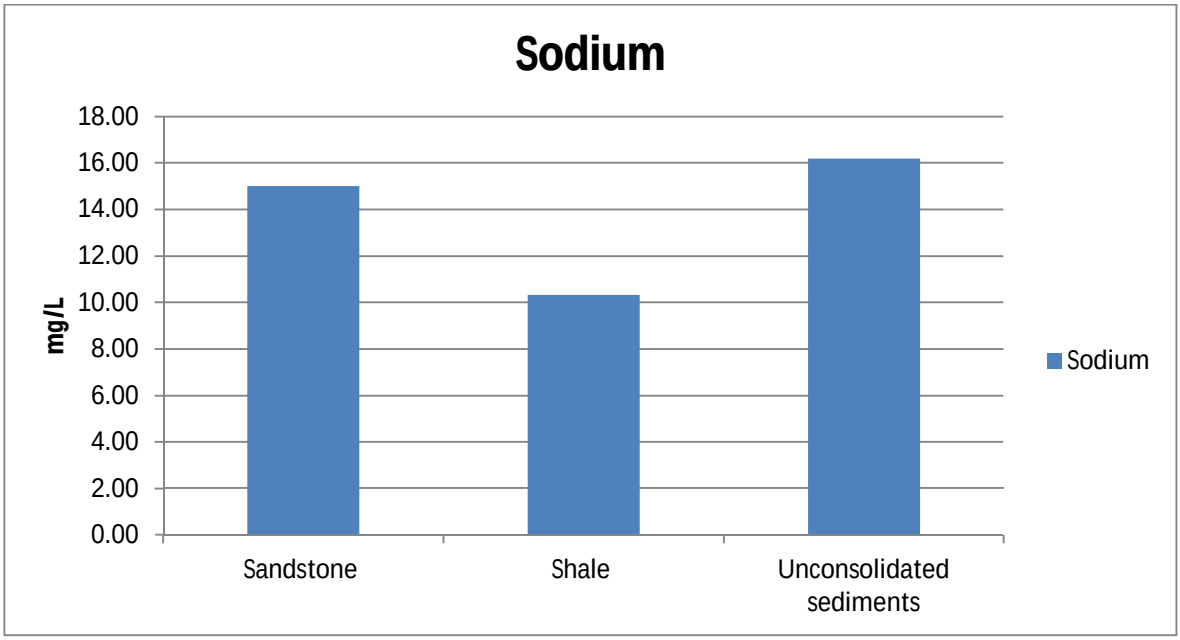
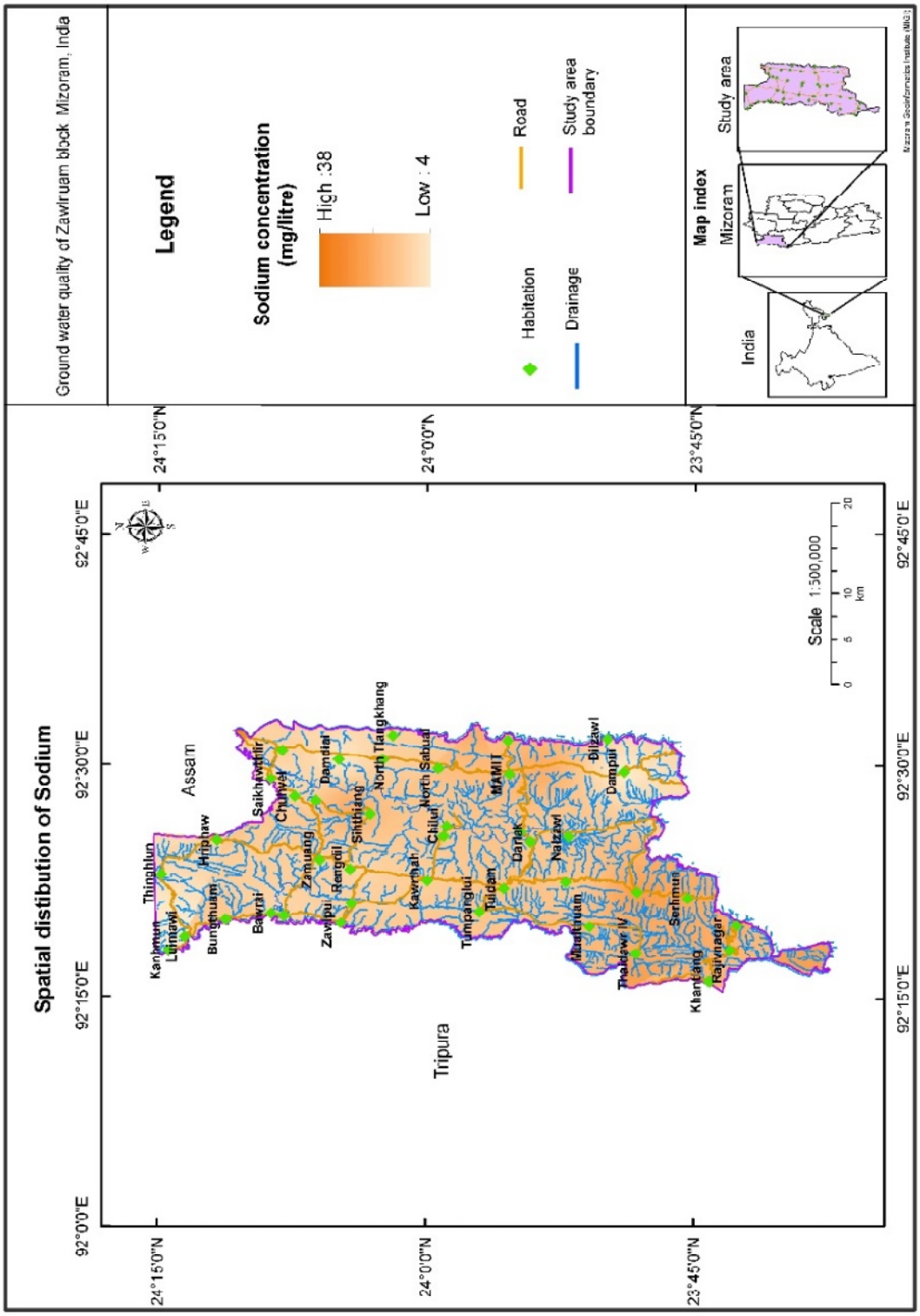


Figure 29: Sodium in terms of lithological units

Regarding lithology, sodium is highest in unconsolidated sediments and lowest in shale.



Map 45: Spatial distribution of Sodium

6.12. Potassium: The concentration of potassium in raw and treated water ranges between <1 and 8 mg/L

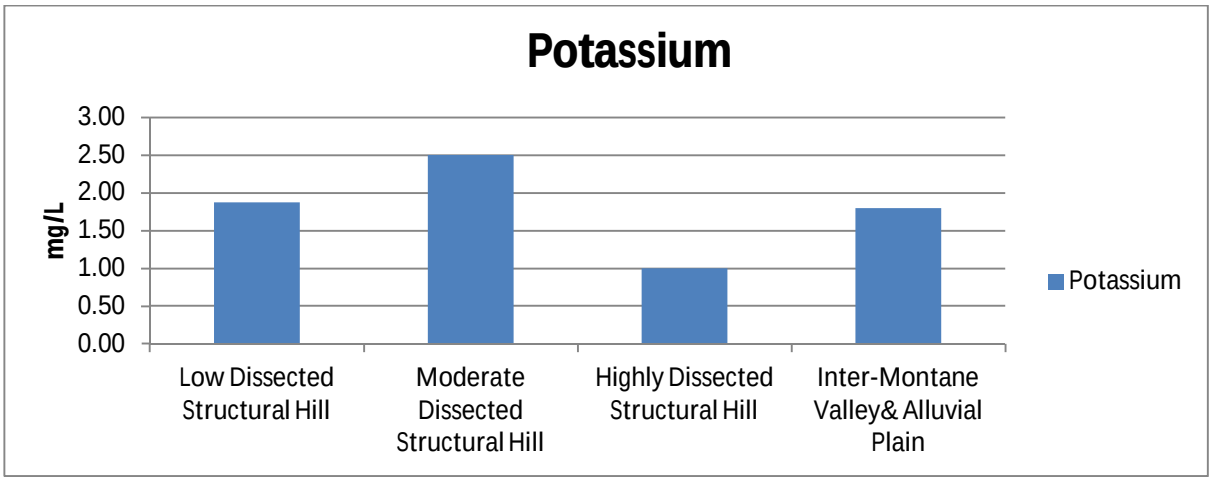


Figure 30 : Potassium in terms of geomorphic units

It is observed that the level of potassium is highest in the moderately dissected structural hill and lowest in the highly dissected structural hill in the study area.

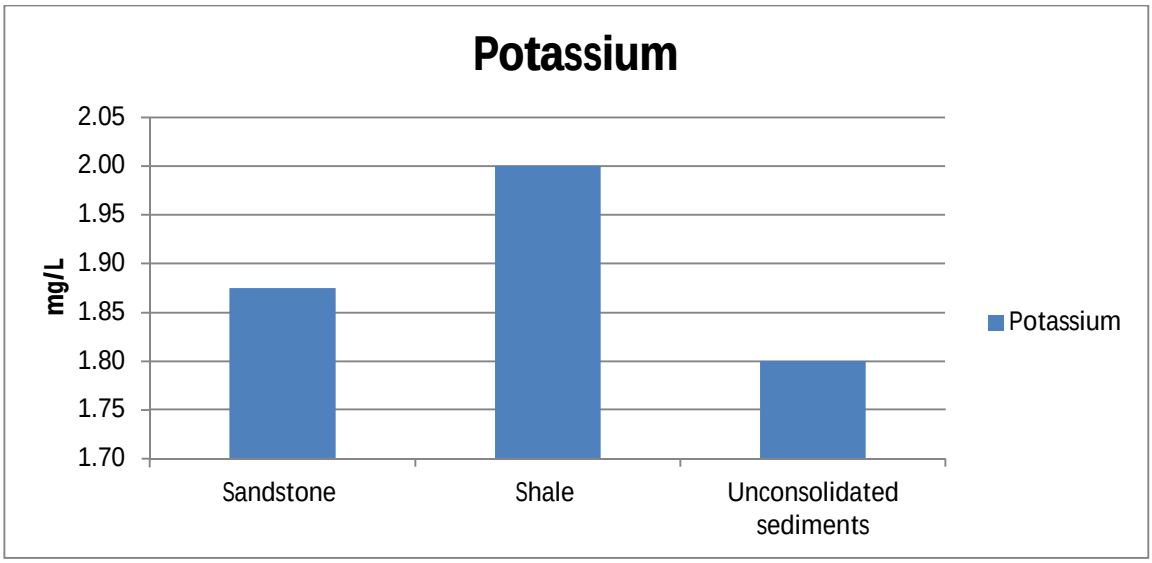
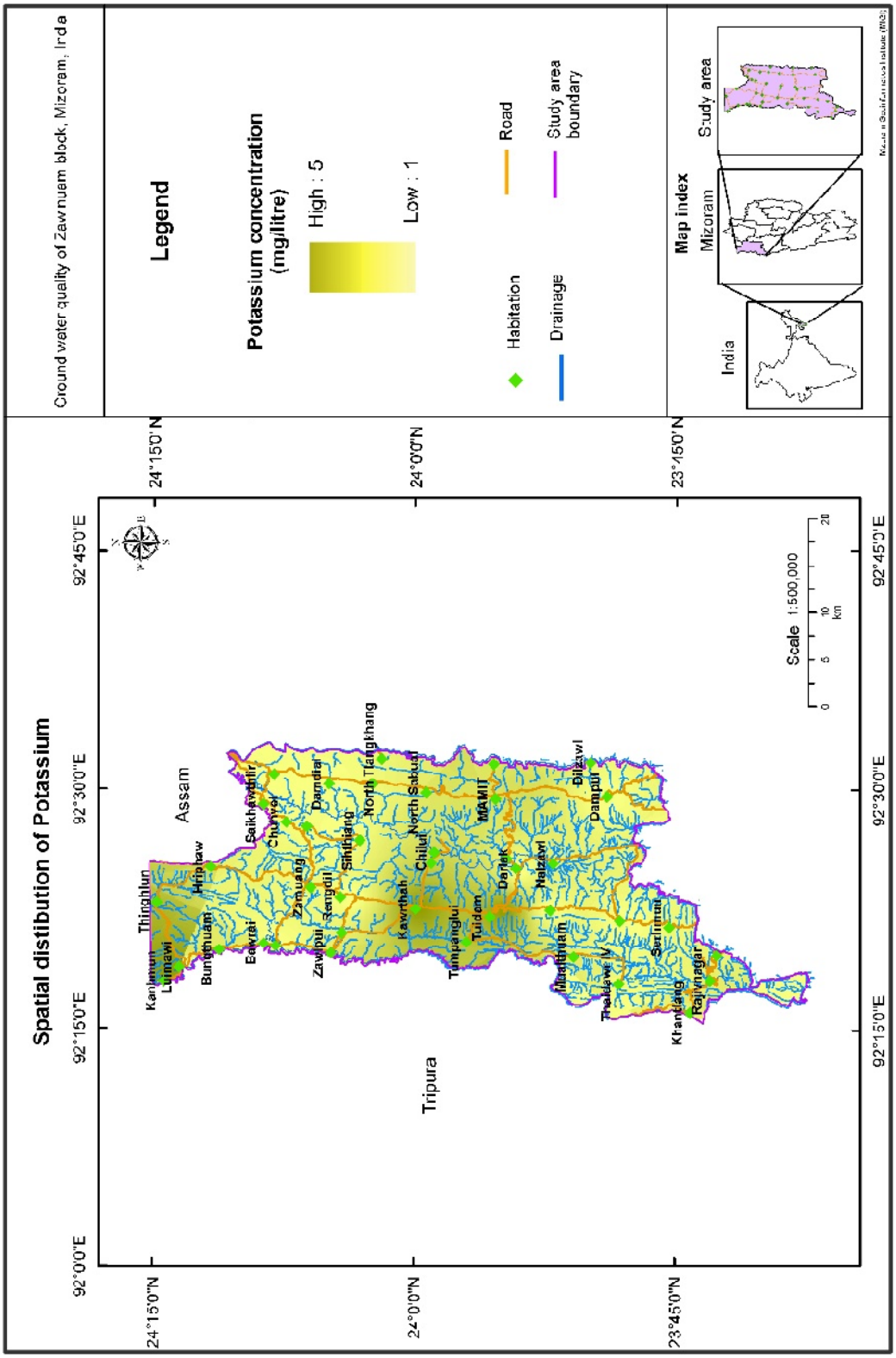


Figure 31 : Potassium in terms of lithoilogical units

For lithological point of view, potassium is highest in shale and lowest in unconsolidated sediments



Map 46: Spatial distribution of Potassium

6.13. Chloride: A suggested limit of chloride concentration is 250 mg/L.

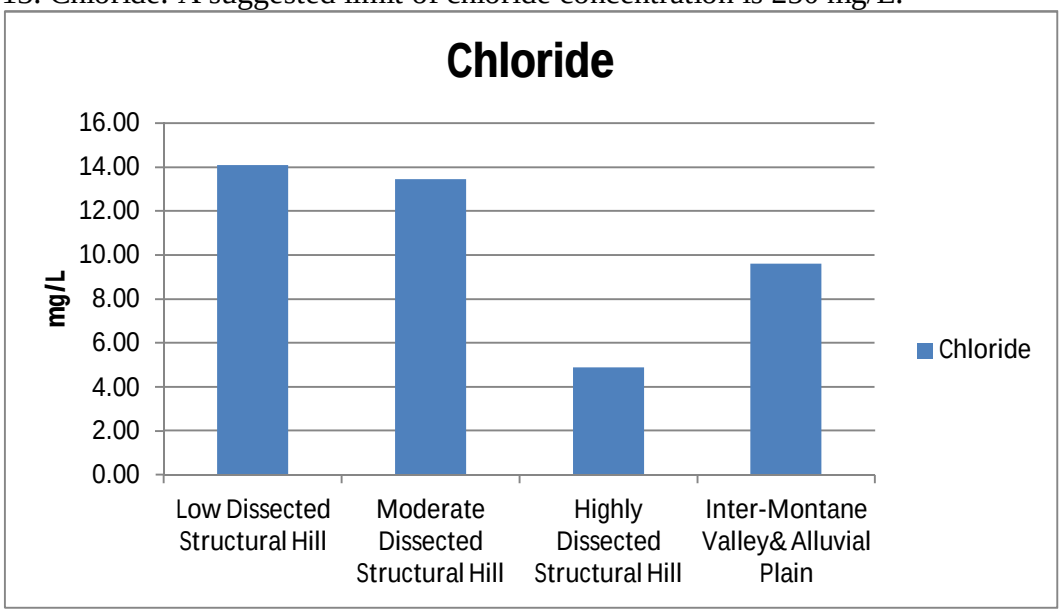


Figure 32 : Chloride in terms of geomorphic units

With regard to geomorphic units, chloride levels are highest in low dissected structural hills and lowest in highly dissected structural hills.

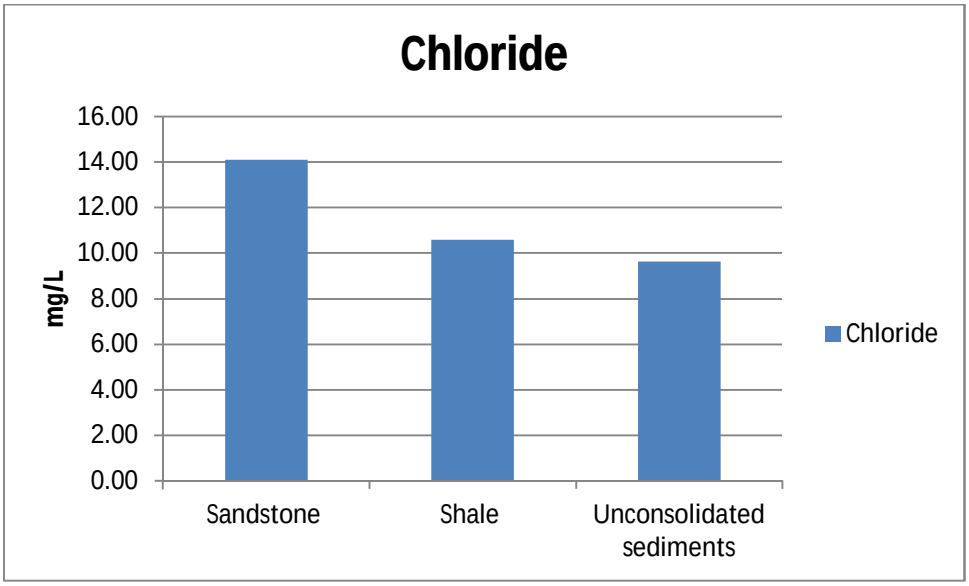
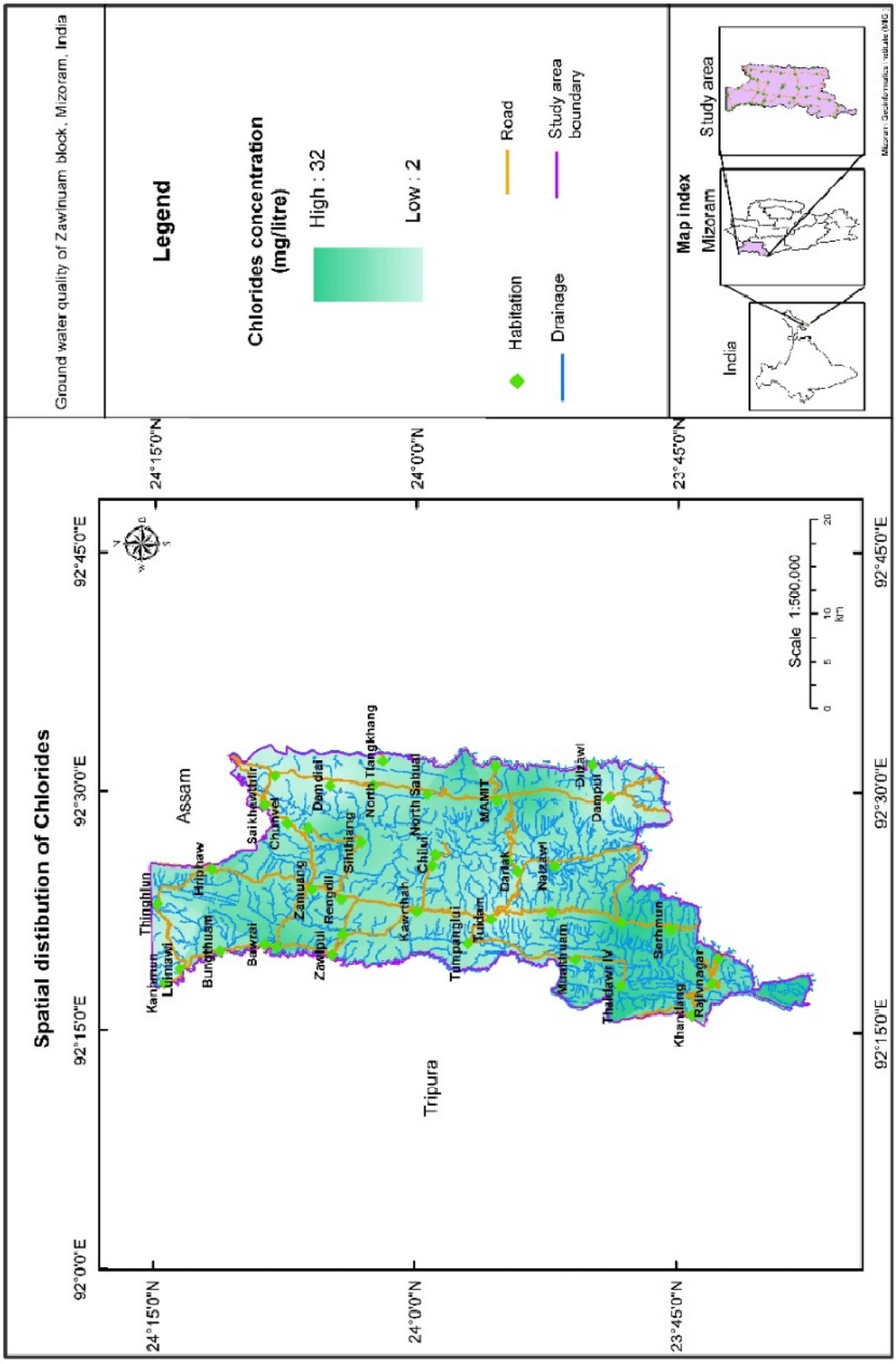


Figure 33: Chloride in terms of lithological units

In terms of lithology, the highest chloride levels are found in sandstone, while the lowest levels are found in unconsolidated sediments.



Map 47: Spatial distribution of Chloride

6.14. Nitrate: The chemical composition of rocks containing nitrates can affect the levels of nitrates in groundwater. Human activities like using fertilizers and disposing of household waste can also lead to nitrate pollution in groundwater. According to BIS IS 10500: 2012, nitrate concentrations are categorized into three ranges: <45 mg/L, 45-100 mg/L, and >100 mg/L. As per the BIS classification, the groundwater in different parts of the research area falls well within the Desirable class.

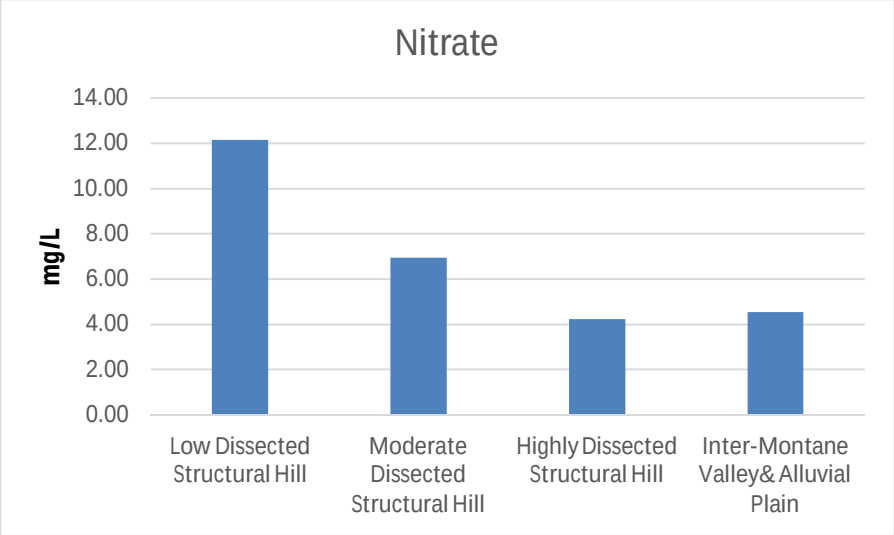


Figure 34 : Nitrate in terms of geomorphic units

In terms of geomorphic units, nitrate levels are highest in low dissected structural hills and lowest in highly dissected structural hills.

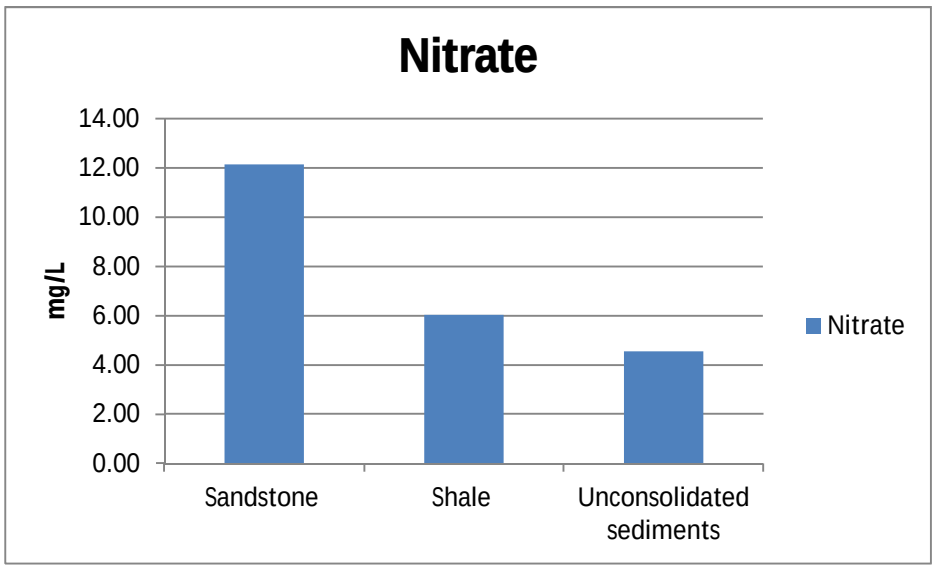
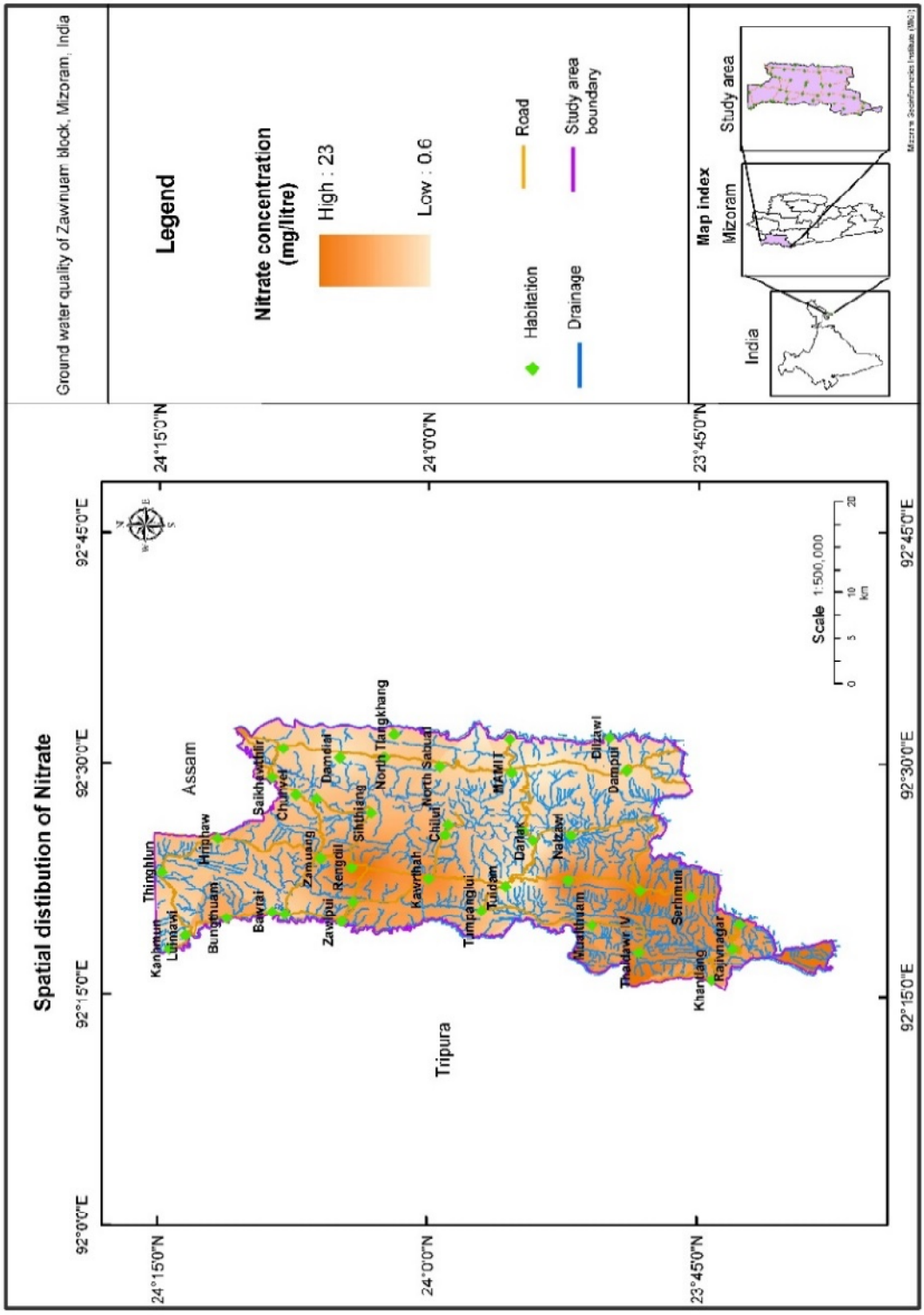


Figure 35 : Nitrate in terms of lithological units

Regarding lithology, the nitrate concentration is highest in sandstone and lowest in unconsolidated sediments.



Map 48: Spatial distribution of Nitrate

6.15. Sulphate: According to BIS IS 10500: 2012, sulphate is categorized into three groups: desirable level <200 mg/L, permissible level 200-400 mg/L, and non-potable >400 mg/L.

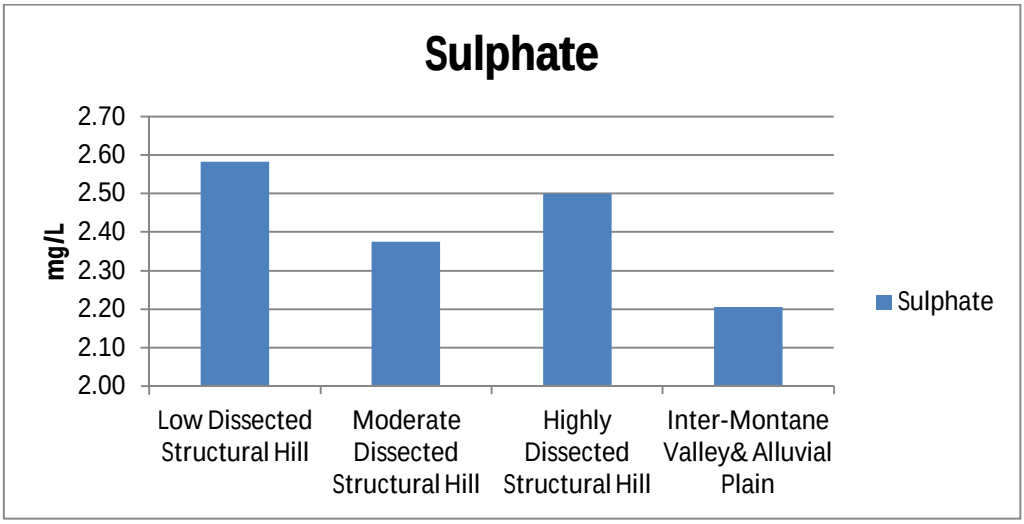


Figure 36 : Sulphate in terms of geomorphic units

From a geomorphological perspective, the highest sulphate levels are found in low-dissected structural hills, while the lowest levels are found in intermontane valleys and alluvial plains.

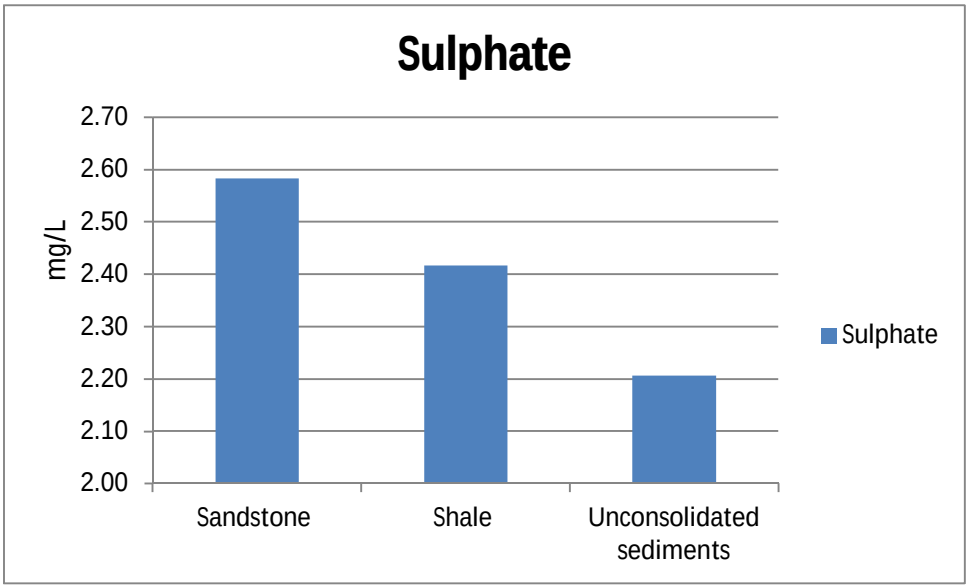
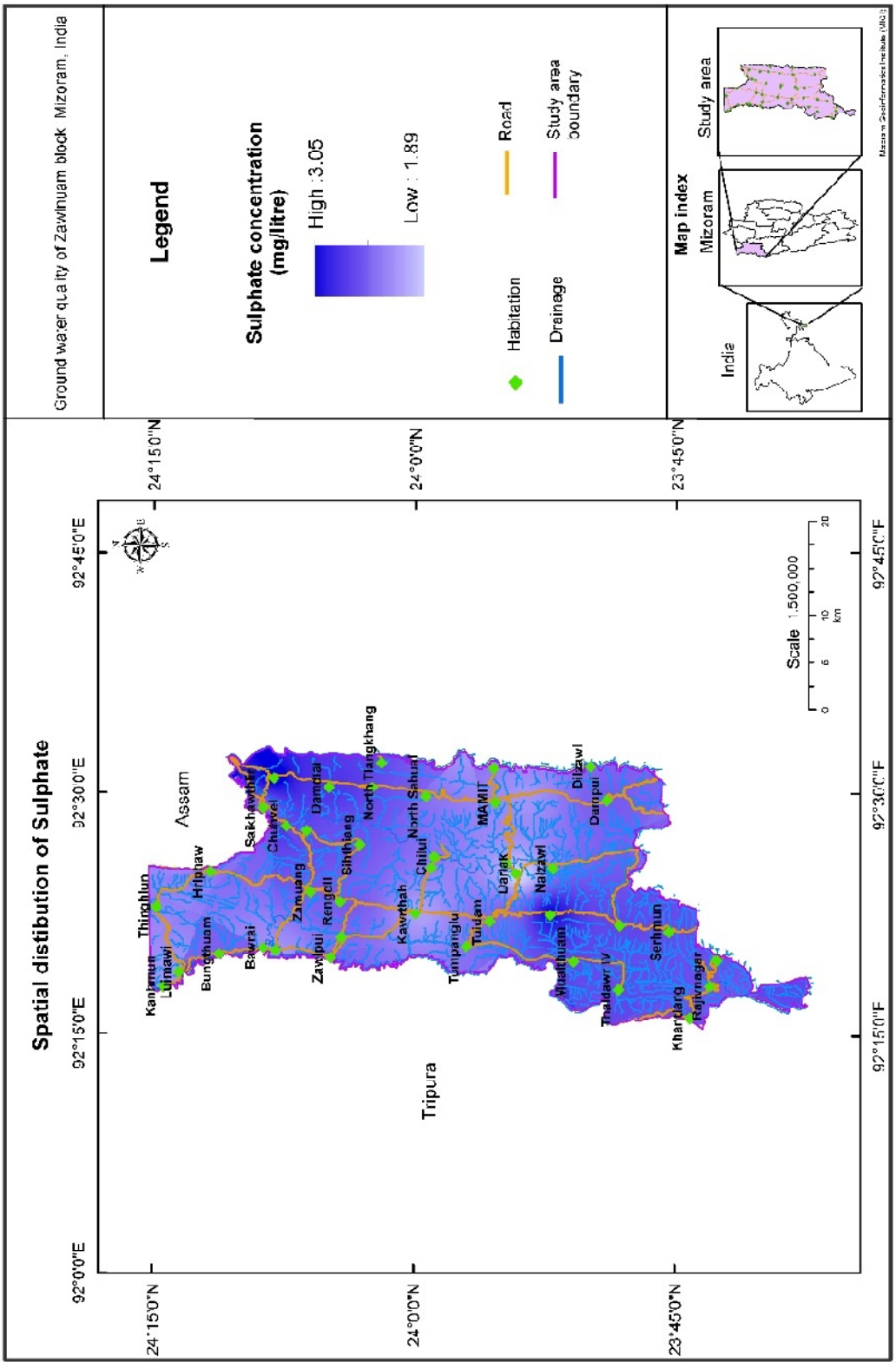


Figure 37 : Sulphate in terms of lithological units

Concerning lithology, the highest concentration of sulphate is found in sandstone, while the lowest concentration is found in unconsolidated sediments.



Map 49: Spatial distribution of Sulphate

6.16. E. Coli: The most common species in the faecal coliform group is Escherichia coli, or E. coli. Unlike other common bacterial groups that make up coliforms, E. coli is typically not found growing and multiplying in the environment. Therefore, E. coli is considered to be the coliform bacteria species that most accurately indicates faecal contamination and the potential presence of pathogens. Coliforms have contaminated a small number of water sources in the research area.

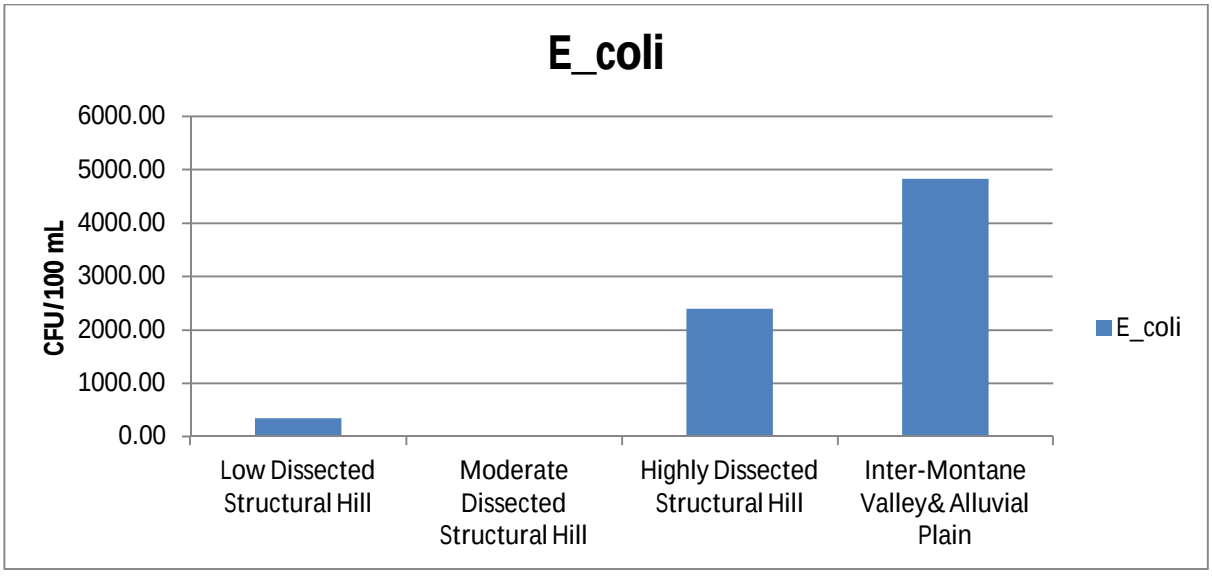


Figure 38 : E. Coli in terms of geomorphic units

In terms of geomorphic units, E. coli levels are highest in intermontane valleys and alluvial plains and lowest in moderately dissected structural hills.

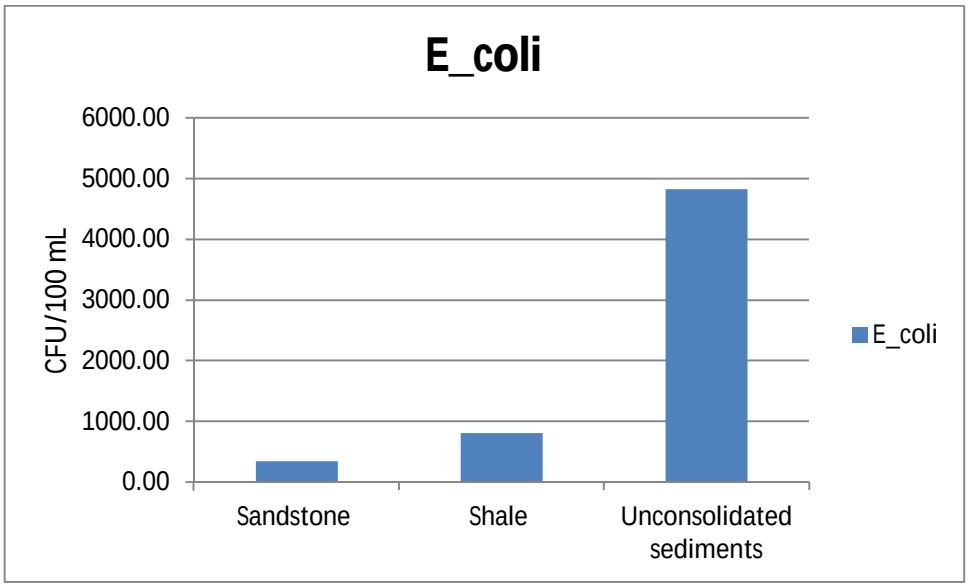


Figure 39 : E. Coli in terms of lithological units

With regards to lithology, E. coli is highest in unconsolidated sediments and lowest in sandstone.

6.17. Chromium: According to BIS IS 10500: 2012, chromium is divided into desirable <0.05 mg/L and non- potable >0.05 mg/L.

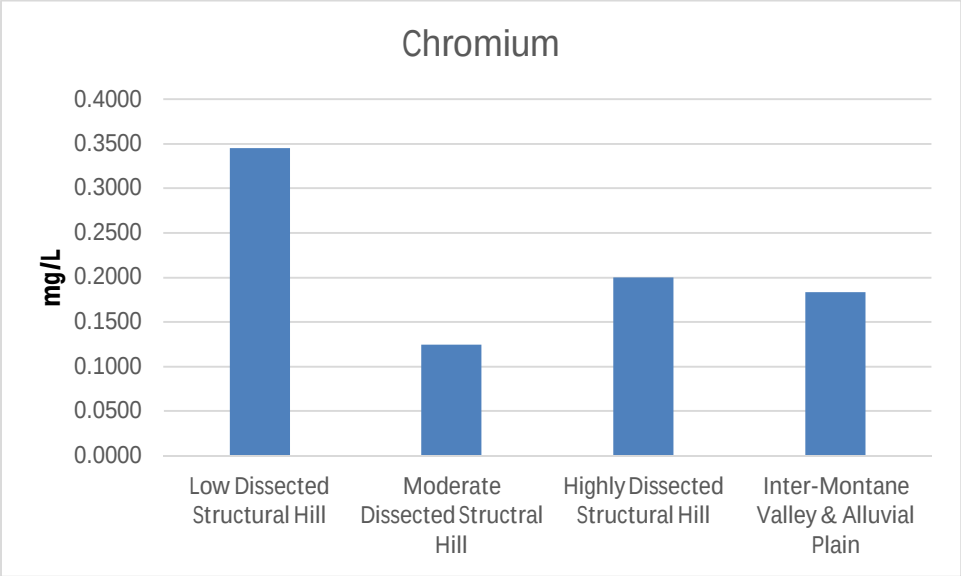


Figure 40 : Chromium in terms of geomorphic units

Concerning geomorphic units, chromium levels are highest in low dissected structural hills and lowest in moderately dissected structural hills.

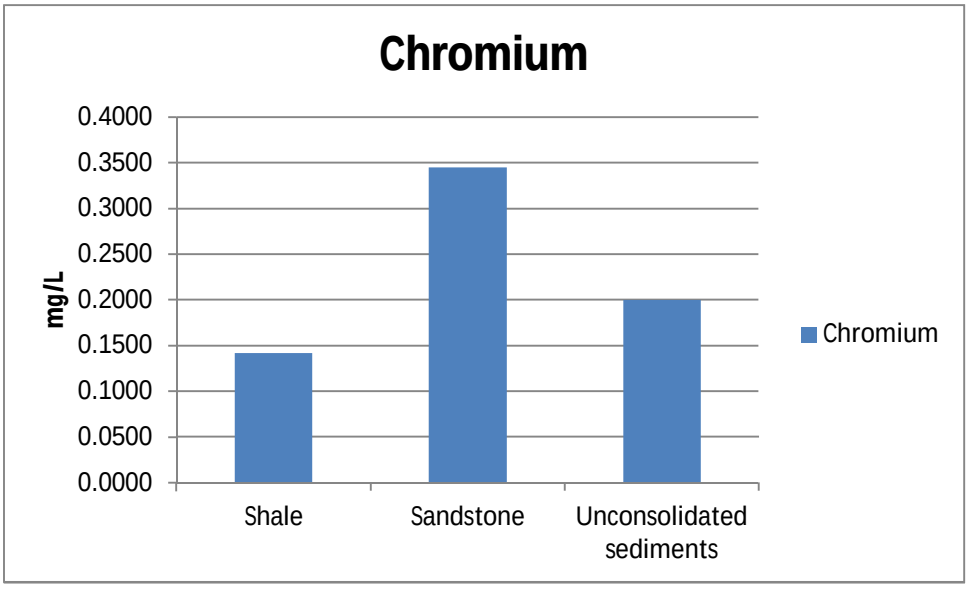
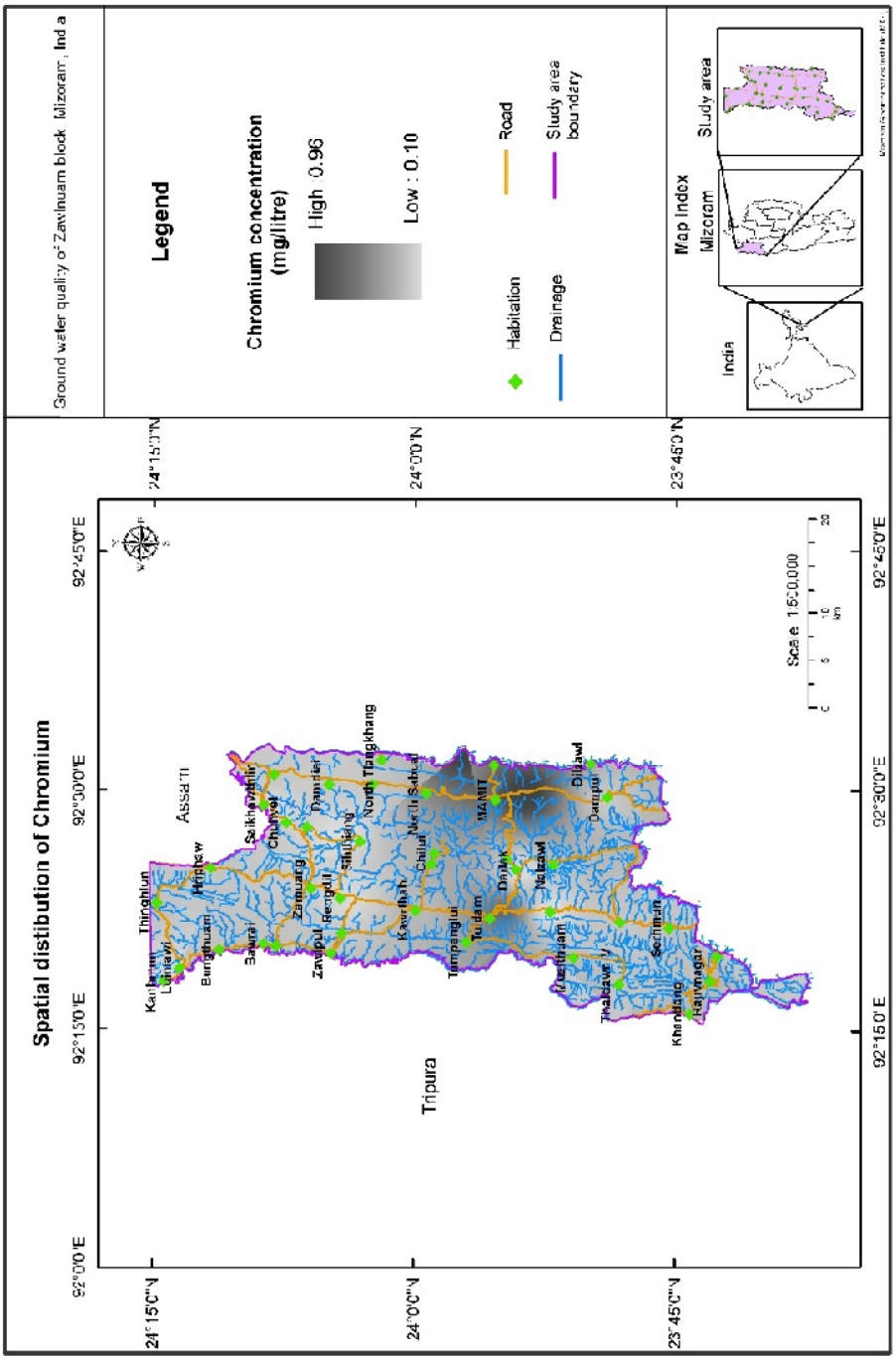


Figure 41 : Chromium in terms of lithological units

With regards to lithology, chromium is highest in sandstone and lowest in shale



Map 50: Spatial distribution of Chromium

6.18. Arsenic: According to BIS IS 10500: 2012, arsenic is divided into desirable <0.05 mg/L and non- potable >0.05 mg/L. All the samples fall as potable.

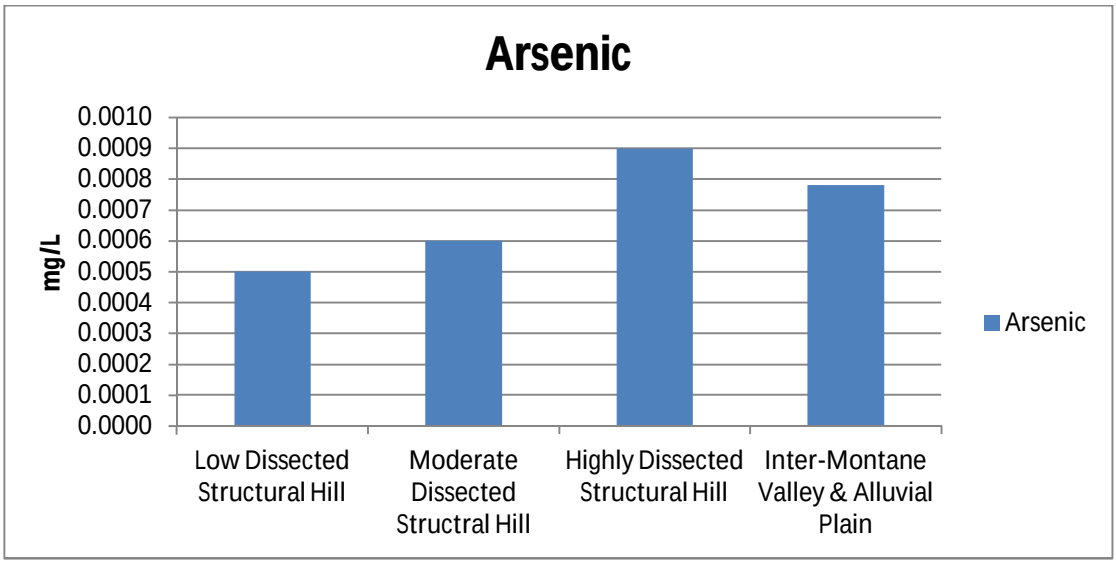


Figure 42 : Arsenic in terms of geomorphic units

Pertaining to geomorphic units, arsenic is highest in Highly dissected structural hill and lowest in low dissected structural hill.

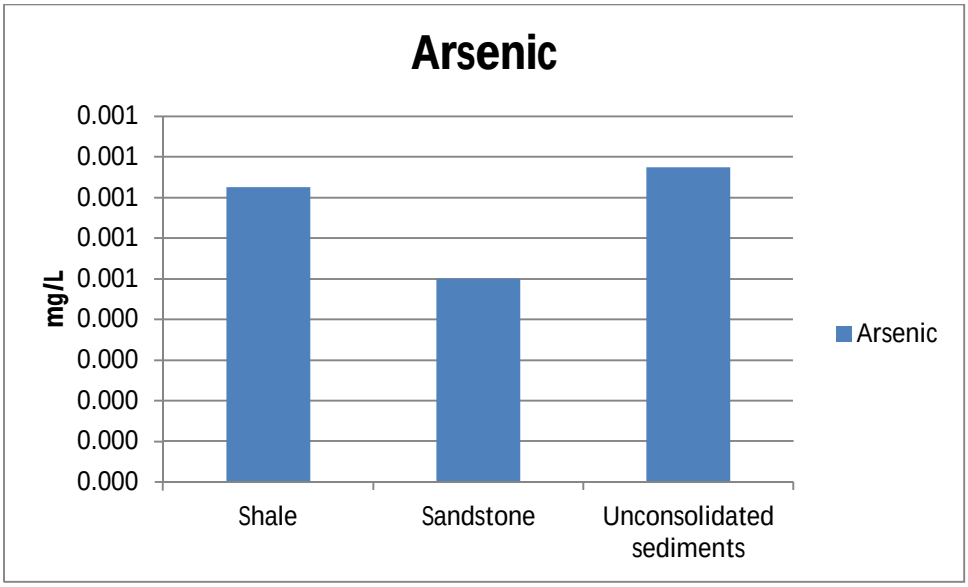
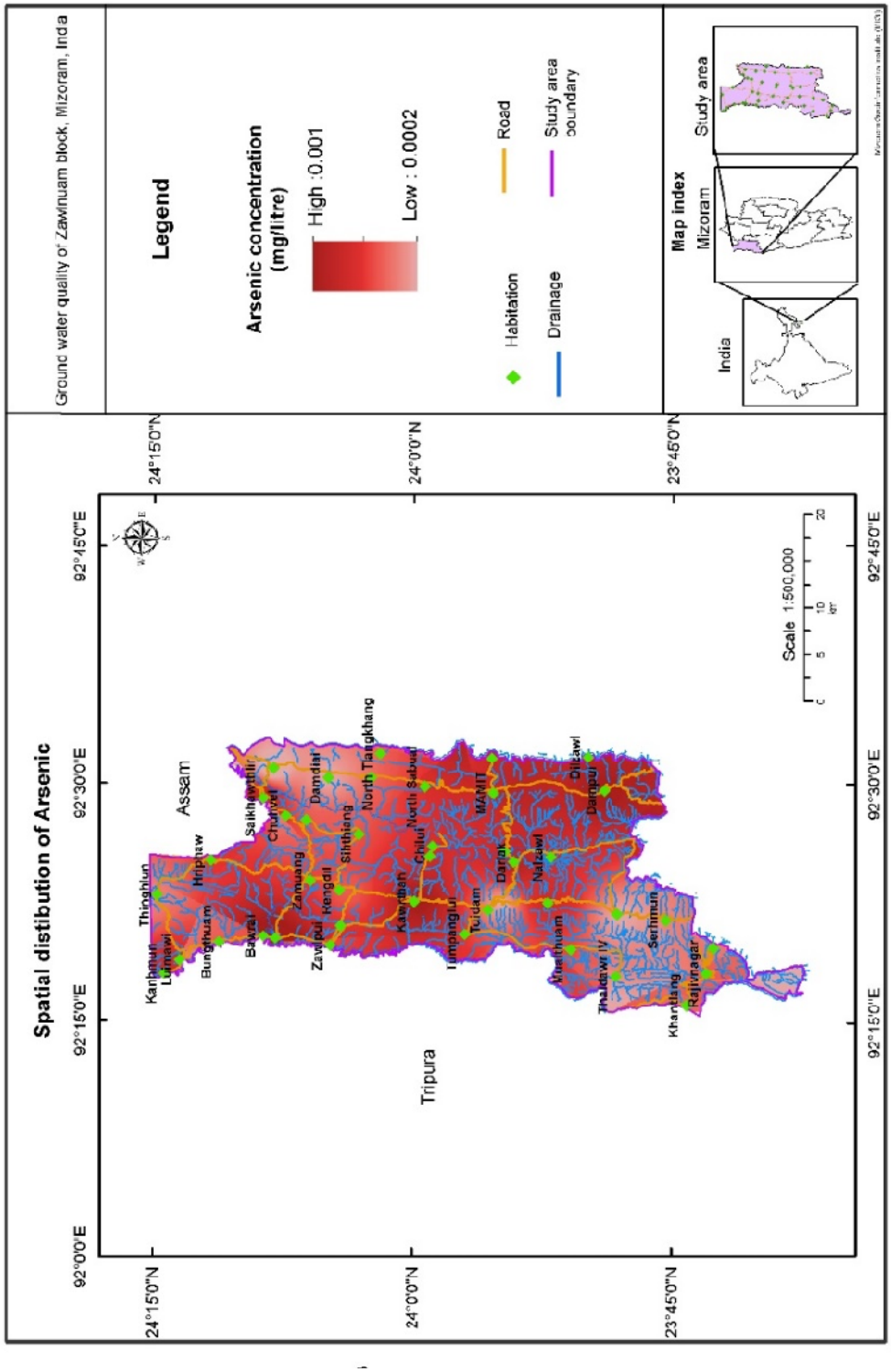


Figure 43 : Arsenic in terms of lithological units

Considering lithology, arsenic is highest in unconsolidated sediments and lowest in sandstone.



Map 51: Spatial distribution of Arsenic

6.19. Cadmium: According to BIS IS 10500: 2012, cadmium is divided into desirable <0.01 mg/L and non- potable >0.01 mg/L. All the samples fall as potable.

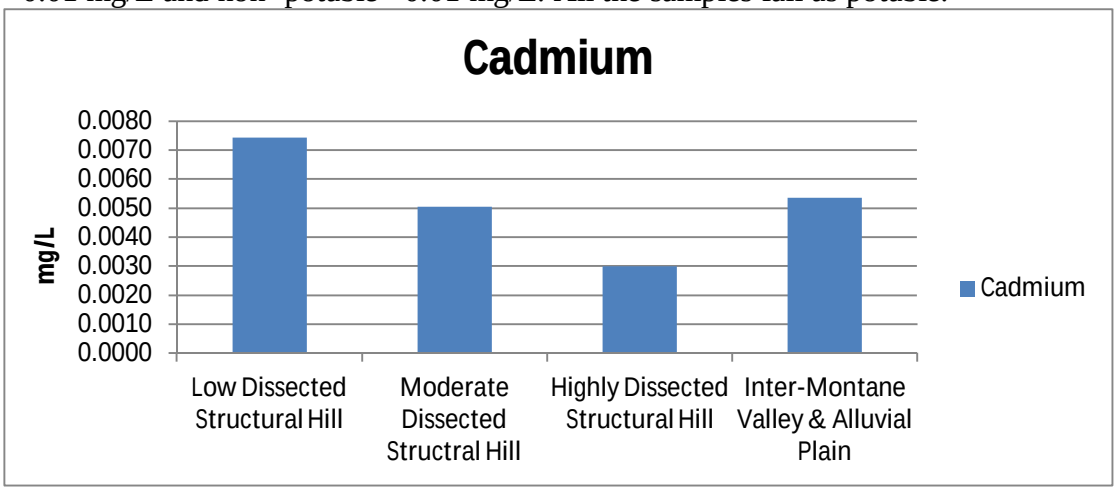


Figure 44: Cadmium in terms of geomorphic units

In terms of geomorphic units, cadmium is highest in low dissected structural hill and lowest in highly dissected structural hill.

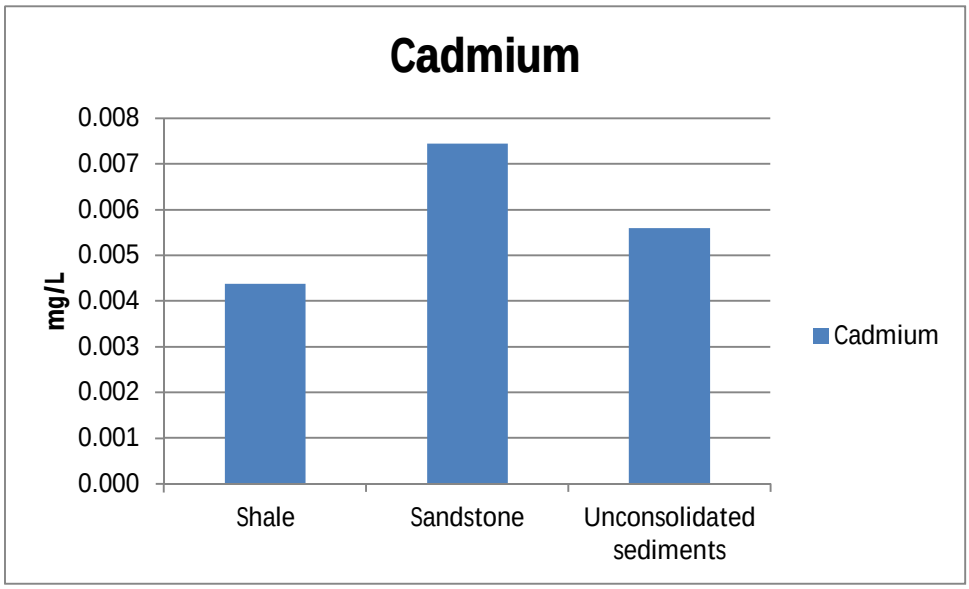
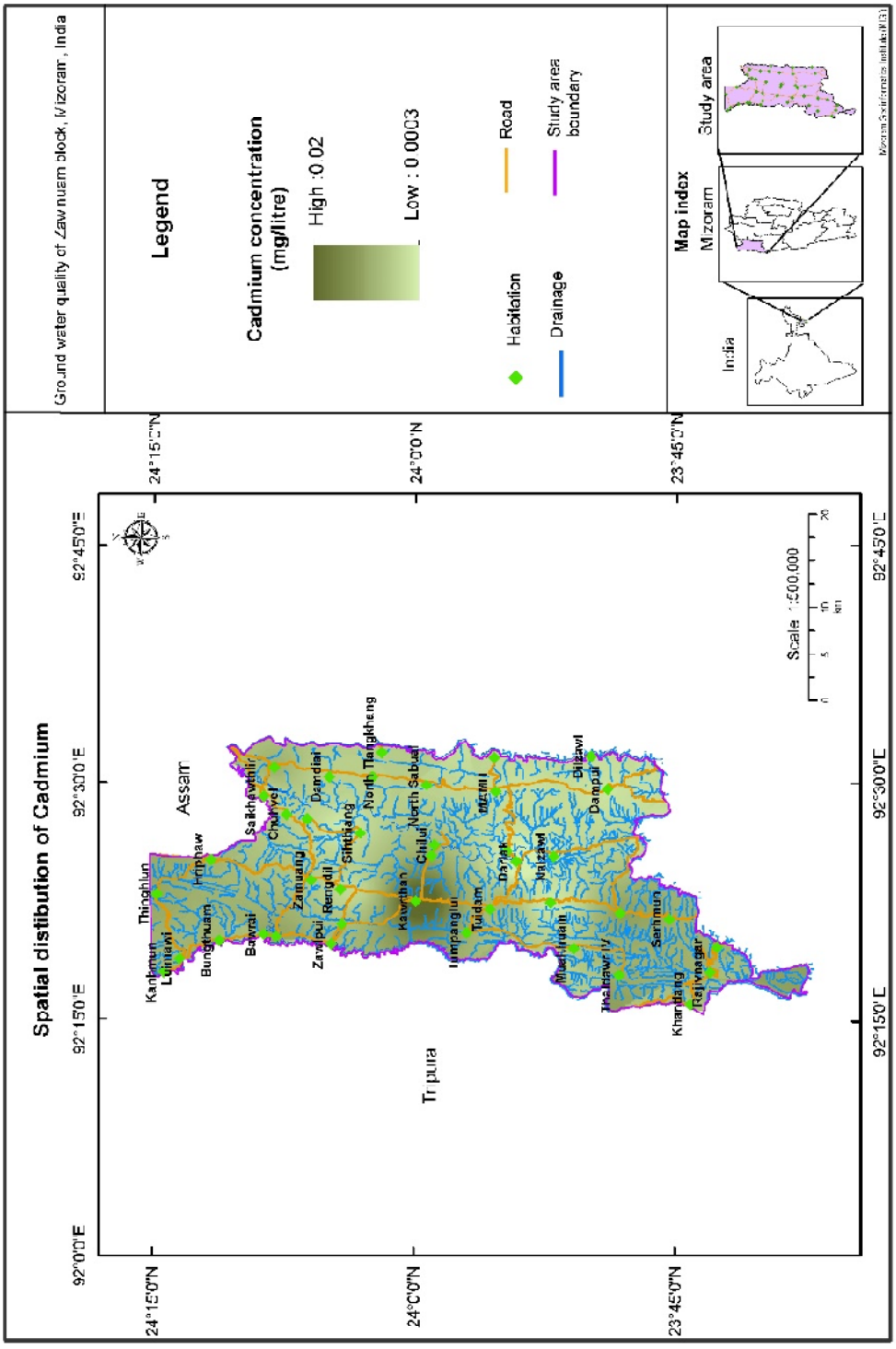


Figure 45: Cadmium in terms of lithological units

With regards to lithology, cadmium is highest in sandstone and lowest in shale.



Map 52: Spatial distribution of Cadmium

6.20. Nickel: According to BIS IS 10500: 2012, nickel permissible limit is 0.02 mg/L.

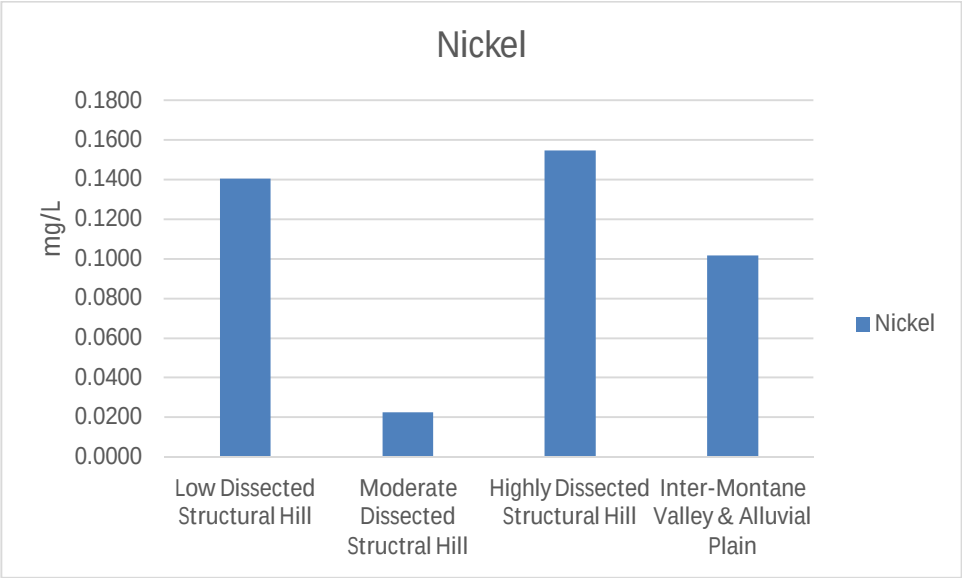


Figure 46: Nickel in terms of geomorphic units

For geomorphic unit, nickel is highest in highly dissected structural hill and lowest in moderate dissected structural hill.

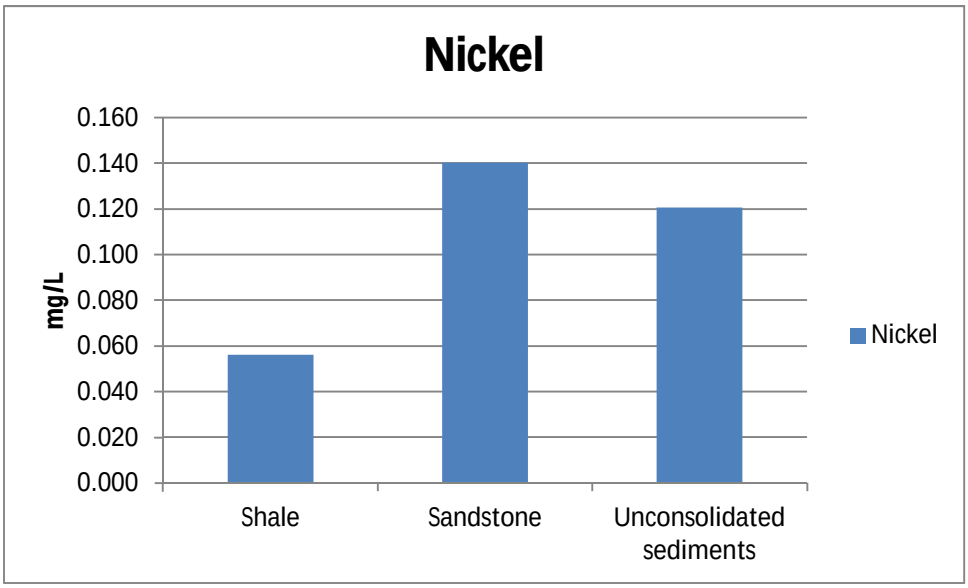
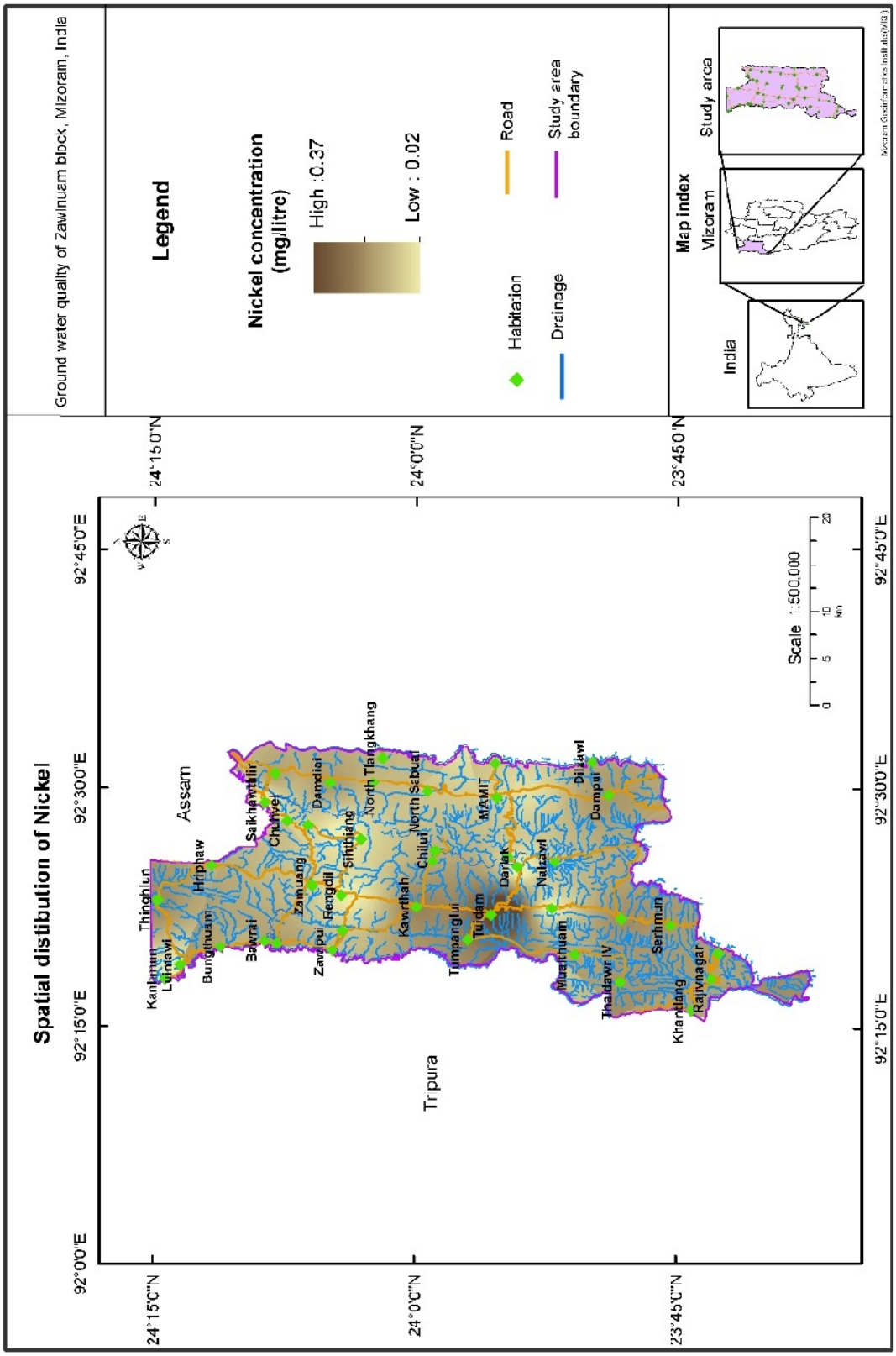


Figure 47: Nickel in terms of lithological units

With regards to lithology, nickel is highest in sandstone and lowest in shale.



Map 53: Spatial distribution of Nickel

6.21. Manganese: In accordance with BIS IS 10500: 2012, manganese is classified into three ranges: 0–0.1 mg/L, 0.1–0.3 mg/L, and >0.3 mg/L. Manganese occurs naturally in soils and can erode into surface and ground water sources. However, in some areas, human activities also contribute significantly to manganese pollution in water.

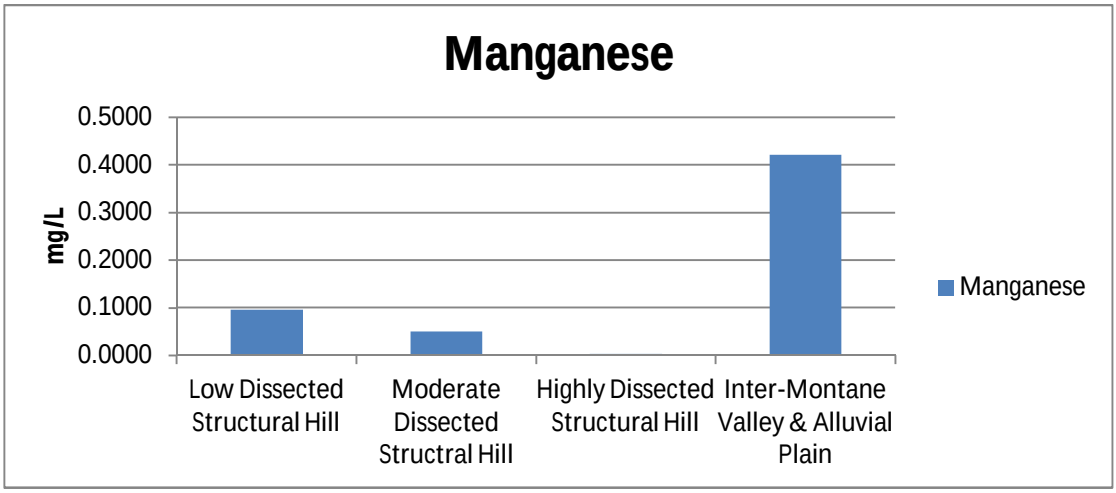


Figure 48: Manganese in terms of geomorphic units

Considering geomorphic unit, manganese is highest in inter-montane valley and alluvial plain and lowest in highly dissected structural hill.

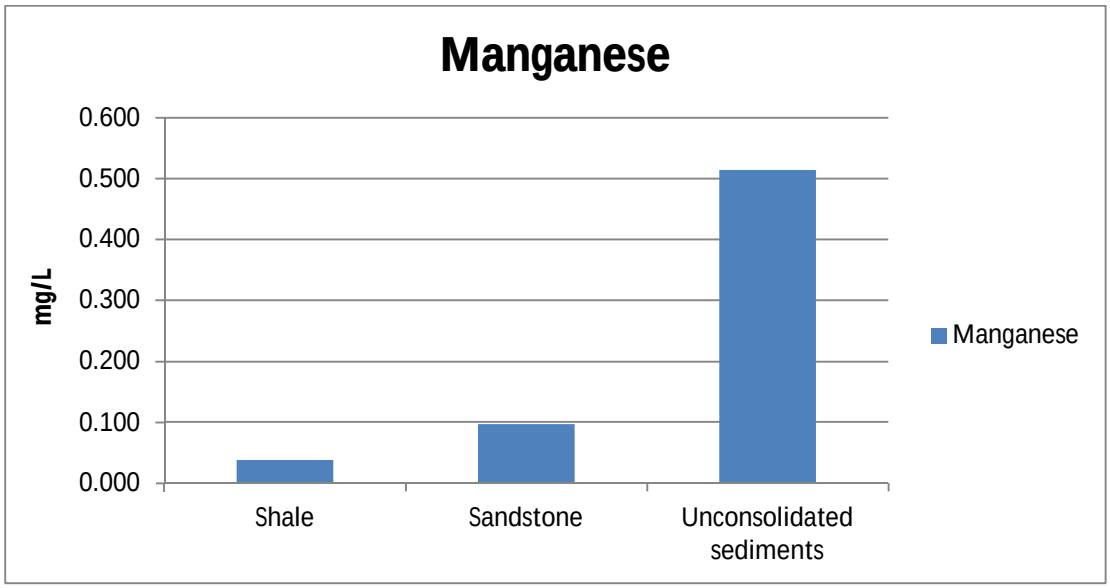
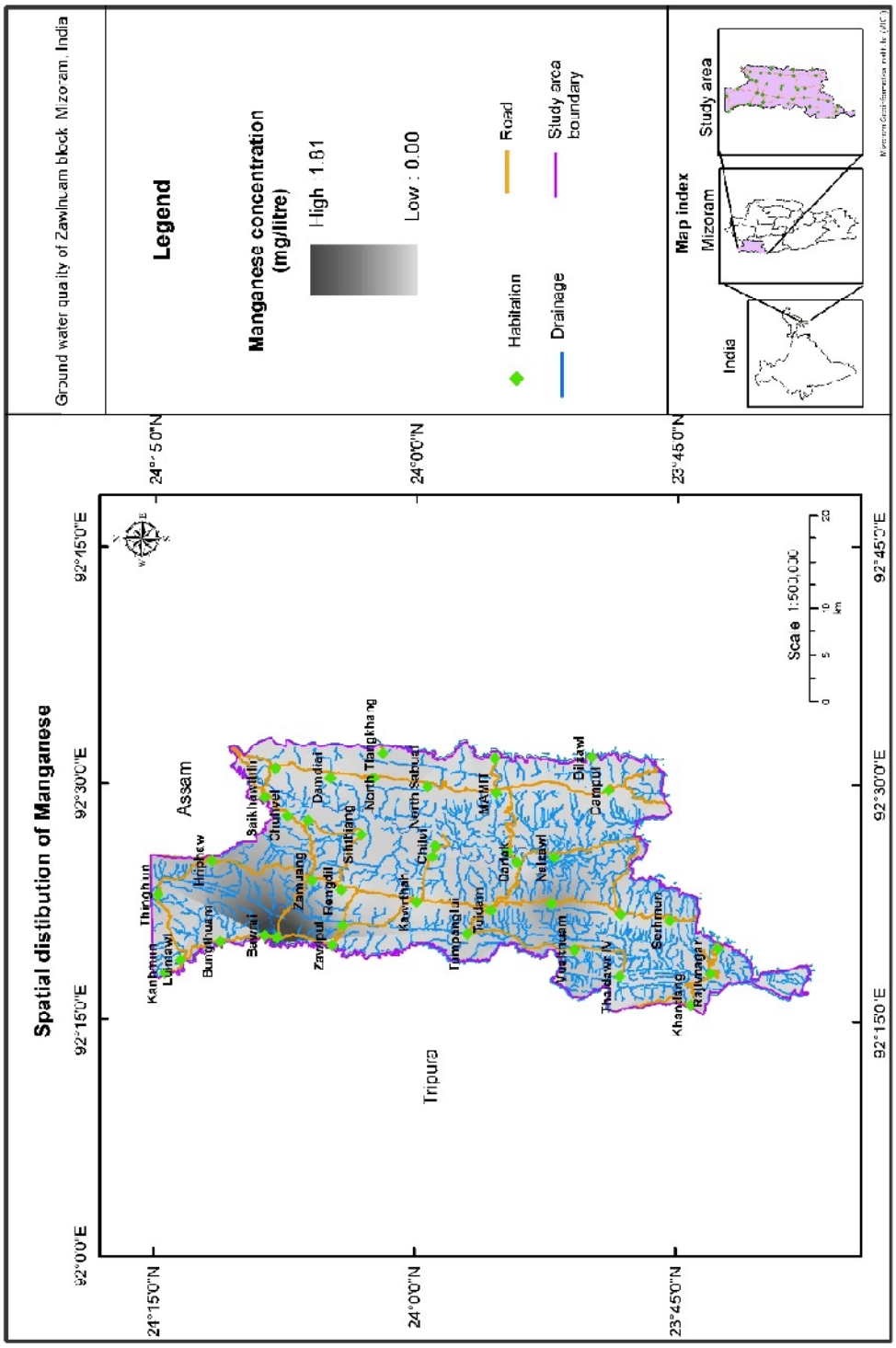


Figure 49: Manganese in terms of lithological units

Regarding lithology, manganese is highest in unconsolidated sediments and lowest in shale.



Map 54: Spatial distribution of Manganese

6.22. Mercury: According to BIS IS 10500: 2012, mercury is classified as desirable at <0.001 mg/L and non-potable at >0.001 mg/L.

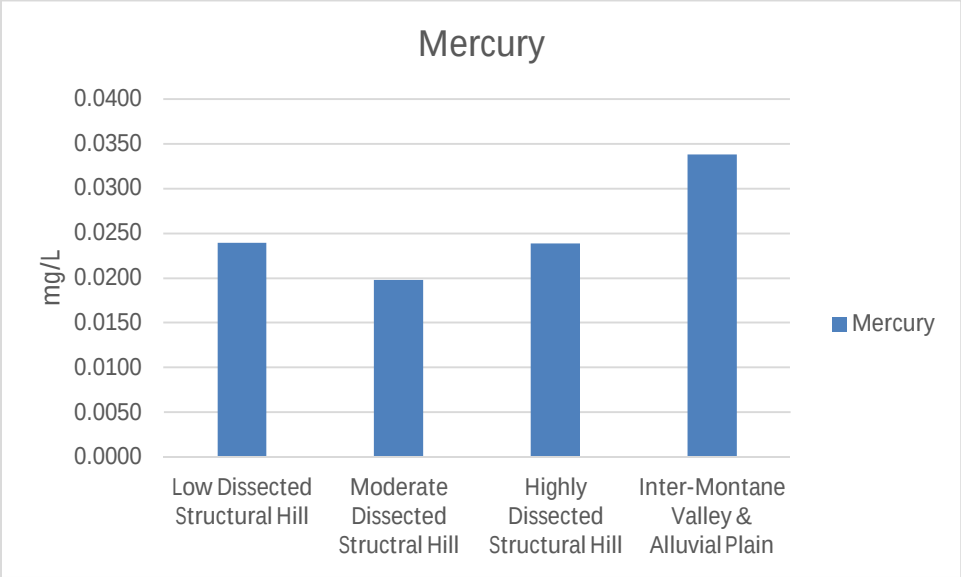


Figure 50: Mercury in terms of geomorphic units

In terms of geomorphic unit, mercury is highest in inter- montane valley and alluvial plain and lowest in moderate dissected structural hill.

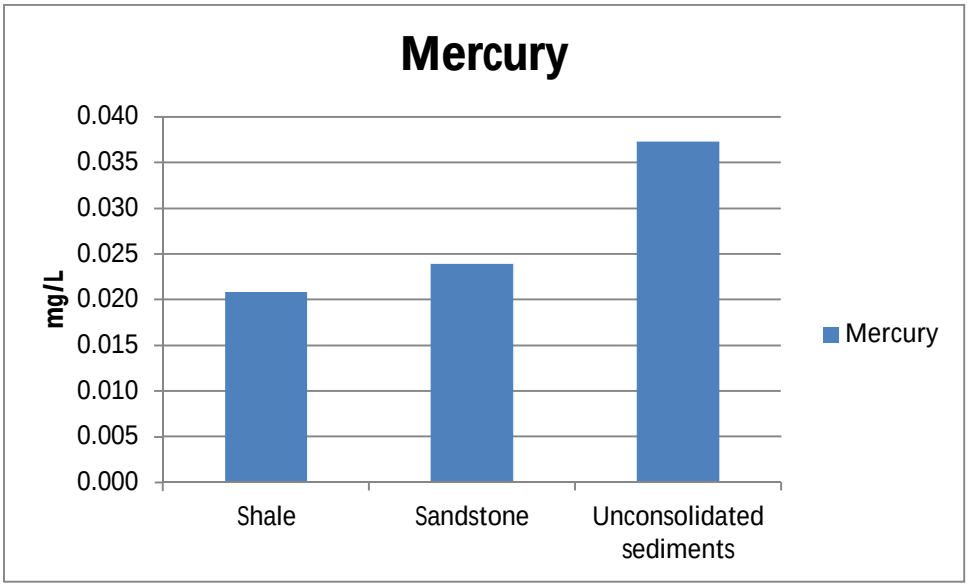
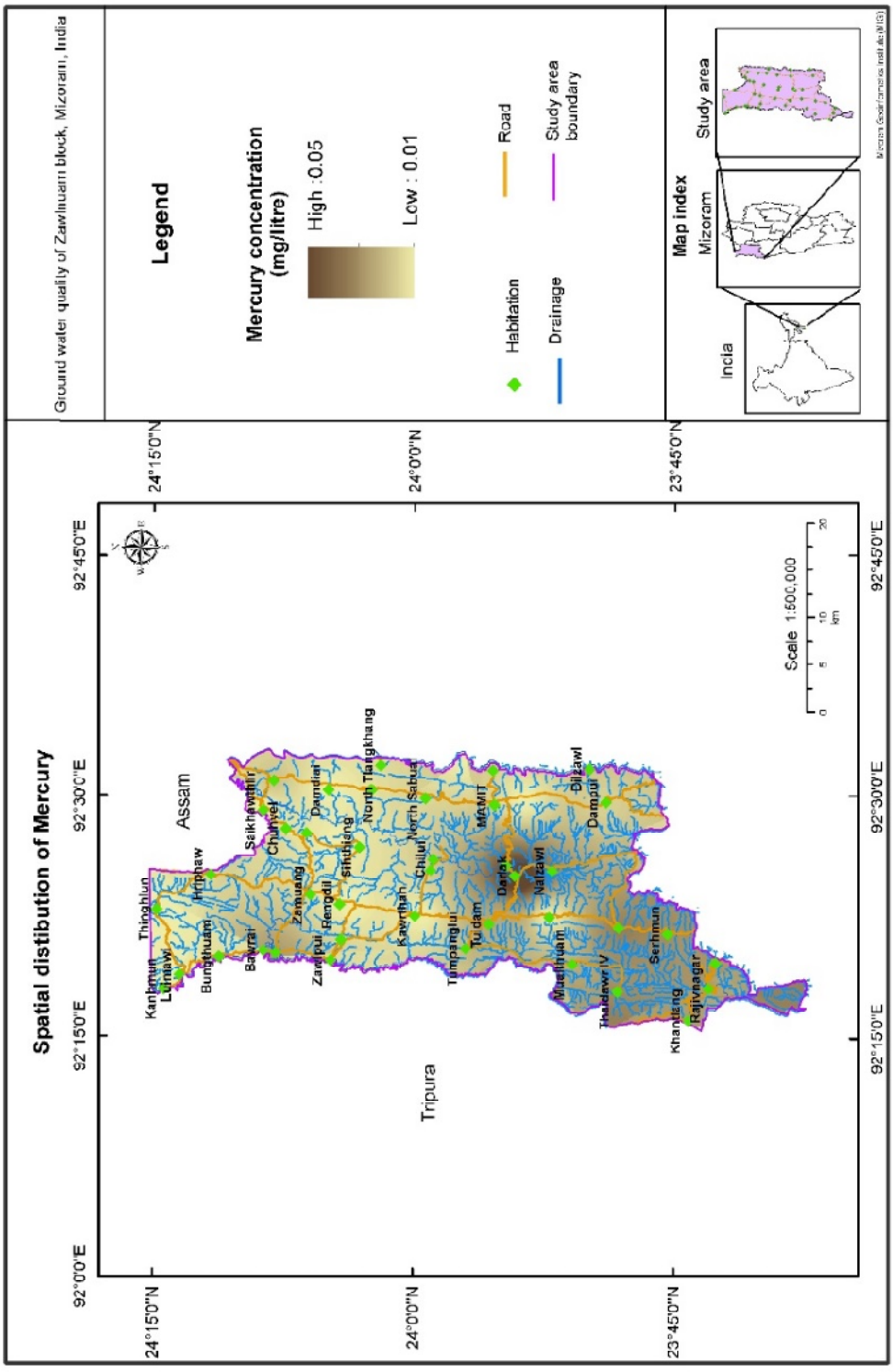


Figure 51: Mercury in terms of lithological units

With regards to lithology, mercury is highest in unconsolidated sediments and lowest in shale.



Map 55: Spatial distribution of Mercury

6.23. Zinc: According to BIS IS 10500: 2012, arsenic is categorized as follows: desirable <5 mg/L, permissible limit 5-15 mg/L, and non-potable >15 mg/L. All the samples are within the potable range.

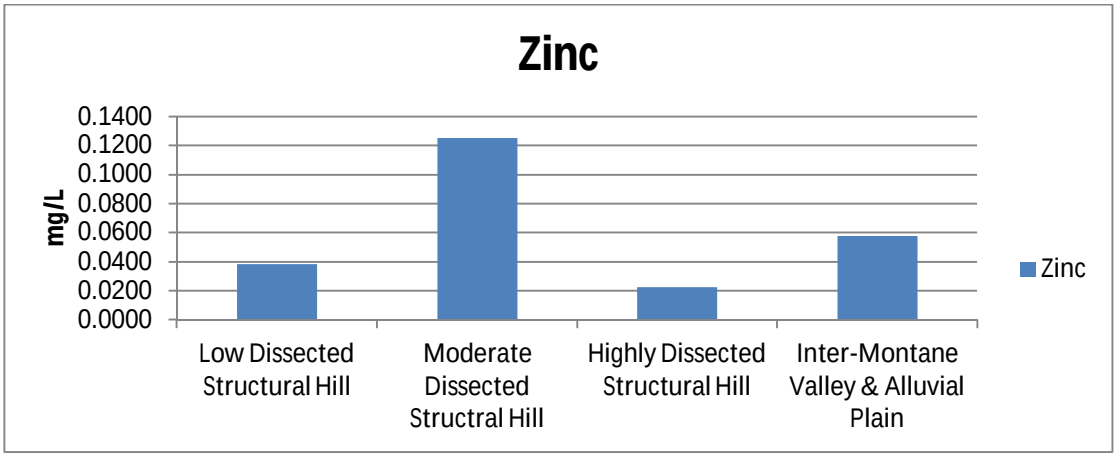


Figure 52: Zinc in terms of geomorphic units

Considering geomorphic unit, zinc is highest in moderate dissected structural hill and lowest in highly dissected structural hill.

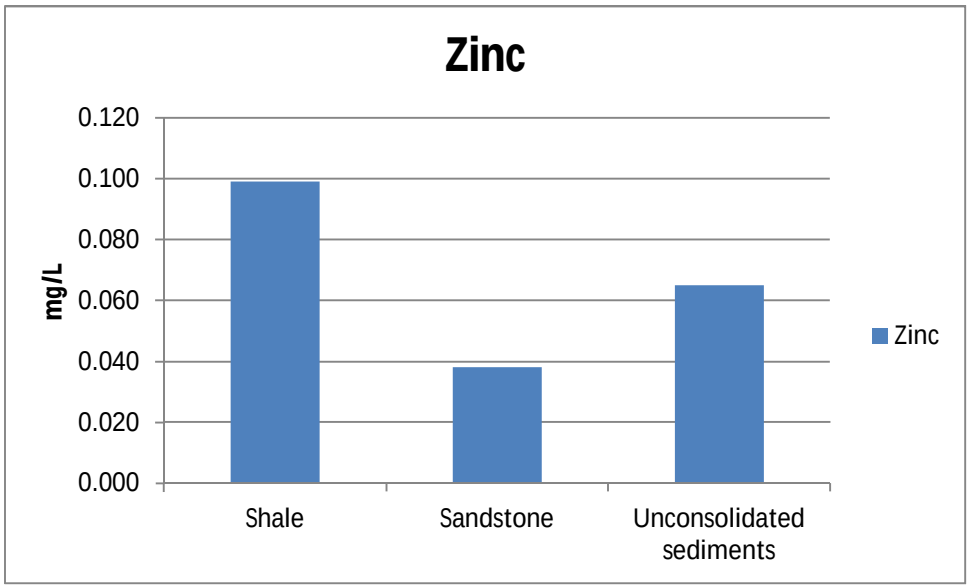
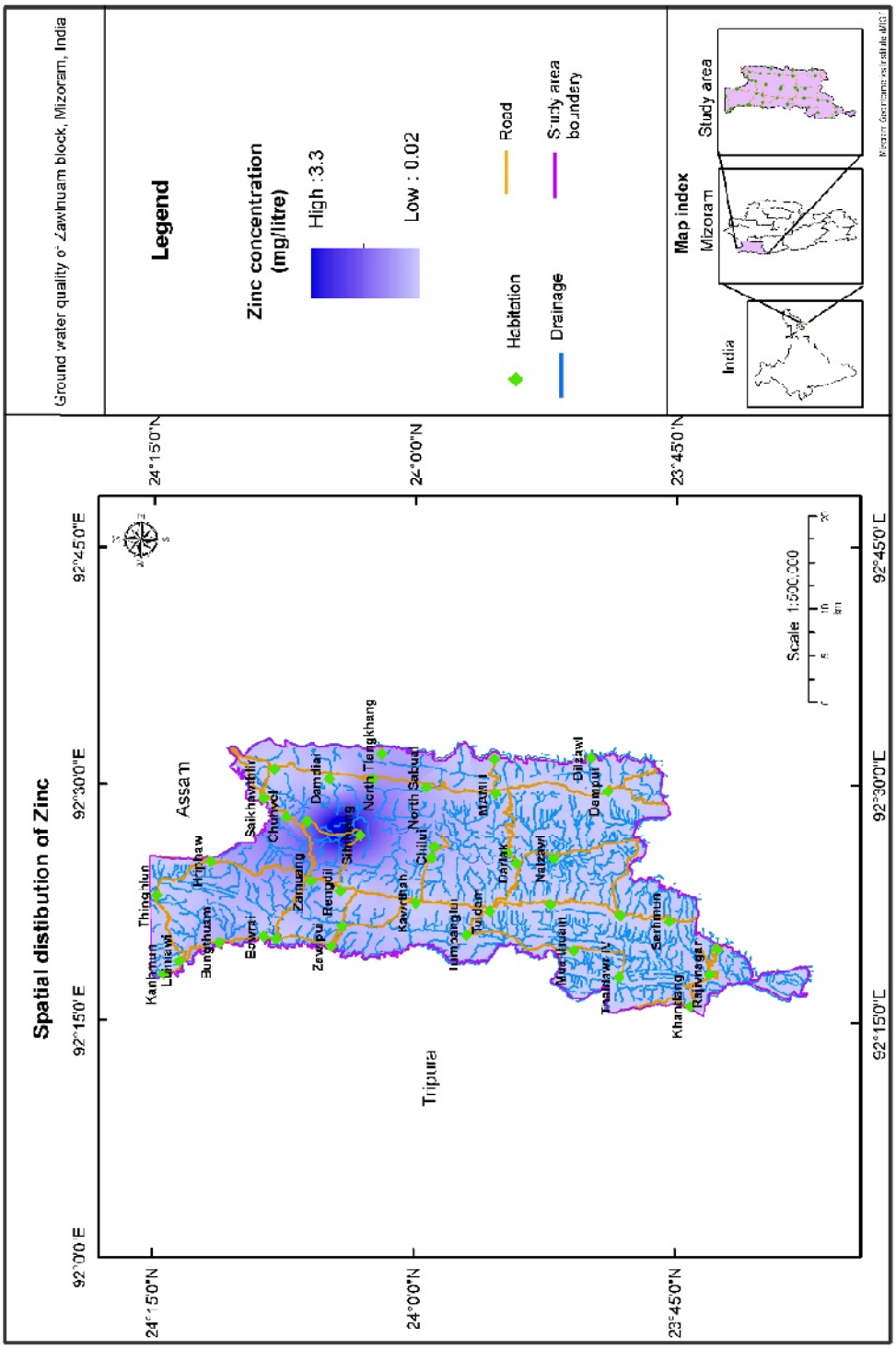


Figure 53: Zinc in terms of lithological units

In terms of lithology, zinc is highest in Shale and lowest in sandstone.



Map 56: Spatial distribution of Zinc

CHAPTER- VII

RESULT AND DISCUSSION

The study for ground water potential was carried out based on various parameters. The process involved a comprehensive analysis of factors such as lithology, geomorphology, geological structure, and drainage patterns. This involved the utilization of satellite data, along with detailed fieldwork to prepare maps that depicted the aforementioned parameters. Additionally, maps and records from the Geological Survey of India (GSI) were referred to for further insights. Rainfall data was obtained from the India Meteorological Department (IMD) using Geographic Information System (GIS) technology. Furthermore, land use/land cover, slope, and soil data were collected from the Mizoram Remote Sensing Application Centre (MIRSAC).

The integration of all the thematic data mentioned above facilitated the preparation of a comprehensive ground water potential map of the study area, namely the Zawlnuam R.D. Block.

The results of the ground water potential map were meticulously cross-checked with information obtained from detailed fieldwork. The study area was categorized into different classes based on ground water potential. It was observed that areas with very good ground water potential were generally situated in low-lying regions overlain by unconsolidated areas. The geomorphic units and materials in these areas formed the best aquifers, thereby suggesting the presence of shallow ground water.

In contrast, areas with good ground water potential were predominantly found on hill slopes with permeable rocks such as sandstone and fractured shale. These areas exhibited promising potential for ground water availability.

Moderate ground water potential areas were identified in the hill slopes lying between the valley and hill top. In these areas, the aquifers were mainly formed by fractured and fissured rocks, which are indicative of secondary porosity.

Conversely, the poor ground water potential class was primarily associated with hill tops and ridges with steep slopes. These areas were characterized as run-off zones, as the rainwater received by them generally flowed without significant infiltration.

In the physico-chemical assessment of the study area, a total of 8 parameters were taken into consideration to comprehensively evaluate the water quality. Firstly, the pH levels of the study area were found to be generally low during the monsoon season, especially in the southern part. However, the average pH of the study area was within the desirable limit. This indicates a potential seasonal variation in pH levels, which could be attributed to factors such as precipitation and environmental changes.

Secondly, the Total Dissolved Solid (TDS) content of the ground water in the study area was noted to be within the desirable limit, indicating that it does not pose any significant threat to the water quality.

Moving on to the assessment of Total Alkalinity, it was found to be highest during the post-monsoon season, yet it remained under the permissible limit. This suggests that the water's alkalinity levels, while fluctuating seasonally, do not pose a threat to the overall water quality.

Similarly, the Total Chloride levels in the study area were observed to be highest during the monsoon season. However, the average concentration of total chlorides was within the desirable limit, indicating a satisfactory level of water quality in this aspect.

The assessment of Total Hardness of the ground water revealed that it was highest during the pre-monsoon season, but its average total hardness fell within the permissible limit, signifying acceptable water quality standards.

Furthermore, the study area exhibited high Turbidity in the northern side, suggesting a need for further analysis and potential measures to address this aspect of water quality.

Iron content was found to be high during the pre-monsoon season in the northern side, but it fell within the desirable limit during the post-monsoon and monsoon seasons, indicating a seasonal fluctuation in iron levels.

Additionally, the conductivity of the ground water was within the desirable limit, indicating that it does not pose any significant threat to the water quality.

In terms of bacteriological examination, contamination was observed in every water source, indicating that the water should not be used directly from the point source and should be treated before domestic use. The origins of contamination appear to be linked to anthropogenic activities, with potential sources including the construction of restrooms, pig farms, and other operations.

Moreover, when considering the geomorphological units, it was observed that various parameters such as pH, TDS, Total alkalinity, iron, total hardness, and conductivity exhibited disparities across different structural hills and valleys. This highlights the influence of geological features on water quality variations within the study area.

From a lithological perspective, it was noted that different types of sediments and rock formations exhibited varying levels of water quality parameters, further emphasizing the geological influence on water quality.

The results of this investigation clearly demonstrate that ground water quality can vary seasonally, with variations in the concentration of components primarily attributed to rainfall and other environmental factors.

CHAPTER- VIII

SUMMARY AND CONCLUSION

8.1. Summary

The findings of the present study indicate that the Zawlnuam R.D. Block in Mizoram possesses significant groundwater potential, surpassing that of most other rural areas in the state. Geographically bounded by Assam to the north and Tripura to the west, the area also demonstrates the potential to develop into a key commercial hub within Mizoram. With increasing population growth and industrial development, demand for groundwater is projected to rise considerably. The agricultural sector of the block, which benefits from favourable agro-climatic and geomorphological conditions, is also expected to rely more heavily on groundwater for irrigation.

Groundwater quality in the area currently falls within desirable and permissible limits. However, over-extraction coupled with the impacts of climate change poses risks of both depletion and deterioration in quality. Consequently, the study underscores the importance of implementing artificial recharge strategies to ensure sustainable management. Overall, the results suggest that the Zawlnuam R.D. Block may represent the most promising groundwater reserve among rural blocks in Mizoram.

The integration of advanced geospatial technologies such as Remote Sensing and Geographic Information Systems (GIS), in conjunction with traditional survey methods, has proven to be highly effective for hydrogeological investigations. The use of digital elevation models (DEMs) significantly enhances the mapping of lineaments and geomorphological features. Remote sensing and GIS together provide accurate lithological, structural, and geomorphological maps, offering considerable savings in time and cost while delivering results of high hydrogeological relevance.

GIS serves as a powerful tool for analyzing and quantifying multivariate parameters influencing groundwater occurrence. It facilitates the delineation of groundwater potential and scarcity zones, while field validation ensures reliability of results. By enabling the integration and analysis of diverse datasets, GIS allows for a detailed understanding of aquifer characteristics through both spatial and statistical methods.

The creation of a groundwater potential map, developed by integrating multiple thematic layers, highlights the hydrogeological significance of rock types, structural features, and landforms. Landform classification using DEM-derived topographic data, combined with local knowledge, provides a systematic and quantitative assessment of groundwater potential.

The study reveals that lithological and structural variations significantly influence groundwater availability. For example, argillaceous rocks yield groundwater mainly through structural porosities, while arenaceous formations rely on primary porosity. Valley-fill deposits, fractured bedrock zones, alluvial plains, and unconsolidated intermontane sediments exhibit high groundwater potential, whereas rough terrains restrict occurrence to drainage channels. Structural features such as lineament density and fracture intersections are strongly correlated with high-yield wells and springs.

Groundwater potential in the area has been classified into Very Good, Good, Moderate, and Poor categories based on geomorphological and lithological attributes. The correlation between groundwater occurrence and geological factors emphasizes the importance of integrating geomorphology, lithology, and structure into groundwater prospecting and exploitation strategies.

The study also establishes the pivotal role of geospatial technologies—including GPS, remote sensing, and GIS—in groundwater exploration, development, and management. These methods enable cost-effective, spatially accurate analyses that complement traditional field techniques, ultimately facilitating informed decision-making for sustainable groundwater utilization.

The application of GIS in groundwater quality assessment has demonstrated its utility as a robust analytical tool. Comprehensive data acquisition is a prerequisite for accurate quality evaluation. The analysis of physico-chemical parameters indicates that, overall, groundwater in the study area meets desirable and permissible limits for drinking and irrigation purposes.

Groundwater, unlike surface water, moves slowly within aquifers and remains in prolonged contact with surrounding lithologies, gradually assimilating dissolved constituents. Although most aquifer materials exhibit low solubility, the mineralogical composition can significantly affect water chemistry. In some areas, naturally occurring elements such as chromium, cadmium, nickel, manganese, and mercury

exceed permissible limits, requiring further monitoring and management. Conversely, concentrations of calcium, magnesium, potassium, sodium, chloride, nitrate, sulphate, arsenic, and zinc remain within safe levels.

Iron contamination is a localized issue, particularly in water drawn from hand pumps before the monsoon season. Elevated iron concentrations render water unsuitable for drinking, though some springs maintain acceptable levels. Regular monitoring is therefore recommended. Variations in water quality are also influenced by landform, lithology, grain size of aquifer materials, and groundwater flow paths.

Overall, while groundwater quality in the study area is largely within safe limits, localized contamination risks highlight the necessity of continuous monitoring and systematic quality management.

This study has established the groundwater potential of the Zawlnuam R.D. Block; however, the remaining 27 Rural Development Blocks of Mizoram require similar hydrogeological investigations. A state-wide hydrogeological information system should be developed to support sustainable groundwater utilization. Future assessments should incorporate geo-environmental variables such as slope, aspect, soil type, and land use/land cover to refine groundwater potential mapping.

Given the reliance of rural Mizoram on springs, it is recommended to conduct systematic spring inventories and quality assessments. Continuous monitoring of spring water quality is essential to identify non-potable sources and to design effective management strategies. In view of climate change, research should also focus on its impacts on groundwater recharge and spring flow, with emphasis on developing spring rejuvenation techniques.

Furthermore, the potential for anthropogenic contamination, even in areas currently free from industrial activity, necessitates aquifer vulnerability studies and the establishment of long-term monitoring frameworks. Recharge estimation and assessment of overexploitation risks must also be prioritized to prevent resource depletion.

Before the development of boreholes or wells, detailed investigations of potential groundwater zones are strongly advised to ensure sustainable yield and cost-effective utilization. Collectively, these measures will contribute to the long-term conservation, management, and sustainable use of groundwater resources in Mizoram.

8.2. Conclusion on hydrogeological studies

The use of new technologies such as remote sensing and Geographic Information System (GIS) has proven to be beneficial for researching geological, structural and geomorphological conditions in addition to traditional surveys. Digital elevation model data has been found to improve lineament and geomorphological mapping. The findings indicate that remote sensing and GIS can be trusted to produce precise maps of lithology, geomorphology and lineament, saving a significant amount of time and yielding high-quality results that are hydrogeologically significant.

In groundwater investigations, integrating the two technologies has shown to be an effective technique. An effective instrument for analyzing and quantifying such multivariate characteristics of groundwater occurrence is the GIS. Delineating groundwater prospects and shortage zones can be greatly helped by it. Large-scale data integration and analysis are made easier by GIS tools, while field research helps to confirm findings. Combining all of these methods provides a deeper comprehension of the characteristics regulating the occurrence of groundwater.

In the field of hydrogeological study, remote sensing and geographic information systems have emerged as key instruments for evaluating, tracking, and protecting groundwater supplies. It makes it possible to manipulate and analyse each layer of spatial data separately. It is employed in the modelling and analysis of the relationships between the layers. It is a quick and economical method for generating useful information about lineaments, geomorphology, geology and other topics that aid in determining the groundwater potential zone. Once the information is produced, GIS techniques are very cost- and time-effective and offer several advantages over traditional methods. Additionally essential are traditional methods to completely comprehend the hydrogeological characteristics of mountainous aquifers.

Understanding the relationship between different parameters and explaining the characteristics of aquifers was made possible by the integration of several data layers in a GIS environment, followed by spatial and statistical analysis of the data. This demonstrates the power of a GIS and its capacity to carry out statistical and spatial analysis using a variety of data formats. The hydrogeological significance of diverse

rock kinds, structures, and landform types is demonstrated by the groundwater potential map that was created by integrating several thematic maps.

The integration of various data layers in a GIS environment allowed for a better understanding of the relationship between different parameters and the explanation of aquifer characteristics. This approach involved both spatial and statistical analysis of the data, showcasing the capabilities of GIS in handling diverse data formats and conducting in-depth analysis. The creation of a groundwater potential map, achieved by integrating multiple thematic maps, effectively illustrates the hydrogeological significance of various rock types, structures, and landform variations.

Understanding different types of landforms is important for assessing the potential for groundwater. Topographic information from digital elevation models can provide valuable details about the characteristics of the land surface. Typically, classifying the different landforms in a landscape involves interpreting remote sensing data or conducting traditional field surveys, which can be time-consuming and unpredictable. However, a more accurate identification of landforms is possible when local topographic knowledge is combined with a numerical description of the land surface. By using digital elevation models as a starting point, we can classify different topographic regions into categories of landforms. This approach has proven to be helpful in creating a detailed description of landforms, which is useful for assessing groundwater potential. Additionally, it allows for systematic examination and quantification of spatial variations in surface shapes.

Analysis using GIS and field research has shown that the presence of different types of rocks, structures, and landforms has a significant impact on the occurrence of groundwater. In areas dominated by argillaceous rock, structures play a major role in influencing the availability and storage of ground water. High yields are attributed to primary and secondary porosities. A flat topography with thick lineaments characterizes high ground water potential. In regions with a high concentration of arenaceous rocks, major porosity serves as the primary aquifer for groundwater storage. Rough terrain leads to groundwater being primarily found in drainage channels with valley fill deposits. Integrated aquifer systems composed of valley fill deposits and fractures along drainage channels exhibit high groundwater potential.

Bedrock cracks are crucial in controlling ground water availability in semi-consolidated rocks. Locations consisting of unconsolidated materials with bedrock fractures are promising for groundwater investigation. Dense lineaments on alluvial flood plains present excellent groundwater prospects. High yields are often associated with the cover of unconsolidated sediments in intermontane valleys, fractured valleys, and alluvial plains.

Large linear features, intersections of linear features, and similar structural characteristics with closely spaced fractures are often linked to high-yield wells and springs. These are important in hydrogeology because they represent potential areas for groundwater exploration. Low-yield boreholes near prominent linear features are caused by the scattered distribution of hard rock aquifers and poor site selection.

The area's groundwater potentiality was classified into Very Good, Good, Moderate, and Poor classes based on detailed geomorphological and lithological analysis. The current study has demonstrated a direct correlation between groundwater availability and the region's unique geomorphology, lithology, and geological structure. This correlation provides valuable insights into the factors that influence ground water availability and can be used to guide the selection of suitable locations for groundwater exploitation.

The study's findings highlight the significance of considering geomorphological and lithological factors when assessing groundwater potential. By integrating these factors into the decision-making process, it becomes possible to identify areas with high potential for groundwater exploitation. Moreover, the study emphasizes the importance of understanding the geological structure of the area, as it plays a crucial role in determining groundwater availability.

Furthermore, the study underscores the pivotal role of geospatial technologies in groundwater management, development and delineation. The utilization of technologies such as GPS, remote sensing and GIS has proven to be instrumental in accurately mapping and analyzing groundwater resources. These tools enable a comprehensive understanding of the spatial distribution of groundwater potential, allowing for informed decision-making in resource management and development.

In conclusion, the study's comprehensive analysis of groundwater potentiality, coupled with the integration of geospatial technologies, offers valuable insights for effective groundwater management and development. By leveraging the direct correlation between geomorphology, lithology and geological structure, decision-makers can make informed choices regarding groundwater exploitation and sustainable resource utilization. The study's findings serve as a significant contribution to the field of geoscience and provide a framework for addressing challenges related to groundwater management in similar regions.

8.3. Conclusion on ground water quality assessment

The integration of Geographic Information Systems (GIS) has proven to be an exceptionally effective and powerful tool for the comprehensive analysis of groundwater quality. Prior to undertaking an analysis of groundwater quality within a GIS system, it is imperative to amass a significant volume of data. The analysis of the physico-chemical features of groundwater in a given area reveals that, at present, there exists no imminent major threat to its quality.

In stark contrast to surface water in streams, groundwater within an aquifer exhibits a notably sluggish movement and maintains extensive contact with the surrounding rock or silt. The majority of aquifers are comprised of minerals that exhibit an extremely slow rate of dissolution into groundwater, or the geological components of the aquifer are generally inert. Nevertheless, as long as groundwater remains in contact with the aquifer, it gradually assimilates an increasing quantity of dissolved particles.

In certain geographical locations, the rock or sediment contains specific minerals that possess the potential to contaminate the water with substances rendering it unsuitable for human consumption or agricultural purposes. Contamination may also emanate from exceptionally elevated concentrations of the pertinent element within the aquifer material. In other instances, the composition of the aquifer may consist of ordinary rock or silt, yet a particular characteristic of the water or the aquifer facilitates the accumulation of contamination to unsafe levels.

The physico-chemical characteristics of groundwater vary contingent upon the landform, which may be attributed to the movement of ground water from higher to lower elevations. The concentration of certain elements may undergo alterations during transit, transitioning from lower to higher concentrations or vice versa.

Distinct varieties of rock exhibit varying impacts on groundwater quality. The duration required for water to percolate through aquifers, the chemical composition of the rocks, the grain size of litho units, and the geological formations of the rocks collectively influence the purity of groundwater.

The groundwater in the study area meets the desirable limits for pH, TDS, total alkalinity, total chloride, total hardness, and electrical conductivity.However, hand pumps often contain high levels of iron, especially before the monsoon season, which may exceed the permissible limit. Water with elevated iron concentration should not be used for drinking. Some of the study area springs have iron levels within permissible bounds, but they need regular monitoring.

The concentration of calcium, magnesium, potassium, sodium, chloride, nitrate, sulphate, arsenic and zinc in the groundwater within the study area are within desirable and permissible limits.

On the other hand, the concentration of chromium, cadmium, nickel, manganese and mercury in some springs exceeds the permissible limit, requiring further analysis and regular monitoring.

8.4. Recommendation

The study area in Mizoram, one of the 28 Rural Development Blocks, has been the focus of detailed research on its groundwater potentiality. However, the remaining 27 R.D. Blocks in Mizoram await comprehensive study of their groundwater potential. It is imperative to conduct further studies and research to establish a hydrogeological information system that would facilitate a more extensive and beneficial utilization of groundwater resources. Geo-environmental variables such as aspect, slope, type of soil, and land use/cover can significantly impact groundwater occurrence, and it is

recommended to conduct groundwater prospecting using these characteristics to enhance the precision of evaluating groundwater potential.

In rural Mizoram, springs are the most significant water sources, and it is recommended to undertake further spring inventories and evaluations. Additionally, in the current scenario, it is crucial to conduct research on the impact of climate change on groundwater and develop strategies for revitalizing springs. Continuous monitoring of springs within permissible limits across various criteria in the study region is essential to identify and manage springs with potential non-potable classification, calling for the development of a reliable groundwater monitoring system.

Furthermore, the potential for anthropogenic sources of contamination and pollution at the surface or depth to impact groundwater underscores the need for research on aquifer susceptibility to contamination. Even in the absence of industrial pollution in the area presently, there may be a risk of significant water contamination in the near future, necessitating continuous quality monitoring of suspect springs.

An assessment of ground water resources is vital to prevent overexploitation, and recharge estimation is crucial for resource evaluation, warranting further in-depth research. It is advisable to conduct a thorough investigation of potential ground water zones before drilling boreholes or digging wells to ensure sustainable and efficient utilization of groundwater resources.

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TITLE OF THE THESIS	**:**	**GROUND WATER POTENTIAL MAPPING AND WATER QUALITY ASSESMENT OF ZAWLNUAM RD BLOCK, MAMIT DISTRICT, MIZORAM, INDIA**

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DATE OF ADMISSION	:	08.09.2021

APPROVAL OF RESEARCH PROPOSAL :

1. DRC	:	06.04.2022
2. BOS	:	24.05.2022
3. SCHOOL BOARD	:	10.06.2022

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Indian Journal of Natural Sciences www.tnsroindia.org.in ©IJONS

Vol.14 / Issue 79 / Aug / 2023 *International Bimonthly (Print) – Open Access* *ISSN: 0976 – 0997*

RESEARCH ARTICLE

Ground Water Exploration using Remote Sensing and GIS in Zawlnuam Rural Development Block, Mizoram, India

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Received: 26 Sep 2022 Revised: 22 Mar 2023 Accepted: 30 June 2023

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ABSTRACT

Growth of human population, climate change, soil contamination and rapid urbanization increase the demand for water supply. Surface water resource is often inadequate to meet this ever-increasing demand. Consequently, ground water resources need to be explored and harnessed not only for domestic purposes, but also for irrigation and industrial purposes. Advent of scientific techniques for identifying ground water prospective areas for large scale exploration enables us to save time and money.Zawlnuam rural development block in Mamit district of Mizoram, India is endowed with abundant rainfall and number of perennial streams. However, rapid growth of population leads to insufficiency of water resources within the area. Ground water resources may solve this chronic crisis for water scarcity. The present study makes use of geographic information systems (GIS) and remote sensing data to identify the potential locations for ground water availability. Important geospatial aspects which are responsible for the presence of ground water within the district were identified. Accordingly, three thematic layers viz., geomorphology, lithology, geological structures like faults and lineaments were generated. These thematic layers were then combined to form the hydrogeomorphic units which are treated as the aquifers. The final maps show the ground water conditions of the area in terms of prospect. The final output can be utilized for exploration, development and management of ground water resources.

Keywords: GIS, Ground water, Remote Sensing, Zawlnuam block.

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Vol.15 / Issue 88 / Feb / 2025 *International Bimonthly (Print) – Open Access* *ISSN: 0976 – 0997*

RESEARCH ARTICLE

Water Quality Assessment during Pre-Monsoon Season in Zawlnuam R.D.Block, Mamit District, Mizoram, India., using Water Quality Index-Weighted Arithmetic (WQI-WA) Method

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ABSTRACT

The quality of water is now known to be just as important as the quantity. It contains contaminants in solution from its movement and location. The quality of water is needed to be known as it is the main purpose for potable, irrigation and industrial activities. The aim of the study is to assess the water quality of Zawlnuam R.D. Block, Mamit, Mizoram, India during pre-monsoon season. Samples were collected from various villages within the study area. They were analyzed based on seven parameters namely Iron, Chlorides, TDS, Alkalinity, pH, Turbidity and Hardness using Water Quality Index-Weighted Arithmetic (WQI-WA) Method. The calculated value is classified in five categories ranges from Excellent water quality to Unsuitable for drinking purpose. The results obtain under this study provides various decision for various location within the area of interest.

Keywords: Ground Water, Surface water, Water quality, Pre- monsoon, Zawlnuam RD Block, Water Quality Index, Weighted Arithmetic Method.

INTRODUCTION

Ground water is one of the most important natural resources and the largest reachable source of fresh water for supplying the ever-increasing demand [1]. The ground water in natural systems usually contains dissolved solids,

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Mizoram University

for participating in the International Workshop on "Geodynamics & Geophysical Methods for Exploration & Geohazards" & Presented a paper entitled "Water Quality Assessment during Pre-Monsoon session in Zawlnuam RD Block, Mamit District, Mizoram, India" held on 12th & 13th July, 2023, at Seminar Hall PUC.

Jointly organized by Department of Geology & Geophysics, Pachhunga University College and Department of Geology, Govt. Zirtiri Residential Science College, Aizawl, Mizoram.

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Ms. Teresa Lalrinengi, delivered an Oral Presentation on "*Ground water exploration using remote sensing and GIS in Zawlnuam Rural Development Block, Mizoram, India.*" at the National Seminar, jointly organized by Department of Geology, Mizoram University, and Mizoram Science, Technology & Innovation Council (MISTIC), on 09th-10th May 2023, held at the Mizoram University, Aizawl, India.

(Prof. B.P. Mishra)

(Dr.Jimmy Lalnunmawia)

ABSTRACT

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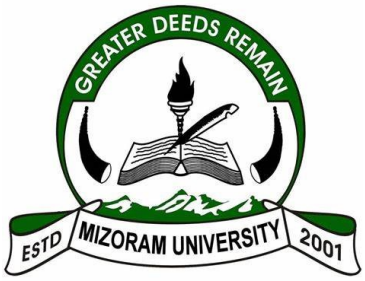

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Abstract : The study highlights the significant groundwater potential of a region in Mizoram in Northeast India which outperforms other rural areas in the state. Located between Assam to the north and Tripura to the west, the study area has the potential to become an important commercial hub. As the population and industries grow the demand for groundwater is expected to rise. Additionally, Zawlnuam R.D. Block, with its favorable agricultural conditions, will likely see an increased use of groundwater for irrigation. The groundwater quality in the region currently meets desirable and permissible standards. A groundwater potential map was generated using Geographic Information System (GIS), rigorous geological fieldwork and monitoring of the potable water quality by Physico-chemical methods. The study composed of comprehensive analysis coupled with the integration of geospatial technologies which offers valuable insights for effective groundwater management and development. By leveraging the direct correlation between geomorphology, lithology and geological structure, decision-makers can make informed choices regarding groundwater exploitation and sustainable resource utilization. The study's findings serve as a significant contribution to the field of geoscience and provide a framework for addressing challenges related to groundwater management in similar regions.

Keywords: Groundwater, potential, management, GIS, Zawlnuam, Mizoram.

1. INTRODUCTION

1.1. Introduction:

Groundwater is the primary source of domestic, agricultural and industrial use in urban and rural areas as well as the most valuable resource for sustainable groundwater management. As groundwater is the most preferred resource due to its less contamination than surface water, assessing groundwater by generating groundwater potential map will significantly affect the sustainable management of groundwater resources in the study area as well as the state or the country by identifying the potential areas of groundwater for better utility which will improve the livelihood of the community (Tolche,2020). Groundwater potential mapping can be defined as a tool for the systematic development and planning of water resources. The distribution, occurrence and movement of groundwater is based on the hydrogeological and morphological features of the study area.

The occurrences of groundwater in hilly terrain are mainly restricted to weak zones such as fracture, lineament and weathered residuum. These tectonic elements create seepage conduits which are sources of springs. These springs are utilized as a main source of water supply for the population. The general discharges of the springs are meagre in high altitudes which progressively increase down slope.

The low linear ridges are characterized by low permeability and infiltration capacity. They act as run off zones. The moderate linear ridges comprise hard and compact sandstone, shale, siltstone which are characterized by very low permeability and infiltration capacity that act as runoff zones. Groundwater potential is low and groundwater structure may be feasible in suitable locations of valley portions.

Since the dawn of history, water has been an essential basic need for every livelihood of mankind; therefore, it is certain that there is no life of any kind on the earth without water as all biological life is dependent on water. The clean and sanitary environment is closely associated with the availability of water. Water is an important factor and due to increase in population, the needs of water also increases

while the availability of potable water decreases. In rural areas where population growth rate is determined, the scarcity of water increases which may affect the development of the area so a few instances of water with reasonable accuracy is impossible and a daunting task. The water resources consumed in the rural areas are mainly from the streams, lakes, rivers, ponds, wells, etc. which is further drawn for household use. Water accessed for drinking can be polluted by point and non- point sources which affect the water quality. The sources may include industrial and sewage discharge, urban and agricultural runoff, excess use of fertilizer and pesticides, drought and floods due to lack of education and awareness. Geographic information system based studies have acquired a lot of traction in groundwater research in recent years since they are quick and provide first-hand knowledge on the resource for future development.

1.2. Scope of Study

Hydrogeological studies have been quite sparse in north east India and Mizoram in general. The groundwater has been an invaluable resource for different livelihoods both in urban and rural India. However, the emphasis and the approach to develop and find new water sources have been very limited. In view of the dwindling level of water sources in Mizoram and keeping in view the increasing population, it is important to develop a groundwater potential map and assessing the groundwater quality for Zawlnuam RD Block and its surrounding areas for development.As a result, the proposed study will deal with the goal of determining the groundwater potential for Zawlnuam RD Block in Mamit district. These hydrogeological studies will be carried out using Geographic Information Systems (GIS) which provide accurate parameters to evaluate and compiled hydrogeological and spatial models such as maps, aerial photographs, soil type, slope, land use, satellite images, etc. GIS is an important and useful tool for scientific study of water resources which is especially practical as water is in motion and also solved the water resources related problems. Hence, with the advance of GIS technology, we can generate different hydrological data, integrate, stimulate, analyze, manage and manipulate into a manageable system.

Mamit district is currently amongst one of the 112 aspirational districts in India as declared by *Niti Aayog*. The district has a population of 85,757 people, according to the 2011 census. The district has a population density of 28 people per sq.km. Its population grew at a 36.59 percent annual pace from 2001 to 2011.

1.3. Aim and Objectives:

This research work aims to evaluate the current status of the ground water resources of the district and identifying potential zones of ground water recharge for rejuvenation of ground water resources.

The main objectives of the present study are:

1) To prepare geological, geomorphological, lithological, structural, rainfall, land use/land cover, slope, soil and drainage thematic maps.
2) To prepare a groundwater potential map for Zawlnuam RD Block in Mamit district.
3) To identify zones of potential ground water recharge areas to augment artificial recharge.
4) To assess the physico-chemical groundwater quality of different water sources.
5) To assess the geological impact of rock-water interaction on the quality of potable water.
6) To demarcate vulnerable water sources in the area along with potable remedial measures.

2. REVIEW OF LITERATURE

Saaty (1980) introduced the Analytic Hierarchy Process (AHP) as a decision-making tool designed to facilitate the selection of optimal solutions from a set of alternatives based on a predefined set of evaluation criteria. This method has seen widespread application in the generation of groundwater potential maps through the integration of remote sensing techniques.

Shah et al. (2001) projected a looming crisis of groundwater overexploitation, underscoring the necessity not only for innovative supply-side interventions but also for the implementation of diverse corrective measures that necessitate a shift from resource development to resource conservation.

In a study conducted by Kumar et al. (2009), an analysis of water samples from the Tuichhuahen river in Kolasib district was carried out to assess the physico-chemical and bacteriological characteristics, aiming to determine the potable water's quality. The results indicated that water supplied by the PHED exhibited better quality compared to that from the tuikhurs. However, both sources, utilized for drinking and domestic purposes, were found to generally adhere to the tolerance limits.

Subsequently, Kumar et al. (2011) conducted research on arsenic pollution levels in potable water within the northern region of Mizoram state and southern Assam state in India. The study revealed that certain locations in the alluvial sediment aquifers in southern Assam exceeded the permissible arsenic levels, while no detectable arsenic contamination was found in Mizoram.

In another study, Blick (2017) characterized and assessed the quality of drinkable water sources in Mizoram's SW Lawngtlai district. Elevated concentrations of lead, manganese, and arsenic were observed, surpassing permissible levels. Moreover, a correlation was noted between low-lying areas and the obstruction of groundwater movement, with rock-water interaction being suggested as the cause of the high

arsenic concentrations, and sedimentation in shallow wells leading to elevated manganese levels.

In their more recent work, Kumar et al. (2020) emphasized the importance of integrating indigenous knowledge and active participation of native communities in disaster risk reduction and management, particularly in addressing water scarcity in Mizoram.

Furthermore, Kumar et al. (2013) utilized GIS-based techniques to map groundwater quality in the central portion of Proddatur town, Y.S.R. Kadapa district, Andhra Pradesh, India. Water samples from forty-three wells were collected, and various parameters including pH, total hardness, calcium, magnesium, chloride, fluoride, and alkalinity were analyzed using Arc GIS 9.3 and GPS technology.

In a separate study by Lalchhingpuii et al. (2011) the analysis of Sulphate, phosphate-P, and nitrate-N contents of Tlawng river near Aizawl City, India revealed that sulphate levels remained within the approved range established by WHO and BIS. The study also found that sulphate readings were lower during the monsoon season and higher post-monsoon, potentially due to increased biological activity and decreased river flow. Additionally, the study highlighted the impact of sulphate on sewage corrosion, odor, and phytoplankton growth. Phosphate levels observed during the study period were within the permissible limits set by BIS and WHO, with higher values in the pre-monsoon and monsoon seasons attributed to anthropogenic sources. The study emphasized the role of phosphate as a necessary plant nutrient and its influence on phytoplankton growth in aquatic environments.Furthermore, the study found that nitrate values remained within the allowable range provided by BIS and WHO, with low nitrate amounts in winter and higher values during the rainy season. The study emphasized the diverse uses of nitrates in the chemical industry and highlighted its significance as an essential nutrient for aquatic life. The Royal Commission further affirmed the high-quality nitrate levels in River Tlawng.

Vaux (2011) illuminated the array of options offered by groundwater storage for augmenting storage capacity and enhancing overall water supply. Notably, the author

underscored the increasing value of groundwater amid shortages, underscoring the imperative of sound groundwater management in realizing its full potential, which hinges on adherence to established economic principles.

Bhatnagar et al. (2014) investigated the impact of open-pit limestone mining on groundwater in the Katni River watershed in Madhya Pradesh, India. Their methodology involved using Survey of India Topographical maps and Indian Remote Sensing Satellite (IRS) images from the LISS III sensor. They also collected village-level water quality data and utilized satellite images for lithology and geomorphology analysis.

Similarly, Kumaravel et al. (2014) conducted a study along the east coast of Tamil Nadu state and Pondicherry union territory, analyzing thirteen groundwater samples from bore wells for pH, TDS, calcium, magnesium, sodium, potassium, HCO3, SO4, and fluoride. The study involved the use of geospatial technology and GIS to map the groundwater quality, with measurements of electrical conductivity and pH being made in the field.

Moreover, Lalbiakmawia and R. Lalruatkima (2014) utilized geospatial technology to map groundwater potential zones in Serchhip District, Mizoram, and concluded that parameters such as land use/land cover, slope, geomorphology, lithology, and geological structure directly influence groundwater availability. They highlighted the significance of remote sensing and GIS in groundwater management and delineation.

Against the backdrop of population growth and climate change, Sharma et al. (2015) conducted a study revealing that groundwater scarcity in Bihar could plummet to levels significantly below the minimum thresholds set by the Government of India and the World Health Organization unless immediate corrective measures are taken.

Kulkarni et al. (2015) emphasized the significance of hydrogeological features and socioeconomic factors in determining groundwater typology and dependency.

In a study by Lalbiakmawia (2015), the use of Remote Sensing and GIS techniques

for groundwater potential zones mapping in Mamit district, Mizoram revealed the direct association of geo-environmental factors such as land use/land cover, slope, geomorphology, lithology, and geological structure with the occurrence of groundwater. These factors were identified as crucial parameters for selecting suitable areas for groundwater exploitation.

Building on this, Saha et al. (2015) underscored the insensitivity of mean monthly rainfall trends to altitude, emphasizing the urgent need for the development of effective water management strategies to address water scarcity issues and enhance the resilience of rabi agriculture in Mizoram. Hence, the creation of groundwater potential maps emerges as a vital priority in this context.

H. Laldintluanga et al. (2016) conducted an assessment of rural water quality in Aizawl, Mamit, and Serchhip Districts of Mizoram, India. They observed acceptable pH levels in spring water but noted low pH levels in water samples from reservoirs and tube wells, potentially due to prevalent sandstone and shale, and highlighted the impact of forest fires and rainfall on water quality.

Anbazhagan and Jothibasu (2016) conducted a study on groundwater mapping in southern India, specifically in the Uppar Odai sub-basin of the Amaravati River basin. Their research involved assigning weights and rankings to thematic layers based on their influence on groundwater occurrence, and they utilized ArcGIS 9.3 for spatial integration.

In a comprehensive review, Mechlem (2016) emphasized the critical issues that warrant attention in water law, particularly in the effective management and preservation of groundwater resources. The author provided an extensive overview of prevailing groundwater legislation practices while delving into recent trends and advancements in response to contemporary concerns.

Listyani R.A. (2016) delved into the impact of rock minerals on groundwater quality in the Jakarta Quaternary groundwater basin, leveraging petrographic analysis, XRD, and chemical analysis of groundwater and rock samples. Their investigation revealed the profound influence of the mineralogical composition of rock on groundwater quality, attributing the majority of abundant soluble elements in groundwater to silicate mineral weathering. Moreover, the proliferation of issues relating to potable water quality deterioration stemming from pollution, overexploitation, population growth, rapid industrialization, and mismanagement of water resources necessitates concerted efforts to assess and monitor water bodies across mainland India, particularly given the heavy reliance of rural populations on groundwater for various needs.

Andualem and Demeke (2019) focused on the Upper Blue Nile Basin in Ethiopia, aiming to develop a groundwater potential map using GIS and remote sensing. They assigned weights to various thematic layers such as land cover, drainage density, lineament density, soil, geology, slope, and geomorphology to create groundwater potential maps.

Moreover, Shimpi et al. (2019) harnessed remote sensing and GIS techniques to delineate groundwater potential zones in Boro-Chikli, Maharashtra, India. Their approach involved the amalgamation and overlay of various thematic layers and data, such as lithology, geomorphology, land use and land cover, slope, and drainage, to generate a comprehensive groundwater potential map.

Tolche (2020) explored the potential applications of weighted index overlay analysis in assessing groundwater potential using GIS techniques. The resulting groundwater map proved instrumental in identifying suitable sites for groundwater resource exploitation.

Biswas and Azyu (2021) studied 12 villages in the Phullen RD Block and identified

Tuikhur or village spring source (VSS) and piped water supply as the main sources of water, along with rainwater harvesting and water from streams or rivers. They noted a decline in the perennial status of springs due to inadequate spring shed management.

In a related study, Lalbiakmawia et al. (2023) conducted ground water exploration using Remote Sensing and GIS in Zawlnuam RD Block, Mizoram. Their findings concluded that the overlay analysis of lithological, geomorphological and structural layers in a GIS environment facilitated the delineation of aquifers. Different types of aquifers were identified based on their geomorphic classes and lithological units.

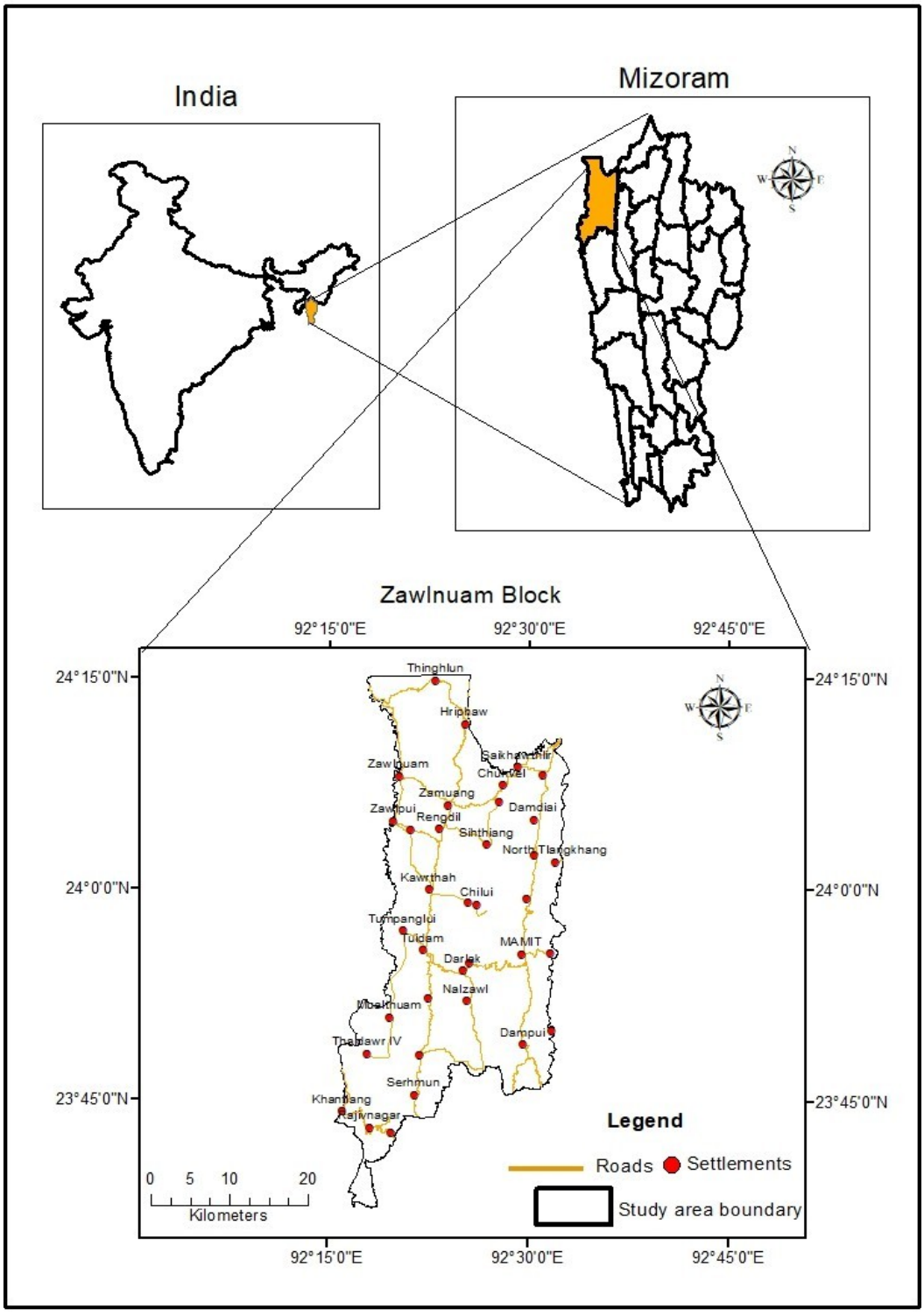
Biswas et al. (2023) used AHP-TOPSIS and AHP-VIKOR models to map spring water suitability and watershed vulnerability in Aizawl District, identifying central areas as both highly suitable and heavily impacted by human activities, with ROC analysis validating model accuracy.

Ritse et al. (2020) analysed long-term LULC changes in Nagaland, revealing rapid urbanization with loss of forest and agricultural lands, increased aquaculture in Dimapur, and waterbody shrinkage in Kohima linked to poor urban planning.

Aherwar et al. (2023) reviewed RS-GIS integration for groundwater mapping, highlighting its cost-effectiveness in data-scarce areas but noting challenges like non-standardized methods, subjective layer weighting, and the need for field validation.

3. STUDY AREA

The propose study area of Zawlnuam RD block is located in the north western section of Mamit district in the north western part of Mizoram which borders Tripura to the west. The study area is located in the north western part of Mizoram between 23º 40’ 38.88”N to 24º 15’ 12.60’ N Latitudes and 92º 15’ 13.18’E to 92º33’ 00” E Longitudes. It is bounded to the north by Assam state, on the south by Mamit RD block, on the east by Kolasib district and to the west by Bangladesh. The total geographical area of Zawlnuam block is approximately 1170 sq. km and it falls in the Survey of India Topo sheet Nos. 83 D/7, 83 D/8, 83 D/11, 83 D/12, 84 A/5, 84 A/6 and 84 A/9. The study area enjoys a moderate climate owing to its tropical location. It is neither very hot nor too cold throughout the year. The area is easily accessible by road transportation from different parts of the state. Location of study area is shown in Map 1.



Map 1: Location of the study area

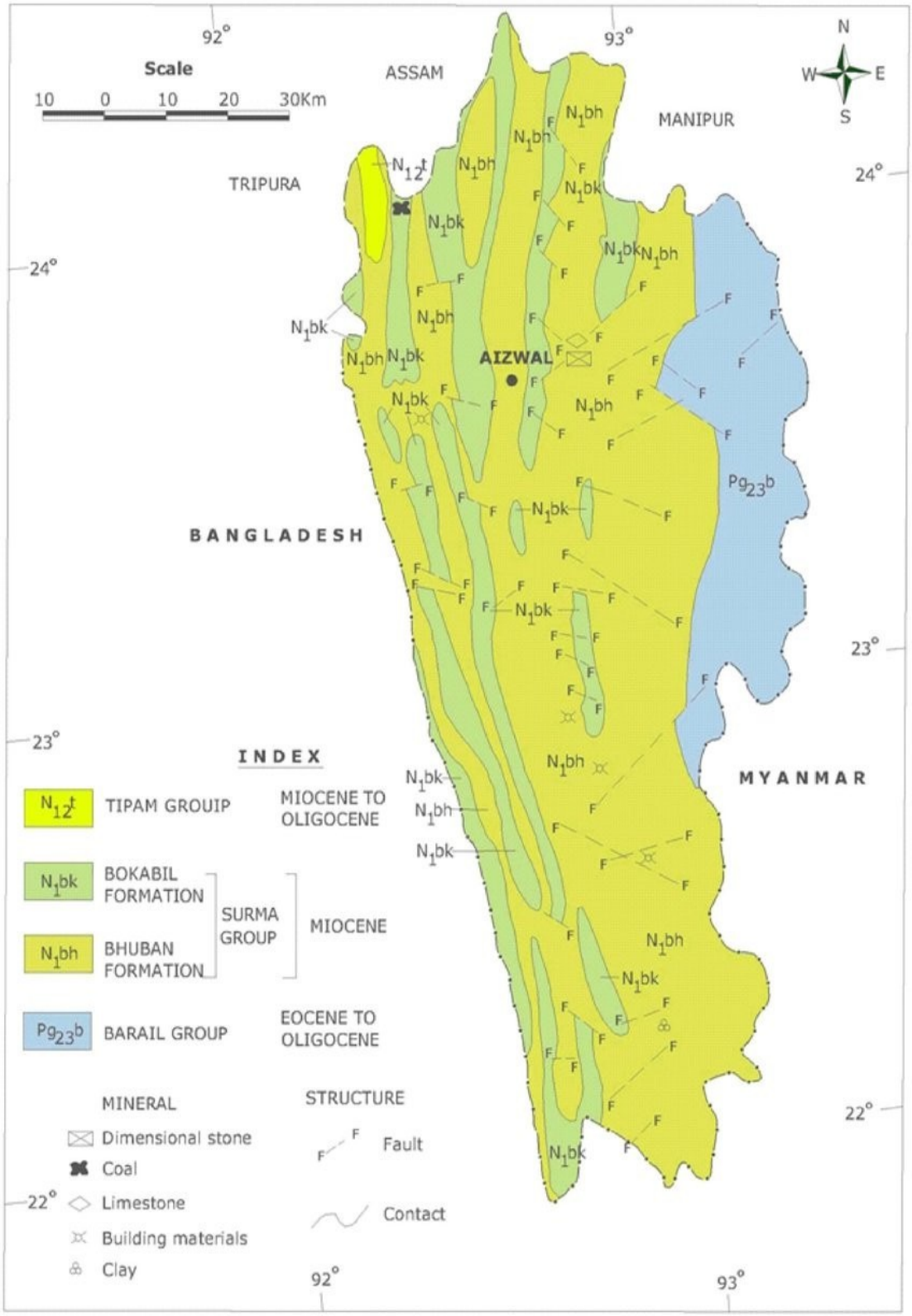
Rocks of Mizoram generally represent the Surma group which are from Upper Oligocene to Miocene Age. Also, rocks from Barail group (Oligocene) to the Holocene age are also found in different areas across Mizoram. Normally, arenaceous and argillaceous rocks are the dominant rocks across the state and these exposures are quite often associated with siltstone, clay and gravel. Evidences of conformable and transition contacts are quite sharp and the stratigraphy are defined by folded sediments. High degree of slopes, immense rock folding, troughs, ridges, crests, ridges, valleys and hills define the landscape. The lithology is marked by thick soil cover and colluviums often represent the overburden material. Intercalated sandstone and shale normally represent the stratigraphy and the lithology are defined by high degree of weathering, evidences of erosional features, marked by joint sets, presence of weak zones like local faults and fractures. At many places, nodules and concretions represent the Bhuban rocks of the Surma group. Cross stratification, ripple marks and laminations are found in many rocks. Ichnofossils, plant fossils, echinoids, gastropods, crustaceans and vertebrate fossils are noticed in many areas. Unfortunately, no major mineral has been reported in the state.

The exposed rocks of Zawlnuam town in Mamit represent mainly weathered shale, sandstone and siltstones representing Bhuban rocks of the Surma group. The rocks usually have thick soil cover as the overburden material with cross bedding and other structural features present in the exposed rocks. The stratigraphic succession of Mizoram and regional geology are shown in Table 1 and Fig. 2 respectively.

Table 1: Stratigraphic succession of Mizoram (Modified after Ganju, 1974 and Karunakaran, 1975, Mandaokar, 2000; Tiwari *et. al.*, 2003)

Age	Group	Formation	Unit	Thickness (m)	Generalized lithology	Depositional Environment
Recent alluvium	-	-	-		Silt, clay, gravel	River deposits
Early Pliocene To Late Miocene	Tipam	-	-	+900	Friables and stone With occasional clay bands	Stream deposits
Miocene To Upper Oligocene	Surma	Bokabil	-	+950	Shale With siltstone and sandstone	Shallow marine
		Bhuban	Upper Bhuban	+1100	Arenaceous with sandstone, Shale and siltstone	Shallow marine, near shore to lagoonal
			Middle Bhuban	+3000	Argillaceous with shale and Siltstone	Deltaic Complex
			Lower Bhuban	+900	Arenaceous with sandstone and silty shale	Shallow marine
Oligocene	Barail	-	-	+3000	Shale, siltstone and sandstone	Shallow marine

Table 1: Generalized Stratigraphy Succession of Mizoram



Map 2: Geological map of Mizoram

4. METHODOLOGY

The study area primary research inputs will be derived from remote sensing data, geological maps and geological field studies. These sources will be integrated and analyzed using Geographic Information System (GIS) technology. Remote sensing and GIS techniques have revolutionized natural resource surveys due to their efficiency and cost-effectiveness. These techniques find extensive applications in geo-sciences, particularly in ground water studies. By combining satellite data with ground truth information, researchers can identify and delineate geological structures, geomorphic features, and hydraulic characteristics that serve as indicators of ground water presence.

GIS is a computer-based tool used for collecting, managing, and displaying spatially referenced data. It supports decision-making in various contexts, such as planning and environmental management. GIS is essentially a database management system that stores spatial information along with its attributes, enabling retrieval, processing, and analysis to address geographical queries.

The integration of common database operations with unique visualization and geographic analysis capabilities sets GIS apart from other information systems. This makes GIS valuable for explaining events, predicting outcomes, and planning strategies across public and private enterprises.

The term "Geographic Information System" reflects its nature as an information system containing a database of spatially distributed objects, activities, or events. These can be represented by points, lines, or surfaces, which can be superimposed to create meaningful maps. Each GIS layer consists of a map view and a data view, allowing for the visual representation of data and the display of specific attributes. Moreover, GIS provides a comprehensive set of tools for capturing, storing, retrieving, transforming, and visualizing real-world spatial data for specialized applications.

Remote sensing involves obtaining information about the Earth's surface without direct contact. This is achieved through the collection and analysis of reflected or emitted energy. Remote sensing data is typically obtained through the sensing of electromagnetic radiation, with sensors such as cameras being commonly used for this purpose. Parameters such as tone, color, size, shape, pattern, association, and location are analyzed to interpret satellite remote sensing data, allowing for the description of lithology, drainage patterns, and subsurface structures. Geologists can utilize remote sensing imagery to identify potential exploration sites by delineating structures and identifying associated lithologies.

The applications of remote sensing imagery are diverse and include mapping land use and cover, agricultural monitoring, soil mapping, urban planning, and surveying of geomorphological features. The methodology for remote sensing and GIS technology is typically divided into three phases: pre-field, field, and post-field work.

During the pre-field phase, satellite data of the study area is acquired, and various information such as literature, maps, socio-economic data, and meteorological data are collected from multiple sources. The satellite imagery is then aligned with Survey of India toposheets, and base maps for different themes are prepared. Contour and slope maps are also generated, and printed pre-field maps are used for field verification.

The field phase involves ground confirmation and data collection, which is crucial for remote sensing technology. Ground information is collected during field visits to verify doubtful areas on the pre-field interpreted maps. Information that cannot be obtained from satellite data, such as the location of springs and groundwater samples, is collected during fieldwork, often using GPS for recording geographical locations.
In the post-field phase, the finalized maps are adjusted as necessary, and the collected field data is studied and analyzed. Water samples are analyzed in the laboratory, and derived data is prepared using primary layers. Area calculations are performed to determine spatial coverage, and a report is generated, including a description, a map of ground water prospects and quality, and an action plan for ground water resources

development.

The methodology involves the analysis of various groundwater controlling factors including geomorphology, lithology, geological structures, slope, land use/land cover and rainfall.

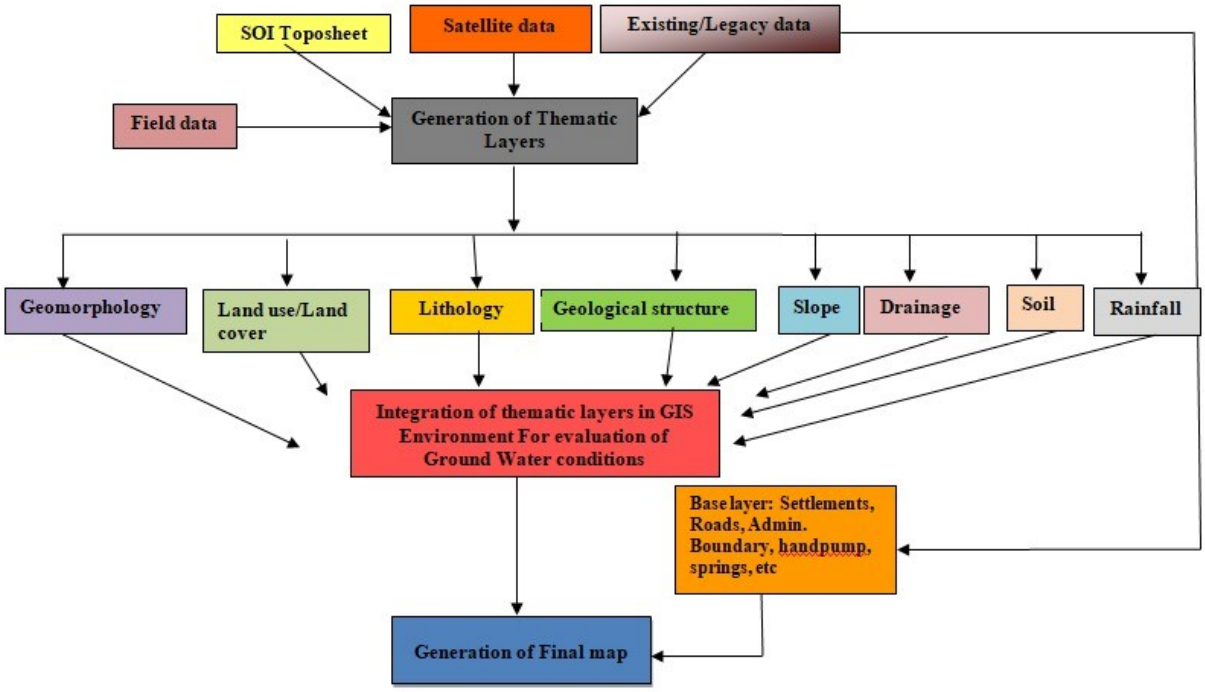


Figure 2: Flow Chart of methodology

Geomorphology plays a crucial role in the assessment of groundwater potential and prospect, as well as in the management of groundwater resources. It also aids in the identification of suitable artificial recharge sites. Valleys are particularly favorable areas in this regard. When considering lithological parameters, factors such as geological boundaries and porosity should be taken into account. Unconsolidated material units are perceived to offer greater potential for groundwater occurrence.

In terms of geological structures, lineaments are significant features from a groundwater perspective. High yielding wells and springs are often associated with large lineaments and corresponding structural features. Fractures that are hydraulically connected with alluvium and weathered bedrock constitute optimal aquifers. Lineaments serve as pathways for groundwater movement and contribute to

groundwater recharge potential.

Aspect data and maps are derived from Digital Elevation Models (DEM) generated from elevation (contour) data of the study area. The aspects of an area may impact the physico-chemical properties of water quality.

The slope angle plays a crucial role in groundwater availability and replenishment. However, anthropogenic activities can lead to dynamic changes in the slope angles of landforms, thereby reducing the accuracy of the maps.

Land use/land cover significantly influences natural groundwater recharge to aquifers. Impermeable pavements and urban structures hinder the natural recharge process. It is well-established that recharge is higher in cultivable and irrigated land compared to wasteland and settlements.

Rainfall data collected from various sources is the primary source for recharging groundwater. Therefore, incorporating rainfall data is essential in the methodology.

All geo-environmental factors that influence the quantity and quality of groundwater are represented in layers. Each layer is assigned a rank and weightage, and then integrated in a GIS environment to generate the final groundwater potential map and groundwater quality map of the study area.

Groundwater chemistry is influenced by various factors such as geological conditions, the extent of chemical weathering of different types of rocks, the quality of recharged water, and inputs from sources other than water interaction. These factors and their interactions contribute to the complexity of groundwater quality. Therefore, the assessment of groundwater quality involves the methodology of groundwater quality mapping, which can be divided into three main parts.

The first part involves organizing the raw-input data into a GIS database, specifically as a layer of groundwater samples.

The second part entails creating groundwater quality layers for each chemical element

from the GIS database.

The third part involves analyzing the groundwater quality element-wise in relation to rock types and geomorphological classes and presenting the results in charts and maps. Ground water samples were collected to determine the concentration of trace elements like iron, chloride, nitrate, sulphate, chromium, arsenic, cadmium, nickel, manganese, mercury and zinc. All the samples were acidified with 5% nitric acid and preserved at 4°C temperature before testing. The testing equipment include iCE Series 3000 Atomic Absorption Spectrophotometer.2.6 (9th May 2023)

A flow chart illustrating the steps and process involved in ground water quality analysis and mapping has been formulated as below.

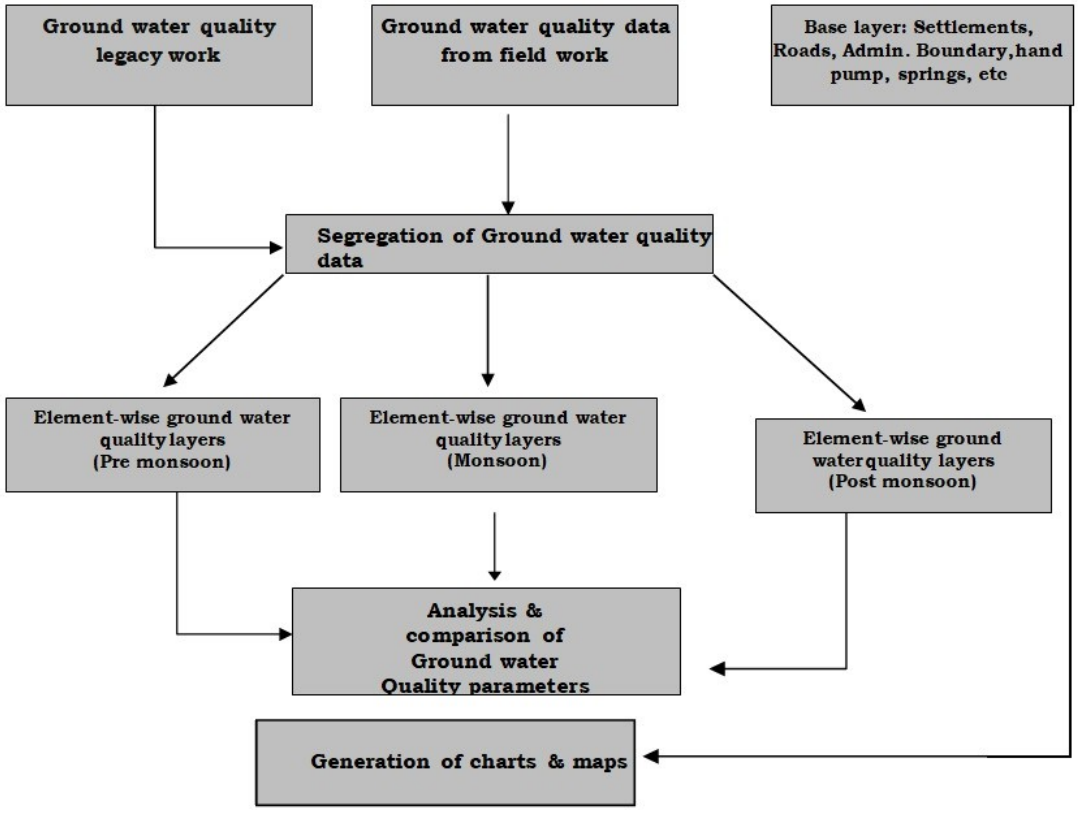


Figure 3: Flow chart of methodology for ground water quality assessment

4.1. Field Methods

Understanding rocks and water in their natural surroundings and their natural interaction to one another requires geological field and laboratory studies. Therefore, rigorous geological fieldworks were carried out during the study to complete the objectives. Field work include sample collections during pre-monsoon, monsoon and post-monsoon seasons and accordingly the GPS readings was recorded from the selected locations. The sampling was done according to the recommendations of the

APHA and AWWA by following the grab sampling method.

4.2. Laboratory methods

4.2.1. Data consisting of satellite Landsat-8, SRTM DEM (30m resolution) from United States Geological Survey, toposheet from Survey of India (1:50,000) and georeferenced maps was used.

4.2.2. The interpreted data was cross checked and correlated with ground validations.

4.2.3. GIS analysis of the resultant output.

4.2.4. DEM of 10 m accuracy was used for the preparation of thematic maps using hydrology tools in ArcMap 10.4 software.

4.2.5. Mapping of geomorphology, lithology, structural layers with the inclusion of base map generated from administrative, settlements, road networks, railway lines etc. from existing/ legacy data such as Survey of India, Geological Survey of India, Statistical Handbook of Mizoram editions.

In order to gain a comprehensive understanding of the natural interactions between rocks and water, it was essential to conduct extensive geological fieldwork and laboratory studies. The fieldwork involved the collection of samples during pre-monsoon, monsoon, and post-monsoon seasons, with GPS readings recorded at specific locations. These sampling procedures adhered to the guidelines set forth by the APHA and AWWA, utilizing the grab sampling method.

In the laboratory, a variety of data sources were employed, including satellite imagery such as Landsat-8, SRTM DEM from the United States Geological Survey, and georeferenced maps. The interpreted data was meticulously cross-checked and correlated with ground validations. Furthermore, GIS analysis was instrumental in processing the resultant output, with a focus on utilizing a 10m accuracy DEM for the creation of thematic maps using hydrology tools in ArcMap 10.4 software. This mapping included the depiction of geomorphology, lithology, and structural layers, integrating base maps generated from existing data sources such as Survey of India, Geological Survey of India, and Statistical Handbook of Mizoram editions. The integration of different thematic maps for the generation of a groundwater potential

map was achieved through the application of the Analytic Hierarchy Process (AHP). The chemical analysis of water samples involved the use of various instruments and methods. The pH of the water samples was measured using a digital instrument, while the Total Dissolved Solids were determined through a gravimetric method. Turbidity was assessed using a turbidity meter, and bacteriological tests were conducted using a water testing kit. Additionally, total Chlorides, total alkalinity, Total Hardness, Magnesium, Calcium, and Chloride were estimated using titrimetric methods, while Sulphate and nitrate were measured utilizing a UV Visible Spectrophotometer. Alkali metals such as Na and K were detected using a Flame Photometer, and heavy metals (e.g., Arsenic, Nickel, etc.) were identified through the iCE Series 3000 Atomic Absorption Spectrophotometer.2.6. Analytic Hierarchy Process (AHP) was used for the integration of the different thematic maps for generation of groundwater potential map.

The pH of the water samples was measured by using digital instrument and Total Dissolved Solids was measured by gravimetric method, Turbidity by turbidity meter, and bacteriological test is done by using water testing kit, total Chlorides, total alkalinity, Total Hardness, Magnesium, Calcium, Chloride were estimated by titrimetric method. Sulphate and nitrate were estimated by UV Visible Spectrophotometer. Alkali metals like Na and K are detected by Flame Photometer and heavy metals (e.g., Arsenic, Nickel etc.) were detected by iCE Series 3000 Atomic Absorption Spectrophotometer.

5. GROUND WATER MAPPING FOR ZAWLNUAM RD BLOCK

The geological formations in Mizoram mainly consist of rocks from the Surma group, spanning from the Upper Oligocene to Miocene Age, as well as rocks from the Barail group (Oligocene) to the Holocene Age. Predominantly, Mizoram is characterized by arenaceous and argillaceous rocks, often accompanied by siltstone, clay, and gravel. The stratigraphy is defined by folded sediments and distinct conformable and transition contacts, with the landscape featuring steep slopes, extensive rock folding, troughs, ridges, crests, valleys, and hills. The lithology is marked by a thick soil cover, and intercalated sandstone and shale are commonly found. Furthermore, weathering, erosional features, joint sets, and the presence of weak zones such as local faults and fractures contribute to the defining characteristics of the lithology.

The distribution of groundwater in Mizoram varies based on lithology, geomorphology, and rainfall patterns. In high relief areas like the Zawlnuam RD block, characterized by steep topographic slopes and specific geological features, the groundwater potential is limited to intermontane and fractured valleys due to high run-off and limited rainwater infiltration. Unfortunately, the exploitation of groundwater often occurs without comprehensive knowledge of its distribution in both temporal and spatial dimensions, leading to the drilling of unproductive wells and subsequent financial losses for users. Over-exploitation has also resulted in wells gradually drying up over time, necessitating artificial recharge in regions where natural recharge is insufficient. Despite this, there are still areas in the state where the full potential of groundwater remains untapped.

Efforts to map the groundwater potential involve gathering data on geology, hydrology, topography, land use, and climate, as well as identifying key features such as fractures, lineaments, and drainage patterns through fieldwork and remote sensing techniques. The integration and validation of these datasets are crucial in the creation of groundwater potential maps, which aid in identifying suitable areas for well drilling, managing water resources, and understanding groundwater systems.

5.1. Hydrogeological units

Muhammad Salik Javaid and Shaukat Ali Khan (2017) categorized the rock types in the research region into semi-consolidated formations and unconsolidated formations from a hydrogeological perspective. The region was divided into two hydrogeological units: the semi-consolidated/hard rock unit and the unconsolidated unit. Unconsolidated rocks with minimal alluvial thickness were found in intermontane valleys, broken valleys, and shallow alluvial plain, with shallow groundwater conditions. The semi-consolidated unit mainly comprised shale and sandstone, with tectonic disruptions causing secondary porosity. Due to the hilly terrain with slopes of more than 20%, surface runoff was the primary source of precipitation, and ground water storage options included secondary porosity and structural control in aquifers at higher elevations. The primary source of springs was aquifers in valley-filled locations. According to the Central Ground Water Board ground water investigation, deep tube wells with a depth range of 200 m tapping into Tertiary sandstone had varying production potential. Overlay analysis in a GIS setting integrated geomorphological, lithological, land use/land cover, rainfall, drainage, slope, soil, and structural layers to define aquifers, considering primary and secondary porosity and permeability. Aquifers were defined as cohesive units of geomorphology, lithology, and structure, capable of supporting wells and springs. Aquifers, as geological formations containing enough water to support wells and streams, were discussed along with their significance and characteristics. The mapping of combined lithological-structural-geomorphic units involved the use of polygon and line features to represent units derived from geological structures and overlay analysis. The resulting polygon features are then labeled with alphabetic codes such as Fracture Valley, Shallow Alluvial Plain, Inter-Montane Valley, Less Dissected Structural Hill, Moderately Dissected Structural Hill and Highly Dissected Structural Hill.

5.2. Classification of aquifer materials:

Based on their material content, the aquifer material is divided into the following groups taking into account the porosity and permeability of the geological strata placed in the subsurface at different levels.

Unconsolidated Soils: Mostly Quarternary structure rocks with semi-consolidated sediments that have primary porosity and permeability are known as permeable rocks with alluvial flood plains representing the unconsolidated sediments.

Broken Rock: These are hard rock areas that are broken and typically serve as channels for groundwater flow.

Impermeable Rocks (IR): These are rocks, such as vast shale, that act as a barrier to the movement of groundwater because they lack significant porosity and permeability to the movement of groundwater because they lack significant porosity and permeability.

5.3. Ground water potential classification of the study area

In the legend, the final map is divided into "Very good," "Good," "Moderate," and "Poor" prospect areas based on the combination of ground water governing criteria such as geomorphology, lithology, and geological structures. Here's a brief description of each class:

5.3.1. Very-good prospect area: This area is characterized by low-lying regions, fracture valleys, and intermontane valleys. It also encompasses the convergence of lineaments and the presence of unconsolidated sediments, such as clayey sand, gravel, sand, and silt. These sediments, due to their larger pore spaces between grains, exhibit high percolation rates, thereby enhancing their capacity to retain water. Promising prospective sites can be identified in and around the areas of Luimawi, Zawlnuam, Zawlpui, Lungmawi, Bawngva, Darlak, Nalzawl, Bawrai and Phaizau.

5.3.2 Good prospect area. This area includes all remaining areas restricted by geological structure, as well as additional low-lying places with gentle slopes. Sandstones are considered suitable aquifers due to their ability to store and transfer water through pore spaces and interstices between grains. This zone also encompasses areas where exposed sandstones are present.

5.3.3 Moderate Prospect Area: This refers to locations where the water-yielding capabilities and recharging condition of the underlying materials are neither

inadequate nor optimal. Topographically, this area includes the gently sloping slopes of the hills. Even though the lithology may contain good water-bearing rock formations like sandstone, the sloping topography with high run-off reduces the potential. The moderate zone is typically found in poor water-bearing rock formations such as silty shale, which are further characterized by the presence of secondary structures. The moderate zone in the study area is evenly distributed and can be found in and around Mamit.

5.3.4 Area of poor prospect: This area is primarily found in higher elevations. A larger portion of precipitation in high relief areas runs off as surface runoff, making it difficult for it to penetrate below the ground's surface. Therefore, it is typically considered that the groundwater output is modest. The groundwater yield of elevated places is often poor unless they are accompanied by geological structures, have a high drainage density, and have a suitable rock formation that can hold water. The poor zone is primarily found around ridgelines. This zone, which makes up a small portion of the study region, is primarily high in terms of aerial extent and includes Dampui, N. Tlangkhang, Khantlang, Thaidawr, and Mualthuam.

Map 3: Ground Water Prospect Map of Zawlnuam Block, Mizoram, India.

5.4. Identifying areas for recharging ground water:

In rapidly urbanizing areas with a growing population, the demand for water supply is on the rise. This surge in demand often leads to the depletion of both surface and ground water resources. The fluctuation of ground water levels during periods of abundance and scarcity in hilly regions like Mizoram highlights the urgent need for the construction of recharge structures. The primary aim is to establish a comprehensive geo-database to identify suitable sites for the construction of ground water recharge structures within the study area. This involves conducting thorough analyses of the hydrogeological conditions and creating detailed maps using GIS techniques. The process begins with the generation of geo-spatial data, including base layers such as road, habitation, tube well, spring, and drainage layers. Subsequently, suitable sites for constructing recharge structures near springs and wells will be mapped. The resulting database will be invaluable for administrators, decision makers, and developmental planners, ensuring an adequate water supply for all households in the area.

As urbanization accelerates and populations grow, the demand for water supply increases proportionally. In many cases, the available surface water resources are insufficient to meet the escalating demand for water supply. Consequently, extensive development of ground water resources has occurred, with significant tapping and utilization. In areas plagued by persistent drought and water scarcity, ground water resources have emerged as a viable solution to the problem. Thus, ground water resources are now utilized not only for domestic purposes but also for irrigation and agricultural activities.

Currently, ground water is predominantly used for domestic purposes and, to a lesser extent, for agricultural activities within the area. The extraction of water from springs for domestic use remains a common practice in many villages in the region. This underscores the importance of sustainable management and conservation of ground water resources to ensure continued access to water for both domestic and agricultural needs.

Cutting-edge research has been conducted by various experts in India to address the critical issue of ground water development and recharge in hard-rock terrains. By utilizing advanced technologies such as remote sensing and GIS, these studies have successfully identified potential sites for artificial recharge structures in drought-prone areas. The integration of thematic information layers and geomatics techniques has allowed for the precise mapping and modeling of ground water recharge zones, leading to the identification of suitable locations for rainwater harvesting and artificial recharge structures. These efforts have not only contributed to the development of innovative methodologies for ground water recharge studies but also provided valuable insights for implementing artificial recharge schemes in specific regions. The use of GIS-based models has further enhanced the accuracy of site selection and suitability analysis, taking into account various local environmental and hydrogeological conditions. Overall, these studies represent a significant step forward in the field of ground water management and have the potential to make a meaningful impact on water resource sustainability in hard-rock terrains.

The research conducted by various scholars from different institutes in India focused on using GIS and remote sensing techniques for identifying suitable sites for artificial recharge and water harvesting structures. The studies involved the integration of various thematic layers such as geomorphology, geology, land use, and drainage patterns into GIS for accurate site selection. The aim was to apply these techniques to establish basic information for rainwater harvesting and artificial recharge structures in different regions of India, ensuring the optimal and judicious use of groundwater resources.

The identification of potential recharge zones in the selected watershed was conducted by A. Valliammai, K. Balathanduytham, D. Tamilmani, and C. Mayilswami from Tamil Nadu Agricultural University, Coimbatore, India. The study utilized remote sensing data and GIS techniques. Using ARC/INFO GIS software, thematic layers such as soil, land use, geology, geomorphology, lineament, and drainage were prepared and integrated to identify areas suitable for artificial recharge.

Methods for selecting recharge areas:

The project will utilize standard Geographic Information System (GIS) techniques, such as data processing, digitization and geo-referencing. The resulting data will be used to create a base map featuring essential elements like roads, drainage, and administrative boundaries. Additionally, thematic maps will be generated using various sources including Survey of India Topographic maps, literature, and field surveys. These thematic layers will be used to identify suitable sites for recharge structures, with each parameter categorized and assigned weightage values based on their importance. The methodology will adhere to the guidelines provided by the Central Ground Water Board, Ministry of Water Resources. Finally, the thematic layers will be integrated and analyzed in a GIS environment to determine suitable areas for the construction of ground water recharge structures. The final maps will be produced in print format and stored in a computer system for monitoring and updates. Flowchart for Methodology of standard GIS techniques is given below:

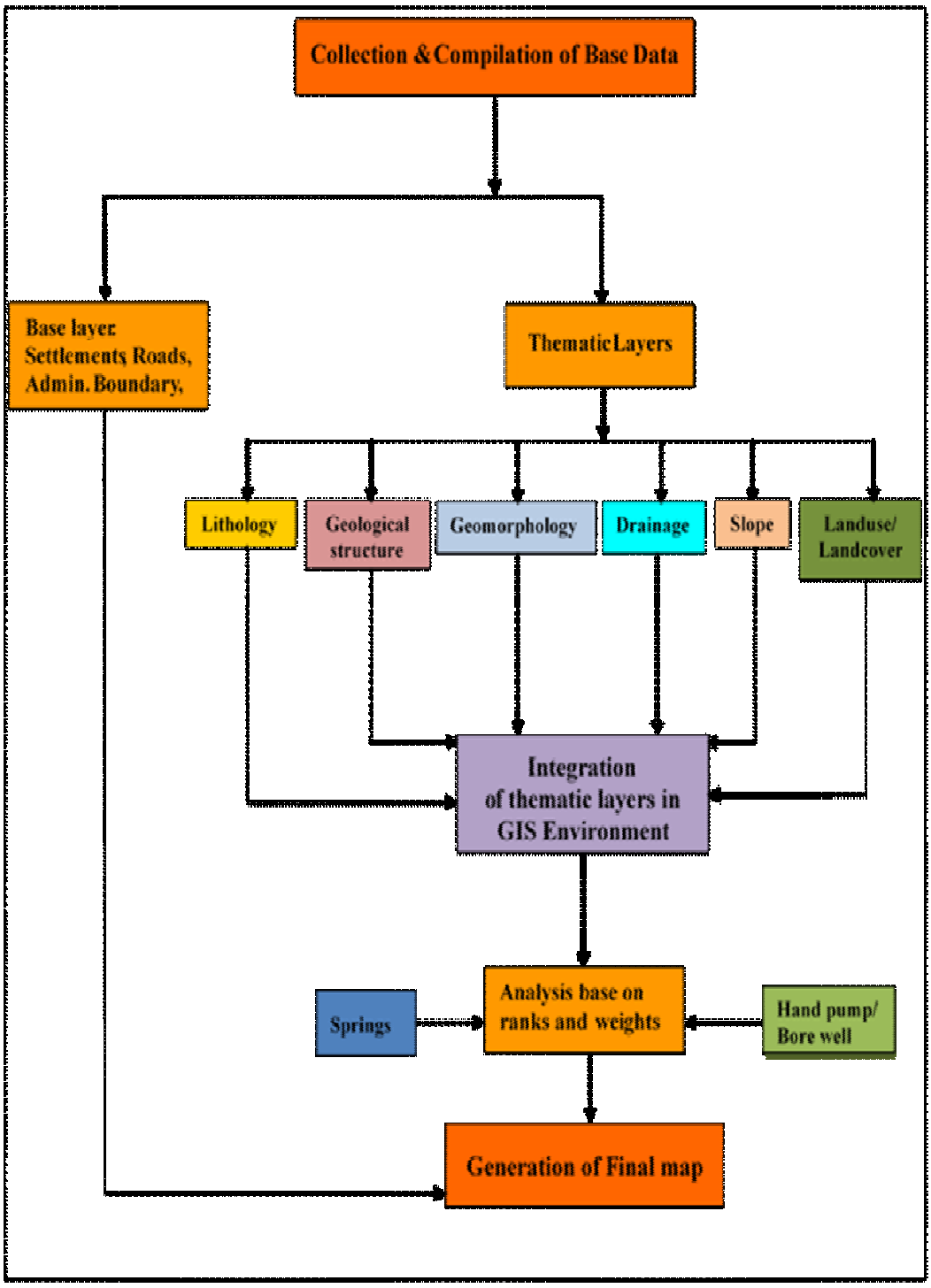


Figure 4: Flow chart of methodology for identifying areas for recharging ground water

5.5. NEED FOR ARTIFICIAL RECHARGE

Natural replenishment of ground water reservoir is a slow process and is often unable to keep pace with the exploitation of ground water resources. This has resulted in declining ground water levels and depletion of ground water resources. Artificial recharge efforts are basically aimed at augmentation of the natural movement of surface water into ground water reservoir through suitable civil construction techniques. Such techniques interrelate and integrate the source water to ground water reservoir and are dependent on the hydrogeological situation of the area concerned.

Occurrence of rainfall in Mizoram is mostly limited to about three months in a year. The natural recharge to ground water reservoir is restricted to this period only in a major part of the state. Artificial recharge techniques aim at extending the recharge period in the post-monsoon season for about three or more months, resulting in enhanced sustainability of ground water sources during the lean season.

In areas where climatic conditions are not favourable for creating surface storage, artificial recharge techniques have to be adopted for diverting most of the surface storage to the ground water reservoirs within the shortest possible time.

In hilly states like Mizoram, even though the rainfall is comparatively high, scarcity of water is often felt in the post-monsoon season, as most of the water available is lost as surface runoff. Springs, the major source of water in such terrains, are also depleted during the post monsoon period. In such areas, rainwater harnessing and small surface storages at strategic locations in the recharge areas of the springs can provide sustainable yields to the springs as well as enhance the recharge of ground water during and after the rainy season.

Artificial recharge techniques play a significant role in mitigating the impacts of water scarcity by effectively managing the surface water and enhancing the sustainability of ground water sources.

5.6 SCOPE FOR ARTIFICIAL RECHARGE:

Artificial recharge of groundwater in Mizoram can be accomplished using check dams, gabion structures, and weirs. This method is typically employed in the following scenarios:

1. Areas where groundwater levels are continuously declining
2. Areas where a significant volume of the aquifer has been desaturated
3. Areas where groundwater availability is insufficient during dry months
4. Areas where there is potential for improving the quality of groundwater or addressing salinity ingress into fresh water aquifers.

In our study area, the relevant point would be number 3, as there is significant fluctuation in groundwater levels and quantity. Constructing artificial recharge structures aims to produce economically viable filtered water and store enough water during the operating season to meet the year-round demand. These structures will replenish springs and wells in the area, catering to domestic and agricultural water needs.

Natural recharge can range from minimal to almost all of the runoff from a drainage area. Artificial recharge can be used to supplement naturally recharged water where available. Recharge methods must be customized to suit specific situations.

5.7. IDENTIFICATION OF AREA

The identification of suitable areas for artificial recharge was carried out using the Geographical Information System (GIS) technique. Geological factors such as lithology, lineaments, and geomorphology were mapped and analyzed. Additionally, important factors like drainage pattern, drainage density, land use/land cover, slope morphometry, groundwater level, and rainfall were taken into consideration.

5.8. SOURCE WATER AVAILABILITY:

The availability of source water, a key requirement for recharging groundwater, is primarily assessed in terms of surplus monsoon runoff that is currently not being utilized. This assessment is based on the pattern, frequency, and spatial and temporal variations of monsoon rainfall. These variations, along with the drainage pattern and density, determine the availability of source water. The physical, chemical, and biological quality of the recharge water also plays a role in planning and selecting recharge methods.

In our study area, there is abundant source water due to ample rainfall and perennial streams.

5.9. AQUIFERS/HYDROGEOLOGICAL ASPECTS:

The state is geologically comprised of unconsolidated sediments such as gravel, sand, silt and clay, as well as semi-consolidated rocks like sandstone, siltstone, shale, and limestone. From a hydrogeological perspective, these unconsolidated and semi-consolidated rocks are considered ideal. The area is intersected by numerous lineaments as part of a linear belt of folds that includes Mizoram and its surrounding areas. The area shows signs of tectonic folding and faulting, resulting in linear structural features. The prominent directions are NNW – SSE and E-W, with less prominent ones in almost all directions, such as NNE – SSW. Lineaments vary in length.

Digital Elevation Models, satellite imagery and ground checks can be used to delineate these lineaments. These lineament zones are highly productive for constructing bore wells, offering good potential for recharge through suitable techniques.

Water storage within the earth's crust depends on geological processes that have created voids capable of absorbing, transmitting, storing and yielding water. Earth materials contain numerous voids, some of which are large enough to transmit water freely while others are too small preventing the transmission of water due to surface tension exceeding hydrostatic pressures.

The useful storage capacity of ground water is not determined by the porosity of the reservoir, but rather by the amount of water that the reservoir can yield through gravity drainage, known as specific yield. It's the difference between porosity and field moisture capacity. Potential aquifers below the zone of soil moisture are already at field capacity, so most of the recharged water can either be recovered or will move to natural discharge areas.

The following conditions indicate possibilities for artificial recharge:

1. Formations of sand, gravel, or highly fractured rocks, either underground or exposed over a large area or in stream channels.
2. The presence of fractured or faulted zones, or numerous small cavities in rock formations, either underground or exposed on the land surface or in stream channels.
3. The absence of barriers to the horizontal or vertical movement of ground water.
4. Feasible locations for the installation of recharge structures, such as check dams, gabions, and weirs.

However, the above conditions do not necessarily indicate possibilities for beneficial recharge. The water may emerge in nearby springs or channels, or may recharge an aquifer that is so deep that recovery is impractical. These conditions should be carefully studied to determine whether recharge is feasible.

Geological reports, ground-water reports, well logs and descriptions of stratigraphic sections can indicate the possibility of groundwater recharge, storage and recovery. This preliminary information may warrant a detailed groundwater investigation.

Groundwater recharge can be influenced by factors such as the season of the year, intensity and duration of precipitation, topography, vegetative cover, soils, land use, evapotranspiration, and availability of storage. The rates and amounts of recharge may be improved by:

1. Increasing opportunity time by regulating the flow of water over the intake area
2. Desilting and removing materials or debris that might seal the intake area
3. Planting or improving the growth of deep-rooted vegetation
4. Diversions from less to more suitable intake areas

When selecting the proper location of sites for artificial recharge, the following factors must be considered:

1. Water availability, source, turbidity, quality etc.
2. Surface soils
3. Depth to aquifer
4. Geologic structure and capacity of the groundwater reservoir
5. The presence of aquicludes
6. Movement of groundwater
7. Location of withdrawal area

An investigation to determine the location, extent, permeability and other physical characteristics of the surface and the various underlying strata is necessary to select the site best adapted to artificial recharge. The greatest volumes and rates of recharge are possible in thick formations of pervious sands and gravels or porous rocks.

The Controlling Stratum:

It is important to identify the stratum that will control the infiltration rate if injection wells are not used. This is typically the least permeable stratum between the aquifer and the recharge surface, taking into account its thickness. The recharge rates are determined by the stratum with the lowest quotient of permeability divided by thickness, assuming a constant water head. Identifying the controlling stratum may require drilling, testing, and sampling, as small drill cores may not provide an accurate picture of the fracturing and jointing in a rock formation.

The water table's proximity to the ground surface significantly affects recharge. When the water table is close to the surface, there is limited opportunity for recharge. Some water may be stored shallowly, but once this space is filled, any excess infiltration will flow back to the stream channel or other discharge area. The impact of a shallow water table may be partly mitigated if the groundwater gradient is steep. In an aquifer with good permeability, this will rapidly remove water from the recharge area.

In Mizoram, all these factors and conditions were taken into consideration when selecting suitable areas for artificial recharge of groundwater.

5.10. ADVANTAGES OF ARTIFICIAL RECHARGE:

The advantages of artificially recharging groundwater aquifers are as follows:

a) No need for large storage structures to store water; required structures are small and cost-effective.

b) Enhances the dependable yield of wells and hand pumps.

c) Negligible losses compared to losses in surface storages.

d) Improved water quality due to dilution of harmful chemicals/salts.

e) No adverse effects such as inundation of large surface areas and loss of crops.

f) No displacement of local population and loss of scarce agricultural land, etc.

g) Reduction in the cost of energy for lifting water, especially where the rise in groundwater level is substantial.

h) Utilizes surplus surface runoff which would otherwise drain off.

i) Biological purity is very high.

j) Minimum temperature variation.

k) It is environmentally friendly, controls soil erosion and flood, and provides sufficient soil moisture even during summer months.

l) Water stored underground is relatively immune to natural and man-made catastrophes.

m) It provides a natural distribution system between recharge and discharge points.

5.11. PROPOSED STRUCTURES:

Artificial recharge structures such as check dams, gabion structures, and weirs are all suitable in different parts of the state. The maps below show the areas suitable for artificial recharge. However, due to space limitations, the scale of the maps may not allow for a detailed representation of all suitable areas.

5.11.1. Check Dam

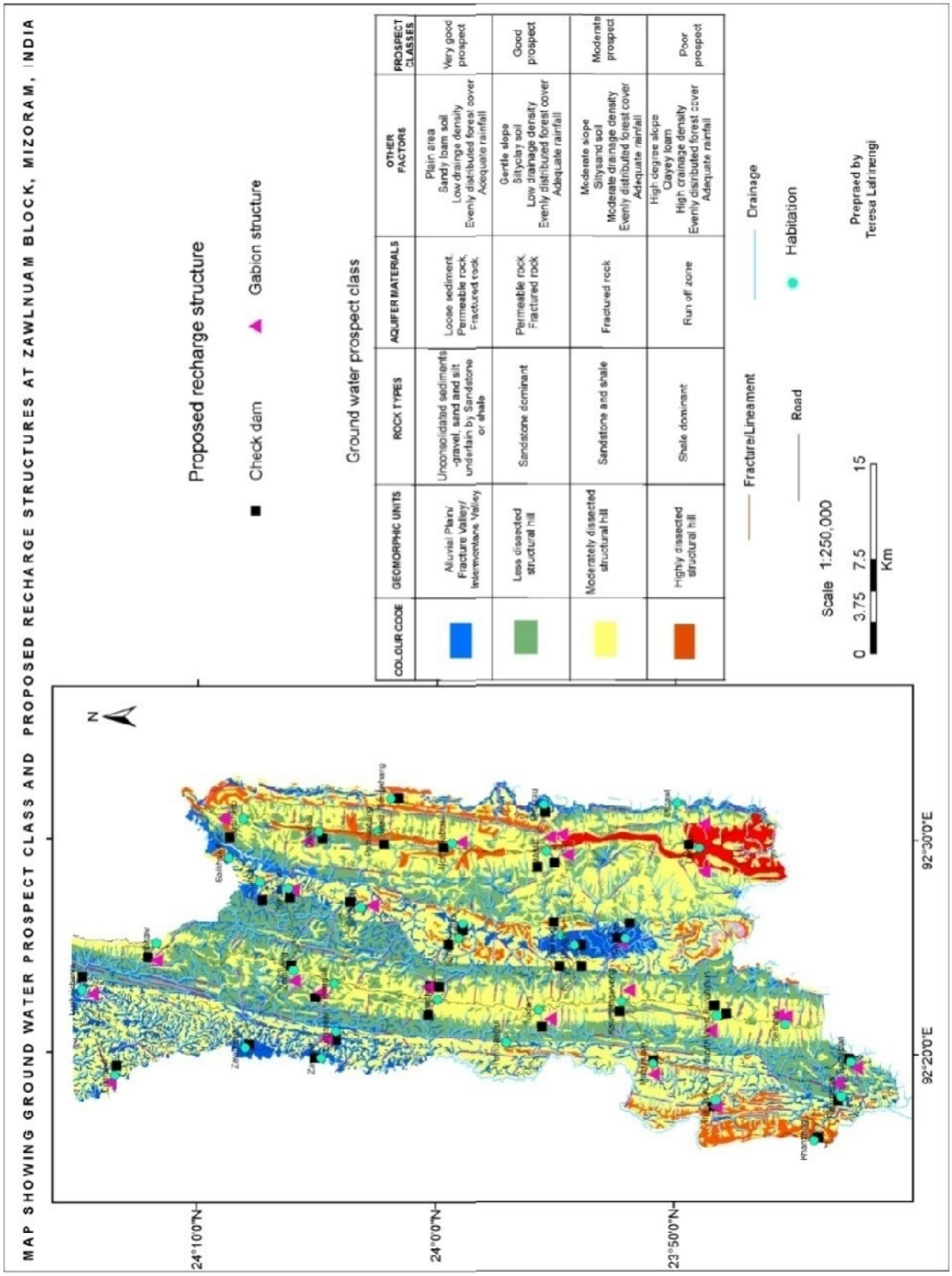
A check dam is a permanent structure built across natural drainage to recharge or replenish the groundwater of an area. It can also be used to reduce the speed of concentrated flows. Check dams are typically installed on first and second order streams in foothill zones and on slopes with a gradient of 3:1 or less, or in areas with a slope of 0-5%. Constructing check dams across rivers is a method to retain surface

runoff and increase groundwater recharge. In regions like Mizoram and many parts of India, where rivers flow for only a few days during the monsoon, check dams can help capture and store the surface runoff, reducing flooding and allowing more time for water to infiltrate the river bed and recharge the groundwater. This can also improve groundwater quality if the impounded water is protected from contamination. Researchers have studied the impact of check dams on groundwater potential and have identified several suitable sites for check dam construction in Mizoram.

5.11.2. Gabion Structure

A gabion structure is a semi-permeable barrier made of boulders encased in a steel wire mesh and anchored to the stream bank. Its purpose is to slow down the flow of storm water in a small watercourse, allowing water to infiltrate the ground and preventing soil erosion.

Gabions are commonly used across small streams to conserve stream flows without causing significant submergence beyond the stream course. Local boulders are enclosed in a steel wire mesh and placed across the stream to create a small dam, anchored to the streamside. These structures are typically around 0.5 meters high and are used in streams with widths of about 10 to 15 meters. When there is excess water, it overflows the structure, storing some water for recharge purposes. Over time, the silt content of the stream water is deposited in the gaps between the boulders, making the structure more impermeable. Gabion structures are commonly employed in many parts of the country, and Mizoram, a state in India, has great potential for implementing these structures.



Map 4: Ground water prospect class and proposed recharged structures at Zawlnuam Block, Mizoram, India

6. PHYSICO-CHEMICAL ASSESSMENT OF WATER SOURCES

The study utilized GIS software to develop base maps for spatial analysis, incorporating layers such as settlements, road types, administrative boundaries, drainage, and water bodies. Groundwater quality was assessed using physico-chemical characteristics gathered from various sites within the research region. To create element-wise groundwater quality layers, point features from the GIS data source were interpolated using the Inverse Distance Weighted method, which considers the concentration values of a single element as the Z value. This method is commonly used for interpolating scatter points and is widely applied in mapping groundwater quality. It operates on the principle that closer points exert a greater influence on the interpolating surface, with weights decreasing as distance increases. The region of influence for each sampled location is determined by the value of the inverse-distance weighting power. Groundwater samples were collected from 16-point sources, including hand pumps/tubewells and springs (Tuikhur), primarily used for domestic and agricultural purposes. Samples were collected during the pre-monsoon, monsoon, and post-monsoon seasons and underwent laboratory analysis to assess significant factors related to groundwater quality. The data from all three seasons were compared to evaluate rock-water interaction based on lithological and geomorphological origins (Ambica et al., 2017; Khadri and Pande, 2015; Kumar et al., 2015; Mishra, 2014; Mahalingam et al, 2014; Narsimha et al., 2013; Boominathan et al., 2015; Rani and Chaudhary, 2015; Shyamala and Jeyanthi, 2017; Singh and Khan, 2011; Teli et al., 2014; RGNDWM, 2011; Tikle et al., 2012; Arif et al., 2014; Gnanachandrasamy et al., 2015).

The study utilized the Inverse Distance Weighted (IDW) approach to create spatial distributions of groundwater quality for different seasons using ArcGIS software. IDW is a deterministic technique that uses a weighted average of known point values to estimate values at unknown points. The analysis considered the geo-coordinates and concentration of each parameter to assess groundwater quality according to BIS guidelines. Spatial variation maps were created for each parameter, divided into desirable, permissible, and non-potable classes. Additionally, the study computed the concentration of groundwater quality parameters in various rock types and geomorphological classes and presented the findings in bar charts.

7. RESULT AND DISCUSSION

The study for ground water potential was carried out based on various parameters. The process involved a comprehensive analysis of factors such as lithology, geomorphology, geological structure, and drainage patterns. This involved the utilization of satellite data, along with detailed fieldwork to prepare maps that depicted the aforementioned parameters. Additionally, maps and records from the Geological Survey of India (GSI) were referred to for further insights. Rainfall data was obtained from the India Meteorological Department (IMD) using Geographic Information System (GIS) technology. Furthermore, land use/land cover, slope, and soil data were collected from the Mizoram Remote Sensing Application Centre (MIRSAC).

The integration of all the thematic data mentioned above facilitated the preparation of a comprehensive ground water potential map of the study area, namely the Zawlnuam R.D. Block.

The results of the ground water potential map were meticulously cross-checked with information obtained from detailed fieldwork. The study area was categorized into different classes based on ground water potential. It was observed that areas with very good ground water potential were generally situated in low-lying regions overlain by unconsolidated areas. The geomorphic units and materials in these areas formed the best aquifers, thereby suggesting the presence of shallow ground water.

In contrast, areas with good ground water potential were predominantly found on hill slopes with permeable rocks such as sandstone and fractured shale. These areas exhibited promising potential for ground water availability.

Moderate ground water potential areas were identified in the hill slopes lying between the valley and hill top. In these areas, the aquifers were mainly formed by fractured and fissured rocks, which are indicative of secondary porosity.

Conversely, the poor ground water potential class was primarily associated with hill tops and ridges with steep slopes. These areas were characterized as run-off zones, as the rainwater received by them generally flowed without significant infiltration.
In the physico-chemical assessment of the study area, a total of 8 parameters were taken into consideration to comprehensively evaluate the water quality. Firstly, the pH levels of the study area were found to be generally low during the monsoon season, especially in the southern part. However, the average pH of the study area was within the desirable limit. This indicates a potential seasonal variation in pH levels, which could be attributed to factors such as precipitation and environmental changes.

Secondly, the Total Dissolved Solid (TDS) content of the ground water in the study area was noted to be within the desirable limit, indicating that it does not pose any significant threat to the water quality.

Moving on to the assessment of Total Alkalinity, it was found to be highest during the post-monsoon season, yet it remained under the permissible limit. This suggests that the water's alkalinity levels, while fluctuating seasonally, do not pose a threat to the overall water quality.

Similarly, the Total Chloride levels in the study area were observed to be highest during the monsoon season. However, the average concentration of total chlorides was within the desirable limit, indicating a satisfactory level of water quality in this aspect.

The assessment of Total Hardness of the ground water revealed that it was highest during the pre-monsoon season, but its average total hardness fell within the permissible limit, signifying acceptable water quality standards.

Furthermore, the study area exhibited high Turbidity in the northern side, suggesting a need for further analysis and potential measures to address this aspect of water quality.

Iron content was found to be high during the pre-monsoon season in the northern side, but it fell within the desirable limit during the post-monsoon and monsoon seasons, indicating a seasonal fluctuation in iron levels.

Additionally, the electrical conductivity (e- conductivity) of the ground water was within the desirable limit, indicating that it does not pose any significant threat to the water quality.

In terms of bacteriological examination, contamination was observed in every water source, indicating that the water should not be used directly from the point source and should be treated before domestic use. The origins of contamination appear to be linked to anthropogenic activities, with potential sources including the construction of restrooms, pig farms, and other operations.

Moreover, when considering the geomorphological units, it was observed that various parameters such as pH, TDS, Total alkalinity, iron, total hardness, and e-conductivity exhibited disparities across different structural hills and valleys. This highlights the influence of geological features on water quality variations within the study area.

From a lithological perspective, it was noted that different types of sediments and rock formations exhibited varying levels of water quality parameters, further emphasizing the geological influence on water quality.

The results of this investigation clearly demonstrate that ground water quality can vary seasonally, with variations in the concentration of components primarily attributed to rainfall and other environmental factors.

8. CONCLUSION AND RECOMMENDATION

8.1. Conclusion on hydrogeological studies

The use of new technologies such as remote sensing and Geographic Information System (GIS) has proven to be beneficial for researching geological, structural and geomorphological conditions in addition to traditional surveys. Digital elevation

model data has been found to improve lineament and geomorphological mapping. The findings indicate that remote sensing and GIS can be trusted to produce precise maps of lithology, geomorphology and lineament, saving a significant amount of time and yielding high-quality results that are hydrogeologically significant.

In groundwater investigations, integrating the two technologies has shown to be an effective technique. An effective instrument for analyzing and quantifying such multivariate characteristics of groundwater occurrence is the GIS. Delineating groundwater prospects and shortage zones can be greatly helped by it. Large-scale data integration and analysis are made easier by GIS tools, while field research helps to confirm findings. Combining all of these methods provides a deeper comprehension of the characteristics regulating the occurrence of groundwater.

In the field of hydrogeological study, remote sensing and geographic information systems have emerged as key instruments for evaluating, tracking, and protecting groundwater supplies. It makes it possible to manipulate and analyse each layer of spatial data separately. It is employed in the modelling and analysis of the relationships between the layers. It is a quick and economical method for generating useful information about lineaments, geomorphology, geology and other topics that aid in determining the groundwater potential zone. Once the information is produced, GIS techniques are very cost- and time-effective and offer several advantages over traditional methods. Additionally essential are traditional methods to completely comprehend the hydrogeological characteristics of mountainous aquifers.

Understanding the relationship between different parameters and explaining the characteristics of aquifers was made possible by the integration of several data layers in a GIS environment, followed by spatial and statistical analysis of the data. This demonstrates the power of a GIS and its capacity to carry out statistical and spatial analysis using a variety of data formats. The hydrogeological significance of diverse rock kinds, structures, and landform types is demonstrated by the groundwater potential map that was created by integrating several thematic maps.

The integration of various data layers in a GIS environment allowed for a better understanding of the relationship between different parameters and the explanation of aquifer characteristics. This approach involved both spatial and statistical analysis of the data, showcasing the capabilities of GIS in handling diverse data formats and conducting in-depth analysis. The creation of a groundwater potential map, achieved by integrating multiple thematic maps, effectively illustrates the hydrogeological significance of various rock types, structures, and landform variations.

Understanding different types of landforms is important for assessing the potential for groundwater. Topographic information from digital elevation models can provide valuable details about the characteristics of the land surface. Typically, classifying the different landforms in a landscape involves interpreting remote sensing data or conducting traditional field surveys, which can be time-consuming and unpredictable. However, a more accurate identification of landforms is possible when local topographic knowledge is combined with a numerical description of the land surface. By using digital elevation models as a starting point, we can classify different topographic regions into categories of landforms. This approach has proven to be helpful in creating a detailed description of landforms, which is useful for assessing groundwater potential. Additionally, it allows for systematic examination and quantification of spatial variations in surface shapes.

Analysis using GIS and field research has shown that the presence of different types of rocks, structures, and landforms has a significant impact on the occurrence of groundwater. In areas dominated by argillaceous rock, structures play a major role in influencing the availability and storage of ground water. High yields are attributed to primary and secondary porosities. A flat topography with thick lineaments characterizes high ground water potential. In regions with a high concentration of arenaceous rocks, major porosity serves as the primary aquifer for groundwater storage. Rough terrain leads to groundwater being primarily found in drainage channels with valley fill deposits. Integrated aquifer systems composed of valley fill deposits and fractures along drainage channels exhibit high groundwater potential. Bedrock cracks are crucial in controlling ground water availability in semi-

consolidated rocks. Locations consisting of unconsolidated materials with bedrock fractures are promising for groundwater investigation. Dense lineaments on alluvial flood plains present excellent groundwater prospects. High yields are often associated with the cover of unconsolidated sediments in intermontane valleys, fractured valleys, and alluvial plains.

Large linear features, intersections of linear features, and similar structural characteristics with closely spaced fractures are often linked to high-yield wells and springs. These are important in hydrogeology because they represent potential areas for groundwater exploration. Low-yield boreholes near prominent linear features are caused by the scattered distribution of hard rock aquifers and poor site selection.

The area's groundwater potentiality was classified into Very Good, Good, Moderate, and Poor classes based on detailed geomorphological and lithological analysis. The current study has demonstrated a direct correlation between groundwater availability and the region's unique geomorphology, lithology, and geological structure. This correlation provides valuable insights into the factors that influence ground water availability and can be used to guide the selection of suitable locations for groundwater exploitation.

The study's findings highlight the significance of considering geomorphological and lithological factors when assessing groundwater potential. By integrating these factors into the decision-making process, it becomes possible to identify areas with high potential for groundwater exploitation. Moreover, the study emphasizes the importance of understanding the geological structure of the area, as it plays a crucial role in determining groundwater availability.

Furthermore, the study underscores the pivotal role of geospatial technologies in groundwater management, development and delineation. The utilization of technologies such as GPS, remote sensing and GIS has proven to be instrumental in accurately mapping and analyzing groundwater resources. These tools enable a comprehensive understanding of the spatial distribution of groundwater potential,

allowing for informed decision-making in resource management and development.

In conclusion, the study's comprehensive analysis of groundwater potentiality, coupled with the integration of geospatial technologies, offers valuable insights for effective groundwater management and development. By leveraging the direct correlation between geomorphology, lithology and geological structure, decision-makers can make informed choices regarding groundwater exploitation and sustainable resource utilization. The study's findings serve as a significant contribution to the field of geoscience and provide a framework for addressing challenges related to groundwater management in similar regions.

8.2. Conclusion on ground water quality assessment

The integration of Geographic Information Systems (GIS) has proven to be an exceptionally effective and powerful tool for the comprehensive analysis of groundwater quality. Prior to undertaking an analysis of groundwater quality within a GIS system, it is imperative to amass a significant volume of data. The analysis of the physico-chemical features of groundwater in a given area reveals that, at present, there exists no imminent major threat to its quality.

In stark contrast to surface water in streams, groundwater within an aquifer exhibits a notably sluggish movement and maintains extensive contact with the surrounding rock or silt. The majority of aquifers are comprised of minerals that exhibit an extremely slow rate of dissolution into groundwater, or the geological components of the aquifer are generally inert. Nevertheless, as long as groundwater remains in contact with the aquifer, it gradually assimilates an increasing quantity of dissolved particles.

In certain geographical locations, the rock or sediment contains specific minerals that possess the potential to contaminate the water with substances rendering it unsuitable for human consumption or agricultural purposes. Contamination may also emanate from exceptionally elevated concentrations of the pertinent element within the aquifer material. In other instances, the composition of the aquifer may consist of ordinary rock or silt, yet a particular characteristic of the water or the aquifer facilitates the accumulation of contamination to unsafe levels.

The physico-chemical characteristics of groundwater vary contingent upon the landform, which may be attributed to the movement of ground water from higher to lower elevations. The concentration of certain elements may undergo alterations during transit, transitioning from lower to higher concentrations or vice versa.

Distinct varieties of rock exhibit varying impacts on groundwater quality. The duration required for water to percolate through aquifers, the chemical composition of the rocks, the grain size of litho units, and the geological formations of the rocks collectively influence the purity of groundwater.

The groundwater in the study area meets the desirable limits for pH, TDS, total alkalinity, total chloride, total hardness, and electrical conductivity. However, hand pumps often contain high levels of iron, especially before the monsoon season, which may exceed the permissible limit. Water with elevated iron concentration should not be used for drinking. Some of the study area springs have iron levels within permissible bounds, but they need regular monitoring.

The concentration of calcium, magnesium, potassium, sodium, chloride, nitrate, sulphate, arsenic and zinc in the groundwater within the study area are within desirable and permissible limits.

On the other hand, the concentration of chromium, cadmium, nickel, manganese and mercury in some springs exceeds the permissible limit, requiring further analysis and regular monitoring.

8.3. Recommendation

The study area in Mizoram, one of the 28 Rural Development Blocks, has been the focus of detailed research on its groundwater potentiality. However, the remaining 27 R.D. Blocks in Mizoram await comprehensive study of their groundwater potential. It is imperative to conduct further studies and research to establish a hydrogeological information system that would facilitate a more extensive and beneficial utilization of groundwater resources. Geo-environmental variables such as aspect, slope, type of

soil, and land use/cover can significantly impact groundwater occurrence, and it is recommended to conduct groundwater prospecting using these characteristics to enhance the precision of evaluating groundwater potential.

In rural Mizoram, springs are the most significant water sources, and it is recommended to undertake further spring inventories and evaluations. Additionally, in the current scenario, it is crucial to conduct research on the impact of climate change on groundwater and develop strategies for revitalizing springs. Continuous monitoring of springs within permissible limits across various criteria in the study region is essential to identify and manage springs with potential non-potable classification, calling for the development of a reliable groundwater monitoring system.

Furthermore, the potential for anthropogenic sources of contamination and pollution at the surface or depth to impact groundwater underscores the need for research on aquifer susceptibility to contamination. Even in the absence of industrial pollution in the area presently, there may be a risk of significant water contamination in the near future, necessitating continuous quality monitoring of suspect springs.

An assessment of ground water resources is vital to prevent overexploitation, and recharge estimation is crucial for resource evaluation, warranting further in-depth research. It is advisable to conduct a thorough investigation of potential ground water zones before drilling boreholes or digging wells to ensure sustainable and efficient utilization of groundwater resources.