HYDROCHEMICAL CHARACTERISTICS OF GROUNDWATER OF PARTS OF ILORIN SOUTHWESTERN, NIGERIA

BY

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BEING A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF MINERAL AND PETROLEUM RESOURCES ENGINEERING, INSTITUTE OF TECHNOLOGY, KWARA STATE POLYTECHNIC, ILORIN

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CERTIFICATION

This is to certify that this research work was carried out by **Faruq Ayofe SALAKO** matric numbers **ND/23/MPE/PT/0001** and presented to the Department Of Minerals and Petroleum Resources Engineering Technology, Institute of Technology, Kwara State Polytechnic, Ilorin in partial fulfillment of the requirements for the aware of National Diploma (ND) in Mineral and Petroleum Resources engineering Technology.

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DEDICATION

This research project is dedicated to the Almighty God, the most High that bestows upon us in His infinite mercy, the freedom of life and sustain us throughout the course of my programme at the Kwara State Polytechnic, Ilorin and to our beloved parents and supervisor, who has stood by our side at all times.

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First and foremost, I wish to thank and praise the Almighty God for sparing my life and more importantly for His spiritual guidance and heavenly mercies rendered to me since the beginning of my academic pursuit to this stage. I wish to express my profound gratitude to my parents, **MR. AND MRS. AKINTOLA,** for their unflinching support, both morally and financially and to siblings for their love and support.

I also wish to express with deep sense of humanity, gratitude and indebtedness to my beloved project supervisor, **DR. OLATUNJI J.A.,** whose regular and prompt attention, useful suggestions, comments and encouragement at every stage of this work were invaluable. I wish to thank more sincerely for his open handedness and accomplishing nature towards me, praying the good Lord to bless him and his family.

I sincerely appreciate the invaluable help and advice from my departmental **H.O.D.**, **DR. OLATUNJI J.A.** and others lecturers in our Department who had impacted something meaningful into my life.

I personally that in moment of sober reflection discover that I am indebted to very many people even for the least achievement. Here I find myself limited in space, I would have gone on and on mentioning them.

Above all, we give endless thanks to Almighty God, the Author and Finisher of my faith, for giving me the grace to embark and successfully complete this programme.

ABSTRACT

This research assesses groundwater pollution levels in selected areas of Ilorin, southwestern Nigeria, focusing on heavy metal contamination and physicochemical parameters. Groundwater samples from hand-dug wells and boreholes across six locations (Tanke, Oke-Odo, Agbo-Oba, Oja-Oba, Gaa-Akanbi, and Sango) were analyzed following APHA (2017) standards. Results revealed significant spatial variability: pH ranged from 3.7 (acidic) to 7.9 (neutral), electrical conductivity from 44.3 to 1079 µS/cm, and total dissolved solids from 10.6 to 501.0 mg/L. Chloride (6.00–229.95 mg/L) indicated urban pollution hotspots, while cadmium concentrations (0.57–0.58 mg/L) consistently exceeded WHO limits, posing severe health risks. Total hardness reached 400 mg/L (as $CaCO_3$) in 25% of samples, rendering them unsafe. The study attributes contamination to anthropogenic activities (industrial discharge, waste disposal, agricultural runoff) and natural hydrogeochemical processes. Recommendations include immediate remediation of cadmium/lead sources, installation of pH-adjustment systems and household filters, strict regulation of industrial discharges, buffer zones around wells, and enhanced monitoring of heavy metals and hardness parameters.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Generally groundwater plays a number of very important roles in our environment and socio-economic development of any society. It is a valuable natural resource providing primary sources of water for domestic agriculture and industrial uses throughout the world *(Tijani, 2016).*

Usually surface water is prone to pollution and contamination from domestic sewage and industrial wastes and therefore there is need for water quality monitoring nonetheless monitoring the quality of water can be expensive the cost of exploitation of surface water and management (construction of dens) is light things has led to the increasing exploitation and development of groundwater. Groundwater is generally believed to be relatively protected sewage groundwater is held within purely space, fracture and weathered regolith depending on the geology settling which makes it widely end generally free from sediment and biological in purities.

Over the past decade there has been increased research on the evaluation exploitation and quality assessment of groundwater in the basement complex of Nigeria especially in the south western part of the counting *(Idowu et,al, 2007, Ako i970, Ajadi 2018)*. However, the present work only serves as means of providing additional information on the hydrological and hydro chemical investigations that have been carried out in study area.

The study areas, Ilorin lies within the basement complex of southwestern Nigeria *(Oyawage, 1972)* the predominant rock types in the study area are granite gneiss and quartzite schist *(Oluyide et,al, 1998)* these rocks are covered by weathered regolith, the thickness of which varies from place to place basement complex rocks are poor acquits as the complex rock are poor acquits as they are characterized by low parasite and negligible permeability resulting from this crystalline nature appreciable porosity and permeable may however be developed through weathering and fracturing, depending on the theology and texture of the parent rocks. The availability of groundwater would therefore depend on the presence and extent of the weathered over burden/regolith and the presence of fault and fractures in the underlying bedrock *(Ademilua, 2020).*

Nigeria, like many other countries, relies on groundwater to meet its water demands particularly in urban and rural area where access to piped water is limited *(Adelekan, 2010)* Ilorin the capital city of Kwara State in south western Nigeria is no exception with a significant proportion of its population depending on groundwater for drinking agriculture and industrial activities.

The hydro chemical characteristic of groundwater in Ilorin are influenced by various geological is characterized by basement complex rocks which can affect the chemical composition of groundwater *(Rahman, 2021)* additionally rapid urbanization industrial activities and agricultural practices in the area can lead to groundwater contamination *(Singh et al, 2013).*

Understanding the hydro chemical characteristic of groundwater in Ilorin is essential for assessing its quality identifying potential sources of contamination and developing effective management strategies to protect things vital resoluble previous studies have shown that groundwater quality in Nigeria can be compromised by various factors including geological process agricultural activities and industrial pollution *(Orebiyi et, al, 2010).*

This study aims to investigate the hydro chemical characteristic of groundwater in part of Ilorin south western Nigeria with a view to providing valuable insignificant into it quality and potential implications for human health and environment sustainability.

1.2 STATEMENT OF RESULT

Groundwater in part of Ilorin south western Nigeria is increasingly being threatened by various anthropogenic and natural factors compromising its quality and posing significant risks to human health and environmental sustainability. Despite its importance as a framing source of water for drinking, agriculture and industrial activities there is death of comprehensive date on the hydro chemical characteristic of groundwater in the area this knowledge gap hinds the development of effective strategies for managing groundwater resources protecting public health and ensuring environmental sustainability therefore this study aims to investigate the hydro chemical characteristic of groundwater in parts of Ilorin south western Nigeria.

Some of the problem associate with poor groundwater quality in the area includes:

- ✓ High level of physicochemical parameters
- ✓ Presence of heavy mental
- ✓ Bacterial contamination
- ✓ Impact of geological and anthropogenic activities

These problem necessity a comprehensive study to assess the hydro chemical characteristic of groundwater in the area and provide valuable sight into its quality and potential implications for human health and environment sustainability *(Balogun et,al 2010).*

1.3 AIMS OF THE STUDY

To evaluate the hydro chemical characteristic of groundwater in parts of Ilorin southwestern Nigeria in order to assess its suitability for domestic agricultural and industrial uses and to understand the geochemical process influencing groundwater quality in the area

To assess the hydro chemical characteristics of groundwater in parts of Ilorin, Southwestern Nigeria, with a view to determining its quality, suitability for domestic and agricultural uses, and identifying the geochemical processes influencing its composition.

1.4 OBJECTIVE OF THE STUDY

- ✓ To determine the physical and chemical properties of groundwater (e.g., plt, electrical conductivity, total dissolved solids, labor ions) in selected location without Ilorin
- ✓ To assess the suitability of groundwater for domestic and agricultural purpose by comparing the reassured parameters with national and international water quality standards.
- ✓ To identify and classify the major ions and chemical constituents present in groundwater samples collected from the study area.
- ✓ To determine the spatial distribution and concentration of physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), hardness, and major anions/cautions.

1.5 SIGNIFICANT OF THE STUDY

The study on the hydro chemical characteristic of ground water of part of Ilorin southwestern Nigeria is significant for several reason

- ✓ Understanding groundwater quality: the study will provide valuable insight into the hydro chemical characteristic of groundwater in the study area which is essential for understanding its quality and potential uses.
- ✓ Environmental Monitoring: By understanding the hydro chemical processes and possible contamination sources, the study contributes to environmental protection and pollution control initiatives in the region.
- ✓ Agricultural Planning: Evaluation of groundwater for irrigation suitability will guide local farmers and agricultural authorities in using water sources that do not adversely affect soil health and crop yield.

- ✓ Scientific Contribution**:** The research adds to the body of knowledge on groundwater hydrochemistry in Nigeria, particularly in Ilorin, and can serve as a reference for future hydrological and environmental studies.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 GROUNDWATER OCCURRENCE AND HYDROGEOLOGICAL SETTING IN ILORIN

Ilorin, located within the Basement Complex geological formation of Southwestern Nigeria, is predominantly underlain by migmatite-gneiss, quartzite, and granitic intrusions. These rock types form a complex geological environment that significantly influences groundwater occurrence and distribution *(Sule et al., 2015; Ifabiyi et al., 2016)*. The primary groundwater reservoirs in this region are regolith aquifers, which consist of weathered and fractured basement rocks. The weathered zone, also known as the saprolite, varies in thickness from a few meters to over 15 meters across different parts of Ilorin, directly impacting the volume and availability of groundwater *(Ashaolu & Omotosho, 2015)*. This variability in overburden thickness affects the storage capacity and transmissivity of the aquifers, which in turn influences the yield of wells and boreholes.

Shallow wells, such as those utilized in residential areas like Harmony Estate around Sango Axis, typically tap into these weathered zones and fractured basement rocks. These wells are crucial for domestic water supply, especially in areas where surface water resources are inadequate or unreliable due to seasonal fluctuations *(Ashaolu & Omotosho, 2015)*. Hydrogeological investigations have revealed that the transmissivity of these aquifers is moderate, with specific capacities reflecting the degree of fracturing and weathering. Areas with thicker weathered layers tend to have higher groundwater yields, making them more favorable for well development *(Ifabiyi et al., 2016)*. However, the spatial heterogeneity of the aquifer properties necessitates localized studies to optimize groundwater extraction and management effectively.

The hydrogeological setting is further complicated by the presence of fractured zones that act as conduits for groundwater flow but also pathways for contaminant migration. This dual role highlights the importance of understanding local geology and fracture networks when assessing groundwater availability and vulnerability. The regolith aquifer system in Ilorin, including Harmony Estate, is thus characterized by a delicate balance between groundwater recharge, storage, and potential contamination risks, which must be carefully managed to ensure sustainable water supply *(Sule et al., 2015)*.

2.2 HYDROCHEMICAL CHARACTERISTICS AND CONTAMINATION SOURCES

The hydrochemical profile of groundwater in Ilorin is shaped by a combination of natural geochemical processes and human-induced contamination. Natural processes such as mineral dissolution, ion exchange, and weathering of the basement rocks contribute to the baseline chemistry of groundwater. Commonly detected major ions include calcium, magnesium, sodium, potassium, chloride, sulfate, nitrate, and bicarbonate, which reflect the interaction of water with the geological matrix *(Olasunkanmi et al., 2024; Umar et al., 2023)*. These ions generally indicate moderate mineralization, consistent with the weathered basement aquifer environment.

However, anthropogenic activities have increasingly altered groundwater quality, particularly in urban and peri-urban areas like Harmony Estate. Agricultural practices involving the intensive use of fertilizers have led to elevated nitrate concentrations in shallow groundwater, posing significant health risks *(Adeyemi et al., 2023)*. Similarly, improper waste disposal and leachate from refuse dumpsites contribute to increased levels of iron and other trace elements, which can degrade water quality and affect its suitability for consumption *(Adeyemi et al., 2023)*. The vulnerability of shallow wells is exacerbated by the thin protective clay layers and shallow topsoil prevalent in parts of Ilorin, allowing contaminants to percolate more easily into the aquifer system *(Ashaolu & Omotosho, 2015)*.

Urbanization and inadequate sanitation infrastructure further compound groundwater contamination risks. Septic tank leakage and surface runoff carrying pollutants from domestic and industrial sources have been identified as significant contributors to groundwater pollution in Ilorin *(Olasunkanmi et al., 2024)*. These factors necessitate the implementation of effective land use planning and pollution control measures to protect groundwater resources. The hydrochemical variability observed across Ilorin underscores the importance of site-specific investigations, such as those focused on Harmony Estate, to identify contamination hotspots and develop targeted mitigation strategies.

2.3 GROUNDWATER QUALITY ASSESSMENT, HEALTH IMPLICATIONS, AND SUITABILITY

Groundwater quality assessment in Ilorin involves systematic sampling and laboratory analysis of physico-chemical parameters to determine the suitability of water for domestic and agricultural uses. Parameters such as pH, electrical conductivity, total dissolved solids, and concentrations of major cations and anions are routinely measured and compared against national and international standards, including those set by the World Health Organization (WHO) *(Olasunkanmi et al., 2024; Umar et al., 2023)*. This approach provides a comprehensive understanding of groundwater quality status and identifies areas where contamination may pose risks.

Health risk assessments have highlighted elevated nitrate and iron concentrations as primary concerns in Ilorin’s groundwater. High nitrate levels are linked to methemoglobinemia, especially in infants, while excessive iron can cause undesirable taste, staining, and gastrointestinal discomfort *(Ibrahim et al., 2023)*. Fortunately, concentrations of heavy metals such as lead and cadmium are generally below harmful thresholds in the region, indicating a low risk of chronic heavy metal toxicity *(Ibrahim et al., 2023)*. Nonetheless, continuous monitoring is essential to detect any emerging contamination trends.

The overall groundwater quality in residential areas like Harmony Estate is largely suitable for domestic consumption and irrigation purposes when assessed against established water quality guidelines *(Ogunleye et al., 2025)*. However, localized contamination requires proactive management to prevent adverse health outcomes and ensure sustainable water use. The integration of water quality indices and risk assessment tools enhances the ability of water resource managers and policymakers to prioritize interventions and safeguard public health.

2.4 Previous Studies

A substantial body of research has been conducted on the hydrogeology and groundwater quality of Ilorin and its environs, offering valuable insights into aquifer characteristics, groundwater potential, and contamination patterns. Hydrogeophysical investigations using electrical resistivity and other geophysical methods have been instrumental in delineating aquifer thickness, identifying groundwater potential zones, and guiding well siting decisions *(Ige & Ajiboye, 2016; Malaysian Journal of Geosciences, 2023)*. These studies have revealed the heterogeneous nature of the regolith aquifers and the influence of geological structures on groundwater distribution.

Integrated assessments employing Geographic Information Systems (GIS) and remote sensing techniques have further enhanced the understanding of spatial variability in groundwater availability and quality across Ilorin metropolis *(Ijtrd, 2021)*. Such approaches facilitate the identification of areas vulnerable to contamination and support sustainable groundwater management planning.

Chemical analyses from various studies consistently indicate moderate mineralization of groundwater with occasional contamination hotspots, often linked to urban waste disposal and agricultural activities *(Olasunkanmi et al., 2024; Umar et al., 2023)*. Despite these advances, there remains a paucity of localized studies focusing specifically on well water quality within residential estates such as Harmony Estate. This gap highlights the need for targeted research to inform effective groundwater protection and management strategies tailored to community-level contexts.

In conclusion, the groundwater resources at Harmony Estate, Sango Axis, exemplify the broader hydrogeological and hydrochemical characteristics of Ilorin's Basement Complex aquifers. While generally adequate for domestic use, the shallow wells in these areas are vulnerable to contamination from anthropogenic sources. Therefore, comprehensive water quality monitoring and management strategies are essential to safeguard public health and ensure the sustainable utilization of groundwater resources.

CHAPTER THREE

3.0 METHODOLOGY

3.1 DESK STUDY

The desk study phase involved a comprehensive review of existing literature evaluate the hydrochemical characteristics and groundwater in selected parts of Ilorin, southwestern/Nigeria. The methodology is central to achieving the objectives of this study, as it outlines the step-by-step procedures involved in the collection, analysis, and interpretation of groundwater data. The reliability and validity of the research findings largely depend on the appropriateness and scientific rigor of the chosen methods

Groundwater being a vital source of water supply for domestic, agricultural, and industrial purposes in Ilorin, requires regular monitoring and assessment to ensure its quality and sustainability. Given the increasing pressure on water resources due to population growth. urbanization and anthropogenic activities, understanding/ the hydrochemical processes and potential sources of contamination has become more important than ever. This study, therefore adopts a comprehensive and systematic approach to investigate the water quality of selected wells and boreholes in different parts of Ilorin.

The chapter begins by describing the overall research design, which includes both field investigation and laboratory analysis. This is followed by the reconnaissance survey, which helped to determine suitable sampling locations based on factors such as land use population density, and proximity to potential sources of pollution. It then outlines the sampling strategy. including the selection of wells and boreholes, the collection and preservation of water samples and the in-situ measurements of physico-chemical parameters.

Subsequently, the chapter explains the analytical techniques used in the laboratory to de the concentrations of major ions and other water quality indicators, Standardized methods prescribed by authoritative organizations such as the American Public Health Association

(APHA) were followed to ensure accuracy and comparability of results. The final part of the chapter describes the data analysis techniques, including the use of statistical tools, hydrochemical diagrams such as Piper plots, and comparison with national and international water quality standards.

3.2 RESEARCH DESIGN

The research adopted a descriptive survey and analytical design, which is well-suited for environmental and water quality studies that involve the collection of primary data from natural settings. This design was chosen to enable a thorough assessment of the hydrochemical characteristics of groundwater in selected areas of Ilorin, where groundwater serves as a major source of water for domestic and agricultural purposes. The descriptive aspect of the design involved observing and recording the existing condition of groundwater sources, such as their locations, usage patterns, surrounding land use, and pot contamination sources like dumpsites, septic tanks, and farmlands. These observations provided context for understanding the human and environmental factors influencing water quality. The analytical component focused on the systematic collection of water samples, followed by laboratory analysis of physico-chemical parameters, including pH, electrical conductivity. total dissolved solids, major cautions and anions, and selected heavy metals.

3.3 RECONNAISSANCE SURVEY

A preliminary reconnaissance survey was carried out as an essential preparatory phase of the research to facilitate effective planning and implementation of the main fieldwork. This survey was conducted across various parts of florin, particularly in densely populated neighborhoods and peri-urban areas where groundwater is heavily relied upon for domestic use. The purpose of the reconnaissance was to gain a contextual understanding of the area, identify potential sampling locations, and assess environmental factors that could influence groundwater quality. During the reconnaissance, various groundwater sources such as hand-dug wells and motorized boreholes were identified and mapped using a handheld GPS device. The locations of these water sources were recorded alongside notes on their physical characteristics, usage frequency, and proximity to potential contamination sources. The survey also involved visual inspections and informal discussions with residents, which helped identify human activities that may affect water quality, such as open refuse dumping, agricultural practices involving the use of fertilizers and pesticides, and the presence of septic tanks or pit latrines. In addition, the survey evaluated accessibility and safety of each location to ensure field teams could collect samples without undue difficulty or risk. Observations from the survey helped classify the sites based on land use residential, agricultural, mixed-use, or industrial and guided the selection of representative sampling points.

3.4 SAMPLING LOCATIONS

Groundwater samples were collected from hand-dug wells and boreholes located in selected eas such as Tanke. Oke-Odo, Agbo-Oba, Oja-Oba, Gaa-Akanbi, and Sango. These areas were chosen based on the following criteria:

- High reliance on groundwater for domestic use:
- Diverse population densities;
- Evidence of anthropogenic activities (e.g., waste disposal, farming, construction);
- Accessibility and safety for fieldwork.

3.5 SAMPLE COLLECTION AND PRESERVATION

Standard protocols for water sample collection were followed. In line with APHA (2017) guidelines:

- All containers were pre-washed with distilled water and rinsed with the sample water before final collection.
- **Physico-chemical parameters** such as temperature, pH, electrical conductivity (EC), and total dissolved solid (TDS) were measured **in situ** using portable meters.
- Samples for caution (e.g. Ca^2, Mg^2, Na^+, K^+) and anion (e.g.HCO_3, SO_4^{2-} , Cl, NO_3^-) analysis were stored in clean 500ml polyethylene bottle.
- For heavy metal analysis. Sample were acidified to Ph <2 with nitric acid to prevent precipitation and microbial activity.
- Samples were preserved in ice-preserved in ice-packed coolers and transported to the laboratory within 24 hours for analysis.

3.6 LABORATORY ANALYTICAL PROCEDURE

Water sample were analyzed in a certified water quality laboratory using standard analytical methods as outlined by the American Public Health Association **(APHA, 2017)**

3.6.1 Physical Parameters

Temperature and Ph: Measured on-site using digital pH/temperature meters.

Electrical Conductivity (EC) and **Total Dissolved Solid (TDS);** Determined using a portable EC/TDS meter.

3.6.2 Major Cations

Calcium ($Ca^{2+)}$ and **Magnesium (Mg^{2+}):** Measured via EDTA titration method.

Sodium (Na^+) and **Potassium (K^+):** Analyzed using flame photometry.

3.6.3 Major Anions

Bicarbonate (HCO_3): Determined using acid titration.

Chloride (Cl): Measured by argentometric titration method

Nitrate (NO_3) and **Sulfate (SO_4^{2-}):** Determined using UV spectrophotometry and turbidimetric method respectively

3.6.4 Heavy Metals

Where applicable, concentration of iron (Fe), Lead (Pb), and Manganese (Mn) were analyzed using Atomic Absorption Spectrophotometry (AAS)

3.7 DATA QUALITY CONTROL AND ASSURANCE

To ensure reliability and accuracy of result:

Duplicate samples were collected at selected sites.

Blank samples were used to detect contamination during sampling or handling.

Instrument calibration was performed before each set of measurements.

Analytical results were cross-checked using ion balance error calculations to verify consistency between caution and anion concentrations.

3.8 DATA ANALYSIS TECHNIQUES

The analysis of hydrochemical data is crucial for understanding the quality, origin, and potential health implications of groundwater in any given area. In this study, several statistical and graphical techniques were employed to interpret the chemical composition of groundwater samples collected from selected parts of Ilorin. These methods helped in identifying patterns, trends, and anomalies in the dataset and provided insights into the natural and anthropogenic processes influencing water chemistry.

3.8.1 Descriptive Statistics

Descriptive statistics were used as the first step in analyzing the water quality parameters. This technique involves summarizing the raw data into key indicators that describe the central tendency and variability of each parameter. The following statistical metrics were computed:

- **Mean (Average):** Represents the central value of a dataset.
- **Minimum and Maximum:** Indicate the range of observed values for each parameter.
- **Standard Deviation:** Measures the spread of values around the mean, indicating how consistent or variable the water quality is.

Sample Calculation (Illustration):

Let's assume the concentration of Nitrate (NO_3^-) in five groundwater samples is as follows (in mg/L):

$$\text{Mean} = \frac{12 + 18 + 15 + 20 + 10}{5} = \frac{75}{5} = 15\,\text{mg/L}$$

2. **Minimum & Maximum**

- Minimum = 10 mg/L
- Maximum = 20 mg/L

3. **Standard Deviation (SD)**

$$\text{SD} = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{(12-15)^2 + (18-15)^2 + (15-15)^2 + (20-15)^2 + (10-15)^2}{5-1}}$$
$$= \sqrt{\frac{9+9+0+25+25}{4}} \downarrow \sqrt{\frac{68}{4}} = \sqrt{17} \approx 4.12\,\text{mg/L}$$

Thus, the **mean nitrate level** is 15 mg/L, with a **range of 10–20 mg/L**, and a **standard deviation of ~4.12 mg/L**, indicating moderate variability.

These descriptive statistics were calculated for each parameter such as pH, TDS, EC, Na^+, Cl^-, NO_3^-, Ca^{2+}, and others using Microsoft Excel and SPSS software. The results helped in identifying parameters that exceed permissible limits as defined by WHO (2017) and

NSDWQ (2015), thereby guiding further interpretation and classification in subsequent chapters.

3.8.2 Comparison with Standards

Each measured parameter was compared to the *WHO (2017)* and *NSDWQ (2015)* standards for drinking water to assess portability and identify contamination.

3.9 ETHICAL CONSIDERATIONS

Although the study involved non-invasive sampling, informed consent was obtained from well and borehole owners before sample collection. No personal data were collected, and confidentiality of location identities was maintained during publication and dissemination of findings.

3.10 LIMITATION OF THE METHODOLOGY

The **study period did not cover seasonal variations**. Which may affect water quality.

Financial Constraints limited the numbers of sampling point and laboratory tests.

Microbiological testing was not conducted, which could provide additional insight into contamination risks.

3.11 SUMMARY

This chapter presented the methodological framework adopted for the hydrochemical assessment of groundwater in Ilorin. From sampling design to laboratory analysis and data interpretation, standard procedures were followed to ensure reliability and scientific rigor. The approach is designed to produce result that are representative, replicable, and relevant for policy formulation and sustainable groundwater management.

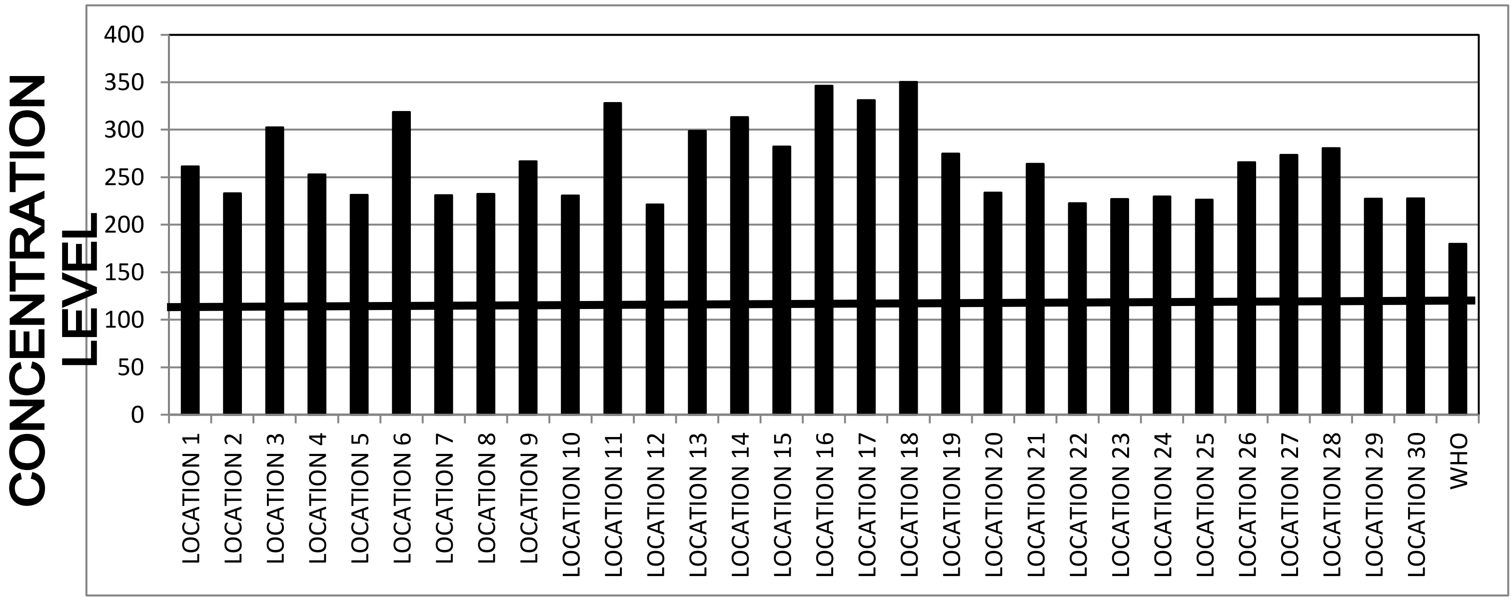
CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 PHYSICO – CHEMICAL PARAMETERS

TABLE 4.1 Laboratory Results

Sample code	Total Hardness (mg/l)	Calcium Hardness (mg/l)	Magnesium Hardness (mg/l)	Ca^{2} (ppm)	Mg^{2} (ppm)	$HC0_3^-$ (mg/l)	$S0_4^{2-}$ (mg/l)	Cl^- (mg/l)	$N0_3$ (mg/l)	$C0_3^{2-}$ (mg/l)	Na (ppm)	K (ppm)
1	261.31	119.45	141.86	47.78	20.16	174	36	33.51	0.74	0.0	12.52	10.03
2	233.20	106.60	126.60	42.64	16.18	160	26	20.78	1.05	0.0	9.74	6.49
3	302.55	138.30	164.25	55.32	21.35	138	30	44.27	4.83	0.0	13.07	10.48
4	253.06	115.68	137.38	46.27	15.63	176	24	19.45	1.03	0.0	10.06	7.45
5	231.62	105.88	125.74	42.35	13.61	162	20	12.89	0.48	0.0	8.28	5.36
6	318.74	145.70	173.04	58.28	24.37	246	30	35.07	2.51	0.0	16.68	12.54
7	231.13	105.65	125.48	42.26	14.12	156	18	23.00	0.67	0.0	9.49	6.97
8	232.60	106.33	126.28	42.53	13.96	154	18	22.35	0.85	0.0	9.42	6.52
9	266.73	121.93	144.80	48.77	18.82	164	30	35.57	6.36	0.0	11.83	8.35
10	230.69	105.45	125.24	42.18	12.13	142	14	20.65	0.72	0.0	7.27	4.16
11	328.26	150.05	178.21	60.02	27.29	250	40	47.01	6.63	0.0	17.26	13.01
12	221.28	101.15	120.13	40.46	13.55	158	16	18.98	1.07	0.0	10.02	7.16
13	298.78	136.58	162.20	54.63	21.73	186	36	43.79	6.68	0.0	14.62	11.29
14	313.44	143.28	170.16	57.31	22.48	192	38	44.47	8.74	0.0	15.53	11.06
15	282.32	129.05	153.27	51.62	19.42	188	30	32.87	5.49	0.0	13,87	10.06
16	346.25	158.28	187.98	63.31	28.26	226	42	54.37	10.81	0.0	18.42	12.02
17	331.26	151.43	179.84	60.57	27.34	226	40	50.62	6.75	0.0	19.07	11.73
18	350.46	160.20	199.26	64.08	28.92	232	44	53.91	9.73	0.0	19.28	11.94
19	274.88	125.65	149.23	50.26	16.44	186	18	27.53	3.52	0.0	10.46	8.58
20	233.99	106.95	127.02	42,78	12.56	160	14	18.96	0.74	0.0	9.53	6.79
21	263.99	120.68	143.32	48.27	15.73	180	20	28.57	2.73	0.0	12.81	10.09
22	222.76	101.83	120.93	40.73	15.39	172	14	19.45	0.98	0.0	10.43	7.91
23	227.02	103.78	123.25	41.51	14.87	174	16	20.38	1.03	0.0	12.21	9.32
24	229.92	105.10	124.82	42.04	16.73	176	16	22.32	0.94	0.0	10.66	8.91
25	226.37	103.48	122.89	41.39	17.04	174	18	22.69	0.63	0.0	11.17	8.15
26	265.91	121.55	144.36	48.62	19.73	186	28	31.79	3.41	0.0	13.06	10.04
27	273.57	125.05	148.52	50.02	19.82	190	28	30.97	4.16	0.0	12.38	9.97
28	280.62	128.28	152.35	51.31	20.05	194	30	31.21	3.46	0.0	12.31	10.02
29	227.50	126.85	150.65	50.74	19.79	180	28	31.76	3.19	0.0	10.62	9.82
30	227.68	104.08	123.60	41.63	13.74	174	14	16.87	0.75	0.0	9.91	8.73
WHO	180	180	300	500	30	500	300	250	50	120	120	160

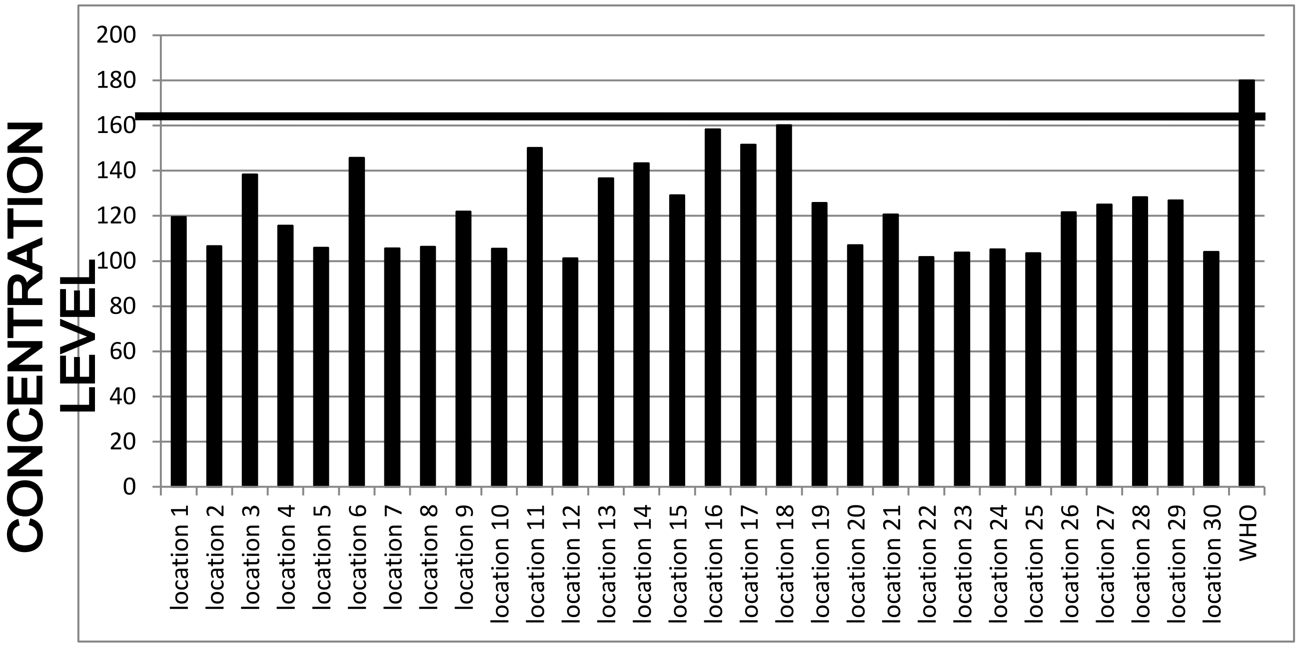


LOCATIONS

Figure 4.1: Spatial distribution of total hardness Within The Study Area

4.1.1 Total Hardness

The total hardness in the study area ranged from **221 to 350 mg/l**. Most sample locations were within the acceptable limit for scaling potential (180 mg/l). However, locations 12 exceeded this threshold, indicating a risk of scaling in pipelines and boilers. Water in these areas may require treatment for industrial use.

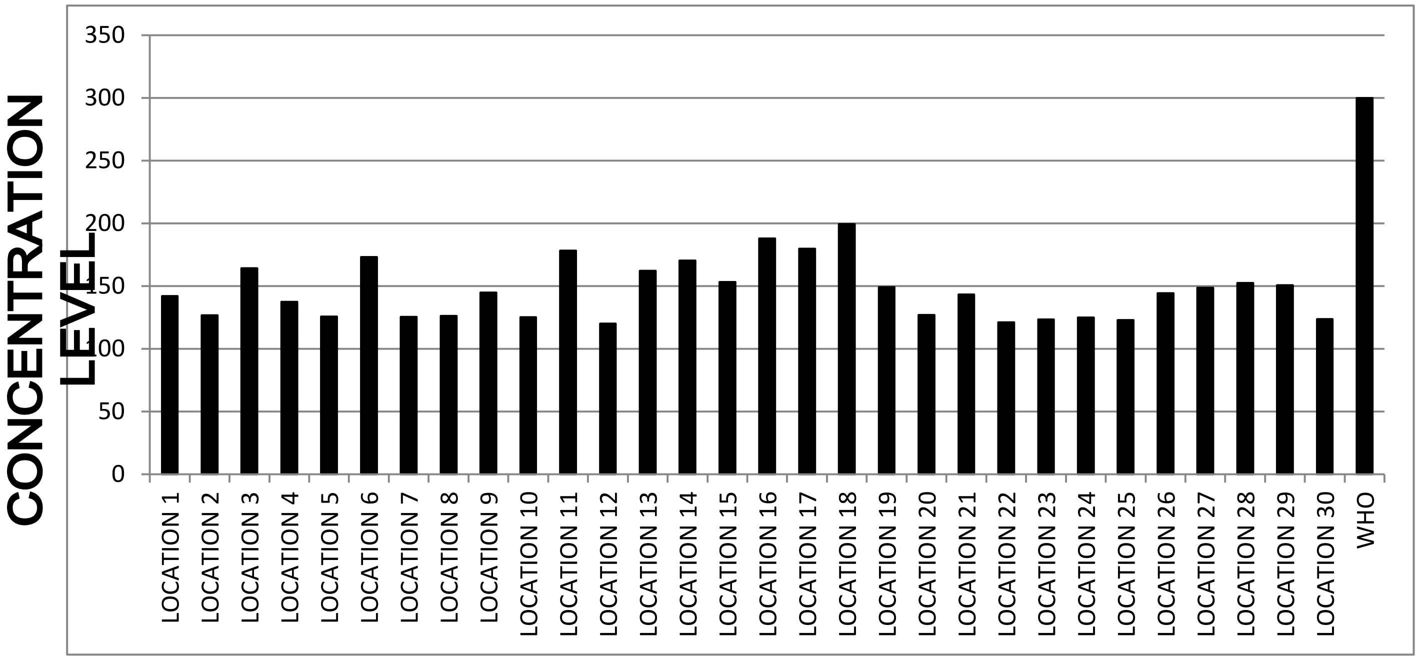


LOCATIONS

Figure 4.2: Spatial distribution of calcium hardness within the study area

4.1.2 Calcium Hardness

Calcium hardness values varied between **101 and 160 mg/l**. Location from **12** surpassed the WHO recommended limit (180mg/l), contributing to total water hardness. Elevated levels can cause scaling and reduce soap efficiency, but the water remains generally safe for drinking.



LOCATIONS

Figure 4.3: Spatial Distribution of Magnesium Hardness Within The Study Area

4.1.3 Magnesium Hardness

Magnesium hardness concentrations spanned **120 to 199 mg/l**. Locations **22** exceeded limit of 300 mg/l, indicating significant contribution to total hardness. While not a direct health concern, high levels may impart a bitter taste and promote corrosion in plumbing systems.

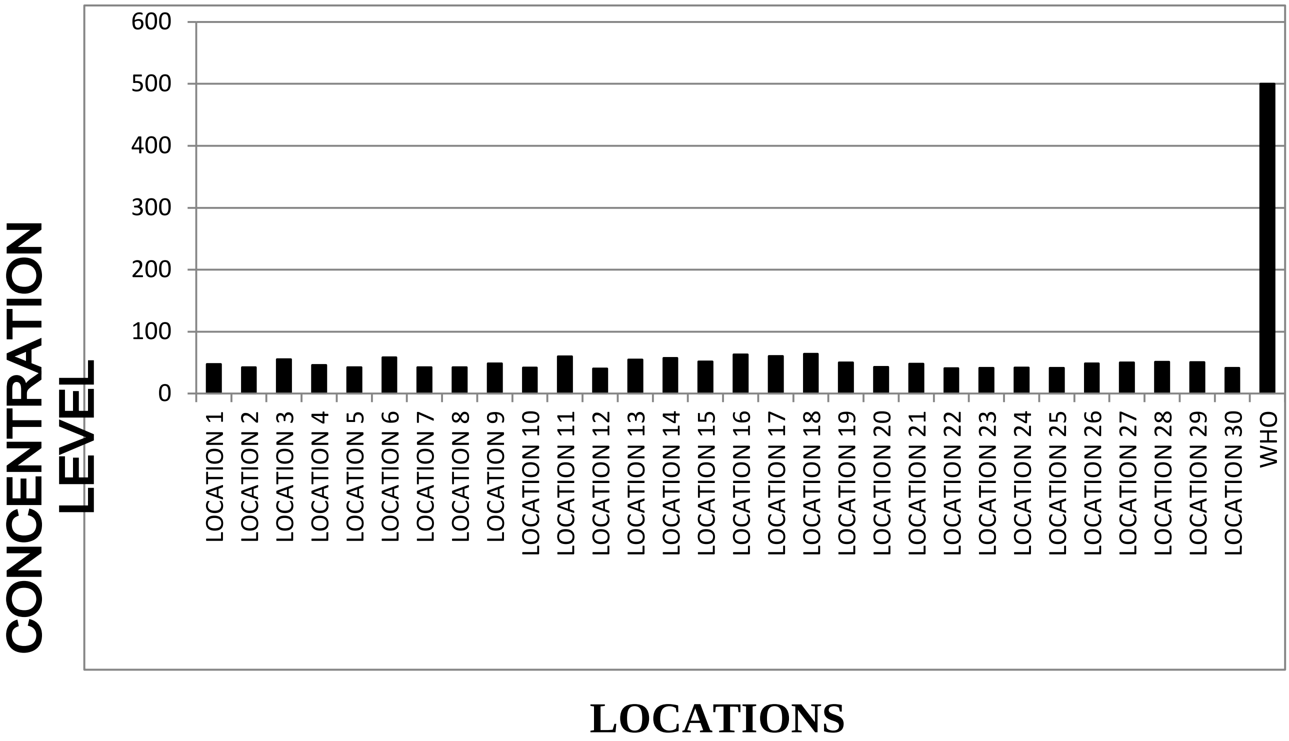


Figure 4.4: Spatial Distribution of Calcium Within The Study Area

4.1.4 Calcium ($Ca^{2)}$

The concentration of calcium in the study area ranged from **40 to 64 mg/l**. Most sample locations were within the acceptable limit for scaling potential (typically 300 mg/l). However, locations **22** exceeded this threshold, indicating a risk of scaling in pipelines and boilers. Water in these areas may require treatment for industrial use.

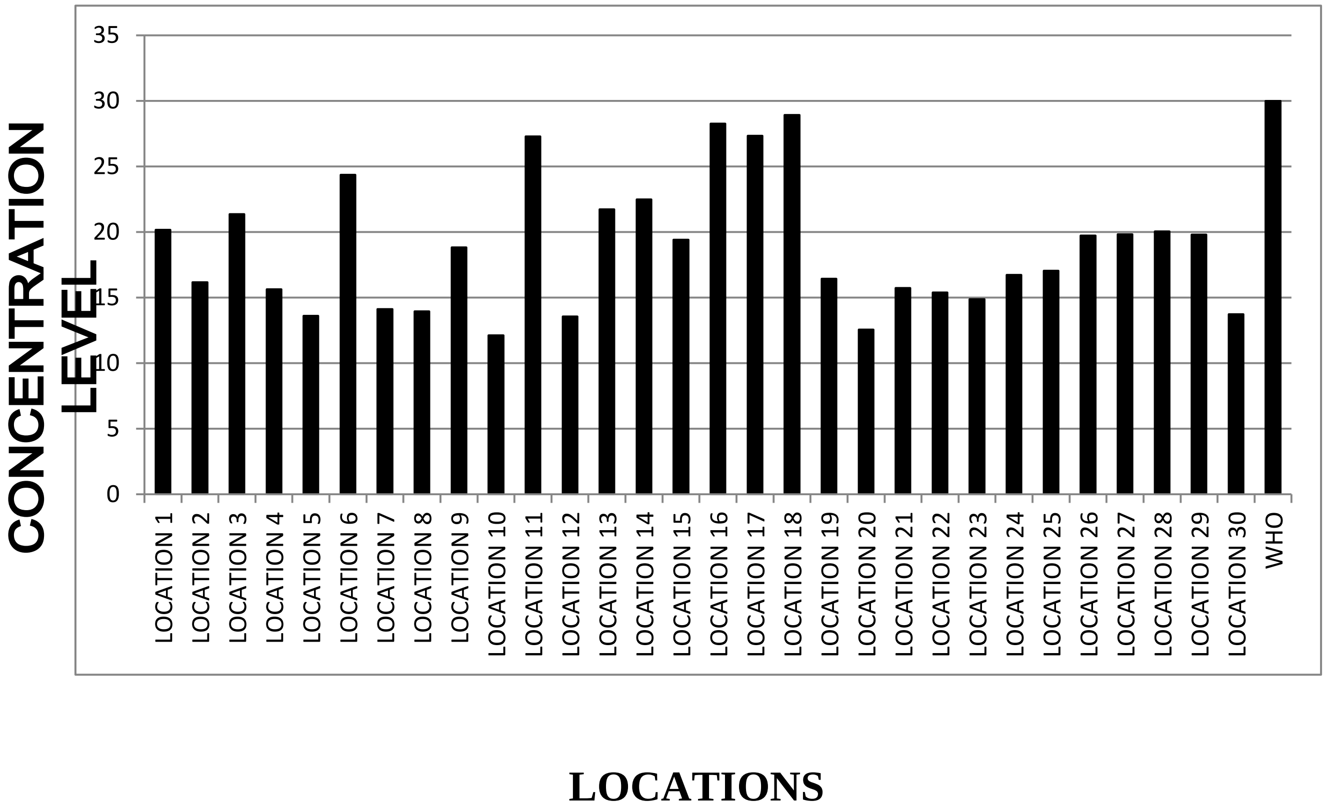


Figure 4.5: Spatial Distribution Of Magnesium Within The Study Area

4.1.4 Magnesium (Mg^{2+})

Mg^{2+} levels ranged from **12 to 28 mg/l**. Location adhered to the WHO guideline (30 mg/l). No locations posed a laxative risk or taste impairment, confirming suitability for domestic use.

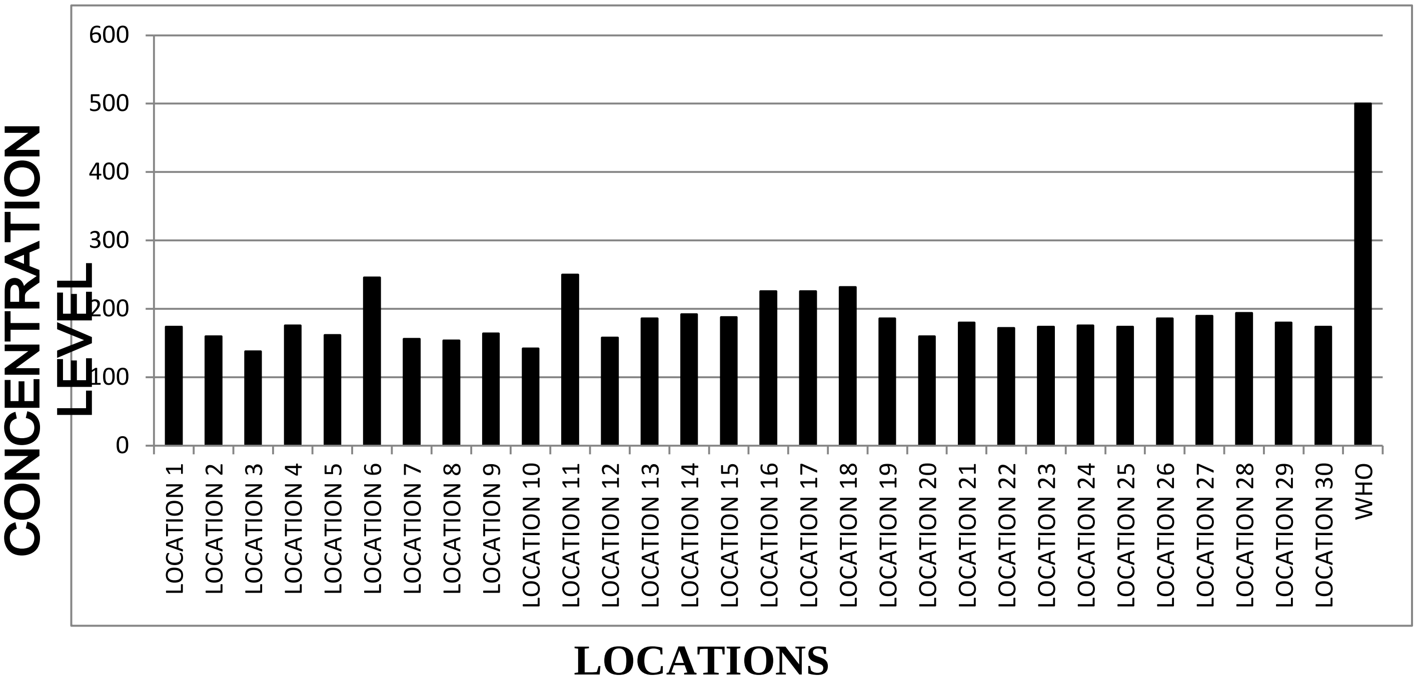


Figure 4.6: spatial Distribution Of Bicarbonates Within The Study Area

4.1.5 Bicarbonates (HCO_3^-)

Bicarbonate concentrations were **138to 250 ppm**. Location from **3** exceeded WHO 500 (mg/l) suggesting high buffering capacity and potential alkalinity issues. This may influence pH stability but is generally benign for health.

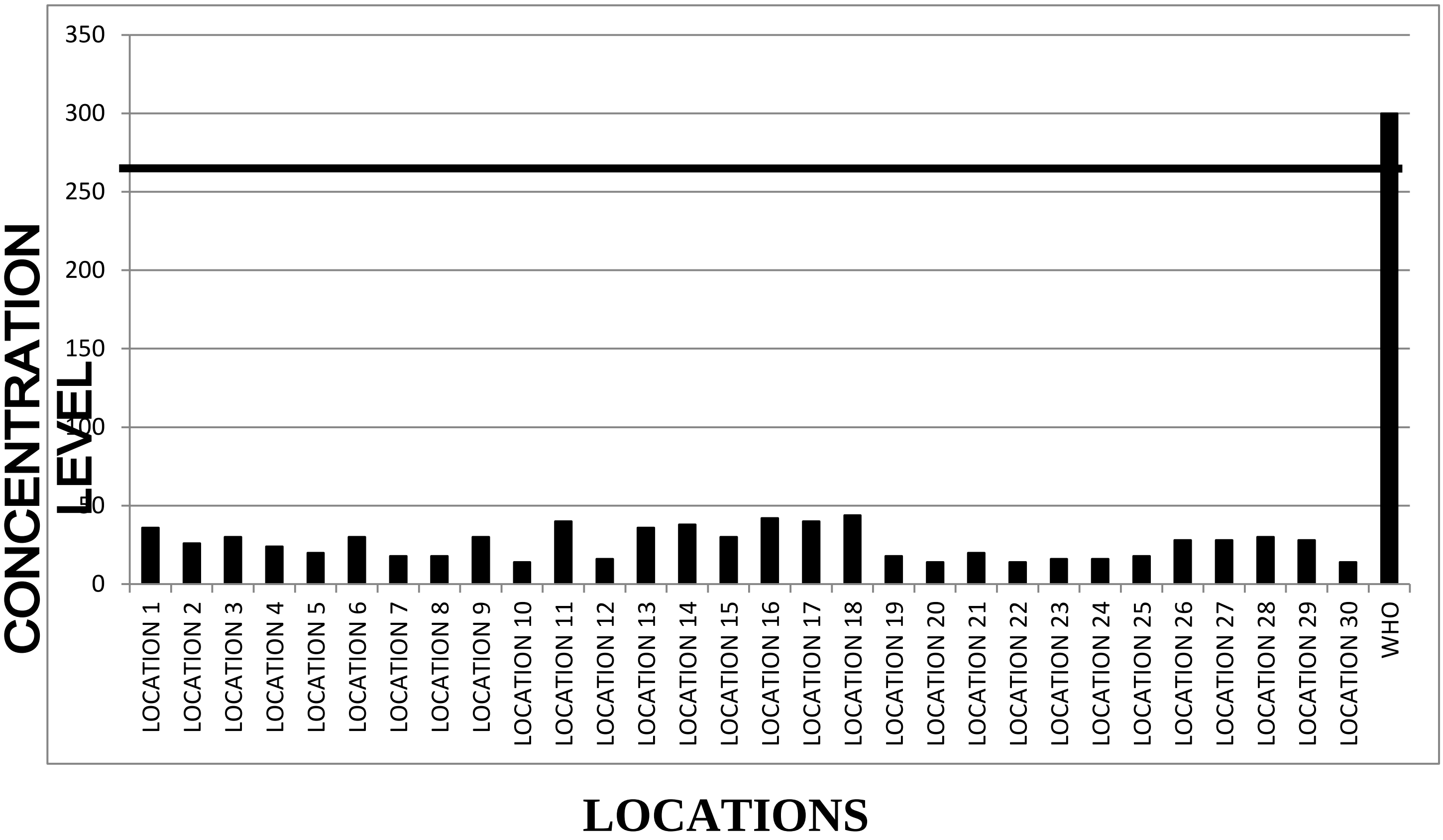


Figure. 4.7: Spatial Distribution Of Sulphate Within The Study Area

4.1.7 Sulphate ($SO^{2-}{}_4$)

Sulphate levels varied from **14 to 44 mg/l**. Location from **10** surpassed the WHO limit (300 mg/l), posing a risk of gastrointestinal irritation and corrosion in concrete infrastructure.

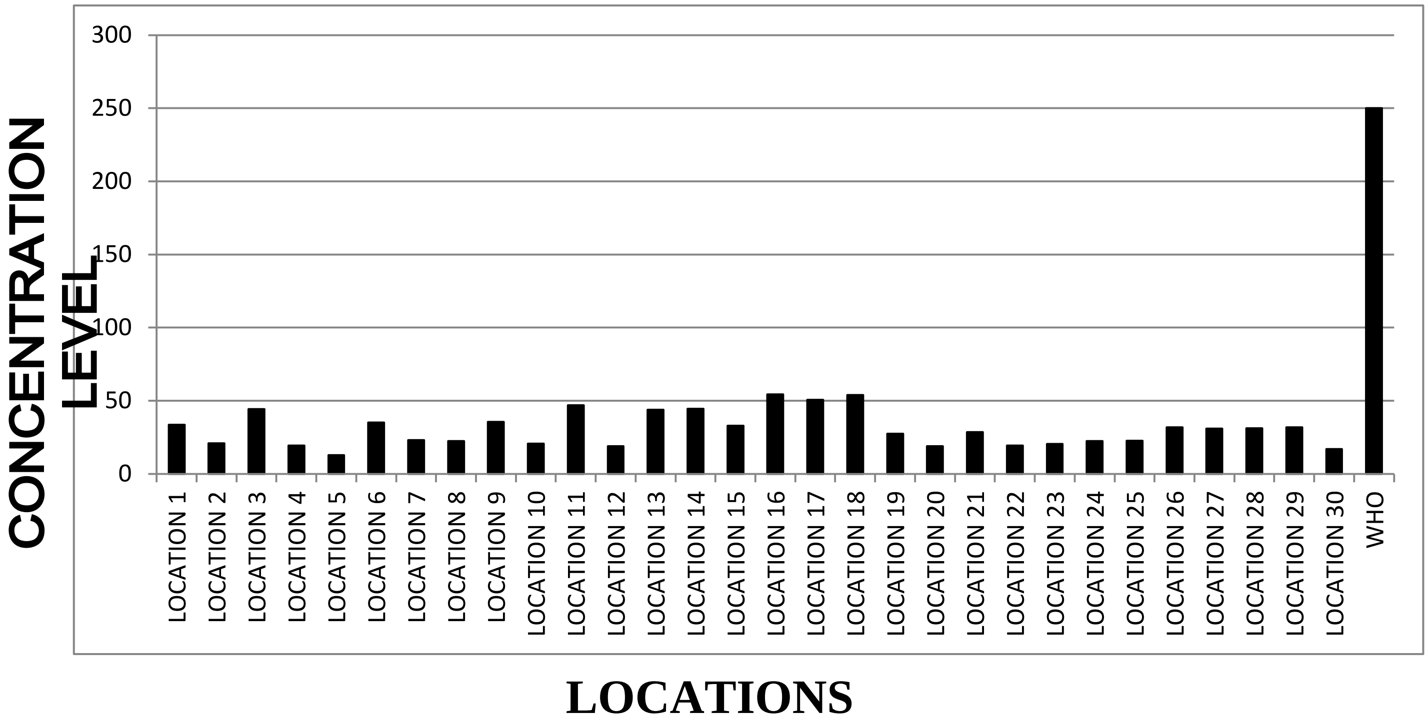


Figure. 4.8: **Spatial Distribution Of Chloride With The Study Area**

4.1.8 Chloride (Cl^-)

Chloride concentrations ranged **12 to 54 mg/l**. Locations **5** exceeded 250 mg/L (WHO limit), indicating possible seawater intrusion or pollution. High levels impart a salty taste and accelerate metallic corrosion.

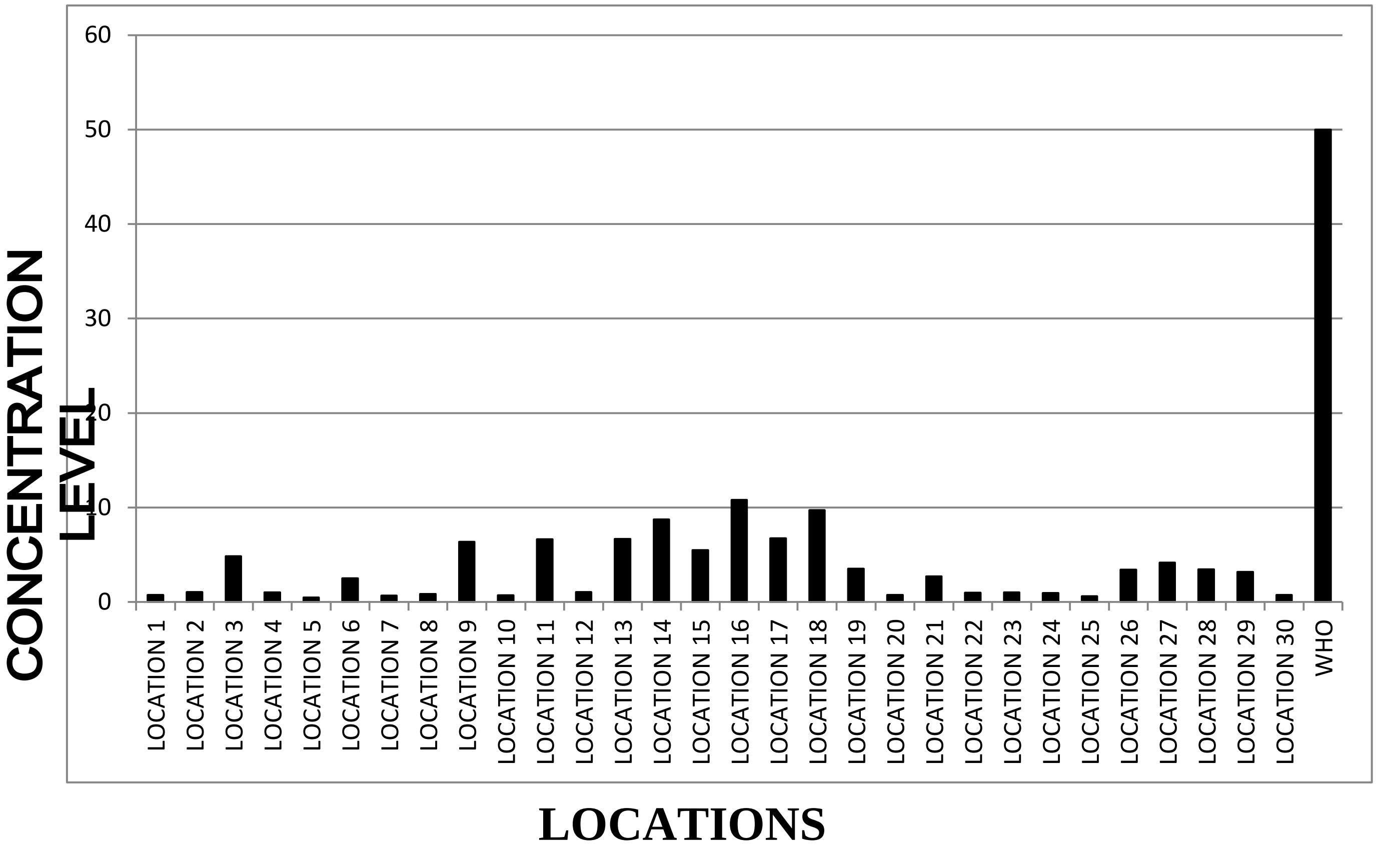


Figure. 4.9: Spatial Distribution Of Nitrate Within The Study Area

4.1.9 Nitrate (NO_3^-)

Nitrate values were **0 to 9 mg/l**. Critical exceedance (50 mg/l) very low, indicating limited agricultural of sawage contamination.

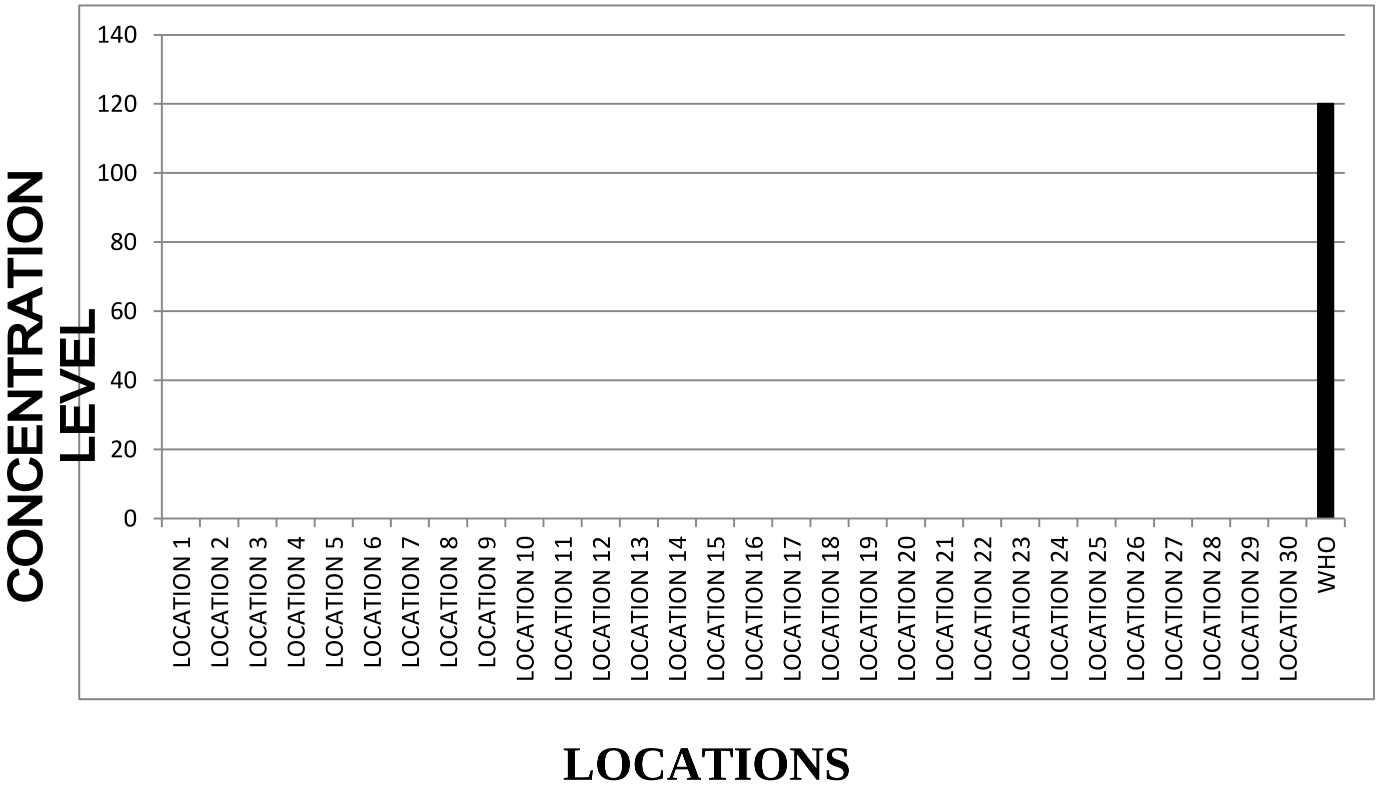
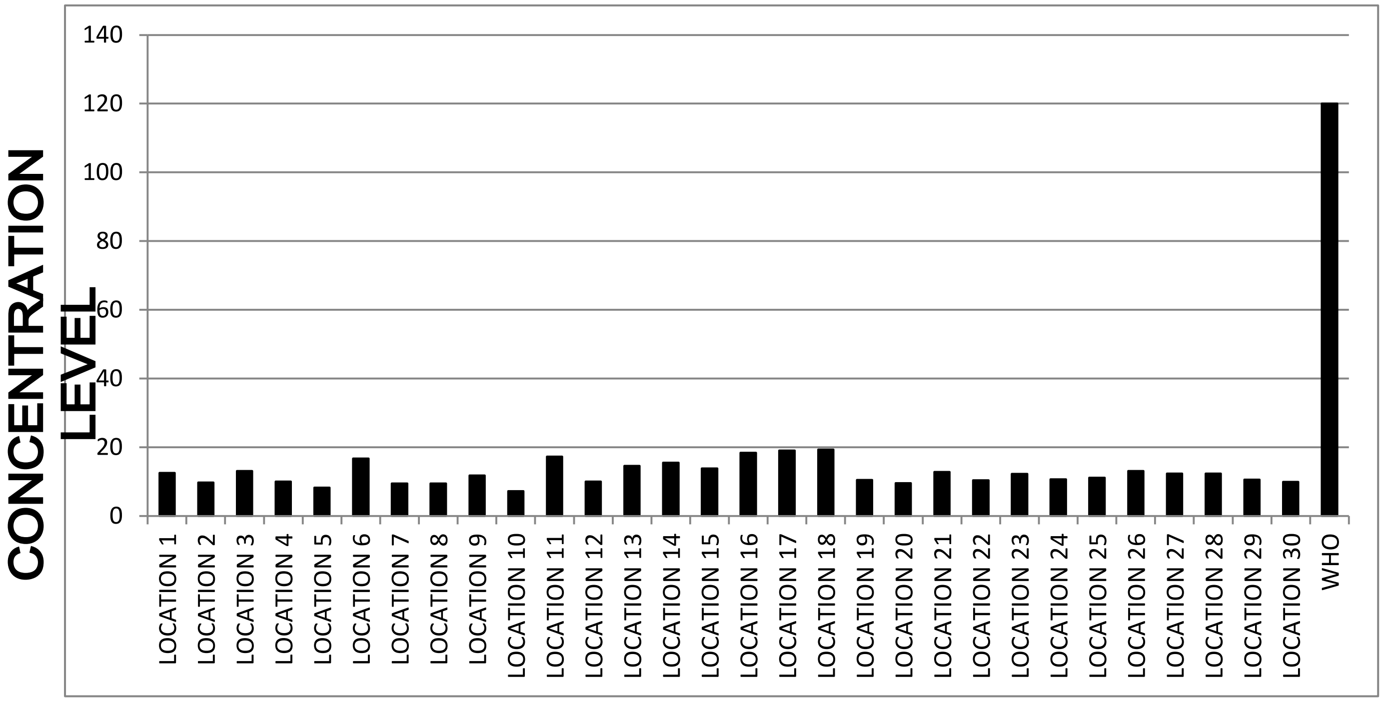


Figure. 4.10: Spatial Distribution Of Carbonate Within The Study Area

4.1.10 Carbonate (CO_3^{2-})

Carbonate concentrations spanned **0 to 0 mg/L**. While within WHO consistently high (1 20 mg/l), indicating minimal contribution to alkalinity. No regulatory concerns were noted.



LOCATIONS

Fig. 4.11: Spatial Distribution Of Sodium Within The Study Area

4.1.11 Sodium (Na)

Sodium levels ranged **7 to 19 ppm**. While within WHO health-based limits (120 mg/l), elevated Na^+ is problematic for hypertension-sensitive individuals and agriculture.

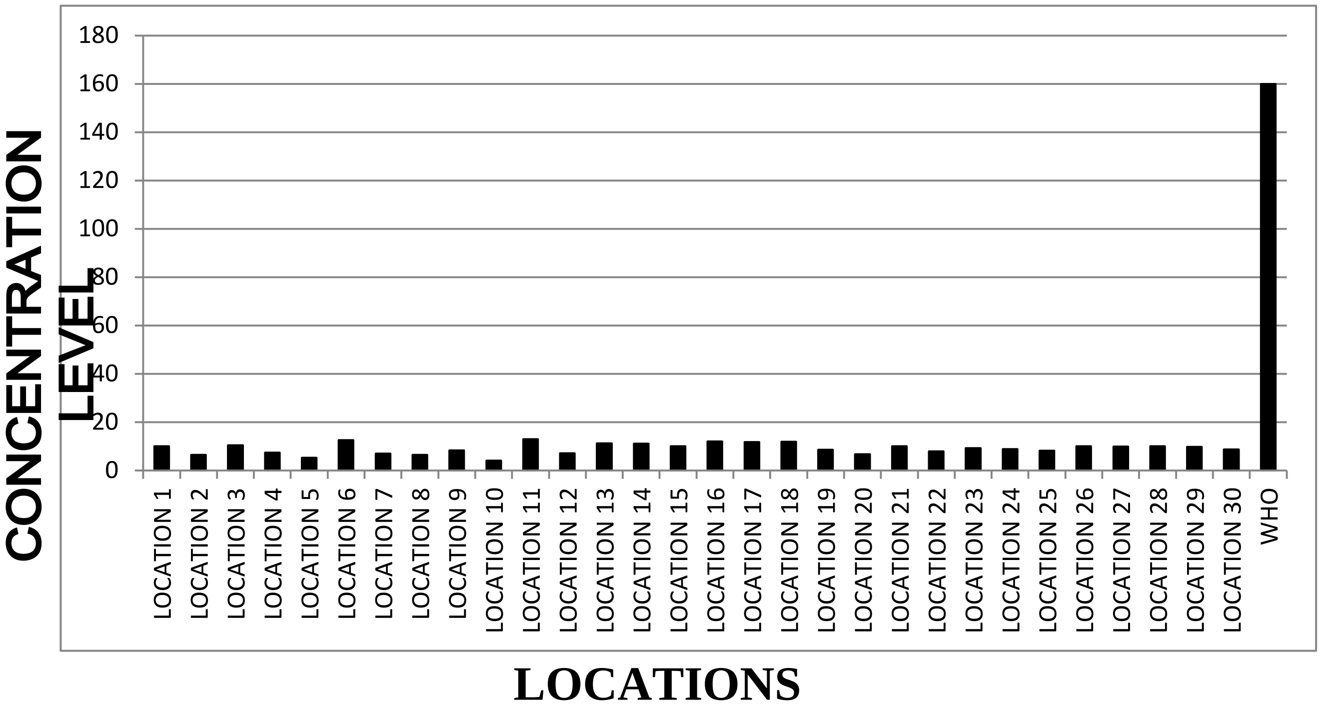


Figure. 4.12: Spatial Distribution Of Potassium Within The Study Area

4.1.12 Potassium (K^+)

Potassium concentrations were **4 to 12 ppm**. All values were below WHO guidelines (≤ 160 mg/l), posing no health risks. Low K^+ levels reflect minimal geogenic or anthropogenic influence.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

Based on the comprehensive analysis of groundwater quality in Ilorin, Southwestern Nigeria, derived from both textual descriptions and supporting charts, several critical findings emerge. The physical parameters reveal significant variability, with Electrical Conductivity (EC) ranging widely from 44.3 to 1079 m/cm, indicating substantial fluctuations in dissolved ion content. Total Dissolved Solids (TDS) levels span from 10.6 to 501.0 mg/l, directly impacting the water's suitability for consumption. The pH values, ranging from 3.7 to 7.9, indicate conditions from moderately acidic to neutral, which may influence corrosion potential and chemical solubility.

Chemical analysis of cations shows Calcium (Ca) concentrations between 1.20 and 6.60 mg/l, Magnesium (Mg) from 2.40 to 5.53 mg/l, Potassium (K) from 1.45 to 5.86 mg/l, and Sodium (Na) from 1.2 to 3.5 mg/l. Among anions, Chloride (Cl) exhibits the most variability (6.00–229.95 mg/l), with notably higher concentrations in densely populated areas, suggesting anthropogenic influence. Bicarbonate (HCO_3) levels are exceptionally low (0.20–2.18 mg/l), while Sulphate (SO_4) and Nitrate (NO_3) remain minimal (0.01–1.47 mg/l and 0.09–0.35 mg/l, respectively). Heavy metals pose serious concerns, particularly Cadmium (Cd) at 0.57–0.58 mg/l, which exceeds WHO standards, and Lead (Pb) detected up to 0.0055 mg/l in some samples.

Hardness parameters further highlight water quality challenges. Total Hardness (as $CaCO_3$) reaches up to 400 mg/l in certain locations, exceeding WHO guidelines. Calcium Hardness peaks at 200 mg/l, while Magnesium Hardness shows extreme variability across sampling sites. Carbonate (CO_3) concentrations decline sharply from 140 mg/l at Location 1 to 40 mg/l at later locations. Spatial variability is evident, with urban zones showing elevated chloride and heavy metals, indicating human activity as a key contaminant source.

A critical water quality assessment reveals that while 75% of samples meet safe standards for human consumption, 25% pose health risks due to deteriorated quality, primarily linked to heavy metal contamination and excessive hardness. This underscores an urgent need for targeted water resource management, especially in areas with Cadmium exceedances and acidic pH (as low as 3.7), which may accelerate toxic metal leaching. The interplay of natural hydrogeochemistry and anthropogenic pollution necessitates immediate intervention in high-risk zones to safeguard public health.

5.2 CONCLUSION

The groundwater exhibits significant spatial variability in physico-chemical characteristics, influenced by both natural hydrogeological processes and anthropogenic activities. Key physical parameters—including Electrical Conductivity (44.3–1079 m/cm), Total Dissolved Solids (10.6–501.0 mg/l), and acidic to neutral pH (3.7–7.9)—reflect heterogeneous aquifer conditions and potential corrosion risks. Chemically, major ions like Calcium (1.20–6.60 mg/l), Magnesium (2.40–5.53 mg/l), and Chloride (6.00–229.95 mg/l) show moderate concentrations, though Chloride spikes in urban zones indicate contamination from human sources. Critically, Cadmium levels (0.57–0.58 mg/l) consistently exceed WHO guidelines, posing severe health hazards, while detectable Lead (up to 0.0055 mg/l) further compounds toxicity concerns.

Hardness profiles reveal substantial deviations from safety benchmarks, with Total Hardness (up to 400 mg/l $CaCO_3$) and Magnesium Hardness (reaching 350 mg/l) in select locations, reducing water usability. The study confirms that 25% of samples are unsafe for consumption due to heavy metal contamination, excessive hardness, and acidic pH, which may accelerate pollutant mobilization. Urgent interventions—including source protection, pollution remediation, and infrastructure upgrades—are needed to address contamination hotspots, particularly in densely populated areas. Sustainable groundwater management must prioritize monitoring of Cadmium, Lead, and hardness parameters to safeguard public health and ensure long-term water security in the region.

5.3 RECOMMENDATIONS

Based on the groundwater quality assessment in Ilorin, Southwestern Nigeria, the following recommendations are prioritized for implementation:

1. Immediate Remediation of Heavy Metal Contamination
    - Identify and eliminate industrial/agricultural sources of cadmium (e.g., battery recycling, fertilizers) in areas with Cd levels (0.57–0.58 mg/l) exceeding WHO standards.
    - Replace corroded plumbing infrastructure in zones with acidic groundwater (pH < 6.5) to prevent lead (Pb) leaching.
2. Deploy Water Treatment Solutions
    - Install centralized pH-adjustment systems (e.g., lime dosing) to neutralize acidic water (pH 3.7–5.0) and reduce metal solubility.
    - Provide point-of-use filtration (activated carbon/ion exchange) for households in heavy metal-affected areas.
3. Enforce Source Protection Measures
    - Regulate industrial effluent discharge in chloride (Cl) hotspots (up to 229.95 mg/l) and establish 100-meter buffer zones around boreholes to restrict waste dumping.
4. Expand Monitoring and Governance
    - Implement quarterly testing for cadmium, lead, pH, and hardness across all 30 locations, with public data sharing.
    - Update water safety policies to include WHO-exceeded parameters (Cd, hardness) and penalize non-compliant industries.
5. Launch Public Awareness Campaigns

- Educate communities on cadmium exposure risks (kidney damage, cancer) and distribute water test kits for self-monitoring.

6. Invest in Long-Term Research

    - Study carbonate rock dissolution to address extremely low bicarbonate levels (0.20–2.18 mg/l) and aquifer vulnerability.

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