# DETERMINATION OF GROUND WATER FLOW DIRECTION IN IYUKU, AUCHI, EDO STATE

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**UNIVERSITY OF BENIN**

**BENIN CITY**

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**A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA.**

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**FEBUARY, 2025.**

# CERTIFICATION

This is to certify that this project work, titled "**DETERMINATION OF GROUND WATER FLOW DIRECTION IN IYUKU, AUCHI, EDO STATE"** was carried out by Benjamin Chukwuma OMENKA with Matriculation Number LSC1903737, of the Department of Science Laboratory Technology, Faculty of Life Sciences, University of Benin, Benin City, Edo State, under the supervision of Dr. K. Ojeaga

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# DEDICATION

This Project work is dedicated to Almighty God

# ACKNOWLEDGEMENT

First and foremost, I would like to express my profound gratitude to Almighty God for ensuring the successful completion of my project work with remarkable ease.

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## TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# ABSTRACT

This study provides a comprehensive analysis of groundwater flow direction in Iyuku, Auchi, offering valuable insights into hydrogeological conditions and the factors influencing groundwater movement. The wells were chosen to ensure spatial coverage of different geological formations and topographical variations. Key parameters such as hydraulic head, ground surface elevation, and static water level were measured using a Global Positioning System (GPS) device and a dip meter. The hydraulic head was calculated by subtracting the water table depth from the surface elevation, providing insights into groundwater movement. A total number of ten (10) hydraulic head values were analyzed which ranges from 121.92 to 297.882. The collected data were processed using ArcGIS 10.8 software, which was utilized to generate a potentiometric surface map indicating groundwater flow direction. The GIS-based methodology allowed for precise mapping and visualization of the spatial distribution of groundwater movement within the study area. The results of the study revealed that groundwater in Iyuku, Auchi, predominantly flows from the northeastern region toward the southwestern region. This flow pattern is driven by variations in hydraulic head, which is influenced by factors such as topography, geological formations, and groundwater recharge and discharge zones. The presence of fractured basement rocks and sedimentary deposits in the area plays a crucial role in groundwater movement by creating pathways for water infiltration and flow. Furthermore, the study identified that unregulated human activities, such as improper waste disposal, sewage leaks, and agricultural runoff, pose significant risks to groundwater quality, especially in downstream areas where contaminants may accumulate.

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND OF THE STUDY

Groundwater is a critical resource for sustaining life, supporting ecosystems, and fueling economic activities. It accounts for nearly 30% of the world's freshwater resources and over 98% of available freshwater that is not locked in glaciers or ice caps (Shiklomanov,1993). Many communities, especially in arid and semi-arid regions, rely on groundwater as their primary source of drinking water, as well as for agriculture and industrial use. Globally, groundwater is used to irrigate approximately 38% of the world's agricultural land, which highlights its crucial role in food security (Siebert *et al*., 2014). Given its importance, understanding the movement of groundwater—especially its flow direction is vital for ensuring sustainable use and protecting water quality. The flow of groundwater is primarily driven by the hydraulic gradient, the difference in pressure or hydraulic head between two points. Water moves from areas of higher hydraulic head to areas of lower hydraulic head, typically from recharge zones (where water enters the aquifer) to discharge zones (where water exits, such as springs, rivers, or wells). The direction of groundwater flow is influenced by various factors, including the permeability of the geological formations through which it flows, the topography of the land, and human activities such as groundwater extraction (Freeze and Cherry,1979). Accurately determining groundwater flow direction is essential for water resource management, pollution control, and ecological preservation.

In recent years, the study of groundwater flow direction has gained increasing attention due to growing concerns about groundwater depletion, contamination risk, and the impacts of climate change. Over-extraction of groundwater, particularly in regions where demand for water exceeds natural recharge rates, has led to the depletion of aquifers, a phenomenon often exacerbated by the lack of understanding of groundwater flow dynamics (Gleeson *et al*., 2012). Additionally, contaminants such as nitrates from agricultural runoff or industrial chemicals can spread through groundwater systems, following the natural flow direction, and pose risks to drinking water supplies and ecosystems (Foster and Chilton, 2003). Understanding groundwater flow direction is thus essential for predicting the movement of contaminants and design of effective landfill.

Groundwater-dependent ecosystems, including wetlands, rivers, and lakes, also rely on the continuous inflow of groundwater to maintain their ecological balance. Changes in groundwater flow direction, often caused by human activities such as groundwater pumping or land-use changes, can disrupt these ecosystems, leading to habitat degradation and loss of biodiversity (Winter *et al*., 1998). For example, in many regions, groundwater extraction for agriculture or urban development has lowered water tables, reducing the baseflow to rivers and wetlands. Such disruptions can have cascading effects on the broader environment, making the study of groundwater flow direction crucial for conservation efforts.

Human-induced changes, such as urbanization and groundwater pumping, also alter natural groundwater flow patterns. In urban areas, the construction of impervious surfaces (e.g., roads, buildings) reduces the infiltration of water into the ground, thereby changing the recharge rates and potentially shifting the flow direction (Barlow and Leake, 2012). Additionally, the extraction of groundwater for industrial or agricultural purposes creates localized changes in the flow direction by creating cones of depression around wells. This can lead to the migration of water from previously unaffected areas, altering regional groundwater dynamics and impacting the availability of water for various uses.

Given the complexities of groundwater flow and the various factors that influence its direction, there is a pressing need for detailed studies that provide insights into local groundwater dynamics. This study aims to contribute to that understanding by determining the groundwater flow direction within a specific study area. By employing field data collection, mapping techniques, and Geographic Information System (GIS) tools, the study will provide a comprehensive analysis of groundwater movement, with a focus on identifying critical recharge and discharge areas. The findings will be valuable not only for water resource management but also for mitigating groundwater contamination risks, preserving groundwater-dependent ecosystems, and informing sustainable development practices.

## 1.2 Statement of the Research Problem

Despite its importance, accurately determining groundwater flow direction remains a complex task. The flow of groundwater is often unseen, occurring beneath the surface through porous materials, fractured rocks, or karst formations. Many factors influence the movement of groundwater, including geology, topography, hydraulic conductivity, aquifer characteristics, recharge rates, and human activities such as pumping and irrigation. Determining the flow direction is essential for several applications.

In many developing regions, over-extraction of groundwater without a clear understanding of flow patterns has led to critical problems, including aquifer depletion, saltwater intrusion, and land subsidence. Similarly, in industrial areas, groundwater contamination can spread, posing a threat to human health and ecosystems if the flow direction is not understood and managed appropriately.

## 1.3 Aim and Objectives of the Study

The primary aim of this research is to determine the groundwater flow direction in the study area and to understand the factors that control its movement.

The Specific objectives of the study are to:

i. To determine the depth into water table

ii. To determine the ground surface elevation

iii. To determine the hydraulic head

iv. To produce a ground water contour map.

## 1.4 Research Questions

In order to meet the objectives of this study, the following research questions will be addressed:

i. What are the main hydro geological characteristics of the study area that influence groundwater flow?

ii. What is the groundwater flow direction and how is it spatially distributed?

iii. How do natural factors (such as topography and geology) and human factors (such as pumping and land use) influence the flow direction?

iv. Are there any significant areas of groundwater recharge or discharge within the study area, and how do they relate to the overall flow pattern?

v. What methods are most effective for determining groundwater flow direction in this specific geological setting?

## 1.5 Significance of the study

The study is significant for several reasons. Firstly, providing crucial information for sustainable groundwater use, especially in regions prone to over-extraction and water scarcity. Secondly, the findings of this study will provide valuable support for environmental Protection by identifying flow paths, the study can help in the protection of sensitive ecosystems such as wetlands and rivers that rely on groundwater discharge. Additionally, the study will be

vital for identifying contamination risks and design effective longitude and latitude landfill system.

Furthermore, the study will be beneficial to Civil engineering projects that interact with the groundwater system, such as roads, dams, and urban development, will benefit from a detailed understanding of groundwater behavior.

## 1.6 Scope of the Study

The scope of this study involves determining the groundwater flow direction within a specified area, focusing on the hydrogeological characteristics that influence flow patterns, such as geology, topography, and hydraulic gradients. The research will include the collection of field data from monitoring wells to construct water table contour maps and analyze groundwater levels. Geographic Information System (GIS) tools will be used to map the flow direction and identify critical recharge and discharge zones. Additionally, the study will examine the impact of human activities, such as groundwater extraction and land use changes, on the flow dynamics. The research is limited to the study area and does not cover broader regional groundwater systems, but its findings may provide insights for similar settings.

## 1.7 Justification of the Study

Groundwater is an increasingly important resource, especially in regions where surface water is limited or unreliable. With rising demand for water driven by population growth, agriculture, and industrialization, the need for sustainable groundwater management is more critical than ever. Proper understanding of groundwater flow direction is fundamental for achieving sustainable management goals. However, despite its importance, the complexities of groundwater flow are often misunderstood or overlooked, particularly in regions where data is scarce or where groundwater use is unregulated.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Theoretical Foundations of Groundwater Flow

Groundwater flow is primarily driven by differences in hydraulic head, which represents the potential energy available to move groundwater. The hydraulic head is composed of two components: elevation head (due to gravity) and pressure head (due to the weight of overlying water). Groundwater moves from areas of higher hydraulic head to areas of lower hydraulic head, following the path of least resistance (Freeze and Cherry, 1979). This movement is described mathematically by Darcy's Law, which is central to groundwater hydraulics and is used to estimate groundwater flow rates and directions.

### 2.1.1 Darcy's Law

Darcy's Law is one of the most fundamental concepts in hydrogeology. It states that the flow of groundwater through a porous medium is proportional to the hydraulic gradient (the difference in hydraulic head between two points) and the permeability (or hydraulic conductivity) of the medium. The law is expressed as:

$$Q = -K \cdot A \cdot \frac{dh}{dl}$$

Where:

$Q$ is the volumetric flow rate of groundwater ($m^3/s$),

$K$ is the hydraulic conductivity ($m/s$),

$A$ is the cross-sectional area perpendicular to flow ($m^2$), and

$\frac{dh}{dl}$ is the hydraulic gradient (m/m), which is the change in hydraulic head per unit distance along the flow path.

This equation forms the basis for calculating groundwater flow in aquifers and is crucial for determining flow direction, as groundwater naturally moves from high to low hydraulic head areas (Bear, 1972). Understanding the principles of Darcy's Law is key to any study of groundwater flow because it explains how geological properties and hydraulic gradients interact to influence flow patterns.

### 2.1.2 Aquifer Properties and Groundwater Flow

Aquifers are geological formations that can store, transmit, and yield groundwater to wells or springs. Aquifers are classified into two main types: unconfined and confined. In unconfined aquifers, the water table marks the upper boundary of the saturated zone, and water can move freely in response to changes in recharge or extraction. In confined aquifers, groundwater is trapped between impermeable layers, and its flow is primarily horizontal due to the pressure imposed by the overlying confining layer (Todd and Mays, 2015).

The permeability and porosity of aquifer materials significantly affect the direction and velocity of groundwater flow. Porous materials such as sand and gravel have higher permeability, allowing for faster and more directional flow, while less permeable materials such as clay or silt impede flow, creating more complex patterns (Fetter, 1999). The presence of fractures or faults in the geological substrate can also influence flow direction, as these features often act as conduits or barriers to groundwater movement (Singhal and Gupta, 2010). Understanding these properties is crucial for determining groundwater flow direction, as they control how and where water moves within an aquifer.

### 2.2 Methods for Determining Groundwater Flow Direction

Several methods have been developed over the years to accurately determine groundwater flow direction, each with its strengths and limitations. These methods range from traditional field-based approaches that involve direct measurement of groundwater levels to sophisticated computational techniques that model groundwater flow in complex systems. The choice of method depends on factors such as the scale of the study, available resources, and the specific objectives of the research.

### 2.2.1 Field-Based Approaches

One of the most commonly used field-based methods for determining groundwater flow direction is the construction of water table or potentiometric surface maps. This method involves installing a network of monitoring wells across the study area to measure the hydraulic head at each location. By plotting these measurements on a map, researchers can create contour lines of equal hydraulic head (isopotential lines), which reveal the general direction of groundwater flow. Groundwater typically flows perpendicular to these contour lines, moving from areas of high hydraulic head (recharge zones) to areas of low hydraulic head (discharge zones) (Anderson and Woessner, 1992 ).

Another field-based method is the use of tracer tests. Tracers, which can be chemical, isotopic, or dye-based, are introduced into the groundwater system and monitored as they move through the aquifer. By observing the direction and velocity of the tracer's movement, researchers can infer the groundwater flow direction and rate. Tracer tests are particularly useful for understanding contaminant transport within aquifers, as they provide direct evidence of how water and dissolved substances move through the subsurface (Domenico and Schwartz, 1998 ). However, tracer tests can be time-consuming and costly, especially over large areas

### 2.2.2 Geophysical Methods

Geophysical methods are increasingly being used to complement traditional field approaches in determining groundwater flow direction. Techniques such as electrical resistivity tomography (ERT), ground-penetrating radar (GPR), and seismic refraction provide indirect data on subsurface properties, which can be used to infer groundwater flow patterns. These methods are particularly useful in areas where direct measurement of groundwater levels is difficult or where the geology is complex, as they allow for the mapping of subsurface structures

and the identification of preferential flow paths (Loke, 2004

### 2.2.3 Numerical Modeling

Numerical modeling has become a widely adopted approach for simulating groundwater flow and determining flow direction in complex aquifer systems. Models such as MODFLOW, developed by the U.S. Geological Survey, use finite difference or finite element methods to solve the groundwater flow equation based on input parameters such as hydraulic conductivity, recharge rates, and boundary conditions (Harbaugh, 2005). These models allow for the simulation of groundwater flow under various scenarios, providing a detailed picture of flow patterns over time.

In recent years, Geographic Information Systems (GIS) have been integrated with groundwater models to enhance the spatial representation of groundwater flow. GIS-based models allow researchers to incorporate spatial data on topography, land use, and hydrogeology into groundwater flow simulations, making it easier to visualize flow direction across large areas (Liao *et al*., 2014). These models have been used extensively in regional groundwater management studies, as they provide a comprehensive view of how groundwater moves through complex landscapes.

## 2.3 Factors Influencing Groundwater Flow Direction

Groundwater flow direction is influenced by a variety of factors, both natural and human-induced. Understanding these factors is essential for accurately predicting how groundwater moves and for managing groundwater resources effectively.

### 2.3.1 Geological and Hydrogeological Factors

The geological characteristics of the aquifer, including its permeability and porosity, are the primary determinants of groundwater flow direction. Highly permeable materials such as sand, gravel, or fractured rock allow for more straightforward and rapid groundwater flow, while less permeable materials such as clay or shale restrict flow, often causing it to divert around low-permeability zones (Fetter, 1999 In heterogeneous aquifers, the presence of layers with varying permeability can create complex flow patterns, with water flowing along preferential paths determined by the geological structure. The presence of faults, fractures, and other geological discontinuities can also influence groundwater flow direction. Faults and fractures can act as conduits for rapid groundwater flow, especially in otherwise low-permeability formations, while in some cases, they can serve as barriers, impeding flow across them (Singhal and Gupta, 2010). Understanding the structural geology of an aquifer is therefore essential for accurately determining flow direction, especially in areas with significant tectonic activity or complex stratigraphy.

### 2.3.2 Topography and Surface Water Interactions

Topography plays a significant role in determining groundwater flow direction, as groundwater generally follows the slope of the land surface. In mountainous regions, groundwater typically flows from high-elevation recharge areas to lower-elevation discharge areas such as rivers, lakes, or springs (Winter *et al*., 1998). In flat areas, flow may be slower and more diffuse, making it more challenging to determine the precise direction of groundwater movement. The interaction between groundwater and surface water is also an important consideration, as groundwater contributes to the baseflow of rivers and streams, and changes in groundwater flow direction can affect surface water levels (Barlow and Leake, 2012).

### 2.3.3 Human Activities

Human activities such as groundwater extraction, urbanization, and agriculture can significantly alter natural groundwater flow directions. Groundwater extraction, particularly through deep wells, can create cones of depression in the water table around pumping sites, which can lead to changes in the local hydraulic gradient and cause groundwater to flow toward the extraction point (Barlow and Leake, 2012). This can result in the depletion of nearby aquifers, a reduction in the baseflow to rivers and streams, and changes in groundwater surface water interactions.

Urbanization, especially the construction of impervious surfaces such as roads and buildings, reduces the natural recharge of groundwater by preventing rainwater from infiltrating the ground. Instead, surface runoff increases, often leading to flooding and erosion. The reduction in recharge can lower groundwater levels and disrupt natural flow patterns (Zume and Tarhule, 2008). Additionally, urbanization can introduce contaminants into groundwater, particularly from industrial activities, septic systems, and waste disposal sites, further complicating the understanding and management of groundwater flow. Agricultural activities also have significant impacts on groundwater flow. The extensive use of irrigation systems alters recharge rates, often resulting in the over-extraction of groundwater in arid and semi-arid regions. The use of agrochemicals, such as fertilizers and pesticides, introduces contaminants into the groundwater system, and the flow direction becomes crucial in predicting the movement of these pollutants (Scanlon *et al*., 2005). Understanding how human activities modify groundwater flow is essential for creating sustainable water management strategies that account for both resource availability and environmental protection.

## 2.4 Groundwater Flow Direction and Contamination

One of the most critical applications of determining groundwater flow direction is in the context of groundwater contamination. Contaminants introduced into the subsurface from sources such as agricultural runoff, industrial waste, leaking underground storage tanks, or landfills can be transported through groundwater systems, posing a risk to human health and ecosystems. The flow direction plays a vital role in predicting the movement of these contaminants and designing effective remediation strategies.

### 2.4.1 Contaminant Transport Mechanisms

Contaminant transport in groundwater occurs through a combination of processes, including advection, dispersion, and chemical reactions. Advection refers to the transport of contaminants by the bulk movement of groundwater in the direction of the flow. Dispersion causes contaminants to spread out from the center of the flow path due to variations in flow velocity within the porous medium (Domenico and Schwartz, 1998). In addition, chemical reactions such as adsorption, degradation, and precipitation can affect the mobility and persistence of contaminants.

Numerical models of contaminant transport, such as MT3DMS (Modular Three-Dimensional Transport Model), are often used to simulate the movement of pollutants in groundwater systems. These models combine information about groundwater flow direction, aquifer properties, and contaminant characteristics to predict how and where contaminants will move over time (Zheng and Wang, 1999). Accurate predictions of contaminant spread are critical for managing contaminated sites, protecting drinking water sources, and safeguarding public health.

### 2.4.2 Case Studies of Contaminant Transport

Several case studies have demonstrated the importance of understanding groundwater flow direction in managing contamination risks. For example, in industrial areas where hazardous chemicals have been improperly disposed of, groundwater flow models have been used to trace the movement of toxic plumes toward residential areas or drinking water wells. In one well-known case in Woburn, Massachusetts, groundwater contamination from a tannery led to a cluster of leukemia cases among children in the area. Understanding the groundwater flow direction was crucial for identifying the source of contamination and for guiding cleanup efforts (Fetter, 1999).

In agricultural regions, nitrate contamination from fertilizer use has become a widespread issue, particularly in areas with shallow groundwater tables. Groundwater flow models have been employed to predict the movement of nitrate plumes and assess the risks to drinking water sources. Similarly, the use of pesticides in agriculture has resulted in long-lasting contamination of groundwater, and understanding the flow direction is essential for preventing further spread (Nolan *et al*., 1997). These examples highlight the importance of accurately determining groundwater flow direction in mitigating contamination risks and protecting water quality.

## 2.5 Implications for Water Resource Management

The determination of groundwater flow direction has far-reaching implications for water resource management, particularly in regions where groundwater is a critical source of drinking water, irrigation, and industrial use. Effective management of groundwater resources requires a clear understanding of how groundwater moves, where it is recharged and discharged, and how human activities and environmental factors affect its flow.

### 2.5.1 Managing Groundwater Extraction

Sustainable management of groundwater extraction depends on accurately determining the direction and rate of groundwater flow. Over-extraction of groundwater can lead to a range of problems, including the depletion of aquifers, land subsidence, and reduced flows to rivers and streams (Konikow and Kendy, 2005). By understanding groundwater flow direction, water managers can identify recharge zones and ensure that groundwater is extracted at sustainable rates, preventing long-term damage to aquifer systems. In some regions, managed aquifer recharge (MAR) techniques are used to artificially increase groundwater recharge, particularly in areas facing water scarcity. These techniques rely on precise knowledge of groundwater flow direction to ensure that the recharged water is effectively distributed within the aquifer (Dillon *et al*., 2019).

### 2.5.2 Protecting Water Quality

Groundwater quality is closely linked to flow direction, particularly in areas where contaminants are present. Groundwater flow models are used to assess the vulnerability of drinking water wells to contamination and to design protection zones that prevent contaminants from reaching critical water supplies. In many countries, wellhead protection programs have been established to regulate land use in areas where groundwater flow paths lead to public water supply wells (EPA, 2004). These programs rely on accurate determinations of flow direction to define the areas most at risk and to implement land-use restrictions or remediation efforts to protect water quality.

### 2.5.3 Climate Change and Groundwater Flow

Climate change poses additional challenges to groundwater management, as shifts in precipitation patterns, increased evaporation, and changes in recharge rates are expected to alter groundwater flow dynamics. In arid and semi-arid regions, where groundwater is already under stress, these changes may exacerbate water scarcity and increase competition for limited resources (Taylor *et al*., 2013). Predicting how groundwater flow direction will change in response to climate variability is critical for adapting water management practices to ensure long-term sustainability. Numerical models that integrate climate data with groundwater flow simulations are increasingly being used to project future changes in groundwater systems and to inform policy decisions (Wada *et al*., 2014).

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 STUDY AREA

The study area, Auchi and its environs, is located in the northern part of Edo State, Nigeria. It serves as a major gateway to northern Nigeria and is emerging as an industrial hub due to its rich mineral resources. The area lies approximately at Latitude 7°N and Longitude 6°E.

## 3.2 GEOLOGY OF THE STUDY AREA

The geology of Auchi and its surrounding areas is characterized by a combination of Precambrian Basement Complex rocks and Cretaceous sedimentary formations. The area falls within the Southwestern Basement Complex of Nigeria, which has undergone multiple geological transformations due to tectonic and magmatic processes.

The Precambrian Basement Complex in Auchi consists of Migmatite-Gneiss Complex which are high-grade metamorphic rocks formed through partial melting and recrystallization. The gneisses exhibit foliation and banding due to mineral segregation. They contain quartz, feldspar, biotite, and hornblende minerals. Metasedimentary and Meta-Igneous Rocks which include Quartzite schists and amphibolite schists that represent metamorphosed sedimentary and volcanic rocks. Marbles occur in localized regions, indicating past carbonate-rich deposits subjected to metamorphism. These rocks have undergone polyphase deformation, leading to multiple folding and faulting events. Porphyritic Older Granites includes Intrusive igneous rocks that cut through the metamorphic rocks. The granites are medium to coarse-grained and contain feldspar phenocrysts, indicating slow cooling. They show evidence of jointing and fracturing, which can influence groundwater movement.

Cretaceous Sedimentary Rocks (Lokoja-Basange Formation) overlies the Basement Complex and belong to the Lokoja-Basange Formation of the Bida Basin. The sediments consist of sandstones, conglomerates, siltstones, and shales. The presence of ironstone deposits suggests fluvial and deltaic depositional environments.

The area has been subjected to multiple deformation events, leading to: Foliation and lineations, with schists aligned in N-S and S-E directions. Joints and fractures in granites, which serve as potential groundwater pathways. Evidence of Pan-African orogeny, which caused regional metamorphism and structural reworking.

Fractured basement rocks provide secondary porosity for groundwater storage. Sandstones and conglomerates in the Lokoja-Basange Formation serve as potential aquifers. The presence of faults and fractures can enhance groundwater flow or act as barriers, influencing flow direction and recharge zones.

## 3.3 MATERIALS FOR DETERMINING GROUNDWATER FLOW DIRECTION

The following materials and equipment were used in the study:

Global Positioning System (GPS) Device, Tape Meter, Dip Meter/Water Level Indicator, ArcGIS 10.8 / QGIS Software, Topographic and Geological Maps, Field Notebook and Pen, Computer/Laptop, Microsoft Excel/SPSS

## 3.4 DETERMINATION OF GROUNDWATER FLOW DIRECTION

The method for determining groundwater flow direction in the study area follows the approach of Oborie and Nwankwoala (2017). This method involves measuring ground elevations, geographic coordinates (latitude and longitude), and water table depths in selected hand-dug wells using a GPS device and tape meter.

## 3,5 METHODOLOGY

1. Selection of Hand-Dug Wells

Due to difficulty in accessing cased boreholes, the study focused on ten (10) hand-dug wells distributed across the study area. The wells were selected to ensure good spatial coverage of the study area.

2. Measurement of Groundwater Elevation

The elevation, latitude, and longitude of each well were recorded using a Global Positioning System (GPS). The depth to water table was measured directly using a tape meter.

The hydraulic head (HH) was then calculated using the formula:

Hydraulic Head =Ground Elevation - Depth to Water Table

Where:

Ground Elevation = Elevation of the ground surface at the well location (measured using GPS).

Depth to Water Table = Vertical distance from the ground surface to the water level inside the well (measured using a tape meter).

Hydraulic Head (HH) = The potential energy available to drive groundwater flow.

3. Creation of Potentiometric Surface Map

The individual hydraulic head measurements were plotted using ArcGIS 10.8. A potentiometric map was generated by interpolating the data to create equipotential lines. Equipotential lines represent lines of equal pressure and hydraulic head, indicating zones of similar groundwater potential.

4. Determination of Groundwater Flow Direction

Groundwater flows from areas of higher hydraulic head to lower hydraulic head.

Flow direction arrows were drawn perpendicular to the equipotential lines to indicate groundwater movement.

## 3.6 GIS-BASED METHODOLOGY

1. Data Collection and Georeferencing

GPS coordinates of boreholes, wells, and other monitoring points were recorded in the field. These points were imported into ArcGIS/QGIS for mapping. Existing geological and topographic maps were digitized and georeferenced for spatial analysis.

2. Groundwater Contour Mapping

Water table elevations were interpolated using Inverse Distance Weighting (IDW) or Kriging methods in GIS. A groundwater contour map was generated to visualize water table fluctuations. Flow direction arrows were drawn perpendicular to contour lines, showing groundwater movement.

### 3. Structural Overlay Analysis

The groundwater flow map was overlaid with fault lines, fractures, and lithological boundaries to assess geological control on groundwater movement. Lineament analysis was performed using satellite imagery to identify subsurface fractures influencing flow paths.

# CHAPER FOUR

## 4.0 PRESENTATION OF RESULTS

## 4.1 DIRECTION OF GROUNDWATER FLOW DIRECTION

The result of parameters used for determining the groundwater flows direction is presented in Table 4.1 below. Result of Groundwater flow model generated using the ArcGis 10.8 is presented in Figure 4.2.

**Table 4.1: Parameters for Determination of Groundwater Flow Direction**

| Sampling points | Latitude | Longitude | Static water Level | Elevation | Hydraulic Head |
|---|---|---|---|---|---|
| HDW 1 | 7.150770667 | 6.247801 | 3.76 | 267.032 | 263.272 |
| HDW 2 | 7.158268972 | 6.247105278 | 3.19 | 300.509 | 297.319 |
| HDW 3 | 7.161671361 | 6.247359111 | 3.11 | 300.992 | 297.882 |
| HDW 4 | 7.15375 | 6.249527778 | 3.16 | 269.268 | 266.108 |
| BORDA 5 | 7.159972222 | 6.250916667 | 3.23 | 291.334 | 288.104 |
| HDW 6 | 7.092888889 | 6.228555556 | 10.08 | 132 | 121.92 |
| HDW 7 | 7.147777778 | 6.185611111 | 1.68 | 140 | 138.32 |
| HDW 8 | 7.0973098 | 6.2878188 | 15 | 285 | 270 |
| BORDA 9 | 7.149755 | 6.179714 | 4.3 | 146 | 141.7 |
| BORDA 10 | 7.145563 | 6.18481 | 4.1 | 142 | 137.9 |

BORDA= Benin Owena River Basin Development Authority, Benin city

Hydraulic head (HH) = Ground surface elevation (GSE) – Static water level (SWL)

HDW= Hand dug wells

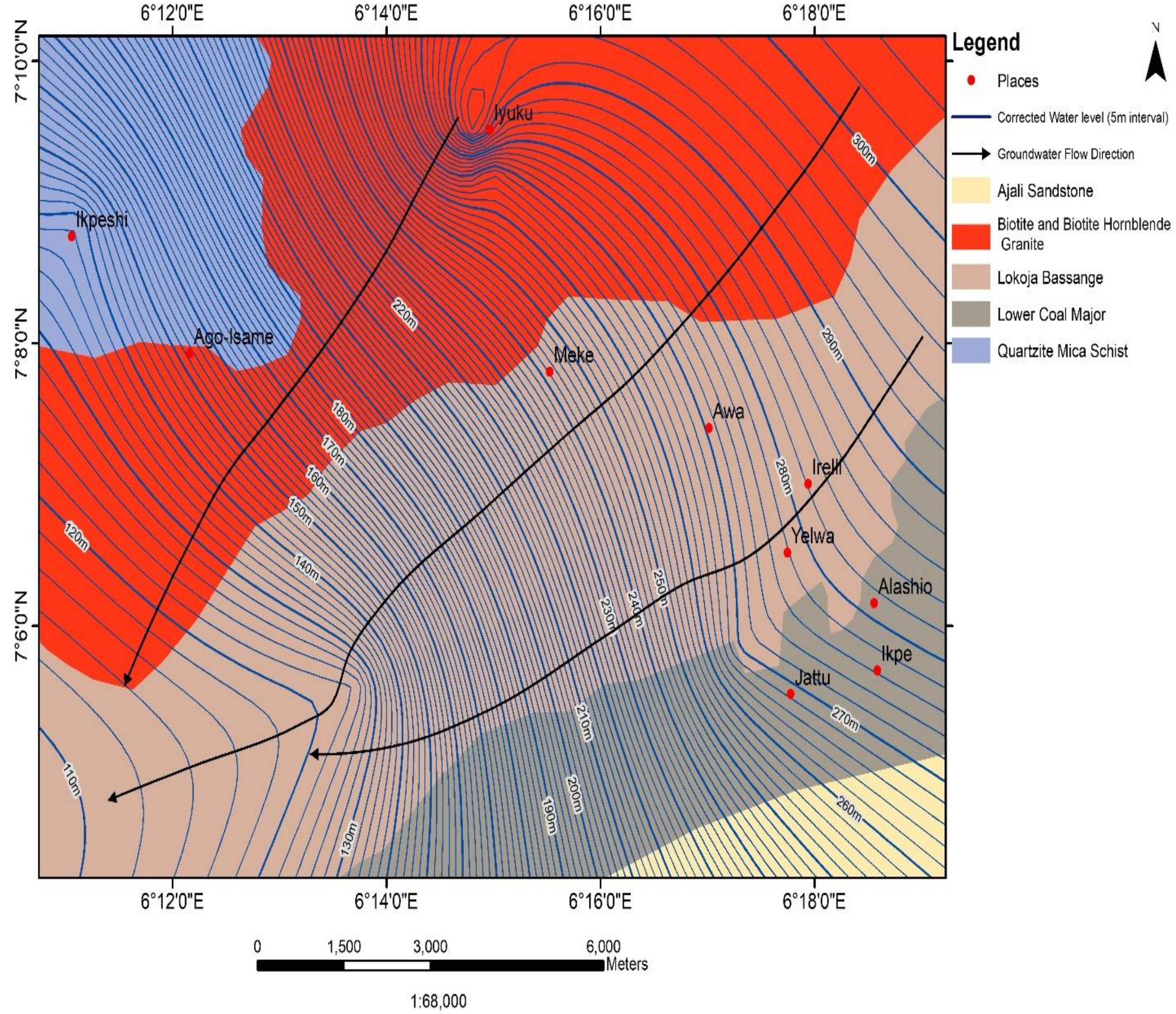

Figure 4.1: Contour map indicating groundwater flow direction in the area of study

# CHAPTER FIVE

# DISCUSSION, CONCLUSION AND RECOMMENDATION

## 5.1 DISCUSSION

It was found in that groundwater flows from the northeastern flank to southwestern flanks within the study area owing to high hydraulic heads in the region as depicted in Figure 4.2. it also observerd from the direction of flow map that geology of the different rock types might influence the chemistry of flow in the area of study. The implication is that unregulated anthropogenic activities such as improper waste disposal, leaks from septic and underground tanks in the northeastern flank may pose signficant threat to groundwater resources in southwestern of the study area and environs. The flow model also suggests that groundwater resource at Southwest and Northwestern parts of the area more prone to contaminants migrating from the region of high hydrualic head (northeast) of the study area.

## 5.2 CONCLUSION

This study successfully analyzed the groundwater flow direction in Iyuku, Auchi, Edo State, revealing a dominant movement from the North-East to the South-West. The flow pattern is shaped by factors such as topography, hydraulic gradient, and geological formations. Given this flow direction, pollutants originating in the North-Eastern region could easily be transported downstream, posing a risk to water quality in the South-Western areas.

The research highlights the importance of groundwater management to prevent contamination and ensure sustainable water use. Proper land-use planning is necessary to minimize pollution risks, particularly in areas where groundwater serves as a major water source for residents. Additionally, continuous monitoring is crucial for detecting changes in groundwater movement and quality over time.

## 5.3 RECOMMEDATION

To safeguard groundwater resources, the study recommends strategic placement of boreholes in cleaner upstream areas, stricter waste disposal regulations, and improved public awareness on water conservation. Authorities should enforce environmental policies that control industrial discharges, sewage leaks, and agricultural activities that could degrade water quality. Sustainable development planning should also prioritize protection of groundwater recharge zones and the prevention of over-extraction.

By adopting these measures, the long-term quality and availability of groundwater in Iyuku can be maintained, ensuring safe water for both current and future generations

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