

**GEOCHEMISTRY OF POTABLE AND SALINE WATER SOURCES
IN AND AROUND MAMIT TOWN, MIZORAM**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY**

B. RAMNGAIHAWMA

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**DEPARTMENT OF GEOLOGY
SCHOOL OF EARTH SCIENCES & NATURAL RESOURCES
MANAGEMENT, MIZORAM UNIVERSITY**

OCTOBER, 2021

*Dedicated
To
Our Dearly Son*



SANGPUIA BAWLTE

(23.11.2021 – 7.04.2022)

**GEOCHEMISTRY OF POTABLE AND SALINE WATER SOURCES IN AND
AROUND MAMIT TOWN, MIZORAM**

BY

B. RAMNGAIHAWMA
Department of Geology

Supervisor
Prof. SHIVA KUMAR

Joint Supervisor
Prof. V.K BHARATI

Submitted

**In partial fulfillment of the requirement of the Degree of Doctor of Philosophy
in Geology of Mizoram University, Aizawl**



DEPARTMENT OF GEOLOGY
MIZORAM UNIVERSITY
(A Central University established by an Act of Parliament)
भौमिकी विभाग, मिज़ोरम विश्वविद्यालय
Mizoram : Aizawl - 796004
मिज़ोरम : आइज़ोल - ७९६००४

Shiva Kumar
Professor & Head

Email: geologymzu@gmail.com

CERTIFICATE

*This is to certify that the thesis entitled “**Geochemistry of potable and saline water sources in and around Mamit town, Mizoram**” written by **B. Ramngaihawma** for the award of Doctor of Philosophy in Geology has been written under our supervision.*

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

Date:

(Prof. SHIVA KUMAR)

Supervisor
Department of Geology
Mizoram University

(Prof. V.K BHARATI)

Joint Supervisor
Department of Chemistry
Government Kolasib College

MIZORAM UNIVERSITY

October, 2021

DECLARATION

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

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Geology.

Date:
Place: Aizawl, Mizoram

(B.RAMNGAIHAWMA)
Research scholar

Head
Department of Geology
Mizoram University

(Prof. SHIVA KUMAR)
Supervisor

(Prof. V.K BHARATI)
Joint Supervisor

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Date:

Place: Aizawl

(B. RAMNGAIHAWMA)

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CHAPTER 1: INTRODUCTION

1.1 GENERAL

All life forms on the earth bank on water and life without water is impractical. The importance of water has been escalating more and more since the demand for good quality freshwater upsurges nowadays. Freshwater is one of the most vital resources and consumption of freshwater is increasing as the world's population is rapidly growing since decades ago. Water is a very important required substance to sustain vital activities of humans such as nutrition, respiration, circulation, excretion, and reproduction (Kılıç, 2020). Meanwhile, the consequence of urbanization and industrialization leads to spoiling the water (Mishra and Bhatt, 2008). Many countries have not been able to cope with the rising exigency to maintain a sustainable level of supply and demand of freshwater. As a result of tourism and recreation, they provide significant social and economic benefits, as well as cultural and aesthetic value to people all over the world (Arain et al., 2008).

Water is one of the most important elements of our environment. In spite of a large amount of water covering the surface of the earth, fresh water comprises only 2.6% of all the water reserves globally while ocean water accounts for 97.40% of the earth's water. Out of this meagre amount of fresh water, a large part of it is stored as deep groundwater or bounded in glaciers and ice caps that were not directly accessible to mankind. Approximately, 12% of total freshwater is available for human consumption which occurs in lakes, rivers, streams, and shallow groundwater. In the region of arid and semi-arid, groundwater may constitute as high as 80% of the total water resources. The amount of water available in the atmosphere is estimated to be 1×10^{-5} of the total water resources of the world (Rao, 1979). Water moves downward to reach the subsurface from the ground surface through natural or artificial recharge. In unsaturated zones, water flows under gravity, and in saturated zones movement of water is regulated by the hydraulic gradient within the subsurface. Again, groundwater is discharged to rivers and streams, as a spring, or by plant transpiration. Pumping from wells may also be used to discharge it. Groundwater storage may be much more advantageous than surface storage, which is prone to substantial evaporation.

World Health Organisation (WHO) reports that 785 million people do not have access to basic drinking water, including 144 million who rely on surface water. At least 2 billion people worldwide consume untreated faeces-contaminated water. Half of the world's inhabitants will be living in water-stressed areas by 2025 (WHO, 2019). In India, more than 600 million people are facing severe water shortages and about three-fourths of all households do not have access to safe drinking water. It is also indicated that India's water demand would outstrip supply by a factor of two by 2030, threatening hundreds of millions with extreme water shortages (Rana and Guleria, 2018). The Union Ministry of Water Resources has estimated an increase in water demand from 813 BCMs (Billion Cubic Meters) in 2010 to 1093 BCMs in 2025. About 85 % of the rural population is solely dependent on groundwater, which is depleting at a fast rate, while 60% of the urban population is dependent on surface water sources, where the availability and quality are questionable (Dar et al., 2020). India, being the world's second-most populous nation, encompasses just 4% of the world's freshwater reserves and a little change in weather patterns and extended non-rainy season readily instigate a shortage of water. About 226 million people lack access to safe water and about 70 percent of the population (about 640 million) lack basic sanitation facilities in India (Chigurupati, 2008). In a general sense, a person needs a minimum of 50 litres of water per day for his daily basic needs and about 3 litres for his daily drinking purposes, but this criterion is usually not met in any part of the world.

1.2 WATER QUALITY

One of the most critical environmental issues in the world today is the inadequate availability of good quality freshwater. The assessment of the quality of water is crucial as the quality of potable water has a direct impact on the welfare of human beings. The systematic analysis and assessment of water data in which the chemical, physical, and biological quality are examined to ensure the natural and anthropogenic impact on the quality of water is a prerequisite to observe water quality. The monitoring approach defines multiple evaluations and serves as a foundation for emphasizing the best possible use in achieving the strategic objectives. Regular monitoring and evaluation of water quality serve as the foundation for curbing water pollution and are essential components in preserving human health and the

environment. It quantifies the existing and emerging water quality problems and also the extent and spatial range of availability of water.

Water quality is likely to fluctuate from one source to another as it comprises different components. The natural process and human activities influence the quality of surface and groundwater resources (Prajapati et al., 2018). Any change in its natural quality may result that the water becoming inappropriate for its intended usage. Population explosion and fast-growing development may hamper the water quality and increases the demand for various purposes in every part of the world. Rapid urbanization and increased agricultural activities have resulted in the degradation of the water quality (Venugopal et al., 2008) owing to excessive resource usage and disposal of waste products. Insufficiency of water occurs in an area when the rate of supply of water is less than the water demand. So, the socio-economic development of any region, to a certain extent, is depending on the requirement of water for drinking and domestic use. Rapid urban development areas affect groundwater quality due to excessive use of resources and waste disposal execution (Kaur and Sharma, 2020).

The water used for drinking purposes should be free from any toxic elements, living and non-living organisms, and an excessive amount of minerals that may be hazardous to health (Reddy et al., 2013). The water which is free of pathogens and hazardous elements is potable. Potable water should also be clear, not saline, and free from compounds that can cause colour, taste, and odour (Pritchard et al., 2007). Since the quality of drinking water is a health issue the water to be supplied to the public should be sufficient to meet the demand and it should be clean, palatable, and chemically pure for various uses. The poor quality adversely affects the growth of plants as well as human health (Kumar et al., 2009; Todd, 2007; Karanth, 1997). Since safe water plays a key role in maintaining human health, cross-contaminated water leads to 80% of diseases in many developing countries (De Jesus et al., 2015). Water is suitable when its quality is suitable for the purpose it is sought. The suitability of natural water depends upon the criteria of acceptable quality for that use. Therefore, water quality standards have been established to serve as guides for determining water quality for specific activities and limiting contamination of water bodies. A value of acceptable ranges was set up for physical, chemical, and biological characteristics of

water to specify the nature of water for various purposes. Thus, countries adopted water quality standards to safeguard community health governed by regulatory authorities like BIS, ICMR, USEPA, WHO, etc. The measured physical, chemical, and biological characters of water were compared with drinking water standards to evaluate the quality of such water. Water quality guidelines provide basic scientific information about water quality parameters and ecologically relevant toxicological threshold values to protect specific water uses (Lawson, 2011).

The problems related to chemical constituents of potable water arise mainly from their ability to cause adverse health effects after prolonged periods of exposure, of particular concern, are contaminants that have cumulative toxic properties (Sinha, 2018). For several decades, billions of people in developing countries have to face various problems to maintain a safe water supply system for safe water access (Bereskie et al., 2018). The assessment of the quality of water involves the examination of the physical, chemical, and biological status of water in its natural quality and its uses which may have an impact on human health. Water-borne pathogen contamination in ambient water bodies and related diseases are a major water quality concern throughout the world (Pandey et al., 2014). Human activities have a great impact on the degradation of natural water quality by improper disposal of human wastes into water sources. So that, disease-causing organisms (pathogens) transmitted via drinking water are predominantly of faecal origin (and therefore known as enteric pathogens) (Hunter et al., 2003; (Ashbolt, 2004). In developing countries, of the 37 diseases identified as major causes of death, 21 are related to water and sanitation. Water-borne diseases are causing more than 4 million infant and child deaths every year in developing countries (Chigurupati, 2008).

Some of the major water quality issues in water bodies include the presence of pathogens (like bacteria, fungi, virus, protozoan, etc.), organic and inorganic matter, suspended solids, heavy metals such as Cadmium, Lead, Mercury, Nickel, Iron, etc. and elements like Fluoride and the possible sources of such contaminants in water bodies are agriculture runoff, domestic and industrial wastewater (Sharma et al., 2021). Besides anthropogenic activities, sometimes contaminants also occurred through a natural process (Ali and Ahmad, 2020). The geology of a particular area has a

tremendous influence on the occurrence and quality of water and its movement in as much as the zone of saturation lies in the rock and other earth material. The earth's water-bearing formations act as conduits for transmission and as reservoirs for the storage of water (Todd, 2007). Hence, groundwater contains mineral ions that are dissolved from soil particles, sediments, and rocks as the water moves through the pores or fractures of the rock formation. Quality problems may also occur due to salts from the root zone due to percolating excess irrigation water. The chemical budget of major ions and heavy metals is important in determining the quality of groundwater (Venugopal et al., 2008). Heavy metals are highly toxic and can cause damaging effects even at very low concentrations (Chennaiah et al. 2014). Therefore, impairment of groundwater quality due to heavy metals is always given serious consideration for their harmful effects on humans. The chemical composition of groundwater is controlled by many factors; including the composition of precipitation, geologic structure, mineralogy of watershed aquifers, and geological processes within the aquifers (André et al., 2005). Most groundwater contains a wide variety of dissolved inorganic chemicals and to a much-limited extent naturally occurring organic constituents. These dissolved constituents are responsible for the quality of groundwater and their concentrations level fluctuate owing to changing rainwater discharge in different seasons. Thus, the analysis of water can provide valuable information on the occurrence and movement of groundwater.

The degradation of water quality has a harmful influence on the nature of water and always limits its copious uses for different purposes. As the link between water quality and human activity is tightly interwoven, issues relating to water quality are normally caused by the harmful effects of human activities. Then again, the deterioration of water quality has brought on troublesome situations to humans after consuming it. The contamination of water is directly related to the degree of contamination of our environment (Hanaa et al., 2000). Water Aid India Country Strategy (2016-2021) reported that in India, approximately 76 million peoples lack access to safe water and more than 140,000 children died due to diarrhoeal infection every year. Every year over 38 million Indians are shown to infect with water-borne diseases (Kurunthachalam, 2013). Because water quality concerns are closely tied to

water consumption, strategies for water quality evaluation should rely on water sources, their proposed uses, the requirement of water quality, and the prescribed quality standards to assure compliance. Thus, regular monitoring of data and related evaluations constitute the foundation for the efficient management of drinking water quality.

1.3 LOCATION AND ACCESSIBILITY OF STUDY AREA

Mizoram is one of the seven sister states located at the southernmost tip of India's North East region. Geographically, it is located between latitude 21° 58' N to 24° 35' N and longitude 92° 15' E to 93° 29' E. It covers an area of 21,081 sq. km with a cross length of 285 Km from north to south and 115 Km from east to west. This state is shaped like a sandwich between Myanmar in the east and Bangladesh in the west and sharing its borders with Manipur in the east, Assam in the north, and Tripura in the west. It has as much as 404 Km of international border with Myanmar and 318 Km. with Bangladesh. As per Census 2011, Mizoram has recorded a population of 1,097,206 (Census 2011).

The study area is located in the central region of Mamit district in the north-western part of Mizoram. Geographically, the area of study lies between latitudes N 23°38'26.00" to N 23°56'57.02" and longitudes E 92°27'03.04" to E 92°30'24.00" which falls in parts of the Survey of India Toposheets No. 84 A/5 and 84 A/6 (Fig. 1). Mamit district is bounded on the north by Assam, on the west by Tripura state and Bangladesh, on the south by Lunglei district, and the east by Kolasib district and Aizawl district. It occupies an area of 3025.75 sq. km with an average elevation of approximately 718 m from sea level. The important rivers flowing through the district are Tlawng, Tut, Langkaih, Teirei, Khawthlangtuipui, and Mar. Mamit town is the main administrative headquarters of Mamit district. The district is traversed by various good road networks across the entire district. The NH 44A starts from Sairang town in Aizawl district passes across the Mamit district in the middle passing through various villages and joins the Zampui hill ranges of Tripura state. For transporting agricultural products, several link roads were also constructed within the district.

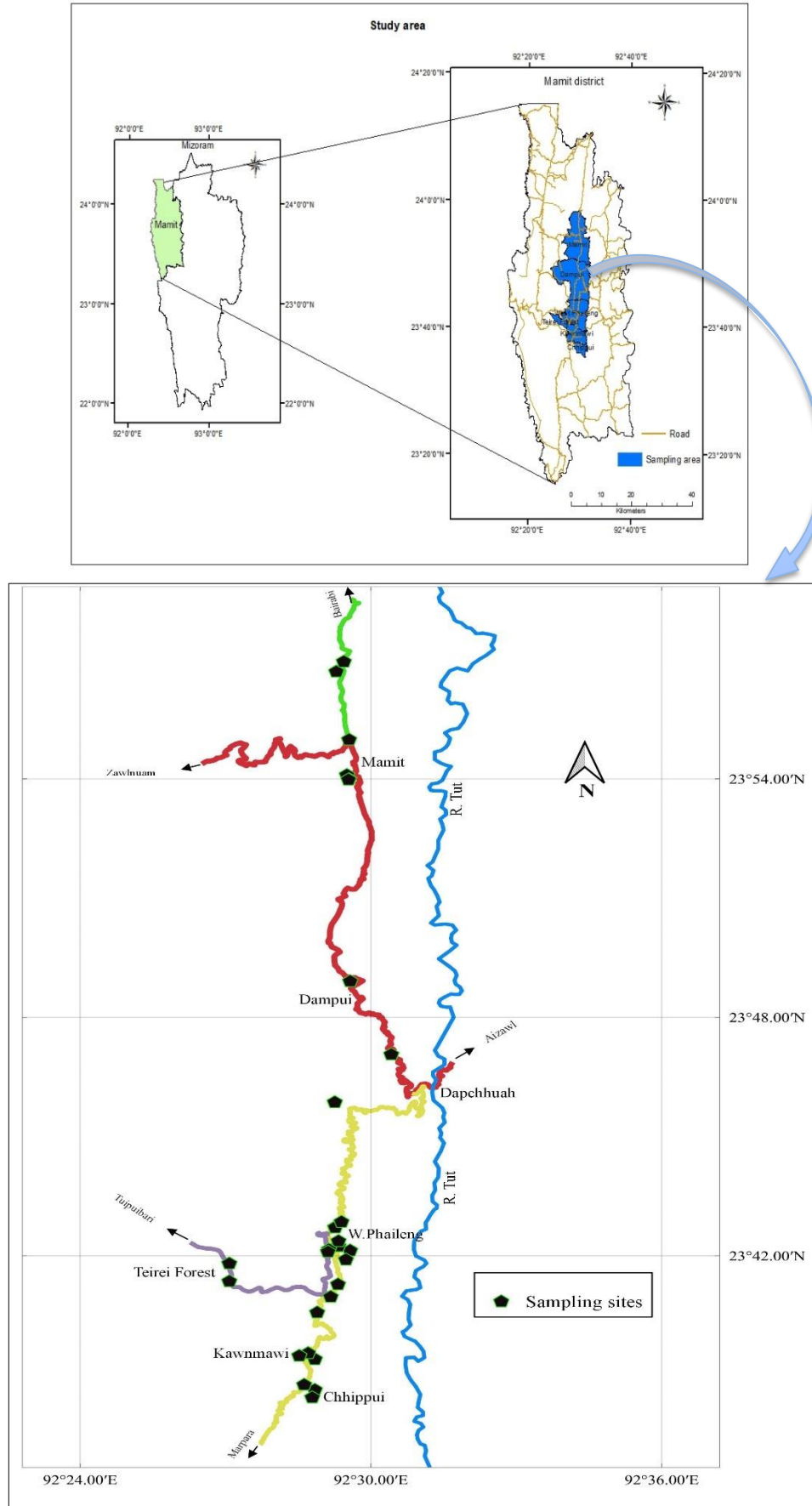


Fig 1: Location of the sampling area

1.4 CLIMATE AND RAINFALL

Mizoram is covered by the Tropical Monsoon climate. It experiences a mild climate where summer is usually not too hot, but winter is fairly cold. The climate of Mamit district is also moderate all year round, characterized by a reasonably cold winter period and not very hot summer time. The district, therefore, receives a sufficient amount of rainfall as it comes under the influence of the South-West monsoon characterized by a humid tropical climate with lengthy summer and shorter winter. The coldest season, winter, commences in late November. The temperature varies from 9°C to 24°C during this season and it receives little rainfall from the North East monsoon, which is substantially less than the other seasons. The spring season begins in the second half of February. It is the shortest season with moderate temperatures. The summer season is the warmest season with temperatures ranging from 24°C to 36°C. The district receives abundant monsoon rain during this period, which usually starts to set out at the beginning of May. Though the temperature does not significantly change throughout the year, it began to drop quickly in November and reaches its lowest point in January, which is the coldest month of the year.

Table 1: Monthly rainfall data of study area (in mm)

Month	Year				
	2014	2015	2016	2017	2018
January	0	5.5	0	0	0
February	10.8	15.25	49.6	16.7	3.2
March	53.7	63.8	166.3	192.1	48.5
April	67.6	411	313.4	416	148.1
May	449.5	335.7	488.4	345.3	406.7
June	279.6	256.6	362.6	799	766.8
July	406.4	380.6	290.7	390.9	468.7
August	238.4	426.9	440	523.5	330.6
September	383.5	317.4	312.5	303.1	199.8
October	66.8	167.6	171.4	397.2	130.9
November	6.5	0	92.4	4	13.8
December	0	0	0	105.3	0.5
Total	1962.8	2380.35	2687.3	3493.1	2517.6

(Source: Directorate of Economics & Statistics, Government of Mizoram)

Mizoram receives an abundant amount of monsoon rain usually from May to October with an average rainfall of 2500 to 3000 cm per year. Generally, South West Monsoon begins to set on late May. Mamit district also receives heavy rainfall during the monsoon season and is one of the wettest districts in Mizoram. The average rainfall of the Mamit district is 2577.5 mm. Rainfall data of the study area has been given in the table 1.

1.5 PEOPLE AND THEIR LIVING CONDITIONS

According to Census 2011, Mamit district is the least urbanised district in Mizoram where 82.75 % of the population lives in rural areas of villages. The density of population is 29 persons per sq. km. The majority of the population in the district depends on agriculture and allied activities to make their living and a very less proportion of the population is engaged in other sectors such as construction, business, manufacturing, etc. Shifting cultivation (also known as jhumming) is widely practiced while terrace cultivation is also prevalent in some parts of the district. Mamit district is one of the most backward districts in Mizoram. The economic condition of the population is somewhat low as compared to other districts due to a lack of infrastructure and good facilities for education and health, especially in rural areas. ICSSR survey report (2009) shows that about three-fourths of households depend on public sources for drinking water, while the rest depend upon other sources like private and natural sources. There are a large number of springs, particularly near the settlements, at various places throughout the district.

The dominant people living in Mizoram are Mizo and it is composed of several sub-tribes such as Lusei, Mara, Lai, Hmar, Ralte, Paite, etc. while some other minorities were also inhabited mostly in the western flank of the state. Likewise, the dominant tribe within Mamit district is Mizo followed by Chakma and Bru who are dwelling in the western and northern border of the district. Against a total Scheduled Tribes population of 94.4 % in the state, the Scheduled Tribes population of Mamit district is 95.0 %. The majority of the population were Christians constituting more than 90% of the population. Buddhism is the second largest religion comprising mostly the Chakma community. Apart from Christmas and New Year festivals, the Mizo people celebrate Chapchar Kut which is a festival attributed to the harvesting of rice

and other agricultural items from the field. Chakma celebrates their New Year festival called Biju during the last part of the year and first part of the New Year while Reang, also known as Tuikuk or Bru celebrates Buishu during the month of April.

1.6 FOREST AND VEGETATION

Nearly the entire region of Mizoram is known for its huge diversity ecosystem and rich biodiversity. A large area of the state is covered by forest. The forests are a crucial resource on which depends the livelihood of the majority of the population in Mizoram. Tropical moist deciduous forests and bamboo are the most common form of vegetation. Bamboo is deeply linked to the lifestyle of the people of Mizoram owing to its wide range of uses. Several trees, shrubs, climbers, and herbs provide vegetables, fruits, timber, fuel, medicines, and fibres. According to the India State of Forest Report (2019), 85.41% of the total geographical area of Mizoram is covered by forest, the highest amongst the state in India.

Tropical wet evergreen forests are the main type of forest found in the Mamit district. In a few areas, moist deciduous forests and semi-evergreen forests are scattered within the district mainly on the hill slope. Several species of vegetation are abundant in this region. The forests in the district have been classified base on their density as Dense forests, Medium Dense forests, and Less Dense forests. Bamboo forests are also abundantly distributed within the entire district. Dampa Tiger Reserve, the largest sanctuary in Mizoram is situated in the western part of Mamit district.

1.7 PHYSIOGRAPHY

1.7.1 Drainage System

As the landscape of Mizoram encompasses the north-south running off the steep hill ranges, a deep gorge is formed between the hill ranges. So, the direction of river flow is along the north-south direction in Mizoram. Thus, the drainage pattern dominating in the area may be classified as a trellis type of drainage pattern where the parallel running tributaries join the main streams at a high degree (SOER, 2016). A dendritic and sub-dendritic pattern of drainage were also prominent in Mizoram.

Several rivers flow through the Mamit district. Some of the most important rivers are Tlawng, Tut, Teirei, Langkaih, Khawthlangtupui, and Mar rivers, where the

entire area is drained by these rivers (ICAR-ATARI-III, 2015). The drainage system in Mamit district can be divided into two: North flowing drainage system and the south-flowing drainage system. The north-flowing drainage system comprises Tlawng, which is the longest river in Mizoram, Tut, Teirei, and Langkaih. These north-flowing rivers show the drainage patterns of angulated, dendritic to sub-dendritic. On the other hand, the south-flowing rivers in the district were Khawthlangtuipui and Mar river which shows dendritic to sub-dendritic drainage patterns. The north-flowing river drained larger areas than the south-flowing river. Apart from these, various streams and rivulets of different lengths and sizes were present in the district, which are primarily seasonal in nature. Generally, the streams of Mamit district are youthful stage, and the drainage system is described as dendritic in nature.

1.7.2 Geomorphology

The general physiography of Mizoram is characterised by a very immature first order topography comprising north-south trending anticlinal ridges and synclinal valleys, steep slopes, and narrow gorges associated with complex drainage basins. There is a general increase in the altitude of the hills from west to east. In the study area, the main geomorphic units are structural hills which were characterized mainly by less prominent ridges with intervening valleys (Lalbiakmawia, 2015). Running water is the controlling factor for the process of weathering and denudation. Based on the nature of lithology, relief, drainage, and structural pattern, the Mamit district has been divided into two major units as denudostructural hills and valleys (CGWB, 2013).

Denudostructural hills represent a larger part of the district which primarily consists of compact and fine-grained sandstone, shale, siltstone, mudstone, and limestone. The trending of anticline and syncline, and structural attitude remains prominent. A meandering pattern with a profusely dissected ridge characterized the drainage. Meanwhile, the valleys are sparsely distributed in a small area trending N-S direction in the district. The width of the valley generally increases towards the north and south.

1.8 SCOPE OF THE STUDY

The paramount significance of water in various forms has a deep impact on the socio-economic growth of the community. Whereas the requirement for water for various purposes is increasing at a fast rate, its pollution level is also going up which eventually reduced the availability of sufficient potable quality of water. Precipitation is the main source of surface and groundwater. But, in a hilly and rugged topography of Mizoram, high relief and steep slopes actuated surface runoff thus obstructing extensive infiltration of rainwater into the ground. Therefore, the prospective of groundwater is considered to be limited. The small amount of water infiltrated into the ground are confined into weak zones, which act as seepage channel. Consequently, the water percolates into the ground as seepages and springs. A basin-like structure is set up at a suitable place to impound and collect the percolating water from the springs; this is locally called 'Tuikhur'. It is the main source of water supply, especially in rural communities.

According to the Census of India, 2011, approximately 85% of the households in Mamit district did not received treated water but depends on untreated private sources and other sources for their drinking purposes. Reckoned on private sources as the main drinking purposes by rural poor people is a matter of serious concern. Many springs or Tuikhur were found close by of the settlement, but most of the springs are not productive during dry seasons. A total of 2,705 households in urban and 3089 households in rural areas were given water connections from the state government (PHED, 2020). During the non-rainy season, the water supplied by the Public Health Engineering department (PHED) is not always sufficient for the connection provided by households. This inadequacy has forced the people to use spring or Tuikhur and hand pumps for their daily needs. Moreover, the people of the rural area who were not covered by the supply of water from PHED also mainly count on spring or Tuikhur water, rainwater harvesting, and hand pump for their household purposes. Then, the people consumed and used water directly from its sources. In such circumstances, it is highly imperative to ascertain the quality of water as the people consume it without any treatment. Keeping this a vista, this study is aimed at examining and understanding the nature and level of contamination of potable water with chemical concentrations

and also to determine the geological control on the presence or absence of different elemental concentrations in water.

1.9 OBJECTIVES OF THE STUDY

The objectives of the study are: -

- 1) To measure the physico-chemical and bacteriological properties of potable and saline water in the study areas.
- 2) To assess the impact of rock-water interaction on the quality of potable and saline water in the study areas.
- 3) To demarcate vulnerable water sources in the area and suggest remedial measures.

1.10 LITERATURE REVIEW

Water quality is assessed and evaluated based on physical, chemical, and biological analyses of a water sample. The chemical quality analysis consists of the determination of the concentrations of the inorganic constituents present in water while organic and radiological constituents are normally of concern where the groundwater is contaminated by human activities. Geochemical studies provide a complete knowledge of the water resources of the hydrological regime. A good number of studies have been made worldwide on different aspects of water quality analysis to quantify the nature of water. Al-Dulaimi and Younes, (2017) have studied the potable water quality in Baghdad city, Iraq. They compared the quality of tap water with bottled water and inferred that TDS and Sulphate were relatively high in some parts of the city. They have also suggested conducting radiological analyses to expose the war effect on water resources. Salman and Ahmed (2015) described that the relation between rock type and its relative abundance of ions could be derived from the geochemical composition of groundwater. Likewise, the abundance of Na^+ and Cl^- ions in the groundwater is related to the leaching of minerals salts such as halite. Hem (1985) reported that the presence of HCO_3^- in water is due to the biochemical process taking place in the soil by carbon dioxide extracted from the atmosphere. When the rainwater reacts with carbon dioxide in the vadose zone, carbonic acid is formed which facilitated calcite and dolomite precipitation in soil (Merrits et al., 1997). Efobo et al., (2020) determined groundwater conditions and hydrogeochemistry of the Sombreiro-

Warri Deltaic Plain Deposit in the Vicinity of Agbarho, Nigeria. They have identified that precipitation is the main controlling factor of groundwater chemistry. As the depth increase, the pH of groundwater increased due to carbonate dissolution with Na^+ ion replacement (Adams et al., 2001; Parkhurst, 1995). Dissolved solids present in natural water mainly consisted of bicarbonates, carbonates, chlorides, calcium, iron, nitrates, magnesium, manganese, phosphates, potassium, sulphates, and sodium. These dissolved solids come from the dissolution of lime, gypsum, and other dissolved minerals of soil (Etim et al., 2013).

Groundwater quality analysis conducted by Amadi et al., (2014) in the Eastern Niger Delta, Nigeria identified that improper sanitation, salt intrusion, and high iron content were the main causes of soil and water pollution. This is because anthropogenic activities and intrusion of seawater were prevalent in this area. Mixing of groundwater with seawater and dissolution of gypsum were the two principal processes that governed the high concentration of dissolved solids in groundwater. Moreover, the concentration of dissolved solids in water can be increased exclusively by gypsum dissolution (Ging et al., 1996). Modibo Sidibé et al., (2019) carried out studies on groundwater quality and groundwater mineralization process. Using Rock Ware AQ.QA software the groundwater type of different aquifers was determined. They used Piper and Schöeller diagrams to show the nature of the relationship between the groups. Gibbs diagrams were also deployed to delineate the hydrochemical process on the groundwater's chemistry. According to Gibbs (1970), Ca and Na were the two major cations that characterized freshwater and high-saline water bodies of the world's surface waters respectively. A clear conception of carbonate equilibria is imperative to comprehend the weathering process, surface and groundwater chemistry, and global climate (Andersen, 2002). Gerba and Mc Nabb (1981) have reported that the transport of pathogens and microbial activity into groundwater led to microbial groundwater pollution. Ibe et al., (2005) carried out the bacteriological analysis of borehole water in Uli, Nigeria, and identified the presence of faecal coliform in water samples caused by anthropogenic activities.

Sami et al., (1988) inferred that safe disposal of excrement, improvement of insanitation and personal habits, and also simple hygienic education were essential for

the prevention of water pollution. Dunaieva et al., (2019) performed water quality analysis of different physico-chemical parameters and those parameters were mapped in QGIS 2.18. They have discussed the significance of the GIS environment for simulating and visualizing spatial water quality parameters. They also reported that the quality of groundwater and surface water has no significant relation. Mahmood et al., (2019) analyzed potable water quality for different physicochemical and biological parameters and outlined that the distribution system of water has a high impact on the quality of tap water. They also added that corrosion of pipes incurred trace metals in the water. Marcus (2019) emphasized the use of artificial intelligence for resolving the intricate problems in maintaining and monitoring water quality. Doha (2007) has conducted a potable water quality survey and evaluation by analyzing various physico-parameters. The values of analysed parameters obtained were compared with the recommended standard and the quality-prone areas were established. Nqowana et al., (2018) examined the physico-chemical and microbial water quality of potable water and identified the presence of *Vibrio cholera* and *Aeromonas hydrophila* in the water.

Kawo and Karuppanan (2018) used the water quality index to evaluate the quality of water for drinking purposes. They employed a Piper plot to show the water types and hydrogeochemical facies. Varnosfaderany et al., (2009) assessed water quality using National Sanitation Foundation Water Quality Index (NSF WQI). They have founded that to highlight the real water quality of the river ecosystem, the calculation of WQI should be based on both physico-chemical parameters and biological indices so that a comprehensive assessment of water quality could be achieved. Salem et al., (2000) determined the relationship between drinking water quality and heavy minerals concerning its effect on human health in some parts of the Great Cairo Cities, Egypt. They have revealed that the prevalent diseases such as renal failure, liver cirrhosis, hair loss, and chronic anaemia in the study area were caused by consuming drinking water contaminated with heavy metals such as Pb, Cd, Cu, Mo, Ni, and Cr released from industrial wastes and agriculture activities. The biological processes do not have an impact on the water composition of small streams and rivers on account of rapid flow, on the other hand, large and slow-moving rivers have enough time for biodegradation and excretion processes to alter water composition (Ibanez et

al., 2007). An investigation to determine the impact of lithology, relief, water discharge, and anthropogenic activities on different rivers has been carried out by Shiller and Boyle, (1987); Cameron et al., (1995) to ascertain the presence of metals and trace elements.

Fluoride content in groundwater might be due to the dissolution of granites and volcanic rocks in a different region (Apambire et al., 1997). Chae et al., (2007) studied fluorine geochemistry in bedrock groundwater and concluded that the composition of metamorphic rocks and granitoid minerals were the sources of fluoride content in groundwater. But a study made by Saether et al., (1995) described that hard rock has not always contributed to the higher amount of fluoride in groundwater. The water-rock interaction of different aquifers and its relations to fluoride concentration has been studied by different scholars (Nordstrom and Jenne, 1977; Gaciri and Davies, 1993). Water-rock interaction and fluoride concentrations are directly correlated (Gizaw, 1996). Kim and Jeong, (2005) also discussed that anthropogenic pollute from the land surface has a negative relationship with fluoride in groundwater.

Several studies have been conducted on the physico-chemical and bacteriological analysis of water quality (Dar et al., 2020; Rinsha and Asokan, 2017; Manjare et al., 2010; Simpi et al., 2011). The monitoring water quality of the Narmada River was carried out by Saluja (2018) by analysing different physico-chemical parameters. Statistical analysis through the correlation method was employed to assess the degree of association between different parameters. The result showed that the Narmada River water quality is not safe for drinking purposes but suitable for domestic and irrigation uses. Selvakumar et al., (2017) inferred that the evaporation process, the controlling mechanism of groundwater chemistry, is governed by arid conditions and anthropogenic activities in their study area. They have used multivariate statistical methods to delineate the natural and anthropogenic impacts on the contamination of water. Singh et al., (2017) conducted a comparative study of physico-chemical and bacteriological assessment on drinking water samples from an urban area of Patna district, Bihar. They identified the presence of coliform in water samples originate from improper treatment of human waste. GIS technology was employed by Suresh et al., (2014) for hydrogeochemical studies of groundwater. Spatial distribution maps

were prepared from the evaluated geochemical data to establish the groundwater quality zones for drinking purposes. Pallavi et al., (2019) carried out a detailed physico-chemical and bacteriological analysis of water samples at different seasons to understand the seasonal variation of water quality.

Water Quality Index (WQI) provides a simple indication of water quality that manifests the general water quality of a particular location depending on water quality parameters. The WQI is a mathematical equation that transformed several water quality data into a single number (Stambuk, 1999). Several water quality indices have been formulated by different national and international organizations such as Weight Arithmetic Water Quality Index (WAWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Oregon Water Quality Index (OWQI), etc. (Tyagi et al., 2013). Khan et al., (2020) used two water quality index methods (WAWQI and CCMEWQI) to evaluate the quality of drinking water. They have found out that in the WAMWQI method categorization of water is in a wider range than the corresponding CCMEWQI method under the dominance of low acceptable range parameters. Eugene Lamare and Singh (2016) evaluated the water quality status in the Limestone mining area of Meghalaya using the CCMEWQI method and identified that activities at cement plants have more influenced on the water quality than limestone mining in the study area. Batabyal and Chakraborty (2015) employed the NSFWQI method to assess groundwater quality for drinking purposes. They have observed that the quality of water is good during pre-monsoon but poor in the post-monsoon period. Several studies were also carried out to quantify the quality of water using the WAMWQI method (Prajapati and Bilas 2018; Bhutiani et al., 2018); Kangabam et al., (2017) Ramakrishnaiah et al., (2008).

The contaminations of water quality due to the presence of heavy metals were a serious concern owing to their hazardous effects on human health. Arain et al., (2008) performed an elemental analysis of Manchar Lake water and reported that the values of Al, As, Ca, Cd, Fe, Mg, Na, K, Ni, Pb, and Se were higher than the permissible limit prescribed by WHO. Lawson (2011) determined the concentrations of Fe, Zn, Mn, Cd, Cr, and Pb in water were by Atomic Absorption Spectrophotometer (AAS) and

inferred that these heavy metals concentrations were higher than the maximum contaminant level (MCL) of USEPA guidelines. Chennaiah et al., (2014) accomplished the investigation of heavy metal concentrations in drinking water with emphasis on human health. Determination of concentration of 16 elements (As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, V, and Zn) in the water samples was carried out using ICP-MS (Perkin-Elmer SciexElan DRC II). The result showed that six heavy metals (Cr, Fe, Mn, Ni, Pb, and Zn) concentrations were above the highest permissible limits of the WHO and BIS standards. Changes in hydrochemical facies of groundwater can be comprehended by plotting the concentration of major cation and anion on different graphical representations. The hydrochemical facies of groundwater in Tumkur Taluk, Karnataka State, India was interpreted by Sadashivaiah et al., (2008) using Piper trilinear diagram and concluded that hydrochemical facies does not change during the study period which indicates that most of the major ions are natural in origin. Venugopal et al., (2008) investigated the hydrochemical of the groundwater and the seasonal effect on the chemical budget of ions along the course of the polluted river Adyar. Different analytical methods and diagrams were used to evaluate the water quality for irrigation such as US Salinity Laboratory's, Wilcox's diagrams, Kelly's ratio, and magnesium ratio, and Gibb's diagram. Tiwari and Singh (2014) carried out a hydrogeochemical investigation of groundwater resources of the Paragraph district and they reported that groundwater of the area is alkaline in nature and HCO_3^- , Cl^- , Mg^{2+} , Na^+ , and Ca^{2+} are the major contributing ions to the dissolved solids.

The hydrogeochemical process controlling the quality of groundwater was carried out in Imphal and Thoubal district of Manipur, India by Oinam et al., (2012). They reported several brine springs in the Thoubal district which were localized due to the inherent lithology of the study area. Gibb's plot was used to show the chemical composition of groundwater which was controlled by the natural weathering processes irrespective of seasons. Kumar et al., (2014) studied the geochemical characteristics of groundwater and drinking water quality. They have identified Na-Cl and mixed Ca-Mg-Cl type of water using Piper trilinear diagram. From Gibb's diagram, they also revealed that all the water samples were rock-water interaction dominance and

evaporation dominance. Hydrogeochemical investigations were carried out to analyse the groundwater-seawater interactions in a coastal aquifer along the East coast of Cuddalore district in Tamil Nadu, Southern India (Kumar, 2016) and inferred that groundwater chemistry of the southern region, and to a certain extent in the central region, is largely affected by the seawater mixing with the groundwater. They have applied Hydrochemical Facies Evaluation Diagram (HFE-D), Principal Component Analysis (PCA), ionic ratios, hydrochemical ionic changes models, and Salinity Mixing Index (SMI) models to understand the salinization process in the study area. Venkatramanan et al., (2013) applied multivariate statistical analysis such as correlation, factor, and cluster analyses to understand the geochemical processes that control groundwater geochemistry and water quality status.

Kumar et al., (2010) assessed potable water quality in Kolasib, Mizoram using different physico-chemical and bacteriological analysis. They have revealed that the water supplied by the PHED is better than the Tuikhur water. The hydrogeochemistry of groundwater in Champhai, Mizoram was studied by Thambidurai et al., (2014) and has inferred that groundwater is undersaturated to calcite, dolomite, aragonite, gypsum, and anhydrite. They computed aqueous speciation and saturation index (SI) were using PHREEQC base on water composition. A Piper diagram was utilized to interpret the hydrogeochemical data. Lalbiakmawia, (2015) employed geospatial technology to map the spatial variability and different classes of groundwater quality in the Mamit district. Bharati et al., (2007); Thasangzuala and Mishra (2014); Lalhmangaihuali et al., (2019) reported higher values of some physical characters of water from Aizawl City which required purification before use for drinking purposes. Blick and Kumar, (2017) assessed potable water quality of surface water and hand pump in Siaha town by analysing different physico-parameters. They have described the water as below the permissible limit and can be used for drinking purposes. Moorthy et al., (1986) reported the presence of saline spring in the western part of Mizoram.

PLATE – I



A. Venghlui Tuikhur, W. Phaileng



B. Vengthar Tuikhur, W. Phaileng



C. Khurpui, Chhippui



D. Malsawma Tuikhur, Kawnmawi



E. Lungsir Tuikhur, Mamit



F. Sakhisih, Mamit

PLATE – II



A. Hand pump, Kawnmawi



B. Hand pump, W. Phaileng



C. Dap chi lui



D. PHED Lab. Lunglei



E. MP-AES instrument at CIL, MZU for metal analyses

CHAPTER 2: GEOLOGICAL SETTING

2.1 GENERAL GEOLOGY OF MIZORAM

Mizoram forms a part of the Neogene Surma basin to the west of the Arakan Yoma subduction-collision zone, which represents the northward extension of the Sumatra-Java trench (Nandy et al., 1983). Geologically, it is a part of the Tripura-Mizoram miogeosynclinal basin exhibiting repetitive succession of Paleogene and Neogene rocks which has been evolved after the regional upliftment of Barail sediments (Evans, 1964). The fold belt of Mizoram constituted very tight and elongated asymmetrical anticlines with broad synclines showing the slightly arcuate shape and convex westward (Shrivastava et al, 1979). The sequences are folded into a series of E-W dipping anticlines and synclines plunging longitudinally which were trending in the N-S direction (Ganju, 1975 and Ganguly, 1975). The general strike of the rock formations is N-S with a dip amount between 20° to 50° either towards east or west. Older rocks crop out towards the east and a general increase in sedimentary thickness and the argillaceous component is also apparent in the same direction (Shrivastava et al., 1979). Mizoram is occupied by Tertiary rocks which consist of alternations of shale, sandy shale, mudstone, shaly sandstone, and sandstones with thin bands of conglomerate (Sarma, 1966). The topography is largely control and manifested by the lithology of the area. The Surma rock formation of Mizoram comprises thickly bedded sandstones, shale, and mudstones with diverse stratigraphic horizons (Tiwari and Kumar, 1996). Generally, the arenaceous rocks occur in the higher ground whereas the argillaceous group of rocks occupies lower grounds (GSI, 2011). Siltstones exhibited massive, hard, and grey colour with prominent bedding planes whereas shale beds show thinly laminated splintery patterns. La-Touche (1891), the first worker who established the stratigraphy of Mizoram described that the area is comprised of flysch sequences of shale and sandstone deposited in the late Tertiary period.

The Tertiary rock sequence of Mizoram is classified into 3 distinct groups such as Barail, Surma, and Tipam, and the stratigraphic succession is worked out by

Karunakaran (1974) and Ganju (1975). Recently, some modifications have been made after detail geological studies with the help of modern technology (Tiwari and Kachhara 2003; Mandaokar, 2000; Tiwari et al., 2011) where the stratigraphic sequence of Mizoram is divided into the Barail (Oligocene), the Surma (Lower to Middle Miocene) and the Tipam groups (upper Miocene to early Pliocene) in the ascending order (Table 2.). The Surma group comprises of Bhuban and Bokabil Formation. Bhuban Formation is divided into three units, such as Upper Bhuban, Middle Bhuban, and Lower Bhuban.

The Lower Bhuban rock is exclusively found on the anticlinal cores of high amplitude folds whereas the Middle Bhuban rock occupies the cores of low amplitude anticlines on the limbs of the folds. The Upper Bhuban sediment is located at the anticlines in the western part and synclinal cores in the central and eastern parts of Mizoram. Bokabil and Tipam rocks are found in the western and north-western parts only which are restricted to the cores of synclines (Jokhan and Venkataraman,1984).

2.2 GEOLOGY OF STUDY AREA

The sedimentary rocks exposed in the study area were represented by Bhuban formation belonging to the Surma group of tertiary age. Based on the character of lithology Bhuban formation is further divided into Lower, Middle, and Upper (Bhattacharya, 1983). The rock formations are folded in a series of anticlines and synclines trending in N-S. The Lower Bhuban formation is restricted along the hilltop of Phaileng hill range as small patches in the area. Very hard, compact, grey to bluish grey and fine-grained sandstone is the dominant rock interlaminates with shale which is sometimes iron-stained exhibiting variegated colour on weathering. Lower Bhuban is conformably overlain by the middle Bhuban formation where argillaceous rocks of splintery greenish shale interlaminated with sandstone and siltstone are predominantly associated with thick beds of soft Mudstone. The presence of thick sandstones beds is observed in some places. Generally, sandstones are found to be thinly bedded, compact, and hard with fine to very fine-grained and mostly bluish-grey in colour. These sandstones are extensively used for building and road constructions. The predominantly arenaceous Upper Bhuban conformably overlies the middle-Bhuban

formation. It constitutes medium to fine-grained, hard, compact massive, and prominent bedded sandstone with shale and siltstone intercalated. Deposited shell limestone is also found in sandstone rock in lenticular bands pattern. The Bokabil formations of rocks conformably overlie the Bhuban rocks formation. Bokabil rocks are characterized by a soft and loose thin bed of ferruginised sandstone intercalated with mudstone.

The study area is characterized mainly by ridgelines with intervening valleys. The lithology and structural process determined and modified the topography of the area which is substantiated by the formation of anticlines, synclines, linear ridges, and valleys. Generally, the folded beds are trending in N-S to roughly NNW-SSE directions which dip 20°-70° on either side of the flanks. Both primary and secondary structures are recognized in the study area where prominent primary bedding and laminated bedding are common. Convolute bedding, cross-bedding, cross laminations, ripple marks are also noticed. Small scale cross-bedding structures observed in the Middle and Upper Bhuban Formations specify the depositional environment of shallow marine to deltaic. Distortion of strata in the area induced significant folding and faulting and other linear structural features as a part of a linear belt of folds. The presence of fault effaced the strike of the beds at some places. Generally, joints are found to be tight and widely spaced but the shale bands exhibited close-spaced joints.

Table 2: Stratigraphic succession of Mizoram after Karunakaran, (1974) and Ganju, (1975).

Age	Group	Formations	Units	Thickness (in m)	Generalized Lithology	Depositional Environment
Recent Alluvium					Silt, clay and gravel	River deposits
Early Pliocene to Late Miocene	Tipam			+900	Friable sandstone with occasional clay bands	Stream deposits
Miocene to Upper Oligocene	S U R M A A	Bokabil		+950	Shale with siltstone and sandstone	Shallow marine
		B	Upper Bhuban	+1100	Arenaceous with sandstone, shale and siltstone	Shallow marine, near shore to lagoonal
		H				
		U	Middle Bhuban	+3000	Argillaceous with shale, siltstone	Deltaic complex
B						
A	Lower Bhuban	+900	Arenaceous with sandstone and silty-shale	Shallow marine		
Oligocene	Barail			+3000	Shale, siltstone and sandstone	Shallow marine
Data source	Karunakaran, 1974; Ganju, 1975				Tiwari and Kachhara, 2003; Mandaokar, 2000	

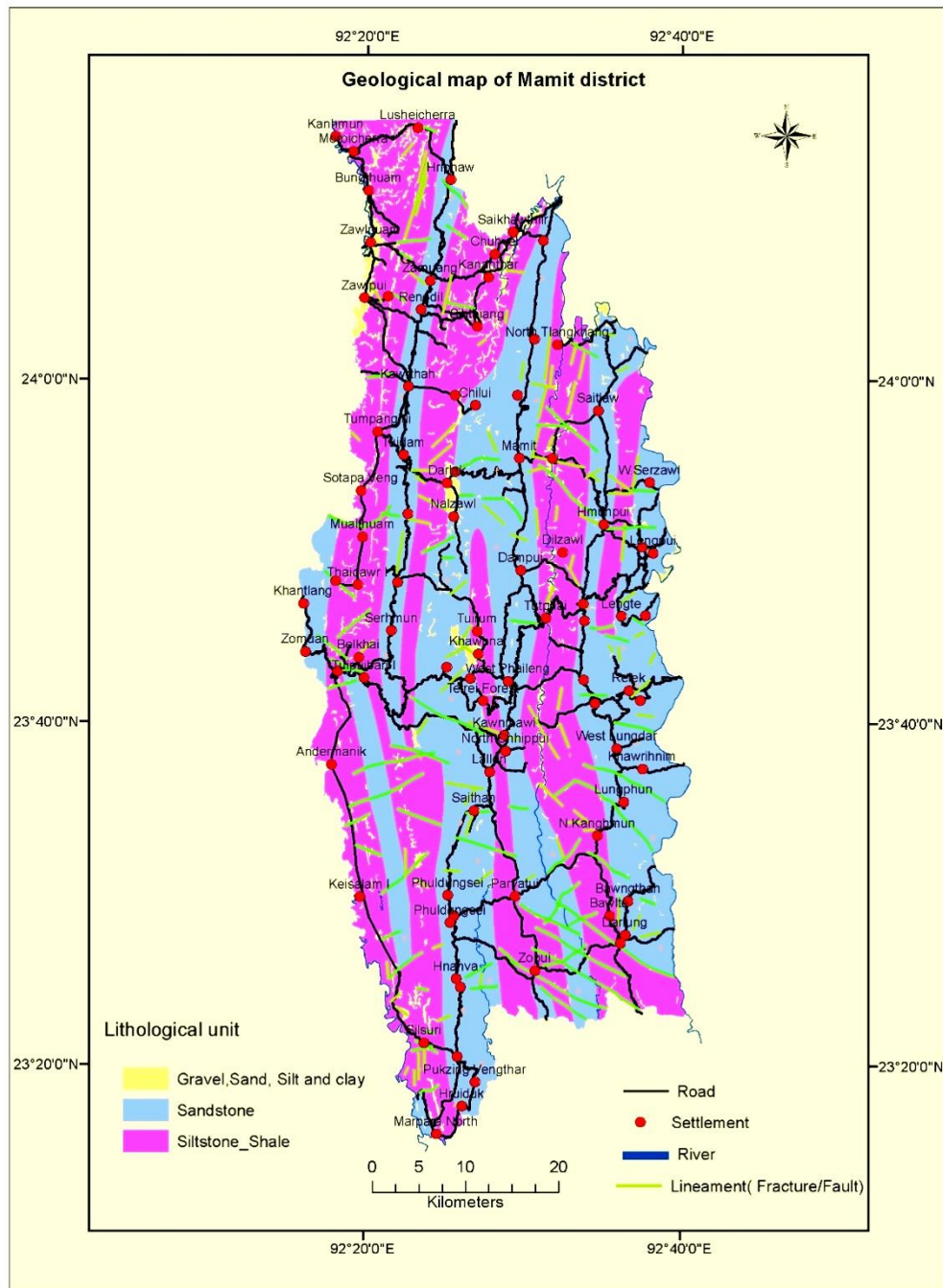


Fig 2: Geological map of Mamit district

CHAPTER 3: METHODOLOGY

Assessment and evaluation of water before being used for drinking and other domestic purposes is indispensable. Different physico-chemical and bacteriological parameters of water should be analysed to quantify the suitability of water for various uses. But, the selection and preference of parameters for water analysis rely on the intention to work with that water and the range of water quality demand for its specific purposes. The present study mainly involves the assessment of potable water quality in the study area. The methodology included fieldwork, laboratory work, and analysis of field and laboratory data.

3.1 FIELDWORK

Fieldwork expedition mainly encompasses surveying sampling sites and sampling of water samples in situ. From the observed potable water sources in several sampling sites of the study area, only perennial water sources upon which the populace depends to satisfy their daily requirement were selected for analysis. A checklist was prepared before fieldwork to ensure that everything is not left behind during fieldwork. It is of prime importance to select the representative sampling sites and applying suitable sampling techniques.

3.1.1 Survey and selection of sampling location

Traditionally, the main purpose for water quality evaluation has been the need to determine if the quality of water is adequate for the proposed applications. As it is a prerequisite to emphasize the relevant information and the currently available information regarding the sampling locations before the water sampling process and analysis, a comprehensive survey was carried out in sampling sites. Scarcity of water is prevalent in the study area. The study area covered a portion of both W. Phaileng R.D Block and Zawlnuam R.D Block in Mamit district. According to the Census of India, 2011, from the total households of 17,204 in Mamit district, only 2,433 (14.14%) households receive a proper drinking water supply. The total number of households having tap water from treated sources in W. Phaileng and Zawlnuam R.D Blocks are 4,263 (0.73%) and 9,231 (21.68%) respectively. The PHE Department

provided drinking water supply in Mamit town and there is an ongoing work for water supply scheme in W. Phaileng during the field survey. In other rural areas, PHED implemented a gravity feed system to provide water to the residents. Although the whole households were not covered, these water supplies maintained by PHED are irregular and inadequate for the populace to meet their daily requirement. To sort out the problems of insufficiency of water, the people have to depend on untreated water sources from spring water (Tuikhur) and hand pump, especially during non-rainy seasons. At the distance of about 10 km from W. Phaileng town saline spring also known as Dap chi Lui, is located at the bank of Dap River within the Dampui village area. The salty water source joins with the Dap River. The percolating saltwater never dried; instead, it flows constantly more or less at the same rate in the full length of the season. In earlier times, the people of different villages, mostly from the western part of Mizoram, used to extract salt from this place and this natural salt was the only source for the people of Mizoram for centuries. The salt extracted by local people from this place had its local brand name Dap Salt. Only with the availability of iodized salt, the use of this natural salt decreased substantially.

Several Tuikhurs have been identified in the study area, whereas only a meagre number of hand pumps were observed. During the field survey, some of the hand pumps and Tuikhur were out of order while others did not produce water sufficiently and dried up during the non-monsoon period. Therefore, the perennial portable water sources, upon which the people depend to compensate their daily demand, were selected for its quality analysis. Six sampling stations were verified in the study area and from those six sampling stations, 30 sampling sites were picked out including 17 Tuikhur and 3 hand pump water sources for conducting water sampling.

3.1.2 Sampling procedures

The collection of water samples starts from the pre-monsoon season of 2016 which continued consecutively for three years till post-monsoon of 2018. Water samples from each sampling site was collected during pre-monsoon, monsoon, and post-monsoon within a period of one calendar year. The time elapsed for collecting samples in each respective season is sometimes, significantly depending on the extent of the rainy season. The size of the sample also varies according to the application of

analytical methods and the number of parameters used. The method of grab sampling was followed to obtain water samples because of homogeneous water samples in the area. Samples for physico-chemical analysis were collected in already washed and rinsed two 500 ml bottles, one of which was preserved with 10% HNO₃ for heavy metal analysis at the laboratory. The sample bottles were closed tightly to avoid any spillage during transportation. Likewise, a water sample for bacteriological analysis was collected in a sterile 500 ml bottle at each sampling site. Any relevant and supporting information concerning the samples was also recorded in the field (Table 3). It is common practice to do in-situ testing of some parameters at the sampling site because of their easily altered character during transportation. Thus, determinations of a few physical parameters were done readily while collecting water samples.

3.1.3 Type of sample and sample code

In the present study, a grab sample is taken from perennial water sources which comprised of potable water from Tuikhur, hand pump water, and saline water from different locations. A sample code is provided for all water samples regarding their sampling place to distinguish them easily (Table 3).

3.2 LABORATORY WORK

The samples collected from the sampling sites were brought to the laboratory with no delay and were treated with appropriate preservation for further analysis. At the laboratory, physico-chemical and bacteriological parameter analysis were performed. The assessment of water samples for their physical characteristics comprised an analysis of pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Turbidity. On the other hand, the chemical analysis comprises Total Alkalinity (TA), Total Hardness (TH), Chloride (Cl⁻), Fluoride (F⁻), Bicarbonate (HCO₃⁻), Sulphate (SO₄²⁻), Nitrate (NO₃⁻), and determination of metals and heavy metals such as Iron (Fe), Zinc (Zn), Cadmium (Cd), Magnesium (Mg), Copper (Cu), Nickel (Ni), Lead (Pb), Sodium (Na), Calcium (Ca), Potassium (K), Manganese (Mn), Chromium (Cr), Cobalt (Co), and Arsenic (As). Multiple tube dilution method of Total Coliform test was used for bacteriological analysis.

Table 3: Name and location of Tuikhur

Sl. No	Name of Tuikhur	Location	Type of Sources	Sample Code	Elevation	GPS Location
1	YMA Tuikhur	Chhippui	Spring	C-1	680 m	N 23°38'37.6" E 92°28'49.3"
2	Khurpui	Chhippui	Spring	C-2	732 m	N 23°38'26.0" E 92°28'46.1"
3	Dap chi Lui	Dampui	Saline Spring	D-1	256 m	N 23°45'51.9" E 92°29'14.0"
4	Dampui Tuikhur	Dampui	Spring	D-2	946 m	N 23°48'54.5" E 92°29'33.1"
5	Dampui Road Tuikhur	Dampui	Spring	D-3	503 m	N 23°47'04.0" E 92°30'24.0"
6	Tuithang	Kawnmawi	Spring	K-1	633 m	N 23°39'23.9" E 92°28'49.3"
7	Hand Pump	Kawnmawi	Hand Pump	K-2	704 m	N 23°39'33.0" E 92°28'41.0"
8	Pu Malsawma Tuikhur	Kawnmawi	Spring	K-3	696 m	N 23°39'29.0" E 92°28'30.0"
9	Marpara Road Tuikhur	Kawnmawi	Spring	K-4	680 m	N 23°38'45.2" E 92°28'36.1"
10	Substation Tuikhur	Kawnmawi	Spring	K-5	759 m	N 23°40'34.4" E 92°28'52.2"
11	Lungsir Tuikhur	Mamit	Spring	M-1	764 m	N 23°54'06.0" E 92°29'29.0"
12	Field Veng Tukhur	Mamit	Spring	M-2	810 m	N 23°54'59.4" E 92°29'31.7"
13	Dinthar Tuikhur	Mamit	Spring	M-3	748 m	N 23°56'42.1" E 92°29'15.9"
14	Zahuata Tuikhur	Mamit	Spring	M-4	798 m	N 23°56'57.2" E 92°29'25.2"
15	Luangpawl Khurpui	Mamit	Spring	M-5	825 m	N 23°53'59.4" E 92°29'31.7"
16	Luangpawl Tuikhur	Mamit	Spring	M-6	851 m	N 23°53'59.0" E 92°29'31.0"
17	Venghloi Tuikhur	W.Phaileng	Spring	P-1	838 m	N 23°42'08.0" E 92°29'33.0"
18	Vengthar Tuikhur	W.Phaileng	Spring	P-2	810 m	N 23°41'54.2" E 92°29'27.8"
19	Tuitlar	W.Phaileng	Spring	P-3	748 m	N 23°40'58.0" E 92°29'09.0"
20	Mauchikawn Tuikhur	W.Phaileng	Spring	P-4	757 m	N 23°41'16.8" E 92°29'18.0"
21	Kanan Tuikhur	W.Phaileng	Spring	P-5	765 m	N 23°42'14.5" E 92°29'18.4"
22	Kanan Hand Pump	W.Phaileng	Hand Pump	P-6	761 m	N 23°42'14.5" E 92°29'18.4"

23	Anga Tuikhur	W.Phaileng	Spring	P-7	721 m	N 23°42'22.2" E 92°29'18.6"
24	Vety Tuikhur	W.Phaileng	Spring	P-8	604 m	N 23°42'09.3" E 92°29'06.7"
25	Vai Tuikhur	W.Phaileng	Spring	P-9	590 m	N 23°42'06.0" E 92°29'05.6"
26	Aizawl Road Hand Pump	W.Phaileng	Hand Pump	P-10	685 m	N 23°42'42.8" E 92°29'14.4"
27	Aizawl Road Tuikhur	W.Phaileng	Spring	P-11	685 m	N 23°42'42.8" E 92°29'14.4"
28	Zakamlo Lui	W.Phaileng	Spring	P-12	700 m	N 23°42'51.2" E 92°29'22.3"
29	Teirei Tuikhur	Teirei Forest	Spring	T-1	269 m	N 23°41'21.4" E 92°27'16.7"
30	Dampa Lui	Teirei Forest	Spring	T-2	273 m	N 23°41'48.3" E 92°27'03.4"

3.2.1 Physical Parameters

Some of the physical parameters were measured in the field at the time of sample collection. Testing fresh samples which are not polluted in the field itself is a major benefit of field analysis. pH, electrical conductivity, and total dissolved solids were observed in-situ using portable pH and TDS meter. The remaining physical parameter along with chemical and bacteriological parameters was analysed in the laboratory.

3.2.1.1 pH:

The pH value of water indicates its alkalinity or acidity. It is a measure of the hydrogen ion concentration of water. Mathematically, pH is the logarithm to the base of the reciprocal of the hydrogen ion concentrations. Thus,

$$\text{pH} = -\log_{10} H$$

where the concentration of hydrogen ion in moles per litre

Being a logarithm, the pH value has no units and is just a number. When the water molecule breaks down, it divides into a positive hydrogen ion (H^+) and a negative hydrogen ion (OH^-). If the concentration of OH^- ions is increased or more than H^+ in a solution, the pH values decrease. Similarly, if the concentration of OH^- ions decreased or less than H^+ in a solution, the pH value will increase. Thus, a pH value of 7 indicates a neutral solution while a pH value less than 7 represents an acidic solution, and a pH value more than 7 means the solution is alkaline or basic. The

temperature of the water has a significant influence on determining the neutrality of water. It is preferable to determine the pH value of water in the field at the time it was collected. Therefore, pH values were measured in situ using a portable pH device (HM Digital, PH-80).

3.2.1.2 Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of the capacity of water to conduct electrical currents. Since pure liquid water is a bad conductor, the presence of charged ionic species in the solution makes the water conductive. Therefore, the conductance measurement of water indicates ion concentration in water and is directly related to the concentration of dissolved salts in water. The more concentration of ions in water, the higher is the conductivity of water. The electrical conductivity of water is also affected by temperature, types, and concentrations of various ions. When the temperature is increases by 1° C, conductance increases by about 2 percent. EC is measured in mhos or $\mu\text{S}/\text{cm}$. The values of electrical conductivity were measured in the field itself by EC/TDS meter (Ravki Digital, TDS/EC meter).

3.2.1.3 Total Dissolve Solids (TDS):

Total dissolved solids (TDS) are the total concentration of dissolved minerals in the water. Several ions were presented in water which includes major cations such as calcium, magnesium, sodium, and potassium and major anions like chloride, sulphate, carbonate, bicarbonate. Minor constituents and trace elements were also present in small quantities but could have a high impact on water quality. For most water, TDS values can be estimated quickly and conveniently by multiplying the value of EC by 0.64 i.e., $\text{TDS} = \text{EC} \times 0.64$. In the present study, TDS values of water samples were determined using EC/TDS meter (Ravki Digital, TDS/EC meter) from the sampling sites.

3.2.1.4 Turbidity:

Turbidity is muddiness in water and is a measure of the cloudiness of water due to the presence of suspended material in water. Silts and clays from soil erosion, industrial waste, and intense rain always caused the turbidity of water. High-level turbidity can cause staining of materials, fittings, and clothes exposed during washing

apart from interfering with the effectiveness of treatment processes but most particles that induced turbidity have no health significance (WHO, 2017). The turbidity values of water samples were determined by a Nepheloturbidimeter (Systronics Digital Nepheloturbidimeter-132) in NTU (Nepheloturbidity Unit) using hydrazine sulphate and hexamethylene tetramene as standards.

3.2.1.4.1 Reagents and Standards

- (a) 100 ml solution was prepared by dissolving 1g of hydrazine sulphate in distilled water.
- (b) Another 100 ml solution was prepared by dissolving 10g of hexamethylene tetraamine in 100 ml of distilled water.

From solutions (a) and (b), 5 ml each of the solutions were pipetted out in a 100 ml volumetric flask and was kept at 25°C for 24 hours. The solution was again filling to the mark with distilled water. This is a suspension with 400 NTU and a standard solution of 40 NTU has been prepared by diluting 10 ml of this stock solution with 100 ml distilled water which can last for one week.

3.2.1.4.2 Procedure

- (a) Using 40 NTU standard solutions prepared, the nephelometer was set at 100 and each percent on the scale equals 0.4 NTU.
- (b) The sample was stirred till all the air bubbles subside.
- (c) The sample was put in the nephelometer sample tube and the reading was recorded.

3.2.1.4.3 Calculation: Turbidity = Nephelometer reading x 0.4 x dilution factor

3.2.2 Chemical Parameters

A detailed study of the chemical quality of water and its relation with the environment is of prime importance. Chemical analysis is the basis of interpretation of its quality in relation to lithology and climate. Different parameters employed for analysis of chemical characteristics of water samples were given below.

3.2.2.1 Total Alkalinity:

Alkalinity is the capacity of water to neutralize acid and is determined by titration with standard acid indicated by colour to an endpoint of pH 4.5. Groundwater with a pH less than 7 may have measurable alkalinity due to the presence of carbonate and bicarbonate ions. Chloride, sulphate, and nitrate ions do not contribute to alkalinity. Hydroxide ions and silicate may have some influence on alkalinity when the pH is above 9.0. Carbonate is present above a pH of 8.2 while Bicarbonate is present above a pH of 4.5.

3.2.2.1.1 Reagents

- (a) Phenolphthalein indicator solution: (In 1litre of distilled water 5g of Phenolphthalein disodium salt was dissolved)
- (b) Standard sulphuric acid (0.02N strength)
- (c) Methyl orange indicator solution (in 1 litre of distilled water 0.05g of methyl orange was dissolved).

3.2.2.1.2 Procedure

- (a) 2/3 drops of Phenolphthalein indicator were added to 50ml water samples. No change in colour indicates Phenolphthalein becomes alkalinity nil. If pink colour appears, it was titrated against 0.02N H₂SO₄ till the colours disappear.
- (b) 2/3 drops of methyl orange indicator were added to the sample and titrated with 0.02N H₂SO₄ till the colour changes from yellow to pink.

3.2.2.1.3 Calculation:

$$P - \text{Alkalinity as CaCO}_3, \text{ mg/l} = \frac{\text{ml of acid consumed} \times 0.02 \times 50000}{\text{ml of Sample taken}}$$

$$\text{Total Alkalinity as CaCO}_3, \text{ mg/l} = \frac{\text{ml of acid consumed till end} \times 0.02 \times 50000}{\text{ml of Sample taken}}$$

3.2.2.2 Total hardness:

Hardness in water is primarily caused by calcium and magnesium cations. Heavy metals like iron and manganese also contribute to hardness. There were three types of hardness determination, such as total hardness, carbonate hardness, and non-carbonate hardness. The total hardness is the sum of the other two. Carbonate hardness

is mainly caused by calcium and magnesium bicarbonate and a minor amount of their carbonates. It is also called temporary hardness. While non-carbonate hardness, also called permanent hardness, is caused by sulphates and chlorides of magnesium and calcium. Total hardness was determined by EDTA titrimetric method.

3.2.2.2.1 Reagents

- (a) Buffer solution (16.9g of NH_4Cl is dissolved in 143ml Conc. NH_4OH . A mixture of 1.179g of A.R. disodium salt of EDTA and 780mg of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (or 644mg of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$) is dissolved in 50ml distilled water. The two solutions were mixed with stirring and dilute with distilled water to 250ml.
- (b) Inhibitor (4.5g of $\text{NH}_2\text{OH} \cdot \text{HCl}$ was mixed with 100 ml of ethyl alcohol).
- (c) Indicator (0.5g of Erichrome Black T dye and inhibitor was mixed).
- (d) Standard EDTA titrant (0.01M) (3.723gms A.R disodium salt of EDTA was dissolved and diluted with distilled water to 1L).

3.2.2.2.2 Procedure

- (a) In 50ml of the water sample, 1ml of buffer solution and a pinch of Erichrome Black T (1-2 drops of EBT solution) were added.
- (b) It was titrated with EDTA till colour of the wine red becomes blue.

3.2.2.2.3 Calculation:

$$\text{Total Hardness as CaCO}_3 = \frac{A \times B \times 1000 \text{ mg/l}}{\text{ml of Sample}}$$

Where, A = ml titration for Sample.

B = mg CaCO_3 equivalent to 1.0ml EDTA titrant.

3.2.2.3 Chloride:

Chloride is a major dissolved constituent of most waters but it is a minor constituent of the earth's crust. The presence of chlorides in water is determined by a volumetric method involving titration of a silver nitrate solution.

3.2.2.3.1 Reagents

- (a) Standard silver nitrate (0.0141N) (2.395g of Silver Nitrate was dissolved dilute to 1L of distilled water)

- (b) Standard sodium chloride solution (0.0141N) (824.0mg of sodium chloride was dissolved in distilled water and dilute to 1L)
- (c) Potassium chromate indicator solution (50g Potassium chromate was dissolved in distilled water and AgNO₃ (Silver Nitrate) solution was added till red precipitate is formed. After leaving for 12 hours, the solution was filtered and diluted with distilled water to 1L).

3.2.2.3.2 Procedure

- (a) In 100ml of the sample, 1ml of K₂CrO₄ indicator solution was added.
- (b) The solution was titrated against standard silver nitrate solution of known strength till the endpoint, which was reddish-pink.
- (c) The same experiment was done for blank.

3.2.2.3.3 Calculation

$$\text{Cl}^-(\text{mg/l}) = (A-B) \times N \times 35.45 \times 1000/\text{ml sample}$$

Where, A = ml AgNO₃ for sample,

B = ml AgNO₃ for blank,

N = normality of AgNO₃ solution

3.2.2.4 Nitrate:

Nitrate in natural water mostly comes from organic sources or industrial and agricultural chemicals. Nitrate compounds are highly soluble and concentration more than the local average in water may indicate pollution. The ultraviolet spectrophotometer was used to determined nitrate in the water sample.

3.2.2.4.1 Reagents

- (a) Stock nitrate solution: Potassium nitrate (KNO₃) (0.7218g of dry KNO₃ was dissolved in distilled water and diluted to 1L).
- (b) Intermediate nitrate solution: (Distilled water and 100ml of stock nitrate solution was diluted to 1000ml).
- (c) Hydrochloric acid solution (1N).

3.2.2.4.2 Procedure

- (a) In 50ml of sample, 1ml of HCl solution was added.

- (b) Calibration standards of NO_3^- were prepared by diluting 50ml of intermediate nitrate solution, in the range of 0 to 7mg/L NO_3^- -N.
- (c) NO_3 reading was recorded from a spectrophotometer using a wavelength of 220nm after absorbance was set at zero. A wavelength of 275nm was used to determine interference.

3.2.2.4.3 Calculation

To obtain absorbance due to NO_3 , twice the absorbance reading at 275nm was subtracted from the reading at 220nm. The sample concentrations were obtained from the standard curve when absorbance due to NO_3 was plotted against NO_3 -N concentration.

3.2.2.5 Sulphate:

Sulphate is mainly dissolved from most sedimentary rocks. It occurs in water largely in oxidized form, it may also be present as sulphides. The turbidimetric method was employed to estimate sulphate in a water sample where sulphate absorbance was measured by spectrophotometer.

3.2.2.5.1 Reagents

- (a) Conditioning reagent (300ml of distilled water was mixed with 30ml HCl, 100ml 95% ethyl alcohol, 75g sodium chloride, and 50ml of glycerol).
- (b) Barium chloride crystals (BaCl_2).
- (c) Standard sulphate solution (147.9mg of sodium sulphate was dissolved and diluted with distilled water to make 1L volume).

3.2.2.5.2 Procedure

- (a) 100ml of sample and 5.0ml of the conditioning reagent were mixed.
- (b) A spoonful of Barium chloride crystals (BaCl_2) was added and stirred at a constant speed for exactly one minute.
- (c) Then, the solution was readily poured into the absorbance cell of the spectrophotometer at 420nm.
- (d) The turbidity reading was taken every 30 seconds for 4 minutes.
- (e) The highest turbidity reading taken within 4 minutes was the main reading.

- (f) A standard sulphate calibration curve was prepared and sulphate concentration was obtained by comparing the turbidity reading with a standard curve.

3.2.2.5.3 Calculation

$$\text{Sulphate (SO}_4^{2-}\text{) mg/l} = \frac{\text{mg SO}_4 \times 1000}{\text{ml sample}}$$

3.2.2.6 Fluoride:

Most fluorides were generally low in solubility and amounts of fluorides present in waters were limited and in low concentration. Fluoride in groundwater comes from fluorite minerals while apatite and mica also contributed to the formation of fluoride. Analysis of fluoride concentrations in water samples was done by UV/VIS spectrophotometer using Spectroquant Pharo 300 model.

3.2.2.6.1 Principle

The constituent of an analysed sample is transformed to a colourful compound using reagents which improves detecting sensitivity. Some cell tests already included all essential reagents. The colour intensity of a solution is proportional to the concentration of the corresponding analyte in a certain range and this effective range has already been recorded for all test kits in the photometers.

3.2.2.6.2 Procedure

- (a) The pH was adjusted in the range of 3-8 and the **F sens** method was selected.
- (b) 10ml of the sample was pipetted out in a reaction cell and mixed.
- (c) A blank solution was prepared by mixing 10ml of distilled water in a second reaction cell.
- (d) 1 level blue micro spoon of reagent (F-1K) was added to both the cells.
- (e) The cells were stirred till the reagent dissolved and leave for 15 minutes (reaction time).
- (f) The two solutions were poured into separate 50mm cells and the reading in the photometer was determined.

3.2.2.7 Metals and Heavy Metals

Elemental analysis of the water samples was performed on Agilent 4100 MPAES (Microwave Plasma Atomic Emission Spectrometry) at Central

Instrumentation Laboratory (CIL), Mizoram University. The elemental analysis involves a determination of metals and heavy metals like Iron (Fe), Zinc (Zn), Cadmium (Cd), Magnesium (Mg), Copper (Cu), Nickel (Ni), Lead (Pb), Sodium (Na), Calcium (Ca), Potassium (K), Manganese (Mn), Chromium (Cr), Cobalt (Co), and Arsenic (As).

3.2.2.7.1 Microwave Plasma Atomic Emission Spectrometry (MPAES)

MPAES is an analytical technique used for simultaneous determination of multiple elements, which provides fast analysis and high sensitivity with low detection limits than the conventional flame atomic absorption spectrometers (FAA). The basic working principle in MPAES is that when external energy is applied to certain elements, its atom gets excited and emits a wavelengths pattern of radiation forming an emission spectrum. The microwave-induced plasma is the source of atomic emission in MPAES; hence, a careful operation is highly recommended.

3.2.3 Bacteriological Parameters

The bacteriological quality of water is as significant as its physical and chemical quality which can be determined by analysis of coliform bacteria. The disease-causing organisms, also known as pathogens, mostly come from human or animal faeces, industrial wastes, and municipal wastes into the water. It is difficult to detect each pathogenic organism in water. But, easily identified and less harmful bacteria, called indicator organisms, were indirectly used to detect pathogens. Normally, these non-pathogenic organisms were not found in freshwater and the presence of them in water indicates possible faecal contamination. In the present study, bacteriological assessment of water samples is done by testing the presence of coliform bacteria. The result is express in terms of the Most Probable Number (MPN).

3.2.3.1 Total Coliform:

Coliform bacteria were called indicator organisms. The coliform group bacteria consist of rod-shaped, non-spore-forming aerobic bacteria. The presence of the coliform group renders water unfits for human consumption. Though coliform bacteria themselves were non-pathogenic, their presence in water may indicate the

presence of other harmful pathogenic bacteria. In a coliform test, the coliform bacteria are reported in terms of the number of coliform bacteria in a given quantity of water.

3.2.3.1.1 Procedure

Multiple tube fermentation technique was employed in coliform test and the results were reported as a most probable number (MPN) index. The MPN index is computed by comparing the number of positive to statistical tables (Table 3). The value is expressed as MPN per 100ml of sample.

3.2.3.1.2 Presumptive Test:

- (a) This test was performed to detect the presence of coliform in the water sample. A lactose broth medium was used for the estimation of coliforms.
- (b) Lactose broth media of single and double strength was prepared to have an inverted Durham tube.
- (c) Three sets of test tubes with three tubes in each set were prepared. One set of test tubes contained 10ml of double strength and the other two have 10ml of single strength media.
- (d) 10ml of water was transferred to each of the DS broth tubes by sterilized pipettes. Again, 1ml and 0.1ml of water sample to the remaining two sets of SS broth respectively.
- (e) The test tubes were incubated at 37°C for 24 hours and the gas productions in Durham's tube has been observed.
- (f) The number of positive tubes from each set was counted and compared with a statistical chart to find coliform count per 100ml water sample.

3.2.3.1.3 Confirmed Test:

- (a) Confirm test was done to confirm the presence of coliforms from the positive tube by inoculating EMB (eosin methylene blue) agar plate in duplicate.
- (b) The plates were incubated at 37°C and 44.5°C respectively for 24 hours.
- (c) Colonies formed by coliform in the media were observed.

Table 3.1: MPN determination table from multiple tube tests

No. of Positive tubes out of			MPN per 100ml	No. of Positive tubes out of			MPN per 100ml
10ml	1.0ml	0.1ml		10ml	1.0ml	0.1ml	
Tube	Tube	Tube		Tube	Tube	Tube	
0	0	0	-	2	0	0	9.1
0	0	1	3	2	0	1	14
0	0	2	6	2	0	2	20
0	0	3	9	2	0	3	26
0	1	0	3	2	1	0	15
0	1	1	(6.1)7	2	1	1	20
0	1	2	(9.2)10	2	1	2	27
0	1	3	12	2	1	3	34
0	2	0	(6.2)7	2	2	0	21
0	2	1	(9.3)10	2	2	1	28
0	2	2	12	2	2	2	35
0	2	3	16	2	2	3	42
0	3	0	9.4	2	3	0	29
0	3	1	13	2	3	1	36
0	3	2	16	2	3	2	44
0	3	3	19	2	3	3	53
1	0	0	3.6	3	0	0	23
1	0	1	7.2	3	0	1	39
1	0	2	11	3	0	2	64
1	0	3	15	3	0	3	95
1	1	0	7.3	3	1	0	43
1	1	1	11	3	1	1	75
1	1	2	15	3	1	2	120
1	1	3	19	3	1	3	160
1	2	0	11	3	2	0	93
1	2	1	15	3	2	1	150
1	2	2	20	3	2	2	210
1	2	3	24	3	2	3	290
1	3	0	16	3	3	0	240
1	3	1	20	3	3	1	460
1	3	2	24	3	3	2	1100
1	3	3	29	3	3	3	2400

3.2.4 Correlation coefficient

The studies of the interrelationship of different variables are useful tools in research analysis. Correlation is a statistical method used to measure and assess the strength of a linear relationship between two variables. Since there were various types of correlation coefficients, the right choice of selecting the correlation coefficient type relies on the sorts of variables being examined. The study of correlation is very simple that may minimize the level of uncertainty and easy to calculate and interpret the relationship between data. Correlation analysis mostly exercises to pairs of variables and usually they are present in a table known as a correlation matrix.

Pearson's correlation is one of the most commonly used correlation coefficients in linear regression which is only suitable for quantitative variables. It is denoted by r , the value of which signifies the relationship of variables. It is expressed as the following equation:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

where x and y indicate two different parameters; n represents a total number of observations.

When $r = 1$, it means that a strong positive correlation between variables and the value $r = -1$ indicates a strong negative correlation. When $r = 0$, there is no correlation between variables. In other words, a value greater than 0 is an indication of a positive correlation (when one variable value increases, the other variable value also increases), and a value less than 0 is an indication of a negative correlation (when one variable increases, the other variable value decreases). Pearson's correlation coefficient computations have been intended to not impact the calculation by measurement units of the variables used.

3.2.5 Gibb's Diagram

Gibb's diagram has been used to describe the mechanisms that controlled the chemistry of water. According to Gibbs (1970), the chemical composition of water is mainly controlled by atmospheric precipitation, evaporation, and rock-water

interaction. In the Gibbs diagram, the association between the chemical composition of water and the aquifer properties was depicted. The diagram consists of three zones such as rainfall dominance, evaporation dominance, and rock dominance. The water samples were plotted against the ratios of $\text{Na}^+(\text{Na}^+ + \text{Ca}^{2+})$ versus TDS and of $\text{Cl}^-(\text{Cl}^- + \text{HCO}_3^-)$ versus TDS to elucidate the source of chemical constituents of water. When the samples fall within the rock dominance zone, it means that the chemical weathering process in subsurface rock was responsible for the quality of that water sample. Likewise, the water samples fall in the rainfall dominance and evaporation dominance zone was an indication of precipitation and evaporation as the main governing factor of water quality respectively. In some cases, the samples may fall outside the plot may indicate other processes such as anthropogenic activities which controlled the water quality.

3.2.6 Piper's Trilinear Diagram

The piper diagram is a useful analytical tool for extracting the sources of chemical constituents dissolved in water. The Piper plot makes it possible to easily compare the water sample chemistry, detect water samples exhibiting similar chemical properties, and establish the hydro-geochemical facies. It consists of two lower triangular fields and a central diamond-shaped field. The proportion of cations as a percentage of their epm (equivalents per million) and anions as the percentage of their epm, are plotted as a single point in the lower left and the right triangles respectively. These are projected upward parallel to the sides of the triangles to give on the diamond-shaped field to show the total ion concentrations. The concentrations of three cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+) + potassium (K^+) and concentration of three anions such as chloride (Cl^-), sulphate (SO_4^{2-}), and carbonate (CO_3^{2-}) + bicarbonate (HCO_3^-) was used. Based on the cation and anion dominance and locations of each sample on the diagrams, the water was classified and its hydrochemical facies was evaluated. The lithological aspects of the aquifer, residence time, and movement of water significantly influence the classification of water. Piper diagram can also reveal the extent to which fresh and saltwater were mingled.

3.2.7 Water Quality Index (WQI)

The water quality index is a convenient tool to determine the water quality and represent it in a simple unitless value to easily communicate by the public. It integrates all the parameters while comparing with the standards recommended by the authorities to safeguard human health. It also provides a common framework for comparing a wide range of complex measured data with prescribed standard limits. The water quality index summarizes and simplifies all the raw analytical data by merging them into a single value. The overall water quality index value obtained for each sampling site is the influence of all the parameters incorporated in the study. There are various categories of WQI such as public indices, specific consumption indices, planning indices, and statistical indices. Different methods of water quality index have been proposed by several organizations viz. Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI), Nemerow Pollution Index (NPI), etc. There is no universally accepted index and all these indices have merits and demerits. In the present study, the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) was used to infer the water quality of the study area, because it is best suited for more than one season sampling, otherwise the number of failed variables will be inconsistent.

3.2.7.1 Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI):

The CCME WQI is developed by the Canadian Council of Ministers of the Environment (CCME) and it is one of the most essential approaches to describe a wide range of variables into a single data point incorporating multiple measures.

3.2.7.1.1 Calculation of CCME WQI method

Calculation in CCME WQI method is done using the following equation:

$$WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

where F_1 – Scope (percentage of variables that do not meet their objectives)
 F_2 – Frequency (percentage of individual tests that do not meet objectives)
 F_3 – Amplitude (amount by which failed test values do not meet their objectives)

3.2.7.1.2 Calculation of Scope (F_1)

Scope represents the percentage of parameters, whose guidelines are not met. It can be calculated as:

$$F_1 = \frac{\text{Number of Failed Variables}}{\text{Total Number of Variables}} \times 100$$

3.2.7.1.3 Calculation of Frequency (F_2)

Frequency indicates the percentage of individual tests which do not meet guidelines (i.e., “failed tests”). It is calculated as:

$$F_2 = \frac{\text{Number of Failed Tests}}{\text{Total Number of Tests}} \times 100$$

3.2.7.1.4 Calculation of Amplitude (F_3)

Amplitude indicates the amount by which failed test values do not meet their guidelines, and is calculated in three steps.

Step 1: Calculation of excursion

The number of times an individual concentration exceeds a guideline is termed an excursion. It is calculated as when:

the test value must exceed the guideline as

$$excursion_i = \left(\frac{\text{Failed Test Value}_i}{\text{Guidelines}_j} \right) - 1$$

the test value must not fall below the guideline:

$$excursion_i = \left(\frac{\text{Guidelines}_j}{\text{Failed Test Value}_i} \right) - 1$$

Step 2: Calculation of the normalized sum of excursions, or nse

The collective amount by which individual tests are out of compliance with guidelines is calculated by summing the excursions of individual tests and dividing by the total number of tests that failed guidelines.

$$nse = \left(\frac{\sum excursion_i}{Number\ of\ Tests} \right)$$

Step 3: Calculation of Amplitude (F₃)

F₃ is then calculated after calculating *nse* to yield a value between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01nse + 0.01} \right)$$

The WQI was then calculated from the F₁, F₂, and F₃ values, and the score obtained was categorized base on the following classification table:

Table 3.2: CCME WQI categorization

WQI Value	Rating
95-100	Excellent water quality
80-94	Good water quality
60-79	Fair water quality
45-59	Marginal water quality
0-44	Poor water quality

CHAPTER 4: RESULTS

The results of the physico-chemical and bacteriological analysis of the water samples from Pre-monsoon 2016 to Post-monsoon 2018 are presented in the table 4-A to 4-I and 4.1. The results obtained are compare with the standard limits prescribed by WHO (2017) and BIS (2012) to understand its suitability for drinking purposes. The results of the analysed water samples are described in order of their physical, chemical, and bacteriological characteristics for all the seasons during which the samples were collected. Besides, the results of Water Quality Index (Table 4.2-A to 4.2-C), Correlation co-efficient (Table 4.3-A to 4.3-C), Gibb's diagram (Fig. 3-A to 3-C) and Piper's diagram (Fig. 4-A to 4-D) are also present in this chapter.

4.1 PHYSICAL PARAMETERS

The results of the analysis of various physical parameters are described below:

4.1.1 pH:

The pH values of water samples have not shown a significant variation during the whole assessment period. In the pre-monsoon season of 2016, the obtained pH value ranges from a minimum of 7.5 to a maximum of 8.2. The mean value of pH during this season is 8.1 (Table 4-A). In the monsoon period of the same year, the minimum value is slightly lower to 6.5, while the maximum value is 8.2 with a mean value of 7.4 (Table 4-B). The post-monsoon water samples show the highest mean value of 7.9 within this year. The minimum and maximum values are 7 and 8.2 respectively (Table 4-C). In the year 2017, the pH value of pre-monsoon varies from 7.4 to 8.2 with an average value of 7.9 (Table 4-D). The minimum value of monsoon samples is lower, as in the previous year, to 5.2 with a maximum value of 8.2. The mean value during this season is 7.4 (Table 4-E). The post-monsoon sample shows the value ranges from a minimum of 6.6 and a maximum of 8.2 with a mean value of 7.6 (Table 4-F). Similar to the previous years, there are no considerable changes in the pH value recorded from each season in 2018. During the pre-monsoon season, the lowest value recorded is 7.6, whereas the highest value is 8.2. The mean value obtained from all the samples is 8.0 (Table 4-G). The minimum and maximum values of monsoon

samples are 6.0 and 8.1 respectively with an average value of 6.9 (Table 4-H). In the post-monsoon period, a minimum value of 7.0 and a maximum value of 8.2 are recorded, while the mean value of the sample is 7.8 (Table 4-I).

The results of pH values obtained in each season within the assessment period show that the pH values in the monsoon season slightly decline to compare the values of other seasons. On the other hand, the pre-monsoon and post-monsoon values are more or less similar every year.

4.1.2 Turbidity:

The turbidity values of the pre-monsoon season in 2016 range from 0.1 NTU to 1.3 NTU (Table 4-A), while, the values obtained during the monsoon season vary from 0.1 NTU to 2.6 NTU (Table 4-B). During the post-monsoon season, the values ranged from 0.1 NTU to 1.1 NTU (Table 4-C). In 2017, the water samples of the pre-monsoon period have values between 0.1 and 1 NTU (Table 4-D). The monsoon period values ranged from 0.1 NTU to 1 NTU (Table 4-E) and the post-monsoon period in the same year recorded 0.1 NTU to 1 NTU turbidity value (Table 4-F). In the pre-monsoon period of 2018, the turbidity is found to vary from 0.1 NTU to 0.9 NTU (Table 4-G), while, the turbidity values range from 0.2 NTU to 1.5 NTU for monsoon (Table 4-H) and 0.3 NTU to 0.9 NTU for the post-monsoon period (Table 4-I). In general, an appreciable increase in turbidity value is noticed during the monsoon period of each year.

4.1.3 Electrical Conductivity (EC):

Remarkable changes in electrical conductivity values of water samples are observed in every season of each year. In the pre-monsoon season of 2016, the maximum and minimum EC values obtained are 2100 $\mu\text{S}/\text{cm}$ and 60 $\mu\text{S}/\text{cm}$ respectively. The mean value in this period was 206 $\mu\text{S}/\text{cm}$ (Table 4-A). The monsoon period recorded the maximum value of 1150 $\mu\text{S}/\text{cm}$ and minimum value of 46 $\mu\text{S}/\text{cm}$ with a mean value of 131 $\mu\text{S}/\text{cm}$ (Table 4-B). During the post-monsoon period, the EC value fluctuates from 43 $\mu\text{S}/\text{cm}$ to 2650 $\mu\text{S}/\text{cm}$ and the mean value being 217 $\mu\text{S}/\text{cm}$ (Table 4-C). In 2017, the EC values ranges between 59 $\mu\text{S}/\text{cm}$ and 2160 $\mu\text{S}/\text{cm}$ with a mean value of 205 $\mu\text{S}/\text{cm}$ during pre-monsoon (Table 4-D), 25 $\mu\text{S}/\text{cm}$ and 1417 $\mu\text{S}/\text{cm}$

with a mean value of 141 $\mu\text{S}/\text{cm}$ during the monsoon period (Table 4-E), and 50 $\mu\text{S}/\text{cm}$ and 2800 $\mu\text{S}/\text{cm}$ during the post-monsoon period with a mean value of 223 $\mu\text{S}/\text{cm}$ (Table 4-F). The pre-monsoon period of 2018 recorded EC varies from 62 $\mu\text{S}/\text{cm}$ to 1940 $\mu\text{S}/\text{cm}$ with a mean value of 204 $\mu\text{S}/\text{cm}$ (Table 4-G), while during monsoon season the value ranges from 31 $\mu\text{S}/\text{cm}$ to 1400 $\mu\text{S}/\text{cm}$ with a mean value of 137 $\mu\text{S}/\text{cm}$ (Table 4-H). The EC value of post-monsoon is found between 54 $\mu\text{S}/\text{cm}$ and 2500 $\mu\text{S}/\text{cm}$ and the mean value obtained is 219 $\mu\text{S}/\text{cm}$ (Table 4-I).

The EC value of water samples is found to fluctuate extensively. The result shows that the highest EC value is distinctly observed in D-1 and a little higher value is also recorded in hand pump water every season. It is observed that the values of EC are slightly decreasing during monsoon than the other season every year.

4.1.4 Total Dissolve Solids (TDS):

TDS value of water samples also shows a considerable variation seasonally. The pre-monsoon period of 2016 has a minimum and a maximum value of 30 mg/l and 1220 mg/l respectively. The mean value in this season is 107 mg/l (Table 4-A). During the monsoon period, the minimum value is 30 mg/l and the maximum value was 930 mg/l while the mean value of all the water samples is 81 mg/l (Table 4-B). The value of post-monsoon samples varies from 25 mg/l to 1620 mg/l with a mean value of 118 mg/l (Table 4-C). In 2017, pre-monsoon samples recorded a value ranging between 27 mg/l and 1250 mg/l, and the mean value is 10 mg/l (Table 4-D). The monsoon sample fluctuates from 15 mg/l to 900 mg/l with a mean value of 79 mg/l (Table 4-E). Post-monsoon attained a minimum value of 25 mg/l, a maximum value of 1700 mg/l, and a mean value is 121 mg/l in that season (Table 4-F). The TDS values acquired in 2018 also keep a similar pattern as in the previous years. The pre-monsoon value ranges from 31 mg/l to 1300 mg/l and the mean value was 111 mg/l (Table 4-G). Monsoon value varies between a minimum of 15 mg/l and a maximum of 950 mg/l with a mean value of 76 mg/l (Table 4-H). Post-monsoon samples showed the values ranged from 28 mg/l to 1675 mg/l and the mean value obtained is 124 mg/l (Table 4-I).

From the analysis of TDS and comparing the result obtained in each year, it is obvious that the TDS values are normally decreased during the monsoon period. Higher TDS values are found in D-1 samples every season. Hand pump water samples (K-2, P-6 & P-10) also exhibited the TDS values somewhat more than the rest of the water samples.

4.2 CHEMICAL PARAMETERS

The chemical parameters of all the water samples are analysed in the laboratory. The results of those analysed chemical parameters are described below:

4.2.1 Total Alkalinity (TA):

The concentration of total alkalinity ranges between 4 mg/l - 250 mg/l and mean value 26 mg/l during pre-monsoon, 2016 (Table 4-A). The monsoon period in the same year has a mean value of 37 mg/l and value varies from 16 mg/l to 250 mg/l (Table 4-B), while post-monsoon samples were ranging between 16 mg/l and 260 mg/l with a mean value of 40 mg/l (Table 4-C). The values obtained in the pre-monsoon of 2017 range from 15 mg/l to 150 mg/l and the mean value is 46 mg/l (Table 4-D). During the monsoon period, the mean value is 36 mg/l and the minimum and maximum values are 18 mg/l and 230 mg/l respectively (Table 4-E). Post-monsoon samples show a value between 19 mg/l and 265 mg/l and a mean value of 40 mg/l (Table 4-F). In 2018, pre-monsoon samples recorded a minimum value of 47 mg/l, a maximum value of 490 mg/l, and a mean value of 106 mg/l (Table 4-G), while the mean value of monsoon samples is 31 mg/l in the monsoon period with a minimum value of 16 mg/l and maximum value of 190 mg/l (Table 4-H). The post-monsoon value changes from 20 mg/l to 500 mg/l and the mean value obtained is 50 mg/l (Table 4-I).

The concentration of total alkalinity in all the samples shows a significant variation in which the D-1 sample has the highest value in all seasons within the assessment periods. Higher values of total alkalinity are also found in the handpump sample. Since the pH values of water in all seasons are between 6.5 and 8.2, bicarbonate and alkalinity have the same value in the present study.

4.2.2 Total Hardness (TH):

Determination of total hardness during pre-monsoon of 2016 showed the values ranging between 20 mg/l and 940 mg/l with a mean value of 111 mg/l (Table 4-A). Monsoon sample values ranged from 28 mg/l to 500 mg/l and the mean value is 85 mg/l (Table 4-B). Post-monsoon recorded a minimum value of 44 mg/l, a maximum value of 460 mg/l, and a mean value of 108 mg/l (Table 4-C). The concentrations of TH during pre-monsoon of 2017 are between a minimum of 21 mg/l and a maximum of 230 mg/l, while the mean value is 93 mg/l (Table 4-D). The minimum and maximum values during monsoon are 30 mg/l and 420 mg/l respectively, with a mean value of 78 mg/l (Table 4-E). The post-monsoon value varies between 43 mg/l and 468 mg/l with a mean value of 108 mg/l (Table 4-F). In 2018, pre-monsoon samples have a value ranging from 47 mg/l to 490 mg/l and the mean value is 106 mg/l (Table 4-G). Monsoon values ranged between 40 mg/l and 450 mg/l with a mean value of 77 mg/l (Table 4-H). Post-monsoon samples show the value varies from 45 mg/l to 490 mg/l and the mean value is 113 mg/l (Table 4-I). The values of total hardness observed in all seasons do not fluctuate significantly during the study period.

4.2.3 Chloride (Cl):

The content of total chloride in the pre-monsoon season of 2016 has a mean value of 55 mg/l where the highest value is 940 mg/l and the lowest being only 5 mg/l (Table 4-A). During monsoon season, it showed the values varying between 5 mg/l and 400 mg/l. The mean value derived is 31 mg/l (Table 4-B). While the post-monsoon values significantly varied from 10 mg/l to 1500 mg/l with the mean value of 109 mg/l (Table 4-C). In 2017, fluctuation of Cl values is also recorded ranging from 8 mg/l to 1023 mg/l and the mean value of 57 mg/l during pre-monsoon season (Table 4-D). A monsoon value varies between 5 mg/l and 380 mg/l, and a mean value of 28 mg/l is obtained (Table 4-E). The post-monsoon values also fluctuated from 10 mg/l to 1550 mg/l acquiring a mean value of 72 mg/l (Table 4-F). The pre-monsoon of 2018 presented the content of Cl ranging from 11.5 mg/l to 1200 mg/l and the mean value is 64 mg/l (Table 4-G), whereas the value varies from 8 mg/l to 1050 mg/l with a mean value of 50 mg/l in the monsoon period (Table 4-H). In the post-monsoon period, the value is found between 14 mg/l and 1600 mg/l, the mean value found is 77 mg/l (Table

4-I). A considerable high content of Cl is noticed from D-1 samples every season, while the rest of the samples showed a similar pattern of variations.

4.2.4 Nitrate (NO₃):

Nitrate concentrations found in the water samples are very less varying between 0.27 mg/l and 0.83 mg/l in pre-monsoon 2016. The mean value in that season is 0.43 mg/l (Table 4-A). In the monsoon season, it ranges from 0.19 mg/l to 0.75 mg/l, and the mean value is found to be 0.35 mg/l (Table 4-B). During post-monsoon, the minimum value recorded is 0.28 mg/l, while the maximum value is 0.82 mg/l with a mean value of 0.44 mg/l (Table 4-C). The values varying between 0.28 mg/l and 0.82 mg/l with a mean value of 0.44 mg/l are obtained in the pre-monsoon of 2017 (Table 4-D) and in the monsoon period of the same year, the concentrations of nitrate are ranging from 0.20 mg/l to 0.76 mg/l and mean value is 0.36 mg/l (Table 4-E). In the post-monsoon period, the values attained are between a minimum of 0.29 mg/l and 0.81 mg/l with the mean value of 0.45 mg/l (Table 4-F). In the pre-monsoon of 2018, the concentrations of nitrate are confined between 0.27 mg/l and 0.82 mg/l with a mean value of 0.44 mg/l (Table 4-G), whereas the values of the monsoon sample vary from 0.18 mg/l to 0.75 mg/l and the mean value is 0.36 mg/l (Table 4-H). The post-monsoon sample shows the content of nitrate ranging from 0.29 mg/l to 0.85 mg/l and a mean value of 0.45 mg/l (Table 4-I). In all seasons, the water samples are generally low in nitrate concentration.

4.2.5 Sulphate (SO₄):

The observed values of sulphate are comparatively low in all seasons. In 2016, the sulphate value of the pre-monsoon season ranges from 1.23 mg/l to 325 mg/l and the mean value attained is 13.95 mg/l (Table 4-A). Monsoon season has a value that fluctuates from 0.46 mg/l to 300 mg/l and a mean value of 12.2 mg/l (Table 4-B). Post-monsoon recorded values vary between 1.25 mg/l and 328 mg/l, while the mean value is 14.08 mg/l (Table 4-C). Pre-monsoon of 2017 has a fluctuation of sulphate values between 1.09 mg/l and 298 mg/l with a mean value of 12.94 mg/l (Table 4-D). The mean value derived from the monsoon period is 0.36 mg/l where the minimum and maximum values are 0.46 mg/l and 290 mg/l (Table 4-E). During the post-monsoon period, the value ranges from a minimum of 1.13 mg/l to a maximum of 300 mg/l with

a mean value of 13.01 mg/l (Table 4-F). In the pre-monsoon of 2018, its concentrations differ from a minimum value of 1.34 mg/l to 320 mg/l. The mean value during that period is 13.8 mg/l (Table 4-G). The monsoon values also fluctuated between 0.45 mg/l and 310 mg/l with a mean value of 12.55 mg/l (Table 4-H). Post-monsoon has recorded sulphate content varies from 1.32 mg/l to 322 mg/l and the value of mean is 13.9 mg/l (Table 4-I).

4.2.6 Fluoride (F):

Fluoride concentrations are found to be low in the water samples. In 2016, its value changes from a minimum of 0.21 mg/l to a maximum of 0.45 mg/l, and the mean value derived is 0.33 mg/l (Table 4-A). In the monsoon period, the value decrease to a minimum of 0.16 mg/l and stretch out to a maximum of 0.39 mg/l with a mean value of 0.27 mg/l (Table 4-B). The post-monsoon result reads the value between 0.25 mg/l and 0.5 mg/l with mean value of 0.39 mg/l (Table 4-C). Pre-monsoon values of 2017 indicates the difference between 0.24 mg/l and 0.45 mg/l, and the mean value is 0.34 mg/l (Table 4-D). Monsoon samples have the concentration of fluoride varying between 0.17 mg/l and 0.38 mg/l, mean value in that season is 0.27 mg/l (Table 4-E). During post-monsoon season, its values vary from 0.23 mg/l to 0.45 mg/l with a mean value of 0.36 mg/l (Table 4-F). Fluctuations of fluoride value are ranged from 0.25 mg/l to 0.46 mg/l in the pre-monsoon season of 2018 having a mean value of 0.35 mg/l (Table 4-G). While its values encompassed from 0.17 mg/l to 0.38 mg/l with a mean value of 0.28 mg/l in monsoon season (Table 4-H). Post-monsoon season record variation of the values between 0.25 mg/l and 0.47 mg/l and mean value obtained is 0.36 mg/l (Table 4-I).

4.2.7 Iron (Fe):

Iron concentrations in water are found to be higher, mostly in hand pump samples, while the rest of the samples had a relatively low value. The pre-monsoon period of 2016 shows the iron concentration ranging from a minimum of 0.02 mg/l to a maximum of 1.4 mg/l. The mean value observed during that season is 0.3 mg/l (Table 4-A). The monsoon period of 2017 had values varying between 0.00 mg/l and 1.03 mg/l, with a mean value of 0.12 mg/l (Table 4-E). Meanwhile, the post-monsoon period of 2018 showed a fluctuation in an iron concentration varying from 0.04 mg/l

to 1.42 mg/l. The mean value obtained from the analysis of water in that period is 0.37 mg/l (Table 4-I). In some water samples, the value of iron is very low. The K-3 sample had a value of less than the detection limit in the pre-monsoon of 2016. Likewise, the C-1 sample during the post-monsoon of 2018 show a value below the detection limit.

4.2.8 Magnesium (Mg):

The magnesium value of the water sample differs from a minimum value of 1.28 mg/l to 16.64 mg/l in the pre-monsoon season of 2016. The mean value derive for that season is 4.81 mg/l. The P-5 sample record the highest level of magnesium and the lowest is detected in D-1 (Table 4-A). In the monsoon season of 2017, the water samples show the values fluctuate from 1.01 mg/l to 9.04 mg/l with a mean value of 1.68 mg/l. The highest value is detected from the P-5 water sample, but the lowest value is shown by P-9 and P-10 (Table 4-E). During the post-monsoon of 2018, the magnesium value varies between 1.35 mg/l to 16.7 mg/l, and the mean value record is 4.97 mg/l. As in the previous year, the P-5 sample show the highest value in all water samples, while the D-1 sample record the lowest value of magnesium (Table 4-I).

4.2.9 Sodium (Na):

In the pre-monsoon season of 2016, the sodium content in water samples range from a minimum value of 5.56 mg/l to a maximum value of 626.677 mg/l and its mean value is 28.27 mg/l (Table 4-A). In the monsoon season of 2017, the concentration varies between 2.98 mg/l and 253.33 mg/l, acquiring a mean value of 13.85 mg/l (Table 4-E). In 2018, the observe values of sodium during the post-monsoon season are relatively high, which range from 4.07 mg/l to 1066 mg/l and the mean value record is 42.65 mg/l (Table 4-I). The sodium concentration is noticeably high in D-1 water samples for the whole assessment period, whereas the lowest content of sodium during the pre-monsoon of 2016 and monsoon of 2017 is determined from the P-1 water sample, and the M-4 sample show the lowest value during the post-monsoon of 2018.

4.2.10 Calcium (Ca):

Calcium concentrations in the pre-monsoon season of 2016 varied from 1.76 mg/l to 36.58 mg/l, and the mean value is found at 7.63 mg/l (Table 4-A). The values

range from a minimum of 0.88 mg/l to a maximum of 26.81 mg/l during the monsoon season in 2017, with a mean value of 3.89 mg/l (Table 4-E). In the post-monsoon season of 2018, the value of calcium fluctuated from a minimum value of 1.25 mg/l to a maximum value of 30.57 mg/l and the mean value is 6.93 mg/l (Table 4-I). Generally, all the hand pump water shows a relatively higher value of calcium than the other samples, with the highest value being observe from the K-2 water sample in all seasons.

4.2.11 Potassium (K):

The concentration of potassium is found to be the highest in the D-1 water samples every year. The determination of potassium in the pre-monsoon period of 2016 show that the values range from 0.79 mg/l to 126 mg/l with a mean value of 5.43 mg/l (Table 4-A). The highest and lowest values are detected on D-1 and P-12 respectively in that season. The monsoon season in 2017 had values ranging between 0.02 mg/l and 97.83 mg/l with a mean value of 3.89 mg/l (Table 4-E). The D-1 sample exhibit the highest level of potassium, while the lowest level is observed in the M-1 water sample. Meanwhile, the post-monsoon season of 2018 record values varying from a minimum of 0.09 mg/l to a maximum of 100.3 mg/l, and the mean value is 4.53 mg/l (Table 4-I). During that period, the highest value is notice in the D-1 sample, whereas the lowest value is detected in the P-7 water sample.

4.2.12 Manganese (Mn):

The manganese concentration in the water is found to be between 0.00 mg/l and 0.1 mg/l in the pre-monsoon season of 2106 with a mean value of 0.01 mg/l (Table 4-A). K-2 record the highest value of manganese for that season. The values in the 2017 monsoon water samples range from 0.00 mg/l to 0.23 mg/l, the highest level being found in the P-6 sample. The mean value observe is 0.01 mg/l (Table 4-E). In the post-monsoon season of 2018, the manganese value ranges from 0.00 mg/l to 0.28 mg/l and the mean value is 0.03 mg/l (Table 4-I). The highest value of manganese is again found in the K-2 water. Several samples show no manganese concentration in any season.

4.2.13 Zinc (Zn):

The concentrations of zinc determined from the samples are low in all seasons. In 2016, it fluctuates from a minimum value of 0.02 mg/l to a maximum value of 0.32 mg/l with a mean value of 0.19 mg/l during the pre-monsoon season (Table 4-A). During the 2017 monsoon season, the value ranges between a minimum of 0.00 mg/l and a maximum of 0.05 mg/l, with a mean value of 0.01 mg/l (Table 4-E). The post-monsoon sample value for 2018 varies from a minimum value of 0.03 mg/l to a maximum value of 0.35 mg/l and the mean value obtained is 0.21 mg/l (Table 4-I). In many of the samples, the concentration of zinc is too low and it is below the detection limit.

4.2.14 Cadmium (Cd):

The concentration of cadmium is found to be below the limit of detection in the water samples during the whole assessment period.

4.2.15 Copper (Cu):

The content of copper is detected in a few samples. In the pre-monsoon of 2016, only seven samples record the presence of copper, with one sample showing a value of 0.05 mg/l and the rest having values of 0.1 mg/l (Table 4-A). In the monsoon of 2017, only one sample shows the presence of copper with a value of 0.01 mg/l (Table 4-E). In the post-monsoon of 2018, copper values are detected only in eight samples in which the value varies from 0.00 mg/l to 0.05 mg/l with a mean value of 0.01 mg/l (Table 4-I).

4.2.16 Nickel (Ni):

The nickel concentration is found to occur constantly at 0.01 mg/l in the samples where the nickel is determined in the 2016 pre-monsoon period (Table 4-A). In the monsoon season of 2017, only one sample (P-6) records the occurrence of nickel, and the value being 0.01 mg/l (Table 4-E). In the post-monsoon of 2018, a value of 0.01 mg/l is observed from the samples where the presence of nickel is detected (Table 4-I).

4.2.17 Lead (Pb):

Lead concentration was found only in the K-1 water sample with a value of 0.01 mg/l during the post-monsoon season of 2016 (Table 4-A), whereas the presence of lead is not determined in other seasons within the study period.

4.2.18 Chromium (Cr):

Chromium was found to occur only in the M-2 water sample with a value of 0.01 mg/l during the pre-monsoon of 2016 (Table 4-A). It is detected in the D-1 and P-1 water during the monsoon season of 2017 with a value of 0.03 mg/l and 0.02 mg/l respectively (Table 4-E). In the post-monsoon of 2018, the only sample which show the presence of chromium is M-2 with a value of 0.01 mg/l (Table 4-I).

4.2.19 Cobalt (Co):

In the pre-monsoon of 2016, the cobalt content in the water fluctuate to a maximum of 0.04 mg/l, which is found only in six samples (Table 4-A). But in the monsoon season of 2017, the same range of cobalt value is shown by seven samples (Table 4-E). The post-monsoon season of 2018 show that its value range to a maximum of 0.44 mg/l (Table 4-I) and its level is below the detection limit in most of the water samples.

4.2.20 Arsenic (As):

The concentration of arsenic in all the water samples is very low below the detection limit.

4.3 BACTERIOLOGICAL PARAMETERS

The bacteriological characteristics of water samples are carried out by the MPN method using the multiple tube fermentation technique.

4.3.1 Most Probable Number (MPN):

The result of MPN determine from different water samples is present in table 4.1. In the pre-monsoon period of 2016, MPN is found to be varies from 4 to 15/100 ml, where 10 samples (C-2, K-1, M-1, M-2, M-3, M-5, M-6, P-2, P-8, and P-9) out of 30 have the values above the permissible limit. It has been observed that only these water samples show the presence of coliform during the entire period of study. The same water samples are again found to have the MPN values ranging from 7 to 23/100

ml and 7 to 16/100 ml in the monsoon and post-monsoon period of the same year respectively. The pre-monsoon period of 2107 shows the MPN ranging between 4/100 ml and 15/100 ml, while the monsoon and post-monsoon seasons in the same year have MPN ranged from 7/100 ml to 29/100 ml and 6/100 ml to 21/100 ml respectively. In 2018, MPN varies from a minimum of 3/100 ml to 16/100 ml during the pre-monsoon season. Monsoon season samples exhibit variation of MPN from 6/100 ml to 28/100 ml and the post-monsoon season shows a variation of MPN from 4/100 ml to 21/100 ml.

4.4 WATER QUALITY INDEX (WQI)

The CCME WQI values of the study area have been summarized in tables 4.2-A, 4.2-B, and 4.2-C. The calculation is carried out based on 13 parameters involving the total tests of 39. The water quality index during 2016 (Table 4.2-A) show that the water quality is categorized into fair, good, and excellent. From all the 30 analysed water samples, 87% (26 samples) of the total samples are excellent and 10% (3 samples) of the total samples are good quality, while one sample is categorized as fair quality. According to the CCME WQI table, the D-1 sample is categorized as fair quality having a WQI value of 79.9 with 4 failed tests. The F_1 , F_2 , and F_3 values are 15.4, 10.3, and 29.5 respectively. The K-2 sample is found to be having a WQI value of 89.5 and is rated under good quality. It also exhibits F_1 , F_2 , and F_3 values as 15.4, 5.1, and 8.1 respectively with 2 failed tests. The P-6 and P-10 showed F_1 , F_2 , and F_3 values as 15.4, 5.1, 8 and 7.7, 2.6, 8.6 respectively. The WQI value of P-6 is 89.6 and P-10 is 93.2. The number of failed tests incorporate with these samples are 2 and 1 respectively.

The WQI value of 2017 (Table 4.2-B) shows a similar trend of water quality as the previous year in that the majority of the samples (90%) are excellent. The D-1 is categorized as fair quality with the WQI value of 79.1. The F_1 , F_2 , and F_3 values are 15.4, 12.8, and 30.1 respectively with 5 failed tests. The WQI value of P-6 is observed as 89.9 having the F_1 value of 15.4, F_2 of 5.1, and F_3 of 6.4. Accordingly, it has been categorized under good quality having 2 failed tests. The P-10 sample exhibit a WQI value of 94.4 and 1 failed test which comes under the good category. It also has the corresponding value of F_1 , F_2 , and F_3 as 7.7, 2.6, and 5.9 respectively.

In the case of WQI value in 2018 (Table 4.2-C), the water samples range from fair to excellent quality. Around 77% of the total samples are excellent in quality, while one sample is fair and another six samples are categorized under good quality. The D-1 sample is again found under the fair category with the WQI value of 78.2 and 6 failed tests. It also shows an F_1 value of 15.4, F_2 of 15.4, and F_3 of 30.9. The K-2, K-3, M-6, P-1, P-6, and P-10 samples are of good quality. The P-6 sample show the lowest WQI value among the samples under good quality. The WQI value of P-6 is 89.3 with the F_1 , F_2 , and F_3 values of 15.4, 5.1, and 8.9 respectively.

4.5 CORRELATION COEFFICIENT

The correlations between different parameters are worked out using Pearson's correlation. In the pre-monsoon season of 2016, pH is negatively correlated with most of the parameters (Table 4.3-A). A strong positive correlation of EC is found with TDS (0.9996), TA (0.9582), Cl (0.9711), SO_4 (0.9871), HCO_3 (0.9582), Na (0.9864), and K (0.9859). TDS is positively correlated with TA (0.9611), Cl (0.9753), SO_4 (0.991), HCO_3 (0.9611), Cu (0.9012), Na (0.9904), and K (0.99). A positive correlation between TA and Cl (0.9414), TA and SO_4 (0.959), TA and HCO_3 (1), TA and Na (0.9576), TA and K (0.961) is also observed. Other parameters which show a positive correlation are Cl and NO_3 (0.9884), Cl and HCO_3 (0.9414), Cl and Cu (0.9159), Cl and Na (0.9884), Cl and K (0.9879), SO_4 and HCO_3 (0.959), SO_4 and Cu (0.9051), SO_4 and K (0.9997), HCO_3 and Na (0.9576), HCO_3 and K (0.961), Cu and Na (0.9058), Cu and K (0.9068), Na and K (0.9998). Meanwhile, some parameters such as turbidity, NO_3 , F, Fe, Zn, Mg, Pb, Co, Ni, Mn, and Cr have a low correlation with other parameters.

A similar type of correlations is also found in the monsoon period of 2017 (Table 4.3-B). EC and TDS (0.9975), EC and TA (0.9792), EC and TH (0.9757), EC and Cl (0.9553), EC and SO_4 (0.959), EC and HCO_3 (0.9792), EC and Na (0.9584), and EC and K (0.9586) all had high positive correlation values. TDS has a strong positive correlation with TA (0.9847), TH (0.972), Cl (0.9717), SO_4 (0.9757), HCO_3 (0.9847), K (0.9751). TA is also positively correlated with TH (0.9569), Cl (0.9608), SO_4 (0.9682), HCO_3 (1), Na (0.9657), and K (0.9679). Besides, highly positive correlation values are determined between TH and Cl (0.9205), TH and SO_4 (0.9238),

TH and HCO₃ (0.9569), TH and Na (0.9219), TH and K (0.9239), Cl and SO₄ (0.9954), Cl and HCO₃ (0.9608), Cl and Na (0.9942), Cl and K (0.9955), SO₄ and HCO₃ (0.9682), SO₄ and Na (0.9995), SO₄ and K (0.9992), HCO₃ and Na (0.9657), HCO₃ and K (0.9679), Na and K (0.9984). A high negative correlation is not observed during this season.

In the post-monsoon season of 2018 (Table 4.3-C), EC again show a positive correlation with TDS (0.9979), TA (0.9891), TH (0.9533), Cl (0.9704), SO₄ (0.9705), HCO₃ (0.9891), Na (0.9687) and K (0.9744). TDS has a positive correlation with TA (0.9954), TH (0.9398), Cl (0.9837), SO₄ (0.9838), HCO₃ (0.9954), Na (0.9825) and K (0.9866). TA correlate positively with TH (0.9187), Cl (0.9898), SO₄ (0.9904), HCO₃ (1), Na (0.9892) and K (0.9936). CL is positively correlated with SO₄ (0.9996), HCO₃ (0.9898), Na (0.9998) and K (0.9985). A positive correlation is also found between SO₄ and HCO₃ (0.9904), TH and HCO₃ (0.9187), SO₄ and Na (0.9998), SO₄ and K (0.9984), HCO₃ and Na (0.9892), HCO₃ and K (0.9936), Na and K (0.9982).

4.6 GIBB'S DIAGRAM

The relationship between the composition of water and the characteristics of aquifer lithology has been established using the Gibbs diagram by identifying the dominant source of dissolved ions present in water. Precipitation dominance, evaporation dominance, and rock–water interaction dominance zones are shown in Gibb's diagram and it is obtained by plotting TDS against $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$ and $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$. In the pre-monsoon of 2016, the majority of the samples fall in the rock-water interaction field and a few of them fell in the precipitation dominance field (Fig. 3-A). However, all the samples fall within the zone of rock-water interaction in the monsoon period of 2017 (Fig 3-B). In the pre-monsoon season of 2018, the samples are again falling in the rock dominance and precipitation dominance areas (Fig 3-C).

4.7 PIPER'S TRILINEAR DIAGRAM

Piper's plot for the water samples is presented in figures 4-A, 4-B, 4-C, and 4-D. According to the distribution of ions in the Piper diagram during the pre-monsoon of 2016 (Fig. 4-B), most of the samples fall in the B zone, while two samples (K-2 and P-10) fall in the A zone, another two samples (M-2 and P-5) in C and one sample (D-

1) fall in D zone of the cation triangle. In the anion triangle, six samples (K-1, K-2, K-4, K-5, M-2, and T-2) are located in the zone of E and three samples (C-2, D-3, and K-3) fall in the zone of B, while the rest of the samples are in the G zone. In the diamond field of the diagram, seven samples (K-1, K-2, K-4, K-5, M-2, P-2, and T-2) locate in zone 5, and seven samples (P-5, P-6, P-7, P-8, P-9, P-10, and P-12) accumulate in zone 6. Zone 7 encompass only the D-1 sample and fifteen samples (C-1, C-2, D-2, D-3, K-3, M-1, M-3, M-4, M-5, M-6, P-1, P-3, P-4, P-11, and T-1) distribute in zone 9.

In 2017 (Fig 4-C), the distribution of samples during the monsoon season is found to be three samples (K-2, P-6, and P-10) in the A zone, two samples (M-2 and P-5) in the C zone, nine samples (C-2, D-1, D-2, D-3, K-1, K-4, P-3, P-4, and P-12) in the D zone and the rest of the samples lump in the B zone of cation triangle. Within the anion field of the diagram, twelve samples (D-2, K-2, K-3, K-4, K-5, M-3, P-5, P-6, P-7, P-9, P-10, and P-12) accumulate in the zone of E. In the G zone, ten samples (D-1, C-1, K-1, M-1, M-2, M-4, M-6, P-2, P-3, and T-1) are found to occur and eight samples (C-2, D-3, M-5, P-1, P-4, P-8, P-11, and T-2) fall in the zone of B. The water samples are distributed in zone 5, 7, and 9 within the diamond field. Nine samples (K-2, K-3, K-5, M-3, P-5, P-6, P-7, P-9, and P-10) are locate in zone 5, six samples (C-1, D-1, D-3, K-1, P-3, and P-4) are in zone 7 and fifteen samples (C-2, D-2, K-4, M-1, M-2, M-4, M-5, M-6, P-1, P-2, P-8, P-11, P-12, T-1, and T-2) are distributed in zone 9 of the diagram.

Fig. 4-D present the distribution of water samples during a post-monsoon season of 2018 in the Piper diagram. In the cation ternary plot, 70% of the samples fall in the zone B except, K-3, K-4, M-2, P-3, P-5, and P-7 which are found in zone C, K-2, and P-10 which fall in zone A and D-1 in the zone D. In case of anion ternary plot, D-2, K-2, P-1, P-5, P-7, and P-8 samples fall in the zone E, while C-2, D-3, K-4, and P-9 are located in the field of B. The remaining 20 samples (67% of total samples) are distributed in the field of G. In the diamond field of the diagram, most of the samples (73% of total samples) accumulates in zone 9. D-2, K-2, P-1, P-5, P-6, P-7, and P-8 are found to be presented in zone 5, while the D-1 sample is found in the field of 7.

Table 4-A: Physico-chemical and bacteriological analysis of Pre-Monsoon water samples (2016)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	8.1	0.1	79	40	20	60	15	0.29	2.20	0.25	20
C-2	Spring	Chhippui	8.2	0.3	80	40	20	60	12	0.31	3.05	0.31	20
D-1	Saline Spring	Dampui	8.0	0.5	2100	1220	250	490	940	0.39	325	0.32	250
D-2	Spring	Dampui	7.8	0.3	68	30	22	70	150	0.38	3.12	0.29	22
D-3	Spring	Dampui	8.1	0.2	165	80	24	110	12	0.37	3.28	0.27	24
K-1	Spring	Kawnmawi	8.2	0.3	122	60	18	58	5	0.34	2.52	0.31	18
K-2	Hand Pump	Kawnmawi	8.2	0.9	280	140	64	250	10	0.38	5.15	0.39	64
K-3	Spring	Kawnmawi	7.5	0.5	102	50	16	80	12	0.70	3.14	0.41	16
K-4	Spring	Kawnmawi	8.2	0.3	200	100	32	200	15	0.62	3.25	0.35	32
K-5	Spring	Kawnmawi	8.2	0.4	184	90	36	240	10	0.45	3.51	0.39	36
M-1	Spring	Mamit	7.6	0.3	104	50	22	60	15	0.33	1.23	0.33	22
M-2	Spring	Mamit	8.2	0.8	208	100	30	120	15	0.27	1.28	0.23	30
M-3	Spring	Mamit	8.2	0.5	83	40	14	48	15	0.36	2.23	0.27	14
M-4	Spring	Mamit	8.0	0.7	68	30	20	38	10	0.38	3.14	0.32	20
M-5	Spring	Mamit	7.9	0.6	63	30	20	60	15	0.30	1.58	0.24	20
M-6	Spring	Mamit	8.1	0.8	139	70	20	76	30	0.83	3.02	0.28	20

Contd.

Table 4-A contd.

P-1	Spring	W.Phaileng	7.8	0.1	60	30	20	20	20	0.27	1.51	0.21	20
P-2	Spring	W.Phaileng	8.2	0.1	135	67	7	75	43	0.31	2.75	0.25	7
P-3	Spring	W.Phaileng	8.2	0.6	107	50	6	50	20	0.28	2.59	0.30	6
P-4	Spring	W.Phaileng	8.2	0.2	81	40	4	44	30	0.48	3.85	0.38	4
P-5	Spring	W.Phaileng	8.2	0.2	226	110	16	140	36	0.54	3.64	0.32	16
P-6	Hand Pump	W.Phaileng	8.2	0.3	290	140	4	200	50	0.45	5.34	0.36	4
P-7	Spring	W.Phaileng	8.2	0.3	192	90	4	110	20	0.32	4.05	0.30	4
P-8	Spring	W.Phaileng	8.1	0.3	107	50	4	60	38	0.77	4.11	0.41	4
P-9	Spring	W.Phaileng	8.2	0.3	147	70	4	90	20	0.75	3.73	0.40	4
P-10	Hand Pump	W.Phaileng	7.9	1.3	201	100	10	136	24	0.42	5.51	0.39	10
P-11	Spring	W.Phaileng	8.2	0.3	185	90	10	100	20	0.39	3.57	0.37	10
P-12	Spring	W.Phaileng	8.2	0.5	143	70	4	60	20	0.40	3.39	0.34	4
T-1	Spring	Teirei Forest	8.1	0.3	125	60	20	110	30	0.37	3.86	0.45	20
T-2	Stream	Teirei Forest	8.2	0.3	145	70	24	100	10	0.39	4.02	0.41	24
Mean			8.1	0.4	206	107	26	111	55	0.43	13.95	0.33	25.5
Minimum			7.5	0.1	60	30	4	20	5	0.27	1.23	0.21	4
Maximum			8.2	1.3	2100	1220	250	490	940	0.83	325	0.45	250

Contd.

Table 4-A contd.

**Below detection limit*

Sample No.	Source	Location	Fe	Zn	Cd	Mg	Cu	Ni	Pb	Na	Ca	K	Mn	Cr	Co	As
C-1	Spring	Chhippui	0.2	*	*	4.51	*	0.01	0.00	9.21	5.47	1.80	0.01	0.00	0.04	*
C-2	Spring	Chhippui	0.22	*	*	4.81	0.00	0.01	*	8.57	6.11	1.90	0.00	0.00	*	*
D-1	Saline Spring	Dampui	0.08	*	*	1.28	0.05	0.01	*	626.67	6.25	126.78	0.08	0.00	*	0.00
D-2	Spring	Dampui	0.27	*	*	3.56	0.01	0.01	*	6.85	3.86	1.15	0.00	0.00	0.04	*
D-3	Spring	Dampui	0.25	*	*	3.05	0.00	0.01	*	5.65	3.54	1.05	0.00	0.00	0.00	0.00
K-1	Spring	Kawnmawi	0.08	*	*	2.95	0.00	0.01	0.01	7.96	5.09	1.14	0.00	0.00	0.00	0.00
K-2	Hand Pump	Kawnmawi	1.27	0.02	*	2.76	*	0.01	*	8.36	36.58	1.92	0.1	0.00	*	*
K-3	Spring	Kawnmawi	*	*	*	5.91	*	0.01	*	6.40	4.98	0.82	0.02	0.00	0.00	0.00
K-4	Spring	Kawnmawi	0.09	*	*	4.5	0.00	0.01	*	5.09	3.47	1.12	0.00	0.00	0.00	0.00
K-5	Spring	Kawnmawi	0.08	*	*	4.6	0.01	0.01	*	6.55	4.65	1.09	0.00	0.00	0.00	0.00
M-1	Spring	Mamit	0.02	*	*	2.5	0.01	0.01	*	5.87	4.85	0.85	0.00	0.00	0.00	*
M-2	Spring	Mamit	0.03	0.32	*	13.01	0.01	0.01	*	6.13	11.05	1.90	0.00	0.01	0.02	0.00
M-3	Spring	Mamit	0.15	*	*	3.5	0.00	0.01	*	6.34	4.25	1.05	0.00	0.00	0.00	0.00
M-4	Spring	Mamit	0.16	*	*	3.1	*	0.01	*	5.09	5.68	1.06	0.00	0.00	0.01	0.00
M-5	Spring	Mamit	0.25	*	*	2.74	*	0.01	*	6.34	3.27	1.12	0.01	0.00	0.01	0.00
M-6	Spring	Mamit	0.27	*	*	2.5	0.01	0.01	*	5.89	4.25	1.05	0.00	0.00	0.00	*
P-1	Spring	W.Phaileng	0.47	0.27	*	3.04	*	*	*	4.56	5.93	1.41	0.01	0.00	0.00	*
P-2	Spring	W.Phaileng	0.45	0.15	*	3.5	*	*	*	9.12	8.95	1.05	0.01	0.00	0.00	0.00

Contd.

Table 4-A contd.

P-3	Spring	W.Phaileng	0.08	*	*	4.5	*	0.01	*	7.15	1.76	1.25	0.00	0.00	0.00	0.00
P-4	Spring	W.Phaileng	0.09	*	*	4.05	*	0.01	*	8.45	1.95	1.15	0.00	0.00	0.00	0.00
P-5	Spring	W.Phaileng	0.11	0.07	*	16.64	*	0.01	*	11.61	7.94	1.18	0.01	0.00	*	0.00
P-6	Hand Pump	W.Phaileng	1.3	0.27	*	5	0.00	0.01	*	10.56	17.24	1.75	0.09	0.00	*	*
P-7	Spring	W.Phaileng	0.1	*	*	9	*	0.01	*	7.45	7.97	1.05	0.00	0.00	0.00	0.00
P-8	Spring	W.Phaileng	0.09	*	*	3.5	*	0.01	*	8.72	8.57	1.15	0.01	0.00	0.00	0.00
P-9	Spring	W.Phaileng	0.08	*	*	3	*	0.01	*	9.15	10.58	1.25	0.00	0.00	0.00	0.00
P-10	Hand Pump	W.Phaileng	1.4	0.25	*	4	0.00	0.01	*	10.67	18.97	1.04	0.05	0.00	0.00	0.00
P-11	Spring	W.Phaileng	0.45	*	*	5	0.01	0.01	*	9.56	7.64	1.08	0.00	0.00	0.00	0.00
P-12	Spring	W.Phaileng	0.14	*	*	5.59	*	0.01	*	9.80	4.96	0.79	0.01	0.00	0.01	0.00
T-1	Spring	Teirei Forest	0.23	*	*	5.45	0.00	0.01	*	7.34	6.12	1.05	0.00	0.00	*	*
T-2	Spring	Teirei Forest	0.31	*	*	6.8	*	0.01	*	7.13	6.98	2.00	0.00	0.00	0.00	0.00
Mean			0.3	0.19		4.81	0.01	0.01	0.01	28.27	7.63	5.43	0.01	0.00	0.01	0.00
Minimum			0.02	0.02		1.28	0.00	0.01	0.00	4.56	1.76	0.79	0.00	0.00	0.00	0.00
Maximum			1.4	0.32		16.64	0.05	0.01	0.01	626.67	36.58	126.78	0.1	0.01	0.04	0.00

Table 4-B: Physico-chemical and bacteriological analysis of Monsoon water samples (2016)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC ($\mu\text{S/cm}$)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	8.0	0.4	63	40	20	50	20	0.21	1.70	0.19	20
C-2	Spring	Chhippui	7.3	0.5	60	36	16	28	28	0.23	2.02	0.21	16
D-1	Saline Spring	Dampui	7.9	0.6	1550	930	250	500	400	0.31	300	0.22	250
D-2	Spring	Dampui	6.9	0.4	46	30	30	50	5	0.30	2.32	0.23	30
D-3	Spring	Dampui	7.8	0.5	94	60	40	84	25	0.29	2.68	0.20	40
K-1	Spring	Kawnmawi	8.1	0.7	64	40	30	80	20	0.26	1.32	0.25	30
K-2	Hand Pump	Kawnmawi	8.2	0.6	220	140	66	180	15	0.31	4.35	0.30	66
K-3	Spring	Kawnmawi	7.3	0.7	47	30	40	60	15	0.62	2.74	0.32	40
K-4	Spring	Kawnmawi	8.1	0.5	95	60	38	100	15	0.54	2.04	0.27	38
K-5	Spring	Kawnmawi	8.2	0.9	80	50	30	70	16	0.37	2.54	0.31	30
M-1	Spring	Mamit	7.8	0.7	65	40	28	56	20	0.25	0.63	0.28	28
M-2	Spring	Mamit	8.2	0.8	110	70	26	80	20	0.19	0.51	0.19	26
M-3	Spring	Mamit	6.9	0.9	48	30	20	40	10	0.28	1.75	0.22	20
M-4	Spring	Mamit	6.5	1.7	46	30	20	46	25	0.31	2.01	0.26	20
M-5	Spring	Mamit	6.5	2.3	49	30	26	46	15	0.22	0.67	0.18	26
M-6	Spring	Mamit	6.6	2.6	100	60	20	70	35	0.75	1.82	0.22	20

Contd.

Table 4-B contd.

P-1	Spring	W.Phaileng	7.5	0.1	95	60	30	56	20	0.19	0.46	0.16	30
P-2	Spring	W.Phaileng	7.8	0.1	110	70	20	90	26	0.23	1.05	0.19	20
P-3	Spring	W.Phaileng	8.2	0.6	46	30	32	50	13	0.20	1.43	0.20	32
P-4	Spring	W.Phaileng	8.2	0.2	48	30	30	56	15	0.41	2.61	0.32	30
P-5	Spring	W.Phaileng	8.0	0.2	96	60	34	70	15	0.47	2.18	0.29	34
P-6	Hand Pump	W.Phaileng	8.1	0.3	190	120	44	140	16	0.39	4.86	0.31	44
P-7	Spring	W.Phaileng	8.2	0.3	80	50	30	48	18	0.25	3.10	0.26	30
P-8	Spring	W.Phaileng	8.1	0.3	78	50	26	56	18	0.71	3.27	0.37	26
P-9	Spring	W.Phaileng	8.1	0.3	94	60	36	78	10	0.69	2.96	0.35	36
P-10	Hand Pump	W.Phaileng	8.0	1.3	95	60	36	60	15	0.34	4.09	0.33	36
P-11	Spring	W.Phaileng	8.1	0.3	48	30	18	42	14	0.32	2.85	0.30	18
P-12	Spring	W.Phaileng	8.0	0.5	65	40	30	48	15	0.33	2.27	0.28	30
T-1	Spring	Teirei Forest	8.1	0.3	47	30	20	110	30	0.30	2.78	0.39	20
T-2	Spring	Teirei Forest	8.2	0.3	95	60	24	100	10	0.30	3.05	0.32	24
Mean			7.4	0.6	131	81	37	85	31	0.35	12.2	0.27	37
Minimum			6.5	0.1	46	30	16	28	5	0.19	0.46	0.16	16
Maximum			8.2	2.6	1550	930	250	500	400	0.75	300	0.39	250

Table 4-C: Physico-chemical and bacteriological analysis of Post Monsoon water samples (2016)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC ($\mu\text{S/cm}$)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	8.0	0.9	64	31	20	50	25	0.28	2.50	0.29	20
C-2	Spring	Chhippui	7.3	0.2	72	36	20	76	13	0.32	3.12	0.32	20
D-1	Saline Spring	Dampui	8.0	0.7	2650	1620	260	460	1500	0.38	328	0.40	260
D-2	Spring	Dampui	7.0	0.2	50	30	35	60	10	0.39	3.06	0.38	35
D-3	Spring	Dampui	8.1	0.3	176	89	30	80	20	0.39	3.31	0.35	30
K-1	Spring	Kawnmawi	8.1	0.8	91	45	30	144	20	0.36	2.50	0.40	30
K-2	Hand Pump	Kawnmawi	8.0	0.5	471	237	80	190	30	0.39	5.21	0.46	80
K-3	Spring	Kawnmawi	7.2	1.0	69	34	20	60	20	0.71	3.09	0.49	20
K-4	Spring	Kawnmawi	8.0	0.3	120	60	40	120	25	0.63	3.27	0.42	40
K-5	Spring	Kawnmawi	8.0	0.8	133	69	30	96	27	0.47	3.45	0.47	30
M-1	Spring	Mamit	8.1	0.1	104	51	30	110	22	0.35	1.26	0.37	30
M-2	Spring	Mamit	7.9	0.6	224	113	30	140	25	0.28	1.25	0.28	30
M-3	Spring	Mamit	8.1	0.3	85	41	20	76	18	0.37	2.26	0.35	20
M-4	Spring	Mamit	7.1	0.2	53	27	20	80	23	0.39	3.17	0.39	20
M-5	Spring	Mamit	7.7	1.1	56	28	24	90	24	0.32	1.60	0.30	24
M-6	Spring	Mamit	7.3	0.3	160	77	16	108	36	0.82	3.01	0.37	16

Contd.

Table 4-C contd.

P-1	Spring	W.Phaileng	7.9	0.7	50	25	36	60	18	0.29	1.49	0.25	36
P-2	Spring	W.Phaileng	7.9	0.2	135	68	36	70	32	0.33	3.01	0.28	36
P-3	Spring	W.Phaileng	8.2	0.7	86	40	26	70	18	0.29	2.52	0.37	26
P-4	Spring	W.Phaileng	7.8	0.4	43	28	30	60	20	0.47	3.92	0.46	30
P-5	Spring	W.Phaileng	8.2	0.8	223	96	40	160	20	0.55	3.65	0.40	40
P-6	Hand Pump	W.Phaileng	8.1	0.8	424	213	60	200	28	0.47	5.41	0.42	60
P-7	Spring	W.Phaileng	8.2	0.8	115	60	32	100	12	0.33	4.02	0.38	32
P-8	Spring	W.Phaileng	8.0	0.8	92	41	34	88	14	0.77	4.06	0.47	34
P-9	Spring	W.Phaileng	8.1	0.8	155	80	36	100	20	0.76	3.82	0.48	36
P-10	Hand Pump	W.Phaileng	7.9	1.0	230	114	44	100	30	0.43	5.62	0.44	44
P-11	Spring	W.Phaileng	8.2	0.9	119	58	26	100	20	0.38	3.52	0.46	26
P-12	Spring	W.Phaileng	8.1	0.9	57	34	20	44	24	0.42	3.37	0.39	20
T-1	Spring	Teirei Forest	8.1	0.5	91	37	30	104	26	0.39	3.89	0.50	30
T-2	Stream	Teirei Forest	8.2	0.5	102	54	36	88	28	0.40	4.00	0.47	36
Mean			7.9	0.6	217	118	40	109	72	0.44	14.08	0.39	40
Minimum			7	0.1	43	25	16	44	10	0.28	1.25	0.25	16
Maximum			8.2	1.1	2650	1620	260	460	1500	0.82	328	0.5	260

Table 4-D: Physico-chemical and bacteriological analysis of Pre-Monsoon water samples (2017)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC (μ S/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	8.0	0.1	71	37	19	60	15	0.30	2.31	0.27	19
C-2	Spring	Chhippui	8.1	0.4	75	39	18	61	13	0.32	3.40	0.29	18
D-1	Saline Spring	Dampui	7.8	0.6	2160	1250	84	88	1023	0.37	298	0.31	84
D-2	Spring	Dampui	7.6	0.2	70	31	21	68	150	0.45	3.12	0.37	21
D-3	Spring	Dampui	8.0	0.3	160	78	25	108	10	0.32	3.52	0.28	25
K-1	Spring	Kawnmawi	8.1	0.3	125	60	19	55	8	0.36	2.26	0.26	19
K-2	Hand Pump	Kawnmawi	8.1	0.7	280	135	65	220	10	0.42	5.19	0.40	65
K-3	Spring	Kawnmawi	7.4	0.6	100	48	15	70	10	0.71	3.74	0.38	15
K-4	Spring	Kawnmawi	8.0	0.4	195	95	30	180	12	0.65	3.19	0.36	30
K-5	Spring	Kawnmawi	8.1	0.5	180	90	35	230	10	0.41	3.26	0.35	35
M-1	Spring	Mamit	7.5	0.4	100	50	21	56	16	0.36	1.25	0.28	21
M-2	Spring	Mamit	8.1	0.6	200	98	28	115	14	0.28	1.09	0.24	28
M-3	Spring	Mamit	8.2	0.5	80	39	15	45	13	0.33	2.86	0.30	15
M-4	Spring	Mamit	7.9	0.5	65	28	18	34	10	0.39	3.16	0.29	18
M-5	Spring	Mamit	7.9	0.7	61	27	20	58	13	0.28	1.23	0.27	20
M-6	Spring	Mamit	8.0	0.9	135	68	31	75	28	0.82	2.73	0.31	31

Contd.

Table 4-D contd.

P-1	Spring	W.Phaileng	7.6	0.2	59	30	18	21	18	0.28	1.16	0.25	18
P-2	Spring	W.Phaileng	8.1	0.2	130	60	58	73	41	0.33	2.35	0.29	58
P-3	Spring	W.Phaileng	8.2	0.5	105	48	27	47	19	0.30	2.47	0.34	27
P-4	Spring	W.Phaileng	8.1	0.3	80	38	35	42	29	0.52	3.14	0.37	35
P-5	Spring	W.Phaileng	8.1	0.3	220	108	65	135	35	0.56	3.20	0.41	65
P-6	Hand Pump	W.Phaileng	8.1	0.4	285	140	150	195	48	0.45	5.38	0.43	150
P-7	Spring	W.Phaileng	8.1	0.3	190	87	80	108	20	0.35	4.08	0.33	80
P-8	Spring	W.Phaileng	8.0	0.4	105	50	43	58	35	0.79	3.98	0.39	43
P-9	Spring	W.Phaileng	8.1	0.3	145	68	67	88	21	0.75	3.07	0.36	67
P-10	Hand Pump	W.Phaileng	7.7	1.0	200	98	103	135	23	0.44	5.36	0.43	103
P-11	Spring	W.Phaileng	8.1	0.2	180	89	79	102	21	0.40	3.15	0.38	79
P-12	Spring	W.Phaileng	8.1	0.4	140	67	45	58	18	0.42	3.27	0.45	45
T-1	Spring	Teirei Forest	8.0	0.3	122	60	80	105	28	0.37	3.43	0.42	80
T-2	Spring	Teirei Forest	8.1	0.3	142	68	75	98	10	0.39	3.97	0.38	75
Mean			7.9	0.4	205	106	46	93	57	0.44	12.94	0.34	46
Minimum			7.4	0.1	59	27	15	21	8	0.28	1.09	0.24	15
Maximum			8.2	1	2160	1250	150	230	1023	0.82	298	0.45	150

Table 4-E: Physico-chemical and bacteriological analysis of Monsoon water samples (2017)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	7.3	0.5	69	40	20	50	20	0.22	1.75	0.21	20
C-2	Spring	Chhippui	7.2	0.5	70	34	18	30	10	0.24	2.10	0.23	18
D-1	Saline Spring	Dampui	7.5	0.7	1417	900	230	420	380	0.30	290	0.26	230
D-2	Spring	Dampui	7.0	0.4	25	15	30	50	5	0.37	2.30	0.28	30
D-3	Spring	Dampui	8.1	0.5	160	81	45	80	25	0.24	2.65	0.23	45
K-1	Spring	Kawnmawi	8.0	0.8	65	40	30	82	20	0.28	1.37	0.21	30
K-2	Hand Pump	Kawnmawi	7.5	0.9	382	193	66	160	15	0.34	4.45	0.32	66
K-3	Spring	Kawnmawi	6.9	0.7	49	25	40	55	15	0.65	2.81	0.30	40
K-4	Spring	Kawnmawi	8.0	0.5	100	60	35	95	15	0.57	2.20	0.29	35
K-5	Spring	Kawnmawi	7.0	0.9	79	39	30	70	15	0.35	2.18	0.28	30
M-1	Spring	Mamit	7.0	0.7	67	40	26	55	22	0.28	0.60	0.22	26
M-2	Spring	Mamit	8.2	0.8	154	77	27	80	20	0.21	0.46	0.17	27
M-3	Spring	Mamit	6.5	0.9	45	27	20	38	10	0.25	1.92	0.26	20
M-4	Spring	Mamit	7.3	0.8	52	26	22	45	24	0.32	2.09	0.23	22
M-5	Spring	Mamit	7.3	1.0	60	30	26	45	15	0.21	0.65	0.21	26
M-6	Spring	Mamit	7.2	0.9	122	60	21	68	34	0.76	1.86	0.26	21

Contd.

Table 4-E contd.

P-1	Spring	W.Phaileng	7.7	0.1	51	25	26	50	15	0.20	0.51	0.19	26
P-2	Spring	W.Phaileng	7.2	0.1	128	63	20	70	20	0.25	1.15	0.21	20
P-3	Spring	W.Phaileng	8.2	0.1	57	28	30	45	20	0.22	1.52	0.26	30
P-4	Spring	W.Phaileng	8.2	0.2	46	28	28	50	15	0.44	2.58	0.31	28
P-5	Spring	W.Phaileng	7.6	0.2	105	52	30	67	15	0.48	2.21	0.32	30
P-6	Hand Pump	W.Phaileng	7.3	0.7	282	141	42	120	15	0.38	4.91	0.35	42
P-7	Spring	W.Phaileng	8.1	0.3	75	45	30	45	15	0.27	3.08	0.29	30
P-8	Spring	W.Phaileng	8.0	0.3	78	47	26	50	16	0.73	3.30	0.34	26
P-9	Spring	W.Phaileng	8.1	0.3	100	60	35	75	10	0.68	2.98	0.32	35
P-10	Hand Pump	W.Phaileng	7.8	1.0	140	70	35	70	10	0.36	4.12	0.38	35
P-11	Spring	W.Phaileng	8.0	0.2	49	24	18	40	10	0.33	2.87	0.30	18
P-12	Spring	W.Phaileng	7.7	0.3	47	25	28	45	10	0.35	2.29	0.33	28
T-1	Spring	Teirei Forest	8.0	0.3	46	28	20	100	20	0.29	2.76	0.35	20
T-2	Stream	Teirei Forest	8.2	0.2	118	58	20	96	10	0.32	3.04	0.29	20
Mean			7.6	0.5	141	79	36	78	28	0.36	11.89	0.27	36
Minimum			6.5	0.1	25	15	18	30	5	0.2	0.46	0.17	18
Maximum			8.2	1	1417	900	230	420	380	0.76	290	0.38	230

Contd.

Table 4-E contd.

**Below detection limit*

Sample No.	Source	Location	Fe	Zn	Cd	Mg	Cu	Ni	Pb	Na	Ca	K	Mn	Cr	Co	As
C-1	Spring	Chhippui	0.10	*	*	1.01	*	0.00	*	7.25	2.80	0.91	0.00	0.00	*	*
C-2	Spring	Chhippui	0.05	*	*	1.20	0.00	0.00	*	5.28	2.65	0.10	0.00	0.00	*	*
D-1	Saline Spring	Dampui	0.06	*	0.00	1.08	0.00	*	*	253.33	4.97	97.83	0.06	0.03	*	0.00
D-2	Spring	Dampui	0.03	*	0.00	1.06	0.00	0.01	*	4.26	1.67	0.66	0.00	0.00	0.04	*
D-3	Spring	Dampui	0.05	*	*	1.05	0.00	0.00	0.00	3.72	1.56	0.50	0.00	0.00	0.00	0.00
K-1	Spring	Kawnmawi	0.03	*	*	1.05	0.00	0.00	0.00	5.27	2.09	0.11	0.00	0.00	0.00	0.00
K-2	Hand Pump	Kawnmawi	0.28	*	0.00	1.06	*	0.00	*	6.24	26.81	1.54	0.10	0.00	*	*
K-3	Spring	Kawnmawi	0.00	*	0.00	1.55	*	*	0.00	4.23	2.66	0.80	0.01	0.00	*	0.00
K-4	Spring	Kawnmawi	0.10	*	*	1.05	0.00	0.00	0.00	4.09	1.25	0.92	0.00	0.00	0.00	0.00
K-5	Spring	Kawnmawi	0.02	*	*	2.06	0.01	0.00	0.00	5.23	3.09	0.10	0.00	0.00	0.00	0.00
M-1	Spring	Mamit	0.00	*	*	1.05	0.00	0.00	*	3.56	2.95	1.05	0.00	0.00	0.00	*
M-2	Spring	Mamit	0.02	0.02	*	9.02	0.00	0.01	*	4.34	9.39	1.16	0.00	0.00	0.02	0.00
M-3	Spring	Mamit	0.01	*	*	1.05	0.00	0.00	0.00	4.87	2.65	0.09	0.00	0.00	0.00	0.00
M-4	Spring	Mamit	0.06	*	*	1.01	*	0.00	0.00	3.45	3.15	0.08	0.00	0.00	0.01	0.00
M-5	Spring	Mamit	0.06	*	*	1.14	0.00	0.01	*	3.04	2.21	0.65	0.01	0.00	0.01	*
M-6	Spring	Mamit	0.01	*	*	1.05	0.00	0.00	0.00	3.96	2.25	0.22	0.01	0.00	0.01	*
P-1	Spring	W.Phaileng	0.32	0.05	*	1.05	*	*	*	2.98	4.08	2.81	0.04	0.02	0.04	*
P-2	Spring	W.Phaileng	0.01	0.00	*	1.05	*	0.01	*	7.86	7.18	0.31	0.02	0.00	0.01	0.00

Contd.

Table 4-E contd.

P-3	Spring	W.Phaileng	0.01	*	*	1.15	*	0.00	*	4.12	0.88	1.05	0.00	0.00	*	0.00
P-4	Spring	W.Phaileng	0.01	*	*	1.05	0.00	0.00	*	6.15	0.90	0.25	0.00	0.00	0.00	0.00
P-5	Spring	W.Phaileng	0.00	0.02	0.00	9.04	*	0.00	*	8.95	6.82	0.72	0.00	0.00	*	0.00
P-6	Hand Pump	W.Phaileng	1.02	0.00	*	1.05	0.00	0.01	0.00	7.86	15.71	1.27	0.23	0.00	*	*
P-7	Spring	W.Phaileng	0.00	*	*	1.09	*	0.00	0.00	5.76	5.12	0.02	0.00	0.00	0.00	0.00
P-8	Spring	W.Phaileng	0.00	*	*	1.25	*	0.00	0.00	6.84	6.05	0.25	0.00	0.00	0.00	0.00
P-9	Spring	W.Phaileng	0.10	*	0.00	1.01	*	0.00	*	7.89	8.73	0.68	0.02	0.00	*	0.00
P-10	Hand Pump	W.Phaileng	1.03	*	*	1.01	0.00	0.00	0.00	9.54	16.21	0.40	0.10	0.00	0.00	0.00
P-11	Spring	W.Phaileng	0.05	*	*	1.02	0.00	0.00	0.00	7.58	5.42	0.09	0.00	0.00	0.00	0.00
P-12	Spring	W.Phaileng	0.04	*	*	1.05	*	0.00	*	7.14	2.73	0.61	0.00	0.00	*	0.00
T-1	Spring	Teirei Forest	0.03	*	*	1.25	0.00	0.00	0.00	5.24	4.06	0.45	0.00	0.00	*	*
T-2	Stream	Teirei Forest	0.10	*	*	1.80	*	0.00	*	5.38	4.76	1.03	0.00	0.00	*	0.00
Mean			0.12	0.01	0.00	1.68	0.00	0.00	0.00	13.85	5.36	3.89	0.02	0.00	0.01	0.00
Minimum			0.00	0.00	0.00	1.01	0.00	0.00	0.00	2.98	0.88	0.02	0.00	0.00	0.00	0.00
Maximum			1.03	0.05	0.00	9.04	0.01	0.01	0.00	253.33	26.81	97.83	0.23	0.03	0.04	0.00

Table 4-F: Physico-chemical and bacteriological analysis of Post-Monsoon water samples (2017)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	7.9	0.3	67	37	25	52	22	0.32	2.35	0.33	25
C-2	Spring	Chhippui	7.5	0.2	71	35	22	70	13	0.33	3.38	0.30	22
D-1	Saline Spring	Dampui	6.8	0.7	2800	1700	265	468	1550	0.39	300	0.32	265
D-2	Spring	Dampui	7.1	0.3	50	31	33	58	10	0.44	3.16	0.36	33
D-3	Spring	Dampui	8.1	0.2	175	87	30	82	20	0.35	3.50	0.28	30
K-1	Spring	Kawnmawi	8.0	0.3	95	50	30	145	22	0.37	2.31	0.30	30
K-2	Hand Pump	Kawnmawi	7.4	0.5	417	208	78	185	25	0.41	5.10	0.42	78
K-3	Spring	Kawnmawi	6.6	0.5	66	33	20	60	19	0.73	3.62	0.39	20
K-4	Spring	Kawnmawi	8.2	0.3	238	119	39	118	23	0.67	3.20	0.42	39
K-5	Spring	Kawnmawi	7.6	0.8	118	59	30	95	25	0.42	3.22	0.40	30
M-1	Spring	Mamit	8.2	0.1	100	50	30	108	20	0.35	1.27	0.31	30
M-2	Spring	Mamit	7.8	0.5	220	110	30	138	25	0.29	1.15	0.23	30
M-3	Spring	Mamit	8.2	0.4	82	40	22	75	16	0.35	2.85	0.31	22
M-4	Spring	Mamit	7.0	0.2	52	25	20	78	20	0.40	3.18	0.31	20
M-5	Spring	Mamit	7.5	0.8	55	26	25	91	25	0.29	1.25	0.26	25
M-6	Spring	Mamit	7.0	0.4	160	75	19	105	35	0.81	2.68	0.34	19

Contd.

Table 4-F contd.

P-1	Spring	W.Phaileng	7.5	0.7	52	26	35	58	17	0.29	1.13	0.27	35
P-2	Spring	W.Phaileng	6.6	0.2	130	64	35	70	30	0.35	2.42	0.28	35
P-3	Spring	W.Phaileng	8.1	0.7	77	38	25	68	18	0.32	2.45	0.37	25
P-4	Spring	W.Phaileng	7.7	0.4	57	28	30	59	19	0.51	3.21	0.39	30
P-5	Spring	W.Phaileng	8.1	0.8	225	112	40	156	20	0.55	3.25	0.40	40
P-6	Hand Pump	W.Phaileng	7.2	0.8	512	256	58	198	26	0.46	5.45	0.45	58
P-7	Spring	W.Phaileng	8.0	0.8	104	52	31	98	10	0.37	4.02	0.37	31
P-8	Spring	W.Phaileng	7.6	0.8	93	46	33	85	15	0.78	3.85	0.38	33
P-9	Spring	W.Phaileng	8.2	0.8	147	74	35	96	18	0.77	3.08	0.39	35
P-10	Hand Pump	W.Phaileng	7.1	1.0	162	81	40	97	30	0.45	5.39	0.44	40
P-11	Spring	W.Phaileng	8.1	0.9	98	49	24	98	20	0.41	3.17	0.40	24
P-12	Spring	W.Phaileng	7.9	0.9	56	28	20	43	22	0.43	3.32	0.44	20
T-1	Spring	Teirei Forest	8.2	0.5	97	48	28	100	24	0.36	3.48	0.40	28
T-2	Stream	Teirei Forest	8.1	0.5	116	57	35	85	26	0.39	3.87	0.39	35
Mean			7.6	0.5	223	121	40	108	72	0.45	13.01	0.36	40
Minimum			6.6	0.1	50	25	19	43	10	0.29	1.13	0.23	19
Maximum			8.2	1	2800	1700	265	468	1550	0.81	300	0.45	265

Table 4-G: Physico-chemical and bacteriological analysis of Pre-Monsoon water samples (2018)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC ($\mu\text{S/cm}$)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	8.1	0.1	79	40	64	72	15	0.32	2.35	0.28	64
C-2	Spring	Chhippui	8.1	0.4	82	41	62	68	18	0.33	3.51	0.31	62
D-1	Saline Spring	Dampui	7.9	0.5	1940	1300	230	490	1200	0.40	320	0.34	230
D-2	Spring	Dampui	7.7	0.3	73	32	43	65	160	0.42	3.24	0.29	43
D-3	Spring	Dampui	7.8	0.2	165	77	26	105	12	0.35	3.13	0.32	26
K-1	Spring	Kawnmawi	8.0	0.2	130	68	50	70	12	0.38	2.54	0.33	50
K-2	Hand Pump	Kawnmawi	8.2	0.6	290	142	88	102	39.9	0.42	5.95	0.37	88
K-3	Spring	Kawnmawi	7.6	0.5	105	52	50	64	24.9	0.70	3.65	0.40	50
K-4	Spring	Kawnmawi	8.1	0.4	205	100	55	200	16	0.65	3.47	0.38	55
K-5	Spring	Kawnmawi	8.2	0.5	190	95	48	68	14.9	0.45	3.39	0.36	48
M-1	Spring	Mamit	7.6	0.3	105	53	44	62	18	0.35	1.58	0.34	44
M-2	Spring	Mamit	8.2	0.6	200	98	92	120	15	0.30	1.34	0.26	92
M-3	Spring	Mamit	8.2	0.5	85	40	35	50	15	0.37	2.86	0.31	35
M-4	Spring	Mamit	8.1	0.6	68	32	30	47	12	0.40	3.34	0.35	30
M-5	Spring	Mamit	7.8	0.7	65	31	32	61	15	0.29	1.43	0.29	32
M-6	Spring	Mamit	8.0	0.8	140	71	42	78	32	0.80	2.35	0.28	42

Contd.

Table 4-G contd.

P-1	Spring	W.Phaileng	7.9	0.2	62	31	73	88	20.9	0.27	1.54	0.25	73
P-2	Spring	W.Phaileng	8.1	0.3	133	65	68	114	23.4	0.30	2.34	0.27	68
P-3	Spring	W.Phaileng	8.2	0.5	108	52	66	86	19.9	0.29	2.68	0.33	66
P-4	Spring	W.Phaileng	8.1	0.3	80	38	55	82	29	0.49	3.42	0.38	55
P-5	Spring	W.Phaileng	8.2	0.3	230	115	94	126	25.9	0.52	3.36	0.41	94
P-6	Hand Pump	W.Phaileng	8.1	0.4	295	142	108	144	31.4	0.45	5.67	0.39	108
P-7	Spring	W.Phaileng	8.2	0.4	195	90	44	74	11.5	0.34	4.03	0.34	44
P-8	Spring	W.Phaileng	8.1	0.4	108	52	76	88	15.9	0.82	4.07	0.45	76
P-9	Spring	W.Phaileng	8.2	0.4	150	71	98	116	18.9	0.75	3.92	0.40	98
P-10	Hand Pump	W.Phaileng	7.9	0.9	210	105	122	148	27.9	0.42	4.87	0.43	122
P-11	Spring	W.Phaileng	8.2	0.3	190	90	76	92	19.5	0.40	3.24	0.37	76
P-12	Spring	W.Phaileng	8.2	0.4	145	73	68	82	18.9	0.42	3.37	0.39	68
T-1	Spring	Teirei Forest	8.1	0.4	130	65	88	115	26	0.37	3.78	0.46	88
T-2	Spring	Teirei Forest	8.2	0.3	147	75	79	103	18	0.39	4.06	0.41	79
Mean			8.0	0.4	204	111	70	106	64	0.44	13.8	0.35	70.2
Minimum			7.6	0.1	62	31	26	47	11.5	0.27	1.34	0.25	26
Maximum			8.2	0.9	1940	1300	230	490	1200	0.82	320	0.46	230

Contd.

Table 4-H: Physico-chemical and bacteriological analysis of Monsoon water samples (2018)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	7.1	0.3	68	34	16	60	15	0.23	1.71	0.22	16
C-2	Spring	Chhippui	7.0	0.4	70	35	17	45	16	0.25	2.09	0.25	17
D-1	Saline Spring	Dampui	6.5	1.0	1400	950	190	450	1050	0.32	310	0.26	190
D-2	Spring	Dampui	7.0	0.7	31	15	27	75	8	0.35	2.29	0.24	27
D-3	Spring	Dampui	8.1	0.5	158	78	45	80	25	0.27	2.69	0.25	45
K-1	Spring	Kawnmawi	7.0	0.9	110	55	26	60	18	0.30	1.36	0.26	26
K-2	Hand Pump	Kawnmawi	7.0	1.5	129	64	46	150	16	0.35	4.20	0.29	46
K-3	Spring	Kawnmawi	7.0	0.8	47	23	38	45	14	0.63	2.79	0.33	38
K-4	Spring	Kawnmawi	7.5	0.7	83	41	27	90	16	0.58	2.13	0.27	27
K-5	Spring	Kawnmawi	6.5	0.8	71	35	28	60	17	0.38	2.25	0.29	28
M-1	Spring	Mamit	6.6	0.9	97	48	24	40	22	0.27	0.71	0.25	24
M-2	Spring	Mamit	7.5	0.8	137	68	27	75	18	0.22	0.52	0.18	27
M-3	Spring	Mamit	7.0	0.9	82	41	26	55	15	0.29	1.95	0.25	26
M-4	Spring	Mamit	7.0	0.9	53	26	20	50	12	0.33	2.07	0.27	20
M-5	Spring	Mamit	6.5	0.9	41	20	18	40	10	0.23	0.68	0.22	18
M-6	Spring	Mamit	7.0	0.9	132	66	22	60	29	0.73	1.79	0.21	22

Contd.

Table 4-H contd.

P-1	Spring	W.Phaileng	7.0	0.2	88	44	20	50	20	0.18	0.45	0.17	20
P-2	Spring	W.Phaileng	6.5	0.5	134	67	17	75	22	0.22	1.16	0.20	17
P-3	Spring	W.Phaileng	7.5	0.7	47	22	16	65	15	0.21	1.55	0.25	16
P-4	Spring	W.Phaileng	7.0	0.6	46	23	22	68	17	0.42	2.53	0.33	22
P-5	Spring	W.Phaileng	7.5	0.5	87	43	28	62	13	0.45	2.23	0.35	28
P-6	Hand Pump	W.Phaileng	7.0	0.7	284	142	40	105	15	0.39	4.78	0.32	40
P-7	Spring	W.Phaileng	7.5	0.6	63	31	28	44	13	0.26	3.12	0.28	28
P-8	Spring	W.Phaileng	6.5	0.8	103	51	25	45	15	0.75	3.29	0.38	25
P-9	Spring	W.Phaileng	6.5	0.9	139	67	30	70	12	0.67	3.03	0.36	30
P-10	Hand Pump	W.Phaileng	6.5	1.0	76	39	27	60	10	0.35	4.15	0.37	27
P-11	Spring	W.Phaileng	6.5	0.8	81	40	16	40	12	0.34	2.82	0.32	16
P-12	Spring	W.Phaileng	7.5	0.6	53	26	27	46	14	0.34	2.30	0.31	27
T-1	Spring	Teirei Forest	8.0	0.3	89	44	18	75	15	0.29	2.75	0.38	18
T-2	Spring	Teirei Forest	7.5	0.5	100	50	19	70	10	0.32	3.07	0.33	19
Mean			7.0	0.7	137	76	31	77	50	0.36	12.55	0.28	31
Minimum			6.5	0.2	31	15	16	40	8	0.18	0.45	0.17	16
Maximum			8.1	1.5	1400	950	190	450	1050	0.75	310	0.38	190

Table 4-I: Physico-chemical and bacteriological analysis of Post Monsoon water samples (2018)

Sample No.	Source	Location	pH	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	F (mg/l)	HCO ₃ (mg/l)
C-1	Spring	Chhippui	7.8	0.4	68	39	26	50	25	0.35	2.45	0.29	26
C-2	Spring	Chhippui	7.5	0.5	75	40	25	75	14	0.34	3.48	0.33	25
D-1	Saline Spring	Dampui	7.9	0.6	2500	1675	500	490	1600	0.42	322	0.36	500
D-2	Spring	Dampui	7.2	0.4	55	30	37	62	15	0.43	3.36	0.31	37
D-3	Spring	Dampui	8.0	0.3	180	90	33	85	22	0.37	3.10	0.31	33
K-1	Spring	Kawnmawi	7.9	0.6	96	52	32	150	25	0.39	2.57	0.34	32
K-2	Hand Pump	Kawnmawi	7.5	0.5	480	250	82	195	35	0.41	5.75	0.39	82
K-3	Spring	Kawnmawi	7.0	0.9	68	35	22	63	25	0.72	3.62	0.44	22
K-4	Spring	Kawnmawi	8.1	0.4	235	115	42	125	28	0.67	3.53	0.41	42
K-5	Spring	Kawnmawi	7.9	0.7	128	60	28	90	23	0.47	3.37	0.38	28
M-1	Spring	Mamit	8.1	0.3	105	53	32	115	25	0.34	1.61	0.37	32
M-2	Spring	Mamit	7.9	0.6	228	115	33	142	28	0.29	1.32	0.25	33
M-3	Spring	Mamit	8.1	0.4	86	43	22	78	20	0.35	2.90	0.32	22
M-4	Spring	Mamit	7.5	0.4	55	29	25	82	22	0.41	3.38	0.37	25
M-5	Spring	Mamit	7.8	0.9	57	30	26	95	26	0.31	1.39	0.28	26
M-6	Spring	Mamit	7.5	0.5	170	80	20	120	38	0.83	2.38	0.29	20

Contd.

Table 4-I contd.

P-1	Spring	W.Phaileng	7.8	0.5	54	28	38	62	20	0.30	1.48	0.27	38
P-2	Spring	W.Phaileng	7.6	0.3	128	65	38	75	33	0.29	2.32	0.26	38
P-3	Spring	W.Phaileng	8.0	0.6	85	42	28	75	20	0.31	2.67	0.34	28
P-4	Spring	W.Phaileng	7.9	0.5	58	30	32	62	22	0.52	3.45	0.37	32
P-5	Spring	W.Phaileng	8.0	0.6	230	115	45	162	22	0.51	3.38	0.44	45
P-6	Hand Pump	W.Phaileng	7.5	0.8	520	260	65	205	30	0.47	5.75	0.41	65
P-7	Spring	W.Phaileng	8.1	0.9	110	56	32	96	15	0.33	3.97	0.35	32
P-8	Spring	W.Phaileng	7.9	0.8	95	48	36	90	17	0.85	4.01	0.47	36
P-9	Spring	W.Phaileng	8.1	0.8	150	76	34	98	18	0.77	4.02	0.42	34
P-10	Hand Pimp	W.Phaileng	7.8	0.9	180	90	42	102	31	0.45	4.51	0.44	42
P-11	Spring	W.Phaileng	8.1	0.8	105	52	25	100	18	0.41	3.29	0.39	25
P-12	Spring	W.Phaileng	8.0	0.8	58	30	22	45	25	0.41	3.35	0.39	22
T-1	Spring	Teirei Forest	8.1	0.6	95	45	26	105	25	0.36	3.89	0.46	26
T-2	Stream	Teirei Forest	8.2	0.6	118	58	38	90	28	0.38	4.02	0.41	38
Mean			7.8	0.6	219	124	50	113	77	0.45	13.9	0.36	50
Minimum			7	0.3	54	28	20	45	14	0.29	1.32	0.25	20
Maximum			8.2	0.9	2500	1675	500	490	1600	0.85	322	0.47	500

Contd.

Table 4-I contd.

**Below detection limit*

Sample No.	Source	Location	Fe	Zn	Cd	Mg	Cu	Ni	Pb	Na	Ca	K	Mn	Cr	Co	As
C-1	Spring	Chhippui	*	*	*	4.71	*	0.01	*	10.71	5.13	1.01	0.02	0.00	0.06	*
C-2	Spring	Chhippui	0.35	*	*	4.95	0.00	0.01	*	7.86	5.69	1.10	0.00	0.00	*	*
D-1	Saline Spring	Dampui	0.12	*	*	1.35	0.05	0.01	*	1066.67	5.24	100.30	0.10	0.00	*	0.00
D-2	Spring	Dampui	0.30	*	*	3.75	0.01	0.01	*	6.17	3.14	1.66	0.00	0.00	0.04	*
D-3	Spring	Dampui	0.25	*	*	3.56	0.00	0.01	0.00	5.25	3.08	1.50	0.00	0.00	0.00	0.00
K-1	Spring	Kawnmawi	0.10	*	*	3.10	0.00	0.01	0.00	7.68	4.68	1.11	0.00	0.00	0.00	0.00
K-2	Hand Pump	Kawnmawi	1.35	0.03	*	2.79	*	0.01	*	8.14	30.57	5.73	0.28	0.00	*	*
K-3	Spring	Kawnmawi	1.03	*	*	6.24	*	0.01	*	5.48	4.12	0.31	0.03	0.00	0.00	0.00
K-4	Spring	Kawnmawi	0.11	*	*	4.71	0.01	0.01	0.00	4.97	2.09	1.22	0.00	0.00	0.00	0.00
K-5	Spring	Kawnmawi	0.09	*	*	4.89	0.01	0.01	0.00	7.34	4.54	1.10	0.00	0.00	0.00	0.00
M-1	Spring	Mamit	0.04	*	*	2.91	0.02	0.01	*	4.68	3.94	0.09	0.00	0.00	0.00	*
M-2	Spring	Mamit	0.09	0.35	*	13.03	0.05	0.01	*	8.83	10.58	1.42	0.01	0.01	0.44	0.00
M-3	Spring	Mamit	0.16	*	*	3.52	0.01	0.01	0.00	6.89	4.13	0.09	0.00	0.00	0.00	0.00
M-4	Spring	Mamit	0.16	*	*	3.20	*	0.01	*	4.07	5.09	1.39	0.01	0.00	0.01	0.00
M-5	Spring	Mamit	0.58	*	*	2.76	*	0.01	0.00	4.44	3.02	0.34	0.03	0.00	0.01	0.00
M-6	Spring	Mamit	0.31	*	*	2.55	0.00	0.01	0.00	6.10	4.08	1.02	0.01	0.00	0.01	*
P-1	Spring	W.Phaileng	0.71	0.30	*	3.10	*	*	*	4.15	5.89	2.82	0.03	0.00	0.00	*
P-2	Spring	W.Phaileng	0.22	0.17	*	3.60	*	*	*	8.32	8.05	2.69	0.02	0.00	0.00	0.00

Contd.

Table 4-I contd.

P-3	Spring	W.Phaileng	0.08	*	*	4.51	*	*	*	5.38	1.25	0.66	0.01	0.00	0.00	0.00
P-4	Spring	W.Phaileng	0.10	*	*	4.10	*	0.00	*	7.43	1.45	1.25	0.00	0.00	0.00	0.00
P-5	Spring	W.Phaileng	0.08	0.09	*	16.70	*	*	*	10.37	7.56	0.48	0.01	0.00	*	0.00
P-6	Hand Pump	W.Phaileng	1.35	0.28	*	5.10	0.00	0.01	0.00	9.56	16.92	1.77	0.23	0.00	*	*
P-7	Spring	W.Phaileng	0.12	*	*	9.05	*	0.00	0.00	6.98	7.58	1.02	0.00	0.00	0.00	0.00
P-8	Spring	W.Phaileng	0.09	*	*	3.5	*	0.00	*	7.76	8.04	0.37	0.01	0.00	0.00	0.00
P-9	Spring	W.Phaileng	0.11	*	*	3.71	*	0.00	*	9.20	10.14	0.21	0.01	0.00	0.00	0.00
P-10	Hand Pump	W.Phaileng	1.42	0.27	*	4.20	0.00	0.00	0.00	11.45	18.08	1.45	0.10	0.00	0.00	0.00
P-11	Spring	W.Phaileng	0.50	*	*	5.30	0.02	0.00	0.00	10.22	7.15	1.09	0.00	0.00	0.00	0.00
P-12	Spring	W.Phaileng	0.52	*	*	5.50	*	0.00	*	9.60	4.18	0.41	0.02	0.00	0.02	0.00
T-1	Spring	Teirei Forest	0.30	*	*	5.83	0.00	0.00	0.00	6.98	6.02	1.15	0.00	0.00	*	*
T-2	Spring	Teirei Forest	0.20	*	*	6.81	*	*	0.00	6.93	6.56	1.09	0.01	0.00	0.00	0.00
Mean			0.37	0.21		4.97	0.01	0.01	0.00	42.65	6.93	4.53	0.03	0.00	0.02	0.00
Minimum			0.04	0.03		1.35	0.00	0.00	0.00	4.07	1.25	0.09	0.00	0.00	0.00	0.00
Maximum			1.42	0.35		16.7	0.05	0.01	0.00	1066.67	30.57	100.3	0.28	0.01	0.44	0.00

Table 4.1: MPN of water sample

Sample No.	2016			2017			2018		
	PRM	MON	POM	PRM	MON	POM	PRM	MON	POM
C-1	0	0	0	0	0	0	0	0	0
C-2	9	14	11	6	20	11	7	16	11
D-1	0	0	0	0	0	0	0	0	0
D-2	0	0	0	0	0	0	0	0	0
D-3	0	0	0	0	0	0	0	0	0
K-1	14	20	16	15	21	21	16	28	20
K-2	0	0	0	0	0	0	0	0	0
K-3	0	0	0	0	0	0	0	0	0
K-4	0	0	0	0	0	0	0	0	0
K-5	7	9	7	9	9	9	7	9	9
M-1	15	23	16	11	27	16	14	27	21
M-2	4	7	6	4	7	6	3	6	4
M-3	7	15	9	6	9	7	7	9	6
M-4	0	0	0	0	0	0	0	0	0
M-5	6	15	9	6	9	9	9	14	9
M-6	9	21	11	9	16	11	9	15	11
P-1	0	0	0	0	0	0	0	0	0
P-2	11	23	14	9	29	14	9	21	9
P-3	0	0	0	0	0	0	0	0	0
P-4	0	0	0	0	0	0	0	0	0
P-5	0	0	0	0	0	0	0	0	0
P-6	0	0	0	0	0	0	0	0	0
P-7	0	0	0	0	0	0	0	0	0
P-8	7	9	9	9	9	9	7	9	9
P-9	6	9	7	4	7	6	6	7	4
P-10	0	0	0	0	0	0	0	0	0
P-11	0	0	0	0	0	0	0	0	0
P-12	0	0	0	0	0	0	0	0	0
T-1	0	0	0	0	0	0	0	0	0
T-2	0	0	0	0	0	0	0	0	0

Table 4.2-A: Water Quality Index (2016)

Station	Index Period	F1	F2	F3	CCME WQI	WQI Category	Sum of Failed Tests	Normalized Sum of Excursion	Total Samples	Total Variables	Actual Variables Tested	Total Tests	Number of Failed Tests	Number of Passed Tests
C-1	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
C-2	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
D-1	2016	15.4	10.3	29.5	79.9	FAIR	16.4	0.4	3	13	13	39	4	35
D-2	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
D-3	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-1	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-2	2016	15.4	5.1	8.1	89.5	GOOD	3.4	0.1	3	13	13	39	2	37
K-3	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	38	0	38
K-4	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-5	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-1	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-2	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-3	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-4	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-5	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-6	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39

Contd.

Table 4.2-A contd.

P-1	2016	7.7	2.6	1.4	95.2	EXCELLENT	0.6	0	3	13	13	39	1	38
P-2	2016	7.7	2.6	1.3	95.3	EXCELLENT	0.5	0	3	13	13	39	1	38
P-3	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-4	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-5	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-6	2016	15.4	5.1	8	89.6	GOOD	3.4	0.1	3	13	13	39	2	37
P-7	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-8	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-9	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-10	2016	7.7	2.6	8.6	93.2	GOOD	3.7	0.1	3	13	13	39	1	38
P-11	2016	7.7	2.6	1.3	95.3	EXCELLENT	0.5	0	3	13	13	39	1	38
P-12	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
T-1	2016	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
T-2	2016	7.7	2.6	0.1	95.3	EXCELLENT	0	0	3	13	13	39	1	38

Table 4.2-B: Water Quality Index (2017)

Station	Index Period	F1	F2	F3	CCME WQI	WQI Category	Sum of Failed Tests	Normalized Sum of Excursion	Total Samples	Total Variables	Actual Variables Tested	Total Tests	Number of Failed Tests	Number of Passed Tests
C-1	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
C-2	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
D-1	2017	15.4	12.8	30.1	79.1	FAIR	16.8	0.4	3	13	13	39	5	34
D-2	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
D-3	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-1	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-2	2017	7.7	2.6	0.1	95.3	EXCELLENT	0	0	3	13	13	39	1	38
K-3	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-4	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-5	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-1	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-2	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-3	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-4	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-5	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-6	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39

Contd.

Table 4.2-B contd.

P-1	2017	7.7	2.6	0.2	95.3	EXCELLENT	0.1	0	3	13	13	39	1	38
P-2	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-3	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-4	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-5	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-6	2017	15.4	5.1	6.4	89.9	GOOD	2.7	0.1	3	13	13	39	2	37
P-7	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-8	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-9	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-10	2017	7.7	2.6	5.9	94.2	GOOD	2.4	0.1	3	13	13	39	1	38
P-11	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-12	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
T-1	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
T-2	2017	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39

Table 4.2-C: Water Quality Index (2018)

Station	Index Period	F1	F2	F3	CCME WQI	WQI Category	Sum of Failed Tests	Normalized Sum of Excursion	Total Samples	Total Variables	Actual Variables Tested	Total Tests	Number of Failed Tests	Number of Passed Tests
C-1	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
C-2	2018	7.7	2.6	0.4	95.3	EXCELLENT	0.2	0	3	13	13	39	1	38
D-1	2018	15.4	15.4	30.9	78.2	FAIR	17.5	0.4	3	13	13	39	6	33
D-2	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
D-3	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-1	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-2	2018	15.4	5.1	8.8	89.4	GOOD	3.8	0.1	3	13	13	39	2	37
K-3	2018	7.7	2.6	5.9	94.2	GOOD	2.4	0.1	3	13	13	39	1	38
K-4	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
K-5	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-1	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-2	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-3	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-4	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
M-5	2018	7.7	2.6	2.3	95.1	EXCELLENT	0.9	0	3	13	13	39	1	38
M-6	2018	7.7	2.6	0.1	95.3	EXCELLENT	0	0	3	13	13	39	1	38

Contd.

Table 4.2-C contd.

P-1	2018	7.7	2.6	3.4	94.9	GOOD	1.4	0	3	13	13	39	1	38
P-2	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-3	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-4	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-5	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-6	2018	15.4	5.1	8.9	89.3	GOOD	3.8	0.1	3	13	13	39	2	37
P-7	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-8	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-9	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
P-10	2018	7.7	2.6	8.7	93.1	GOOD	3.7	0.1	3	13	13	39	1	38
P-11	2018	7.7	2.6	1.7	95.2	EXCELLENT	0.7	0	3	13	13	39	1	38
P-12	2018	7.7	2.6	1.8	95.2	EXCELLENT	0.7	0	3	13	13	39	1	38
T-1	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39
T-2	2018	0	0	0	100	EXCELLENT	0	0	3	13	13	39	0	39

Table 4.3-A: Correlation Co-efficient of Pre-Monsoon water sample (2016)

Parameter	pH	Turbidity	EC	TDS	TA	TH	Cl	NO ₃	SO ₄	F	HCO ₃	Fe
pH	1											
Turbidity	-0.1068	1										
EC	-0.0083	0.0991	1									
TDS	-0.0198	0.0936	0.9996	1								
TA	-0.087	0.1279	0.9582	0.9611	1							
TH	0.1254	0.186	0.8568	0.8464	0.8425	1						
Cl	-0.1075	0.0323	0.9711	0.9753	0.9414	0.7614	1					
NO₃	-0.047	0.0706	-0.0237	-0.0266	-0.0854	0.0516	-0.0365	1				
SO₄	-0.074	0.0607	0.9871	0.991	0.959	0.7829	0.9884	-0.0401	1			
F	0.0405	0.1126	0.0259	0.0175	-0.0244	0.2266	-0.0354	0.47	-0.0123	1		
HCO₃	-0.0870	0.1279	0.9582	0.9611	1	0.8425	0.9414	-0.0854	0.959	-0.0244	1	
Fe	-0.0501	0.4291	-0.0126	-0.0257	-0.0503	0.2114	-0.0892	-0.1114	-0.0957	0.166	-0.0503	1
Zn	-0.4047	0.2219	-0.0248	-0.0346	-0.0988	0.0331	-0.0749	-0.2275	-0.0865	-0.2838	-0.0988	0.5171
Mg	0.2449	-0.0559	-0.1426	-0.1561	-0.215	-0.0363	-0.2111	-0.0407	-0.2117	-0.0354	-0.215	-0.1571
Cu	-0.1467	0.1039	0.8983	0.9012	0.8977	0.7363	0.9159	-0.0249	0.9051	-0.0693	0.8977	-0.1613
Ni	0.1144	0.3242	0.0815	0.0747	0.0738	0.1855	0.0384	0.242	0.0547	0.4259	0.0738	-0.1238
Pb	0.1192	-0.0845	-0.0439	-0.0417	-0.0321	-0.1074	-0.0563	-0.1072	-0.0368	-0.0552	-0.0321	-0.107
Na	-0.0737	0.0561	0.9864	0.9904	0.9576	0.7784	0.9884	-0.0449	0.9999	-0.02	0.9576	-0.1006
Ca	0.144	0.462	0.076	0.0594	0.0887	0.347	-0.0471	-0.0095	-0.0285	0.2744	0.0887	0.7899
K	-0.0742	0.0563	0.9859	0.99	0.961	0.7789	0.9879	-0.0504	0.9997	-0.0264	0.961	-0.1021
Mn	-0.0313	0.3636	0.538	0.5265	0.5052	0.6713	0.4488	-0.0158	0.4594	0.2029	0.5052	0.7269
Cr	0.1192	0.2675	0.0009	-0.0061	0.0192	0.0194	-0.0451	-0.1925	-0.0407	-0.2959	0.0192	-0.1324
Co	-0.159	-0.0551	-0.1243	-0.118	-0.0433	-0.1806	0.0028	-0.2621	-0.0818	-0.3833	-0.0433	-0.1114
MPN	-0.0382	-0.1441	-0.2393	-0.2353	-0.2621	-0.2932	-0.2312	0.3219	-0.2194	0.1625	-0.2621	-0.2609

Contd.

Table 4.3-A contd.

Parameter	Zn	Mg	Cu	Ni	Pb	Na	Ca	K	Mn	Cr	Co	MPN
Zn	1											
Mg	0.2894	1										
Cu	-0.0639	-0.1746	1									
Ni	-0.4583	0.1333	0.1034	1								
Pb	-0.0868	-0.1118	-0.0718	0.0496	1							
Na	-0.0845	-0.2072	0.9058	0.0515	-0.0339	1						
Ca	0.3619	0.0248	-0.0877	0.0077	-0.0718	-0.0329	1					
K	-0.082	-0.2092	0.9068	0.0498	-0.0354	0.9998	-0.0323	1				
Mn	0.3194	-0.1697	0.3205	0.0358	-0.0927	0.4555	0.7561	0.4547	1			
Cr	0.5307	0.4924	0.124	0.0496	-0.0345	-0.037	0.0967	-0.0291	-0.0927	1		
Co	0.0181	0.0734	0.0411	0.1098	-0.0763	-0.0767	-0.1244	-0.073	-0.1358	0.2759	1	
MPN	-0.2199	-0.1129	-0.1407	-0.0253	0.427	-0.2144	-0.1395	-0.2219	-0.321	-0.1579	-0.3196	1

Table 4.3-B: Correlation Co-efficient of Monsoon water sample (2017)

Parameter	pH	Turbidity	EC	TDS	TA	TH	Cl	NO ₃	SO ₄	F	HCO ₃	Fe
pH	1											
Turbidity	-0.5009	1										
EC	0.0666	0.1924	1									
TDS	0.0657	0.1741	0.9975	1								
TA	0.0616	0.1758	0.9792	0.9847	1							
TH	0.1171	0.1831	0.9757	0.972	0.9569	1						
Cl	0.0062	0.1268	0.9553	0.9717	0.9608	0.9205	1					
NO₃	-0.1977	-0.0003	-0.0622	-0.0588	-0.0319	-0.0307	-0.0672	1				
SO₄	0.0316	0.1102	0.959	0.9757	0.9682	0.9238	0.9954	-0.0669	1			
F	0.2027	-0.1085	0.0178	0.0074	0.037	0.0738	-0.0812	0.5019	-0.0296	1		
HCO₃	0.0616	0.1758	0.9792	0.9847	1	0.9569	0.9608	-0.0319	0.9682	0.037	1	
Fe	0.0935	0.2713	0.1095	0.0727	0.0508	0.1109	-0.0616	-0.0396	-0.0326	0.4148	0.0508	1
Zn	0.1457	-0.2524	-0.0667	-0.0702	-0.0694	-0.0768	-0.055	-0.1866	-0.0636	-0.3325	-0.0694	0.0735
Mg	0.1613	-0.0183	-0.0221	-0.0349	-0.0603	-0.0203	-0.0516	-0.0197	-0.061	-0.129	-0.0603	-0.1358
Cu	-0.08	0.2355	-0.0467	-0.0479	-0.0288	-0.0221	-0.0374	-0.0153	-0.0349	0.0234	-0.0288	-0.0735
Ni	-0.1928	0.1114	-0.0207	-0.0405	-0.0814	-0.0337	-0.09	-0.2241	-0.0865	-0.2481	-0.0814	0.1912
Na	0.0427	0.1009	0.9584	0.975	0.9657	0.9219	0.9942	-0.0667	0.9995	-0.0233	0.9657	-0.0274
Ca	0.1698	0.2655	0.24	0.1844	0.1546	0.2618	-0.0276	0.0268	-0.0009	0.3951	0.1546	0.6261
K	0.0337	0.104	0.9586	0.9751	0.9679	0.9239	0.9955	-0.0797	0.9992	-0.0525	0.9679	-0.0344
Mn	0.0205	0.2752	0.3588	0.3136	0.2846	0.362	0.1468	0.0018	0.1692	0.373	0.2846	0.8725
Cr	0.064	-0.0593	0.7703	0.7867	0.789	0.7352	0.8213	-0.171	0.8224	-0.2046	0.789	0.0456
Co	-0.2934	-0.1044	-0.1278	-0.1246	-0.1134	-0.1404	-0.0875	-0.1686	-0.0908	-0.4158	-0.1134	-0.0125
MPN	-0.0852	-0.0922	-0.1722	-0.1615	-0.2052	-0.1928	-0.1206	0.1824	-0.1489	-0.2388	-0.2052	-0.2368

Contd.

Table 4.3-B contd.

Parameter	Zn	Mg	Cu	Ni	Na	Ca	K	Mn	Cr	Co	MPN
Zn	1										
Mg	0.4402	1									
Cu	-0.0554	0.0358	1								
Ni	0.0445	0.2227	-0.083	1							
Na	-0.062	-0.0504	-0.036	-0.0842	1						
Ca	0.0279	0.1182	-0.0774	0.1538	0.0062	1					
K	-0.0327	-0.052	-0.0403	-0.0789	0.9984	-0.0036	1				
Mn	0.014	-0.1329	-0.0785	0.3024	0.1713	0.7181	0.1683	1			
Cr	0.4427	-0.0808	-0.0486	-0.117	0.8194	-0.0359	0.8387	0.1769	1		
Co	0.6218	0.1153	-0.082	0.4799	-0.0978	-0.1071	-0.0669	-0.0533	0.2808	1	
MPN	-0.186	-0.1348	-0.0817	0.0393	-0.139	-0.1177	-0.1521	-0.2056	-0.2015	-0.1058	1

Table 4.3-C: Correlation Co-efficient of Post-Monsoon water sample (2018)

Parameter	pH	Turbidity	EC	TDS	TA	TH	Cl	NO ₃	SO ₄	F	HCO ₃	Fe
pH	1											
Turbidity	0.0199	1										
EC	0.0148	0.015	1									
TDS	0.0207	0.0111	0.9979	1								
TA	0.0256	-0.0005	0.9891	0.9954	1							
TH	0.045	0.0469	0.9533	0.9398	0.9187	1						
Cl	0.0437	0.0011	0.9704	0.9837	0.9898	0.8818	1					
NO₃	-0.1876	0.2616	-0.0068	-0.0166	-0.0355	0.0121	-0.032	1				
SO₄	0.0447	0.0091	0.9705	0.9838	0.9904	0.8809	0.9996	-0.0282	1			
F	0.146	0.4502	0.0447	0.0304	0.0267	0.1024	-0.0076	0.4946	0.0067	1		
HCO₃	0.0256	-0.0005	0.9891	0.9954	1	0.9187	0.9898	-0.0355	0.9904	0.0267	1	
Fe	-0.4791	0.4004	0.0263	-0.0068	-0.0295	0.0652	-0.103	0.0246	-0.1017	0.2357	-0.0295	1
Zn	-0.1262	0.097	0.0263	-0.0116	-0.0315	0.0733	-0.082	-0.2365	-0.0896	-0.2196	-0.0315	0.4371
Mg	0.1807	0.2019	-0.1736	-0.1875	-0.209	-0.0685	-0.2214	-0.084	-0.2195	0.1442	-0.209	-0.1443
Cu	0.1616	-0.0857	0.6193	0.6238	0.6082	0.6121	0.6253	-0.1797	0.6197	-0.2212	0.6082	-0.235
Ni	-0.4337	-0.333	0.2124	0.2023	0.1654	0.2566	0.1665	-0.0246	0.1599	-0.337	0.1654	0.0413
Na	0.0487	0.0068	0.9687	0.9825	0.9892	0.8787	0.9998	-0.0335	0.9998	-0.0034	0.9892	-0.1089
Ca	-0.1891	0.2137	0.1399	0.0949	0.0674	0.2577	-0.0459	-0.0051	-0.043	0.2434	0.0674	0.6905
K	0.0283	-0.0126	0.9744	0.9866	0.9936	0.8866	0.9985	-0.048	0.9984	-0.0167	0.9936	-0.0824
Mn	-0.3304	0.1646	0.3963	0.3509	0.3182	0.4727	0.2061	-0.0243	0.2076	0.1828	0.3182	0.7616
Cr	0.0474	0.0032	0.0038	-0.0059	-0.0363	0.0679	-0.0318	-0.1877	-0.0407	-0.3427	-0.0363	-0.1249
Co	0.0033	-0.031	-0.018	-0.0248	-0.0524	0.0279	-0.0437	-0.2018	-0.0529	-0.3927	-0.0524	-0.1469
MPN	0.1262	-0.1091	-0.2336	-0.2238	-0.2128	-0.1104	-0.1932	0.311	-0.1931	0.1183	-0.2128	-0.4045

Contd.

Table 4.3-C contd.

Parameter	Zn	Mg	Cu	Ni	Na	Ca	K	Mn	Cr	Co	MPN
Zn	1										
Mg	0.2968	1									
Cu	0.209	0.1314	1								
Ni	-0.1186	-0.2489	0.2986	1							
Na	-0.0853	-0.2155	0.6259	0.1591	1						
Ca	0.4258	0.0521	-0.0424	-0.0212	-0.0494	1					
K	-0.0688	-0.2292	0.6209	0.1668	0.9982	-0.0132	1				
Mn	0.3433	-0.1645	-0.0055	0.194	0.1991	0.846	0.2357	1			
Cr	0.5336	0.489	0.6254	0.1624	-0.033	0.117	-0.0324	-0.061	1		
Co	0.5025	0.4719	0.6081	0.2003	-0.0444	0.0876	-0.0445	-0.0777	0.9863	1	
MPN	-0.3504	-0.1912	-0.1157	0.0991	-0.1908	-0.2243	-0.2105	-0.3433	-0.1895	-0.201	1

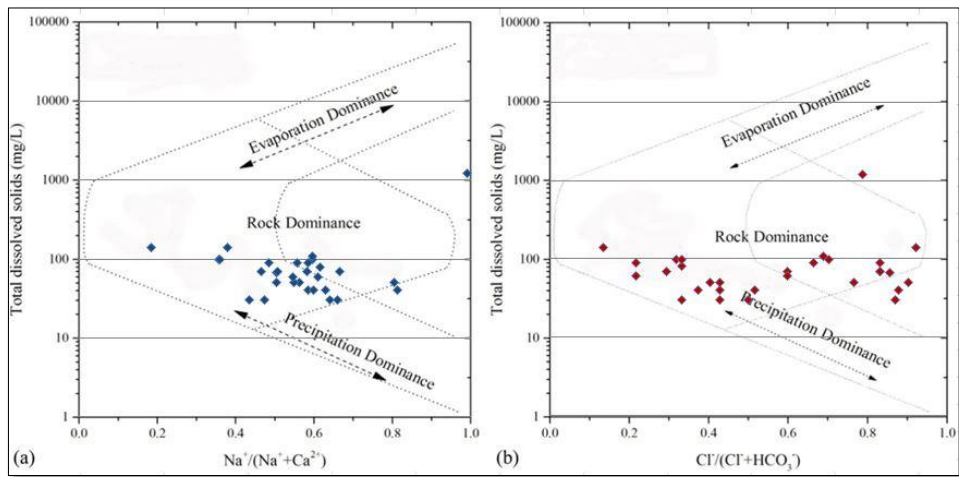


Fig. 3-A: Gibb's diagram of water samples (2016)

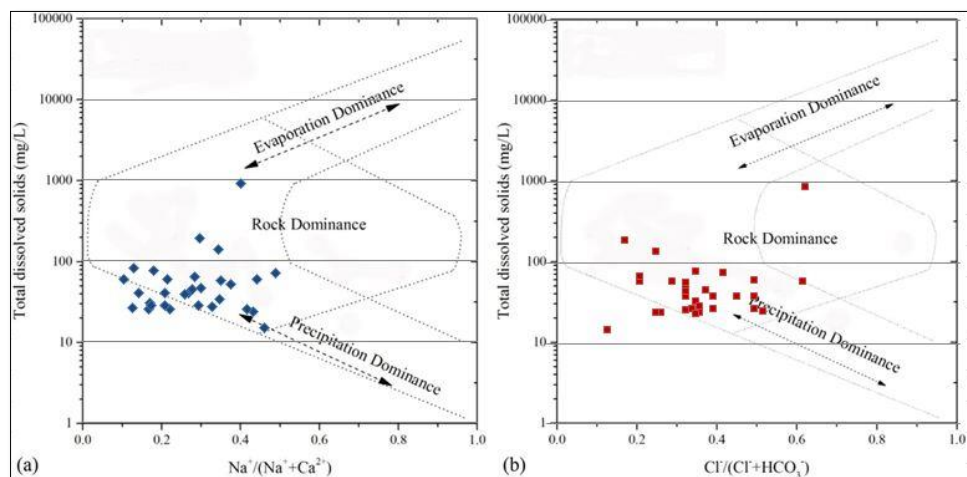


Fig. 3-B: Gibb's diagram of water samples (2017)

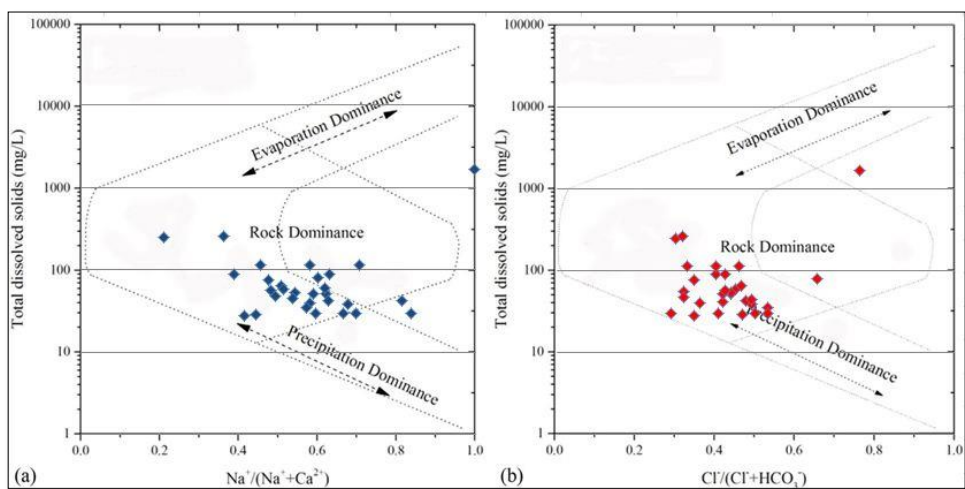


Fig. 3-C: Gibb's diagram of water samples (2018)

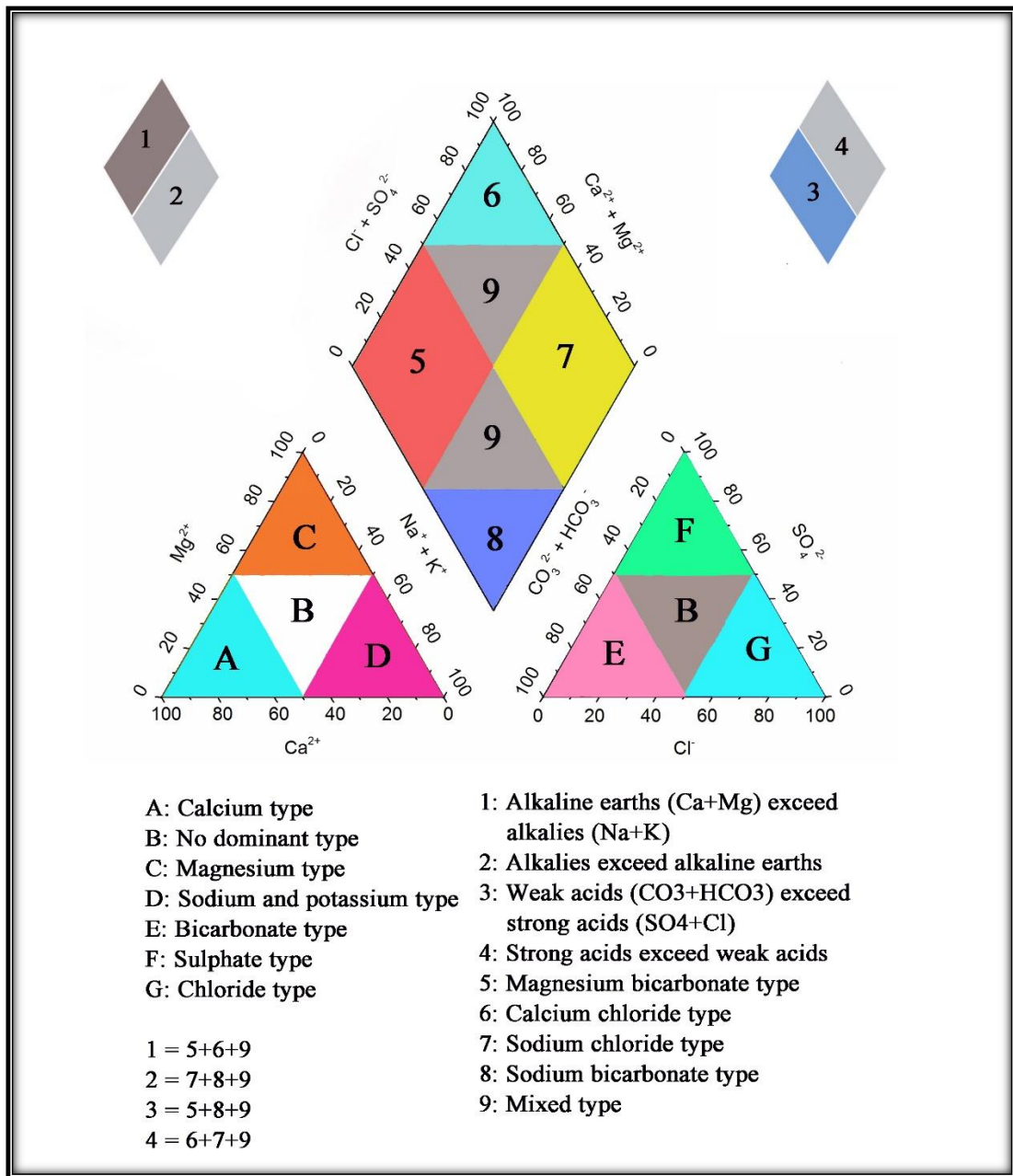


Fig. 4-A: Classification of hydrochemical facies using the Piper diagram

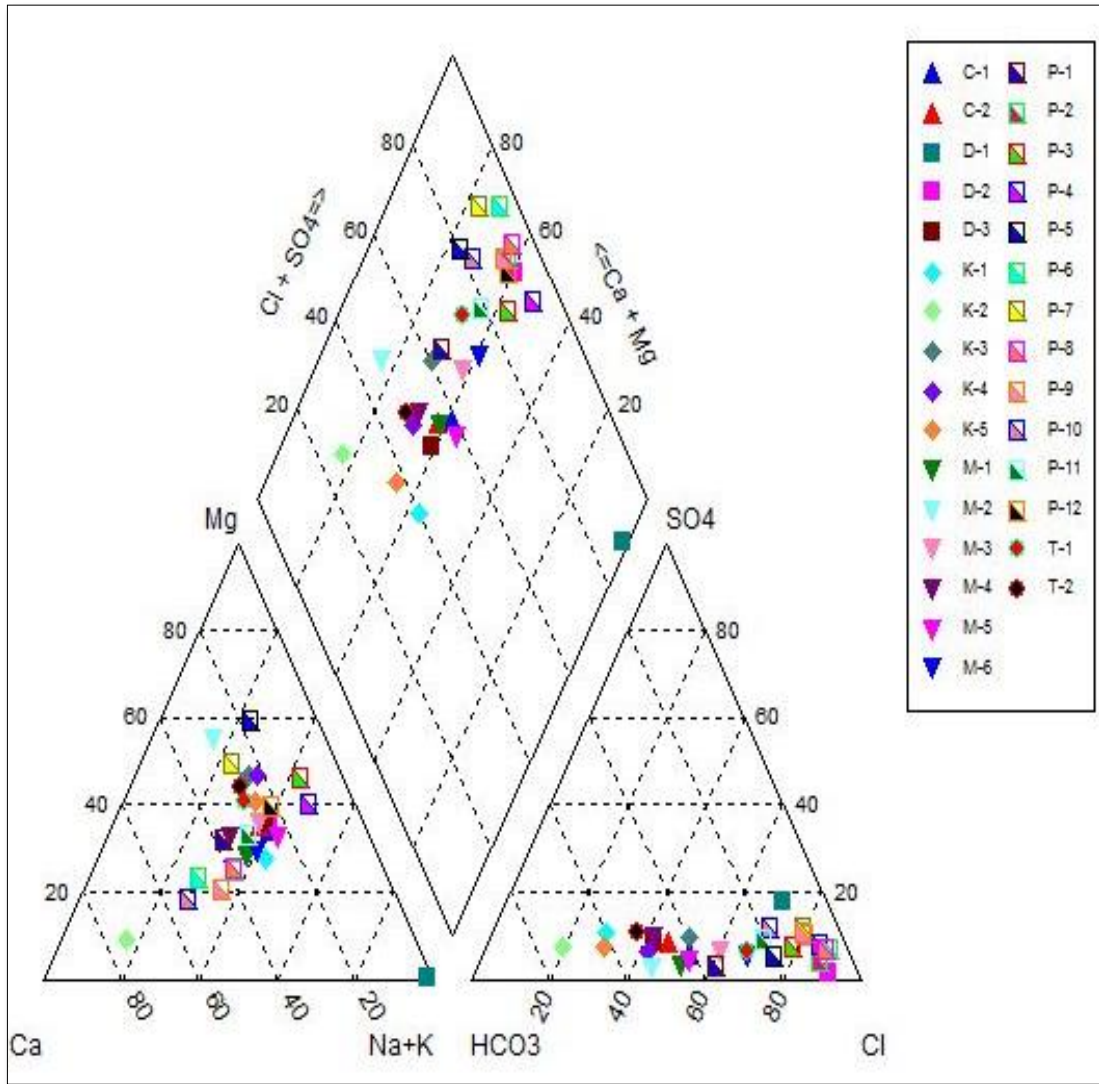


Fig. 4-B: Piper plot of water samples (2016)

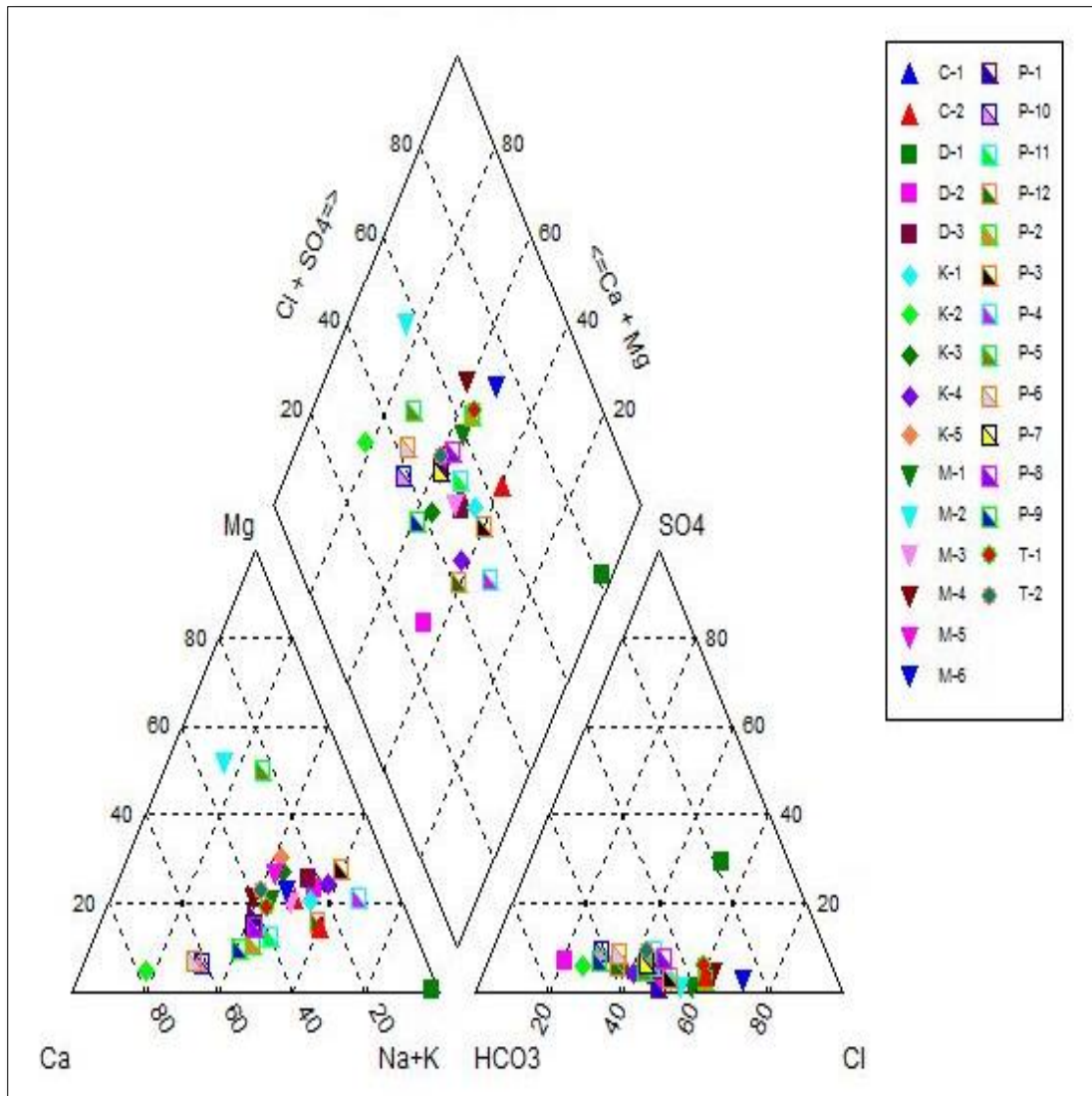


Fig. 4-C: Piper plot of water samples (2017)

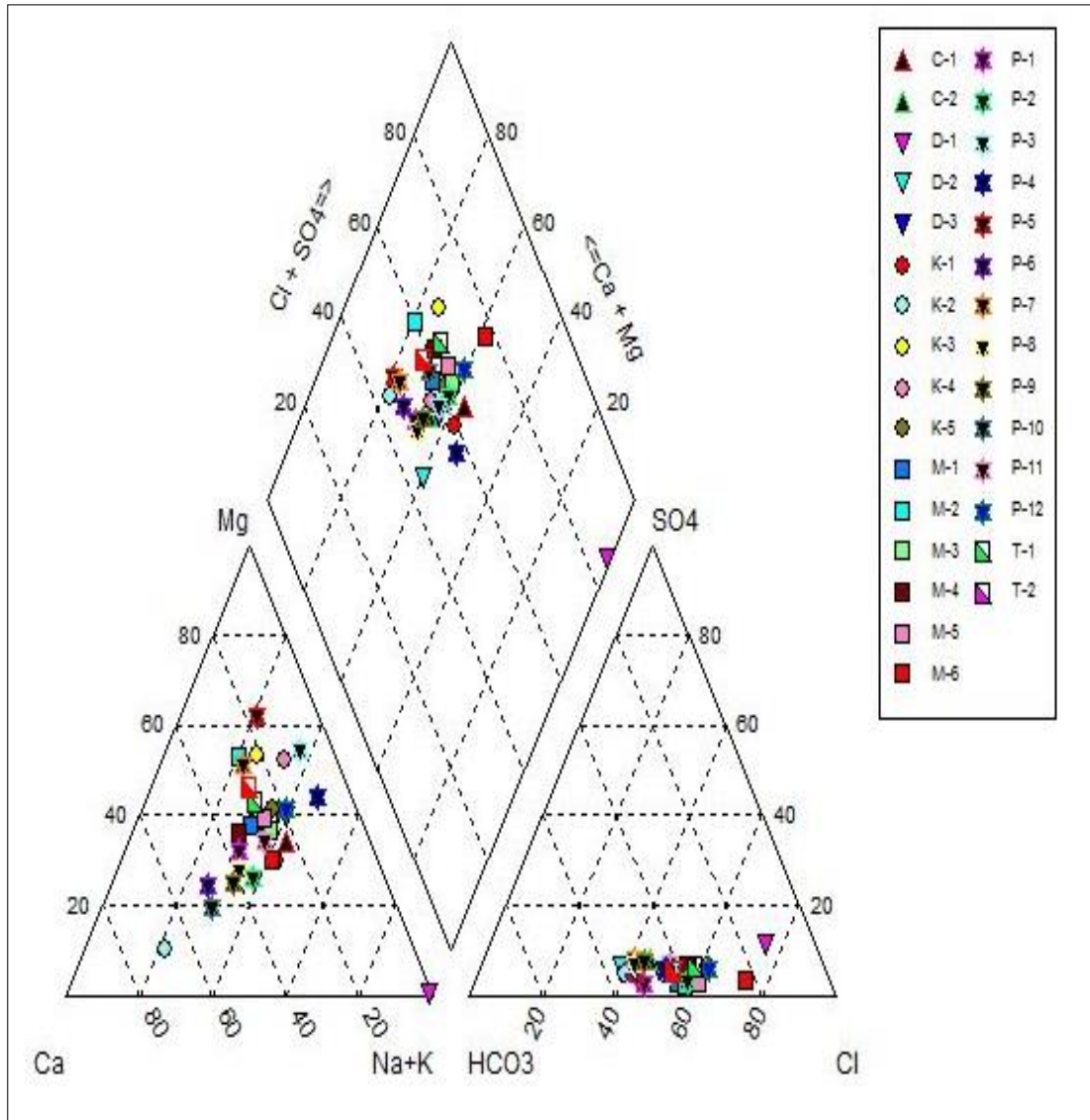


Fig. 4-D: Piper plot of water samples (2018)

CHAPTER 5: DISCUSSION

The water pollution and shortage of water have been the severe critical challenges facing the present humankind. Despite huge reserves of water globally, the accessible amount of freshwater is very less. At the same time, the rapid increase in population has incurred depletion of water resources and contamination of water due to the increasing demands of irrigation and human consumption (Bhat et al., 2016). WHO (2019) reported that more than 700 million of the population in the world lack basic drinking water. Determination of drinking water quality has been indispensable as it is directly linked with human welfare. Recognition of the origins and hydrochemistry of water is of prime importance to ensure access to good quality water for the population (Gao et al., 2019). The hydrogeochemical processes may vary with respect to space and time (Thin et al., 2018). In the present study, 30 water samples are analysed for different physico-chemical and bacteriological parameters. The water samples include 26 Tuikhur water, 3 borehole hand pump water, and one saline water collected from different sampling sites in the study area. The analysed data are compared with the drinking water standard to ensure its suitability for drinking purposes. The CCME WQI water quality is presented in a simple and easily communicable way. The scatter plot is drawn to determine the hydrogeochemical evolution of the samples. The factors controlling the hydrochemistry of water are delineated by plotting Gibb's diagram whereas Piper's plot is deployed to establish the hydrochemical facies of water. To understand the relationship between each parameter Pearson's correlation coefficient is utilized in the study.

5.1 WATER QUALITY PARAMETERS

5.1.1 Physico-chemical characteristics of water sample

The pH value in natural water is reliant on the $\text{CO}_2\text{-CO}_3\text{-HCO}_3$ equilibrium. When this equilibrium is altered, it might induce changes in the pH value of water. The presence of phosphates, silicates, borate, fluorides, and some salt in dissociated form may also influence the pH variation (Karanth, 2016). Because the pH regulated all chemical and biochemical reactions, it is an important parameter (Lalparmawii and

Mishra, 2012). In the present study, the pH value ranges from 6.5 to 8.2 in all seasons. The mean values obtained indicate that the water is slightly alkaline in nature. The pre-monsoon and post-monsoon values are slightly higher in comparison to the monsoon values. The lower values in the monsoon period may be attributed to the dilution of water during rainy seasons (Pallavi et al., 2019). Rainfall during the monsoon period also dissolves certain minerals in the sedimentary rocks like sandstone and shale which may cause a lower pH value of water (Lalbiakmawia et al., 2020). All the values obtained are within the prescribed limit of WHO and BIS.

Turbidity of water is due to the presence of suspended material. Drinking high turbidity water is likely to cause a risk to health as excessive turbidity can protect pathogenic microorganisms from disinfectants and boost bacterial growth during storage (Tiwari et al., 2015). The analysed water samples show that the turbidity is lower than the permissible limit of BIS (5 NTU) in all seasons. Borehole hand pump water samples have a little higher value as compare to the Tuikhur water samples which further shows a higher value during monsoon seasons. This slightly increasing turbidity value during the monsoon period indicate that there may be the presence of inorganic particulate matter and non-soluble metal oxides (Shigut et al., 2017).

The electrical conductivity (EC) of water is its ability to conduct electrical currents. EC indicates the ion concentration in water and higher values of EC in water signifies a higher concentration of ions in water. The EC of water samples in the present study reveal a wide range of values. The D-1 sample show a high levels of EC value every season indicating a higher amount of dissolved inorganic substances present in water. The pre-monsoon and post-monsoon values are higher when compared to the monsoon value, which suggest the enrichment of salt due to enhance evaporation in the pre-and post-monsoon and could also be due to the inflow of high quantum of domestic sewage (Kumar et al., 2009; Gayathri, 2013). While the lower value during the monsoon is an indicative of dilute groundwater due to rainfall (Kumar et al., 2010). EC and TDS are strongly correlated in every season.

The total concentration of dissolved constituents (minerals) in water is referred to as total dissolved solids (TDS). It comprises inorganic salts (principally calcium,

magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and small amounts of organic matter that are dissolved in water (WHO, 2017). It is always related to lithology, the residence time of the water below the surface and weathering processes of an area, sewage from urban and industrial waste. A high TDS value is observed from the D-1 sample in all the seasons in the present study. The acceptable limit of TDS prescribe by BIS (2012) is 500 mg/l and the highest permissible limit for the same is 2000 mg/l. The presence of TDS above this limit in groundwater would cause undesirable taste and gastrointestinal irritation (Selvakumar et al., 2014). Thus, the D-1 sample show the values above the highest permissible limit during post-monsoon of 2016, pre- and post-monsoon of 2017, and post-monsoon of 2018 seasons. The higher values may be attributed to the weathering processes in the subsurface region, resulting in higher ionic concentrations. All other samples are well below the acceptable limit. It is also observed that hand pump water attains slightly higher values than Tuikhur water. Lower values of TDS during monsoon may be attributed to dilution due to the high influx of water in the rainy season.

Alkalinity is a measure of the acid-neutralizing ability of water. it is normally due to the presence of bicarbonate, carbonate, and hydroxide compound of calcium, sodium, and potassium (Patil and Patil, 2010). The BIS set a standard limit of alkalinity in drinking water which should range between 200 mg/l to 600 mg/l. The analysed data in this study show values lower than the permissible limit. Both D-1 and handpump water has a higher value than the other water samples. Absence of carbonate and hydroxide ions in the water indicate that bicarbonate ion seems to be the main causes of alkalinity in the water samples of the study area.

Hardness is the quality in water that destroys the property of soap to form lather. Hardness determination is usually reported as total hardness, carbonate hardness, and non-carbonate hardness. Total hardness is the sum of the other two. The hardness of the water in the present study does not show a significant variation in different seasons. When compared with the drinking water standard made by BIS (2012) (600 mg/l), all the samples fall within the permissible limit. The TH values of the D-1 sample show the highest amongst the water samples in all the seasons. Seasonally, the pre- and post-monsoon values are slightly higher than the monsoon

values. The increase in hardness can be attributed to the decrease in water volume and increase in the rate of evaporation at high temperatures (Thirupathaiah, 2012).

Chloride is an important anion constituent that occurs naturally in water. Various sources contributed presence of chloride in water such as weathering of rocks, seepage from sewage and wastewater, seawater intrusion, and industrial activity. It is regarded as a vital nutrient of human health and is primarily derived from foods, with only a small proportion of the normal intake of drinking water. Chloride occurs naturally in some sedimentary bedrock layers, particularly shale, and the high content of Chloride in groundwater may give a salty taste, can corrode pipes, pumps, and plumbing fixtures (Mor et al., 2009). The guidelines for WHO (2017) and BIS (2012) recommend a desirable limit for chloride levels of 250 mg/l in water. In the present study, Cl⁻ concentration of D-1 water is more than the permissible limit (250 mg/l) of WHO (2017) and BIS (2012) regardless of the season. The post-monsoon seasons generally showed a higher concentration of Cl⁻ than the other seasons which may be due to seepage with rainwater during the rainy season ascending to the aquifer that increased the Cl⁻ the content of the groundwater (Mor et al., 2009). Since no other springs of this type were found adjacent to the sampling site, it indicates that the presence of confined aquifers (Oinam et al., 2012). The concentration levels of Chloride in other samples are below the permissible limit of the standard.

Generally, nitrate concentration in water is not derived from rocks. Nitrates in natural water come from organic sources or industrial and agricultural chemicals, sewage wastes, etc. Epidemiological evidence suggests that nitrate-nitrogen exposure is strongly associated with several diseases, such as methemoglobinemia (blue baby syndrome), gastric cancer, thyroid disease, and diabetes (Kumar et al., 2011). Nitrate concentrations in the present study are low ranging between 0.18 mg/l and 0.85 mg/l. The value lies below the acceptable limit of WHO (50 mg/l) and BIS (45 mg/l) within the assessment period irrespective of the seasons. Less use of fertilizers and algal assimilation may be another reason for the low content of NO₃⁻ in water samples (Chimwanza et al, 2006).

Sulphate in water may be derived from beds of gypsum, sodium sulphate deposits, and some types of shale. It is a naturally occurring ion in almost all kinds of water bodies and is a major contributor to total hardness (Mor et al., 2009). Sulphate is considered to be non-toxic for humans, but it is likely to react with human organs if the concentration exceeds the maximum allowable limit (Kumar et al., 2015). Sulphate concentrations in the D-1 sample in the study area shows the highest value which ranges from 290 mg/l to 328 mg/l. However, all the values are below the maximum permissible limit in all the samples.

The principal sources of fluoride in groundwater are mineral fluorite, but apatite and mica also contributed to the formation of fluoride. Since their solubility is low, the concentration of fluorides in waters was generally low. A small quantity of fluoride is required for the healthy growth of teeth and prevention of dental caries, but high levels of excess fluoride intake from drinking water cause crippling skeletal fluoride (Mor et al., 20019). The presence of fluoride in drinking water may cause mottling of teeth depending upon the concentration of fluoride, the age of the child, and the amount of water consumed. The highest permissible limit prescribed by WHO (2017) and BIS (2012) for fluoride in drinking water is 1.5 mg/l. The concentration of fluoride in the present study is found to be ranging from 0.17 mg/l to 0.5 mg/l which are lower than the permissible limit in all the water samples every season. The low level of fluoride in water samples may be attributed to the lack of fluoride-bearing minerals in the strata through which water is filtering (Bharati, 2011).

Iron is dissolved practically from all rocks particularly from the mineral pyroxene, magnetite, pyrite, etc. It is commonly present in igneous rocks and also present as a trace in sedimentary rocks. Water may dissolve iron from metallic iron in pump sets, casing, and distribution pipes, etc. Iron is an essential element in human nutrition and the estimated minimum daily requirement for iron depends on age, sex, and iron bioavailability and ranges from about 10 to 50 mg/day (Chennaiah et al., 2014). A large concentration of iron in water causes an unpleasant taste and favours the slimy growth of iron bacteria. In the study area, all the hand pump samples have a concentration of iron higher than the permissible limit (0.3 mg/l) in all the seasons. This higher value may be due to the leaching of cast iron pipe in the hand pump

(Ramngaihawma et al., 2021). Among the Tuikhur samples, C-2, K-3, M-5, M-6, P-1, P-2, P-11, P-12, and T-2 also have a slightly higher value of iron in different seasons. While in other samples, the value of iron was lower than the prescribed limit and the concentration was even below the detection limit in some water samples. According to WHO (2017), the levels of iron found in drinking water is not of health concern.

The common sources of magnesium and are dolomite, olivine, serpentine, talk, etc. They also occur in conjunction with calcium minerals. The geochemistry of magnesium is quite similar to that of calcium. Magnesium is beneficial for the heart and nervous system of the human body. It also works as a laxative. The magnesium concentration of all the water samples is less than the prescribed permissible limit. Calcium is dissolved practically from all rocks but is usually found in greater quantities in water leaching deposits of limestone, dolomite, gypsum, or gypsiferous shale. Calcium is useful in providing essential micronutrients, but the recommendation regarding the minimum concentration of calcium element was not made because of the uncertainties surrounding mineral nutrition from drinking water (WHO, 2017). The fluctuation of calcium in the water samples is within the standard prescribed limit.

Sodium in natural water comes mainly from the weathering of plagioclase feldspar. They are carried away from rocks and sediments in solution. Clay minerals may release large quantities of exchangeable sodium. Ancient brines, seawater, industrial waters, and sewage may add some sodium (Ramakrishnan, 1998). In the general case, sodium is the dominant ion among the cations and is present in most of the natural waters because of the silicate weathering and/or dissolution of soil salts stored by the influences of evaporation, anthropogenic activities, agricultural activities, and poor drainage conditions (Kumar, 2015). The sodium concentration of most water samples in the present study is low as compare to the standard limit of WHO (2107). But, the D-1 samples show high values of sodium all the season ranging from 253.33 mg/l to 1066.67 mg/l which may result from the dissolution of silicate minerals and/or cation exchange. A slightly decreasing value is observed in the monsoon period due to the high amount of water diluting the concentration of sodium. Potassium is derived during the process of weathering rocks. All the natural water contains measurable amounts of potassium and is essential to animal nutrition. The

source of potassium in potable water is weathering of silicate minerals especially potassium feldspar and mica (Allan and Castillo, 2006). Potassium is a dietary requirement for human being which protect the heart and arteries and may also prevent cardiovascular diseases. The concentration of potassium in the water samples of the study area ranges from 0.06 mg/l to 126 mg/l. The low concentration of potassium may be attributed to the resistance of potash minerals to weathering and decomposition.

Manganese is one of the most abundant metals in Earth's crust, usually occurring with iron (WHO, 2017). It resembles iron in its chemical behaviour and occurrence, but its concentration is generally less than iron and is often found in iron-containing waters. Manganese in drinking water is associated with neurological damage (Chennaiah et al., 2014). Chemically it can be considered a close relative of iron since it occurs in much the same forms as iron. The concentration of manganese in hand pump waters is higher than the Tuikhur waters in the study area in all seasons. The value of manganese in hand pump water ranges from 0.05 mg/l to 0.28 mg/l. Several samples are also found to have no manganese concentration in different seasons. None of the water samples in each season exceed the highest permissible limit.

Zinc is a very common substance and many foodstuffs contain a certain amount of zinc. It is one of the important trace elements that play a vital role in the physiological and metabolic process of many organisms (Mebrahtu and Zerabruk, 2011). The concentration of zinc in water is higher in an area of zinc mine. Industrial activity and waste combustion also add to the concentration of zinc. Zinc in trace or small concentration is essential for health and shortage of it may cause loss of appetite, decreased sense of taste and smell, and slow healing of a wound. Most of the water samples in the present study have a concentration of zinc below the detection limit. The highest zinc concentration observe is 0.35 mg/l from M-2 during post-monsoon of 2018 which was well within the acceptable limit. Cadmium is found in nature largely in the form of sulphide and as an impurity in zinc-lead ores. Sources of Cd in water include weathering of minerals and soils, discharge of domestic effluents, and urban storm-water runoff containing Cd-laden materials (Lawson, 2011). It is considered to have an undesirable toxic effect, usually causing nausea. In this study,

cadmium concentration in water samples has not been observed and is found below the limit of detection in all the seasons.

Copper minerals are relatively insoluble and only very low concentrations can be expected from natural sources. It imparts a disagreeable metallic taste to water. Excessive intake of copper may induce nausea, vomiting, diarrhoea, and headaches. Only a few samples showed the presence of copper in the study area. The standard value of copper in drinking water prescribed by WHO (2017) and BIS (2012) are 2 mg/l and 1.5 mg/l respectively. The observed copper values are well below the permissible limit in all the seasons. The presence of nickel in drinking water is due to leaching from metals, such as pipes and fittings. It may also be added into groundwaters from the dissolution of nickel ore-bearing formation of rocks. Its toxicity is enhanced in the presence of other metals such as cobalt, copper, iron, and zinc in drinking water (Hanaa et al., 2000). The acceptable limit of nickel in drinking water is 0.02 mg/l and there is no relaxation beyond this value. The highest nickel concentration in the present water samples is 0.01 mg/l which is within the acceptable limit of the standard and its value in some water samples is found to be below the detection limit. Lead is considered as a toxic metal that higher concentration in drinking water is harmful which may cause mental retardation, kidney, and neurological disorder, hypertension, etc. Lead is the most significant of all the heavy metals because it is toxic, very common, and harmful even in small amounts (Gregoriadou et al., 2001). The presence of lead in drinking water should not exceed 0.1 mg/l and there is no relaxation for the upper limit. From all the water samples analysed, only K-1 shows the presence of lead concentration in the post-monsoon 2018. The concentration of lead is not found in other samples in all seasons.

The main sources of chromium in water are industrial sewage and mining sites. A very little amount of chromium is needed by our body and excess intake of this form may cause irritation of the skin, digestive problems, and lung cancer (Jamshaid et al., 2018). In the majority of the water samples concentration of chromium is not observed during the study is carried out. Only four samples show the presence of chromium where its concentration is less than the acceptable limit i.e., 0.05 mg/l. The concentration of cobalt is observed from a few samples and most of the samples recorded zero

concentration of cobalt and the value below the limit of detection. The WHO (2017) and BIS (2012) do not specify the permissible limit of cobalt present in water. Cobalt is a naturally occurring element and inhalation and dermal exposure to cobalt in humans can result in sensitization (Chennaiah, et al., 2014).

Arsenic is a toxic element present naturally in some water, but the occurrence of quantities detrimental to health is rare. Insecticides, weed killers, and many industrial effluents contain Arsenic that are potential sources of water pollution. Long-term exposure to high levels of inorganic arsenic includes pigmentation changes, skin lesions, and hard patches on the palms, and in extreme conditions, skin cancer, and tumours in kidneys, lungs, bladder, and liver may result (Jamshaid, 2018). The concentration of arsenic was not detected from the water samples in all three seasons during the assessment period.

5.1.2 Bacteriological characteristics of water

The bacteriological analysis of water is performed to identify the presence of pathogens which are disease-causing organisms. Coliform bacteria are non-pathogenic bacteria normally found in the intestinal tract of animals and humans. They are an indicator organism and the presence of these organisms in water is an indication of contamination with fecal pathogens. High coliform populations in all the water samples are an indication of poor sanitary conditions in the community (Bharati, 2011). The water samples are analysed for the presence of total coliform in the present study using multiple tube fermentation technique and the value is expressed as MPN per 100 ml of sample. The water samples which exceeded the MPN value indicate the presence of coliform (Kanth, et al., 2018). The WHO (2017) and BIS (2012) prescribed that the presence of coliform in drinking water should be nil/100 ml.

The MPN values of the water samples ranged between 3/100 ml to 29/100 during the whole period of study (Table 4.1 & Fig. 5.1). Out of 30 water samples, 10 samples (C-2, K-1, M-1, M-2, M-3, M-5, M-6, P-2, P-8, and P-9) have the MPN values which specifies that coliform is present in such water samples. The higher value may be attributed to the use of pit latrines, piggeries, and poultries (Rajurkar et al, 2003). This is evident from the fact that improper human waste management, piggeries, and

poulties are prevalent in the sampling site nearby where the presence of coliform is deduced in water. The coliform density is found to be higher during the monsoon season. It is because the bacteriological load is highest during the onset of monsoon since faecal matter around the water sources is flushed into the water sources (Dhawde et al., 2018).

5.2 WATER QUALITY INDEX

A water quality index is a single numeric value that can describe the overall water quality in the simplest form of an index at ascertain location and time based on several water quality parameters (Prajapati and Bilas, 2018). Among the proposed different methods of water quality index, the CCME WQI method is employed incorporating various physico-chemical analysed data to deduce the water quality in the present study. In the CCME WQI method, the calculated WQI values are categorized into five, and ratings are given based on the degree of WQI values such as excellent, good, fair, marginal, and poor. A total of 13 variables are studied which involved 39 tests each for the three index periods.

From the result of the calculate water quality index values, it has been inferred that the D-1 sample is categorized as fair quality in all three index periods as it engages with a different number of failed tests in each period. The lower value of WQI for the D-1 sample may be attributed to the higher value of TDS along with a high concentration of chloride. These two parameters also show the highest failed tests data in the D-1 sample. The high-value trending of TDS and Cl is record in all the seasons within the three index periods. Besides, all the hand pump water samples (K-2, P-6, and P-10) are also found to have good quality during the whole index period, except in 2017 (Table 4.2-B) where the K-2 samples shows excellent quality. The iron concentration in hand pump water samples is generally high exceeding the permissible limit in all seasons which attributed to the lower value of WQI for these water samples. In the index period of 2018, the observed WQI value of K-3 and P-1 samples are 94.2 and 94.9 respectively, and categorize under good quality. But these samples are found in the good category in the other years.

5.3 DRINKING WATER SUITABILITY OF THE SAMPLES

Water is one of the prime elements crucial for the sustenance of life which further influence socio-economic growth. The suitability of water for a specific purpose depends upon its acceptable quality which may differ from one region to another. The analysed water samples from the study area are compare with the WHO (2017) and BIS (2012) standard for drinking water (Table 5.1) to determine its suitability for drinking purposes. It has been observed from the analysis that most of the physico-chemical characters of the samples are found to be within the standard limit and suitable for drinking purposes. However, the D-1 samples show a contrast quality in every season than the other water samples.

It is apparent from the result that the levels of EC, TDS, and Cl in the D-1 sample is above the highest permissible limit. Base on the salinity classification of water with respect to their TDS values (Robinove et al., 1958), the D-1 sample is classified as slightly saline water (Table 5). Hence, it may be considered unsuitable for drinking purposes. Iron content in the hand pump water is slightly higher than the permissible limit of drinking water standard in almost all the seasons producing a metallic taste. But it has been agreed that iron does not cause a direct health effect on a human. Except for iron, all the heavy metals have their level below the acceptable limit. As the presence of coliform bacteria is detected in the water samples of C-2, K-1, M-1, M-2, M-3, M-5, M-6, P-2, P-8, and P-9, direct consumption of those waters may be unsafe and prior treatment is imperative before consumption.

Table 5: Salinity classification of water

Class	Total Dissolve Solids (ppm)
Freshwater	<1000
Slightly saline	1,000 – 3,000
Moderately saline	3,000 – 10,000
Very saline	10,000 – 35,000
Brine	>35,000

Table 5.1: Drinking water quality standards

Parameters	WHO Standard (2017)	BIS Standard (2012)
pH	6.5 – 8.5	6.5 – 8.5
Turbidity	–	1 - 5 NTU
Electrical Conductivity	<2500 μ S/cm	–
Total Dissolve Solids	–	500 – 2000
Total Hardness	–	200 – 600
Total Alkalinity	–	200 – 600
Chloride	250	250 – 1000
Nitrate	50	45
Sulphate	250	200 – 400
Fluoride	1.5	1.0 – 1.5
Iron	–	<0.3 ppm
Zinc	3 ppm	5 – 15 ppm
Magnesium	–	30 – 100 ppm
Sodium	200 ppm	–
Calcium	–	75 – 200 ppm
Copper	<2 ppm	0.05 – 1.5 ppm
Potassium	–	–
Manganese	0.5 ppm	0.1 – 0.3 ppm
Cadmium	<0.003 ppm	<0.003 ppm
Nickel	<0.02 ppm	<0.02 ppm
Lead	<0.01 ppm	<0.01 ppm
Chromium	<0.05 ppm	<0.05 ppm
Cobalt	–	–
Arsenic	<0.01 ppm	<0.01 ppm

5.4 GEOCHEMICAL EVOLUTION OF WATER

The chemical analysis of major ion's binding characteristics may give some insight into the geochemical properties of the water source which induced variation in water quality. Scatter diagrams are used to describe the geological process and the sources of major components of water in the study area. Generally speaking, the dissolved major cations and anions in the groundwater are mainly imparted by the weathering processes of silicate and carbonate. As silicate weathering is one of the most important geochemical processes controlling the major ions chemistry of the

groundwater, it can be understood by estimating the ratio between total cations versus (Na+K) and (Ca+Mg) from the water quality data (Thin, et al., 2018; Kumar, et al., 2006). In the scatter diagram of total cation vs (K+Na) (Fig. 5-A), the majority of the samples fall above 1:1 equiline indicating the silicate weathering as the main geological process which governs the contributions of sodium and potassium ions to the groundwater (Stallard and Edmond 1983). Further, Na and K ions may also add to groundwater by weathering of feldspar. In the total cation vs (Ca+Mg) plot (Fig. 5-B), all the samples are above 1:1 equiline which indicates calcium and magnesium ions come from weathering of silicate minerals (Ghrefat, 2014).

The scatter plot of Ca+Mg vs SO_4+HCO_3 is indicative of the origin of major components on groundwater. If the samples cluster along or close to the 1:1 line, the dissolutions of calcite, dolomite, and gypsum are the dominant reactions in a system (Kumar, et al., 2006). The excess of Ca+Mg over SO_4+HCO_3 signifies the influence of carbonate weathering whereas the excess of SO_4+HCO_3 implies a non-carbonate source. This plot can also be used to determine the process of ion exchange that if the samples are falling above the 1:1 line, reverse ion exchange is a dominant reaction in groundwater, while the samples below the 1:1 line suggest the ion exchange as a dominant process (Gao, et al., 2019). The Ca+Mg vs SO_4+HCO_3 plot (Fig. 5-C) shows that most of the samples are located above the 1:1 line except the D-1 sample which falls far below the 1:1 line indicating the reverse ionic exchange as the significant process affecting the composition of water. Deviation of a majority of the samples from the 1:1 line in the Ca+Mg vs SO_4+HCO_3 and Ca vs SO_4 plot (Fig. 5-D) reflect the prevalence of both silicate and carbonate weathering as a geochemical process, while the dissolution of calcite, dolomite, and gypsum are not the dominant sources of calcium, magnesium, and sulphate in water. The plot Ca+Mg vs Cl (Fig. 5-E) showing calcium and magnesium do not increase with salinity is an indication of reverse ion exchange except for a few samples.

The ratio of (Ca+Mg)/ HCO_3 (Fig. 5-G) also suggests that Ca and Mg are added to the solution at a lesser rate than the HCO_3 ratio as some of the samples are found at a ratio below 1 (Kumar, et al., 2016). However, the sources of Ca and Mg may attribute to carbonate and silicate weathering since the samples spread above and below 3 of

(Ca+Mg)/HCO₃ ratio. If the evaporation process is dominant, assuming that no mineral species are precipitated, the Na/Cl ratio would be unchanged (Jankowski and Acworth 1997). The plot of Na/Cl vs EC (Fig. 5-F) shows an incline trend line which signifies that evaporation may not be the dominant process for the geochemistry of water. This result has also been justified by Gibb's diagram. If halite dissolution is responsible for the occurrence of sodium, the Na/Cl molar ratio should be approximately equal to 1, whereas a ratio greater than 1 is typically interpreted as sodium released from a silicate weathering reaction (Meybeck, 1987). The molar Na/Cl ratio of the water samples in the present study reveal that the majority of the samples are having Na/Cl molar ratio above 1 indicating that weathering of silicate minerals is the process that derived Na into water. D-1 samples have Na/Cl molar ratio approximately equal to 1 which indicates halite dissolution in water. The lower molar ratio in some samples is probably the result of the ion exchange of Na for Ca and Mg in clays (Tiwari and Singh, 2014).

The halite dissolution in water releases equal concentrations of Na and Cl into the solution and the resulting Na/Cl molar ratio will be approximately one (Hounslow, 1995). The Na vs Cl plot (Fig. 5-H) showed that the sodium concentration of most of the samples exceeds over chloride concentration distributing above 1:1 equiline which indicates silicate weathering as the source of sodium. Meanwhile, D-1 samples are found along 1:1 equiline suggesting both sodium and chloride released from halite dissolution. Likewise, deviating the samples from the 1:1 line in the Ca+Mg vs HCO₃ plot (Fig.5-I) indicates that carbonate weathering is not the principal geochemical process that controls the water chemistry.

5.5 MECHANISMS CONTROLLING THE WATER CHEMISTRY

Generally, some of the natural components like lithology of the area, subsurface structure, and hydrogeological aspects have greatly influenced the geochemistry of water. Gibb's diagram is use to understand the relationship between water composition with their respective aquifer characteristics such as rock-water interaction, rainfall dominance (chemistry of precipitated water), and evaporation dominance (rate of evaporation) for groundwater chemistry (Selvakumar, et al., 2017). In the present study, Gibb's diagram has been employed to determine controlling factors of the hydrochemistry of water from different sources. The concentration of

TDS is compared with the weight ratio of $\text{Na}/(\text{Na}+\text{Ca})$ and $\text{Cl}/(\text{Cl}+\text{HCO}_3)$ to understand the mechanisms controlling the water chemistry (Gibbs, 1970). From the Gibbs diagram of water samples in the study area, most of the samples are distributed within the rock-water interaction dominance zone except a few samples which fall in the precipitation dominance zone. The samples lumping in the rock-water interaction dominance zone is an indication of the chemical weathering of rock-forming minerals as the principal process that controls the contribution of ions in water. D-1 sample is always found to be located at the upper part of the zone suggesting the higher value of TDS and a little influence of evaporation on the chemistry of water. Since the sampling site of D-1 is thickly covered by vegetation, the transpiration of the vegetation may result in a larger evaporation discharge (Li, et al., 2021). It has been observed that a few water samples are found outside the solid line, which may indicate the other process controlling the chemistry of groundwater, such as cation exchange (Wang, et al., 2019) or anthropogenic activities.

5.6 HYDROGEOCHEMICAL FACIES

Facies are recognizable parts of various characters belonging to any genetically related system and hydrochemical facies are distinct zones that possess cation and anion concentration categories (Sadashivaiah et al., 2008). To understand the hydrogeochemical facies of water in the study area, a Piper diagram is drawn by Aquachem 2014 in the present work. The classification of hydrochemical facies of water samples is based on their location in the ternary plots (Fig. 4-A). The Piper plot allows easy visual chemical comparisons of the chemistry of water samples, identification of water with similar chemical characteristics, evaluation of mixing among waters having different characteristics, and possible determination of the chemical evolution of groundwater (Ging, et al., 1996).

From the Piper plot, the samples of 2016 concentrate in the zone 5, 6, 7 and 9 of the diamond field. The dominant water types may arrange as mixed types > Mg- HCO_3 , Ca-Cl > Na-Cl. The distribution of samples in the zone 1 and 2 indicate that the alkaline earth metal ions exceed the alkali metal ions, while the location of the samples in zone 3 and 4 infer that strong acids are higher than that of weak acids. For cations, 80% of the samples are no dominant type falling in zone B. Two samples each fall in

the A and C zone of calcium and magnesium dominant type respectively. One sample fall in zone D where sodium and potassium are dominant ions. 70% of the samples are chloride dominant type in the anion triangle. Only three samples are no dominant type whereas six samples fall in the E zone indicating bicarbonate dominant type of water. The water types of 2017 samples in order of abundance are mixed type $> \text{Mg-HCO}_3 > \text{Na-Cl}$. The larger number of samples in zone 1 than zone 2 suggests the dominance of alkaline earth ions over alkali metal ions. When comparing the distribution of water samples in zone 3 and zone 4, it has been observed that strong acids exceed weak acids. For cations, the majority of the samples are no dominant type, three samples are calcium dominant, two samples are magnesium dominant and another nine samples are falls in zone D where sodium and potassium dominate. In the case of the anion field, twelve samples are bicarbonate dominant falling in the E zone. Zone B encompasses eight samples indicating no dominant type and ten samples are falling in zone G where chloride dominates. Similar water types of the previous year are found from the water samples in 2018. All the samples accumulate in the zone 9, 5 and 7 of a diamond field where the water types obtain are mixed types $> \text{Mg-HCO}_3 > \text{Na-Cl}$. The accumulation of samples in zone 1 indicates the predominance of alkaline earth metals exceeding the alkali metals. It is also observed that strong acids exceed weak acids since most of the samples are found to be distributed in zone 4. Concerning cations, 70% (21 samples) of the water samples fell in the B zone of no dominant types, two samples are calcium dominant, six samples are magnesium dominant and one sample is sodium and potassium dominant type. Further, in the anion field, 67% (20 samples) are chloride dominant falling in the G zone. Six samples are bicarbonate type and another four water samples are no dominant type. Thus, the hydrogeochemical facies of water in the present study can be classify as water types of mixed types, Mg-HCO_3 , Ca-Cl , and Na-Cl .

5.7 CORRELATION ANALYSIS

Correlation analysis is a statistical method applied to measure and assess the strength of the relationship between two hydrochemical parameters. A high correlation coefficient implies a good strong relationship between the two variables, and a correlation coefficient of approximately zero implies that there is no relationship

between the two variables (Venkatraman, et al., 2013). In the present work, Pearson's correlation coefficient is used to establish the relationship between various parameters. Strong positive correlations are found between EC and TDS in all the samples which indicates that the conductivity of the water samples increases as the dissolved constituents in the water increase. EC is also strongly correlated with TA, TH, Cl, SO₄, HCO₃, Na, K in all the seasons indicating that these ions take part in various physico-chemical reactions. There is a strong positive correlation between Na and Cl suggesting the same source of these ions. pH shows a negative or low correlation with all the parameters. TDS exhibits a positively high correlation with TA, TH, Cl, SO₄, HCO₃, Cu, Na, and K indicating that these may be the sources of dissolved constituents in water. A strong correlation between SO₄ and HCO₃ may be inferred as an ionic exchange process occurring in the aquifer. Some parameters such as turbidity, NO₃, F, Fe, Zn, Mg, Pb, Co, Ni, Mn, and Cr have a low correlation with other parameters.

Table 5.2: Characterization of water samples based on Piper tri-linear diagram

Sub-division of the diamond field	Characteristics of corresponding subdivisions of diamond-shaped fields	Percentage of samples in this category		
		2016	2017	2018
1	Alkaline earth (Ca+Mg) exceeds alkalies (Na+K)	97	70	97
2	Alkalies exceed alkaline earth	3	30	3
3	Weak acids (CO ₃ +HCO ₃) exceed Strong acids (SO ₄ +Cl)	23	30	23
4	Strong acids exceed weak acids	77	70	77
5	Magnesium-bicarbonate type	23.5	30	23
6	Calcium-chloride type	23.5	0	0
7	Sodium-chloride type	3	20	3
8	Sodium-bicarbonate type	0	0	0
9	Mixed type (No cation-anion exceed 50%)	50	50	74

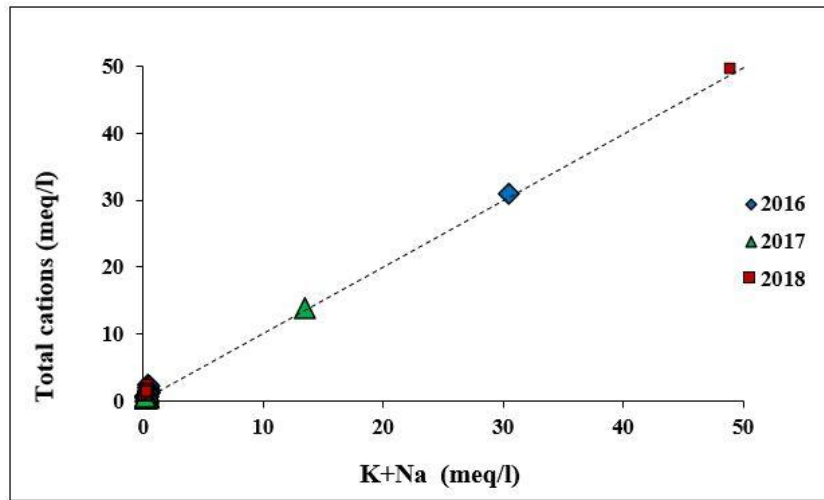


Fig. 5-A: Total cations vs K+Na

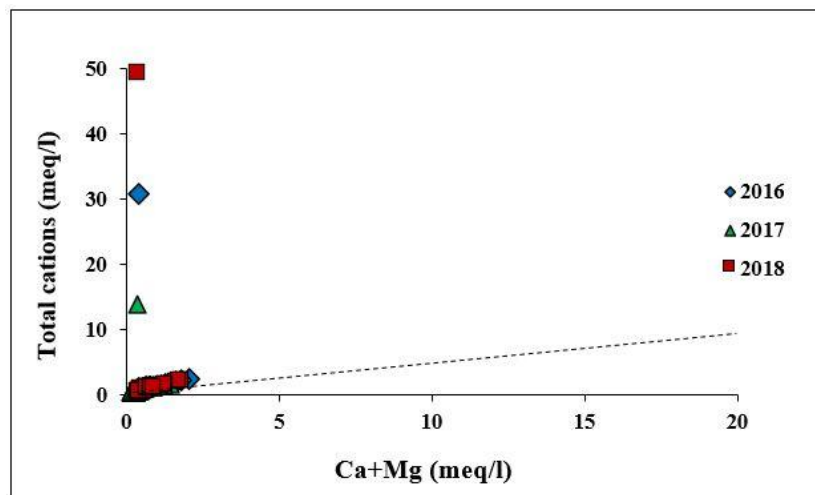


Fig. 5-B: Total cations vs Ca+Mg

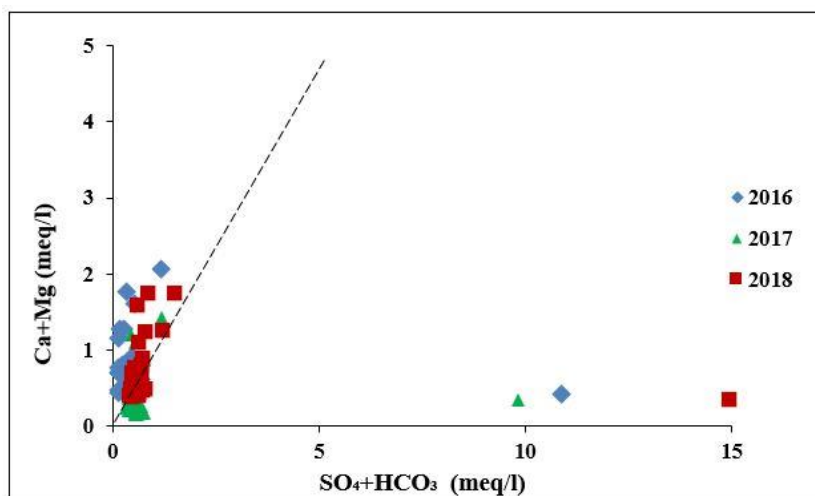


Fig. 5-C: Ca+Mg vs SO₄+HCO₃

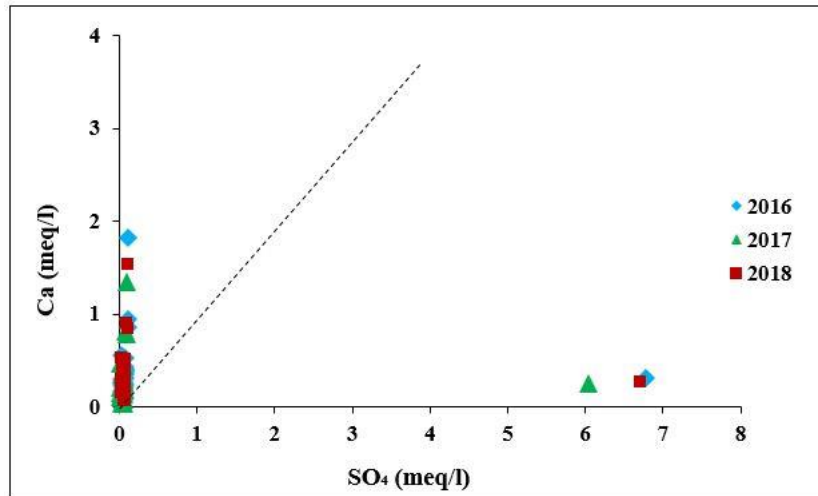


Fig. 5-D: Ca vs SO₄

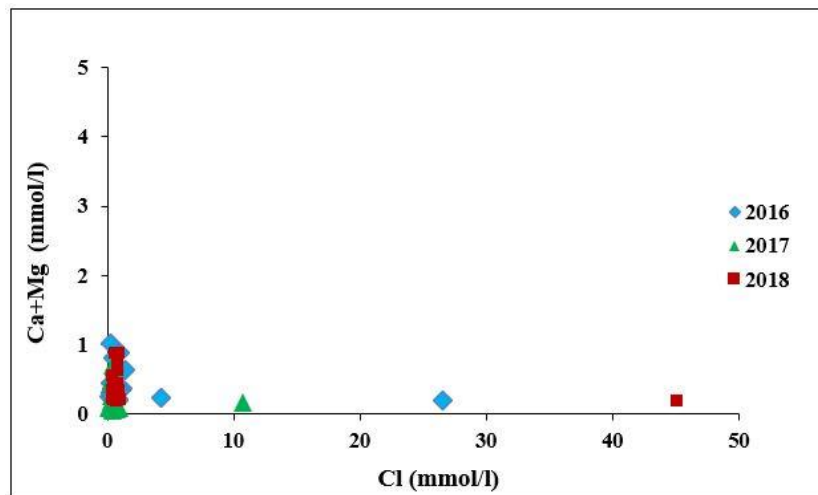


Fig. 5-E: Ca+Mg vs Cl

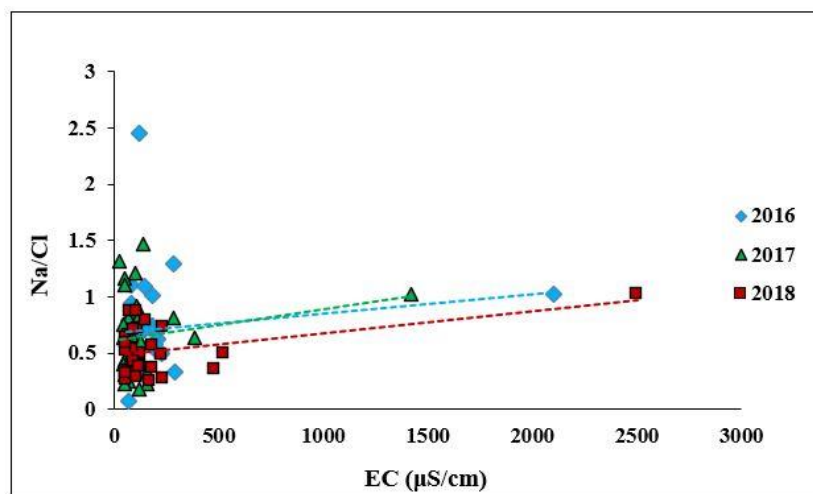


Fig. 5-F: Ca+Mg/HCO₃ vs Cl

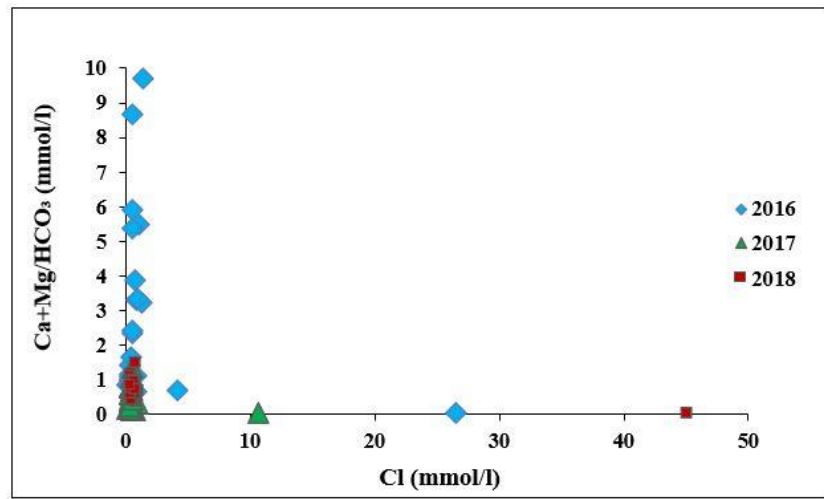


Fig. 5-G: Na/Cl vs EC

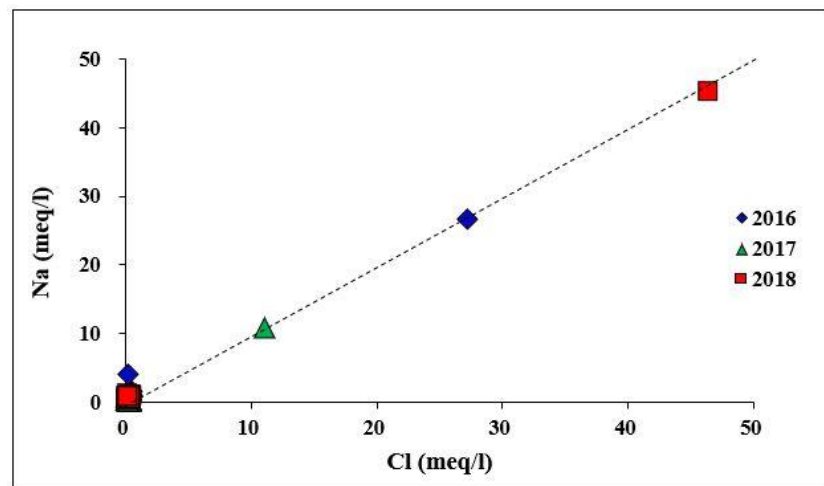


Fig. 5-H: Na vs Cl

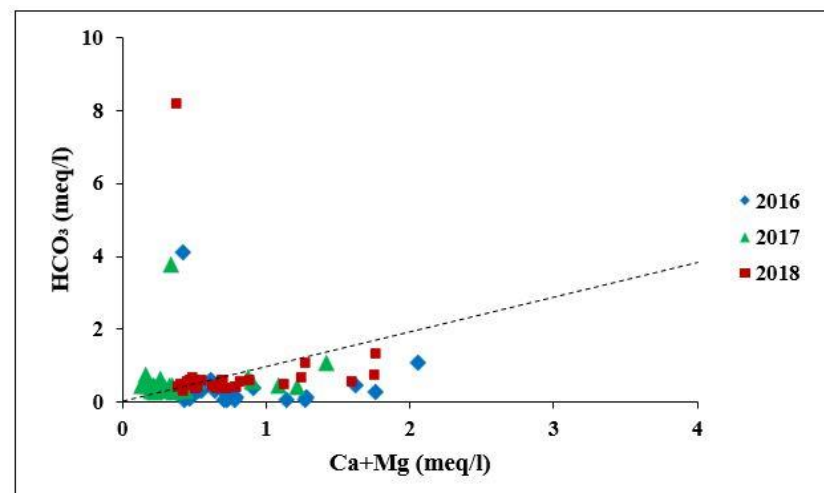


Fig. 5-I: Ca+Mg vs HCO₃

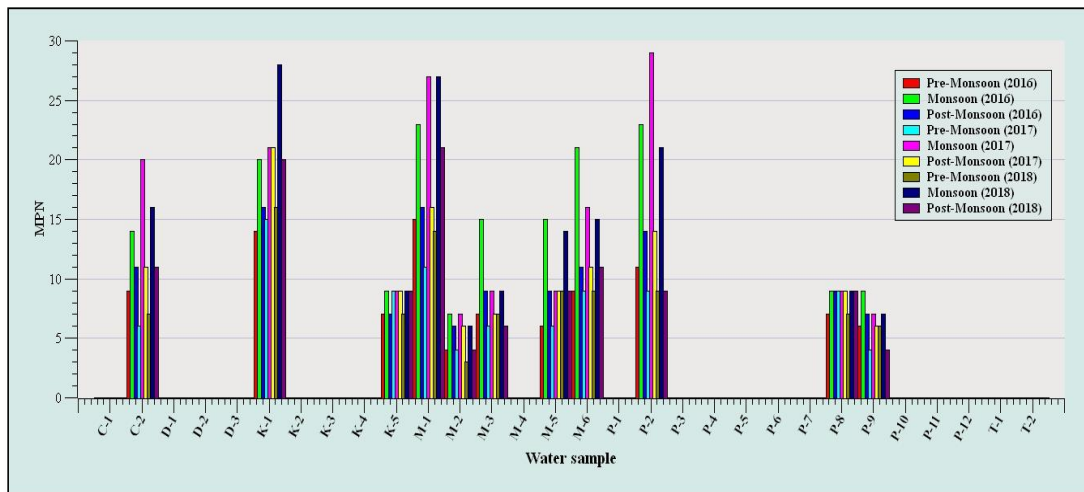


Fig. 5.1: Variation of MPN

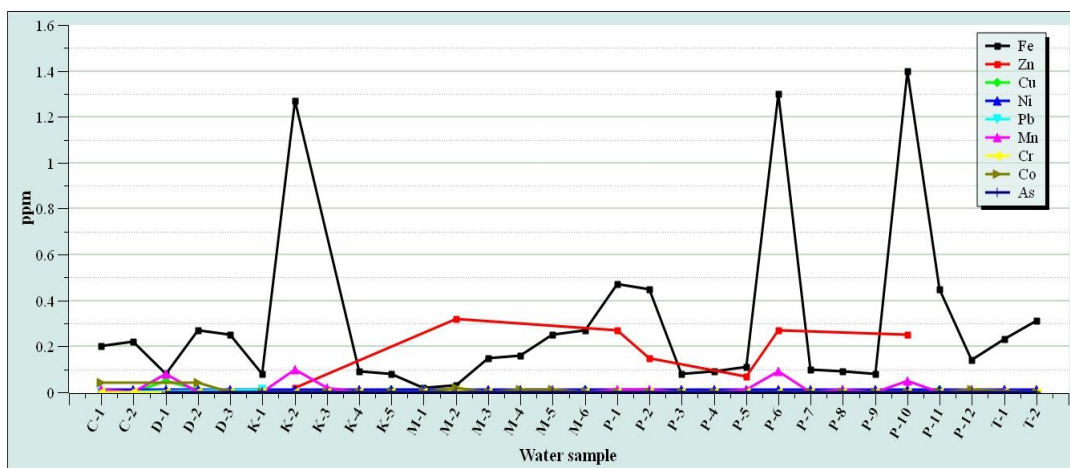


Fig. 5.2-A: Heavy metals in water sample (2016)

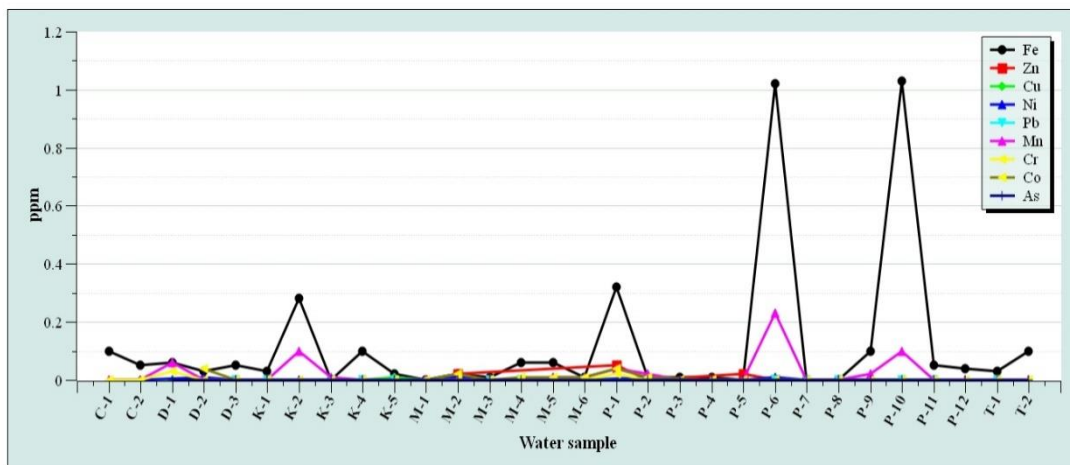


Fig. 5.2-B: Heavy metals in water sample (2017)

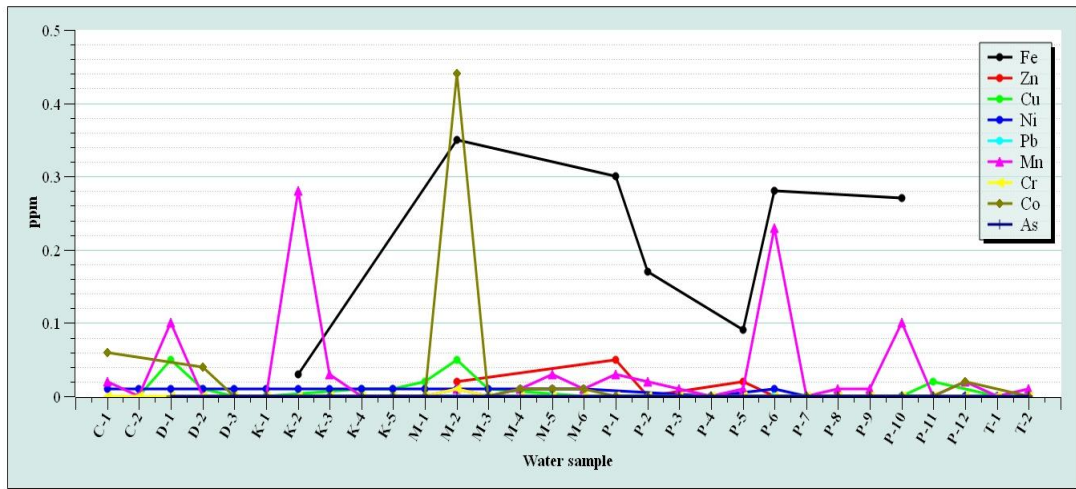


Fig 5.2-C: Heavy metals in water sample (2018)

CHAPTER 6: CONCLUSION

The drinking water status of Mamit district has been improved in recent years due to various efforts taken by the government. However, only 14.14% of total households receives tap water from treated sources while the rest of the households rely on untreated water sources (Census, 2011). The principal sources of drinking water for those households are Tuikhur, hand pump and rainwater harvesting, which they usually consume without prior treatment. Consuming untreated water is a serious concern that may have dire consequences for the health of a person. Meanwhile, the treated water supply is also very limited for those water connections provided households especially during dry periods. In such circumstances, the people have to count on secondary water sources to compensate their daily requirements of water for various purposes. Thus, determining the water quality of such water sources is of the essence to discern its suitability for human consumption. Therefore, in view of the above conditions, the water sources of Mamit and its adjoining areas are selected in the present study for the physico-chemical, bacteriological, and geochemical studies. Totally, 30 water samples had been collected from the selected 6 sampling sites during the pre-monsoon, monsoon, and post-monsoon from 2016 to 2018 to assess its quality based on physical, chemical and bacteriological characteristics. Thus, based on the observations through various analysis of the water samples in the study area, the following conclusions are drawn:

- From the assessment of different physico-chemical characteristics of the water samples, it is observed that all the water, except the D-1 sample, shows a value below the permissible limit prescribed by WHO (2017) and BIS (2012), suggesting no significant pollution of potable water sources. It can be concluded from these observations that the water samples, except the D-1 sample, are suitable for consumption.
- The analysis of the D-1 sample shows a higher value of EC, TDS, and Cl exceeding the permissible limit of WHO (2017) and BIS (2012) in most of the seasons. Further, it is classified as slightly saline water base on its TDS

value. Therefore, the D-1 water source has been considered unfit for human consumption.

- The pH values of water samples range from 6.5 to 8.2 in all seasons which signifies that the water is slightly alkaline in nature but all the values are well below the acceptable limit in every season.
- The concentrations of iron in the hand pump water samples exceed the permissible limit, which may be ascribed to corrosion of cast iron pipe from the hand pump. A metallic taste is also observed from the hand pump water samples. However, iron has been considered a secondary contaminant, and its concentration levels in drinking water are not a health hazard.
- The concentrations of various chemical parameters such as, total hardness, alkalinity, nitrate, sulphate, fluoride, bicarbonate, magnesium, calcium, potassium and sodium are found below the permissible limit prescribed by WHO (2017) and BIS (2012).
- The levels of heavy metals such as Zinc, Cadmium, Copper, Nickel, Lead, Manganese, Chromium, Cobalt, and Arsenic are well below the permissible limit in every season. In some water samples the concentrations of heavy metals are found even below the limit of detection.
- From the bacteriological examination of the water samples, 10 samples such as C-2, K-1, M-1, M-2, M-3, M-5, M-6, P-2, P-8, and P-9 exhibit the presence of coliform bacteria every season during the investigating period. Hence, those water sources are considered to be unsafe for direct human consumption. The occurrence of coliform in water samples is substantiated by the practices of piggeries, poultry farms, pit latrines, and unhygienic waste disposal which are prevalent within reach of those sampling sites. It is therefore imperative and recommended to boil the water before consumption to prevent the spread of water-borne diseases.
- According to the CCME water quality index, the water samples are categorized from fair to excellent. The majority of the water samples are classified as excellent quality. The D-1 sample and the hand pump water samples (K-2, P-6, and P-10) are categorized as fair and good quality

respectively. Fluctuation of parameters' value has induced some water samples into their respective categories of fair and good.

- Hydrogeochemical analysis of major ions using scatter plot confirms that silicate weathering, carbonate weathering, ion exchange, and dissolution of ions are the main geochemical processes responsible for the presence of ions in the water sample. The concentration of sodium and chloride in the D-1 sample is released from halite dissolution, leaving the water slightly saline.
- Pearson's correlation coefficient shows strong positive correlations between EC and TDS in all the samples which indicates that the conductivity of the water samples increases as the dissolved constituents in the water increase. EC is also strongly correlate with TA, TH, Cl, SO₄, HCO₃, Na, and K in all the seasons indicating that these ions take part in various physico-chemical reactions. There is a strong positive correlation between Na and Cl suggesting the same source of these ions. TDS exhibits a positively high correlation with TA, TH, Cl, SO₄, HCO₃, Cu, Na, and K indicating that these may be the sources of dissolved constituents in water. A strong correlation between SO₄ and HCO₃ infer the occurrence of ionic exchange process in the aquifer.
- Gibb's diagram also elucidates the controlling mechanisms of water chemistry, indicating that the chemical weathering of rock-forming minerals is the principal process that controls the contribution of ions in water.
- The Piper trilinear diagram reveal the hydrogeochemical facies of water which can be classified as water types of mixed types, Mg-HCO₃, Ca-Cl, and Na-Cl. It also suggests the dominance of alkaline earth metals over alkali metals and strong acids exceed weak acids in the water samples under study.

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BIO - DATA

1. NAME : B. RAMNGAIHAWMA
2. FATHER'S NAME : B. RALZUALA (L)
3. MOTHER'S NAME : LALTANPUII
4. NATIONALITY : INDIAN
5. SEX : MALE
6. ADDRESS : LEMONVALE HOMESTAY,
RAMZOTLANG, SERKAWN
LUNGLEI, MIZORAM
PIN CODE – 796701
7. EMAIL : buanga18@gmail.com

(B. RAMNGAIHAWMA)

PARTICULARS OF THE CANDIDATE

NAME OF CANDIDATE : B. RAMNGAIHAWMA

DEGREE : Ph.D

DEPARTMENT : Geology

TITLE OF THESIS : Geochemistry of Potable And Saline Water Sources
In And Around Mamit Town

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Dated 14th Feb, 2020

(Prof. SHIVA KUMAR)
Head
Department of Geology
Mizoram University

ABSTRACT

GEOCHEMISTRY OF POTABLE AND SALINE WATER SOURCES IN AND AROUND MAMIT TOWN, MIZORAM

B. RAMNGAIHAWMA



**DEPARTMENT OF GEOLOGY
MIZORAM UNIVERSITY**

Water is one of the most important elements of our environment. It is an important required substance to sustain vital activities of humans such as nutrition, respiration, circulation, excretion, and reproduction (Kılıç, 2020). Meagre amount of freshwater is available in the earth despite the fact that huge amount of water covering the surface of the earth. According to WHO (2019), 785 million people lack access to basic drinking water worldwide while about 226 million people lack access to safe water in India (Chigurupati, 2008). Water quality is likely to fluctuate from one source to another as it comprises different components. The natural process and human activities influence the quality of surface and groundwater resources (Prajapati et al., 2018). Any change in its natural quality may result that the water becoming inappropriate for its intended usage. Rapid urbanization and increased agricultural activities have resulted in the degradation of the water quality (Venugopal et al., 2008) owing to excessive resource usage and disposal of waste products. The water used for drinking purposes should be free from any toxic elements, living and non-living organisms, and an excessive amount of minerals that may be hazardous to health (Reddy et al., 2013). The presence of excessive chemical constituents and water-borne pathogens in drinking water may cause adverse health effects on human. Thus, regular monitoring of data and related evaluations constitute the foundation for the efficient management of drinking water quality.

The area under investigation is located in Mamit district which lies between latitudes N 23°38'26.00" to N 23°56'57.02" and longitudes E 92°27'03.04" to E 92°30'24.00". It falls in parts of the Survey of India Toposheets No. 84 A/5 and 84 A/6. Mamit district is bounded on the north by Assam, on the west by Tripura state and Bangladesh, on the south by Lunglei district, and the east by Kolasib district and Aizawl district. It occupies an area of 3025.75 sq. km with an average elevation of approximately 718 m from sea level. Mamit town is the main administrative headquarters of Mamit district. According to Census 2011, 82.75 % of the population lives in rural areas of villages in Mamit district.

Precipitation is the main source of surface and groundwater. But, in a hilly and rugged topography of Mizoram, high relief and steep slopes actuated surface runoff thus obstructing extensive infiltration of rainwater into the ground. Therefore, the

prospective of groundwater is considered to be limited. The small amount of water infiltrated into the ground are confined into weak zones, which act as seepage channel. Consequently, the water percolates into the ground as seepages and springs. A basin-like structure is set up at a suitable place to impound and collect the percolating water from the springs; this is locally called 'Tuikhur'. It is the main source of water supply, especially in rural communities.

A total of 2,705 households in urban and 3089 households in rural areas of Mamit district were given water connections from the state government (PHED, 2020). During the non-rainy season, the water supplied by the PHE department is not always sufficient for the connection provided households. This inadequacy has forced the people to use spring or Tuikhur and hand pumps for their daily basic drinking water. Moreover, the people of the rural area who were not covered by the supply of water from PHED also mainly count on spring or Tuikhur water, rainwater harvesting, and hand pump for their household purposes. The water obtained from secondary sources were consumed and used directly from its sources without any treatment. Therefore, it is necessary to establish the quality of drinking water as the people consume it without any distillation processes. The study is aimed at examining and understanding the nature and level of contamination of potable water with chemical concentrations and also to determine the geological control on the presence or absence of different elemental concentrations in water. The investigation has been carried out with the following objectives: -

- 1) To measure the physico-chemical and bacteriological properties of potable and saline water in the study areas.
- 2) To assess the impact of rock-water interaction on the quality of potable and saline water in the study areas.
- 3) To demarcate vulnerable water sources in the area and suggest remedial measures.

Mizoram forms a part of the Neogene Surma basin to the west of the Arakan Yoma subduction-collision zone, which represents the northward extension of the Sumatra-Java trench (Nandy et al., 1983). The sedimentary rocks exposed in the study

area were represented by Bhuban formation belonging to the Surma group of tertiary age. Based on the character of lithology Bhuban formation is further divided into Lower, Middle, and Upper (Bhattacharya, 1983). The rock formations are folded in a series of anticlines and synclines trending in N-S. It is also characterized mainly by ridgelines with intervening valleys. The lithology and structural process determined and modified the topography of the area which is substantiated by the formation of anticlines, synclines, linear ridges, and valleys. Generally, the folded beds are trending in N-S to roughly NNW-SSE directions which dip 20°-70° on either side of the flanks.

The methodology of the present study included fieldwork, laboratory work, and analysis of field and laboratory data. Six sampling stations were verified in the study area and from those six sampling stations, 30 sampling sites were picked out including 17 Tuikhur and 3 hand pump water sources for conducting water sampling. Water samples from each sampling site was collected during pre-monsoon, monsoon, and post-monsoon within a period of one calendar year. The method of grab sampling was followed to procure water samples because of homogeneous water samples in the area. Samples for physico-chemical analysis were collected in already washed and rinsed two 500 ml bottles, one of which was preserved with 10% HNO₃ for heavy metal analysis at the laboratory. The sample bottles were closed tightly to avoid any spillage during transportation. Likewise, a water sample for bacteriological analysis was collected in a sterile 500 ml bottle at each sampling site. A sample code is provided for all water samples regarding their sampling place to distinguish them easily

The physical characteristics of water samples such as, pH, electrical conductivity, and total dissolved solids were observed in-situ using portable pH meter (HM Digital, PH-80) and EC/TDS meter (Ravki Digital, TDS/EC meter). The turbidity values of water samples were determined by a Nepheloturbidimeter (Systronics Digital Nepheloturbidimeter-132) in NTU using hydrazine sulphate and hexamethylene tetramene as standards. Alkalinity is determined by titration with standard acid indicated by colour while Total Hardness was determined by EDTA titrimetric method. Chlorides in water is determined by a volumetric method involving titration of a silver nitrate solution and the ultraviolet spectrophotometer was used to determined nitrate in the water sample. The turbidimetric method was employed to

estimated sulphate in a water sample where sulphate absorbance was measured by spectrophotometer. Analysis of fluoride concentrations in water samples was done by UV/VIS spectrophotometer using Spectroquant Pharo 300 model. Elemental analysis of the water samples was performed on Agilent 4100 MPAES (Microwave Plasma Atomic Emission Spectrometry) at Central Instrumentation Laboratory (CIL), Mizoram University. The elemental analysis involves a determination of metals and heavy metals like Iron (Fe), Zinc (Zn), Cadmium (Cd), Magnesium (Mg), Copper (Cu), Nickel (Ni), Lead (Pb), Sodium (Na), Calcium (Ca), Potassium (K), Manganese (Mn), Chromium (Cr), Cobalt (Co), and Arsenic (As). Multiple tube dilution method of Total Coliform test was used for bacteriological analysis and the results were reported as a most probable number (MPN) index.

The interrelationship of different variables was determined using Pearson's correlation coefficient and Gibb's diagram has been used to describe the mechanisms that controlled the chemistry of water. The Piper plot was employed to establish the hydro-geochemical facies of water samples. The CCME water quality index was used to determine the water quality and represent it in a simple unitless value.

The results obtained are compared with the standard limits prescribed by WHO (2017) and BIS (2012) to understand its suitability for drinking purposes. Based on the assessment of different physico-chemical characteristics of the water samples, it is observed that all the water except the D-1 sample, shows no significant pollution and are suitable for consumption. The analysis of the D-1 sample exhibits a higher value of EC, TDS, and Cl exceeding the permissible of drinking water quality standard prescribed by WHO (2017) and BIS (2012) in most of the seasons. Further, it is classified as slightly saline water and is unfit for drinking purposes.

The pH value ranges from 6.5 to 8.2 in all seasons which indicated that the water is slightly alkaline in nature. The lower values in the monsoon period may be attributed to the dilution of water during rainy seasons. The hand pump water samples have a little higher value as compared to the Tuikhur water samples which further showed a higher value during monsoon seasons. This slightly increased turbidity value during the monsoon period indicated that there may be the presence of inorganic

particulate matter and non-soluble metal oxides. The D-1 sample shows a high level of EC and TDS values every season indicating a higher amount of dissolved inorganic substances present in water. The higher values may be attributed to the weathering processes in the subsurface region, resulting in higher ionic concentrations.

The concentrations of various chemical parameters such as, total hardness, alkalinity, nitrate, sulphate, fluoride, bicarbonate, magnesium, calcium, potassium and sodium are found below the permissible limit prescribed by WHO (2017) and BIS (2012). Chloride concentration of D-1 water is more than the permissible limit (250 mg/l) of WHO (2017) and BIS (2012) regardless of the season. The post-monsoon seasons generally shows a higher concentration of Cl^- than the other seasons which may be due to seepage with rainwater during the rainy season ascending to the aquifer that increased the Cl^- the content of the groundwater (Mor et al., 2009). The concentrations of iron in hand pump water samples exceed the permissible limit (0.3 mg/l), which may be ascribed to corrosion of cast iron pipe from the hand pump and as a result, a metallic taste was observed from the hand pump water samples. However, iron has been considered a secondary contaminant, and its concentration levels in drinking water are not a health hazard.

The levels of heavy metals such as Zinc, Cadmium, Copper, Nickel, Lead, Manganese, Chromium, Cobalt, and Arsenic in all the water samples are well below the permissible limit. The concentrations of heavy metals in some waters are found even below the limit of detection. From the bacteriological examination, 10 samples exhibit the presence of coliform bacteria irrespective of the seasons and are hence, unfit for drinking purposes. The occurrence of coliform in water samples is substantiated by the common practices of piggeries, poultry farms, pit latrines, and unhygienic waste disposal in those areas. It is therefore imperative and recommend to boil the water before consumption to prevent the spread of water-borne diseases.

According to the CCME water quality index, the water samples are categorized from fair to excellent. The majority of the water samples are classified as excellent quality. Fluctuation of parameters' value has induced some water samples into their respective categories of fair and good. The D-1 sample is categorized as fair quality.

The lower value of WQI for the D-1 sample may be attributed to the higher value of TDS along with a high concentration of chloride. The hand pump water samples (K-2, P-6, and P-10) are also found to have good quality during the whole index period except in 2017 where the K-2 sample is showing excellent quality. The iron concentration in hand pump water samples is generally high exceeding the permissible limit in all seasons which attributed to the lower value of WQI for these water samples.

Using scatter diagrams, the geological process and the sources of major components of water in the study area are described. Hydrogeochemical analysis of major ions confirms that silicate weathering, carbonate weathering, ion exchange, and dissolution of ions are the main geochemical processes responsible for the presence of ions in the water sample. The concentration of sodium and chloride in the D-1 sample is released from halite dissolution, leaving the water slightly saline. Pearson's correlation coefficient shows strong positive correlations between EC and TDS in all the samples which indicates that the conductivity of the water samples increases as the dissolved constituents in the water increases. EC is also strongly correlate with TA, TH, Cl, SO₄, HCO₃, Na, and K in all the seasons indicating that these ions take part in various physico-chemical reactions. There is a strong positive correlation between Na and Cl suggesting the same source of these ions. TDS exhibits a positively high correlation with TA, TH, Cl, SO₄, HCO₃, Cu, Na, and K indicating that these may be the sources of dissolved constituents in water. A strong correlation between SO₄ and HCO₃ infer the occurrence of ionic exchange process in the aquifer.

Gibb's diagram also elucidates the controlling mechanisms of water chemistry. It is inferred that the chemical weathering of rock-forming minerals is the principal process that controls the contribution of ions in water. The Piper trilinear diagram reveal the hydrogeochemical facies of water which can be classified as water types of mixed types, Mg-HCO₃, Ca-Cl, and Na-Cl. It also suggests the dominance of alkaline earth metals over alkali metals and strong acids exceed weak acids in the water samples under study.