HYDROGEOCHEMICAL STUDIES OF GROUNDWATER IN PARTS OF DIMAPUR DISTRICT, NAGALAND WITH SPECIAL REFERENCE TO GROUNDWATER QUALITY

Rudowhelie Peseyie

DEPARTMENT OF GEOLOGY
Nagaland University 2020

HYDROGEOCHEMICAL STUDIES OF GROUNDWATER IN PARTS OF DIMAPUR DISTRICT, NAGALAND WITH SPECIAL REFERENCE TO GROUNDWATER QUALITY

By

Mr. Rudowhelie Peseyie

Submitted
In partial fulfillment of the requirement of the Degree of
Doctor of Philosophy in Geology
Nagaland University

DEPARTMENT OF GEOLOGY

NAGALAND UNIVERSITY

Prof. B.V. Rao
MSc, PG. Dip in GWG & PhD
Department of Geology
Nagaland University,
Kohima Campus, Meriema

Mobile: 08837489243
Email: bvrao@nagalanduniversity.ac.in
bvrao97@yahoo.com

Kohima, Dated: 25-3-2020

Certificate

This is to certify that the thesis entitled "Hydro-geochemical studies of groundwater in parts of Dimapur district with special reference to groundwater quality" submitted by **Mr. Rudowhelie Peseyie** bearing Registration No: 622/2014, 20th May 2014 for the degree of Doctorate of Philosophy in Geology, Nagaland University is based on the work carried out by him under my supervision and guidance.

I certify that the work contained in this thesis has not been previously submitted for any degree /diploma or any academic award to any University/Institute and that the sources from which ideas are borrowed have been duly referred to. The candidate has fulfilled all conditions laid down by the university.

(Prof. B.V. Rao)
Research Supervisor& Head

ABSTRACT

The study area (in parts of Dimapur District) lies within latitude 93º 41’00” E to93 º50’10”E and longitude 25º46’30” N to25º58’30”N and falls in the Survey of India(SOI) Toposheet Nos.83G/9 and 83G/13 having an area of about 173Sq.Km (Fig-1). The study area is bounded by Assam mainly on the North, East and West direction.

Dimapur district is exposed on the North Western part of the outer most Belt of Schuppen which is an en-echelon thrust known as the “Naga thrust” . The study area comprises Palaeogene, Neogene and Quaternary litho-tectonic units. The palaeogene are represented by Laisong, Jenam and Renji of Barail Group. The Neogene rocks of the study area are represented by Surma and Tipam Group. Quaternary rocks are represented by the Pleistocene-Recent sediments that make up the terraces and alluvium respectively.

Hydro-geologically, the study area falls under Unconsolidated Formations are found in low lying alluvium plain area. The valleys are mostly structurally controlled and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulders. Due to the coarse texture of the unconsolidated rocks the alluvial plain has high permeability and high specific yield; hence the study area represents the potential aquifer zones like Dimapur valley for groundwater development.

The occurrences and movement of groundwater in any area is governed by several factors such as topography, lithology, geological structures, depth of weathering, extent of fractures, porosity, slope, drainage pattern, landforms, land use/land cover, climate conditions and interrelation between these factors.

Groundwater forms the important source of water supply in the study area; its main uses are for drinking, domestic purposes, agriculture and industries. Compared to surface water, it has a constant composition, temperature, and is safer from contamination, chemical, radiogenic and biological pollution. Further, the groundwater acts as primary source in arid and semi-arid regions and of surface water in humid regions. Since groundwater is an important reliable source of drinking water in Dimapur District, protection of its quality should become a high priority management goal.

Dimapur town have been growing at an alarming rate over the past few decades. Thus, trend of urbanization is an anthropogenic outcome of the process of economic growth through industrialization, consequently facing the traditional environmental problems such as lack of sanitation, water supply, lack of open space and recreational areas, traffic congestion etc. The groundwater as well as the surface water is greatly polluted as the rivers passing through or passing by the side of the town are highly polluted. The water for human consumption is sourced from groundwater wells without biochemical treatment and the level of pollution has become a major cause of concern. In order to understand and evaluate such problems, it is essential to carry out qualitative and quantitative studies before making recommendation on their uses.

Keeping this view, the present study aims to trace the groundwater resources and assessment of groundwater quality for drinking and irrigation purpose in the study area based on the hydrogeology, geomorphology and hydro-geochemistry. The present study has been presented in the form of Ph.D. thesis comprising seven chapters.

Chapter1. Introduction provides the general information on the study area including location, accessibility & communication, physiographic, drainage, climate and rainfall, soil, flora & fauna, human habitation, literature survey, previous works on the study area and aim & scope of work.

Chapter II (Geological setting and hydrogeology) includes the regional geology, geology of Nagaland, hydro-geology of the study area, and tectonic setting. Various lithological units of the study area are identified. The Dimapur alluvial plain comes under unconsolidated unit and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulders.

Chapter III Methodology: Various field and laboratory techniques have been described. Field work includes the study of geology and collection of groundwater samples during pre and post monsoon periods. Laboratory work includes the estimation various physical and chemical parameters by using various equipments as per the standard procedures. Piper diagram is used to classify the ground water.

Chapter IV focuses on hydro-geomorphology of the study area that occurs at elevation ranging between 139.5m amsl to 220m amsl as flat with gentle undulations and valley fills called Dimapur alluvial plain. Geo-morphologically, two main land forms are identified in the study area are piedmont and floodplain. The litho log reveals that in the piedmont zone there are three confined aquifers with 9m- 12m in thickness. Another litho log from floodplain area reveals that there are at least five confined aquifers zones with the thickness ranging from 1.5m to 34m.The piezometric water levels in the study area are ranging from about147m in the piedmont zones and about 113m in the floodplain zones.

Chapter V Hydro-geochemistry: 53 groundwater samples were analyzed for physical and chemical parameters like Turbidity, Electrical conductance (EC), pH, Total Hardness (TH), Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate (HCO_3), Chloride (Cl), Iron (Fe), sulphate (SO_4) and fluoride (F) . The data were compared with standards of BIS and WHO to assess the quality of groundwater in the study area. In addition to that some trace elements (metals) like Copper (Cu), Zinc (Zn), Nickel (Ni) and Arsenic (As) were estimated and presented.

Chapter **V**I Discussion: focuses mainly on the groundwater resources and its quality for drinking and irrigation purposes based on the hydrogeology, geomorphology and hydro geochemistry.

Finally, Chapter VII summarizes the work carried on the study area on the bases of present investigations and the conclusions have been recorded.

The salient features of the present research work are as follows:

- Hydro-geologically the study area consist mainly of alluvial plain comes under unconsolidated unit and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulders

- Geo-morphological study reveals that the study area has multiple confined aquifers. The aquifers have high permeability due to coarse texture, have high water table gradient, and can transmit large quantities of water to the wells.

- Physical parameters like turbidity shows that 88.68% and 90.57% of samples are within desirable limit, for drinking purpose during the pre &post-monsoon respectively..

- The pH of the tested water samples indicates that the groundwater in the study area is acidic to neutral in nature. Majority of the groundwater samples have the pH between 4 and 8.5 indicating bicarbonate type of water.

- The TDS values falls under useful category for irrigation and 98.11% of the groundwater falls under desirable category for drinking.95.6 % in respect of Total hardness (TH) falls under desirable limit for drinking purpose during pre-and post-monsoon period.

- In the study area all the groundwater samples with respect to calcium(98.11%) and magnesium (94.34%), bicarbonate, and Cl falls under desirable limit for drinking purpose in both the seasons.

- It is found that 41.51% and 62.26% with respect of iron are within acceptable limit for drinking purpose as per BIS .The SO_4 content in all the groundwater samples of the area found to be within acceptable limit for drinking purpose.

- With respect to sodium (Na) that 73.58% and 77.35% of groundwater samples falls under acceptable limit for drinking water.

- The concentration of Zn and Ni are found to be within acceptable limit for drinking purposes in both the seasons. Arsenic (As) concentration in most of the samples are found to be below detection limit.

- Piper's Trilinear Diagram reveals that majority of the groundwater samples shows alkalis exceeding alkaline earth during pre-monsoon period, and the remaining samples shows strong acids exceeding weak acids. In post-monsoon period 29 samples out of 53 shows alkalis exceeding alkaline earth and 29 samples show weak acids exceeding strong acids. 12samples in pre-monsoon and 20 samples in post-monsoon show neutral.

- SAR shows that most of the groundwater samples during pre-monsoon period and 81.1% during post-monsoon period falls in excellent class for irrigation purposes.

- USDA diagram reveals that 73.8 % of groundwater samples fall in Good water category for irrigation purposes. Further permeability Index shows that 97% of the groundwater samples during pre and post-monsoon respectively falls under class I and class II i.e. Good and Suitable category for irrigation purpose.

- Residual Sodium Carbonate (RSC) reveals that most of the samples in pre and post-monsoon are suitable for irrigation purpose.

- Kelley's Ratio, also shows that most of the samples suitable for irrigation purpose.

- Overall study reveals that the groundwater in the study area is good for drinking purpose and suitable for irrigation purposes.

.

***

DECLARATION

I, Mr**. Rudowhelie Peseyie,** do hereby declare that the subject matter of this thesis is the record of the investigations done by me under the supervision of Dr. B.V. Rao Professor and Head, Department of Geology, Nagaland University, Kohima Campus, Meriema. The work contained in this thesis is original and in part or in full, has not been submitted by me for any research degree to any other university/Institute.

This thesis is being submitted to the Nagaland University for the award of degree of Doctor of Philosophy degree in Geology

(Prof. B.V. Rao)
Research Supervisor & Head

(Mr. Rudowhelie Peseyie)
Candidate

Acknowledgement

At the outset, I am very grateful to my supervisor Dr. B. V. Rao, Professor& Head, Department of Geology, Nagaland University, Kohima, for giving me the opportunity to pursue my research under his excellent guidance. As a teacher and a mentor, extending his constant support, encouragement and invaluable guidance during the entire course of my research are invaluable.. I record my profound sense of gratitude to him.

I would like to express my sincere gratitude to Prof. G. T. Thong, Dr. S. K. Srivastava and other faculty of the Department of Geology, for their valuable suggestions and help.

I would like to express my sincere thanks to Mr. Husazo Epao Principal Patkai Christian College (Autonomous) for granting Study Leave for my research work. I am very thankful to Dr. T. Pieru, Dean of Sciences and Dr. Devila Devi, Head, and the faculty, Department of Geology, Patkai Christian College (Autonomous) for their suggestions and timely help during the course of my research work.

I would also like to express my sincere thanks to UGC (NERO) Gauhati for granting Teacher Fellowship to enable me to carry out my research work.

My sincere thanks goes to Mr. G. Kenye and Mr. Wangthan, Directors, DGM, Govt of Nagaland, Dimapur for granting permission to use their library and laboratory.

I am thankful to all my colleagues Ms. Vilavonuo Keditsu. Ms. Akhrulu Vero, Mr. Sheyamong P, Mr. Keneisazo Nagi who have helped me in various capacities during the course of my research work.

I will not be doing justice if I don’t thanks Mrs. B.V. Rao who has always been so cordial and good hospitality whenever I used to visit their residence during my research work.

I am very grateful to my loving wife Mrs. Pinuo Nakhro for her moral and financial support. I am gratefully acknowledged the encouragement and inspiration from my daughters and my mother’s prayer support.

(Mr. Rudowhelie Peseyie)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Lists of plates

along the NH 39.

Abbreviations:

ACZ	- Agro Climate Zone
$AgNO^3$	- Silver Nitrate
AHP	- Analytic Hierarchy Process
Al	- Alluminium
Alf	-Alfisols
APHA	- American Public Health Association
As	- Arsenic
amsl	- Above mean sea level
B.C	- Before Christ
$BaSO_4$	- Barium Sulphate
BDL	- Below Detection Limit
Bgl	- Below Ground Level
BIS	- Bureau of Indian Standard
C	- Celsius
C1	- Low salinity
C2	- Medium salinity
C3	- High salinity
C4	- Very high salinity
Ca	- Calcium
$CaSO_4 2H2O$	- Calcium Sulphate Dehydrate
Cl	- Chlorine
Cm	- Centimeter
CO_3	- Carbonate
Cu	- Copper

DBTS	- Deposition of Heterogeneous Transitional Lithology
DC	- Deputy Commissioner
DGM	- Directorate of Geology and Mining
Dip	- Diploma
Dr	- Doctor
E	- East
EC	- Electrical Conductance
EDTA	- Ethylene Diamine Tetra Acetic acid
EPA	- Environment Protection Agency
Et al	- And others
Etc	- Etcetera
F	- Fluoride
Fe	- Iron
Fig	- Figure
GIS	- Geographic Information System
Govt	- Government
GPS	- Global Positioning System
HCO_3	- Bicarbonates
H_2CO_3	- Carbonic Acid
IBR	- Indo- Burman Ranges
ICAR	- The Indian Council of Agricultural Research
IOM	- International Organization for Migration
K	- Potassium
Km	- Kilometer
Lat & long	- Latitude and Longitude

Max	- Maximum
Mg	- Magnesium
Mg/day	- Milligram per day
Mg/l	- Milligrams per liter
$MgSO_4$	- Magnesium Sulphate
Mn	- Manganese
Mr.	- Mister
MSc	- Master of Science
N	- North
NA	- Not applicable
Na	- Sodium
Na_2SO_4	- Sodium Sulphate
NaCl	- Sodium Chloride
NE	- North East
NE-SW	- Northeast- Southwest
NEH	- National Endowment for the Humanities
NERO	- North Eastern Regional Office
NH	- National Highway
Ni	- Nickel
NNE-SSW	- North-North-East-South-South-West
NO_3	- Nitrate
NOB	- The Naga Ophiolite Belt
NSCIR	- National Seminar on Chemistry in Interdisciplinary Research
NTU	- Nephelometric Turbidity Units
Oct	- October

ONGC	- Oil and Natural Gas Corporation
pH	- Potentia Hydrogeni
PhD	- Doctor of Philosophy
PI	- Permeability Index
pp	- Pages
ppm	- Parts per million
Prof-	- Professor
RSC	- Residual Sodium Carbonate
RSE	- Relative Standard Error
S-W	- South-West
S1	- Low sodium water
S2	- Medium sodium water
S3	- High sodium water
S4	- Very high sodium water
SAR	- Sodium Absorption Ratio
Si	- Silicon
SO_4	- Sulphate
SOI	- Survey of India
TDS	- Total Dissolved Solids
TH	- Total Hardness
UGC	- University Grants Commission
USDA	- United States Department of Agriculture.
Vl	- Volume
WHO	- World Health Organization

WS.NO	- Water Sample Number
Zn	- Zinc

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

India, being the cradle of one of the oldest civilizations, has a long history of discovery and used of groundwater resources. The excavations at Mohenjo-Daro have discovered dug wells existing in 3000 B.C. The writing of Vishnu Kautilya during 300 B.C indicated that groundwater was used for irrigation. In the beginning the civilization was established close to the perennial rivers like Sindhu (Indus) and Ganga. Later on, due to the spread of civilization away from major perennial rivers into the valleys of smaller seasonal rivers and streams; people start using groundwater for drinking water and irrigation. Even in those days it was known that groundwater is cleaner than surface water and hence better for drinking purpose. Therefore, by the side of a flowing river women used to dig small pits on the sandy bank, a few meters away from the river, and take filtered groundwater in their pots for domestic use. This practice has continued till today (Limaye, 2003).

Potable water is the fundamental human need, and to maintain fundamental hygiene adequate potable drinking water supply is a must (W.H.O, 1993, 2004). This basic constituent of life is present everywhere in the universe and it covers 75% of the earth. However, pure water can never be found in nature because pure water is composed of one oxygen atom covalently bonded to two hydrogen atoms. Their attraction for the shared electrons is not equal, the oxygen atom is more electronegative (an atom's tendency to attract electrons). The polarity of water molecules is a result of the negatively charged electrons tends to spend more time around the oxygen. Water is a good solvent due to its polarity hence, water in nature contains a number of impurities in varying amounts. As water moves through the hydrologic cycle it intersects with atmosphere, soils and sub-surface geologic formations. This course of nature affects the chemical composition and its constituents.

Water is a valuable and the most commonly used resource. Resources of surface water may pollute and unavailable at site because it is exploited since hundreds of years till these days or even may fail to fulfill the requirement of supply. Water occurs in the zone of saturation where all the interconnected pores are occupied by water that is under hydrostatic pressure is called groundwater. Structural features like fractures and fault zones, sub-surface barrier like dykes and sills, colluvial-alluvial deposits, weathered zones and vesicular lava are the favorable locations of groundwater repositories.

Groundwater occurs commonly and is widely distributed. Apart from polar icecaps and glaciers groundwater form the biggest resource of clean water on the earth. The amount of fresh water in lakes and reservoirs are 30 times less than the amount of fresh water in the subsurface water within 800m from the ground surface. The amount of subsurface water in between ground surface to the depth of 800m is over 300 times the amount of fresh water in stream channels, at any one time (Raghunath, (2006). However, any amount of water available for any use, its quality should be assessing so that it would not cause hazards for human beings, as well as animals and plants. Subsurface water resources of the third world countries including India are getting increasingly polluted because of unchecked and unplanned activities of man such as unplanned and untreated waste disposal of domestic and industrial effluents.

Water, the universal solvent has the power to dissolve minerals constituents in the soil and rocks in course of their journey through the subsurface formations. These dissolved minerals constitute the total dissolved solids in subsurface water. Back and Barnes, (1965) stated that the quantities and to some extent the quality of subsurface water is associated with the geological formations, vegetation covered, rivers, streams, lakes, swampy areas and also near-by industrial establishments.

The possible pollutants in groundwater are practically limitless. The wide ranges of pollutants found in subsurface water are organic, inorganic chemicals, biological, physical and radiological types. The degree and extent of pollution of subsurface water are mainly depends on the amount and concentration of the pollutants. It is also depending on hydrologic properties of rocks, hydraulic gradient, depth to the water table as well as the time factors. When applied on the subsurface water, the pollutants travel largely downward till they reach the water table and then move laterally. Shallow water table increases the risk of pollution. The fined grained soil has natural filtration properties and generally when subsurface water passes through 3-5 meters of the fine-grained soil removes a greater part of the harmful bacteria. Sujatha, (2002) stated that the horizontal path of flow of chemical pollution is more extensive than that of bacterial pollution.

Some of the most important factors effecting the chemical composition of water according to Handa (1969) are physical and chemical distinctiveness of the rocks through which surface water is circulating, geology of the area, climate and effect of the plant cover, role of microorganisms, chemical, physical and mineral characteristics, topography of the area, mixing with connate water, role of man in environmental pollution that bringing about changes in hydrological cycle.

The quality of subsurface water and its management is a very important anxiety for humankind since it is directly coupled with the welfare of human being. Clean and potable water is the fundamental human need to all, and to maintain the primary sanitation sufficient clean drinking water supply is necessary W.H.O, (1993). Todd (1980) stated that presently the quality and quantity of groundwater is equally important. The quantity of surface water available for any purpose, without assessing it quality would cause hazards generally to all the living beings and particularly to human kind. It is, therefore indispensable to assess the suitability of subsurface water to be used for drinking purpose so that the subsurface water to be used for drinking would be free from minerals, organisms and elements that are harmful to our health.

The different between subsurface water pollution and surface water pollution is that subsurface water once polluted may continue to remain in the underground for ten or even hundreds of years. This marked the dissimilarity between surface water pollution and subsurface water pollution. To reclaim polluted subsurface water is much more difficult, time consuming and expensive comparing to reclaiming of polluted surface water. It may take decades or even centuries to get fresh water from polluted aquifer. It is therefore very important for every entity to give our best effort to prevent, ease and eliminate subsurface water pollution.

1.2 IMPORTANCE OF GROUNDWATER

Groundwater resources of the world form the most dependable source of essential water supply all over the world; its main uses are for drinking, agriculture and industrial purposes, etc.

1. Groundwater has a stable composition, temperature, and is safer from contamination, chemical, radiogenic and biological pollution as compared to surface water.
2. Groundwater acts as primary source in the region of severe lack of available water like desert and dry land and also acts as an important factor in determining stability construction of engineering works, it causes landslides and subsidence.
3. Groundwater supply is more dependable than the seasonal, unpredictable surface water and provides fence against water paucity and drought. Moreover, groundwater has fewer organic pollutants and cheaper to develop.

4. Unlike other natural resources, groundwater is present all over the world. Generally, groundwater is renewed during a past of each year and can get throughout the year, provided that there is adequate replacement and the source is protected from pollution.

1.3 LOCATION OF THE STUDY AREA

Nagaland is the sixteenth state formed of the Indian Union. Geographically, it lies towards the north-eastern margin of India. The state of Nagaland is bordering with a country called Burma in the east and the neighbouring states, Arunachal Pradesh, Assam and Manipur in the North West, West and South respectively. The Naga Hills are the westernmost morpho-tectonic unit of the Myanmar orogen that continues into the eastern syntaxial bend of the Himalayas in the north. The central lowlands of Myanmar lie on its east and the Mikir Hills Precambrian Massif and the Brahmaputra trough containing Miocene to Quaternary sediments lie in the west.

The study area covering Dimapur plain lies within latitude 93º 41’00” E to 93 º50’10”E and longitude 25º46’30”N to 25º58’30”N and lies in the Toposheet Nos.83G/9 and 83G/13 of the Survey of India (SOI) having an area of about 173SqKm. The Dimapur plain is surrounded by the state of Assam on the North, East and West, and the South-east is bounded by Medziphema Block of Dimapur district. The location map is given in figure 1.

1.4 ACCESSIBILITY AND COMMUNICATION

Dimapur is the biggest town and commercial capital of Nagaland. It is the only town having Railway station and Airport in Nagaland connecting to the other parts of the country. Being the commercial center of the state; it is well connected with the neighboring states like Assam and Manipur through national Highway NH-61, NH-29, and NH-36. The distance from Dimapur to the Kohima (capital town of Nagaland) by road is 74 km. presently the road is widening from doubled to four lane road.

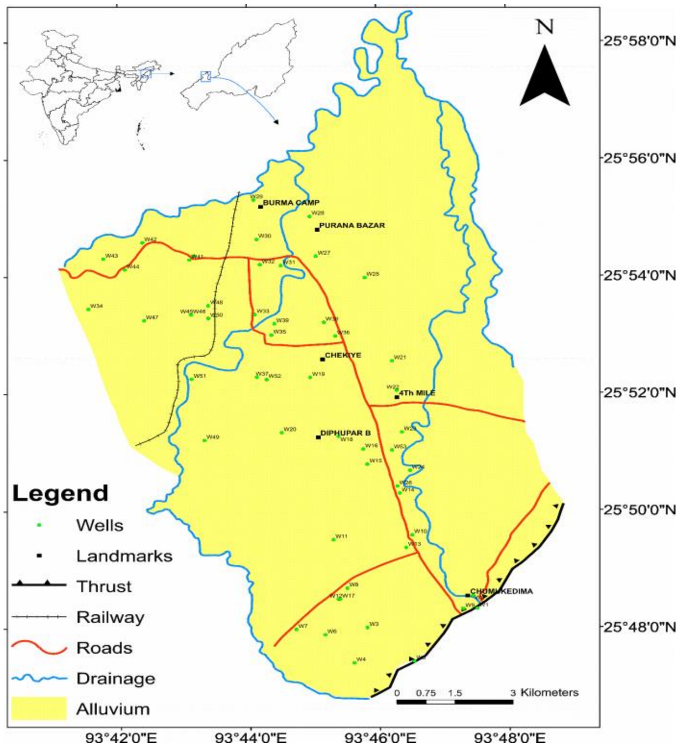


Fig.1: Location map of the study area modified after DGM (2010)

1.5 PHYSIOGRAPHY

Dimapur district lies on the North Western side of the Patkai-Naga hills. It is divided into four physiographic units namely: -

1. Alluvial plains.
2. Low to moderate linear ridge.
3. Moderate structural hills.
4. High structural hills.

Physiographically, the study area, as a whole, shows a plain valley called Dimapur alluvial plain valley occurs at elevations ranging between 139m to 220m alms as flat with gentle undulations and valley fills. It south and east is surrounded by Medziphema Block, north and west by Karbi-Anglong and Golaghat districts of Assam. Dimapur today compared to it old town area has expanded to a great extent by merging with its neighbouring villages to become a city. The present day Dimapur city is a contiguous urban sprawl from Dilai gate and Newfield check-gate bordering Assam up to the foothills of Chumukedima and Seithekiema.

1.6 DRAINAGE

The two main rivers draining the study area are Dhansiri and Chathe rivers. Dhansiri River is originated from Peren district and enters the western most part of the Dimapur district and flows in to north easterly direction. This is a perennial river and drains areas of Dhansiripar, Chumukedima and Dimapur Sadar. The river bed is made up of fine sandy loam. Some of its main tributaries are Lingrijan, Maiju Disa, Nowkathajan, Langlong, Singrijan, Khova, Kiker, Disagaphu Jan, Patharjan, Langthai Disa, Amalumajan, Khuja Disa, Bajijan, Bora Monglu, Ntanki, Ha, Hajakgaraing, Thegarikeru, Hukhaphe Ru, Heza Kwo Reu, Zalte Reu, Kikiebe Lupuo Reu and Zaitei Reu etc.

Diphu (Chathe) river is located at the middle portion of the district flowing into northerly direction and finally converge with Dhansiri River at some 16 Kms away from Dimapur town toward NNE direction. This perennial river drains a large area of Medziphema, Chumukedima and also parts of Nihokhu and Kuhuboto area. The beds of this river are mostly made up of a mantle of boulders, cobbles, gravels, pebbled etc. Some of its main tributaries are Atu Ghoki, Chuza Ru, Khokhi Ru, Jharnapani, Dzumha, Zamha, Te Ru, Dzukou Ru, Tsungu Ru, Kepekhra Ru, Tekhu Ru and Khova Ru, etc. These two main rivers and their tributaries are responsible for shaping the geomorphic landscape of the study area.

1.7 CLIMATE AND RAINFALL

The average annual rainfall is 1504.7mm. The minimum and maximum temperature in the lower plain valley is 12˚C to 37.06˚C and has a relatively humidity ranging from 74% to 93% during summer, however it is much lesser in the hilly areas. The district experiences a sub-tropical to cool temperature type of climate due to variation in altitude levels (DGM, 2010).

Dimapur district lies within humid sub-tropical agro climate zone (ACZ). It is hot and humid during summer and in winter the climate is pleasant i.e. moderately cold. The district enjoys two spells of rain in two seasons- South-west monsoon in summer and Northeast monsoon in winter. Normally the South-west monsoon starts from the first week of May and continuous up to October and the North-east monsoon normally begin in the month of November and last till December. The maximum shares of the rains were received during June to August. The average rainfall is about 100m to 150m. The average annual rainfall for the last ten years recorded by ICAR Jharnapani is given in the table 1 below: -

Table 1: Average annual rainfall (2009 to 2018)

Year	Average rainfall
2009	968.1
2010	1657.3
2011	1679.8
2012	1327.1
2013	1684.7
2014	1178.3
2015	1364.1
2016	1716.0
2017	2137.9
2018 (Up to October)	1281.4

The annual maximum temperature and minimum temperature for the last ten years is recorded as 30.7˚C and 18˚C respectively. The maximum one-day temperature is recorded as 40˚C and minimum one day temperature is recorded as 10˚C (ICAR Jharnapani). The annual maximum and minimum temperature for the last ten years is given in the table 2 below: -

Table 2: Annual average temperatures (Max and minimum) for last ten years (2009-2018)

Year	Max temp	Min temp
2009	29.5	18.6
2010	28.7	18.5
2011	28.5	18.0
2012	28.6	18.5
2013	28.8	18.3
2014	29.4	18.4
2015	29.4	18.6
2016	30.4	18.6
2017	29.4	18.5
2018 (up to Oct.)	30.7	19.2

1.8 SOILS

The soils of Nagaland belong to 4 orders- Inceptisols, Ultisols, Entisols and Alfisols and seven sub-orders, ten great groups and fourteen sub-groups and seventy-two soil families (Maji *et al* 2000). In Dimapur valley Alfisols is dominating. “Alf” refers to alluminium (Al) and iron (Fe) because of their productivity and abundance. They represent important soil orders for food and fibre production. They are deficient in nitrogen and available phosphorus. They have tendency to acidify when heavily cultivated, especially when nitrogenous fertilizers are used. Alfisols are base saturation and are relatively abundant in calcium; magnesium and potassium. They have relatively high native fertility.

1.9 FLORA AND FAUNA

Dimapur valley is endowed with rich vegetation of mixed evergreen forest with thick undergrowth mainly of bamboos, bananas, various shrubs, creepers and grasses and different varieties of forest trees including Bomsum, Hollock, Teak, Nahor, Badam, Bhelu, Neem etc.

A variety of wild animals like wild boars, deer, monkeys, jungle cats, porcupines, eagles, fowls, wild dove, squirrels, pythons and fishes etc are living in the study area. The famous

Zoological Park of Dimapur, located at Rangapahar is 6km away from Dimapur and is a home for many endangers animal species.

1.10 HUMAN HABITATION

In Kachari language the word “Dimapur” means “city of Big-river”, the meaning is related with the people who live in the big river valley. Dimapur town unlike other towns in Nagaland is a homeland for all the tribes of Naga communities. According to 2011 census the population of Dimapur town is 122,834. The Naga tribes dominates Dimapur town comprises about 50% of the town’s population. The other 50% of the town’s population is shared by the prominent groups including indigenous Assamese communities like Kacharis & Boros, Bengalis, Oriyas, Nepalese, Marwari, Punjabis, Tamils, Keralites and the Tibetan traders who have settled in the town. The main occupation of the Dimapurians is business and government servants. Agriculture, handicraft, farming, horticulture etc are hobbies for many people. The peoples are simple, co-operative and hospitable by nature.

1.11 LITERATURE SURVEY

A true review and survey of previous literatures is an essential aspect of a research study. It helps the researcher to organise the knowledge of the specific area of research, which was done earlier and organized the creation of the knowledge. Therefore, an attempt has been made to review the work that has been done previously in the field of hydro-geochemistry.

Not much was known about the stratigraphic of the region before the pioneering works of Evans (1932). Later several workers have attempted on the stratigraphic, structure and tectonic frame worked of the region including those by Mathur and Evans (1964), Brunnschwiller (1966), Acharyya, *et al* (1986), Mathur and Evans (1964) described the geological formations in the region were formed during the period of Tertiary to Quaternary. According to them the primary sedimentary structures in Surma and Tipam groups of rocks indicates fluvial condition of deposition. They give stratigraphic succession of Dimapur and in Dimapur valley alluvium deposit consist of clays, silts, pebbles and boulders which constitute more than 90%.

Piper (1944) contributed in the chemical interpretation of groundwater analysis by using a graphical procedure. Wilcox (1955) classified groundwater for irrigational use. Hem (1975,

1985) Studied and interpreted the chemical characteristics of natural water and Handa (1975) discussed briefly groundwater pollution in India.

Sridhar and Pillai (1973) had conducted field and laboratory investigations of groundwater samples collected from wells located near the sewage channel on the outskirts of Bangalore city, septic tanks on the campus of the Indian Institute of Science and the septic tanks of four industrial establishments. Results of their investigations revealed that all the wells are polluted with sewage pollution.

Samadder, *et al* (2007) explained how Remote sensing data provides information on spatial deposition of geological and geo-physical features such as rock types, faults, landforms, drainage, soil, water bodies etc .Well-log data that help in determining aquifer depth and the lithological details like rock types, numbers of layers, thickness, textures etc that helps to identify the area with favourable aquifer deposition involving aquifer boundaries, areal extent, thickness and volume.

Tiwari and Singh (2014) Assess the quality of subsurface water for domestic, irrigation and other purposes based on physico-chemical parameters of sub-surface water like Potentia hydrogeni, Electrical Conductance, Total Dissolved Solids, Total Hardness, Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Chloride, Nitrate, Sulphate, and Fluoride. They have plotted their analysed data on Piper's trilinear diagram. Groundwater qualities were assessed for irrigation uses considering the values of salinity and sodium hazard by employing SAR, RSE, Percent Sodium and Kelly's Index.

Jharia, *et al* (2016) determined the groundwater potential zone on Saja Block, Chhattisgarh by applying several thematic layers like geology, geomorphology, drainage density, rainfall, groundwater depth etc. by using GIS and remote sensing. They used AHP to decide the measures of several themes for classifying the subsurface water into five potential zones in Saja Block as - very high, high, medium high, medium and low potential zones, which were established using measures assigned and normalized associated with the input of the different themes to subsurface water occurrences.

Rao, *et al* (2016) have worked on "Impact of Urbanization on Groundwater Quality, A Baseline Study" with the intention of introduce a baseline information and to estimate subsurface water quality, its variation in comparison with urbanization and hydro chemical constituents. They also assessed the groundwater quality based on the common parameters like pH, EC, TDS, TH, Ca, etc. and stated that anthropogenic action governs the urban subsurface water which is determined by presents biogenic contaminants in subsurface water.

Laniyan, *et al* (2017) discussed the impact of urbanization on public health at the basement complex of Ibadan, S-W of Nigeria. They also highlighted that most the groundwater contamination that always leads to human health problems result from high concentration of metals such as arsenic, cadmium, lead etc which contaminates groundwater either by geogenic (as a result of weathering of source rocks) or anthropogenic in nature (such as mining, smelting operations, industrial production, domestic and agricultural activities).

Rubia and Jharia (2018) using eight Water Quality Index like alkalinity, Potentia Hydrogeni, Hardness, Chloride, Fluoride, Calcium, Magnesium, and Nitrate. BIS, (2012), were referred to examine the used ability of subsurface water for human consumption and computation of Water Quality Index. Their work indicates that anthropogenic actions are affecting the subsurface water condition of the study area.

Purushothan, *et al* (2017) has worked on "subsurface water pollution in Parts of Nalgonda District, Telagana. They examined the quality of water in Indian perspective as well as WHO drinking water standards by using major cations and anions and also trace/heavy metals of the subsurface water. They interpreted that irregular trace elemental concentration is indicated by phenomenal increase in chemical composition because of the interplay of different processes like groundwater mineralization and hydraulic conductivity through fracture and joint, silicate weathering and dissolution/precipitation processes and also the anthropogenic activities. In order to assess pollution from time to time and to take appropriate management measure they suggest a need for regular groundwater quality monitoring.

DGM (2009) has carried out feasibility studies on Artificial to groundwater in Dimapur District. In 2010 they had carried out on Hydrogeomorphological Mapping in Dimapur Valley. They described geomorphology of Dimapur valley basing on fluvial action of erosion and deposition within the area particularly by Dhansiri and Chathe (Diphu) rivers. Two different types of landforms were delineated for Hydrogeomorphological study as: - Piedmont and flood plain. Hydro-geologically they divide the district into two distinct units as semi-consolidated and unconsolidated formations. Semi-consolidated formation constitutes the hilly terrains and their formations are sedimentary rocks belonging to Barail, Surma and Tipam of Tertiary age comprising of clay, shale, siltstone, ferruginous compact sandstone, pebbles and boulder beds.

Unconsolidation formation occurs in the piedmont alluvial plains and intermontane valley fills area along the foothills of Dimapur-Gaspani areas. This unit is made up of clay, silt, sand, gravels, pebbles, boulders and conglomerate beds of recent alluvial deposits. According to them groundwater prospect is high along sand, gravel and pebble beds in the unconsolidated formation.

Several researchers across the world have focused on groundwater quality including Sujatha and Reddy (2003), Jasrotia and Singh (2007), Prasanth, *et al* ((2012), Selvakumar, *et al* (2017), Kaur, Gorka and Kumar (2018) etc.

1.12 PREVIOUS WORK ON THE STUDY AREA

The Central Ground Water Board, Ministry of Water Resources Govt. of India in early 1970 first carried out groundwater exploration in Nagaland with a few exploratory drillings in Dimapur, Changki and Tizit valleys aims to target the groundwater potential zones and scope for future development in Nagaland.

Subramanian and Deb (1976) carried out systematic hydro-geological survey in Dimapur valley. Their works mainly deals with salient features of geology, geomorphology and hydro-geological scenario.

DGM, Govt. of Nagaland was started groundwater exploration in the state in the later part of 1980, particularly in Dimapur valley. Newmai, A. and Jami, M. (2010) from the DGM had carried out hydro-geological mapping in Dimapur valley. They described geomorphology of Dimapur valley basing on fluvial action of erosion and deposition within the area particularly by Dhansiri and Chathe (Diphu) rivers. They have interpreted the image of landforms on 1:50,000 scale. According to them groundwater prospect is high along sand, gravel and pebble beds in the unconsolidated formation.

Puzari, *et al* (2015) Studied on "Assessment of Groundwater Quality from Dimapur District of Nagaland and Karbi-Anglong District of Assam for Drinking Water and Possible Related Health Hazards. Kshetrimayum and Hegeu (2016) had studied the causes of elevated Iron and Manganese concentrations in surface water and subsurface water and its state of toxicity around Naga Thrust of Assam-Arakan basin. Peseyie and Rao (2017) assessed the quality of subsurface water for drinking purpose in and around Dimapur Town, Nagaland. Peseyie and Rao

(2020) Hydro-geochemically evaluated the groundwater quality in and around Dimapur town, Nagaland.

1.13 AIM AND SCOPE OF WORK

Dimapur town have been growing at an alarming rate over the past few decades. Thus, trend of urbanization is a natural outcome of the process of economics growth through industrialization, consequently facing the traditional environmental problems such as lack of sanitation, water supply, lack of open space and recreational areas, traffic congestion etc. The groundwaters as well as the surface water are greatly polluted as the rivers passing through or passing by the side of the town are highly polluted.

We need water for different purposes like drinking, domestic use, industries, irrigation etc. Each body of water has to be analyzed on a regular basis to confirm its suitability for different purposes.

At current state, in the study area no major industries are being found, but domestic waste that is freely discharged everywhere that polluted the subsurface water. However, in parts of Dimapur district particularly in plain area, the water used for drinking and domestic purposes is sourced from groundwater without bio-chemical treatment hence the quality of groundwater has become a major cause of concern. It is, therefore indispensable to assess the suitability of subsurface water to be used for drinking purpose so that the subsurface water to be used for drinking would be free from minerals, organisms and elements that are harmful to our health.

Taking into account, the present study aims for estimation of subsurface water quality to know its suitability for drinking and irrigating purposes and to know the contamination of groundwater related to pollution in parts of Dimapur District, Nagaland based on hydrogeology, hydrogeomorphology, and hydrochemistry of groundwater.

***

CHAPTER II

GEOLOGICAL SETTING AND HYDROGEOLOGY

2.1 REGIONAL GEOLOGY

The Indian, Eurasian and Sunda plates began converging during the Alpine Orogenesis, which resulted in the development of a tectonically occupied structural framework of Northeast India and the adjoining regions (Tapponier, *et al* 1986). The Indo-Myanmar Orogenic Belt covers a widespread area within the Indian part in the north-eastern states, Separated from the stable block of Mikir Massif by the Dauki-Disang vertical strike-slip fault and the Brahmaputra basin by the plunge called the Naga Thrust, the orogenic band/belt is wrapped by a deposit of clay, silt, and sand called alluvium of Bangladesh on its western fringe and its eastern edge it merges with the central Lowland of Myanmar.

The Naga Orogenic Belt is bounded on the west by the Precambrian Mikir Massif of Assam, with marginal Tertiary shelf sediments on the northwest by Brahmaputra trough lineaments. The Naga Ophiolite Belt (NOB), restricted along the eastern margin of this Orogen, is bounded on the east by Cenozoic sediments of the Central Lowlands of Myanmar and on the west by a tectonic pile of Tertiary over-thrusts known as “Belt of Schuppen”(Mathur & Evans, 1964)and Disang flysch sediments. To the north, it passes into the eastern syntaxial bend of the Himalayas and southward through Chin-Arakan-Yoma-Andaman-Nicobar into the Mentawai group of islands of the Sumatra coast (Mitchell and McKerrow, 1975).Nearly 90 to 95 percent of the surface area of Nagaland is covered by Cenozoic sedimentary and the rest 5 to 10 percent is occupied by igneous and crystalline rocks of Mesozoic-Cenozoic age. Generally, they exhibit a NNE-SSW trend dipping towards Northwest and Southeast with a moderate to steep dip angle.

The orogenic belt is composed mainly of rocks of Upper Cretaceous to Upper Pliocene. The Lower Disang represents The Upper Cretaceous rocks. The Dihing Group denotes the Upper Pliocene rocks. The Mesozoic formations are grouped into a rock of continental shelf deposits and a geosynclinals deposits. The continental shelf deposits are confined to the southern boundary of the Shillong plateau. The geosynclinals deposits are consist of thin sandy bands with a thick heap of repetitive argillaceous sediments. The geosynclinals deposits are spreads across the orogenic belt into Myanmar.

Disang Group can be further subdivided into Lower Disang and Upper Disang. The lower Disang consists of shale with thin flaggy sandstone whereas in the upper Disang the sandstone beds are more and thicker with conglomerates. The conglomerate bed between the lower and upper Disang indicates an unconformity between them. This unconformity indicates an orogenic activity that took place in the Disang sediments which caused folding and low-grade metamorphism. Pascoe (1959) stated that this orogenic activity is responsible for the shallowing of the sedimentary basin where deposition of upper Disang deposits took place.

The lower Disang deposits intermixed with pelagic chert and limestone on the eastern side of the subducting Indian plate. Adjoining the western boundary of the Myanmar plate, the pelagic sediments were deposited. When the land mass (Eurasian and Sunda plates) collided with Indian plate and subducted over it the different facies were brought together. Ultramafic rocks along with the sediments were brought up together. Plutonic and volcanic activities continued and developed Island arcs as a result of continuous activities of plutonic and volcanism. These activities divide the basin into two parts (Merangsoba, 2011).

Nandy, (2017) stated that increased supply of sediments and shallower water deposition is indicated by the thick coal seams in the Barail rocks. The tuffs, volcanic and volcanogenic debris presence in the Barail sediments were derived from Island arcs that are developed due to continuous activities of plutonic and volcanism in the Indo-Myanmar Orogen.

The Tipam formation succeeding Barail was a fluviatile deposit. The sediments in both the basins were deposited with a pronounce unconformity at the base (Nandy, 2017). The Tipam formation and the overlying Dupitila sediments of the Middle Miocene were separated by an unconformity that suggests the upliftment of both the Himalayas and the Indo-Myanmar Orogen.

An unconformity also separates the Dupitila from the overlying Dihing sediments. The regional unconformity that developed in the initial phase of the Himalayan upliftment separates the Palaeogene and Neogene rocks (Kent and Dasgupta, 2004).

2.2 GEOLOGY OF NAGALAND

The geological history of Naga Hills relates to the oblique Subduction and subsequent collision between Indian and Central-Eastern Myanmar continental blocks during the Late Cretaceous-Eocene period. A linear arcuate deep basin developed next to the leading border of the subducting Indian plate in which Disang sediments were deposited. The Disang Group of rocks represents an accretionary prism and associated sediment deposited at Subduction end in the east. The Myanmar Volcanics and the Ophiolite belt seem to have supplied the source material (Pandey, 2005).

Tectonic impulses introduced through changing plate interaction caused swallowing of the basin which in turn led to the deposition of heterogeneous transitional lithology (DBTS). The suturing of the Indian plate with the Myanmar plate resulted in the upliftment of Indo-Burman Ranges (IBR). Oligocene-Miocene molasses basins evolved to the west of the uplifted IBR and provided sites for the deposition of Barail sediments. The Barail rocks are largely marine and partly fluvio-marine. The Surma Group of rocks was deposited in the remnant ocean basins. Late Miocene (Post Surma) folding of the molasses sediments led to the growth of large scale open upright folds which mark the linearity of the mobile belt (The Patkai-Naga-Chin-Arakan-Yoma mobile belt). The deposition of Tipam Group marks the beginning of the fluvial regime followed by the Namsang beds and Dihing Formation. Continuing crustal shortening in the Pliocene period resulted in the development of Schuppen Belt along the western margin of the Inner Fold Belt. Thrust slices in the belt of Schuppen were further affected by the Pleistocene tectonic movements during which the Quaternary deposits were also tilted (Pandey, 2005).

On the basis of morphotectonic elements, the Naga Hills has been longitudinally divided into three distinct units from west to east as follows: -

The Schuppen Belt is demarcated by the Disang Thrust on the east and by the Naga Thrust on the west in Nagaland. Rao, (1983) explained the Schuppen Belt as a complex set of crisscrossing fault with a noncoaxial shear deposits. Aier, *et al* (2011), described the Schuppen Belt as a distinct tectono-geomorphic unit with a width of about 25 km and a length of about 400 km in length it is truncated at the northeast by the Mishmi Thrust and in the southwest by the Dauki Fault. The rock types in the belt of Schuppen include Upper Eocene-Oligocene to Pliocene brackish to freshwater clastic sediments. The upper Eocene-Oligocene is represented by brackish water clastic sediments of Barail and the Mio-Pliocene by non-marine alluvial and fluvial sediments of lowland Surma-Tipam-Namsang-Dihing (Roy and Kacker, 1986).

The Inner Fold Belt in habits the Interior portion of the Naga Hills and is characterized by the geological setting of a large extend of Disang rocks with patchy covers of Barail (Srivastava, *et al* 2012). Owing to their mixed lithology the Palaeogene sediments exposed between Barail and Disang formation in the Inner Belt have been named Disang-Barail Transition by Pandey and Sema, (2005). The Palaeogene rocks in the inner fold belt have been folded into a series of anticlines and synclines. The two major Synclinorium in the inner fold belt is the Patkai Synclinorium in the north and the Kohima Synclinorium in the south.

The Naga Ophiolite Belt (NOB) extending over 90 km in length, with width varying from 2-15 km, occupies an area of about 1000sq. Km. The ophiolites are exposed in the form of an arcuate linear belt between the Disang Formation on the west and the Nimi Formation to the east. The ophiolite complexes comprise mainly of mafic volcanics, mafic and ultramafic cumulates (gabbro, peridotite, pyroxinites), serpentinites and plagiogranites. They are intermingled with oceanic sediments like chert, limestone, and greywacke with minor intrusive (Ranjit, *et al* 2013).

2.3 GEOLOGY OF DIMAPUR DISTRICT

Dimapur district lies toward the North-Western edge, the outermost Belt of Schuppen which an en-echelon thrust called the “Naga thrust” striking NE-SW direction (Acharyya, *et al* 1986). The Naga Thrust separates the up trusted Neogene rocks from the Brahmaputra alluvium of the Dimapur plain (Aier, *et al* 2011). In the Naga Thrust tectonic blocks of older rocks are found entangled within incompetent crushed rocks in the thrust zone suggesting that the thrust is steep-angled and deep-seated as it has brought up older rocks. Srinivasan (2007) described these slivers of rocks as tectonic mélange.

Longkumar *et al* (2019) stated that in part of Dimapur district (study area) is made up of litho-tectonic units of Palaeogene, Neogene, and Quaternary in age. The Palaeogene are represented by Laisong, Jenam, and Renji of Barail Group. The Neogene rocks are represented by Surma and Tipam Group. The Quaternary rocks are denoted by the sediments of Pleistocene to Recent that constitute the terraces and alluvium respectively. The Burmese plate served as the provenance for these sediments. The Barail group of rocks is formed under marine and estuarine environments consisting mainly of arenaceous formations (Nandy, 2017). Platform sediments were started depositing in the basin following the clashed between the two plates (Indian and the Burmese plates). The Primary sedimentary structures in Surma and Tipam group of rocks indicate a fluvial depositional environment. In Dimapur alluvium plain area, the alluvium deposit consists of sand, clays, silts, pebbles, and boulders which constitute more than 90% of the Dimapur plain (Plate 1-a, b, and c). The stratigraphic succession of Dimapur district (Table-3) given by Mathur and Evans (1964) and later modified by the Directorate of Geology & Mining (DGM, 2010).

Table 3. Stratigraphic succession of Dimapur district after Mathur and Evans (1964)modified by DGM, (2010)

	Age	Group	Lithology
QUATERNARY	Recent (Unclassified)	New or Low level Alluvium	Clay, silt and fine clay
	-------------------------Unconformity -------------------------		
	Pleistocene	Older or high-level alluvium	Clay, medium to coarse sand, gravel and boulder deposits.
	-------------------------Unconformity -------------------------		
	Plio-Pleistocene	Dihing	Pebble bed with soft sandy clay, Conglomerate, grit & sandstone
-------------------------Unconformity -------------------------			
TERTIARY	Mio- Pliocene	Dupitila	Pebble bed with soft sandy clay, Conglomerate, grit & sandstone
	-------------------------Unconformity -------------------------		
	Upper Miocene	Tipam	Mottled clay, clay, sandy shale, coarse and ferruginous sandstone and conglomerate
	Lower Miocene	Surma	Shale, sandy shale, siltstone, mudstone & lenticular coarse ferruginous sandstone, alternation of sandstone and shale with thin conglomerate in the lower part
	-------------------------Unconformity -------------------------		
	Upper Eocene	Barail	Bedded sandstone, shale, carboniferous shale, coal, sandy shale interbedded with hard sandstone, well bedded shale with sandstone intercalation at loser bed
	Eocene	Disang	Splintery, dark grey shale, siltstone, mudstone with thin & compact sandstone alternation

The characteristic features of the various groups of geological formations and stratigraphic succession of Dimapur district are described in brief as follows:

Barail Group of rocks are made up of a thick sequence of sandstone interacted with thin papery shale. The Barail are subdivided into the Laisong, Jenam and Renji formations. Piphema and Medziphema area are mostly constituted by the Barail Group of rocks.

The Laisong Formation (Plate 1-d) consists of grey thin to thick-bedded sandstones with ferruginous concretion and often possesses intercalation of siltstone and dark grey carbonaceous shales are exposed along the roadside (NH 29) between Pherima and Medziphema.

The Jenam Formations (Plate 2-a) are grey to dark grey with intercalation of carbonaceous shale and siltstone. Jenam formation is characterized by thin to massive bedded sandstone and is exposed on roadside of NH29 between Piphema and Pherima (Pandey, 2005).

The Renji Formation (Plate2-b) consists of massive and thick-bedded sandstone with minor carbonaceous shale intercalation and is exposed a few kilometres below Piphema along the NH 29.

Surma Group: The Surma Group of rocks is comprised mainly of well-bedded sandstone, siltstone, shale, and conglomerate (Plate2.c) are exposed in Chumukedima, Seithekiema along the Chathe River.

Tipam Group sandstones overlie conformably the Surma rocks (Plate2.d). They consist mainly of arkosic soft sandstones. Minor intercalations of fine sandstone –silt-shale- can also be seen at some places viz; Chumukedima, Seithekiema, Kukidolong, Jharnapani.

Mottled clay and sandy clay of Girujan Clay Formation (Plate3.a) are found on Chathe Riverbank in New Chumukedima.

Namsang Formation: Namsang formation of Dupi-Tila Group consists of blue to bluish-grey clays with intercalated silt and sand are exposed on the four-lane road cutting between Medziphema and Jharnapani (Plate3.b).

Dihing Formation: Consist mainly of thick pebble beds with clays and soft sand is exposed in Medziphema, Jharnapani and New Chumukedima area (Plate3.c).

Plate-1

a

b

c

d

Plate- 1

a) Section of thick Sandy soil near Nagarjan Bridge
b) Pebble bed in Alluvial deposit near Nagarjan Bridge
c) Alternative layers of sandy soil, pebbles and sandy clay
d) Laisong formation at NH 29 in Medziphema

Plate- 2

e

f

g

h

Plate-2

a) Jenam Formation (between Piphema and Pherima)

b) Renji Formation exposed a few kilometres below Piphema along the NH 39.

c) Well bedded Surma Sandstone overlain by massive Tipam Sandstone near Chumukedima Check gate

d) Massive Tipam Sandstone with pockets of coal seam near New Chumukedima

Plate- 3

a

b

c

d

Plate-3

a) Girujan Clay at Kukidolong
b) Namsang Formation exposed a few meters from Medziphema toward Dimapur
c) Dihing Formation Consist mainly of thick pebble beds with clays and soft sand exposed in between Medziphema and Jharnapani
d) High Level Terraces near Chathe River (Chumu 1st gate)

Alluvium and High-Level Terraces: The alluvium covers the plain of Dimapur valley. The high-level terraces occur at various levels above the Chathe River in Chumukedima, Tenyiphe and 4th mile area (Plate3.d). The high-level terraces are dominantly made up of boulder beds with gravels and coarse sands and unsorted clays.

The litho-log from the different parts of the study area constructed by DGM reveals that the area is composed of multiple layers of gravel, sand, shale, clay and a layer of wood that remains in some areas. The clays are of different types- gravely clay, sandy clay, carbonaceous clay, and silty clay.

2.4 HYDROGEOLOGY

The tri-junction of the three major river basins of the region is located in the state of Nagaland. The Brahmaputra River Basin on the Northern and Western side of the state, The Meghna River Basin on the South-west and The Chindwin River Basin on the Eastern side of the state. Barak river sub-basin is situated in the south and the sub-basin of Tizu is situated toward the eastern part of the state. The sub-basins of Dhansiri and Doyang rives covered a major portion of the state.

Tizu, Zungki, Dhansiri, Doyang, Dikhu, Melak/Janzi, and Yangmum rivers are controlling the drainage system of the state, which are tributaries of the main Brahmaputra, Meghna and Chindwin rivers. The highest altitude in the state is 3837m amsl at mount Saramati on the eastern part of Nagaland, and minimum altitude is 140m amsl at Dimapur valley/plain on the south-western side of the state. The drainage pattern is generally dendritic in nature with trellis pattern at places and is controlled by geological structures.

Hydro-geologically, the formations of Nagaland are roughly differentiated into three units as follows: -

i) Consolidation formations: Consolidation formations are confined to high hill ridges towards the south-eastern part of the state along the Myanmar border. Although the rocks are highly fractured with numerous faults, joints, fractures, fissures, and potential sheared zones which can serve as a good aquifers zones. However, the groundwater resources development of the area remains unexplored due to the inaccessibility of the terrain and also difficult to organize heavy duty water well drilling rigs and another logistic constraint.

ii) Semi-consolidated formations: Semi-consolidated formations mostly occur in moderate to high hill ridges comprising of the rocks of the Disang group, Barail group, Surma Group, Tipam group, and Dihing group. The Disang and Surma group of rocks are normally argillaceous while the Barail and Tipam groups are arenaceous sandstone beds. The Disang formation which is highly fractured, splintery and sheared is found to be the most potential for groundwater development in hilly areas.

iii)Unconsolidated formations: In Nagaland, the unconsolidated formations are found in low lying plain areas of the state with narrow, intermontane and open valleys that are found to occur along the foothills bordering upper reaches of Brahmaputra flood plains of Assam. The valleys are mostly structurally controlled and the rock types are mainly of clay, silt, sand, gravel, pebble, cobble and boulder assemblages of unconsolidated nature representing the potential aquifer zones. The potential valley for groundwater development in the state includes Dimapur valley, Medziphema-Jalukie, Baghty, and Tizit-Tiru valleys. Hydro-geological map of the parts of Dimapur district, modified after DGM, (2010) is given in the figure 2.

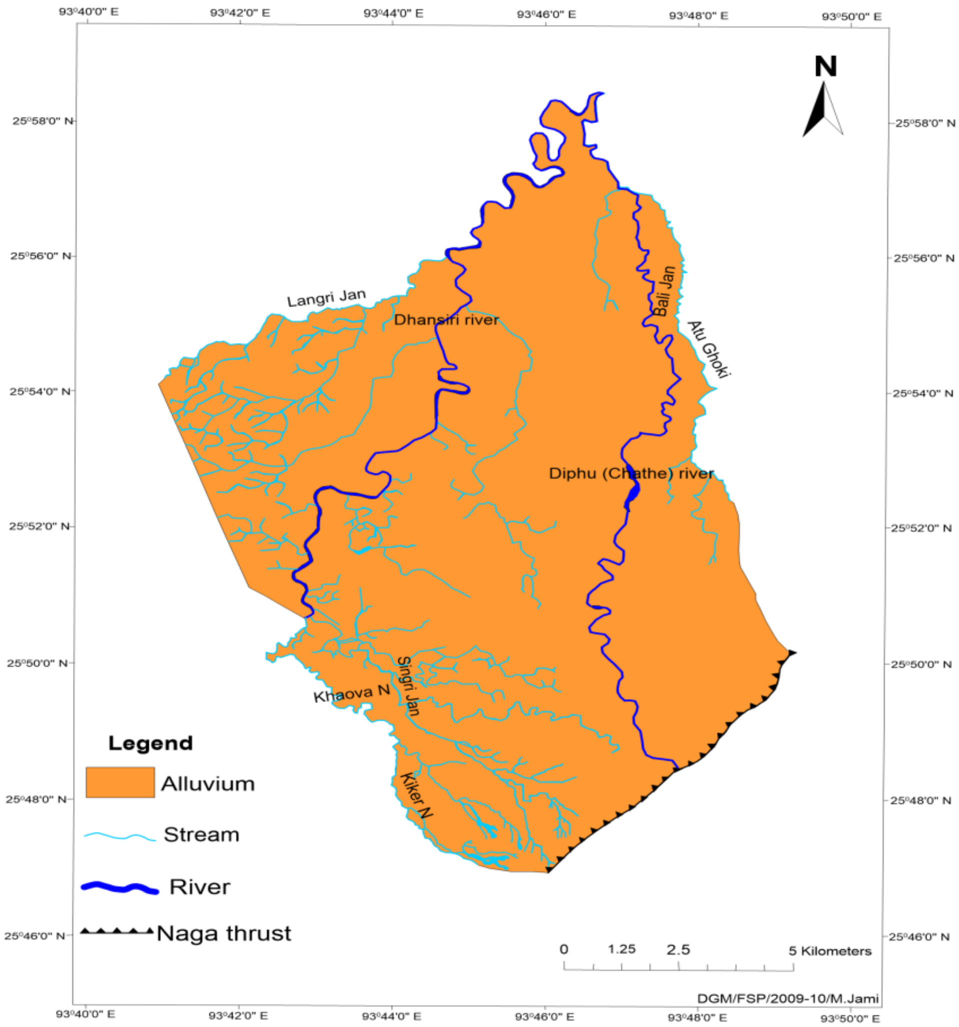


Fig.2 Hydro-geological map of the study area, modified after DGM, (2010)

2.5 TECTONIC SETTING OF THE STUDY AREA

In the Assam-Arakan basin, the Tertiary sediments were deposited during the Late Cretaceous. Burmese plate served as the provenance for these sediments. Barail group of rocks are formed under marine and estuarine environment consisting mainly of arenaceous formation (Murthy, 1983 and Nandy, 2017). Platform sediments started depositing in the basin consequent to the subduction of the Indian plate and the Burmese plate. The presence of conglomerate at the base of Bhuban formation represents a pronounced break in sedimentation and denudation after Renji. The presence of sedimentary structures like ripple marks, load casts, cross beddings and convolute beddings are common in the Surma group of rocks and Tipam sandstone formation. Primary sedimentary structures in Surma and Tipam group of rocks indicate a fluvial condition of deposition. The subduction of the Indian plate is manifested as ductile shortening and migration of different thrust sheets to form the belt of Schuppen. Folds in the thrust sheets represent an episode of ductile shortening in front of moving thrust. The competent sandstone beds transmit the compressive force, whereas the interbedded shale beds behave more or less passively. The belt of Schuppen is comprised of four major thrusts namely :

i) Naga thrust

ii) Sanis-Chungluyimsem thrust

iii) Piphema thrust

iv) Halflong-Disang thrust.

The outermost part of the part of Schuppen is called the Naga thrust. Naga Thrust is exposed intermittingly juxtaposing parts of Tipam or Barail against alluvial deposits of Sub-Resent to Recent (Rao and Murthy, 1980). The Surma are thrust over either the Namsang or Recent to Sub-Recent alluvium along the Naga Thrust. In Dimapur district, the Naga Thrust is marked by an abrupt elevation near Chumukedima which is located at Nichuguard gate, though Naga thrust is not visible as it is covered by sediments, the information received from oil test drilling by ONGC and deep tube well drilling for groundwater by the DGM the presence of the Naga thrust is inferred and the innermost is by the Halflong-Disang thrust. Changing attitudes of beds in Disang shale indicate a series of antiforms and synforms between Piphema to Kohima road. The folds exhibit NNE-SSW axial trend gently plunging towards North (DGM, 2010).

***

CHAPTER III
METHODOLOGY

3.1 INTRODUCTION

Various field and laboratory techniques have been adopted in the present study to decipher the hydrological condition and quality of groundwater. The methodology and instrumentation techniques are given below: -

3.2 FIELDS INVESTIGATION

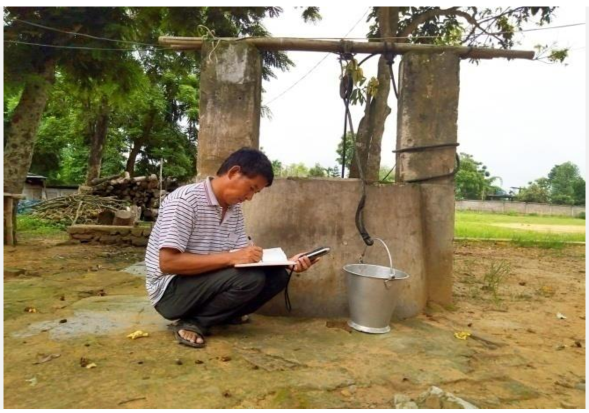
Field investigation involves the study of geology, hydrogeology and hydro-geomorphology of parts of Dimapur district and samples collection of subsurface water in two seasons (onset of pre-monsoon and just after monsoon) periods from representative wells. All together fifty-three wells are chosen and collected groundwater samples from April to May 2017 and November to December 2017 following (APHA 1998) guidelines. Groundwater samples were collected in plastic sample bottles of two-liter capacity. The sample bottles were first washed carefully with acid and followed by distilled water before the collection of groundwater samples. Before the collection of the groundwater sample at the site the sample bottle was cleansed to prevent probable contamination, it is then washed twice with the groundwater and filled with the groundwater sample. On the site observations like location, elevation and name of the place and depth of groundwater table from the surface were noted down on the field diary (Plate 4.a, b, c, and d).

3.3 LABORATORY STUDIES

Fifty-three samples of subsurface water were drawn in different locations in parts of Dimapur district during onset of monsoon and just after monsoon and analyzed as per the standard procedure for various groundwater parameters mention earlier in the introduction chapter to examine subsurface water qualities. Some instruments utilized for assessment of the groundwater quality in laboratory are shown in (Plate5.a, b, c, and d).

Plate- 4

a b



c d

Plate-4

a) Well No-1 at Chumukedima first gate, displaying sample bottle, GPS

b) Collecting water sample at Well No-10 at D Khel, Tenyiphe

c) Measuring Lat & Long at Well No-14 near Saint Joseph church A Khel, Tenyiphe.

d) Measuring groundwater table level at Well No-40 at Holy cross higher secondary School in Dimapur main town.

Table 4. Location, latitudes, longitudes, elevation and water table of the 53 selected wells from the study area.

Well No.	Location of the wells	Latitudes & Longitudes	Elevation (amsl) In meter (m)	Water table (bgl) in m
1	Chumukedima 1st Gate	Lat. N25º48.326' and Long. E93º47.506'	194m	5.2m
2	Chumukedima Ward II	Lat. N25º48.542' and Long. E93º47.440'	185m	11.1m
3	Siuruza colony	Lat. N25º48.003'and Long. E93º45.807'	184m	4.2m
4	Chumukedima Village	Lat. N25º47.401'and Lat. E93º45.604'	190m	10.9m
5	Sabalie Colony	Lat. N25º47.428'and Long. E93º46.528'	191m	2.4m
6	Neiphrolie colony	Lat. N25º47.882'and Long. E93º45.159'	187m	2.1m
7	Kekhriezha colony	Lat. N25º47.976'and Long. E93º44.709'	184m	5.7m
8	Chumukedima village	Lat. N25º48.677'and Long. E93º45.499'	187m	3.5m
9	Chumukedima town	Lat. N25º48.319'and Long. E93º47.291'	186m	5.8m
10	Tenyiphe A Khel	Lat. N25º49.582'and Long. E93º46.509'	183m	3.6m
11	Tenyiphe E Khel	Lat. N25º49.504'and Long. E93º45.293'	184m	3.0m
12	Tenyiphe II	Lat. N25º48.488'and Long. E93º45.368'	183m	7.4m
13	Chumukedima St Joseph Sc.	Lat. N25º49.367'and Long.E93º46.414'	183m	5.6m

14	Tenyiphe	Lat. N25º50.295'and Long. E93º46.321'	183m	9.7m
15	Sovima village	Lat. N25º50.790'and Long. E93º45.824'	180m	13.9m
16	Sovima Tetso College	Lat. N25º51.049'and Long. E93º45.761'	179m	7.6m
17	Tenyiphe II	Lat. N25º48.487'and Long. E93º45.388'	181m	9.3m
18	Sovima Village	Lat. N25º51.269'and Long. E93º45.379'	188m	6.7m
19	Chekiye Village	Lat. N25º52.276'and Long. E93º44.949'	178m	8.8m
20	Chekiye Village	Lat. N25º51.335'and Long. E93º44.504'	187m	10.3m
21	Diphupar	Lat. N25º52.555'and Long. E93º46.212'	181m	12.4m
22	Diphupar	Lat. N25º52.048'and Long. E93º46.282'	159m	Bore-well
23	Diphupar	Lat. N25º51.339'and Long. E93º46.361'	172m	3.9m
24	Sodzulhou Village	Lat. N25º50.683'and Long. E93º46.481'	178m	10.9m
25	Pudumpukori	Lat. N25º53.977'and Long. E93º45.800'	152m	3.8m
26	Pudumpukori	Lat. N25º50.415'and Long. E93º46.284'	158m	4.2m
27	Purana Bazar	Lat. N25º54.344'and Long. E93º45.047'	153m	2.8m
28	Purana Bazar	Lat. N25º55.022'and Long. E93º44.956'	156m	Bore-well

29	Burma Camp	Lat. N25º55.306’and Long. E93º44.088’	145m	Bore-well
30	Burma Camp	Lat. N25º54.634’and Long. E93º44.133’	145m	1.7m
31	Burma Camp	Lat. N25º54.185’and Long. E93º44.505’	152m	Bore-well
32	Half Nagarjan	Lat. N25º54.202’and Long. E93º44.184’	161m	1.1m
33	Nagarjan	Lat. N25º53.352’and Long. E93º44.100’	162m	Bore-well
34	Lungarai Village	Lat. N25º53.452’and Long. E93º41.528’	169m	Bore-well
35	Toulazou Village	Lat. N25º53.000’and Long. E93º44.355’	163m	7.8m
36	Thilixu Village	Lat. N25º52.981’and Long. E93º45.339’	174m	2.3m
37	Phaipijan Village	Lat. N25º52.282’and Long. E93º44.124’	178m	Bore-well
38	Phaipijan Village	Lat. N25º53.214’and Long. E93º45.163’	173m	Bore-well
39	Dimapur Town	Lat. N25º53.194’and Long. E93º44.400’	146m	1.8m
40	Dimapur Town	Lat. N25º54.355’and Long. E93º43.165’	141m	1.6m
41	Dimapur Town	Lat. N25º54.288’and Long. E93º43.093’	151m	Bore-well
42	Dimapur Town	Lat. N25º54.586’and Long. E93º42.765’	171m	Bore-well
43	DGM Office Dimapur	Lat. N25º54.308’and Long. E93º42.000’	175m	Bore-well

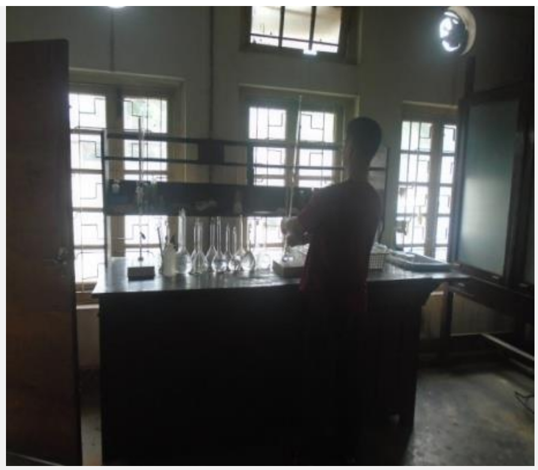
44	Dimapur College	Lat. N25º54.121'and Long. E93º42.095'	162m	Bore-well
45	Kevijau Colony	Lat. N25º53.351'and Long. E93º43.115'	163m	Bore-well
46	Signal Angami	Lat. N25º53.351'and Long. E93º43.115'	180m	Bore-well
47	Seluophe	Lat. N25º53.254'and Long. E93º42.387'	167m	9.3m
48	Thilixu Village	Lat. N25º53.505'and Long. E93º43.381'	184m	Bore-well
49	Thahekhu Village	Lat. N25º51.206'and Long. E93º43.311'	187m	Bore-well
50	Kevijau Colony	Lat. N25º53.291'and Long. E93º43.381'	160m	Bore-well
51	Toulazou Village	Lat. N25º52.250'and Long. E93º43.118'	171m	9.3m
52	2.5 miles	Lat. N25º52.241'and Long. E93º44.275'	165m	3.3m
53	4th Miles	Lat. N25º51.030'and Long. E93º46.204'	154m	0.4m

Plate- 5

a

b

c



d

Plate-5

a) Multiple physical parameter kid

b) Digital Nephelo-turbidity meter

c) Flame Photometer

d) Titrating Table with burettes and flasks at DGM Laboratory

3.3.1 Determination of Turbidity

Turbidity is measured by using an instrument called nephelometer. The turbidity of the water sample is estimated by passing a beam of light through water sample scattered at 90 degrees and measures the intensity of light.. The units of turbidity are Nephelometric Turbidity Units (NTU).

3.3.2 Determination of EC

The EC value of groundwater samples is measured directly by using a conductivity meter. The groundwater samples are kept in a glass beaker and the conductivity meters are immersed within the water samples and the readings displayed are taken directly and tabulated.

3.3.3 Determination of pH

The pH value of the groundwater sample is measured directly by using a pH meter. The essential feature of pH meter is to use a hydrogen sensitive glass electrode, called an indicator electrode and a reference electrode. The pH meter is graduated to directly read in pH units. Standard buffer solution of pH values 4.0, 7.0, 9.2 is used for calibrating the instrument before using it to measure the pH values. The groundwater sample is taken into a beaker and pH meter is dipped in the groundwater sample so that the electrode is immersed in the water sample and the pH value is displayed on the meter is noted and the readings of all the samples are tabulated.

3.3.4 Determination of TH, Ca and Mg

TH of groundwater samples is estimated by titrating against the standard solution EDTA of known strength, using Eriochrome black-T indicator. Ca and Mg ions form wine red color on reacting with Eriochrome black-T in alkaline condition because under alkaline condition EDTA forms soluble chelated complex on reacting with Ca and Mg. On the addition of EDTA as a titrant, Ca and Mg ions get complexed ensuing in a rapid change in color from wine red to blue, indicating the endpoint of a titration. Mg concentration in the groundwater was computed by calculating the difference between TH and Ca.

3.3.5 Determination of TDS

The Gravimetric method is adopted to determine the Total Dissolve solids (TDS), following APHA Standard procedure. This method is adopted because the practical range of determination is 10mg/l to 20,000mg/l and it is applicable to drinking, domestic and industrial purposes.

3.3.6 Determination of Na and K

Na and K ions were estimated using Flame Photometry at DGM lab, Govt of Nagaland, Dimapur. Flame photometer is used to measure the emitted light intensity. When a metal is introduced into the flame, the wavelength of the color of the flame gives information about the amount of the elements present in the sample.

3.3.7 Determination of Cl

Cl was analyzed by titrating with a standard $AgNO_3$ solution. Silver chloride used to precipitate quantitatively before red silver chromate is formed when potassium chromate is used as an indicator.

3.3.8 Determination of Fe

Iron is determined by Spectronic 301Spectrophotometer (Skoog *et. al.* 1963). When iron reacts with o-phenanthroline it produces a colored complex ion and the intensity of this color complex is measured by using a Spectronic 301 Spectrophotometer.

3.3.9 Expression of Analysis

For the proper interpretation and for the ultimate purpose of the water, it is important that uniformity is maintained in the methods of expressing the results of groundwater quality parameters. Keeping this important the most common expression/units are adopted. Turbidity is expressed in NTU (Nephelometric Turbidity Unit) and EC is indicated in microsiemens/cm at 25^{o}C and every other parameter is indicated in mg/l. The outcomes are presented in tabular forms.

3.4 TRACE ELEMENTS (METALS)

24 groundwater samples in parts of the Dimapur district were taken during two seasons and examined for heavy metals/trace elements at the laboratory of Indian Council of Agricultural Research for NEH Region, Umiam, Meghalaya using Atomic Absorption Spectrophotometer. The following trace elements/heavy metals were analyzed: Copper, Zinc, Nickel, and Arsenic. The analytical data are given in the tabular forms.

3.5 DATA PROCESSING AND ANALYTICAL TECHNIQUES

The following data processing and analytical techniques have been carried out with the measured and derived water quality parameters.

3.5.1 Piper Diagram

Piper (1944) proposed trilinear diagram to categorize subsurface water on the basis of geochemical attributes of the constituting ionic concentration. Piper diagram is made up of three distinct fields, a diamond-shaped field between the two triangular fields, situated at the lower left and the lower right. The sub-divisions of the diamond-shaped field is given below:-

Sub division 1(5+9+6) = (Ca & Mg) exceeds (Na & K).

Sub division 2 (8+9+7) = (Na & K) exceeds (Ca & Mg).

Sub division 3 (5+9+8) = (CO_3& HCO_3) exceeds (SO_4& Cl)

Sub division 4 (6+9+7) = (SO_4& Cl) exceeds (CO_3& HCO_3)

Sub division 5 = Magnesium bicarbonate type

Sub division 6 = Calcium chloride type

Sub division 7 = Sodium Chloride type

Sub division 8 = Sodium bicarbonate type

Sub division 9 = Mixed type (Neutral Water).

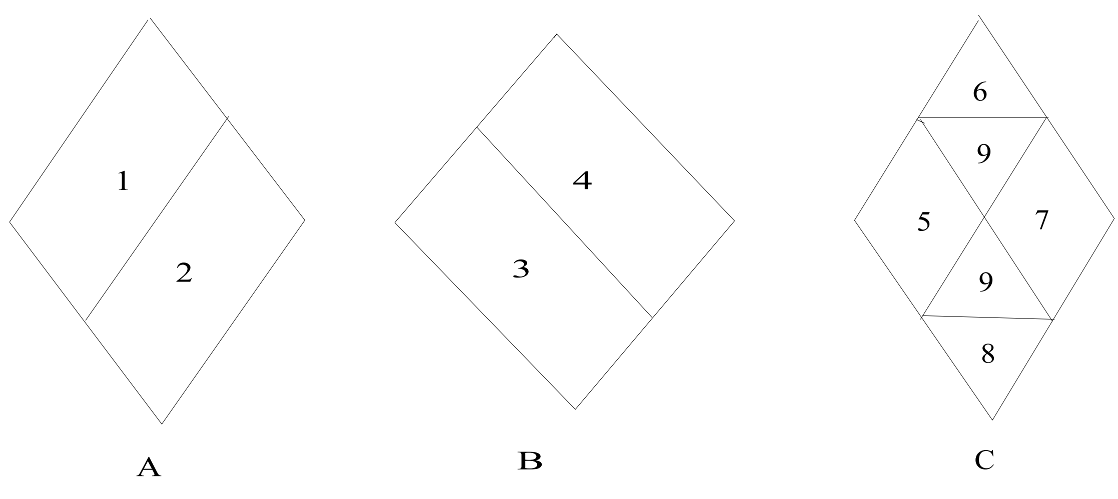


Fig 3: Showing sub-division of Trilinear Diagram

3.5.2 USDA Diagram

Salinity hazard classification of the groundwater according to USDA after Richards (1954) is shown in figure no-11 (pre-monsoon) and figure no-12 (post-monsoon) used two parameters namely electrical conductance represent salinity along x-axis and sodium hazard along the y-axis. The x-axis is further, classified into four parts as very high, high, moderate, and low salinity hazards and the y-axis is also divided into four parts as a low sodium hazards, medium sodium hazards, high sodium hazards and very high sodium hazards. The entire diagram is partitioned as sixteen different combinations of salinity and sodium levels.

3.5.3 Salinity Hazard

Low salinity water (C_1): In most of the soils this water would be utilized for the irrigation of most crops.

Medium salinity water (C_2): This water would be utilized in irrigating crops that have moderate salt resistance.

High salinity water (C_3): This water would not be utilized in soils that have limited action or process of draining.

Very high salinity water (C_4): Under normal conditions, this water is not applicable for irrigating purposes.

3.5.4 Sodium Hazard

Low sodium water (S_1): This water could be utilized for irrigating in almost all soils type.

Medium sodium water (S_2): This type of water could be securely utilized in irrigating soils of high proportion of sand.

High sodium water (S_3): This water could not be utilized for irrigating in most soils as it produces hazardous exchangeable sodium.

Very high sodium water (S_4): This water, in general, is not good enough for irrigating purposes.

Permeability Index, by Doneen, (1964), Sodium Adsorption Ratio, by Todd, (1959), Residual Sodium Carbonate, and Magnesium Ratio Eaton, (1950), etc. These methods/parameters are used to categorize and to explain the fundamental characters of the chemical constituents of the subsurface water and its applicability for irrigation purposes.

***

CHAPTER IV

HYDRO-GEOMORPHOLOGY

4.1 INTRODUCTION

Geomorphology is the science that describes the form of the land surface of the earth and its evolution in relation to structures, exogenic and endogenic processes and the factor of time (Enayat 1985). The exogenic processes like weathering, erosion, denudation, transportation, deposition and endogenetic processes resulting from internal forces like diatropism and volcanism are responsible for the formation and evolution of landforms. Worchester (1965) defined Geomorphology as the interpretive description of the relief features of the earth.

Geomorphology has vast applied aspects in various human needs and activities like land use, agriculture, communication, trade, mineral exploration, tapping water resources, etc. The spatial distribution of groundwater prospect is closely related to geomorphology and associated features and the remote sensing data provides useful information that made it convenient to delineate the spatial distribution of subsurface water prospect classes Sinha et al (1990). Remote sensing data are very useful in groundwater studies as it provides information on the current spatial deposition of geological and geophysical features such as rock types, faults, landforms, drainage, soil, water bodies, etc in a highly cost-effective manner (Jaswal, *et al* 2003).

The Hydro-geological map of parts of Dimapur District mainly the Dimapur alluvial plain (modified after DGM) is given in figure 4. Dimapur alluvial plain occurs at an elevation ranging between 139.5m amsl to 220m amsl as flat with gentle undulations and valley fills. Various geomorphic features formed by fluvial actions of rivers called fluvial landforms in and around Dimapur town, some prominent features like meander scars (paleo-channels) are found to exist between 5th mile of Dimapur-Kohima highway and Chumukedima area extending northwest up to Patharjan. Point bars are located toward the south of Thahekhu in between old Dhansiri Bridge and Half Nagarjan. Natural levee or bunds are located in Phaipijan, Burma Camp, Kushiabil, and Deragojan, etc. Horseshoe/oxbow lakes are located near Trithrongse village, Half Nagarjan area surrounding Urra villa and Yimkonglenden colony near United Naga village towards Referral Hospital. Lakes/ponds are located at Padumpukhuri, Purana Bazar, Nagarjan, Bamonpukhuri along the Dhansiri and Diphu (Chathe) rivers.

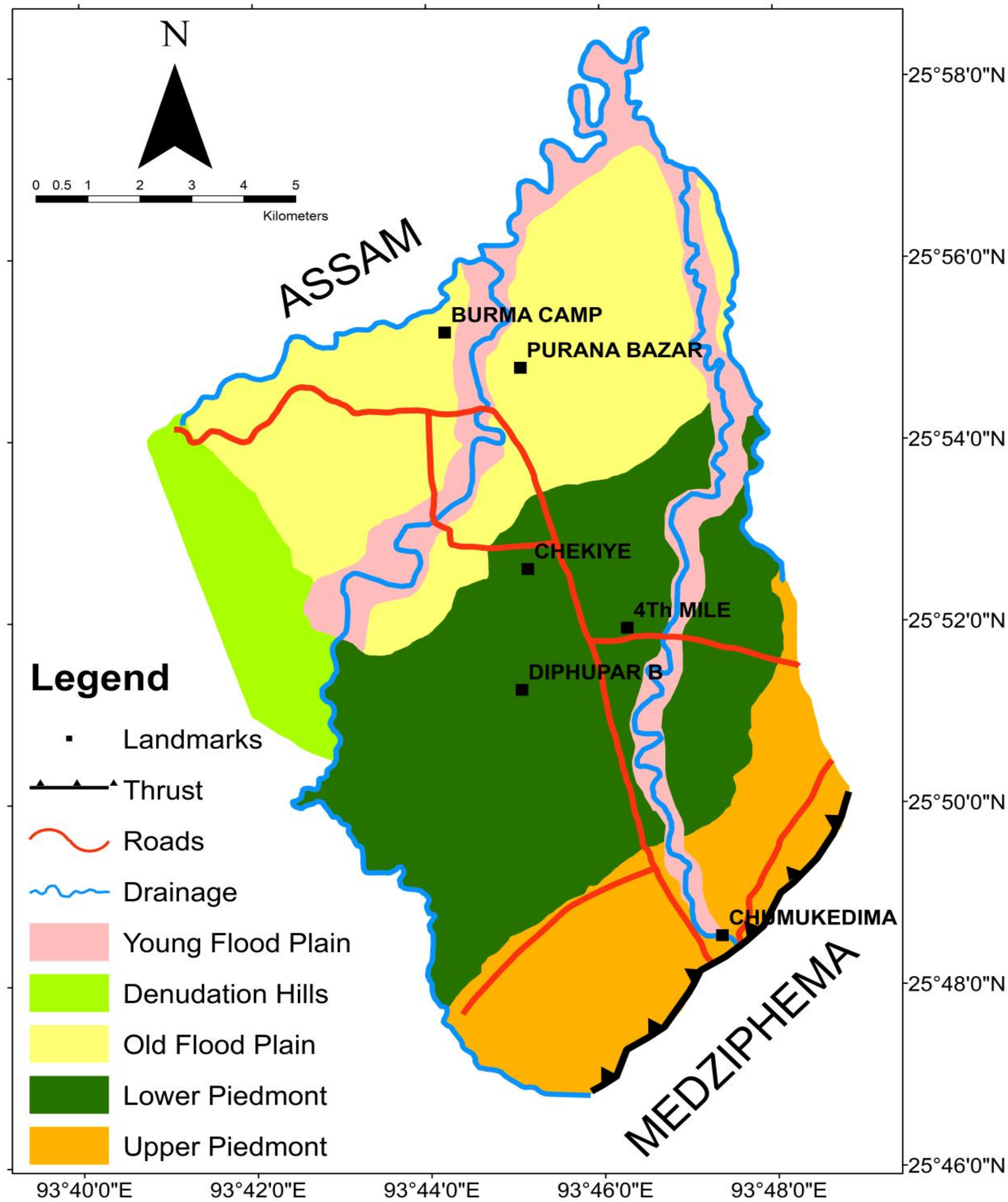


Fig 4: Hydro-geomorphological map of the study area modified after (DGM, 2010).

According to Raghunath (2006) Specific yield of groundwater depends upon the coarseness and finesse or roundness and angular nature of the grains and distribution and interconnected pores and compaction of the formation. Characteristics of some common formation materials are given in Table-5 after Raghunath (2006).

Two different types of landforms are identified within the study area and described as piedmont and floodplain based on fluvial action of erosion and deposition along the Dhansiri and Chathe rivers.

Table 5: Characteristics of some common formation materials after Raghunath (2006)

Formation Materials	Porosity (%)	Specific Yield (%)
Clay	45 - 55	1 - 10
Sand	35 - 40	10- 30
Gravel	30 - 40	15 - 30
Sandstone	10 - 20	5 - 15
Shale	1 - 10	0.5 - 5

4.2 PIEDMONT

Fluvial deposits occur at the foothills of mountains and landforms of high relief and intermontane valleys are called piedmont deposits. They comprise alluvial fans and cones, as well as talus, rain-wash, soil creep and mudflows (Karanth, 1989). Closely spaced alluvial fans coalesce into piedmont alluvial plains. Swamp and lakes may be formed in the depressions along their lower, outer margins (Twenhofel, 1961). The detached clay layers in the zone of aeration in the piedmont zone may give rise to perch groundwater bodies (Karanth, 1964). In the piedmont zone, the finer-grained clay and silty clay layers act as aquitard and confined the subsurface water in the lower aquifers. The occurrences of subsurface water in the piedmont deposits depend on several criteria like the size of the catchment upstream of the cone and quantity of water discharged into the deposits, shape of the cone, structures, thickness and permeability of the deposits and the nature of the basement rocks. Because of the coarse texture of the deposits, heavy recharge occurs from the percolating of water from influent streams. The piedmont aquifers have high permeability due to coarse texture, have high water table gradient, and can transmit large quantities of water through the aquifers. The groundwater is quickly drained and replenished, resulting in a large water table fluctuation in the piedmont zone.

The piedmont zone stretching from the flat plains of Dimapur town up to the moderate hill slopes of Patkai – Chumukedima range that runs in a NE – SW direction. This zone is classified into upper piedmont and lower piedmont.

4.2.1 Upper Piedmont

The upper piedmont is situated in the uppermost part of the alluvial plain of Dimapur. It is extending from Chumukedima slope till 6th mile of the Dimapur-Kohima highway area. In this zone unconsolidated sediments comprising of pebbles, gravels, sands, silts and clays deposits with variable runoff and infiltration characteristics. Litho-log of a well-constructed by DGM at camp area in Chumukedima is given in the figure. 5. From this litho-log it is inferred that from the ground surface up to 16 m is composed of sandy clay, 16 m to 25m is gravely sand, 25 m to 46 m is composed of carbonaceous clay, 46 m to 58 m is gravel and pebbles, 58 m to 61 m is a clay layer. Again, from 61 m to 67.5 m is composed of gravel, sand, shale and gas, 67.5 m up to 73 m is sandstone. From the litho-log, it is confirmed that there are three confined aquifer zones. It is found that the piezometric water level is at 158 m amsl DGM (2010).

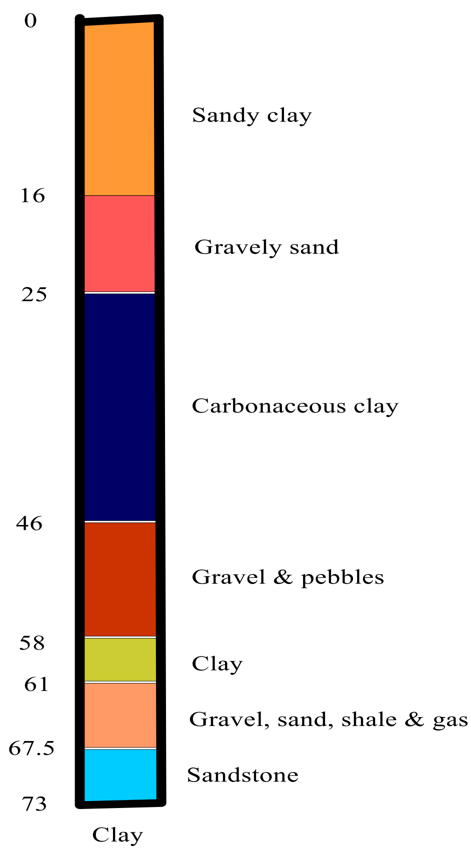


Fig.5: Litho log at Camp area (Chumukedima)

Another well was constructed at Global University, Sodzulhou village, i.e. somewhere in the middle of the upper piedmont zone. From the ground surface, up to 9 m is composed of gravely clay, 9 m to 26 m is sand and gravel, 26 m to 30 m is carbonaceous clay and wood remains. Sand layer follows it from 30m to 37m up to 51.5m is made up of sand and wood remains. The upper subsurface water is a confined aquifer that extent from 9 m to 26m from the ground surface. There is another confined aquifer starting from 30m to 51.5 m from the ground surface. The piezometric water level is at 147.77m. amsl. The litho-log at Sodzulhou Village is given in figure 6.

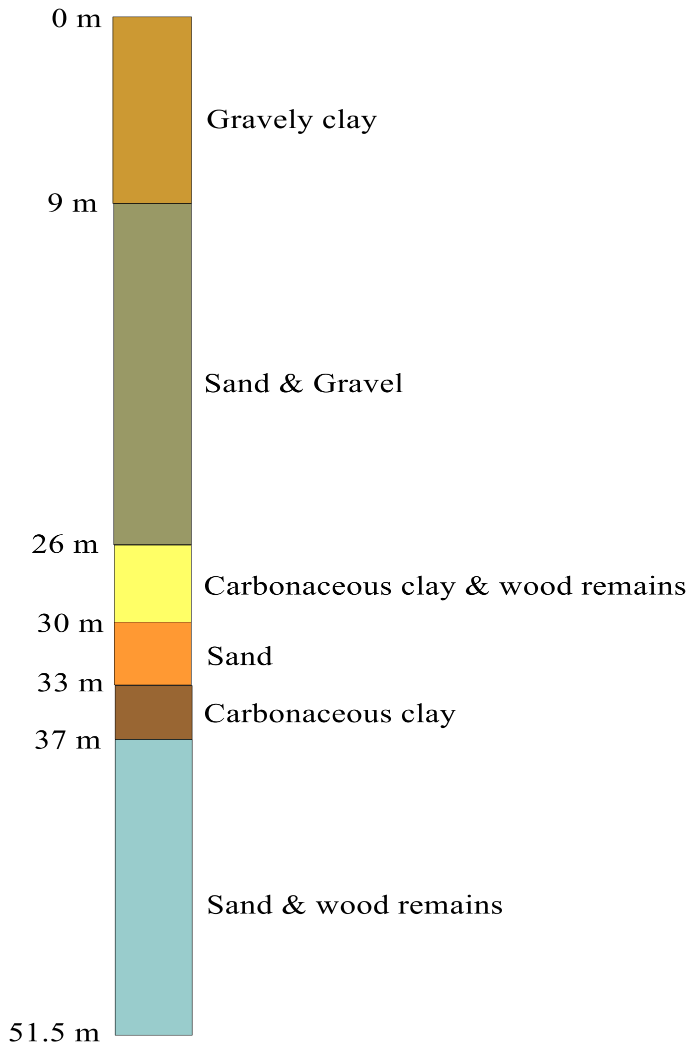


Fig.6: Litho-log at Sodzulhou village

4.2.2 Lower piedmont

This geomorphic unit is located between 2.30-mile and 6th mile of the Dimapur-Kohima highway area just north of the upper piedmont zone. The geomorphologic characteristic of the unit is similar to upper piedmont landform except for altitude and slope, which is relatively low and gravel and pebble zone is located at a deeper depth. This zone has an equal groundwater prospect varying from shallow to deep aquifer zones (DGM.2010). Flood plain deposits may accumulate a considerable amount of mineral, essentially salts of sodium and calcium carbonate in soil and from open water bodies. This is so because of the fineness of sediments which favors capillary ascent of water through the soil from a considerable depth of the water table.

4.3 FLOOD PLAIN

Leopold, 1964 described a floodplain as a narrow piece of moderately horizontal land adjoining a stream that overflowed at a time of high tide. A floodplain is made up of arenaceous and argillaceous sediments of unconsolidated nature, they are rapidly eroded during floods or they may deposit new layers of mud, silts, and sand. The river may change its course and shift from one side of the floodplain to the other. Compared to the piedmonts, the deposits of the flood plains are better stratified, the bulk of the sediments consisting of gravels, sand, silts, and clays where the percentage of silt and clay increases conforming to the maturity of the rivers. The sediments attain better sorting and have a lesser range of grain-size distribution.

Flood plain deposits may accumulate a considerable amount of minerals, essentially salts of sodium and calcium carbonate in soil and from open water bodies. This is due to the fineness of sediments which favors the capillary ascent of water through the soil from a considerable depth of the water table.

The flood plains that come under active flood during monsoon season are called young flood plain. Small patches of these types of landform have been identified on the western side of Dhansiri river course such as in Lahorijan, Kushiabil, Burma Camp, Bank Colony, Rajbari Fort, Urra Villa, Yimkonglenden Colony, Half Nagarjan, Rangapahar Crossing, etc. Those flood plains that do not come under active flood plain are known as an old flood plain or upper alluvial plain. Old flood plains are found spreading over many places in the study area including Dimapur main town. The litho-log from the well-constructed by DGM,2010, in an old flood plain in figure 7 (at DC Office, Dimapur) reveals that the upper 12m from the ground surface is composed of silty clay, 12m to 18m is sand, 18m to 39m is clay horizon, 39m to 42m is sand again, 42m to 55m is clay, 55m to 61m is sandy clay and wood remains, 61m to 74m is clay horizon, 74m to 80m is fine sand and wood remains,80m to 88m is clay, 88m to 89.5m is sand,89.5m to 101m is clay, 101m to 110m is sand, 110m to 116m is clay, 116m to 140m is sand and 140m to 143m is clay again. The litho log from this well reveals that there are multiple confined aquifers.

The piezometric water level in this well is at 113.3m amsl. In the flood plain sand content is quite dominant indicating a good prospect for groundwater.

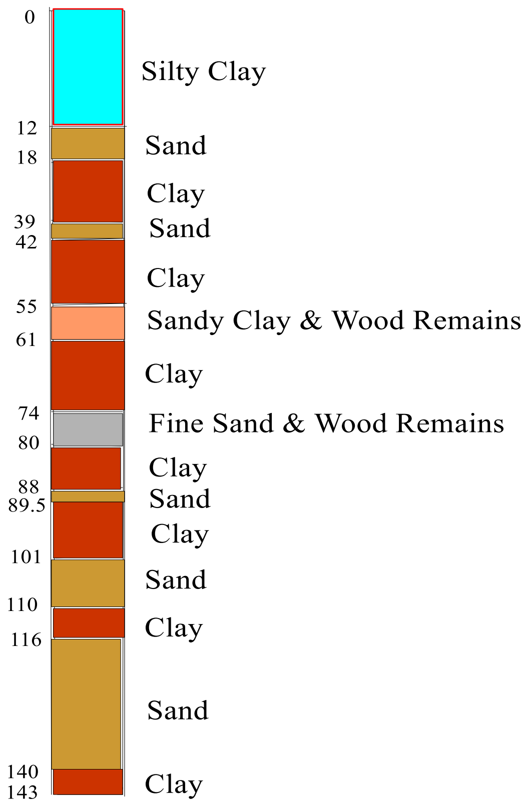


Fig. 7: Litholog at DC office Dimapur

***

CHAPTER -V

HYDRO-GEOCHEMISTRY

5.1 INTRODUCTION

Both surface and subsurface water are widely utilized natural resources for consumption and agricultural purposes. Most of the surface water resources especially the rivers, streams, and lakes are highly polluted due to anthropogenic activities and are becoming short of supply or easily unavailable at the site due to exploitation from time to time. Hence, greater importance has been given to groundwater. Water is present everywhere in the universe and covers 75% of the earth. However, pure water can never be found in nature because pure water contains only two molecules of hydrogen and one molecule of oxygen. Water is also a good solvent due to its polarity; hence, water in nature contains a number of impurities in varying amounts.

The knowledge of hydrogeochemistry is indispensable in the determination of the origin of the chemical composition of the subsurface water (Thilagavathi, *et al* (2012). Glynn *et al* (2005) Stated that geochemical reaction along groundwater flow paths can lead to regional disparities in water constituent that develop during the course of flow and the sources of water entering groundwater systems also have been differentiated depending on the presence of inert constituents or tracers.

The wide range of pollutants found in groundwater samples is organic and inorganic chemicals, biological, physical and radiological types. Groundwater moves through soil and subsurface geologic formations dissolve soluble minerals and precipitates secondary minerals that affect the composition and constituents of groundwater. Water quality also gets altered during the course of movement in the hydrological cycle. Appelo and Postma, (1993) stated that groundwater quality also gets modified by the water mixing with leaching fertilizers, manure and organic processes.

Water is a fundamental human need, it is directly associated with human health. WHO, (1993) stated that potable water is a fundamental human need and to maintain fundamental hygiene sufficient clean drinking water supply is necessary. Therefore, it is indispensable to properly assess the value or usability of water available for any use in order not to cause hazards for mankind, animals and the plants. The water for human consumption should not contain any poisonous elements, harmful viruses and bacteria, and unwarranted minerals that are detrimental for our wellbeing. Hence, the important groundwater parameters like Turbidity, Electrical conductance, potentia hydrogeni, Total Hardness, Total Dissolved Solids and major elements as well as some trace/heavy metals like, Cu, Zn, Ni and As are analyzed to examine the quality of groundwater in parts of Dimapur district.

5.2 RESULTS OF HYDRO-GEOCHEMICAL DATA

53 groundwater samples in part of Dimapur district were evaluated for physico-chemical parameters and the data are given in tabular forms.

Table 6: Analytical data of the groundwater samples of the study area (Pre-monsoon)

SL. NO	SP.NO	Turbidity. NTU	E.C MS/Cm	pH VALUE	TDS Mg/l	TH Mg/l	Ca Mg/l	Mg Mg/l	HCO_3 Mg/l	Cl Mg/l	Fe Mg/l	SO_4 Mg/l	F Mg/l	Na Mg/l	K
1	WS.NO. 1	3.9	1142	6.5	172	84.63	20.00	8.41	64	51.98	0.59	8	ND	19.00	12.50
2	WS.NO. 2	3.3	680	5.8	251	100.02	18.46	13.08	14	83.97	1.2	7	ND	6.00	12.00
3	WS.NO. 3	3.2	574	6.7	269	134.65	29.23	25.62	118	71.98	0.56	12	ND	84.7	62.60
4	WS.NO. 4	1.4	240	6.3	130	65.40	20.00	3.72	78	5.99	0.47	7	ND	10.63	13.50
5	WS.NO. 5	1.2	810	7.2	384	234.67	9.23	51.42	268	21.96	0.56	15	ND	76.1	17.30
6	WS.NO. 6	3.2	191	6.2	91	30.78	10.77	0.93	28	27.99	2.2	6	ND	14.25	6.00
7	WS.NO. 7	1.6	412	7.9	230	100.87	21.54	11.42	168	7.99	0.68	19	ND	14.25	8.00
8	WS.NO. 8	2.0	86	6.0	34	23.08	9.23	0.00	8	27.98	0.76	4	ND	6.5	2.00
9	WS.NO. 9	1.6	416	6.7	211	146.19	35.39	26.92	68	25.99	0.95	15	ND	39.00	8.30
10	WS.NO. 10	1.3	406	6.0	194	92.33	18.46	11.22	38	53.98	1.1	18	ND	18.00	16.00
11	WS.NO. 11	2.3	220	6.4	111	57.71	15.39	4.86	46	15.60	3.32	8	ND	16.50	14.00
12	WS.NO. 12	1.7	214	6.0	110	11.54	3.08	0.94	12	29.78	0.65	6	ND	75.4	21.30
13	WS.NO. 13	3.4	342	5.7	164	65.40	10.77	9.35	4	34.03	0.41	12	ND	78.5	18.20
14	WS.NO. 14	0.4	104	5.4	41	23.08	4.62	2.80	2	1.42	0.24	5	ND	12.00	4.00
15	WS.NO. 15	1.1	38	6.7	20	3.85	0.00	0.00	4	1.42	0.32	4	ND	12.00	4.00
16	WS.NO. 16	1.6	174	5.8	87	15.39	4.62	0.94	10	12.76	0.38	6	ND	61.50	11.90
17	WS.NO. 17	0.1	280	5.1	147	42.32	18.47	4	2	39.70	0.27	18	ND	12.25	10.00
18	WS.NO. 18	0.5	62	5.2	26	3.85	0.00	0.00	2	0.00	0.28	3	ND	6.10	5.40
19	WS.NO. 19	0.3	106	5.5	46	7.69	3.08	0.00	6	2.84	0.28	4	ND	18.00	10.00
20	WS.NO. 20	0.2	416	6.9	185	142.34	35.12	13.09	124	15.60	0.35	22	ND	16.00	8.00
21	WS.NO. 21	0.4	274	5.9	143	73.09	13.85	9.35	6	29.78	0.33	15	ND	66.6	15.70
22	WS.NO. 22	0.2	236	5.6	122	50.11	13.85	3.76	14	22.69	0.32	10	ND	10.00	16.00
23	WS.NO. 23	18.1	198	5.9	105	34.62	6.16	4.67	10	19.85	0.82	7	ND	59.80	13.20
24	WS.NO. 24	0.4	210	4.5	108	34.62	9.12	3.09	4	15.60	0.32	8	ND	11.25	9.00
25	WS.NO. 25	0.1	154	7.3	82	69.25	13.84	8.42	74	0.00	0.27	5	ND	22.20	41.80
26	WS.NO. 26	58.4	138	6.7	123	103.87	19.86	13.09	104	1.42	0.31	12	ND	13.00	9.00
27	WS.NO.27	1.8	140	6.6	71	61.55	12.31	7.48	68	1.42	0.25	5	ND	12.00	10.00
28	WS.NO.28	0.1	1120	7.2	538	257.75	21.54	49.54	212	82.24	0.28	29	ND	185.30	75.60

29	WS.NO. 29	0.4	102	6.3	54	34.62	7.7	3.74	44	0.00	0.33	4	ND	6.00	9.00
30	WS.NO. 30	0.5	596	6.8	318	200.05	29.24	30.85	136	60.97	0.27	25	ND	10.87	15.00
31	WS.NO. 31	65.5	112	6.1	62	46.16	9.2	5.61	36	0.00	2.5	8	ND	14.00	14.00
32	WS.NO. 32	0.6	372	6.9	195	150.04	30.78	17.76	108	24.11	0.31	18	ND	51.20	41.80
33	WS.NO. 33	0.1	181	5.1	97	46.16	13.85	2.51	4	24.11	0.27	8	ND	17.00	10.00
34	WS.NO. 34	0.1	106	5.3	51	23.08	10.78	2.14	12	7.09	0.25	5	ND	8.50	4.00
35	WS.NO. 35	0.3	126	6.1	75	30.78	9.40	1.87	8	11.34	0.33	10	ND	35.10	10.20
36	WS.NO. 36	0.2	252	6.2	220	107.72	29.24	8.42	16	75.15	0.26	22	ND	12.50	12.00
37	WS.NO. 37	2.1	126	6.6	75	61.55	18.62	4.02	62	0.00	0.5	8	ND	9.10	9.10
38	WS.NO. 38	6.3	119	5.2	66	23.08	7.70	0.93	4	9.93	0.9	8	ND	6.00	16.00
39	WS.NO. 39	0.2	311	6.0	168	65.40	19.23	3.46	22	51.05	0.26	12	ND	100.60	35.10
40	WS.NO. 40	0.2	386	6.9	198	111.57	35.56	5.61	130	28.36	0.32	16	ND	11.00	9.75
41	WS.NO. 41	0.2	100	6.6	40	34.62	7.69	3.74	42	1.42	0.22	5	ND	14.50	10.00
42	WS.NO. 42	0.1	101	5.7	46	26.93	10.71	2.3	14	4.25	0.27	9	ND	9.80	6.20
43	WS.NO. 43	0.1	202	5.2	105	19.24	3.82	0.00	112	2.83	0.25	10	ND	14.00	8.00
44	WS.NO. 44	0.2	178	6.4	91	50.01	11.98	4.67	76	8.50	0.23	8	ND	10.83	12.50
45	WS.NO. 45	0.2	116	5.6	59	30.78	9.06	1.87	10	11.34	0.27	5	ND	16.40	12.40
46	WS.NO. 46	0.5	154	5.3	80	26.93	7.69	1.87	6	15.80	0.20	7	ND	18.00	8.00
47	WS.NO. 47	0.1	162	6.4	86	57.70	32.32	1.90	64	5.67	0.26	10	ND	16.00	9.25
48	WS.NO. 48	0.3	101	5.8	37	15.39	9.23	1.80	24	1.42	0.32	2	ND	12.60	4.20
49	WS.NO. 49	5.5	198	5.4	103	46.16	20.77	2.70	12	18.43	0.37	8	ND	15.00	2.00
50	WS.NO. 50	11.3	173	5.3	91	46.16	16.93	0.93	10	34.03	0.6	6	ND	8.50	14.00
51	WS.NO. 51	0.6	112	7.8	53	11.54	12.64	1.40	30	5.67	0.18	4	ND	14.00	10.00
52	WS.NO. 52	0.8	231	5.6	146	34.62	6.16	4.68	6	53.88	0.26	12	ND	106.3	15.00
53	WS.NO. 53	0.1	138	5.1	76	23.08	4.62	2.80	16	14.18	0.21	13	ND	11.00	12.25

Table7: Analytical data of the groundwater samples from the study area (Post-monsoon).

SL. NO	SP.NO	Turbidity. NTU	E.C MS/Cm	pH VALUE	TDS Mg/l	TH Mg/l	Ca Mg/l	Mg Mg/l	HCO_3 Mg/l	Cl Mg/l	Fe Mg/l	SO_4 Mg/l	F Mg/l	Na Mg/l	K
1	WS.NO. 1	0.4	1170	6.1	174	92.07	19.22	10.70	100	36.87	0.36	6	ND	9.25	4.00
2	WS.NO. 2	0.1	630	5.2	218	68.05	8.00	11.67	24	49.63	0.14	4	ND	11.00	14.00
3	WS.NO. 3	2.2	340	6.3	161	52.04	11.21	5.84	44	34.03	0.38	8	ND	51.9	70.1
4	WS.NO. 4	3.2	110	6.1	50	28.02	8.01	1.95	28	4.25	0.45	2	ND	13.00	8.00
5	WS.NO. 5	0.2	604	7.0	361	268.21	24.02	50.58	252	17.02	0.28	13	ND	86.20	13.80
6	WS.NO. 6	1.4	196	6.2	92	32.03	4.80	4.87	32	18.43	0.38	4	ND	8.00	2.00
7	WS.NO. 7	0.1	396	7.2	207	116.09	27.22	11.67	184	5.67	0.12	16	ND	10.66	2.00
8	WS.NO. 8	3.1	46	5.6	21	12.01	3.20	0.97	4	1.42	0.56	2	ND	5.90	1.10
9	WS.NO. 9	0.5	246	6.3	117	64.05	12.81	7.78	76	12.76	0.22	10	ND	32.60	2.80
10	WS.NO. 10	0.1	392	6.8	181	80.06	20.82	6.81	60	25.52	0.09	15	ND	8.75	14.00
11	WS.NO. 11	0.4	203	5.7	90	36.03	11.21	1.94	20	19.85	0.25	6	ND	8.00	0.00
12	WS.NO. 12	0.3	196	5.7	75	12.01	9.61	0.00	24	22.69	0.32	5	ND	42.30	8.20
13	WS.NO. 13	0.2	294	5.8	91	32.03	11.21	0.97	12	21.27	0.16	7	ND	37.40	5.00
14	WS.NO. 14	0.2	102	5.1	40	20.02	6.41	0.97	4	5.67	0.09	4	ND	2.00	6.00
15	WS.NO. 15	0.2	114	6.2	59	32.03	20.82	0.00	24	5.67	0.12	9	ND	1.50	6.00
16	WS.NO. 16	0.2	162	5.5	78	32.03	9.61	1.95	20	12.32	0.09	4	ND	40.60	6.10
17	WS.NO. 17	0.6	530	4.2	296	140.11	51.24	2.92	5	46.79	0.06	23	ND	8.75	9.00
18	WS.NO. 18	0.3	53	5.3	29	12.00	3.20	0.97	5	1.35	0.22	4	ND	5.90	3.70

19	WS.NO. 19	0.6	314	7.4	224	160.13	54.44	5.84	172.00	21.27	0.21	12	ND	9.00	2.00
20	WS.NO. 20	0.4	434	5.1	272	90.03	456.20	55.02	0.00	68.13	0.26	90	ND	3.50	12.00
21	WS.NO. 21	4.2	176	7.9	61	36.03	11.21	1.95	28.00	4.25	0.46	4	ND	8.90	5.40
22	WS.NO. 22	0.1	212	5.1	99	56.04	19.21	1.94	8.00	25.52	0.18	6	ND	11.00	8.00
23	WS.NO. 23	0.2	286	5.8	159	48.04	14.41	2.92	8.00	41.12	0.14	12	ND	68.10	12.30
24	WS.NO. 24	0.1	294	3.5	174	52.04	16.01	2.92	2.00	38.29	0.07	10	ND	12.50	6.00
25	WS.NO. 25	0.1	166	6.6	87	64.05	16.01	5.83	76.00	1.51	0.22	6	ND	14.00	2.90
26	WS.NO. 26	0.4	552	7.0	325	124.10	30.42	11.67	112.00	85.08	0.37	28	ND	13.00	2.00
27	WS.NO.27	0.4	153	6.6	79	48.03	12.81	3.89	64.00	2.83	0.16	7	ND	5.00	13.00
28	WS.NO.28	0.3	1211	7.2	610	272.22	64.05	27.24	272.00	80.83	0.22	37	ND	187.30	73.50
29	WS.NO. 29	8.8	103	5.9	55	44.03	9.61	4.86	12.00	2.83	2.8	5	ND	1.00	9.00
30	WS.NO. 30	1.6	817	6.8	450	240.19	40.03	34.05	264.00	75.15	2.2	29	ND	9.50	1425
31	WS.NO. 31	18.8	118	6.1	65	52.04	16.01	8.75	48.00	1.62	5.2	9	ND	2.00	14.00
32	WS.NO. 32	0.1	467	6.9	258	176.14	49.63	12.65	168.00	32.61	0.28	24	ND	45.90	26.30
33	WS.NO. 33	0.1	216	4.8	140	44.03	12.81	2.92	16.00	34.03	0.21	12	ND	12.00	13.20
34	WS.NO. 34	8.2	110	5.4	62	28.02	8.01	1.72	8.00	7.09	0.14	8	ND	4.00	2.00
35	WS.NO. 35	0.2	156	5.8	78	40.03	11.21	2.92	12.00	15.60	1.80	15	ND	22.50	4.30
36	WS.NO. 36	0.1	340	6.4	180	100.08	28.82	6.81	60.00	29.78	0.34	14	ND	8.00	14..00
37	WS.NO. 37	2.20	118	6.2	66	48.04	14.41	2.92	48	0.00	0.85	5	ND	4.10	3.90
38	WS.NO. 38	1.40	128	4.9	70	32.02	6.41	3.89	5	8.51	0.59	10	ND	6.50	10.00
39	WS.NO. 39	0.10	322	5.2	189	68.05	16.01	6.81	9	48.21	0.46	18	ND	87.70	16.60

40	WS.NO. 40	7.80	426	6.5	225	132.01	40.03	7.78	140	25.52	4.8	21	ND	5.00	10.00
41	WS.NO. 41	0.70	108	6.6	43	36.02	8.00	3.89	32	1.82	0.17	7	ND	1.00	14.00
42	WS.NO. 42	0.40	118	5.3	61	32.02	11.21	0.97	20	8.51	0.16	13	ND	7.20	2.60
43	WS.NO. 43	0.50	240	7.2	130	24.02	16.01	1.45	124	1.59	0.12	4	ND	2.50	10.00
44	WS.NO. 44	1.20	206	6.5	109	56.04	9.60	7.78	80	5.67	0.34	11	ND	8.50	12.00
45	WS.NO. 45	0.20	138	5.8	79	36.03	12.81	0.99	6	12.76	0.41	3	ND	11.70	5.70
46	WS.NO. 46	0.30	161	5.2	82	32.01	8.00	2.72	3	12.76	0.15	3	ND	6.00	8.00
47	WS.NO. 47	3.30	206	6.5	116	80.06	25.62	3.89	60	8.50	0.08	13	ND	1.00	10.00
48	WS.NO. 48	0.20	102	6.2	38	28.02	8.00	1.75	20	1.46	0.27	3	ND	5.60	2.00
49	WS.NO. 49	0.90	209	5.3	112	40.03	14.41	0.82	6	15.22	0.22	4	ND	11.00	4.00
50	WS.NO. 50	11.90	188	5.3	100	36.03	12.81	0.97	3	28.36	3.8	7	ND	6.50	8.00
51	WS.NO. 51	0.20	114	6.1	69	14.03	11.21	3.89	16	4.25	0.23	6	ND	4.00	12.00
52	WS.NO. 52	0.20	391	5.7	208	60.04	12.81	6.81	6	45.38	0.14	18	ND	110.5	11.00
53	WS.NO. 53	0.20	126	5.4	65	28.02	4.80	3.89	8	8.51	0.11	7	ND	3.50	10.50

5.2.1 Turbidity

The cloudiness or haziness of water that looks like smoke in the air is called turbidity. It is caused by the growth of photo-plankton and anthropogenic actions such as construction, mining and agriculture activities. The key test of water quality is the measurement of turbidity. It is measure in NTU (Nepthelometric Unit). According to BIS (2012), the turbidity value up to 5NTU is acceptable and up to 10NTU is permissible. The representative groundwater samples vary in their turbidity from 0.1NTU to 65.5NTU in pre-monsoon samples and 0.1NTU to 18.8 NTU in post-monsoon samples.

5.2.2 Electrical Conductance

The capability of water to carry electrical current is its electrical conductance and it differs both in number and types of ions the present in water. The electrical conductance of groundwater is dependent on the amount of ions present in the groundwater. Majority of the dissolved inorganic constituents in the groundwater are in their ionized type and therefore affect its electrical conductance. When Na^+, K^+, Mg^{+2} react with Cl^- and SO_4^{2-} they form water-soluble compounds like NaCl, Na_2SO_4, etc.

The electrical conductance of the representative samples in part of Dimapur district varies from 38microsiemens/cm to 1142 microsiemens/cm in pre-monsoon samples and it is 46microsiemens/cm to 1211 microsiemens/cm in post-monsoon samples.

5.2.3 Potentia Hydrogeni

Potentia hydrogeni is the scale to measure acidic or basic water. Water that has lower pH is acidic and that has a higher pH value more than 7 is basic and water with pH value 7 is neutral water. Fletcher (1986) stated that the equilibrium between CO_2, CO_3 and H_2CO_3 ions is most often controlled by the pH of natural water. Sodium-carbonate-bicarbonate waters have their pH more than 8.5 whereas bicarbonate waters have their pH value in between 4.0 to 8.5 and water comprising free acids derived from oxidizing sulphide minerals has their pH less than 4.0.

The pH of the representative groundwater samples in parts of Dimapur district ranges from 3.5 to 7.9. During the onset of monsoon it is 4.5 to 7.9 and just after the monsoon it is 3.5 to 7.9.

5.2.4 Total Dissolved Solids

(Nag, *et al* 2013) stated that TDS in water include all ionized or not ionized solid materials in solution excluding suspended sediments, colloids and dissolved gases. The major constituents of the total dissolved solids in groundwater consist of bicarbonate, sulphates and chlorides of calcium, magnesium and sodium and silica (Karanth, 1989).

The representative samples of groundwater in parts of Dimapur district shows variation in their TDS values from 20mg/l to 538mg/l with the average concentration of 128.06mg/l in the onset of monsoon samples and in the samples of just after the monsoon it is vary from 21mg/l to 610mg/l with the average concentration of 141.13mg/l.

The subsurface water in parts of Dimapur district falls under Fresh Water category as per Freeze and Cherry's (1979). According to Annon's (1946) classification the groundwater in part of Dimapur district falls under useful for irrigation for all the representative samples in both the seasons. According to the classification of (BIS: 10500-2012) for TDS. 98.11% (52 samples) falls under desirable category for safe drinking and 1.89% (1 sample) falls under permissible limit for safe drinking type in both the seasons respectively.

Table 8: Groundwater classification based on TDS (after Freeze and Cherry, 1979)

TDS mg/l	Category
0-1000	Fresh water
1000 – 10,000	Brackish water
10,000 – 1,00,000	Saline water
>1,00,000	Brine water

Table 9: Groundwater classification based on TDS (after Annon's 1979)

TDS mg/l	Category
Up to 500	Desirable for Drinking
500 –1000	Permissible for Drinking
Up to 3000	Useful for Irrigation
Above 3000	Unfit for Drinking and Irrigation

5.2.5 Total Hardness

Water hardness is defined as the amount of Ca and Mg ions presence in water. Hard water is formed when groundwater moves through the deposits of Ca and Mg carbonates, bicarbonates and sulfates. Ca and Mg in water react with soap and produce soap curb which is insoluble and sticky and cannot be removed by rinsing. Hence hardness of water is described as the power of destroying soap which is caused by the amount of Ca and Mg ions presence in water with the mixture of CO3, HCO_3, SO_4 and NO_3 constituents and is reported in milligram per liter (mg/l).

According to BIS (2012) the TH value up to 300mg/l is acceptable and up to 600mg/l is permissible for drinking. In part of Dimapur district the TH value of groundwater in pre-monsoon samples varies from 3.85mg/l to 257mg/l and in post-monsoon samples it is vary from 12mg/l to 272mg/l.

5.2.6 Calcium

Ca which forms a main constituent of rock minerals in many rocks and is among the most plentiful metals on the earth crust. In most natural water presence of Ca contributes a major component of solutes (Sujatha, 2002). The highest acceptable limit and maximum permissible limit for drinking set by BIS (2012) is 75mg/l and 200mg/l respectively.

The representative samples of groundwater in parts of Dimapur district vary in their Ca concentration from 0.0mg/l to 32.32mg/l during onset of monsoon period. It is ranges from 3.20mg/l to 456.20mg/l just after monsoon.

5.2.7 Magnesium

Magnesium being among the most common elements in the crust of the earth, it is found present in all-natural waters. The sources of Mg are mafic minerals (pyroxene, amphibole, and olivine), dolomite, chlorite and clay minerals.

BIS (2012) set the highest acceptable limit for drinking purpose at 30mg/l and maximum permissible is up to 100mg/l. Concentration of Mg in subsurface-water in parts of Dimapur district is varying from 0.0mg/l to 51.42mg/l with the average concentration of 7.65mg/l in the onset of monsoon samples, and in just after monsoon samples it is vary from 0.0mg/l to 55.02mg/l with an average concentration of 7.07mg/l.

5.2.8 Sodium

Natural sources of Na are K and Plagioclase feldspar group of minerals and clay minerals. The most significant source of Na in subsurface water is the sodium salts that saturated in the shallow water tracts, intrusion of salt water in the coastal areas and water that were trapped in the pores of sedimentary rocks (Karanth, 1989).

Sodium salts are practically present in all foodstuffs. It is essential to human life. They form an important part of blood plasma and in functioning of the nervous system. Sodium salts help in controlling muscle contraction and aiding digestive processes. However, too much sodium in the foodstuffs can injure kidneys and cause high blood pressure. Discriminating effects of sodium salts include unsettled stomach, cerebral and pulmonary edema etc. (Elton and Narzareno, 1963). It is therefore important to know how much sodium is present in your foodstuffs for your health.

The Na content in the representative subsurface water samples differ from 6.00mg/l to 185.30mg/l during onset of monsoon and its average concentration is 28.76mg/l and in the samples of just after monsoon it is vary from 1.00mg/l to 187.30mg/l with their average value of 20.85mg/l.

Table 10: Dietary Reference Intake Values of K (IOM, 2004)

	Age group	Dietary Reference Intake (g/day)
Infant	0 to 6 months	0.4g/day
	7 to 12 months	0.7g/day
Children	1 to 3 years	3.0 g/day
	4 to 8 years	3.8 g/day
Male youth and Adult	9 to 13 years	4.5 g/day
	14 to >70 years	4.7 g/day
Female youth and Adult	9 to 13 years	4.5 g/day
	14 to >70 years	4.7 g/day
Pregnancy	NA	4.7 g/day
Lactation	NA	5.1 g/day

5.2.9 Potassium

Main source of K in groundwater is feldspar, micas and the feldspathoids. In groundwater, the amount of K is much lower than the amount of Na, Ca and Mg (Kumar *et al* 2015). Potassium is released slowly upon dissolution of rocks, consequently concentration increases as residence increases. The two reasons that are responsible for the low concentration of K in subsurface water are – fighting capacity of K minerals to decompose by weathering and addiction of K in clay minerals during weathering (Karanth, 1989).

Potassium is commonly occurring in all-natural waters as it is widely occurring in the environment. Potassium is an essential element for human nutrition. Undesirable health effects are unlikely to occur in healthy persons due to consumption of potassium from drinking water. However, high intake of K may cause so many complications like chest tightness, shortness of breath and heart failure etc.

Some of the important functions of K are nerve stimulus, muscle contractions, regulation of blood pressure etc. Complications due to shortage of K may lead to weakness of muscle, disorder in heart rhythm etc. K shortage may lead to complication like kidney diseases because the kidneys regulate the physical balance of K (lenntech.com).

In the representative groundwater samples in parts of Dimapur the concentration of K varies from 2.00mg/l to 75.60mg/l and its average concentration is 14.43mg/l in the samples of onset of monsoon and in the samples of just after monsoon concentration of K varies from 0.00mg/l to 73.50mg/l and the average value is 10.57mg/l.

5.2.10 Alkalinity

The salts of carbonates and bicarbonates along with hydroxyl ions in the free salts make natural subsurface water alkaline. The ability of water to neutralize acids is called alkalinity of water.

Carbonate and bicarbonate ions in the subsurface water are most commonly caused by the dissolved CO_2 in rain water (Karanth, 1989). Hardness and alkalinity of water is influence by the presence of bicarbonate in water. The pH of groundwater shows the types of CO_2 present. When the pH of water is less than 4.5 it indicates the presence of carbonic acid, if the pH of groundwater is between 4.5 and 8.2 it indicates bicarbonate type of water and pH more than 8.2 it indicates carbonate type of water. The water containing bicarbonate up to 600mg/l is considered acceptable for drinking and it is good for the purposes of irrigation.

The amount of bicarbonate in subsurface water in parts of Dimapur district is varying from 2.00mg/l to 268.00mg/l and the average value is 48.30mg/l in the onset-monsoon samples and in the samples of just after monsoon varies from 0.00mg/l to 272.00mg/l and it average value is 53.47mg/l.

5.2.11 Chloride

In nature chlorides are widely dispersed as salts of sodium, potassium, and calcium. Hence chloride is found in natural waters. Chloride in surface and subsurface waters mainly comes from both natural and anthropogenic sources. The natural sources of chloride in subsurface water are because of the weathering of igneous and sedimentary rocks as well as intrusion of sea water in the coastal area. The anthropogenic sources of chloride in surface and subsurface water are from the use of inorganic fertilizers, landfill leachates, irrigation drainage etc.

Chloride content in the groundwater in parts of Dimapur district in pre-monsoon samples are varying from 0.00mg/l to 83.97mg/l and it average concentration is 22.18mg/l and in the samples of after-monsoon the concentration of chloride is varying from 0.00mg/l to 85.08mg/l and it average concentration is 21.62mg/l.

5.2.12 Iron

Iron is the fourth most abundant major constituents in the rocks next only to O, Si and Al. Iron is present mostly as oxide, carbonate and hydroxide in sandstone, shale and limestone. Naturally, iron occurs as a metal in minerals, soils and rocks, in subsurface water, subsurface water that comes into contact with these mineral soils and rocks dissolving them and released iron and manganese to the groundwater along with the other constituents. The dissolution of iron in subsurface water is relying upon the extent of the amount of oxygen present in water. There are two forms of iron Fe^{+2} and Fe^{3}. $Fe^{+2}$are highly soluble whereas Fe^{3+} will not be readily form a solution.

Iron content in the groundwater representative samples in parts of Dimapur district during onset-monsoon period ranges from 0.18mg/l to 2.5mg/ and in the samples of after-monsoon period iron content varies from 0.06mg/l to 5.2mg/l. Iron concentration is high in the groundwater in many places during dry season (onset of monsoon).

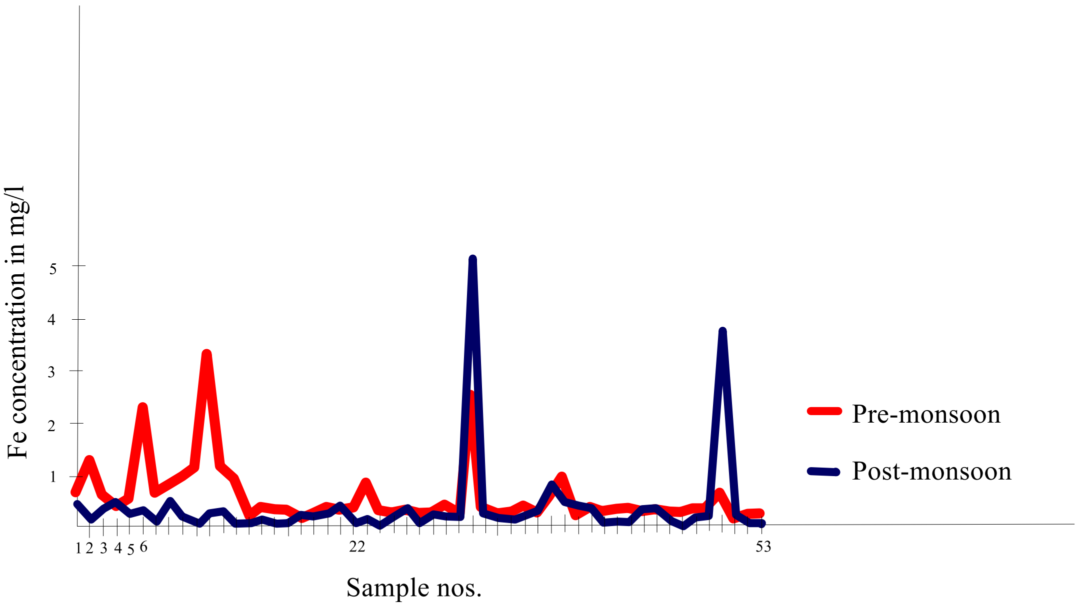


Figure 8: Seasonal variations in Fe concentration in groundwater of the study area

5.2.13 Sulphate

Naturally Sulphate occurs in many minerals such as $BaSO_4$, $MgSO_47H_2O$ and $CaSO_42H_2O$ Greenwood and Earnshaw (1984).

Comparing to the other anions sulphate is one of the least toxic, however, at high concentration may cause noticeable taste as concentration of sulphate in water increases above 500mg/l. The distribution systems may also get decomposed because of the presence of sulphate in water. Concentration exceeds 250mg/l may cause gastrointestinal irritation (Raghunath 1987). It may cause laxative effect at concentration of 1000mg/l to 1200mg/l. According to BIS (2012) 200mg/l and 400mg/l. is considered the maximum extent of acceptance and highest extent of permissible for safe drinking.

Sulphate content in the groundwater samples in parts of Dimapur district varies from 2.00mg/l to 29.00mg/l and it average concentration is 10.06mg/l in the onset-monsoon samples and in the after-monsoon samples it is varying from 2.00mg/l to 90mg/l and it average concentration is 11.75mg/l.

5.2.14 Fluoride

Important minerals from which fluoride is released into groundwater are fluorite, apatite, certain amphiboles and micas. Beside fluorine bearing minerals, fluoride is released into the subsurface water by the manufacture and used of phosphate fertilizers. Edmund and Smedley

(2013) stated that in the country with crystalline rocks rich in fluoride minerals such as granites and volcanic rocks the groundwater tends to have high fluoride content.

Food and Nutrition Board, Institute of Medicine stated that fluoride in more than 10mg per day is harmful for adults and children above 8 years. Low concentration of fluoride such as 1mg/l is considered useful for preventing tooth decay. However, dental caries and tooth decay are caused by the insufficient amount of fluoride in food and drinking water. Tiemann (2013) stared that elevated concentration may cause dental and skeletal fluorosis. Park (2015) stated that fluorides are defluorated by phosphate, which reduces water that contains high level of fluorides to optimum levels.

The acceptable limit for fluoride in safe drinking water as per BIS (2012) is 1.0mg/l and maximum limit of permissible is 1.5mg/l. However, fluoride is found to be below detection limit in the groundwater samples in part of Dimapur district.

5.3 TRILINEAR DIAGRAM

Trilinear diagram was proposed by Piper (1944) to classify groundwater. It includes two triangular fields at the lower right and lower left and a diamond-shaped field.

The pre-monsoon samples in parts of Dimapur district reveal the following water types after plotting on the Piper's trilinear diagram.

Sub division 1=2, 7, 8, 9, 20, 26, 30, 31, 32, 34, 36, 37, 40, 42, 44, 47, 48, 49, 51 = 19 samples.

Subdivision 2=1, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 27, 28, 29, 33, 35, 38, 39, 41, 43, 45, 46, 50, 52, 53=34 samples (Alkalis exceeds Alkaline earth).

Sub division 3= 1, 3, 4, 5, 7, 9, 11, 20, 25, 26, 27, 28, 29, 30, 31, 32, 37, 40, 41, 42, 43, 44, 47, 48, 51= 25 samples.

Sub division 4 = 2, 6, 8, 10, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 33, 34, 35, 36, 38, 39, 45, 46, 49, 50, 52, 53 = 28 samples (Strong acids exceeds weak acids).

Sub division 5 = 7, 9, 20, 26, 30, 31, 32, 37, 40, 42, 44, 47, 48, 51 = 14 samples.

Sub division 6 = 2 = 1sample.

Sub division 7 = 6, 10, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 33, 35, 38, 39, 45, 46, 50, 52, 53 = 23 samples (Alkalis and Strong Acids).

Sub division 8 = 25, 41, 43 = 3 samples.

Sub division 9 = 1, 3, 4, 5, 8, 11, 27, 28, 29, 34, 36, 49 = 12 samples.

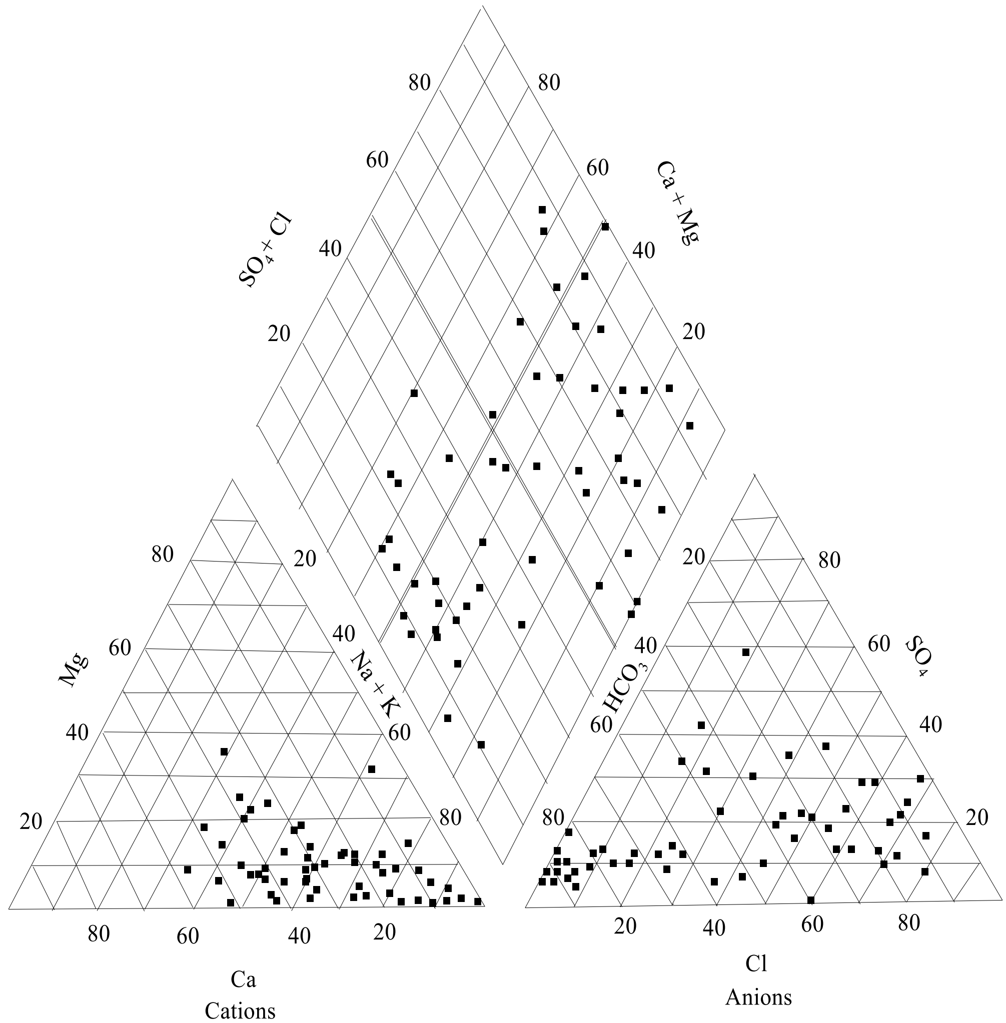


Fig 9: Graphical representation of groundwater samples during pre-monsoon season after Piper (1944)

The post-monsoon samples in parts of Dimapur district reveal the following water types after plotting on trilinear diagram: -

Sub division 1 = 1, 7, 10, 11, 15, 17, 19, 20, 22, 24, 25, 26, 29, 30, 31, 34, 36, 37, 40, 42, 43, 47, 48, 49 = 24 samples

Sub division 2 = 2, 3, 4, 5, 6, 8, 9, 12, 13, 14, 16, 18, 21, 23, 27, 28, 32, 33, 35, 38, 39, 41, 44, 45, 46, 50, 51, 52, 53= 29 samples (Alkalis exceeds Alkaline earth).

Sub division 3 = 1,3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 19, 21, 25, 27, 28, 29, 30, 31, 32, 36, 37, 40, 41, 43, 44, 47, 48, 51 = 29 samples (Weak Acids exceeds Strong Acids).

Sub division 4 = 2, 11, 12, 13, 14, 15, 17, 20, 22, 23, 24, 26, 33, 34, 35, 38, 39, 42, 45, 46, 49, 50, 52, 53 = 24 samples.

Sub division 5 = 1, 7, 10, 15, 19, 25, 29, 30, 31, 36, 37, 40, 43, 47, 48 = 15 samples

Sub division 6 =17, 20 = 2 samples

Sub division 7 = 2, 12, 13, 14, 18, 23, 33, 35, 38, 39, 45, 46, 50, 52, 53 = 15 samples

Sub division 8 = 4 = 1 sample

Sub division 9 = 3, 5, 6, 8, 9, 11, 16, 21, 22, 24, 26, 27, 28, 32, 34, 41, 42, 44, 49, 51 = 20 samples (Not a single Cat ion and Anion pair exceeds 50% i.e. Neutral Water).

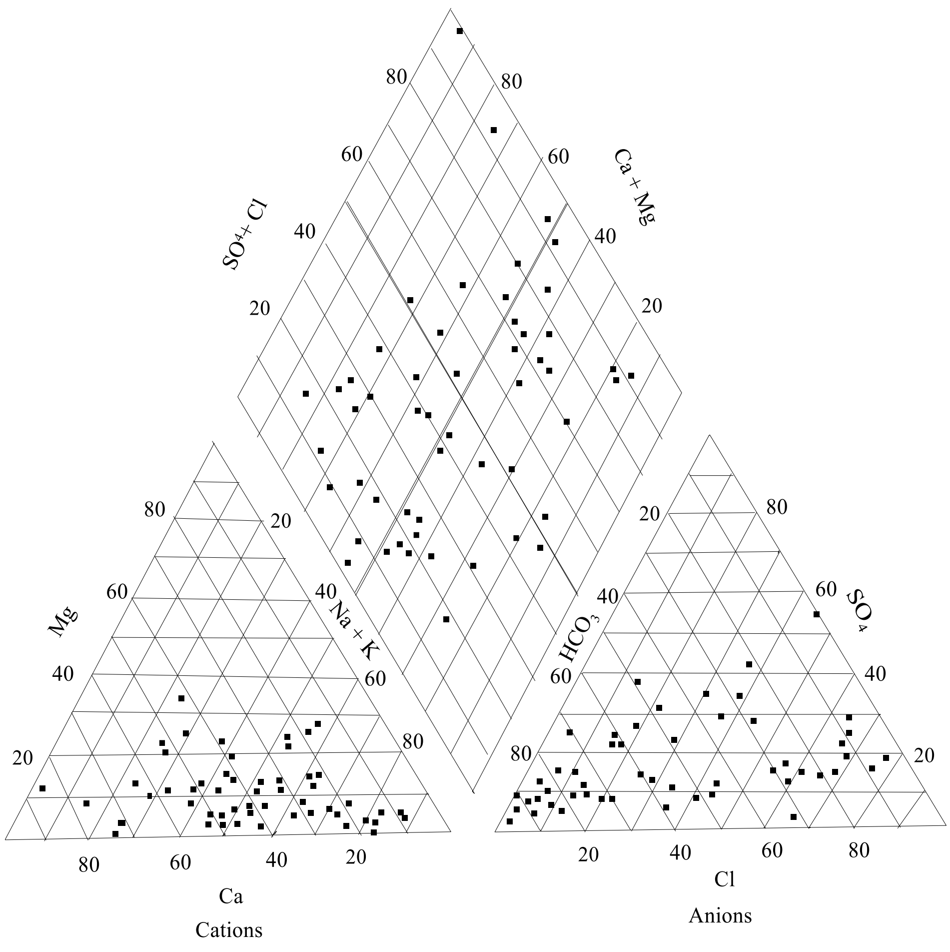


Fig 10: Graphical representation of groundwater samples during post-monsoon season after Piper (1944)

5.4 GROUNDWATER QUALITY FOR IRRIGATION

To find out the appropriateness of the subsurface water in parts of Dimapur district for the purpose of irrigation the following methods were used, Sodium Absorption Ratio (SAR), USDA graphical method, Magnesium Ratio, Permeability index etc.

5.4.1 Sodium Adsorption Ratio (SAR)

In the management of soils affected by sodium, the appropriateness of the subsurface water for irrigational use is decided based on the value of sodium adsorption ratio (SAR). The amount of Na relative to Ca and Mg in the subsurface water is measure by (SAR). The more the value of sodium adsorption ratio the less is the water suitable for irrigation. The higher the amount of Na in the soil the lesser is the permeability and infiltration capacity of the soil which causes problems in crops production. The following equation is used by Richards (1954) to calculated (SAR).

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

Table 11: Todd's water classification for SAR value

SAR	Water class
Less than 10	Excellent
10 to 18	Good
19 to 26	Fair
More than 26	Poor

SAR=<10 = Excellent water: Can be used for irrigation in almost all soils with low levels of harmful exchangeable sodium. If crops that are sensitive to sodium are grown with this water, it will harm the crops due to the accumulation of harmful sodium in it.

SAR=10 – 18= Good water: Can be used for irrigation in coarse textural soil or organic soils because these soils have good permeability. However, if gypsum is absent in fine textural soils it produces sodium hazard due to low soil leaching. SAR= 18- 26 = Fair water: This water can generate a detrimental quantity of transferable Na if used for irrigation, therefore required special soil management, like addition of organic substances.

SAR= >26 = Poor water are generally unsuitable for irrigation purposes.

In parts of Dimapur district the onset-monsoon samples shows the SAR values from 0.0mg/l to 53.21mg/l with 39 samples (73.6%) falls in excellent class, 6 samples (11.3%) in good class, 3 samples (5.7%) in fair class and 5 samples (9.4%) falls in poor class of water for irrigation. During post-monsoon period the SAR value ranging from 0.21mg/l to 35.28mg/l with 43 samples (81.1%) in excellent class, 5 samples (9.4%) falls in good class, 3 samples (5.7%) in fair class and 2 samples (3.8%) falls in poor class of water for irrigation purposes.

5.4.2 Salinity Hazard

Salinity hazard classification of the groundwater according to USDA after Richards (1954) used two parameters namely electrical conductance represent salinity along x-axis and SAR represent sodium hazard along y-axis. Along the x-axis salinity hazard levels is categorized into low, medium, high and very high and along the y-axis sodium hazard levels is categorized into low, medium, high and very high. The entire diagram was partitioned into sixteen different combinations of salinity and sodium levels.

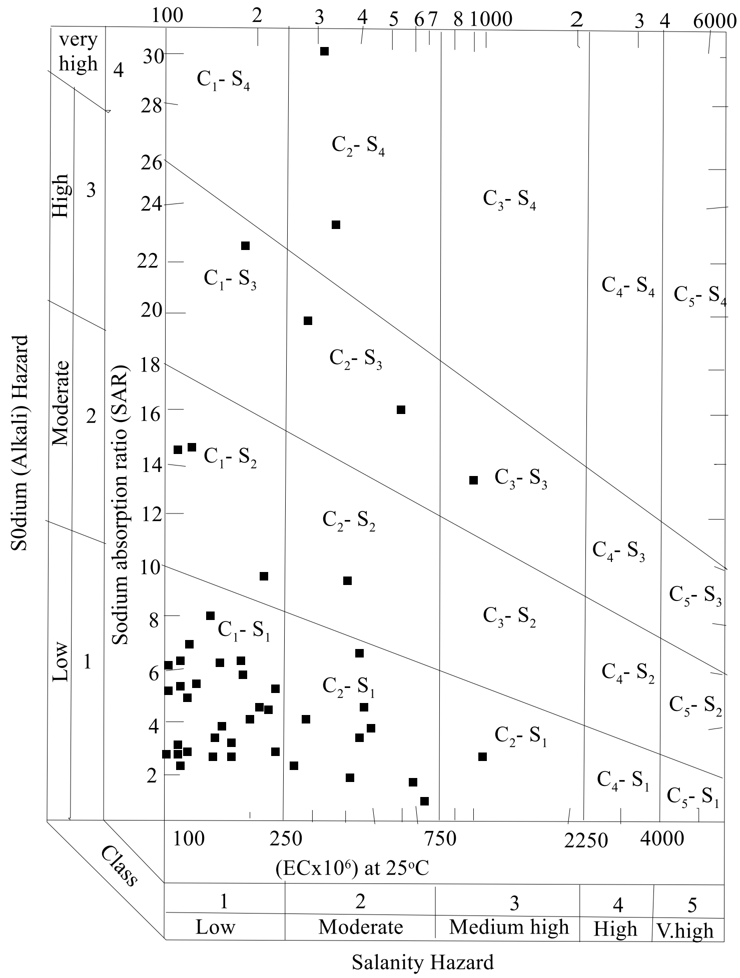


Fig11: Salinity hazard classification of the groundwater according to USDA after Richards (1954) (pre-monsoon)

Low-salinity water (C_1): This water can be utilized for irrigational purposes in majority of the soils for most of the crops.

Medium salinity water (C_2): This water can be utilized for irrigation to grow the crops that have modest salt forbearance.

High salinity water (C_3): This water is not useful in soils with constrained drainage.

Very high salinity water (C_4): Under normal conditions this water is unsuitable for irrigational purposes.

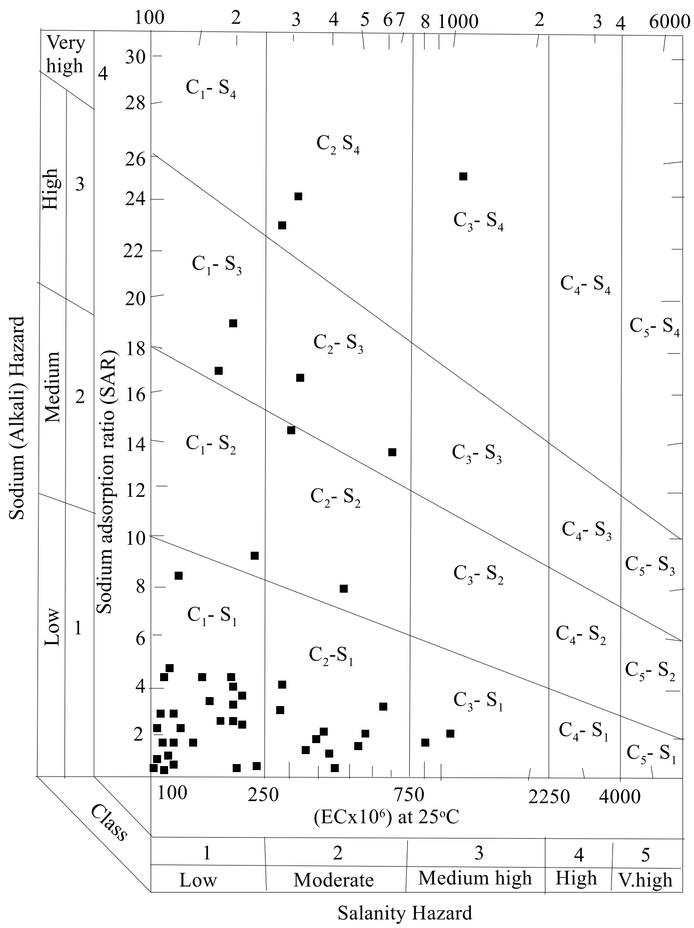


Fig 12: Salinity hazard classification of the groundwater according to USDA after Richards (1954) (post-monsoon)

5.4.3 Sodium Hazard

Low sodium water (S_1): Low sodium water can be employed for irrigational activities on majority of the soils.

Medium sodium water (S_2): This water could be safely used as irrigation in coarse texture soils.

High sodium water (S_3): This water produces detrimental levels of alterable sodium in the majority of soils.

Very high sodium water (S_4): This water is customarily not satisfactorily employed for irrigational purposes.

Based on the USDA diagram the subsurface water in parts of Dimapur district can be classified into three categories which are shown in the tabular form in table 12.

Table12: Classification of groundwater in the study area based on USDA diagrams

Season	Category	No. of Samples	%
Pre-monsoon	Good waters	36	67.92
	Moderate waters	8	15.09
	Bad Waters	3	5.66
Post-monsoon	Good Waters	42	79.24
	Moderate Waters	7	13.20
	Bad Waters	2	3.77
6 samples in pre-monsoon samples and 3 samples in post-monsoon samples are out of range.			

It is found that 67.92% of onset-monsoon samples and 79.24% of after-monsoon samples of the groundwater in parts of Dimapur district are within Good waters class for irrigational purposes.

5.4.4 Mg Ratio

The elements of calcium, magnesium and the other alkaline-earth metals jointly form the total hardness of water. However, other alkaline earth metals are normally so poorly concentrated in water that their contribution to the total hardness can be neglected. Normally Ca and Mg sustain a condition of stability in almost all waters. In the state of stability more Mg being present in water which affects the soil quality results in decreasing the crop yielding. The Mg ratio is calculated by the formula:

$$Magnesium\ Ratio = \frac{Mg^{\ 2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Magnesium ration in the subsurface water in the onset-monsoon in parts of Dimapur district vary from 0.0 to 84.78 and in after-monsoon subsurface water samples the magnesium ratio differs from 0.0 to 67.80. Only 3 water samples (5.66%) contain magnesium ratio above 50% while the rest 94.44% falls below 50% in both the seasons.

5.4.5 Permeability Index

Permeability refers to whether and how water can flow through a rock or soil. Permeability data is often used in studies of groundwater and in particular during investigation of population or aquifer contamination. A high concentration of alkaline earth metals in soil results in decreasing the soil infiltration and permeability which in turn leads to decrease in crop production.

The permeability Index (PI) is calculated by the formula:

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

In 1964 Doneen classified water based on PI is as follows: -

Class I= Permeability Index more than 75%

Class II= Permeability Index is 25% to 75%

Class III= Permeability Index is less than 25%.

It is found that in parts of Dimapur district 92% (52 samples) of subsurface water during onset of monsoon and 96% (51 samples) of subsurface water after-monsoon are falls within class I and class II i.e. good and suitable class for irrigational use as per their permeability index.

5.4.6 Residual Sodium Carbonate (RSC)

Hopkins, *et al* (2007) stated that when dissolved sodium is more than dissolved magnesium in water. Clay soil undergoes dispersions and considerably reduces the infiltration ability of clay soil. Eaton (1950) stated that if water used for irrigation contains excess of CO_3^{2-} $+HCO_3^-$, it increases the pH of the soil. Calcium and magnesium in the soil solution can be precipitated by carbonate and bicarbonate ions form Ca, Mg Carbonate. RSC index is thus employed to estimate the suitability of surface water for irrigational use in clay soil.

Table 13: Showing the result and rating of groundwater in the study area based on RSC

RSC mg/l	Irrigation class	No. of Samples	
		Pre -monsoon	Post -monsoon
<1.25	Suitable	24	21
1.25-2.5	Marginal	01	0
>2.5	unsuitable	28	32

RSC is obtained by the formula,

$$RSC = \left({CO_3}^{2-} + {HCO_3}^{-}\right) - (Ca^{2+} + Mg^{2+})$$

According to USDA (Richard,1954), a groundwater with RSC index lower than 1.25 mg/l in water is probably suitable for irrigation and water with RSC less than 1.75 to 2.5 mg/l are marginal quality and water with RSC index value over 2.5 mg/l are unfavorable for irrigational purposes. It found that 45.28% of the subsurface water in parts of Dimapur district during onset-monsoon and 39.62% of after-monsoon period are falls within suitable category for irrigational purposes.

5.4.7 Kelly's Ratio

Kelly, (1946) measured the level of Na against the level of Ca+Mg by the following formula.

$$Kelly's\ Ratio = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+})}$$

Table14: Categorization of the groundwater in the study area based on Kelly's ratio.

Kelly's ratio	Category	Total % Pre-monsoon	Total % Post monsoon
>1	Suitable	28	39
<1	unsuitable	25	14

Water that contains an excess amount of sodium has Kelly's ratio value higher than one and it is found that such waters are not favorable for irrigational used. Therefore, the groundwater that has Kelly's ratio value lesser than one are preferable for irrigational used.

As per Kelly's ratio the subsurface water in parts of Dimapur district there are 28 (52.83%) samples of the onset-monsoon water and 39 (73.58%) samples of the after-monsoon water are found suitable for irrigation purpose.

5.5 TRACE ELEMENTS

Karanth (1989) stated that certain metallic constituents were present in subsurface water in very less amount or traces normally not more than 1ppm. These elements are called trace elements or trace metals.

The trace elements are distributed in a variety of rocks type. The general association of nickel, cobalt, chromium and titanium are with basic and ultra-basic igneous rocks. Zinc, tin, arsenic, lead, copper, beryllium and strontium as well as radioactive elements are usually occurred along with igneous rocks of intermediate and acid type and also the metamorphic rocks which is intruded by acid igneous rocks. Some trace elements like arsenic, bismuth and cadmium are sulphides; titanium and beryllium are oxides and silicates whereas barium and strontium are carbonates and silicates. The common minerals of nickel and cobalt are sulphides and arsenide's and that of tin are sulphides and oxides. The common minerals of zinc, copper and lead includes sulphides, oxides and carbonates and common minerals of chromium is an oxide.

Purushothan, *et al* (2017) stated that the most significant sources of natural occurrence of trace elements into the water bodies are the rock water interaction. Khan, *et al* (2013) stated that because of the human activities like vehicular exhaust, application of fertilizers and pesticides etc increased the amount of trace elements in surface water. Sujatha (2002) stated that human activities like municipal sewage and industrial effluent introduce trace elements directly into the groundwater.

Trace elements are also called as heavy metals by Freeze and Cherry (1979). Presence of these heavy metals in trace amount is useful for healthy growth of plants and human metabolism and in excess amount of the same element is harmful for human's health (Chapman, 1992). Potentially toxic trace elements were introduced into the environment through the natural phenomenon or action or by unscrupulous human involvement create problems for human health. Estimation of these trace elements/metals in groundwater in parts of Dimapur district is therefore very essential because the presence of these trace elements may adversely affect the well-being of the water consumers.

In the present work 24 groundwater samples collected in part of Dimapur district were analyzed for heavy metals like copper, zinc, nickel and arsenic. The presence these trace elements/ heavy metals may be transported to the study area from the ultra-mafic rocks of the Naga ophiolite belt like nickel-cobalt ferrous magnetite, peridotite and paragonite due to tectonic activities that took place during Naga ophiolite belt formation. Polizzotto, *et al* (2008) stated that arsenic is derived in nature from weather-beaten sediments from the Himalayan region and come into solution subsequent reductive discharge from solid phases in an environment lack free oxygen, (preventing normal life for organisms that depends on oxygen) and contaminate groundwater in Asia. In the same manner arsenic may be derived from Naga ophiolite sediments and contaminate the subsurface water in part of Dimapur district because generally the direction of flows of rivers from north to south.

24 representative samples of subsurface water were collected in part of Dimapur district was analyzed for the trace elements /metals like Cu, Zn, Ni and As. The data are given in the tabular form.

Table 15: Result of the analyzed trace elements (pre-monsoon)

Sample No.	Copper (Cu) mg/l	Zinc (Zn) mg/l	Nickel (Ni) mg/l	Arsenic (As) mg/l
1	0.086	0.104	BDL	BDL
2	0.101	0.044	BDL	BDL
3	0.077	0.111	BDL	0.034
4	0.093	0.046	BDL	BDL
5	0.092	0.097	BDL	BDL
6	0.075	0.034	BDL	BDL
7	0.119	0.097	BDL	BDL
8	0.118	0.110	BDL	BDL
9	0.006	0.060	BDL	BDL
10	0.115	0.155	BDL	BDL
11	0.121	0.197	BDL	BDL
12	0.118	0.055	BDL	BDL
13	0.133	0.090	BDL	BDL
14	0.131	0.106	BDL	BDL
15	0.140	0.065	BDL	BDL
16	0.150	0.052	BDL	BDL
17	0.129	0.068	BDL	BDL
18	0.147	0.042	BDL	BDL
19	0.144	0.103	BDL	BDL
20	0.165	0.102	BDL	0.005
21	0.164	0.057	BDL	BDL
22	0.139	0.068	BDL	BDL
23	0.170	0.052	BDL	BDL
24	0.153	0.047	BDL	BDL

BDL= Below Detection Limit

Table 16: Results of the analyzed trace element (post- monsoon)

Sample No.	Copper (Cu) mg/l	Zinc (Zn) mg/l	Nickel (Ni) mg/l	Arsenic (As) mg/l
1	0.800	0.340	BDL	BDL
2	0.646	0.232	BDL	BDL
3	1.601	0.177	BDL	0.012
4	2.252	0.367	BDL	BDL
5	1.478	0.641	BDL	BDL
6	1.081	0.175	BDL	BDL
7	1.231	0.246	BDL	BDL
8	0.847	0.215	BDL	BDL
9	1.537	0.199	BDL	BDL
10	1.854	0.208	BDL	BDL
11	1.057	0.241	BDL	BDL
12	1.215	0.297	BDL	BDL
13	1.590	0.357	BDL	BDL
14	0.636	0.281	BDL	BDL
15	0.732	0.396	BDL	BDL
16	0.859	0.249	BDL	BDL
17	1.317	0.257	BDL	BDL
18	1.628	0.121	BDL	BDL
19	1.460	0.342	BDL	BDL
20	0.423	0.948	BDL	0.002
21	0.764	0.233	BDL	BDL
22	0.868	0.154	BDL	BDL
23	2.457	0.209	BDL	BDL
24	0.063	0.139	BDL	BDL

BDL= Below Detection Limit

5.5.1 Copper

Copper occur in native state as well as compound. Common minerals of copper include sulphides, oxides and carbonates. Copper is usually occurring in association with igneous rocks of intermediate and acidic type and metamorphic rocks which is intruded by acid igneous rocks (Karanth 1989).

Copper in a water supply may hinder the intended domestic uses of water. Galvanized iron and steel fittings were corroded by the presence of Cu in water. Copper also stained laundry and sanitary wares (Park, 2015). Concentration of Cu can increase several mg/l if the water is remaining motionless in the pipe for quite a long time.

Tiwari *et al* (2013) stated that Cu in a very small amount is important for human metabolism and the development of hemoglobin. The intake of Cu from food is normally 3mg/day but excess intake of Cu could increase the risk of our health (Krishna and Govil 2004). Acute gastritis pain might be occurred in some people when Cu amount in drinking water is found to be more than 3mg/l, long tern ingestion to copper cause liver cirrhosis in adult and an undesirable bitter taste to water(WHO 1993).

The concentration of copper in the groundwater in parts of Dimapur district in pre-monsoon samples are found to be 0.006 mg/l to 0.170mg/l and in the post-monsoon samples it is from 0.063mg/l to 2.252mg/l.

5.5.2 Zinc

Zinc occurs generally in association with intermediate and acidic igneous rocks. The common mineral of zinc includes sulphides, oxides and carbonates. The principal zinc ores are sphalerite and wurzite. Undesirable astringent taste of water is imparted by the presence of zinc in water. If the concentrations of zinc in water are more than 5mg/l opalescent may appear on the surface of water and greasy film may develop on boiling these effects may also noticeable at concentration as low as3mg/l (Park, 2015).

Purushothan, *et al* (2017) stated that Zinc is an indispensable metal found in almost all kind of food and drinkable water. An adult daily requirement of zinc is 15-22mg/day (WHO, 2004). Dwarfism is caused by zinc deficiency whereas excessive zinc causes lot of health complication in humans such as vomiting, dehydration etc.

BIS (2012) set the maximum acceptable value of zinc in potable water at 5.0mg/l. In parts of Dimapur district in the samples of onset-monsoon water the amount of zinc is found from 0.034mg/l to 0.197mg/l and in the samples of after-monsoon water the concentration of zinc is 0.139mg/l to 0.948mg/l.

5.5.3 Nickel

The common minerals of nickels are sulphides and arsenide. Nickel may contaminant drinking water due to leaching of metals from water pipe and fittings. Nickel may also present in groundwater due to the dissolution from nickel ores bearing rocks such as basic and ultra-basic igneous rocks. It is stated by Tiwari, et al (2013) that nickel is found in micro-organism and in some of the enzymes in plants. Iron adsorption and metabolism in human body is enhancing by nickel. Barzilay (1999) stated that rigorous contact of nickel by the human body is associated with multiple chemical sign or symptoms.

The analytical data of groundwater samples collected in parts of Dimapur district reveals that the concentration of nickel is below detection limit as compared to BIS (2014).

5.5.4 Arsenic (As)

Arsenic occurs in association with igneous rocks of intermediate and acidic types and metamorphic rocks intruded by acid igneous rocks. Arsenic occurs in the environment in many oxidation states but in water it is mostly occur as the inorganic forms as As^{+3} and As^{+5}. Smedley (2008) stated that organic forms of arsenic may become more important in water affected by industrial pollution even though organic forms of arsenics are rarely significant in groundwater. Arsenic compounds are releasing in groundwater during mining. (Puzari *et. al* 2015) stated that arsenic from the soils and worn-out rocks dissolves and enters groundwater. Arsenic may be introduced into groundwater from anthropogenic activities such as industrial effluents, pesticides, insecticides and herbicides. In nature arsenic may also introduced into groundwater from atmospheric deposition. Polizzotto, *et al* (2008) stated that groundwater are contaminated by arsenic that may come from the eroded sediments and come into solution subsequent reductive discharge from solid phases in an environment lack free oxygen, (preventing normal life for organisms that depends on oxygen).

Bucher, *et al* (1991) stated that serious health hazards are caused by unwarranted quantity of arsenic in potable water. Rahman, *et al* (2003) stated that arsenic in its elementary form is very toxic and carcinogenic, presence of minute quantity of arsenic in drinking water may cause create lot of health complication.

BIS (2012) placed the highest level of acceptance of arsenic in drinking water is 0.01mg/l. In parts of Dimapur district arsenic concentration is found to be from 0.002mg/l to 0.034mg/l. In most of the groundwater samples arsenic is found to be below detection limit, however in sample no.3 it is found that the concentration of arsenic is 0.034mg/l in the onset-monsoon and after-monsoon sample it is 0.012 mg /l.

***

CHAPTER VI

DISCUSSION

This chapter focuses mainly on the groundwater resources and its quality based on the hydrogeology, hydrogeomorphology and hydrogeochemistry.

6.1 HYDROGEOLOGY

Geologically, in parts of Dimapur district (study area) is composed of litho-tectonic units of Palaeogene, Neogene and Quaternary rocks. The rocks of palaeogene are represented by Laisong, Jenam and Renji of Barail Group. The rocks of Neogene are typified by Surma and Tipam Group. Quaternary rocks are typified by the high level terraces and alluvial deposits of Pleistocene-Recent age. The Burmese plate served as the provenance for these sediments. The Primary sedimentary structures in Surma and Tipam group of rocks indicate fluvial depositional environment.

The occurrences of subsurface water and its movement in any basin is dependent on the various factors like topographical features, types of rocks, geological structures such as fault, fold, joint, fracture etc. Depth of weathering, permeability of rocks, drainage pattern, landforms, land use/land cover, climate conditions and interrelation between these factors (Greenbaum, 1992).

Groundwater occurrences and movement is control by the geohydrological characteristics of geological formations. The subsurface geology of parts of Dimapur district as reveals by the litho log consist of alluvium deposit of sand, clays, silts, pebbles and boulders which constitute more than 90% of the plain area (Fig 5, 6 and 7). Because of the coarse texture of the deposits in the study area heavy recharge occurs from percolating of water from influent rivers Chathe and Dhansiri Rivers which controlled the groundwater quality to a great extent.

Hydrogeologically the Dimapur alluvial plain (parts of Dimapur district) comes under unconsolidated unit. It is structurally controlled and consist of argillaceous, arenaceous and rudaceous types of rocks of unconsolidated nature. Due to the coarse texture of the unconsolidated rocks the alluvial plain has high permeability and high specific yield, hence hydrogeologically the study area representing the potential aquifer zones for groundwater development.

6.2 GEOMORPHOLOGY

Geomorphological two main landforms identified in the study area are piedmont and floodplain. Geomorphic features like paleochannels, natural levee, horse shoe/oxbow lakes etc. indicate fluvial environment of deposition. The litho log (Fig 5) reveals that in the piedmont zone there are three confined aquifers with 9m 12m in thickness. Another litho log from floodplain area (Fig 7) reveals that there are at least five confined aquifers zones having the thickness of 1.5m to 34m. The piezometric surface in the piedmont zones is located at about147m and in the floodplain zones it is located at about 113m.

The litho log reveals that the study area consists mainly of alluvium deposits and there are multiple horizons of pebbles, gravel, sand, silt and clays indicating multiple confined aquifers. The aquifers in the study area have high permeability due to coarse texture, have high water table gradient, and can transmit large quantities of water to the wells.

The coarse texture of the deposit in the study area allowed groundwater to quickly drained and replenished, resulting in a large water fluctuation especially in the piedmont zones. Some of the wells in the piedmont zone of the study area dried up during dry season this may be because the clay layers in the zone of aeration in the piedmont zone may give rise to perch aquifers.

Flood plain deposits may accumulate considerable amount of minerals, essentially salts of sodium and calcium carbonate in soil and from open water bodies. This is due to fineness of sediments which favors capillary ascent of water through the soil from considerable depth of the water table.

6.3 HYDRO-GEOCHEMISTRY

Total 106 groundwater samples were taken from parts of Dimapur district during the onset-monsoon and after-monsoon season and they were studied for various quality parameters of groundwater (physico-chemical) such as Turbidity, EC, pH, TH, TDS, Ca, Mg, Na, K, HCO_3, Cl, Fe, SO_4 and F etc. The analytical parameters are used to judge the quality of subsurface water in parts of Dimapur district.

6.3.1 Turbidity

The turbidity of the groundwater in parts of Dimapur district in the onset-monsoon samples is 0.1NTU to 65.5NTU with the average value of 3.96NTU. In the after-monsoon samples it is 0.1NTU to 18.8 NTU with the average value of 1.7 NTU. In the onset-monsoon samples 88.68% are within acceptable limit, whereas 3.77% are within permissible limit and 7.55% are unacceptable for drinking. In the after-monsoon samples 90.57% are within acceptable limit and 5.66% are within permissible limit whereas 3.77% are unacceptable for drinking purpose.

The high value of turbidity in the subsurface water in parts of Dimapur district may be because of the growth of photo-plankton and human activities that disturb land such as construction of four lane roads, mining of pebbles and gravels in the river bank, earth filling of the swampy area and agricultural activities.

6.3.2 Electrical Conductance (EC)

The electrical conductance of the groundwater samples in parts of Dimapur district is found to be from 38microsiemens/cm to 1142 microsiemens/cm with the average of 266microsiemens/cm during period of onset-monsoon and 46microsiemens/cm to 1211 microsiemens/cm with average value of 287microsiemens/cm during after-monsoon period. Pure water does not conduct electricity, however water being universal solvent it dissolve many substances around it and become a good electrical conductance. EPA (2001) stated that water that has good electrical conductance has no health complication; it simply indicates the content of mineral salt in water

6.3.3 Potentia Hydrogeni (pH)

The pH of the groundwater in parts of Dimapur district is found to be 4.5 to 7.9 during pre-monsoon, with the average of 6.25 and in the after-monsoon period it is found to be from 3.5 to 7.9 with an average of 5.99. It is found that 90.57% (48 samples) are acidic and 9.43% (5 samples) are alkaline, 32.07% (17 samples) are desirable drinking whereas 67.93% (36 samples) are undesirable for drinking in onset-monsoon period. In the after-monsoon period it is found that 86.8% (46 samples) are acidic and 13.2% (7 samples) are alkaline, 28.3% are desirable for drinking and 71.7% are undesirable for drinking purpose.

Majority of the subsurface water samples in parts of Dimapur district have their pH value between 4 to 8.5 indicating bicarbonate type of water (Fletcher, 1986). The alkaline nature of subsurface water in parts of Dimapur district may be because of the used of cement in all types of construction works like four lane roads, buildings, dams etc.

6.3.4 Total Dissolved Solids

The subsurface water in parts of Dimapur district with respect to TDS it is varied from 20mg/l to 538mg/l in the onset-monsoon samples and their average value is 128.06mg/l. In the after-monsoon samples it is varied from 21mg/l to 610mg/l with their average value of 141.13mg/l.

With respect to TDS the subsurface water in parts of Dimapur district falls under Fresh Water category (Freeze and Cherry, 1979). According to Annon and other (1946) the subsurface water in parts of Dimapur district falls under useful category for irrigation for all the groundwater samples. According to the classification of TDS (BIS: 10500-2012) 98.11% (52 samples falls under desirable for drinking category and 1.89% (1 sample) falls under permissible limit for drinking category in both the onset and after-monsoon seasons respectively. Hence the subsurface water in parts of Dimapur district as per their TDS value it is desirable for drinking and useful for irrigation purposes.

6.3.5 Total Hardness (TH)

The total hardness of the subsurface water in parts of Dimapur district during the onset of the monsoon it is found to be 3.85mg/l to 257mg/l and their average is found to be 64.04mg/l. In the after-monsoon period it is found to be 12mg/l to 272mg/l and their average value is 67.65mg/l. It is found that during the onset of monsoon 96.23% (51 samples out of 53) the TH falls under desirable limit for drinking and 3.77% (2 samples out of 53) falls under permissible limit for drinking purpose and during post-monsoon it is found that 94.34% (50 samples out of 53) falls under desirable limit for drinking purpose and 5.66% (3 samples out of 53) are found to be within the limit of permissible for drinking purpose.

6.3.6 Calcium (Ca)

The Calcium (Ca) concentration in the subsurface water samples in parts of Dimapur district during the onset of monsoon period varies from 0.0mg/l to 32.32mg/l and its average value is 14.58mg/l. In the after monsoon period it is found to be 3.20mg/l to 456.20mg/l and their average value is 25.77mg/l. In parts of Dimapur district (study area) all the subsurface water samples in both the seasons falls within the limit of desirable for drinking except sample no.20 which exceed the highest limit of permissible for drinking during the period of after monsoon.

6.3.7 Magnesium (Mg)

Magnesium (Mg) content in the subsurface water in parts of Dimapur district during the onset of monsoon period is varying from 0.0mg/l to 51.42mg/l and their average value is 7.65mg/l. During the after monsoon period it is found to be from 0.0mg/l to 55.02mg/l and their average value is 7.07mg/l. It is found that 94.34% (50 samples out of 53) are within desirable limit and 5.66% (3 samples) are within permissible limit in both the seasons. Magnesium is present in all natural waters and it source is mostly from mafic minerals, chlorite and clay minerals.

6.3.8 Sodium (Na)

In parts of Dimapur district the amount of sodium in the onset monsoon samples of the subsurface water differs from 6.00mg/l to 185.30mg/l and their average value is 28.76mg/l and during the after monsoon period it is 1.00mg/l to 187.30mg/l with the average concentration of 20.85mg/l. In parts of Dimapur district (study area) 73.58% (39 samples) of groundwater in the onset monsoon period and 77.35% (41 samples) of groundwater in after monsoon period falls under acceptable limit for drinking water as per (W.H.O, 2004). Sodium concentration increases in groundwater during pre-monsoon as sodium salts do not take active chemical reaction. Further, Mekro, V. (2016) stated that Na is added to groundwater due to the leakage of sea water those are embedded in Surma sandstones through fractures, joints and other openings which are controlled by tectonic activities.

6.3.9 Potassium (K)

In parts of Dimapur district (the study area) the amount of K content in the subsurface water fluctuated from 2.00mg/l to 75.60mg/l and their average concentration value is 14.43mg/l during the period of onset monsoon and 0.00mg/l to 73.50mg/l with the average concentration of 10.57mg/l during the period of after monsoon. It is found that 26 samples of the onset monsoon period and 34 samples of the after monsoon period are within the limit of acceptable for drinking purpose as per (WHO, 2004). Potassium is commonly occurs in all-natural waters as it is widely occurring in the environment. Vital function of K in human body includes nerve stimulus, contractions of muscles, and regulation of blood pressure and dissolution of protein. Potassium also protects the heart and arteries. K deficiency may lead to dejection or unhappiness, failing muscle and chaos in heart rhythm. K deficiency may also lead to kidney disorder and chronic diarrhea.

6.3.10 Alkalinity (CO_3^{-2}& HCO_3^{-})

The bicarbonate content in the subsurface water in parts of Dimapur district during the onset of monsoon period is varying from 2.00mg/l to 268.00mg/l and its average content is 48.30mg/l and during the period of after monsoon it is 0.00mg/l to 272.00mg/l with its average concentration of 53.47mg/l. The water containing up to 600mg/l of bicarbonate may be utilized for domestic as well as irrigational purposes. Hence the groundwater in parts of Dimapur district with respect to their bicarbonate contain it is good for domestic as well as irrigational purposes. All the groundwater samples in parts of Dimapur district with respect to their carbonate concentration falls within the limit of permissible for safe drinking as per BIS in both seasons.

6.3.11 Chloride (Cl)

Chloride content in the subsurface water in parts of Dimapur district is varying from 0.00mg/l to 83.97mg/l with the average content of 22.18mg/l during the onset of monsoon and during the period of after monsoon it is differs from 0.00mg/l to 85.08mg/l with the average content of 21.62mg/l. All the subsurface water samples in parts of Dimapur district are within limit of desirable in both the seasons. The source of chlorine in the subsurface water had been sedimentary rocks, sewage, industrial effluents and urbanization.

6.3.12 Iron (Fe)

The concentration of iron in the subsurface water in parts of Dimapur district is found to be differs from 0.18mg/l to 2.5mg/l during the period of the onset monsoon and during the period of after monsoon it is differs from 0.06mg/l to 5.2mg/l. It is found that 41.51% (22 samples) during the onset of monsoon period and 62.26% (33 samples) in the after monsoon period are found to be within limit of acceptable for drinking as per BIS (2012).

It is found that Fe content is high in parts of Dimapur district during the period of after monsoon. This may be due to the geological formation of the area and also the discharges of Fe and Mn contaminated waters into the subsurface water in the flood plains of Dimapur from the Chathe river as influent-river (Kshetrimayum and Hegeu, 2016).

It is found that the dissolved iron content varies seasonally in the subsurface water in parts of Dimapur district for a given well. During the period of high discharge with an influx of oxygenated water from the surface to the subsurface water may prevent iron from dissolving and the subsurface water has low concentration of iron. However, during dry season the subsurface water is poor in oxygen, hence the iron dissolves more readily and the subsurface water in parts of Dimapur district have high content of iron in many places during onset of monsoon.

6.3.13 Sulphate (SO_4)

In the study area the amount of sulphate in the subsurface water differs from 2.00mg/l to 29.00mg/l with the average amount of 10.06mg/l during the onset of monsoon period and during the period of after monsoon it is varying from 2.00mg/l to 90mg/l with the average amount of 11.75mg/l. All the subsurface water samples in parts of Dimapur district are found to be within the limit of acceptable for drinking purpose as per BIS (2012).

6.3.14 Fluoride (F)

The fluoride content in the subsurface water samples in parts of Dimapur district is found to be below detection limit, this may be due to the lack of fluorine-bearing minerals like fluoropatite, amphiboles and micas. According to BIS the highest acceptable limit of fluoride is 1.0mg/l and the highest limit of permissible is 1.5mg/l. Low concentration fluoride such as 1mg/l is considered useful for preventing tooth decay. However inadequate fluoride might cause health complications such as dental caries and decompose of teeth. Again, excessive fluoride may lead to changes in bone structures making the bones very weak and brittle (Tiemann, 2013).

6.4 PIPER'S DIAGRAM

The following water types are identified based on Piper (1944) trilinear diagrams during the onset of monsoon and after monsoon periods in parts of Dimapur district.

During the onset of monsoon period the greater parts of the subsurface water samples in parts of Dimapur district reveals that alkalis exceeds alkaline earth and strong acids surpass weak acids. A good amount of samples in the onset of monsoon period reveal not a single cation and anion pair surpass 50% indicating neutral type.

During the period of after monsoon the subsurface water in parts of Dimapur district shows that the greater parts of the subsurface water samples are alkalis are more than alkaline earth and weak acids are more than strong acids and a good number of samples shows neutral type of water.

On the cationic and anionic triangles it is found that Na +K type of subsurface water is leading in the cationic triangle and HCO_3 type of water is dominant in anionic triangle in both the seasons.

6.5 ESTIMATION OF GROUNDWATER QUALITY FOR AGRCULTURAL USE

To find out the usability of the subsurface water for agricultural use, the following methods were used, Sodium Absorption Ratio (SAR), USDA graphical method, Magnesium Ratio, Permeability index, RSC (Residual Sodium Carbonate) and Kelly's Ratio.

6.5.1 Sodium Adsorption Ratio (SAR)

In parts of Dimapur district (the study area) the SAR values are ranging from 0.0mg/l to 53.21mg/l during pre-monsoon period with 39 samples (73.6%) falls in excellent class, 6 samples (11.3%) in good class, 3 samples (5.7%) in fair class and 5 samples (9.4%) falls in poor class of water for irrigation. During post-monsoon period the SAR value ranging from 0.21mg/l to 35.28mg/l with 43 samples (81.1%) in excellent class, 5 samples (9.4%) falls in good class, 3 samples (5.7%) in fair class and 2 samples (3.8%) falls in poor class of water for irrigation purposes.

6.5.2 USDA diagram

As per USDA diagram, that 36 samples (67.92%) falls under good waters and 8 samples falls (15.09%) under moderate waters and 3 samples (5.66%) falls under bad waters category during pre-monsoon.42 samples (79.24%) falls under good waters, 7 samples (13.2%) falls under moderate and 2 samples (3.77%) falls under bad water category during post monsoon. Six samples and three samples of subsurface water in parts of Dimapur district are out of range during the onset of monsoon and after monsoon periods respectively. It is found that 67.92% and 79.24% of subsurface water in parts of Dimapur district during the onset of monsoon and after monsoon period respectively are within Good waters class for irrigation purposes.

6.5.3 Mg Ratio

In parts of Dimapur district it is found that during the onset of monsoon period Magnesium ratio was found to be from 0.0 to 84.78 and after monsoon period it raises from 0.0 to 67.80. Only 3 samples (5.66%) of the groundwater in the study area contain magnesium ratio above 50% while the rest 94.44% falls below 50% in both the seasons. The high concentration of magnesium in water adversely affects the soil quality by converting it to alkaline and this in turn decrease the crop yielding.

6.5.4 Permeability Index (PI)

According to Doneen’s classification of (PI) 92% and 96% of the subsurface water samples in parts of Dimapur district during the onset of monsoon and after monsoon respectively falls under class I and class II i.e. Good and suitable category for agricultural use.

6.5.5 Residual Sodium Carbonate (RSC)

According to USDA, a RSC lower than 1.25 mg/l in water is probably useful for agricultural purposes and with RSC less than 1.75 to 2.5 mg/l are rated as marginal quality and water containing RSC value more than 2.5 mg/l are rated as unsuitable for agricultural purposes. As per the RSC data of the groundwater samples in parts of Dimapur district, 45.28% and 39.62% of the groundwater samples falls under suitable category for irrigation during the onset of monsoon and after monsoon period respectively.

6.5.6 Kelly's Ratio

It is found that 28 samples (52.83%) and 39 samples (73.58%) of the subsurface water in parts of Dimapur district during the onset of monsoon and after monsoon representatively is found to be under suitable category for irrigational use according to Kelly's ratio.

6.6 TRACE ELEMENT

The subsurface water samples in parts of Dimapur district are analyzed for heavy metals like copper, zinc, nickel and arsenic. These metals are occurring in ground water in less quantity (less than 1ppm) because the study area is belonging to alluvium plain area consist of sand, silt, pebbles etc. Karanth (1989) stated that certain metallic constituents were present in subsurface water in very less amount or traces normally not more than 1ppm. These elements are called trace elements or trace metals.

The presence these trace elements/ heavy metals may be transported to the study area from the mafic, ultra-mafic rocks of the Naga ophiolite belt like nickel-cobalt ferrous magnetite, peridotite and paragonite due to tectonic activities that took place during Naga Ophiolite belt formation. These trace elements may also be added to the groundwater due the human activities like vehicular exhaust, application of fertilizers and pesticides etc Khan, *et al* (2013) and human activities like municipal sewage and industrial effluent introduce trace elements directly into the groundwater (Sujatha, 2002). Presence of these heavy metals in trace amount is useful for healthy growth of plants and human metabolism and in excess amount of the same element is harmful for human's health (Chapman, 1992).

Polizzotto, *et al* (2008) stated that arsenic is derived in nature from weather-beaten sediments from the Himalayan region and come into solution subsequent reductive discharge from solid phases in an environment lack free oxygen, (preventing normal life for organisms that depends on oxygen) and contaminate groundwater in Asia. In the same manner arsenic may be derived from Naga ophiolite sediments and contaminate the subsurface water in part of Dimapur district because generally the direction of flows of rivers from north to south.

6.6.1 Copper (Cu)

In parts of Dimapur district the amount of copper in the subsurface water samples ranging from 0.006 mg/l to 0.170mg/l during the onset of monsoon period. Only one sample (sample no

9) falls within acceptable limit and the rest 23 samples falls within permissible limit. The amount of Cu in the subsurface water in parts of Dimapur district ranging from 0.063mg/l to 2.457mg/l in after monsoon period samples. All the groundwater samples are exceeding acceptable limit during post-monsoon period. Seven samples (i.e. 29%) are exceeding permissible limit for drinking as per BIS (2012).

Presence of Cu in a very small amount is important for human metabolism and the development of hemoglobin (Tiwari *et al*, 2013). The intake of Cu from food is normally 3mg/day but excess intake of Cu could increase the risk of our health (Krishna and Govil 2004). Acute gastritis pain might be occurred in some people when Cu amount in drinking water is found to be more than 3mg/l, long tern ingestion to copper cause liver cirrhosis in adult and an undesirable bitter taste to water(WHO 1993).

6.6.2 Zinc (Zn)

Zinc occurs generally in association with intermediate and acidic igneous rocks. The common mineral of zinc includes sulphides, oxides and carbonates. The principal zinc ores are sphalerite and wurzite. Zinc is an indispensable metal found in almost all kind of food and drinkable water (Purushothan, *et al*, 2017). An adult daily requirement of zinc is 15-22mg/day (WHO, 2004). Dwarfism is caused by zinc deficiency whereas excessive zinc causes lot of health complication in humans such as vomiting, dehydration etc.

The highest acceptable limit of zinc in water for drinking purpose is 5.0mg/l according to BIS (2012). In parts of Dimapur district the amount of zinc in the subsurface water samples are ranging from 0.034mg/l to 0.197mg/l during the onset of monsoon period and 0.139mg/l to 0.948mg/l during the period of after monsoon. Hence all the subsurface water samples in parts of Dimapur district is found to be within the limit of acceptable for drinking purpose.

6.6.3 Nickel (Ni)

The common minerals of nickels are sulphides and arsenide. The presence of Nickel in groundwater may be due to the dissolution from nickel ores bearing rocks such as basic and ultra-basic igneous rocks. Nickel may contaminant drinking water due to leaching of metals from water pipe and fittings. It is stated by Tiwari, et al (2013) that nickel is found in micro-organism and in some of the enzymes in plants.

The analytical data of groundwater samples collected in parts of Dimapur district reveals that the concentration of nickel is below detection limit as compared to BIS (2014).

6.6.4 Arsenic (As)

The concentration of arsenic in parts of Dimapur district varies from 0.002 to 0.034mg/l. In most of the groundwater samples arsenic is found to be below detection limit, however in sample no.3 it is found that the concentration of arsenic is 0.034 and 0.012 mg /l during the onset of monsoon and after monsoon respectively which is above the permissible limit for drinking as per BIS and in the sample no.20 it is 0.005mg/l and 0.002mg/l during the onset of monsoon and after monsoon respectively which lies within permissible limit.

The presence of arsenic in the subsurface water in parts of Dimapur district may be transported from the ultra-mafic rocks of the Naga Ophiolite belt due to tectonic activities or through paleo-channels because generally rivers flows from north to south, or it may come from the soils and worn-out rocks that dissolves and enters groundwater (Puzari *et. al* 2015). Arsenic may be introduced into groundwater from anthropogenic activities or arsenic may also introduced into groundwater from atmospheric deposition in nature.

Arsenic may come from the eroded sediments that enters solution following reductive released from solid phases under anaerobic condition and contaminates the subsurface water in parts of Dimapur district as stated by Polizzotto, *et al* (2008).

.

***

CHAPTER VII
SUMMARY AND CONCLUSIONS

The study area (in part of Dimapur District) lies within latitude 93º 41’00” E to 93 º50’10”E and longitude 25º46’30” N to25º58’30”N and falls in the Survey of India(SOI) Toposheet Nos.83G/9 and 83G/13 having an area of about 173Sq.Km (Fig-1). The study area is bounded by Assam mainly on the North, East and West direction.

Dimapur district is exposed on the North Western part of the outer most Belt of Schuppen which is an en-echelon thrust known as the “Naga thrust”. The study area comprises Palaeogene, Neogene and Quaternary litho-tectonic units. The palaeogene are represented by Laisong, Jenam and Renji of Barail Group. The Neogene rocks of the study area are represented by Surma and Tipam Group. Quaternary rocks are represented by the Pleistocene-Recent sediments that make up the terraces and alluvium respectively. In Dimapur alluvium plain area, the alluvium deposit consists of sand, clays, silts, pebbles and boulders which constitute more than 90% of the Dimapur plain.

Hydro-geologically, the formations of Nagaland are broadly differentiated into three units as:-

i) Consolidated Formations
ii) Semi-consolidated Formations and
iii) Unconsolidated Formation

i) Consolidated Formations: Consolidated Formations are highly fractured with numerous faults, joints, fractures, fissures and potential sheared zones helps for the development of groundwater. However, the groundwater resources development of the area remains unexplored due to inaccessibility of the terrain and also difficult to deploy heavy duty water well drilling rigs and other logistic constrains.

ii) Semi-consolidated Formations: Semi-consolidated Formations are represented by the Disang group, the Barail group, the Surma group, the Tipam group and the Dihing group. The Disang and Surma group of rocks are normally argillaceous while the Barail and Tipam groups are arenaceous sandstone beds. The Disang formation which is highly fractured, splintery and sheared is found to be most potential for groundwater development in hilly areas.

iii) Unconsolidated Formations: Unconsolidated Formations are found in low lying plain areas on Western and the North-Western part of the state with narrow, intermontane and open valleys found to occur along the foothills bordering upper reaches of Brahmaputra flood plains of Assam. The valleys are mostly structurally controlled and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulder assemblages of unconsolidated nature representing the potential aquifer zones. The potential valley for groundwater development in the state includes Dimapur valley, Medziphema-Jalukie, Baghty and Tizit-Tiru valleys.

The occurrences and movement of groundwater in any area is governed by several factors such as topography, lithology, geological structures, depth of weathering, extent of fractures, porosity, slope, drainage pattern, landforms, land use/land cover, climate conditions and interrelation between these factors.

Hydro-geologically, the Dimapur alluvial plain comes under unconsolidated unit. It is structurally controlled and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulder assemblages of unconsolidated nature. Due to the coarse texture of the unconsolidated rocks the alluvial plain has high permeability and high specific yield, hence hydrogeologically; the study area represents the potential aquifer zones for groundwater development.

Geomorphologicaly, the two main landforms identified in the study area are piedmont and floodplain. Geomorphic features like paleochannels, natural levee, horse shoe/oxbow lakes etc. indicate fluvial environment of deposition. The litho log reveals that in the piedmont zone there are three confined aquifers with 9m- 12m in thickness. Another litho log from floodplain area reveals that there are at least five confined aquifers zones with the thickness ranging from 1.5m to 34m. The piezometric water levels in the study area are ranging from about147m in the piedmont zones and about 113m in the floodplain zones.

Dimapur town have been growing at an alarming rate over the past few decades. Thus, trend of urbanization is an anthropogenic outcome of the process of economic growth through industrialization, consequently facing the traditional environmental problems such as lack of sanitation, water supply, lack of open space and recreational areas, traffic congestion etc. The groundwater as well as the surface water is greatly polluted as the rivers passing through or passing by the side of the town are highly polluted. At present, there are no major industries in and around Dimapur area, but human activities like household waste water and garbage are directly discharged into the area. The water for human consumption is sourced from groundwater wells without biochemical treatment and the level of pollution has become a major cause of concern.

Groundwater forms the important source of essential water supply throughout the world; its main uses are for drinking, domestic purposes, agriculture and industries. Compared to surface water, it has a constant composition, temperature, and is safer from contamination, chemical, radiogenic and biological pollution. Further, the groundwater acts as primary source in arid and semi-arid regions and of surface water in humid regions. Groundwater pollution has now become a major issue in the development of water resources management of natural resources and the protection of the environment. Since groundwater is an important reliable source of drinking water in Dimapur District, protection of its quality should become a high priority management goal.

The quality of groundwater is of great importance in exploring the suitability of a particular groundwater for use, public water supply, irrigation and industrial application. In order to understand and evaluate such problems, it is essential to carry out qualitative and quantitative studies before making recommendation on their uses.

Keeping this view, the present study aims to trace the groundwater resources and assessment of groundwater quality for drinking and irrigation purpose in parts of Dimapur district, Nagaland.

Based on the hydrogeology, geomorphology and hydro-geochemistry the present study has been presented in the form of Ph.D. thesis comprising seven chapters.

The first chapter gives the general information on the study area including location, accessibility & communication, physiographic, drainage, climate and rainfall, soil, flora & fauna, human habitation, literature survey, previous works on the study area and aim & scope of work.

The second chapter includes the regional geology, geology of Nagaland and the study area, hydro-geology and tectonic setting. Various lithological units of the study area are identified based on field relations and petrography. Hydro-geologically the Dimapur alluvial plain comes under unconsolidated unit and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulders. The alluvial plain has high permeability and high specific yield, representing the potential aquifer zones for groundwater development in the study area.

Chapter III Methodology: Various field and laboratory techniques have been described. Field work includes the study of geology and collection of groundwater samples during pre and post monsoon periods. Laboratory work includes the estimation various physical and chemical parameters by using various equipments as per the standard procedures. Piper diagram is used to classify the ground water.

Chapter IV focuses on hydro-geomorphology of the study area that occurs at elevation ranging between 139.5m amsl to 220m amsl as flat with gentle undulations and valley fills called Dimapur alluvial plain, some prominent features like meander scars (paleo-channels), point bars, natural levee or bunds, horse shoe/ oxbow lakes etc. are identified. Further, the litho log reveals that the study area consists mainly of alluvium deposits and indicates multiple confined aquifers. The aquifers have high permeability due to coarse texture, have high water table gradient, and can transmit large quantities of water to the wells.

Chapter V Hydro-geochemistry: 53 groundwater samples were analyzed for physical and chemical parameters like Turbidity, Electrical conductance (EC), pH, Total Hardness (TH), Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate (HCO_3), Chloride (Cl), Iron (Fe), sulphate (SO_4) and fluoride (F) . The data were processed and interpreted to assess the quality of groundwater in the study area. In addition to that some trace elements (metals) like Copper (Cu), Zinc (Zn), Nickel (Ni) and Arsenic (As) were estimated and presented.

Chapter **V**I Discussion: focuses mainly on the groundwater resources and its quality for drinking and irrigation purposes based on the hydrogeology, geomorphology and hydro geochemistry.

Finally, Chapter VII summarizes the work carried on the study area on the bases of present investigations and the conclusions have been recorded.

The salient features of the present research work are as follows:

- Hydro-geologically the study area consists mainly of alluvial plain comes under unconsolidated unit and the rock types consist of clay, silt, sand, gravel, pebble, cobble and boulders

- Geo-morphological study reveals that the study area has multiple confined aquifers. The aquifers have high permeability due to coarse texture, have high water table gradient, and can transmit large quantities of water to the wells.
- Physical parameters like turbidity shows that 88.68% of samples are within desirable limit, 3.77% are within permissible limit and 7.55% are undesirable for drinking purpose during the pre-monsoon. 90.57% of post-monsoon samples are within desirable limit and 5.66% are within permissible limit and 3.77% are undesirable for drinking purpose.
- The pH of the tested water samples indicates that the groundwater in the study area is acidic to neutral in nature. Majority of the groundwater samples have the pH between 4 and 8.5 indicating bicarbonate type of water. Further, it is found that 32.07% and 28.3% of water samples are desirable during pre and post monsoon and the rest become undesirable for dinking purposes.
- The TDS values indicates that all the groundwater samples in the study area falls under useful category for irrigation and 98.11% of the groundwater falls under desirable category for drinking.
- It is found that 96.23% (51 out of 53 samples) in respect of Total hardness (TH) falls under desirable limit during pre-monsoon and 94.34% (50 samples out of 53) falls under desirable limit for drinking purpose during post-monsoon.
- In the study area all the groundwater samples with respect to calcium (98.11%) and magnesium (94.34%) falls under desirable limit for drinking purpose in both the seasons.
- With respect to bicarbonate, all the groundwater samples in the study area are found to be within permissible limit. But Cl concentration is within desirable limit during both seasons.
- The concentration of iron in the groundwater of the study area ranges from 0.18mg/l to 2.5mg/l during pre-monsoon and 0.06mg/l to 5.2mg/l during post-monsoon. It is found that 41.51% (22 samples) during pre-monsoon period and 62.26% (33 samples) in post-monsoon period are within acceptable limit for drinking purpose as per BIS.
- The SO_4 content in all the groundwater samples of the study area found to be within acceptable limit for drinking purpose. Fluoride is detected only in one sample which falls within acceptable limit for drinking purpose.

- Concentration of sodium (Na) in groundwater samples in the study area indicates that 73.58% (39 samples) of groundwater in pre-monsoon and 77.35% (41 samples) of groundwater in post-monsoon fall under acceptable limit for drinking water as per (W.H.O, 2004).
- The concentration of K in groundwater samples (26) in pre-monsoon period and 34 samples in post-monsoon fall within acceptable limit for drinking purpose.
- 95.83% of the groundwater samples during pre-monsoon and 100% during post-monsoon are exceeding acceptable limit in their Cu concentration.
- The concentration of Zn and Ni are found to be within acceptable limit for drinking purposes in both the seasons.
- Arsenic (As) concentration in most of the samples are found to be below detection limit, however, sample No.3 exceeds acceptable limit for drinking purpose as per BIS (2012) in both the seasons.
- Piper's Trilinear Diagram reveals that majority of the groundwater samples (34 samples) shows alkalis exceeding alkaline earth during pre-monsoon period, and 28 samples shows strong acids exceeding weak acids.
- In post-monsoon period 29 samples shows alkalis exceeding alkaline earth and 29 samples shows weak acids exceeding strong acids. 12 samples in pre-monsoon and 20 samples in post-monsoon show neutral.
- SAR shows that 73.6% of groundwater samples during pre-monsoon period and 81.1% during post-monsoon period falls in excellent class for irrigation purposes.
- USDA diagram reveals that 67.92% of groundwater during pre-monsoon and 79.24% during pre-monsoon falls in Good water category for irrigation purposes.
- Mg ratio shows that 94.44% of the samples in the study area falls below 50% in both the seasons. However, 5.66% of the groundwater in the study area shows that the Mg ratio is above 50%.
- Permeability Index shows that 98% and 96% of the groundwater samples during pre-monsoon and post-monsoon respectively falls under class I and class II i.e. Good and Suitable category for irrigation purpose.

- Residual Sodium Carbonate (RSC) reveals that 24 samples in pre-monsoon and 21 samples in post-monsoon are suitable for irrigation purpose and 28 samples in pre-monsoon and 32 samples in post-monsoon period are unsuitable for irrigation purpose.
- Kelley's Ratio, shows that 28 samples in pre-monsoon and 39 samples in post-monsoon period are suitable for irrigation purpose.
- Overall study reveals that the groundwater in the study area is fairly good for drinking purpose and suitable for irrigation.

***

References:

Aier, I., Luirei, K., Bhakuni, S.S., Thong, G.T. and Kothyari, G.C. (2011): Geomorphic evolution of Medziphema intermontane basin and Quaternary deformation in the Schuppen belt, Nagaland, NE India. Zeitschrift fiir Geomorphologie v.55 (2) pp247-265

Acharyya, S. K., Roy, D.K. and Ghosh, S.C. (1986) Stratigraphy and emplacement history of the Naga Hills Ophiolite, northern Indo-Burmese range. Proc. 11th Symp. Micropal. Stra., Geol. Min. Metal. Soc. India. Bull. 57.pp 1-17.

Annon, (1946): Drinking Water Standards. Jour. Amer. Water Works Assoc., v 38 pp 361-370

APHA, (1998): Standard Methods for Examination of Water and Waste Water (20thEdn) NW Washington, DC. American Public Health Association.

Appello, C. A. J., Postma, D. (1993) Geochemistry, groundwater and pollution, Balkema Press, Rotterdam. The Netherlands, P536

Back, W. and Barnes, I. (1965) Relation electrochemical potentials and iron content to groundwater flow patterns. USGS Professional paper 498-C. Reston, Virginia: USGS.

Barzilay, J.I. (1999): The water we drink: Water Quality and its effect on health. New Brunswick New Jersey, Rutgers University Press. Pp152.

BIS (2012) Indian Standards Specification for Drinking Water. IS: 10500: 2012, 2nd Rev, BIS, New Delhi.

Brunnschweiler, R.P. (1966): On the geology of Indo-Burman ranges, Jour. Geol. Soc. Aust.v13 (1), pp 127-194.

Bucher, J.R., Hejtmancik, M.R., Toft, J.D.H., Persing, R.L., Eustis, S.L. and Haseman, J.K. (1991) Result and conclusions of the National Toxicology Programm’s rodent carcinogenicity studies with sodium fluoride. Int. Jour. Cancer, v48. pp733-737.

Chapman, D. (1992) Water Quality Assessment: A Guide to the Use of Biota, Sediments and water in Environmental Monitoring, Chapman and Hall, London, U.K.

DGM (2009) Feasibility studies on Artificial Recharge to Groundwater in Dimapur District. (F.S 2008- 2009) DGM.

DGM (2010): Hydro-geomorphological mapping in Dimapur Valley using Integrated Remote Sensing and GIS techniques. DGM. Tech. Sl. No.13 F.S. 2009-2010. P.37

Doneen, L.D. (1964) Water Quality for Agriculture. Department of Irrigation, University of California, Davis. P48.

Eaton, E.M. (1950) Significance of Carbonate in Irrigation Water. Soil Science, v69. pp123-133.

Edmund, W.M. and Smedly, P.L. (2013) Fluoride in Natural Waters. Chapter 12.

Elton, L. W., Elton, W.J. and Narzareno, J. P. (1963) Pathology of Acute Salt poisoning in infants. Amer. Jour. Of Clinical Pathology. V39. Pp252-264.

Enayat Ahmad. (1985) Geomorphology. Published by Kalyani Publication.p403.

EPA (2001) Parameters of water quality: Interpretation and Standards. Environmental Protection Agency: Wexford.

Evans, P(1932) Tertiary succession in Assam. Trans. Min. Geol. Soc. India, v5, pp.80-96.

Fletcher, G.D. (1986) Groundwater and wells.2nd Edn . Published by Johnson Division, Sr. Paul Mimnesalu p1089.liffs, p.604.

Freeze, A.R. and Cherry, A. (1979) Groundwater, Published by Prentice Hall, Inc., Eaglewood Cliffs, 604p

Glynn, P. and Plummer, L. N.(2005) Geochemistry and the understanding of groundwater systems. Hydrogeology Journal. V13, pp263-287

Greenbaum, D.(1992) Structural influences on the occurrences of groundwater in SE Zimbabwe. In: Hydrology of Crystalline Basement Aquifers in Africa. Wright, E.P., Burges, W.G. (Edn). Geological Society Special Publication. Bath, v66. Pp77-85.

Greenwood, N.N. and Earnshaw, A. (1984) Chemistry of the elements. Oxford, Pergamon Press.

Handa, B. K. (1969) Description and Classification of media for Hydro chemical investigations. In: Proc. Groundwater Studies in Arid and Semi Arid Regions, Roorkee, India.

Handa, B. K. (1975)“Groundwater Pollution in India” Proc. Nat. Sym. On Hydrology. University of Roorkee. V.1 pp34-49.

Hem, J. D.(1975) Study and Interpretation of the Chemical Characteristics of Natural Water, GSWS. Paper 1473.

Hem, J. D.(1985) Study and Interpretation of Chemical Characteristics of Natural Water. U.S.Geol.Surv. Water Supply Paper 2254. p264.

Hopkins, B.G., Horneck, D.A., Stevens,R.G., Ellsworth, J.W. and Sullivan, D.M. (2007) Managing Irrigation Water Quality for Crop Production in the specific Northwest. Oregon State University Extension catalog. P.29.

IOM.(2004) Dietary Reference intake for water, Potassium, Sodium, Chloride and Sulphate. Prepared by the Institute of Medicine. Washington, DC, National Academic Press.

Jaswal, R.K., Mukherjee, S., Krishnamurthy, J. and Saxena, R. (2003) Role of Remote sensing and geographic information system techniques for generating of groundwater prospect zones towards rural development – an approach. Internat. Jour. Remote Sensing, V 24, pp993-1008.

Jasrotia, A.s. and Singh, R. (2007) Hydro geochemistry and groundwater Quality, Around Devak and Rui Watersheds of Jammu Region, Jammu and Kashmir. Jour. Geol. Soc. India. v 69 pp1042-1054.

Jharia, D.C., Kumar, T., Gobinath, M., Diwan, P. and Kishore, N. (2016) Assessment of groundwater potential zone using remote sensing, GIS and multi criteria decision analysis techniques. Jour. Geol. Soc. India, v 88. Pp 481-492.

Karanth, K. R. (1964) Pumping Tests on wells in the Dun of Dehradun district and Tarai-Bhabar in Nanital District, U.P. India. Minerals, V.18 (4) pp318-324.

Karanth, K. R. (1989) Hydrology, Tata McGraw Hill Publishing Company Limited, New Delhi, p458.

Kaur, J., Gorka, R. and Kumar, R. (2018) Hydro geochemistry and Groundwater Quality Assessment of Poonch District, Jammu and Kashmir, India. Jour. Appl. Geochem. V.20 (2) pp192-204.

Kelley, W.P. (1946) Permissible Composition and concentration of Irrigated Waters, In: Proc. Amer. Soc. Civil Eng. P.607

Kent, W.N and Dasgupta, U. (2004) Structural evolution in response to fold and thrust belt tectonics in northern Assam. A key to hydrocarbon exploration in the Jaipur anticline area. Marine and Petroleum Geology. v21(7) pp785-803.

Khan, K., Lu, Y., Khan, H., Istiaq, M., Khan, S., Waqas, M., Wei, L. and Wang, T. (2013) Heavy metals in agricultural soils and crops and their health risks in Swat district, Northern Pakistan. Food Chemistry and Toxicology. V. 58. Pp 449-458.

Krishna, A.K. and Govil, P.K.(2004) Heavy metal contamination of soil around Pal Industrial area, Rajasthan, India. Environ. Geol. V.47. pp.38-44.

Kshetrimayum, S.K. and Hegeu, H. (2016) The state of toxicity and cause of elevated Iron and Manganese concentrations in surface water and groundwater around Naga Thrust of Assam-Arakan basin, Northeastern India. Environ. Earth. Sci. (2016) 75: 604. (D0110.1007/s12665-016-5372-4.)

Kumar, S.K., Logeshkumaran, A., Magesh, N.S., Godson, P.S, Chandrasekar, N. (2015) Hydro-geochemistry and application of Water Quality Index (WQI) for groundwater Quality Assessment, Anna Nagar, part of Chennai City. Tamil Nadu, India. Appl. Water. Sci. V.5. pp335-343.

Laniyan, T.A., Ariyo, S.O. and Bayewu, O.O. (2017) Geochemical assessment of groundwater in a typical urban settlement. Jour. Appl. Geochem, v19(2). Pp131-137.

Lenntech,Potassium(K)andwater,https://www.lenntech.com/periodic/water/potassium/potassium-and-water.htm

Limaye, S.D. (2003) Some aspects of sustainable development of groundwater in India. Eight IGC'S Prof. Jhingran memorial lecture. 90th Session of the Indian Science Congress, Bangalore. P 22.

Longkumar, L., Luiri, K., Moiya, J. N. and Thong, G.T.(2019) Morphotectonic and geotectonic activity of the Schuppen Belt of Mokokchung, Nagaland, India. Journal of Asian Earth Sciences. 170. Pp138-154

Maji, A. K., Dubey, P. N., Verma, T. P., Chamuah, G. S., Sehgal, J. and Velayuthan, M. (2000) Soils of Nagaland: their kinds, distribution, characterization and interpretations for optimizing land use, NBSS Publs. 67b. NBSS & LUP, Nagpur, P28.

Mathur, L.P. and Evans, P. (1964) Oil in India. 22nd Session International Geological Congress Proceedings. Pp.7-52.

Mekro, V. (2016) Brine and other Mineral Spring from Kohima (Nagaland) and Senapati (Manipur) districts. Recent trends in Earth Science Research with special reference to NE India. pp.291-314

Merangsoba, (2011) Petrology and Geochemistry of the serpentinites of the Ophiolite suite from part of Phek district, Nagaland with emphasis on their genesis. Unpublished PhD. Thesis submitted to NU.

Mitchell, A.H.G. and McKerrow, W.S.(1975) Analogous evolution of the Burma Orogen and the Scottish Caledonides. Geol. Soc. Amer. Bull. V86. Pp 305-315.

Murthy, K.N. (1983). Geology and hydrocarbon prospects of Recent Assam Shelf: advances and present status. In petroliferous basins of India. Petroleum Asia Jour., Dehra Dun.

Nag, S. K. and Ghost, P. (2013) Variation in Groundwater Levels and Water Quality in Chhatna Block, Bankura district, West Bengal – A GIS Approach. Jour. Geol. Soc. India. V.81. pp.261- 280

Nandy, D. R.(2017) Geodynamics of Northeastern India and the adjoining region. Rev. edn. Published by C. Sasi Kumar for Scientific Book Centre. P271.

Newmai, A. and Jami, M. (DGM 2010) Hydrogeomorphological Mapping in Dimapur Valley using Integrated Remote Sensing and GIS Techniques.

Pascoe, E.H. (1959) A manual of the geology of India and Burma, 3rdedn.(Calcutta: Govt of India Press), p 2130.

Pandey, N. (2005): Geology of Nagaland, National seminar on “Geology and energy Resources of North-East India: progress and perspectives” and AGM of the GSI Souvenir, pp. 17-22.

Pandey, N. and Sema L. (2005) Facies analysis of Palaeogene Disang-Barail Transitional Sequence in parts of Kohima Synclinorium, Kohima dist., Nagaland, North East, India (Abs) Seminar at Dehradun 30p

Park, K.(2015) Textbook of Preventive and Social Medicine. 23rdEdn. Published by M/S Banarsidas Bhanot. 1167, Prem Nagar, Jabalpur, India. Chapter 12. Pp.705-731.

Peseyie, R. and Rao, B.V. (2017)Assessment of groundwater quality for drinking purpose in and around Dimapur town, Nagaland. Jour. Appl. Geochem. v. 19 (4). Pp 464-470.

Peseyie, R. and Rao, B. V. (2020)Hydro-geochemical Evaluation of Groundwater Quality in and around Dimapur town, Nagaland. Recent advances in Earth Science Research in North East India, edited by Prof B.V. Rao. ISBN No 978-93-89262-08-7

Piper, A.M. (1944) A graphical procedure in the geo-chemical interpretation of water analysis. Trans. Amer. Geophys. Union. V.25 pp914-923

Polizzotto, M.L., Kocar, B.D., Benner, S.G., Sampson, M. and Fendorf, S.(2008) Near-Surface Wetland Sediments as a source of arsenic release to Groundwater in Asia. Nature. V. 454 pp 505-509.

Prasanth, S.S., Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N. and Gangadhar, K. (2012) Evaluation of Groundwater Quality and its suitability for Drinking and Agricultural use in the Coastal Stretch of Alappuzha district, Kerala, India. Applied Water Science. V.2 pp165-175

Purushotham, D., Linga, D., Netramani Sagar., Mishra, S., Naga Vinod, G.,Venkatesham, K. and Saikrishna, K. (2017) Groundwater Contamination in parts of Nalgonda district , Telagana, India as Revealed by Trace Elemental Studies. Jour. Geol. Soc. India. V.90 pp447- 458

Puzari, A., Khan, P., Thakur, D., Kumar, M., Shanu, K., Chutia, P. and Ahmed, Z.(2015) Quality Assessment of Drinking Water from Dimapur district of Nagaland and Karbi-Anglong district of Assam for possible related health hazards. Current World Environment. V.10(2) pp634- 640.

Raghunath, H. M.(2006) Ground Water, Published by New Age International (P) Limited. New Delhi. P.504.

Rahman, M.H., Rahman, M.M., Watanabe, C. and Yamamoto, K. (2003) Arsenic Contamination of Groundwater in Bangladesh and its remedial measures, In: Arsenic Contamination in Groundwater – Technical and Policy Dimensions, Proceeding of the UNU – NIES International Workshop, United Nations University, Tokyo, Japan. Pp 9-21.

Ranjit, N., Rao, B. V. and Merangsoba.(2013) Clinopyroxene composition of the gabbro from the Naga ophiolite belt; New evidence on supra-Subduction zone type magma genesis. Jour. Appl. Geochem. V.15, (1). Pp 61-69

Rao, A. (1983): Geology and hydrocarbon potential of part Assam-Arakan basin and its adjacent region: In petroliferous basins of India: Petroleum Asia Journal., Dehradun, L.L. Bhandari, et al (ed.), pp127-158.

Rao, A.R. and Murthy, K.N. (1980) The origin of Naga Thrust, Naga Hills, Assam. Bulletin of Oil and Natural Gas Commission. V17(2).

Rao, P.N., Prasad, K.M., Madhusudhan, B.J., Krishna, V.S.R., Anand, A.V.S.S. and Madhnure, P. (2016) Impact of urbanization on groundwater quality in Vijayawada Urban Agglomeration, Andhra Pradesh, Jour. Geol. Soc. India, v87. Pp539-552.

Richards, L. A. (1954) Diagnosis and Improvement of Saline Alkali Soils. Agriculture. 160 Handbook 60.U.S Department of Agriculture Washington DC.V. 78(2) p 154.

Roy, R. K. and Kacker, R.N. (1986) Ophiolites and Indian Plate Margin (edn) N.C. Ghose and S. Varadarajan. Pp197-221

Rubia Khan and Jhariya, D.C. (2018) Hydro geochemistry and Groundwater Quality Assessment for Drinking and Irrigation Purposes of Raipur City, Chhattisgarh. Jour. Geol. Soc. India.v.91.pp 475-482.

Samadder, R. K. and Gupta, R. P. (2007) Conjunctive Use of Well-log and Remote Sensing Data for Interpreting Shallow Aquifer Geometry in Ganga Plains. Jour. Geol. Soc. India. V.69 pp 925-932.

Selvakumar, S., Ramkumar, K., Chandrasekar, N., Magesh, N.S. and Kaleraj, S. (2017) Groundwater Quality and its Suitability for Drinking and Irrigational Use in the Southern Tiruchirappalli district, Tamil Nadu, India. Applied Water Science. V.7, pp 411-420.

Sinha, R.S., Kumar, A. and Saxena, R.C. (1990) Hydrological Appraisal in part of Sharada Sahayak Command Area of U.P.- A Study based on Remotely Sensed Data. Proc. Natl. Symp. On Remote Sensing for agricultural Application. New Delhi, pp 364-370.

Skoog, D.A., West, D.M., Holler, F.J. and Crouch, S.R. (1963): Fundamentals of Analytical Chemistry. 9th.Edition. Published by Brooks/Cole in 2014. P 1090.

Smedley, P.L. (2008) Sources and Distribution of Arsenic in Groundwater and Aquifers: Arsenic in Groundwater: A World Problem. Appelo, C.A.J. (Editor) Proceeding of an IAH Seminar, Utrecht, November, 2006. Pp 4-32.

Sridhar, M. and Pillai, S.(1973) Pollution of groundwater at Bangalore. Proc. Symp. Environ. Poll. Nagpur, India, pp59-70.

Srinivasan, V. (2007) Regional Structural Configuration and Seismic Pattern of "Belt of Schuppen" in Northeast India. Jour. Geol. Soc. India. v. 70 pp801-814.

Srivastava, S.K., Jamir, B. and Sentinungsang, S., (2012) Palaeoenviromental analysis of the Oligocene Barail Sediments in and around Jotsoma, Kohima, Nagaland, India: National Seminar on "Sediments and Sedimentary Rock: Resource Potential, Depositional Processes, Implication to Ecosystem and Environmental Changes". Pp 96-97.

Subramanian and Deb (1976) Systematic Hydro-geological Survey in Dimapur Valley of Kohima District. CGWB.

Sujatha, D., (2002) Hydro-geochemical Studies in the South Eastern part of Ranga Reddy District, Andhra Pradesh. Unpublished PhD. Thesis submitted to Osmania University, Hyderabad.

Sujatha, D. and Reddy, R.B.(2003) Quality Characterization of Groundwater in the South-Eastern part of Ranga Reddy district, Andhra Pradesh, India. Environmental Geology. V.44(5) pp579-586.

Tapponnier, P., Peltzer, G. and Armijo, R. (1986) On the mechanics of the collision between India and Asia, in *Collision Tectonics*, edited by Coward, M.P., and A.C Ries. Geol. Soc. London Special publication 19, pp 115-157.

Thilagavathi, R., Chidambaram, S., Prasanna, M.V., Thivya, S. and Singaraja, C .(2012) Study on groundwater geochemistry and water quality in layered aquifers system of Pondicherry region, Northeast India. Applied water Science. v2 pp253-269

Tiemann, M. (2013) Fluoride in Drinking Water: A Review of fluoridation and Regulation Issues. Congressional Research Service (CRS) Report for Congress. pp 1-21.

Tiwari, A. K. and Singh, A. K.,(2014) Hydrogeochemical investigation and groundwater quality assessment of Pratapgarh District, Uttar Pradesh. Jour. Geol. Soc. India, v 83. Pp329-343.

Tiwari, R.N., Mishra, S. and Pandey, P. (2013) Study of major and trace elements in groundwater of Birsighpur area, Satna district, Madhya Pradesh, India. Int. Jour. of Water Resources and Environmental Engineering. V.5 (7) pp 380-386.

Todd, D.K. (1959) Groundwater Hydrology. Toppan Company Ltd. Tokyo.

Todd, D.K. (1980) Groundwater Hydrology, 2ndEdn. John Willey and Sons. P 535.

Trivedy, R.K. and Goel, P.K.(1986) Chemical and Biological Methods for Water Pollution Studies. Environmental Publication, (Karad, India) V.6. pp10-12.

Twenhofel, (1961) Treatise on Sedimentation, Dover Publications, Inc., New York. P926.

(W.H.O), (1993) Guidelines for Drinking Water Quality, 2nd Edition, V.1 p188.

(W.H.O), (2004) Guidelines for Drinking Water Quality, World Health Organization, Geneva, Switzerland.

(W.H.O), (2004) Sulfate in Drinking Water. Background document for Development of WHO Guidelines for Drinking Water Quality. p 8.

Worchester, P. G.(1965) A Textbook of Geomorphology. Van Nostrand, 2ndEdn, East-West, New Delhi, p584.

Wilcox, L. V., (1955) Classification and use of Irrigation Water, U.S. Department of Agriculture, Circular 969.

***

PAPERS PUBLISHED

1. R. Peseyie and Rao. B.V (2017) Assessment of groundwater quality for drinking purpose in and around Dimapur Town, Nagaland. Journal of Applied Geochemistry v19 (4) pp464-470.

2. R.Peseyie and Rao. B.V (2020) Chemistry of Groundwater and its suitability for drinking purpose in and around Chumukedima Town, Dimapur District,