SEASONAL MONITORING OF GROUND WATER QUALITY IN AIZAWL CITY, MIZORAM

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

ZONUNTHARI

MZU REGISTRATION NO.: 1600765

Ph. D REGISTRATION NO.: MZU/Ph.D./1041 of 31.05.2017

DEPARTMENT OF ENVIRONMENTAL SCIENCE

SCHOOL OF EARTH SCIENCE AND NATURAL RESOURCES MANAGEMENT

AUGUST, 2023

SEASONAL MONITORING OF GROUND WATER QUALITY IN AIZAWL CITY, MIZORAM

BY

ZONUNTHARI

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Prof. P.K. RAI

Supervisor

Department of Environmental Science

Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Environmental Science of Mizoram University, Aizawl.

MIZORAM UNIVERSITY

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Post Box No.:190, Phone No: 0389-2330532 Fax: 0389-2330385,
E-mail: febesmzu@yahoo.co.in

SUPERVISOR' S CERTIFICATE

This is to certify that the Ph.D. thesis entitled **"SEASONAL MONITORING OF GROUND WATER QUALITY IN AIZAWL CITY, MIZORAM"** submitted by Mrs**. ZONUNTHARI (**Reg. No. MZU/Ph.D./1041 of 31.05.2017) for the award of Ph.D. degree of Department of Environmental Science, Mizoram University embodies the original work carried out under my supervision. She is a bonafide research scholar and the work is worthy of being considered for the award of the Ph. D degree. The work has not been submitted for award of any degree or any other Institute or University of learning.

(Prof. P.K. RAI)
Supervisor
Department of Environmental Science,
Mizoram University

Date: 12.02.2024
Place: Aizawl

DECLARATION

Mizoram University

August, 2023

I **Zonunthari**, 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 Environmental Science.

.

(ZONUNTHARI)
Research Scholar

(Prof. P. K. RAI)
Supervisor
Department of Environmental Science
Mizoram University

Head
Department of Environmental Science
Mizoram University

Dated: 12.02.2024
Place: Aizawl

ACKNOWLEDGEMENT

First and foremost, I thank the Almighty God for leading me throughout this research and for giving me the grace, wisdom and knowledge to complete this endeavor.

I would like to express my sincere gratitude to my supervisor, Prof. P K Rai, Department of Environmental science for his help and support throughout the research. His advice had benefited me immensely and he has played a big role in the working and completion of this thesis.

I would like to thank all the teaching and non-teaching staff of the Department of Environmental Science for their assistance and aid during the course of the entire research.

I am deeply grateful to my parents, my family and friends for the love and encouragement I received from them, and for backing me up and assisting me in the entire course of this study.

I would like to give my sincere gratitude to Emacaree S Nongtri and Roger Bruce Syngkli for their constant help during the entire research work.

I would like to thank my friends and research scholars for the valuable aid provided by them which had brought me to this point.

I would like to express my thanks to the staff at Mizoram Pollution Control Board for allowing me to use their laboratory and for providing their support in terms of water quality analysis

I would like to thank my friends Dr. Lalzahawmi Chenkual and Dr. C Zoramthara for their constant support during the entire research period.

I would like to thank the Department of Chemistry, Mizoram university for their help in the research by allowing the use of their laboratory and their support in terms of analysis of water quality

Words fail to express the help and support of my husband, Mr. K Shangpliang and my daughter Cynthia Lalhlupuii Shangpliang. This research in its entirety would not have been possible without them.

Date: 12.02.2024 (ZONUNTHARI)

Place: Aizawl Research Scholar

CONTENTS

CHAPTERS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS AND PHOTO PLATES

CHAPTER-1

INTRODUCTION

1.1. Components of environment

Water, air and soil form the basic components of our planet. The water body in the earth, consisting of oceans, rivers, and lakes which constitute the hydrosphere. The huge envelope of air along with its various gaseous molecules spread out in different layers and varying densities constitute the atmosphere. The earth, or the soil with numerous layers forming the depth of the soil profile, including its various topographical features such as mountains, plateaus, and grasslands are collectively known as the lithosphere. The hydrosphere, atmosphere and lithosphere interact with biotic and abiotic factors and form a link of life which constitutes the biosphere.

Water is a vital necessity for the functioning of an ecosystem and the whole biosphere of the planet. It is an integral component of environment required for various life processes and hence our persistence on the earth. It exists as water vapour in the air, ground water, and surface water (oceans, lakes, glaciers, rivers) in the rock and soil though a systematic process called the hydrological cycle. It covers ¾ th of the earth's surface, causing our planet to be called the 'blue planet'.

Water can exist in three states, solid (ice), liquid, and gas (vapour). Its chemical formula is H_2O and is a molecule in which hydrogen and oxygen are bonded by covalent bonds. Liquid water will evaporate as vapour at a temperature of 100°C and will freeze and eventually turn to ice at a temperature of 0°C. Water has an amphoteric nature which means that it can perform both acidic and basic functions. The particular attribute of water is that it can accept a proton and donate a pair of electrons through the lone pair of oxygen, thereby accomplishing its amphoteric properties. It has earned the name of being the universal solvent because it has a polar nature and has the ability to dissolve a large number of substances. This is because of the existence of positive and negative charges in the hydrogen and oxygen ends respectively, due to which it can potentially dissociate many inorganic molecules.

1.2. Importance of water

Water plays a big role in the life of all living organisms. It constitutes 70% of the human body and up to 50 % - 97% of animal bodies in terms of weight. Not only does it quench the thirst and water requirement of animal bodies, it is an essential raw material for the process of photosynthesis. Through plants manufacture food, for which all life forms depend on directly or indirectly. It is an indispensable part of daily human lives as it is mainly used for cleaning, drinking, and washing which is necessary for sanitation. It is used by industries for maintaining cleanliness, mixing and dyeing chemicals and for cooling machines.

Water has its own irreplaceable use in agriculture. This is mainly because of the need for irrigation of crops and normal garden plants which require water. This can be carried out in different ways such as drip irrigation, sprinkling irrigation, and canals. Besides irrigation, it is required for the application of fertilizers, pesticides, insecticides, and weedicides. In relation to vegetation, water is needed, especially in dry and arid regions where droughts occur most of the year. Water is needed for plants to grow, and roots of plants bind the soil, therefore, water indirectly helps in preventing soil erosion as well. Majority of forests types also depend upon the availability of water in the region, namely, tropical evergreen forests need abundant water resources, monsoon forests or deciduous forests with moderate water and rainfall, dry deciduous forest with irregular rainfall and water, and scrubs and deserts with minimal rainfall. Therefore, availability of water plays an important role in the type and distribution of flora found in the particular region.

Water is a much-needed resource in our modern heavy industries. Not only does water maintain sanitation, it helps to cool overheated machinery for better efficiency in production. Not only that, but water is also needed for washing raw materials, especially those dependent on the primary sector. It is used for dying and mixing in textile industries and for chemical solvents in chemical and medical industries. Water is the basic need which guides the location of industries, and all livelihood, for that matter, as the very first civilizations were found in near rivers.

Water is also used to produce power supply. This is done by converting the kinetic or potential energy of water into mechanical and electrical energy. Water, for this purpose, is utilized by forming dams and reservoirs. When water is impounded in a dam, it collects the water in the upstream and is released into turbines when required so that energy may be generated. Tidal waves in the oceans are also used for this purpose, as dams are built to convert mechanical to electrical energy in the same way. In thermal power plants as well, water is still required as heat energy is used to turn water into steam which then spins turbines. Therefore, a large portion of our energy production comes from water.

Water serves as an indispensable mode of transport. It carries people and goods to various places, especially regions where roads and railways have not been introduced so far. It is the cheapest and easiest means of transport. It is very convenient to carry heavy and bulky goods over medium or far distances. It supports trade between different parts of the world. Therefore, river and coastline ports have been the symbols of economic prosperity of a country since ancient times, for instance, Indian trade flourished in medieval periods due to its peninsular location and several sea routes connecting it to different countries.

1.3. Distribution of water

Generally, about 97% of total water available on earth is locked away as saline ocean water and is not suitable for consumption. Only 3% of the remaining water is delineated as freshwater. However, 69% of the freshwater resides in glaciers and ice caps, 30% is found underground as ground water and less than 1% is available for human use. Since, less than one percent of fresh water is available for human use, its proper conservation and management is prerequisite for sustainable use. Fresh water has become a scarce commodity due to overexploitation and pollution of water resulting from rapid industrialization and urbanization. Water, a vital necessity for life, has been degraded due to industrial impacts and domestic mismanagement. Proper assessment of ground water has been over-ruled by its overexploitation, such that measures of control ceases to be effective. Water is a national asset and is to be accessible to citizens in proper quantity, quality, equity, and fairness (Chaudhary *et al.,* 2002).

Water availability in the country mainly depends on topographical features such as rivers and lakes, as well as the rainfall pattern in a region. In India, particularly, people are blessed with a large number of natural water lakes and rivers, both snows fed (Himalayan Rivers such as Ganges, Brahmaputra, etc.) and rain fed (Peninsular Rivers such as Krishna, Godavari, Mahanadi, etc.). The rainfall pattern in our country involves south west monsoons and north east monsoons. South west wind brings the high moisture air from the oceans and cause rainfall in the whole country, whereas north east monsoons tend to cause high rainfall and cyclones in the eastern coast.

1.4. Surface and Ground water

Surface water is water resource found on the earth's surface, received through precipitation such as rainfall or snowfall. It is easily recharged through precipitation and is thereafter lost through evaporation. The major components of are oceans, lakes, and rivers. Surface water resources can be either snow fed and perennial (Himalayan rivers) or rain fed and seasonal (peninsular rivers).

The term ground water is usually reserved for the sub-surface water that occurs beneath the water table in soils and geologic formation that are fully saturated. It is the water that seeps through the porous spaces in soil or crevices of rocks in the earth's crust to be stored in large aquifers. It is recharged through sub surface seepage into the ground and can be accessed through wells or tube wells dug into the ground. They may also come out naturally in the form of springs. This water constitutes the water table. Ground water is one of the most vital natural resources and the largest available source of fresh water (Kumar, 2013). Therefore, finding prospective areas for ground water, monitoring and conserving this resource have become highly crucial for the present civilization (Rokade *et al*., 2004; Kumar and Kumar, 2011). It supports drinking water supply; livestock needs irrigation, industrial and many commercial activities.

1.5 Water pollution and its harmful effect

Water, when in shortage, can lead to social problems, droughts and famines. Whereas water in excess can cause floods and unstable surroundings. Therefore, there rises a need for proper management of water. Water, when not managed properly, can remain stagnant in areas, becoming a very suitable breeding ground for pests, mosquitoes, bacteria and other undesirable pathogenic organisms. Pathogenic organisms may cause discomfort and various ailments, such as malaria, dengue, plagues, flu, etc. can also be a carrier of various water-borne diseases such as cholera, diarrhea, typhoid, and hepatitis. Pathogenic microbes can also lead to epidemics and, in worst case scenarios, even a pandemic. These undesirable events can cause the lives of many people and even harm the development in a country. For instance, the world has experienced seven major pandemics of cholera over the period of hundreds of years, killing millions of people each time (1817-1824, 1829-1837, 1846-1860, 1863-1875, 1881-1896, 1899-1923, 1961- ongoing). These pandemics generally started from the unhygienic slums of the Ganges and spread throughout the world.

Though water is generally neutral, rainwater can be slightly acidic due to the reaction between compounds of carbon and nitrogen present in air. This acidic water can be detrimental to every aspect of economic development. Firstly, it turns rivers and lakes acidic which harms aquatic life immensely. The consequences of such happenings are already manifested in global aquatic ecosystems, for instance, the river Ganges. This acidic precipitation can also affect the vegetation as it turns the soil acidic. This can be life threatening for certain plants, and it may destroy whole forests. This type of rainfall also has a destructive effect on monuments and buildings, as acid can corrode marbles, natural stones and certain materials used for construction. The wildlife and fauna of a region can be harmed from this phenomenon as well. Therefore, availability of clean water and adequate sanitation facilities are of prime importance for limiting waterborne diseases.

The ground water quality and sanitation facilities of a village in southern India were examined using Geographic Information System (GIS) tools (Megha *et* *al*., 2015). In this study, well water samples were tested for microbial contamination and it was found to be microbiologically unfit for consumption. Analysis using direct observations supplemented by GIS maps revealed poor planning, design of the wells and improper sitting of wells from latrines which were found to be the possible reasons of ground water contamination. Many researchers across the globe (Shomar *et al*., 2010; Magesh *et al*., 2013) have carried out studies with spatial technologies and interpreted the quality of ground water. Mapping the spatial distributions of major elements and their interpolation with the geology and land use/land cover maps in GIS environment (Zhang *et al*., 2013) have contributed for the better understanding of the chemical processes of water and the methods of their acquisition.

1.6. Ground water and its pollution

Ground water is generally less susceptible to contamination and pollution when compared to surface water bodies. Also, the natural impurities in rainwater, which replenishes ground water systems, get removed while infiltrating through soil strata. But, in India, where ground water is intensively used for irrigation and industrial purposes, a variety of land and water based human activities are causing pollution of this precious resource (Majumder and Sivaramakrishnan, 2014). Importantly, ground water can also be contaminated by naturally occurring sources. When pollutants are of a certain form or type, it is known as ground water contamination rather than pollution. This type of pollution can occur due to leakage in pipelines, sewers, and petrol stations. Untreated water from industries, effluents from wastewater, and sewage contribute significantly to the total ground water pollution. In agriculture, overuse of pesticides, insecticides, and fertilizers are also a major pollutant. Usage of such polluted ground water can cause hazards to public health and can even be the cause of various epidemics. Such pollutants can create contaminant plume, usually within an aquifer. When the ground water moves, it disperses such pollutants within the aquifer and contamination occurs over a wide area.

Ground water quality comprises the physical, chemical, and biological qualities of ground water. Temperature, turbidity, color, taste and odor make up the list of physical water quality parameters. Since ground water resource is colorless, odorless, and without specific taste, we are typically most concerned with its chemical and biological qualities. As the quality of ground water changes with respect to varying seasons, this can hinder the agricultural and industrial functions in an economy, therefore, the nature and constitution of ground water is as essential as its accessibility (Lalbiakmawia *et al.*, 2020).

United Nations' Sustainable Development Goals (SDGs) especially, SDG 6, focuses on ensuring the availability and sustainable management of water and sanitation for human well-being. The overall goal of a ground water quality assessment programme is to obtain a comprehensive picture of the spatial distribution of ground water quality and of the changes in time that occur, either naturally, or under anthropogenic influence (Dohare *et al*., 2014). Ground water can be contaminated when rainwater carry impurities into streams as runoff or through leaching. Leaching is the downward movement of a dissolved substance through the soil (Ramaia *et al*., 2014). Also, ground water is contaminated through the excessive use of fertilizer in agro-ecosystems (Altman and Parizek, 1995; Khajuria, 2016; Sangita *et al*., 2016).

With rapid increase in population and industrial growth, ground water quality is increasingly being threatened by disposal of urban and industrial solid waste. Open dumping is the most common way to dispose municipal and industrial wastes. Untreated and improper disposal of domestic and industrial effluents are the chief causes of drinking water contamination (Jamshaid *et al.*, 2018). Subsequent leaching of toxic contaminants through the dumping site also leads to extensive contamination of ground water at many places. It has been estimated that once pollution enters the sub-surface environment, it may remain concealed for many years; rendering ground water unsuitable for consumption and other domestic uses (Raju, 2012).

The COVID 19 pandemic has had a noticeable impact on the current world-wide situation. Closing down of factories and industries have significantly improved air quality and other physical pollution. Nonetheless, studies have shown that it has led to a large generation of biomedical wastes (Adnan *et al.*, 2022). Several studies have shown that rapid recycling and production of pharmaceutical have resulted in the growth of heavy metal contamination (Adnan *et al.*, 2022). These contaminants can further pollute the ground water, due to which proper management and effective measures have become a necessity.

The outbreak of COVID 19 pandemic exerted multiple effects on ground water resources. Study of ground water samples during COVID 19 period were compared with the pre COVID in Coimbatore, Tamil Nadu, India and this period proved to be an advantageous opportunity to test the main cause of water contamination (Karunanidhi *et al.*, 2021). In this study, all industries were closed down and effluents discharges were reduced significantly. As a result, it was concluded that the ground water previously unfit for consumption returned to levels suitable for human use.

1.7 Heavy metal pollution and its health impact

Inorganic pollutants e.g., heavy metals, which when present in higher concentrations than the permissible or prescribed limits, contaminate both soil and aquatic bodies pose serious threat to environment as well as human health (Rai, 2012; Pathak and Pathak, 2016; Singh and Rai, 2016). Heavy metals tend to combine with the biomolecules with-in human organs to cause various health ailments when consumed beyond bio-recommended limits (Sharma and Singh, 2015). The industrial revolution facilitated the contamination of the biosphere with harmful heavy metals. Subjection and contact with heavy metals can cause various chronic diseases and can pose to be a problem in the path of development (Rai, 2009; Rai, 2012; Singh and Rai 2016; Sankhla and Kumar, 2019). An efficient method of ground water preservation is needed due to the major health and environmental concerns caused by heavy metal pollution of ground water (Rai, 2009).

1.7.1. Global scenario of heavy metal contamination

Ground water in Bulawayo, Zimbabwe is the main cause of growing health risks due to its high contamination with lead (Pb) and Cadmium (Cd) that has surpassed permissible limits set by the World Health Organization (WHO) in regard to quality of drinking water (Teta and Hikua, 2017). Population explosion, economic development and ecological management plans have disclosed the growing issue of heavy metal consumption in Malaysia (Ismanto *et al.*, 2023).

Ground water pollution not only affects the human health, but the whole of the connecting link of life, the ecosystem as well. Mainly used for nutrition by humans, livestock raised in farms also depend on ground water in most farming regions through wells, tube wells, and handpumps. The well-being of livestock is also at risk due to ground water pollution. A case study in Karu, central Nigeria, have presented the need for continuous assessment and monitoring of ground water quality, as results show that poultry farms around stone quarries and factories have suffered damage due to heavy metal contamination of ground water in their respective regions (Kana, 2022).

Urbanization in Pakistan have caused unwanted discharges in the River Ravi and River Kabul, damaging the ecosystem health around these regions increasingly, and this can be detrimental to the health at all stages of consumption as the aquatic organisms consume these contaminants which are further consumed by human beings (Afzaala *et al*., 2022). A study conducted in the Meghna Ghat industrial area in Bangladesh, a valuable area for potential development, shows that the concentrations of Chromium (Cr), Cadmium (Cd), and Lead (Pb) have surpassed the permissible standards set by Bangladesh and concluded that the area needed extended long-term monitoring (Rahman *et al*., 2020). Mining activities can pose a serious threat to the quality of ground water, as various minerals in the earth's crust are usually released and get absorbed further without proper filtration into the aquifers. A study carried out in the Sunan coal mines of China reported the notable use of ground water as the main source of water by the residents near the mining area (Wang *et al*., 2022). In this study, the contamination by various heavy metals such as

Iron (Fe), Manganese (Mn), and Cr were above the permissible limits, with the main carcinogenic factor being Cr, implying that sole consumption of this ground water may not be safe.

1.7.2. National scenario of water quality and heavy metal contamination

Ground water of lower Ganga plain of West Bengal experienced arsenic contamination in 1984. The study of ground water in the lower Ganga basin reveals that the combined factor of contaminant levels and consumption rate can pose harmful risks for the consumers and to combat such vulnerability, artificial recharge and ground water harvesting have been suggested to augment ground water storage, improve the quality of ground water, and supplement domestic water supply (Mukherji and Singh, 2022).

Punjab, Haryana, Himachal Pradesh and Uttar Pradesh experienced first traces of Arsenic contamination in India. The presence of excess of Arsenic in ground water sources in India and other countries have a direct and indirect impact on human health (Sankhla *et al.*, 2018). Three districts of U.P. viz. Ballia, Gazipur, and Varanasi were on the hit list during October, 2003 – August, 2005 in relation to Arsenic pollution in ground water (Chaurasia *et al.*, 2012). Further, Hazarika and Bhuyan, (2013) reported that the ground water resources of Gujarat, Andhra Pradesh, Kerala, Delhi and Haryana were contaminated by heavy metals like Lead, Cadmium, Zinc and Mercury. Ground water in Laksar and Khanpur blocks in Haridwar district, Uttarakhand are the most vulnerable to health hazards due to high concentration of As, Cd and Cr in the ground water (Khan and Rai, 2022). In Ramgarh, Jharkhand, India, Fe (iron) concentration exceeded permissible limit due to anthropogenic effluents from ferro alloys, non-ferrous alloys, sponge iron, foundry, instrument manufacturing industries, and welding industries in the study area (Kumar *et al.*, 2020).

A study in the capital city of India, Delhi, shows that the high concentration of metals like Zn, Ni, Cr, Pb, and As have made the ground water in the area unfit for human consumption and domestic usage as the quality of ground water has been degraded by such chemical constituents (Dinakaran *et al.*, 2021). The coal and fly ash around thermal power plants have been noted to have a very high concentration of heavy metal contamination which has surpassed the safety standard limits and have found to be unfit for drinking purposes (Verma *et al*., 2016; Vig *et al*., 2022).

Aquifers can also be contaminated by the discharge of wastes produced by various human activities of development and sustenance such as agricultural practices, industrial functions, and domestic wastes. A study in the Yamuna basin showed that the underground water in the study area is largely affected by the growing wastes that is being accumulated in the river by the processes of development (Ahmed *et al*., 2022).

1.7.3. North-Eastern India scenario of water quality and heavy metal contamination

Ground water is a crucial source of water consumption. Due to lack of adequate fresh surface water, ground water is a vital substitute for both domestic and agricultural usage in many places, namely, West Jaintia Hills, Meghalaya (Eugene *et al*., 2014). Mining of coal and other minerals from the earth's crust are a significant aspect for the growth of a country's economy. Almost all growing industries depend on the mining industry for the required raw materials. The technological and infrastructural developments are unable to be carried on long-term without the mining industry. Therefore, mining and extraction of minerals are an indispensable part of development. However, this extraction of precious resources also poses a significant threat to the safety of a region. A study carried out in the coal mines of Meghalaya and Assam, comparing underground mines and open cast mining, have concluded that the mining of coal in the regions had a hazardous impact on the ground water quality as they have been contaminated by the seepage of heavy metals released during the mining process (Shylla *et al*., 2020). This study suggests that efficient and practical measures be undertaken to restrain and keep in check the heavy metal percolation into the ground water. A case study in Meghalaya, India, reveals that limestone extraction from the earth's crust should be undertaken with utmost care and caution in order to prevent the degradation of ground water quality (Lamare and Singh, 2016).

In the Upper Brahmaputra Flood Plain (UBF) the As concentration with variable seasonal changes and clamour require attention for long term monitoring to secure adequate water resources to shelter the people who are in a vulnerable position (Goswami *et al.*, 2022). A study that has been carried out in Guwahati reveals that urbanization in Arsenic concentration zones will be detrimental to people who are dependent on ground water sources (Singh *et al*., 2020). A study was carried out in ground water in Shillong, Meghalaya, India, which concluded that the properties of ground water in the region are under the influence of the biological process of rock weathering as well as atmospheric precipitation (Jain *et al*., 2021).

Percolation of fluorine from fluoride containing minerals from the disintegration of igneous rocks in the Karbi Anglong district of Assam have posed as a critical health hazard as the concentration of fluorine in the ground water have exceeded permissible limits set by WHO, and with that, serious attention and proper precaution is the need of the hour (Hanse *et al.*, 2019).

1.7.4. Regional scenario of water quality and heavy metal contamination

Since the population of Aizawl increased drastically in the last few decades, water scarcity became one of the main issues for the sustainable human use. The tuikhurs are generally capable of supplying very small amounts of water, and are therefore generally not regarded as a source of public water supplies for large communities. The State Government implemented greater Aizawl water supply Scheme I and II in 1988 and 2007 respectively by lifting water using pumping machineries from River Tlawng which is one of the major rivers in Mizoram. The Government also installed many shallow handpump tubewells within Aizawl which are very useful in solving the water scarcity problem in the city even though the water quality is seriously doubtful. The major cause of depletion of ground water is the continued pumping of ground water through handpumps and this depletion leads to shortage of adequate water resources to meet the region-specific requirements, to such an extent that 1.2 billion people are unable to access sufficient portable water (Thakare, 2019).

The spring river flowing beside the landfill areas of Tuirial, Mizoram, has been heavily contaminated as no sound pathway for the flow of river water has been secured, leading to complete exposure of the flowing water to the wastes and contaminants found in the landfill site (Laskar *et al.*, 2022). Explosion of population leading to urbanization and large growth of urban centres generates industrial wastes, along with the combined effect of agricultural systems such as unsystematic use of synthetic fertilizers, inefficient irrigation, shifting cultivation and improper crop rotation (Lalbiakmawia and Kumar, 2022). The discharge of untreated effluents along with sewage has largely accelerated the degrading of the quality of water resources, both surface as well as ground water (Lalbiakmawia and Kumar, 2022).

Several studies on the assessment of water quality have been carried out in the state Mizoram (Malsawma, 2005; Hnamte, 2007; Mishra, 2009; Lalchhingpuii, 2011; Lalchhuanawma, 2011; Sunar and Mishra, 2016; Chenkual and Mishra, 2016), however, no systematic and comprehensive study has been done in ground water (handpump tubewells) in Aizawl city which serves as a primary drinking water source for many households in almost all the localities. Moreover, there exist negligible studies to assess on heavy metals contamination of ground water in Aizawl.

1.8.1 Scope of the study

The majority of research works on the water quality were conducted in developing countries. These studies focused on surface and borehole water quality with hardly any work being undertaken on shallow wells. In Aizawl City as well as in all the other towns and villages of Mizoram, public bore wells have been drilled and installed by the Public Health Engineering Department (PHED) of the State Government. It was done to meet the water requirements of the households in that area whereas borewell installation for private use is virtually not done till date. In Aizawl city, the treated water is supplied through pipeline connections by the PHED which is not sufficient to meet the daily requirements of water for drinking and other household activities of the local people. Moreover, as river is the sole source of water for pipeline connections, the quantity supplied through thus connection is highly variable due to seasonality of rainfall and also due to technical difficulties which often occurred in the vast network of pipelines on the rough terrain of Aizawl City. Majority of the families are depending on secondary sources of water like rain water, tuikhur (water storage point fed by water seepages from rock strata), and hand pump tubewells installed by the State Government. In the proposed study area, most of the family which depend on hand pump tube wells as primary household water, consume it without any treatment or sanitization. As Mizoram State holds the population with one of the highest percentages of cancer patients in the world and Aizawl district tops all other districts in the country with highest incidence rates for cancer among both male (273.4:1, 00,000) and females (227.8:1, 00,000), it is crucial to conduct the assessment of the water quality in the Aizawl City (Indian Express, 2014). Henceforth, this work will help to assess the water quality for drinking purpose and also explain the source of contaminations, so that proper remedial measures can be explored. In the light of above-mentioned remarks, it is pertinent to investigate the ground water quality of Aizawl which concentrates most of the population of Mizoram. Since ground water quality is inextricably linked with quality of life and health of people in Aizawl, present proposed work aims to investigate it seasonally with following objectives.

1.8.2. Objectives

1. To evaluate the ground water quality of selected sites in Aizawl city.
2. To determine the metal content of ground water in the selected sites.
3. To formulate appropriate strategies for water quality management.

CHAPTER-2

REVIEW OF LITERATURE

2.1 International

Urbanization and increasing demand for potable water results in the digging of ground water which jeopardized its quality and quantity. Ground water in Eskisehir plain, Turkey was found to be heavily polluted by nitrogen compounds like ammonia, nitrite and nitrate due to farming in the area (Kacaroglu and Gunay, 1997). It has been predicted that about 50% of total water utilised for domestic usage is derived from ground water resources (UNESCO, 2022). Study of potable water by Gadgil (1998) reveals that it has been unavailable for nearly 1.1 billion people in the world and about 400 adolescents attain mortality per hour due to consumption of polluted ground water.

Ground water deterioration is caused due to human activities such as unsystematic use of fertilizers, improper discharge of wastes, and industrial activities. Overuse of ground water leads to sidewise access of seawater in the North area and upward movement of the older sediments and hence overuse of ground water must be restricted in Mazandaran Province, Northern Iran (Khairy and Janardhana, 2016). Abanyie *et al*. (2016) have studied potability of water from dug wells of Bolgatanga town, Ghana and found out that the water in the study area crosses permissible limit of World Health Organization (WHO) for some parameters like, Total coliform, faecal coliform, acidity, Conductivity, turbidity and total dissolved solids and proper management should be done in the study area. Also, Fallahzadeh *et al.* (2016) have investigated the nitrite and nitrate contamination of drinking water wells using Geographic Information System (GIS) technique in Yazd City, Iran and observed that it was within the permissible limit according to National standard of Iran (NO1053). Hamutoko *et al*. (2016) studied ground water vulnerability to pollution based on Niipele, sub-basin of Cuvelai-Etosha Basin, Namibia and observed that the ground water in the study area is susceptible to pollution and specific hydrogeological investigation of mapping of hydrotropes is needed. In West Africa, Central Burkina Faso ground water around Bombore gold mineralized zone was found to contain Chloride, Phosphate and bacteria which indicates anthropogenic activities. Pb and As were also found to exceed the acceptable limit prescribed by WHO (Sako *et al.*, 2016).

Monsoon seasons bringing rainfall tend to increase the percolation of water into the sub surface of the ground, thereby, carrying with it various components present in the soil. A case study of such samples during monsoon indicates that the arrival of rainfall promotes the seepage of pollutants into the water table, therefore, an efficient ground water regulation scheme to provide better quality ground water is the need of the hour (Manikandan *et al.*, 2020). It is also observed that ground water within the riverine communities is much more prone to pollution when compared to ground water in an upland area. Previous studies suggested that larger percentage of ground water showed presence of coliform. Further findings suggested that geochemical processes such as rock water interaction, seawater intrusion and precipitation influence ground water quality within the study area (Eyankware and Ephraim, 2021).

A study of ground water pollution and its health impact was carried out in the terrestrial area in China where farming and industrial activities were abundant. The study revealed that total hardness, nitrate, nitrite, total dissolved solids, sulphate, and fluorides are the major pollutants in the area therefore, the ground water is not fit for public use and need urgent management (Wu and Sun, 2016). An evaluation of the ground water in the Ghaen Plain of Iran had revealed that the level of Total Dissolved Solids (TDS) and Calcium were well beyond the safety limits set by WHO and scientific agencies of Iran, therefore, studies for the removal of the causes of contamination is necessary to enhance ground water quality (Naseh *et al.*, 2018). For conserving and protecting ground water from pollution, it is essential to examine the amount of dissolved oxygen, and for this purpose, an artificial intelligence (AI) machine known as support vector machine (SVM) was set up (Ji *et al.*, 2017). A study in the urban centers of Sialkot, Pakistan reveals that turbidity of the ground water in the study area was above the acceptable standards set by WHO and Pakistan Standards and Quality Control Authority (PSQCA) (Ullah *et al.*, 2009). Assessment of ground water in Vijaypur, Aurangabad in India has reported that the amount of TDS has exceeded that limits set by WHO and Bureau of Indian Standards (BIS), leading to the degraded state of ground water quality, possibly facilitated by unsystematic agricultural use of chemicals (Deshpande *et al.,* 2012).

In historical perspective, Smith *et al*. (2000) noted that maximum As contamination was found in Ground water of Bangladesh and hence it is essential to test the presence of As in Ground water. In Bangladesh, many tube-wells have been drilled to avoid disease resulting due to the consumption of As polluted ground water, thus, potable water has reduced from 97% to 51.2% (Nahar, 2009). A study of As pollution in the Simav Plain, Turkey, reveals that high concentrations of As from natural sources as well as anthropogenic influences were found in the local water sources and has greatly affected human health in the area, this has led to growing rates of gastrointestinal cancers in the study area (Gunduz *et al*., 2010). Water quality parameters tested in Girei Town, Nigeria indicates that Calcium (Ca), Magnesium (Mg), Chloride, lead, turbidity, total fecal coliform is alarming as they exceed WHO permissible limits of drinking water (Burmanu *et al*., 2014). Hazard Index (HI) was tested for ground water in Akwa, IBOM State, Nigeria and found that the trace metal pairs like Cd-Al, Cr-Al, Fe-B, Pd-Cd, and Pb-Cr crosses permissible limits which leads to human health issues and needs proper administration in the study area (Inam *et al*., 2014). In Northwest Bank of Palestine, ground water is the major source of potable water and it was reported that it contains (0.02-0.124 g/L) of Thallium (Tl), an extremely hazardous element beyond the permissible limit of WHO (Malassa *et at*., 2014). Ground water contamination due to heavy metals in North Western Romania is mainly due to mining activities which are in the downstream of dams which may be harmful to the crops, livestock, and human residing in the area (Modoi *et al.,* 2014). Further, Adedeji and Alayinka in 2015 have tested the water quality parameters like Calcium, Magnesium, Sodium(Na), Potassium(K), Chlorine(Cl), Sulphate(SO_4) and heavy metals like Cd, Cr, Copper(Cu), Fe, Pb and Zn in Ikorodu, Nigeria and detected that Fe and Pb were present above the desirable limit of WHO and NIS, therefore reported that the major reason was textile discharge percolating from the permeable soil into the ground water which can affect the people who consume the water in the study area.

In relation to inorganic pollutants, Elumalai *et al*. (2017) investigated the heavy metal in ground water from South Africa and noted the presence of Boron(B), Nickel (Ni), and Zn within the permissible limit. However, Cd and Lithium (Li) slightly exceeded the desired limit whereas Silver (Ag), Cu, Mn, and Pb were quite high, thereby making ground water unfit for drinking. Herein, major contaminants sources contaminating the ground water were industries, mining, geogenic, and agricultural reasons. Assessment of ground water is crucial for environmental safety and public health. The ground water pollution issues in China have been improved due to public awareness and a wider field of research development which is directly linked with public health (Li *et al*., 2017).

High levels of As, fluoride and TDS in the ground water is a major cause of waterborne diseases like skin disorders and asthma, therefore, should not be used without adequate testing (Kumar *et al*., 2022). Aliyu *et al*. (2018) assessed the physical, chemical properties including heavy metals in ground water from Argungu, Kebbi State, Nigeria and reported that all the physio-chemical parameters were within the permissible limit. However, Cerium (Ce) and Ni exceeded permissible limit in some of the samples while Cobalt (Co) and Pb were present above the permissible limit in few samples, causing negative impact for the people who consume the water in the study area. Physico-chemical parameters tested in hand-pump water in Onueke Eza, Nigeria proclaim that except pH and total hardness, all the tested parameters were within permissible limit and correlation study showed that climate change affected temperature, chloride and nitrate levels and the ground water needs to be sanitized to prevent public health hazards (Samuel *et al*., 2018). Ground water exploitation was studied by Hozi *et al.* in 2018 in the vicinity of Ardakan plain, Yazd and concluded that the traditional digging of wells and farming are the reason of major fall of ground water in the area. Ground water is polluted due to some industrial effluents and poor management which leads to excess heavy metal contamination like Cu, Fe, Pb and Cd in wells of Baghdad City in Iraq (Kamal *et al.*, 2018). Ground water pollution is a severe problem and it has an impact on living beings. So, it is necessary to control and protect it from various agricultural activities like excess use of agrochemicals such as fertilizers and pesticides (Khanna and Gupta, 2018). Shakoor *et al*. in 2018 investigated the evaluation of As contamination potential in the aquifers of Punjab, Pakistan and reported that the study area was contaminated by As, Manganese, Calcium, Magnesium, Chloride, Carbonate, bicarbonate and Sulphate well-above the permissible limit prescribed by WHO. Ground Water quality assessment in Noakhali, Bangladesh reveals that it is polluted due to excessive pathogens and of high range of some physico-chemical parameters, hence actions should be taken before human consumption (Prosun *et al.,* 2018).

In Vietnam, public health of millions was threatened due to the consumption of high-level concentration of As present in the tube-wells and hence it is urgent to inform and educate the people about the toxicity and decontamination remedy (Luu, 2019). A case study in Punjab and Khyber Pakhtunkhwa, Pakistan showed that Chromium, Nickel, Manganese, and As are beyond the permissible limit prescribed by WHO and inter-metal interaction and principal component analysis indicated that heavy metal contamination may be due to man-made and topographical effects which require adequate management before usage (Hussain *et al*., 2019). Proper monitoring of ground water is a must because ground water is the main source of drinking water worldwide. It was reported that Perfluorinated compounds (PFC’s) have been detected in ground water which is toxic to human health (Kurwadkar, 2019).

It was observed that the phosphate levels and turbidity of ground water are the most exceedingly influenced characteristic by the unsystematic agricultural practices (Bastos *et al.*, 2021). Studies on the ground water contamination in different countries with varying physical and climatic features have suggested that different measures be taken to deal with the problem of ground water pollution in each region, taking into consideration their respective environments (Li *et al*., 2021). In this study, the dependency of human populations on ground water was pointed out and the need for investments for the purpose of investigating the contamination levels along with the suitable remedial measures.

A study was carried out in worldwide sedimentary ground water basins, which revealed that the water founded in such sites constituted considerable quantities of lithium (Li) and could possibly be regarded as a valuable potential resource in view of the growing demand for lithium in the future (Dugamin *et al.*, 2021). On account of growing industrialization and urbanization, climate change is a notable factor that has threatened our planet. Studies show that the consequences of climate change include unsystematic and unpredictable rainfall patterns, which has increased the dependency of the primary sector on ground water that can be detrimental in the long run (Mora *et al.*, 2022).

Although the re-use of waste water and sewage for irrigation and farming purposes have served as a sustainable technique of resource planning, it has posed as a significant threat to the quality of ground water due to the increased leaching of constituent pollutants, which sources, leading to the growing requirement of proper agricultural management plans for the sustainable use of ground water (Parihari *et al.*, 2023).

Another component of water pollution are the phosphate molecules present in synthetic detergents (Chen *et al.*, 2022).Ground water samples in Nigeria have shown to have phosphate levels which were higher than the recommended standards of scientific agencies, and even more so in the monsoon season (Ekere *et al.*, 2019).The COVID 19 pandemic period has led to a reduction of pollution in the water, however, the water was mainly contaminated by the virus in addition to the reduced level of maintenance procedures such as recycling and purging of the water. (Manoiu *et al*., 2022).

2.2 National

Choudhary and Naik in 2015 investigated the physico-chemical parameters of ground water quality analysis in Kalburagi, Karnataka, India and identified that this area has been polluted by Municipal effluent and overuse of ground water and needs proper decontamination before public use. Further, Chowdhury and Giridhar (2015) investigated the spatial distribution of ground water quality after rainwater recharge in Jawaharlal Nehru Technological University campus, Hyderabad, India and observed that spatial distribution of Nitrate and Potassium in excessive concentration at open ponds. According to Singh *et al*. (2015) in Ranchi area, Jharkhand, India 85% of the ground water in the area are suitable for drinking purpose whereas 15% of the sample need proper treatment before public utilization. The main sources for total dissolved solids, salinity, and conductivity were from farming and discharge of wastewater and also from technical waste (Pramanik and Kuity, 2016).

Tiwari *et al*. (2016) examined heavy metal contamination in ground water by using Geographic Information System (GIS) technique in West Bokaro coal fields and observed that metal concentration is higher before monsoon than post-monsoon and Al, Fe, Mn, and Ni are found to exceed the permissible limits and regular analysis was suggested before public usage. In this context, the high concentration of metals was due to mining and topographic outcome. In 2016, Ground water quality assessment in Bist-Doab, Punjab, India was done by analysing water quality Index which reported that seven parameters like pH, Total dissolved solids (TDS), Total Hardness, Fluoride, Chloride, Sulphate, and nitrate were within the permissible limit. However regular monitoring is necessary to protect ground water from harmful pollution from agricultural effects in the study area (Krishnan *et al*., 2016). A case study of ground water pollution in Sheri Nala Basin, Maharashtra, India reveals that the ground water contains TH, TDS, and Cl beyond permissible limit due to Industrial effluent and improper discharge of wastewater and it leads to high rate of diseases like Typhoid, gastroenteritis, dysentery and diarrhea in the study area (Yadav and Sawant, 2016). Evaluation of 45 ground water samples in Chikalthana, Maharashtra, India indicates that the water samples are mostly saline in all seasons and hence not suitable for drinking purpose and proper management is immediately needed (Aher and Deshpande, 2016).

In 2017, Ground water quality of Andhra University campus, Vishakhapatnam was found to be fit for consumption throughout the year (Rao *et al.*, 2017). Asanousilamma *et al.* (2018) investigated heavy metal pollution in ground water and its correlation with physical parameters at selected industrial areas of Guntur, Andhra Pradesh, India and figured out that some heavy metals like Pb, Cd, Cr, and Ni showed higher concentrations when compared with the previous years and need proper analysis. The neighboring site of Vellakal dumping area, Madurai, Tamil Nadu, India in 2018 was also altered due to seepage of leachate. Physio-chemical parameters like Electrical Conductivity (EC), total hardness, TDS, Calcium, Magnesium, and chloride exceeded the desired limit and the area need landfill and proper observation of ground water (Banupriya *et al*., 2018). Gowd and Shivasharanapa (2018) investigated physicochemical characteristics of ground water of Gurmitkal town, Karnataka, India by GIS method and observed that the water quality standards are within the permissible limit. Singh *et al.* (2018) have studied the ground water chemistry and human health risk assessment of east Singhbum, Jharkhand, India and found out that the ground water was highly contaminated by Cd, Pb, and Cr. In addition, they have observed high Hazard Index (>1) of heavy metals which indicated threat to human health.

Most of the potable water has been reserved with-in the underground portion of earth crust. Ground water restoration components that have to be considered in urban cities was found to be more than the natural restoration component, hence, this may imply that ground water in urban areas is more contaminated than rural areas. (Wakode *et al*., 2018). Adults are more accessible to the carcinogenic threat compared to children (Kashyap *et al*., 2018). As is the main pollutant of ground water which can be carcinogenic and pose serious threats to the health of inhabitants in the industrial area of northern India (Kashyap *et al*., 2018). Bansal and Dwivedi (2018) have studied assessment of ground water quality using water quality index and physico-chemical parameters. They (Bansal and Dwivedi, 2018) observed that the water quality standard of the rainy season is different from the summer season and hence periodic observation is necessary for the study area. Sridharan and Nathan (2018) studied a chemometric tool to study the mechanism of As contamination of ground water of Puducherry, South East coast of India and observed that marine sediments rich in As and Fe compounds and organic matters were identified as the major reasons of ground water pollution. The geographical dissemination map of TDS, TA, TH, Chloride, Fluoride, Potassium and pH exceeded the acceptable standard set by the Water Quality Index (WQI) in Coimbatore, Tamil Nadu, therefore, special attention and effective measures should be undertaken in regions of polluted ground water (Ezhilarasi and Kumar, 2018). Ground water parameters like alkalinity, total dissolved solids and bacteria were above permissible limit of BIS in Omti Nala and this is mainly due to lining work done by Municipal Corporation, Jabalpur in the affected area (Arora *et al*., 2018).

A study from Ground water of Ganges-Brahmaputra River basin reveals that As is present in most of the ground water and the source may be Arsenopyrite (FeAsS) and further research is needed for the study area (Singh, 2006). Consumption of contaminated water is a vital problem in the whole world. The amount of dissolved oxygen in a unit volume of water is usually less than the same unit volume of air. However, it was found that the amount of dissolved oxygen in water can further be reduced due to decay of plants and animals and intake of oxygen by organisms (Hanipha and Hussain, 2013). This study has shown that the amount of dissolved oxygen is less in the ground water of Tamil Nadu.

The nitrates and phosphates present in agricultural materials like fertilizers and pesticides is causing pollution to the quality of ground water, which is one of the main sources of drinking water, and, therefore, makes the application of safe and conservative measures very important in the present method of farming (Srivastav, 2020). A study had reported that uranium poisoning of ground water has been facilitated by di-ammonium phosphate (DAP) fertilizers used in agriculture (Singh *et al.*, 2022).

Studies in south India have shown that high chloride level in water have made people susceptible to constipation, therefore, chloride level can be taken as a measure of pollution of water (Sirajudeen *et al*., 2020). Chloride levels beyond 250 mg/L were revealed to cause cardiovascular diseases (Kumar *et al.*,2020). Potable water quality can be diminished due to improper disposal of effluent and overuse of resource. Ground water samples studied in Baghpat district, Uttar Pradesh, India discloses that water samples from hand-pumps were tested for EC, TDS, total alkalinity, and total hardness with recorded values beyond permissible limit, hence was not suitable for consumption (Singh *et al*., 2014). Heavy metal pollution Index

(HPI) study of ground water in Gulf of Mannar and Palk Strait. Tamil Nadu, India indicated that As, Manganese, Zinc, Cadmium, Chromium, Copper and Lead have exceeded the permissible limit and are highly toxic (Balakrishnan and Ramu, 2016). Ground water quality analysis in Gurgaon, Haryana, India reveals that due to lack of Industrial and household wastewater management, ground water quality has been deteriorated and it should be treated before utilization (Warish *et al*., 2017).

Prolong use of high concentration of As in the agriculture area can lead to aggregation of this metalloid in the soil which could reach plants and impose hazardous influence on food chain. As contamination was studied (Singhal *et al*., 2018) in Ambagarh Chowki Block, Chhattisgarh, India and found that the studied hand-pumps contained As beyond permissible limit prescribed by WHO, both in dry and wet seasons.

Iron occurs in water as ferrous and ferric form. It can blemish our clothing and utensils if present in excess. A study of contamination of Iron in ground water in Moradabad city, Uttar Pradesh, India demonstrated that water samples collected from hand-pumps were found to exceed permissible limit of Iron especially in summer season and hence these hand-pump water needed proper investigation before utilization (Kumar and Sinha, 2018). Heavy metals like Cd when present more than desirable limit can lead to major health effects like kidney failure, lung cancer and many more diseases like hypercalciuria and prostate cancer. A case study in ground water in western Uttar Pradesh, India observed that concentration of Cadmium was found beyond permissible limit hence it was harmful for utilization (Idrees *et al.*, 2018). In India, a study of ground water in Ganges River basin confirmed to be contaminated by pharmaceuticals personal care products (PPCPs) which can lead to health effect on consumption (Sharma *et al.*, 2019).

The ground water in the rocky terrain of Medak, Telangana, India surrounded with basaltic rocks, granites, gneiss and laterites, was tested with the GIS and the Ground water Quality Index (GWQI) which revealed that the nitrate concentrations and fluoride concentrations in the water exceeded the safety limits set by the WHO, thereby, making it unfit for consumption and necessitating the need for proper management of ground water (Adimalla and Taloor, 2020).

An assessment on Uranium containing ground water revealed that the presence of uranium has a direct impact on the quality of the ground water as it increased the TDS levels, EC, total hardness, contamination by metals and decreased the acidity of the assessed water, making people conscious and alert about the need for purity and better-quality ground water (Singh *et al*., 2021).

Since the health hazards caused by consuming polluted ground water is directly proportional to the amount of consumption, the concentration of contaminants can be taken as the basis for identifying potential health risks. Long term exposure to carcinogenic and non-carcinogenic heavy metal contamination (such as As and Cd), even in small quantities at a times can have severe ill effects on the human body (Kayastha *et al*., 2022). Thus, purification of ground water through either natural or artificial means, becomes an urgent necessity (Kayastha *et al*., 2022). It has also been revealed that the ground water in coastal region of Tamil Nadu was not considered portable due to the pollution caused by TDS contaminants (Rawat *et al.,* 2018). Chloride levels and TDS have been found to have exceeded permissible limits in the ground water in the arid regions of Rajasthan, emphasizing need for evaluation and conservation of the ground water in the study area (Rahman *et al*., 2020).

Pollution of water with heavy metals and agricultural materials above safety standards have caused decline in water volume of urban areas. and most of the water requirement in rural areas are met extensively by ground water (Malyan, 2019).

An assessment of ground water samples in Himachal Pradesh had determined that the percolated water was polluted by physico-chemical characteristics that surpassed the acceptable standards set by agencies such as leachate pollution index (LPI), water quality index (WQI) and heavy metal pollution index (HPI) (Sharma *et al*., 2020). The two-year quarantine caused by the COVID-19 pandemic has significantly reduced the amount of pollution by metals, and has led to proactive merits due to restriction on industrial activities (Karunanidhi *et al*., 2021).

2.3 Northeast

A study of seasonal distribution of trace metals in ground and surface water of Golaghat district, Assam, India reported that Chromium, Manganese, Nickel, Cadmium and As were beyond permissible limit of WHO and hence regular observation is needed (Boarh and Misra, 2010). The heavy metals like Aluminium, Lead and Cadmium exceed permissible limit laid by WHO in the tested Ground Water samples in Dhemaji district, Assam, India and the contamination results in the trend Al>Pb>Cd>As in both dry and rainy season (Buragohain *et al*., 2010). Water quality Parameters including heavy metals was studied by (Banerjee *et al*., 2011) in North and South Tripura, India and observed that As crosses permissible limit prescribed by WHO, and moreover Iron and Manganese concentration goes parallel but their concentration was controlled by pH and hence the water in the study area needs proper treatment before public use. The interrelationship between As and phosphate shows that the mobilization of As is due to the evolution of modern agricultural (Oinam *et al*., 2011).

Ground water samples of Dehema J, District of Assam, India was found to be contaminated by As and care has to be taken by Government for the people who are dependent on ground water in the study area (Buragohain and Sharma, 2012). Haloi and Sharma, (2012) investigated ground water quality of Brahmaputra flood plain, Barpeta District, Assam, India and reported that Iron, Manganese and Lead concentration in few samples exceeded the permissible limit prescribed by WHO, whereas Cadmium contamination exceeded only in four sampling sites. Hence the people in the study area should be notified to drink only safe water. Assessment of quality analysis of ground water in greater Guwahati, Assam, India reported that most of the tested parameters were within desirable limits except chloride and iron crosses permissible limit which can cause harm to human health (Islam *et al*., 2014).

A report on physicochemical study of water quality of lakes of Udaipur City Tripura, India discloses that Biological Oxygen demand, Ammonia Nitrogen and Turbidity exceed the permissible limit proposed by BIS which may be due to discharge from drainage and hence the lake needs immediate proper protection (Lodh *et al*., 2014). In coal-mining areas of Meghalaya, India, water contamination was acknowledged and water quality parameters like pH, EC, Sulphate, Biological Oxygen demand, Dissolved Oxygen and Iron were above the desired limit which shows the degeneration of the water quality in the study area (Swer and Singh, 2014). In limestone mining areas of Jaintia Hills, Meghalaya, India, water quality parameters were tested both before and after monsoon season which revealed that all the parameters exceed the desirable limit (Eugene and Singh, 2014). This water contamination can be due to the flow of wastage from the cement factory and therefore proper management is required to protect drinking water of the area (Eugene and Singh, 2014).

In northeast India, many institutions and researchers reported As contamination which causes many skin diseases and even cancer cases are also observed but the people are still in shortage of sanitized drinking water (Saurav *et al*., 2015). Chandrashekhar *et al*. (2016) have studied contamination of As in the ground water and its influence on irrigation in Manipur valley, India. Since the people of Manipur have used surface water for irrigation therefore it caused exposure of less than 10 ppb As consumption, therefore, no serious threats to human health was observed from the study area (Chandrashekhar *et al*., 2016). Kanungo in 2016 has studied the seasonal variation in ground water and identified that 27% of the sample were safe, 18% exceeded the permissible limit and 3% of the sample were shockingly high in As concentration in Pre and Post-monsoon season. In North-east India, coal mining caused many negative impacts like topographical destruction, soil abrasion, disturbances of ecosystem and contamination of air, aquatic and soil. Coal mining also affects some physico-chemical nature such as elevation of sulphur volatile substance, low ash content and heavy metals like Fe, Mg, Cd and Pb etc. which needs a proper technique to control various kinds of pollution (Chabukdhara and Singh, 2016). Borah *et al*. (2018) have investigated the contemporary distribution and mobility of Zn, As and Cu in Brahmaputra River bed, Assam, India and concluded that the texture of the soil controls metal mobility in the river bed which need to be regulated for the well-being of the environment and human society. Bora *et al*. (2017) studied water quality assessment using water quality Index in Kolong River, Assam, India and observed that the river needs proper management like restricting wastewater discharge from urbanization and also solid waste must be taken care for sustainable development of the river. A case study in North-east India, some districts of Manipur and Assam showed that Fe and As are interrelated more in the state of Manipur and discharge of As in the aquifer needs to be taken care of for better maintenance of ground water quality in the study area (Gupta and Singh, 2019).

Ferrate (VI) has been shown to be a potential factor that helps in deteriorating the contaminants of water pollution due to its quality of being able to oxidise in the proximity of various particles, and therefore, acts as a disinfectant (Lalthazuala *et al.*, 2022).

2.4 Mizoram

In Mizoram, water quality had been tested by many researchers and their studies have resulted that the tested parameters were mostly within permissible limits set by various agencies. Hnamte (2007) investigated some of the spring water quality of the eastern region of Aizawl, Mizoram, India and observed that turbidity value is moderately high in some places in pre-monsoon but it is within the permissible limit. With reference to physico-chemical and bacteriological parameters studied in Kolasib district Mizoram, India, drinking water supplied by the government was cleaner than the sub-surface water (Kumar *et al*., 2009). Water quality of Aizawl, Mizoram, India was examined by Thasangzuala and Mishra in 2014 and observed that almost all the water quality parameters meet the desired limit given by WHO (2008), United States Public Health Service (USPH) (1962). Indian Council of Medical Research (ICMR) (1996) and BIS (2003) but for one sampling site, the turbidity is slightly higher than the permissible limit and also observed that Total dissolved solids and electrical conductance were directly correlated.

Water quality parameters studied in Tamdil Lake, Mizoram, India indicated that the lake is a rich and healthy ecosystem which can sustain many living systems and the lake needs proper care and protection from contamination (Chenkual and Mishra, 2016). Blick *et al.* in 2016 have studied the As contamination of drinking water in Chawngte, Lawngtlai district, Mizoram reveals that As and turbidity are moderately above the permissible limit of 0.05mg/l and 5 NTU. A study of physico-chemical parameters of drinking water from hand-pump and sub-surface water (tuikhur) in Saiha, Mizoram, India reveals that all the tested parameters except Iron were within the permissible limit prescribed by WHO and BIS and can be utilised by the public (Blick and Kumar, 2017).

A study carried out in Serlui river with respect to arrival and withdrawal of monsoon concluded that the acidity, chlorine levels and hardness of the water were safe and within permissible limits, however, the BOD exceeded the acceptable standard (Laldinpuii and Mishra, 2019).

An investigation was put through to assess the usage and capacity of the ground water in vanvatelui basin using e-TOPSIS model (Barman and Biswas, 2022). This study was proved to be helpful to the legislature of states, local councils, municipalities and the government in ensuring the preservation and proper management of ground water in order to collect and conserve water which will aid in times of scarcity and arid periods. Laskar *et al.* in 2022 studied spring water quality of Tuirial landfill site in Aizawl, Mizoram and concluded that spring water often gets contaminated due to lack of appropriate planning and protection against the landfill.

CHAPTER-3

METHODOLOGY

3.1 Description of study area

3.1.1 Mizoram: Location and geographical Features

Mizoram, situated between 92˚15’ E to 93˚29’ E longitudes and 21˚58’ N to 24˚35’ N latitudes, is a state of India located in the extreme south of north eastern part of India. With dimensions measuring 277 km from North to South, and 121 km from East to West, the total geographical area of Mizoram is about 21,081 square kilometers. It shares its borders with the states of Assam, Manipur, and Tripura, as well as with the neighboring countries of Bangladesh and Myanmar. Mizoram is divided into eleven districts namely, Aizawl, Lunglei, Siaha, Champhai, Kolasib, Serchhip, Lawngtlai, Mamit, Saitual, Khawzawl and Hnahthial.

The terrain of Mizoram is hilly and rocky, with most of the land covered by dense forests. The state is situated on the eastern slopes of the Himalayas, with the highest peak being Phawngpui (also known as the Blue Mountain), which stands at an altitude of 2,157 meters. The state's major rivers include the Tlawng, Tuivawl, and Kolodyne, all of which are important sources of water for irrigation and hydroelectric power generation.

Owing to its position with the tropic of cancer passing through it, Mizoram has a subtropical climate. The summers are dry and hot, the winters are mild and cool. The south west monsoon which brings rain to the country, brings a high amount of rainfall to the state, which amounts up to a range of 2100 mm to 3500 mm in the months of May to September (Forest Survey of India, 2019). The pattern of rainfall has always significantly influenced the supply of domestic water as well as the sustenance of the environment (Konapala *et al.*, 2020).

The climate, topography and geology of the state has a significant influence in the weathering of rocks, which forms different types of soil, namely, red soil, yellow soil and laterite soil. The pH of the soil is slightly low and has a deficiency of certain minerals. Most of the citizens are involved in the primary sector, and is the main factor of the economy of the state.

3.2 Description of study site

Aizawl is the capital city of Mizoram which is situated on the top of a ridge running in north-south direction. It covers a total area of 3,576 sq.km. It is located in the northern part of Mizoram between N23º43.076 to N23º46.571 latitude and E92º42.389 to E92º44.448 longitude. The average altitude of Aizawl city is 1,132 meters from mean sea level (msl) and the population of the city according to 2011 census is 4,04,054 (male - 2,01,072, female - 2,02,982). Aizawl is the political, administration, educational, commercial, cultural and social centre of the State (Census, 2011). The entire Aizawl district is under the direct influence of south – west monsoon, with average rainfall of 3155.3 mm (MIRSAC, 2012). In summer, the temperature ranges from 18-33C, and in the winter 11-24C (Zomuanpuii *et al,* 2020).

The Public Health Engineering Department (PHED) of the state has provided sufficient water supply in rural and urban areas and the number of water systems such as piped water, hand pumps and rainwater harvesting facilities have increased significantly (Hnamte, 2013; Lalchhuanawma, 2016).

3.2.1 Selection of sampling sites

To fulfil the objectives of the present study, ground water samples from thirteen handpumps and one tap source for reference were collected for detailed analysis of water quality or physico-chemical characteristics. This was done to generalized an analysis of the portability of ground water in comparison to tap water, as tap water has been sanitized by the water supply department, in contrast to the unfiltered ground water utilized by the public.

SITE 1: Bawngkawn Handpump (near Hrangbana Petrol pump)– From our investigation, about 30 to 40 families are depending on this handpump, out of which more than 20 families use it for drinking purpose.

SITE 2: Chaltlang Handpump (near Sericulture Office) – More than 20 families use this handpump for drinking and many people use it for washing clothes and cleaning vehicles.

SITE 3: Ramhlun South Handpump (near Ramhlun South Presbyterian Church) – This handpump is used by many families living in this locality for drinking purpose and for washing clothes.

SITE 4: Republic Vengthlang Handpump (near Republic Presbyterian Church) – Many families depend on this for drinking and washing clothes.

SITE 5: Republic Vengchhak Handpump – Local residential people depend on this water source for drinking purpose, especially during dry or summer season.

SITE 6: Tuikual Handpump (near Coreens Bakery Industry)– There are many people who do not have PHED water connection in this locality and they are completely dependent this handpump for drinking purpose.

SITE 7: Kanan Handpump (near Kanan Baptist Church of Mizoram) - This handpump is a major source of water for many families living in this locality,especially those who are residing in rented houses.

SITE 8: Ramhlun South Hand pump (near Ramhlun south Baptist church) - This handpump water is the main source of water for many families living in this locality for drinking and household purpose throughout the year.

SITE 9: Tap water-In addition to several Hand-pump driven water samples, one tap water sample was collected which was supplied by Mizoram PHED near Pollution Control Board Office.

SITE 10: Bethlehem Hand-pump (near Bethlehem taxi stand)– This Hand-pump is a major source of water for many families living in this locality for the whole year, especially those who are residing in rented house.

SITE 11: Durtlang (near Govt Zirtiri Residential Science College) – This Hand-pump is used by some families during winter season and a time when water scarcity is more.

SITE 12: Durtlang (near Durtlang Presbyterian Church)- This Hand-pump water is the main source of water for many families living in this locality for drinking and household purpose throughout the year.

SITE 13: Ramhlun North (near Ramhlun North Vegetable Market)- This Hand-pump is a major source of water for many families living in this locality, especially those who are residing in rented house. This water source is particularly relevant when there exists water scarcity during dry season.

SITE 14: Industry Peng (near Salvation Army Church)- This Hand-pump is used by many families for drinking and domestic purposes.

It is worth mentioning that the treated PHED tap water samples of site 9 in fact acted as reference to compare the ground water samples from other selected sites.

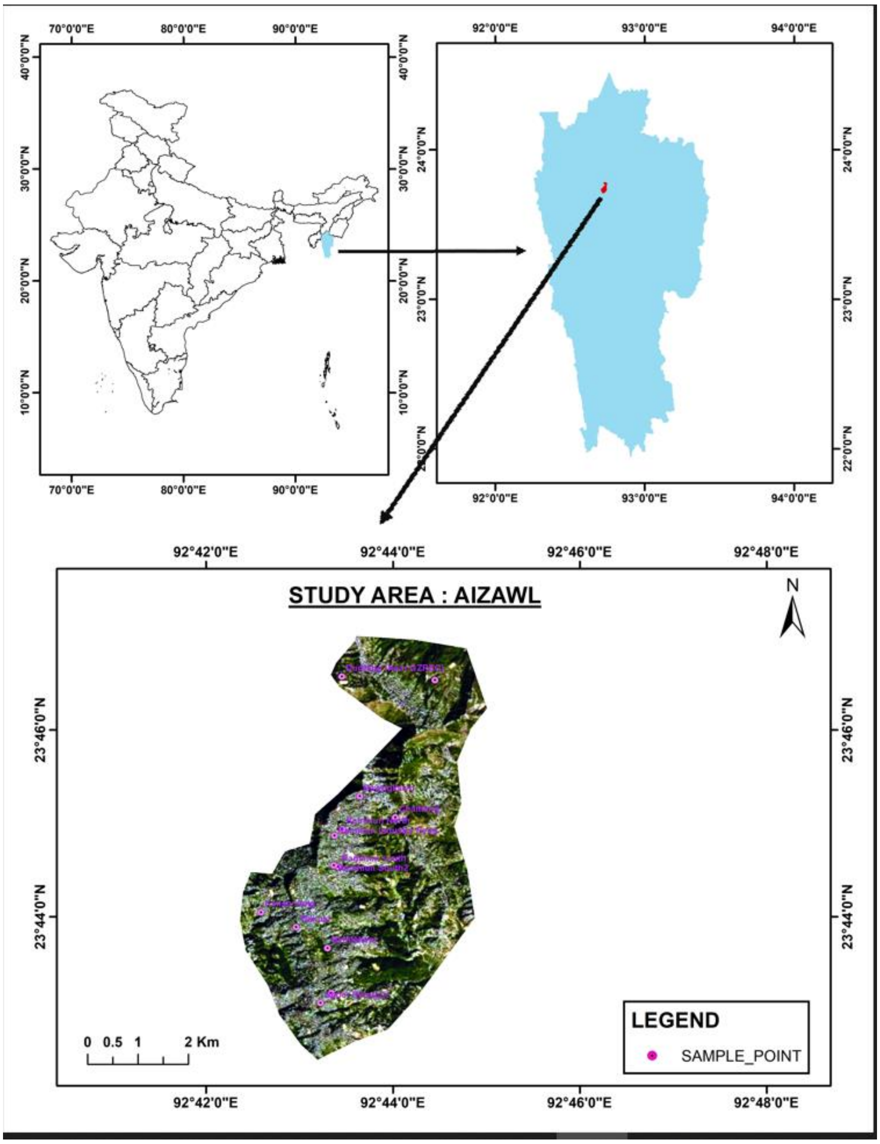

Fig 3.1: Location map of study area

‘

Photo plate 3.1: Site 1- Bawngkawn Handpump
(near Hrangbana Petrol pump)

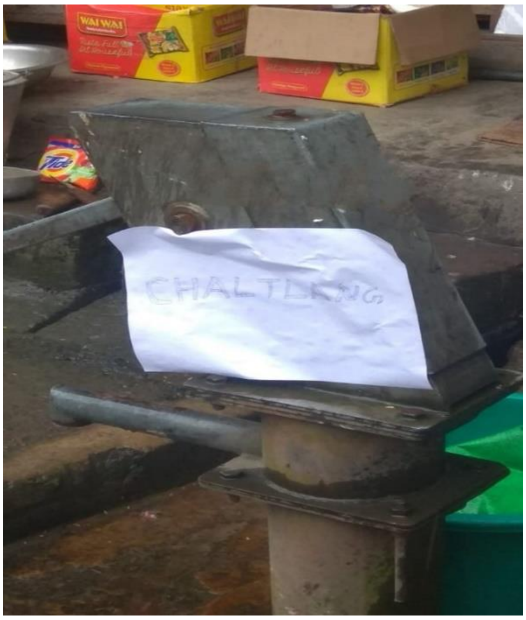

Photo plate 3.2: Site-2 Chaltlang Handpump (Near Sericulture Office)

Photo plate 3.3: Site 3- Ramhlun South Handpump (Near Ramhlun South Presbyterian Church)

Photo plate 3. 4: Site 4- Republic Vengthlang Handpump (near Republic Presbyterian church)

Photo plate 3. 5: Site 5- Republic Vengchhak Handpump

Photo plate 3. 6: Site 6- Tuikual Handpump (near Coreens Bakery Industry)

Photo plate 3. 7: Site 7- Kanan Handpump (near Kanan Baptist Church of

Photo plate 3. 8: Site 8- Ramhlun South Hand pump (near ramhlun south Baptist church)

Photo plate 3. 9: Site 9- Tap water (supplied by Mizoram PHED)

Photo plate 3. 10: Site 10- Bethlehem Hand-pump (near Bethlehem taxi stand)

Photo plate 3. 11: Site 11- Durtlang (near Govt Zirtiri Residential Science College)

Photo plate 3. 12: Site 12- Durtlang (near Presbyterian Church)

Photo plate 3. 13: Site 13- Ramhlun North (near Ramhlun North Vegetable Market)-

Photo plate 3. 14: Site 14- Industry Peng (near Salvation Army Church)

3.3 Collection of Water Sample

Handpump and tubewell water samples were collected (in triplicate) from different localities of Aizawl City under five major zonations viz. Central, North, South, East and West part of Aizawl City on a monthly interval for two successive years i.e., from January, 2018 to December,2018, and January, 2019 to December, 2019. The geographical location of each sampling point was recorded using Global Positioning System (GPS). The various physicochemical characteristics viz., Turbidity, Total Dissolved Solids (TDS), Total Hardness (TH), Total Alkalinity (TA), Chloride, Calcium, Phosphate-P, Nitrite-N, N-Ammonia, Dissolved Oxygen (DO), were analysed during the said study period. Temperature and pH of the water samples were recorded at the sampling sites and samples were fixed at site for estimation of DO of water.

3.4 Methods for physico-chemical analysis of water

(i) Temperature

A simple centigrade thermometer with a precision of 0.1degree Celsius was used to measure the temperature of water.

(ii) pH

Portable pH Meter was used to measure the pH of water samples.

(iii) Turbidity

Turbidity of water samples were measured by using Nephelometer/ Turbidity meter and the value was expressed in NTU (Nephelometric Turbidity Unit).

(iv) Total dissolved solids (TDS)

Measurement of TDS of water was done by evaporation and filtration method and the value was expressed in mg/L. TDS was calculated as follow

$$\mathrm{TDS} = \frac{(\mathrm{W2} - \mathrm{W1}) \times 1000}{\mathrm{V}}$$

where, W1 = Final weight of residue + dish.

W2= Initial weight of dish.

V = Volume of the sample taken in ml

(v) Chloride

The chloride content of water was measured using argentometric titration method (Mohr's method) and the value was expressed in mg/L. Standardised Silver nitrate (0.0141N) solution was used as a titrant. Chloride content was calculated as follows:

$$\text{Chloride content} = \frac{A \times N \times 34.45 \times 1000}{Volume of water sample\ used (ml)}$$

where, A = Volume of titrant used

N = Normality of titrant

(vi) Total Alkalinity

The total alkalinity was determined by potentiometric titration method and the value was expressed in mg/L of $CaCO_3$. Standardised Sulphuric acid (0.02N) was used as a titrant to bring the pH of sample at 8.3 (phenolphthalein alkalinity) and to pH of 3.7 (methyl orange alkalinity). Total alkalinity was calculated as follows:

$$\text{Total alkalinity} = \frac{(\text{A} - \text{B}) \times 1000}{\text{Volume of water sample used(ml)}}$$

where,

A = Alkalinity due to Phenolphthalein,

B = Alkalinity due to Methyl Orange

(vii) Total Hardness

Total hardness is measured by using EDTA titration method.

$$\text{Total hardness (as } CaCO_3 \text{ mg/L)} = \frac{CxDx\ 1000}{\text{Vol.of sample taken}}$$

Where, C = Volume of EDTA (titrant) required by sample for titration.

D = 1mg $CaCO_3$ equivalent to 1ml EDTA titrant (1mg for 0.01 M EDTA used)

(ix) Calcium

Concentration of calcium has been measured by using EDTA titration method.

Concentration of calcium (mg/L)

$$= \frac{\text{Volume of EDTA consumed x Molarity of EDTA x At weight of calcium x1000}}{\text{Vol. of sample taken}}$$

(x) Nitrite-N

Diazotization method was employed for determining Nitrite-N content in water samples. The development of colour was observed with the help of Spectrophotometer and compared with the calibration curve. The value will be expressed in mg/L. The value was calculated using the following formula,

Concentration of N-NO_2 in mg/L = R x m f x D (Dilution factor/no of times of dilution)

Where,

R= Absorbance reading of sample

mf= absorbance/Conc

(xi) Phosphate-P

Stannous Chloride calorimetric method was used for determination of Phosphate-P content present in water samples. The absorbance of color was observed using Spectrophotometer. The results were expressed in mg/L.

Concentration of Phosphate mg/L=Rx mf

Where,

R= Absorbance reading of sample

mf =absorbance/Conc.

(xii) Nitrogen Ammonia

Calorimetric method was used for determining N-NH_3 present in water sample. The absorbance of colour was observed using spectrophotometer. The results were expressed in mg/L.

Conc of N-NH_3 in mg/l =R x mf x D (no of times dilution)

Where, R = Absorbance reading of sample

mf = absorbance/Conc.

(xiii) Dissolved oxygen

DO content of water was determined using the modified Winkler's Azide method and the value was expressed in mg/L. DO content was calculated as follows,

$$\text{DO content} = \frac{\text{V} \times \text{N} \times 8 \times 1000}{\text{Volume of water sample used (ml)}}$$

where, V = Volume of titrant used

N = normality of titrant

3.5 Analysis of water for metals:

Pertaining to estimation of certain metals like copper (Cu), lead (Pb), zinc (Zn), iron (Fe), Nickel (Ni), Manganese (Mn) and Arsenic (As). Ground water samples were acid digested as described elsewhere (APHA,2005; Singh and Rai, 2016). Samples were analysed with Shimadzu AA-7000, Atomic Absorption Spectrophotometer (AAS) which is available in Chemistry Department Laboratory, Mizoram University, Mizoram.

For the above quality parameters, the methods as described in “Standard Methods for the Examination of water and waste water” prescribed by the “American Public Health Association (APHA,2005)” has been adopted for analysis of water quality parameters.

Table 3.1 The geographic **location of sampling sites recorded using Garmin etrex-30**

SAMPLE NO.	LOCALITY	GPS LOCATION	ELEVATION (in meters)	ZONATION
1	Bawngkawn	N23^{0}45.288 E92^{0}43.642	1015	North
2	Chaltlang	N23^{0}45.064 E92^{0}43.382	1099	North
3	Ramhlun South	N23^{0}44.535 E92^{0}43.410	1008	East
4	Republic Vengthlang	N23^{0}43.182 E*92 ^{0}43.341*	977	South
5	Republic Upper	N23^{0}43.076 E*92 ^{0}43.223*	1086	South
6	Tuikual	N23^{0}43.886 E92^{0}42.963	1002	West
7	Kanan	N23^{0}73.551 E92^{0}7093	1000	West
8	Ramhlun South	N23^{0}44.550 *E92 ^{0}43.366*	1032	Central
9	Tap water	N23^{0}73022 E92^{0}70534	958	
10	Bethlehem	N23^{0}43.662 *E92 ^{0}43.296*	940	East
11	Durtlang (Near Govt Zirtiri Residential Science College)	N23^{0}46.571 E*92 ^{0}43.453*	1184	North
12	Durtlang (Near Presbyterian Church)	N23^{0}46.532 *E92 ^{0}44.448*	1237	North
13	Ramhlun North	N23^{0}44.936 *E92 ^{0}43.455*	1075	Central
14	Ramhlun Industry peng	N23^{0}44.868 *E92 ^{0}43.371*	1075	Central

CHAPTER – 4

RESULTS

The results of the present study on physio chemical characteristics and heavy metals content of ground water and the impact of pollutants on the quality of ground water in fourteen sampling sites in different parts of Aizawl city over a period of two years (2018 and 2019) are given as follows:

Water Quality Characteristics

4.1. Physico-chemical properties

4.1.1. Temperature

The temperature values of water from all fourteen sites were recorded in the pre-monsoon, monsoon and post-monsoon seasons, respectively. The temperature of water ranged from 18.5°C (site 12 in pre-monsoon season) and 26°C (sites 3, 4, 5, 10, 13, 14 in monsoon season) in the year 2018. However, in the year 2019, the temperature ranged from 18.5°C (site 12 in pre-monsoon season) to 26°C (site 14 in monsoon and post-monsoon seasons). The overall temperature in both the years ranged from 18.5°C to 26°C. Generally, present study observed that temperature of ground water was lowest in pre-monsoon season and highest in monsoon season.

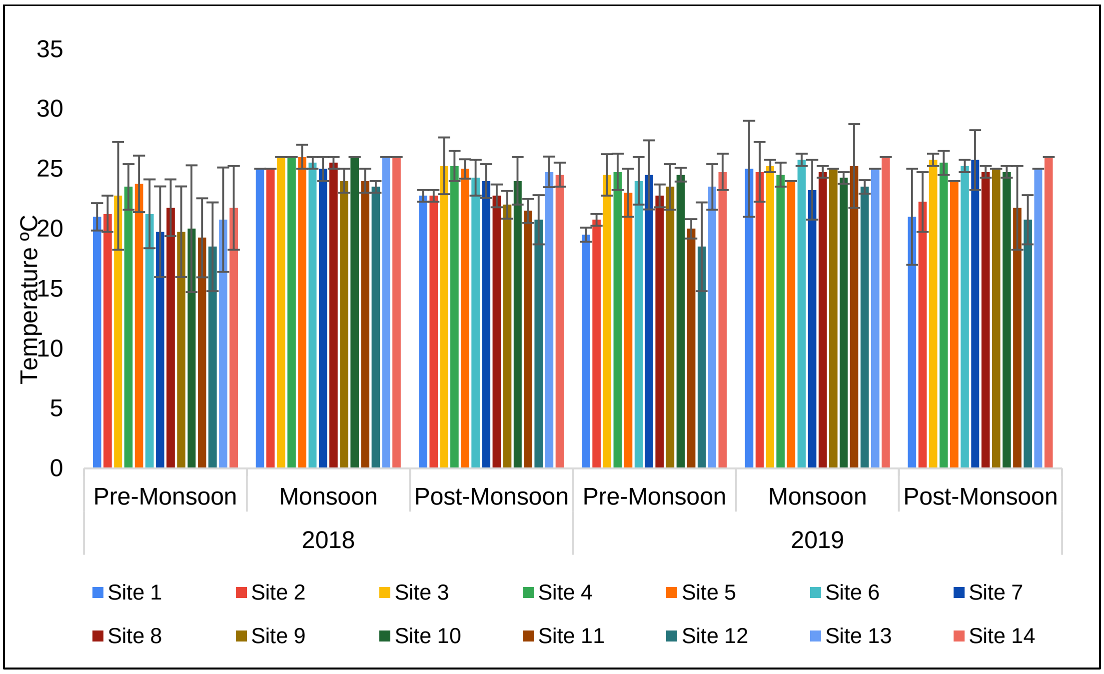

Fig.4.1: Seasonal variation in temperature of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.2. pH

The pH values of all the samples from the 14 different sites have been recorded seasonally i.e., pre-monsoon, monsoon, and post-monsoon seasons. The range of pH recorded in 2018 was from 5.725 (site 13 in pre-monsoon season) to 7.9 (site 9 in pre- monsoon season). However, the range of pH in the year 2019 was from 5.35 (site 13 in post-monsoon season) to 7.45 (site 12 in monsoon season). Therefore, the total range of pH in the two years (2018-19) was from 5.35 to 7.9. The pH ranges were found to be lower during pre-monsoon and post-monsoon seasons than during the monsoon season.

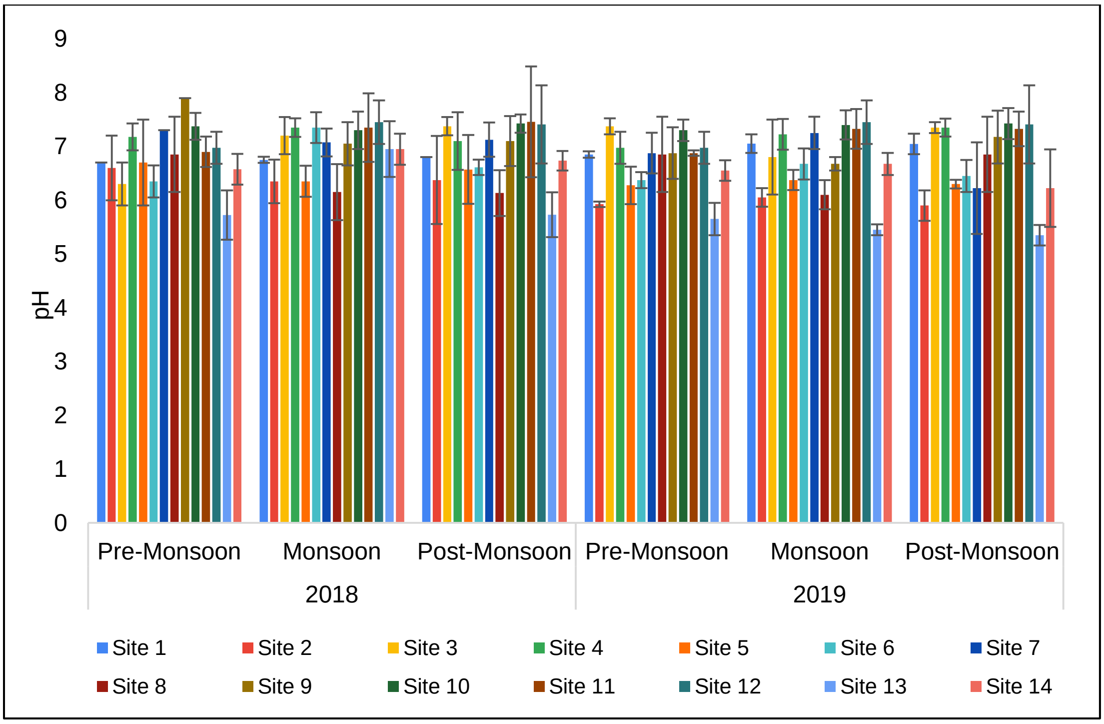

Fig.4.2: Seasonal variation in pH of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.3 . Turbidity

The turbidity of all samples were recorded for two years on the basis of pre-monsoon, monsoon and post-monsoon seasons respectively. The turbidity of ground water ranged from 0.1 NTU (site 9 in post-monsoon season) to 15.275 NTU (site 14 in post-monsoon season) in the year 2018. The turbidity ranged from 0.2 NTU (site 10 in pre-monsoon season) to 80.9 NTU (site 11 in post-monsoon season) in the year 2019. Therefore, the range of turbidity in the two years (2018-19) was from 0.1 NTU to 80.9 NTU. Seasonal variations revealed that turbidity was usually lowest in pre-monsoon season, followed by the monsoon season while it was highest in post- monsoon season.

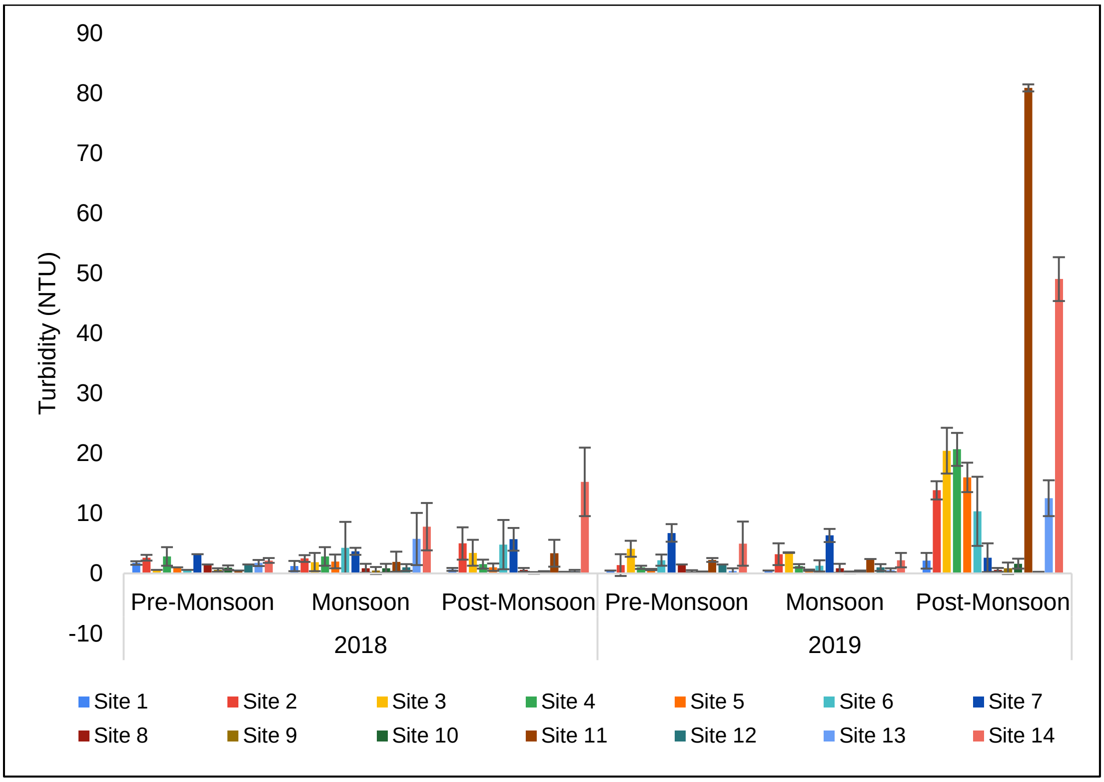

Fig.4.3: Seasonal variation in turbidity of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.4 . Total Dissolved Solids (TDS)

The Total Dissolved Solids for all 14 sites were recorded for the Year 2018 and 2019 . In the year 2018, the Total Dissolved Solids of ground water ranged from 39.5 mg/L (site 9 in post-monsoon season) to 268 mg/L (site 6 in monsoon season) , whereas in 2019, the range of Total Dissolved Solids in ground water ranged from 16 mg/L (site 9 in pre-monsoon and post-monsoon sesasons) to 246.25 mg/L (site 6 in pre-monsoon season). The overall range of Total Dissolved Solids during 2018-19 was from 16 mg/L to 268 mg/L.The values of Total Dissolved Solids in ground water varied in different seasons.

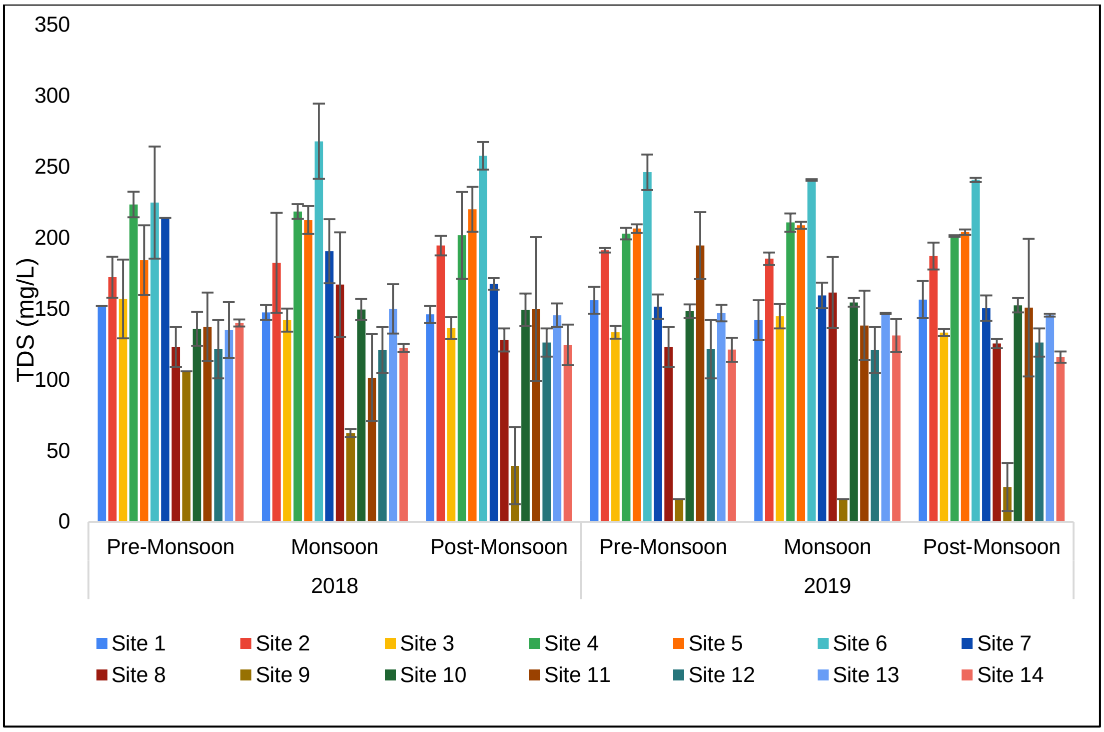

Fig.4.4: Seasonal variation in TDS of ground water in the different selected study site (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.5. Chloride (Cl)

The chloride levels in the ground water samples were observed and recorded during study period (i.e., 2018-19). In 2018, the chloride levels ranged from 5.075 mg/L (site 9 in post-monsoon season) to 86.025 mg/L (site 6 in pre-monsoon season). In 2019 , the chloride levels ranged from 3.1625 mg/L (site 9 in post-monsoon season) to 81.51 mg/L (site 2 in mosoon season). The overall range of chloride levels during 2018-19 ranged from 3.1625 mg/L to 86.025 mg/L.

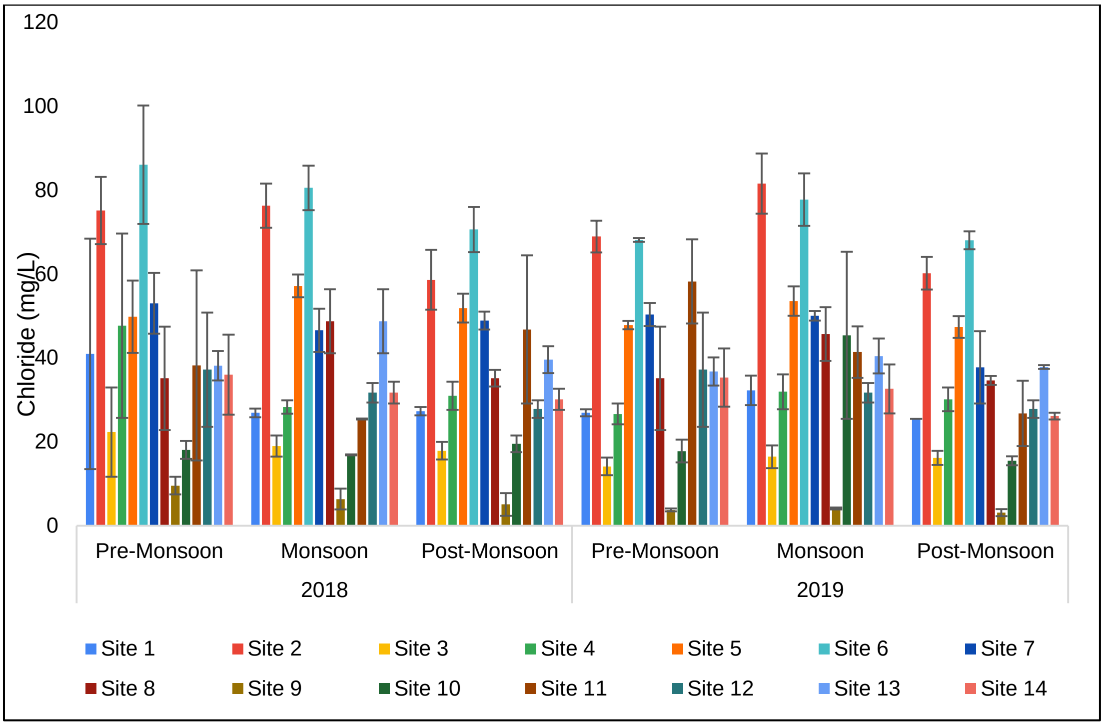

Fig.4.5: Seasonal variation in Chloride of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.6. Total Alkalinity

The total alkalinity of the ground water at all sites were recorded were noted during the study period (i.e., 2018-19). The total alkalinity ranged from 9.25 mg/L (site 9 in post-monsoon season) to 198.75 mg/L (site 4 in pre-monsoon season) in the year 2018. However , in the year 2019, the total alkalinity ranged from 11.9 mg/L (site 9 in post-monsoon season) to 250.9 mg/L (site 4 in pre-monsoon season). Therefore, the overall range of total alkalinity during 2018-19 ranged from 9.25 mg/L to 250.9 mg/L. Seasonal variations revealed that the total alkalinity of the ground water samples was highest in pre-monsoon and lowest in post-monsoon seasons.

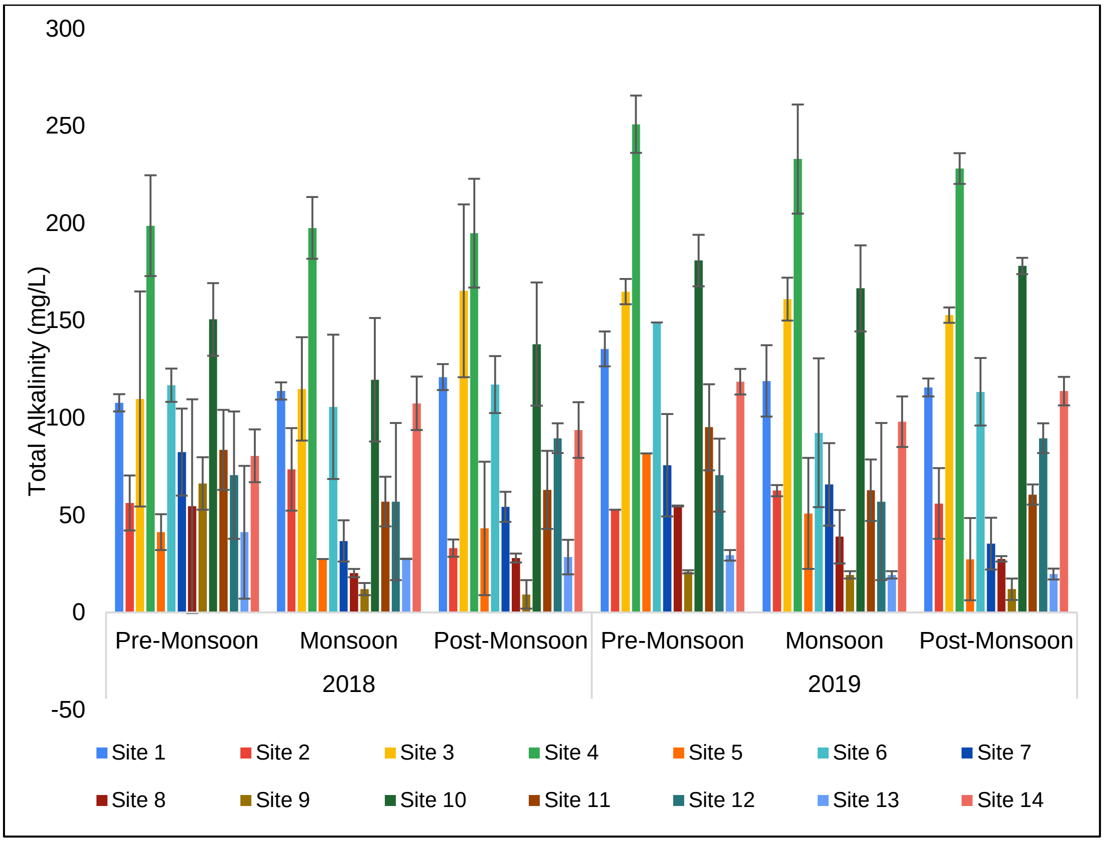

Fig.4.6: Seasonal variation in Total Alkalinity of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.7. Total Hardness

The total hardness of ground water at all 14 sites were tested and recorded during the study period i.e., 2018-19. The total hardness ranged from 11.1 mg/L (site 9 in post-monsoon season) to 242.5 mg/L (site 6 in pre-monsoon season) in 2018. In 2019, however, the range of total hardness was from 11 mg/L (site 9 in post-monsoon season) to 212.5 mg/L (site 6 in pre-monsoon season). The range of total hardness in the two yearsi.e., 2018-19 was from 11 mg/L to 242.5 mg/L. Seasonal variations revealed that thetotal hardness was lowest in post-monsoon season, followed by monsoon season while it was noted highest in pre-monsoon season.

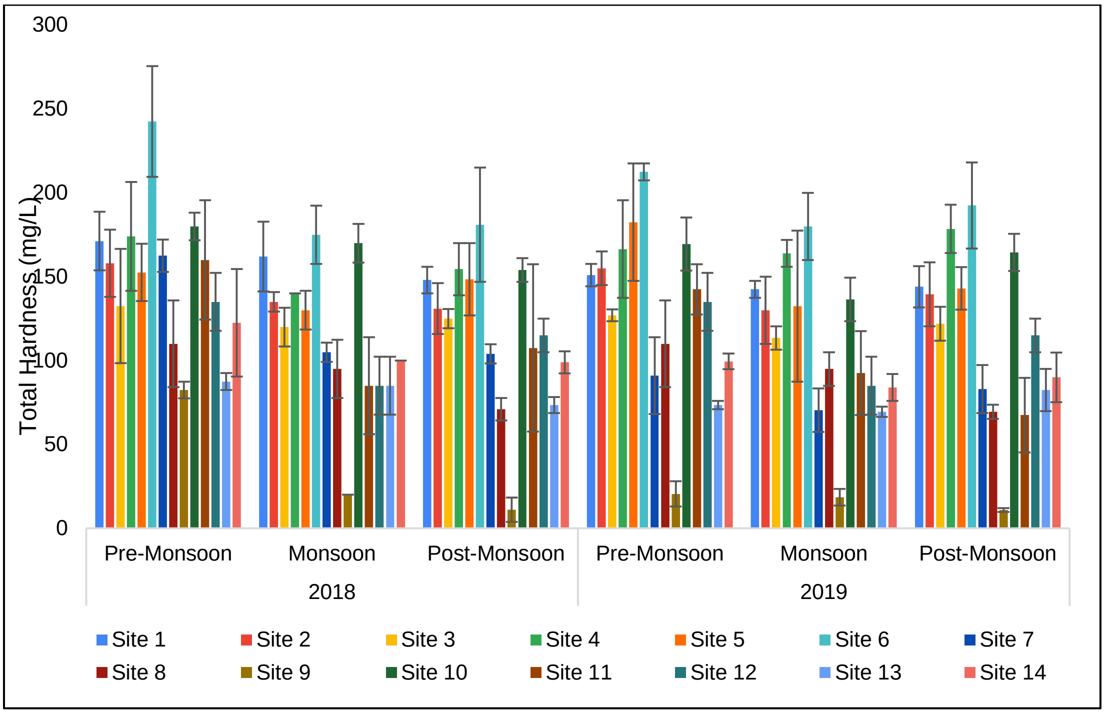

Fig.4.7: Seasonal variation in Total Hardness of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.8. Calcium (Ca)

The calcium levels in all the samples were tested and recorded. In 2018, the range of calcium levels was from 3.6 mg/L (site 9 in post-monsoon season) to 71 mg/L (site 6 in pre-monsoon season). However, in 2019, the range of calcium levels was from 2.2 mg/L (site 9 in post-monsoon season) to 50.8 mg/L (site 6 in pre-monsoon season). The overall range of calcium levels in the two years i.e., 2018-19 was from 2.2 mg/L to 71 mg/L. Seasonal variations revealed that the calcium levels were highest in pre-monsoon season and lowest in post-monsoon season.

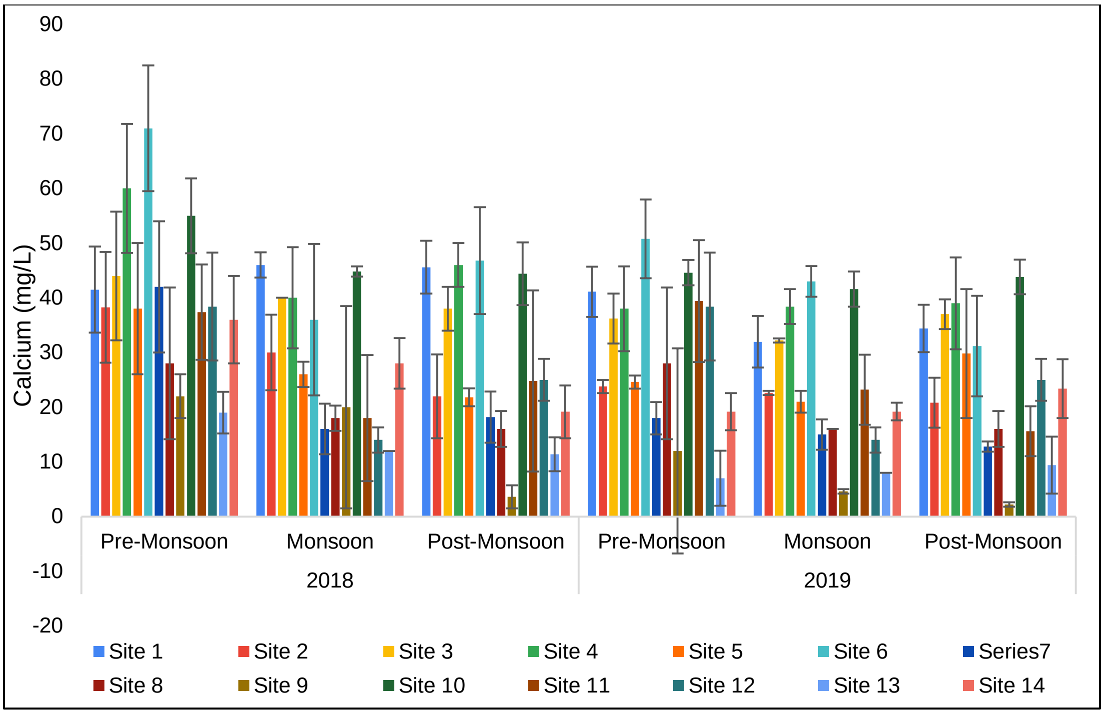

Fig.4.8: Seasonal variation in Calcium of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.9. Phosphate

The phosphate levels of all samples were recorded for two years (2018-19). In 2018, the phosphate levels ranged from 0.007 mg/L (site 1 in post-monsoon season) to 0.6365 mg/L (site 3 in monsoon season). In 2019, however, the phosphate levels ranged from 0 (site 1 in monsoon season) to 0.2155 mg/L (site 13 in pre-monsoon season). The phosphate levels ranged from 0 mg/L to 0.6365 mg/L in the two consecutive years i.e., 2018-19.

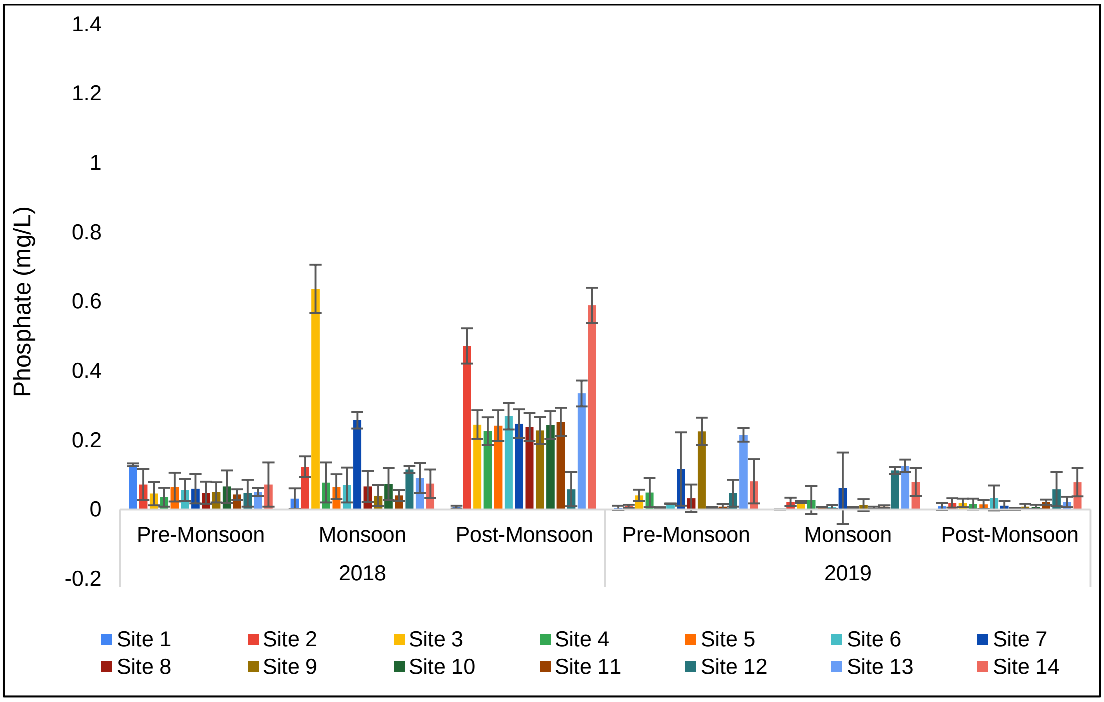

Fig.4.9: Seasonal variation in Phosphate of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.10. Nitrogen Ammonia (N-NH_3)

The N-NH_3 levels in all samples from the 14 sites were recorded during 2018-19. The range of N-NH_3 levels was from 0.091 mg/L (site 5 in monsoon season) to 1.816 mg/L (site 13 in post-monsoon season) in the year 2018. The N-NH_3 levels in 2019 ranged from 0.056 mg/L (site 7 in post-monsoon season) to 1.1485 mg/L (site 8 in post-monsoon seasons). Seasonal variations revealed the of N-NH_3 in the two years ranged from 0.056 mg/L to 1.816 mg/L.

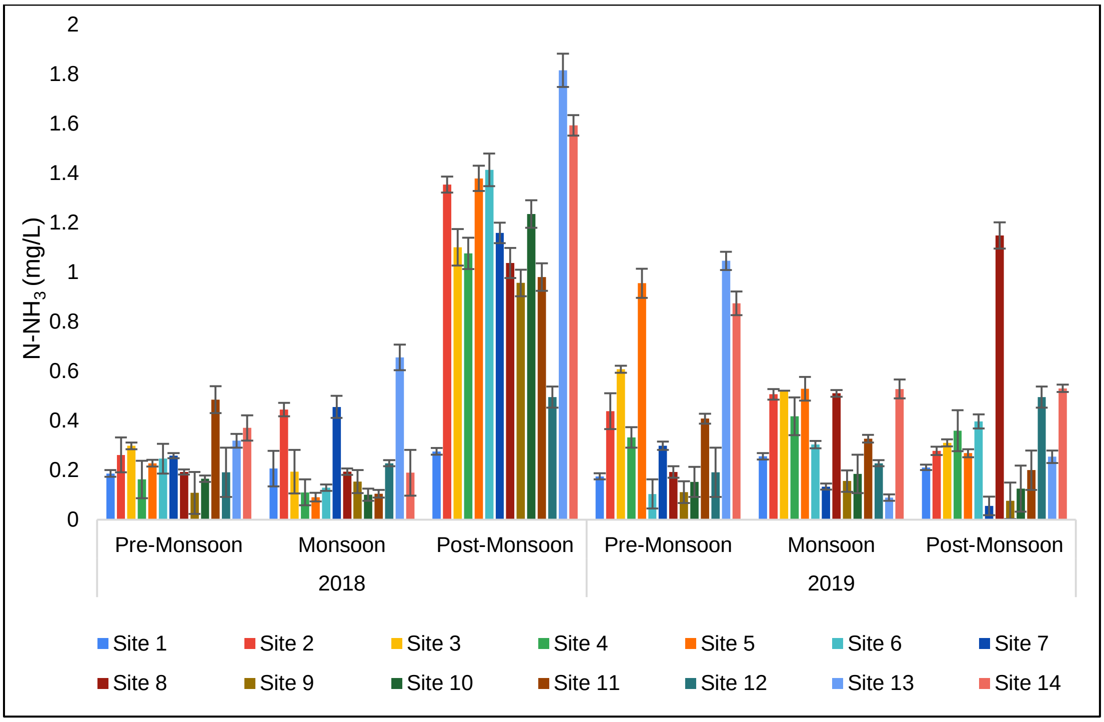

Fig.4.10: Seasonal variation in N-NH_3 of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.11. Nitrogen Nitrite (N-NO_2)

The N-NO_2 levels of all samples from the 14 sites were tested and recorded. In the year 2018, the N-NO_2 levels ranged from 0.00775 mg/L (site 9 in the post-monsoon) to 0.745 mg/L (site 2 in post-monsoon season). In the year 2019, however, the N-NO_2 levels ranged from 0.00375 mg/L (site 11 in pre-monsoon season) to 0.885 mg/L (site 5 in pre-monsoon season). The overall range of N-NO_2 in the two consecutive years (2018-19) was from 0.00375 mg/L to 0.885 mg/L.

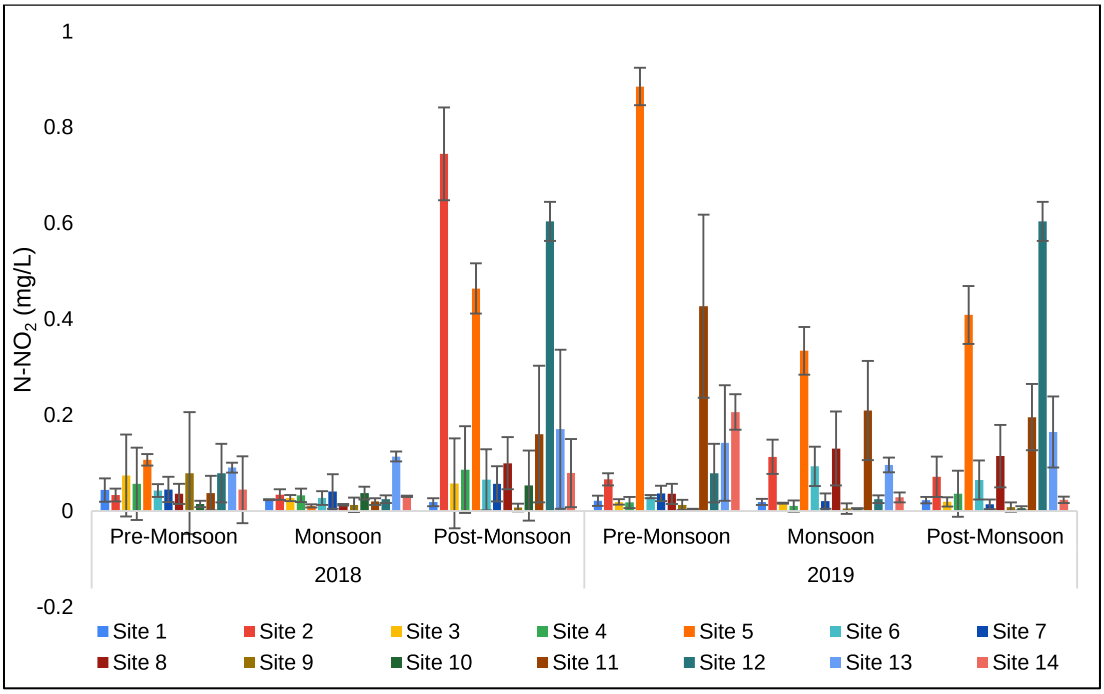

Fig.4.11: Seasonal variation in N-NO_2 of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.1.12. Dissolved Oxygen (DO)

The level of Dissolved Oxygen in the two years i.e., 2018-19 were tested and recorded. In the year 2018, the level of Dissolved Oxygen ranged from 1.85 mg/L (site2 in monsoon season) to 6.2 mg/L (site 9 in pre-monsoon season), whereas in the year 2019, it ranged from 1.75 mg/L (site 14 in monsoon season) to 6.46 mg/L (site 9 in pre-monsoon). The total range of Dissolved Oxygen in the two years (i.e., 2018-19) was from 1.75 mg/L to 6.46 mg/L. It was observed that the level of Dissolved Oxygen was the lowest in monsoon season and highest in pre-monsoon season.

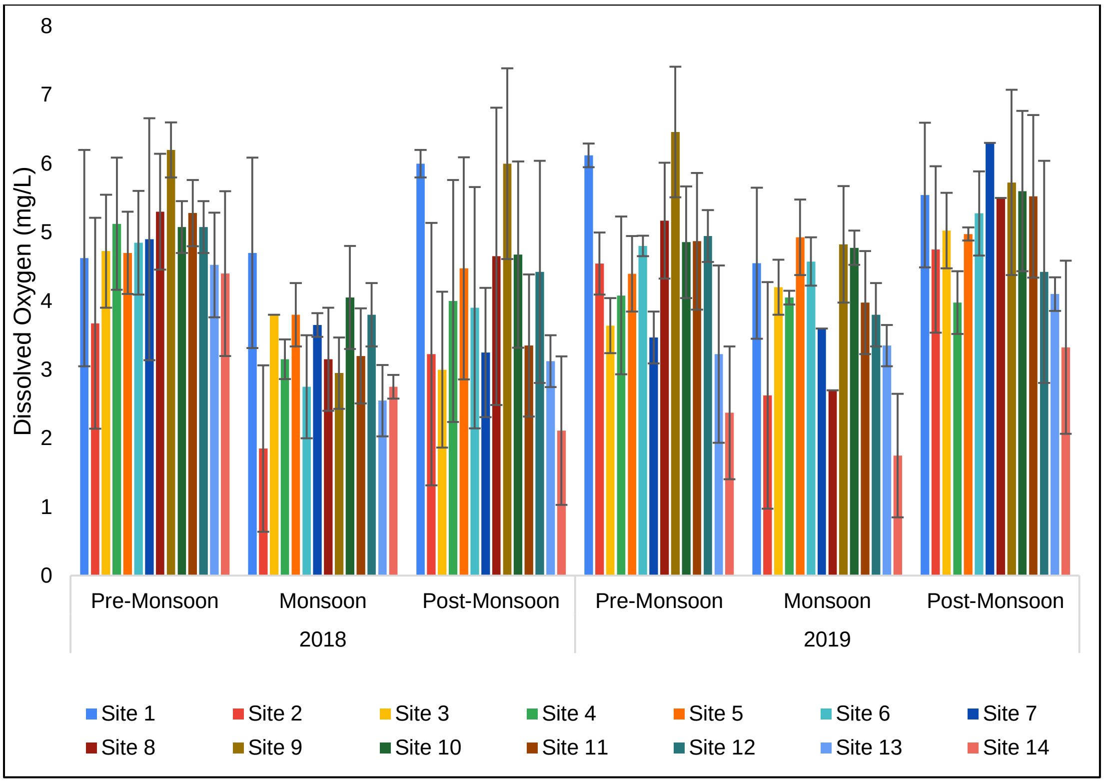

Fig.4.12: Seasonal variation in Dissolved Oxygen of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.2. Heavy Metals

The concentrations of heavy metals in the ground water were recorded at the fourteen sites of Aizawl during 2018-19.

4.2.1. Zinc (Zn)

During 2018, the zinc concentrations in ground water ranged from 0 mg/L (sites 1, 2, 7, 13 and 14 in pre-monsoon season and site 8 in all seasons, pre-monsoon, monsoon and post-monsoon) to 1.7076 mg/L (site 10 in pre-monsoon season). Whereas, in 2019, the zinc levels ranged from 0 mg/L (sites 8 in pre-monsoon season and site 9 and 12 in all seasons, pre monsoon, monsoon and post-monsoon) to 2.196 mg/L (site 5 in pre- monsoon season). Therefore, during the entire study period of 2018-2019, the Zn values ranged from 0 mg/L to 2.196 mg/L. The zinc levels were found to be highest in pre-monsoon, followed by monsoon and least in post-monsoon seasons respectively.

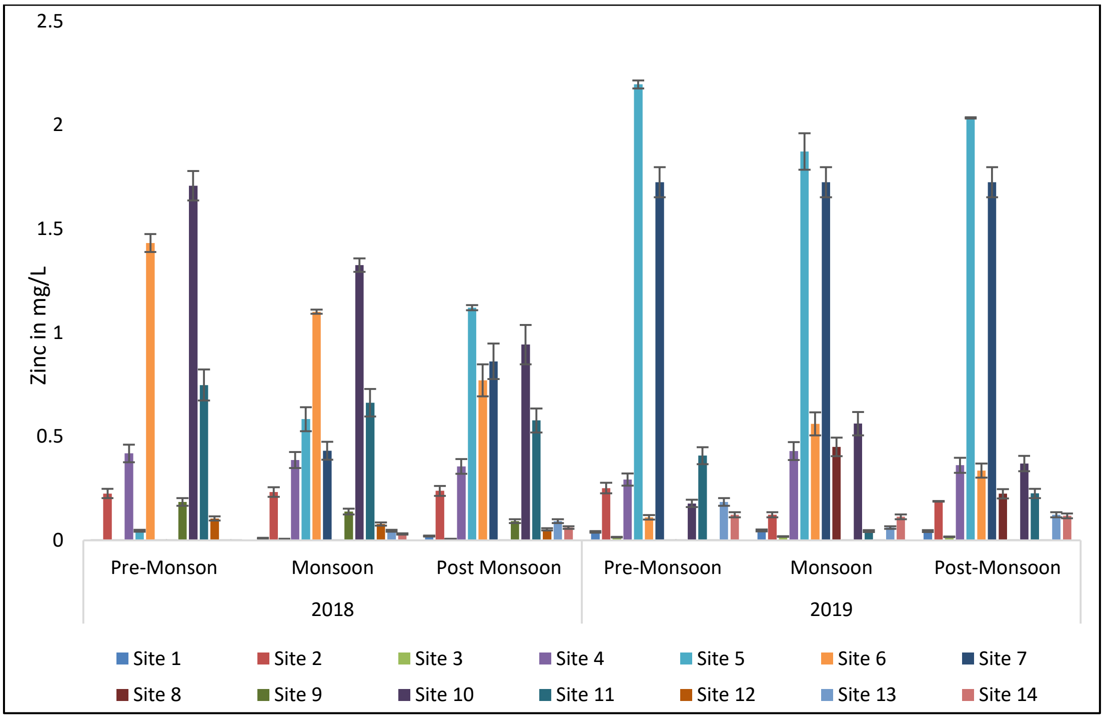

Fig.4.13: Seasonal variation in Zinc of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.2.2. Lead (Pb)

The levels of Pb were tested and recorded for all 14 sites in the two years. The results of this test indicated that lead contamination in all these sites were non-existent in all seasons.

4.2.3. Copper (Cu)

In 2018 the copper levels in ground water ranged from 0 mg/L (sites 1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10 ,11 ,13 and 14 in pre-monsoon season, sites 8 and 9 in monsoon season and sites 8 and 9 in post-monsoon season) to 0.0189 mg/L (site 12 in pre-monsoon season). In the year 2019, the copper levels ranged from 0 mg/L (sites 8 and 9 in all seasons, pre-monsoon, monsoon and post-monsoon as well as site 12 in post-monsoon season) to 0.00945 mg/L (site 12 in pre-monsoon season). The total range in both the years was from 0 mg/L to 0.0189 mg/L. The copper levels were found to be highest in pre-monsoon followed by monsoon and least in post-monsoon seasons respectively.

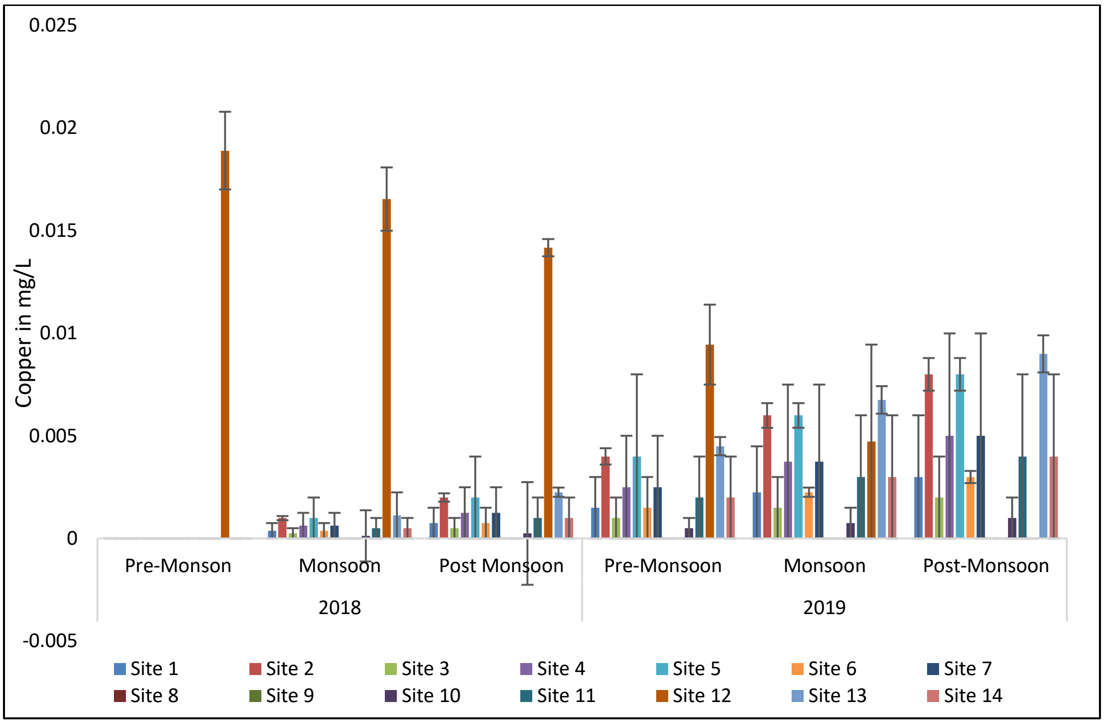

Fig. 1.14. Seasonal variation in Copper of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.2.4. Nickel (Ni)

The nickel concentration in the ground water of all the fourteen sites were tested and recorded. It was concluded that the nickel levels were nil in all the sites and in all the seasons as well.

4.2.5. Iron (Fe)

In the year 2018, the total range of iron concentration in ground water was found to be from 0 mg/L (sites 1, 4, 6, 9, 11, 12, 13 and 14 in pre-monsoon season, sites 1, 4, 6, 9, 12 and 13 in monsoon season, and sites 1, 4, 9, 12 and 13 in post-monsoon season) to 1.162 mg/L (site 7 in pre-monsoon season). In 2019, the range of iron levels was from 0 mg/L (sites 1, 2, 4, 5, 8, 9, 10, 12 and 13 in pre-monsoon season, sites 1, 4, 9, 12 and 13 in monsoon season and sites 2, 4, 6, 9, 12 and 13 in post-monsoon season) to 0.7496 mg/L (site 1 in post-monsoon season). The total range observed in the two years was from 0 mg/L to 1.162 mg/L. The iron level seems to be highest in pre-monsoon and lowest in post-monsoon.

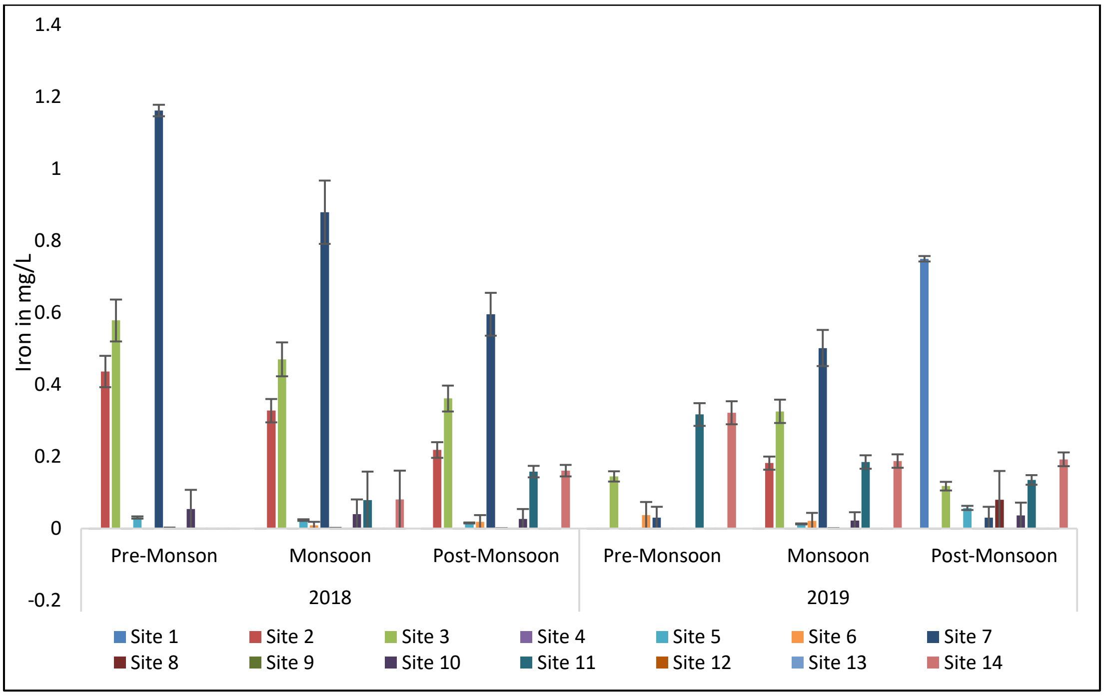

Fig.4.15: Seasonal variation in Iron of ground water in the different selected study sites(mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.2.6. Manganese (Mn)

During the year 2018, the range of manganese levels in ground water was from 0 mg/L (sites 1, 4, 6, 9, 11, 12, 13, and 14 in pre-monsoon season, sites 9 and 12 in monsoon season and sites 9 and 12 in post-monsoon season) to 0.329 mg/L (site 13 in post-monsoon season). In 2019, the range was from 0 mg/L (sites8, 9 and 12 in pre-monsoon season, sites 9 and 12 in monsoon season and sites 9 and 12 in post-monsoon seasons respectively) to 0.6892 mg/L (site 14 in post-monsoon). The total range of manganese levels was from 0 mg/L to 0.6892 mg/L. The manganese level varies in different seasons.

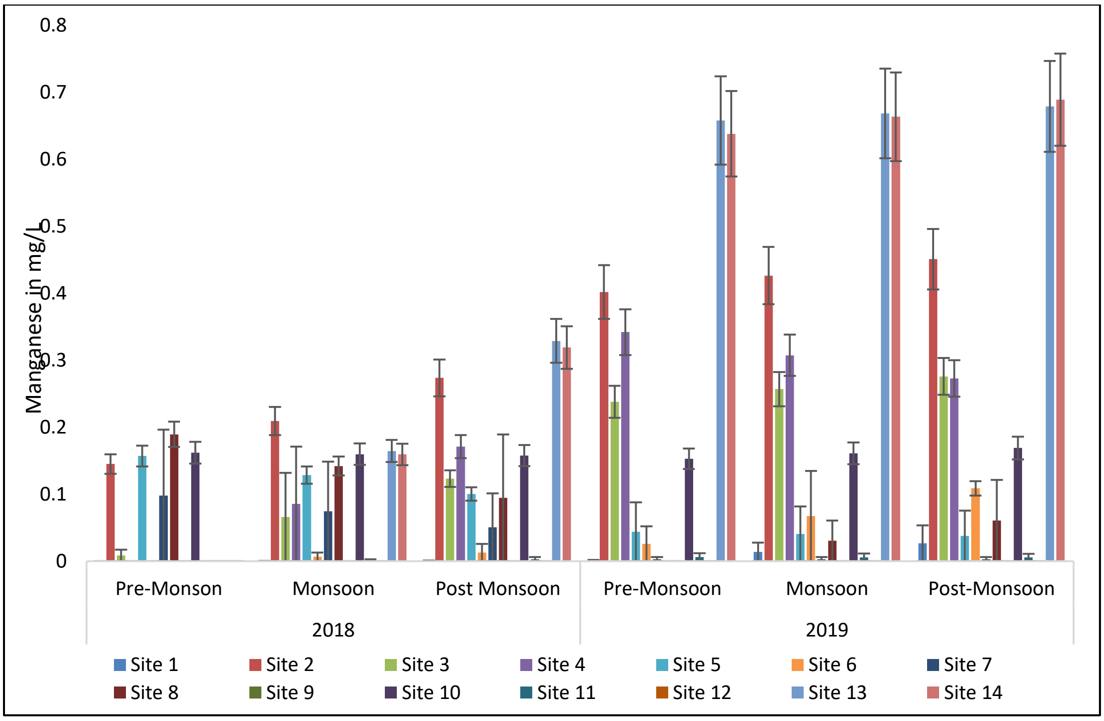

Fig.4.16: Seasonal variation in Manganese of ground water in the different selected study sites (mean values ± sd) (Site 9 is Tap water taken as a reference sample)

4.2.7. Arsenic (As)

Although the arsenic levels from all the sites were tested, all the results turned out to be 0, implying that contamination by arsenic is nonexistent.

CHAPTER- 5

DISCUSSION

5.1 Assessment of physico-chemical parameters

Pollution of water has caused acute shortage of freshwater and has posed a major threat for people (Ferdous *et al*., 2019). Several chemical, physical, and biological (e.g., presence of microorganisms) characteristics determine the ground water quality. The physico-chemical characteristics of ground water tend to change continuously due to natural and anthropogenic contaminants (Awoyemi *et al.*, 2014). The conservation and management of ground water is extremely essential as it is the main source of drinking water in many regions (Boateng *et al*., 2016). Since ground water is used in many human activities such as power generation, irrigation, drinking, and other domestic, industrial and agricultural activities, its quality is of utmost importance in the human well-being. Deterioration in the ground water quality can potentially threaten the human health (Amiri *et al.*,2014; Kayastha *et al.*, 2022; Vig *et al*., 2023).

Ground water is especially essential in dry areas with little surface water, and act as the potable water for drinking and household uses (Noori, 2014). The evaluation of ground water quality is further required to supplement domestic water supply, which is the basic need for human life and a critical factor for United Nations sustainable development goal (specifically, SDG 6) (Gao, 2020). SDG 6 includes targets related to improving access to safe and affordable drinking water, sanitation facilities, and the sustainable management of water resources. Ground water is a significant component of the global water cycle and plays a crucial role in supporting various ecosystems, agriculture, and human needs, thereby linked to UN-SDGs.

National and International agencies such as Bureau of Indian Standards (BIS, 2012), Indian Council of Medical Research (ICMR, 1975) United States Public Health (USPH,1962), and World Health Organization (WHO, 2008) have established limits and standards for the characteristics of quality of portable water. The water quality standards for drinking water given by various scientific agencies and range of values obtained in present study is presented in Table 5.1.

Table 5.1: Water quality standards for different physico chemical parameters and range of values recorded in present investigation.

Parameter	Water quality standards				Water quality range during present investigation
	ICMR	BIS	USPH	WHO	
Temperature(C°)	N/A	40	N/A	30	18.5-26
pH (Nano mole L^{-1})	6.0-8.5	6.5-8.5	6.0-8.5	6.5-9.2	5.35-7.9
Turbidity (NTU)	2.5	1	5	5	0.1-80.9
TDS (mg/L)	500	300	500	1000	16-268
Chloride(mg/L)	200	250	250	250	3.16-86.02
Total alkalinity (mg/L $CaCO_3$)	200	200	120	200-600	9.25-250.9
Total Hardness (mg/L $CaCO_3$)	300	300	N/A	300	11-242.5
Calcium (mg/L)	75	200	250	100-200	2.2-71
Phosphate-P (mg/L)	N/A	N/A	0.1	N/A	0-0.63
Nitrogen Ammonia (mg/L)	1.5	0.5	1.5	0.5	0.056-1.816
Nitrate-Nitrogen (mg/L)	150	45	45	50	0.003-0.88
Dissolved Oxygen (mg/L)	N/A	3	4.0-6.0	4.0-6.0	1.75 - 6.46

5.1.1 Temperature

The temperature of water plays a primary role in its composition as it determines the type of organisms that live in it, the solubility of various compounds, the expansion of its surface and various other physical, chemical, and biological characteristics (Dey *et al.*, 2021). The current scenario of global warming and climate change has a temporal effect on the temperature of ground water, which may change the integral aspects such as acidity and dissolved oxygen, thereby making the purification process difficult (Riedel, 2019). Climate change, as a whole, has had a major effect on the ground water. The ground water quality is highly influenced by climate change, as it alters the water table and endangers the ecosystems (Menberg *et al.*,2014).

Rise in temperature of water during the monsoon months led to increase in dissolved oxygen and pH of water, which intensify the metal contamination and making the water unsafe for drinking (Ngabirano *et al*., 2016). The temperature of ground water in the depths of the crust remains unchanged, although shallow ground water was found to shift towards lower temperature in the winter season (Yabusaki *et al*., 2022).

The temperature of ground water in the present study area was found to be highest in monsoon season in both the years i.e., 2018 and 2019, possibly due to the increased percolation due to rainfall, which traps the heat retained in the different layers of soil surface. Increased seepage of water also results in greater growth of microorganisms, whose activities raise the temperature of the ground. The temperature of ground water was found to be lowest in pre-monsoon season on account of dry weather and less moisture, allowing the soil to be airy and thus, release more heat. The temperature observed does not exceed the permissible standards set by scientific agencies. A similar trend was observed by Makwe and Chup (2013), Dey *et al.* (2021), Yabusaki and Shibasaki, (2022).

A positive and significant correlation of temperature was obtained with TDS (0.542(29%)). On the contrary, a negative and significant correlation was obtained with Cu (-0.539(-28%)).

Statistically, two-way ANOVA revealed that the values of temperature recorded in ground water were significant ($p<0.001$) both between sites and seasons.

5.1.2 pH

The pH (negative algorithm of hydrogen ion) of water is tested in terms of the amount of H^+ ions present in the water. It is necessary to maintain a proper pH level for healthy consumption of drinking water. The pH of water does not necessarily have an immediate impact on human health, but it can influence the amount of calcium and magnesium ions, which make water hard and deteriorate the drinking water quality (WHO, 2011). Urban centers with dense populations have been found to have slightly acidic ground water (Prasanth *et al.*, 2012). This acidity may be either due to human activities like dumping of waste and unsystematic agricultural practices or natural processes such as disintegration of rocks in the aquifers.

Frequent intake of ground water with pH ranging from 7-7.8 can be dangerous and can cause ailments. With regard to the risk caused by acidity of water on human health, water should be treated before consumption (Dirisu *et al.*, 2016). Water with pH level lower than 7 has the risk of being abrasive and dangerous, thereby contaminating the water which can affect its quality (Singh and Hussain, 2016).

In the present study, the pH value in pre-monsoon season and post-monsoon seasons were found to be lower than in the monsoon season. This was true for both the years i.e., 2018-2019. The pH value was found to increase during monsoon season. Particularly at site 13, the pH level was observed to be lower than the permissible limits set by various agencies in the pre-monsoon and post-monsoon seasons in the years, 2018- 2019.This can be due to the dilution of ground water from high percolation of water in the rainy monsoon season, which eventually lowers the acidity and hence results an increase in the pH values. The low pH level in dry seasons may be due to continuous weathering of minerals in the aquifers and the effects of acid rain. The pH level of ground water was lower in dry seasons than monsoon season, and even more so in confined aquifers than in unconfined aquifers, usually due to the disintegration of minerals and dissolved carbon dioxide (Suresh *et al*., 2011; Zhou *et al*., 2015; Laldintluanga *et al*., 2016).

A negative and significant correlation was obtained with, N-NH_3 (-0.549(-29%)), Mn (-0.557(-32%)).

Two-way ANOVA revealed that the values of pH recorded in ground water were significant ($p<0.001$) between the sites.

5.1.3 Turbidity

Turbidity is the state of the water where the suspension or dissolution of certain solids which make the water opaque or translucent in appearance. It is a visible or ready to observe sign of water pollution (Arshad *et al.*, 2021). The surface runoff and percolation of wastes have caused a high level of turbidity in the ground water, which directly affects the perforation of sunlight and photosynthesis altogether (Mairizki and Cahyaningsih, 2016). Alterations in the land use pattern, especially in terms of industrial activities like mining, is posing a significant threat to the quality of ground water through increase in turbidity (Gbedzi *et al*., 2022). Water with high level of turbidity is not fit for human use, and natural coagulant should be used for treating turbid water (Hussain *et al*., 2019).

. It is known that turbidity of ground water can vary seasonally, depending on its exposure to the surface. In the present assessment, it was found that turbidity of ground water was high in post-monsoon and monsoon seasons and low in pre-monsoon season. This may be due to lack of surface runoff and frequent seepage of sewage during the dry pre-monsoon season. This slows the weathering of rocks which also adds to the low level of turbidity in the pre-monsoon season. Almost all sites showed turbidity levels within permissible limits set by BIS, however, some sites have exceeded permissible limits in post-monsoon season in both the years. Site 2, 13, and 14 have far exceeded the acceptable standard of turbidity during the year 2018, whereas sites 2,3,4,5,6,7,11,13 and 14 exceeded the standard in 2019. These exceeding observations for turbidity were mostly observed in the monsoon and post-monsoon seasons. The turbidity of boreholes is generally higher during monsoon and that of hand dug wells were higher in summer (Olushola *et al*., 2014). The overland flow of water during monsoon may be a great contributor to the high level of turbidity, which exceeded the acceptable standards set by WHO.

A positive and significant correlation of turbidity was obtained with phosphate (0.575(32%)), N-NH_3 (0.558(30%)). On the contrary, a negative and highly significant correlation was obtained with DO (-0.735(-53%)).

Statistically, Two-way ANOVA revealed that the values of turbidity recorded in ground water were significant ($p<0.001$) between the seasons.

5.1.4 Total Dissolved Solids

Total Dissolved Solids (TDS) of water indicates the measure of the total dissolved organic or inorganic molecules. Water is also polluted by the high amount of TDS produced by the extortion of fossil fuels which makes water unfit for drinking and domestic uses (Wilson *et al.,* 2014). Large amount of TDS makes water unsuitable for drinking as the amount of dissolved oxygen gets reduced (Saravanakumar and Kumar, 2011). The percolation of sediments along-with water degrades the quality of water by increasing the amount of TDS (Mohammad *et al*., 2017). Overuse of ground water and anthropogenic factors have contributed to the high level of TDS (Selvakumar *et al*., 2017).

The present analysis had concluded that TDS of ground water varies in different seasons.The overall range of Total Dissolved Solids was from 16 mg/L to 268 mg/L. These observations are all within permissible limits and pose no human health risks.

A positive and significant correlation of TDS was obtained with temperature (0.542(29%)), Chloride (0.791(62%)), TH (0.792(62%)), Calcium (0.580(33%)).

Two-way ANOVA revealed that the values of Total Dissolved Solids recorded in ground water were significant ($p<0.001$) between the sites.

5.1.5 Chloride

Chlorine is used for disinfection of drinking water in most cases, however, high levels of chlorine in water may cause a number of health hazards such as diarrhea, stomach problems, dry skin and vomiting (Bashir *et al*., 2012). Chloride from road tar seeps to the ground water mainly through sewage and overland flow of waste water (Perera *et al.,* 2013; Roy, 2019). Chloride values are above acceptable limits in areas with lava flows, sediment depositions and near the sea-basins (Biddau *et al.,* 2017).

New agricultural practices in eastern regions have resulted in decline of chloride levels in ground water, which recommend the proper water quality analysis of ground water (Koh *et al.,* 2017). Ground water pollution with chloride is mostly due to human activities and industrial functions (Dohare *et al.,* 2014). Large amount of chlorine in water can be detrimental to marine organisms and also poses hazards to human health (Kumar and Singh, 2015). Chlorine contaminations also adversely influence cardiovascular systems, excretory systems, and digestion (Saleem *et al*., 2016). If the difference between chlorine levels and surface runoffs in the present scenario continue as it is, then after a few decades, the chloride levels in the water table will exceed the maximum permissible limits as reported elsewhere (McDaris *et al*., 2022).

Chloride compounds from potassium fertilizers had influenced ground water chloride levels significantly, leading to rise in chloride concentrations in the summer when compared to rainy season (Adnani *et al*., 2018; Hoque *et al*., 2019). The reason for the slight decrease in chloride concentration in monsoon was mainly due to dilution of ground water by rainfall (Younsi *et al*., 2001; Adnani *et al*., 2020). In the present study, the chloride levels in all the sites were found to be variable in the different seasons. The overall range of chloride levels was from 3.1625 mg/L to 86.025 mg/L. These levels were well within the acceptable standards set by scientific agencies.

A positive and significant correlation of Chloride was obtained with TDS (0.791(62%)), TH (0.521(27%)). On the contrary, a negative and significant correlation was obtained with pH (-0.513(-26%)), DO (-0.529(-27%)).

Statistically, two-way ANOVA revealed that the values of Chloride recorded in ground water were significant ($p<0.001$) both between the sites and seasons.

5.1.6 Total Alkalinity

Total alkalinity is the measure of the total alkaline compounds present in the water which is able to neutralize the acidity of water. Total alkalinity is mainly due to the amount of dissolved carbon dioxide in the water (Patil *et al*., 2018). Industrial effluents and untreated wastes add to the high concentration of alkalinity (Sudarshan *et al.*, 2019).

Schaeperclaus (1990) categorized the aquatic ecosystem into three groups based on their alkalinity values as follows:

Table 5:2 Classification of Total Alkalinity and its interrelationship with productivity

Water Quality	Total Alkalinity value (mg/L $CaCO_3$)
Less productive	0-15
Medium productive	15-100
Highly productive	100-250

In the present study, it is observed that the total alkalinity of the ground water samples was highest in pre-monsoon and lowest in post-monsoon seasons. The total alkalinity was noted in the range of 9.25 mg/L to 250.9 mg/L during 2018-19. Based on the classification in the table, 5.2, some sites were shown to be highly productive in almost all the seasons in both the years, 2018 – 2019, whereas most of the sites were mostly within the range of medium productivity in most seasons in both the years. Present result was supported by (Dey *et al.*, 2020), which stated that the total alkalinity was highest in the dry summer months while it was recorded lowest during winter season. This can be due to the increased seepage of rainwater during the monsoon seasons, which subsequently dilute the water. Due to high rate of evaporation of water, contaminants present in water may break down, causing the level of total alkalinity to rise significantly during dry seasons. The seawater intrusion in coastal areas may also cause the concentration to be higher during pre-monsoon (Balakrishnan *et al.*, 2017).

A positive and significant correlation of TA was obtained with TH (0.632(39%)), Calcium (0.872(75%)).

Statistically, Two-way ANOVA revealed that the values of total alkalinity recorded in ground water were significant ($p<0.001$) both between the sites and seasons.

5.1.7 Total Hardness

The hardness of water is determined by the amount of calcium and magnesium ions present in the water in addition to a variety of metals, sulphates, and chlorides (Boyd, 2015). The long-term consumption of hard water can have detrimental effects on human health and cause cardiovascular diseases, diabetes, kidney stones, and even reproductive failure (Sarala and Babu, 2012; Sengupta, 2013; Ram *et al.*, 2021). The domestic suitability of water use can also be hampered by high levels of hardness, for instance, soap functioning is minimized in hard water which is inconvenient for washing and cleaning purposes. The total hardness of water is an efficient means of evaluating the portability of water, and its usage in industries (Birajdar *et al*., 2017).

Sawyer (1960) and Saravanakumar and Kumar (2011) have classified water as follows:

Table 5:3 Classification of Total Hardness

Water quality	Total Hardness (Mg/LCaCO3)
Soft	0 – <75
Moderately hard	75- <150
Hard	150- <300
Very hard	>300

In the present study, it was found that the range of total hardness in the two years (2018 – 2019), ranged from 11 mg/L to 242.5 mg/L. Total hardness was lowest in post-monsoon season, followed by monsoon season and was highest in pre-monsoon season. This can be due to the dilution of water in the monsoon season. In the hot and dry pre-monsoon season, concentration of hard minerals in ground water increases due to lack of rain.

The results were all within permissible limits set by various regulatory agencies. Nonetheless, based on the above classification, site 9 can be categorised as soft, sites 2, 3, 7, 8, 11, 12, 13 and 14 are considered moderately hard, while sites 1, 4, 5, 6 and 10 are classified as hard in both the years.

Presence of Magnesium sulphate in ground water leads to increased total hardness of water (Sirajudeen *et al.*, 2013). Untreated domestic wastes can also significantly increase the total hardness of water (Raju *et al*., 2014).

A positive and significant correlation of TH was obtained with TDS (0.792(62%)), Chloride (0.521(27%)), TA (0.632(39%), Calcium (0.888(77%)) and Zn (0.619(37%)).

Two-way ANOVA revealed that the values of total hardness recorded in ground water were significant ($p<0.001$) both between the sites and seasons.

5.1.8 Calcium

The seasonal variation of calcium in ground water can depend on several factors, including changes in temperature, precipitation, and land use.

In areas with distinct seasonal changes, such as temperate regions, calcium concentrations in ground water may be higher in the winter and spring when there is more precipitation and snowmelt. This is because calcium is a common mineral found in rocks and soils, and as water flows through these materials, it can dissolve and carry calcium ions with it.

In the present study, the calcium level in water is a great indicator of the ground water quality. High calcium levels were detected in pre-monsoon season and lowest in post-monsoon season. The overall range of calcium levels in the two years i.e., 2018 – 2019 was from 2.2 mg/L to 71 mg/L .The range of calcium levels were all within permissible limits set by various agencies. The same result was also concluded by Ahouansou *et al.,* (2018) who stated that calcium levels were higher in summer than monsoon. The untreated disposal of wastes and wastewater intensifiees the contamination of natural water with calcium ions (Sudarshan *et al*., 2019).

A positive and significant correlation of Calcium was obtained with TDS (0.580(33%)), TA (0.872(75%)), TH (0.888(77%)) and Zn (0.534(28%)).

Statistically, two-way ANOVA revealed that the values of Calcium recorded in ground water were significant ($p<0.001$) both between the sites and seasons.

5.1.9 Phosphate

Observation of the level of phosphate in ground water is an effective way of determining its quality. Phosphate in water is usually contributed by soil erosion, human and animal wastes, cleaning detergents, and industrial effluents (Grizzetti *et al.,* 2012; Hart *et al.,* 2010). In the present study, the total range of phosphate levels in the two consecutive years was from 0 mg/L to 0.6365 mg/L which was noted with distinct seasonal differences.

Phosphorus contamination can lead to eutrophication through the increase in growth of algae, which further consumes most of the dissolved oxygen in water, thus posing a serious threat to aquatic life (Shen *et al*., 2020; Meinikmann *et al.,* 2015).

Ecological habitats are vastly limited by phosphate containing materials, which brings the need for managing the input of phosphorus in the aquatic ecosystems (Holman *et al.,* 2008). It has also been observed that the presence of phosphate compounds can enhance the discharge of arsenic in the ground water, thereby increasing the intensity of heavy metal contamination (Lin *et al.,* 2016).

The phosphate levels ranged from 0 mg/L to 0.6365 mg/L in the two consecutive years i.e., 2018-19. All the sites have slightly exceeded the permissible limits of phosphate set by USPH in the year 2018, and particularly in the post monsoon season, whereas in 2019, in pre-monsoon, only sites, 7,9 and 13 and in monsoon, site12 and 13 have exceeded the permissible limits. This may be due to the overland flow of water which can percolate down to act as potential contributor of phosphate in ground water.

The agricultural practices of using fertilizers have led to a large concentration of phosphorus in the soil horizons, which in turn can contaminate the ground water (Nyirenda *et al.*, 2019; Warrack *et al.*, 2022; Yang *et al*., 2023). This study also states that the phosphate contamination has led to worldwide threat on the safety of aquatic organisms and the safe use of water.

A positive and significant correlation of phosphate was obtained with turbidity (0.575(32%)), N-NH3(0.574(32%)), Fe (0.589(33%)). On the contrary, a negative and significant correlation was obtained with DO (-0.701(49%)).

Two-way ANOVA revealed that the values of Phosphate recorded in ground water were significant ($p<0.001$) between the sites.

5.1.10 N-NH_3

The presence of N-NH_3 (ammonia) in ground water can be an indication of contamination from various sources such as agricultural activities, landfills, wastewater treatment plants, or industrial processes. (Wang *et al.*, 2021) The levels of ammonia in ground water can vary depending on the source of contamination, the geology of the area, and the ground water flow rate.

Excessive levels of ammonia in ground water can have adverse effects on the environment and human health (Li *et al*., 2020). For example, ammonia can lower the pH of water and cause eutrophication, which can lead to the death of aquatic organisms. Ammonia can also react with other chemicals in the water to form harmful compounds such as nitrites and nitrates, which can be hazardous to human health. Untreated nitrogen compounds in the wastes when discharged into the landfills can cause ammonium contamination (Aziz *et al.*, 2004).

The total range of N-NH_3 in the two years, 2018 – 2019, observed was from 0.056 mg/L to 1.816 mg/L. The present study has observed that the amount of N-NH_3varies in the different seasons, highest being in the post-monsoon season. In the year 2018, N-NH_3 values were within permissible limits at all the sites during the pre-monsoon and monsoon season. On contrary, almost all of the sites exceeded the limits set by WHO and BIS in the post-monsoon season during the year 2018. In

2019, all sites were within permissible limits of WHO and BIS, with the exception of sites 3, 5, 13 and 14 in pre-monsoon season and site 8 in post-monsoon season. All sites except 13 and 14 in post-monsoon were within acceptable limits of ICMR and USPH during the year 2018. The same result was also concluded by (Bhattrai *et al*., 2015), who stated that the ammonium levels were higher after precipitation. There were variations in the concentration of ammonium during summer and rainy seasons, the contamination being higher in rainy season as also reported in other studies (Yatigammana *et al*., 2014).

A positive and significant correlation of N-NH3 was obtained with turbidity (0.558(30%)), Mn (0.646(40)) and phosphate (0.574(32)). On the contrary, a negative and significant correlation was obtained with pH (-0.549(-29%)), DO (-0.810(-65%)).

Statistically, two-way ANOVA revealed that the values of N-NH_3 recorded in ground water were significant ($p<0.001$) between the season.

5.1.11 N-NO_2

N-NO_2, or nitrite can be present as contaminant in ground water. Nitrite is a naturally occurring chemical that is produced when nitrogen compounds in fertilizers, sewage, or animal waste break down in the soil (Szymczyk *et al.,* 2010). Nitrite can also be derived from natural sources like lightning strikes or forest fires. However, elevated levels of nitrite in ground water can be a cause for concern as it can be harmful to human health. Nitrite can react with haemoglobin in the blood and reduce its ability to carry oxygen, leading to a condition or disease called methemoglobinemia. This condition is especially dangerous for infants and young children. Nitrite can also be detrimental as it may combine with biomolecules in the human stomach which may be carcinogenic (Gray, 1994).

In the present study, the overall range of N-NO_2 in the two consecutive years i.e., 2018 – 2019 ranged from 0.00375 mg/L to 0.885 mg/L. The present observations were all found to be under the maximum permissible limits set by the regulatory agencies. In this respect, Asare *et al.* (2009) also stated that in their study, nitrite levels were mostly under permissible limits, however the high variations in concentrations were mostly attributed to the influence of anthropogenic factors (Wu *et al*., 2013; Wang *et al*., 2020). High nitrite levels beyond acceptable limits are usually due to the combined influence of ammonium, organic nitrogen, and nitrite compounds (Tong *et al*., 2022).

Seepage of water during monsoon can cause fluctuations in the concentration of nitrite, but the extent of contamination remains unchanged during the summer season (Akiwumi *et al.,* 2012).

A positive and significant correlation of N-NO2 was obtained with copper (0.560(31%)).

Statistically, two-way ANOVA revealed that the values of N-NO2 recorded in ground water were significant ($p<0.001$) between the sites.

5.1.12 DO

Dissolved oxygen in ground water refers to the presence of oxygen molecules in the ground water, which can be important for the survival of aquatic organisms and for the overall health of the ground water system.

The amount of dissolved oxygen in ground water depends on several factors, including the rate of oxygen diffusion from the atmosphere, the amount of organic matter present in the water, and the rate of microbial respiration in the ground water (Kale, 2016). Ground water that is in contact with the atmosphere has high levels of organic matter usually with higher levels of dissolved oxygen.

The amount of dissolved oxygen in ground water can differ in different seasons. In the present study, the total range of Dissolved Oxygen in the two years i.e., 2018 – 2019 ranged from 1.75 mg/L to 6.46 mg/L. Further, it was observed that the level of Dissolved Oxygen was lowest in monsoon season and highest in pre-monsoon season, but overall; the results were within permissible limits. This may be due to the fact that soil and aquifer are more aerated during dry seasons in contrast to rainy season and there may be consumption of dissolved oxygen by aerobic microorganisms.

Concentration of dissolved oxygen in ground water is an important characteristic for the determination of its quality. The presence of dissolved oxygen is essential for the life of aerobic organisms (Sirajudeen *et al.*, 2014). The concentration of dissolved oxygen in water may vary depending on the temperature of the water, seasonal changes, and elevation (Kale, 2016). The level of dissolved oxygen can be reduced by the influence of aerobic organisms, decay of biota, and untreated wastes (Sahu *et al.*, 2000). The decrease in the amount of dissolved oxygen can result in degradation of the ground water quality (Laskar *et al*., 2022).

A negative and significant correlation was obtained with Turbidity (-0.735(-53%)), Chloride (-0.529(-27%)), phosphate (-0.701(49%)), N-NH3 (-0.810(-65%)), and Mn (-0.582(-33%)).

Statistically, two-way ANOVA revealed that the values of Dissolved Oxygen recorded in ground water were significant ($p<0.001$) both between the sites and seasons.

5.2 Heavy Metal

Ground water has served as a dependable source of water for domestic, agricultural, and industrial usage in many regions. However, human activities have significantly affected the quality of ground water in many ways. Such activities like industrial functions create wastes and effluents which cause heavy metal contamination of ground water (Selvakumar *et al.*, 2017; Wang *et al.*, 2022). These heavy metal contaminants such as Arsenic can have disastrous effects on the health of human beings and the environment (Rai, 2021).

Untreated disposal of wastes, domestic sewage, and industrial effluents are the major causes of heavy metal pollution in ground water (Sirajudeen and Pravinkumar, 2021). High consumption of heavy metal contaminated water can cause health hazards which can be chronic to global society, especially in developing countries, proper assessment of water is being neglected (Khalid *et al.*, 2020).

In addition to ground water, surface water resources such as freshwater lakes also face significant contamination by heavy metals which pose serious threats to the aquatic environment (Maanan *et al.,* 2015).

Table 5:4 Water quality standards for different heavy metals and range of values in present investigation.

Parameters	Water quality standards				Water quality range during present investigation
	WHO	BIS	USPH	ICMR	
Fe	0.3	0.3	0.3	1.0	0 mg/L to 1.162
Zn	3	5	N/A	N/A	0 -2.196
Mn	0.4	0.1	N/A	N/A	0- 0.6892
Pb	0.01	0.01	N/A	N/A	0
Cu	2	2	N/A	N/A	0 -0.0189
Ni	0.02	0.02	N/A	N/A	0
As	0.01	0.01	N/A	N/A	0

5.2.1 Iron (Fe)

Iron is an essential element for human metabolism and ecological functions, however, its excess concentrations due to rusting of iron and its dissolution in water can cause health hazards. Iron is a common contaminant in handpump water, especially in areas with high iron concentration in the ground or soil. This can occur when the water source is located in an area with iron-rich rocks or when the pipes or handpump components themselves are made of iron or steel with high propensity towards rusting.

Consuming iron contaminated water may pose a significant health risk and can have adverse effects on the aesthetic qualities of the water. Consumption of large amounts of iron contaminated water can cause major health hazards such as cancer, cardiac disorders and problems related to nerves and the liver (Kumar *et al.*, 2017). High levels of iron can cause the water to taste metallic and have a reddish-brown colour, which may not be appealing to drink and use for other purposes (USEPA 1994). Yellow colour of water and mild odour may also act as indicators of iron contamination in water (Hossain *et al.*, 2015).

Both geogenic and anthropogenic factors contribute to environmental degradation in terms of iron dissolution in ground water (Achary, 2014). Iron may remain as solution in ground water due to low level of oxygen (Boumaza *et al.,* 2021). This study also states that the iron levels found in ground water may be from untreated discharge of wastes, and percolation of surface water, and disintegration of minerals. Naturally, iron is a major element of the earth's crust and is also present in the soil as volcanic rocks or sediments that can lead to the contamination of ground water sources (Taouil *et al.,* 2014). Therefore, interaction of iron with ground water makes up a major bulk of the iron contamination in water (Sarkar and Shekhar, 2018). It is a matter of great concern that high pollution of water by iron has been observed in many areas with heavy population (CGWB, 2015).

Seasonal changes in temperature, humidity and rainfall can have huge impacts on the levels of iron. In the present study, the total range observed in the two years 2018 – 2019 was from 0 mg/L to 1.162 mg/L. The iron level seems to be highest in pre- monsoon and lowest in post-monsoon. The heavy precipitation in the area, causing increased leaching can be the main reason for this. Site 7 in pre-monsoon season has exceeded the acceptable standards set by various scientific agencies. This can be attributed to the rusting of iron associated with the handpumps and further seepage to ground water.

A positive and significant correlation of Fe was obtained with phosphate (0.589(33%)).

Statistically, Two-way ANOVA revealed that the values of Iron recorded in ground water were significant ($p<0.001$) between sites.

5.2.2 Zinc (Zn)

Zinc is a naturally occurring element and is often found in rocks, soil, and water. Large amount of zinc in water can be a distinctive sign of zinc contamination, which may be derived from both natural means and human activities (Noulas *et al*., 2018). Zinc contamination in ground water can occur due to a variety of reasons, such as industrial activities, mining, agriculture, and natural weathering of rocks and soils. This accessibility of zinc in ground water and its lethal effect has attracted considerable attention in previous studies (Mishra, 2014).

Zinc can be harmful to human population when present in excess concentrations with-in ground water (Wei *et al*., 2008). Excessive zinc in ground water can have adverse effects on human health and the environment. High consumption of zinc from water or its intake from the atmosphere and troposphere for a long period may have serious health impacts, causing a variety of problems related to the digestive tract, respiration, and nervous system (Rahimzadeh et *al*., 2020). Zinc contamination can also impact aquatic ecosystems by affecting the growth and reproduction of aquatic organisms.

Despite such risk in case of excessive consumption, zinc can have plentiful beneficial uses. Zinc has a profound importance in heredity and protein synthesis and is much needed for life processes (Wei *et al*., 2008). It is an important mineral useful for improving the human defensive system as it provides immunity (Rezaee and Ghazvini, 2022). Zinc is also important for the functioning of the human physiology and industrial functions such as galvanization and production of alloys, as well as the preparation of medicines (Kiran, 2012).

Zinc levels in ground water may vary in different seasons due to changes in rate of percolation, increased runoffs, evaporation rate and humidity. In the present study, the total range of zinc levels in both the years i.e., 2018 – 2019 was observed to be from 0 mg/L to 2.196 mg/L. The zinc levels were found to be in descending order, the highest in pre-monsoon, then monsoon and lowest in post-monsoon seasons respectively. This can be due to dilution of ground water from increased rainfall.

A positive and significant correlation of Zn was obtained with TH (0.619(37%)) and Calcium (0.534(28%)).

Statistically, Two-way ANOVA revealed that the values of Zinc recorded in ground water were significant ($p<0.001$) between sites.

5.2.3 Manganese (Mn)

Manganese is a naturally occurring element in the Earth's crust, and it can be found in rocks, soils, and ground water. Anthropogenic factors as well as sub surface seepage are the main causes of manganese pollution (Joode *et al.,* 2016). This contamination is also facilitated by the decrease in the level of dissolved oxygen in the water (Jaudon *et al*., 1989).

Human activities can also contribute to manganese contamination in ground water. For example, manganese can be used in the production of steel, batteries, and other products, and it can enter ground water through industrial discharges, spills, or leaks. Manganese can also be used as a pesticide or herbicide, and it can enter ground water through agricultural activities. Although small amounts trace elements are helpful for health, excessive manganese levels can be lethal (Kousa *et al.*, 2021). People who consume a lot of tea may have higher manganese levels (World Health Organization 2004).

High levels of manganese contamination in ground water results in discoloration of water and corrosion of pipelines, which further poses risks to human health by disrupting the normal functioning of the nervous system (Therdkiattikul *et al*., 2020). Manganese contamination of water has been found to have a profound connection with children academic capability and nervous functions (Bouchard *et al*., 2011; Khan *et al*., 2014).

Manganese contamination occurs more frequently in ground water than surface water (Thomas *et al.*, 1994). This may be because of the seepage of manganese from the minerals present in the earth’s crust and the aquifers. Therefore, heavy mines can be detrimental to aquatic environment as it releases heavy amounts of manganese (Li *et al.*, 2019).

The manganese level varies in different seasons. In the present study, the manganese levels ranged from 0 mg/L to 0.6892 mg/L. Heavy rainfall and the consequent change in weather conditions can alter manganese levels.

A positive and significant correlation of Mn was obtained with N-NH3 (0.646(40%)). On the contrary, a negative and significant correlation was obtained with pH (-0.557(-30%)) and DO (-0.582(-33%)).

Two-way ANOVA revealed that the values of Manganese recorded in ground water were significant ($p<0.001$) both between sites and seasons.

5.2.4 Lead (Pb)

Lead is a naturally occurring metal in the earth's crust. Lead contamination of ground water may occur due to multiple reasons such as corrosion of pipelines, leaching from surface water, and discharge of industrial effluents. Coal ash and incomplete burning of fuels may have a considerable role in lead contamination (Islam *et al.*, 2018). Discharge off untreated wastes, sewage, and suspended particles influence lead contamination (Gong *et al.*, 2014).

Lead contamination of water poses a significant threat to human health and may threaten a wide area (Triantafyllidou *et al.*, 2021). Exposure to lead-contaminated ground water can have serious health effects, especially in infants and pregnant women. It can cause, behavioral and learning difficulties, damage to the nervous system, and other organs (Triantafyllidou *et al.*, 2021).

Children are more vulnerable than adults towards exposure to lead contamination (Endale *et al.*, 2021). Lead is very lethal even in small traces and can also cause developmental problems in children while in adults it results in hypertension and kidney damages (USEPA 2014). Lead toxicity can also lead to disruptions of brain functions and skeletal growth, and cancer of liver and other organs (Adeyemi *et al.*, 2021).

Anthropogenic factors such as alloy formations, iron factories and metallurgic activities also contribute to lead contamination (Kumar *et al.,* 2022). Lead pollution also occurs through industrial, domestic and agricultural means (Devic *et al.,* 2014). Disposal of wastes in urban areas and fossil fuel emissions can increase lead levels in urban centers (Hassanzadeh *et al.,* 2011). Contaminations of soil with petroleum products significantly contribute to lead pollution in ground water (Walraven *et al*., 2014).

In the present study, the results of our tests indicated that lead concentrations at all the sites were well-below permissible limits in all seasons. This can be attributed to the lack of industries in the state and hence the low level of industrial effluents and untreated wastes.

5.2.5 Copper (Cu)

Copper is essential for the human body and its deficiency results in nutritional anaemia as it helps to produce red blood cells and strengthen the immune system (Adeyemi and Ojekunle, 2021). However, moderate and high levels of copper can cause gastrointestinal distress and acute toxicity which may severely affect the liver (USEPA 1994).

Copper is a naturally occurring element and is found in many minerals and ores. When copper is released into the environment, it can bind to soil particles and get transported into ground water. Copper can be released directly into ground water from mineral ores, industrial effluents, and waste materials (Adeyemi and Ojekunle., 2021).

Copper mining and smelting operations, as well as copper-containing pipes and plumbing fixtures are also sources of copper pollution. Sewage, smelt furnaces, and tailing leaks are also sources of copper in water (Gong *et al.,* 2014).

Copper is an active element present in vitamins and supplements for health and is consumed regularly by humans and other animals (Ackah *et al*., 2014). However, excessive levels of copper in drinking water can cause health problems, including gastrointestinal issues and liver and kidney damage. In addition, high copper concentrations in ground water can harm aquatic life and disrupt ecosystems. High copper contaminations have also cause concerns pertaining to the soil resilience towards other stressors (Liu *et al.,* 2021).

Copper levels will inevitably fluctuate as the ground undergoes changes due to change in weather conditions in different seasons. In the present study, the range of copper in both the years i.e., 2018 – 2019 was observed from 0 mg/L to 0.0189 mg/L. Furthermore, a slight decrease in copper levels from pre-monsoon to monsoon and least in post-monsoon had been observed. This might be due to increased seepage of water in monsoon season.

A positive and significant correlation of copper was obtained with N-NO2 (0.560(31%)). On the contrary, a negative and significant correlation was obtained with temperature (-0.539(-28%)).

Two-way ANOVA revealed that the values of copper recorded in ground water were significant ($p<0.001$) both between sites and seasons.

5.2.6 Nickel (Ni)

Nickel is a naturally occurring element found in rocks and soil. Nickel often derives its origin from agriculture and industrial functions (Bhalerao *et al.,* 2015). However, industrial activities such as mining, smelting, electroplating, and petroleum refining can introduce nickel into ground water. Nickel is popularly used in the urban industries and inhabitants and civilians are eventually exposed to it through nutrition, atmosphere and water supply (Cempel *et al.,* 2006).

Nickel contamination of ground water can also occur from corrosion of pipes (Adhikari *et al.*, 2022). The use of low levels of nickel in agriculture may promote growth and development of crops, however, overuse of nickel containing fertilizers and chemicals have also raised nickel pollution with several negative effects (Hassan *et al.*, 2019).

Consumption of nickel contaminated ground water can pose serious risk to human health and the environment. Nickel is a lethal element and can pose potential threats to the surface and ground water quality (Naggar *et al*., 2021). High levels of nickel in drinking water can cause skin allergies, respiratory problems, and cancer. Nickel-contaminated ground water can also harm aquatic life and damage ecosystems.

To prevent nickel contamination of ground water, it is important to properly manage industrial activities and waste disposal practices. In addition, regular monitoring and testing of ground water sources can help identify and address nickel contamination before it becomes a serious problem.

In the present study, nickel levels were not detected at all the sites and during all the seasons. Lack of modern agricultural practices and industrial development in Aizawl can be a major cause for the absence of nickel.

5.2.7 Arsenic (As)

Arsenic is a naturally occurring element found in rocks and soil, and can enter ground water through natural processes such as weathering and erosion. Arsenic contamination of ground water is a serious problem in many parts of the world, with more than 90% pollution being from geogenic influences (Shaji *et al.,* 2021). Industrial activities such as mining and the excessive use of pesticides and fertilizers can also contribute to arsenic contamination of ground water pollution (Stachnik *et al*., 2020).

Arsenic contamination of water can result in multiple human health risks (Hebbar *et al.*, 2016). Long-term exposure to high levels of arsenic in drinking water can lead to skin problems, cardiac disorders, neurological damage, and cancer of many organs such as lungs, kidneys, and bladder (Shaji *et al*., 2021).

Arsenic contamination of ground water can result in large-scale public health crises in several countries such as Bangladesh (Rahaman *et al*., 2022). Southeast Asian countries with large populations suffer considerable risks from arsenic contamination of ground water sources (Shukla *et al*., 2020; Abhinav *et al*., 2016). The geology of the aquifers also contributes to the arsenic contamination as seen in areas like river basins (Chakraborty *et al*., 2015). Arsenic pollution enforces large numbers of civilians to suffer from the hazardous consequences to their health (Chetia *et al*., 2011).

In certain parts of India, arsenic levels have been observed to be beyond permissible limits (Pandey *et al*., 2015). Ground water from the agricultural areas in Punjab was particularly contaminated with arsenic (Krishan *et al*., 2023). The water supply in west Bengal also contains arsenic contaminants despite the operation of PHED tube wells and pipelines (Mazumdar *et al*., 2020). The population along the Gangetic plains have also faced health complications due to arsenic pollution (Kumar *et al*., 2016; Alam *et al.,* 2016).

In the present study, arsenic levels from all the sites were tested, and all the results recorded the absence of arsenic. The obvious reasons for this are the low level of agricultural activity and minimal industrial pollution in the Aizawl.

CHAPTER-6

SUMMARY, CONCLUSION AND MANAGEMENT STRATEGIES

Ground water refers to the water present beneath the Earth's surface in the soil, sediments, and rocks. It occupies the porous spaces between particles or crevices in the earth’s crust, forming aquifers, which are underground reservoirs that can store and transmit water. Ground water is an important natural resource and plays a significant role in sustaining ecosystems, supporting agriculture, and supplying potable water for millions of people worldwide (Dangar *et al*., 2021).

Ground water originates from various sources, including precipitation such as rainfall and snowfall, surface water bodies such as lakes and rivers, and percolation of water into the ground. (Mishra and Chandok, 2022). It is replenished through a process of seepage and leaching, where water seeps downward through the soil and infiltrates into the aquifers. Aquifers are geologic formations that can store and transmit water. Ground water recharge occurs through percolation of precipitation or surface water, or through interactions with rivers, lakes, or other water bodies. Ground water often provides water to springs, seeps into streams, lakes, or oceans, or is abstracted through wells for human use. Ground water quality differs depending on the characteristics of the aquifer and the sources of recharge.

Generally, ground water is considered to be of high quality due to natural filtration processes that occur as water moves through the subsurface. However, it is often polluted by chemicals, bacteria, and other substances. The ground water quality influenced by geogenic and anthropogenic factors pose considerable risks to human health (Kumar *et al.,* 2022). Ground water is commonly accessed through wells and handpumps, which are drilled or dug to reach the water-bearing aquifers.

The management and protection of ground water resources is essential to ensure their sustainability and availability. This includes implementing responsible water use practices, monitoring ground water levels and quality, promoting recharge areas, and preventing pollution from activities that could affect ground water quality. Sustainable management of ground water is essential for meeting water demands and preserving the environment. With this aim, the following objectives were taken up in the present study:

1. To evaluate the ground water quality of selected Sites in Aizawl city.
2. To determine the metal content of ground water in the selected Sites.
3. To formulate appropriate strategies for water quality management.

To fulfil the objectives of the present study, thirteen handpump water and one tap water sample were selected for collection of water samples and analysis of water quality characteristics, Site 1 (Bawngkawn Handpump, near Hrangbana Petrol pump, site 2(Chaltlang Handpump, near Sericulture Office, site 3(Ramhlun South Handpump, near Ramhlun South Presbyterian Church), site 4 (Republic Vengthlang Handpump, near Republic Presbyterian Church), site 5 (Republic Vengchhak Handpump), site 6(Tuikual Handpump, near Coreens Bakery Industry), site 7 (Kanan Handpump, near Kanan Baptist Church of Mizoram), site 8 (Ramhlun South Hand pump, near Ramhlun south Baptist church), site 9 (Tap water, supplied by Mizoram PHED Sample was collected from Pollution Control Board Office), site10 (Bethlehem Hand-pump, near Bethlehem taxi stand), site 11 (Durtlang, near Govt Zirtiri Residential Science College), site 12 (Durtlang, near Durtlang Presbyterian Church), site 13 (Ramhlun North, near Ramhlun North Vegetable Market) and site 14 (Industry Peng, near Salvation Army Church).

During the study period, Handpump and tubewell water samples were collected from different localities of Aizawl City under five major zonations viz. Central, North, South, East and West part of Aizawl City on a monthly interval for two successive years i.e., from January, 2018 to December, 2018, and January, 2019 to December, 2019. The geographical location of each sampling point was recorded using Global Positioning System (GPS). The various physicochemical characteristics viz., Temperature, pH, Turbidity, Total Dissolved Solids, Total Hardness, Total Alkalinity, Chloride, Calcium, Phosphate-P, Nitrite-N, N-NH_3, Dissolved Oxygen (DO) and the presence of heavy metal contaminants were analysed during the said study period. To examine the above quality parameters, the methods as described in

“Standard Methods for the Examination of water and waste water” prescribed by the “American Public Health Association (APHA,2005)” has been adopted for analysis of water quality parameters. The samples were tested and observed seasonally, i.e., in terms of pre- monsoon (February – May), monsoon (June – September) and post-monsoon (October – January). To check the validity and significance of the data observed during the study period, two-way analysis of variance (ANOVA) and Pearson correlation coefficient was also done.

The results observed in the present study with respect to the chosen physico chemical characteristics and its impact are as follows:

1. The temperature ranged from 18.5°C (site 12 in pre-monsoon season in 2018 and 2019) to 26°C (sites 3, 4, 5, 10, 13, 14 in monsoon season in 2018 and site 14 in monsoon and post-monsoon seasons in 2019). It was observed that temperature of ground water was the lowest in pre-monsoon season and highest in monsoon season in both the years i.e., 2018 and 2019.
2. The range of pH during the study period (2018 and 2019), was from 5.35 (site 13 in post-monsoon season in 2019) to 7.9 (site 9 in pre-monsoon season in 2018). The pH ranges were found to be lower during pre-monsoon and post-monsoon seasons than during the monsoon season in both the years i.e., 2018 and 2019.
3. The range of turbidity in during the study period (2018 and 2019) was from 0.1 NTU (site 9 in post-monsoon season in 2018) to 80.9 NTU (site 11 in post-monsoon season in 2019). It was observed that turbidity was usually lowest in pre-monsoon season, a little higher in the monsoon season and highest in post-monsoon season during both the years i.e., 2018 and 2019.
4. The range of TDS was from 16 mg/L (site 9 in pre-monsoon and post-monsoon seasons in 2019) to 268 mg/L (site 6 in monsoon season in 2018). It was observed that the TDS in ground water varies in different seasons during both the years i.e., 2018 and 2019.
5. The overall range of chloride levels was from 3.1625 mg/L (site 9 in post-monsoon season in 2019) to 86.025 mg/L (site 6 in pre-monsoon season in 2018).

6. The overall range of total alkalinity was from 9.25 mg/L (site 9 in post-monsoon season in 2018) to 250.9 mg/L (site 4 in pre-monsoon season in 2019). It was observed that the total alkalinity of the ground water samples is highest in pre-monsoon and lowest in post-monsoon seasons during both the years i.e., 2018 and 2019.
7. The range of total hardness during the study period (2018 and 2019) was from 11 mg/L (site 9 in post-monsoon season in 2019) to 242.5 mg/L (site 6 in pre-monsoon season in 2018). It was observed that total hardness was the lowest in post-monsoon season, followed by monsoon season and was the highest in pre-monsoon season during both the years i.e., 2018 and 2019.
8. The range of calcium levels during the study period (2018 and 2019) was from 2.2 mg/L (site 9 in post-monsoon season in 2019) to 71 mg/L (site 6 in pre-monsoon season in 2018). It can be concluded that the calcium levels are highest in pre-monsoon season and lowest in post-monsoon season during both the years i.e., 2018 and 2019.
9. The range of phosphate levels during the study period (2018 and 2019) was from 0 mg/L (site 1 in monsoon season in 2019) to 0.6365 mg/L (site 3 in monsoon season in 2018).
10. The range of $N\text{-}NH_3$ during the study period (2018 and 2019) was from 0.056 mg/L (site 7 in post-monsoon season in 2019) to 1.816 mg/L (site 13 in post-monsoon season during2018).
11. The overall range of $N\text{-}NO_2$ during the study period (2018 and 2019) was from 0.00375 mg/L (site 11 in pre-monsoon season in 2019) to 0.885 mg/L (site 5 in pre-monsoon season in 2019).
12. The range of Dissolved Oxygen during the study period (2018 and 2019) was from 1.75 mg/L (site 14 in monsoon season in 2019) to 6.46 mg/L (site 9 in pre-monsoon in 2019). it was observed that the level of Dissolved Oxygen was the lowest in monsoon season and highest during pre-monsoon season.
13. During the entire study period of 2018-2019, the Zn values ranged from 0 mg/L (sites 1, 2, 7, 13 and 14 in pre-monsoon season and site 8 in all seasons, pre-monsoon, monsoon and post-monsoon in 2018 as well as sites 8 in pre-monsoon season and site 9 and 12 in all seasons, pre-monsoon, monsoon and

post-monsoon in 2019) to 2.196 mg/L (site 5 in pre-monsoon season in 2019). The zinc levels were found to be highest in pre-monsoon, followed by monsoon and least during post-monsoon seasons respectively.

14. The range of copper during the study period (2018 and 2019)was from 0 mg/L (sites 1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10 ,11 ,13 and 14 in pre-monsoon season, sites 8 and 9 in monsoon season and sites 8 and 9 in post-monsoon season in 2018 as well as sites 8 and 9 in all seasons, pre-monsoon, monsoon and post-monsoon as well as site 12 in post-monsoon season in 2019) to 0.0189 mg/L (site 12 in pre-monsoon season in 2018). The slight decrease in copper levels from pre-monsoon to monsoon and least in post-monsoon has been observed.

15. The range of Iron observed during the study period (2018 and 2019) was from 0 mg/L (sites 1, 4, 6, 9, 11, 12, 13 and 14 in pre-monsoon season, sites 1, 4, 6, 9, 12 and 13 in monsoon season, and sites 1, 4, 9, 12 and 13 in 2018 as well as sites 1, 2, 4, 5, 8, 9, 10, 12 and 13 in pre-monsoon season, sites 1, 4, 9, 12 and 13 in monsoon season and sites 2, 4, 6, 9, 12 and 13 in post-monsoon season in 2019) to 1.162 mg/L (site 7 in pre-monsoon season in 2018). The iron level seems to be highest in pre-monsoon and lowest in post-monsoon.

16. The range of manganese levels during the study period (2018 and 2019) was from 0 mg/L (sites 1, 4, 6, 9, 11, 12, 13, and 14 in pre-monsoon season, sites 9 and 12 in monsoon season and sites 9 and 12 in post-monsoon season in 2018 as well as sites 8, 9 and 12 in pre-monsoon season, sites 9 and 12 in monsoon season and sites 9 and 12 in post-monsoon seasons respectively in 2019) to 0.6892 mg/L (site 14 in post-monsoon in 2019). The manganese level varies in different seasons.

The results in relation to the physico chemical characteristics of ground water samples were within permissible limits set by various scientific agencies except sites 2, 13 and 14 which exceeded the acceptable standard of turbidity during the year 2018, along with sites 2,3,4,5,6,7,11,13 and 14 which exceeded the standard during 2019. These exceeding observations were found mostly in the monsoon and post-monsoon seasons. This may be due to the overland flow of water during monsoon which can be potential contributor to the high level of turbidity. Sites 3, 5, 13 and 14 in pre-monsoon season and site 8 in post-monsoon season during 2019 and sites 13 and 14 in post-monsoon of 2018 exceeded permissible standard of ammonium. This can again be attributed to the high amount of precipitation in the monsoon season. In addition, all the sites have slightly exceeded the permissible limits of phosphate in the year 2018, and particularly in the post monsoon season, whereas in 2019, only few sites have exceeded the permissible limits. This may be due to the overland flow of water during monsoon which can percolate down to act as potential contributor of phosphate in ground water.

The heavy metal analysis was also found to be relatively safe and acceptable as fixed by regulatory scientific agencies, with a few exceptions. At site 7 in pre-monsoon season, iron (Fe) concentrations have exceeded the acceptable standards set by various scientific agencies. This can be attributed to the rusting and corrosion of Fe from the appliances used in the handpumps. Whereas, sites 13 and 14 during 2019 exceeded the permissible standards of manganese levels set by various regulatory agencies. The changes in climatic variables of the study area and rate of use of ground water, along with heavy rainfall can cause manganese levels to fluctuate.

In present study, observed results of Fe and Mn exceed safety standards that can be detrimental for the public health and require thorough investigation into its causes. Remedial measures are required for the management and control of water quality to ensure the safety and wellbeing of concerned people. This can further be strengthened through the implementation of laws for disposal of wastes, implementation of water management plans, promoting rainwater harvesting and recharge of ground water, as well as constant monitoring of water source.

The iron compound ferrate is known broadly for its use in ecological uses in filtering water and treatment of sewage, as it can be used abundantly without ecological side effects (Rai *et al.*, 2018). This study also concludes that ferrate can be used extensively as a green chemical in various processes to attain sustainable development due to its diverse capabilities as oxidants, coagulants and disinfectants.

The use of plant extricates in treatment of water was investigated and was found to have significant benefits in improving water quality in terms of various physico-chemical parameters such as acidity, turbidity, and hardness (Alam *et al*., 2020).

In the present water quality analysis, sanitized water by the PHE department was taken as a reference. A comparison was made between the tap water and ground water samples collected from different sampling sites. In relation to temperature and pH the degree of difference between tap water and ground water was minimal. On the contrary, TDS, chloride, total alkalinity, total hardness, DO and calcium levels of ground water samples from almost all the sites were found to be significantly higher than the tap water in all the seasons and study period. The N-NO_2, Zinc and Copper levels in the ground water and tap water samples were found to have only a slight difference in all the observed seasons. The levels of turbidity, N-NH_3, phosphate iron and manganese dissolved in ground water samples was found to be significantly higher than the levels found in tap water samples in all seasons.

MANAGEMENT STRATEGIES/ MITIGATION

In present study, it was observed that the few water quality parameters like turbidity, ammonia, phosphate, iron and manganese have exceeded the permissible limit set by various agencies. Since these parameters also exceeded slightly, therefore, simple pre-treatment methods or strategies can be formulated for ground water quality management. To this end, frequent water quality monitoring and remedial measures are required for the management of ground water to ensure the public health safety and human well-being. The use of phytotechnology and green chemicals like ferrate compounds (with dual role as coagulants and disinfectants) in water treatment plants should be investigated thoroughly in future studies for safe use of ground water resources (Rai *et al.,* 2018).

In past studies, turbidity has demonstrated a positive and significant correlation with Fe and Mn (Fahimah *et al.*, 2023). This observation of Fahimah *et al.* (2023) was similar to present finding pertaining to ground water quality in Aizawl. Several chemical and biological methods are devised to mitigate the excess turbidity, ammonia, phosphate, iron and manganese in ground water. In recent studies, use of biological or natural products like peels of the *Opuntia ficus-indica* fruit was devised as an alternative to traditional inorganic coagulants for ground water treatment (Otálora *et al*., 2023). The mature okra was dried and pulverized to act as efficient flocculating biopolymer in ground water treatment, especially for effective removal of turbidity (Jesus *et al.,* 2013).

The acute exposures to high levels of ammonia have also been associated with several human diseases (Dey *et al*., 2022). The removal of ammonia from contaminated water by application of natural biosorbents like orange peels, coconut wire, and tea waste was found to be effective, simple, economical, and environment-friendly than traditional chemical methods (Dey *et al*., 2022). Application of algal biomass such as of *S. quadricauda* also showed effective results in ammonia and phosphate removal from contaminated water (Shawky *et al.,* 2015). Phosphate is considered to be the primary limiting factor in abiotic and biotic systems. However, for removing excess phosphate ions in wastewater, the synthesized vaterite polymorph of porous calcium carbonate (VPPCC) nanoparticles are observed to be a potential candidate (Senarathna *et al*., 2020).

Rainwater on infiltration in the soil and underlying geologic formations can dissolve iron, thereby causing it to seep into aquifers that serve as ground water sources. Although iron is an essential mineral for human, its presence in ground water above a threshold level make the water unusable mainly for aesthetic considerations such as discoloration, metallic taste, odor, turbidity and staining of laundry. Iron is mainly present in water either the soluble ferrous iron or the insoluble ferric iron (Beenakumari, 2009). Iron levels greater than 0.3 mg/L can impose adverse human health effects (Chaturvedi and Dave, 2012). For removal of excess iron, charcoal/ash–sand filtration systems can precipitate Fe either as geothite or ferrihydrite (Chaturvedi and Dave, 2012). A method for removal of iron from water by using the modified coconut shell charcoal has been systematically investigated and has been found to be very effective when its level was below 0.3 ppm (Beenakumari, 2009).

Increased Fe and Mn concentrations may be detrimental for the public health and require adequate management. The combined usage of alum and potassium permanganate ($KMnO_4$) has been found to be very effective in removing Fe^{2+} and Mn from the ground water (Nizam and Zainuddin, 2023). Also, the same chemical combination can remove other parameters such as colour, turbidity, cations, and pH (Nizam and Zainuddin, 2023). Rice husk, rice straw, and pottery are also noted as effective adsorbents for the removal of Fe (III) and Mn (Π) from ground water (Abo-Elmagd, 2019). Among these adsorbents, rice husk was noted as the best filter media in removing Fe (III) and Mn (Π) from ground water (Abo-Elmagd, 2019).

In context of present study site, research and development efforts should be supported to find innovative solutions for ground water quality management. New technologies and methodologies (e.g., use of green chemicals and bioremediation) must be explored for contaminant removal and prevention. Water quality standards and regulations should be strictly enforced to regulate various contaminants in ground water. Furthermore, ground water recharge techniques and rainwater harvesting should be promoted to replenish the aquifers. This can help offset the depletion caused by excessive pumping and provide cleaner water through natural filtration. Proper waste management practices, including recycling and safe disposal of hazardous waste should be implemented. Small-scale enterprises in Aizawl should be encouraged to adopt cleaner production methods and treat their effluents before discharge.

A comprehensive long-term plan must be developed for sustainable ground water management in Aizawl to safeguard public health in long-term. This plan should be adaptive and consider the impact of climate change, population growth, and other factors on ground water quality. The public, community leaders, and stakeholders should be educated about the importance of ground water quality and its sustainable management. Community participation and cooperation should be encouraged in implementing the strategies. Awareness campaigns can also focus on reducing activities that contribute to ground water contamination.

APPENDICES

APPENDIX I

Correlation coefficient (r) between the water quality parameters for two years data (January 2018 – December 2019)

	Temperature	*pH*	*Turbidity*	*TDS*	*Chloride*	*TA*	*TH*	*Calcium*	*Phosphate*	*N-NH₃*	*N-NO2*	*DO*	*Zinc*	*Copper*	*Fe*	*Mn*
Temperature	1															
pH	-0.409	1														
Turbidity	0.290	-0.212	1													
TDS	0.542*	-0.239	0.198	1												
Chloride	0.181	-0.513*	0.303	0.791**	1											
TA	0.385	0.412	0.082	0.367	-0.131	1										
TH	0.345	0.031	0.064	0.792**	0.522*	0.633*	1									
Calcium	0.373	0.272	-0.023	0.580*	0.161	0.872**	0.888**	1								
Phosphate	0.451	-0.205	0.576*	0.064	0.068	0.061	-0.049	-0.016	1							
N-NH3	0.384	-0.549*	0.558*	0.213	0.397	-0.292	-0.125	-0.322	0.574*	1						
N-NO2	-0.170	-0.305	-0.058	0.118	0.413	-0.361	-0.007	-0.276	0.025	0.166	1					
DO	0.298	0.457	-0.735*	-0.307	-0.529*	0.057	-0.070	0.116	-0.701*	-0.810**	-0.362	1				
Zinc	0.057	0.343	-0.132	0.458	0.261	0.295	0.619*	0.534*	-0.192	0.042	-0.162	0.088	1			
Copper	-0.539*	0.242	-0.184	-0.186	-0.055	-0.081	-0.092	-0.157	-0.297	-0.330	0.560*	0.113	-0.195	1		
Fe	0.050	0.128	0.298	0.177	0.144	-0.058	0.024	-0.055	0.589*	0.228	-0.021	-0.305	-0.068	-0.142	1	
Mn	0.494	-0.557*	0.344	0.139	0.208	-0.133	-0.006	-0.150	0.462	0.647*	0.306	-0.582*	-0.022	-0.292	0.096	1

APPENDIX II

Two-way ANOVA for temperature as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	111.857887	13	8.604453	8.024222	2.8672E-09	1.873880
Between Seasons	159.289435	5	31.857887	29.709587	1.4186E-15	2.356028
Error	69.700149	65	1.072310			
Total	340.847470	83				

Two-way ANOVA for pH as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	16.359127	13	1.258394	12.152584	7.7467E-13	1.873879951
Between Seasons	0.699874	5	0.139975	1.351766	0.254139	2.356027822
Error	6.730720	65	0.103550			
Total	23.789721	83				

Two-way ANOVA for Turbidity as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	1611.847329	13	123.988256	1.481609	0.148591	1.873880
Between Seasons	2433.683787	5	486.736757	5.816304	0.000169	2.356028
Error	5439.517359	65	83.684882			
Total	9485.048475	83				

Two-way ANOVA for Total Dissolved Solids as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	180564.232887	13	13889.556376	47.277972	5.2497E-28	1.873880
Between Seasons	739.801339	5	147.960268	0.503635	0.772431	2.356028
Error	19096.021577	65	293.784947			
Total	200400.055804	83				

Two-way ANOVA for Chloride as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	27485.021803	WWW	2114.232446	56.055966	3.6659E-30	1.873880
Between Seasons	861.068012	5	172.213602	4.566007	0.001248	2.356028
Error	2451.569727	65	37.716457			
Total	30797.659543	83				

Two-way ANOVA for Total Alkalinity as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	246623.511111	13	18971.039316	74.998462	6.2878E-34	1.873880
Between Seasons	6484.706252	5	1296.941250	5.127215	0.000503	2.356028
Error	16441.904655	65	252.952379			
Total	269550.122019	83				

Two-way ANOVA for Total Hardness as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	143661.096339	13	11050.85356	51.09376338	5.5249E-29	1.873880
Between Seasons	15295.860863	5	3059.172173	14.14412183	2.3471E-09	2.356028
Error	14058.574554	65	216.2857624			
Total	173015.531756	83				

Two-way ANOVA for Calcium as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	11124.625506	13	855.740424	28.554103	6.8941E-22	1.873880
Between Seasons	2721.898839	5	544.379768	18.164709	3.0906E-11	2.356028
Error	1947.990744	65	29.969088			
Total	15794.515089	83				

Two-way ANOVA for Phosphate as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	0.135739	13	0.010441	1.210491	0.292500	1.873880
Between Seasons	0.554791	5	0.110958	12.863547	1.0569E-08	2.356028
Error	0.560676	65	0.008626			
Total	1.251206	83				

Two-way ANOVA for N-NH_3 as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	1.700030	13	0.130772	2.384317	0.011025	1.873880
Between Seasons	8.150679	5	1.630136	29.721764	1.4058E-15	2.356028
Error	3.565025	65	0.054847			
Total	13.415733	83				

Two-way ANOVA for N-NO_2 as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	0.820228	13	0.063094	3.419144	0.000485	1.873880
Between Seasons	0.244376	5	0.048875	2.648590	0.030603	2.356028
Error	1.199464	65	0.018453			
Total	2.264067	83				

Two-way ANOVA for Dissolved Oxygen as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	37.292917	13	2.868686	7.244156	1.7280E-08	1.873880
Between Seasons	30.429853	5	6.085971	15.368611	5.9115E-10	2.356028
Error	25.740002	65	0.396000			
Total	93.462772	83				

Two-way ANOVA for Zn as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	14.654	13	1.127	7.197	1.9E-08	1.874
Between Seasons	0.070	5	0.014	0.090	0.994	2.356
Error	10.180	65	0.157			
Total	24.904	83				

Two-way ANOVA for Cu as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	0.001	13	4.317E-05	6.376	1.424E-07	1.874
Between Seasons	5.808E-05	5	1.162E-05	1.716	1.435E-01	2.356
Error	0.0004	65	6.770E-06			
Total	0.001	83				

Two-way ANOVA for Fe as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	1.921	13	0.148	5.186	3.14E-06	1.874
Between Seasons	0.083	5	0.017	0.582	0.714	2.356
Error	1.852	65	0.028			
Total	3.857	83				

Two-way ANOVA for Mn as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Sites	1.729	13	0.133	9.558	1.07E-10	1.874
Between Seasons	0.254	5	0.051	3.655	5.63E-03	2.356
Error	0.904	65	0.014			
Total	2.887	83				

REFERENCES

Abanyie, S. K., Boateng, A. and Ampofo, S. (2016). Investigating the probability of water from dug wells: A case Study of the Bolgatanga Township, Ghana. *African Journal of environmental and research technology*, 10(10): 307-315.

Abed, S., Hussain, S. and Pradhan, V. (2011). Seasonal variation of ground water parameters in the Godavari basin at Paithan town. *Archives of Applied Science Research,* 3 (4):296-299.

Abhinav, A., Navin, S., Kumar, A., Kumar, R., Ali, M., Verma, S.K. and Ghosh, A.K. (2016). Prevalence of high arsenic concentration in Darbhanga district of Bihar: health assessment. *J Environ Anal Toxicol*, 6:410.

Abo-Elmagd, A.M., El-Din, E.B., Hegazy and Bakry, A.Y (2019). Removal of Iron and Manganese from Groundwater by Adsorption on Agricultural Residues and Natural Waste Materials. *Australian Journal of Basic and Applied Sciences*, 13(8): 104-111.

Achary, G.S. (2014). Studies on Ground Water Pollution due to Iron Content in Bhubaneswar, Odisha, India. *International Journal of Current Engineering and Technology*, 4(1).

Ackah, M., Anim, A.K., Zakaria, N., Osei, J., Nyarko, E.S., Gyamfi, E.T., Tulasi, D., Brown, S.E., Hanson, J. and Bentil, N.O. (2014). Determination of some heavy metal levels in soft drinkson the Ghanaian market using atomic absorption spectrometry method. *Environ Monit Assess*, 186: 8499 – 8507.

Adedeji, O.H. and Olayinka, O. O. (2015). Assessment of Groundwater contamination by textile effluent discharges in Ikorodu, Nigeria. *Applied Environmental Research,* 37(1): 35-48.

Adeyemi, A.A. and Ojekunle, Z.O. (2021). Concentrations and health risk assessment of industrial heavy metals pollution in groundwater in Ogun state, Nigeria. *Scientific African*,11.

Adhikari, S., Yanuar, E. and Ng, D.Q. (2022). Widespread nickel contamination in drinking water supplies of elementary schools in Taichung, Taiwan. *Environ Sci Pollut Res,* 29: 12531–12539.

Adimalla, N. and Taloor, A.K. (2020). Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using Geographic Information System (GIS) and groundwater quality index (GWQI) techniques. *Groundwater for Sustainable Development,* 10: 100288.

Adnan, M., Xiao, B., Xiao, P., Zhao, P. and Bibi, S. (2022). Heavy metal, waste. Covid 19, rapid industrialization in this modern era- Fit for sustainable future. *Sustainability,* 14(4746).

Adnani I.E.L., Younsi, A., Namr, K.I., Achheb, A.E.I. and Irzan, E.M. (2020). Assessment of Seasonal and Spatial Variation of Groundwater Quality in the Coastal Sahel of Doukkala, Morocco. *Nature Environment and Pollution Technology, An International Quarterly Scientific Journal,* 19(1):17-28.

Adnani, I.E.L., Younsi, A., Namr, K. I., Achheb, A.E.I. and Irzan, E.M. (2018). The influence of anthropogenic activities on groundwater quality of southwest region of El Jadida city (Sahel of Doukkala, Morocco), *European Journal of Scientific Research*, 151: 96-111.

Afzaala, M., Hameeda, S., Liaqatb, I., Khanc, A.A., Manand, H.A., Shahide, R. and Altafe, M. (2022). Heavy metals contamination in water, sediments and fish of freshwater ecosystems in Pakistan. *Water Practice & Technology,* 17(5).

Aher, K. R. and Deshpande, S. M. (2016). Geochemistry and evaluation of groundwater pollution in Chikalthana area of Aurangabad district, Maharashtra, India. *Journal of Applied Geochemistry,* 18(2): 192-202.

Ahmed, S., Akhtar, N., Rahman, A., Mondal, N.C., Khurshid, S., Sarah, S., Khan, M.M.A. and Kamboj, V. (2022). Evaluating groundwater pollution with emphasizing heavy metal hotspots in an urbanized alluvium watershed of Yamuna River, northern India. *Environmental Nanotechnology, Monitoring & Management,* 18:100744.

Ahouansou, D.M.M., Agodzo, S.K., Awoye, O.H.R., Balle, R.G.A. and Sintondji, L.O.C. (2018). Analysis of the Seasonal Variation of Groundwater Quality in a Highly Cultivated Catchment, Northern Benin. *American Journal of Water Resources,* 6(6): 224-234.

Akiwumi, O.O., Eletta, O.A. and Odebunmi, O. (2012). Analysis of Nitrates and Nitrites in Groundwater of Ilorin Environs. *Journal of Environmental Science and Engineering,* 1: 656-662.

Alam, M.O., Shaikh, W.A., Chakraborty, S., Avishek, K. and Bhattacharya, T. (2016). Groundwater Arsenic Contamination and Potential Health Risk Assessment of Gangetic Plains of Jharkhand, India. *Expo Health,* 8; 125–142.

Alam, M.W., Pandey, P., Khan, F., Souayeh, B. and Farhan, M. (2020). Study to Investigate the Potential of Combined Extract of Leaves and Seeds of Moringa oleifera in Groundwater Purification. *Int. J. Environ. Res. Public Health,* 17(20): 7468.

Aliyu, A. K., Birmn-yauri, U. A., Umar, K. J., Isa, S. A. and Nasiru, M. K. (2018). Assessment of some physiochemical Parameters and heavy metals in Ground Water from sandy areas of Argungu Emirate, Kebbi State, Nigeria. *International journal of engineering sciences and research technology.* 13(1): 1-5.

Altman, S.J. and Parizek, R.R. (1995.*)* Dilution of Non-Point Source Nitrate in Groundwater. *J. Environ. Quality,* 24:707-717.

Amiri, V., Rezaei, M. and Sohrabi, N. (2014). Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. *Environmental Earth Sciences,* 72: 3479–3490.

APHA, (2005) Standard methods for the examination of water and wastewater: 21st Edition as prescribed by American Public Health Association, *American Water Works Association and Water Environment Federation, Washington, D.C.*

Arora, G., Sharma, A., and Bhatia, R.K., (2018). Comparative study of Physico-chemical parameters of groundwater near Omti Nala before and after lining. *International Research Journal of Engineering and Technology,* 05(05) :1826-1832.

Arshad, A., Iqbal, M. and Waheed, A. (2021). Groundwater quality assessment near Nullah Lai stream of Pakistan. *Central Asian Journal of Environmental Science and Technology Innovation,* 2 :45-51.

Asanousilamma, O., Swamy, A.V.V.S. and Alhadad, A. A. (2018). Assessment of Heavy Metal Pollution in groundwater and its correlation with other physical parameters at selected industrial areas of Guntur, A. P. India. *International Journal of Scientific Research in Science, Engineering and Technology*, 4(1): 917-919.

Asare, O.D.A., Darko, H.F. and Asante, K. A. (2009). Groundwater quality assessment of Akatsi, Adidome and Ho districts in the Volta Region of Ghana, *Desalination*, 248(1–3): 446-452.

Awoyemi, O.M., Achudume, A.C. and Okoya, A.A. (2014). The Physicochemical Quality of Groundwater in Relation to Surface Water Pollution in Majidun Area of Ikorodu, Lagos State, Nigeria. *American Journal of Water Resources*, 2(5):126-133.

AWWA, (2012) Standard Methods for examination of water and wastewater. 22nd Edition, Washington American Public Health Association, American Water Works Association, *Water Environment Federation*, 1360.

Aziz, H.A., Adlan, M.N., Zahari, M.S.M. and Alias, S. (2004). Removal of ammoniacal nitrogen (N-NH3) from municipal solid waste leachate by using activated carbon and limestone. *Waste Management & Research*, 22(5):371-375.

Balakrishnan, A. and Ramu, A. (2016). Evaluation of heavy metal pollution index (HPI) of groundwater in and around the coastal area of Gulf of Mannar biosphere and Palk strait. *Journal of advanced chemical sciences,* 2(3):331-333.

Balakrishnan, A. and Ramu, A. (2017). Seasonal variations of ground water quality in and around Gulf of Mannar coastal aquifers, *J. Env. Sci. Pollut. Res,* 3(2): 186–188.

Banerjee, S., Das, B., Umlong, I. M., Devi, R. R., Kalita, H., Saikia, L. B., Borah, K., Raul, P. K. and Singh, L. (2011). Heavy metal contamination of underground water in Indo Bangla Border Districts of Tripura India. *International Journal of Chemical Research,* 3 (1): 516-522.

Bansal, J. and Dwivedi A.K. (2018). Assessment of groundwater quality by using water quality index and physicochemical parameters. *Review paper*: *International Journal of Engineering Science and Research Technology*, 7(2): 170-174.

Banupriya, R., Vibesh, D., Surya, P. and Suresh. (2018). Impact of Leachate on Groundwater around Vellakal dumping site, Madurai, Tamil Nadu, India. *International Research Journal of Engineering and Technology*, 05(04): 699-705.

Barman, J. and Biswas, B. (2022). Application of e-TOPSIS for Ground Water Potentiality Zonation using Morphometric Parameters and Geospatial

Technology of Vanvate Lui Basin, Mizoram, NE India. *Journal of the Geological Society of India*, 98:1385–1394.

Bashir, M.T., Ali, S. and Bashir, A. (2012). Health Effects from Exposure to Sulphates and Chlorides in Drinking Water. *Pakistan Journal of Medical and Health Science*, 6(3).

Beenakumari, K.S. (2009). Removal of iron from water using modified coconut shell charcoal as adsorbent. *Curr World Environ*, 4(2).

Bhalerao, S.A., Sharma, A.S. and Poojari, A.C. (2015). Toxicity of Nickel in Plants. *Int. J. Pure App. Biosci*, 3 (2): 345-355.

Bhattrai, B.D., Kwak, S. and Heo, W. (2015). Assessment of water quality variations under non-rainy and rainy conditions by principal component analysis techniques in Lake Doam watershed, Korea. *J. Ecol. Environ,* 38(2): 145-156.

Biddau,R., Cidu, R., Lorrai, M. and Mulas, M.G. (2017).Assessing background values of chloride, sulfate and fluoride in groundwater: A geochemical-statistical approach at a regional scale. *Journal of Geochemical Exploration*, 181: 243-255.

Birajdar, S.N., Vedpathak, S.G. and Chanshetti, U.B. (2017). The Effect of Seasonal Variation on Physicochemical Properties of Tubewell Water of Latur District (MS), India. *Journal of Environmental Science, Toxicology and Food Technology,* 11(10): 58-63.

Blick, J. and Kumar, S. (2017). Assessment of potable water quality of surface water (tuikhur) and hand-pumps in Saiha, Southern Mizoram. *Science vision*, 17(3): 163-171.

Blick, J., Kumar, S., Bharati, V. K. and Kumar, S. (2016). Status of arsenic contamination in potable water in Chawngte, Lawngtlai District, Mizoram, India. *Science Vision*, 16(2): 74-81.

Boarh, M. and Misra, A.K. (2010). Seasonal distribution of trace metals in ground and surface water of Golaghat district, Assam,India. *E-Journal of chemistry,* 7(S1): S465-S473.

Boateng, T.K., Opoku, F., Acquaah, S.O. and Akoto, O. (2016). Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality, Ghana. *Environmental Earth Sciences,* 75: 489.

Bora, M., Dulal, C. and Goswami. (2017). Water quality assessment in terms of water quality index (WQI): Case Study of the Kolong River, Assam, India. *Applied Water Science,* 7:3125-3135.

Borah, R., Taki, K., Gogoi, A., Das, P. and Kumar, M. (2018). Contemporary distribution and impending mobility of arsenic, copper and zinc in tropical (Brahmaputra) river bed sediments in Assam, India. *Ecotoxicology and Environment safety*, 161: 769-776.

Bouchard, M.F., Sauvé, S., Barbeau, B., Legrand, M., Brodeur, M.E., Bouffard, T., Limoges, E., Bellinger, D.C. and Mergler, D. (2011). Intellectual impairment in school-age children exposed to manganese from drinking water. *Environ. Health Perspect*, 119:138-143.

Boumaza, B., Chekushina, T.V., Vorobyev, K.A. and Schesnyak, L.E. (2021). The heavy metal pollution in groundwater, surface and spring water in phosphorite mining area of Tebessa (Algeria). *Environmental Nanotechnology, Monitoring & Management*, 16: 100591.

Boyd, C.E. (2015). Total Hardness. In: Water Quality. *Springer*, *Cham*. https://doi.org/10.1007/978-3-319-17446-4_

Buragohain, M. and Sharma, H.P. (2012). A Study on the spatial distribution of arsenic in groundwater samples of Dhemasi District of Assam India by using ARC view GIS software. *Scientific review and chemical communication,* 2(1): 7-11.

Buragohain, M., Bhuyan, B. and Sharma, H. P. (2010). Seasonal variations of Lead, Arsenic, Cadmium and Aluminium contamination of groundwater in Dhemaji district, Assam, India. *Environmental monitoring and assessment,* 170:342-351.

Burmamu, B. R., Law, P. L., Madaki, S. Y. and Aliyu. (2014). Environmental burden of surface and groundwater quality: How big are the contaminants in Girei Town, Nigeria? *International Journal of Engineering Sciences and Research Technology*, 3(3): 1287-1293.

Cempel, M. and Nikel, G. (2006). Nickel: A Review of Its Sources and Environmental Toxicology. *Journal of Environmental Studies*, 15(3):375-382.

Central Ground Water Board. 2015.

Chabukdhara, M. and Singh, O.P. (2016). Coal mining in North-east India: an overview of environmental issues and treatment approaches. *International journal of coal science and technology*, 3(2): 87-96.

Chakraborty, M., Mukherjee, A. and Ahmed, K.M. (2015). A review of groundwater arsenic in the Bengal basin, Bangladesh and India: from source to sink. *Curr Pollut Rep*, 1:220–247.

Chandrasekhar, A. K., Chandrasekharam, D. and Faroog, S. H. (2016). Contamination and mobilization of Arsenic in the soil and groundwater and its influence on the irrigated crops, Manipur valley, India. *Environmental Earth Science*, 75: 142.

Chaturvedi, S and Dave, P.N (2012). Removal of iron for safe drinking water. *Desalination,* 303: 1-11.

Chaudhary, V., Jacks, G. and Gustafsson, J.E. (2002). An analysis of groundwater vulnerability and water policy reform in India. *Environmental Management and Health,* 13(2): 175-193.

Chaurasia, N., Mishra, A. and Pandey. S.K. (2012). Fingerprint of Arsenic Contamination Water in India. *A Review Journal of Forensic Research,* 3 (10):100-172.

Chenkual, L. and Mishra, B.P. (2016). Assessment of seasonal variation in chemical characteristics of Tamdil Lake, Mizoram, Northeast India. *International Journal of Scientific Engineering and Applied Science,* (IJSEAS*)*, 2(7):157-165.

Chetia, M., Chatterjee, S., Banerjee, S., Nath, M.J., Singh, L., Srivastava, R.B. and Sarma, H.P. (2011). Groundwater arsenic contamination in Brahmaputra River basin: a water quality assessment in Golaghat (Assam), India. *Environ Monit Assess*, 173: 371–385.

Choudhary, R. S. and Naik, M.I. (2015). Studies on the physicochemical parameters of groundwater quality analysis in and around Kalburagi, Karnataka, India. *International journal of scientific Engineering and Research*, 5(7): 121-127.

Chowdhury, K. D. and Giridhar, M.V.V.S. (2015). Spatial distribution of groundwater quality after rainwater recharge in JNTUH campus, Hyderabad, India. *International Journal of Research in Engineering and Technology,* 04(11): 134-141.

Dangar, S., Asoka, A. and Mishra, V. (2021). Causes and implications of groundwater depletion in India: A review, *Journal of Hydrology,* 596.

Deshpande S.M. and Aher K.R. (2012). Evaluation of Groundwater Quality and its Suitability for Drinking and Agriculture use in Parts of Vaijapur, District Aurangabad, MS, India. *Research Journal of Chemical Sciences*,2(1): 25-31.

Devic, D., Djordjevic, D. and Sakan, S. (2014). Natural and anthropogenic factors affecting the groundwater quality in Serbia. *Science of The Total Environment*, 468–469: 933-942.

Dey, S., Botta, R., Kallam, R., Angadala, R. and Andugala, J. (2020). Seasonal variation in water quality parameters of Gudlavalleru Engineering College Pond. *Current Research in Green and Sustainable Chemistry,* 4: 100058.

Dey, S., Botta, S., Kallam, R., Angadala, R. and Andugala, J. (2021). Seasonal variation in water quality parameters of Gudlavalleru Engineering College Pond. *Current Research in Green and Sustainable Chemistry,* 4(100058).

Dey, S., Charan, S.S., Pallavi, U., Sreenivasulu, A. and Haripavan, N (2022). The removal of ammonia from contaminated water by using various solid waste biosorbents, *Energy Nexus,* 7.

Dinakaran, J., Abbas, N.S., Arora, S., Bhardwaj, S. and Kaula, B.C. (2021). Assessment of heavy Metals in groundwater of different locations of national capital region, Delhi, India. *Curr World Environ,* 16(1).

Dirisu, C.G., Mafiana, M.O., Dirisu, G.B. and Amodu, R. (2016). Level of pH in drinking water of an oil and gas producing community and perceived biological and health implications. *European Journal of Basic and Applied Sciences,* 3(3): 2059-3058.

Dohare, D., Deshpande, S. and Kotiya, A. (2014). Analysis of Ground Water Quality Parameters: A Review. *Research Journal of Engineering Sciences,* 3(5) :26-31.

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

Elumalai, V., Brindha, K. and Laksmanan, E. (2017). Human Exposure risk assessment due to heavy metals in groundwater by pollution index and multivariate statistical methods: A case study from South Africa Water. *Water,* 9(234): 1-16.

Endale, Y. T., Ambelu, A., Sahilu, G.G., Mees, B. and Laing, G. D. (2021). Exposure and health risk assessment from consumption of Pb contaminated water in Addis Ababa, Ethiopia. *Heliyon*,7(9).

Eugene, L. R. and Singh, O. P. (2014). Degradation in water quality due to limestone mining in East Jaintia Hills, Meghalaya, India. *International Research Journal of Environmental Sciences*, 3(5):13-20.

Eugene, L.R., Shylla, R. and Singh O.P. (2014). Assessment of groundwater quality from dug wells in West Jaintia Hills, Meghalaya, India. *International Journal of Environmental Sciences*, 5(3).

Ezhilarasi M. and Senthil Kumar V. (2018). Geochemical analysis for groundwater quality using Geospatial application. *International Research Journal of Engineering and Technology*, 05(04): 2682-2687.

Fahimah, N., Salami, I.R.S.S., Oginawati, K. and Yutika Thaher, Y.N (2023). Variations of groundwater turbidity in the Bandung regency, Indonesia: From community-used water quality monitoring data, *HydroResearch*, 6: 216-227.

Fallahzadeh, R. A., Almodaresi, S. A., Dashti, M. M., Fattahi, A., Sadeghnia, M., Eslami, H., Khosravi, R., Minaee, R. P. and Taghavi, M. (2016). Zoning of nitrite and nitrate concentration in G.W. using Geography information System, Case study: Drinking water wells in Yazd city. *Journal of Geoscience and Environment Protection,* 4: 91-96.

Ferdous, J., Rahman, M.T.U. and Ghosh, S.K. (2019). Detection of Total Dissolved Solids from Landsat 8 oli image in coastal Bangladesh. *Proceedings of the International conference on climate change*, 3(1).

Forest Survey of India. (2019). Indian State of Forest Report. Ministry of Forest.

Gadgil, A. (1998). Drinking water in developing countries. *Annual review of energy and the environment*, 23: 253-286.

Gao, Y., Qian, H., Ren, W., Wang, H., Liu, F. and Yang, F. (2020). Hydrogeochemical characterization and quality assessment of groundwater based on integrated-weight water quality index in a concentrated urban area. *Journal of Cleaner Production*, 260: 121006.

Gbedzi, D.D., Ofosu, E.A., Morty, E.M., Yeboah, A.O., Nyantakyi, E.K., Siabi, E.K., Abdallah, F., Domfeh, M.K. and Minkah, A.A. (2022). Impact of mining on land use land cover change and water quality in the Asutifi North District of Ghana, West Africa. *Environmental Challenges,* 6: 100441.

Gong, X., Chen, Z. and Luo, Z. (2014). Spatial distribution, temporal variation, and sources of heavy metal pollution in groundwater of a century-old nonferrous metal mining and smelting area in China. *Environ Monit Assess*, 186: 9101–9116.

Goswami, R., Neog, N., Bhagat, C., Hdeib, R., Mahlknecht, J. and Kumar, M. (2022). Arsenic in the groundwater of the Upper Brahmaputra Floodplain, variability, health risks and potential impacts. *Chemosphere,* 306.

Gowd, M. R. and Shivasharanapa, G. (2018). Studies on the physicochemical characteristics of groundwater of Gurmitkal town Karnataka, India and mapping by GIS method. *International Research Journal of Engineering and Technology,* 05(07): 1169-1173.

Gray, N.F. (1994). Drinking Water Quality: Problems and Solutions, McGraw Hill, New York, 118-130.

Grizzetti, B., Bouraoui, F. and Aloe, A. (2012). Changes of nitrogen and phosphorus loads to European seas. *Glob. Chang. Biol*, 18 (2): 769-782

Gunduz, O., Simsek, C. and Hasozbek, A. (2010). Arsenic pollution in the groundwater of Simav Plain, Turkey: its impact on water quality and human health. *Water and soil pollution*, 205: 43-62.

Gunduz, O., Simsek, C. and Hasozbek, A. (2010). Arsenic pollution in the groundwater of Simav plain, Turkey: Its impact on water quality and human health. *Water Air Soil Pollution,* 205: 43-62.

Gupta, A. and Singh, E.J. (2019). Arsenic-Iron relationship in aquifers of North-east India: Implications for public health and the environment. *Environmental Management*, 63(4): 437-443.

Haloi N. and Sharma, H.P. (2012). Heavy metal contaminations in the groundwater of Brahmaputra flood plain: as an assessment of water quality in Barpeta District, Assam, India. *Environmental monitoring and assessment*, 184(10): 6229-6237.

Hamutoko, J. T., Wanke H. and Voigt, H. J. (2016). Estimation of groundwater vulnerability to pollution based on drastic in the Niipele, sub-basin of the Cuvelai Etosha Basin, Namibia. *Physics and Chemistry of the earth,* 96:46-54.

Hanse, A., Chabukdhara, M., Baruah, S.G., Boruah, H. and Gupta, S.K. (2019). Fluoride contamination in groundwater and associated health risks in Karbi Anglong district, Assam, Northeast, India. *Environ monit assess,* 191(782).

Hart, M. R., Quin, B. F. and Nguyen, M. L. (2010). Phosphorus Runoff from Agricultural Land and Direct Fertilizer Effects. *J. Environ. Qual,* 33: 1954.

Hassan, M.U., Chattha, M.U., Khan, I., Chattha, M. B., Aamer, M., Ali, M.N.A., Khan, M.A.U. and Khan, T.A. (2019). Nickel toxicity in plants: reasons, toxic effects, tolerance mechanisms, and remediation possibilities—a review. *Environ Sci Pollut Res*, 26: 12673–12688.

Hassanzadeh, R., Abbasnejad, A. and Hamzeh, M.A. (2011). Assessment of Groundwater Pollution in Kerman Urban Areas. *Journal of Environmental Studies*, 36(56).

Hazarika, S. and Bhuyan, B. (2013). Assessment of Groundwater Quality with Reference to Fluoride, Arsenic and Iron in Tea Garden Belt of Lakhimpur district, Assam, India. *Pelagia Research Library Advances in Applied Science Research*, 4(2):93-97.

Hebbar, A. and Janardhan, M.R. (2016). Arsenic contamination in groundwater of the areas surrounding Ingaldhal, Chitradurga district, Karnataka state. *Int J Geol Agric Environ Sci*, 6:1–7.

Hnamte, *V.* (2007). Water quality analysis of various spring around eastern part of Aizawl, Mizoram, *M.Sc. dissertation submitted in Department of Geology,* Mizoram University.

Hnamte, V. (2013). Economics of public water supply in Mizoram (A case study of Aizawl water supply scheme). *Adissertation submitted in partial fulfilment of master of philosophy in Economics, Mizoram University*.

Holman, I., Whelan, M., Howden, N.J.K. and Bellamy, P.H. (2008). Phosphorus in Groundwater—An Overlooked Contributor to Eutrophication? *Hydrological Processes,* 22(26): 5121 – 5127.

Hoque, A., Hossen, M.A., Islam M.F. and Mahmud, M.I.U. (2019). Seasonal variation of salinity of ground water at Patenga area of Chittagong district in Bangladesh. *Progressive Agriculture*, 30(1): 65-70.

Hossain, D., Islam, M.S., Sultana, N. and Tusher, T.R. (2015). Assessment of Iron Contamination in Groundwater at Tangail Municipality, Bangladesh. *Journal of Environmental Science and Natural Resources,* 6(1).

Hozi, S. H., Khatounabadi, S. A., Dodangeh, E., Eslamion, S., Askari, K. O. A., Singh, V. P. and Dalezios, N.R. (2018). Investigating of the most important reasons of consumed exploitation of Groundwater's sources, Ardakan- plain case Study, Yazd, Iran. *International Journal of Emerging Engineering Research and Technology,* (10): 1-6.

Hussain, S., Ghouri, A.S. and Ahmad, A. (2019). Pine cone extract as natural coagulant for purification of turbid water. *Heliyon*, 5 (3).

Hussain, S., Rehman, M. H. U., Khanam, K., Sheer, A., Kebin, Z. and Jianjun, Y. (2019). Health risk assessment of different of different heavy metals dissolved in drinking water. *International Journal of Environmental Research and public health*, 16(10):1737-1750.

Idrees, N., Tabassum, B., Allah, E. F. A., Hashem, A., Sarah, R. and Hashem, M. (2018). Groundwater contamination with cadmium concentrations in some west U. P. Regions, India. *Saudi Journal of Biological Sciences,* 25:1365-1368.

Inam, E., Elim, U. J. and Offiong, N. O. (2014). Assessment of Human Health Risk associated with the presence of trace metals in groundwater supplies in Akwa Ibom State, Nigeria. *World Journal of applied science and Technology*, 6(1):55-65.

Indian Express-(2014) Mizoram: Almost 2,500 new cancer patients, more 1,300 deaths in last two years. Indian Express, 7 November, 2014 (http://indianexpress.com/article/india/india-others/mizoram-almost-2500-new-cancer-patients-more-than-1300-deaths-in-last-two-years/); Accessed 11-2-2017

Islam, F. F., Choudhury, N., Saikuai, J. and Dey, Y. (2014). Quality analysis of Groundwater in greater Guwahati. *Journal of Civil Engineering and Environmental Technology,* 1(4): 40-44.

Islam, M.M., Karim, M.R., Zheng, X. and Li, X. (2018). Heavy Metal and Metalloid Pollution of Soil, Water and Foods in Bangladesh: A Critical Review. *Int. J. Environ. Res. Public Health,* 15(12): 2825.

Ismanto, A., Hadibarata, T., Widada, S., Indrayanti, E., Ismunarti, D.H., Satinatunnajah, N., Kusumastuti, W., Dwiningsih, Y. and Alkahtani, J. (2023). Groundwater contamination status in Malaysia: level of heavy metal, source, health impact, and remediation technologies. *Bioprocess and Biosystems Engineering*, 46: 467-482.

Jain, C.K., Sanjay, K., Sharma, S.K. and Singh, S. (2021). Assessment of groundwater quality and determination of hydrochemical evolution of groundwater in Shillong, Meghalaya India. *Appl. Sci*, 3:33.

Jamshaid, M., Khan, A.A., Ahmed, K. and Saleem, M. (2018). Heavy metal in drinking water and its effect on Human health and its treatment techniques – a review. *International Journal ofBiosciences*,12(4) :223-240.

Jaudon, P., Massiani, C., Galea, J., Rey, J. and Vacelet, E. (1989). Groundwater pollution by manganese. Manganese speciation: Application to the selection and discussion of an in-situ groundwater treatment. *Science of The Total Environment*, (84):169-183.

Jesus, E.D., Cruz, P.V., Pacifino, J.A. and Silva, A.S. (2013). Removal of Turbidity, Suspended Solids and Ions of Fe from Aqueous Solution using Okra Powder by Coagulation-Flocculation Process. *American Journal of Water Resources*, 1(3): 20-23.

Joode, B.W.J., Barbeau, B., Bouchard, M.F., Mora, A. M., Skytt, A., Córdoba,L., Quesada,R., Lundh, T., Lindh, C.H. and Mergler, D. (2016). Manganese concentrations in drinking water from villages near banana plantations with aerial mancozeb spraying in Costa Rica: Results from the Infants. *Environmental Health Study*, 215: 247-257.

Kacaroglu, F. and Gunay, G. (1997). Impacts of human activities on groundwater quality of an alluvial aquifer: A case study of the Eskisehir plain, Turkey. *Hydrogeology Journal*, 5(4): 60-70.

Kale, V.S. (2016). Consequence of Temperature, pH, Turbidity and Dissolved Oxygen Water Quality Parameters. International Advanced Research. *Journal in Science, Engineering and Technology*, 3(8).

Kamal, B., Paruany, A., Ali, A. J. A., Hussain, K. I., Khalaf, H. S. and Alias, M. F. (2018). Assessment of heavy metals in some groundwater wells at Baghdad City/Iraq. *Journal of Global Pharma Technology*, 10(03): 62-70.

Kana, A.A. (2022). Heavy metal assessment of groundwater quality in part of Karu, Central Nigeria. *Water practice and technology,* 17 (9): 1802-1817.

Kanungo, T. D. (2016). Seasonal variations of groundwater arsenic at Silchar, Assam and its correlation with the flood plains and landfill area. *Current science*, 111(10): 1680-1686.

Karunanidhi, D., Aravinthasamy, P., Deepali, M., Subramani, T. and Shankar, K. (2021). Ground water pollution and human health risks in an industrialized region of south India: Impacts of the COVID-19 Lockdown and the monsoon cycles. *Arch Environ Contam Toxicol*, 80(1):259-276.

Kashyap, R., Verma, K, S., Sanjay, K., Uniyal. and Bhardwaj, S. K. (2018). Geospatial distribution of metal(oid)s and human health risk assessment due to intake of contaminated groundwater around an industrial hub of northern India. *Environmental monitoring and assessment*, 190: 136.

Kayastha, V., Patel, J., Kathrani, N., Varjani, S., Bilal, M., Show, P.L., Kim, S.H., Bontempi ,E., Bhatia, S.K. and Bui, X.T. (2022). New Insights in factors affecting ground water quality with focus on health risk assessment and remediation techniques. *Environmental Research,* 212(A):113171.

Khairy, H. and Janardhana, M. K. (2016). Impact of the geological setting and anthropogenic activities on groundwater salinization: A case study on semi-confined coastal aquifer in Mazandaran Province, Northern Iran. *Indian society of applied Geochemist*, 18(2): 203-214.

Khajuria, A. (2016). Impact of Nitrate Consumption: Case Study of Punjab, India. *Journal of Water Resource and Protection*, 8: 211-216.

Khalid, S., Shahid, M., Natasha., Shah, A. H., Saeed, F., Ali, M., Qaisrani, S.A. and Dumat, C. (2020). Heavy metal contamination and exposure risk assessment via drinking groundwater in Vehari, Pakistan. *Environ Sci Pollut Res,* 27: 39852–39864.

Khan, K., Factor-litvak, P., Wasserman, G.A., Liu, X., Ahmed, E., Parvez, F., Slavkovich, V., Levy, D., Mey, J., Geen, A.V. and Graziano, J.H. (2014). Manganese exposure from drinking water and children' s classroom behavior in Bangladesh. *Environ. Heal. Perspect*, 119: 1501-1506.

Khan, M.U. and Rai, N. (2022). Arsenic and selected heavy metal enrichment and its health risk assessment in groundwater of Haridwar district, Uttarakhand, India. *Environmental Earth Sciences,* 81(337).

Khanna, R. and Gupta. (2018). Agrochemicals as a potential cause of groundwater pollution; A review. *International Journal of Chemical studies.* 6(3): 985-990.

Kiran, K. (2012). Spectrophotometric Determination of Zinc in Water Samples Using 3-Hydroxybenzylaminobenzoic Acid. *Chem Sci Trans,* 1(3): 669-673.

Koh, EH., Lee, S.H., Kaown, D., Moon, H.S., Lee, E., Lee, K.K. and Kang, B.R. (2017). Impacts of land use change and groundwater management on long-term nitrate-nitrogen and chloride trends in groundwater of Jeju Island, Korea. *Environ Earth Sci,* 76(176).

Konapala, G., Mishra, A.K., Wada, Y. and Mann, M.E. (2020). Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. *Nat Commun,* 11: 3044.

Kousa, A., Komulainen, H., Hatakka, T., Backman, B. and Hartikainen, S. (2021). Variation in groundwater manganese in Finland. *Environ Geochem Health,* 43:1193-111.

Krishan, G., Ghosh, S. and Virk, H.S. (2023). Arsenic pollution and associated human health hazards in Rupnagar district, Punjab, India. *Environ Sci Pollut Res Int,* doi: 10.1007/s11356-023-27247-z.

Krishnan, G., Rao, M. S. and Singh, S. (2016). Water quality of groundwater in different geomorphological units in Bist-Doab, Punjab, India. *The Research Journal,* 2(2): 1-4.

Kumar, A., Rahman, M., Iqubal, M., Ali, M., Niraj, P.K., Anand, G., Kumar, P., Abhinav. and Ghosh, A. K. (2016). Ground water arsenic contamination: A local survey in India. *Int J Prev Med*, 7(100).

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

Kumar, C.P. (2013). Assessment and strategies for development potential of deeper confined aquifers in India. *Asian Academic Research Journal of Multidisciplinaryl*, 1(8): 247-258.

Kumar, L. and Singh, S. K. (2015). Removal of chloride from ground water by Bio adsorption. *International Journal of Advanced Research*, 3 (5): 140-154.

Kumar, N. and Sinha, D. K. (2018). Seasonal variation of Iron in underground drinking water source in and around Moradabad City, Uttar Pradesh, India. *International Journal of Applied Engineering Research,* 13(13):11062-11068.

Kumar, R., Singh, S., Kumar, R. and Sharma, P. (2022). Groundwater Quality Characterization for Safe Drinking Water Supply in Sheikhpura District of Bihar, India: A Geospatial Approach. *Front. Water*, 24(4).

Kumar, S., Bharti, V.K., Singh, K.B. and Singh, T.N. (2009). Quality assessment of potable water in the town of Kolasib, Mizoram (India). *Environmental Earth Science*, 61(1): 115-121.

Kumar, S., Toppo, S., Kumar, A., Tewari, G., Beck, A., Bachan, V. and Singh, T. B. N. (2020). Assessment of heavy metal pollution in the groundwater of industrial area: a case study from Ramgarh, Jharkhand, India. *International Journal of Environmental Analytical Chemistry*, 102(18): 7290-7312.

Kumar, V., Bharti, P.K., Talwar, M., Tyagi, A.K. and Kumar, P. (2017). Studies on high iron content in water resources of Moradabad district (UP), India. *Water Science*, 31(1): 44-51.

Kurwadkar, S. (2019). Occurrence and distribution of organic and inorganic pollutants in groundwater. *Water Environment Research*, 1-8.

Lalbiakmawia, F. and Kumar, S. (2022). Chapter 2 - Status of hydrogeochemistry of water quality in Mizoram: A review. *Current Directions in Water Scarcity Research*, 5:19-26.

Lalbiakmawia, F., Bhavati, V.K. and Kumar, S. (2020). Assessment of seasonal variation of groundwater quality in the northern arcuate of Mizoram, India using geo-spatial technology. *Journal of Geomatics,* 14(1).

Lalchhingpuii. (2011). Status of water Quality of Tlawng River in the vicinity of Aizawl city, Mizoram, *A Ph.D. thesis submitted to Environmental Science, Department of Environmental Science, Mizoram University, India.*

Lalchhuanawma, H.C. (2016). Urban water services and service level benchmark standards in Aizawl Municipal area. *Senhri Journal of Multi-disciplinary Studies (A National Refereed Journal),* 1 (1) :65-77.

Lalchhuanawma, S. (2011). Comparative study of quality of surface water and groundwater in southern part of Aizawl City. *M.Sc. dissertation submitted in Department of Environmental Science, Mizoram University, India*.

Laldinpuii, H. and Mishra, B. P. (2019). Assessment of the chemical characteristics of river Serlui-A in Aizawl, Mizoram, North East, India. *Environment and Ecology*, 37(4) :1141-1146.

Laldintluanga, H., Lalbiakmawia, F. and Lalbiaknungi, R. (2016). Assessment of Rural Water Quality in Aizawl, Mamit and Serchhip District of Mizoram, India. *International Journal of Science Technology & Engineering*, 3(6):111-118.

Lalthazuala, L., Lalhmunsiama, L., Chhakchhuak, V., Tiwari, D., Soon, C.S. and Mok, L.S. (2022). Newer Insights on Ferrate (VI) Reactions with Various Water Pollutants: A Review. *Applied Chemistry for Engineering*, 33(3): 258-271.

Lamare, R.E. and Singh, O.P. (2016). Limestone mining and its environmental implications in Meghalaya, India. Department of environmental studies, North eastern hill university, Shillong-793022, Meghalaya, India. *ENVIS Bulletin Himalayan ecology,* 24.

Laskar, N., Singh, U., Kumar, R. and Meena, S.K. (2022). Spring water quality and assessment of associated health risks around the urban Tuirial landfill site in Aizawl, Mizoram, India. *Groundwater for Sustainable Development*, 17(100726).

Laskar, N., Singh, U., Kumar, R. and Meena, S.K. (2022). Spring water quality and assessment of associated health risks around the urban Tuirial landfill site in Aizawl, Mizoram, India. *Groundwater for Sustainable Development*, 17(1–2):100726.

Li, D., Xu, X., Li, Z., Wang, T. and Wang, C. (2020). Detection methods of ammonia nitrogen in water: A review. *TrAC Trends in Analytical Chemistry*, 127:115890.

Li, P., Karunanidhi, D., Subramani, T. and Srinivasamoorthy, I. (2021). Sources and Consequences of Groundwater Contamination. *Arch Environ Contam Toxicol*, 80; 1-10.

Li, P., Tian, R., Xue, C. and Wu, J. (2017). Progress, opportunities and key fields for groundwater quality research under the impacts of human activities in China with a special focus on Western China. *Environmental Science and Pollution Research*, 24: 13224-13234.

Li, Y., Xu, X. Z., Ma, H. and Hursthouse, A. S. (2019). Removal of Manganese (II) from Acid Mine Wastewater: A Review of the Challenges and Opportunities with Special Emphasis on Mn-Oxidizing Bacteria and Microalgae. *Water*, 11(12): 2493.

Lin, T.Y., Wei, C.C., Huang, C.W., Chang, C.H., Hsu, F.L. and Liao, V.H.C. (2016). Both Phosphorus Fertilizers and Indigenous Bacteria Enhance Arsenic

Release into Groundwater in Arsenic-Contaminated Aquifers. *J. Agric. Food Chem*, 64 (11): 2214–2222.

Liu, Y., Zhang, R., Sun, Z., Shen, Q., Li, Y., Wang, Y., Xia, S., Zhao, J. and Wang, X. (2021). Remediation of artificially contaminated soil and groundwater with copper using hydroxyapatite/calcium silicate hydrate recovered from phosphorus-rich wastewater. *Environmental Pollution*, 272:115978.

Lodh, R., Paul, R., Karmakar, B. and Das, M. K. (2014). Physico-Chemical studies of water quality with special reference to ancient lakes of Udaipur City, Tripura, India. *International Journal of Scientific and Research Publications,* 4(6):1-9.

Luu, L. (2019). Remarks on the current quality of groundwater in Vietnam. *Environmental science and pollution research*, 26(2): 1163-1169.

Maanan, M., Saddik, M., Maanan, M., Chaibi, M., Assobhei, O. and Zourarah, B. (2015). Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. *Ecological Indicators,* 48: 616-626.

Magesh, N.S., Krishnakumar, S., Chandrasekar, N. and Soundranayagam, J. P. (2013) Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India. *Arab J Geosci*, 6 (11): 4179–4189.

Mairizki, F. and Cahyaningsih, C. (2016). Groundwater Quality Analysis in the Coastal of Bengkalis City Using Geochemistry Approach. *Journal of dynamics*, 1(2).

Majumder, A. and Sivaramakrishnan, L. (2014) Groundwater budgeting in alluvial Damodar fan delta: A study in semi-critical Pandua block of West Bengal, India. *International Journal of Geology, Earth & Environmental Sciences,* 4(3): 23-37.

Makwe, E. and Chup, C. (2013). Seasonal variation in physico-chemical properties of groundwater around Karu abattoir. *Ethiopian Journal of Environmental Studies and Management*, 6(5).

Malassa, H., Hadidoun, M., Khatib, M. A., Rimawi, F. A. and Qutob, M. A. (2014). Assessment of groundwater pollution with heavy metals in North West Bank/Palestine by ICP-MS. *Journal of Environmental Protection*, 5: 54-59.

Malsawma, V.L. (2005). Hydrological studies of western Aizawl with special reference to Surface and sub-surface water resource development, Mizoram, India. *An M.Sc Dissertation submitted in Department of Geology, Mizoram University, India.*

Manikandan, E., Rajmohan, N. and Anbazhagan, S. (2020). Monsoon impact on groundwater chemistry and geochemical process in the shallow hard rock aquifer. *Catena*, 195: 104766.

Mazumder, D. N. G., Ghosh, A.K., Majumdar, K.K., Mukherjee, S. and Majumder, P.K. (2020). Ground Water Arsenic Contamination in Malda, West Bengal, India: Epidemiology and Efficacy of Mitigation Measures. *Int J Med. Public Health*, 10(1):34-37.

McDaris, J.R., Feinberg, J.M., Runkel, A.C., Levine, J., Kasahara, S. and Alexander Jr, E.C. (2022). Documentation and Prediction of Increasing Groundwater Chloride in the Twin Cities, Minnesota. *https://doi.org/10.1111/gwat.13227*

Megha, P. U., Kavya, P., Murugan, S. and Harikumar, P.S. (2015) Sanitation Mapping of Groundwater Contamination in a Rural Village of India. *Journal of Environmental Protection*, 6: 34-44.

Meinikmann, K., Hupfer, M. and Lewandowski, J. (2015). Phosphorus in groundwater discharge – A potential source for lake eutrophication. *Journal of Hydrology*, 524: 214-226.

Meinzer, O. E. (1934). The history and development of history and development of groundwater hydrology. *Journal of the Washington Academy of Sciences*, 24(1):6-32.

Menberg, K., Blum, P., Kurylyk, B. L. and Bayer, P. (2014). Observed groundwater temperature response to recent climate change. *Hydrol Earth Syst Sci,* 18: 4453–4466.

MIRSAC, (2012) Meteorological Data of Mizoram. Mizoram Remote Sensing.

Mishra, B.P. (2009) Status of the quality of spring water, the major source of drinking water in Mizoram, India*, Ecology Environment & Conservation, 15(1): 159-165.*

Mishra, V. (2014). Biosorption of zinc ion: a deep comprehension. *Appl Water Sci,* 4: 311–332.

Mishra, V.S. and Chandok, G.K. (2022). Evaluation of portability of different water sources at District Jabalpur, Madhya Pradesh. *Journal of Emerging Technologies and Innovative Research (JETIR),* 9(4).

Modoi, O. C., Roba, C., Torok, Z. and Ozunu, A. (2014). Environmental risks due to heavy metal pollution of water resulted from mining wastes in NW Romania. *Environment Engineering and Management Journal*, 13(9): 2325-2336.

Mohammad, A.H., Abdullat, G. and Alzughoul, K. (2017). Changes in Total Dissolved Solids Concentration during Infiltration through Soils (Rain, Fresh Groundwater and Treated Wastewater). *Journal of Environmental Protection*, 8(1).

Mora, A., Martinez, J.A.T., Capparelli, M.V., Zabala, A. and Mahlknecht, J. (2022). Effects of wastewater irrigation on groundwater quality: An overview. *Current Opinion in Environmental Science and Health,* 25: 100322.

Mukherji, I. and Singh, U.K. (2022). Environmental fate and healing exposures of the geogenic and anthropogenic contaminants in potable ground water of lower Ganga Basin in India. *Geoscience frontiers,* 13(3).

Naggar, A.E., Ahmed, N., Mosa, A., Niazi, N.K., Yousaf, B., Sharma, A., Sarkar, B., Cai, Y., Scott, X. and Chang, S.X. (2021). Nickel in soil and water: Sources, biogeochemistry, and remediation using biochar. *Journal of Hazardous Materials*, 419:126421.

Nahar, N. (2009). Causes and distribution of arsenic contamination in Bangladesh: Evidence from the literature. *Water Policy*, 11: 362-378.

Ngabirano, H., Byamugisha, D. and Ntambi, E. (2016). Effects of Seasonal Variations in Physical Parameters on Quality of Gravity Flow Water in Kyanamira Sub-County, Kabale District, Uganda. *Journal of Water Resource and Protection,* 8:13.

Nizam, K.H.S. and Zainuddin, N.S. (2023). Removal of Iron and Manganese in Groundwater Using Alum and Potassium Permanganate. *Advances in Science and Technology*, 127.

Noori, S.M.S., Ebrahimi, K. and Liaghat, A.M. (2014). Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer, Iran. *Environmental Earth Sciences*, 71: 3827–3843.

Noulas, C., Tziouvalekas, M. and Karyotis, T. (2018). Zinc in soils, water and food crops. *Journal of Trace Elements in Medicine and Biology*, 49: 252-260.

Nyirenda, K., Sichilima, S.N. and Mwale, B.L. (2019). Seasonal Variations of Nitrate and Phosphate Levels in Groundwater: A Case Study of Mpongwe Farming Block in Zambia. *Journal of Environment Protection and Sustainable Development,* 5(1): 7-13.

Oinam, J. D., Ramanatha, A. L., Linda, A. and Singh, G. (2011). A study of arsenic, iron and other dissolved ion variations in the Groundwater of Bishnupur District, Manipur, India. *Environmental Earth Science,* 62:1183-1195.

Olushola, M., Awoyemi., Albert, C., Achudume., Aderonke, A. and Okoya. (2014). The Physicochemical Quality of Groundwater inRelation to Surface Water Pollution in Majidun Area of Ikorodu, Lagos State, Nigeria. *American Journal of Water Resources*, 2(5): 126-133.

Otálora, M.C., Torres, A. W., Lara, C.R., Gómez Castaño, J.A.C. and Cifuentes GR (2023).. Evaluation of Turbidity and Color Removal in Water Treatment: A Comparative Study between Opuntia ficus-indica Fruit Peel Mucilage and FeCl3. *Polymers*, 15(1):217.

Pandey, N., Lehri, A., Mehrotra, S. and Srivastava, J.B. (2015). Arsenic pollution scenario in eastern UP. India: a review. *Int Res J Environ Sci*, 4:83–86.

Parihari, S., Chatterjee, D., Das, K. and Bhattacharya, R.K. (2023). Chapter 4- Role of groundwater potentiality and soil nutrient status on agricultural productivity: A case study in Paschim Medinipur District, West Bengal. *Case Studies in Geospatial Applications to Groundwater Resources.* 67-90.

Pathak, M. and Pathak, R. (2016). Arsenic Attenuation through Phytochemistry. *The NEHU Journal*, 15 (1): 131-142.

Patil, A., Patil, S. and Sathe, S. (2018) Water quality index of Belawale Khurd Reservoir of Kolhapur district (MH) (India). *J Ind Bot Soc*, 97 (1&2): 131—135.

Perera, N., Gharabaghi, B. and Howard, K. (2013). Groundwater chloride response in the Highland Creek watershed due to road salt application: A re-assessment after 20years. *Journal of Hydrology*, 479.

Pramanick, S. and Kuity, D.R. (2016). Relation between depth and quality of Groundwater sources, Raipur (C. G.). *Journal of Applied Geochemistry, 18*(1): 90-96.

Prasanth, S.V.S., Magesh, N.S., Jitheshlal, K.V., Chandrasekhar, N. and Ganghadar, K. (2012). Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. *Appl Water Sci,* 2: 165–175.

Prosun, T.A., Rahaman, M. S., Rikta, S.Y. and Rahman, M. A. (2018). Drinking water quality assessment from groundwater sources in Noakhali, Bangladesh. *International Journal of Development and Sustainability*, 7(5): 1676-1687.

Rahaman, M.S., Mise, N. and Ichihara, S. (2022). Arsenic contamination in food chain in Bangladesh: A review on health hazards, socioeconomic impacts and implications. *Hygiene and Environmental Health Advances*, 2(100004).

Rahimzadeh, M.R., Kazemi, S. and Moghadamnia, A.A. (2020). Zinc Poisoning - Symptoms, Causes, Treatments. *Mini Rev Med Chem*, 20(15):1489-1498.

Rahman, M.A.T.M.T., Paul, M., Bhoumik, N., Hassan, M., Alam, M.K. and Aktar, Z. (2020). Heavy metal pollution assessment in the groundwater of the Meghna Ghat industrial area, Bangladesh, by using water pollution indices approach. *Applied water science*, 10:186.

Rai, P.K. (2009). Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. *Critical Reviews in Environmental Science and Technology*, 39(9): 697–753.

Rai, P.K. (2012). An Eco-sustainable Green Approach for Heavy metals Management: Two Case Studies of Developing Industrial Region-Review. *Environmental Monitoring and Assessment*,184: 421–448.

Rai, P.K. (2021). Heavy metals and arsenic phytoremediation potential of invasive alien wetland plants Phragmites karka and Arundo donax: Water-Energy-Food (W-E-F) Nexus linked sustainability implications. *Bioresource Technology Reports*, (15):100741.

Rai, P.K., Lee, J., Kailasa, S., Kwon, E.E., Tsang, Y.F., Ok, Y. and Kim, J.H. (2018). A critical review of ferrate (VI)-based remediation of soil and groundwater. *Environmental Research (ELSEVIER)*, 160; 420-448.

Raju, N.J. (2012). Evaluation of Hydro-geochemical Processes in the Pleistocene Aquifers of Middle Ganga Plain, Uttar Pradesh, India. *Environmental Earth Sciences*, 65: 1291-1308.

Raju, P.A.R.K., Reddy M.S.R., Raghuram P., Babu, G.S., Rambabu, T. and Kumar, J.J. (2014). Alkalinity and Hardness Variation in Ground Waters of East Godavari District due to Aquaculture. *IJFAS*, 1(6): 121-127.

Ram, A., Tiwari, S.K., Pandey, H.K., Chaurasia, A.K., Singh, S. and Singh, Y.V. (2021). Groundwater quality assessment using water quality index (WQI) under GIS framework. *Appl Water* Sci, 11(46).

Ramaiah, V.G., Krishnaiah, S., Naik, M. and Shankara. (2014). Leachate Characterization and Assessment of Ground Water Pollution near MSW Dumpsite of Mavallipura, Bangalore. *Int. Journal of Engineering Research and Applications*, 4(1): 267-271.

Rao, G. V. R. S., Abbulu, Y. and Sreejani, T. P. (2017). WQI Based Studies on Groundwater quality at Andra University campus, Visakhapatnam. *International Journal of Science Technology and Engineering*, 3(09): 213-218.

Rezaee, M. and Ghazvini, P.T.M. (2022). Rapid and efficient determination of zinc in water samples by graphite furnace atomic absorption spectrometry after homogeneous liquid-liquid microextraction via flotation assistance. *Bull. Chem. Soc. Ethiop*, 36(1): 1-11.

Riedel, T. (2019). Temperature-associated changes in groundwater quality. *Journal of Hydrology,* 572: 206-212.

Rokade, V.M., Kundal, P. and Joshi A.K. (2004). Water resources Development Action plan for Sasti Watershed, Chadrapur District, Maharashtra using remote sensing and Geographic Information System. *Journal of the Indian Society of Remote Sensing,* 32(4): 359-368.

Roy, J.W. (2019). Endobenthic Organisms Exposed to Chronically High Chloride from Groundwater Discharging along Freshwater Urban Streams and Lakeshores. *Environ. Sci. Technol*, 53(16): 9389–9397.

Sahu B.K., Rao R.J., Behara, S.K. and Pandit, R.K. (2000). Effect of pollutants on the dissolved oxygen concentration of the river ganga at Kanpur, in pollution and bio monitoring of Indian rivers. *ABD publication, Jaipur, India,* 168-170.

Sako, A., Bamba, O. and Gordio, A. (2016). Hydrogeochemical processes controlling groundwater quality around Bombore gold mineralized zone, Central Burkina Faso. *Journal of Geochemical Exploration,* 170: 58-71.

Saleem, M., Hussain, A., Mahmood, G. and Dubey, S. (2016) Analysis of groundwater quality using water quality index: A case study of greater Noida (Region), Uttar Pradesh (U.P), India. *Cogent Engineering*, 3(1).

Samuel, O., John, N. and Federick, O. (2018). Physico-chemical studies of public hand-pump borehole water in Onueke, Ezza Local government area of Ebony; state, Nigeria. *American journal of quantum chemistry and molecular spectroscopy*, 2(2): 31-38.

Sangita, P., Ingole, S. and Tale. (2016). Review on Toxicity assessment for carcinogenic soil contaminants. *The Pharmaceutical and Chemical Journal,* 3(2):139-144.

Sankhla, M.I., Kumar, R. and Agrawal, P. (2018). Arsenic in water contamination and toxic effect on human health: current scenario of India. *Journal of Forensic Science and Criminal Investigation*, 10(2).

Sankhla, M.S. and Kumar, R. (2019). Contaminant of heavy metals in groundwater and its toxic effects on human health and environment. *Int Environ Sci Nat Res,* 18(5): 555996.

Sarala, C. and Babu, R. (2012). Assessment of Groundwater Quality Parameters in and around Jawaharnagar, Hyderabad. *International Journal of Scientific and Research Publications*, 2 (10).

Saravanakumar, K. and Kumar, R.R. (2011). Analysis of water quality parameters of groundwater near Ambattur industrial area, Tamil Nadu, India. *Ind. J. Sci. Technol*, 4(5):560-562.

Sarkar, A. and Shekhar, S. (2018). Iron contamination in the waters of Upper Yamuna basin. *Groundwater for Sustainable Development*, 7: 421-429.

Saurav, D., Sudipta, B.S., Jyoti, L.P., Madhumita, B., Yadav, R.N.S. and Mridul, C. (2015). Groundwater arsenic contamination in north-eastern states of India. *Journal of environmental research and development*, 9(03): 621-632.

Sawyer, C.H. (1960). Chemistry for Sanitary Engineers. Mc Graw Hill Book Co., New York.

Schaeperclaus, W., Kulow, H. and Schreckenbach, K. (1990). Fischkrankheiten, Berlin: Akademie-Verlag.

Selvakumar, S., Chandrasekar, N. and Kumar, G. (2017). Hydrogeochemical characteristics and groundwater contamination in the rapid urban development areas of Coimbatore, India. *Water Resources and Industry,* 17: 26-33.

Selvakumar, S., Ramkumar, K., Chandrasekar, N., Magesh, N. S. and Kaliraj, S. (2017). Groundwater quality and its suitability for drinking and irrigational use in the Southern Tiru chirappalli district, Tamil Nadu, India. *Appl Water Sci,* 7: 411–420.

Senarathna, D. D. T. T. D., Abeysooriya, K. H. D. N., Dunuweera, S. P., Ekanayake, B. P. K., Wijenayake, W. M. H. K. and Rajapakse, R. M. G.(2020). Removal of Phosphate from Aqueous Solutions Using Chemically Synthesized Vaterite Polymorph of Porous Calcium Carbonate Nanoparticles under Optimized Conditions. *Journal of Nanomaterials*, 2020.

Sengupta, P. (2013). Potential Health Impacts of Hard Water. *International journal of preventive medicine*, 4(8): 866–875.

Shaji, E., Santosh, M., Sarath, K.V., Prakash, P., Deepchand, V. and Divya, B.V. (2021). Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula. *Geoscience Frontiers,* 12(3):101079.

Shakoor, M. B., Bibi, I., Niazi, N. K., Shahid, M., Nawaz, M. F., Farooqi. A., Naidu, R., Rahman, M. M., Murtaza, G. and Luttge, A. (2018). The evaluation of

Arsenic contamination potential, speciation and hydrogeochemical behaviour in aquifers of Punjab, Pakistan. *Chemosphere*, 199:737-746.

Sharma, B.M., Becanova, J., Scheringear, M., Sharma, A., Bharat, G. K., Whitehead, P. G., Klanavo, J. and Nizetto. L. (2019). Health and ecological risk assessment of emerging contaminants (pharmaceuticals, personal care products, and artificial sweetness) in surface and groundwater (drinking water) in the Ganges River Basin, India. *Science of the total environment,* 646:1459-1467.

Sharma, V. and Singh, P. (2015). Heavy metal pollution and its effect on environment and human health, *International Journal of Recent Scientific Research*, 6(12): 7752-7755.

Shawky, H.A., Gwad, A.M.A., Bayomi, A.M. and Mottaleb, M.S.A.A. (2015). Removal of Ammonia and Phosphate from Water Resources using Free and Immobilized Microalgae. *International Journal of Environment*, 4(3): 193-203.

Shayannejad, M., Zadeh, Z. E., Tehrani, M. J., Zamani, N., Eslamian, S., Bazani, M. M., Singh, V. P., Kazemi, M., Askarik, O. A., Majidifar, Z. and Dastgerdi, H. R. S. (2017). Evaluation of groundwater quality for industrial using GIS in the mountainous region of Isfahan province, Isfahan, Iran. *International Journal of constructive research in civil Engineering*, 3(3): 24-37.

Shen, L.Q., Amatulli, G., Sethi, T., Raymond, P. and Domisch, S. (2020). Estimating nitrogen and phosphorus concentrations in streams and rivers, within a machine learning framework. *Sci Data,* 7: 161.

Shomar, B., Fakher, S. A. and Yahya, A. (2010). Assessment of Groundwater Quality in the Gaza Strip, Palestine Using GIS Mapping. *J. Water Resource and Protection*, 2: 93-104.

Shukla, A., Awasthi, S., Chauhan, R. and Srivastava, S. (2020). The Status of Arsenic Contamination in India. Arsenic in Drinking Water and Food. *Springer, Singapore*,1-12.

Shylla, L., Barik, S.K. and Joshi, S.R. (2020). Impact assessment of heavy metal contamination on water quality of underground and open-cast coal mines. *The NEHU Journal,* 18(2): 58-72.

Singh, A. K. (2006). Chemistry of arsenic in groundwater of Ganges-Brahmaputra River basin. *Current Science,* 91(5):599-606.

Singh, A., Patel, A.K., Deka, J. P., Das, A., Kumar, A. and Kumar, M. (2020). Prediction of Arsenic vulnerable zones in the groundwater environment of a rapidly urbanizing setup, Guwahati, India. *Geochemistry,* 80(4).

Singh, M., Tapadia, K., Jhariya, D. and Sahu, P. (2021). Evaluation of uranium containing ground water quality and non-carcinogenic risk assessment in inhabitant of Bijapur District of Chhattisgarh, Central India. *J Radio anal Nucl Chem*, 327: 939–947.

Singh, M.M. and Rai, P.K. (2016) Microcosm investigation of Fe (iron) removal using macrophytes of Ramsar lake: A phytoremediation approach; *International Journal of phytoremediation,* 18 (12): 1231-1236.

Singh, P., Tiwari, A. K. and Singh, P.K. (2015). Assessment of groundwater quality of Ranchi Township area, Jharkhand, India by using water quality index method. *International Journal of Chemtech Research*, 7(01): 73-79.

Singh, R. S., Gupta, A. K., Khanna, D. R., Mohan. U., Suhas., Singh, P., Bhutiani, R. and Tiagi, V. (2014). Physico-chemical investigation and quality assessment if groundwater(hand-pump) of Baghpat district, Uttar Pradesh, India. *International Journal of Research in Biosciences, agriculture, and technology,* 2(2):775-783.

Singh, S. and Hussian, A. (2016). Water quality index development for groundwater quality assessment of Greater Noida sub-basin, Uttar Pradesh, India. *Cogent Engineering*, 3:1.

Singh, U. K., Ramanathan, A. L. and Subramanian, V. (2018). Groundwater Chemistry and Human Health Risk Assesment in the Mining Region of East Singhbum, Jharkhand, India. *Chemosphere,* 204: 501-513.

Singhal, V. K., Anurag., Rathya, G. R. and Kumar, T. (2018). Arsenic concentration in drinking water of Ambagarh Chowki Block, Rajnandgaon (Chhattisgarh). *International Journal of Ethnical Studies,* 6(2):733-739.

Sirajudeen, J. and Pravinkumar, J. (2021). Heavy metal analysis of groundwater of Thirukoviloor, Villuppuram, Tamil Nadu, India. *Materials Today: Proceedings*, 36(4): 828-831.

Sirajudeen, J., Manikandan, S.A. and Manivel, V. (2013). Water quality index of ground water around Ampikapuram area near Uyyakondan channel Tiruchirappalli District, Tamil Nadu, India. *Arch Appl Sci Resear,* 5(3): 21–26.

Sirajudeen, J., Mohidheen, M.K. and Vahith, R. A. (2014). Physico-chemical contamination of groundwater in and around Tirunelveli district, Tamil Nadu. *Advances in Applied Science Research*, 5(2): 49-54.

Smith, A. H., Lingas, E. O. and Rahman M. (2000). Contamination of drinking water by arsenic in Bangladesh: A public health emergency. *Bulletin of the World Health Organization,* 78(9): 1093-1103.

Sridharan, M. and Nathan, D. S. (2018). Chemometric tool to study the mechanism of Arsenic contamination in groundwater of Puducherry region, South East coast of India. *Chemosphere*, 208: 303-315.

Stachnik, Ł., Korabiewski, B., Raczyk, J., Kopuch, M. and Wieczorec, M. (2020). Arsenic pollution in Quaternary sediments and water near a former gold mine. *Sci Rep*, 10: 18458.

Sudarshan, P., Mahesh, M. K. and Ramachandra, T. V. (2019). Assessment of Seasonal Variation in Water Quality and Water Quality Index (WQI) of Hebbal Lake, Bangalore, India. *Environment and Ecology,* 37 (1B): 309-317.

Sunar, S. and Mishra, B.P. (2016). Assessing the impact of Hydroelectric Power Projecton, the water quality of Serlui river in Kolasib district, Mizoram, North-East India. *International Research Journal of Environmental science*, 5(9): 40-44.

Suresh, B., Manjappa, S. and Puttaiah, E.T. (2011). Phytoplankton dynamics and seasonal variation in Tungabhadra River, India. *Int. J. Water Res. Environ. Eng*, 3(14): 370-379.

Swer, S. and Singh, O. P. (2004). Status of water quality in coal mining areas of Meghalaya, India. *Proceeding of National Seminar on Environmental Engineering with special reference on mining Environment, Indian Institute of Mines, Dhanbad,* 1-9.

Szymczyk, S. Pawluczuk, j. and Stepiery, A. (2010). Seasonal variability of mineral nitrogen in groundwater of hydrogenic soils. *Journal of Elementology,* 15(4).

Taouil, H., Ahmed, S.I., Assyry, A.E., Hajjaji, N. and Srhiri, A. (2014). Evaluation of metal pollution: Aluminum, Zinc, Iron and Copper of Tiykomiyne well water (East Morocco). *J. Mater. Environ. Sci*, 5 (1) :177-182.

Teta, C. and Hikwa, T. (2017). Heavy metal contamination of groundwater from an unlined landfill in Bulawayo, Zimbabwe. *Journal of health and pollution,* 7(15): 18-27.

Thakare, J. N. (2019). Importance of water management. *International Journal of Science and Research Publications, IJSRP*, 9(7).

Thasangzuala, Z. R. and Mishra, B. P. (2014). Physical characteristics of Public drinking water in Aizawl City, Mizoram, India. *International Journal of Engineering and Technical Research*, 2(10): 56-60.

Therdkiattikul, N., Ratpukdi, T., Kidkhunthod, P., Chanlek, N. and Ratpukdi, S.S. (2020). Manganese-contaminated groundwater treatment by novel bacterial isolates: kinetic study and mechanism analysis using synchrotron-based techniques. *Scientific Reports*, 10:13391.

Thomas, N.E., Khan, K.T., Di, B. and MacQuarrie, K. (1994). Temporal changes in manganese changes in fredricton, New Brunswick, aquifer. *Ground Water*, 32: 650-656.

Tiwari, A.K., Singh, P.K. and Singh, A.K. (2016). Estimation of heavy metal contamination in groundwater and development of a heavy metal pollution index by using GIS Technique. *Bulletin of Environmental Contamination and Toxicology*, 96: 508-515.

Tong, X., Tang, H., Gan, R., Li, Z., He, X. and Gu, S. (2022). Characteristics and Causes of Changing Groundwater Quality in the Boundary Line of the Middle and Lower Yellow River (Right Bank). *Water*, 14(12).

Triantafyllidou, S., Burkhardt, J., Tully, J., Cahalan, K., DeSantis, M., Lytle, D. and Schock, M. (2021). Variability and sampling of lead (Pb) in drinking water: Assessing potential human exposure depends on the sampling protocol. *Environment International*, 146:106259.

Ullah, R., Malik, R. N. and Qadir, A. (2009). Assessment of groundwater contamination in an industrial city, Sialkot, Pakistan. *African Journal of Environmental Science and Technology*, 3(12).

USEPA (1994) Water quality standards handbook: 2nd ed. EPA-823-B-94-005a, b. National Technical Information Service, Springfield, VA.

USEPA (2014) Drinking Water Contaminants. Available from: https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants. Accessed on 1 July 2016.

Verma, C., Madan, S. and Hussain, A. (2016). Heavy metal contamination of groundwater due to fly ash disposal of coal-fired thermal power plant, Parichha, Jhansi, India. *Cogent Engineering*, 3:1.

Vig, N., Ravindra, K. and Mor, S. (2022). Heavy metal pollution assessment of groundwater and associated health risks around coal thermal power plant, Punjab, India. *Int. J. Environ. Sci. Technol*, https://doi.org/10.1007/s13762-022-04284-8.

Vig, N., Ravindra, K. and Mor, S. (2023). Heavy metal pollution assessment of groundwater and associated health risks around coal thermal power plant, Punjab, India. *Int. J. Environ. Sci. Technol*, 20: 6259–6274.

Wakode, H. B., Baier. K., Jha, R. and Azzam. (2018). Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad India. *International Soil and Water Conservation Research*, 6: 51-62.

Walraven, N., Os, B.J.H.V., Klaver, G.T., Middelburg, J.J. and Davies, G.R. (2014). The lead (Pb) isotope signature, behaviour and fate of traffic-related lead pollution in roadside soils in The Netherlands. *Science of The Total Environment*, 472: 888-900.

Wang, L., He, Z. and Li, J. (2020). Assessing the land use type and environment factors affecting groundwater nitrogen in an arid oasis in northwestern China. *Environ Sci Pollut Res*, 27: 40061–40074.

Wang, L., Tao, Y., Su, B., Wang, L. and Liu, P. (2022). Environmental and Health Risks Posed by Heavy Metal Contamination of Groundwater in the Sunan Coal Mine, China. *Toxics*, 10(7): 390.

Wang, Z., Zhao, X., Xie, T., Wen, N. and Yao, J. A. (2021). Comprehensive Evaluation Model of Ammonia Pollution Trends in a Groundwater Source Area along a River in Residential Areas. *Water*, 13(14): 1924.

Warish., Masood, A., Ahmad, T. and Hasan, N. (2017). A case study of groundwater quality analysis surrounding Gurgaon canal (NCR Mewat). *International Research Journal of Engineering and Technology*, 04(06): 1800-1805.

Warrack, J., Kang, M. and Sperber, C.V. (2022). Groundwater phosphorus concentrations: global trends and links with agricultural and oil and gas activities. *Environ. Res. Lett*, 17: 014014.

Wei, L., Zhang, X., Dai, Y., Huang, J., Xie, Y.H. and Xiao, K. (2008). Online Preconcentration and Determination of Trace Amounts of Zinc in Nature Waters. *Journal of Analytical Methods in Chemistry*, 2008: 742319.

WHO, (2011). World Health Organization. Guidelines for Drinking-Water Quality, 4th ed.*; World Health Organization: Geneva, Switzerland,* 542.

Wilson, J.M., Wang, Y. and Van Briesen, J.M. (2014). Sources of High Total Dissolved Solids to Drinking Water Supply in Southwestern Pennsylvania. *Journal of Environmental Engineering*, 140(5).

World Health Organization 2004.

Wu, J. and Sun, Z. (2016). Evaluation of Shallow Groundwater Contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, Midwest, China. *Exposure and health*, 8(3): 31.

Wu, J., Li, P., Qian, H. and Chen, J. (2013). Groundwater Pollution in and Around a Paper Wastewater-Irrigated Area, Northwest China. *Fourth International Conference on Digital Manufacturing & Automation, Shinan, China*, 649-652.

Xia, X., Teng, Y. and Zhai, Y. (2022). Biogeochemistry of Iron Enrichment in Groundwater: An Indicator of Environmental Pollution and Its Management. *Sustainability,* 14: 7059.

Yabusaki, S. and Shibasaki. (2022). Seasonal Variation in Groundwater Quality Revealed by the Multi-tracer near the Coastal Area of Sendai, Japan. *Japan Soc. Hydrol and Water Resour*, 35(3): 192-201.

Yadav, J. J. and Sawant, P. T. (2016). Ground Water pollution in Sheri Nala Basin, Sangli District, Maharashtra, India and its impact on Health- A case study. *Journal of Applied Geochemistry,* 18(1): 76-89.

Yang, H., Wang, P., Chen, A., Ye, Y., Chen, Q., Cui, R. and Zhang, D. (2023). Prediction of phosphorus concentrations in shallow groundwater in intensive agricultural regions based on machine learning. *Chemosphere*, 313:137623.

Yatigammana, S., Perera, B. and Atukorala, N. (2014). Seasonal Water Quality Changes in Reservoirs in Different Climatic Regions of Sri Lanka. *Journal of Ecotechnology Research*, 17(1): 17-22.

Zhang, W., Kinniburgh, D. and Gabos, S. (2013) Assessment of Groundwater Quality in Alberta, Canada Using GIS Mapping. *Proceedings* of *3rd International Conf*, 199.

Zhou, X., Shen, Y., Zhang, H., Song, C., Li, J. and Liu, Y. (2015). Hydrochemistry of the natural low pH groundwater in the coastal aquifers near Beihai, China. *J. Ocean Univ. China,* 14: 475-483.

Zomuanpuii, R., Hmar, C.L., Lallawmzuala, K., Hlimpuia, L., Balabaskaran, N.P. and Senthil, N.K. (2020). Epidemiology of malaria and chloroquine resistance in Mizoram, northeastern India, a malaria-endemic region bordering Myanmar. *Malar J*, 19 (1): 95.

BIODATA

NAME	:	ZONUNTHARI
		DEPARTMENT OF ENVIRONMENTAL SCIENCE
		MIZORAM UNIVERSITY
CONTACT NO	:	9436146953
EMAIL-ID	:	zonunishan@gmail.com
TITLE OF THESIS	:	SEASONAL MONITORING OF GROUND WATER QUALITY IN AIZAWL CITY, MIZORAM
SUPERVISOR	:	Prof. P.K. RAI
		DEPARTMENT OF ENVIRONMENTAL SCIENCE
		MIZORAM UNIVERSITY

PAPER/POSTER PRESENTATION

1. Presented a poster entitled "Evaluation of ground water quality from selected handpumps in Aizawl city, Mizoram, India" in the international conference on recent advances in animal sciences held from 6^{th}-8^{th} November 2019 organized by Pachhunga University College, Aizawl, India.
2. Presented a paper entitled "Ground water Quality Monitoring and Assessment in Aizawl city, Mizoram, India" in the Third National Seminar on Natural Resources Management for Sustainable Development held during 7^{th}-8^{th} November, 2019, organized by the Department of Geography and Resource Management, School of Earth Sciences and Natural Resource Management, Mizoram University in collaboration with Geography Association of Mizoram.
3. Presented a paper entitled "Ground water quality Monitoring and assessment in Aizawl city, Mizoram, India" in the 12^{th}Annual Convention

of Biotechnology and Pharmacy (ABAP) and International Conference on Biodiversity, Environment and Human Health: Innovations and Emerging Trends (BEHIET 2018) organized at the School of Life Sciences, Mizoram University, Aizawl, Mizoram during 12th-14th November, 2018.

PAPER PUBLICATION

A. Journal articles

1. Zonunthari, Nongtri, E.S., Syngkli, R.B., Lalnuntluanga and Rai, P.K. (2023). Seasonal monitoring of ground water quality in Aizawl, Mizoram, Northeast India. *Applied Ecology and Environmental Sciences,* 11(3): 71-78.
2. Zonunthari, Lalawmpuii and Rai, P.K. (2023). Ground water quality monitoring and assessment in socioeconomically distinct Aizawl district, Mizoram, North-East India. *Indian Journal of Environmental Protection*, 43(9): 850-857.
3. Zonunthari, Nongtri, E.S., Lalnuntluanga and Rai, P.K. (2023). Spatio-temporal variations of physico-chemical characteristics and heavy metals in ground water of an Indo Burma hotspot region. *Indian Journal of Science and Technology,* 16(30): 1-8.
4. Zonunthari, Rai, P.K, Lalnuntluanga, Zirlianngura and Nongtri, E.S. (2023). Assessment Of Physico-chemical Characteristics and identification of ground water quality indicator parameters in Aizawl, Mizoram, North-East India. *Journal of Applied and Natural Science,* 15(4): 1572-1581.

B. Book Chapter

1. Zonunthari and Rai (2019). Ground water quality monitoring and assessment in Aizawl city, Mizoram, India. Natural Resource Management for Sustainable Development, 11-21, ISBN: 9788170196549.

PERSONAL DETAILS

Fathers name	:	Mr. Bawla
Mothers Name	:	Mrs. Lalkungi
Language	:	English, Mizo
Nationality	:	Indian

DECLARATION

I hereby declare that the above information is correct to the best of my knowledge

(ZONUNTHARI)

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	:	Zonunthari
DEGREE	:	Ph.D.
DEPARTMENT	:	Environmental Science
TITLE OF THESIS	:	Seasonal Monitoring of Ground water quality in Aizawl city, Mizoram.
DATE OF ADMISSION	:	10.08.2016.

APPROVAL OF RESEARCH PROPOSAL

1. DRC	:	27.03.2017
2. BOS	:	7.04.2017
3. SCHOOL BOARD	:	31.05.2017
4. MZU REGISTRATION NO	:	160076
5. Ph,D. REGISTRATION NO & DATE	:	MZU/Ph.D./1041 of 31.05.2017
6. EXTENSION	:	Extension up to 30. 05.2024 (No.16-2/MZU(Acad)/21/179-182) Dated 30th August, 2022

Head
Department of Environmental Science

ABSTRACT

SEASONAL MONITORING OF GROUND WATER QUALITY IN AIZAWL CITY, MIZORAM

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

ZONUNTHARI

MZU REGISTRATION NO.: 1600765

Ph. D REGISTRATION NO.: MZU/Ph.D./1041 of 31.05.2017

DEPARTMENT OF ENVIRONMENTAL SCIENCE

SCHOOL OF EARTH SCIENCE AND NATURAL RESOURCES MANAGEMENT

AUGUST, 2023

SEASONAL MONITORING OF GROUND WATER QUALITY IN AIZAWL CITY, MIZORAM

BY

ZONUNTHARI

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Prof. P.K. RAI

Supervisor

Department of Environmental Science

Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Environmental Science of Mizoram University, Aizawl.

Abstract

Water is a vital necessity for the functioning of an ecosystem and the whole biosphere of the planet. It is an integral component of environment required for various life processes and hence our persistence on the earth. It exists as water vapour in the air, ground water and surface water (oceans, lakes, glaciers, rivers) in the rock and soil though a systematic process called the hydrological cycle. It covers ¾ th of the earth's surface, causing our planet to be called the 'blue planet'. Water plays a big role in the life of all living organisms. It constitutes 70% of the human body and up to 50 % - 97% of animal bodies in terms of weight. Not only does it quench the thirst and water requirement of animal bodies, it is an essential raw material for the process of photosynthesis. Through plants manufacture food, for which all life forms depend on directly or indirectly. It is an indispensable part of daily human lives as it is mainly used for cleaning, drinking, washing, etc and is necessary for sanitation. It is used by industries for maintaining cleanliness, mixing and dyeing chemicals and for cooling machine.

Water has its own irreplaceable use in agriculture. This is mainly because of the need for irrigation of crops and normal garden plants which require water. This can be carried out in different ways such as drip irrigation, sprinkling irrigation, and canals. Besides irrigation, it is required for the application of fertilizers, pesticides, insecticides, and weedicides. In relation to vegetation, water is needed, especially in dry and arid regions where droughts occur most of the year. Water is needed for plants to grow, and roots of plants bind the soil, therefore, water indirectly helps in preventing soil erosion as well. Majority of forests types also depend upon the availability of water in the region, namely, tropical evergreen forests need abundant water resources, monsoon forests or deciduous forests with moderate water and rainfall, dry deciduous forest with irregular rainfall and water, and scrubs and deserts with minimal rainfall. Therefore, availability of water plays an important role in the type and distribution of flora found in the particular region.

Water is a much-needed resource in our modern heavy industries. Not only does water maintain sanitation, it helps to cool overheated machinery for better efficiency in production. Not only that, but water is also needed for washing raw

materials, especially those dependent on the primary sector. It is used for dying and mixing in textile industries and for chemical solvents in chemical and medical industries. Water is the basic need which guides the location of industries, and all livelihood, for that matter, as the very first civilizations were found in near rivers.

Surface water is water resource found on the earth's surface, received through precipitation such as rainfall or snowfall. It is easily recharged through precipitation and is thereafter lost through evaporation. The major components of are oceans, lakes, and rivers. Surface water resources can be either snow fed and perennial (Himalayan rivers) or rain fed and seasonal (peninsular rivers).

The term ground water is usually reserved for the sub-surface water that occurs beneath the water table in soils and geologic formation that are fully saturated. It is the water that seeps through the porous spaces in soil or crevices of rocks in the earth's crust to be stored in large aquifers. It is recharged through sub surface seepage into the ground and can be accessed through wells or tube wells dug into the ground. They may also come out naturally in the form of springs.

Ground water quality comprises the physical, chemical, and biological qualities of ground water. Temperature, turbidity, colour, taste and odour make up the list of physical water quality parameters. Since ground water resource is colourless, odourless and without specific taste, we are typically most concerned with its chemical and biological qualities. SDG 6, which is part of the United Nations' Sustainable Development Goals, focuses on ensuring the availability and sustainable management of water and sanitation for all.

Water, when in shortage, can lead to social problems, droughts and famines. Whereas water in excess can cause floods and unstable surroundings. Therefore, there rises a need for proper management of water. Water, when not managed properly, can remain stagnant in areas, becoming a very suitable breeding ground for pests, mosquitoes, bacteria and other undesirable pathogenic organisms. Pathogenic organisms may cause discomfort and various ailments, such as malaria, dengue, plagues, flu, etc. can also be a carrier of various water-borne diseases such as cholera, diarrhea, typhoid, and hepatitis. Pathogenic microbes can also lead to epidemics and, in worst case scenarios, even a pandemic. These undesirable events can cause the lives of many people and even harm the development in a country. For instance, the world has experienced seven major pandemics of cholera over the period of hundreds of years, killing millions of people each time (1817-1824, 1829-1837, 1846-1860, 1863-1875, 1881-1896, 1899-1923, 1961- ongoing). These pandemics generally started from the unhygienic slums of the Ganges and spread throughout the world.

Generally, about 97% of total water available on earth is locked away as saline ocean water and is not suitable for consumption. Only 3% of the remaining water is delineated as freshwater. However, 69% of the freshwater resides in glaciers and ice caps, 30% is found underground as ground water and less than 1% is available for human use. Fresh water has become a scarce commodity due to overexploitation and pollution of water resulting from rapid industrialization and urbanization. Water, a vital necessity for life, has been degraded due to industrial impacts and domestic mismanagement

With rapid increase in population and industrial growth, ground water quality is increasingly being threatened by disposal of urban and industrial solid waste. Open dumping is the most common way to dispose municipal and industrial wastes. Inorganic pollutants e.g., heavy metals, which when present in higher concentrations than the permissible or prescribed limits, contaminate both soil and aquatic bodies pose serious threat to environment as well as human health. Since, less than one percent of fresh water is available for human use, its proper conservation and management is prerequisite for sustainable use.

Ground water is generally less susceptible to contamination and pollution when compared to surface water bodies. Also, the natural impurities in rainwater, which replenishes ground water systems, get removed while infiltrating through soil strata. But, in India, where ground water is intensively used for irrigation and industrial purposes, a variety of land and water based human activities are causing pollution of this precious resource. When pollutants are of a certain form or type, it is known as ground water contamination rather than pollution. This type of pollution can occur due to leakage in pipelines, sewers, and petrol stations. Untreated water from industries, effluents from wastewater, and sewage contribute significantly to the total ground water pollution. In agriculture, overuse of pesticides, insecticides, and fertilizers are also a major pollutant. Usage of such polluted ground water can cause hazards to public health and can even be the cause of various epidemics. Such pollutants can create contaminant plume, usually within an aquifer. When the ground water moves, it disperses such pollutants within the aquifer and contamination occurs over a wide area.

Ground water pollution not only affects the human health, but the whole of the connecting link of life, the ecosystem as well. Mainly used for nutrition by humans, livestock raised in farms also depend on ground water in most farming regions through wells, tube wells, and handpumps. The well-being of livestock is also at risk due to ground water pollution.

Since the population of Aizawl increased drastically in the last few decades, water scarcity became one of the main issues for the public. The tuikhurs are generally capable of supplying very small amounts of water, and are therefore generally not regarded as a source of public water supplies for large communities. The State Government implemented greater Aizawl water supply Scheme I and II in 1988 and 2007 respectively by lifting water using pumping machineries from River Tlawng which is one of the major rivers in Mizoram. The Government also installed many shallow handpump tubewells within Aizawl which are very useful in solving the water scarcity problem in the city even though the water quality is seriously doubtful due to unsanitization.

The study site Aizawl is the capital city of Mizoram which is situated on the top of a ridge running in north-south direction. It covers a total area of 3,576 sq.km. It is located in the northern part of Mizoram between N23^{o}43.076 to N23^{o}46.571 latitude and E92^{o}42.389 to E92^{o}44.448 longitude. The average altitude of Aizawl city is 1,132 meters from mean sea level (msl) and the population of the city according to 2011 census is 4,04,054 (male 2,01.072, female – 2,02,982).

The majority of research works on the water quality were conducted in developing countries. These studies focused on surface and borehole water quality with hardly any work being undertaken on shallow wells. In Aizawl City as well as in all the other towns and villages of Mizoram, public bore wells have been drilled and installed by the Public Health Engineering Department (PHED) of the State Government. It was done to meet the water requirements of the households in that area whereas borewell installation for private use is virtually not done till date.

In Aizawl city, the treated water is supplied through pipeline connections by the PHED which is not sufficient to meet the daily requirements of water for drinking and other household activities of the local people. Moreover, as river is the sole source of water for pipeline connections, the quantity supplied through thus connection is highly variable due to seasonality of rainfall and also due to technical difficulties which often occurred in the vast network of pipelines on the rough terrain of Aizawl City. Majority of the families are depending on secondary sources of water like rain water, tuikhur (water storage point fed by water seepages from rock strata), and hand pump tubewells installed by the State Government. In the proposed study area, most of the family which depend on hand pump tube wells as primary household water, consume it without any treatment or sanitization. As Mizoram State holds the population with one of the highest percentages of cancer patients in the world and Aizawl district tops all other districts in the country with highest incidence rates for cancer among both male (273.4:1, 00,000) and females (227.8:1, 00,000), it is crucial to conduct the assessment of the water quality in the Aizawl City (Indian Express, 2014). Henceforth, this work will help to assess the water quality for drinking purpose and also explain the source of contaminations, so that proper remedial measures can be explored. In the light of above-mentioned remarks, it is pertinent to investigate the ground water quality of Aizawl which concentrates most of the population of Mizoram.

Since ground water quality is inextricably linked with quality of life and health of people in Aizawl, present proposed work aims to investigate it seasonally with following objectives: i). To evaluate the ground water quality of selected sites in

Aizawl city. ii). To determine the metal content of ground water in the selected sites. iii). To formulate appropriate strategies for water quality management.

To fulfil the objectives of the present study, thirteen handpump water and one tap water sample for reference were selected for collection of water samples and analysis of water quality characteristics, Site 1 (Bawngkawn Handpump, near Hrangbana Petrol pump, site 2(Chaltlang Handpump, near Sericulture Office, site 3(Ramhlun South Handpump, near Ramhlun South Presbyterian Church), site 4 (Republic Vengthlang Handpump, near Republic Presbyterian Church), site 5 (Republic Vengchhak Handpump), site 6(Tuikual Handpump, near Coreens Bakery Industry), site 7 (Kanan Handpump, near Kanan Baptist Church of Mizoram), site 8 (Ramhlun South Hand pump, near Ramhlun south Baptist church), site 9 (Tap water, supplied by Mizoram PHED Sample was collected from Pollution Control Board Office), site10 (Bethlehem Hand-pump, near Bethlehem taxi stand), site 11 (Durtlang, near Govt Zirtiri Residential Science College), site 12 (Durtlang, near Durtlang Presbyterian Church), site 13 (Ramhlun North, near Ramhlun North Vegetable Market) and site 14 (Industry Peng, near Salvation Army Church).

Handpump and tubewell water samples were collected (in triplicate) from different localities of Aizawl City under five major zonations viz. Central, North, South, East and West part of Aizawl City on a monthly interval for two successive years i.e., from January, 2018 to December,2018, and January, 2019 to December, 2019. The geographical location of each sampling point was recorded using Global Positioning System (GPS). The various physicochemical characteristics viz., Turbidity, Total Dissolved Solids, Total Hardness, Total Alkalinity, Chloride, Calcium, Phosphate-P, Nitrite-N, N-Ammonia, Dissolved Oxygen (DO), were analysed during the said study period. Temperature and pH of the water samples were recorded at the sampling sites and samples were fixed at site for estimation of DO of water.

Estimation of certain metals like copper (Cu), lead (Pb), zinc (Zn), iron (Fe), Nickel (Ni), Manganese (Mn) and Arsenic (As). Ground water samples were acid digested as described elsewhere (APHA,2005; Singh and Rai, 2016). Samples were analysed with Shimadzu AA-7000, Atomic Absorption Spectrophotometer (AAS) which is available in Chemistry Department Laboratory, Mizoram University, Mizoram.

For the above quality parameters, the methods as described in "Standard Methods for the Examination of water and waste water" prescribed by the "American Public Health Association (APHA,2005)" has been adopted for analysis of water quality parameters.

The samples were tested and observed seasonally, i.e., in terms of pre-monsoon (February – May), monsoon (June – September) and post-monsoon (October – January). To check the validity and significance of the data observed during the study period, two-way analysis of variance (ANOVA) and Pearson correlation coefficient was also done.

The results in relation to the physico chemical characteristics of ground water samples were within permissible limits set by various scientific agencies except sites 2, 13 and 14 which exceeded the acceptable standard of turbidity during the year 2018, along with sites 2,3,4,5,6,7,11,13 and 14 which exceeded the standard during 2019. These exceeding observations were found mostly in the monsoon and post-monsoon seasons. This may be due to the overland flow of water during monsoon which can be potential contributor to the high level of turbidity. Sites 3, 5, 13 and 14 in pre-monsoon season and site 8 in post-monsoon season during 2019 and sites 13 and 14 in post-monsoon of 2018 exceeded permissible standard of ammonium. This can again be attributed to the high amount of precipitation in the monsoon season. In addition, all the sites have slightly exceeded the permissible limits of phosphate in the year 2018, and particularly in the post monsoon season, whereas in 2019, only few sites have exceeded the permissible limits. This may be due to the overland flow of water during monsoon which can percolate down to act as potential contributor of phosphate in ground water.

The heavy metal analysis was also found to be relatively safe and acceptable as fixed by regulatory scientific agencies, with a few exceptions. At site 7 in pre-monsoon season, iron (Fe) concentrations have exceeded the acceptable standards set by various scientific agencies. This can be attributed to the rusting of Fe used in the handpumps. Whereas, sites 13 and 14 during 2019 exceeded the permissible standards of manganese levels set by various regulatory agencies. The changes in climatic variables of the study area and rate of use of ground water, along with heavy rainfall can cause manganese levels to fluctuate.

In present study, observed results of Fe and Mn exceed safety standards that can be detrimental for the public health and require thorough investigation into its causes. Remedial measures are required for the management and control of water quality to ensure the safety and wellbeing of concerned people.\This can further be strengthened through the implementation of laws for disposal of wastes, implementation of water management plans, promoting rainwater harvesting and recharge of ground water, as well as constant monitoring of water source.

In the present water quality analysis, sanitized water by the PHE department was taken as a reference. A comparison was made between the tap water and ground water samples collected from different sampling sites. In relation to temperature and pH the degree of difference between tap water and ground water was minimal. On the contrary, TDS, chloride, total alkalinity, total hardness, DO and calcium levels of ground water samples from almost all the sites were found to be significantly higher than the tap water in all the seasons and study period. The $N\text{-}NO_2$, Zinc and Copper levels in the ground water and tap water samples were found to have only a slight difference in all the observed seasons. The levels of turbidity, $N\text{-}NH_3$, phosphate iron and manganese dissolved in ground water samples was found to be significantly higher than the levels found in tap water samples in all seasons.

In context of present study site, research and development efforts should be supported to find innovative solutions for ground water quality management. New technologies and methodologies (e.g., use of green chemicals and bioremediation) must be explored for contaminant removal and prevention. Water quality standards and regulations should be strictly enforced to regulate various contaminants in ground water. Furthermore, ground water recharge techniques and rainwater harvesting should be promoted to replenish the aquifers. This can help offset the depletion caused by excessive pumping and provide cleaner water through natural filtration. Proper waste management practices, including recycling and safe disposal of hazardous waste should be implemented. Small-scale enterprises in Aizawl should be encouraged to adopt cleaner production methods and treat their effluents before discharge.

A comprehensive long-term plan must be developed for sustainable ground water management in Aizawl to safeguard public health in long-term. This plan should be adaptive and consider the impact of climate change, population growth, and other factors on ground water quality. The public, community leaders, and stakeholders should be educated about the importance of ground water quality and its sustainable management. Community participation and cooperation should be encouraged in implementing the strategies.