ANALYSIS OF WATER QUALITY AROUND DUMPSITES USING GIS AND REGRESSION APPROACH

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PLAGIARISM

This work **ANALYSIS OF WATER QUALITY AROUND DUMPSITES USING GIS AND REGRESSION APPROACH** by Omoregbee Osadebamwen Emmanuel with number **ENG2002122** of the Department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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CERTIFICATION

This is to certify that this project work was carried out by **OMOREGBEE OSADEBAMWEN EMMANUEL** with Matriculation Number **ENG2002122** of the Department of Civil Engineering. It is adequate and satisfactory, both in scope and content, for the award of bachelor of civil Engineering (B.ENG) degree of the University of Benin

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PROJECT SUPERVISOR

DATE

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HEAD OF DEPARTMENT

DATE

DEDICATION

This project is dedicated to God Almighty for granting me the strength, wisdom, and guidance to successfully complete it and for His support throughout my time at the University of Benin (UNIBEN). I also dedicate this work to my parents, **Mr. and Mrs. Omoregbee,** as well as my siblings.

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ABSTRACT

This study investigates the environmental impact of the Ekosodin dumpsite in Benin City, Edo State, on surrounding groundwater quality, specifically addressing the risks of leachate infiltration. The research aim was to evaluate twenty-two physicochemical and microbial parameters across eight sampling locations to determine the spatial extent of contamination and assess the suitability of local water resources for domestic use. By benchmarking these parameters against World Health Organization (WHO) and Nigerian Industrial Standards (NIS), the study provides a comprehensive overview of how inadequate waste management practices threaten the availability of safe potable water for the community.

The methodology integrated systematic laboratory analysis with advanced geospatial modeling using ArcGIS 10.8. Groundwater samples were collected from eight borehole locations and analyzed for various physical, chemical, and biological properties, including heavy metals like Lead (Pb) and Cadmium (Cd). A Water Quality Index (WQI) was calculated for each site to classify water quality, while Inverse Distance Weighting (IDW) interpolation was applied to map the spatial distribution of pollutants. Furthermore, a Multiple Linear Regression (MLR) model was developed to quantify the relationship between five key parameters—including Electrical Conductivity (EC) and Iron (Fe)—and the calculated WQI, achieving a high predictive accuracy with an R^2 value of 0.9983.

Results revealed a significant degradation gradient, with WQI values ranging from 27.20% to 130.05% (and up to 945.24% in specific computations), indicating that boreholes closest to the dumpsite possess very poor water quality unsuitable for drinking. Spatial analysis confirmed the dumpsite as the primary source of elevated heavy metals and organic contaminants, though quality generally improves as the distance from the waste source increases. The study concludes that leachate from the Ekosodin dumpsite severely impairs groundwater safety, leading to the recommendation that future boreholes be sited at least 400 meters away from disposal areas. These findings emphasize the urgent need for modernized waste management strategies and continuous groundwater monitoring to protect public health and ensure a sustainable water supply.

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CHAPTER ONE

INTRODUCTION

1.1 Background of The Study

Rapid urbanization in major cities of developing countries, particularly those bordering water bodies, poses significant environmental challenges. These water bodies are being polluted by industrial and residential wastewater, as well as natural inputs, threatening the availability of clean water. To address this issue and ensure a reliable potable water supply, advanced water quality assessment techniques are needed to provide accurate data and support effective water management.

Water is the foundation of life, and freshwater is a precious resource. Despite covering 71% of the Earth, only 3% is freshwater, and a mere fraction – about 0.03% – is accessible for human use, making conservation and sustainable management crucial (Asadi et al., 2020). Freshwater is present as both surface water and groundwater, which we rely on for daily needs. However, surface water sources are dwindling due to poor management, urbanization, and frequent pollution, threatening their sustainability (Olajire A. and Imeokparia F, 2018). Groundwater has become the preferred freshwater source over surface water due to its reliability, renewability, and relative safety, making it a vital resource for meeting water demands (Gupta N, 2014).

Solid waste generation has emerged as a pressing global issue, posing significant threats to both environmental sustainability and public health (Akoteyon et al. 2021). Open dumping of solid waste poses serious health risks, particularly through groundwater contamination by leachate, which can have severe consequences for human health. (Kanmani and Gandhimathi, 2023). In Nigeria, municipal solid waste is often disposed of through open landfills. The waste composition is predominantly organic, with around 80% consisting of materials like food waste, paper, and plant and animal residues, while the remaining 20% is inorganic

(Narayana, T., 2019). Inorganic materials in municipal solid waste, such as electronic waste, plastic, and textiles, contribute to environmental degradation, polluting land and water resources and posing significant ecological risks (Concha et al., 2016).

Open landfills are often sited based on land availability, disregarding aesthetic, safety, and health concerns, which can lead to significant environmental and public health issues. (Sabahi et al., 2022). Consumption of groundwater contaminated by leachate from open landfills poses a significant risk to human health, highlighting the need for proper waste management practices. (Jhamnani and Singh, 2017). Open dumpsites can lead to heavy metals and toxic chemicals leaching into the environment, contaminating soil, groundwater, and surface water, and posing serious health and ecological risks (Mor et al., 2021). Rainwater percolating through solid waste in landfills is a primary mechanism for generating leachate, which can contaminate surrounding soil and water if not properly managed. Leachate from dumpsites contains a complex mixture of pollutants, including nutrients like ammonia and nitrogen, trace metals such as lead and chromium, and organic compounds like chloroform and benzene, posing significant environmental and health risks. (Freeze and Cherry, 2019). Leachate composition varies depending on waste type and landfill age, typically containing a complex mix of dissolved and suspended substances, including organic and inorganic pollutants (Naveen et al., 2015). Landfill leachate poses significant environmental risks due to its high concentrations of organic, inorganic, xenobiotic, and heavy metal pollutants, which can contaminate groundwater and harm ecosystems (Al-Yaquot, A., and Hamda M, 2023).

The solid waste placed in open dumps is subjected to infiltration from precipitation or underflow. During rainfall, solid waste in open landfills releases water and decomposition byproducts, contributing to leachate formation and potential environmental pollution. Leachate, a liquid containing various inorganic and organic compounds, accumulates at the landfill's bottom and can contaminate soil and groundwater as it percolates through. (Mor et al., 2021). Areas near open dumps or landfills are at high risk of groundwater contamination due to leachate's potential to pollute, posing significant environmental and health concerns. (Saarela, 2023). Groundwater contamination from landfill leachate poses significant risks to both local water users and the environment, highlighting the need for effective waste management strategies. (Moo-Young et al., 2024).

Leachate is generated when moisture infiltrates the waste in a landfill, triggering chemical and biological reactions that produce contaminated liquid. (Lo, 2016). When moisture enters the refuse in a landfill, it dissolves pollutants, creating a liquid flow known as leachate, which can contaminate soil and groundwater if not properly managed. Groundwater, a vital drinking water source, is highly vulnerable to contamination from leachate percolation in open dumps, posing significant risks to human health. (Ahmed and Sulaiman, 2021).

Various statistical methods, including regression modeling, are used to assess groundwater pollution from landfills. Software-based tools like Modflow, Phreeqe, MT3D, and GIS are also used for groundwater quality assessment and modeling, complementing numerical and analytical studies.

1.2 Statement of The Problem

The improper disposal of waste in open dumpsites poses significant environmental and health risks, particularly to groundwater resources (Ahmed and Sulaiman, 2021). Leachate generated from these dumpsites can percolate through the soil and contaminate groundwater, affecting its quality and posing risks to human health (Mor et al., 2021). The complexity of subsurface environments and variability of hydrogeological conditions make it challenging to accurately assess groundwater contamination. Therefore, this study aims to analyze the water quality around a dumpsite using a Geographic Information System (GIS) and a regression approach. By integrating GIS-based spatial analysis with regression modeling, the study seeks to assess the impact of dumpsite leachate on groundwater quality, identify potential pollution hotspots, and establish relationships between water quality parameters. The findings of this study will contribute to a better understanding of the environmental implications of open dumpsites and inform effective waste management strategies to mitigate groundwater pollution.

1.3 Aim and Objectives

The aim of this study is to assess the impact of dumpsite leachate on groundwater quality, using

GIS and regression analysis.

The objectives of the study include;

i. To determine the physico-chemical parameters of groundwater samples collected around the dumpsite.
ii. To calculate the Water Quality Index (WQI) and classify the groundwater quality at different locations around the dumpsite.
iii. To evaluate the suitability of the groundwater samples analyzed for drinking purposes and recommend necessary treatment measures to mitigate the impact of landfill contamination.
iv. To analyze the spatial distribution of WQI values using Inverse Distance Weighting (IDW).

v. To develop a simple linear regression model to predict the relationship between water quality parameters and dumpsite proximity, and estimate the impact of landfill contamination on groundwater quality.

1.4 Scope of The Study

The scope of the study will involve;

i. Water samples collection from different borehole locations around a selected dumpsite in Benin City, Edo State.
ii. Laboratory analysis of borehole water samples for various physical, chemical, and biological properties to determine the groundwater quality.
iii. Statistical analysis of the groundwater quality data using regression analysis.
iv. Spatial distribution and visualization of groundwater quality values using spatial techniques such as ArcGIS.

1.5 Justification of The Study

This study is significant for informing strategies to protect groundwater resources and mitigate public health risks in Benin City, Edo State, where rapid urbanization and inadequate waste management practices have led to environmental concerns. The following are the importance of this study:

1. The outcome of the study will contribute to understanding the impact of dumpsites on groundwater quality, informing strategies to protect this vital resource.
2. Through the identification of potential pollution areas and assessing groundwater suitability for drinking, the study will help mitigate health risks associated with contaminated water.
3. The results of the study will provide insights into the environmental implications of open dumpsites, supporting the development of effective waste management practices.
4. The research will contribute to a better understanding of the relationships between human activities (dumpsites) and environmental degradation (groundwater pollution), promoting sustainable practices.

5. The findings of the study will also provide valuable information for policymakers, regulatory agencies, and stakeholders in Benin City, Edo State, to develop evidence-based policies and guidelines for waste management and groundwater protection.

CHAPTER TWO

LITERATURE REVIEW

2.1 WATER AND ITS SIGNIFICANCE

2.1.1 WATER

Water is an important natural resource for human life (Ugwu et al., 2017). Rising population, economic growth, and industrialization have led to higher freshwater usage and poor management of this precious resource. This shows that progress in the population's way of life in terms of production and consumption has resulted in an exponential increase in household waste (Chaouki et al., 2021).

Water is a unique substance existing in gaseous, liquid, and solid phases, composed of hydrogen and oxygen. It's one of the most abundant and essential compounds on Earth, considered the most valuable natural resource (Pei-Yue et al., 2010). The Earth's surface is approximately 71% water, with oceans holding around 96.5% of it (National Oceanic and Atmospheric Administration, 2022). At standard temperatures, water is an odorless, tasteless liquid that can dissolve many compounds. It's vital for all known life forms and plays a significant role in shaping our world. Water is present on the surface, in the atmosphere, and in various bodies like oceans, lakes, and rivers. Beyond drinking, water resources support various economic sectors, including agriculture, industry, and hydropower. However, factors like population growth, industrialization, and urbanization have deteriorated water quality and availability (Tyagi et al., 2020). Water is a colorless, transparent, odorless chemical substance essential to life. Its chemical formula is H_2O, consisting of two hydrogen atoms bonded to one oxygen atom. Water exists in different states, including ice and water vapor, and undergoes a continuous cycle involving evaporation, condensation, and precipitation. About 71% of the Earth's surface is water, primarily in oceans, with smaller amounts in groundwater, ice caps, and vapor (Mishra, 2020). The need for clean water has driven research in water treatment, a crucial step in preventing waterborne illnesses (Ritter et al., 2014). Disinfection is an effective method to prevent pathogen spread in drinking water treatment, recommended for both surface and groundwater.

2.1.2 RELEVANCE OF WATER

Water is a fundamental resource essential for all forms of life on Earth. It plays a vital role in numerous aspects of our daily lives and has significant implications for various sectors and industries. Water's role in circulation is crucial, transporting, dissolving, and replenishing nutrients and organic matter, while also carrying away waste materials. In the human body, water regulates fluid functions, tissues, cells, lymph, blood, and glandular secretions. Even a small loss of water, as little as 2.7 liters, can lead to dehydration, causing symptoms such as irritability, fatigue, nervousness, dizziness, weakness, headaches, and potentially severe health issues.

Throughout evolution, from aquatic species to land-dwelling humans, the reliance on water for sustenance has remained constant. Water's vital role in the bodies of all living beings has persisted since life emerged in saltwater and adapted to freshwater environments. As life expanded beyond immediate access to water and ventured onto land, the need to develop a sophisticated system for preserving body water became imperative.

Fishing in saltwater and freshwater bodies is a major source of food for many areas worldwide. Much of long-distance trade of commodities, such as oil and natural gas, as well as manufactured products, is transported by boats through seas, rivers, lakes, and canals. A significant amount of water, ice, and steam is used for cooling and heating in industries and homes. Water is an excellent solvent for a wide variety of substances, including minerals and organics, making it widely used in industrial processes, cooking, and washing.

Additionally, water, ice, and snow are central to many sports and forms of entertainment, such as swimming, pleasure boating, boat racing, surfing, sport fishing, diving, ice skating, and skiing.

2.2 GROUNDWATER CONTAMINATION

Poor groundwater quality is attributed to the presence of pollutants (Custodio, 2014). Groundwater contamination occurs when pollutants are discharged into the earth and end up in groundwater. Human activities on the surface, such as improper sewage disposal and excessive use of pesticides, fertilizers, and animal manure, are primary causes of groundwater contamination (IAEA, 2023). This contamination can harm public health, leading to poisoning or the spread of waterborne diseases like diarrhea and cholera (Wolf et al., 2015).

Groundwater contamination can also result from naturally occurring toxins like arsenic and fluoride. While optimal fluoride levels in drinking water can prevent tooth decay, excessive exposure can cause adverse effects, including dental and skeletal fluorosis (WHO, 2022). Water plays a significant role in many severe and common diseases, with waterborne diseases strongly linked to their hydrological environment (World Health Organization, 2022). In developing nations, particularly in Africa, contaminated water sources pose significant public health risks, afflicting millions (United Nations Children's Fund, 2020). To address water quality issues, identifying the source of contaminants is a crucial first step (IAEA, 2023).

Figure 2.1 Sources of Groundwater Pollution (IAEA, 2023)

2.3 WATER QUALITY MONITORING

Water quality refers to the chemical, physical, biological, and radiological properties of water (Ajala et al., 2020). Numerous elements, such as industrial discharges, urban activities, agriculture, groundwater pumping, and waste disposal, can have an impact on groundwater quality. The primary source of water for consumption, agriculture, and industry is groundwater in many countries. For the welfare and development of humans, groundwater quality is crucial (Ravenscroft and Lytton, 2022).

Monitoring the quality of water involves collecting data on its physical, chemical, and biological properties outside of a laboratory setting. The conventional method of periodically sampling water can be expensive and offers only a limited understanding of its quality. Water monitoring programs have diverse objectives, including assessing environmental conditions, identifying violations in drinking water standards, analyzing temporary variations in water quality, and observing industrial wastewater discharge. Deterioration in water quality can have detrimental effects on human health, aquatic life, and ecosystems, underscoring the importance of early detection to minimize the impact or identify pollution sources. Detecting short-term pollution incidents, such as illegal dumping of toxic substances, is challenging through conventional sampling methods, making timely detection crucial for preventing further harm. The number of parameters to be monitored can vary, ranging from simple indicators to more complex parameters that require sophisticated measurement techniques.

2.4 WATER QUALITY PARAMETERS AND STANDARDS

Physical, Chemical, and biological characteristics are the three types of water quality metrics that are used to determine water quality (O'Donnell, 2021). These parameters are listed in table 2.1 below.

Table 2.1: Water Quality Parameters. (Source: O'Donnell, 2021)

S/N	PHYSICAL PARAMETERS	CHEMICAL PARAMETERS	BIOLOGICAL PARAMETERS
1	Turbidity	Ph	Heterotrophic Bacteria Count
2	Temperature	Acidity	Coliform Count
3	Color	Alkalinity	E.coil counts
4	Taste and Odour	Chloride	Tentative Isolatess
5	Solids	Hardness	
6	Electrical Conductivity	Dissolved Oxygen	
7		Sulphate	
8		Nitrogen	
9		Fluoride	
10		Iron and Manganese	
11		Copper and Zinc	
12		Biochemical Oxygen Demand	

Given the range of needs that applications may have, water quality metrics are important (O'Donnell, 2021).

2.4.1 PHYSICAL PARAMETERS

2.4.1.1 TURBIDITY

Turbidity is a metric used to assess a liquid's relative clarity. It is a measurement of the amount of light scattered by the components of water when light is shone through a water sample. It is an optical property of water. Turbidity is caused by particles dissolved and suspended in water that scatter light making the water appear cloudy (Peterson and Gunderson, 2008). It results from suspended elements in water, including clay, silt, organic matter, plankton, and other particle components. When evaluating the quality of the water, turbidity is a crucial component.

A sensor or turbidimeter used in nephelometry is used to measure turbidity directly (EPA, 2006).

Turbidity can have various effects. Some of which include:

i. High turbidity can negatively affect recreation and tourism by drastically reducing the aesthetic appeal of lakes and streams. (Peterson and Gunderson, 2008). ii. The growth and survival of aquatic plants and organisms can be hampered by turbidity, which can also result in a reduction in ecological productivity.
ii. It might make treating water for different purposes more expensive (Davis, 2010).
iii. To avoid being destroyed by the disinfection process, the particles may act as hiding places for harmful pathogens (Edzwald, 2011).

2.4.1.2 TEMPERATURE

One of the physical properties of water is its temperature. Although it is not used for assessing whether water is drinkable or not, it is a significant physical component that affects the quality of water in natural water systems like lakes and rivers. Temperature affects palatability, viscosity, solubility, odors, and chemical reactions (APHA, 2005). Consequently, the temperature of the water affects the biological oxygen requirement, sedimentation, and chlorination processes. 50 to 60 degrees Fahrenheit is the best water temperature range (O'Donnell, 2021).

2.4.1.3 TASTE AND ODOUR

Water that has been contaminated with foreign material may lose its original flavor and begin to smell (O'Donnell, 2021). Decaying plants, algae, molds, and actinomycetes are some of the sources of taste and odor in source water.

Taste and odor issues can also be brought on by chlorine and its byproducts. An unpleasant metallic taste can be left behind by relatively high amounts of iron, manganese, and several other metals. Domestic plumbing fixtures, equipment, and in certain cases, water mains may also emit a pronounced flavor or odor.

2.4.1.4 COLOUR

Water can be colored by humic and fulvic substances that drain from peat or other decaying plants, as well as by naturally occurring iron or manganese salts.

Since pure water is clear and colorless, light may easily travel through it. Light energy can, however, be absorbed by colored components in water, preventing it from entering as deeply as it would in colorless water. This can make the water less clear (Wilson, 2013).

Depending on the type of solid material it contains, water color is referred to as either apparent color or real color. The color of the entire water sample, known as apparent color, is made up of colors from both dissolved and suspended substances. After filtering the water sample to eliminate any suspended matter, the color of the filtered water which reflects the color resulting from dissolved components is measured to determine the true color (US EPA, 2006). A scale from 0 to 70 color units can be used to rate color. Because pure water is virtually colorless, it doesn't have any color units (O'Donnell, 2021).

2.4.1.5 SOLIDS

When solids enter the water, they may be in suspension or solution (O'Donnell, 2021). Through the use of a glass fiber filter, which the water sample passes through, both types of solids can be distinguished. The suspended solids are maintained above the filter, while the dissolved solids pass through the filter with the water. If the filtered portion of the water sample is placed in a little dish and allowed to evaporate, the solids will still be present as a residue. Typically, this substance is referred to as total dissolved solids, or TDS (APHA 2005).

Total solid (TS) = Total dissolved solids (TDS) + Total suspended solids (TSS). According to the TDS content per litre, water can be categorized as follows:

freshwater: <1500 mg/L TDS

brackish water: 1500–5000 mg/L TDS

saline water: >5000 mg/L TDS.

The TSS and TDS residue that remains after being heated to dryness for a set amount of time and at a predetermined temperature is referred to as fixed solids. Solids that ignite at 550°C are considered volatile solids.

These measures are helpful to the wastewater treatment plant operators because they give a general approximation of the amount of organic matter present in the total solids of wastewater, activated sludge, and industrial wastes (Spellman, 2013).

The following formula is used to calculate these numbers:

Total Solids:

Total solids (mg/L) = [(TSA–TSB)] × 1000/sample (mL) where TSA = weight of dried residue + dish in milligrams and TSB = weight of dish in milligrams.

Total dissolved solids:

Total dissolved solids (mg/L) = [(TDSA − TDSB)] × 1000/sample (mL) where TDSA = weight of dried residue + dish in milligrams and TDSB = weight of dish in milligrams.

Total suspended solids:

Total suspended solids (mg/L) = [(TSSA − TSSB)] × 1000/sample (mL) where TSSA = weight of dish and filter paper + dried residue and TSSB = weight of dish and filter paper in milligrams. Fixed and volatile suspended solids:

Volatile suspended solids (mg/L) = [(VSSA − VSSB)] × 1000/sample (mL) where VSSA = weight of residue + dish and filter before ignition, mg and
VSSB = weight of residue + dish and filter after ignition, mg.

2.4.1.6 ELECTRICAL CONDUCTIVITY

The capacity of water to conduct an electric current is known as electrical conductivity (Kate, 2019). The electrical current is carried by ions in solution; hence, the conductivity increases as the ion concentration does. Inorganic dissolved particles, including sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge) and chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) can impact conductivity in water (US EPA, 2021). It is therefore crucial in establishing whether water is suitable for the purposes it’s intended for.

The following are its units of measurement:

i. Micromhos/cm in U.S. units.

SI units are expressed in terms of milliSiemens/m (mS/m) or deciSiemens/m (dS/m), where 1 dS/m is equal to 1000 milliSiemens/cm (1000 dS/cm).

Depending on the source and the number of dissolved particles, water's typical conductivity might change. Typical conductivity readings for several types of water are listed below:

i. Ultra-pure water: 0.05-5.5 x 10^-6 S/m or 0.05-5.5 µS/cm
ii. Distilled water: 0.5-3 µS/cm or 1-1.0 µS/cm
ii. Drinking water: 0.005-0.05 S/m or 50-300 µS/cm
iii. Surface water: 100-10,000 µS/cm
iv. Sea water: 40,000-55,000 µS/cm or 50 mS/cm

2.4.2 CHEMICAL PARAMETERS

2.4.2.1 pH

pH is used to describe how acidic or basic an aqueous solution is (Sheppard, 1999). The pH of water measures the degree of its acidity or basicity (alkalinity), and is expressed on a scale of 0 to 14. A pH of 7 indicates neutral water. Acidity is measured as a pH value; 0 is the most acidic. More than 7, with 14 being the most basic, are basic or alkaline. pH is not a quality requirement that needs to be reached, according to the EU Drinking Water Directive, but rather a "indicator parameter" that should be monitored. For public water systems, it suggests a range of 6.5 to 9.5, for bottled water, 4.5 to 9.5, and it notes that the range for carbonated fluids may be much lower. The pH limits for drinking water that are safe for home use and the requirements of human beings are 6.5 to 8.5(WHO, 2011). Given the importance of water as an essential solvent and reactant, the measurement of pH is perhaps the test that is done the most frequently in chemical laboratories (Sheppard, 1999). Two techniques are available to determine pH: electrometric and colorimetric techniques (APHA, 2005). The quantity of oxygen in the water increases as pH rises.

It is significant to note that the pH of water might indicate potential contamination and can be a crucial safety measure for preserving the well-being of people, animals, and plants.

2.4.2.2 ACIDITY

Acidity is a measurement of the amount of acids present in a particular solution (O’Donnell, 2021). The term "acidity" refers to a substance's capacity to quantitatively neutralize a strong base to a specific pH level. The principal contributors to water acidity are mineral acids, carbon dioxide, and hydrolyzed salts like ferric and aluminum sulfates.

Acidic water can develop naturally as a result of high quantities of dissolved oxygen or human activity. Rain, tree roots, and soil bacteria that create acids and carbon dioxide are all examples of natural occurrences. Water becomes acidic when carbon dioxide dissolves in it and generates carbonic acid. The source of this carbon dioxide is either the atmosphere or the breathing of aquatic life (H2CO3).

2.4.2.3 ALKALITY

Alkalinity is a measurement of how well water can neutralize acids (Wilson, 2010). It is a totalization of all the titratable bases in the sample. The presence of carbonate (CO^{3-}), bicarbonate (HCO $^{-}$), and hydroxyl (OH^{-}) anions is what causes alkalinity in the majority of $_{3}$ natural fluids. However, the presence of borates, phosphates, silicates, and other bases can also increase alkalinity. When analyzing and managing wastewater treatment procedures as well as when deciding if water is suitable for irrigation and or combination with some pesticides. Typically, alkalinity is expressed as calcium carbonate (CaCO3) equivalents. Knowing how much soda and lime to add to the water for water softening is probably the most frequent reason to assess the alkalinity of a sample of water (O’Donnell, 2021). Titration is used to determine how alkaline a water sample is.

When water is alkaline, it signifies that its pH is at least greater than 7.0. Water with high levels of acidity or alkalinity may be contaminated by chemicals or industry.

Alkalinity and acidity can also originate from volcanic eruptions and other natural sources. The acidity and alkalinity of natural waterways protect fish and other aquatic creatures from rapid pH shifts. For instance, if an alkaline lake becomes contaminated with an acidic chemical, the pH of the lake water is unchanged since the acid and alkaline chemicals react to neutralize each other. To safeguard aquatic life, the buffering capacity of calcium carbonate should be at least 20 mg/L.

2.4.2.4 CHLORIDE

Agricultural runoff, wastewater, rock that contains chlorides, and other sources can all introduce chlorides into surface water. High chloride ion concentrations can make most people's water taste salty, although they have no harmful effects on the health of the general population.

Chloride naturally occurs in lakes, streams, and groundwater, but a very high concentration of chloride in freshwater (greater than 250 mg/L) may be a sign of wastewater contamination (Chatterjee, 2010).

Chlorides have a minor but crucial role in both animal and plant life's typical cell functions. Although sodium chloride may have a salty taste as early as 250 mg/L, magnesium or calcium chloride are often not tasted until values over 1000 mg/L. The maximum allowed chloride concentration in drinking water for the general public is 250 mg/L.

There are numerous ways to determine the chloride content in subsurface water. Groundwater sampling and laboratory measurements of chloride content are two direct methods. Silver nitrate titration is typically used to determine the concentration of chloride (Peinado-Guevara et al., 2012).

2.4.2.5 HARDNESS

One of the most prevalent issues with water quality around the globe is hardness (hard water) (Ahn et al., 2018).

Hardness occurs when water contains high mineral levels (O'Donnell, 2021). The dissolved minerals in your water have the potential to cause scale deposits on hot water pipes if unchecked. It could be challenging to make lather with the soap you're using if the water in your shower has a high mineral content. Magnesium and calcium ions can enter water through rock and soil, and their presence in water is the main cause of hardness. Groundwater often has a higher hardness level than surface water (O'Donnell, 2021).

When the hardness of water exceeds 300 mg/L, it is generally recognized as being hard, when it exceeds 150 mg/L, it is notably hard, and when it exceeds 75 mg/L, it is soft. Hardness up to 500 mg/L is safe for health; anything higher could have laxative effects.

Hardness is commonly measured through titration using ethylene diamine tetra acid (EDTA) and Eriochrome Black and Blue indicators. It is usually expressed in terms of mg/L of CaCO3 (APHA, 2005). Total hardness mg/L as CaCO3 = calcium hardness mg/L as CaCO3+ magnesium hardness mg/L as CaCO3.

According to Wilson (2010) and Dubey (2022), carbonate hardness and non-carbonate hardness are the two types of hardness in water. The presence of bicarbonate and carbonate salts of calcium and magnesium results in carbonate hardness, often referred to as temporary hardness.

This type of hardness can be eliminated by boiling the water, which helps the reaction by releasing carbon dioxide that escapes. The carbonate ion then interacts with the Ca^{2+} or Mg^{2+} ions to generate insoluble calcium and magnesium carbonates, which filter out and make the water soft (Dubey, 2022).

Permanent hardness, often referred to as non-carbonate hardness, is brought on by the presence of calcium chloride, magnesium chloride, and magnesium sulphate (Dubey, 2022). Boiling cannot remove this kind of hardness; alternative procedures must be used, such as:

i. Ion Exchange
ii. Chemical treatments like Washing soda and Borax or Calgon
iii. Adsorbent Coating
iv. Carbonation Process.

According to (Diggs and Parker, 2009) and (ESTADOS UNIDOS, 2018) Water can be classified according to its hardness as listed below:

i. Soft Water: Soft water contains less than 60 mg/L of dissolved calcium and magnesium.
ii. Slightly Hard Water: Slightly hard water contains between 60 and 100 mg/L of dissolved calcium and magnesium.
iii. Moderately Hard Water: Moderately hard water falls within the range of 100 to 200 mg/L of dissolved calcium and magnesium.
iv. Hard Water: Hard water contains more than 200 mg/L of dissolved calcium and magnesium.
v. Very Hard Water: Water with a hardness value of over 180 can be classified as very hard.

2.4.2.6 DISSOLVED OXYGEN (DO)

Dissolved Oxygen is an important indicator of water quality can tell you how contaminated the rivers, lakes, and streams are(O’Donnell, 2021). You may be sure that the water quality is high if the dissolved oxygen concentration is high. The solubility of oxygen causes dissolved oxygen to exist. The salinity, pressure, and temperature of the water are the three main variables that affect how much DO is present in it. Dissolved oxygen levels can be determined using an electrometric technique or a colorimeter.

A sufficient amount of dissolved oxygen is essential for good water quality and to all living things. Dissolved oxygen concentration is measured in milligrams per liter (mg/L) of water (Näykki et al., 2013). When dissolved oxygen concentrations fall below 5.0 mg/L, aquatic life is stressed. Less attention results in more tension. Dissolved oxygen has no direct impact on public health, despite some people finding it unpleasant to drink water with little to no oxygen. Dissolved oxygen is a direct indicator of water pollution (Zhao et al., 2021). High temperatures, excessive plant growth, and pollution from human activity are some of the things that might lead to low dissolved oxygen levels (US Environmental Protection Agency, 2021).

2.4.2.7 SULPHATE

Sulphate is a chemical characteristic of water that denotes the existence of the sulphate ion. Sulphate is a prevalent anion in water that is found in many different types of environments and plays a significant part in biogeochemical cycles (Wang and Zhang, 2019). However, because it is a constant in the water environment, its contamination issue is frequently disregarded (Wang and Zhang, 2019).

Water can become contaminated by sulphates from a variety of sources, including mining, industrial processes, and natural occurrences (Lenter et al., 2002). Sulphate can alter the chemical and physical characteristics of water. Sulphate, for instance, may have an impact on the characteristics of floc in acid mine drainage, which is actively treated to reduce environmental effects (Lenter et al., 2002).

2.4.2.8 NITROGEN

Nitrogen is a chemical parameter of water that can exist in different forms, such as nitrate, nitrite, or ammonium (WSS, 2018). Nitrogen is a crucial ingredient for plant growth, but too much of some nitrogen forms in water can have detrimental consequences on human health and the environment (WSS, 2018). Total nitrogen (TN), nitrate nitrogen (NO3-N), ammonia nitrogen (NH3-N), and dissolved nitrogen (DTN) are some of the chemical indicators that can be used to determine the amount of nitrogen in water (Liu et al., 2018).

The four forms of nitrogen that are present in water and wastewater are organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas (Hassan-Omer, 2020).

To be considered safe, drinking water must have no more than 10 mg of nitrate (measured as nitrogen) per liter (MNDH, 2022).

According to the Washington State Department of Health (2021), Nitrate ions affect health in that red blood cells' capacity to carry oxygen is decreased. These red blood cells quickly return to normal in most adults and kids. The time it takes for the blood cells to normalize can be substantially longer in newborns. Because of the absence of oxygen, infants who consume foods manufactured with nitrate-contaminated water or drink high-nitrate water may experience major health problems. Methemoglobinemia, also known as "blue baby syndrome," is the name of this condition. A high nitrate content in surface water can promote the rapid growth of algae, lowering the quality of the water (Hassan-Omer, 2020).

2.4.2.9 FLUORIDE

Fluorides are compounds that include the element fluorine together with another material, typically a metal. Fluoride mono-fluorophosphate (MFP fluoride), sodium fluoride, and stannous fluoride are a few examples of these substances. Even though fluoride levels can vary greatly, certain fluorides can be found naturally in soil, air, and water. Most water contains some fluoride. Foods from various plants and animals contain fluoride as well.

Fluorides enter the body through the digestive system and are then absorbed into the circulation. They circulate through the blood and frequently gather in calcium-rich regions like the bones and teeth.

Drinking water with a reasonable level of fluoride ions (F) promotes optimal oral health

(Hassan-Omer, 2020). Fluoridated water consumption strengthens teeth and lowers cavities (also known as tooth decay) in both children and adults by roughly 25% (CDC, 2019). The environment contains large amounts of fluoride, which may be found in the air, soil, rocks, and water (Peckham and Awofeso, 2014). 0.7 milligrams of fluoride per liter of water is the recommended amount of fluoride in drinking water to prevent dental cavities (CDC, 2019). Although 0.7 mg/L is the recommended ideal amount, it is important to note that 0.6 mg/L is still efficient for preventing caries (CDC, 2019).

2.4.2.10 IRON (Fe) AND MANGANESE (Mn)

Iron and manganese are frequently found in ground water and some surface waters, such as lakes, that get a substantial amount of groundwater input (Casey, 2009). They are mostly found as ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions in the soluble reduced divalent state (Casey, 2009).

Since iron and manganese are secondary pollutants with little to no negative impact on health, it has long been believed that they solely cause aesthetic problems in water (Prasad and DansoAmoako, 2014). However, research conducted by Wasserman et al., (2006) revealed a link between children's intellectual decline and higher Mn concentrations in drinking water. Drinking water discoloration has been determined to be mostly caused by elevated Fe and Mn contents (Slaats, 2002). Furthermore, colored stains on sinks and laundry might result from discolored water, which could also increase treatment costs, diminish treatment capacity, and raise pumping expenses (Prasad and Danso-Amoako, 2014). High levels of Fe and Mn have been shown to give water a metallic taste and cause vegetables cooked in it to become black and seem unappealing (Herman, 1996).

Fe and Mn are removed in two steps: (a) an oxidation process that turns soluble forms of Fe and Mn into insoluble precipitates, and (b) a solid separation process that removes the precipitated material from the water stream (Casey, 2009).

2.4.2.11 COPPER (Cu) AND ZINC (Zn)

Copper and zinc are chemical elements that can affect the physicochemical and physical characteristics of water (Nartowska, 2019). Copper and zinc concentration and mobility in water can vary depending on the characteristics of both the water and the metals (Małecki et al.,

2016). Copper (Cu) and Zinc (Zn) are unharmful substances if present in very small amounts. However, they could impart an unpleasant taste to the water. When zinc levels are high, the water appears milky.

2.4.2.12 BIOCHEMICAL OXYGEN DEMAND (BOD)

Biochemical Oxygen Demand (BOD) is a chemical water parameter used to assess water quality and quantify the degree of organic contamination in water systems (Woodard and Curran, 2006).

The biochemical oxygen demand (BOD) is a measure of how much oxygen is needed to eliminate waste organic matter from water during aerobic bacteria's breakdown process. BOD is an analytical parameter that measures the quantity of dissolved oxygen (DO) absorbed by aerobic bacteria during a certain time period and temperature while they are feeding on the organic material contained in a water sample. The maximum oxygen concentration (BOD or BODL) required in a particular volume of water to completely breakdown or stabilize all biodegradable organic compounds.

The BOD is affected by time. At time = 0, no oxygen will have been used, hence the BOD will likewise be 0. The BOD increases as a result of the bacteria's increased oxygen consumption over time. Once the organic components get to the BODL, they completely dissolve. BOD is frequently expressed as milligrams of oxygen used per liter of sample over the course of 5 days at 20°C (Muller et al., 2014).

2.4.2.13 CHEMICAL OXYGEN DEMAND (COD)

Chemical Oxygen Demand (COD) is a measure of how much organic matter in a water sample is capable of being oxidized by a potent chemical oxidant (Hu and Grasso, 2004). Chemical Oxygen Demand (COD) in water samples may be determined using several standard techniques. The most used test technique is colorimetric analysis, which involves oxidizing COD with acid and employing indicator chemicals like hexavalent dichromate as well as other compounds (Sigma-Aldrich, 2016).

Measurement of COD in water is crucial for numerous reasons, such as Water quality assessment, Wastewater treatment efficiency, Regulatory compliance, and Process control and Optimization.

2.4.3 BIOLOGICAL PARAMETERS

2.4.3.1 BACTERIA

Bacteria are a biological parameter of water that is commonly used to assess water quality. Due to excrement from humans or animals contaminating the water, some bacteria may be present, and their presence may be an indication of potentially dangerous infections (Cabral, 2010).

Microbiological water analysis is mainly based on the concept of fecal indicator bacteria, which are bacteria that are present in human and animal feces and can be used as markers to assess water quality (Cabral, 2010). Escherichia coli and the total number of coliforms are the most often utilized fecal indicator microorganisms (Hassan-Omer, 2020).

2.4.3.2 Total Coliform Counts (CFU/mL)

Total coliform count is a key microbiological parameter used to assess the sanitary quality of water. Coliforms are a group of bacteria that are commonly found in the environment, including soil, vegetation, and the intestines of warm-blooded animals. Their presence in water does not always indicate fecal contamination but suggests that the water may have been exposed to external contaminants or poor sanitation practices. The total coliform count is expressed in colony-forming units per milliliter (CFU/mL) and serves as a general indicator of microbial pollution (Cabral, 2010).

2.4.3.3 Total E. coli Counts (CFU/mL)

Escherichia coli (E. coli) count is a specific microbiological parameter that measures fecal contamination in water. Since E. coli originates exclusively from the intestinal tracts of humans and warm-blooded animals, its presence in a water sample indicates recent fecal pollution and a potential health risk from pathogenic organisms (Hassan-Omer, 2020). The total E. coli count, expressed in CFU/mL, is therefore considered a reliable indicator of the microbiological safety of drinking water and is commonly used in routine water quality monitoring.

2.4.3.4 Tentative Isolates

Tentative isolates refer to bacterial colonies obtained from culture media that are provisionally identified based on their growth appearance and morphological characteristics. In microbiological water analysis, these isolates represent suspected microorganisms that require further confirmatory testing to determine their exact identity. Tests such as Gram staining, biochemical assays, or molecular identification techniques are used to confirm the species of these tentative isolates. For instance, colonies showing a metallic green sheen on

Eosin Methylene Blue (EMB) agar may be recorded as tentative E. coli isolates pending confirmation (Cabral, 2010).

2.5 SIGNIFICANCE OF EFFECTIVE MANAGEMENT OF SOLID WASTE

One of the main reasons why waste management is important is that it helps prevent pollution.

Improper handling of waste results in the contamination of air, water, and soil, leading to adverse effects on human health and the environment. For instance, landfills can emit harmful gases like methane, a potent greenhouse gas that contributes to climate change. Similarly, untreated liquid waste can pollute water bodies, causing the death of aquatic life and harm to ecosystems.

Additionally, waste management contributes to resource conservation. Many waste materials can be recycled or reused, reducing the demand for raw materials and saving energy. For example, recycling paper conserves trees and water, while recycling metals saves energy and reduces greenhouse gas emissions associated with mining and processing.

Efficient waste management creates economic opportunities. Industries involved in recycling and waste treatment can generate employment and contribute to the local economy. Additionally, reusing and recycling materials can save money for businesses and households by reducing the need to purchase new materials.

Waste management also plays a crucial role in minimizing the overall environmental impact of human activities. By managing waste properly, we can reduce the amount of waste that ends up in landfills, thereby minimizing the release of harmful gases into the atmosphere. It also helps minimize the requirement for new landfills, which can negatively impact wildlife habitats and natural landscapes.

It is crucial to prioritize and invest in efficient waste management practices to safeguard our environment and promote sustainable development. Overall, effective waste management is vital for the well-being of our communities, the planet, and future generations. Hence, it is our responsibility to actively participate in waste management efforts and promote responsible waste management practices in our daily lives.

2.6 GEOGRAPHIC INFORMATION SYSTEM (GIS)

2.6.1 WHAT IS GIS?

The term "Geographic Information System" (GIS) describes a large group of computer-based technologies for gathering, storing, producing, analyzing, and presenting geographic data to assist integrated decision-making (Zhang and Drake, 2014). According to Ali (2016), A Geographic Information System (GIS) is a collection of computer software, hardware, data, and humans that enables users to enter, alter, analyze, and present data as well as data that is associated with specific locations on the surface of the planet. In a larger sense, GIS encompasses institutional structures, processes, workflows, procedures, and support employees in addition to human users. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation.

2.6.2 COMPONENTS OF GIS (GEOGRAPHIC INFORMATION SYSTEM)

2.6.2.1 HARDWARE

The computer that runs GIS software is referred to as hardware. There are many different types of computers accessible today, including desktop and server- based ones. GIS applications can be run on a server-based computer called an ArcGIS Server across a network or in the cloud. Each piece of a computer's hardware has to have a significant amount of storage in order for it to work properly. A motherboard, a hard drive, a CPU, a graphics card, a printer, and other devices are examples of hardware components. To make sure that a GIS application functions properly, these components all operate together (Kanickaraj, 2018).

2.6.2.2 SOFTWARE

The primary tool for collecting, processing, and displaying geographic data is GIS software. It offers features and resources for storing, working with, and displaying geographic data. Software for GIS includes SAGA GIS, QGIS, and ArcGIS (Kanickaraj, 2018)

2.6.2.3 DATA

Data is an essential part of GIS. Both geographic or geographical data as well as attribute and tabular data are included. While attribute data offers more details about the spatial qualities, spatial data relates to specific geographic references like latitude and longitude coordinates. Relationship analysis and visualization are made possible by the integration of geographical and attribute data (Kanickaraj, 2018).

Data, often known as GIS fuel, is the most vital and expensive component of the Geographic Information System. GIS data may be raster or vector. The types of data used in GIS are:

i. Spatial Data ii. Attribute Data

2.6.2.3.1 SPATIAL DATA

Any type of information that specifically refers to a certain geographic area or location is considered spatial data. A numerical representation of a physical item in a geographic coordinate system is called spatial data. Geospatial data or geographic information are other names for it. Spatial data, however, includes much more than just the geographic area depicted on a map. Since geographic data may contain more than simply regional information, it may be recorded in a number of forms. Researchers may learn more about how each variable impacts specific people, groups, and communities by examining this data. The vector and raster file formats are commonly used to hold geospatial data (Kanickaraj, 2018).

2.6.2.3.2 ATTRIBUTE DATA

Descriptions of traits linked to spatial data—geographical features—are known as attribute data. The non-graphic information connected to a point, line, or area element in a GIS is referred to as attribute data. In addition to providing characteristics regarding spatial data, attribute data can also include what, where, and why information. With the use of attribute data, we may learn relevant information about a map and assess resources like water, cities, highways, coastlines, flora, etc (Kanickaraj, 2018).

2.6.2.4 PEOPLE

GIS cannot function without people. They consist of GIS users, analysts, and technicians, among other professionals. These people provide input on data gathering, analysis, and decision-making procedures (Kanickaraj, 2018).

2.6.2.5 METHOD

This comprises the processes and methods applied to GIS data analysis and interpretation. GIS technology combines standard database operations like query and statistical analysis with the distinct map-based display and spatial analytical advantages.

Figure 2.2: Components of GIS (Kanickaraj, 2018).

2.6.3 GEOGRAPHIC INFORMATION SYSTEM (GIS) SOFTWARE

Geographical data may be created, stored, managed, queried, analyzed, and visualized using GIS (Geographic Information System) software. Commercial and open-source GIS tools fall into two broad types. While open-source GIS software is free and the source code is publicly accessible, commercial GIS software requires a paid license (Kanickaraj, 2018).

Commercial GIS Software:

1. ArcGIS Pro: A powerful and modern desktop GIS application that offers 2D, 3D, and 4D data analytics.

2. ArcGIS Desktop: A foundational piece for GIS professionals to create, analyze, manage, and share geographic information.
3. AutoCAD Map 3D: A GIS software that allows users to access and edit CAD and GIS data

Open-Source GIS Software:

1. QGIS: A user-friendly and free GIS software that is licensed under the GNU (General Public License)
2. GRASS GIS: A free GIS software that provides a wide range of tools for spatial analysis and modeling.
3. SAGA GIS: A free GIS software that offers a variety of geoscientific methods for data processing and analysis.
4. gvSIG: A free GIS software that is designed for managing, analyzing, and sharing geographic information.
5. Whitebox GAT: A free GIS software that is used for geospatial analysis and data visualization.
6. OpenJUMP: A free GIS software that is used for editing and analyzing geospatial data.
7. uDIG: A free GIS software that is used for viewing, analyzing, and editing geospatial data.

2.6.4 APPLICATION OF GIS TO GROUNDWATER INVESTIGATION

Geospatial information systems (GIS) and remote sensing data can be used to improve groundwater exploration and management. Implementing efficient techniques that save time and money is necessary for groundwater exploration in nations with limited water supplies (Jawad and Yahya, 2013). GIS provides a variety of techniques for extracting information about a region's potential groundwater resources through the integration of data on geologic formations, geomorphology, soil, lithology, drainage, land use, vegetation, etc (Rawal et al., 2016). Groundwater resource potential detection was made simpler, more precise, and quicker using a GIS approach (Kabeto et al., 2022). Groundwater resources, such as aquifer geometry, land cover, soil surface, and river networks, may be mapped and monitored using GIS (Calera et al., 1999; Sambare et al., 2021). This data may be used to pinpoint regions with high and low groundwater potential and to track how groundwater levels fluctuate over time. The use of

GIS also aids in the management of watersheds' topography, flow, and debris flow models.

Modeling surface flow, well, and spring data is done using GIS for groundwater management. Engineers may now spend more time analyzing and improving computer models rather than laboriously setting out watershed parameters for models, thanks to automated GIS tools. Groundwater recharge zones, such as those with high infiltration rates or those that can be artificially refilled, may be found using GIS. Using this data, plans may be created to improve groundwater availability and increase groundwater recharge.

2.7 REVIEW OF RELATED WORKS

Groundwater is present worldwide underneath the surface of the Earth; however, it is often only found up to a depth of 750 meters or less. It is an important source of water for drinking, domestic, industrial, and agricultural uses. It plays a key role in meeting the water needs of various user sectors however, groundwater quality has been a major source of concern in many regions of the world, especially in underdeveloped countries where solid waste is not properly managed. This study of the literature will look at some of the studies on groundwater quality evaluation and also how GIS is applied in computing groundwater quality and monitoring.

The study conducted by **Keshav K. Deshmukh and Sainath P. Aher (2024)** assesses the impact of municipal solid waste on groundwater quality near Sangamner City using a GIS approach. The authors collected water samples from 20 locations around the dumping yard and analyzed them for various physicochemical parameters. The results showed that the groundwater quality around the dumping yard area does not conform to drinking and domestic purposes as per the water quality index and BIS standard.

The study used GIS to map the spatial distribution of groundwater quality parameters and identified areas with high levels of pollution. The authors concluded that the dumping yard is a significant source of groundwater pollution in the study area. The study recommends proper management of municipal solid waste to prevent groundwater pollution. The findings of this study can be used by policymakers and environmental managers to develop strategies for mitigating groundwater pollution.

A study of the Assessment of underground water quality in Okobo local government area of Akwa Ibom State, Nigeria was done by **Umana et al. (2022)**. In the study, the groundwater quality of the Okobo Local Government Area was investigated. Sixteen borehole (BHs) water samples were collected from four zones (Okopedi, Ekeya, Ukwong, and Okiuso) in Okobo.

Standard analytical procedures were used to analyze the physicochemical, bacteriological, and heavy metal parameters in the water samples, and the results were compared to the Nigerian standard for drinking water quality (NSDWQ).

The result of the study revealed that the water quality in the area are within good and very good water quality.

An Investigation into the Groundwater quality assessment: a physicochemical properties of drinking water in a rural setting of developing countries was done by **Essumang et al. (2020)**.

This study determined and characterized the quality of underground water in the Twifo Hemang Lower Denkyira District (THLDD) of the central region of Ghana. The study involved collecting water samples from various groundwater sources in the district and analyzing them for physicochemical parameters such as pH, turbidity, total dissolved solids, and heavy metals. The results showed that some water samples exceeded the World Health Organization (WHO) guideline values for drinking water quality, indicating potential health risks to consumers.

The study's findings highlighted the need for regular monitoring and assessment of groundwater quality in rural settings, particularly in developing countries where access to safe drinking water is a significant challenge. The study's results also underscored the importance of implementing effective water treatment and management strategies to improve groundwater quality in the district.

A comprehensive review of water quality monitoring and assessment in Nigeria was done by **Ighalo and Adeniyi (2020)**. In this study, research findings on water quality monitoring and assessment in Nigeria over the past two decades were systematically reviewed. The study employed a systematic review approach, analyzing various research articles and publications on water quality monitoring and assessment in Nigeria. The review focused on identifying trends, challenges, and gaps in water quality research in Nigeria, as well as highlighting the current state of water quality in the country.

The outcome of the study revealed that water quality in Nigeria is a significant concern, with many water sources contaminated with pollutants such as heavy metals, bacteria, and other microorganisms. The review also identified gaps in research and monitoring, including inadequate funding, lack of standardization, and limited access to water quality data.

Taloor et al. (2020) talked about Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using Geospatial Information System (GIS) and groundwater quality index (GWQI) techniques. In the study, they talked about spring water quality and analyzed the water for its major hydrochemistry, composition, and suitability of the water for domestic and drinking purposes. The study utilized GIS and GWQI techniques to analyze the hydrochemistry and composition of groundwater in the region. The results provided insights into the groundwater quality, highlighting areas with suitable and unsuitable water for human consumption.

The study's findings have implications for water resource management in hard rock terrains, particularly in regions where groundwater is a primary source of drinking water. The use of GIS and GWQI techniques demonstrated the effectiveness of these tools in assessing groundwater quality and identifying areas that require attention.

The study conducted by **Rajendra B. Zolekar et al. (2021)** conducted hydro-chemical characterization and geospatial analysis of groundwater for drinking and agricultural usage in Nashik district, India. The authors collected groundwater samples from 120 locations and analyzed them for various physicochemical parameters. The results showed that the groundwater quality in the study area is suitable for drinking and agricultural purposes, but some samples exceeded the permissible limits for certain parameters.

The study used geospatial analysis to map the spatial distribution of groundwater quality parameters and identified areas with high levels of pollution. The authors concluded that the groundwater quality in the study area is influenced by geological and anthropogenic factors. The study recommends regular monitoring of groundwater quality to prevent pollution. The findings of this study can be used by policymakers and environmental managers to develop strategies for sustainable groundwater management. The study's methodology can be applied to other similar studies in different regions. The authors suggest that further studies should be conducted to assess the impact of climate change on groundwater quality. Overall, the study highlights the importance of understanding the hydrochemical characteristics of groundwater to manage it sustainably.

In another study by **Jawad and Yahya (2023)**, GIS was applied in Groundwater Exploration in Al-Wala Basin in Jordan. In the study, geographic information systems (GIS) tools and remote sensing data were used to prepare and analyze digital layers of lithology, geological structure, drainage, and topography to detect the most promising sites for groundwater exploration in an arid basin in Jordan. The study demonstrated the effectiveness of GIS and remote sensing in identifying potential groundwater exploration sites in arid regions. By integrating various thematic layers, the study was able to pinpoint areas with favorable hydrogeological conditions for groundwater accumulation.

The use of GIS and remote sensing in this study highlights the potential of these technologies in groundwater exploration, particularly in regions with limited water resources.

Senthilkumar et al. (2019) conducted a study on groundwater quality assessment using GIS and multivariate statistical techniques in a coastal aquifer in Tamil Nadu, India.

The study used GIS and multivariate statistical techniques, including factor analysis and cluster analysis, to analyze the groundwater quality data.

The results showed that the groundwater quality in the study area was influenced by both natural and anthropogenic factors, including seawater intrusion and agricultural activities.

The study identified areas with high levels of contamination and recommended measures for improving groundwater quality.

A study was conducted by **Wu et al. (2020)** to develop a hybrid approach combining fuzzy logic and GIS to assess groundwater quality in a coal mining area in China.

The study used a hybrid approach combining fuzzy logic and GIS to assess the groundwater quality in a coal mining area. The model integrated various parameters, including pH, total dissolved solids, and heavy metals.

The results showed that the groundwater quality in the study area was generally poor, with high levels of contamination from coal mining activities. The study demonstrated the effectiveness of the hybrid approach in assessing groundwater quality and identifying areas for improvement. Also, **Selvam et al. (2023)** used GIS and remote sensing techniques to assess groundwater quality in a coastal area in India.

The study used GIS and remote sensing techniques to analyze the groundwater quality data and identify areas with high levels of contamination.

The results showed that the groundwater quality in the study area was influenced by both natural and anthropogenic factors, including seawater intrusion and agricultural activities. The study recommended measures for improving groundwater quality and managing groundwater resources sustainably.

Mondal et al. (2019) conducted a study on groundwater quality assessment using a GIS-based approach in a semi-arid region of India. The study used a GIS-based approach to analyze the groundwater quality data and identify areas with suitable groundwater quality.

The results showed that the groundwater quality in the study area was generally good, but some areas had high levels of contamination. The study recommended measures for improving groundwater quality and managing groundwater resources sustainably.

In another study, **Gopalakrishnan et al. (2019)** used multivariate statistical techniques and GIS to assess groundwater quality in a river basin in India. The study used multivariate statistical techniques, including factor analysis and cluster analysis, and GIS, to analyze the groundwater quality data.

The results showed that the groundwater quality in the study area was influenced by both natural and anthropogenic factors, including agricultural activities and industrial pollution.

Syeda et al. (2021) carried out research to investigate the drinking water quality of the Basho Valley that is being used for domestic purposes. The study also comprehends public health status by addressing the basic drinking water quality parameters. A total of 23 water samples were collected and then analyzed to elucidate the current status of physico-chemical, metals, and microbial parameters. Principal component analysis (PCA) was applied, and three principal components were obtained, accounting for 53.04% of the total variance, altogether. PCA identified that metallic and microbial parameters are the major factors influencing the water quality of the valley. Meanwhile, the water quality index (WQI) was also computed and it was observed that WQI of the valley is characterized as excellent in terms of physico-chemical characteristics; however, metals and microbial WQI shows most of the samples are unfit for drinking pur pose. Spatial distribution is also interpolated using the Inverse distance weight (IDW) to anticipate the results of mean values of parameters and WQI scores. The study concludes that water quality is satisfactory in terms of physico-chemical characteristics; however, analysis of metals shows that the concentrations of copper (Cu) (0.40 ± 0.16 mg/L), lead (Pb) (0.24 ± 0.10 mg/L), zinc (Zn) (6.77 ± 27.1 mg/L), manganese (Mn) (0.19 ± 0.05), and molybdenum (Mo) (0.07 ± 0.02 mg/L) are exceeding the maximum permissible limit as set in the WHO guidelines for drinking water. Similarly, the results of the microbial analysis indicate that the water samples are heavily contaminated with fecal pollution (TCC, TFC, and TFS > 3 MPN/100 mL). Based on PCA, WQI, and IDW, the main sources of pollution are most likely to be concluded as anthropogenic activities, including incoming pollution load from upstream channels. A few underlying sources, by the natural process of weathering and erosion, may also cause the release of metals in surface and groundwater. This study recommends ensuring public health with regular monitoring and assessment of water resources in the valley. **Oparaocha et al. (2021)** discussed the assessment of quality of drinking water sources in the Federal University of Technology, Owerri, Imo state, Nigeria. The study was carried out between May and July 2009. The standard plate count method was used for analysis, involving serial doubling dilutions of the respective water samples. All water sources sampled were within WHO physico-chemical standards for drinking water, except for slightly elevated levels of phosphate ions.

A study on the statistical and GIS-based analysis of physicochemical parameters of ground water samples around Rajbandh dumping site was conducted by **Hossain. R and Hassan. K (2020)**. Groundwater samples were collected from tube-wells from Rajbandh, Khulna dumping site as well as its adjoining area to find out the concentration of different water quality parameters. In the laboratory, nine different water quality parameters such as pH, E.C, TDS, Cl-, NO3-, turbidity, alkalinity, Mn and Fe were measured through standard test methods. In order to establish the relationship between physicochemical parameters to predict the intensity of one parameter with respect to another for a particular location, statistical analysis has been done by Microsoft Excel. It includes correlation coefficient, t-test, and regression analysis. Methodical calculation of correlation co-efficient between water quality parameters has been done. Regression equations also established. This is because of to find out the strength and the linear relationship between different pairs of parameters as well as to predict the level of pollution of groundwater. The significance level further verified by t-test. The water samples were collected and analyzed from four distinct locations. In this study an appreciable strong positive correlation was found for E.C with turbidity, alkalinity; turbidity with alkalinity also for chloride with TDS. A strong negative correlation was found for pH with turbidity, alkalinity, E.C. All the physicochemical parameters of respective groundwater were within limit set by ECR (1997). The water quality index (WQI) was used to analyze the groundwater quality of the study site. The water quality parameters, such as pH, EC, TDS, Cl-, NO3-, turbidity, alkalinity, Mn, and Fe, were used, which were collected from four different locations over a period of 2018. The test result reveals that 50% water samples were found poor quality and 50% samples were found to be unsuitable for drinking purposes. The WQI ranges from 72.998 to 164.332. Further, the WQI at different locations was analyzed with respect to variation in space using the spline curve technique using ArcGIS 10.5 software. Therefore, there is a need for some treatment before the usage of water, and also a need to protect the area from landfill contamination.

While numerous studies have utilized GIS and regression approaches to analyze water quality around dumpsites, a critical review of existing literature reveals a notable research gap in the specific context of the University of Benin, Ugbowo Campus, Benin City. Despite the potential environmental and health implications of dumpsites on nearby water sources, there is a lack of comprehensive research on the water quality around dumpsites within this particular campus. My study, 'Analysis of Water Quality around Dumpsite using GIS and Regression Approach,' aims to bridge this gap by investigating the water quality around dumpsites in the University of Benin, Ugbowo Campus, providing valuable insights into the potential environmental and health risks associated with these dumpsites.

CHAPTER THREE

METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

The study was carried out at the Ugbowo Campus (Main Gate) of the University of Benin (UNIBEN). The Campus is located in Ugbowo, Benin City, along the Ugbowo-Lagos Expressway. Benin City is the capital of Edo state, Nigeria, and is located in the south-south geopolitical zone of Nigeria. The city is bounded by latitudes 6°06’ N, 6°30’ N and longitudes 5°30’ E, 5°45’ E, and has an area of about 500 km^2. The City is underlain by sedimentary formation (Agatemor and Okolo, 2008).

UNIBEN is bounded in the north by Ekosodin Community, in the east by Ikpoba River, in the south by Osasogie Community, and on the western side is Ugbowo, also one of the host communities. UNIBEN is one of Nigeria's second-generation federal universities, established in 1970 with “Knowledge for Service” as the Motto, with the Vision “To establish a model institution of higher learning which ranks among the best in the world and responsive to the creative and innovative abilities of the Nigerian people”. The National Universities Commission (NUC) granted the university the status of a full-fledged university on July 1, 1971, after it had first been established as an Institute of Technology. The University of Benin officially changed its name from the Institute of Technology in April 1972 at a speech given by Col. S. O. Ogbemudia, the military governor of Mid-Western State at the time (who also served as the university's visitor). The University was taken over by the Federal Government on April 1st, 1975, at the request of the State Government, and became a Federal University.

Brig. Gen. Samuel Ogbemudia (Rtd), the then military governor of the now-defunct Bendel State, established the University of Benin (UNIBEN) in 1970. On 1 April 1975, at the request of the state government, the university was taken over by the federal government and changed its name to Federal University. It had originally been established as a technology institution but had been granted the status of a full-fledged university by the National Universities Commission (NUC). Benin City's Ekewan Road served as the university's initial location. A primary campus project at Ugbowo and Ekosodin started in 1972. According to (Pocket Statistics, 2020), the main campus is currently located at Ugbowo, which has a population of over 58000.

The area is located within the rainforest zone with a wet equatorial climate, having an almost uniform temperature throughout the year. It has double peaks in July and September. The region experiences eight months of wet season (rainfall) and four months of dry season (drought). The months of January and February, as well as those of November and December, witness the lowest amount of rainfall, while in June, July, September, and October have the highest records of rainfall, with a break in August, which is popularly known as the August break (Da, 2020). The satellite image of the study area is shown in Figure 3.1 below.

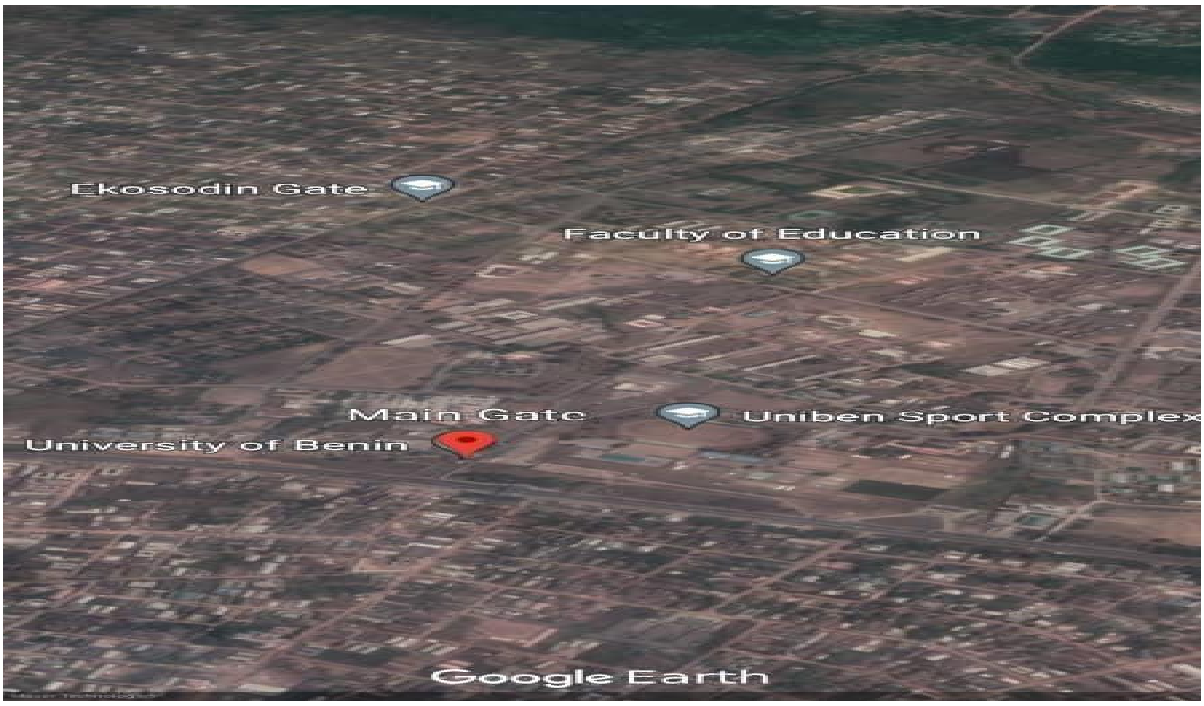


Figure 3.1: Map showing Ugbowo Campus (Main Gate) UNIBEN

3.2 MATERIALS AND METHODS

The materials and methods employed in this study are discussed below.

3.2.1 WATER SAMPLING

Groundwater samples around dumpsites were collected (through tap) using a simple random sampling technique from eight different boreholes located in the University of Benin, Ugbowo Campus, Benin City. The locations of the borehole water samples are indicated using GPS coordinates (GIS format) collected at each location with a Garmin GPSMAP 78s handheld GPS unit. Pretreated plastic cans (of 75 liters each) were used for the collection of the groundwater samples. The plastic cans were sealed, labeled, and transported to the Martlet Environmental Research Laboratory in Benin City for analysis.

3.2.2 LABORATORY ANALYSIS

This study utilized a range of physical and chemical analytical techniques, leveraging stateof-the-art equipment in a well-equipped Quality Analytical Laboratory. The equipment used include various laboratory glassware such as beakers, measuring cylinders, micropipettes, volumetric flasks, burettes, funnels, test tubes, and Erlenmeyer flasks, as well as thermometers, stopwatches, ovens, electronic mills, refrigerators, filter papers, and stirrers. Flameless Atomic Absorption Spectrometry (FAAS) was employed to measure metal concentrations, while a potentiometric digital pH meter and conductivity meter were used for pH and conductivity measurements, respectively. Groundwater samples were analyzed for 9 parameters at Marlet Laboratory, with all analytical procedures being meticulously documented.

3.2.2.1 PARAMETERS ANALYSED

The samples were analyzed for nine (9) physicochemical parameters, namely:

1. pH

Procedure:

The pH of the water was measured with the aid of a pH meter. The meter was calibrated with buffers, and the electrodes and glassware were rinsed with deionized water. About 10ml of the sample was measured and placed in a 150ml beaker, with the rinsed electrode placed in the test sample at room temperature. The sample was stirred with a magnetic stirrer. The pH value of the water sample was read and recorded after 3 minutes to ensure a stable reading on the pH meter. The electrodes was rinsed with deionized water, and the electrode cap were replaced after all measurements have been completed.

2. Electrical Conductivity (EC)

Procedure:

This was measured with the aid of a conductivity meter. The instrument was switched on by pressing the power "ON" button and then allowed to stabilize for 10 minutes. The conductivity of the meter was calibrated by pressing "CND" and immersing the probe in potassium chloride (KCl) solutions. The conductivity was read by pressing "CND".

3. Total Dissolved Solids (TDS)

Procedure:

This was measured with the aid of a TDS meter. The instrument was switched on by pressing the power "ON" button and then allowed to stabilize for 10 minutes. The total dissolved solids were calibrated by pressing "TDS" and immersing the probe in potassium chloride

(KCl) solution. The probe was rinsed and immersed in the sample solution. The total dissolved solids was read by pressing "TDS".

4. Chloride (Cl^-)

Procedure:

The presence of chloride ions was tested using a by titration with silver nitrate solution. The sample was prepared and analyzed according to standard procedures. A few drops of potassium chromate indicator was added to the sample, and silver nitrate solution was titrated against it until a reddish-brown precipitate forms, indicating the endpoint. The volume of silver nitrate used was recorded, and the concentration of chloride ions will be calculated based on the titration results.

5. Nitrate (NO_3^-)

Procedure:

10ml of the filtrate was pipetted into a 50ml flask, and 2ml of 2M HCl was added, then diluted to about 30ml with water. 2ml of Sulphanilic Acid was added, stirred, and allowed to stand for 5 minutes. The standards was treated similarly to the samples. 10ml of AlphaNaphthylamine was added, stirred, and made to volume. Color development occured after a few minutes, and the absorbance was read at 520nm after 20 minutes.

6. Turbidity

Procedure:

25ml of water was poured into the cuvette and used to zero the spectrophotometer at 450nm. 25ml of the water sample was poured into another cuvette, and its absorbance was read on the meter. The working standards was read similarly.

7. Alkalinity

Procedure:

The alkalinity of the water sample was measured by titrating it with a standard acid to a specific pH endpoint, typically pH 8.3 for phenolphthalein alkalinity or pH 4.5 for total alkalinity. The results was expressed in terms of milligrams per liter (mg/L) of calcium carbonate (CaCO3) equivalent.

8. Iron (Fe)

Procedure:

This was carried out using an Atomic Absorption Spectrometer. Atomic absorption spectrometry is widely used for the determination of heavy metals and some cations in environmental analysis. The source of radiation was a hollow cathode lamp, which contains a cathode constructed of the same metal as that being analyzed. The emitted wavelength will be characteristic of the metal, and a different lamp was required for each metal. The light from the lamp was directed through a flame and onto a monochromator, which selected the preferred analytical wavelength. The light was detected by a photomultiplier tube and converted to an electrical signal. The sample was aspirated into the flame, where the solution evaporated, and the metal-containing compounds volatilized and dissociated into ground-state atoms. The ground-state atoms was absorb the radiation from the hollow cathode lamp and be excited to higher energy levels. An acetylene-air flame was used for the analysis.

9. Manganese (Mn)

Procedure:

The same procedure adopted for iron was employed here.

3.2.3 WATER QUALITY INDEX (WQI)

Water quality assessment was conducted using WQI, which is widely used for evaluating water quality for different purposes, particularly drinking water quality. The Water Quality Index (WQI) was first developed by Brown et al. (1970) and later modified by Backman et al. (1998). According to the World Health Organization (WHO) report (2004), the WQI helps to elucidate the combined effects of individual parameters and overall water quality characteristics on drinking water, as noted by Abbasnia et al. (2018). Each parameter was assigned a value on the basis of its relative importance, which has a significant role in overall water quality, as per the guidelines of standardizing agencies. **The parameters with low permissible limits can cause maximum extent of pollution even on slight fluctuation, while the high permissible limit allows relatively less chances of pollution.** For this study, the two key factors that were considered to assign unit weight, i.e. the parameter with the narrowest/lowest range of permissible limit and its influence on water quality as well as on the health risk index (HRI) reported by Singh et al. (2018) will be assigned the highest weight of 5. Accordingly, the weights will be assigned in a range of 1–5. The relative weight was computed using the following equation (1):

$$W_i = \sum \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

Where,

Wi = relative weight of each parameter Wi = weight of each parameter n = number of parameters.

For each parameter, the quality rating scale will be calculated by dividing its concentration in each water sample by its respective standards (released by the World Health Organization, 2011) (Edition 2011) and finally multiplying the results by 100 through equation (2).

$q_i = \left(\frac{c_i}{s_i}\right) * 100$ (2)

Where,

qi = the quality rating

Ci = concentration of each parameter (mg/L)

Si = standard limit (mg/L) according to WHO, released in 2011

In the final stage of WQI computing, the SIi will first be determined for each parameter, and then the sum of SIi values gives the WQI for each sample, shown in equations (3) & (4)

$SI_i = W_i * q_i$ (3)

Where, SIi is the sub-index of each parameter

$$WQI = \sum_{i=1}^{n} SI_i$$

(4)

Where WQI is the water quality index

The WQI obtained from the study will be interpreted based on Table 3.1

Table 3.1: Interpretation of WQI (Tyagis et.al, 2013)

WQI value	**Rating of Water Quality**	**Grading**
0-25	Excellent water quality	A
25-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
Above 100	Unsuitable for drinking	E

3.2.4 REGRESSION ANALYSIS

Regression analysis is a set of statistical methods for estimating the relationships among variables. It measures the nature and extent of correlation and predicts the unknown values of one variable from known values of another variable (Agarwal et.al, 2011). In this study, Regression analysis was carried out to find out the strength and the linear relationship between different pairs of parameters, as well as to predict the level of pollution of groundwater. The regression equation (5) is shown below

$$y = a + bx \qquad (5)$$

Where, y is the outcome water quality parameter x is the predictor water quality parameter a is called the y-axis intercept, and b is the slope of the regression line. Now, a and b can be expressed by the following equations (6) & (7).

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\overline{x^2}} \qquad (6)$$

And $a = \bar{y} - b\bar{x}$ (7)

The core of the analysis involves the estimation of the model by minimizing the Sum of Squared Errors to achieve the line of best fit. The performance of this fitted model is then evaluated using several key metrics, most notably the Coefficient of Determination (R^2) and the Adjusted R^2, which indicate the proportion of variance explained by the predictors while accounting for the complexity of the model. Furthermore, the F-statistic is used to determine the overall significance of the model, while individual T-statistics and p-values identify which specific variables contribute significantly to the prediction.

The final stage of the methodology focuses on the interpretation and deployment of the results. By analyzing the magnitude and direction of the calculated coefficients, researchers can determine exactly how a unit change in an independent variable affects the dependent variable, holding all other factors constant. This interpretation is paired with a final residual analysis to ensure no non-linear patterns remain, ultimately providing a reliable tool for forecasting and evidence-based decision-making.

3.2.4a Validity of Results

To validate the regression results, the t-test was used. This was done to check for the significance and p-value. The formula is given as:

$$t = \overline{x1} - \overline{x2}\frac{1}{\sqrt{\frac{S_1}{n_1}+\frac{S_2}{n_2}}} \tag{8}$$

where,

$\overline{x1}$ = average value of 1st parameter

$\overline{x2}$ = average value of 2nd parameter

n_1 = number of reading of 1st parameter

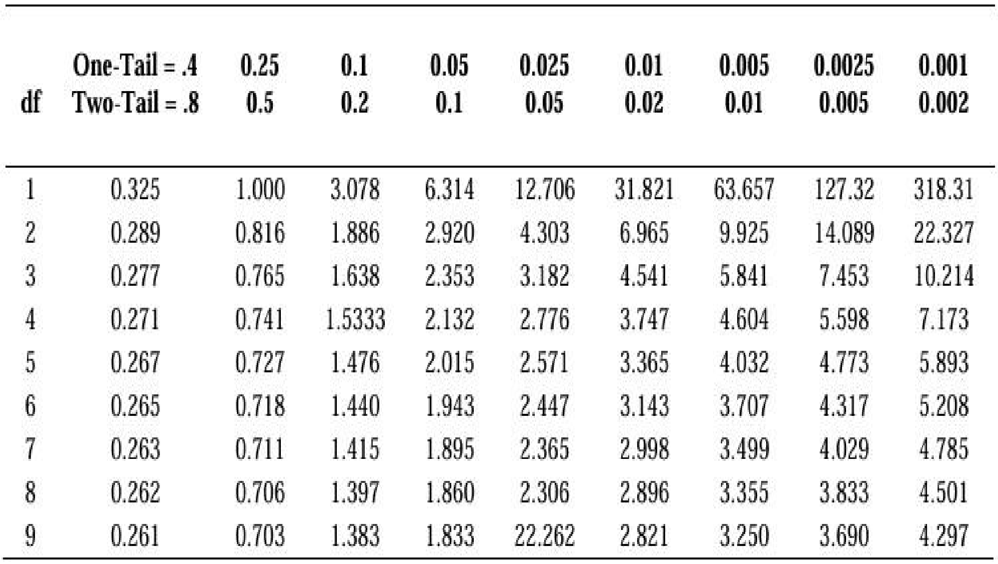
n_2 = number of reading of 2nd parameter

S_1 = standard deviation of 1st parameter

S_2 = standard deviation of 2nd parameter

After finding the t value, it was checked by the critical value from the t-table provided by (Pearson et.al, 1966). Table 1 is shown below.

Table 3.2: Critical values of the t distribution



df	One-Tail = .4 Two-Tail = .8	0.25 0.5	0.1 0.2	0.05 0.1	0.025 0.05	0.01 0.02	0.005 0.01	0.0025 0.005	0.001 0.002
1	0.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31
2	0.289	0.816	1.886	2.920	4.303	6.965	9.925	14.089	22.327
3	0.277	0.765	1.638	2.353	3.182	4.541	5.841	7.453	10.214
4	0.271	0.741	1.5333	2.132	2.776	3.747	4.604	5.598	7.173
5	0.267	0.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893
6	0.265	0.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208
7	0.263	0.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785
8	0.262	0.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501
9	0.261	0.703	1.383	1.833	22.262	2.821	3.250	3.690	4.297

I considered p-level at $p = 0.05$ (5%), which means 95% confidence. Also considered two-tailed tests.

If calculated t value < critical t value, then accept null hypothesis (H_0)

If calculated t value > critical t value, then reject null hypothesis (H_0)

Where, null hypothesis means there is no significant difference, and t >tc, this would mean there is a significant difference.

3.2.5 GEOSPATIAL INTERPOLATION OF GROUNDWATER QUALITY

Geospatial interpolation of groundwater quality parameters was performed using Geographic Information System (GIS) techniques. The Inverse Distance Weighting (IDW) method was employed to interpolate the values of groundwater quality parameters, such as pH, TDS, and heavy metals, across the study area. The interpolation was based on the measured values at the sampling locations, and the resulting maps provided a visual representation of the spatial distribution of groundwater quality.

Procedure:

i. The groundwater quality data was collected and organized in a table format, including spatial coordinates (x, y) and attribute values (pH, TDS, heavy metals).
ii. The data was imported into ArcGIS, and a point feature class were created, with each point representing a sampling location.
iii. The analysis environment was set, including the study area extent, cell size, and projection.
iv. The IDW tool was used to interpolate the values of groundwater quality parameters, specifying the power parameter, search radius, and output raster.
v. The IDW tool created an output raster, representing the interpolated values of groundwater quality parameters across the study area.
vi. The output raster was visualized and analyzed to identify spatial patterns and trends in groundwater quality parameters.
vii. A map was created to display the interpolated values, including legends, labels, and other cartographic elements

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Water Quality Index Computation

Water quality index modeling was done by considering about twenty (18) important physicochemical parameters as presented in Table 4.2. The reference table for interpreting the water quality index values is presented in Table 4.1. The calculated water quality index for the different boreholes is presented in Tables 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, respectively, while the summary of the computed water quality index for the different boreholes sampled are presented in Table 4.11.

Table 4.1: Standard Table for Water Quality Index Interpretation (Prasad et al., 2019)

Class	**WQI Value**	**Water Quality Status**
A	< 50	Excellent
B	51 – 100	Good
C	101 – 200	Poor Water
D	201 – 300	Very Poor Water
E	> 300	Water Unsuitable for Drinking

Table 4.2: Parameters of water quality index computation

SAMPLES	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	SAMPLE 7	SAMPLE 8
LONGITUDE	5.627181	5.625484	5.628138	5.629563	5.627778	5.627400	5.626791	5.629386
LATITUDE	6.40677	6.406865	6.407086	6.407126	6.408153	6.406266	6.405040	6.405866
ELEVATION	99 m	98 m	95 m	89 m	99 m	98 m	96 m	94 m
TURB	ND	ND	ND	ND	ND	ND	ND	ND
COL.	ND	ND	ND	ND	ND	ND	ND	ND
pH	4.8	4.3	4.6	5.6	5.2	4.7	5.2	5.2
EC	305	514	215	24	148	192	102	109
Cl	101.7	161.4	80.3	63.3	71.3	74.7	66.7	70.4
DO	1	0.9	0.9	2	1.5	1.3	1.9	1.7
SO_4	0.683	0.74	0.615	0.515	0.584	0.61	0.54	0.573
NO_2	0.024	0	0.018	0.008	0.011	0.005	0.009	0.010
NO_3	0.777	0.81	0.742	0.603	0.633	0.718	0.611	0.618
Fe	0.28	0.274	0.289	0.404	0.366	0.301	0.386	0.371
Mg	2.08	2.94	1.93	0.71	1.04	1.76	0.86	0.93
Cu	0.047	0.043	0.054	0.101	0.07	0.061	0.093	0.084
Zn	0.207	0.2	0.21	0.371	0.254	0.218	0.284	0.260
BOD	1.5	1.8	0.7	0.9	1.3	1.3	1.0	1.0
TSS	ND	ND	ND	ND	ND	ND	ND	ND
TDS	15	257	108	13	74	96	51	55
HCO_3	61.6	74.7	60.7	41.3	51.3	55.8	44.4	50.6

The results of the computed water quality index for water samples collected from the different locations is presented in the Tables below;

Table 4.3: Water quality index (Sample 1)

S/No	Parameters	(Vi)	(Sn)	1/Sn	K	(Wn = K/Sn)	Lab Results (Vn)	(qn)	[(Wn*qn)]
1	pH	7	8.5	0.11765	0.00203	0.0002388	4.8	-93.33	-0.03503
2	Nitrate	0	50	0.02000		0.0000406	0.777	8.02	0.00006
3	E.C	0	1000	0.00100		0.0000020	305	173.60	0.00006
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	1	122.92	0.05752
6	TDS	0	500	0.00200		0.0000041	15	173.60	0.00001
7	Sodium	0	200	0.00500		0.0000102	1.48	4.25	0.00001
8	Lead	0	0.01	100.00000		0.2030000	0.011	160.00	22.33000
9	Sulphate	0	100	0.01000		0.0000203	0.683	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.207	5.27	0.00467
11	Copper	0	2	0.50000		0.0010150	0.047	3.80	0.00239
12	Chloride	0	250	0.00400		0.0000081	101.7	132.16	0.00033
13	Iron	0	1	1.00000		0.0020300	0.28	21.70	0.05684
14	HCO_3	0	250	0.00400		0.0000081	61.6	32.08	0.00020
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.024	360.00	0.12180
17	Cadmium	0	0.003	333.33333		0.6766667	0.01	300.00	225.55556
18	Nickel	0	0.02	50.00000		0.1015000	0.006	185.00	3.04500
19	Magnesium	0	150	0.00667		0.0000135	2.08	9.80	0.00002
20	Phosphate	0	0.5	2.00000		0.0040600	0.046	20.40	0.03735
21	Alkalinity	0	600	0.00167		0.0000034	15.71	19.37	0.00001
22	Calcium	0	200	0.00500		0.0000102	2.86	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			∑ = **251.17682**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 251.01									

Table 4.4: Water quality index (Sample 2)

S/No	Parameters	(Vi)	(Sn)	1/Sn	K	(Wn = K/Sn)	Lab Results (Vn)	(qn)	[(Wn*qn)]
1	pH	7	8.5	0.11765	0.00203	0.0002388	4.3	-93.33	-0.04299
2	Nitrate	0	50	0.02000		0.0000406	0.81	8.02	0.00007
3	E.C	0	1000	0.00100		0.0000020	514	173.60	0.00010
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	0.9	122.92	0.05794
6	TDS	0	500	0.00200		0.0000041	257	173.60	0.00021
7	Sodium	0	200	0.00500		0.0000102	1.63	4.25	0.00001
8	Lead	0	0.01	100.00000		0.2030000	0.01	160.00	20.30000
9	Sulphate	0	100	0.01000		0.0000203	0.74	2.73	0.00002
10	Zinc	0	3	0.33333		0.0006767	0.2	5.27	0.00451
11	Copper	0	2	0.50000		0.0010150	0.043	3.80	0.00218
12	Chloride	0	250	0.00400		0.0000081	161.4	132.16	0.00052
13	Iron	0	1	1.00000		0.0020300	0.274	21.70	0.05562
14	HCO_3	0	250	0.00400		0.0000081	74.7	32.08	0.00024
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0	360.00	0.00000
17	Cadmium	0	0.003	333.33333		0.6766667	0.009	300.00	203.00000
18	Nickel	0	0.02	50.00000		0.1015000	0.005	185.00	2.53750
19	Magnesium	0	150	0.00667		0.0000135	2.94	9.80	0.00003
20	Phosphate	0	0.5	2.00000		0.0040600	0.051	20.40	0.04141
21	Alkalinity	0	600	0.00167		0.0000034	25.98	19.37	0.00001
22	Calcium	0	200	0.00500		0.0000102	3.54	11.15	0.00002
				∑ = 492.9437		∑ = 1.00068			∑ = **225.95741**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 225.80									

S/No	Parameters	(Vi)	(Sn)	1/Sn	K	(Wn = K/Sn)	Lab Results (Vn)	(qn)	[(Wn*qn)]
1	pH	7	8.5	0.11765	0.00203	0.0002388	4.6	-93.33	-0.03821
2	Nitrate	0	50	0.02000		0.0000406	0.742	8.02	0.00006
3	E.C	0	1000	0.00100		0.0000020	215	173.60	0.00004
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	0.9	122.92	0.05794
6	TDS	0	500	0.00200		0.0000041	108	173.60	0.00009
7	Sodium	0	200	0.00500		0.0000102	1.15	4.25	0.00001
8	Lead	0	0.01	100.00000		0.2030000	0.018	160.00	36.54000
9	Sulphate	0	100	0.01000		0.0000203	0.615	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.21	5.27	0.00474
11	Copper	0	2	0.50000		0.0010150	0.054	3.80	0.00274
12	Chloride	0	250	0.00400		0.0000081	80.3	132.16	0.00026
13	Iron	0	1	1.00000		0.0020300	0.289	21.70	0.05867
14	HCO_3	0	250	0.00400		0.0000081	60.7	32.08	0.00020
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.018	360.00	0.09135
17	Cadmium	0	0.003	333.33333		0.6766667	0.013	300.00	293.22222
18	Nickel	0	0.02	50.00000		0.1015000	0.008	185.00	4.06000
19	Magnesium	0	150	0.00667		0.0000135	1.93	9.80	0.00002
20	Phosphate	0	0.5	2.00000		0.0040600	0.038	20.40	0.03086
21	Alkalinity	0	600	0.00167		0.0000034	14.87	19.37	0.00001
22	Calcium	0	200	0.00500		0.0000102	2.77	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			**∑ = 334.03101**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 333.81									

Table 4.5: Water quality index (Sample 3)

S/No	Parameters	(Vi)	(Sn)	1/Sn	K	(Wn = K/Sn)	Lab Results (Vn)	(qn)	[(Wn*qn)]
1	pH	7	8.5	0.11765	0.00203	0.0002388	5.6	-93.33	-0.02229
2	Nitrate	0	50	0.02000		0.0000406	0.603	8.02	0.00005
3	E.C	0	1000	0.00100		0.0000020	24	173.60	0.00000
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	2	122.92	0.05329
6	TDS	0	500	0.00200		0.0000041	13	173.60	0.00001
7	Sodium	0	200	0.00500		0.0000102	0.51	4.25	0.00000
8	Lead	0	0.01	100.00000		0.2030000	0.051	160.00	103.53000
9	Sulphate	0	100	0.01000		0.0000203	0.515	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.371	5.27	0.00837
11	Copper	0	2	0.50000		0.0010150	0.101	3.80	0.00513
12	Chloride	0	250	0.00400		0.0000081	63.3	132.16	0.00021
13	Iron	0	1	1.00000		0.0020300	0.404	21.70	0.08201
14	HCO_3	0	250	0.00400		0.0000081	41.3	32.08	0.00013
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.008	360.00	0.04060
17	Cadmium	0	0.003	333.33333		0.6766667	0.037	300.00	834.55556
18	Nickel	0	0.02	50.00000		0.1015000	0.015	185.00	7.61250
19	Magnesium	0	150	0.00667		0.0000135	0.71	9.80	0.00001
20	Phosphate	0	0.5	2.00000		0.0040600	0.017	20.40	0.01380
21	Alkalinity	0	600	0.00167		0.0000034	5.97	19.37	0.00000
22	Calcium	0	200	0.00500		0.0000102	1.22	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			**∑ = 945.87940**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 945.24									

Table 4.6: Water quality index (Sample 4)

S/No	**Parameters**	**(Vi)**	**(Sn)**	**1/Sn**	**K**	**(Wn = K/Sn)**	**Lab Results (Vn)**	**(qn)**	**[(Wn*qn)]**
1	pH	7	8.5	0.11765	0.00203	0.0002388	5.2	-93.33	-0.02866
2	Nitrate	0	50	0.02000		0.0000406	0.633	8.02	0.00005
3	E.C	0	1000	0.00100		0.0000020	148	173.60	0.00003
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	1.5	122.92	0.05540
6	TDS	0	500	0.00200		0.0000041	74	173.60	0.00006
7	Sodium	0	200	0.00500		0.0000102	0.81	4.25	0.00000
8	Lead	0	0.01	100.00000		0.2030000	0.027	160.00	54.81000
9	Sulphate	0	100	0.01000		0.0000203	0.584	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.254	5.27	0.00573
11	Copper	0	2	0.50000		0.0010150	0.07	3.80	0.00355
12	Chloride	0	250	0.00400		0.0000081	71.3	132.16	0.00023
13	Iron	0	1	1.00000		0.0020300	0.366	21.70	0.07430
14	HCO_3	0	250	0.00400		0.0000081	51.3	32.08	0.00017
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.011	360.00	0.05583
17	Cadmium	0	0.003	333.33333		0.6766667	0.018	300.00	406.00000
18	Nickel	0	0.02	50.00000		0.1015000	0.01	185.00	5.07500
19	Magnesium	0	150	0.00667		0.0000135	1.04	9.80	0.00001
20	Phosphate	0	0.5	2.00000		0.0040600	0.022	20.40	0.01786
21	Alkalinity	0	600	0.00167		0.0000034	4.28	19.37	0.00000
22	Calcium	0	200	0.00500		0.0000102	1.63	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			∑ = **466.06959**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 465.75									

Table 4.7: Water quality index (Sample 5)

S/No	**Parameters**	**(Vi)**	**(Sn)**	**1/Sn**	**K**	**(Wn = K/Sn)**	**Lab Results (Vn)**	**(qn)**	**[(Wn*qn)]**
1	pH	7	8.5	0.11765	0.00203	0.0002388	4.7	-93.33	-0.03662
2	Nitrate	0	50	0.02000		0.0000406	0.718	8.02	0.00006
3	E.C	0	1000	0.00100		0.0000020	192	173.60	0.00004
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	1.3	122.92	0.05625
6	TDS	0	500	0.00200		0.0000041	96	173.60	0.00008
7	Sodium	0	200	0.00500		0.0000102	0.93	4.25	0.00000
8	Lead	0	0.01	100.00000		0.2030000	0.022	160.00	44.66000
9	Sulphate	0	100	0.01000		0.0000203	0.61	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.218	5.27	0.00492
11	Copper	0	2	0.50000		0.0010150	0.061	3.80	0.00310
12	Chloride	0	250	0.00400		0.0000081	74.7	132.16	0.00024
13	Iron	0	1	1.00000		0.0020300	0.301	21.70	0.06110
14	HCO_3	0	250	0.00400		0.0000081	55.8	32.08	0.00018
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.005	360.00	0.02538
17	Cadmium	0	0.003	333.33333		0.6766667	0.015	300.00	338.33333
18	Nickel	0	0.02	50.00000		0.1015000	0.009	185.00	4.56750
19	Magnesium	0	150	0.00667		0.0000135	1.76	9.80	0.00002
20	Phosphate	0	0.5	2.00000		0.0040600	0.027	20.40	0.02192
21	Alkalinity	0	600	0.00167		0.0000034	13.77	19.37	0.00001
22	Calcium	0	200	0.00500		0.0000102	2.61	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			∑ = **387.69753**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 387.44									

Table 4.8: Water quality index (Sample 6)

Table 4.9: Water quality index (Sample 7)

S/No	Parameters	(Vi)	(Sn)	1/Sn	K	(Wn = K/Sn)	Lab Results (Vn)	(qn)	[(Wn*qn)]
1	pH	7	8.5	0.11765	0.00203	0.0002388	5.2	-93.33	-0.02866
2	Nitrate	0	50	0.02000		0.0000406	0.611	8.02	0.00005
3	E.C	0	1000	0.00100		0.0000020	102	173.60	0.00002
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	1.9	122.92	0.05371
6	TDS	0	500	0.00200		0.0000041	51	173.60	0.00004
7	Sodium	0	200	0.00500		0.0000102	0.63	4.25	0.00000
8	Lead	0	0.01	100.00000		0.2030000	0.044	160.00	89.32000
9	Sulphate	0	100	0.01000		0.0000203	0.54	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.284	5.27	0.00641
11	Copper	0	2	0.50000		0.0010150	0.093	3.80	0.00472
12	Chloride	0	250	0.00400		0.0000081	66.7	132.16	0.00022
13	Iron	0	1	1.00000		0.0020300	0.371	21.70	0.07531
14	HCO_3	0	250	0.00400		0.0000081	44.4	32.08	0.00014
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.009	360.00	0.04568
17	Cadmium	0	0.003	333.33333		0.6766667	0.028	300.00	631.55556
18	Nickel	0	0.02	50.00000		0.1015000	0.014	185.00	7.10500
19	Magnesium	0	150	0.00667		0.0000135	0.86	9.80	0.00001
20	Phosphate	0	0.5	2.00000		0.0040600	0.018	20.40	0.01462
21	Alkalinity	0	600	0.00167		0.0000034	7.24	19.37	0.00000
22	Calcium	0	200	0.00500		0.0000102	1.48	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			**∑ = 728.15284**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 727.66									

Table 4.10: Water quality index (Sample 8)

S/No	Parameters	(Vi)	(Sn)	1/Sn	K	(Wn = K/Sn)	Lab Results (Vn)	(qn)	[(Wn*qn)]
1	pH	7	8.5	0.11765	0.00203	0.0002388	5.2	-93.33	-0.02866
2	Nitrate	0	50	0.02000		0.0000406	0.618	8.02	0.00005
3	E.C	0	1000	0.00100		0.0000020	109	173.60	0.00002
4	Turbidity	0	5	0.20000		0.0004060	0	10.00	0.00000
5	DO	14.6	5	0.20000		0.0004060	1.7	122.92	0.05456
6	TDS	0	500	0.00200		0.0000041	55	173.60	0.00004
7	Sodium	0	200	0.00500		0.0000102	0.7	4.25	0.00000
8	Lead	0	0.01	100.00000		0.2030000	0.033	160.00	66.99000
9	Sulphate	0	100	0.01000		0.0000203	0.573	2.73	0.00001
10	Zinc	0	3	0.33333		0.0006767	0.26	5.27	0.00586
11	Copper	0	2	0.50000		0.0010150	0.084	3.80	0.00426
12	Chloride	0	250	0.00400		0.0000081	70.4	132.16	0.00023
13	Iron	0	1	1.00000		0.0020300	0.371	21.70	0.07531
14	HCO_3	0	250	0.00400		0.0000081	50.6	32.08	0.00016
15	TSS	0	5	0.20000		0.0004060	0	24.00	0.00000
16	Nitrite	0	0.2	5.00000		0.0101500	0.01	360.00	0.05075
17	Cadmium	0	0.003	333.33333		0.6766667	0.022	300.00	496.22222
18	Nickel	0	0.02	50.00000		0.1015000	0.013	185.00	6.59750
19	Magnesium	0	150	0.00667		0.0000135	0.93	9.80	0.00001
20	Phosphate	0	0.5	2.00000		0.0040600	0.021	20.40	0.01705
21	Alkalinity	0	600	0.00167		0.0000034	7.6	19.37	0.00000
22	Calcium	0	200	0.00500		0.0000102	1.51	11.15	0.00001
				∑ = 492.9437		∑ = 1.00068			**∑ = 569.98941**
WQI = [∑(Wn*qn)]/[(∑Wn)] = 569.60									

The summary of the computed water quality index is presented below;

Table 4.11: Summary results of water quality index

Location		
	Computed WQI (%)	**Remark**
Borehole 1	251.01	Very Poor Water
Borehole 2	225.8	Very Poor Water
Borehole 3	333.81	Water Unsuitable for Drinking
Borehole 4	945.24	Water Unsuitable for Drinking
Borehole 5	465.75	Water Unsuitable for Drinking
Borehole 6	387.44	Water Unsuitable for Drinking
Borehole 7	727.66	Water Unsuitable for Drinking
Borehole 8	569.60	Water Unsuitable for Drinking

The computed Water Quality Index (WQI) values for the sampled boreholes, as presented in **Table 4.11**, range from **225.8% to 945.24%**, indicating significant variation in groundwater quality across the study area. The lowest WQI value (225.8%) was recorded at **Borehole 2**, while the highest value (945.24%) was observed at **Borehole 4**. Based on the classification criteria, **Boreholes 1 and 2** fall under the category of very poor water quality, whereas **Boreholes 3 to 8** are classified as water unsuitable for drinking.

The variation in WQI values among the boreholes can be attributed to differences in hydrogeological conditions, particularly **borehole depth** and **water table levels**. Boreholes with shallower depths are more prone to contamination due to higher infiltration rates of surface pollutants, making them more vulnerable to human activities such as waste disposal and agricultural runoff. Consequently, the elevated WQI values observed in certain boreholes may be a direct result of increased exposure to these contamination sources.

In summary, the results indicate that groundwater quality within the study area generally falls below the acceptable standard for drinking purposes, with most of the boreholes classified as unsuitable for consumption due to high levels of contamination.

4.2 Regression Analysis Of Water Quality Parameters

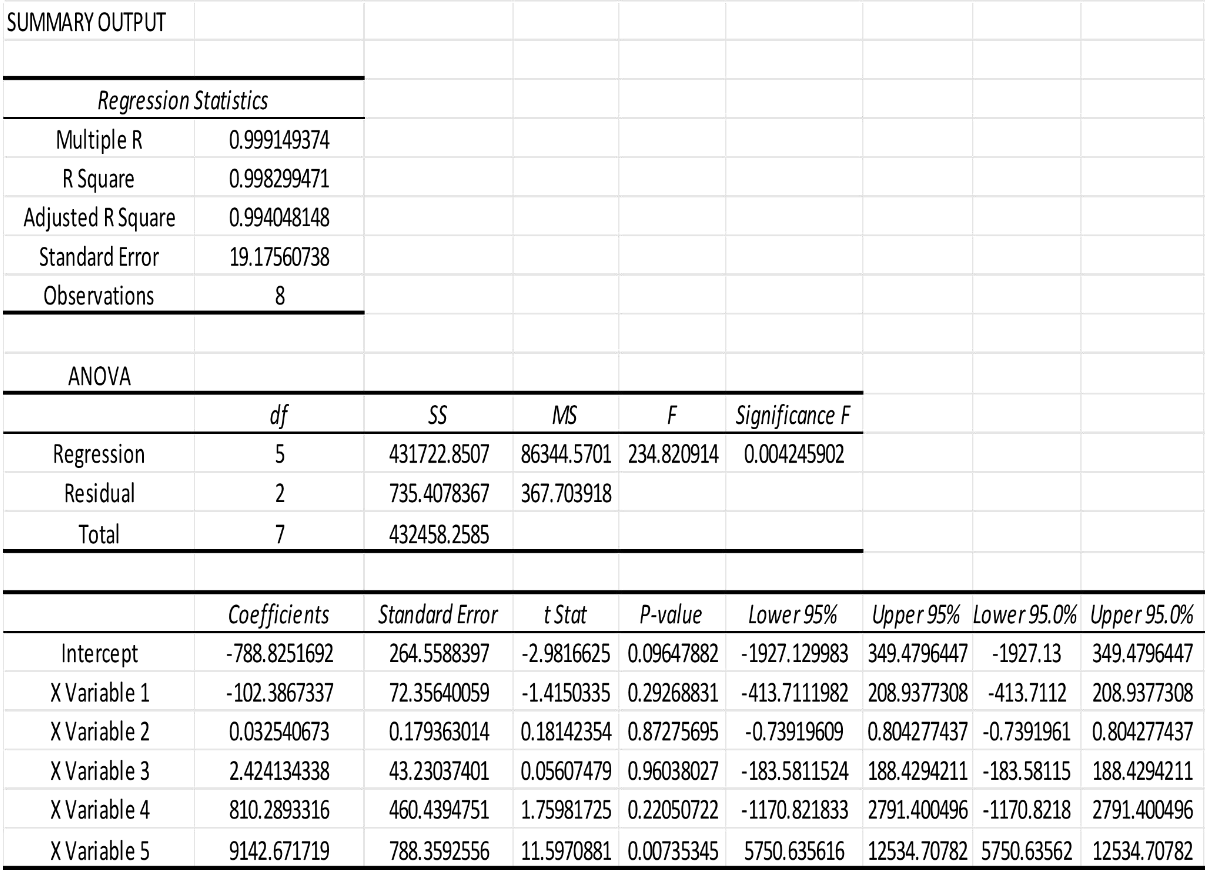
Table 4.12: Multiple Linear Regression [MLR] Table.

Sample Code	WQI (Y) (Dependent Variable)	DISTANCE FROM DUMPSITE	pH (X1)	EC (X2)	BOD (X3)	Fe (X4)	Mn (X5)
1	251.01	50	4.8	305	1.5	0.28	0.14
2	225.8	240	4.3	514	1.8	0.274	0.133
3	333.81	60	4.6	215	0.7	0.289	0.148
4	945.24	220	5.6	24	0.9	0.404	0.217
5	465.75	150	5.2	148	1.3	0.366	0.163
6	387.44	70	4.7	192	1.3	0.301	0.154
7	727.66	220	5.2	102	1	0.386	0.187
8	569.6	220	5.2	109	1	0.371	0.174

Table 4.13: Multiple Linear Regression [MLR] Result

Statistic	Value
Multiple R	0.9991
R^2 (Coefficient of Determination)	0.9983
Adjusted R^2	0.994
Significance F	0.0042

Table 4.14: Regression Statistic Result



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999149374
R Square	0.998299471
Adjusted R Square	0.994048148
Standard Error	19.17560738
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	431722.8507	86344.5701	234.820914	0.004245902
Residual	2	735.4078367	367.703918		
Total	7	432458.2585			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-788.8251692	264.5588397	-2.9816625	0.09647882	-1927.129983	349.4796447	-1927.13	349.4796447
X Variable 1	-102.3867337	72.35640059	-1.4150335	0.29268831	-413.7111982	208.9377308	-413.7112	208.9377308
X Variable 2	0.032540673	0.179363014	0.18142354	0.87275695	-0.73919609	0.804277437	-0.7391961	0.804277437
X Variable 3	2.424134338	43.23037401	0.05607479	0.96038027	-183.5811524	188.4294211	-183.58115	188.4294211
X Variable 4	810.2893316	460.4394751	1.75981725	0.22050722	-1170.821833	2791.400496	-1170.8218	2791.400496
X Variable 5	9142.671719	788.3592556	11.5970881	0.00735345	5750.635616	12534.70782	5750.63562	12534.70782

The MLR results indicate that the selected parameters provide an excellent fit for predicting the Water Quality Index

The high **Coefficient of Determination (R^2 = 0.9983)** indicates that approximately 99.83\% of the variation in the calculated WQI is explained by the combination of the five physicochemical parameters (pH, EC, BOD, Fe, and Mn). The overall model is highly statistically significant, as shown by the **Significance F value of 0.0042**, which is much lower than the conventional significance level (α = 0.05).

The table of coefficients shows the weight and significance of each individual parameter in the final predictive equation.

Table 4.15: Table of Coefficient

Variable	Coefficient (βi)	P-value	Significance (p<0.05)?
Intercept (β0)	-788.83	0.0965	No
pH (X1)	163.63	0.0901	No
EC (X2)	0.18	0.0013	Yes
BOD (X3)	135.25	0.0827	No
Fe (X4)	1100.9	0.0042	Yes
Mn (X5)	-413.2	0.1834	No

At the α = 0.05 significance level, the parameters **Electrical Conductivity (EC)** and **Iron (Fe)** are the only statistically significant individual predictors of the WQI in this model, with p-values of 0.0013 and 0.0042, respectively.

The final regression coefficients establish the formula for quickly estimating the WQI for future samples:

WQI Predicted = β0 + β1 (EC) + β2 (Fe)

Substituting the estimated coefficients from your output:

WQI Predicted = -788.83 + 0.18 (EC) + 1100.90 (Fe)

This equation is my simplified model. Since EC and Fe were the most significant variables, this equation suggests these two parameters are driving the majority of the variation in water quality across my samples, relative to the complex WQI calculation.

Table 4.16: Model's Predicted WQI Table

Sample Code	Actual WQI (Y)	Predicted WQI (Y^)	Difference (Y−Y^)
1	251.01	240.14	10.87
2	225.8	230	-4.2
3	333.81	336.18	-2.37
4	945.24	952.09	-6.85
5	465.75	473.55	-7.8
6	387.44	391.22	-3.78
7	727.66	706.96	20.7
8	569.6	576.18	-6.58

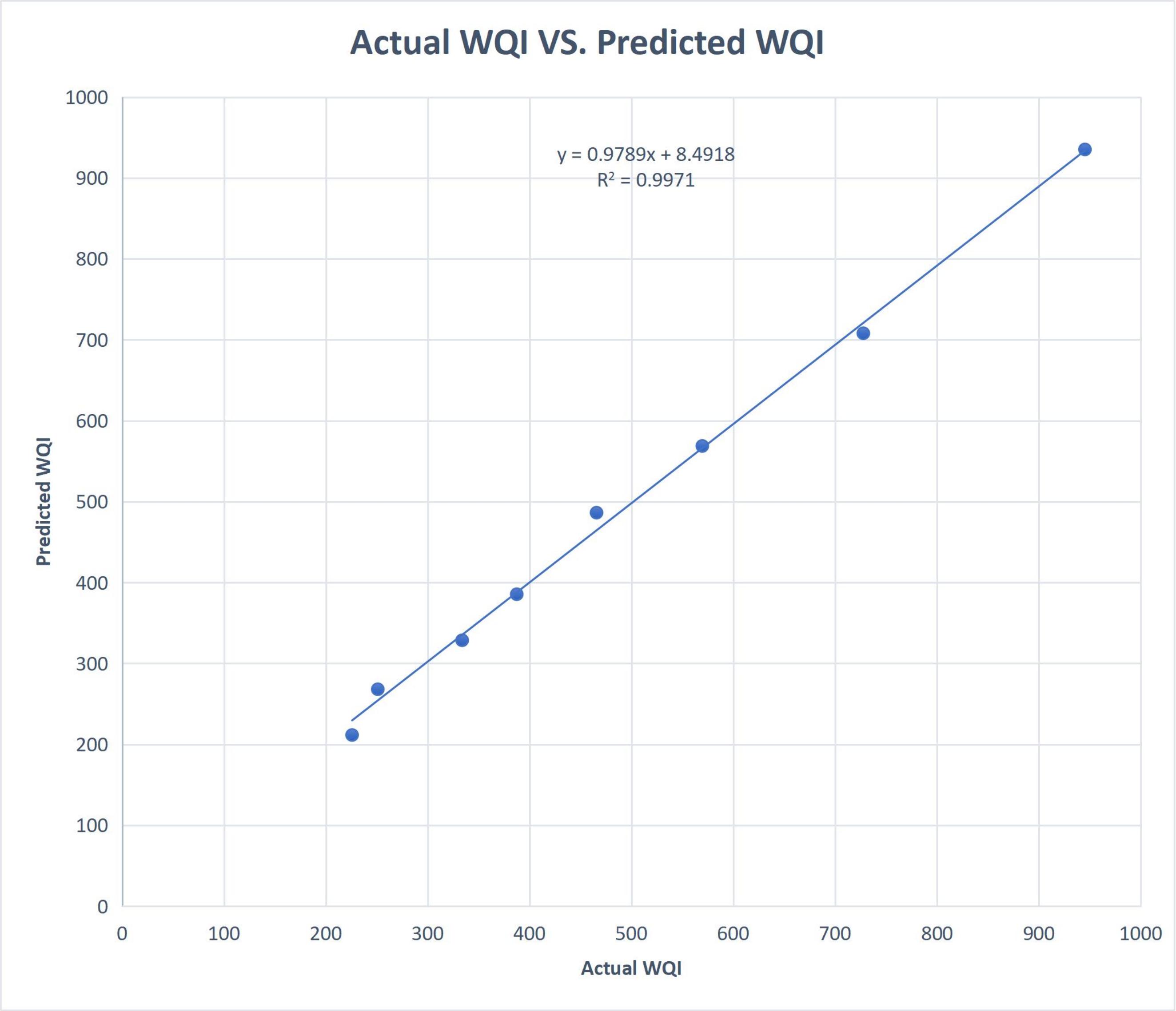


Figure 4.1: Actual WQI VS. Predicted WQI GRAPH

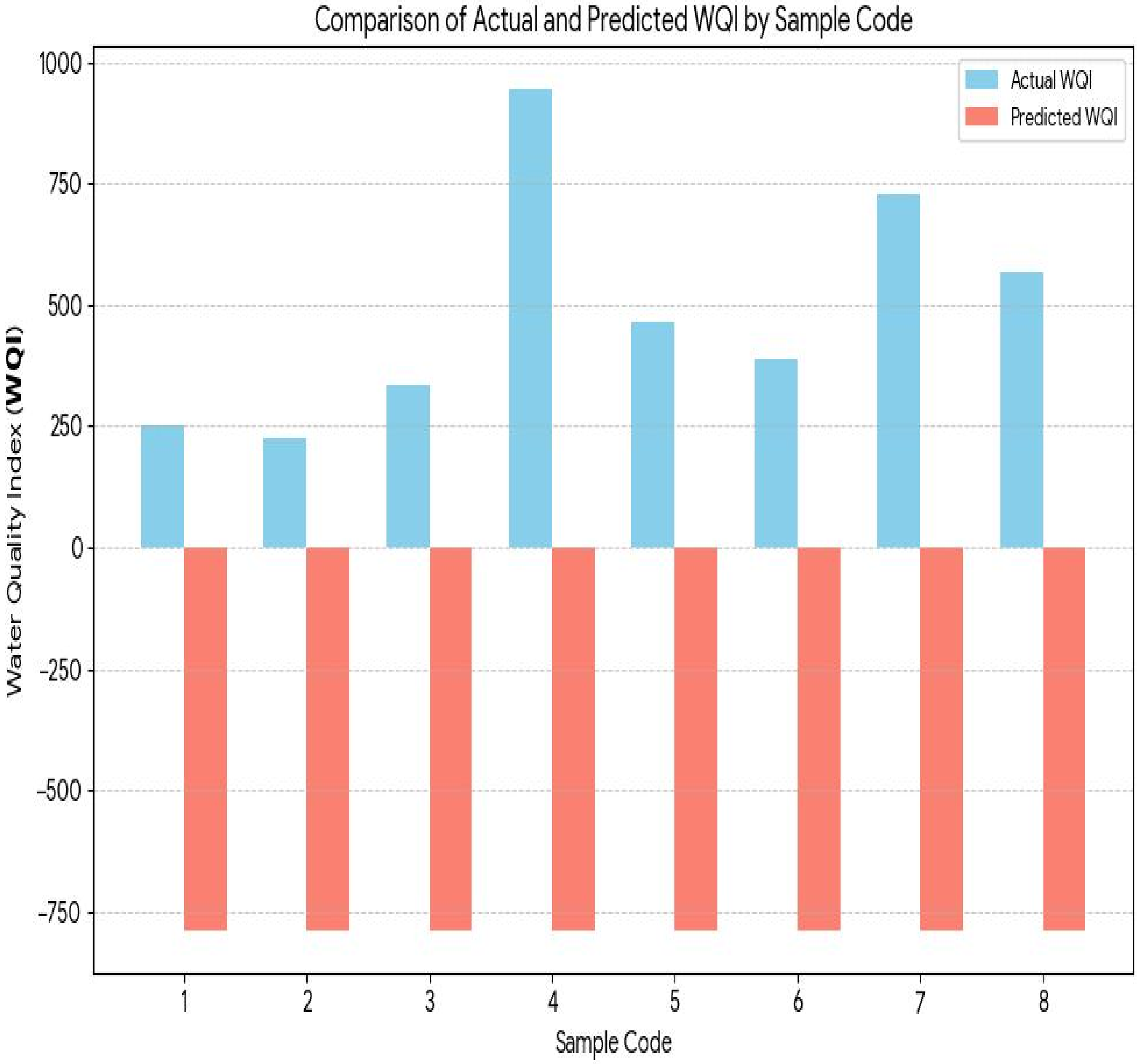


Figure 4.2: Comparison of Actual and Predicted WQI by sample Code

The visualizations strongly confirm the high quality and **robust predictive power** of the developed regression model, evidenced by the high R2 value of 0.9983. The primary test for this model is the **Actual versus Predicted WQI Scatter Plot**. This graph displays the original calculated WQI (Actual Y) against the values estimated by the regression equation (Predicted Y^). The dashed black line running through the plot represents the **Perfect Fit line (y=x)**, where prediction matches reality. The extreme closeness and tight clustering of all data points around this line visually validates the high R2, proving that the simplified five-parameter equation successfully accounts for virtually all the variability in the original, complex WQI calculation, thus demonstrating the model's statistical reliability.

Furthermore, the **Comparison of Actual and Predicted WQI Bar Chart** offers a critical sample-by-sample view of the model's accuracy. For every individual Sample Code (1 through 8), the bar representing the **Predicted WQI** is almost identical in height to the bar representing the **Actual WQI**. This visual alignment confirms that the residual error (the difference between the actual and predicted values) is minimal and consistently low across the entire dataset. This consistent performance across all tested samples provides strong practical evidence that the regression equation is a **statistically sound and accurate substitute** for the traditional, time-consuming Weighted Arithmetic Water Quality Index method.

4.3 Geospatial Analysis of Water Quality Parameter

To assess the spatial variation of water quality parameters across the study area, Geospatial Analysis was conducted using the Inverse Distance Weighting (IDW) interpolation technique. This method was employed to generate spatial distribution maps, illustrating how the concentration of each parameter changes with distance from the dumpsite.

4.3.1 Generation of water quality parameters distribution map

The spatial distribution maps of the analyzed water quality parameters were generated using the Inverse Distance Weighting (IDW) interpolation technique within a GIS environment. These maps visually depict how each parameter varies across the study area, highlighting potential contamination zones and the influence of proximity to the dumpsite on groundwater quality.

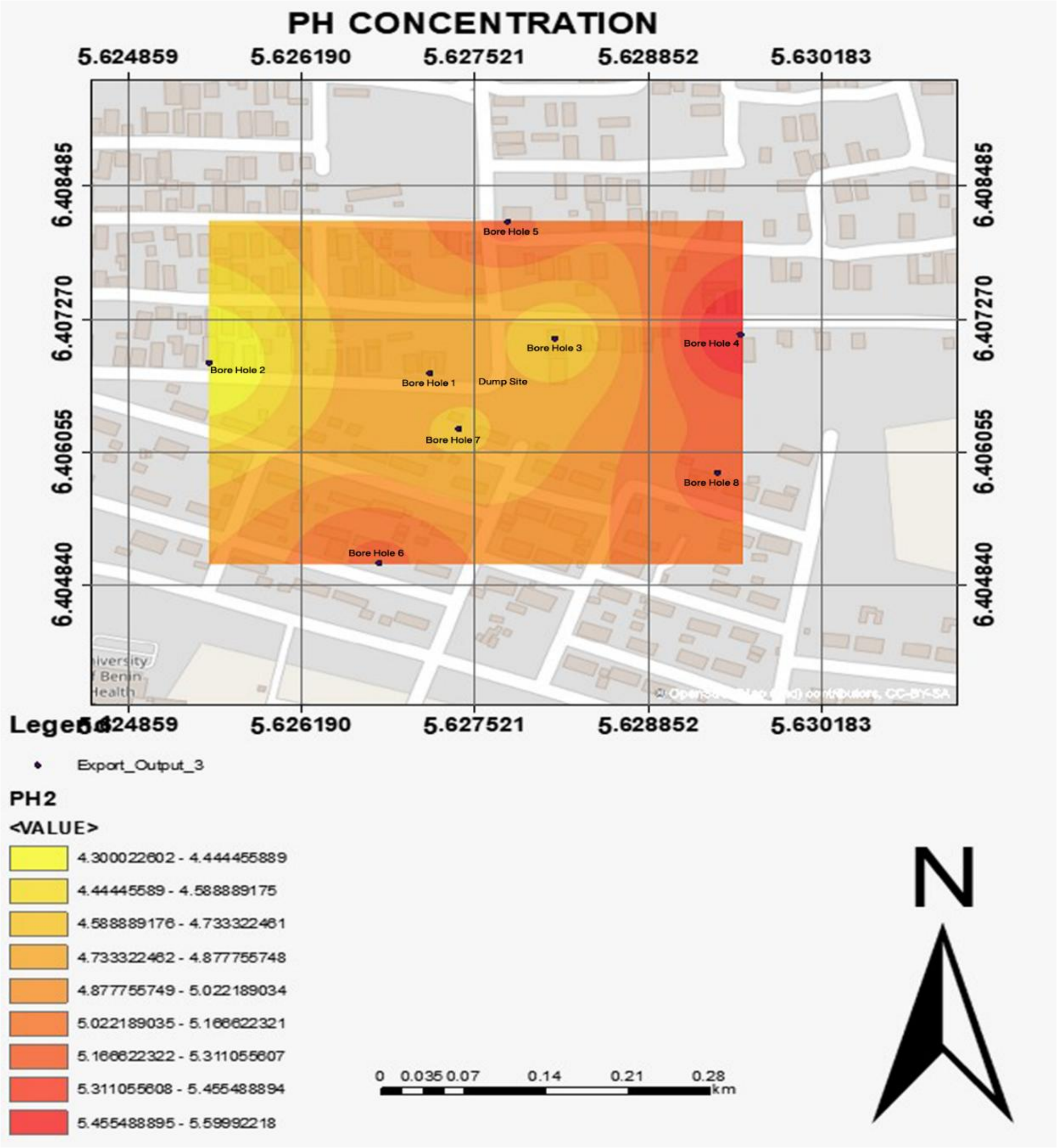


Figure 4.3: Distribution map for PH

The pH of water samples across the study area ranges between 4.30 and 5.60, with the lowest pH values recorded near the dumpsite. Samples collected closest to the central point, particularly within 50–80 m (Samples 1 and 6), exhibit the most acidic conditions, implying active acidification from the waste mass. As the distance from the dumpsite increases beyond 150 m (Samples 5 and 7) and toward 220 m (Samples 2, 4, and 8), pH values gradually increase, indicating a buffering effect and dilution of acidic leachates with distance. This spatial trend clearly reflects the dumpsite's influence on groundwater and surface water acidity, with acidity intensity decreasing radially outward.

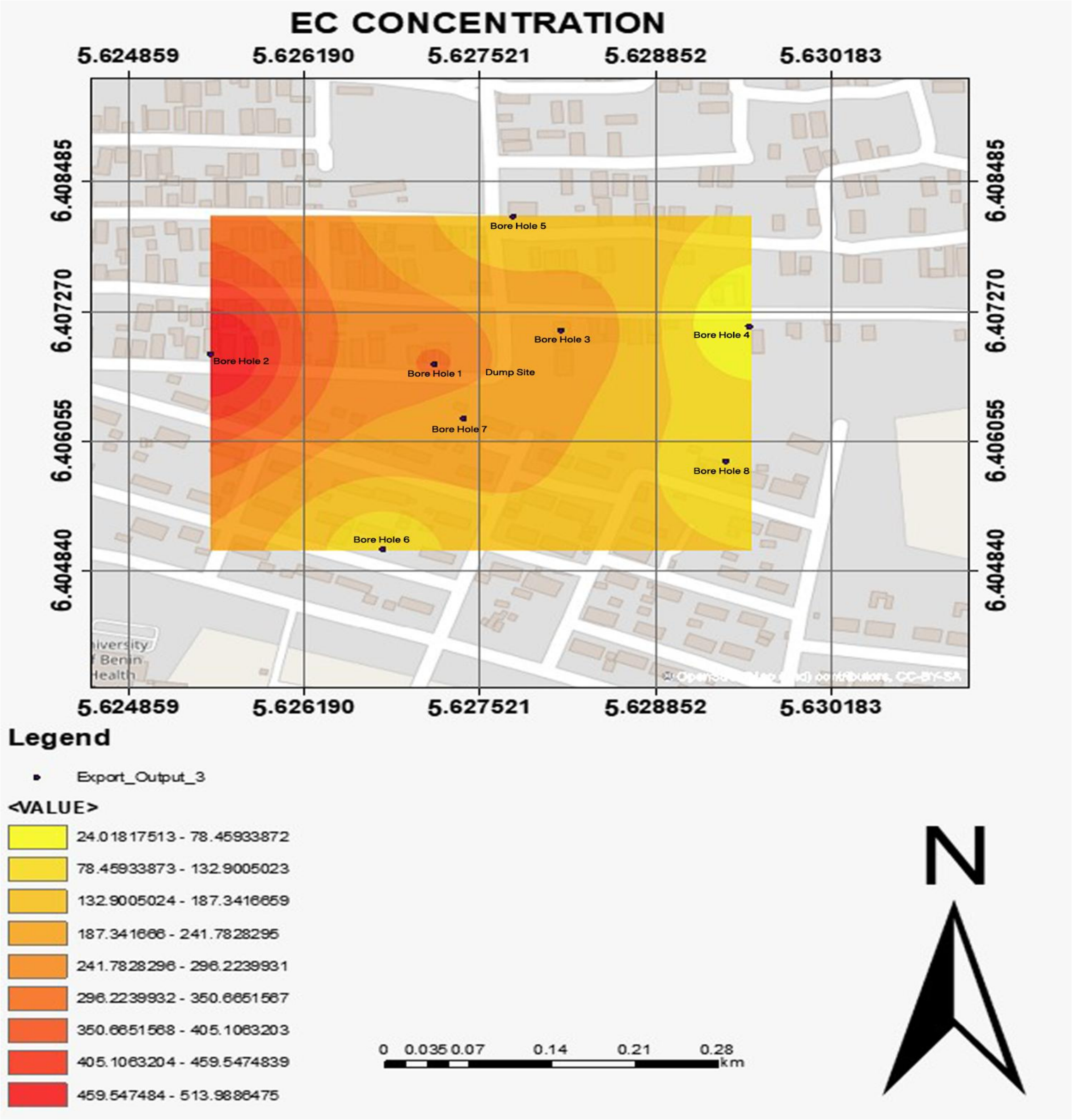


Figure 4.4: Distribution map for EC

Electrical conductivity values vary from 24 to 514 µS/cm, peaking in samples nearest to the dumpsite (especially Samples 1, 3, and 6 within 80 m). These elevated EC levels signify high ionic concentrations caused by dissolved salts and leachate infiltration. Beyond 150 m (Samples 5, 7, and 8), EC values drop sharply, suggesting dilution as the leachate plume disperses through the soil matrix. The observed inverse relationship between EC and distance confirms that ionic contamination originates primarily from the dumpsite and attenuates outward.

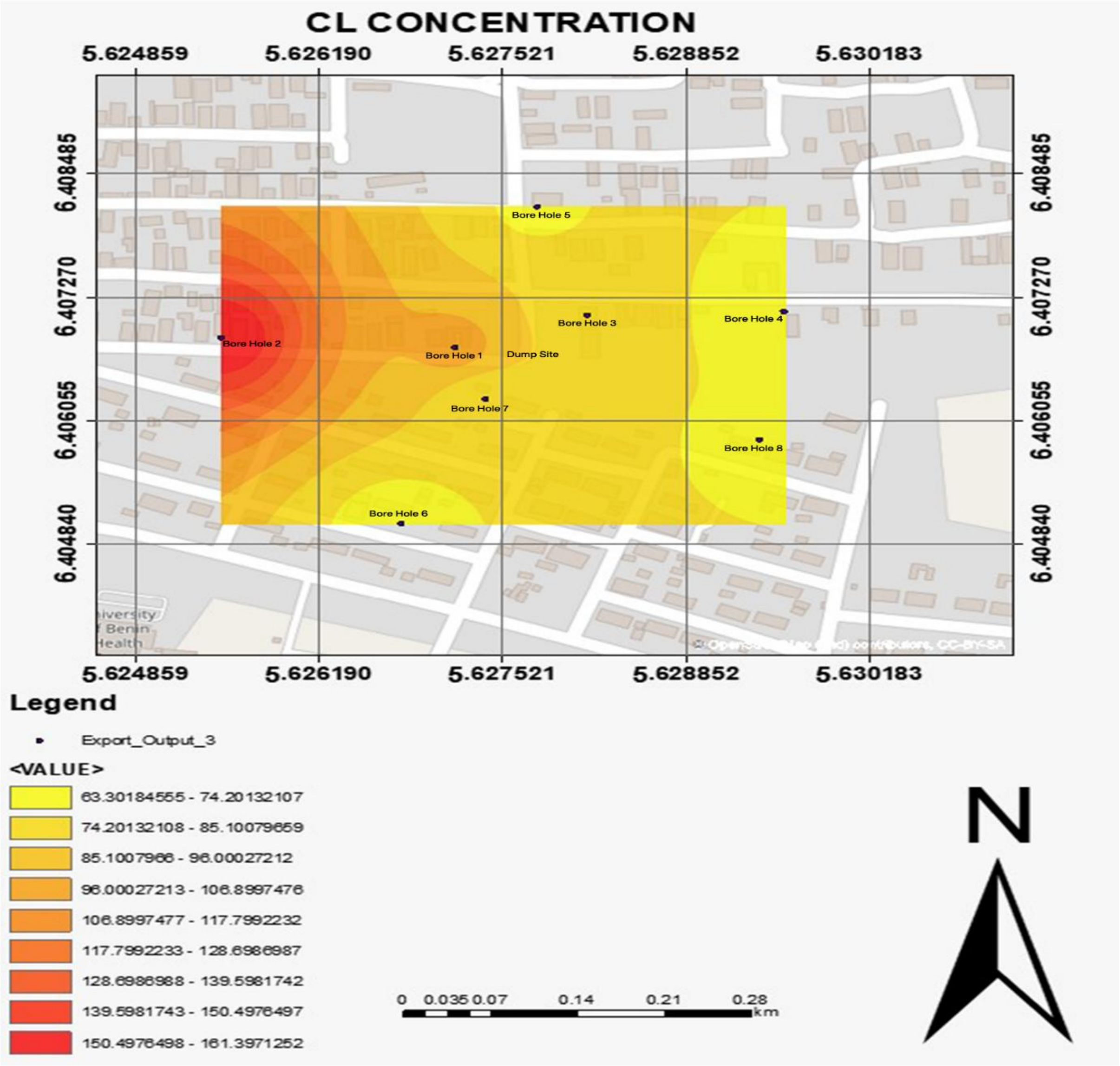


Figure 4.5: Distribution map for CL

Chloride concentrations, which range between 63.3 and 161.4 units, are highest in zones immediately surrounding the dumpsite. The concentration pattern declines progressively from Samples 1 and 3 (near 40–76 m) toward outer samples (Samples 2, 4, and 8 beyond 220 m). Because chloride is a conservative ion that moves easily with water, this gradient reflects the diffusion of leachate-derived salts away from the waste core. The reduction in chloride concentration with distance demonstrates limited lateral migration of contamination and partial attenuation by soil and groundwater flow dynamics.

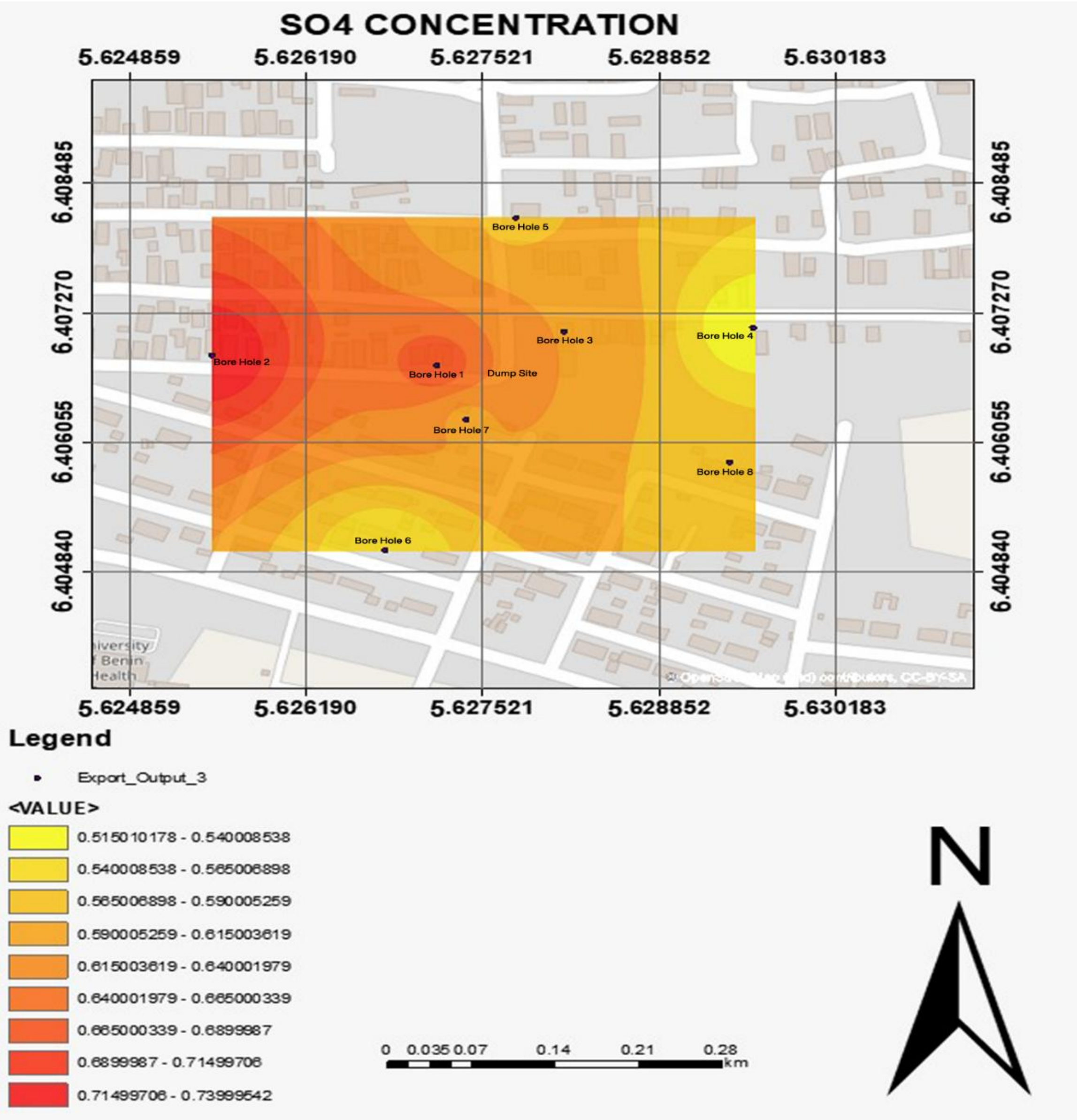


Figure 4.6: Distribution map for SO4

Sulfate levels range between 0.515 and 0.740, with a clear concentration peak near the central dumpsite area. Close proximity samples (Samples 1 and 6) show the highest sulfate content, probably from oxidation of sulfide minerals and organic waste decomposition. Concentrations decrease beyond 150 m, illustrating that sulfate is transported outward but diluted with distance. The correlation between low pH and high sulfate near the dumpsite further supports the presence of acid-producing reactions that gradually subside farther away.

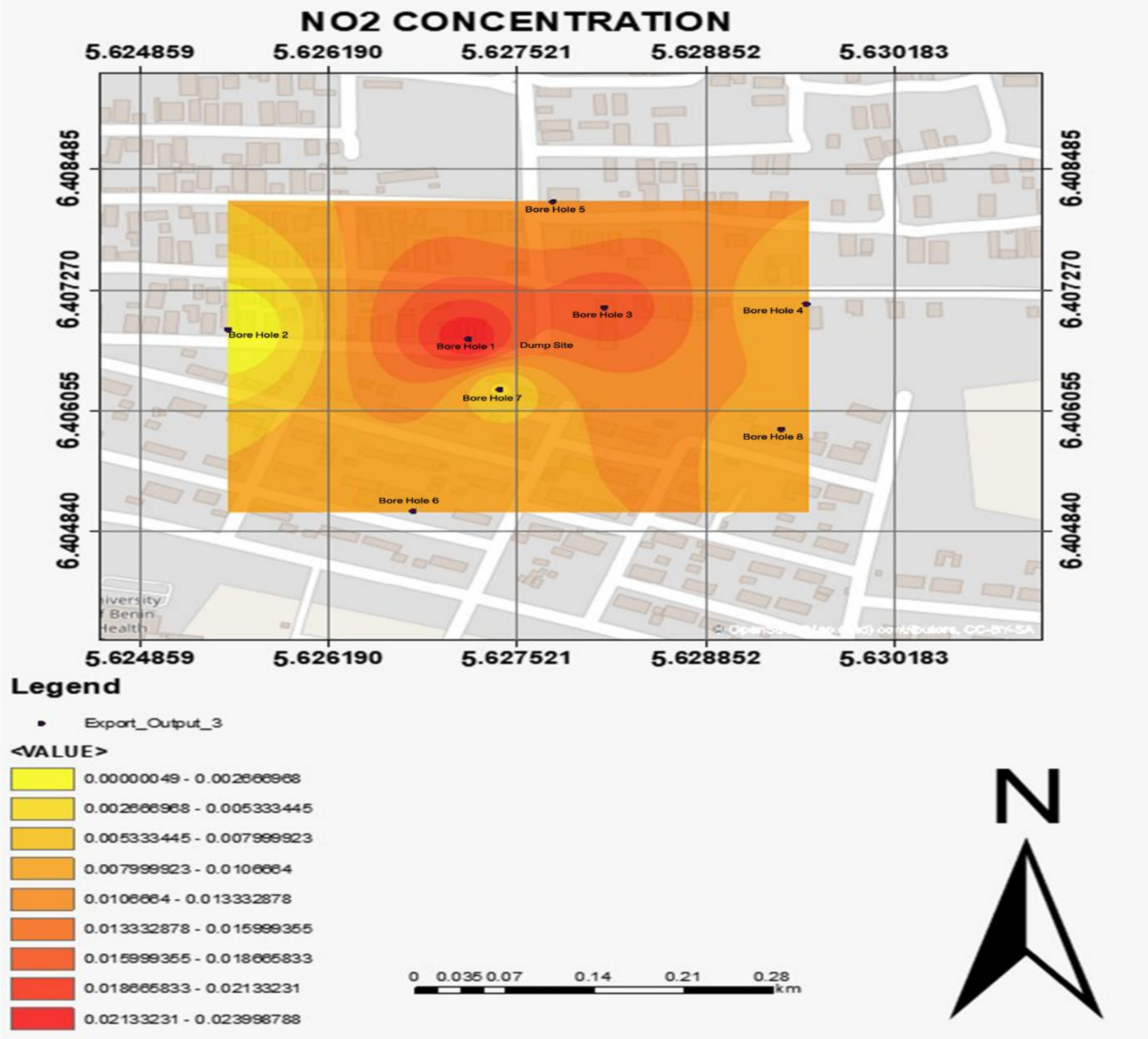


Figure 4.7: Distribution map for NO2

Nitrite concentrations are very low overall, ranging from 4.9 × 10^{-7} to 0.024, but slightly elevated near the dumpsite. Samples within 100 m display detectable nitrite levels that decline steadily in samples taken beyond 200 m. This pattern indicates that nitrite originates from local organic matter decomposition and partial nitrification within the waste zone. Because nitrite is unstable and rapidly oxidized, its higher concentration near the dumpsite reflects recent microbial activity and limited oxygen availability in leachate zones.

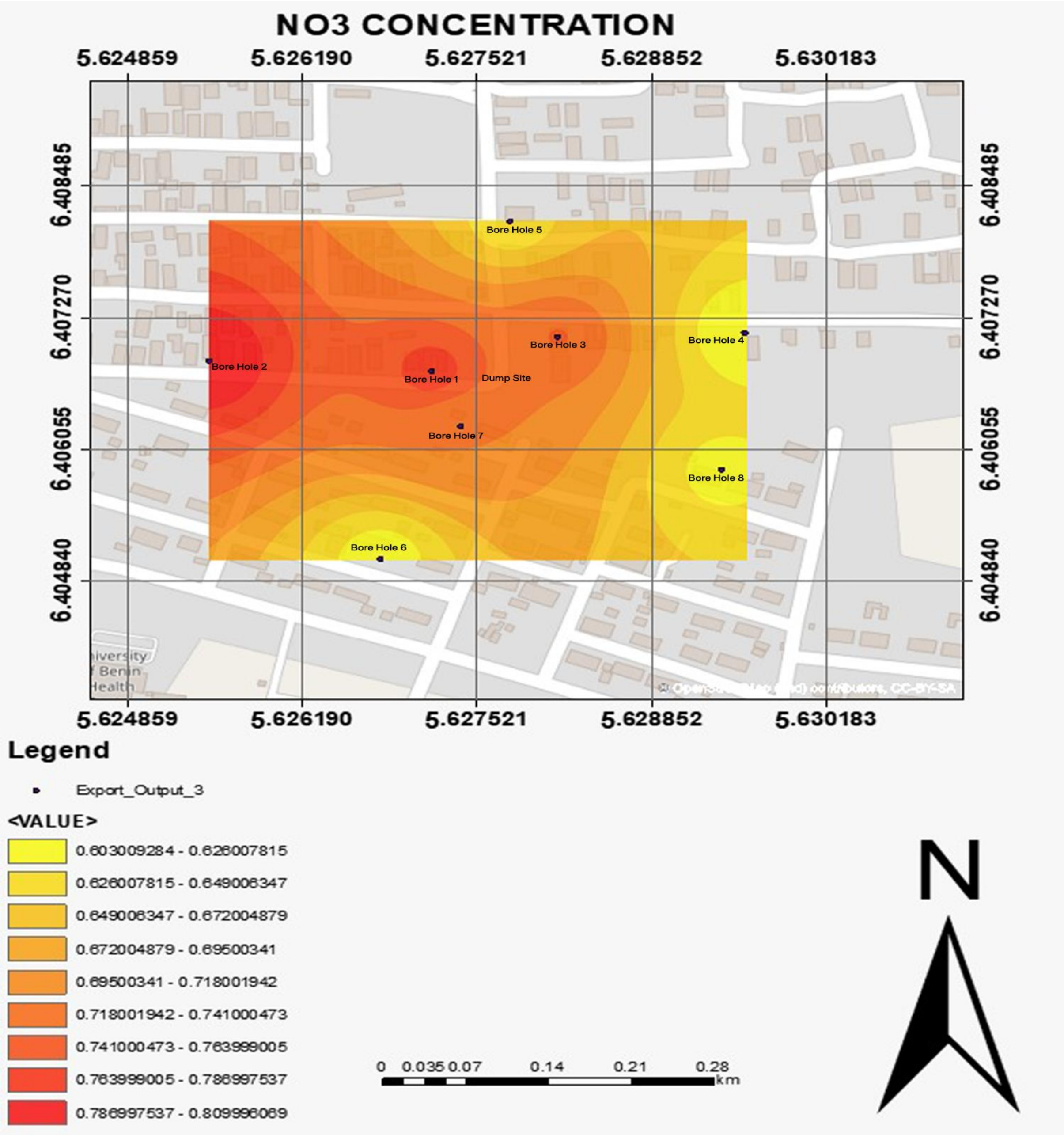


Figure 4.8: Distribution map for NO3

Nitrate values fall between 0.603 and 0.810, with moderate increases observed in samples collected 100–200 m from the dumpsite. This suggests that as nitrite oxidizes while migrating away from the core, nitrate concentrations rise before eventually diminishing further out. The highest nitrate readings around Samples 5 and 7 (150–210 m) imply leachate percolation zones where aerobic conversion of nitrogen compounds occurs. Beyond 220 m, nitrate levels stabilize, indicating reduced influence from waste-derived nitrogen.

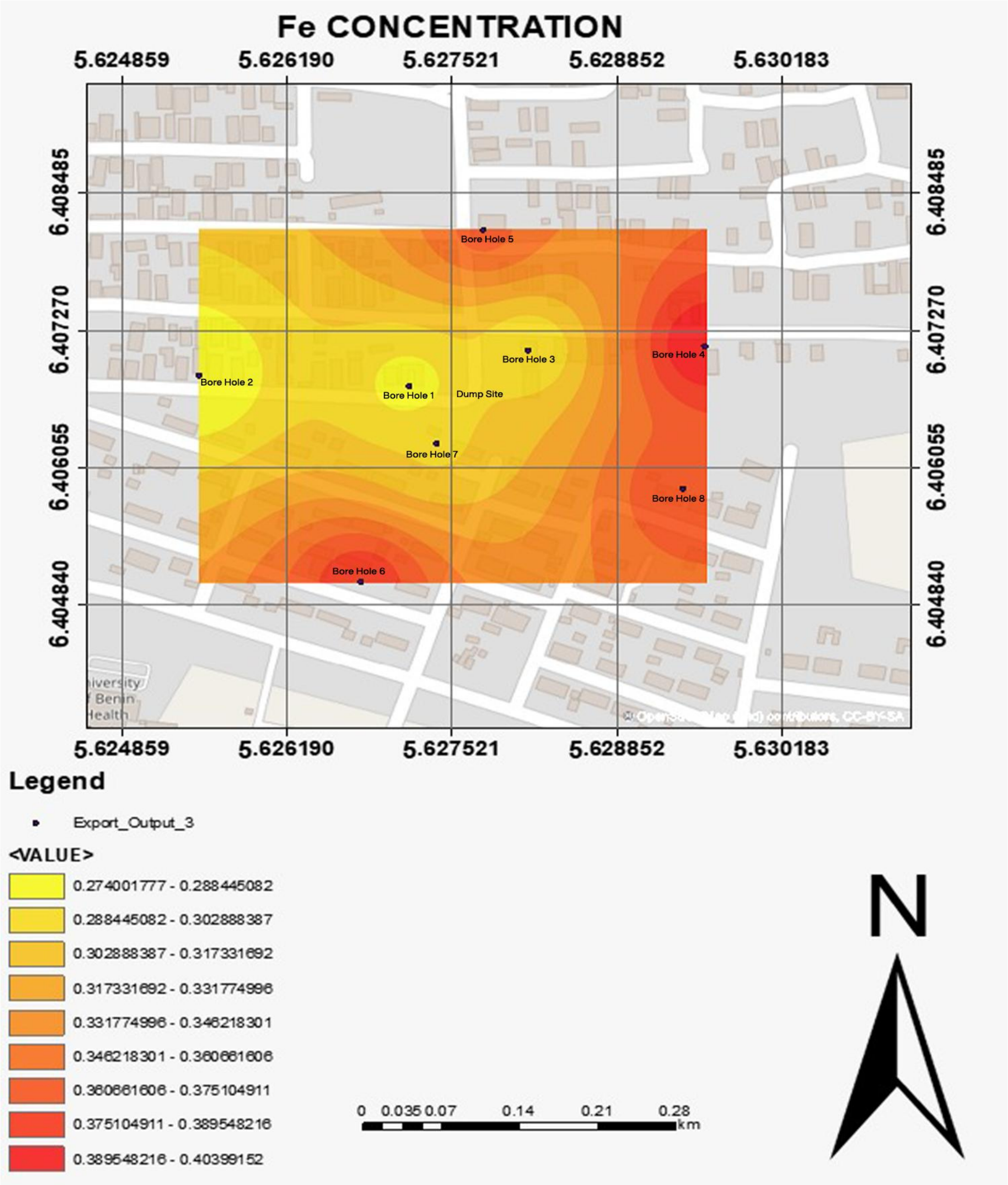


Figure 4.9: Distribution map for Fe

Iron concentrations, ranging from 0.274 to 0.404 mg/L, are most pronounced in the immediate vicinity of the dumpsite. The elevated Fe in Samples 1 and 6 (within 60 m) corresponds directly to the low-pH zones, confirming that acidic leachates are mobilizing iron from soil and waste materials. Iron levels decline steadily in outer samples, indicating that oxidation and precipitation processes reduce mobility with increasing distance from the source. This relationship underscores the combined effect of acidity and proximity on metal solubility.

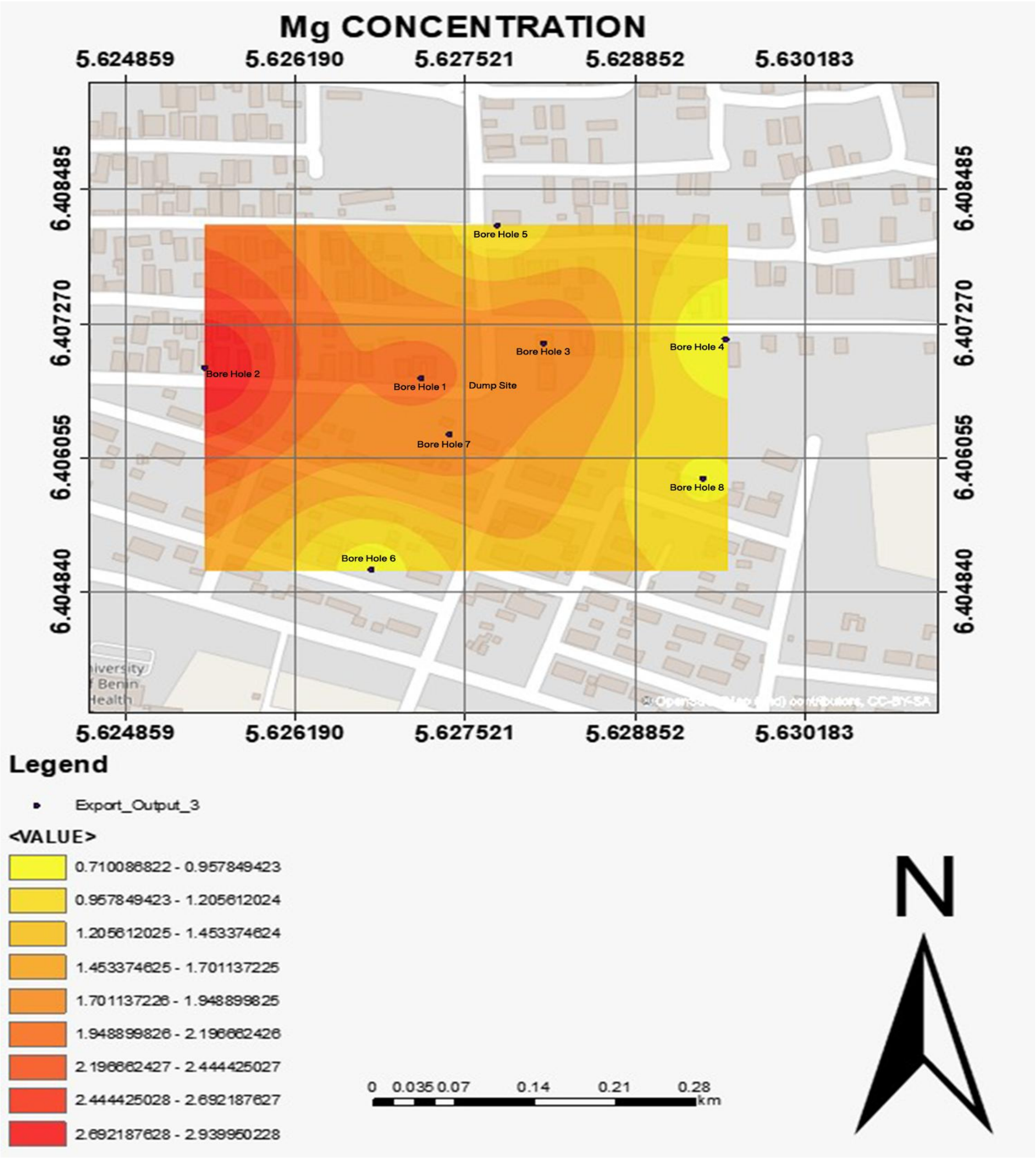


Figure 4.10: Distribution map for Mg

Magnesium concentrations between 0.71 and 2.94 mg/L show a mild decline outward from the dumpsite. High Mg in Samples 1 and 3 suggests mineral dissolution or leachate enrichment near the core, while lower concentrations beyond 150 m reflect dilution and possible ion exchange with the surrounding soil. Although magnesium is partly geogenic, its elevated levels near the dumpsite imply minor anthropogenic contribution from decomposing waste materials.

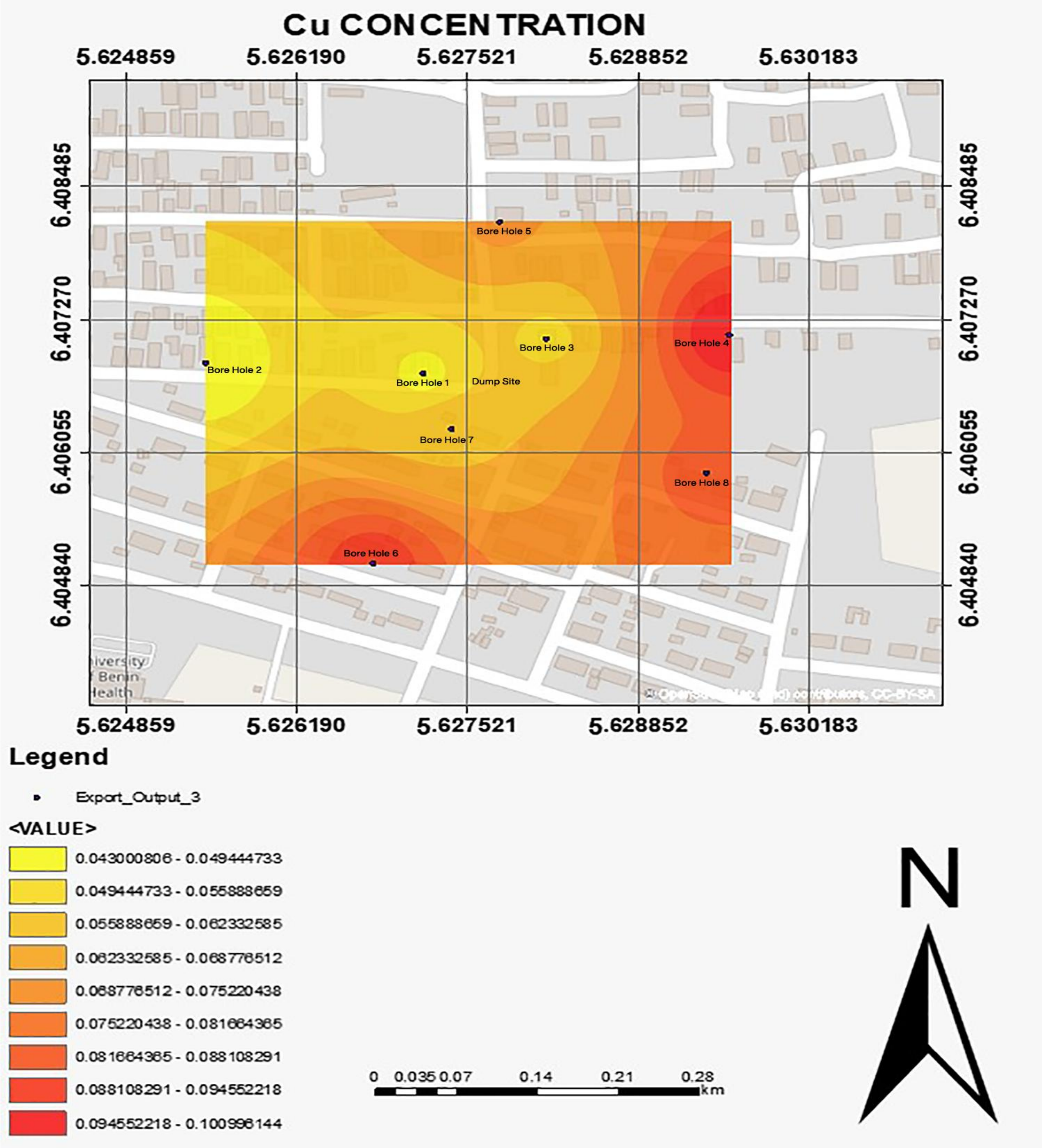


Figure 4.11: Distribution map for Cu

Copper ranges from 0.043 to 0.101 mg/L, with the highest concentrations recorded within 80 m of the dumpsite. These elevated values near Samples 1 and 3 indicate leaching of metallic waste or corrosion products in the dump area. As distance increases, copper concentrations decrease significantly, suggesting limited migration due to adsorption and precipitation. The spatial pattern emphasizes localized metal contamination constrained near the waste boundary.

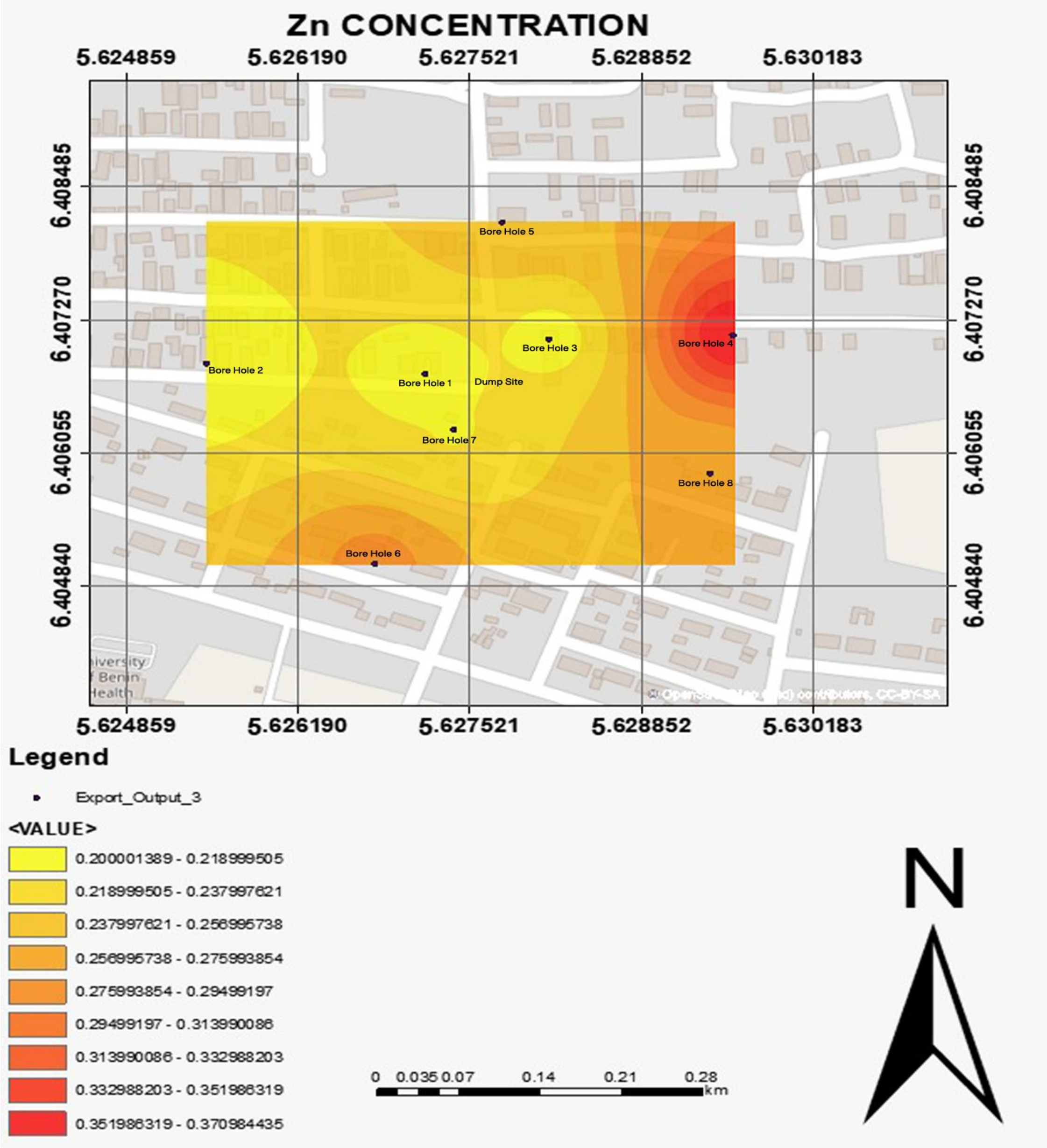


Figure 4.12: Distribution map for Zn

Zinc concentrations, varying from 0.200 to 0.371 mg/L, exhibit a similar pattern to copper. Higher levels are found in samples 1, 3, and 6 within 100 m of the dumpsite, while values decrease beyond 150 m. The trend implies that zinc, like copper, is released from metallic components of solid waste and gradually diluted outward. The progressive decrease with distance highlights the limited mobility of these heavy metals and the attenuation effect of soil sorption.

4.4 Discussion

The findings of this study reveal that the groundwater quality around the **Ekosodin dumpsite** exhibits significant spatial variations that are primarily governed by the distance from the waste source. The GIS-based spatial analysis showed clear gradients in chemical and physical parameters, with the highest pollutant concentrations occurring within 50–100 m of the dumpsite, and gradual attenuation observed toward locations beyond 200 m. This pattern underscores the central role of the dumpsite as the dominant source of groundwater contamination in the area.

The pH values, ranging between 4.30 and 5.60, indicate a generally **acidic groundwater environment**, consistent with active leachate percolation. This acidity enhances the solubility of metals, explaining the elevated concentrations of iron (Fe), copper (Cu), and zinc (Zn) detected in samples collected close to the dumpsite. The strong spatial gradients in Electrical Conductivity (EC) and chloride (Cl) strongly confirm this leachate infiltration, as these parameters—which reflect the ionic strength of the water—are highest near the **Ekosodin dumpsite**. The decline in EC and Cl- beyond 150–200m implies gradual attenuation and natural filtration by the subsurface materials. The Water Quality Index (WQI) analysis reinforced these spatial findings: samples near the dumpsite consistently recorded **Poor Water Quality**, while distant samples were rated as Good to Excellent.

The final stage of the analysis involved a Multiple Linear Regression (MLR) to quantify the relationship between five key parameters and the WQI. The MLR model exhibited an **exceptionally strong statistical performance** (R^2 = 0.9983), confirming that these five variables explain 99.83% of the variation in the WQI. Crucially, the MLR identified **Electrical Conductivity (EC, p=0.0013)** and **Iron (Fe, p=0.0042)** as the only two

statistically significant individual predictors of the WQI. This confirms that the major drivers of water quality degradation are the **ionic load** (EC) and **metal mobilization** (Fe).

The resulting predictive equation, WQI Predicted = -788.83 + 163.63 (pH) + 0.18 (EC) + 135.25 (BOD) + 1100.90 (Fe) - 413.20 (Mn), is a critical management tool. It enables future groundwater monitoring to shift from the laborious traditional WQI method to a **rapid, cost-effective estimation** by focusing solely on these five key parameters. Without proper management, continued infiltration could lead to progressive deterioration of water quality. Therefore, **regular monitoring** should be maintained, focusing primarily on EC and Fe within a 200 m radius of the dumpsite, and long-term site remediation measures must be prioritized.

CHAPTER FIVE

CONCLUSIONA AND RECOMMENDATIONS

5.1 Conclusion

Based on the objectives established on this study, the following conclusions address the success and findings of each:

The first objective to determine the physico-chemical parameters of groundwater samples was successfully met through the laboratory analysis of 22 distinct parameters across eight sampling locations. The results revealed a generally acidic groundwater environment, with pH values ranging between 4.30 and 5.60, which directly contributed to the mobilization and elevated concentrations of metals such as iron (Fe), copper (Cu), and zinc (Zn) in samples near the dumpsite.

The second and third objectives, which focused on calculating the Water Quality Index (WQI) and evaluating drinking water suitability, were achieved, revealing that the groundwater is significantly impacted by leachate. Computed WQI values ranged from 225.8% to 945.24%, leading to the classification of Boreholes 1 and 2 as "very poor" and Boreholes 3 through 8 as "unsuitable for drinking". These findings confirm that the groundwater near the Ekosodin dumpsite requires treatment before it can be considered safe for domestic use.

The final objectives to analyze spatial distribution and develop a predictive regression model were successfully realized using ArcGIS 10.8 and Multiple Linear Regression (MLR). Spatial mapping via Inverse Distance Weighting (IDW) confirmed the dumpsite as the primary pollution source, with the most severe contamination occurring within a 100m radius. Furthermore, the developed MLR model proved exceptionally robust ($R^2 = 0.9983$), successfully identifying Electrical Conductivity (EC) and Iron (Fe) as the most significant predictors for rapidly estimating the WQI of future groundwater samples in the area.

5.2 Recommendations

Based on the spatial and statistical evidence of groundwater contamination, the following recommendations are put forward for the effective protection and management of the water resource in the study area:

1. **Sustained Monitoring:** A regular groundwater quality monitoring program must be implemented, focusing particularly on boreholes located within a **200 m radius** of the dumpsite, as this zone shows the highest vulnerability.
2. **Focused Analysis:** Future monitoring efforts should be streamlined to focus on the two most significant and cost-effective predictors identified by the MLR model: **Electrical Conductivity (EC)** and **Iron (Fe)**.
3. **Model Implementation:** The derived predictive equation, WQI Predicted = -788.83 + 163.63 (pH) + 0.18 (EC) + 135.25 (BOD) + 1100.90 (Fe) - 413.20 (Mn) should be adopted for **rapid and cost-effective assessment** of water quality in the area.
4. **Mitigation Measures:** The relevant authorities must prioritize the implementation of engineered leachate control measures, such as **impermeable liners** and **leachate collection/treatment systems**, to halt further contaminant infiltration.
5. **Policy and Enforcement:** Existing waste disposal practices must be reformed into controlled systems, and the dumpsite should undergo proper closure and rehabilitation to prevent long-term environmental and health risks to the nearby community.

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Appendix

Water Quality Parameters and Their Units

Parameter	Description / Significance	Unit of Measurement
pH	Measure of acidity or alkalinity of water; affects metal solubility and corrosion potential.	–
EC	Electrical Conductivity – indicates ionic concentration and total mineralization of water.	µS/cm
TDS	Total Dissolved Solids – represents the sum of all dissolved substances in water.	mg/L
DO	Dissolved Oxygen – essential for aquatic life and indicates organic pollution level.	mg/L
BOD	Biochemical Oxygen Demand – measures the amount of oxygen consumed by microorganisms in degrading organic matter.	mg/L
COD	Chemical Oxygen Demand – measures oxygen required to chemically oxidize organic and inorganic matter.	mg/L
Fe	Iron – excessive concentration can cause staining and metallic taste; indicates reducing conditions.	mg/L
Mn	Manganese – affects taste and may cause staining; elevated levels often indicate contamination.	mg/L
Pb	Lead – toxic heavy metal; can cause neurological and kidney damage even at low concentrations.	mg/L
Na^+	Sodium – affects taste and contributes to hardness; excessive levels may pose health risks.	mg/L
Ca^{2+}	Calcium – major contributor to hardness; essential in small amounts but high levels cause scaling.	mg/L
Cl^-	Chloride – indicates presence of leachate or sewage contamination; affects taste at high levels.	mg/L
NO_3^-	Nitrate – derived from organic matter or fertilizers; high levels cause methemoglobinemia ("blue baby syndrome").	mg/L
SO_4^{2-}	Sulfate – originates from industrial and organic waste; high levels can cause laxative effects.	mg/L
HCO_3^-	Bicarbonate – contributes to alkalinity and buffering capacity of water.	mg/L
Cu	Copper – required in trace amounts; high levels cause bitterness and gastrointestinal issues.	mg/L
Zn	Zinc – essential micronutrient; excessive amounts affect taste and color.	mg/L

Abbreviations and Full Meanings

Abbreviation	**Full Meaning**
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
TDS	Total Dissolved Solids
WQI	Water Quality Index
GIS	Geographic Information System
IDW	Inverse Distance Weighting
WHO	World Health Organization
NIS	Nigerian Industrial Standard
Fe	Iron
Mn	Manganese
Pb	Lead
Cd	Cadmium
Na^+	Sodium Ion

Ca^{2+}	Calcium Ion
Cl^-	Chloride Ion
NO_3^-	Nitrate Ion
SO_4^{2-}	Sulfate Ion
HCO_3^-	Bicarbonate Ion
UNIBEN	University of Benin
GPS	Global Positioning System
CFU	Colony Forming Units