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HYDROGEOLOGICAL CHARACTERIZATION OF GROUNDWATER RESOURCES IN LWENGO DISTRICT, CENTRAL UGANDA

By

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DECLARATION

I **NAKIYIMBA MILLY** hereby declare that this dissertation is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged.

Signed:..

Date:.......08/07/2026...

APPROVAL

This dissertation titled "Hydrogeological Characterization of Groundwater Resources in Lwengo District, Central Uganda", has been approved by the following supervisors.

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DEDICATION

This work is lovingly dedicated to my beloved mother, whose unwavering love, sacrifices, and constant encouragement have been the foundation of my journey. I am deeply grateful to my lecturers for their guidance, wisdom, and steadfast support, which have profoundly shaped my academic and personal growth. To my entire family and friends, thank you for your continuous motivation, patience, and belief in me throughout this endeavor. Your presence has been a constant source of strength and inspiration, and I share this achievement with each of you.

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List of Acronyms

ATMS	Agro-industrialization, Tourism, Mineral-based Industrial Development, and Science, Technology and Innovation
AQTESOLV	Aquifer Test Solver Software
BH	Borehole
DWRM	Directorate of Water Resources Management
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
GIS	Geographic InFormation System
K	Hydraulic Conductivity
MWE	Ministry of Water and Environment
NDP	National Development Plan
NDPIV	National Development Plan IV
S	Storativity
S_s	Specific Storage
SDG	Sustainable Development Goal
SWL	Static Water Level
T	Transmissivity
TDS	Total Dissolved Solids
WHO	World Health Organization
WL	Water Level

ABSTRACT

This study presents a hydrogeological characterization of groundwater resources in Lwengo District, Central Uganda, focusing on aquifer properties, groundwater flow dynamics, hydrochemical composition and the factors influencing groundwater recharge using secondary datasets from the Directorate of Water Resources Management (DWRM/MWE), including borehole logs, aquifer test reports, topographical information and hydrochemical datasets. Aquifer parameters were estimated from four long-duration pumping tests using the Theis (1935) and Cooper-Jacob (1946) methods, while hydrochemical analyses were used to classify groundwater types and identify controlling geochemical processes.

Results indicate that groundwater occurs mainly within weathered and fractured crystalline basement rocks under confined to semi-confined conditions. Water bearing zones occur at depths of 22–50 m below ground level, with static water levels ranging from 8–20 m. Aquifer parameters indicate low to moderate productivity, with transmissivity values of 0.3–5.5 m^2/day, hydraulic conductivity of 0.02–0.2 m/day and storativity ranging from 2×10^{-5} to 1×10^{-4}. Groundwater recharge is influenced by rainfall, topography, land use and the weathered and fractured basement geology, resulting in spatial variability across the district. Groundwater is predominantly characterized by Ca-Mg-HCO_3 and Ca-Mg-SO_4-Cl facies, controlled mainly by rock–water interaction and silicate weathering. Moderate mineralization was observed, while elevated nitrate and phosphate concentrations in some boreholes suggest localized agricultural and sanitation impacts.

The findings demonstrate that groundwater occurrence in Lwengo District is structurally controlled and spatially heterogeneous, highlighting the importance of integrating geological, structural, geophysical, recharge and water quality assessments for sustainable groundwater resource development and management.

CHAPTER 1: INTRODUCTION

1.1 Background

Groundwater is a vital component of the global hydrological cycle and represents the largest accessible source of freshwater on Earth (Kuang et al., 2024; Zektser & Loaiciga, 1993). It plays an indispensable role in ensuring water security, particularly in regions where surface water is scarce, seasonal, or polluted (Kuang et al., 2024). Globally, groundwater provides about 50% of all drinking water supplies, 40% of irrigated agriculture and approximately 30% of industrial water needs (Guppy et al., 2018; Shirazi et al., 2015). Its importance continues to rise in the face of population growth, climate variability, urbanisation and environmental degradation.

In Sub-Saharan Africa, groundwater serves as the principal source of safe drinking water for up to 75% of the rural population (Guma et al., 2019). Typically accessed through boreholes, protected springs and shallow wells, these groundwater systems act as buffers against surface water shortages, sustaining rural and peri-urban livelihoods during droughts and erratic rainfall (Zektser & Loaiciga, 1993). However, despite this dependence, groundwater in the region remains under-studied, under-monitored and poorly managed, raising concerns over the long-term sustainability of abstractions (Walker et al., 2019).

Uganda exemplifies the growing reliance on groundwater resources, with over 61% of its national water supply derived from groundwater (Nsubuga et al., 2014). Since the early 20th century, the country has invested heavily in groundwater infrastructure, constructing more than 20,000 deep boreholes, 3,000 shallow wells and 12,000 protected springs. These facilities support diverse uses, including domestic supply, livestock watering, small-scale irrigation and industrial development. The reliance on groundwater is particularly pronounced in the cattle corridor, an expansive region characterized by semi-arid conditions and limited surface water availability (MWE, 2020).

Lwengo District, located in the heart of the cattle corridor and within the Rwizi catchment of southwestern Uganda, illustrates many of these water challenges. With a predominantly rural population of about 275,000 people reliant on agriculture and livestock rearing (MWE, 2020), the district experiences prolonged dry spells between May-August and January-March. During these periods, communities often endure acute water shortages, leading to long treks for safe water, competition over limited sources and disproportionate burdens on women and children (Atwongyeire et al., 2018). Previous studies and field observations further report frequent borehole failures linked to declining groundwater levels, poor water quality (notably high salinity and iron concentrations) and inadequate recharge rates (MWE, 2018; Nagawa, 2018). The district's hydrogeology, dominated by crystalline basement rocks, poses additional constraints, as these aquifers are typically low-yielding, discontinuous and strongly influenced by weathering and fracturing (Tindimugaya, 2007).

These challenges underscore the urgent need for a more comprehensive understanding of groundwater systems in basement complex terrains such as Lwengo. Despite the district's heavy reliance on groundwater (with 169 groundwater sources), local hydrogeological knowledge remains limited. Existing borehole datasets are fragmented, aquifer properties such as transmissivity and storage are poorly constrained and water quality monitoring is sparse. Moreover, few studies adequately capture the heterogeneity of fractured and weathered aquifers in the area. This lack of robust hydrogeological inFormation hampers effective planning, borehole development and long-term groundwater management.

Against this backdrop, the current study sought to fill these knowledge gaps by conducting a detailed analytical investigation of groundwater in Lwengo District. The study estimated aquifer hydraulic properties, assessed groundwater quality through geochemical analysis and applied GIS-based hydrogeological mapping using secondary datasets. By generating a localized characterisation of groundwater systems, the research study is expected to strengthen decision-making for groundwater development, maintenance and sustainable use in the district.

1.2 Problem Statement

Despite relying on groundwater as the primary source of domestic and productive water supply, Lwengo District is experiencing a growing water crisis (MWE, 2020). Rapid population growth, increased water demand for domestic and agricultural use, contamination of existing water points and prolonged droughts have placed immense pressure on available groundwater resources (Atwongyeire et al., 2018; Rugumayo et al., 2012). The region's aquifers, formed within weathered and fractured crystalline basement rocks, are typically characterised by low transmissivity, limited storage and spatial variability in productivity (Tindimugaya, 2007). This presents major challenges for planning and developing reliable water supply infrastructure.

In many parts of Lwengo, communities report long travel distances to access clean water and a rising number of abandoned wells due to poor yield or poor water quality (Tembo, 2013). Observations in areas such as Malongo, Ndagwe and Kyazanga sub-counties show that water sources are often contaminated, forcing users to rely on unsafe sources or spend money purchasing water. These challenges are compounded by inadequate technical knowledge of local aquifer systems and limited site-specific datasets on groundwater behaviour.

National and regional water resource assessments provide generalised inFormation but fall short of addressing local variability in aquifer properties. Consequently, water infrastructure development often proceeds without a proper understanding of the subsurface environment, leading to poor investment outcomes and reduced community resilience. According to Gorelick & Zheng (2015), this lack of hydrogeological and geochemical datasets undermines efforts to manage groundwater sustainably, especially in the context of increasing climate extremes and competing water demands.

Therefore, this study offers insights into the aquifer characteristics, hydraulic dynamics and water quality conditions in Lwengo District. It addresses existing knowledge gaps and provides evidence-based guidance for the development of effective groundwater management strategies.

1.3 Objectives

1.3.1 Main objectives

The main objective of the study was to assess the groundwater systems in Lwengo District, generating datasets on their hydraulic behavior and quality of groundwater resources for use in effective resource management.

1.3.2 Specific Objectives

To achieve this aim, the study was guided by the following specific objectives to:

- delineate the main hydrogeological Formations within the study area.
- assess the geochemical quality of groundwater and potential contamination risks.
- evaluate the hydraulic properties of aquifer systems.

1.4 Significance

Sustainable water resources management in Uganda is not only aligned with global development goals but is also a fundamental component of the country's long-term development vision. Uganda's Vision 2040 and its associated National Development Plans (NDPs), including the current NDPIV, outline a strategy to transform the nation from a predominantly subsistence-based economy into a modern and prosperous society. At the heart of this transformation lies the "Ten-Fold Growth Strategy," which aims to expand Uganda's economy tenfold by 2040. This ambitious agenda prioritizes key sectors collectively known as ATMS: Agro-industrialization, Tourism, Mineral-based industrial development (including oil and gas), and Science, Technology, and Innovation, encompassing ICT and the creative economy.

These sectors are inherently water-dependent, making the strategic, sustainable development, and effective management of water resources essential for national development. For example, agro-processing relies heavily on irrigation and clean water inputs; tourism is closely tied to the health and aesthetics of natural water bodies; mineral extraction and oil production demand large volumes of water and carry high risks of pollution; and science and technology sectors often require water for industrial processes, cooling systems, and innovation in water-related technologies. As such, achieving the ten-fold economic growth envisioned in Uganda's development strategy will be unattainable without robust, inclusive, and sustainable water resource development and management mechanisms.

Uganda's commitment to sustainable water management is further reinforced by its alignment with the United Nations' 2030 Agenda for Sustainable Development, particularly Sustainable Development Goal 6 (SDG 6), which seeks to ensure the availability and sustainable management of water and sanitation for all. Specific targets under this goal, such as improving water quality through pollution reduction and expanded wastewater treatment, increasing water-use efficiency across all sectors, and implementing integrated water resources management (IWRM) at all levels, highlight the centrality of reliable groundwater information and management. Groundwater, which supplies over 60% of Uganda's domestic water needs, therefore, is pivotal to achieving these objectives.

At the local scale, Lwengo District demonstrates the critical significance of groundwater for communities, livelihoods, and economic development. The district is heavily reliant on groundwater yet faces frequent borehole failures, declining yields, and deteriorating water quality due to high salinity and iron concentrations. These challenges exacerbate water scarcity and place a disproportionate burden on vulnerable populations, particularly women and children responsible for water collection. The development and management of groundwater in Lwengo are constrained by limited datasets on aquifer architecture, recharge dynamics, transmissivity, storage properties, and geochemical characteristics.

This study directly addresses these knowledge gaps by providing a robust characterization of groundwater systems in Lwengo District. Through estimation of aquifer properties, geochemical analysis, and GIS-based hydrogeological mapping, the research generates localized datasets that can guide informed decisions on borehole siting, design, maintenance, and sustainable water use. In doing so, the study contributes to achieving Uganda's national strategic frameworks by strengthening evidence-based planning for water-dependent sectors, supporting the ATMS growth agenda, and enhancing local resilience against climate variability and water stress.

1.5 Justification

Groundwater development in Lwengo District has expanded rapidly, yet challenges such as poor yields, contamination, and unsustainable abstraction persist. The district depends almost entirely on groundwater for domestic and agricultural needs, but detailed local hydrogeological studies remain scarce, with most assessments relying on regional or national-scale datasets (Katusiime & Schütt, 2020; Okello, 2016).

This study seeks to generate site-specific hydrogeological information to enhance understanding of aquifer characteristics, productivity, and water quality within the crystalline basement terrain. It contributes to evidence-based planning for community water supply, supports sustainable resource management under the Ministry of Water and Environment's groundwater development programs, and aligns with Sustainable Development Goal 6 on clean water and sanitation.

The methodological approach adopted integrates geological interpretation, aquifer test analysis, and hydrochemical evaluation to achieve a comprehensive characterization of the groundwater system. The reliance on secondary datasets, including borehole completion logs, pumping test records, and laboratory-based water quality results, was based on their spatial coverage, data consistency, and suitability for regional-scale synthesis. Analytical interpretation of pumping test data using the Theis (1935) and Cooper-Jacob (1946) methods provided reliable estimates of transmissivity, storativity, and hydraulic conductivity. These models remain appropriate for crystalline basement aquifers where confined or semi-confined conditions approximate the analytical assumptions and where empirical validation through time-drawdown behavior is feasible (Leelaruban & Padmanabhan, 2013).

Hydrochemical analyses were employed to evaluate groundwater quality, identify geochemical facies, and infer recharge mechanisms. The integration of hydro-stratigraphic analysis, pumping test interpretation, and hydrochemical assessment enabled triangulation of results across independent datasets, enhancing the robustness and reliability of interpretations. Collectively, these methods provided a scientifically rigorous and context-specific framework for assessing groundwater occurrence, productivity, and suitability for use in Lwengo District.

1.6 Scope

This study was conducted in Lwengo District, located in south-central Uganda between longitudes 31°10′ E-31°30′ E and latitudes 0°15′ S-0°35′ S, covering an approximate area of 914 km². The investigation focused on the hydrogeological characterization of groundwater resources within the district's crystalline basement aquifer system, emphasizing aquifer geometry, hydraulic properties, and hydrochemical composition.

The research relied exclusively on secondary datasets obtained from the Directorate of Water Resources Management (DWRM) under the Ministry of Water and Environment (MWE). These datasets comprised of 165 borehole completion records (Appendix 4), thirty-eight (38) containing lithological logs, static water levels, drilling depths and yield data, as well as four (4) long-duration (≥ 24 hours) pumping-test datasets from boreholes located at Kyazanga, Lwengo Town Council, Kisekka, and Kkingo. Each of these tests included time-drawdown and recovery data together with corresponding discharge rates. The hydrochemical database contained analyses for major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{2+}) and anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^-), in addition to key physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and turbidity. All datasets represented archived field investigations undertaken between 2000 and 2023, compiled to provide a spatially integrated snapshot of groundwater conditions across the district. No continuous or temporal monitoring was carried out as part of this study.

Spatial analysis and visualization of borehole locations, geological Formations, soils, drainage, and elevation were performed using QGIS version 3.36.3, which enabled the generation of maps depicting the spatial variability of hydrogeological and hydrochemical parameters. This facilitated the integration of geological, topographic, and hydrochemical data within a consistent geospatial framework.

Conceptually, the study adopted a hydrogeological-systems approach that combined geological interpretation, analytical solutions to groundwater flow (Cooper-Jacob, 1946; Theis, 1935), and hydrochemical evaluation to characterize aquifer behavior and water quality. The use of verified secondary data together with classical analytical models provided a scientifically rigorous and cost-effective framework for assessing groundwater occurrence, flow dynamics, and quality within the crystalline basement environment of Lwengo District.

1.7 Conceptual Framework

The conceptual framework of this study represents the hydrogeological system of Lwengo District, illustrating the relationships among geological Formations, aquifer structure, recharge and discharge processes, groundwater flow, and hydrochemical evolution. It provides the theoretical basis that links the physical setting of the study area to the analytical methods used in data interpretation and synthesis.

Groundwater in Lwengo District occurs within the weathered and fractured crystalline basement aquifer system, where the regolith and underlying fracture networks constitute the principal water-bearing zones. Recharge to these aquifers occurs mainly through diffuse rainfall infiltration across permeable soils and structurally weakened zones, particularly along lineaments and valley floors (MacDonald et al., 2008; Tindimugaya, 2007). According to Foster (2012) and Taylor & Howard (1999), the weathered zone serves as the primary groundwater reservoir, while the fractured bedrock facilitates lateral flow. Discharge takes place through borehole abstraction, seepage into wetlands, and baseflow to surface drainage channels. This system typically functions under confined to semi-confined conditions, depending on the degree of weathering and fracture connectivity (Owor et al., 2011; Wright, 1992).

The hydro-stratigraphic framework delineates the vertical and lateral variation of geological units, linking lithology and structural setting to aquifer productivity. The hydraulic framework quantifies aquifer parameters: transmissivity (*T*), hydraulic conductivity (*K*), and storativity (*S*) derived from long-duration pumping-test analyses using the Theis (1935) and Cooper-Jacob (1946) analytical methods. The hydrochemical framework interprets the composition and evolution of groundwater based on major-ion chemistry (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{2+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, F^{-}), providing insights into dominant geochemical processes such as rock–water interaction, ion exchange, and anthropogenic influences.

Spatially, the conceptual framework is bounded by the district's administrative extent (≈ 914 km^2) and vertically by the weathered and fractured zones extending to about 50 m below ground level, representing the main productive aquifer horizons. The datasets analysed in this study span 2015–2023, providing a spatially integrated representation of groundwater conditions within the district.

The framework assumes that the aquifer systems are locally compartmentalized but hydraulically continuous within structural domains; that recharge is primarily from rainfall infiltration rather than regional inflow; and that abstraction through boreholes represents the dominant anthropogenic stress on the system (Guma et al., 2019; Foster, 2012). It further assumes that the secondary datasets obtained from the Directorate of Water Resources Management (DWRM) reliably represent field conditions.

Figure 1.1 presents the work flow adopted for this study, summarizing the key parameters and variables that underpin the hydrogeological characterization approach. The diagram illustrates how geological, hydraulic, and hydrochemical components interact to inform the main objective of this study. The principal parameters include transmissivity (*T*), hydraulic conductivity (*K*), and storativity (*S*), which describe aquifer behaviour from pumping-test analysis, while static water level (*h*), discharge rate (*Q*), and aquifer thickness (*b*) represent variables influencing groundwater flow. Hydrochemical variables such as pH, electrical conductivity (EC), total dissolved solids (TDS), and concentrations of major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-},

Cl^-, NO_3^-, F^-) are included as indicators of groundwater quality and geochemical evolution. In addition, spatial and geological parameters: lithology, fracture density, soil type, and topographic elevation are incorporated as controlling factors for recharge, flow, and discharge processes. These parameters and variables form an integrated workflow that links data acquisition, analysis, and interpretation to the study objectives, providing a scientifically grounded representation of the groundwater system in Lwengo District.

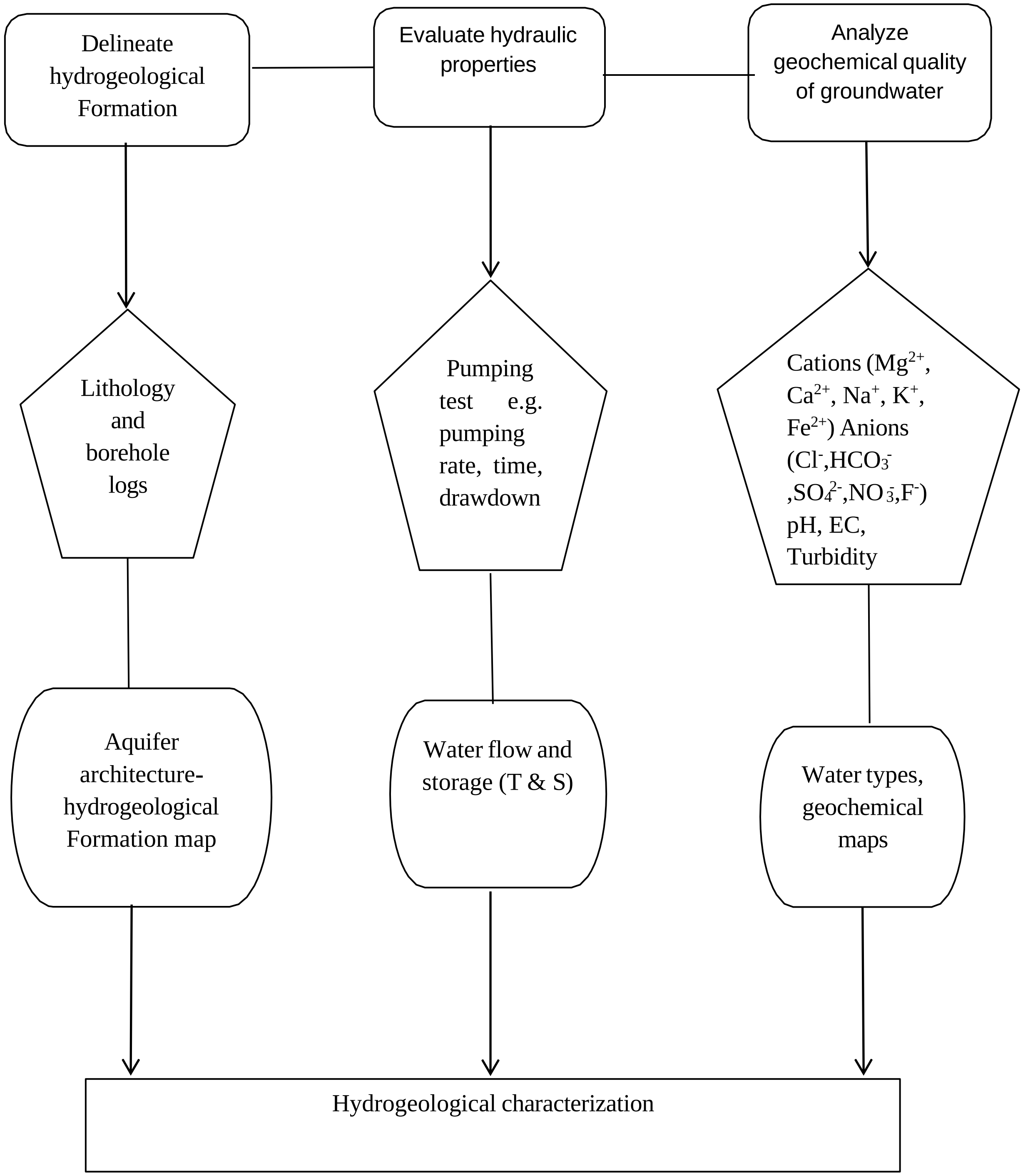

Figure 1.1: Conceptual Framework presents the parameters and variables used in the study approach.

1.8 Dissertation Structure

This dissertation is organized into six chapters, each addressing a specific aspect of the study and collectively contributing to the overall objective of understanding the hydrogeological characteristics of groundwater resources in Lwengo District.

Chapter One: Introduces the study background, problem statement, objectives, significance, Justification, conceptual framework and scope of the study.

Chapter Two: Presents a review of existing literature on groundwater in crystalline basement terrains, previous regional studies and theoretical frameworks.

Chapter Three: Describes the study area and outlines the materials and methods used for data collection, analysis and interpretation.

Chapter Four: Presents the results of the hydrogeological and hydrochemical assessments.

Chapter Five: Discusses the results of the hydrogeological and hydrochemical assessments

Chapter Six: Summarizes key findings, conclusions and provides recommendations for sustainable groundwater management in Lwengo and similar environments.

CHAPTER 2: LITERATURE REVIEW

2.1 Groundwater in Crystalline Basement Terrains

Crystalline basement rocks form the largest part of the hydrogeological framework in sub-
Crystalline basement rocks form the largest part of the hydrogeological framework in sub-
Saharan Africa, covering about 40% of the land area and supporting an estimated 220 million people living in rural areas (Adams, 2009; Lovell, 2009; Titus et al., 2009; Wright, 1992). In Uganda, these rocks occupy approximately 90% of the land area, making basement aquifers the most widespread groundwater source.

Groundwater in crystalline basement terrains is hosted primarily within secondary porosity systems developed through weathering and fracturing (MacDonald et al., 2005; Taylor & Howard, 1999). Unlike sedimentary aquifers, which often exhibit primary porosity and relatively uniform storage characteristics, basement aquifers depend on the weathered regolith and interconnected fracture networks within the underlying bedrock. Their productivity is influenced by the degree of weathering, extent of fracturing, and the connectivity between these features, which makes them inherently heterogeneous (Mäkelä, 2012; MacDonald et al., 2005). Geological structures such as faults, joints, and lineaments often act as preferential flow paths, enhancing transmissivity in otherwise low-permeability Formations (Tindimugaya, 2007).

Basement aquifers are commonly conceptualized as two-layer systems comprising a weathered regolith (saprolite) overlying a fractured bedrock zone (Figure 2-1). The regolith typically serves as the main groundwater storage unit, while the fractured bedrock provides transmissive pathways. Although aquifer yields are generally low and variable due to the fine-grained nature of the regolith and the limited extent of fractures the basal regolith and upper fractured bedrock may sustain low abstraction rates adequate for rural water supply (Fourie et al., 2017; Fourie et al., 2020; Foster, 2015). Productive boreholes are often associated with zones where weathering and fracturing overlap.

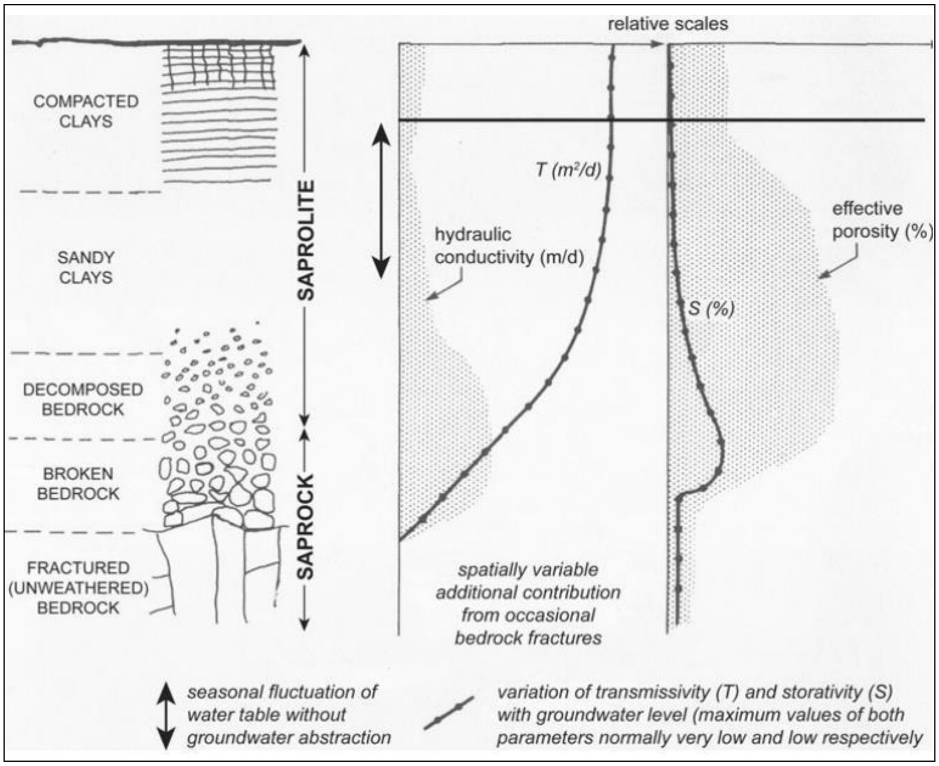

Figure 2.1: Conceptual model of weathered crystalline basement aquifers in Africa (Fourie et al., 2020; Foster, 2015)

Despite their importance, basement aquifers are frequently described as poor or minor aquifers, given their low storage capacity, water quality challenges, and the prevalence of low-yielding boreholes (Owor et al., 2022; Adams, 2009; Lovell, 2009; Titus et al., 2009; Wright, 1992). Borehole yields range from less than 1 m^3/hr to over 10 m^3/hr, with many rural communities experiencing failed boreholes or unsustainable supplies (MWE, 2020). Nevertheless, they remain the primary source of water for large populations across Uganda and sub-Saharan Africa, owing to their wide spatial coverage and active recharge potential (e.g. Foster, 2015; Owor et al., 2009; Tindimugaya, 2007).

The evolution of these aquifers in Uganda has been shaped by tectonically controlled weathering and stripping processes, which determine the development of fluvial, weathered, and fractured bedrock aquifers (Owor et al., 2022). However, the occurrence, movement, and recharge of groundwater in basement terrains remain poorly understood (Chilton & Foster, 1995). The installation of numerous hand-pumped boreholes without systematic hydrogeological assessment highlights the urgent need for detailed, site-specific investigations. This is particularly critical for Lwengo District, where groundwater is heavily relied upon yet inadequately characterized.

2.2 Geological Controls on Groundwater Availability

The geology of southwestern and central Uganda, including Lwengo District, is dominated by Precambrian basement rocks of the Karagwe-Ankolean and Buganda-Toro systems (Doornkamp, 1968; Stheeman, 1932). These Formations consist mainly of metasedimentary rocks such as phyllites, schists, and quartzites intruded by granitic bodies. Their varying degrees of metamorphism and deFormation have produced a structurally complex subsurface environment where groundwater movement is strongly influenced by lithological contrasts and fracture networks (Tindimugaya, 2007).

Across East Africa, similar structural and lithological factors control groundwater availability (Kuria, 2013; Kashaigili, 2010). In central and northern Tanzania, aquifers within granite-gneiss terrains exhibit yields that depend on the depth of weathering and the presence of fractures, while compact quartzites and schists show poor transmissivity (Kashaigili, 2010). In Kenya, aquifer productivity is highest along shear zones and fault lines, which enhance permeability, whereas massive crystalline rocks act as barriers to flow (Kuria, 2013). These findings are consistent with the hydrogeological framework of Uganda, where basement aquifers occur as discontinuous, compartmentalized systems bounded by structural discontinuities (MWE, 2020; Tindimugaya, 2007).

The regional pattern indicates that differential weathering, lithological composition, and structural development together dictate aquifer potential (Foster, 2012). Areas underlain by granitic gneisses and migmatites tend to host relatively thicker weathered mantles that provide storage, while schists and phyllites contribute to confinement and reduced yield (Foster, 2012; Tindimugaya, 2007). Within Lwengo District, variations in lithology and structural orientation likely produce localized aquifers of variable productivity. Previous mapping has not adequately linked these geological variations to groundwater occurrence, a limitation that this study addresses by integrating geological and aquifer test datasets with borehole inFormation.

2.3 Soil types and their hydraulic characteristics

Lwengo District's soil cover is made up of ferralsols, nitisols, plinthosols, and durisols (DWRM, 2023). Each of these types of soil has its own unique hydraulic properties that affect how water gets into the ground and how groundwater gets recharged (FAO, 2014). Ferralsols, which are mostly made up of kaolinitic clays, let water through at a moderate rate but don't hold much water. Nitisols are deep, well-drained, and well-structured, which makes them good for infiltration and recharge. Plinthosols, on the other hand, often have iron-rich plinthite layers that harden permanently when they dry out, making horizons that are almost impossible to penetrate. Durisols, which have ferruginous or calcareous crusts, also make it hard for water to soak in (FAO, 2014).

The correlation between soil type, topography, and recharge potential in Sub-Saharan Africa has been extensively recorded (e.g., MacDonald et al., 2021; Taylor et al., 2013). Research conducted in Uganda's cattle corridor indicates that infiltration is maximized in gently sloping regions characterized by deep, friable soils and vegetative cover, whereas steep slopes and compacted surfaces facilitate surface runoff (MWE, 2020). Similar observations have been recorded in central Tanzania and certain regions of Kenya, where recharge is predominantly localized and episodic, influenced more by rainfall intensity and surface conditions than by annual precipitation totals (Seddon et al., 2021). Recharge estimates for basement terrains throughout the region generally fluctuate between 2 and 10% of mean annual rainfall, highlighting the restricted replenishment capacity of these aquifers (Seiler & Gat, 2007).

The spatial distribution of recharge zones is also affected by the type of soil and the slope. In Lwengo, ferralsols and nitisols on gentle slopes are likely to help water soak into the ground and move through it, while areas with plinthosols and durisols are likely to stop water from soaking in. Prior studies have not specifically investigated the soil–geology–topography–recharge connections in this context. This study employs GIS-based spatial integration to identify and evaluate potential groundwater recharge zones within the district.

2.4 Hydraulic properties of basement crystalline rock aquifers

Basement aquifer productivity is primarily determined by its hydraulic characteristics, specifically its transmissivity (T), hydraulic conductivity (K) and storativity (S). The connectivity between weathered and fractured zones, fracture density and aperture size are the main factors influencing these characteristics in crystalline terrains (e.g., Chilton & Foster, 1995; Wright, 1992). Tindimugaya (2007) claims that because of the limited fracture interconnection, transmissivity values in Uganda's basement aquifers are generally low, typically falling below 2 m^2/day. Similar findings were made by MacDonald et al. (2005), who noted that while locally enhanced zones with intensive fracturing can show noticeably higher values, transmissivity rarely surpasses 5 m^2/day throughout much of Sub-Saharan Africa.

The conventional techniques for figuring out these parameters are still pumping tests, both step-drawdown and constant-rate. While derivative-based analyses are frequently used in semi-confined or leaky situations, classical analytical models like the Theis (1935) and Cooper–Jacob (1946) methods are widely used to estimate transmissivity and storativity. Below are the basic equations (2.1-2.2);

Theis equation (for transient draw down in confined aquifers):

$$s(r,t) = W(u)\frac{Q}{4\pi T}\ , \quad u = \frac{r^2 S}{4Tt} \quad \text{...(2.1)}$$

Cooper-Jacob Approximation (late-time simplification):

$$s=\frac{2.3Q}{4\pi T}log\ (\frac{2.25Tt}{r^2S}) \quad \text{..(2.2)}$$

Where:

K = hydraulic conductivity (m/s), A = cross-sectional area of flow, S = storativity,

Q = pumping rate/ discharge, T = Transmissivity, $W(u)$ = Well function, s = drawdown

Although derivative-based and numerical models have become increasingly common for analysing leaky or heterogeneous aquifers (Kruseman & de Ridder, 1990), the Theis and Cooper-Jacob solutions remain robust for interpreting data from short-duration tests typical of groundwater assessments in rural Africa.

Across East Africa, borehole test datasets reveal pronounced spatial variability in transmissivity and yield, even over short distances. Kashaigili (2010) attributed this to differences in weathering depth, fracture orientation, lithological composition, and degree of mineralization. In Uganda, transmissivity values below 2 m^2/day are typical for crystalline basement aquifers (Tindimugaya, 2007), but localized structural zones such as shear zones and fault intersections, may enhance transmissivity and yield (Owor et al., 2011). This variability underscores the necessity for site-specific testing and structural analysis during groundwater development.

However, regional groundwater assessments continue to face major limitations, including short test durations, inconsistent data recording and lack of standardized interpretation methods, which constrain the reliability of aquifer parameter estimation (MWE, 2020). The integration of geological, structural, and geophysical data with pumping-test analysis is therefore critical for improving the accuracy of hydraulic characterization in basement terrains.

Existing borehole records from Lwengo District indicate low to moderate aquifer productivity, consistent with the typical characteristics of Uganda's crystalline basement systems (MWE, 2020). The limited fracture connectivity and thin weathered zones contribute to low transmissivity and storage. To refine the understanding of aquifer behaviour and groundwater potential in the district, this study applies classical analytical methods to available long-duration pumping test datasets, thereby generating more reliable estimates of transmissivity, hydraulic conductivity, and storativity for the underlying crystalline aquifers.

2.5 Groundwater quality of basement crystalline rock aquifers

Hydrochemical investigations are fundamental for understanding the origin, recharge mechanisms, and overall quality of groundwater in crystalline basement terrains (Zakaria et al., 2021; Glynn & Plummer, 2005). In these environments, the chemistry of groundwater evolves through a combination of mineral-water interactions, ion exchange reactions, and the dissolution or precipitation of minerals within the aquifer matrix (Hyeroba et al., 2024; Owor et al., 2021). The weathered regolith and the underlying fractured bedrock provide limited primary porosity; therefore, most dissolved constituents originate from secondary processes such as silicate and carbonate weathering, oxidation of sulphide minerals, and cation exchange along fracture walls and clay interfaces (Owor et al., 2021; Fourie et al., 2017). These reactions occur slowly under the low groundwater velocities typical of basement systems, allowing extended contact between water and mineral surfaces and resulting in distinct hydrochemical signatures.

In Uganda and across much of East Africa, groundwater within basement aquifers is predominantly of the calcium-magnesium-bicarbonate (Ca-Mg-HCO_3) type, reflecting the dominance of silicate weathering and carbon dioxide dissolution as the principal geochemical processes (Hyeroba et al., 2024; Owor et al., 2021; Karegi, 2020). Within longer flow paths and structurally enhanced zones, the water composition commonly evolves toward mixed Ca-Mg-SO_4-Cl or Ca-Na-Cl facies, which indicate cation exchange, oxidation of sulphide minerals, and the effects of increasing residence time (Hyeroba et al., 2024; Owor et al, 2021). These transitions represent a chemical progression from recently recharged, weakly mineralised waters to more evolved waters enriched in chloride and sulphate ions. Comparable trends have been documented in other African basement environments, where silicate weathering dominates the recharge zones and ion exchange and evaporation influence deeper or more stagnant groundwater (Fourie et al., 2017; Foster, 2015).

Hydrochemical assessments conducted by MWE (2020) and Owor et al. (2021) reveal that groundwater in Uganda's cattle-corridor districts, including Lwengo, typically exhibits moderate to high mineralisation and hardness. Electrical conductivity values generally range between 200 and 2,500 µS/cm, with pH values from 6.0 to 8.2 and hardness levels that may exceed 500 mg/L as $CaCO_3$. These parameters are consistent with the predominance of calcium and magnesium ions derived from the weathering of feldspar and pyroxene minerals in granitic and gneissic rocks. Elevated sulphate concentrations, occasionally above 250 mg/L, have been attributed to oxidation of pyrite and other sulphide minerals in schistose Formations (Hyeroba et al., 2024; Odukoya et al., 2012). Iron and manganese are also frequently elevated in reducing environments where dissolution of ferruginous and manganiferous minerals occurs, a feature characteristic of deeply weathered crystalline terrains (Hyeroba et al., 2024; Abiye et al., 2011).

The spatial variability of groundwater chemistry within basement aquifers is strongly controlled by lithology, degree of weathering, and fracture connectivity (Owor et al., 2011; Tindimugaya, 2007). Areas underlain by granitic and gneissic rocks commonly display high hardness and total dissolved solids because of the abundance of weatherable Ca-rich silicate minerals, whereas quartzitic and sandstone units tend to yield lower ionic concentrations due to their limited mineral solubility (Fourie et al., 2017; Amadi et al., 2017). The heterogeneity of these aquifers implies that chemical characteristics can change significantly even between boreholes located a few kilometres apart. Furthermore, climatic factors influence chemical evolution: in humid tropical zones, high rainfall promotes leaching of bicarbonate and silica, while in semi-arid regions, evaporation enhances the accumulation of chloride and sulphate (Fourie et al., 2020). These patterns highlight the need for contextual interpretation of hydrochemical data that considers geological, structural, and climatic settings simultaneously.

In addition to natural geochemical controls, anthropogenic activities increasingly affect groundwater chemistry in Uganda's basement terrains. Agricultural intensification, livestock farming, and inadequate sanitation contribute to elevated nitrate (NO_3^-) and phosphate (PO_4^{3-}) concentrations in shallow aquifers, especially near settlements and cultivated areas (MWE, 2020; Songa et al., 2015). The infiltration of agricultural runoff and domestic wastewater through permeable soils and fractured regolith introduces reactive nitrogen and phosphorus species that modify groundwater quality and accelerate mineralisation processes. Such contamination is often spatially localized but can raise EC and TDS values, masking natural hydrochemical trends and posing risks to human health and ecosystem integrity. The presence of both natural and anthropogenic solutes therefore necessitates integrated hydrochemical monitoring and spatial analysis to distinguish between geogenic and pollution-derived sources (Owor et al., 2021).

At a greater Sub-Saharan level, the hydrochemical evolution of crystalline basement aquifers exhibits patterns similar to those observed in Uganda. Reviews by Fourie et al. (2020) and Foster (2015) indicate that groundwater in these systems typically evolves from low-salinity Ca-Mg-HCO_3 waters near recharge areas to progressively mineralised Ca-Na-Cl or Na-Cl waters along regional flow paths. The rate and extent of this evolution depend on residence time, temperature, and mineralogical composition. In tropical and subtropical climates, where weathering intensity and evapotranspiration are high, dissolved solids accumulate more rapidly, leading to moderately hard to saline waters. Such findings provide a comparative framework for interpreting the geochemical behaviour of Uganda's crystalline basement aquifers within the broader global context.

Within Lwengo District, the existing datasets analysed by MWE (2020) indicate that groundwater is generally of acceptable quality for domestic use but exhibits localized exceedances of hardness, sulphate, and iron relative to WHO (2017) guideline values. The dominance of calcium, magnesium, and bicarbonate ions demonstrates the influence of rock-water interaction, while elevated sulphate and chloride in some boreholes suggest advanced chemical evolution or minor anthropogenic contributions. These observations are consistent with findings across similar crystalline basement settings in Uganda and elsewhere in sub-Saharan Africa (Hyeroba et al., 2024; Owor et al., 2021; Fourie et al., 2017).

The reviewed studies demonstrate that the hydrochemical properties of groundwater in crystalline basement aquifers are controlled by a combination of geogenic and anthropogenic processes. Silicate weathering, carbonate dissolution, ion exchange, and redox reactions define the natural chemical framework, while agricultural and domestic activities introduce additional solutes that modify the baseline composition. The spatial and temporal variability in these parameters underscores the need for systematic hydrochemical monitoring supported by geological and structural data. Building on this body of work, the present study employs major-ion analysis, facies classification, and spatial mapping to identify the dominant geochemical processes governing groundwater quality in Lwengo District and to assess its suitability for domestic and productive use.

2.6 Groundwater Development and Management Challenges

Groundwater development across Uganda and much of Sub-Saharan Africa has historically been guided more by immediate demand than by systematic scientific assessment (Hyeroba et al., 2024; Tindimugaya, 2007). Borehole drilling programs frequently proceed with limited geological or geophysical input, leading to low drilling success rates, poorly performing wells, and premature borehole failure. This problem reflects the inherently heterogeneous nature of crystalline basement aquifers, where transmissive zones are controlled by discrete fracture systems that require detailed subsurface characterization for reliable targeting (Foster, 2015; Owor et al., 2011). The reliance on empirical or trial-and-error siting, often supported by minimal hydrogeological mapping, results in high costs and inconsistent yields, undermining community confidence in groundwater as a dependable water source.

The absence of comprehensive hydrogeological, hydraulic, and hydrochemical databases further constrains effective water-resources planning. As documented MWE (2020), many borehole completion records remain incomplete or inaccessible, limiting the capacity to evaluate aquifer performance, recharge dynamics, and long-term trends in groundwater quality. The lack of standardized data collection and consistent monitoring impedes the implementation of integrated water-resources management (IWRM) principles. Across the region, institutional challenges such as inadequate funding, limited technical expertise, and weak coordination between central and local authorities exacerbate these deficiencies (MWE, 2020). Consequently, groundwater development is often reactive, driven by community demand, donor priorities, or emergency interventions rather than by strategic hydrogeological planning.

Similar challenges have been noted throughout Sub-Saharan Africa, where increasing dependence on groundwater for domestic supply and agriculture coincides with declining recharge, contamination, and over-abstraction (Hyeroba et al., 2024; Fourie et al., 2020). The limited integration of geological mapping, geophysical surveys, and long-duration test pumping during well development continues to hinder the design of sustainable abstraction schemes (Foster, 2015). Tindimugaya (2007) observed that most groundwater investigations in Uganda remain short-term and localized, rarely incorporating the regional hydrogeological context necessary for long-term resource management. Furthermore, weak enforcement of water-use regulations and insufficient community engagement have reduced the effectiveness of groundwater protection initiatives.

Institutional reform efforts are underway to address these shortcomings. The Directorate of Water Resources Management (DWRM) has initiated catchment-based water-resources management programs aimed at improving data consolidation, enhancing hydrogeological monitoring, and promoting coordinated management among stakeholders (MWE, 2019). These initiatives reflect growing recognition that sustainable groundwater governance requires coupling scientific characterization with participatory management frameworks. Varady et al. (2016) emphasize that effective groundwater governance depends on integrating technical knowledge such as geological mapping and hydrochemical assessment, with stakeholder involvement and adaptive management at both local and national scales.

Within Lwengo District, these national and regional challenges are acutely evident. The district's heavy reliance on groundwater for domestic and agricultural use has been accompanied by frequent borehole failures, declining yields, and localized contamination arising from poor sanitation and agricultural runoff (MWE, 2020). Many boreholes were drilled without adequate understanding of subsurface structure or recharge conditions, resulting in uneven spatial distribution of productive wells. This situation illustrates the broader problem of developing groundwater in basement terrains without comprehensive hydrogeological frameworks. The scarcity of long-duration pumping-test data, limited monitoring of water levels and chemistry, and inadequate maintenance further exacerbate the vulnerability of existing water points.

This study seeks to address part of this gap by synthesizing existing geological, hydrogeological, and hydrochemical datasets to produce a more coherent understanding of aquifer behaviour in Lwengo District. By integrating pumping-test interpretation with geochemical analysis and spatial mapping, the research generates evidence-based insights that can support informed borehole siting, sustainable abstraction, and long-term groundwater management. In doing so, it aligns with Uganda’s ongoing transition from demand-driven water-supply development toward scientifically guided, catchment-based resource management (MWE, 2020).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Extent

Lwengo District lies in south-central Uganda, approximately 180 km southwest of Kampala, between longitudes 31°10′E-31°30′E and latitudes 0°15′S-0°35'S (Figure 3.1). It borders Bukomansimbi and Masaka districts to the east, Lyantonde to the north, Rakai to the south, and Sembabule to the west. The district covers an area of about 914 km^2 and forms part of the greater Lake Victoria Basin. The area is mainly rural, with scattered trading centres and an economy dominated by mixed farming and livestock rearing (Singh & Kagweza, 2022; MWE, 2020).

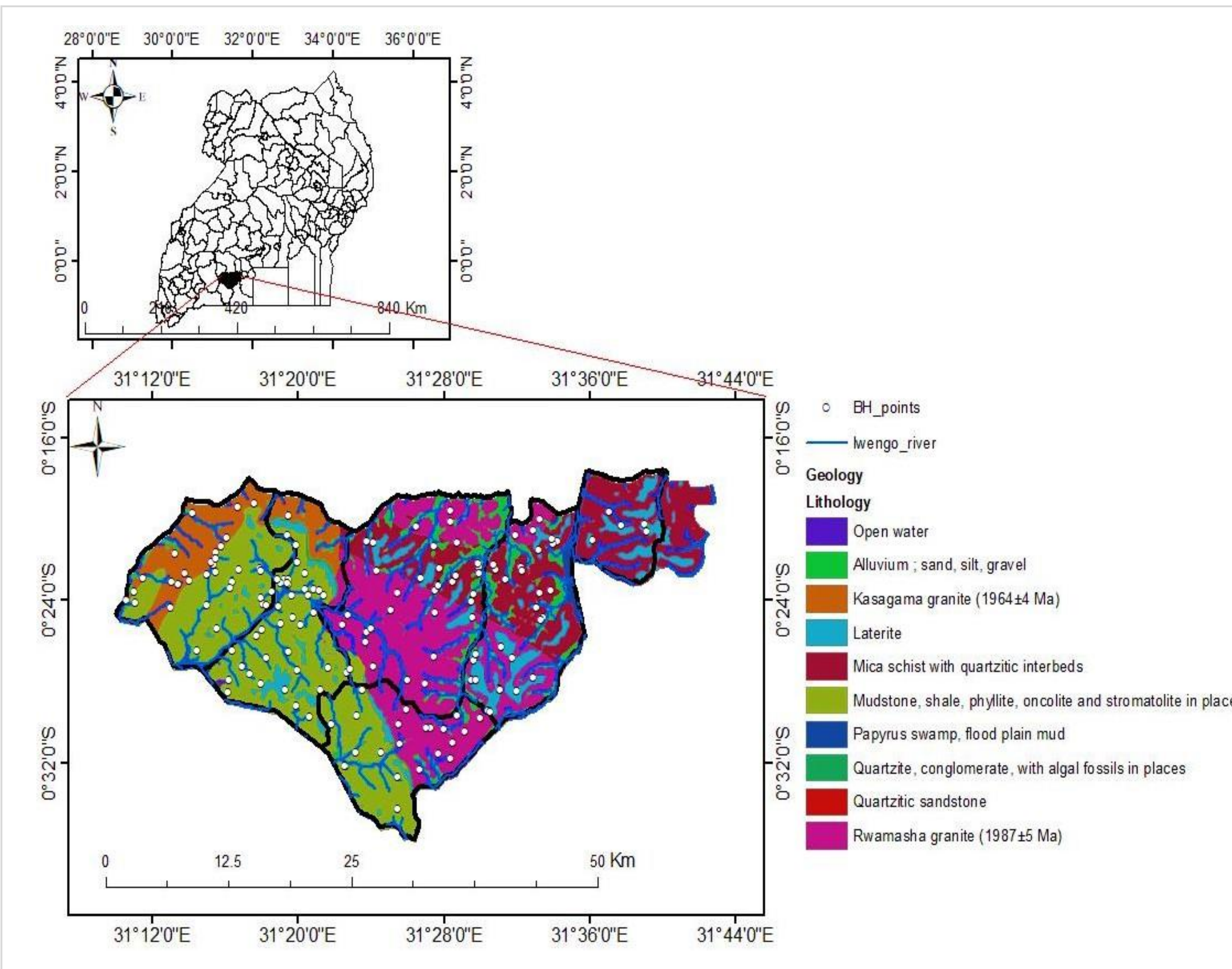

Figure 3.1: Map showing the location of Lwengo District and the distribution of its main geological Formations.

3.1.2 Physiography, climate and drainage

Lwengo District is characterized by a gently undulating landscape typical of the southern central plateau of Uganda, with elevations ranging between approximately 1,100 m and 1,500 m above mean sea level (Figure 3.2). The terrain consists of low hills and broad valleys that merge into extensive wetlands and seasonal swamps. The gently rolling topography influences both surface runoff and groundwater flow, with valley bottoms often acting as discharge zones and potential recharge areas during the rainy seasons.

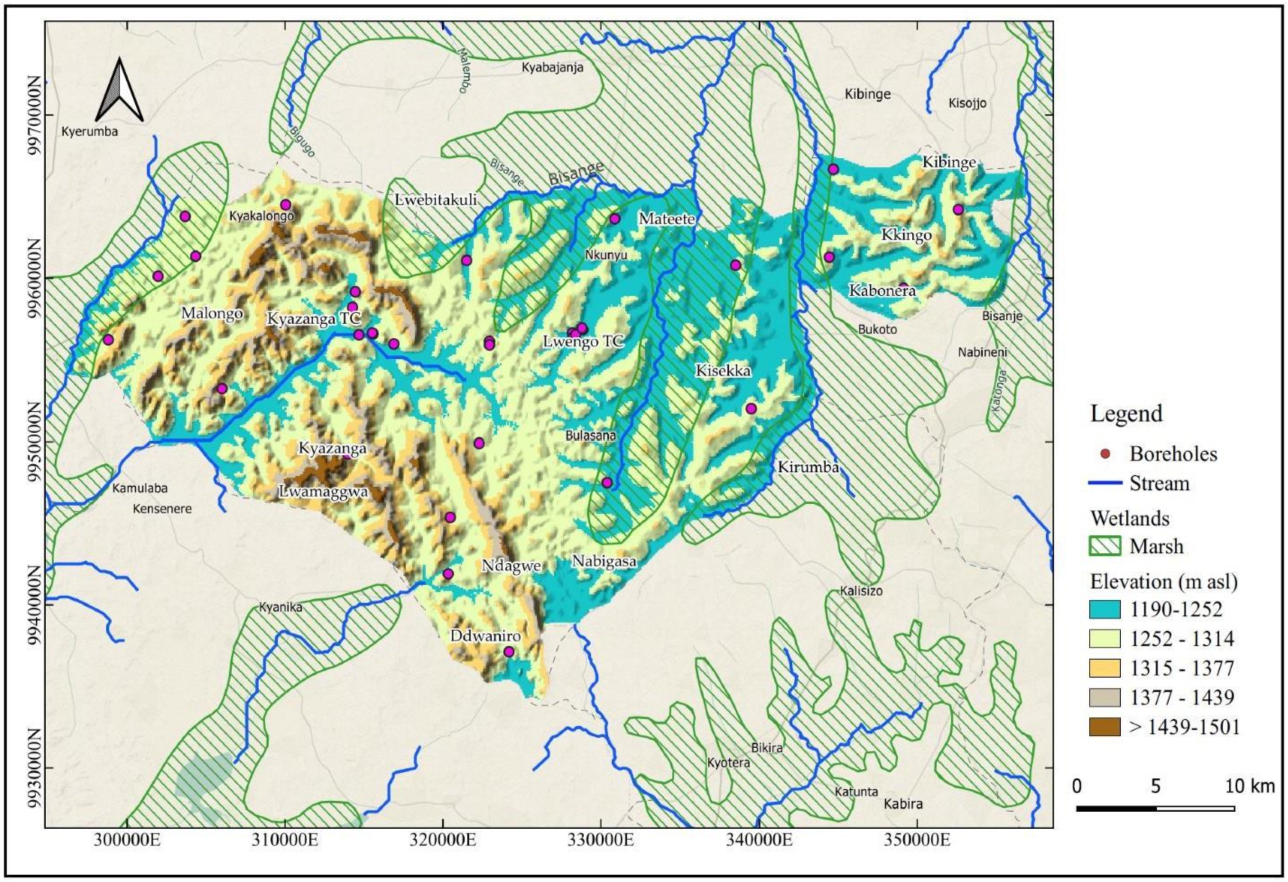

Figure 3.2: Topography and drainage of Lwengo District

Lwengo District experiences a tropical climate that is significantly influenced by both altitude and proximity to the Lake Victoria basin (MWE, 2020). The area is characterized by a bimodal rainfall pattern with two distinct wet seasons; the long rains occurring from March to May and the short rains from September to November. The mean annual rainfall ranges between 900mm and 1,200mm, although spatial and temporal variability is common due to changes in topography and rainfall distribution (MWE, 2020). The intervening dry seasons, from June to August and December to February, are typically marked by reduced humidity, high evapotranspiration rates and low soil moisture content, which collectively affect recharge dynamics and surface water availability. Average temperatures range from about 18 ^{0}C to 30 ^{0}C, with minimal diurnal variation, reflecting the area's humid tropical setting.

The district's drainage pattern is dendritic, reflecting the influence of the underlying crystalline basement rocks. Surface drainage is generally poorly developed, with numerous small streams and wetlands draining into the greater Katonga River system to the North and into Lake Victoria basin to the Southeast. Seasonal wetlands occupy many valley floors and play a vital role in regulating surface water flow, promoting localized recharge and maintaining dry-season baseflow. Human activities, including agriculture and wetland reclamation, have locally altered drainage characteristics, affecting both runoff dynamics and groundwater recharge potential.

3.2 Geology and Soils

A varied collection of lithological units from Uganda's Buganda – Toro and Karagwe – Ankolean rock systems underlie the Lwengo District. Numerous episodes of sedimentation, deformation, metamorphism and granitic intrusion are all part of the lengthy and intricate geological history documented by these Formations. Along with lateritic and alluvial deposits, the main rock types are quartzite, quartzite–conglomerate, quartzitic sandstone, mudstone, phyllite, mica schists with quartzitic interbeds and Rwamasha granite (1,987 ± 5 Ma) and Kasagama granite (1,964 ± 4 Ma) (Figure 3.1).

The largest Formations are the Rwamasha and Kasagama granites, which predominate in the district's central and western regions. Quartz, feldspar and biotite make up the majority of these are medium to coarse grained rocks, which usually weather to form thick regolith mantles. Their structural characteristics and mineral makeup encourage the Formation of weathered and fractured aquifers that can transmit and store groundwater. Depending on the amount of clay accumulation and disintegration, these granites produce lateritic mantles with varying permeabilities under tropical weathering conditions. Granitic terrain-underlain areas typically have moderate to good groundwater potential, especially where jointing and fracturing are well-developed (Sonkamble et al., 2014).

Primarily found in the central and eastern regions of Lwengo, the mica schists with quartzitic interbeds frequently co-exist with metamorphosed sedimentary sequences. The well-developed foliation and fine to medium grained nature of these schists improve secondary porosity and permeability. Locally, the interbedded quartzite layers improve fracture connectivity and offer more groundwater flow channels. According to hydrogeology, these Formations contain aquifers that are moderately productive, especially in areas where structural weaknesses or thick weathering of the schists intersect (Singhal & Gupta, 2010).

Conglomerate Formations, quartzite and quartzitic sandstone dominate the geology of the eastern and southeast zones. Because of their hardness, compactness and poor fractures, these rocks have low primary porosity and little capacity to store groundwater. However, secondary permeability can result in localized low-yield aquifers along joints, bedding planes or fractures. Because of the limited degree of structural deformation in these Formations, borehole yields are usually low and variable.

The district's northwestern and southern regions are primarily home to thin bands of mudstone, shale and phyllite that locally contain stromatolitic and oncolitic structures. Because of their low permeability and typical aquitard behavior, these fine grained metasedimentary rocks prevent vertical percolation. Nevertheless, perched aquifers with a restricted area may be found where they are weathered or fractured.

Lateritic deposits, which are created by severe weathering and leaching of underlying crystalline rocks, are found widely throughout the uplands as surficial cappings. Indurated laterites function as aquitardic layers that prevent infiltration, whereas uncemented laterites are ferruginous, porous and moderately permeable. Particularly along the Lwengo River and its tributaries, valley bottoms and drainage lines are covered in alluvial and swamp deposits, which are composed of sand, silt, clay and organic matter. In the district's hydrogeological system, these loose sediments create shallow, unconfined aquifers that are significant locally and act as important recharge and discharge zones.

The geological framework of Lwengo District is inextricably linked to its hydrogeology. The schist–quartzite assemblages contribute secondary but variable permeability, while the granitic and gneissic Formations, through weathering and fracturing, form the primary aquifer systems. While lateritic and alluvial deposits promote recharge and local groundwater occurrence, quartzite and sandstone units typically function as poor aquifers because of their low storage capacity. Groundwater movement, recharge, and borehole yields are all significantly influenced by the structural fabric, which includes joints, faults and foliation planes. In general, the presence of groundwater in Lwengo is a result of intricate interactions between lithology, structure and weathering level.

Long-term tropical weathering of these basement rocks, influenced by drainage and topography, produced the soils of Lwengo District. According to Figure 3.3, there are four main types of soil; umbric fluvisols, lithic leptosols, haplic ferralsols, and haplic nitisols. Haplic ferralsols, which form over gneissic and granitic terrains, predominate in the eastern and northeastern regions. Rich in iron and aluminum oxides, these well-drained, deeply weathered soils have a low capacity for cation exchange because of heavy leaching. Although limited nutrient retention may affect vegetation cover and evapotranspiration balance, their high permeability facilitates infiltration.

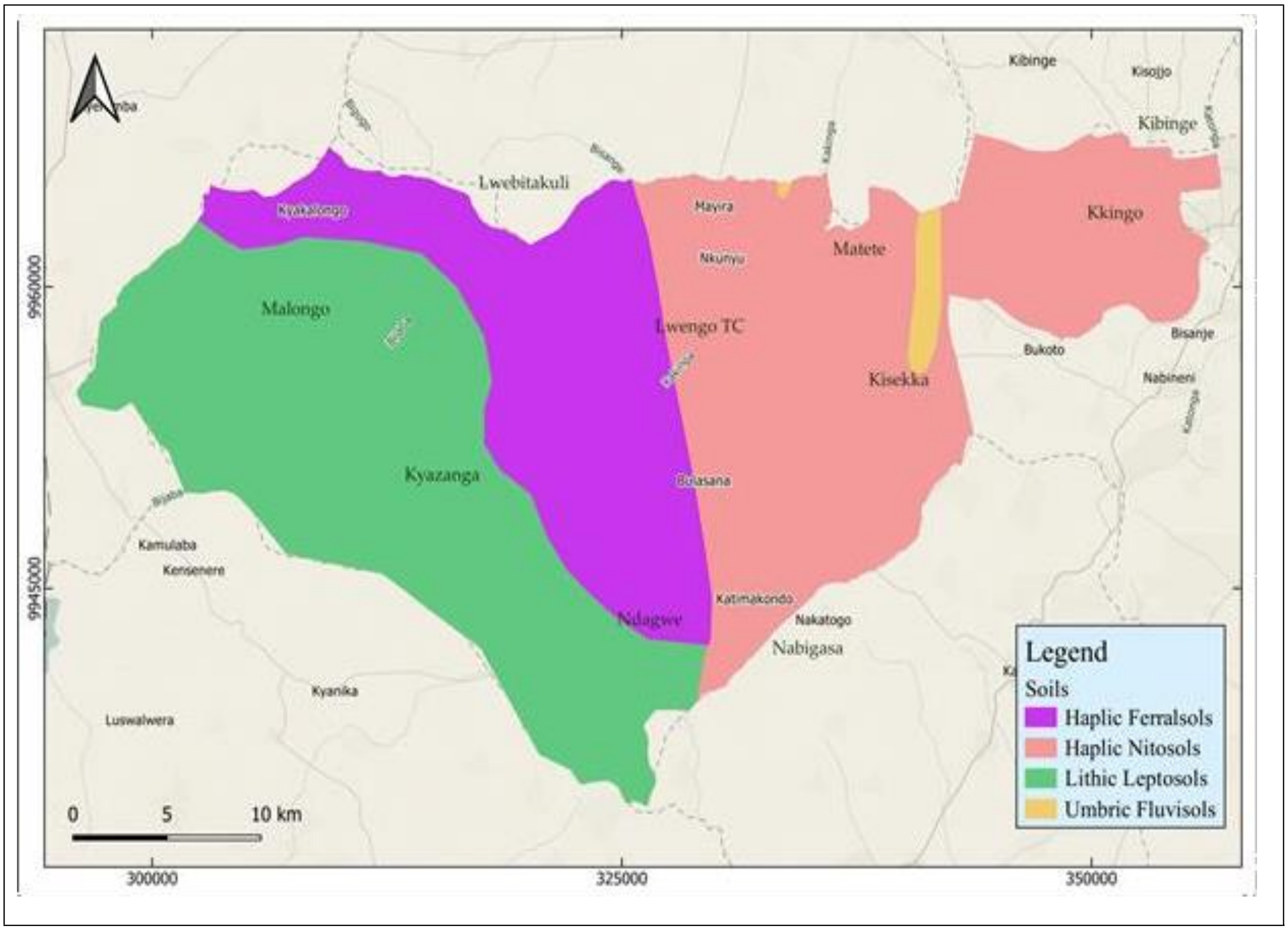

Figure 3.3: Soil distribution map of Lwengo District showing the spatial extent of major soil types.

Haplic Nitisols occur mainly in the central belt around Lwengo Town Council and Ndagwe. These soils have developed from weathered schists and basic gneisses, exhibiting stable structure, strong aggregation, and moderate permeability, making them favourable for infiltration and moderate groundwater recharge. The western uplands (Malongo and Kyanzaanga) are covered by Lithic Leptosols, stony soils derived from quartzitic and granitic rocks. Their limited depth and high gravel content restrict infiltration and reduce groundwater recharge potential. Along valley bottoms and wetland zones, Umbric Fluvisols are found, consisting of young alluvial and organic-rich materials with moderate drainage and high water-holding capacity. These areas act as important recharge-discharge interfaces within the local groundwater system.

The distribution of soil types corresponds closely to the underlying geology, demonstrating the strong interaction between pedogenesis and lithology. Areas underlain by weathered granitic and schistose rocks exhibit more permeable soil profiles that enhance recharge, whereas quartzitic and sandstone areas are characterized by shallow, less permeable soils that limit infiltration. This soil-geology relationship directly influences groundwater availability, aquifer productivity, and the spatial variability of recharge zones within the district.

3.3 Data Collection and Analysis

The Directorate of Water Resources Management (DWRM) provided historical and archived datasets for the study. These datasets included; groundwater chemical analyses, pumping-test results, geophysical survey data, borehole completion logs (Appendix 4) and a variety of hydrogeological and thematic maps. To assess completeness, eliminate inconsistencies and validate their dependability for the intended analyses, all data underwent a thorough quality control and assurance procedure. GPS-based location checks were used for field verification in order to increase accuracy, especially for boreholes and observation wells used for hydrogeological interpretation and spatial mapping.

3.4 Delineation of hydrogeological Formations

Several datasets and analytical methods were used to define the study area's hydrogeological framework. In addition to remotely sensed imagery covering Lwengo District, existing topographical, geological, lithological and structural maps were examined and interpreted. These resources made it easier to identify major hydrogeological units in the first place. To guarantee spatial accuracy, these units were then ground-truthed using handheld GPS devices.
Important subsurface data; such as drilling depth, lithological logs, geographic coordinates, water strike levels, borehole yields and geophysical records (Appendix 5) were supplied by borehole completion reports. In order to deduce stratigraphy, aquifer continuity and subsurface features, these datasets were combined. To complement and validate the borehole datasets, technical reports and published studies unique to Lwengo District were also examined.

Quantum Geographic Information System (QGIS) software (version 3.36.3) was used to integrate and analyze the datasets. The creation of comprehensive soil, hydrogeological and other thematic maps which are crucial for spatial interpretation was made easier by this integration.

Aquifer distribution, geometry, connectivity and recharge potential were clearly understood from the resulting maps, which served as a spatial foundation for further hydrogeological and geochemical analyses.

3.5 Evaluation of hydraulic properties

Pumping test data from four boreholes (BH-01, BH-02, BH-03 and BH-04) were interpreted to evaluate the hydraulic behavior of aquifer systems in the study area (Figure 3.4). Long-duration pumping tests (≥24 hours) were performed on each borehole to record drawdown and recovery behavior under prolonged abstraction. The tests yielded important hydrogeological data that served as the foundation for a quantitative assessment of aquifer performance, such as static water levels, pumping depths, discharge rates and time-drawdown responses.

The primary hydraulic parameters considered were transmissivity (T) and storativity (S), which together describe the aquifer's capacity to transmit and store groundwater. Aquifer Test (AQTESOLV) Version 10.0 was used to implement analytical solutions to groundwater flow in order to compute these parameters. Two traditional analytical techniques were used:

- Theis (1935) type-curve matching-based non-equilibrium method; and
- The straight-line approximation developed by Cooper and Jacob (1946) uses a semi-logarithmic analysis of drawdown data.

Both methods are well known for their ability to accurately measure aquifer capacity and dynamic response to pumping, which offers trustworthy information about groundwater potential and sustainable use in the research region (Leelaruban & Padmanabhan, 2013).

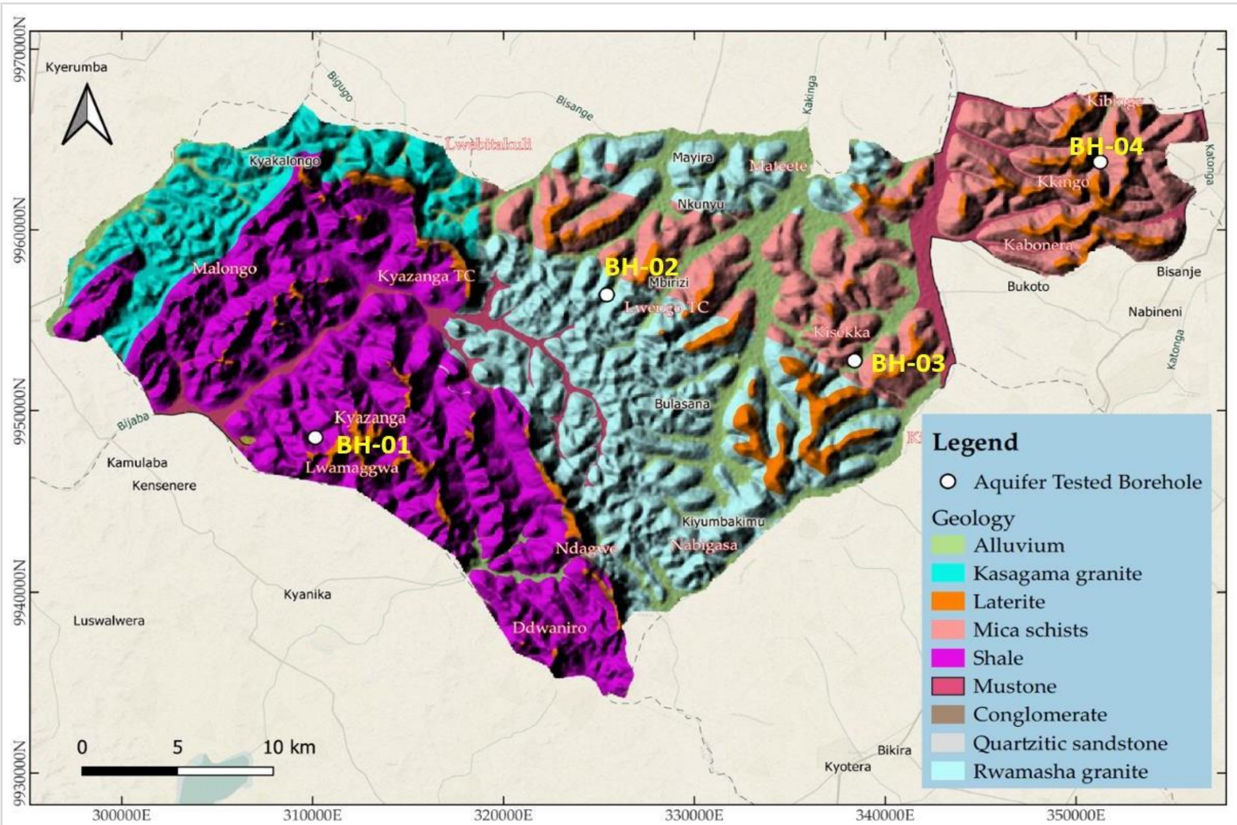

Figure 3.4: The geology map of Lwengo District, showing the distribution of the main rock Formations and the locations of the boreholes that were analyzed (Kkingo (BH-04), Kisekka (BH-O3) [DWD17445], Lwengo TC (BH-02) [DWD44192] and Kyazanga (BH-01)).

The four boreholes were selected because they have reliable long-term pumping test datasets, making them suitable for hydrogeological characterization. Figure 3.4 highlights how the boreholes are spatially distributed across different geological units, which helps explain the variability observed in aquifer property estimates.

The analysis was conducted under several simplifying assumptions inherent to these models. It was assumed that the aquifer is confined, homogeneous, isotropic and of infinite areal extent; that the aquifer thickness is uniform and fully penetrated by the pumping well, that pumping occurs at a constant discharge rate throughout the test period and that water is released instantaneously from storage in response to a decline in hydraulic head. Furthermore, the effects of well bore storage and partial penetration were considered negligible or minimized by focusing on appropriate segments of the drawdown data. These assumptions ensured that the analytical models could be reliably applied to the available datasets.

Through the application of the Theis and Cooper-Jacob methods, transmissivity and storativity values were derived for each borehole, providing quantitative measures of aquifer performance. The results revealed spatial variability in aquifer hydraulic behaviour, reflecting differences in lithological composition, degree of fracturing and degree of weathering across the study area. The long-duration pumping tests enhanced the reliability of the derived parameters, ensuring that the computed transmissivity and storativity values are representative of the true aquifer conditions rather than short-term fluctuations.

3.6 Geochemical Quality Assessment of Groundwater

Groundwater quality was assessed by analysing the chemical composition of water samples from 19 existing boreholes, as recorded in the DWRM archives. The analysis encompassed major cations (Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, Fe^{2+}), major anions (Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, F^{-}) and physio-chemical parameters including electrical conductivity (EC), pH, total dissolved solids (TDS) and turbidity.

To ensure the reliability of the hydrochemical data, ionic charge balance calculations were performed for all water samples (eqn. 3.1). This process provided an essential quality assurance check, verifying that the sum of cation and anion equivalents was within acceptable error margins. Typically, a charge balance discrepancy of less than ±5% indicates reliable analytical results, while values between 5% and 15% are considered marginal and warrant cautious interpretation, as suggested by Holland, 2011.

$$Charge\ Balance\ Error(\%)=\left(\frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}}\right)*100 \qquad (3.1)$$

where, ∑Cations and ∑Anions denote the total concentrations of major cations and anions respectively, expressed in milliequivalents per liter (meq/L).

Spatial patterns in groundwater quality were examined through the development of hydrochemical maps using the Inverse Distance Weighting (IDW) interpolation method implemented in QGIS version 3.36.3. This geostatistical technique enabled the visualization of ion concentration gradients across the study area, offering critical insights into spatial variability and potential contamination zones. IDW is particularly suitable for sparsely distributed datasets, as it does not rely on the assumption of spatial auto correlation (Xu & Zhang, 2023). However, careful interpretation of the resulting maps was carried out, taking into account the methodological assumptions and limitations associated with the IDW approach.

In addition to spatial mapping, graphical methods were employed to further investigate hydrochemical processes. Piper plots were constructed to classify water types, evaluate geochemical evolution, and delineate dominant hydrochemical facies (Piper, 1944). The Gibbs plot (eqns. 3.2 and 3.3) was applied to identify the principal mechanisms controlling groundwater chemistry, such as precipitation dominance, rock-water interaction, or evaporation influence (Gibbs, 1970). The ionic concentrations presented are expressed in milliequivalents per liter (meq/L).

$$Gibbs\ Cation\ Ratio = \frac{K^{+} + Na^{+}}{K^{+} + Na^{+} + Ca^{2+}} \qquad (3.2)$$

$$Gibbs\ Anionic\ Ratio = \frac{Cl^{-}}{Cl^{-} + HCO_3^{-}} \qquad (3.3)$$

Bivariate plots were also utilised to explore the key weathering processes influencing groundwater quality within the region. These analytical techniques have been widely applied in similar studies, such as those by Hyeroba et al. (2024) and Owor et al. (2021), and support a comprehensive understanding of the interactions between groundwater and geological Formations, as well as the overall suitability of groundwater for different water usage

3.7 Analytical and Statistical Methods

Statistical evaluation of hydrochemical datasets was conducted using Microsoft Excel to calculate descriptive statistics, including means, standard deviations and minimum and maximum values. These statistics were compared against World Health Organization (WHO) guidelines to assess compliance with recommended thresholds for drinking water. To further investigate the geochemical controls on groundwater composition, bivariate plots were generated to examine relationships among key parameters and identify prevailing weathering processes. OriginPro version 2022 was used to create Gibbs and Piper plots, which facilitated the identification of geochemical processes such as ion exchange, mineral dissolution and precipitation, as well as the determination of dominant ions in the groundwater samples.

CHAPTER 4: RESULTS

4.1 Delineation of Major Hydrogeological Formations

The hydrogeological setting of Lwengo District is characterized by a heterogeneous assemblage of lithological units comprising metamorphic, and sedimentary Formations (Appendix 2, 3 & 5). The major hydrogeological units are classified as aquitards (lateritic Formations), aquicludes (shales, slates and phyllites), and aquifuges (granites and granite gneisses). The spatial distribution of these Formations is illustrated in Figure 4.1. Aquitards permit limited groundwater movement, while aquicludes and aquifuges offer effective barriers to flow.

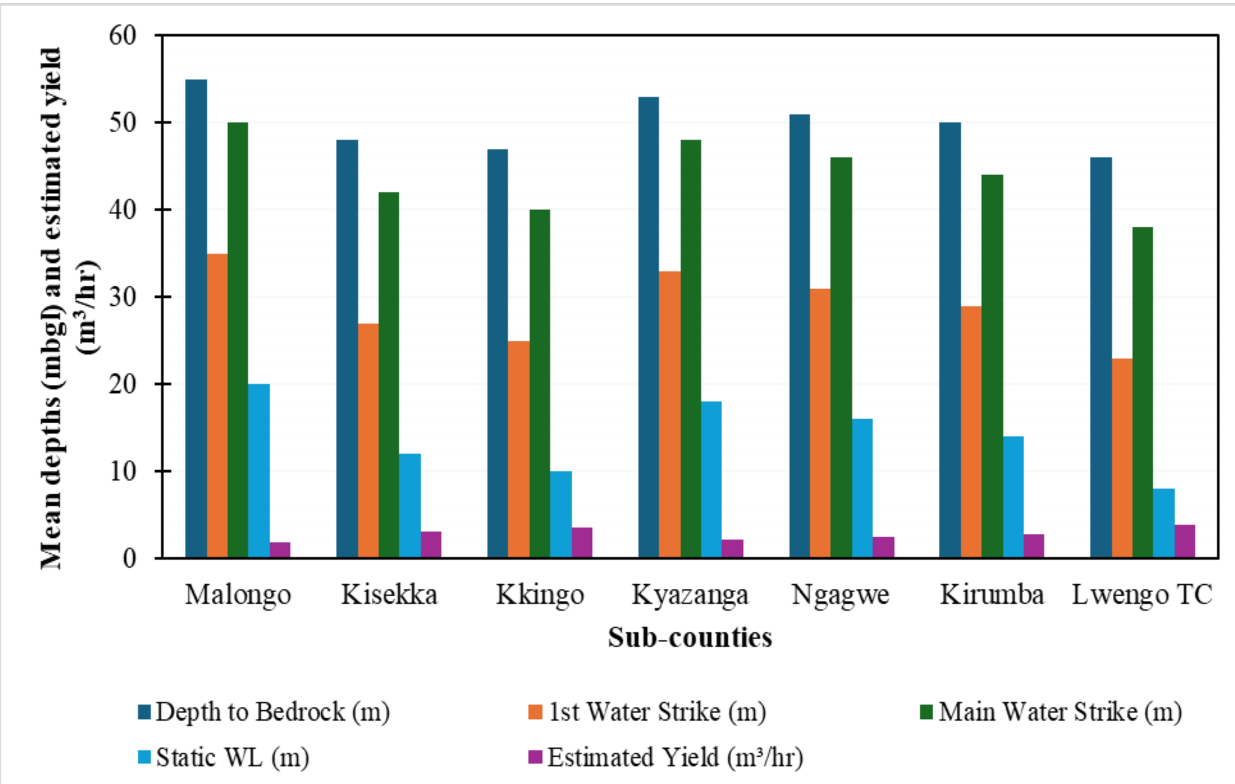

Figure 4.1: Mean groundwater parameters and estimated yields across sub-counties of Lwengo District.

The regional groundwater flow pattern derived from the piezometric datasets indicates a general west-to-east movement, corresponding with topographic relief and the natural drainage direction (Figure 4.2). Areas of potential discharge are identified along the low-lying valley bottoms in areas of Kisekka and Mateete, which act as natural groundwater outlets. The map reveals that recharge zones is dominant in upland areas where permeable weathered mantles are thickest, whereas the valley bottoms act as discharge zones.

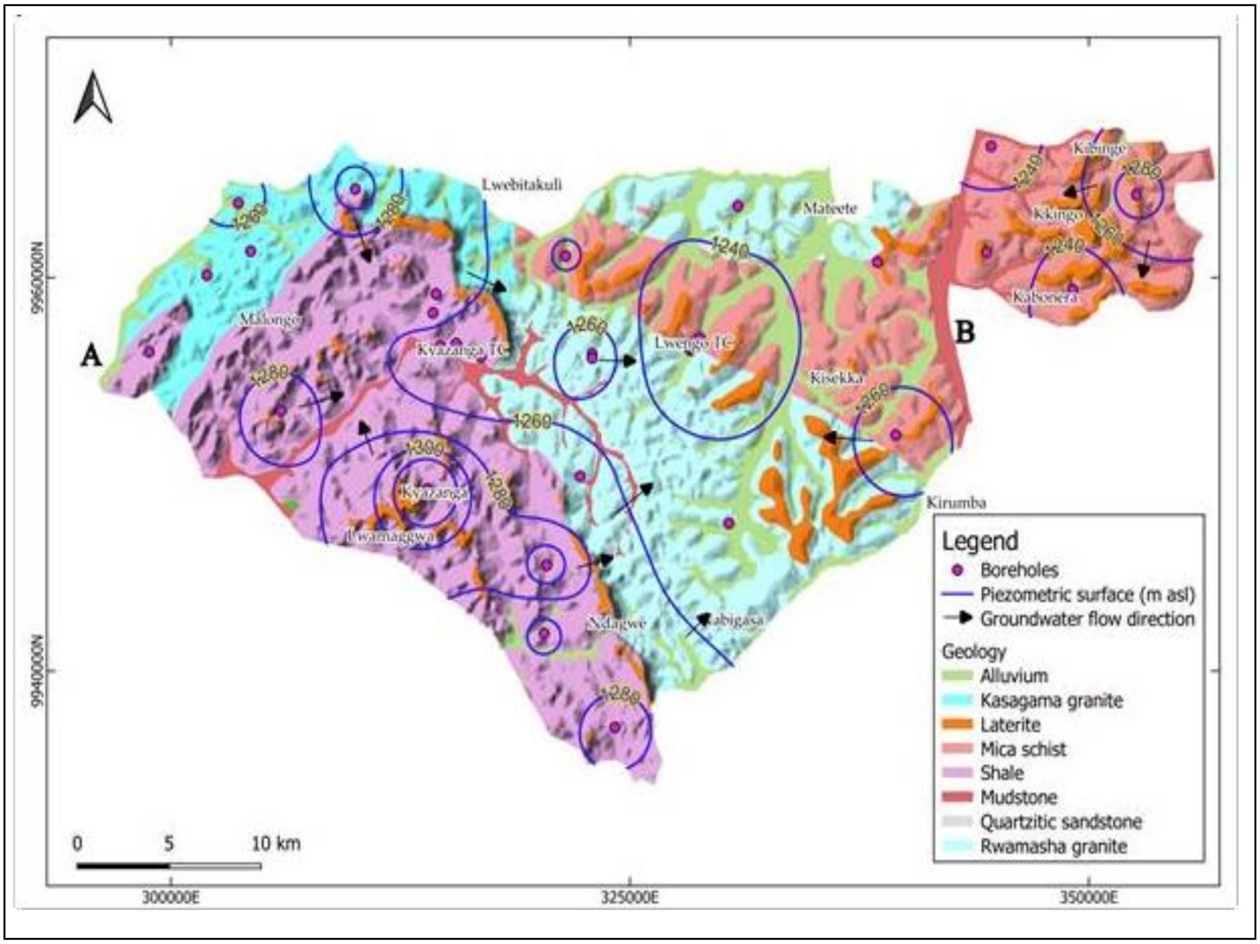

Figure 4.2: Hydrogeological framework and groundwater flow patterns in Lwengo District.

The hydrogeological cross-section along transect AB (Figure 4.3) further illustrates the lateral and vertical variations in lithological composition and aquifer characteristics. The section, approximately 51 km in length, reveals that aquifers are mainly developed within weathered and fractured crystalline rocks, overlain by a thin mantle of lateritic and alluvial deposits. The aquifer thickness averages between 10 and 25 m, with unweathered granitic crystalline bedrock forming the impermeable base. Groundwater static water levels decline progressively from west to east, reflecting the regional hydraulic gradient and flow direction. The cross-section also shows that the upper weathered zones form semi-confined aquifers, while the deeper fractured rocks form confined aquifer systems. The distribution of fractures and fault zones is a significant factor controlling aquifer connectivity and localized storage capacity.

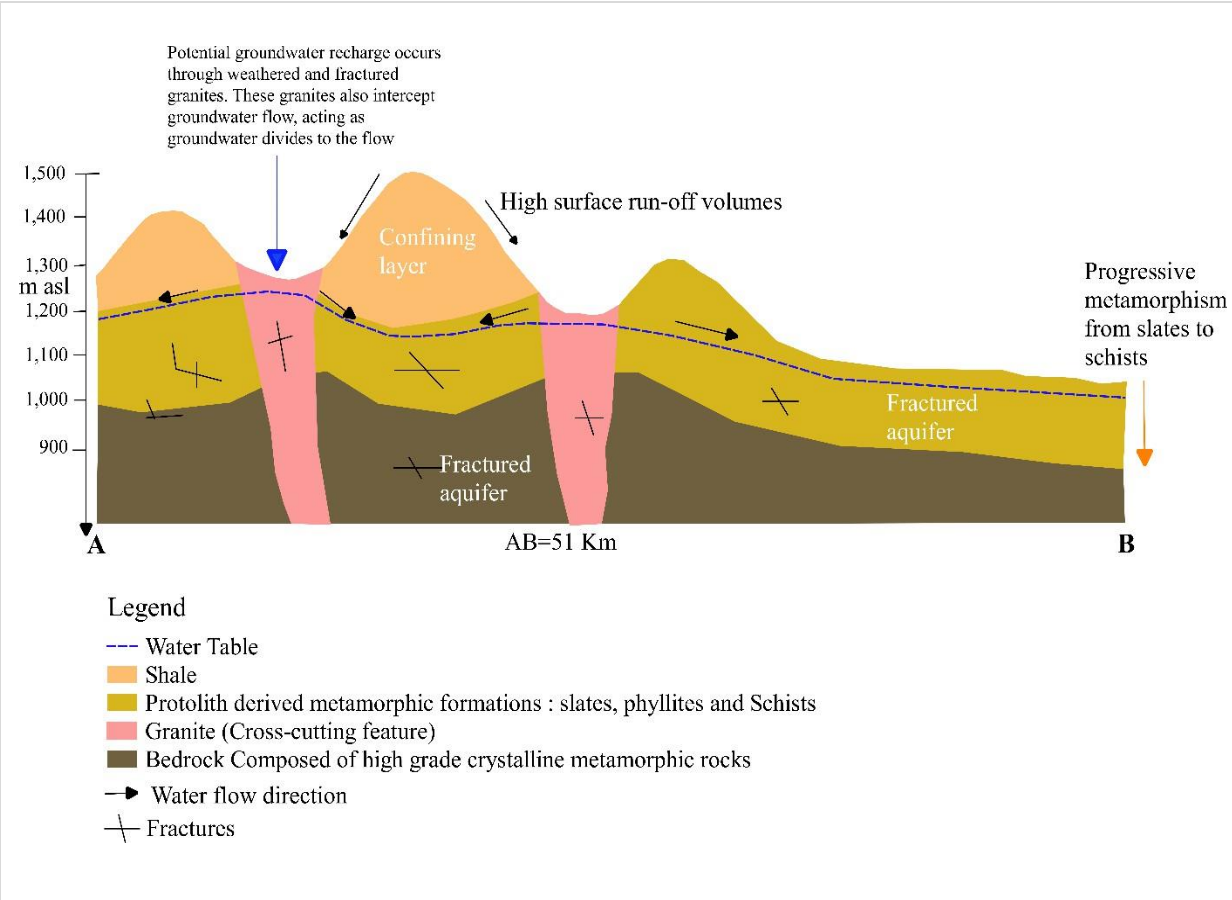

Figure 4.3: Hydrogeological cross-section along transect AB showing lateral variation in aquifer zones and underlying bedrock.

4.2 Evaluation of Hydraulic Properties

The aquifer systems within Lwengo District show distinct spatial variations in hydraulic characteristics, reflecting the heterogeneity of the underlying lithological Formations. The analysis of pumping test data from the four boreholes: Kkingo, DWD17445 (Kisekka), DWD44192 (Lwengo Town Council), and DWD29742 (Kyazanga), provided estimates of transmissivity, aquifer thickness, hydraulic conductivity, storativity, and specific storage (Table 4.1). Transmissivity values range between 0.3 m^2/day and 5.5 m^2/day, with an average of approximately 1.85 m^2/day. The highest transmissivity occurs at Kisekka (DWD17445), which indicates a more developed fracture network and enhanced secondary permeability. The lowest transmissivity value of 0.3 m^2/day is recorded at Kkingo, signifying limited permeability and restricted groundwater flow. The other two boreholes, DWD44192 and DWD29742, exhibit intermediate transmissivity values of 1.1 m^2/day and 0.5 m^2/day, respectively.

Table 4. 1: Aquifer test results for the different boreholes

Borehole	**Used method**	***T*** **(m^2/day)**	***b (m)***	***K*** **(m/day)**	***S***	**S_s (m^{-1})**
Kkingo	Theis	0.3	20.0	0.02	3.0E-5	1.0E-6
	Cooper-Jacob	0.3	20.0	0.02	3.0E-5	1.0E-6
DWD17445	Theis	5.5	24.0	0.2	2.0E-5	2.0E-6
	Cooper-Jacob	5.5	24.0	0.2	2.0E-5	2.0E-6
DWD44192	Theis	1.1	22.0	0.05	1.0E-4	5.0E-6
	Cooper-Jacob	1.1	22.0	0.05	1.0E-4	5.0E-6
DWD29742	Theis	0.5	20.0	0.03	3.0E-5	3.0E-6
	Cooper-Jacob	0.5	20.0	0.03	3.0E-5	3.0E-6

The storativity values vary from 2.0×10^{-5} to 1.0×10^{-4}, while the specific storage ranges between 1.0×10^{-6} and 5.0×10^{-6} m^{-1}. These low storage values indicate confined aquifer conditions, where water release is primarily due to the elastic response of the aquifer matrix and the water itself. Spatially, the boreholes located in the central and eastern parts of the district (Kisekka and Lwengo TC) exhibit relatively higher transmissivity and hydraulic conductivity, reflecting better-developed weathered profiles and fracture systems. The western localities (Kkingo and Kyazanga) show lower transmissivity and hydraulic conductivity, consistent with limited structural development and compact lithology. The aquifer thickness across the four sites ranges from 20 m to 24 m, which corresponds to the weathered and fractured zones that constitute the productive horizons. The hydraulic conductivity values, derived from transmissivity and aquifer thickness, range between 0.02 m/day and 0.20 m/day, indicating generally low permeability. The highest value of 0.20 m/day at Kisekka reflects the presence of relatively high fractured and permeable rock units, whereas Kkingo, with a hydraulic conductivity of 0.02 m/day, represents a relatively compact and less permeable Formation (Figures 4.4 and 4.5).

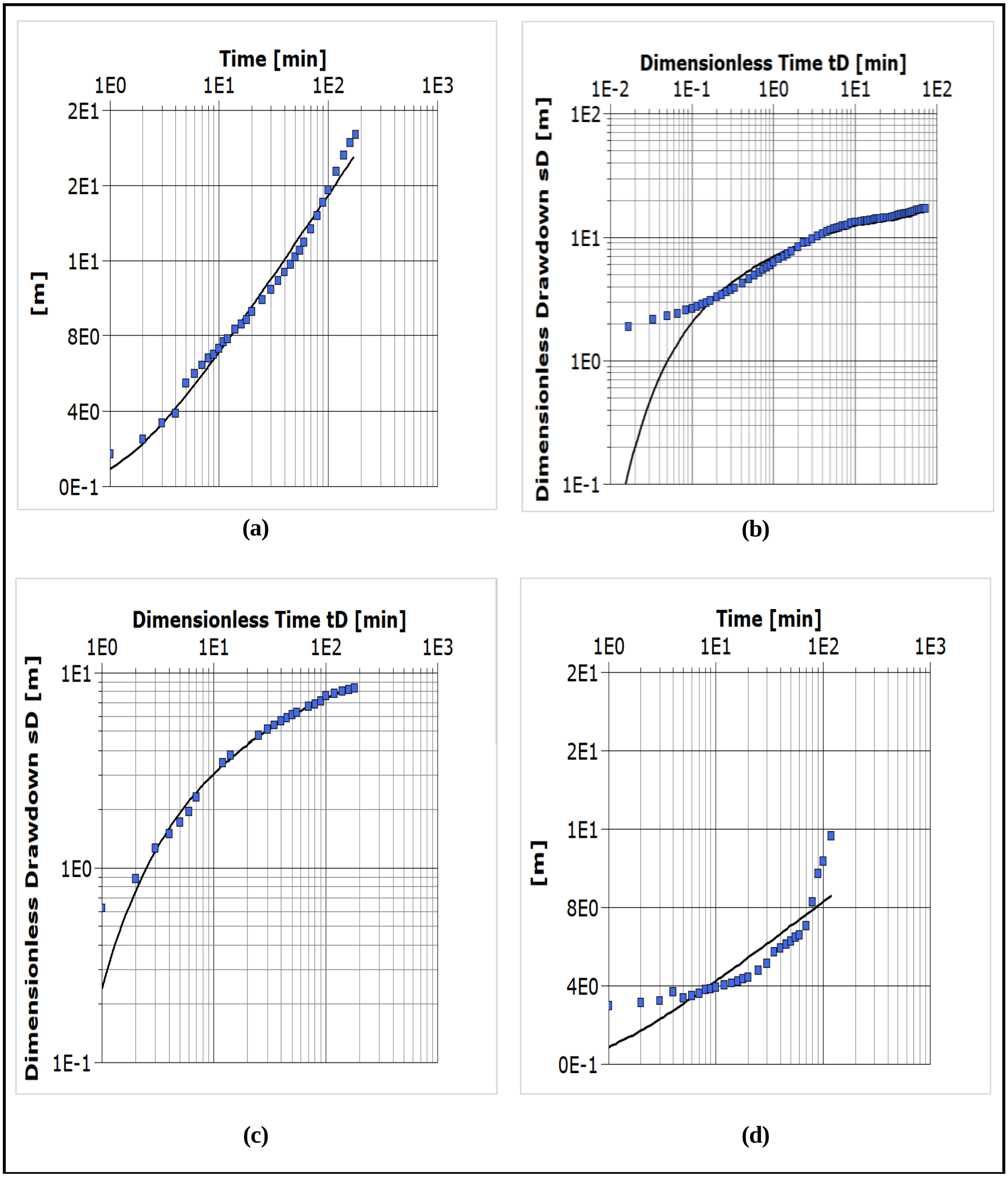

Figure 4. 4: Aquifer Theis results for (a) Kkingo borehole, (b) DWD17445 borehole, (c) DWD44192 borehole and (d) DWD29742 borehole.

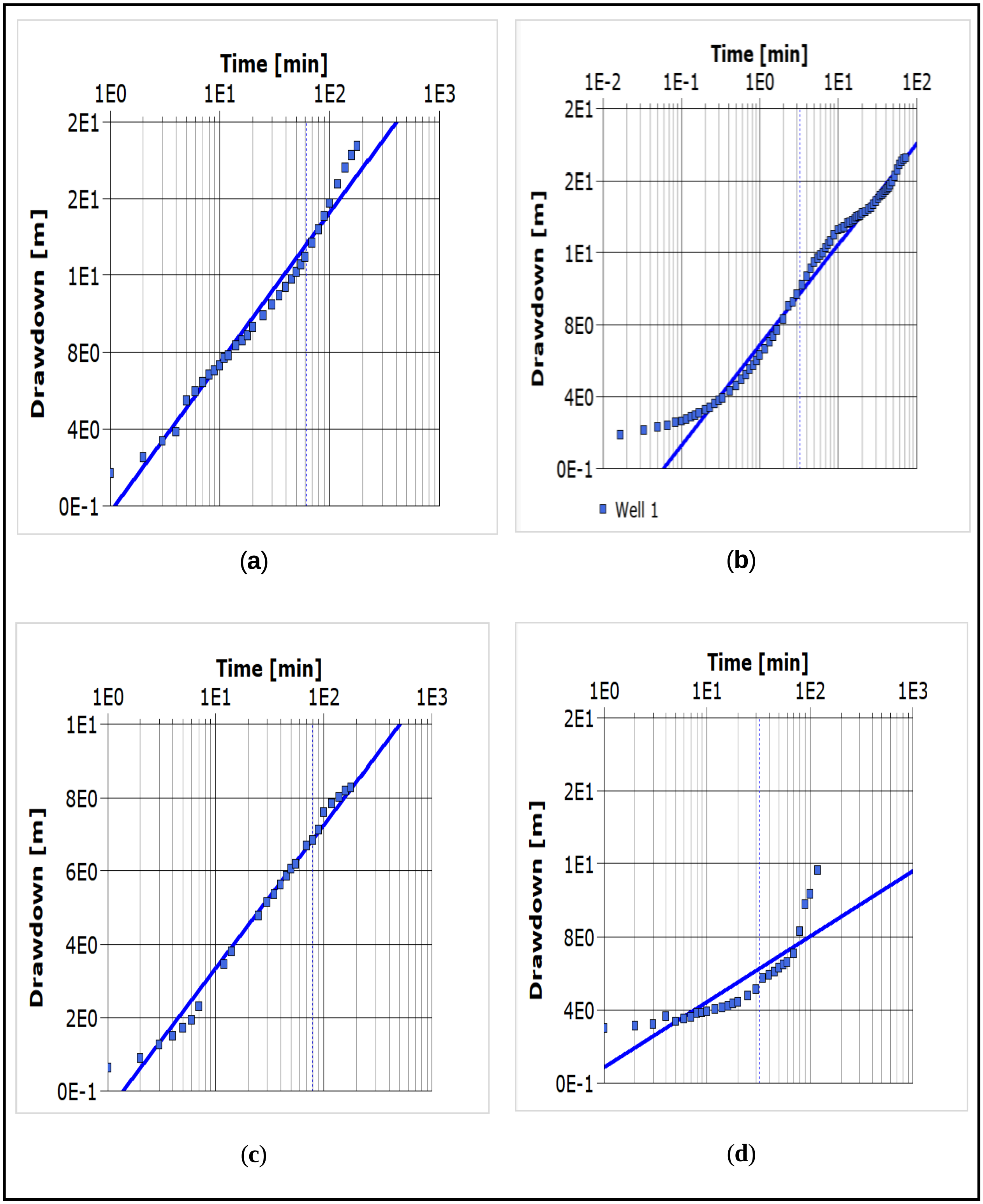

Figure 4.5: Aquifer Cooper-Jacob results for (a) Kkingo borehole, (b) DWD17445 borehole, (c) DWD44192 borehole and (d) DWD29742 borehole.

4.3 Hydrogeochemical Assessment

4.3.1 Descriptive Statistics of Major Ions

Groundwater quality in Lwengo District was assessed using 19 representative water samples analyzed for major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{2+}), major anions (Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, F^{-}), and key physio-chemical parameters including electrical conductivity (EC), pH, total dissolved solids (TDS), and turbidity. The ionic balance calculations indicated that 84% of the samples had a charge balance error within ±5%, signifying acceptable analytical precision and reliability of the laboratory results (Appendix 1).

The descriptive statistics (Table 4.2) demonstrate significant variation in the concentration of the analysed parameters across the study area. Calcium concentrations range from 0.7 to 144 mg/L, with a mean of 59.0 mg/L, while magnesium varies from 0.03 to 51.6 mg/L, with a mean value of 23.5 mg/L. Sodium concentrations range between 8.6 and 134.6 mg/L, averaging 59.9 mg/L, and potassium values vary from 2.8 to 15.1 mg/L, with a mean of 6.6 mg/L. The observed variability in the major cations indicates a wide range of total ionic content among the sampled boreholes.

Among the anions, chloride concentrations range from 16 to 96 mg/L, with an average of 48.6 mg/L. Bicarbonate values vary between 10 and 439.3 mg/L, with a mean of 141.5 mg/L, while sulphate concentrations show the widest range, from 29.9 to 515.6 mg/L, and a mean of 204.7 mg/L. Fluoride concentrations vary from 0.03 to 1.0 mg/L, with a mean value of 0.4 mg/L. Electrical conductivity ranges from 200 to 2460 µS/cm, with a mean of 718.4 µS/cm, indicating notable variability in the dissolved ionic content across the sampling sites.

Table 4. 2: Summary of principal hydrochemical parameters and comparison with WHO (2017) guideline values.

Parameter (n = 19)	Min	Max	Mean	Std. Dev	WHO Limit (2017)	No. Exceedances
Ca (mg/L)	0.7	144	59.0	41.2	100	3
K (mg/L)	2.8	15.1	6.6	3.7	12	2
Mg (mg/L)	0.03	51.6	23.5	15.2	50	1
Na (mg/L)	8.6	134.6	59.9	26.6	200	0

Parameter (*n* = 19)	Min	Max	Mean	Std. Dev	WHO Limit (2017)	No. Exceedances
Cl (mg/L)	16	96	48.6	24.9	250	0
HCO_3 (mg/L)	10	439.3	141.5	130.4	500	0
SO_4 (mg/L)	29.9	515.6	204.7	145	250	8
EC (µS/cm)	200	2460	718.4	609.5	1500	4
F (mg/L)	0.03	1.0	0.4	0.3	1.5	0

The descriptive summary (Table 4.2) shows that groundwater in Lwengo District exhibits moderate mineralization, with elevated calcium and sulphate concentrations recorded in a few locations. Figure 4.6 presents the graphical distribution of the major ions and key physio-chemical parameters, illustrating the magnitude and variability of each measured constituent across the sampled boreholes.

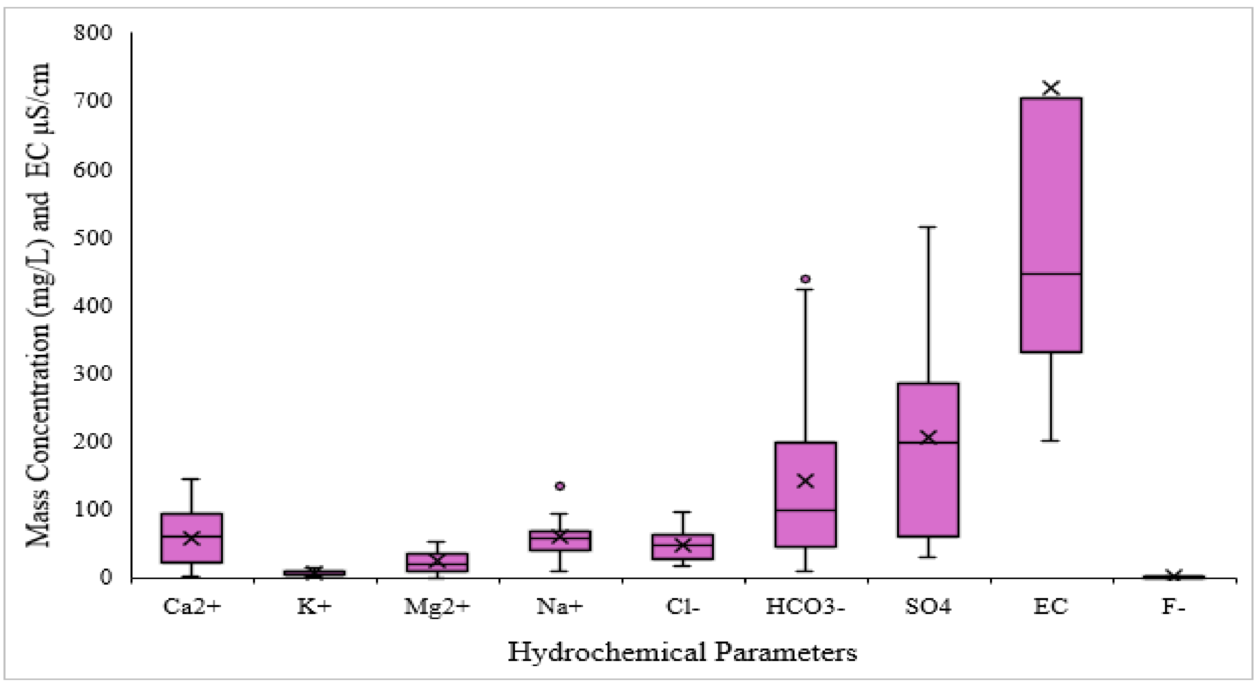

Figure 4.6: Box plot showing distribution of principal hydrochemical parameters in groundwater samples.

4.3.2 Spatial Distribution of Hydrochemical Parameters

The spatial distribution of major cations, anions, and selected physio-chemical parameters across Lwengo District reveals clear patterns of variation that correspond with both geological and topographical settings. The maps were developed using interpolated values from analysed borehole water samples, providing a representation of concentration gradients for each hydrochemical parameter.

Calcium (Ca^{2+}) concentrations display a heterogeneous pattern across the district (Figure 4.7). Elevated calcium levels occur in the western, some parts of central and eastern sub-counties, particularly around Kisekka Kkingo, Matete, Kyazanga, Malongo and Lwengo Town Council, while relatively low concentrations are observed in the western and southern parts, notably around Ndagwe and Malongo. The highest calcium concentrations exceed 100 mg/L, whereas the lowest are below 10 mg/L, indicating substantial spatial variability in groundwater hardness.

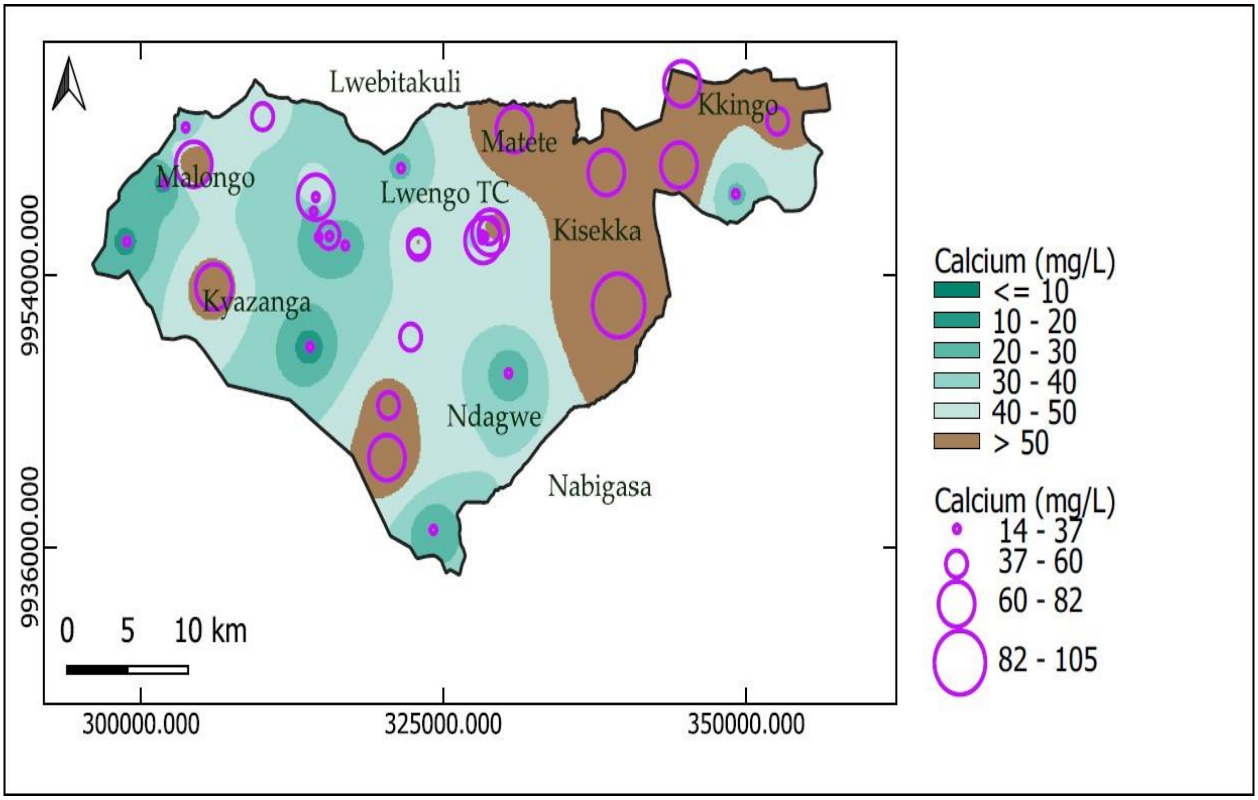

Figure 4.7: Spatial distribution of calcium ions in groundwater within Lwengo District

Magnesium (Mg^{2+}) distribution follows a relatively different pattern to that of calcium, with high concentrations in the southeastern and central zones and lower values toward the western and southern regions (Figure 4.8). Concentrations range from less than 10 mg/L in the low zones to about 50 mg/L in localized areas of Kisekka and Matete.

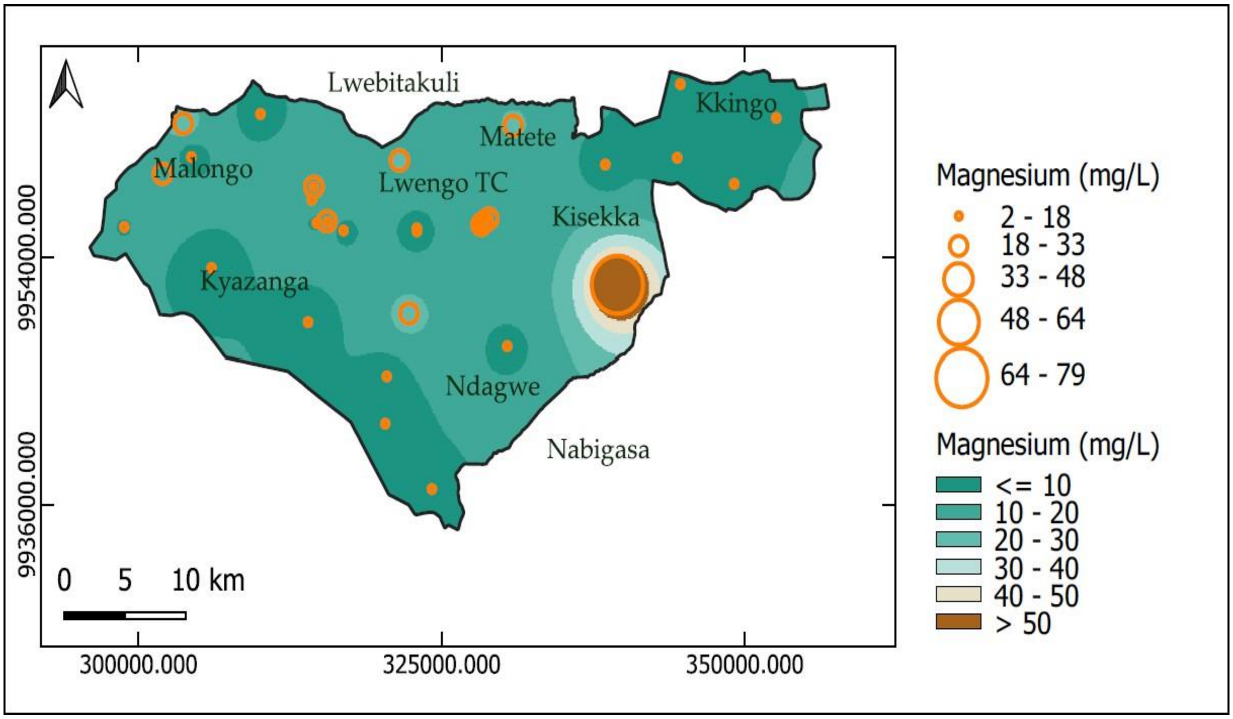

Figure 4.8: Spatial distribution of magnesium ions in groundwater within Lwengo District

Sodium (Na^{+}) concentrations (Figure 4.9) are highest in the central corridor, particularly around Lwengo TC and Matete, where values exceed 100 mg/L. Moderate levels are recorded in Kisekka and Ndagwe, while Malongo and Kyazanga show concentrations below 30 mg/L.

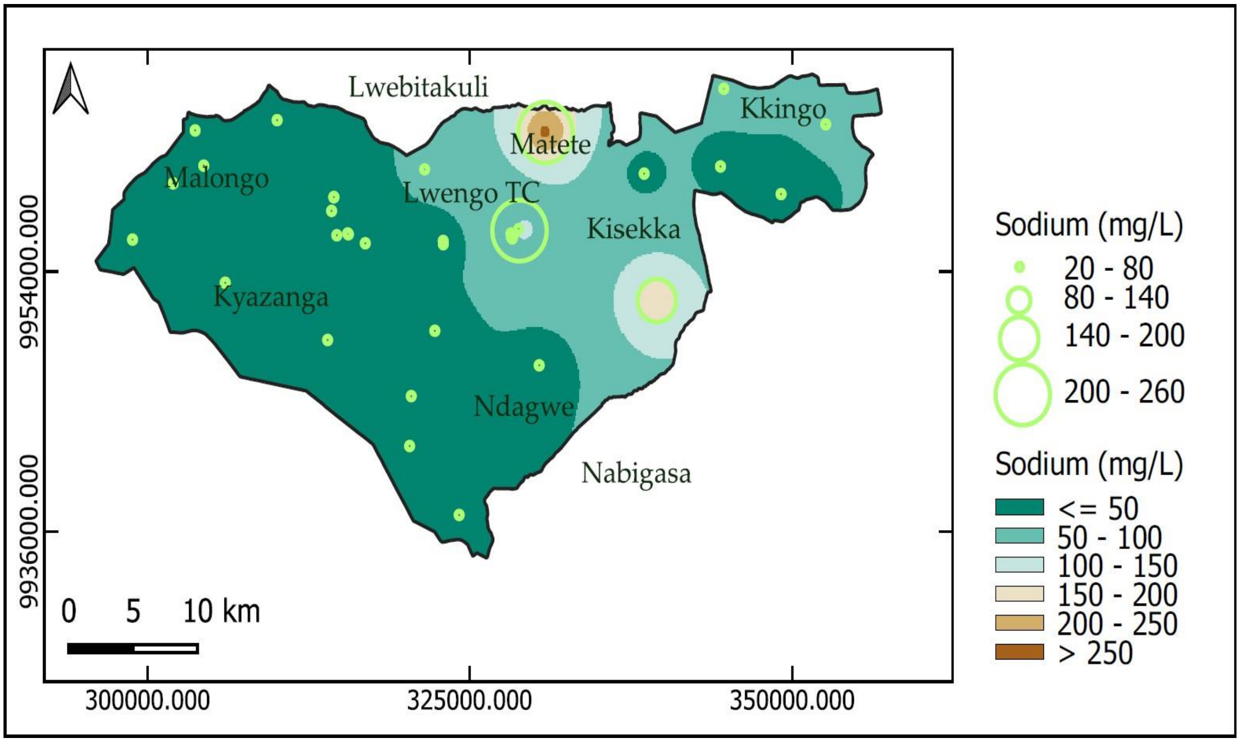

Figure 4.9: Spatial distribution of sodium ions in groundwater within Lwengo District

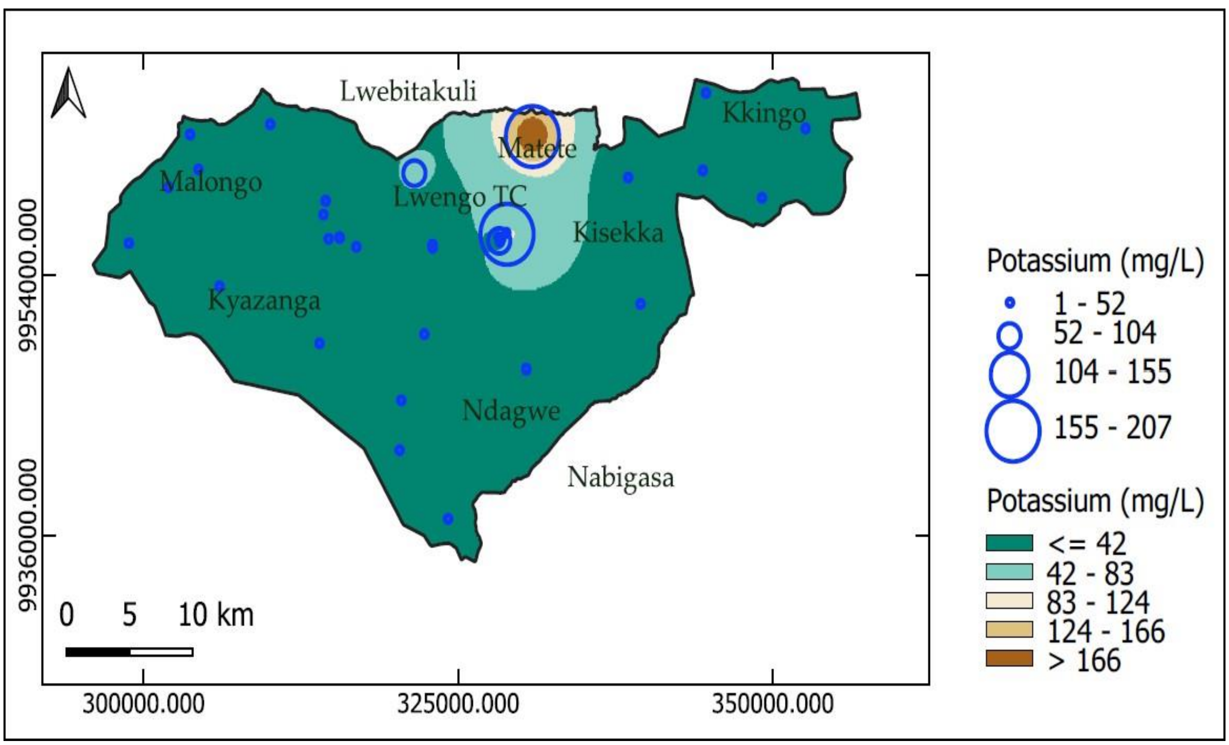

Figure 4.10: Spatial distribution of potassium ions in groundwater within Lwengo District

Potassium (K^+) (Figure 4.10) exhibits a more patchy distribution, with relatively higher concentrations (above 42 mg/L) in Matete and Lwengo TC and generally low values (below 5 mg/L) in most other sub-counties.

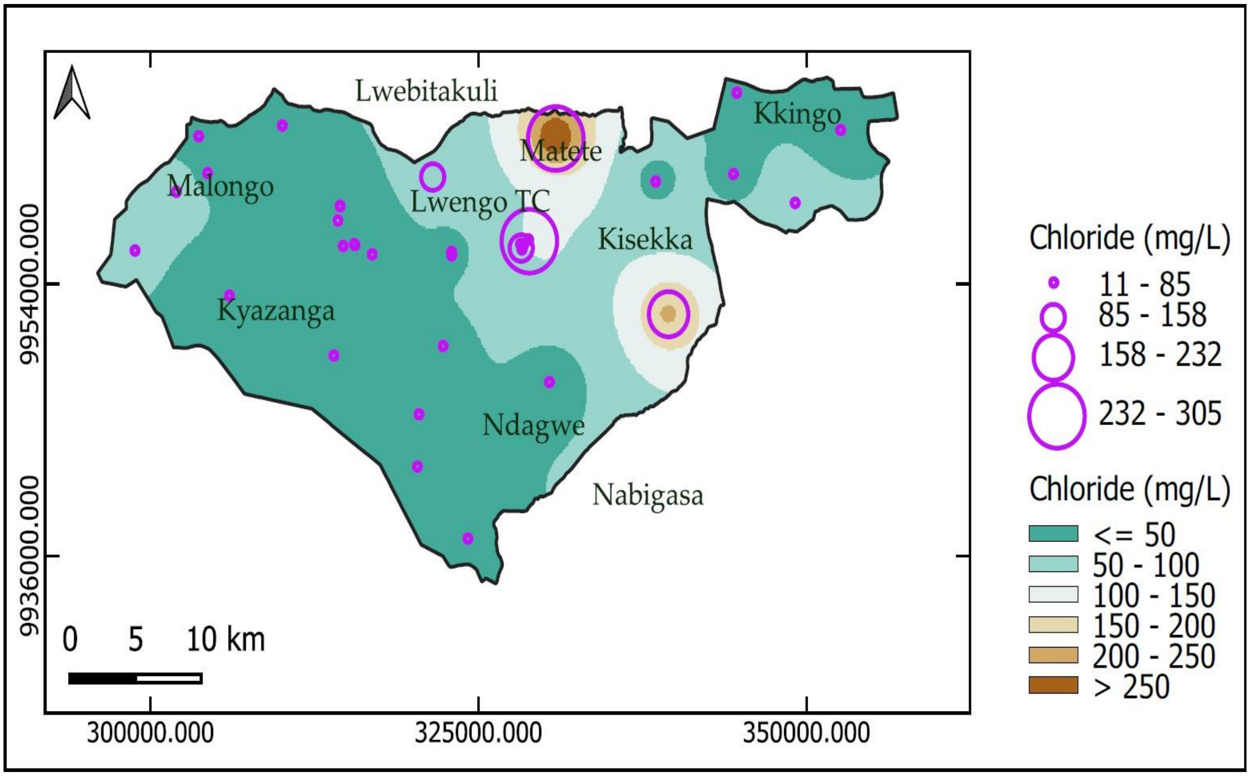

Figure 4.11: Spatial distribution of chloride ions in groundwater within Lwengo District

Among the major anions, chloride (Cl^-) concentrations (Figure 4.11) are elevated in the central and northeastern parts of the district, particularly around Matete, Lwengo TC and Kisekka, with concentrations reaching above 80 mg/L. The western and southern regions record the lowest values, mostly below 50 mg/L.

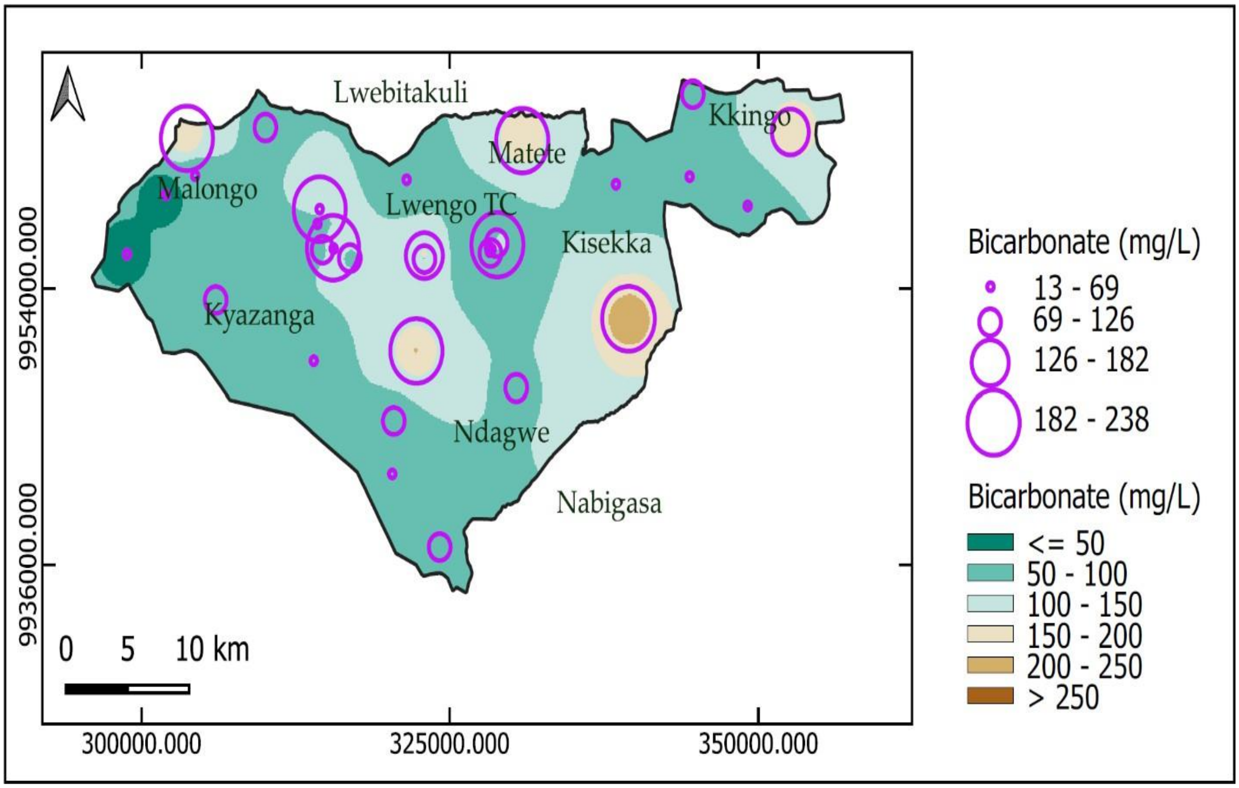

Figure 4.12: Spatial distribution of bicarbonate ions in groundwater within Lwengo District

Bicarbonate (HCO_3^-) distribution (Figure 4.12) shows widespread variability across the district. The highest concentrations (above 150 mg/L) occur in the central and eastern sub-counties, while lower concentrations (< 100 mg/L) are typical of the southwestern parts.

Sulphate (SO_4^{2-}) concentrations (Figure 4.13) range widely from less than 50 mg/L to over 500 mg/L. The highest levels are observed in Kisekka and Lwengo TC, while the lowest occur around Malongo and Kyazanga.

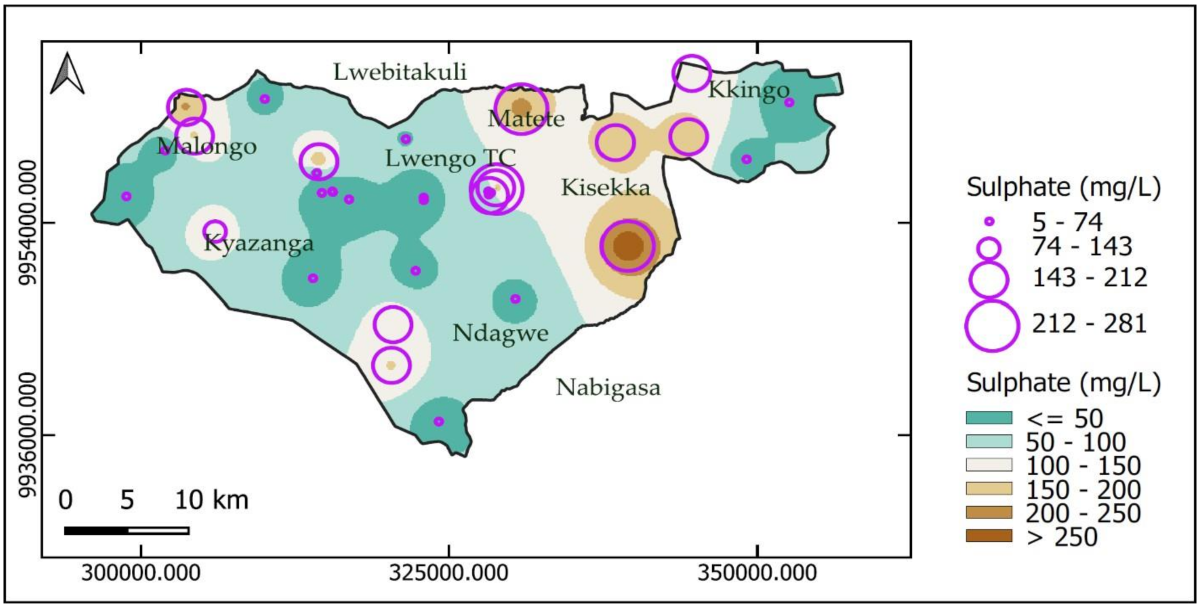

Figure 4.13: Spatial distribution of bicarbonate ions in groundwater within Lwengo District

Fluoride (F^-) occurs at generally low levels throughout the district, with most values below 1.0 mg/L (Figure 4.14). Slightly elevated concentrations (1.0-1.2 mg/L) are localized around central Ndagwe and western Kyazanga, suggesting minor spatial variability.

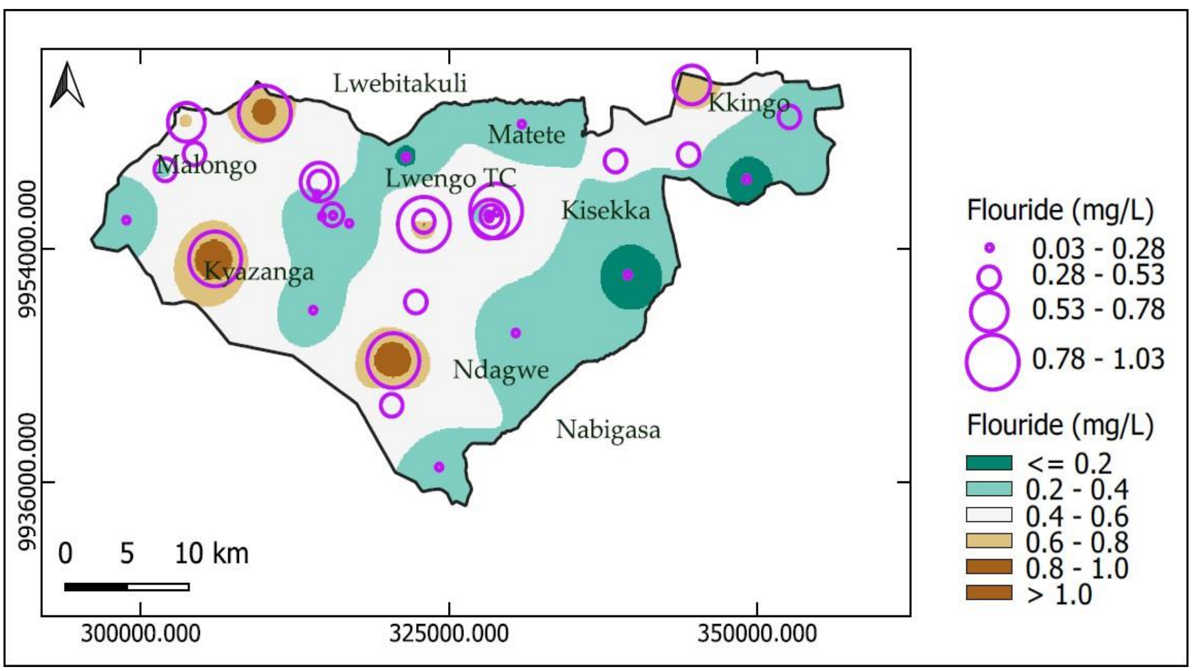

Figure 4.14: Spatial distribution of Fluoride ions in groundwater within Lwengo District

Electrical conductivity (EC) (Figure 4.15A) exhibits a broad range, with the highest readings (>1600 µS/cm) concentrated around Lwengo TC and Matete, while the lowest (<400 µS/cm) occur in Kyazanga and Malongo. The EC distribution corresponds with the general ionic strength of groundwater in these localities.

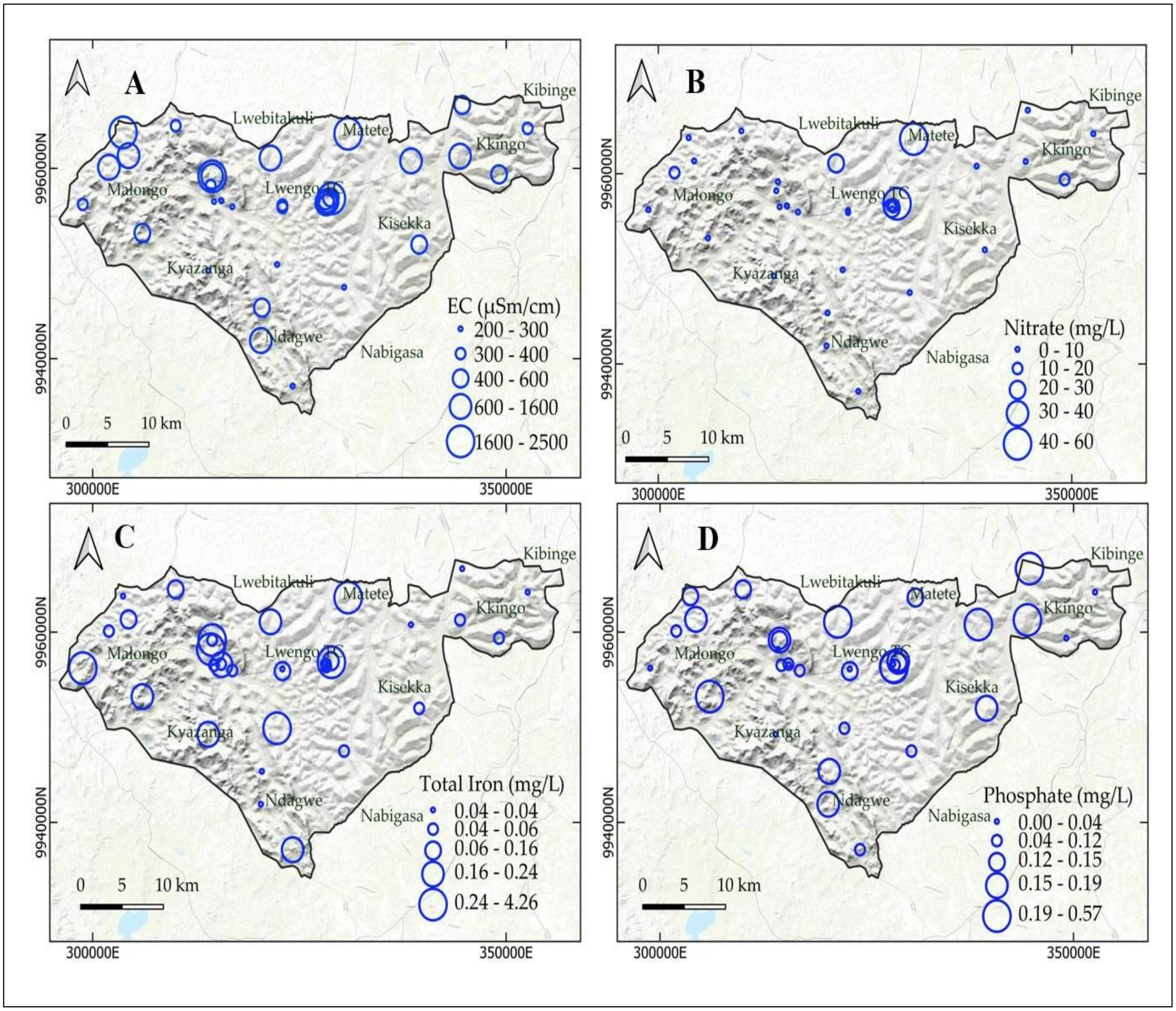

Figure 4.15: Spatial distribution of (A) Electrical Conductivity (EC, µS/cm), (B) Nitrate (mg/L), (C) Total Iron (mg/L), and (D) Phosphate (mg/L) within Lwengo District.

Nitrate (NO_3^-) concentrations (Figure 4.15B) show distinct spatial clustering, with higher values in Lwengo TC and Kkingo, where concentrations exceed 20 mg/L, while the remainder of the district records lower concentrations (< 10 mg/L).

Total Iron (Fe^{2+}) concentrations (Figure 4.15C) show localized high values around Malongo, Kyazanga, and central Lwengo, with concentrations exceeding 1.0 mg/L, while most of the district records values below 0.3 mg/L.

Phosphate (PO_4^{3-}) concentrations (Figure 4.15D) are relatively higher in Lwengo TC, Kisekka, and Kkingo, exceeding 1.5 mg/L, while the western and southern zones generally record low values (< 0.5 mg/L).

4.3.3 Mechanisms Controlling Major Ion Concentrations

The Gibbs diagram (Figure 4.16) illustrates the relationships between total dissolved solids and the ratios of major ions, providing insights into the mechanisms governing groundwater chemistry. The results show that most groundwater samples plot within the rock dominance field, indicating that mineral dissolution and rock-water interaction are the principal processes influencing groundwater composition. No samples plot within the precipitation or evaporation dominance fields, suggesting minimal influence of rainfall dilution or evaporative concentration on the overall chemistry.

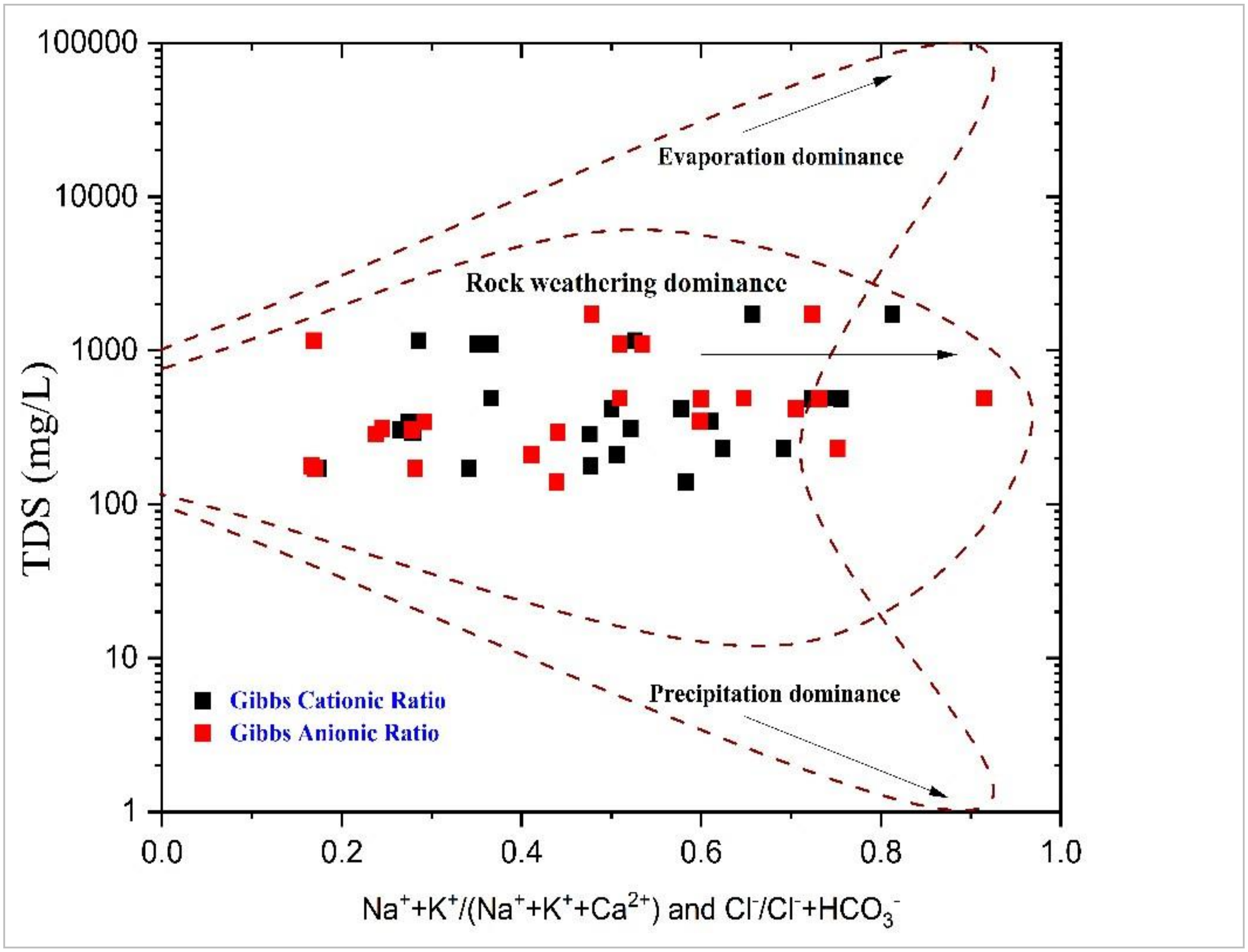

Figure 4.16: Gibbs diagram showing dominant hydrogeochemical processes influencing groundwater chemistry in Lwengo District

4.3.4 Groundwater Facies

Groundwater classification based on the Piper diagram (Figure 4.17) reveals distinct patterns in the distribution of major cations and anions that define the dominant facies within Lwengo District. In the cationic triangular field, most groundwater samples plot toward the calcium (Ca^{2+}) and magnesium (Mg^{2+}) apices, indicating the dominance of alkaline earth metals over alkali elements. A smaller proportion of samples plot closer to the sodium-potassium (Na^+-K^+) corner, showing that only a few groundwater sources contain notable proportions of these ions.

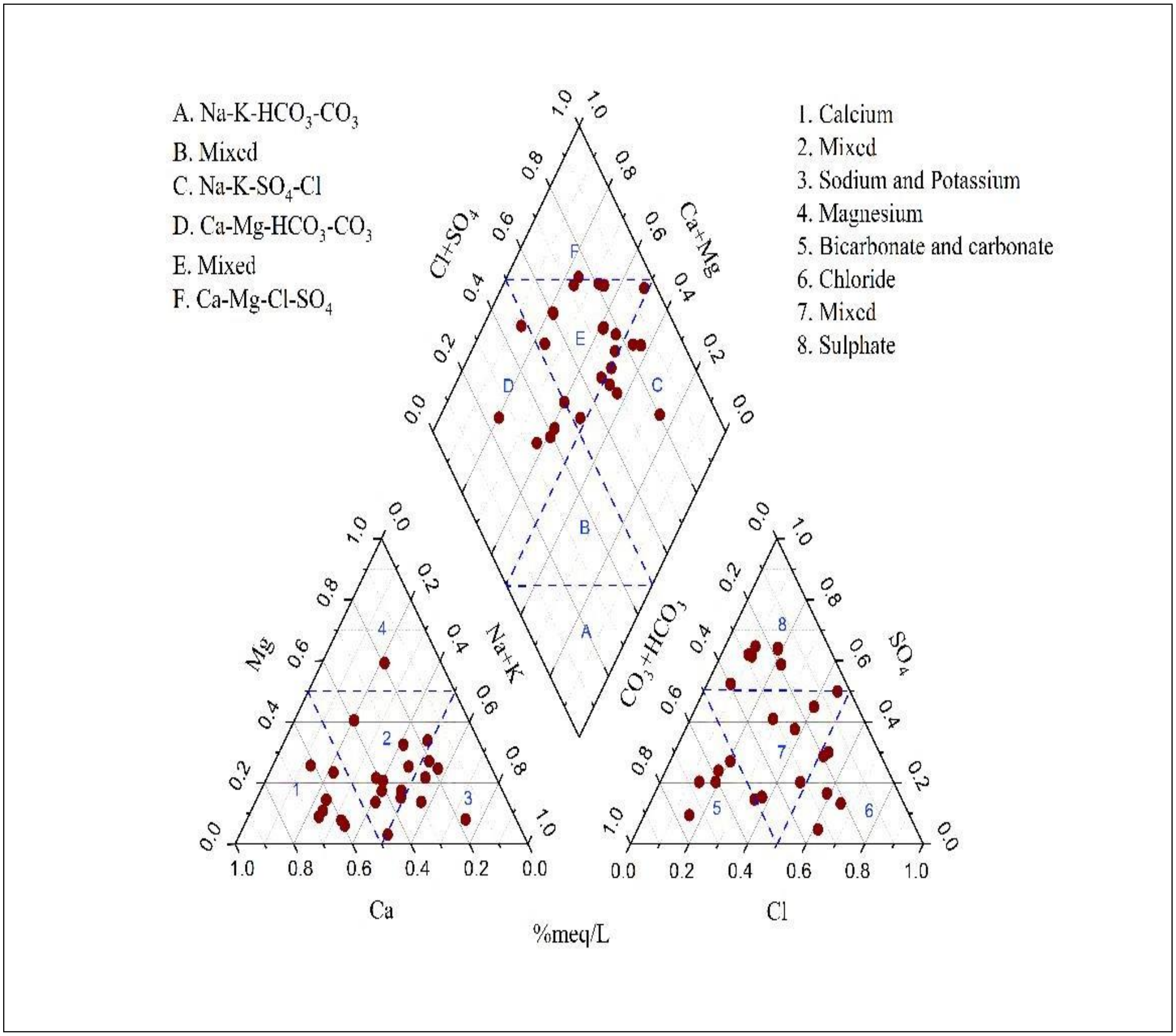

Figure 4.17: Piper diagram showing the groundwater types within Lwengo District

In the anionic triangular field, about 45% of the groundwater samples plot toward the bicarbonate (HCO_3^-) apex, 35% toward the sulphate–chloride (SO_4^{2-}–Cl^-) apices, 15% between the bicarbonate and sulphate corners and only 5% near the chloride end member.

Several groundwater samples (approximately 15%) lie between the bicarbonate and sulphate corners, while only about 5% are distributed near the chloride end member. This distribution indicates that bicarbonate and sulphate are the dominant anions in the groundwater, with chloride occurring in minor proportions.

When projected onto the diamond-shaped central field of the Piper diagram, the groundwater samples cluster mainly within the mixed water type (area E) (60%), Ca-Mg-HCO_3 (16%), and Na-K-SO_4-Cl facies (24%), with no samples plotting in the Ca-Mg-SO_4-Cl and Na-K-HCO_3 fields, respectively. Samples within the mixed field (area E) are characterized by dominant calcium and magnesium cations, combined with higher proportions of sulphate and chloride than bicarbonate anions. The distribution of these facies across the diagram indicates variations in the relative ionic composition of groundwater within the crystalline basement system, reflecting a transition from Ca-Mg-HCO_3 to Ca-Mg-SO_4-Cl and Na-K-SO_4-Cl water types.

CHAPTER 5: DISCUSSIONS

5.1 Hydrogeological Characteristics and Groundwater Flow Dynamics

The hydrogeological configuration of Lwengo District is largely governed by the lithological diversity and structural complexity of its crystalline basement Formations and the overlying younger units (Figure 4.2). The classification of these lithological units into aquitards (lateritic Formations), aquicludes (shales) and aquifuges (granites and gneisses) illustrates the variability in hydraulic properties that define the district's hydrogeological setting. It is, however, important to note that aquitards, aquicludes, and aquifuges can function as aquifers when they are fractured.

Groundwater occurrence is closely linked to the degree of weathering and fracture development within these Formations. The results indicate that productive aquifer horizons occur between 22 and 50 mbgl, with static water levels ranging from 8 to 20 mbgl. This configuration signifies confined to semi-confined aquifer conditions. The weathered zones act as reservoirs, while the underlying fractured bedrock facilitates lateral flow. These findings are consistent with those of Tindimugaya (2007), who noted that groundwater storage in Uganda's basement aquifers occurs mainly within weathered profiles and interconnected fracture systems, and MacDonald et al. (2008), who described similar dual-porosity aquifer structures in Sub-Saharan Africa.

The regional groundwater flow pattern is from the highlands of Lwamaggwa and Ndagwe toward the low-lying areas of Lwengo Town Council and Kyazanga. This west-to-east gradient reflects a topographically driven flow regime typical of weathered basement terrains (Taylor & Howard, 1999). The highland areas serve as recharge zones, facilitated by relatively permeable regolith and open fracture networks, while valley bottoms and wetlands act as discharge areas (Figure 4.2). The presence of these recharge and discharge zones aligns with findings by Owor et al. (2011) in the Lake Victoria Basin, who demonstrated that baseflow to surface systems in Uganda is sustained by localized discharge from fractured basement aquifers.

The cross-sectional profiles confirm lateral and vertical heterogeneity of aquifer materials, where alternating zones of weathered schists, phyllites, and granitic intrusions produce contrasting hydraulic conditions. The observation of reduced yields in quartzitic and phyllitic zones compared to higher yields in weathered granitic and schistose areas closely aligns with findings by Kuria (2013) in Kenya and Kashaigili (2010) in Tanzania, both of whom attributed groundwater productivity in basement terrains to the spatial variability of weathering and fracture intensity. These correlations emphasize that the groundwater system in Lwengo District is structurally controlled and compartmentalized, with water flow localised within discrete fractured zones.

5.2 Analysis of Aquifer Hydraulic Properties

The hydraulic parameters derived from aquifer tests reveal that the groundwater systems of Lwengo District are generally low to moderately productive. The transmissivity values, ranging between 0.3 and 5.5 m^2/day, and hydraulic conductivity values of 0.02-0.20 m/day are within the range commonly reported for crystalline basement aquifers in East Africa. For example, Tindimugaya (2007) reported transmissivity values between 0.1 and 10 m^2/day for central and western Uganda, and Owor et al. (2022) found that weathered crystalline-rock aquifers across Uganda exhibit pervasively low transmissivity, with median values typically below 2 m^2/day, and that increasing borehole depth does not significantly improve yields. The mean transmissivity value of 1.85 m^2/day obtained in this study thus conforms to these regional patterns, reinforcing the general understanding that groundwater productivity in basement rocks is limited by secondary porosity.

Spatial variation in hydraulic properties across the district further underscores the role of structural controls. The Kisekka (DWD17445) borehole, which exhibited the highest transmissivity (5.5 m^2/day) and hydraulic conductivity (0.20 m/day), corresponds to a zone of intense fracturing and weathering. Kkingo (0.3 m^2/day) and Kyazanga (0.5 m^2/day) reflect possible compact, less fractured or weathered lithologies. This pattern of localized transmissivity enhancement along structural discontinuities agrees with the findings of Guma et al. (2019), who noted that in Uganda's basement rocks, transmissivity is often highest in faulted or shear zones.

The storativity values ranging from 2×10^{-5} to 1×10^{-4} and specific storage values between 1×10^{-6} and 5×10^{-6} m^{-1} indicate confined to semi-confined aquifer conditions. These low values are typical of fractured aquifers where storage is predominantly due to elastic expansion of the matrix rather than intergranular porosity (Stober & Bucher, 2007). Such conditions limit the amount of water that can be sustainably withdrawn without significant drawdown, especially during extended pumping periods.

The average aquifer thickness of approximately 22 m, representing the combined depth of weathered and fractured zones, agrees with typical ranges for productive basement aquifers in East Africa, as noted by Kashaigili (2010). The presence of this moderately thick saturated zone supports limited but reliable yields for rural water supply. However, the pronounced variability of hydraulic conductivity and storativity across short distances highlights the heterogeneity of the basement aquifer system, consistent with observations by Hamidu et al. (2014) in Nigeria and Adams (2009) in southern Africa, who emphasized that such aquifers are highly discontinuous and spatially unpredictable. The hydraulic datasets demonstrate that groundwater movement in Lwengo District is predominantly through secondary porosity within the fractured bedrock and saprolite zones. These results reaffirm that successful groundwater abstraction depends on targeting zones of enhanced fracturing and weathering through detailed hydrogeological and geophysical investigations prior to drilling.

5.3 Hydrochemical Characteristics

Groundwater chemistry in Lwengo District reflects both geological control and residence time within the aquifer system. The dominance of Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-}, SO_4^{2-}, and Cl^{-} indicates that mineral weathering, dissolution, and ion exchange are the principal geochemical processes governing water quality. The spatial variation in ionic concentration observed across the district is closely related to the underlying lithological variation and groundwater flow regime.

Higher concentrations of calcium, magnesium, and sulphate recorded in the central and eastern parts of the district (Kisekka, Lwengo TC, and Matete) potentially correspond to areas where prolonged rock-water interaction occurs within fractured metamorphic and granitic units. Lower concentrations in Malongo, Kyazanga, and Ndagwe suggest relatively rapid flow paths and shorter residence times. Similar patterns were reported by Hyeroba et al. (2024) and Owor et al. (2021) in their hydrogeochemical assessments, where increased mineralization was associated with longer residence times and reduced recharge.

The observed electrical conductivity values (200-2460 µS/cm) indicate moderate mineralization and align with results from other crystalline aquifers in Uganda (Owor et al., 2021; Tindimugaya, 2007). The elevated sulphate levels (up to 515 mg/L) in some boreholes may result from the oxidation of pyrite-bearing schists or infiltration from agricultural areas, as documented by Hyeroba et al. (2024). Groundwater hardness, derived from calcium and magnesium concentrations, classifies most water as hard to very hard. While this hardness is not a direct health concern, it may affect domestic water use through scaling and soap inefficiency (Faryadi, 2012). Elevated calcium and sulphate in isolated samples could also contribute to minor aesthetic or health issues such as water taste or laxative effects, as noted by WHO (2017).

5.4 Hydrochemical Facies and Geochemical Processes

The Piper diagram (Figure 4.17) provides a graphical synthesis of groundwater chemistry in the district. In the cationic field, most samples plot near the calcium and magnesium apices, signifying the dominance of divalent cations. In the anionic field, bicarbonate and sulphate predominate, with fewer samples trending toward chloride. When projected into the diamond-shaped field, the samples cluster mainly within the Ca-Mg-HCO_3 and Ca-Mg-SO_4-Cl zones, with a minor grouping in the Na-K-HCO_3 field. This composition indicates mixed water types influenced by rock-water interaction, consistent with crystalline basement groundwater systems described by Hyeroba et al. (2024) and Owor et al. (2021).

The predominance of Ca-Mg-HCO_3 facies suggests recharge by relatively fresh water percolating through weathered rock, whereas the Ca-Mg-SO_4-Cl facies indicates progressive water–rock interaction along flow paths, where sulphate and chloride enrichment occurs. These transitions correspond to the spatial gradient in ion concentration observed in the hydrochemical maps and are comparable to facies evolution patterns reported in East African basement terrains (Zakaria et al., 2021; Karegi, 2020).

5.4.1 Mechanisms Controlling Major Ion Concentrations

The Gibbs plot (Figure 4.16) shows that groundwater samples plot predominantly within the rock dominance field, demonstrating that water chemistry is mainly controlled by mineral weathering rather than atmospheric or evaporative effects. Similar trends have been reported across Sub-Saharan crystalline terrains (Foster, 2012; Gibbs, 1970). To understand the key processes controlling water chemistry, 1:1 trendline plots were used to assess key processes such gypsum, halite and carbonate dissolution. These plots also helped to ascertain the dominant ions for ions summed up within the piper diagram. The Mg^{2+} versus Ca^{2+} bivalent plots (Figure 5.1) indicates that Ca^{2+} is more dominant as compared to Mg^{2+}. This suggests that the weathering processes controlling the concentration of these ions involves Ca-rich rock weathering. The results also suggests that this process does not involve dolomite dissolution as the points plot away from the 1:1 trendline (Hyeroba et al., 2024).

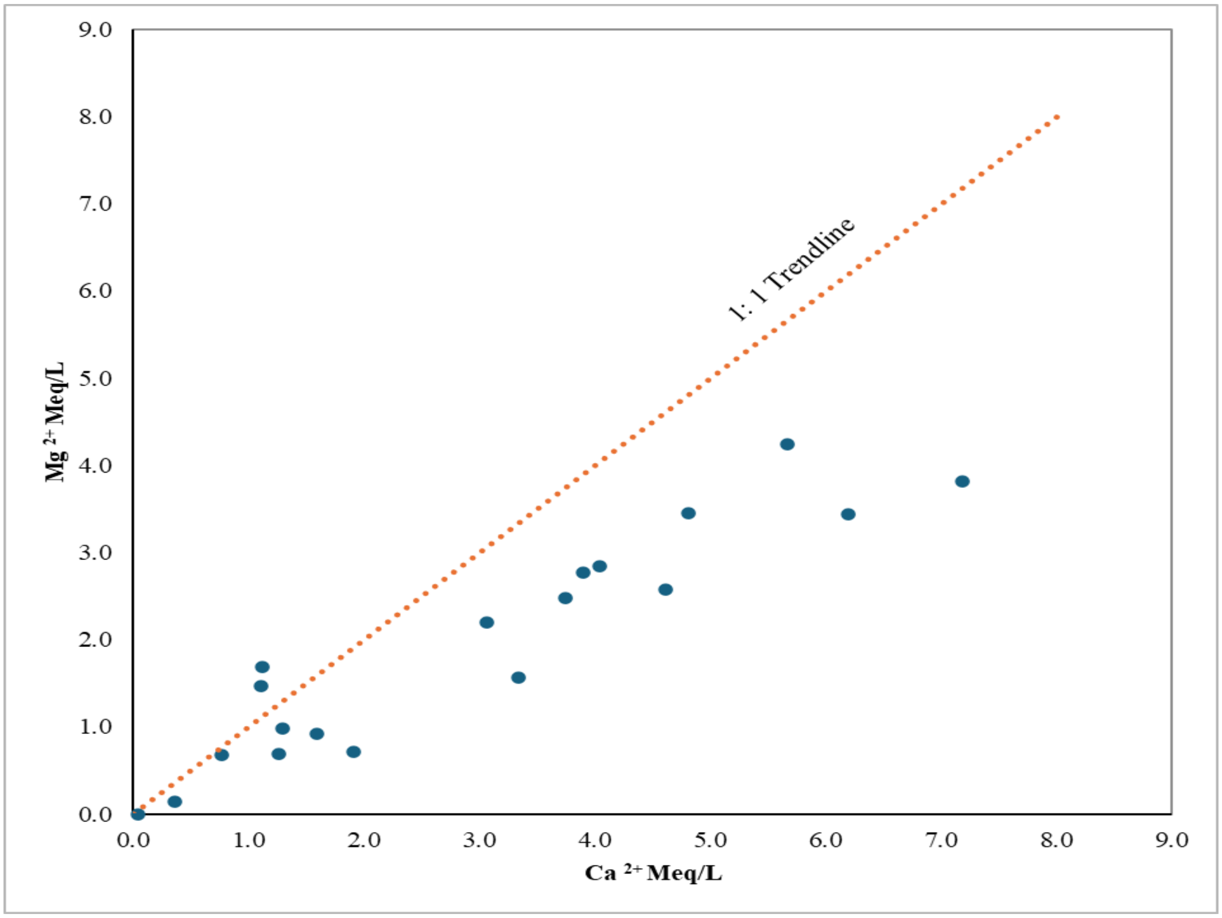

Figure 5.1: Bivariate plot of magnesium (Mg^{2+}) versus calcium (Ca^{2+}) revealing the dominance of these bivalent cations.

The Ca^{2+} versus CO_3^{2-} bivariate plot (Figure 5.2) indicates that calcium carbonate ($CaCO_3$) in the sampled groundwater is not predominantly a result of calcite dissolution, as approximately 80% of the data points deviate from the 1:1 trendline. This deviation suggests that alternative geochemical processes such as ion exchange, weathering of silicate minerals and carbon dioxide dissolution may be influencing the concentrations of calcium and carbonate species in the groundwater.

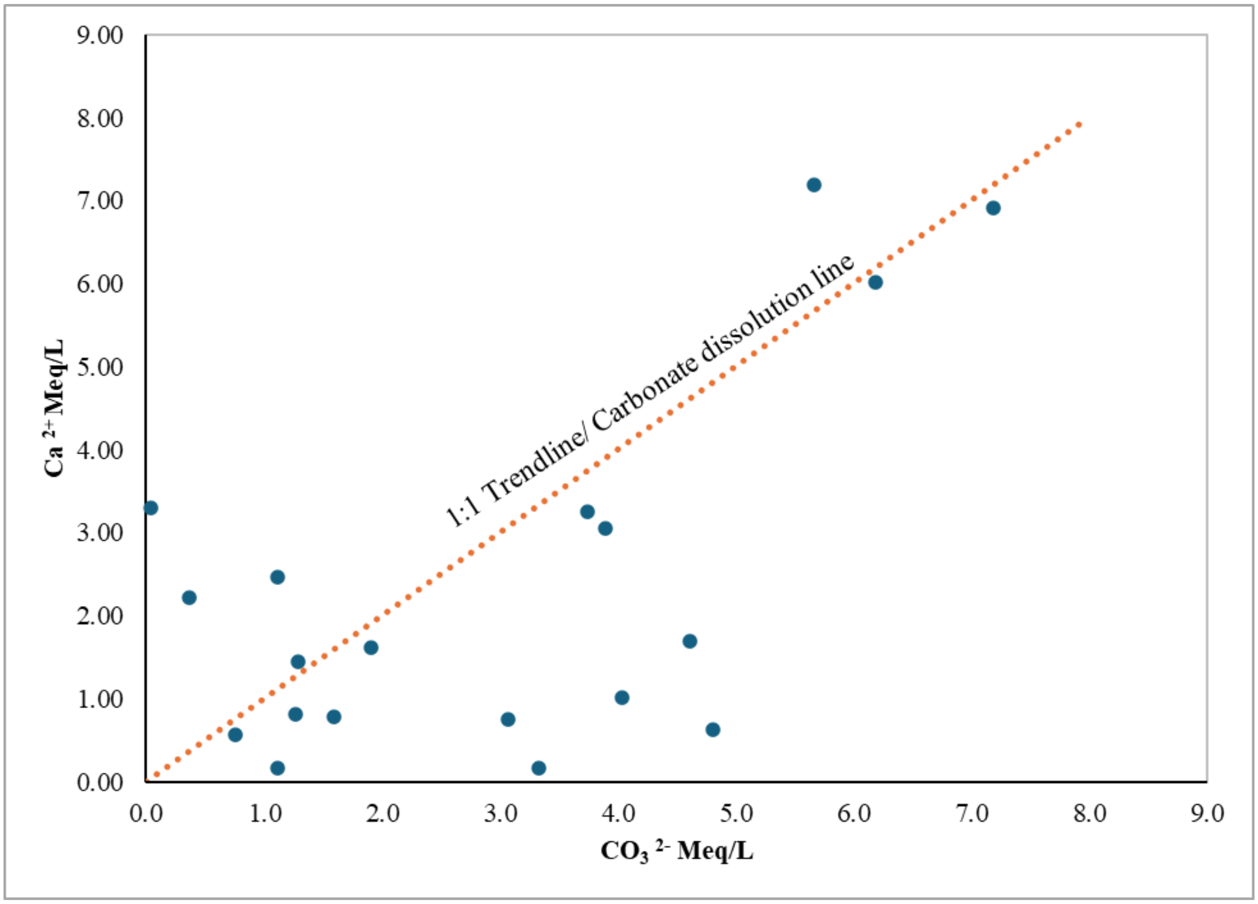

Figure 5.2: Bivariate plot of calcium (Ca^{2+}) versus Carbonate (CO_3^{2-}) revealing the hydrogeochemical process controlling groundwater chemistry

According Owor et al. (2013), calcium in groundwater within the region is potentially derived from the dissolution of calcium-rich silicates (such as plagioclase feldspars), rather than from carbonate minerals alone. Meanwhile, carbonate ions are largely introduced through the dissolution of atmospheric or soil CO_2, forming carbonic acid in water (5.1) which subsequently affects carbonate equilibria.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \qquad (5.1)$$

Carbon dioxide+Water↔Weak Carbonic acid↔Hydrogen ions+Bicarbonate ions

Calcium (Ca^{2+}) versus sulphate (SO_4^{2-}) (Figure 5.3), suggests that calcium sulfate ($CaSO_4$) in the groundwater is not primarily derived from gypsum ($CaSO_4 \cdot 2H_2O$) dissolution, as more than 90% of the samples fall significantly off the 1:1 trendline. This pattern indicates that calcium and sulfate ions occur largely as independent species rather than as coupled products of gypsum weathering.

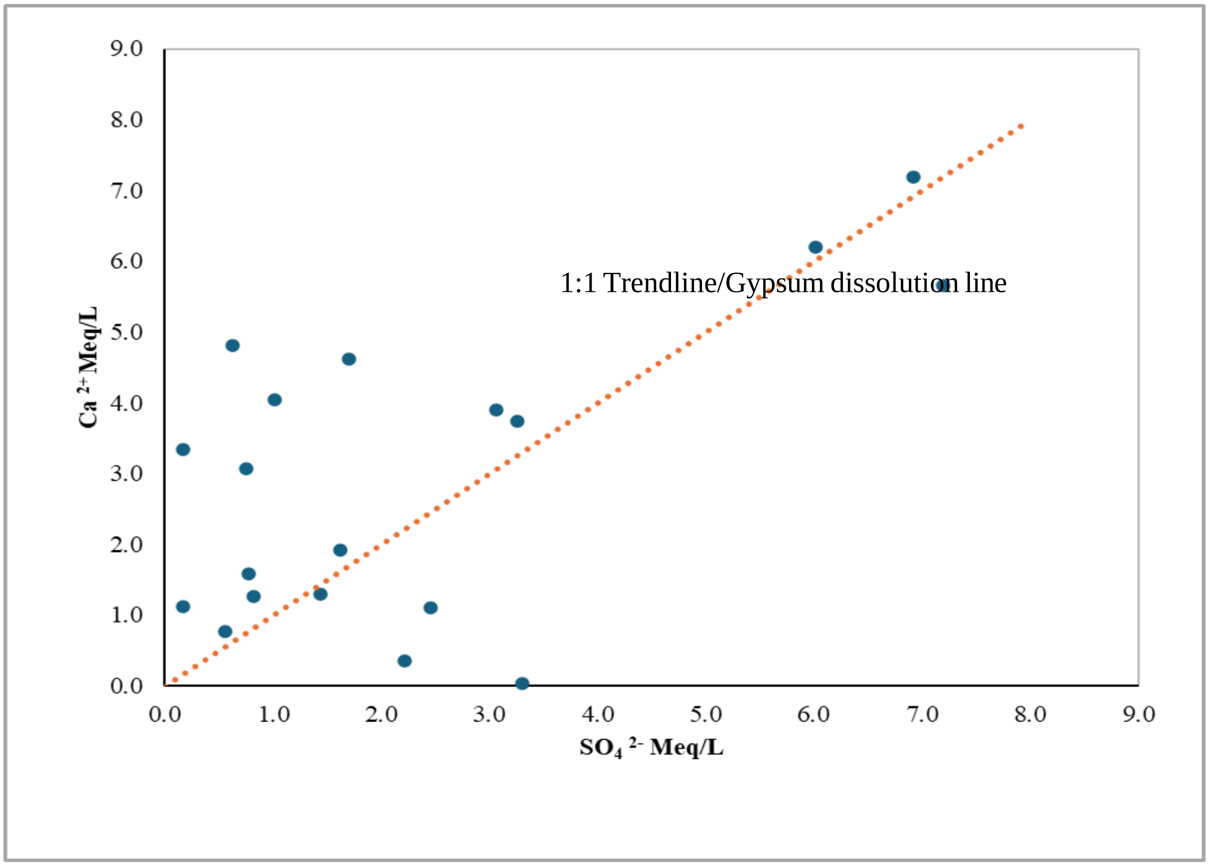

Figure 5.3: Bivariate plot of calcium (Ca^{2+}) versus sulphate (SO_4^{2-}) revealing the hydrogeochemical process controlling groundwater chemistry

According to Owor et al. (2021), the presence of Ca^{2+} in such cases is often attributed to the weathering of calcite-rich feldspars, while SO_4^{2-} concentrations are likely a result of the oxidative dissolution of sulfide minerals (such as pyrite). The respective geochemical reactions below support these interpretations (equations 5.2 and 5.3):

$$CaAl_2Si_2O_8 + 2H^+ + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + Ca^{2+} \quad (5.2)$$

$$Anorthite + Water\ in\ the\ presence\ of\ an\ acid\ (carbonic\ acid) \rightarrow Kaoline + Calcium\ ions$$

$$FeS_2 + \frac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (5.3)$$

The Na^+ versus Cl^- bivariant plot (Figure 5.4) indicates that the presence of NaCl is less due to the dissolution of halite mineral. Previous research within the region conducted by Hyeroba et al. (2024) and Owor et al. (2021) suggest the contribution of anionic exchange to have a control on the Na^+ and Cl^- concentration within regional groundwater.

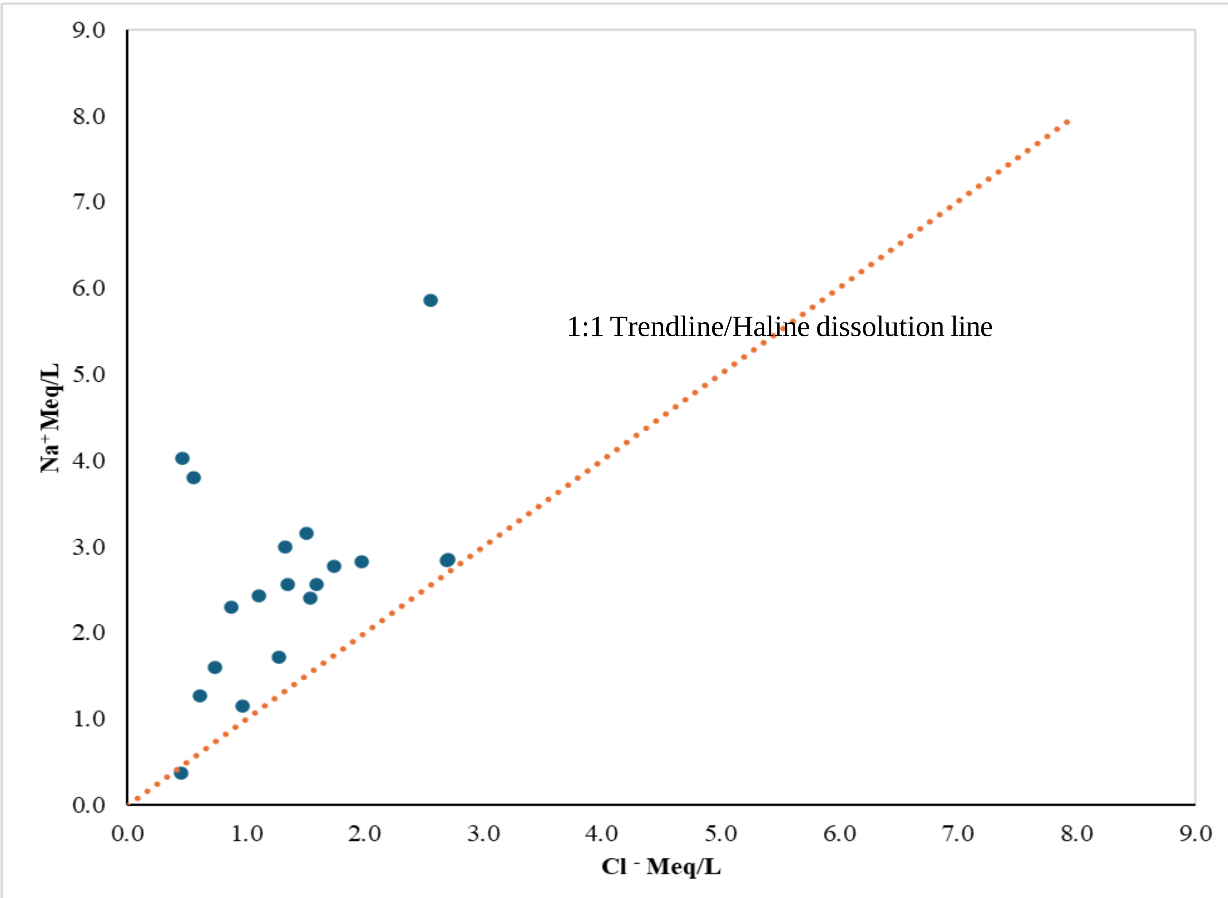

Figure 5.4: Bivariate plot of sodium (Na^+) versus chloride (Cl^-) revealing the hydrogeochemical process controlling groundwater chemistry

HCO_3^- /Na^+ versus Ca^{2+} /Na^+ graphical model (Figure 5.5) indicate that the main process controlling ionic concentration within Lwengo groundwater is mainly silicate weathering of both alkaline and plagioclase felspars. This is in conformity with the findings of the previous scholars such as Owor et al. (2021) who also attributed silicate weathering as the dominant process controlling groundwater chemistry within the region.

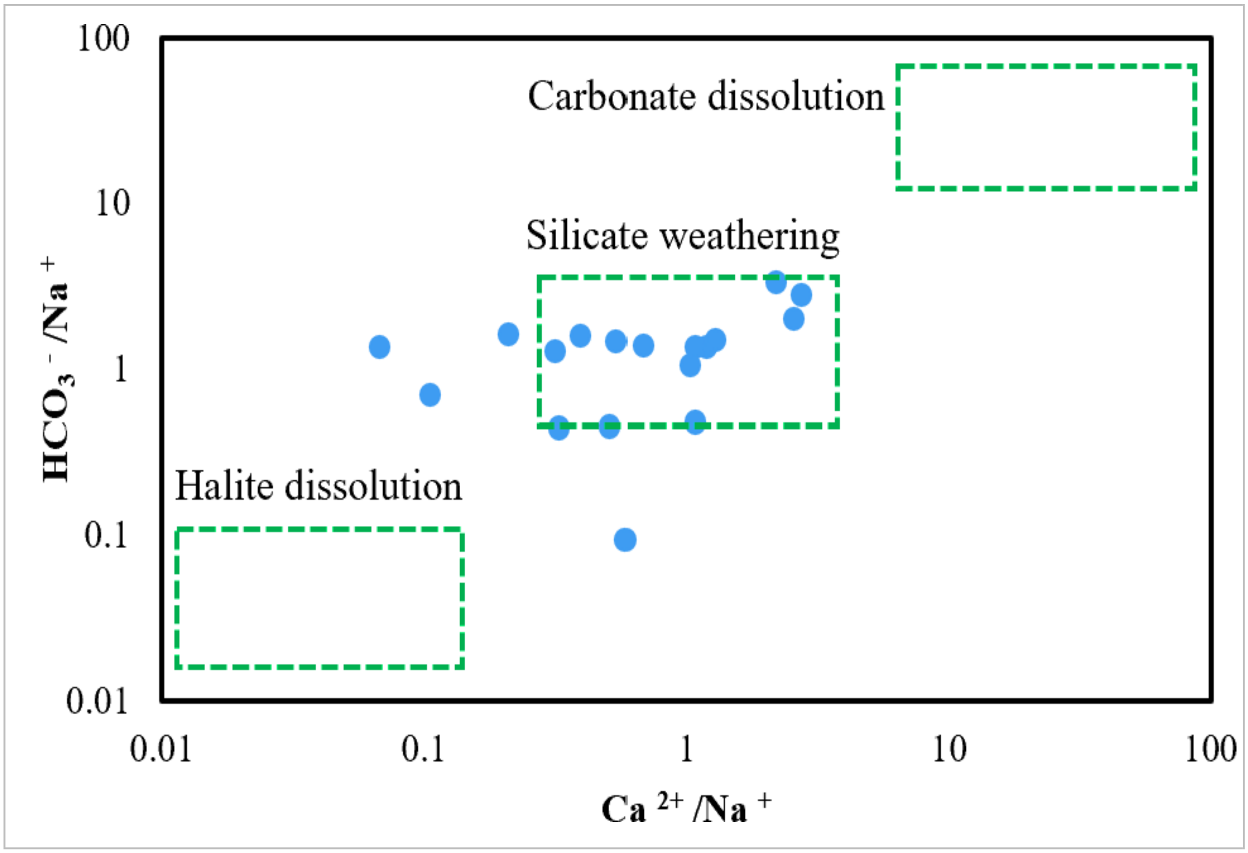

Figure 5.5: HCO_3^-/Na^+ versus chloride Ca^{2+}/Na^+ revealing the hydrogeochemical process controlling groundwater chemistry.

5.5 Anthropogenic Influences on Groundwater Quality

While natural geochemical processes predominate, localized anthropogenic impacts are evident in the distribution of nitrate and phosphate concentrations. Elevated nitrate levels (>20 mg/L) in Lwengo Town Council and Kkingo are indicative of possible contamination from agricultural activities and domestic wastewater infiltration. Similar nutrient enrichment has been documented in rural aquifers of Uganda by Craswell (2021) and Songa et al. (2015), who attributed high nitrate concentrations to fertilizer leaching and poor sanitation management. Elevated phosphate concentrations in Lwengo TC and Kisekka also suggest possible infiltration from agricultural runoff or waste effluents. In contrast, iron enrichment in Malongo and Kyazanga likely reflects the reducing geochemical environment within the weathered aquifers. Although the overall water quality remains suitable for domestic use, these localised enrichments underline the need for continuous groundwater quality monitoring and improved land-use management to prevent further contamination.

5.6 Limitations of the Study

Despite providing valuable insights into the hydrogeological characteristics of Lwengo District, the study has several limitations related to its specific objectives and methods.

i. The number and spatial distribution of boreholes used for aquifer testing may not fully capture the heterogeneity of the weathered basement aquifer system. As a result, localised variations in transmissivity and hydraulic conductivity could be underrepresented.
ii. Most of the aquifer tests were of relatively short duration (24 hours), which may have restricted the accurate characterisation of long-term aquifer responses, storage properties, and boundary effects. This could lead to uncertainty in the derived hydraulic parameters.
iii. The use of standard analytical solutions (for example: Theis or Cooper-Jacob methods) assumes homogeneous and isotropic aquifer conditions, which rarely hold true for fractured or weathered basement systems. These assumptions may have introduced simplifications that affect parameter accuracy.
iv. The study primarily focused on pumping-test datasets and did not incorporate detailed recharge assessments, seasonal variations, or water balance analyses, which are critical for understanding groundwater sustainability.
v. Some datasets, particularly those obtained from existing drilling or pumping records, may have variable quality or incomplete documentation. This may have introduced uncertainty in parameter estimation and comparison with other studies.
vi. The findings are based on point-specific borehole tests and may not fully represent the broader regional hydrogeological context. Extrapolation of results to wider areas should therefore be done cautiously.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objective of this study was to characterize the hydrogeological conditions and assess the groundwater potential of Lwengo District, Central Uganda. To achieve this, the study utilized geological, hydrological and hydrochemical datasets derived from borehole drilling logs, pumping test analyses and water quality records. Analytical solutions of Theis (1935) and Cooper-Jacob (1946) were applied to long-duration pumping test data to estimate aquifer parameters, while geological and topographical inFormation aided in interpreting aquifer structure, recharge mechanisms and groundwater flow systems within the crystalline basement terrain.

The investigation of the geological and hydro-stratigraphic framework established that groundwater occurs within a dual aquifer system comprising a weathered regolith overlying a fractured crystalline basement. The regolith serves as the main groundwater storage zone, while the fractures within the bedrock act as conduits for groundwater transmission. Variations in the thickness of the weathered zone, degree of fracturing and structural alignment were identified as the major controls of groundwater occurrence and yield. Areas with deep weathering profiles and intersecting fracture zones exhibited relatively higher borehole productivity, particularly along valleys and lineaments where recharge is enhanced.

Hydraulic evaluation based on pumping test interpretation revealed transmissivity values ranging from 0.5 to 6.0 m^2/day and hydraulic conductivity between 0.02 and 0.2 m/day, indicating low to moderate aquifer potential typical of crystalline basement systems. Storativity values were generally low varying from 3.0×10^{-5} to 1.0×10^{-4}, suggesting limited groundwater storage capacity. The findings demonstrate that aquifer productivity is spatially variable and primarily dependent on the degree of fracturing and weathering, implying that sustainable abstraction requires site-specific hydrogeological assessment and careful management of pumping regimes.

Hydrochemical analysis showed that groundwater in Lwengo District is generally fresh and suitable for domestic use, with most parameters falling within World Health Organization (2017) standards. The dominant water types are $Ca\text{-}HCO_3$ and $Na\text{-}HCO_3$, reflecting natural water-rock interactions such as silicate weathering and ion exchange. However, localized elevations in nitrate and electrical conductivity suggest anthropogenic influence, particularly from agricultural and domestic sources. The results indicate that groundwater quality remains largely acceptable, though continuous monitoring and protection of recharge zones are essential to maintain its suitability for long-term use.

6.2 Recommendations

Although this study successfully characterized the hydrogeological conditions and groundwater potential of Lwengo District, certain limitations were encountered that provide direction for future work and management interventions. The recommendations presented below are therefore framed in response to these constraints and the major focus areas of the research.

The interpretation of the geological and hydro-stratigraphic framework was based mainly on existing borehole logs and secondary geological data, which limited the spatial resolution of subsurface characterization. It is therefore recommended that future studies incorporate geophysical surveys and additional exploratory drilling to improve understanding of the lateral continuity of aquifer zones, fracture density and weathering depth variations. Such data would refine the conceptual model of groundwater occurrence and enhance accuracy in borehole siting and design.

The hydraulic assessment was limited by the number of available long-duration pumping test datasets, which restricted the representation of aquifer heterogeneity across the district. To address this, more systematic and standardized aquifer testing should be undertaken across different hydrogeological units. This will allow for better quantification of transmissivity and storativity variations and provide a stronger basis for sustainable yield estimation and groundwater resource planning.

In evaluating groundwater quality, the study relied on existing hydrochemical data, which covered a limited temporal and spatial range. Regular and comprehensive water quality monitoring is therefore recommended to capture seasonal variations and detect emerging contamination trends. Priority should be given to parameters such as nitrates and electrical conductivity, which showed localized elevations. Additionally, protection of recharge zones and regulation of agricultural and sanitation practices are essential to safeguard groundwater quality for domestic use.

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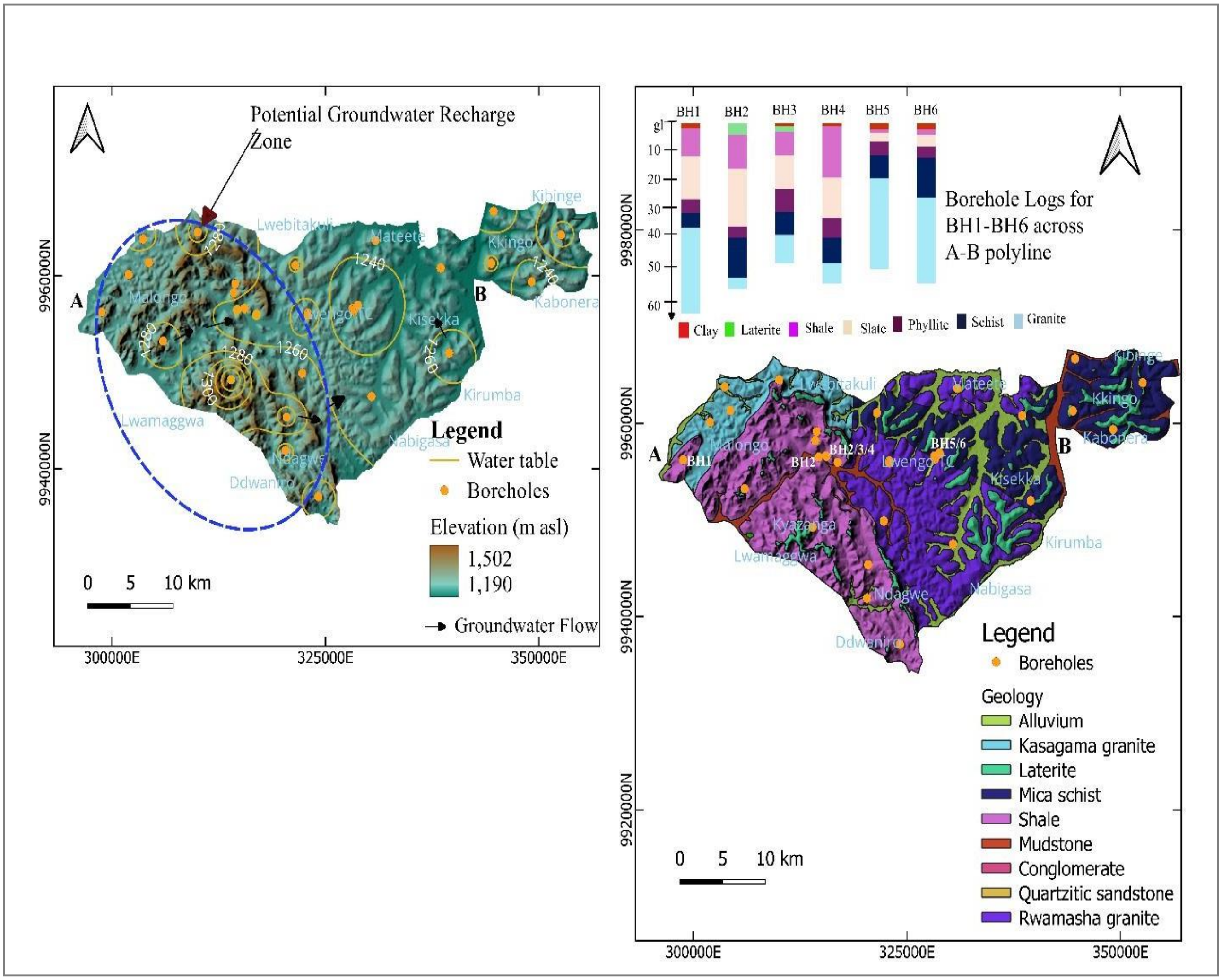
APPENDIX

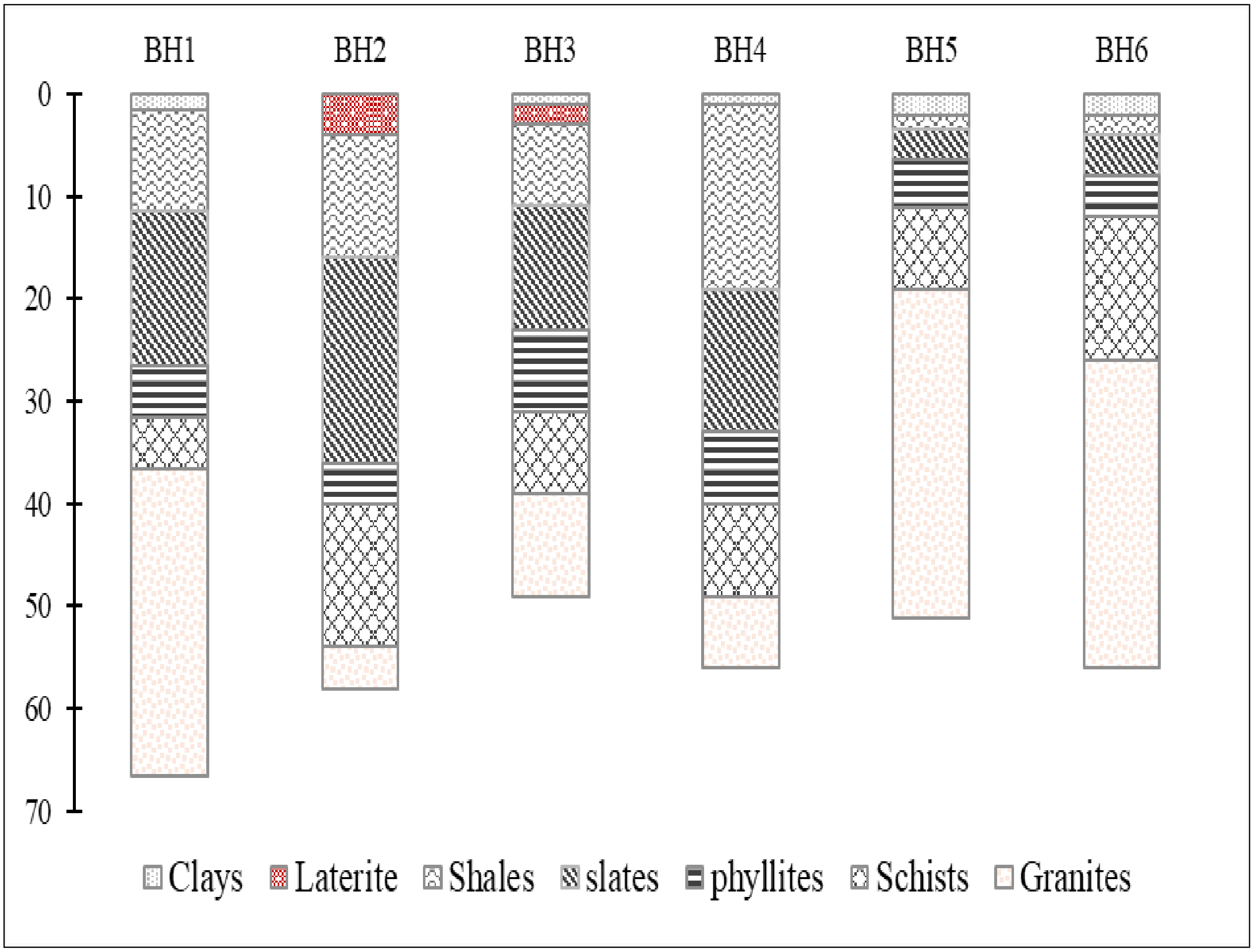
Appendix 1: Charge Balance Error

Sample ID	Ca meq/L	K meq/L	Mg meq/L	Na meq/L	SUM CATION meq/L	Cl meq/L	HCO3 meq/L	SO4 meq/L	SUM ANION meq/L	CBE %
E50726	3.7	0.25	2.477	2.8	9.24	1.74	3.26	4.13	9.13	0.641
E50727	0.8	0.08	0.675	1.7	3.23	1.28	0.56	1.11	2.95	4.46
E50728	6.2	0.39	3.443	5.9	15.88	2.56	6.02	8.96	17.54	-4.98
E50729	7.2	0.37	3.818	2.6	13.93	1.6	6.92	5.93	14.45	-1.81
E50730	0.4	0.12	0.142	3.8	4.43	0.56	2.22	1.66	4.44	-0.12
E50731	3.1	0.08	2.197	2.4	7.74	1.54	0.75	5.56	7.85	-0.73
E50732	0	0.07	0.002	4	4.13	0.46	3.3	0.66	4.42	-3.39
E50733	4	0.15	2.846	2.6	9.6	1.35	1.01	8.17	10.53	-4.63
E50734	5.7	0.22	4.242	2.8	12.95	1.98	7.2	5.41	14.59	-5.96
E50735	4.6	0.28	2.579	3.2	10.63	1.51	1.7	7.85	11.05	-1.97
E50736	1.1	0.1	1.682	1.6	4.5	0.74	0.17	3.37	4.28	2.48
E50737	1.3	0.11	0.986	2.8	5.22	2.69	1.44	0.62	4.75	4.67
E50738	3.3	0.13	1.569	2.4	7.46	1.11	0.16	5.58	6.85	4.28
E50739	1.3	0.13	0.689	0.4	2.46	0.45	0.82	1.1	2.37	1.71
E50740	1.6	0.1	0.921	1.2	3.77	0.97	0.78	1.92	3.67	1.27
E50741	4.8	0.1	3.454	3	11.36	1.33	0.62	10.73	12.69	-5.56
E50742	1.1	0.17	1.465	2.3	5.04	0.87	2.46	2.06	5.39	-3.4
E23/01826	3.9	0.26	2.775	2.8	9.78	2.71	3.06	4.87	10.64	-4.23
E23/01827	1.9	0.09	0.712	1.3	3.98	0.61	1.62	1.26	3.49	6.51

Appendix 2: Delineated hydrogeological Formations with Lwengo District



Appendix 3: Borehole logs for Borehole 1-6 (presented on the geological map in appendix 2)



Appendix 4: Summary of the borehole datasets

District	Lwengo
Total No. of boreholes	165
B/H with locations	137
B/H without locations/ coordinates	137
Total drilled depth	165
Casing length	178
Depth 2 bedrock	141
Lithology	137
Total estimated yield	63
Depth to 1st WS	145
Static water level	61
Constant discharge	41
Steps 1,2,3,4	33
Duration	28

Appendix 5: Raw borehole datasets

DISTRICT	COUNTY	SUBCOUNTY	PARISH	VILLAGE	SOURCENAME	SOURCEID	UTME	UTMNS
LWENGO	BUKOTO			NKYUUSA		DWD10713		
LWENGO	BUKOTO	KISEKKA	NAKATETE	KYAMAGANDA	KYAMAGANDA	CD 3005	337087	9958822
LWENGO	BUKOTO	KISEKKA	KINONI	KINONI	KINONI HEALTH CENTRE	DWD10707		
LWENGO	BUKOTO	KISEKKA	KINONI	KINONI . COMMUNITY CENTRE		DWD10708		
LWENGO	BUKOTO	KISEKKA	KINONI	KINONI	KINONI T.C II	DWD10709		
LWENGO	BUKOTO	KISEKKA	KIWANGALA	KIWANGALA T.C	KIWANGALA T.C	DWD10710		
LWENGO	BUKOTO	KISEKKA	KINONI	KATAALI - KYANGWE	KATAALI - KYANGWE	DWD10714	334882	9947792
LWENGO	BUKOTO	KISEKKA	KIWANGALA	KANKU	KANKU	DWD10715	332580	9948649
LWENGO	BUKOTO	KISEKKA	KINONI	KYANGWE	KITALI-KYANGWE	DWD10715A		
LWENGO	BUKOTO	KISEKKA	KIWANGALA	KANKU		DWD11721	332065	9948649
LWENGO	BUKOTO	KISEKKA	KIWANGALA	KIWANGALA T.C II		DWD11723	335029	9947706
LWENGO	BUKOTO	KISEKKA	BUSUBI	BUSUBI		DWD11727	339057	9956530
LWENGO	BUKOTO	KISEKKA	BUSUBI	BUSUBI II		DWD11729	338735	9955208
LWENGO	BUKOTO	KISEKKA	KINONI	KABOYO	KABOYO	WDD3090	340386	9961018
LWENGO	BUKOTO	KISEKKA	KINONI	KABOYO	KABOYO PRIMARY SCH.	WDD3091	340853	9961227
LWENGO	BUKOTO	KISEKKA	KINONI	KASAMBYA	KASAMBYA	WDD3093	338311	9962156
LWENGO	BUKOTO	KISEKKA	NAKATETE		KYAMAGANDA	WDD4708	337424	9958044
LWENGO	BUKOTO	KISEKKA	KINONI	KINONI	KINONI T.C	WDD8582		
LWENGO	BUKOTO	KISEKKA	KINONI	KINONI	KINONI TOWN	WDD8583	339075	9963250
LWENGO	BUKOTO	KISEKKA	BUSUBI	SEKA MAIN	SEKA MAIN	WDD8584	338917	9960375
LWENGO	BUKOTO	KISEKKA		KYAMAGANDA	KYAMAGANDA	WDD8585	340132	9956772
LWENGO	BUKOTO	KISEKKA	KINONI	KYANGUSE	KYANGUSE	WDD8586	336557	9961776
LWENGO	BUKOTO	KISEKKA	NAKATETE	DEGEYA		WDD8587	334502	9958639
LWENGO	BUKOTO	KISEKKA	NAKATETE	DEGEYA	DEGEYA	WDD8590	334300	9959078
LWENGO	BUKOTO	KISEKKA	NAKATETE	KILYANGOMA	KILYANGOMA	WDD8608		
LWENGO	BUKOTO	KISEKKA	NAKATETE	BUSHWAGA	KILYANGOMA	WDD8609		
LWENGO	BUKOTO	KISEKKA	NAKATETE	DEGEYA	DEGEYA	WDD8610	335548	9957796
LWENGO	BUKOTO	KISEKKA	KYMAGANDA	KYAMAGANDA P/s	KYAMAGANDA	WDD8911	337250	9958489
LWENGO	BUKOTO	KISEKKA		KABOYO	KABOYO	WDD8932	340386	9961018
LWENGO	BUKOTO	KISEKKA	KINONI	NKONI 'B'	NKONI 'B'	WDD8935		
LWENGO	BUKOTO	KISEKKA	KINONI	KINONI	KINONI	WDD8939		
LWENGO	BUKOTO	KISEKKA	KIWANGALA	MIGONOG	BIGONGO	WDD9390	332299	9950380
LWENGO	BUKOTO	KISEKKA	KANKAMBA	BUKOTO	BUKUMBULA	WDD9391	332545	9950930

LWENGO	BUKOTO	KISEKKA		KANKAMBA	KANKAMBA	WDD9392	335118	9951566
LWENGO	BUKOTO	KISEKKA	KIWANGALA	KYAMUKUNZI	KYANUKUZI	WDD9393	336695	9947662
LWENGO	BUKOTO	KISEKKA		NGEREKO	NGEREKO	WDD9394	338341	9948793
LWENGO	BUKOTO	KISEKKA	KIWANGALA	KATOOKE	KATOOKE	WDD9448	333717	9945869
LWENGO	BUKOTO	KKINGO	SSENYA	KASOOKA	KASOOKA	DWD32416		
LWENGO	BUKOTO	KKINGO	SSENYA	KASOOKA	KASOOKA	DWD32417		
LWENGO	BUKOTO	KKINGO	KIGANDA	KYOOKO	KYOOKO	WDD8933	344394	9961286
LWENGO	BUKOTO	KKINGO		NKONU	NGONU 'B'	WDD8934	349685	9962800
LWENGO	BUKOTO	KKINGO		KOSOSO	KISOSO	WDD8936		
LWENGO	BUKOTO	KKINGO		NKONI 'A'	NKONI 'A'	WDD8937	349987	9962151
LWENGO	BUKOTO	KKINGO	SSENYA	KITAMBUZA	KITAMBUZA	WDD8938	352814	9961016
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	LUYEMBE	LUYEMBE 1	DWD16581		
LWENGO	BUKOTO	KYAZANGA	KITOORO	BUKYANAGANDI		DWD16583	312345	9957765
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	NAKETEETE	NAKATETE	DWD16584	314380	9959281
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	KISANA	KISANA	WDD8281	310734	9953127
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	KASAMBYA	KASAMBYA	WDD8282	314658	9953598
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	NAKATEETE	NAKATEETE	WDD8285	315160	9958260
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	KIRUNDA	KIRUMBA	WDD8286	317073	9956325
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	LWEERA	LWEERA	WDD8287	314278	9960912
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	KYAKANYANYA	KYAKANYANYA	WDD8288	313341	9961727
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	KENGWE + KITEREDDE	KENGWE + KITEREDDWE	WDD8289	313510	9963559
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	MPUMUDDE	MPUMUDE	WDD8591	315998	9956866
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	NAGANGABO	NAGANGABO	WDD8593		
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	KITAWULUZI	KITAWULUZI	WDD8594	312631	9953715
LWENGO	BUKOTO	KYAZANGA	KITOORO	KITOORO	GOMBOLOLA HQTS	wdd8612	313005	9957795
LWENGO	BUKOTO	KYAZANGA	KITOORO	NAKATEETE	NAKATEETE SSS & P7	wdd8613	313420	9957708
LWENGO	BUKOTO	KYAZANGA	KITOORO	KITOORO J	KITOORO J	wdd8614	312669	9957383
LWENGO	BUKOTO	KYAZANGA	KITOORO	KITOORO B/A	KITOORO B/A	wdd8615	312340	9957778
LWENGO	BUKOTO	KYAZANGA	KITOORO	KITOORO L	KITOORO L	wdd8616	311746	9956601
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	LUYEMBE	LUYEMBE	wdd8617	313761	9956261
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	KAMITI	KAMITI	WDD8618	312450	9955283
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	LUYEMBE	LUYEMBE	WDD8619	313856	9954271
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	BIJJABA	BIJAABA	WDD8620	313505	9951195
LWENGO	BUKOTO	KYAZANGA	KATUULO	KALYAMEMVU	KALYAMEMVU	WDD8621	310161	9952666
LWENGO	BUKOTO	KYAZANGA	KATUULO	LWENSAMBYA	LWENSAMBYA	wdd8622	311196	9950646

LWENGO	BUKOTO	KYAZANGA	KATUULO	BUSIBO	BUSIBO T/C	WDD8623	309517	9949209
LWENGO	BUKOTO	KYAZANGA	KATUULO	KATUULO	KATULO	WDD8624	307383	9948617
LWENGO	BUKOTO	KYAZANGA	KATUULO	LWEMPAZI	LWEMPAZI	WDD8625	307729	9951315
LWENGO	BUKOTO	KYAZANGA	KITOORO	MOSQUE ZONE	MOSQUE ZONE	WDD8627	313368	9957385
LWENGO	BUKOTO	KYAZANGA	LYAKIBIRIZI	KYAZANGA PRISON + KANYOGOGA	KYAZANGA PRISON	WDD8628	315092	9956861
LWENGO	BUKOTO	KYAZANGA	KAKOMA	BIJAABA T/C	BIJAABA T/C	WDD8629	316699	9947675
LWENGO	BUKOTO	KYAZANGA	KAKOMA	KASAMBYA	KASAMBYA	WDD8630	317555	9949709
LWENGO	BUKOTO	KYAZANGA	KAKOMA	Kanoni	KANONI	WDD9436	319451	9949298
LWENGO	BUKOTO	KYAZANGA	KAKOMA	KYAMPENGERE/NKUNDWA	KYAMPENGERE	WDD9438	314203	9946306
LWENGO	BUKOTO	KYAZANGA	KAKOMA	LWAMONGWA	LWAMONGWA	WDD9439	315643	9945261
LWENGO	BUKOTO	KYAZANGA	BIJJAABA	KATOSI	KATOSI	WDD9440	313083	9947715
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KYAWAGONYA	KYAWAGONYA	CD 2731		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	MBIRIZI		CD 3650	328729	9957235
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	LWENGO	LWENGO	CD 64		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	BIJUGO	BIJUGO	DWD25317		
LWENGO	BUKOTO	LWENGO	KITO	KATOMA RWAYEBERE	KATOMA RWAYEBERE	DWD25318		
LWENGO	BUKOTO	LWENGO	KITO	KATOMA RWAYEBERE	RWAYEBERE	DWD25518B		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	BIJUGO	BIJUGO	DWD25577		
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	HOPE ACADEMY	HOPE ACADEMY	DWD29742		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	MBIRIZI	MBIRIZI	WDD2300		
LWENGO	BUKOTO	LWENGO	MAKONDO *		KYAZANGA	WDD2931		
LWENGO	BUKOTO	LWENGO	MAKONDO *		KYAZANGA TOWNSHIP	WDD2933		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	NAKATEETE	NAKATEETE	WDD2934		
LWENGO	BUKOTO	LWENGO	MAKONDO *		KYAZANGA	WDD2935		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	MBIRIZI	MBIRIZI TRADING CENTRE	WDD3094	328567	9956938
LWENGO	BUKOTO	LWENGO	MUSUBIRO	KYALUTWAKA	KYALUTWAKA	WDD3095	326465	9962531
LWENGO	BUKOTO	LWENGO	MAKONDO *		KYAZANGA "A"	WDD3342		
LWENGO	BUKOTO	LWENGO	MAKONDO *		KYAZANGA	WDD3345	313433	9957250
LWENGO	BUKOTO	LWENGO	MAKONDO *	MAKONDO	MAKONDO HEALTH CENTR	WDD3348		
LWENGO	BUKOTO	LWENGO	MAKONDO *		KYAZANGA	WDD3569		
LWENGO	BUKOTO	LWENGO	MAKONDO *	KYAZANGA	RIO HOLDING I	WDD5830		
LWENGO	BUKOTO	LWENGO	MAKONDO *	KYAZANGA	RIO HOLDING II	WDD5913		
LWENG	BUKOTO	LWENGO		KALISIZO	KALISIZO	WDD8265	32245	995851

O							6	4
LWENGO	BUKOTO	LWENGO		BUGENZI	BUGENZI	WDD8266		
LWENGO	BUKOTO	LWENGO		KALANGALA	KALANGALA	WDD8269	322134	9961041
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KAJJALUBANDA		WDD8270		
LWENGO	BUKOTO	LWENGO	MUSUBIRO	MAYIRA	MAIRA	WDD8579	329941	9964021
LWENGO	BUKOTO	LWENGO	MUSUBIRO	KANYOGOGA	KANYOGOGA	WDD8580	328306	9960771
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KYETUME	KYETUME T/C	WDD8595		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	NYENJE	NYENJE	WDD8596	328352	9954721
LWENGO	BUKOTO	LWENGO	NAKYENYI	NAKYENYI	NAKYENYI T/C	WDD8597	332183	9954288
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KYAWAGONYA	KYABAGONYA	WDD8598	323860	9954918
LWENGO	BUKOTO	LWENGO	KITO	LUTTI	LUTTI P/S	WDD8599	325553	9948633
LWENGO	BUKOTO	LWENGO	KITO	KYASENYA	KYASENYA	WDD8600	322137	9949882
LWENGO	BUKOTO	LWENGO	KITO	KIBONA	KIBONA	WDD8601	327385	9948237
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	KIRYANKUYEGE	KILYANKUYEGE	WDD8602		
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	LWETAMO	LWETAMO P/S	WDD8603	321407	9952908
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KALISIZO	KAMUTUZA	WDD8604	324613	9956567
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	LWETAMU B	LWETAMU	WDD8605	321344	9952033
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	LWETAMO A	LWETAMU	WDD8606	321826	9953251
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KINVUNIKIDDE	KYEVUNYIKIDDE	WDD8607		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	MBIRIZI	MBIRIZI TC	WDD8900	328355	9956723
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	KABALUNGI	KABALUNGI	WDD8901	330168	9957541
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	NAMULABA	NAMULABA	WDD8902	328800	9958710
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	MBIRIZI	MBIRIZI VILLAGE	WDD8903	328726	9957267
LWENGO	BUKOTO	LWENGO	MUSUBIRO	MUWANGI	MUWANGI	WDD8904		
LWENGO	BUKOTO	LWENGO		NKUNGU	NKUNGU	WDD8905	330640	9961141
LWENGO	BUKOTO	LWENGO		MAYIRA	MAYIRA	WDD8907	329922	9963006
LWENGO	BUKOTO	LWENGO	KITO	BUSWAGA	BUSWAGA	WDD8931		
LWENGO	BUKOTO	LWENGO		NKUNGU	NKUNGU	WDD8940	321449	9961172
LWENGO	BUKOTO	LWENGO	NAKYENYI	MINYEGENYA	MIYEGENYA	WDD9376		
LWENGO	BUKOTO	LWENGO	MBIRIZI +MBIRIZI TC	MBIRIZI	MBIRIZI	WDD9378	328729	9957235
LWENGO	BUKOTO	LWENGO	NAKYENYI	LWENSINGA		WDD9387		
LWENGO	BUKOTO	LWENGO	KITO	BULAGAMA (BULASANA)		WDD9388		
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KAJJALUBANDA		WDD9441		
LWENGO	BUKOTO	LWENGO	KYAWAGONYA	KALAGALA	BWANGANYONDO	WDD9442		
LWENGO	BUKOTO	MALONGO	MALONGO	MALONGO	MALONGO	CD 2721	307705	9957530

LWENG O	BUKOTO	MALONGO	MALONGO	LWENTALE	LWENTALE	DWD1658 2		
LWENG O	BUKOTO	MALONGO	KATOVU	KATONGOLE	KATONGOLE	DWD1744 5	30519 0	995811 5
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	LAKWELA/KALA MAJI	DWD3399 8	30219 9	995734 7
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	KATOVU	GS876	30517 1	995820 1
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	KATOVU	WDD2936		
LWENG O	BUKOTO	MALONGO	BIJAABA *	KAKUUTO	KAKUUTO	WDD3341		
LWENG O	BUKOTO	MALONGO	KATOVU	KALAGALA	KALAGALA	WDD8251	30148 7	995515 9
LWENG O	BUKOTO	MALONGO	BIJAABA *	LWENSAMBYA	LWENSAMBYA	WDD8252	35234 1	995334 4
LWENG O	BUKOTO	MALONGO	MALONGO	KIBUBU	KIBUBU	WDD8253	30019 9	995346 5
LWENG O	BUKOTO	MALONGO	KATOVU	LWAMANYA	RWAMAYA	WDD8254	30515 7	995537 3
LWENG O	BUKOTO	MALONGO	MALONGO	NKUKUTE/ LWENTALE	NKUKUTE	WDD8255	30619 5	995333 9
LWENG O	BUKOTO	MALONGO	MALONGO	LWENTALE	LWENTALE P/S	WDD8256		
LWENG O	BUKOTO	MALONGO	KIGEYI	KIGEYI +NYAKALAGU	KIGEYI +NYAKALAGU	WDD8257		
LWENG O	BUKOTO	MALONGO	KIGEYE	RWEEGBUSIS	RWOBUSIS	WDD8262	31052 1	995876 8
LWENG O	BUKOTO	MALONGO	KATOVU	KYAMATAFALI	KYAMATAFALI	WDD8263	30366 0	996372 7
LWENG O	BUKOTO	MALONGO	MALONGO	KAKOMA	KAKOMA	WDD8264	30603 6	995845 2
LWENG O	BUKOTO	MALONGO			KASAANA 'A'	WDD8557	29784 1	995561 2
LWENG O	BUKOTO	MALONGO	KATOVU	KASAMBYA	KASAMBYA	wdd8558	29863 5	995781 9
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	KATOVU	wdd8559		
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	KATOVU SCHQ	wdd8560	30577 4	995907 6
LWENG O	BUKOTO	MALONGO	KATOVU	NTURA	NTURA	WDD8561	30557 1	995930 6
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	KATOVU	WDD8562	30330 4	995767 4
LWENG O	BUKOTO	MALONGO	KATOVU	KAYONZA	KAMUDAALA	wdd8563	30191 4	996005 0
LWENG O	BUKOTO	MALONGO	KATOVU	KAYONZA	KAYONZA A+B	wdd8564	30600 1	996019 0
LWENG O	BUKOTO	MALONGO	KATOVU	KIKORONGWO	KIKORONGO	wdd8565	30715 2	996150 1
LWENG O	BUKOTO	MALONGO	KATOVU	KAKORONGO	KAKORONGWO	wdd8566		
LWENG O	BUKOTO	MALONGO	KATOVU	LWEMIYAGA	LWEMIYAGA	WDD8567	30835 0	996433 0
LWENG O	BUKOTO	MALONGO	KATOVU	KIKASA	KIKASA	WDD8569	29700 8	995587 6
LWENG O	BUKOTO	MALONGO	KATOVU	KYAMATAFALI	KYAMATOFARI & KIKOBA	WDD8570		
LWENG O	BUKOTO	MALONGO		KYAMPALAKATA	KYAMPALAKATA	WDD8571	30419 3	995122 6
LWENG O	BUKOTO	MALONGO	MALONGO	KIGEYE	KIGEYE A	WDD8891		
LWENG O	BUKOTO	MALONGO	KATOVU	MALONGO	MALONGO BAPTIST SCHOOL	WDD8892	30656 3	996077 0
LWENG O	BUKOTO	MALONGO	KATOVU	NTURA B + LWENDEZI	NTURA B + LWENDEZI	WDD8893		
LWENG O	BUKOTO	MALONGO	KATOVU	MATOVU + NGANGO	KITOVU + NGANGO	WDD8894	30159 7	995753 4
LWENG O	BUKOTO	MALONGO	KATOVU	KIGANDA	KIGANDA	WDD8895	31062 2	995856 2

LWENGO	BUKOTO	MALONGO	MALONGO	KAMAZZI	KAMAZZI A	WDD8896	307519	9956929
LWENGO	BUKOTO	MALONGO	MALONGO	MPAMBA/MPAAMA	MPAMBA	WDD8897	311267	9955422
LWENGO	BUKOTO	MALONGO	MALONGO	LWEMBOGO	RWEMBOGO	WDD8898		
LWENGO	BUKOTO	MALONGO	MALONGO	KIGEYE	KIGEYE B	WDD8899	310027	9964696
LWENGO	BUKOTO	NDAGWE	NDAGWE	KAKINDU	KAKINDU	DWD25319	324538	9939766
LWENGO	BUKOTO	NDAGWE	NANYWA	LWAND B/C	LWANGA B/C	DWD25320	322863	9942057
LWENGO	BUKOTO	NDAGWE		NANZIITI	NANZIITI	WDD8573	325426	9945971
LWENGO	BUKOTO	NDAGWE	NDAGWE	KIBANYI	KIBANYI P/S	WDD8574	326852	9940510
LWENGO	BUKOTO	NDAGWE	NDAGWE	KYENANGAAZI	KYENANGAAZI T.C	WDD8575		
LWENGO	BUKOTO	NDAGWE	NDAGWE	KABINGO	KABINGO	WDD8577	324560	9936932
LWENGO	BUKOTO	NDAGWE	NDAGWE	MIJUMA	MIJUMA	WDD8578	327962	9944215
LWENGO	BUKOTO	NDAGWE	MAKONDO	KYAMUKAMA	KYAMUKAMA	WDD9379	332973	9945185
LWENGO	BUKOTO	NDAGWE	NANYWA	KABUNGA	KABUNGA	WDD9380	324736	9944651
LWENGO	BUKOTO	NDAGWE	NANYWA	NAKATEETE	NAKATEETE	WDD9381		
LWENGO	BUKOTO	NDAGWE	MPUMUDDE	NDAGWE	NDAGWE A	WDD9382	320262	9942047
LWENGO	BUKOTO	NDAGWE	NDAGWE	NAMABAALE	NAMABAALE	WDD9383	319347	9940818
LWENGO	BUKOTO	NDAGWE	MPUMUDDE	BUKERERE	BUKERERE	WDD9384	320383	9945405
LWENGO	BUKOTO	NDAGWE	MPUMUDDE	JJAGA	JJAGA T.C	WDD9385	320943	9947765
LWENGO	BUKOTO	NDAGWE		NAKATEETE	NAKATEETE	WDD9386		
LWENGO	BUKOTO	NDAGWE	MAKONDO	KIJAJJASI	KIJAJJASI P/S	WDD9443	329227	9944099
LWENGO	BUKOTO	NDAGWE	MAKONDO	KIGULUKA	KIGULUKA	WDD9444	330124	9942915
LWENGO	BUKOTO	NDAGWE	MAKONDO	KANYOGOGA	KANYOGOGA	WDD9445	329984	9941499
LWENGO	BUKOTO	NDAGWE	MAKONDO	KABUYE	KABUYE T.C	WDD9446	327489	9944301
LWENGO	BUKOTO	NDAGWE	MAKONDO	KIGAJU (KIGANJO)	KIGANJU	WDD9447	328776	9941946
LWENGO	BUKOTO	NDAGWE	MAKONDO	MAKONDO	MAKONDO	WDD9449		
LWENGO	BUKOTO	NDAGWE	MAKONDO	MAKONDO	MAKONDO T.C	WDD9450	331371	9943940
LWENGO	BUKOTO	NDAGWE	NANYWA	NDEBBA	NDEBBA T.C	WDD9451	324846	9942846
LWENGO	LWENGO	LWENGO	NAKYENYI	RWENSINGA	LWENSINGA	DWD77003	332078	9955704
LWENGO	BUKOTO	KINGO	NKONI	KYANGOMA	KYANGOMA	DWD79594	347391	9962668
LWENGO	LWENGO	NDAGWE	NDAGWE	MICHUNDA	ST. DENIS SSS	DWD36436	330682	9945392
LWENGO	BUKOTO WEST	MALONGO	KATOVU	KATONGOLE	KATONGOLE	DWD17445	330519	9958115
LWENGO	BUKOTO	KISEKA	KIWANGALA	KISEKA	KATOOKE	DWD44192	333957	9945700
LWENGO	MALONGO	MALONGO	KATOVU	KATOVU	KATOVU	DWD40443	306088	9959599
LWENGO	BUKOTO	KYAZANGA	KATUULO	BUSIBO	St. JOSEPH BUSIBO	DWD40989	310680	9948278
LWENGO	LWENGO	NDAGWE	MPUMUDDE	LUSAANA	LUSAANA	DWD57732	317866	9944604

LWENG O	BUKOTO	KYAZANGA	BIJABA	BUWUMULIRO	BUWUMULIRO	DWD8328 3	31437 2	994946 6
LWENG O	BUKOTO	KYAZANGA	KATUULO	KATUULO		DWD8328 4	30724 8	994754 0
LWENG O	BUKOTO	KYAZANGA	KATUULO	KAGOOGWA	KAGOOGWA	DWD8328 5	30869 5	994984 0
LWENG O	LWENGO	KYAZANGA TC	BIJABA	LUYMBE	LUYEMBE	DWD5344 4	31600 4	995476 4
LWENG O	BUKOTO WEST	KYAZANGA	BIJABA	MPUMUDDE	MPUMUDDE	DWD5344 5	31545 0	995627 6
LWENG O	LWENGO	KYAZANGA TC	NAKATEETE	NAKATEETE	NAKATEETE	DWD5344 6	31438 0	995928 1
LWENG O	BUKOTO SOUTH	KISEKA	KINKAMBA	KISWERA 2	KISWERA2	DWD7950 0	33936 9	995426 6
LWENG O	BUKOTO SOUTH	KISEKA	KANKAMBA	KISWERA	KISWERA	DWD7949 9	33918 2	995410 7
LWENG O	LWENGO	KINGO	KAGANDA	MPEMBWE	MPEMBWE	DWD6105 4	36110 1	991084 7
LWENG O	BUKOTO WEST	LWENGO TC	KABALUNGI	MBIRIZI	BWAMI 1	DWD1658 9	33287 7	995881 0
LWENG O	BUKOTO WEST	LWENGO TC	KABALUNGI	MBIRIZI	BWAMI 4	DWD1701 8	33287 2	995830 0
LWENG O	BUKOTO WEST	LWENGO TC	KABALUNGI	KINONI	BWAMI 2	DWD1659 1	33270 7	995919 7
LWENG O	BUKOTO	LWENGO	KYAWAGON YA	NAKALINZI	NAKALINZI	DWD5318 6	31976 0	994961 4
LWENG O	BUKOTO WEST	MALONGO	KATOVU	KATOVU CENTRE	KATOVU CENTRE	DWD5318 7	30291 7	995828 5
LWENG O	BUKOTO WEST	KYAZANGA	RYAKIBIRIZI	KIRUMBA	KIRUMBA	DWD5318 9	31661 4	995675 9
LWENG O	BUKOTO	KISEKA	NGEREKO	BUYAGA A	BUYAGA A	DWD4843 7	33621 2	995061 6
LWENG O	BUKOTO	KISEKA	NAKALEMBE	KABOYO	KABOYO	DWD4843 8	34023 1	996147 6
LWENG O	BUKOTO	MALONGO	KATOVU	KATOVU	KATOVU CDC	DWD3399 8	30219 9	995734 7
MASAK A	BUKOTO	KYANAMU KA	MULEMA	KABANDA	KABANDA CDC	DWD3399 7	35768 8	993663 3
LWENG O	BUKOTO	KITOORO	KYAWAGON YA	KYANDAZIMA	KYANDAZIMA	DWD7956 2	DRY	
LWENG O		LWENGO	KYAWAGON YA	LWENTAMU		DWD	32188 3	995281 0