

**EFFECT OF OPEN DUMPSITE LEACHATE ON GROUNDWATER QUALITY: A
CASE STUDY OF SAINT SAVIOUR DUMPSITES, BENIN CITY, EDO STATE,
NIGERIA**

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**A PROJECT WRITTEN IN THE DEPARTMENT OF CHEMISTRY AND SUBMITTED
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REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE DEGREE OF THE
UNIVERSITY OF BENIN, BENIN CITY, NIGERIA.**

MAY, 2026.

CERTIFICATION

This is to certify that this research project was carried out by **Kennedy Aisosa OGBEIFUN** with the matriculation number **PG/PSC1606979** under the supervision of **PROF. MRS. JUSTINA UKPEBOR** in the Department of Chemistry, Faculty of Physical Sciences, University of Benin, Benin City, Edo State

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DEDICATION

This work is dedicated to **God Almighty**, whose grace, protection, and guidance sustained me throughout the course of this research and during my entire stay in school. All glory and honour belong to Him.

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I express my profound gratitude to my beloved brother, Dr. Lawrence Ogbeifun, and my sweet mother, Mrs. Roseline Ogbeifun, whose unwavering love, understanding, prayers, and financial support sustained me throughout my studies at the University of Benin. I am equally thankful to my siblings for their continuous encouragement and care.

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ABSTRACT

Groundwater pollution from improper waste disposal is a growing environmental and public-health concern in rapidly urbanizing regions such as Benin City, Nigeria. The widespread use of unlined, open dumpsites without leachate control has intensified the infiltration of decomposed organic and inorganic wastes into the subsurface, resulting in gradual deterioration of groundwater quality. This study investigates the influence of leachate from two major dumpsites on groundwater in the Saint Saviour area of Ikpoba-Okha LGA, where a dense population relies heavily on groundwater for domestic use. Groundwater samples were collected at radial distances of 100 m, 200 m, and 300 m from Dumpsite 1 and Dumpsite 2. Leachate samples were obtained directly from seepage zones within the waste cells. All samples were analyzed following APHA standard procedures. In situ measurements included temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity. Nutrient parameters—nitrate, phosphate, and sulphate—were determined using UV-Vis spectrophotometry. Heavy metals (Pb, Cd, Cr, Ni, Zn, Fe, Cu, Mn, Ca, Mg, Na, K) were analyzed through acid digestion (leachate) and Atomic Absorption Spectrophotometry (AAS). Results were compared with WHO (2017; 2021) and SON (2015) drinking-water standards. Findings indicate a clear spatial gradient of contamination: pollutant concentrations were highest within the dumpsites and decreased with distance. Leachate exhibited extremely high EC (up to 6,888 $\mu\text{S}/\text{cm}$), elevated TDS ($>3,300$ mg/L), high salinity, and pH values ranging from slightly acidic to neutral (4.70–7.46). These patterns reflect the breakdown of organic refuse, plastics, detergents, metals, and other waste materials. The acidity promotes metal solubility, increasing the mobility of toxic elements. Nutrient concentrations were elevated near the dumpsites, with nitrate (0.481–0.585 mg/L), phosphate (0.429–1.584 mg/L), and sulphate (0.070–1.538 mg/L), indicating early nutrient enrichment from sewage, food waste, and detergents. Though below WHO limits, these values suggest a potential progression toward eutrophication and long-term ecological stress. Heavy metals provided the most significant evidence of contamination. Lead (Pb) reached 0.70 mg/L—over sixty times the WHO guideline of 0.01 mg/L. Cadmium (0.01 mg/L), chromium (0.10 mg/L), and nickel (0.06 mg/L) exceeded or approached recommended limits. Their sources include batteries, electronics, metal scraps, plastics, and paints commonly found in municipal waste. These metals are persistent, non-biodegradable, and pose severe health risks such as neurological damage (Pb), renal dysfunction (Cd), carcinogenicity (Cr^{6+}), and respiratory disorders (Ni). Iron levels (up to 2.50 mg/L) exceeded aesthetic limits, affecting taste and appearance of water. Overall, results show that the shallow aquifers of Saint Saviour, characterized by the permeable sandy soils of the Benin Formation, are highly vulnerable to leachate migration. The findings align with previous studies highlighting groundwater deterioration around unregulated dumpsites in developing urban centers. This study underscores the urgent need for improved waste-management policies, groundwater monitoring, and the prevention of prolonged human exposure to contaminated water sources.

CHAPTER ONE

1.0 INTRODUCTION

Waste disposal remains a significant challenge in Nigerian communities, especially as population growth continues to rise. It involves all processes related to handling waste from its creation to its final disposal. When waste is not properly managed, it can negatively affect water quality and degrade soil composition. As a result, extensive research has been conducted on identifying the depth of clean water aquifers and assessing how modern dumpsites impact soil and groundwater (Ikem *et al.*, 2002; Ojo *et al.*, 2014; Dickenson *et al.*, 2023). Poor waste management can lead to serious environmental issues, as the breakdown of waste materials can alter the chemical and biological makeup of both water and soil resources (Dauda and Osita, 2003; Slomczynska and Slomczynski, 2004; Singh *et al.*, 2008; Regadio *et al.*, 2012; Li *et al.*, 2014).

Open dumpsites can significantly degrade environmental quality, posing serious risks of diseases and other public health challenges for nearby residents (Dong *et al.*, 2008).

Unfortunately, ensuring access to safe groundwater—free from chemical and microbial pollutants—remains difficult in many urban areas due to inadequate waste disposal and management systems. As a result, groundwater contamination caused by leachate migration from dumpsites has become a major environmental issue (Singh *et al.*, 2008). This leachate, consisting of both organic and inorganic byproducts of solid waste decomposition, infiltrates aquifers through rainwater percolation (Ganiyu *et al.*, 2016; Olajojo *et al.*, 2016). The contaminants carry a variety of toxic chemical compounds (Regadio *et al.*, 2012; Yang *et al.*, 2013; Li *et al.*, 2014).

Studies on heavy metals have become a vital tool in monitoring and regulating environmental impact assessments in urban areas (Asuen *et al.*, 2012). The presence of heavy metals can lead to the deterioration of soil organic matter and a reduction in the fertility potential of the topsoil.

Generally, soil interacts more with air and water than with external factors, often binding smaller particles into aggregates (Ukpebor *et al.*, 2003). Soils located near waste disposal sites tend to contain higher levels of organic matter, hazardous substances, and heavy metals compared to soils farther away (Imeokparia *et al.*, 2009; Imasuen and Omorogieva, 2013). Even low concentrations of heavy metal contamination can have long-term impacts on the environment, human health, and groundwater ecosystems (Omorogieva *et al.*, 2013). The sources of heavy metals include industrial and municipal waste, automobile emissions, agricultural activities, and poor land management practices. According to Allen *et al.* (1991), the type of metals and their chemical composition significantly influence their mobility in soil and groundwater. Chemical interactions can prevent metals from being adsorbed or precipitated, enabling their migration through groundwater systems (Evanko and Dzombak, 1997).

These challenges can significantly affect the environment, particularly in areas where effective environmental policies have not been established or enforced to manage the increasing generation of domestic and municipal waste. Benin City lacks an organized waste disposal system and faces poor sanitary conditions. It is essential to investigate the impact of indiscriminate waste disposal on groundwater quality. This study, therefore, aims to address this issue.

1.1 BACKGROUND OF PROBLEM

Groundwater serves as a vital source of drinking water, irrigation, and industrial supply worldwide, particularly in regions where access to treated surface water is limited. However, its

quality is increasingly threatened by poor solid waste management practices, especially the widespread use of unlimited open dumpsites. Leachate generated from these sites often contains heavy metals, organic compounds, and pathogenic microorganisms, which can infiltrate soils and contaminate aquifers (Aljaradin and Persson, 2016).

In many developing countries, including the study area, waste disposal systems are largely unregulated, and groundwater monitoring is minimal. Communities situated near dumpsites frequently relies on shallow wells and boreholes, heightening their exposure to waterborne diseases and toxic pollutants (Naveen *et al.*, 2017). The absence of adequate data on groundwater quality in such areas hampers informed decision-making and sustainable water management. This study therefore seeks to investigate the impact of open dumpsite leachate on groundwater quality in Saint Saviour dumpsite, providing baseline information to support public health protection and improved waste management policies.

1.2 STATEMENT OF PROBLEM

Groundwater is a major source of drinking water and other domestic uses for many communities. However, its quality is at risk due to poor waste management practices, especially the use of open dumpsites. Open dumpsites allow leachate (liquid formed from decomposing waste) to seep through the soil and into groundwater. This leachate often contains harmful substances such as heavy metals, chemicals, and diseases-causing organisms that can pollute water sources.

In the study area, waste is disposed of without proper planning or engineering controls to prevent leachate movement. Many residents rely on shallow wells and boreholes near these dumpsites, which increases their exposure to contaminated water and waterborne diseases. Unfortunately,

there is little information or research on the extent of groundwater pollution caused by these dumpsites.

This situation makes it important to study the effect of open dumpsite leachate on groundwater quality in Saint Saviour. The findings will provide useful data to raise awareness, guide waste management practices and help protect community health.

1.3 JUSTIFICATION OF RESEARCH WORK

Studying the impact of open dumpsite leachate on groundwater quality is crucial for:

Assessing environmental and public health risks associated with waste management practices.

Providing baseline data for policymakers and environmental agencies to develop effective waste management strategies.

Creating awareness on the need for proper waste disposal systems and groundwater protection.

Supporting sustainable development goals (SDGs) related to clean water, sanitation, and environmental sustainability.

1.4 SCOPE OF WORK

This study focuses on assessing the effect of open dumpsite leachate on groundwater quality within Saint Saviour. It involves the collection and analysis of groundwater samples from locations at varying distances from the dumpsite to evaluate levels of heavy metals contaminants. The research will also compare obtained water quality data with national and international water quality standards.

1.5 AIM AND OBJECTIVES

The aim of this research was to evaluate the impact of open dumpsite leachate (heavy metal pollutant Pb, Cd, Cr, Ni, Zn, Fe, Cu, Mg, Na, Mn, Ca, K) on the quality of groundwater in Saint Saviour.

To achieve this aim, the following objectives were sets:

1. Collection of samples from the study area,
2. Extraction of the heavy metal content using acid digestion
3. Assessment of the concentration of heavy metals using an atomic absorption spectrophotometer
4. Comparison of results obtained with set regulatory limits and literature
5. To make suitable recommendation to regulatory bodies and public health officials.

1.6 LITERATURE AND REVIEW

1.6.1 DUMPSITE

A dumpsite is a designated area where solid waste is deposited, often without proper engineering measures, environmental safeguards, or systematic waste management practices. In many cases, dumpsites are open and uncontrolled, allowing waste to accumulate directly on the ground without liners, leachate collection systems, or covering layers. Unlike sanitary landfills, dumpsites lack regulation and monitoring, making them a significant source of environmental pollution. Leachate—a contaminated liquid formed when rainwater filters through waste has the potential to infiltrate soil and potentially contaminate the groundwater. Dumpsites also serve as breeding grounds for pests, emit unpleasant odors, and pose serious risks to public health and the environment.

1.6.2 TYPES OF DUMPSITE

Dumpsites can be classified based on their level of regulation, engineering design, and environmental control measures:

1. **Open Dumpsites:** These are unregulated waste disposal areas where solid waste is dumped directly onto land without environmental controls. They lack liners, leachate collection systems, or gas management facilities. Open dumpsites are common in developing countries and pose high risks of soil, groundwater, and air pollution, as well as public health hazards.
2. **Controlled Dumpsites:** These are partially managed dumpsites where minimal operational measures are in place, such as periodic waste covering, restricted access, or basic drainage systems. Although they are an improvement over open dumps, they still lack the engineering and environmental safeguards of sanitary landfills.

1.6.3 IMAGES OF DUMPSITE



Figure 1.1: Mayomi Dumpsite, Off Saint Saviour, Benin City



Figure 1.2: 100Feet Dumpsite, Off Saint Saviour, Benin City

1.6.4 POLLUTION

Pollution is defined as the introduction of harmful substances or energy into the environment, resulting in adverse effects on human health, vegetation, and the ecological balance of natural systems. It may originate from anthropogenic activities such as industrialization and urban development, or from natural phenomena including volcanic eruptions and wildfires. The presence of pollutants disrupts environmental stability, poses significant health risks, and contributes to the decline of biodiversity.

Types of Pollution

Pollution can be categorized into different types based on the specific component of the environment it impacts. The four primary forms include air, water, soil, and noise pollution, while other notable types are light, thermal, and radioactive pollution. Each category arises from distinct sources, with varying effects on human health and the natural environment.

Major Types of Pollution

- Air Pollution
- Water Pollution
- Soil Pollution
- Noise Pollution
- Light Pollution
- Thermal Pollution
- Radioactive Pollution

1.6.4.1 AIR POLLUTION

Air pollution refers to the degradation of air quality through the introduction of harmful gases, fine particles, and toxic chemicals into the atmosphere. Major sources include emissions from automobiles, industrial activities, burning of fossil fuels, and the use of chemical aerosols. Key air pollutants such as sulphur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM) have severe implications for human health and the environment.

Causes:

- Vehicle exhaust fumes
- Industrial and factory emissions
- Combustion of coal, oil, and other fossil fuels
- Release of chemical sprays and aerosols

Effects:

- Increased risk of respiratory illnesses, asthma, and lung cancer
- Formation of acid rain, which damages soil, vegetation, and infrastructure
- Contribution to the greenhouse effect and global climate change

Air pollution not only poses direct health hazards but also accelerates global warming, thereby intensifying environmental and public health challenges worldwide.

Types of Air Pollutants:

- Primary air pollutants: Emitted directly, like CO, SO₂, and particulate matter.
- Secondary air pollutants: Formed in the atmosphere, such as ground-level ozone and smog.

Knowledge of these distinctions helps us address air pollution more effectively.

1.6.4.2 WATER POLLUTION

Water pollution is the deterioration of water quality caused by the introduction of harmful substances such as chemicals, sewage, and solid waste into rivers, lakes, groundwater, and oceans. Major contributors include industrial effluents, agricultural runoff containing pesticides and

fertilizers, improper waste disposal, and oil spills. These contaminants compromise the safety of water resources, threaten aquatic ecosystems, and pose serious risks to human health.

Causes:

- Industrial discharge of untreated effluents
- Dumping of solid and liquid waste into water bodies
- Agricultural runoff containing pesticides and fertilizers
- Release of sewage and domestic wastewater

Effects:

- Spread of waterborne diseases such as cholera, dysentery, and typhoid
- Destruction of aquatic habitats and reduction in biodiversity
- Contamination of drinking water sources, leading to long-term health hazards

Types of Water Pollution:

- Chemical Pollution: Caused by pesticides, fertilizers, heavy metals, and oil spills.
- Biological Pollution: Arising from microorganisms, organic waste, and sewage.
- Physical Pollution: Resulting from thermal discharges, sedimentation, and suspended solids.

Water pollution not only disrupts aquatic ecosystems but also undermines access to clean drinking water, thereby threatening public health and environmental sustainability.

1.6.4.3 SOIL POLLUTION

Soil pollution refers to the accumulation of hazardous substances such as toxic chemicals, pesticides, heavy metals, and hydrocarbons in the soil. This reduces soil fertility, affects its biological balance, and poses risks to both agriculture and public health. The problem often arises

from improper waste disposal, excessive use of agrochemicals, industrial discharges, and oil or mining activities. Contaminated soils can transfer pollutants into crops, leading to food safety concerns and long-term ecological damage.

Causes:

- Over-application of chemical fertilizers and pesticides
- Industrial effluents, solid waste dumping, and oil leaks
- Mining activities and associated tailings
- Poor urban waste management practices

Effects:

- Reduced agricultural productivity and poor crop yields
- Health hazards through consumption of contaminated food crops
- Soil erosion and loss of soil structure
- Decline of soil biodiversity, including microorganisms and beneficial fauna

Types of Soil Pollution:

- **Industrial Soil Pollution:** Caused by emissions, effluents, and wastes from factories, mining operations, and landfills.
- **Agricultural Soil Pollution:** Results from intensive use of chemical fertilizers, pesticides, and herbicides in non-organic farming.
- **Urban Soil Pollution:** Linked to improper disposal of solid waste, sewage, and construction debris in expanding urban areas.

Effective prevention and control of soil pollution—through sustainable agricultural practices, proper waste management, and environmental regulation—is critical to safeguarding human health, preserving food security, and maintaining ecosystem stability.

1.6.4.4 NOISE POLLUTION

Noise pollution is the presence of excessive, unpleasant, or disruptive sounds in the environment that negatively affect humans, animals, and overall ecological balance. Common sources include road traffic, industrial machinery, construction activities, loudspeakers, and domestic appliances. Prolonged exposure to high noise levels not only leads to hearing impairment but also contributes to sleep disturbances, stress, reduced productivity, and cardiovascular complications.

Causes:

- Road and air traffic congestion
- Industrial and construction activities
- Operation of heavy machinery and equipment
- Loud music, entertainment centers, and household appliances

Effects:

- Hearing loss and impairment of auditory functions
- Increased anxiety, stress, and mental fatigue
- Cardiovascular issues such as hypertension and heart disease
- Reduced concentration, efficiency, and work performance

Types of Noise Pollution:

- Industrial Noise: Generated from factory operations, heavy machinery, and manufacturing plants.

- Transport Noise: Produced by road traffic, railways, and aircraft operations.
- Residential Noise: Originating from household activities, neighborhood events, and community gatherings.

Mitigation strategies such as urban planning, soundproofing, enforcement of noise regulations, and green muffler techniques (using trees and vegetation to absorb sound) can help reduce noise levels in cities and communities.

1.6.5 SOLID WASTE POLLUTION

Solid waste pollution arises when municipal, industrial, or domestic refuse is improperly disposed of, particularly in open dumpsites. These sites are often unregulated, lacking engineered safeguards such as liners, leachate collection systems, or gas management facilities. As a result, they become major sources of environmental pollution, affecting air, water, soil, and public health.

1.6.5.1 Air Pollution from Dumpsites

The uncontrolled decomposition of organic waste in dumpsites generates gases such as methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S), and volatile organic compounds (VOCs). Methane, a potent greenhouse gas, contributes to global warming, while other toxic emissions degrade air quality and cause foul odours. Open burning of refuse—common in urban dumpsites—further releases harmful particulates and toxic chemicals, aggravating respiratory problems and climate change.

1.6.5.2 Water Pollution from Leachate

One of the most severe impacts of dumpsites is the production of leachate—a liquid formed when rainwater percolates through decomposing waste, dissolving organic and inorganic pollutants. This leachate often infiltrates groundwater aquifers or drains into surface water bodies, contaminating

them with heavy metals (e.g., lead, cadmium, copper), pathogens, and chemical residues. Such contamination compromises water quality, making it unsafe for domestic use and posing risks of waterborne diseases such as cholera and dysentery.

1.6.5.3 Soil Pollution from Dumpsites:

Continuous deposition of waste introduces toxic chemicals, plastics, and heavy metals into the soil. This reduces soil fertility, alters microbial balance, and can bioaccumulate in food crops grown nearby, thereby affecting food safety. Hazardous materials like batteries, paints, and electronic waste further increase soil contamination, making dumpsites hotspots of environmental degradation.

1.6.5.4 Noise and Visual Pollution:

In addition to chemical pollution, dumpsites contribute to noise pollution through heavy truck movements and scavenging activities, while their unsightly appearance causes visual blight, lowering the aesthetic and economic value of surrounding communities.

1.6.5.5 Health Implications:

Communities located close to dumpsites face higher risks of respiratory diseases, gastrointestinal infections, skin disorders, and vector-borne illnesses due to flies, mosquitoes, and rodents breeding in waste. Long-term exposure to heavy metals and toxic compounds may also result in cancer, organ damage, and developmental disorders.

1.6.6 HEAVY METALS IN DUMPSITE ENVIRONMENTS AND GROUNDWATER

1.6.6.1 Concept and Relevance

Heavy metals (e.g., Pb, Cd, Cr, Ni, Cu, Zn, Hg, As) are persistent, non-biodegradable elements that accumulate in soils, sediments, and biota. In urban settings, they are widely used as indicators for Environmental Impact Assessment (EIA) and long-term monitoring because they integrate pollution histories and pose chronic health risks through water and food chains (Asuen *et al.*, 2012). Even low-level contamination can yield cumulative ecological and public-health impacts over time (Omorogieva *et al.*, 2013).

1.6.6.2 Sources and Pathways:

Primary sources around urban dumpsites include municipal solid waste, informal industry, automobile emissions, open burning, battery and e-waste fragments, pigments/dyes, agrochemicals, and leachate from decomposing waste. Proximity strongly shapes exposure: soils nearer to dumpsites typically report higher organic load, hazardous constituents, and heavy-metal concentrations than distal locations (Imeokparia *et al.*, 2009; Imasuen and Omorogieva, 2013).

Leachate forms when rainwater percolates through refuse, dissolving/entraining metals and other pollutants before migrating through the vadose zone to aquifers. This process is intensified in open dumps lacking liners, covers, or leachate collection systems. Seasonal rainfall enhances vertical fluxes, accelerating transport to groundwater.

1.6.6.3 Geochemical Behavior (Speciation, Mobility, Retention)

Metal mobility depends on speciation, pH, redox conditions (E_h), ionic strength, competing ions (Cl^- , SO_4^{2-} , HCO_3^-), organic ligands, and the presence of Fe/Mn oxyhydroxides and clay minerals.

Soil processes such as adsorption, complexation, precipitation, and co-precipitation can reduce mobility; conversely, acidic or reducing conditions can re-mobilize adsorbed/precipitated metals. Metal chemistry therefore governs transport in soil–groundwater systems (Allen *et al.*, 1991), while certain conditions prevent adsorption or precipitation, enabling plume migration (Evanko and Dzombak, 1997).

1.6.6.4 Soil Quality and Fertility Impacts:

Heavy metals can degrade soil organic matter, inhibit microbial activity and enzymatic processes, and lower topsoil fertility—with implications for urban agriculture and vegetation resilience around dumpsites (Asuen *et al.*, 2012). Soil structure may aggregate fine particles (cementation/aggregation), but this does not guarantee immobilization of metals; stability of aggregates is itself pH- and organic-matter-dependent (Ukpebor *et al.*, 2003).

1.6.6.5 Groundwater Contamination and Health Risks:

Open dumpsites are repeatedly linked to groundwater contamination by metals and co-pollutants (e.g., ammonium, DOC, chloride, PAHs). Documented toxic effects of metals include neurotoxicity (Pb), renal dysfunction (Cd), carcinogenicity (Cr(VI), As, Ni), and hepatotoxicity (Cu at high levels). Given reliance on shallow aquifers in many urban fringes, the risk to drinking-water safety is acute when no treatment barriers exist.

1.6.6.6 Evidence from Nigerian Context (Illustrative)

Studies around Benin City dumpsites reported elevated metal concentrations relative to earlier baselines (Imeokparia *et al.*, 2009, Ihenyen, 1988), supporting the view that expanding waste loads and inadequate controls intensify local contamination. Similar patterns_higher concentrations at

source, declining with distance/depth—are consistently reported across Nigerian urban centers (Imasuen and Omorogieva, 2013; Omorogieva *et al.*, 2013).

1.6.6.7 Analytical Approaches

Typical workflows include:

- Sampling design: up- and down-gradient wells; nested depths; near- vs. far-field soils.
- Field parameters: pH, EC, Eh, temperature, turbidity.
- Laboratory analysis: digestion (APHA/ISO methods), then AAS/ICP-OES/ICP-MS for metals; DOC, major ions for geochemical context; microbiology where relevant.
- Data evaluation: QA/QC checks; comparison with national standards (e.g., SON), WHO drinking-water guidelines, and risk benchmarks; statistics (ANOVA, correlation, PCA) to apportion sources and co-variations.

1.6.6.8 Factors Controlling Spatial–Temporal Patterns:

- Proximity to dump and hydraulic gradient (controls plume direction/intensity).
- Seasonality: monsoonal rains increase leachate generation and transport.
- Soil properties: texture, CEC, organic matter, Fe/Mn oxides, carbonate content.
- Waste composition and age: more e-waste/batteries often elevates Pb, Cd, Ni; younger dumps tend to produce more biodegradable leachate with complexing agents that enhance metal mobility.
- Management status: presence/absence of liners, capping, drainage.

1.6.6.9 Risk Assessment and Standards Alignment:

Risk is commonly framed via hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR), integrating exposure pathways (ingestion, dermal, inhalation) for

adults/children. Interpreting measured concentrations against regulatory standards and guideline values helps contextualize public-health significance and prioritize interventions.

1.6.6.10 Mitigation and Management:

- Source control: transition from open dumps to controlled dumps and ultimately to sanitary landfills with liners and leachate collection.
- Hydrogeologic barriers: cutoff trenches, permeable reactive barriers (e.g., zero-valent iron, limestone, biochar).
- Soil amendments: immobilization using phosphates, biochar, Fe/Mn oxides to reduce bioavailability.
- Monitoring: long-term networks of wells; seasonal sampling; community reporting.
- Policy levers: enforce waste segregation, e-waste take-back, and periodic audits under Environmental impact assessment frameworks.

CHAPTER TWO

2.0 MATERIALS AND METHODS

2.1 STUDY AREA

The study area is located within Saint Saviour area in Ikpoba-Ohka Local Government Area, Benin City, Edo State, Nigeria. Benin City lies between latitudes 6°14'N and 6°21'N and longitudes 5°37'E and 5°45'E, and is one of the largest urban centers in southern Nigeria. Saint Saviour is a densely populated residential community. The area is characterized by rapid urbanization, mixed residential and commercial land use, and limited waste management infrastructure, which has led to challenges in sanitation and environmental quality. Average annual temperatures range between 25°C and 30°C, and relative humidity is generally high, especially during the rainy season. Saint Saviour is situated on a relatively low-lying terrain with gentle undulating slopes, underlain by coastal plain sands and lateritic soils. The area's geology is typical of the Benin Formation, consisting of unconsolidated sands, gravels, and clay lenses that form shallow aquifers. These aquifers are commonly tapped by hand-dug wells and boreholes, making groundwater a major source of domestic water supply.

2.2 APPARATUS AND EQUIPMENT

1. Volumetric flask
2. Conical flask (250ml, 100ml)
3. Beaker (250ml, 100ml)
4. Glass rod stirrer
5. Measuring cylinder
6. Water meter
7. Spatula

8. Atomic Absorption Spectrophotometer (Bulk Scientific model 210VGP)
9. 100ml sample bottles
10. Funnels
11. Whatman No. 42 filter paper

REAGENTS

1. Distilled Water (H_2O)
2. Conc. Hydrochloric acid (HCl)
3. Buffer solution (pH 7)
4. Conc. perchloric acid (HClO_4)
5. Nitric acid (HNO_3)
6. Potassium Sulphate (K_2SO_4)
7. Barium Chloride (BaCl_2)
8. Potassium Nitrate (KNO_3)
9. Potassium dihydrogen Phosphate (KH_2PO_4)
10. Antimony potassium tartrate ($\text{K}(\text{SbO})\text{C}_4\text{H}_4\text{O}_6 \cdot \frac{1}{2} \text{H}_2\text{O}$)
11. Ammonium molybdate ($(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$)
12. Ascorbic acid ($\text{C}_6\text{H}_6\text{O}_6$)
13. Ethanoic acid (CH_3COOH)
14. Brucine Sulphate ($\text{C}_{23}\text{H}_{26}\text{N}_2\text{O}_4 \cdot \text{H}_2\text{SO}_4$)
15. Starch ($\text{C}_6\text{H}_{10}\text{O}_5$)_n
16. Sodium thiosulphate pentahydrate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$)
17. Sodium azide (NaN_3)
18. Sodium iodide or Potassium iodide (NaI or KI)

19. Sodium hydroxide (NaOH)
20. Maganese(II) sulphate monohydrate (MnSO₄.H₂O)
21. Potassium chromate (K₂CrO₄)
22. Silver Nitrate (AgNO₃)
23. Ethenylbenzene (C₆H₅CH=CH₂)
24. Methyl orange (C₁₄H₁₄N₃NaO₃S)
25. Potassium dichromate (K₂Cr₂O₇)
26. Mercury Sulphate (HgSO₄)
27. Silver Sulphate (Ag₂SO₄)

2.3 SAMPLE COLLECTION

Samples were collected at active leachate seeps/ponded zones within the dumpsite, avoiding surface debris. Samples were handled, preserved and labelled as above.

Groundwater samples were collected from boreholes at different meters away from the dumpsite using plastic containers. The containers were properly rinsed with distilled water and dried to remove any form of impurities before samples were taken. Borehole waters within the distance of 100m, 200m, and 300m respectively away from the dumpsite were used as sampling points for groundwater for both dumpsites and labelled properly for easy identification. These samples were then kept in a container and transported to the laboratory for analysis.

2.4 DETERMINATION OF QUALITY PARAMETERS

On-site measurements of temperature (°C), pH, electrical conductivity (µS/cm), total dissolved solids (ppm), and salinity (ppt) were obtained using a multifunctional water-quality tester. These immediate readings provided baseline information on the physical characteristics of the samples.

Chemical parameters including nitrate, sulphate, and phosphate were analyzed with a spectrophotometer set at wavelengths of 470 nm, 420 nm, and 880 nm respectively. The resulting concentrations were recorded in milligrams per litre (mg/L). Metal analysis was performed through acid digestion of the leachate samples. Each sample was treated with a 1:3 mixture of perchloric acid (HClO₄) and nitric acid (HNO₃) in a digestion tube and heated on a hot plate until the appearance of white perchloric acid fumes indicated complete digestion. After cooling, the digest was diluted to a final volume of 100 mL in a volumetric flask and analyzed using an Atomic Absorption Spectrophotometer (AAS). Water samples were also analyzed with AAS to determine their metal concentrations.

CODES

CODE	DU 1	DU 2	GW (100m)	GW (200m)	GW (300m)	
SAMPLING LOCATION	DUMPSITE 1 (Leachate)	DUMPSITE 2 (Leachate)	Groundwater 100m away from dump	Groundwater 200m away from dump	Groundwater 300m away from dump	

CHAPTER THREE

3.0 RESULTS AND DISCUSSION

3.1 TABLE OF VALUES

Table 3.1: PHYSIOCHEMICAL PROPERTIES OF DUMPSITE 1 – LEACHATE

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	26.3	7.44	1127	560	560	0.552	1.247	0.499
2nd Reading	25.3	7.46	1105	550	551			
3rd Reading	25.3	7.37	1107	551	551			

Table 3.2: PHYSIOCHEMICAL PROPERTIES OF GROUNDWATER 1 – 100 METERS

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	26.6	6.27	68	34	35	0.481	0.734	0.131
2nd Reading	25.0	5.90	90	36	36			
3rd Reading	26.0	6.15	90	35	35			

Table 3.3: PHYSIOCHEMICAL PROPERTIES OF GROUNDWATER 1 – 200 METERS

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	25.0	6.93	70	35	35	0.552	0.429	0.142
2nd Reading	24.0	5.43	80	40	40			
3rd Reading	24.3	5.20	76	37	37			

Table 3.4: PHYSIOCHEMICAL PROPERTIES OF GROUNDWATER 1 – 300 METERS

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	25.4	6.47	146	73	73	0.585	0.895	0.128
2nd Reading	24.8	6.58	146	73	73			
3rd Reading	24.5	6.52	146	73	73			

Table 3.5: PHYSIOCHEMICAL PROPERTIES OF DUMSITE 2 – LEACHATE

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	27.10	6.85	6888	3380	3380	0.578	1.584	1.538
2nd Reading	27.30	6.90	6633	3280	3285			
3rd Reading	26.60	6.90	6538	3213	3218			

Table 3.6: PHYSIOCHEMICAL PROPERTIES OF GROUNDWATER 2 – 100 METERS

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	26.70	7.10	60	31	32	0.543	0.548	0.102
2nd Reading	26.20	6.97	62	32	32			
3rd Reading	26.20	7.02	62	31	32			

Table 3.7: PHYSIOCHEMICAL PROPERTIES OF GROUNDWATER 2 – 200 METERS

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	26.80	4.96	16	8	8	0.510	0.508	0.096
2nd Reading	26.50	4.77	16	8	8			
3rd Reading	26.50	4.88	14	8	8			

Table 3.8: PHYSIOCHEMICAL PROPERTIES OF GROUNDWATER 2 – 300 METERS

	Temperature °C	pH	Electrical Conductivity (E.C); $\mu\text{s}/\text{cm}$	Total Dissolved Solids (TDS); ppm	Salinity ppt	NO ₃ ⁻ At 470nm	PO ₄ ³⁻ At 880nm	SO ₄ ²⁻ At 420nm
1st Reading	26.00	5.11	10	5	5	0.502	0.452	0.070
2nd Reading	26.60	5.01	10	5	5			
3rd Reading	26.60	4.89	10	5	5			

Table 3.9: AVERAGE MEAN OF THE PHYSIOCHEMICAL PROPERTIES OF ALL DUMPSITE AND GROUNDWATER SAMPLES

SAMPLE	NO₃⁻ At 470nm	PO₄³⁻ At 880nm	SO₄²⁻ At 420nm	Temperature °C	pH	Electrical Conductivity (E.C); µs/cm	Total Dissolved Solids (TDS); ppm	Salinity ppt
DU1	0.552	1.247	0.499	25.6	7.42	1113	554	554
GW1(100m)	0.481	0.734	0.131	25.9	6.11	83	35	35
GW1(200m)	0.552	0.429	0.142	24.4	5.85	75	37	37
GW1(300m)	0.585	0.895	0.128	24.9	6.52	146	73	73
DU2	0.578	1.584	1.538	27.0	6.88	6686	3291	3294
GW2(100m)	0.543	0.548	0.102	26.4	7.03	61	31	32
GW2(200m)	0.510	0.508	0.096	26.6	4.87	15	8	8
GW2(300m)	0.502	0.452	0.070	26.2	5.00	10	5	5

This study investigated the impact of open dumpsite leachate on the physicochemical characteristics of groundwater within the Saint Saviour area of Benin City, Edo State, Nigeria. The results obtained from samples collected at varying distances (100 m, 200 m, and 300 m) clearly demonstrate that proximity to the dumpsite significantly affects groundwater quality. The variation in pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, nitrate (NO₃⁻), phosphate (PO₄³⁻), and sulphate (SO₃²⁻) indicates progressive contamination resulting from leachate percolation. When compared with global and national water quality standards such as those

provided by the World Health Organization (WHO, 2017; 2021) and Standards Organisation of Nigeria (SON, 2015), it becomes evident that the groundwater quality in the vicinity of the Saint Saviour dumpsite is under threat.

The pH values obtained in this study ranged from 4.00 to 7.42, representing slightly acidic to near-neutral conditions. The 200 m sample at dumpsite 2 location exhibited the lowest pH (ranging from 4.00 – 4.99), which falls below the WHO permissible drinking water range of 6.5–8.5. This acidity is most likely due to the formation of organic acids such as humic, fulvic, and carboxylic acids during the anaerobic decomposition of organic waste materials. Acidic conditions in groundwater enhance the dissolution of metals and nutrients from soil and rock matrices, increasing the mobility of potentially toxic elements such as lead, cadmium, and zinc (Li *et al.*, 2014; Owamah *et al.*, 2013). Imasuen and Omorogieva (2013) also reported similar acidic pH values in groundwater around Benin City dumpsites, linking them to biodegradation of organic fractions of solid waste. According to WHO (2021), the acidity of groundwater not only affects taste and corrosion but can also accelerate the leaching of heavy metals into drinking water, thereby posing potential health risks. Acidic conditions are further reinforced by the interaction of carbon dioxide produced from microbial respiration with percolating water, forming weak carbonic acid which reduces pH (Singh *et al.*, 2008).

The electrical conductivity (EC) values in this study ranged between 10 $\mu\text{S}/\text{cm}$ and 6,538 $\mu\text{S}/\text{cm}$, with the highest recorded in the dumpsite 2 leachate sample. This pattern indicates a clear trend of decreasing ionic concentration with distance from the dumpsite. Elevated EC near the dumpsite suggests high levels of dissolved ions such as chlorides, nitrates, phosphates, and sulphates leaching from decomposing waste materials. The WHO (2017) recommends EC values not exceeding 1,500 $\mu\text{S}/\text{cm}$ for potable water; thus, the results near the waste source significantly

exceed this limit, confirming pollution. Naveen *et al.* (2017) and Aljaradin and Persson (2016) observed similar conductivity increases near unengineered landfills in India and Jordan, respectively, attributing this to the infiltration of ion-rich leachate. Elevated EC values are symptomatic of advanced stages of leachate migration into subsurface aquifers (Olaajo *et al.*, 2016). Such high ionic strength may alter the hydrogeochemical equilibrium, disrupt aquifer porosity, and cause scaling in pipes and appliances used for domestic purposes.

Total dissolved solids (TDS) levels varied between 5 mg/L and 3,380 mg/L, indicating an accumulation of soluble inorganic substances such as carbonates, chlorides, and sulphates within the aquifer. The WHO and SON recommend that TDS should not exceed 500 mg/L for potable water, as higher concentrations may impart undesirable taste, cause gastrointestinal irritation, and reduce water palatability. The highest TDS value was recorded at the dumpsite 2, signifying intense infiltration of leachate containing organic residues, salts, and minerals. Similar findings were documented by Regadío *et al.* (2012) in Spain and Ganiyu *et al.* (2016) in southwestern Nigeria, where dumpsite proximity significantly elevated TDS levels in nearby wells. The progressive decrease in TDS with distance from the dumpsite (100 m to 300 m) in this study suggests dilution effects and reduced leachate influence as groundwater flows outward. Dauda and Osita (2003) also emphasized that unlined dumpsites allow infiltration of both organic and inorganic contaminants, which persist in subsurface water over extended periods.

The salinity of water samples ranged from 5 mg/L to 3,278 mg/L, following a similar trend to TDS and EC. The high salinity near the dumpsite is attributed to chloride and sodium ions originating from the decomposition of organic waste, household materials, and food residues. The WHO (2017) and FAO (2019) consider salinity levels above 500 mg/L as unsuitable for drinking and irrigation. Elevated salinity not only affects taste but also increases the risk of hypertension and

kidney-related ailments when consumed over time (WHO, 2011; Ukpebor *et al.*, 2003). The correlation between salinity, EC, and TDS indicates that these parameters share common sources—mainly ionic leachate migration through the unsaturated soil zone. Imasuen and Omorogieva (2013) observed comparable results in Benin City, highlighting the danger of unregulated dumpsites on the long-term chemical stability of aquifers. The presence of high salt content also affects soil structure, leading to the hardening of surface soils and reduced permeability, which further modifies local hydrology.

Nitrate (NO_3^-) concentrations recorded in this study ranged between 0.481 and 0.585 mg/L. Although these concentrations are below the WHO limit of 50 mg/L, they provide clear evidence of contamination from anthropogenic sources, especially organic waste and domestic effluents. The low but detectable nitrate concentrations indicate early stages of leachate infiltration, where microbial oxidation of ammonia and organic nitrogen produces nitrate ions. Singh *et al.* (2008) reported similar observations in India, noting that nitrate enrichment in groundwater serves as an early indicator of contamination by waste leachate. Excessive nitrate exposure is known to cause methemoglobinemia in infants and has been linked to other long-term health complications such as gastric cancer (WHO, 2021; WHO, 2011). Studies by Ojo *et al.* (2014) and Olawale *et al.* (2020) also reported increasing nitrate concentrations near Nigerian dumpsites, emphasizing the importance of continuous monitoring to prevent health hazards.

Phosphate (PO_4^{3-}) levels varied between 0.429 mg/L and 1.584 mg/L, with the highest recorded in the dumpsite 2 sample. Phosphate contamination primarily arises from detergents, soaps, decomposed organic waste, and industrial materials disposed of at dumpsites. Although WHO has not established a strict guideline value for phosphate, excessive phosphate can lead to eutrophication and oxygen depletion in water bodies, threatening aquatic life (WHO, 2017;

Regadío *et al.*, 2012). The elevated phosphate concentrations near the dumpsite in this study are consistent with reports by Olowe *et al.* (2019), who found that phosphate pollution around Nigerian urban dumpsites was directly linked to household waste composition. The increase in phosphate levels near Saint Saviour dumpsite reflects the breakdown of phosphorus-containing compounds such as bones, plant residues, and detergents. Elevated phosphate may also indicate nutrient loading from nearby human settlements and stormwater runoff.

Sulphate (SO_4^{2-}) concentrations ranged from 0.070 mg/L to 1.538 mg/L, all of which fall below the WHO recommended maximum value of 250 mg/L. Despite the low levels, the trend indicates higher sulphate concentration near the dumpsite, pointing to leachate infiltration. Sulphate in groundwater often originates from oxidation of sulphur-containing compounds and from waste materials like gypsum and batteries. High sulphate concentrations can cause laxative effects when consumed and contribute to scaling in water systems (Li *et al.*, 2014; WHO, 2021). The slightly increased sulphate near the waste site suggests that leachate generation is contributing to the overall chemical load of the aquifer. Omorogieva *et al.* (2013) found similar patterns in Benin City, where sulphate levels increased with proximity to open waste dumps.

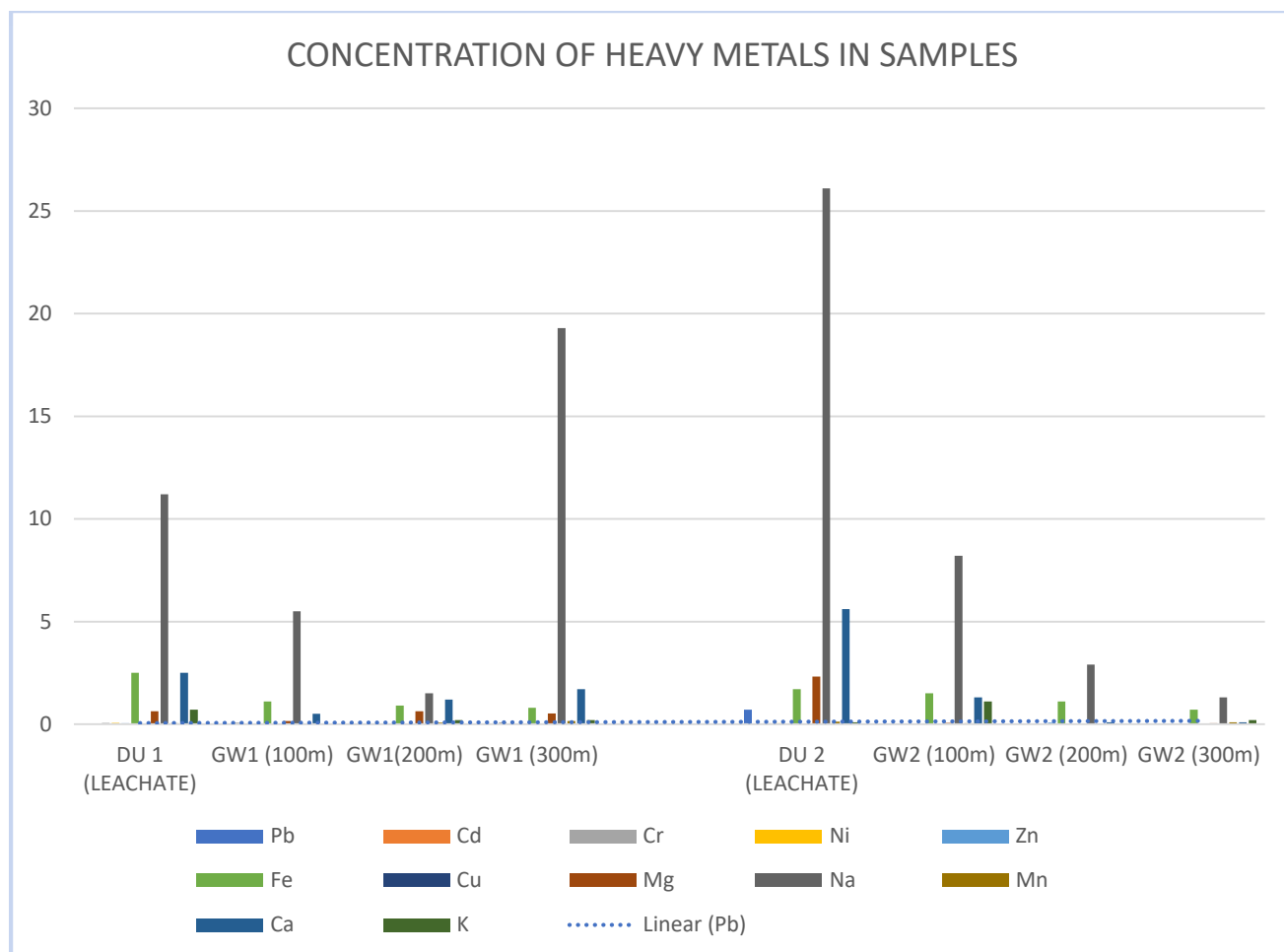
The observed contamination pattern aligns with findings from other regions globally. For instance, Naveen *et al.* (2017) and Aljaradin and Persson (2016) both reported similar trends in Asia and the Middle East, where non-engineered landfills led to leachate percolation into nearby aquifers. Regadío *et al.* (2012) also highlighted comparable leachate impacts in arid regions of Spain. Collectively, these studies reinforce that improper waste disposal remains a critical driver of groundwater pollution in developing countries where waste management infrastructure is inadequate.

In general, all measured parameters—particularly EC, TDS, and salinity—showed elevated levels near the dumpsite and gradual decline with distance, confirming that leachate migration significantly affects groundwater. The acidic nature of some samples further increases the likelihood of heavy metal mobilization even though metals were not directly quantified in this study. Previous research by Asuen *et al.* (2012) and Imeokparia *et al.* (2009) established that open dumpsites in Benin City contain elevated levels of heavy metals such as Pb, Cd, and Zn, which are easily mobilized under acidic conditions. Thus, it is reasonable to infer that heavy metal contamination may accompany the observed physicochemical deterioration of groundwater around the Saint Saviour dumpsite.

TABLE 3.10: Heavy metal concentration (mg/L) obtained for all samples

Sample	Concentration (mg/L)											
	Pb	Cd	Cr	Ni	Zn	Fe	Cu	Mg	Na	Mn	Ca	K
DU 1	0.03	0.01	0.06	0.06	0.04	2.50	0.01	0.63	11.20	0.04	2.50	0.70
GW1(100m)	ND	ND	0.07	ND	0.01	1.10	0.01	0.15	5.50	0.02	0.50	ND
GW1(200m)	ND	ND	0.01	0.01	0.01	0.90	ND	0.63	1.50	0.07	1.20	0.20
GW1(300m)	ND	ND	0.10	0.02	0.01	0.80	0.01	0.52	19.30	0.15	1.70	0.20
DU 2	0.70	ND	0.04	0.05	0.03	1.70	ND	2.32	26.10	0.12	5.60	0.10
GW2(100m)	0.03	ND	0.03	0.02	0.01	1.50	ND	0.06	8.20	0.04	1.30	1.10
GW2(200m)	0.02	ND	0.02	0.02	0.07	1.10	ND	ND	2.90	0.01	0.10	ND
GW2(300m)	0.03	ND	0.03	0.01	ND	0.70	ND	0.05	1.30	0.10	0.10	0.20

ND: Not detected



The concentrations of heavy metals in the water samples (DU1, GW1(100m), GW1(200m), GW1(300m), DU2, GW2(100m), GW2(200m), GW2(300m)) are presented in Table 3.2. The results, expressed in mg/L, were compared with permissible limits recommended by the World Health Organization (WHO, 2021) and the Standards Organization of Nigeria (SON, 2015) through the Nigerian Standard for Drinking Water Quality (NIS 554:2015). Although these standards are designed for drinking water, they provide a useful benchmark for assessing water contamination and evaluating potential risks to human health and aquatic ecosystems. The metals

analyzed included lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), sodium (Na), calcium (Ca), magnesium (Mg), and potassium (K).

Lead (Pb) concentrations ranged from 0.02 to 0.70 mg/L, with the highest level observed in DU2, significantly exceeding the WHO and SON guideline of 0.01 mg/L. Such elevated Pb levels suggest considerable anthropogenic contamination, likely from industrial effluents, vehicular runoff, and improper disposal of batteries and scrap metals (Odili, Njoku and Soyoye, 2018). Lead is persistent in water and sediments, poorly degradable, and bioaccumulates in aquatic organisms. Chronic Pb exposure in humans disrupts heme synthesis, causing anemia, and interferes with neurotransmitter activity, leading to cognitive and behavioral impairments in children. Adults may experience hypertension, kidney damage, reproductive toxicity, cardiovascular disorders, and immune dysfunction (WHO, 2017; Tchounwou et al., 2012). In aquatic ecosystems, Pb inhibits photosynthesis in plants and algae, reduces nutrient uptake, and accumulates in organisms, increasing the risk of entry into the food chain (Alloway, 2013). Pb strongly binds to sediments, limiting mobility but extending environmental persistence, complicating remediation.

Cadmium (Cd) was detected at approximately 0.01 mg/L, exceeding the WHO/SON limit of 0.003 mg/L. Cd is highly toxic even at low concentrations and binds strongly to sulfhydryl groups in proteins, disrupting cellular functions in aquatic organisms (McLaughlin et al., 1999). Its anthropogenic sources include industrial effluents, phosphate fertilizers, battery waste, and incineration residues. In humans, Cd exposure can lead to kidney tubular dysfunction, bone demineralization, osteoporosis, and cancer of the lung and prostate. Chronic exposure induces oxidative stress and endocrine disruption. In aquatic environments, Cd inhibits photosynthesis, reduces plant and algal growth, and interferes with the uptake of essential nutrients such as Zn,

Ca, and Fe. Due to its high mobility in water, Cd is readily bioaccumulated in fish and crops irrigated with contaminated water, increasing dietary risks (Kabata-Pendias, 2011).

Chromium (Cr) concentrations reached 0.10 mg/L, exceeding the permissible limit of 0.05 mg/L. Chromium exists primarily as Cr³⁺ and Cr⁶⁺; Cr³⁺ is essential in trace amounts, whereas Cr⁶⁺ is highly toxic and carcinogenic. Anthropogenic sources include tanning, metal plating, industrial effluents, and chromate-containing wastes. Cr⁶⁺ can penetrate cell membranes, causing oxidative stress, DNA damage, liver and kidney toxicity, and increased lung cancer risk (Shanker et al., 2005). In water, Cr can bind to sediments, affecting its mobility and bioavailability. Aquatic exposure can result in chlorosis, stunted growth, reduced photosynthesis, and impaired nutrient uptake, while accumulation in edible species poses dietary risks.

Nickel (Ni) concentrations reached 0.06 mg/L, approaching the WHO limit of 0.07 mg/L. Ni is essential in trace amounts but toxic at elevated levels. It commonly enters water through industrial discharges, including electroplating, battery production, and fossil fuel combustion. Environmental factors such as pH, dissolved organic matter, and competing cations influence Ni solubility and bioavailability; acidic conditions enhance uptake by aquatic plants and microorganisms (Kabata-Pendias, 2011). Excessive Ni can inhibit photosynthesis in algae, reduce biomass in macrophytes, and disrupt microbial communities, particularly nitrifying and denitrifying bacteria. In humans, chronic Ni exposure can cause dermatitis, respiratory disorders, nephrotoxicity, and has potential carcinogenic effects. Additionally, Ni may interact with other metals (Pb, Cd), increasing cumulative toxicity in both aquatic life and humans.

Zinc (Zn) levels were low (≤ 0.07 mg/L), below the WHO/SON limit of 3.0 mg/L. Despite low concentrations, Zn is an essential micronutrient that supports enzymatic activity, protein synthesis, and photosynthesis in aquatic plants and microorganisms. It also plays a role in growth,

reproduction, and metabolic functions in fish and other aquatic animals. Low Zn levels may indicate limited contamination or potential deficiency for aquatic life, which can affect productivity and ecosystem dynamics. Zn interacts with other metals, such as Cu and Cd; high concentrations of these metals can inhibit Zn uptake, while low Zn availability may increase absorption of toxic metals. In humans, Zn is necessary for immune function, DNA synthesis, and wound healing. Continuous monitoring of Zn is important because even low concentrations influence biological processes and trace-metal balance in aquatic systems.

Iron (Fe) ranged from 0.01 to 2.50 mg/L, exceeding the WHO aesthetic guideline of 0.3 mg/L. Fe is essential for redox reactions in aquatic microorganisms, chlorophyll production, and hemoglobin formation in humans. Elevated Fe reduces the availability of other micronutrients (Cu, Zn, Mn), promotes growth of iron-oxidizing bacteria, and catalyzes reactive oxygen species (ROS) formation, causing oxidative stress in aquatic organisms. Excessive Fe intake in humans can exacerbate conditions such as hemochromatosis and liver toxicity.

Copper (Cu) concentrations were around 0.01 mg/L, below the WHO/SON limit of 1.0 mg/L. Low Cu levels indicate minimal contamination risk. Copper is essential for photosynthesis, respiration, and antioxidant enzyme function in aquatic plants (Kabata-Pendias, 2011). Its bioavailability increases in acidic or polluted waters, potentially causing phytotoxicity such as chlorosis, root inhibition, and oxidative stress. In humans, Cu is necessary for enzymatic reactions, iron metabolism, and neurological function, although excessive intake may result in gastrointestinal or liver problems (ATSDR, 2004).

Sodium (Na) concentrations reached 26.3 mg/L, well below the WHO limit of 200 mg/L. Sodium occurs naturally from rock weathering but can also enter water through agricultural runoff, irrigation return flows, road salts, and wastewater discharge (Hassan *et al.*, 2019). Elevated Na can

alter osmotic pressure in aquatic organisms, leading to stress, reduced growth, or mortality. Long-term irrigation with Na-rich water can cause soil sodicity, decreasing permeability, aeration, and fertility. In humans, Na in water is a minor contributor compared to dietary intake, but prolonged consumption of high-Na water could increase hypertension and cardiovascular risk. Sodium also interacts with other cations, such as Ca and Mg, affecting water hardness and potentially increasing the mobility of toxic metals such as Pb and Cd.

Calcium (Ca), Magnesium (Mg), and Potassium (K) were detected within natural ranges (Ca ≤ 5.6 mg/L; Mg ≤ 3.8 mg/L; K ≤ 1.5 mg/L). These cations are essential for both aquatic life and human nutrition. Ca stabilizes cell walls and membranes in aquatic plants and algae, regulates enzymatic activity, and supports skeletal development in fish. In humans, Ca is vital for bone and tooth health, nerve conduction, muscle contraction, and blood clotting. Mg is central to chlorophyll production, photosynthesis, and enzymatic reactions in aquatic plants, and it maintains osmotic balance in aquatic organisms. In humans, Mg is important for muscle and nerve function, energy metabolism, and cardiovascular health. K regulates osmotic pressure, stomatal function, and carbohydrate transport in aquatic plants, while in humans it supports nerve conduction, cardiovascular function, and electrolyte balance. Together, Ca, Mg, and K influence water hardness, buffering capacity, and pH stability. Their interactions with trace metals can modulate the solubility, mobility, and bioavailability of toxic metals, influencing uptake by aquatic organisms and humans, as well as overall water quality.

Overall, Pb, Cd, and Cr exceeded permissible limits in multiple water samples, Ni approached its threshold, and Fe consistently exceeded the aesthetic guideline, indicating a significant anthropogenic influence, likely from industrial effluents, vehicular runoff, and improper waste disposal. The co-occurrence of multiple metals may lead to synergistic toxicity, disrupting

microbial communities, reducing aquatic productivity, bioaccumulating in organisms, and entering the food chain. Continuous exposure could result in the accumulation of toxic metals in aquatic organisms and humans, potentially causing neurological, renal, skeletal, and carcinogenic effects over time. These results corroborate previous Nigerian studies linking urban pollution and unregulated waste disposal to elevated heavy-metal levels in water (Omorogieva and Tonjoh, 2020; Odili *et al.*, 2018).

3.3 CONTRIBUTION TO KNOWLEDGE

The results from this study further emphasize the health implications of groundwater contamination near dumpsites. Long-term exposure to contaminated water may result in gastrointestinal illnesses, kidney problems, and potential carcinogenic effects depending on the contaminant composition. WHO (2021) warns that poor waste management and lack of groundwater protection contribute significantly to the global burden of waterborne diseases, particularly in densely populated urban areas. Furthermore, high salinity and TDS can cause dehydration and hypertension when consumed continuously, while nitrate and phosphate contribute to the deterioration of aquatic ecosystems and oxygen balance.

From an environmental management perspective, the findings indicate the urgent need for improved waste handling practices in Benin City. Transitioning from open dumpsites to sanitary landfills equipped with liners, leachate collection, and treatment systems is essential to prevent further contamination. Regular groundwater quality monitoring and public health assessments should also be implemented in accordance with WHO (2017) recommendations and Sustainable Development Goal 6 (SDG-6), which emphasizes access to clean water and sanitation. Incorporating community awareness programs on the dangers of consuming untreated groundwater from waste-affected areas is equally vital to safeguard public health.

3.4 CONCLUSION

In summary, the overall pattern of results demonstrates that groundwater in the Saint Saviour area is already experiencing measurable deterioration due to the influence of open waste dumping. Parameters such as pH, EC, TDS, and salinity show strong evidence of contamination, while nitrate, phosphate, and sulphate indicate early warning signals of leachate infiltration. These findings corroborate numerous global and local studies (Imasuen and Omorogieva, 2013; Omorogieva *et al.*, 2013; Regadío *et al.*, 2012; WHO, 2021) and call for urgent regulatory interventions. Sustainable waste management strategies, combined with effective groundwater protection policies, are imperative to prevent irreversible environmental damage and protect human health in Benin City and beyond.

The analysis also revealed heavy metal contamination predominantly of anthropogenic origin. Elevated levels of Pb, Cd, Cr, Ni, and Fe demonstrate potential environmental and human health risks. Even elements within acceptable limits, such as Cu, Mn, Na, Ca, Mg, and K, can interact with toxic metals to influence bioavailability and cumulative toxicity. These findings highlight the urgent need for environmental monitoring, soil remediation, regulatory enforcement, and public awareness programs to mitigate long-term ecological and human health impacts.

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