UNIVERSITY FOR DEVELOPMENT STUDIES

ASSESSMENT OF GROUNDWATER POTENTIAL AND QUALITY FOR URBAN AND PERI-URBAN IRRIGATED AGRICULTURE IN THE WA MUNICIPALITY OF GHANA

BY

DAVID SOGFAA

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(BSc. Agriculture Technology)

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A DESERTATION SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

2023

DECLARATION

DECLARATION BY CANDIDATE

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for a degree at this university or elsewhere. The work of others, which served as sources of information for this study, has been duly acknowledged in the form of references.

David Sogfaa		23/08/2023
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DECLARATION BY SUPERVISORS

I hereby declare that the preparation and presentation of the thesis were supervised per the guidelines on supervision of the thesis laid down by the University for Development Studies.

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ABSTRACT

Groundwater resources have been heavily dependent on for domestic and agricultural purposes since the beginning of time. This study was therefore aimed to evaluate the significance of physical and environment factors on groundwater potential, delineate the groundwater potential zones and determine the water quality in the Wa Municipality of Ghana for irrigated agriculture. Nine (9) layers namely; Geology, lineament density, rainfall, drainage density, soil, landuse and landcover (LULC), topographic wetness index (TWI), slope and elevation were considered for modelling the groundwater potential. Weight was assigned to the layers in order of their importance to groundwater occurrence using the analytic hierarchy process (AHP) at a consistency ratio (0.088) which signifies a very high level of acceptance. Geology (19.9 %) was ranked the highest followed by lineament density (18.9 %), rainfall (12.8 %), drainage density (10.6 %), soil (10.1 %), LULC (9.9%), TWI (8.0 %), slope (5.8%) and elevation (3.9 %). The layers were then integrated using ArcMap to map the groundwater potential zones into four (4) classes of low (145.71 km^2), moderate (130.15 km^2), high (112.39 km^2), and very high (185.33 km^2). The delineated groundwater potential zones were validated using 40 tube wells data for the study area. The prediction accuracy (AUC) of 0.703 was obtained. The study revealed that about 448.43 km^2 land area of the Wa Municipality representing 77.41% of the total area of the municipality has suitable groundwater for irrigation. However, it was discovered that the remaining 22.59 % of the total municipality have concentrations of ammonia (NH_3) (5.2 mg/L), electrical conductivity (EC) (449.9 µS/m), pH (8.9) and turbidity exceeding the acceptable limit of the Food and Agriculture Organization (FAO) and World Health Organization (WHO) standard. Nevertheless, the Wa Municipality generally have a very good groundwater potential both in quantity and quality to ensure sustainable irrigated agriculture. The findings of this study are set to be useful for planners, investors and policy makers for future decision-making regarding irrigation. For a full utilization, there is the need to monitor the groundwater quality especially the ammonia (NH_3), electrical conductivity (EC), pH and turbidity. A further study to determine the heavy metals and biological parameters availability in groundwater for a safe irrigated agriculture is recommended.

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DEDICATION

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ACRONYMS AND ABBREVIATIONS

AHP	Analytics Hierarchy Process
CR	Consistency Ratio
CI	Consistency Index
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GWPI	Groundwater Potential Index
GWPZs	Groundwater Potential Zones
GDP	Gross Domestic Product
GIS	Geographical Information System
GWCL	Ghana Water Company Limited
IDW	Inverse Distance Weight
ISRIC	International Soil Reference and Information Centre
LULC	Landuse and Landcover
MCDM	Multi criteria Decision Making
GIS	Geographical Information System
GWCL	Ghana Water Company Limited
SDG	Sustainable Development Goal
SRTM	Shuttle Radar Topographic Mission
SSA	South Sahara Africa
RCI	Random Consistency Index
RS	Remote Sensing
TWI	Topographic Wetness Index
USGS	United States Geological Survey

CHAPTER ONE

INTRODUCTION

1.1 Background

Agricultural activities are rapidly increasing as human population increases. Hence, the need for continuous groundwater usage (Ramzi and Al-Gburi, 2022). In addition to being one of the world's greatest sources of irrigable water, groundwater is key for maintaining substantial amount for drinking purposes (Mif *et al*., 2021). Approximately, 800 million individuals worldwide engage in urban gardening, which has considerably improved global food security and safety (United Nations, 2015). Low-income urban and peri-urban people in developing nations have been supported by this method for many years. Its appeal to low-income urban dwellers is largely a result of the dearth of official employment opportunities and as a way to supplement household income (United Nations, 2015). In recent years, there has been an increased need to manage urban farming sustainably in developing countries. Urban farming is in competition with population growth brought on by natural rural-urban migration as well as infrastructure expansions for limited resources like space and water for irrigation. (Addo, 2010).

Over the past 50 years, groundwater irrigation has expanded quickly and now provides more than three-quarters of all irrigated land on earth (FAO, 2011). In Asia, groundwater irrigation accounts for over 70 % of agriculture land and this has helped millions of households escape poverty while also significantly contributing to agricultural and food security (Shah, 2015).

The population of the world has grown quickly over the past century, and in the upcoming years it will keep expanding, even though more slowly (United Nations, 2015).

1.2 Problem Statement and Justification

As a result of improving irrigation system and agricultural practice performance, the growth in agricultural water demand is slowing down (Nair and Mirajkar, 2021). Nevertheless, the need for water is getting more and more spatially concentrated due to the rapidly growing population (Al-gburi, 2022), urbanization and climate change variability (Oh *et al*., 2011). Due to rising populations, fast urbanization, industry, agricultural activity and the loss of surface water storage because of sedimentation (Adongo *et al.*, 2021) there is a greater need for water (Chatterjee and Dutta, 2022*;* Ghosh *et al.,* 2022*)*. To boost food production, there may be room to further utilize water resources like groundwater (FAO, 2017). Groundwater detection however required adequate resources and determination because it is an expensive and difficult task to do (Kwami *et al*., 2019). Groundwater resource planning and management had become a significant and difficult task due to the lack of sufficient physical and scientific information about aquifer properties and behavior, including recharging, discharging, base flow, and ecosystems depending on aquifers, and also strong connections between groundwater environment and the welfare of humans, especially given that the effects of local and global climatic change are already visible in Ghana (Zango *et al*., 2014). Due to poor water resource management and environmental deterioration, which have resulted in millions of people having less access to safe and reliable water supplies, Ghana may be approaching a freshwater crisis (Zango *et al.*, 2014). The lengthy dry season in the Upper West Region has additionally caused dugouts and surface streams to dry up. Surface water is extremely susceptible to pollution because of anthropological activities such as farming practices, now making many focuses mostly on using groundwater for their domestic operations due to growing contamination and pollution of surface waters caused by anthropogenic and natural activity (Salifu *et al.*, 2017).

In many regions of the world, shallow wells and lifting tools powered by muscle have been utilized for generations. In the early 1903, at that time 14 % of irrigable land was irrigated, British India (which now consists of Bangladesh, India, and Pakistan) had more than 30 % of its land under irrigation from shallow wells (Aarnoudse *et al*., 2012). Urban and peri-urban agriculture contributes significantly to the food supply of many cities in Sub-Saharan Africa (SSA) and specifically caters to urban diets, greatly increasing the range of foods available on city markets, creating jobs, supporting livelihoods, and reducing poverty (Cofie and Veenhuizen, 2003). According to Zango *et al*. (2023), groundwater is an essential resource for managing the growing food shortages and promoting urban growth.

It is well known that the studied area exclusively uses surface water for irrigated agriculture during the period of no rains, which later dry up then some resort to sewage. It is impossible to overstate the role that agriculture plays in the socioeconomic circumstances of these people in the region (Abdul-Ganiyu and Kpiebaya, 2021). It is also important to state that the industrial sector such as "pure water" manufacturing firms solely depend on groundwater in the region. Groundwater must be used sustainably for a variety of purposes, including domestic, agricultural and industrial uses. As a result, groundwater potential assessment is an important strategy (Berhanu and Hatiye, 2020; Bhadran *et al*., 2022).

Together, Ghana's three northern regions contribute nearly 70 % of the country's total cereal crop and cattle consumption (World Bank, 2010). The majority of Ghanaians' daily meals consist of staple foods including maize (*Zea mays L*.), rice (*Oryza sativa*), S*orghum bicolor*, and millet (*Pennisetum glaucum*), among others. Climate change will cause these commodities' yields to continue declining, increasing food costs and causing food shortages, which will worsen the problems with food security currently present and widen the income gap for rural poor people. In order to sustain year-round agricultural output, it is crucial that groundwater be utilized for domestic purposes and developed as a potent tool for dry season irrigation, especially in semi-arid locations where rainfall is uncertain (Gyamfi, 2014). If stakeholders prioritize managing land and water resources and engage in capturing and exploiting alternate irrigation sources, these conditions can be realized. In the case of the Upper West Region of Ghana, there has not been much research on the groundwater occurrence especially using contemporary methods like remote sensing (RS), geographic information systems (GIS) and the analytics hierarchy process (AHP). Meanwhile, the potential of groundwater resources in the region has been underestimated due to the wrong notion that the groundwater resources of the region are relatively inadequate and usage has been limited to domestic purposes (Salifu *et al*., 2017). Considering the scientific and technological progress, it is now possible to produce maps with data for geological, geomorphological, elevational, drainage density, soil, slope and landuse and landcover (LULC) in order to study the zones with potential for groundwater (Mohamed and Al-Gburi1, 2022). Many research has employed GIS and remote sensing to assess the groundwater potential of their study areas all over the world (Shekhar and Pandey, 2015; Zeinolabedini and Esmaeily, 2015; Alrawi *et al*., 2022; Bhadran *et al*., 2022; Kpiebaya *et al*., 2022). The technique is used in a variety of geological formations and terrain (Thapa *et al*., 2017; Vanum *et al*., 2017; Berhanu and Hatiye, 2020; Doyo, 2020; Tolche, 2020, 2021; Alrawi *et al*., 2022). Thematic layers for rainfall, soil type, slope, lithology, lineaments, and drainage density have all been incorporated in these works, despite the fact that the minimal number of components and the method for allocating weight to these elements vary. For mapping groundwater potential, some researches have used models like weights-of-evidence modeling and multi-criteria decision-making analysis (MCDM) (Lee *et al.*, 2012; Rahmati *et al*., 2015; Tolche, 2020). Other studies have assigned weight to various thematic levels and associated attributes using individual judgments or local information (Saaty, 1980). In order to prepare layers for various factors, employing RS and GIS and integrating the weighted layers, such as geology, slope, soil, lineament density, rainfall, drainage density and landuse and landcover in a geospatial sphere will aid in the identifying possible groundwater zones (Shekhar and Pandey, 2015).

Groundwater is largely consumed and depended on for domestic and agriculture use. Groundwater is increasingly used on a daily basis, particularly in arid and semi-arid regions, because of population growth and agricultural expansion (Al-gburi, 2022). The research-covered literature indicates that one of urban agriculture's many functions is to improve urban sustainability. These responsibilities can be boiled down to employment and income creation

(Zezza and Tasciotti, 2010; International Labour Organization, 2013; Darkey *et al.*, 2014) and food availability (Ackerman *et al.*, 2014; Opitz *et al*., 2016).

The findings of this research can be use by investors, policy makers and planners for future decision making in irrigated agriculture. This would contribute to Sustainable Development Goals including SDGs 1: End Poverty, 2: Zero Hunger, 3: Good Health and Well-Being, 6: Clean Water and Sanitation, 8: Decent Work and Economic Growth.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of the study was to map groundwater potential zones of occurrences in the Wa Municipality of Ghana and assess the water quality for sustainable urban and peri-urban irrigated urban agriculture.

1.3.2 Specific Objectives

The specific objectives of the study were;

1. To evaluate the relevance of physical and environmental factors in determining the occurrence of groundwater in the Wa Municipality.
2. To delineate the zones of groundwater occurrence in the Wa Municipality for sustainable irrigated agriculture.

3. To assess the quality of the groundwater for suitable irrigated agriculture in the Municipality.

1.4 Research Questions

To guide the study, the specific objectives were used to formulate research questions as follows:

1. What is the relevance of physical and environmental factors in determining the occurrence of groundwater in the Wa Municipality?
2. Where are the potential areas for groundwater occurrence in the Wa Municipality?
3. What is the groundwater quality suitability for irrigated agriculture in the Wa Municipality?

1.5 Thesis Structure

This research is divided into five chapters. The background of the research was presented in Chapter One along with the problem statement, justification, study objectives and study questions. The relevant literature on the occurrence of groundwater using different approaches such as the conventional and the GIS and RS and the use of groundwater for irrigation in Ghana and related literature was reviewed in Chapter Two. The utilization of various approaches and procedures for assessment of groundwater were covered in Chapter Three. The study's subject, research tools and resources, and data analysis were all also highlighted in Chapter Three. The findings of the research are presented and discussions were reported in Chapter Four. Last but not the least, the fifth chapter presented a conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Groundwater

Since the beginning of human civilization, groundwater has been essential in the development of society (Ghosh *et al*., 2022). Despite being widely distributed throughout the world, the quality and quantity changes with time and place. Freshwater represents just 3 % of the total water supply, with ice encasing the majority of the remaining 97 %. The amount of groundwater in the total water resource is about 34 %. Less than 1% of all freshwater is found in lakes and rivers (Holden, 2014). Groundwater only makes up 1.69 % of the world's allotted freshwater, which is 2.50 % (Chow, 2008). About 34 % of the freshwater used by human society worldwide comes from groundwater (Dar *et al*., 2011; Ghosh *et al*., 2016; Murmu *et al*., 2019). Through the processes of infiltration and percolation, surface water seeps into the earth. On the earth, groundwater is the mainly consumed by towns, industries and agriculture. Groundwater, which also has the highest concentration of fresh water, contains around 98 % of the world's unfrozen freshwater supplies (Howard, 2015; Kaushal *et al*., 2015).

2.1.1 Relevance of Groundwater

One-third of all freshwater extraction worldwide, according to Das *et al*. (2018), occur through groundwater. Water is an essential resource for any social and economic growth in several areas of the globe where supply of water is scarce (Kordestani *et al*., 2019). For all forms of economic activity, both domestically and internationally, reserves of groundwater are a requirement.

Although pollutants from the surface primarily affects surface water, severe weathering processes of geology, recharge effectiveness, aquifer level, and the origins of some surface elements are also key factors that have an impact on groundwater (Yıldırım, 2021). Because the surface water is closer to the surface, by definition surface water contain less composition of mineral than subsurface water. According to Gbosh *et al*. (2020), surface water is very susceptible to pollution brought on by human activity and drying up due to high temperatures. Additionally, establishing surface water, extraction equipment is costly and takes up more space than groundwater locations. On account of the forementioned merits, groundwater demand for domestic, commercial, agricultural, and other uses is rising steadily each year (Thapa *et al*., 2017). Groundwater demand is increasing in countries like Ghana due to the country's rapid urbanization, population expansion, and economic expansion. Groundwater is among the most frequently used resource for home, industrial and agriculture in the current research area (Yidana *et al*., 2012).

2.1.2. Groundwater for Irrigation

Over the past 50 years, groundwater irrigation has expanded quickly and now provides more than one-third of the world's irrigated land. About 70 % of this is in Asia, where groundwater irrigation has helped millions of households escape poverty while also significantly contributing to agricultural and food security (Shah, 2015). By mitigating the effects of droughts, increasing crop production, and enabling farmers to diversify and access markets for high-value crops. The year-round on-farm water control will helps stabilize smallholder farming. As a result, Vietnam is one of the biggest exporters of Robusta coffee and pepper, and Bangladesh is currently a net exporter of rice (Shah, 2015).

Since the 1950s, groundwater irrigation has increased as a result of inventive advancements in tube well and pumping technologies. In the past, it was believed that the usage of groundwater was only appropriate for dry areas and rechargeable shallow alluvial aquifers like the Ganga River basin (Shah, 2015). However, it moved quickly into Asia's more humid nations as well as into hard-rock regions, like the northern and eastern parts of Sri Lanka and the peninsula of India, where aquifer storage and yields are poor. In the USA, Mexico, Spain, and North Africa, growth has reached its pinnacle (Shah, 2015). In South Asia, where population pressure is increasing, water scarcity is starting to rise. The use of groundwater is just starting to increase in sub-Saharan Africa, south-east Asia (in Indonesia, Vietnam, Laos, Myanmar, and Cambodia), and Latin America (Shah, 2015).

In towns and villages, groundwater is also the main supply of domestic water. Up until a point beyond which cities are forced to obtain their water from far-off reservoirs and aquifers, the groundwater footprint of towns and cities immediately grows with rising population density. The greatest user of groundwater, however, is agriculture, and as towns and cities develop, it is anticipated that agriculture will release groundwater to meet urban demand and other high-value applications. Agriculture's next task will be to increase groundwater productivity since it will need to use less water to produce more food. Many high-income nations depend significantly on groundwater irrigation. In the USA, over 40 % of all irrigation water sources come from groundwater draws, or 67 % of total withdrawals (Shah, 2015).

The entire yearly value of groundwater draft in the USA (for agriculture and other sectors) was $20.9 billion in 2004 (Bitran *et al*., 2014). The projected yearly economic value of groundwater draft in Australia in 2013 was $3.85 billion. US$3.47 billion from irrigation went toward GDP (National Centre for Groundwater Research and Training, 2013).

Groundwater is commonly linked to growing valuable marketable crops. Groundwater is a significant source for irrigation for cash crops in China, where a large-scale survey of farmers revealed that groundwater accounts for 70 % of the cotton crop, 62 % of the oil crop, and 67 % of the vegetable harvest (Wang *et al*., 2007).

The Mediterranean nations offer the best examples of how using groundwater benefits agriculture. 3,900 m^3 compared to 5,000 m^3 less water was applied per hectare by groundwater users in Andalusia, Spain. They boosted farm output value per cubic meter of water to US$9.94 from US$4.6 and increased gross water productivity to US$3.24 per cubic meter from US$097. (Hernandez-Mora *et al*., 2010). According to a study conducted in Spain, groundwater productivity for peppers and tomatoes might reach US$5.52 per cubic square meter, compared to US$0.28 per cubic square meter for cereals, corn, sunflower, and other field crops (Garrido *et al*., 2006).

In 1960, surface resources provided 59 % of the water, while the remaining 41 % was obtained through the aquifer system, according to Navarro-Hernández *et al*. (2020). However, just 16 %

of the water used today for public, urban, agricultural, industrial, and mining activities comes from surface water (Navarro-Hernández., *et al*. 2020). Pumping wells with a depth of up to 1000 m have been utilized to extract groundwater from the deep aquifer because the shallow aquifer has been the most heavily used and is nearly exhausted (López-álvarez *et al*., 2014). Currently, the deep aquifer contributes 96 % of the total amount of groundwater and the shallow aquifer only contributes 4 % (Navarro-Hernández, *et al*., 2020). On the other hand, the aquifer system is overexploited due to groundwater withdrawals of about 153.42 Mm^3 and an annual recharge volume of 78 Mm^3 (Navarro-Hernández, *et al*., 2020).

2.2 Historical Development of Irrigation in Ghana

According to Smith (1969), Irrigation development in Ghana dates back to a little over a century ago. However, the recent discovery shows that small scale irrigation practices existed as early as the 1880s in the Keta Basin of the Volta Region of Ghana, necessitated by the lack of natural conditions preventing shifting cultivation methods practiced elsewhere. In this area, small scale irrigation methods were employed on farmlands by harnessing water on land above flood level between the lagoon and the sandbar, separating it from the sea (Smith, 1969).

The Winneba Water Supply Project was the first Irrigation scheme initiated by the then government in the 1920s (Smith, 1969). The Winneba Irrigation Scheme was then followed by shallow tube well irrigation development in the 1930s in South-Eastern Ghana. Significant expansions were made in the 1950s and '60s in Guinea, Sudan and coastal Savannah belts of the country. This expansion saw about 240 earth dams in the north and about 66 in the Ho-Keta plains in the South being constructed purposely for domestic and agricultural use (Agodzo and Bobobee, 1994). Soon after independence in 1959, the irrigation sector received comprehensive public support to construct the Dawhenya and Asutsuare Irrigation Project, With the Asutsuare Irrigation Project completed in 1967 (Namara *et al.,* 2011). After independence, the government and quasi-government bodies' managed Irrigation projects (Kyei-Baffour and Ofori, 2007). The Land Planning and Soil Conservation Unit of the Ministry of Agriculture were the first of these managerial bodies in the 1960s (Gyarteng, 1994). This unit later evolved into a semi-autonomous public body, the Ghana Irrigation Development Authority (GIDA), in 1977 under the Supreme Military Council (S.M.C.) Decree 85 (Kyei-Baffour and Ofori, 2007). The primary responsibility of this unit is to develop the country's water resources for irrigated farming, livestock watering and aquaculture (Kyei-Baffour and Ofori, 2006). Approximately 19,000 ha of land were developed between the 1960s and 80s (Namara *et al*., 2010).

The World Bank undertook a review of the Irrigational systems in 1986 to formulate new strategies for the subsector. Among the strategies proposed was the emphasis on the investment by African Development Fund, in small scale and low-cost irrigation systems in order for farmer organizations to manage irrigation schemes and also the operation and maintenance of existing systems. There was also the need for capacity building of the Ghana Irrigation Development Authority to help identify, plan and implement irrigation systems. Presently, the Irrigable potential of Ghana is estimated to be about 1.9 million hectares (ha) (FAO, 2005). The area with irrigation facilities is 30,900 ha (Appiah-nkansah, 2009), 8,587 ha have been developed into public irrigation schemes, managed by GIDA (GIDA, 2001). In addition to that, 10,413 ha have been developed under private schemes on land less than 1000 hectares (ha), except the Tono and Kpong Irrigation projects that occupy 2,500 ha lands (FAO, 2005). Twenty-two of such projects have been constructed under the Small-Scale Irrigation Development Project (SSIDP) and six schemes under the Small Farms Irrigation Project (SFIP) (Namara *et al*., 2010).

Small-Scale indigenous farmers are the primary beneficiaries of these irrigation schemes. However, due to low maintenance, most of these schemes are unproductive, driving farmers to result in unconventional and crude irrigation methods accounting for about two-thirds of the total irrigated land in Ghana (Namara *et al*., 2010).

2.3. Groundwater for Domestic Consumption

One-third of the world's population relies on groundwater as their primary source of water, according to the FAO, (2017). More than half of the 7 billion people on the planet now reside in cities and now raises severe concerns about the sustainability of urban water supply. It's estimated that, 90 % of the rural population and 25% of city dwellers are dependent on groundwater for their domestic water needs, respectively in Ghana (Yankey *et al*., 2011). Groundwater is used by roughly 70 % of the Ghanaian populace for a variety of reasons such as the quality, availability, convenience and sustainability (Kortatsi *et al*., 2008) .

2.4 Groundwater Quality

The importance of underground water is immeasurable, however for whichever function its proposed for, for instance for the purpose of irrigation, assessing the quality should not be compromised because it’s very important (Sunkari, 2022). When rivers and drains are insufficient, groundwater has increasingly become the main supplier used in agriculture. As a result, of late, low groundwater quality for irrigation purposes has been a concern due to excessive use of inorganic fertilizer (Gautam *et al*., 2015). Other studies such as Salifu *et al*. (2017) has assessed the suitability of groundwater for irrigation in the upper west region, analyzing parameters such as magnesium adsorption ratio, Kelly’s ratio, electrical conductivity, sodium absorption ratio and others. The main causes of the current stress on the world's water resources are climate and human-made. In many areas with high population densities and economic development, the groundwater-related issues are serious. (Arulbalaji *et al*., 2019).

Water shortage has substantially risen in semi-arid and arid regions as a result of a lack surface water (Masoud *et al.*, 2022). According to studies, the majority of the water supply comes from groundwater resources (Suliman *et al.*, 2022) and are overexploited, with a rate of depletion of 545 km^3/year (Dakhlalla *et al.*, 2016; Makonyo and Msabi, 2021).

2.5 Factors Influencing Groundwater Potential

Lack of insight about the many environmental, meteorological, and topographical aspects makes it difficult to define groundwater potential zones (Makonyo and Msabi, 2021). Additionally, evaluating numerous geographical parameters using evidence-based techniques is part of the delimitation of prospective areas (Malczewski and Rinner, 2015). On the basis of geophysics, geological, and hydrogeological, standard approaches for surveying groundwater have been used in the majority of earlier investigations. For instance, in the Upper region of Ghana, conventional techniques were used in groundwater zoning (Zango *et al*., 2014; Kpiebaya *et al*., 2020; Abdul-Ganiyu and Kpiebaya, 2020, 2021). Based on vertical electrical sounding and magnetic measurements, a hydrogeological study presented a new conceptual model for the SLP aquifer. However, all these methods are costly and time consuming.

In recent studies, the geographic information system and remote sensing are been mostly used in prospecting groundwater zones of potential (Kpiebaya *et al*., 2022). Sawla-Tuna-Kalba and Nandom districts of Ghana, groundwater occurrence mapping has been done using GIS and RS techniques and a comparative analysis of different algorithm in QGIS and ArcGIS (Kpiebaya *et al*., 2022). However, their study did not consider topographic wetness index (TWI) and elevation. Groundwater occurrence and movement in a particular area are generally influenced by topography, lithology, geological structures, fracture density, aperture and connectivity, secondary porosity, groundwater table distribution, groundwater recharge, slope, drainage pattern, landforms, landuse and landcover, climatic conditions, and the interactions between these factors (Oh *et al*., 2011).

According to (Asgher *et al*., 2022; Chatterjee and Dutta, 2022; Ifediegwu, 2022) The occurrence and accessibility of groundwater are influenced by the recharge process, which is governed by a number of factors including physiography, lithological composition, drainage pattern, landuse and landcover as well as climatic variables such as precipitation, temperature, evapotranspiration, etc., and geological development as fractures and lineament characteristics.

2.5.1 Landuse and Landcover Change

Studies of landuse and landcover (LULC) change make an effort to identify the locations, types of landcover, types of transformations taking place, rates or volumes of land change, types of transformations occurring, and driving factors and immediate causes of these modifications (Loveland and Acevedo 2006). Groundwater occurrence and development are also influenced by LULC (Baghel *et al*., 2023). It regulates the rate of infiltration and surface runoff, thus being crucial in the development of the map of the groundwater potential zone. Additionally, according to Misi *et al*. (2018), the classification of LULC offers critical environmental information into places where groundwater accumulates based on human and natural setting interactions. Arshad *et al*. (2020b) stated that while exposed surfaces, bare land, and built-up regions are the least favorable for infiltration, dense forest areas and agricultural have great capacity for groundwater recharge.

LULC is also highly relevant to strategies for disaster risk reduction (DRR) and climate change adaptation due to the rising pressure on land resources brought on by population increase and the expansion of human habitation (Shaw and Banba, 2017).

2.5.2 Lineament Density

According to Edet *et al*. (1997), the lineament density can be measured by dividing the total length of all the lineaments by the whole area under consideration. High groundwater potential can be found in locations with outcropping bedrock and thin regolith, which are represented by high lineament density. Low lineament density area is indicative of a thicker regolith and buried bedrock with low groundwater potential (Esu *et al*., 1994; Magesh *et al*., 2012).

Groundwater occurrence and transport in hard rock terrain are influenced by the degree of tectonic activity (Nag and Ghosh, 2013). Hard rock terrain limits the evolution of groundwater to an interconnected fracture structure. Lineaments are a naturally occurring, directly perceived surface element in satellite images. The zone of the fractured rock system represent the linear features of the geological structure where groundwater sources occurs (Mif *et al*., 2021). The value of the hard rock aquifer lies in the general accessibility of groundwater. According to Thapa *et al*. (2017), groundwater availability and recharging zone in hard rock terrain is heavily concentrated around lineaments and fractured fault zones. Lineament density and groundwater potentiality are intimately connected (Magesh *et al*., 2012).

Analysis related to the study of linear or curvilinear structures from remotely sensed data represent steeply dipping faults or zones of closely spaced fractures, joints, dykes and lithological contacts in the surface or subsurface. The flow and occurrence of groundwater in areas of hard rock is mostly dependent on the secondary porosity and permeability caused by bending, faulting, jointing, etc. The lineament is the most evident structural element that is crucial for groundwater. The lineaments, which can be straight or curved, are important features, particularly in geomorphic and structural analysis (Acharya, 2013). These Lineament features control the infiltration of surface runoff as well as the movement and storage of groundwater and enhances permeability and porosity in the bedrock (Adiat *et al*., 2012).

Studies of Lineament density is to aid in locating boreholes with high yields. However, lineament mapping can sometimes be a bit subjective due to lack of adequate information on the type of feature, depth, dip or infilling represented by a two-dimensional lineament using remote sensing data (Hoffmann and Sander, 2007).

2.5.3 Soil Type

Groundwater recharge is more influenced by soil texture. The ability for groundwater to easily recharge and flow is a feature of a rough textured soil. Clay and silt, which have fine textures, have a lower capacity for infiltration and groundwater recharge (Mif *et al*., 2021). Soil texture is one of the key factors influencing the presence and transport of groundwater (Thapa *et al*., 2017). The soil texture features of the Bankura district in India vary depending on the area of the district, which is a part of the eastern Chotanagpur plateau fringe zone. In the western areas of the district, there are considerable soil textures in the lithic ustochrepts and lithic ustorthents types of soil. The district's interfluvial zones have better water infiltration capabilities. Greater clay concentration in flood plain locations results in reduced groundwater potential (Mif *et al*., 2021).

2.5.4 Drainage Density

The water infiltration capacity of an area depends on many drainage characteristics, including drainage density, frequency, length, profile, eroding capacity, basin shape, and basin forms (Haile *et al*., 2010). Drainage pattern described the type of vegetation in a region, the nature and structure of the geological surface to the subsurface formation (Acharya, 2013). Flow and occurrence of groundwater are a result of high drainage density. Steep soil erosion is caused by a surface with a high slope and narrow contour spacing (Girmay *et al*., 2009). Studies suggest that high drainage density areas may generate groundwater (Guru *et al*., 2017; Pande *et al*., 2018). Important river properties are influenced by the characteristics of the basin. Large basin areas that have accumulated a lot of water effectively recharge the groundwater. The various basin forms and shapes dictate the sediment flow characteristics, which in turn define the potential for groundwater (Mif *et al*., 2021).

2.5.5 Hydro-Geomorphology

The hydro-geomorphology landform refers to the composition, evolution, and stage of the characteristics on the earth's surface. When viewed in this broader context, the understanding of landforms offers cues for assessing groundwater potential zones maps and artificial recharge structures. In the study of Pande *et al*. (2018), basaltic rocks were examined for evidence of dry periods and sub-tropical monsoon climate zones. The porosity of the basaltic rock affects the rock formations' ability to store water for the management of groundwater resources. The ability of the good aquifer zones to store water affects the presence of groundwater (Pande *et al*., 2018). Yidana *et al*. (2015) indicated in their research that the presence of faults, fractures and quartz veins highly influences water-bearing and yielding capacity. Another research that conforms to the above is by Thapa *et al*. (2017), which stated that the varied geomorphic characteristics and how they are arranged together define the potential for groundwater. The ability of groundwater to store water is significantly influenced by the type of rock. Water may be stored and transported through rocks in two different ways: through the pores of an undamaged rock and through fractures in the rock mass. The lithologic map and Lineament account for the significant characteristics of fractures, joints and faults (Doyo, 2020). Similar research done by Mif *et al*. (2021) indicated that other surficial characteristics that affect the occurrence and transport of groundwater are the geomorphological features.

2.3.5.1 Precambrian Basement Rocks of Ghana

The Precambrian Basement Complex (PCB) comprises rocks with low permeability and porosity and covers about 54 % of the study area (Forkuor and Obuobie, 2013). It is categorized into the upper and lower saprolite (regolith), and upper and lower bedrock (sap rock) layers, based on the varying hydrogeological characteristics and uneven fracture networks' anisotropic nature encountered in this zone. The productive zones of this formation are the lower saprolite and upper sap rock layers (Carrier *et al*., 2008).

The upper saprolite is less permeable and unsaturated and usually referred to as a semi confining layer because of its high percentage of secondary clay materials. The presence of coarsely textured materials in the residual soil zone can lead to perched aquifers' formation. In comparison to the upper saprolite, the lower saprolite is highly weathered and is more saturated. It is a zone of enhanced hydraulic conductivity as much of its primary minerals are preserved. In some instances, the saprolite is referred to as a leaky aquifer although it just acts as a reservoir for the underlying fractures (Carrier *et al*., 2008). The basement aquifers are usually confined and have a varying thickness of about 2-20 m and is dependent on the weathered zone's depth and frequencies (Carrier *et al*., 2008).

Transmissivity and permeability of fractures tend to decrease moving towards the bedrock (sap rock) layer and have varied yields ranging from 0.1 to 10 L/s. The upper sap rock has sub-horizontal fractures due to isostatic uplift from surface decompression of overlying materials and has secondary clay minerals in filling and sealing fractures, thereby reducing its permeability (Wright, 1992). Whereas, the lower sap rock (>150 m) has subvertical fractures produced by tectonic forces and produce significant amounts of groundwater (Carrier *et al.*, 2008). The Precambrian Basement Rocks are considered the higher groundwater potential zone with highly variable yields from the basement aquifers. Measured transmissivity varies from 0.20 to 119.0 m^2/day, with an average of 7.40 m^2/day and storativity values ranges from 0.0030 to 0.0080 (Carrier *et al.*, 2008). Average borehole depths are less than 80 m (Agyekum, 2004).

2.3.5.2 Basement Crystalline Rocks

Groundwater is dependent on the prevailing geology (Adiat *et al.*, 2013). It takes place in the rock's fractures and pore spaces where there is considerable interconnection. The paleozoic sedimentary sandstone and limestone rocks are suggested due to their potential gradient and a global average success rate for drilling boreholes of around 77 %, which makes them ideal for groundwater development. With an average drilling success rate of 80 %, the Lower and Upper Birimain (Wa Granite) yields around 0.550 L/s. The SSA belongs to the Precambrian hydrogeological province in terms of categorization (Abdul-Ganiyu and Kpiebaya, 2020). The geology of the area is dominated by the West African Craton's basement crystalline rocks. The basement crystalline rocks are Precambrian in age and primarily comprise Birimain rocks with associated granitoid intrusions (Salifu *et al*., 2017). These rocks include granites that contain biotite and muscovite, granites that contain hornblende, granodiorite, diorite, and gabbro, phyllites, chist, tuffs, basalt, sandstones, siltstones, manganimetries sediments, and extensively deformed metamorphic rocks. Birimian phyllite, slate, schist, tuff, greywacke and lava are all highly foliated and cracked rocks. Significant water may percolate through them where they gather close to the surface. Boreholes in the Upper and Lower Birimian rocks yield an average of 12.7 m^3/h (2794 igph). The weathering zone is about 137 m thick in the north- west area of the Wa Municipality. The regolith in the Wa Municipality is as thick as 140m. The rate of success for all completed tube wells in the Wa granite areas is stated to be 85 % (Dapaah-Siakwan and Gyau-Boakye, 2000). Successful borehole yields ranges from 0.450 to 23.60 m^3/h and 5.4 m^3/h as average. The majority of the boreholes in the Birimian system equipped with manual pumps and are roughly 35 meters deep on average, however, granite is drilled to an average depth of 60 m, making it more challenging in well construction (Adelana *et al*., 2008).

The upper west region's geological setting is fairly complex and varies greatly even on a local scale. However, the formations can be divided into two types: crystalline basement rocks (granites, granodiorites, and granite gneisses) and Birimain formations (metamorphosed volcanics, schists, and phyllites) (https://www.cwsa.gov.gh/upper-west-region-3/). Except where weathered, veined, and/or fractured, the crystalline basement rocks have little to no permeability. Aquifers only develop in crystallized basement rocks as a result of weathering and fracturing of the lithological components. This is caused by the fact that they are deficient in inherent primary porosity and permeability (Steven *et al*., 2022). Groundwater is mostly found in a confined weathered areas, veined intrusions and fractures in the bedrock (Almadani *et al*., 2019). Thick and intensely weathered zones with fractures entrances the bedrock, and generally produce yields from the sustainable underlying aquifers (Ruelleu *et al*., 2010).

2.3.5.3 Groundwater Aquifer

Figure 2.1 is an illustration of aquifers and wells. Aquifers are subsurface geological formations with porous lithological unit saturated with water, which is an essential part of the hydrological system. Water is a versatile natural resource which contributes significantly to the well-being of socio-economic advancement and the preservation of ecological life (Makonyo and Msabi, 2021; Ifediegwu, 2022). The process of replenishing the earth's aquifer with freshwater is typically reliant on the subsurface reservoir (Andualem and Demeke, 2019). Rivers, lakes, and ponds are supplies of surface water storage whereas surface and sub-surface runoff are supplies of subsurface storage. Each aquifer structure has upper and lower aquifers under unconfined and confined condition (Ghosh *et al*., 2016).

Aquifers can be formed by a wide variety of sediments and rocks, such as gravel and cracked limestone. Aquifers may be classed based on the kind of rocks or sediments that make up their composition. It's a popular misperception that aquifers are lakes or rivers beneath. Because aquifers are porous, water is able to penetrate into or out of them, but it is unable to move quickly enough like river. The porosity of the rock affects how quickly groundwater travels via an aquifer (Ponnusamy, 2021).

Aquifers are the source of the majority of groundwater, such as a sizeable portion of our drinking water. A borehole made by boring a hole that extends into the aquifer can generate this water. If we utilize groundwater more quickly than it can regenerate, it could run out. Recharging describes the process by which precipitation replenishes aquifers. Aquifers collapses mostly as a result of over extraction for irrigation (Zhiqiang, 2020). Groundwater gets filtrated by aquifers as it travels via tiny openings, which filters contaminants from the water. However, it is impossible for all the pollutants to get removed by this organic filtering procedure (Eyankware *et al*., 2020).

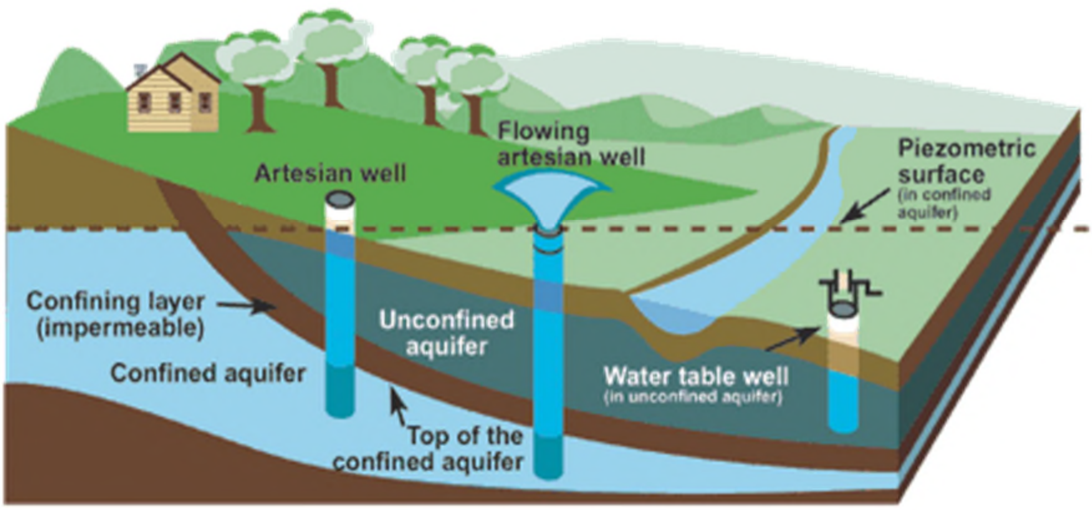

Figure 2.2: Aquifers and Wells
(Source; USGS)

2.5.5.3.1 Confined Aquifer

A restricted aquifer, defined by the United States Geological Survey (USGS), is a subsurface aquifer that is completely filled with water. The aquifer endures pressure since there are impervious layers on top and underneath it. As a result, when a well drills into the aquifer, water oozes to the surface. The confined beds are two layers of impervious rock that enclose a rock that is permeable and retains water (Fenta *et al*., 2020). The confined bed may be made of granite, shale clay, or other materials that tend to shield groundwater from pollution brought on by surface activity like leaking and water from seeping (Hassan *et al*., 2019; Fenta *et al*., 2020). The water table in a catchment is influenced by the type or position of the aquifer system. In confined aquifers the water table is lower but may possess substantial groundwater potential (Pudukkottai and Nadu, 2023).

2.5.5.3.2 Unconfined Aquifer

The United States Geological Survey (USGS) further defined an unconfined aquifer as one that is capable of rising and falling since its water table is at atmospheric pressure. Due to their typical proximity to the earth's surface, confined aquifers are affected by drought conditions earlier than restricted aquifers. Unconfined aquifers are water-storing geological structures that are located extremely near the surface of the earth and may have poor potential (Pudukkottai and Nadu, 2023) They are neither enclosed or covered by an impenetrable bed. An unconfined aquifer's topmost layer of groundwater is known as the water table. The infiltration of terrestrial contaminants makes this type of aquifer more vulnerable to pollution and contamination than restricted aquifers. Depending on how much water is stored and how much pressure from the atmosphere is exerted on that storage, groundwater levels can fluctuate (Hassan *et al.,* 2019; Fenta *et al.*, 2020).

2.5.6 Slope

Another element that affects the hydrology of a particular watershed is the slope of the land's surface. It mostly influences the surface runoff process, which in turn influences how much a watershed's groundwater recharges (Berhanu and Hatiye, 2020). Higher slope values imply steep and undulating terrain, whereas lower slope values suggest gentler slope terrain. While the higher slope parts generate high runoff from the landscape and provide minimal volume of water for groundwater recharge, areas of flat terrain allow rainwater infiltration and percolation (Arshad *et al.*, 2020a). A watershed's topographic gradient has a greater impact on groundwater flow than groundwater level (Grinevskii, 2014). This may be due to a scale issue, where the impact of the topographic gradient cannot be ignored even when the impact of the underlying hydraulic gradient may be minimal. However, slope exposure has a greater impact on groundwater recharge and, thus, groundwater potential, than slope gradient (Rukundo and Doğan, 2019). The gradient of the slope has a direct impact on surface water infiltration. Due to limited time for infiltration, steep slopes cause rapid downward water flow. Flat terrain offers longer retention for rainwater infiltration (Thapa *et al.*, 2017)

2.5.7 Rainfall

Rainfall is one of the most significant sources of groundwater replenishment through percolation (Thapa *et al.*, 2017; Allafta and Opp, 2021; Tinonetsana and Gumindoga, 2022). The quantity of groundwater recharge of a catchment influence the intensity and duration of rainfall in the area (Ponnusamy, 2021). In a similar study in Lafia district in the Nasarawa state of Nigeria, rainfall was ranked second as one of the layers with higher impact on groundwater potential (Ifediegwu, 2022).

2.5.8 Elevation

The groundwater potential of a particular place can be indirectly impacted by elevation or height. According to a study by Sikah *et al*. (2016), areas classified as high groundwater potential points have low elevations and low bedrock apparent resistivity values, while areas classified as low groundwater potential points have higher elevations and higher bedrock apparent resistivity values. It mostly has to do with when it rains, which affects the recharge. As a result, high heights encourage more recharge and guarantee the presence of groundwater in the watershed's low-lying areas (Berhanu and Hatiye, 2020).

2.5.9 Topographic Wetness Index

The Topographic Wetness Index (TWI) was established by Beven and Kirkby (1979) and it the most widely used index in hydrological-based studies. TWI controls the topographic impact on the hydrologic response of a watershed (Mattivi *et al*., 2019). The outcome of a research by Grimm *et al*. (2018) indicated that TWI denotes potential subterranean groundwater infiltration, depending on topographical features and how they affect the area around. TWI is often computed using a hydrologically corrected DEM, which implies that all sinks, including actual depressions, have filled to capacity before TWI calculations. The flow directions, flow accumulations, and slopes of all the grids connected to depressions are changed as a result of the sink-filling pre-processing. Higher TWI values indicate a saturation-prone area, whereas with lower TWI values indicate a saturation-resistant area (Grimm *et al*., 2018; Mattivi *et al*., 2019). The topographic wetness index is characterized by a cell's propensity to accumulate water, enables the identification of advantageous places with concentration and sluggish runoff, and is computed using the below equation (2.1) (Abdelouhed *et al*., 2021).

$TWI = In(\alpha/\tan(b))$………………………………………………. Eqn 2.1

Where:

TWI - Topographic Wetness Index,

α - a particular catchment area, and

b - the slope.

This index presented in equation 2.1 implies steady-state conditions for infiltration and transmissivity conditions that are spatially invariant. The natural logarithm is used to scale the index (Kopecký *et al*., 2021).

2.6 Analytics Hierarchy Process Model

The Analytic Hierarchy Process has been recognized to be effective and has been used by many researchers for groundwater modelling. A related study of groundwater potential assessment using GIS and Analytical Hierarchical Process method was done in Iran (Zeinolabedini and Esmaeily, 2015). In a previous research in Rift Valley Lake Basins Weito Sub Basin, Ethiopia, mapping groundwater potential using remote sensing and GIS was attempted where rainfall, landcover landuse, slope, soil, lithology, drainage, lineaments, and geomorphology were employed as thematic layers in their modelling (Doyo, 2020). The groundwater potential map was created using weights applied to the layers using AHP and overlay analysis in GIS environment. As a result, 1, 15, and 23 % of the watershed were classified as excellent, very good, or good, respectively. 60 % of the land portion has poor or extremely poor groundwater potential. Another study was done in the Karan Basin in Chattisgarh, India, using RS and GIS by Vishwakarma *et al.*, (2014). The researchers mapped the groundwater prospective zones, considering groundwater regulating elements including geology, geomorphology, drainage pattern, water body, settlement, slope. The outcome of the groundwater prospect showed zones of very poor, poor, average, good, very good and excellent zones. Some recent studies such as Danso and Ma (2023) and Mustapha *et al*. (2023) also employed AHP by integrating hydroclimatic and geomorphological criteria in the study of groundwater potential mapping.

2.7 Urban and Peri-urban Agriculture

Food production takes place frequently inside the boundaries of cities and on their immediate outskirts; it is not just a rural phenomenon. Urban agriculture is a subsistence and commercial farming that gives households food and earns money for city residents (Danso *et al*., 2014). However, Cities in Africa differ greatly in the significance of urban agriculture (Nchanji, 2017). Urban agriculture's contribution to global food security is becoming more widely acknowledged, but it is still very loosely measured. Urban and peri-urban agriculture is a subject that presents several definitional difficulties. The terms "urban" and "peri-urban" agriculture can apply to a wide variety of agricultural operations, including crop, livestock, poultry, and aquaculture production, and this at any scale, from small roof-top gardens to more expansive cultivated open spaces (Thebo *et al.*, 2016). Recent studies on urban agriculture describe the qualities and difficulties of growing crops in cities in both developed and developing nations (Hamilton *et al*., 2014). Hence, there is still a significant knowledge deficiency about urban agriculture's regional and worldwide reach.

2.7.1 Urban Irrigated Agriculture in Ghana

Urban vegetable growing in Ghana has existed since the introduction of Europeans. Agriculture was probably encouraged everywhere during the Second World War in order to aid in providing food for the allied forces in the Gold Coast (Ghana). To address the needs of the populace for food during the economic post-independence problems of the 1970s, the government sponsored urban agriculture (Danso *et al*., 2014). Backyard gardening is still a widely recognized social activity today, especially among middle-class people who have enough space, like government officials. On more than six larger locations in the center of Accra, urban vegetables are grown using irrigation. roughly 680 ha of the AMA boundary were predicted to be under maize in 2005, together with 47 ha of vegetables and, with seasonal change, roughly 251 ha of mixed cereal-vegetable systems (Danso *et al*., 2014). Additionally, vegetables are grown in the peri-urban area of Kumasi, where more than 10,000 ha of seasonal vegetable farming were noted (Cornish and Lawrence, 2001). It is twice the area covered by formal irrigation in the entire nation. In Tamale, the majority of vegetable gardening is done alongside stormwater drains, along pipes, or in reservoirs. The majority of farmers move to maize in the wet season, while 60 % of farmers only cultivate vegetables during the dry season. In the dry season, more than half of farmers that use irrigation rely on highly contaminated water sources (Obuobie *et al*., 2006).

2.7.2 Regional Distribution of Urban Irrigated and Rainfed Croplands

The distribution of irrigated and rain-fed croplands varies significantly by region. The urban and non-urban irrigated croplands in South and East Asia covers respectively 49% and 56% of urban irrigated croplands worldwide. Also, 26 % of urban rainfed croplands and 22 % of non-urban rainfed croplands are located in these same two regions. Developed nations make up 44 % of urban rainfed croplands but just 20 % of irrigated croplands in cities. Less than 1 % of urban irrigated and 3 % of urban rainfed croplands are located in Sub-Saharan Africa, although 14 % of non-urban rainfed croplands do. These patterns contrast with that of Asia, where more croplands are found close to metropolitan areas (Thebo *et al*., 2016). Urban croplands statistics are dominated by regions with the greatest irrigated or rainfed cropland. However, it is challenging to directly compare regions because of the large variations in the real size of urban areas in each. By dividing urban farmland area by urban extension land area, it is possible to identify the nations where croplands occupy a greater share of urban land. Urban land allocation for rainfed and irrigated croplands shows different patterns. A bigger percentage of the urban area extent is typically used for irrigated croplands in regions with larger expanses of irrigated farmland. While less dry nations like Namibia and Saudi Arabia have little to no rainfed urban croplands, the fraction of urban area extent used for rainfed croplands closely matches with the regional climate trends. Rainfed croplands make up a larger share of urban land in nations with drier or rainy season climates, such Rwanda and Cambodia (Thebo *et al*., 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The geographical location of the Wa Municipality is presented in figure 3.1. The Wa Municipality is located in the southern part of the Upper West Region of Ghana with Wa as the regional capital. The landmass is about 579 km^2 which falls within latitudes 9º 55″ N and 10º 25″ N and longitude 1º 10″ W and 2º 5″ W. It is boarded to the east by Wa East district, south-west by Wa west district, and to the north by Nadwoli-Kaleo district. The landmass constitutes about 8.3 % of the Upper West Region’s land area. Peasant farming is the main source of income for the inhabitants. Agriculture makes up the majority of the Municipality's economy, followed by trade and industry such as fashion designer, weavers, smock makers and bakers (Ghana Statistical Service, 2010).

The only water supply system in Wa is the Ghana Water Company Limited and its only limited within the Municipality. The existing Wa water supply system relies on groundwater extraction from 24 boreholes situated in four well fields to the north, south, and south-west of Wa. The boreholes have 55,000 m^3 as an average monthly yield (https://www.gwcl.com.gh/upper-west/.

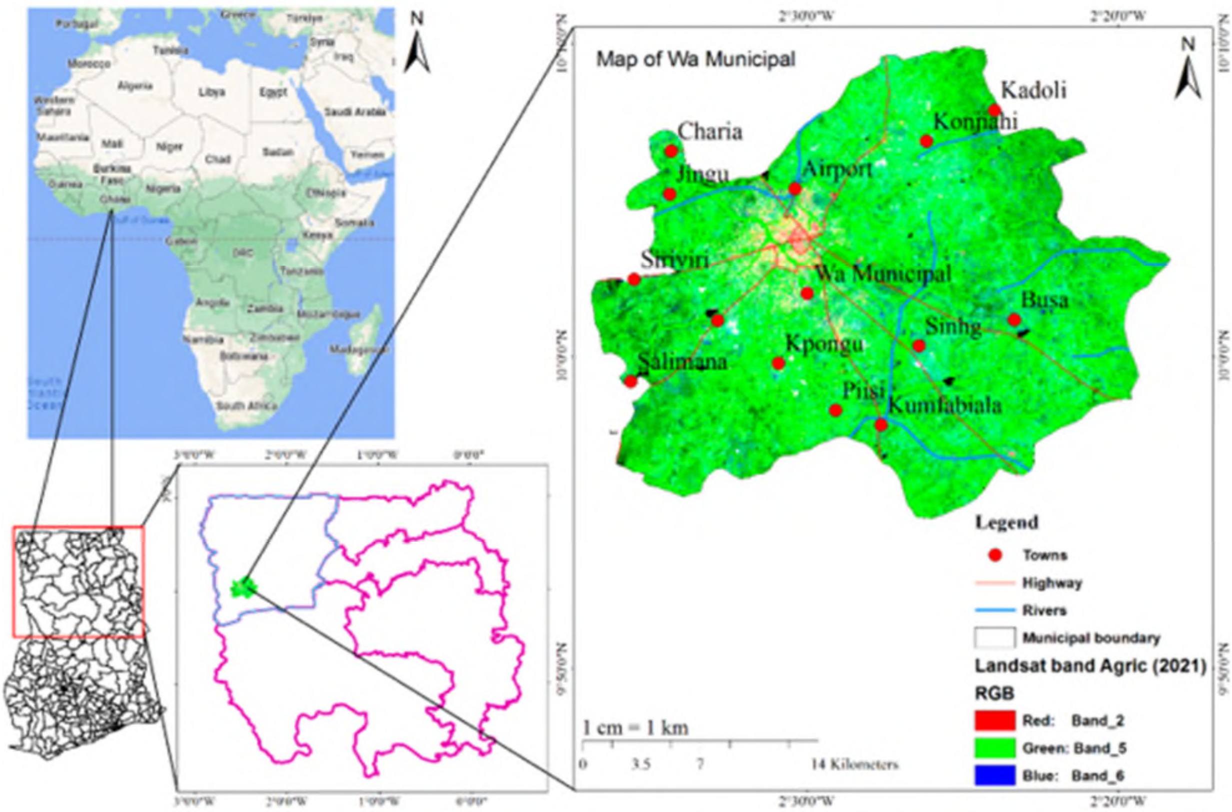

Figure 3.1: Map of Study Area

3.1.1 Topography and Drainage

The Municipality is located in the Savannah high plains, which are typically gently undulating and range in elevation from 160 to 300 meters above sea level (Ghana Statistical Service, 2010). The geography doesn't seem to be an obstacle to agriculture and other physical development, based on the gradual rolling character of the region. The following localities have low elevation; Piisi, Dapouha, Boli, Sing, Biihe, and Busa in the south and Charia, Zingu, and Kperisi in the north (Ghana Statistical Service, 2010). These take the form of valleys that, during the rainy season, collect and hold onto water, making them ideal for the growth of rice and the raising of livestock (Ghana Statistical Service, 2010). The Sing-Bakpong River and its stream and the Billi and its streams are two more drainage systems that have developed as a result of these low elevated terrain. The streams dry up during the prolonged dry season, lowering the amount of water available for use in agriculture, residential use, industry, and construction (Ghana Statistical Service, 2010).

3.1.2 Climate

The Municipality typically experiences just one rainy season from May to October. Annual rainfall measurements range from 750 to 1050 mm. The dry season lasts from November through March or April. High temperatures are typical for the area, with daytime highs of 42 °C and nightly lows of 23 °C. Cooler temperatures are felt in the harmattan winter (December to late February), when the North-East Trade winds affect the area (Loh *et al*., 2020). Due to the harsh weather patterns and low humidity levels of the harmattan, surface waters and soil surfaces become drier, which diminishes the ability for infiltration and lowers recharge to the subsurface aquifer.

2.1.3 Geology

The principal rock types that underlie the study region are the Birimian Supergroup and its accompanying intrusive granitoid. According to Junner (1940), this supergroup is separated into an older upper Birimian formed of metavolcanic rocks and an earlier lower Birimian composed of metasedimentary rocks. Lower Birimian metasedimentary rocks include silicified phyllites, sandstones, slates, and greywackes with turbidite characteristics at the end of the Upper Birimian. The Upper Birimian composed of basaltic and andesitic rocks that underwent metamorphism to produce hornblende-actinolite schists, calcareous schists, and greenstones (Kesse, 1985). The Birimian aquifers' ability to hold water and produce yields is based on faults, veins and fractures. According to Yidana *et al*. (2012), the interconnection of these fissures can produce abundant aquifers with transmissivities ranging from 0.2 to 119 m^2/d, storativity ranges from 0.003 to 0.008, and borehole yields ranging from 0.48 to 36.4 m^3/d.

3.1.4 Vegetation

The Wa township has the characteristics of the Guinea Savannah vegetation, which made up of short grasses, bushes, sporadic fire-resistant and commercially significant trees which includes; shea (*Vitellaria paradoxa*), dawadawa (*Parkia biglobosa*), and baobab (*Adansonia digitata*) (Ghana Statistical Service, 2010). Grazing animals frequently overgraze the grassland. The prolonged dry season is accompanied by practices like indiscriminate tree-felling for fuel. The land becomes bare as a result of these human activities, making it more vulnerable to wind and water erosion as well as high runoff during rainfall (Ghana Statistical Service, 2010).

3.1.5 Soils

Sand, clay, and laterite ochrosols are the soil types present in the research region; these soil types are appropriate for producing cereals and root crops when organic manure and synthetic fertilizers are used. There is great potential to enhance agricultural practices in the Municipality if excellent farming methods and irrigation are implemented (Ghana Statistical Service, 2010).

3.2 Data Acquisition

The data used for the study and their sources are presented in Table 3.1

Table 3.1: Data Source

Data	Data Source	Thematic Map
Digital Elevation Model	www.usgs.earthexplorer.gov	Slope Drainage density Lineament density Elevation TWI
Geological shapefile	Ghana geological survey	Lithology
Rainfall	Ghana Meteorological Agency	Rainfall
Landsat 8 OLI	www.usgs.earthexplorer.gov	Landuse and landcover
Soil shapefile	International Soil Reference And Information Centre (ISRIC, 2011) website (www.isric.org)	Soil
Tube well data	Community Water and Sanitation Agency (CWSA)	Validation

3.3 Research Design

Six (6) steps were used to delineate areas of groundwater potential in the area of study. The first step involved data acquisition, processing and thematic map generation. A reclassification of thematic maps followed by assigning weights to them in order of their importance to groundwater occurrence using a multi-criteria decision-making tool, in other words Analytic Hierarchy Process (AHP). The reclassified maps were integrated by overlaying to delineate potential groundwater zones. Existing groundwater data were then used in validating these zones. The receiver operating characteristic (ROC) curve was employed for the AHP model validation. ROC represents the relationship between true positive rate (TPR) and false positive rate (FPR). TPR is another name for sensitivity which is defined as

$$\text{TPR} = \left(1 - \frac{\text{TP}}{TP+FP}\right) \text{ ….. ………………………………………….. Eqn 3.1}$$

Where:

TP - true positive

FP - false positive

Figure 3.2 is an illustration of the method used in this research.

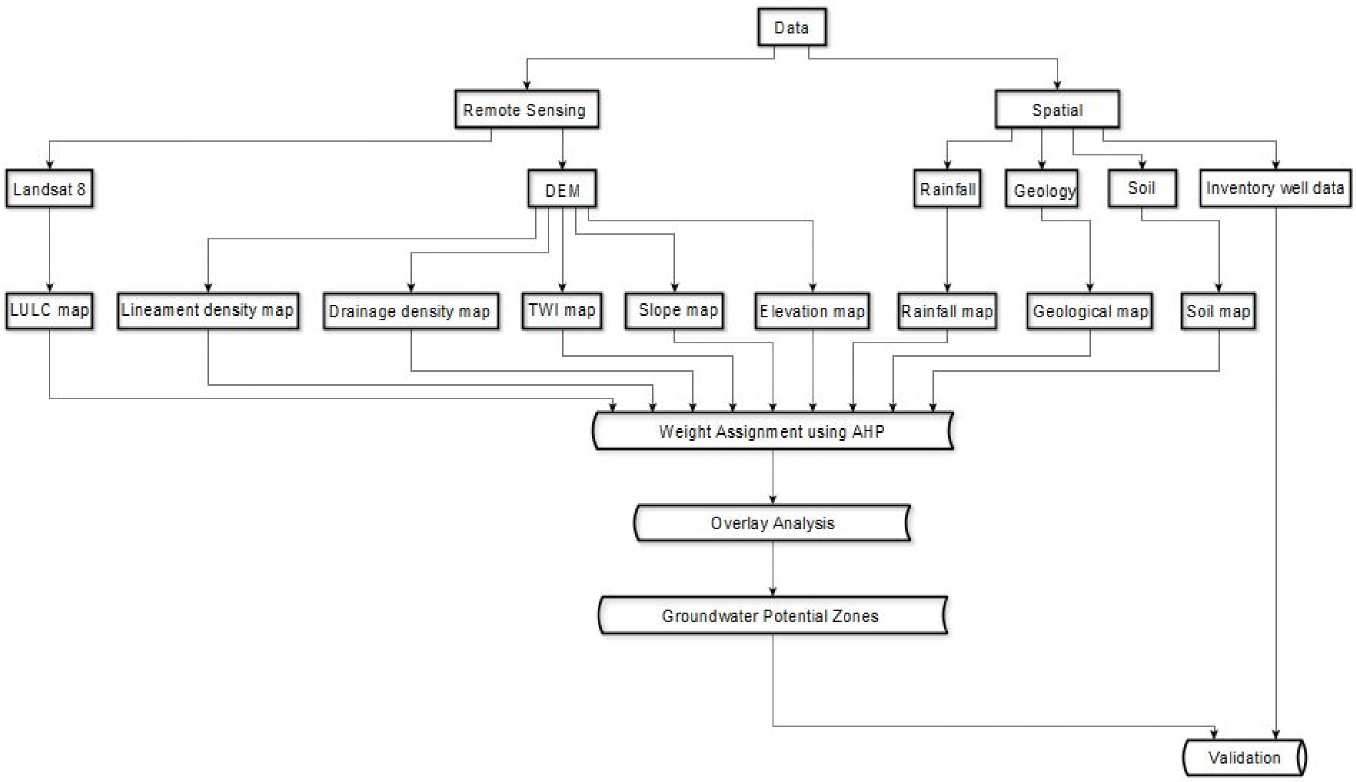

Figure 3.2: Flowchart for Delineating Groundwater Potential Zones in the Wa Municipality

3.3.1 Ground Water Potential Occurrence Assessment

In modelling groundwater, it is imperative to consider the factors that control the availability, movement and storage. The occurrence of groundwater depends on factors such as landuse and landcover, lineament density, Topography Wetness Index, drainage density, elevation, geology, soil, slope and rainfall (Oh *et al*., 2011).

3.3.2 Thematic Layers for the Model

In many research, personal judgment has been employed to assign weights to various thematic factors and their properties, which makes the type and number of factors utilized for delineating groundwater potential by RS and GIS somewhat different from one research to another research (Shekhar and Pandey, 2015). This study used nine (9) criteria such as geology, landuse and landcover, soil type, lineament density, elevation, drainage density, slope, topographic wetness index and rainfall. These layers were integrated using the weighted overlay method in ArcMap 10.8 software. The Analytics Hierarchy Process (AHP) was used in the weight assignment. All the layers were projected to WGS_1984_UTM_Zone_30 N and were all resampled at 30 m of resolution to fit for the overlay.

3.3.2.1 Extraction of Geological information

The aquifers with sedimentary fractures and the basement from the Precambrian, both of which have high local groundwater output, are what define the research area. Understanding the hydrogeological and geological conditions of the research region is crucial for the sustainable and effective groundwater extraction for irrigation (Kyiebaya *et al*., 2020). The geological map of the

Wa Municipality was clipped from the geological shapefile of Ghana using the clip tool from the ArcToolbox of ArcMap. The geology map of the study area was then changed to raster and reclassified using the conversion and reclassification tool from the ArcToolbox. The lithological classes present in the study area were Tamnean Plutonic suite, Birimian supergroup, Eburnean plutonic suite and Mesozoic. Details of the geological units presented in appendix 9.

3.3.2.2 Landuse and Landcover Classification

Landsat image for 2021 was acquired for the Landuse and Landcover (LULC) classification. The maximum likelihood classification algorithm in ArcMap was utilized to recognize and categorize the pixels into LULC classes. In this type of classification, training samples were selected, which enabled the classification and allowed for the attainment of various LULC features. Agriculture (6,5,2), Natural-color (4,3,2), and Color Infrared (5,4,3) are the band combinations of Landsat 8 and were used to classify the general nature of the study area (Liu *et al*., 2018). The ground-truth visualization of the study area was done using google earth pro and also a field visit. Using classification techniques, the pixels in the satellite images were divided into each of the LULC classes and signature file created (Alshari and Gawali, 2021). The study area was classified into six (6) classes which includes; vegetation, forest, bare land, settlements, water bodies and agricultural lands in order to create the LULC map. According to this viewpoint, forest areas are place where trees grow closely together and create a dense canopy. Where various plant species including shrubs and grasses thrive in the absence of a forest canopy was classified as vegetation cover. Some of these regions might eventually turn into farms or towns. Settlements are places where people are housed, in farm, urban, or rural communities. Rivers, streams, dams, and dugouts are examples of waterbodies that was classified. Agricultural land also includes areas used for rainfed farming, irrigation and animal grazing. Barelands are areas including rocky areas and areas without landcover where the soils are barely exposed to runoff and erosion. The classification algorithm that was employed is the maximum likelihood classification algorithm which has been indicated in research as one of the most conventional method used for classification of satellite images with a higher accuracy (Liu *et al*., 2018; Adongo *et al*., 2020). Figure 3.3 presents the landuse and landcover classes that were mapped of Wa Municipality

Vegetation

Agriculture Land

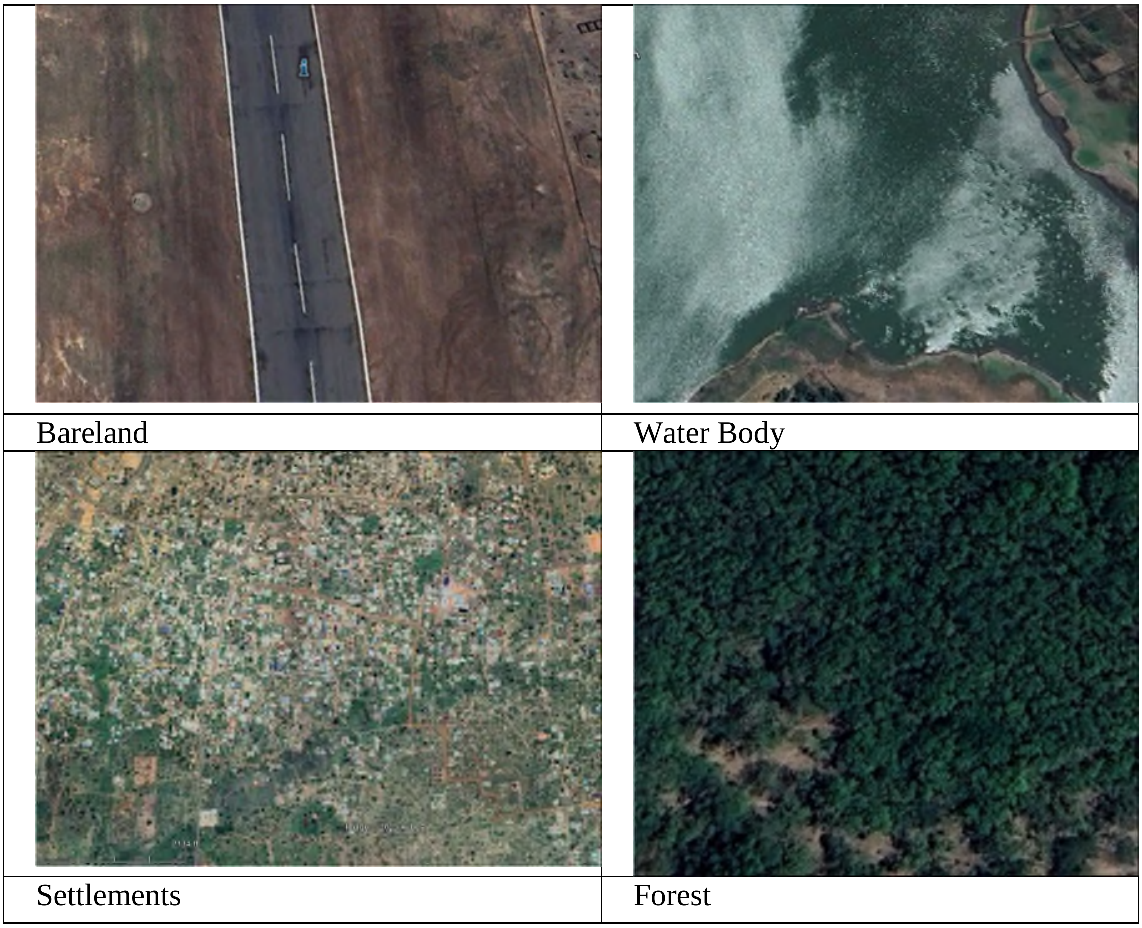

Figure 3.3: LULC Classes of Wa Municipality

Accuracy assessment in landuse and landcover (LULC) mapping is very important because it indicates the degree of correct representation of features classified on the map and the ground-truth features of that area. Base on this, 301 points were created on the various classified classes then convert to *kml file* which was then imported into google earth pro for ground-truth verification for areas that are inaccessible. The producer accuracy, user accuracy, overall accuracy and the Kappa coefficient were then computed using the confusion matrix (Rwanga and Ndambuki, 2017; Wahile *et al*., 2022) (Appendix 8). The Kappa coefficient has been used by many researchers in classification accuracy assessment (Foody, 2020). The total number of right pixels in a category was divided by the total number of pixels in that category as deduced from the total producer to determine the producer's accuracy. This process shows the likelihood that a reference pixel will be accurately identified. By dividing the total number of correctly classified pixels in a category by the total amount of pixels that were classified in that category (total user), one may calculate the user's accuracy, which is a measure of producer accuracy. This method is a reliability indicator that shows the likelihood that a pixel identified on a map or image actually corresponds to that category on the ground. The overall accuracy was calculated by dividing the total correctly classified pixel by the total number of reference pixels (Jog and Dixit, 2016). The Kappa coefficient was calculated using equation 3.2:

$$\text{Kappa coefficient} = \frac{N\sum_{i}^{r} Xij - \sum_{i-1}^{r}(Xi + * X + i)}{N^{2} - \sum_{i-1}^{r}(Xi + * X + i)} \qquad \text{………………….. Eqn 3.2}$$

3.3.2.3 Extraction of Soil information

The study area map was masked from the International Soil Reference and Information Centre (ISRIC) soil shapefile. The soil map was then reclassified for weight assigning and integration with other thematic layers. The soil type found in the study area were the ferric luvisols and lithosols.

3.3.2.4 Lineament Density Determination

According to Magesh *et al*. (2012), the lineament density can be calculated as the sum of all lineaments per square kilometer (km/km^2). The lineament density was therefore calculated using the formular given in equation 3.3.

$$LD = \sum_{i-1}^{n} \frac{Li}{A} \quad \text{.. Eqn 3.3}$$

Where:

LD - Lineament density,

L - Lineament length (km),

i = Lineament number, and

A = Area covered by the lineament (km^2).

Using the hillshade (Appendix 1) feature in ArcGIS 10.3, the lineament density map of the study area was produced from the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM). The lineaments (Appendix 3) were easily visible after hillshading using the Azuthimal combinations of (315 - 45), (200 - 45), (170 - 60), and (55 - 90). The line density was developed after the fractures are drawn as polylines using the editor's keys.

3.3.2.5 Preparation of Elevation data

The Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM), which was acquired from the Earth Explorer website, provided the elevation of the study region. The elevation was then reclassified using the reclassify tool in the ArcToolbox for weight assigning and overlay analysis.

3.3.2.6 Drainage Density Delineation

Drainage density is the measure of the proximity of streams and other similar water bodies. The SRTM DEM was used to delineate the drainage density of the area. Understanding and evaluating aspects of runoff possibility, relief, groundwater penetration, and permeability information are made possible by the knowledge of this variable, which provides an adequate numerical estimate (Roy *et al*., 2020). The drainage density was obtained using the "Hydrology Tool" in ArcMap, following the procedures for Fill DEM, Flow Direction, Flow Accumulation, Stream network (Appendix 2) Stream Order (Appendix 4), and Stream to Feature. The line density tool was finally applied to obtained the drainage density map. The drainage density was reclassified into five (5) classes using natural breaks. Drainage density (km/km^2) was calculated with the Line Density Tool and the Stream Network using equation 3.4 as given by Ifediegwu (2022).

$$D = \sum_{i-1}^{n} \frac{Di}{A} \quad \text{………………………………… Eqn 3.4}$$

Where:

D – drainage density

Di - the total length of the entire streams in stream order i (km), and

A - the basin area (km^2).

3.3.2.7 Creation of Slope Map

The slope map was made from the DEM using the surface of the spatial analyst tool. The slope was classified and reclassified into five (5) classes using natural breaks for the weighted overlay analysis.

3.3.2.8 Topographic Wetness Index (TWI) Determination

The TWI was determined using equation 3.5 (Melese and Belay, 2022):

$$TWI = In(\frac{As}{\tan \beta}) \quad \text{……………………………...Eqn 3.5}$$

Where, the slope is equal to β, and *As* is the total upslope area draining via a point (per unit contour length) gradient (in degree). The *ln tan* index takes into account the propensity of water to collect at each location in the catchment and the propensity of gravitational forces to carry that water down slope. Water infiltration is primarily influenced by the strength of the soil and material characteristics like permeability and pore water pressure (Razandi *et al.*, 2015). In this study, TWI was therefore considered to be one of the influencing groundwater potentials. The TWI map for the study area was developed using the raster calculator by the algorithm of Flow Direction, Flow accumulation, Slope (slope (DEM) *1.570796) / 90, Tan_slope = con (slope > 0, tan (slope), 0.001), Flow accumulation scaled TWI = In (Flow accumulation scaled / tan_slope).

3.3.2.9 Interpolation of Rainfall data

Historical rainfall data (1991-2021) was interpolated using the inverse distance weight (IDW) interpolation tool in the ArcMap toolbox to produce the rainfall distribution map of the study area. The layer was reclassified for integration with the other layers by weight assignment. Areas with higher precipitation possibly may have potentials for groundwater.

3.4 Relevance of Physical and Environmental Factors in the Occurrence of Groundwater

To determine the impact of physical and environmental factor on the groundwater potential occurrence, weights were assigned to the various factors.

3.4.1 Weight Assignment to the Thematic Factors

Nine (9) factors which included; geology, Rainfall, LULC, Soil, slope, lineament density, drainage density and elevation were chosen in this study to delineate the zones where groundwater occur. These nine (9) factors were integrated using the overlay analysis tool in ArcMap where weights were assigned to them according to their intensity in the Municipality and the of level of influence in groundwater occurrences. The weight assignment procedure made use of the AHP. Analytic Hierarchy Process is a tool used in difficult settings for critical decision-making such as groundwater studies (Mustapha *et al.*, 2023) where the criterion with the highest impact on groundwater potential is identified by the experts owns judgement and knowledge of the physical and environmental factors (thematic factors) of the study area. Using the pairwise comparison matrix, the various factors and their classes were paired, compared and ranked based on their relative importance on groundwater potential.

Saaty's Scale of Relative Importance (Table 3.2) was therefore used for rating (1-9) the thematic factors and their classes based on their level of importance in terms of their influences on groundwater potential. The thematic maps were then overlaid to produce the groundwater potential zones with classes of very low, low, high and very high potential.

Table 3.2: Scale of Relative Importance

Level of Importance	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6 and 8	Middle values

A consistency ratio was calculated to determine whether the weights of the various thematic factors and their subclasses were consistent. The consistency index (CI) (Eqn. 3.6) and random consistency index (RCI) were used to produce the consistency ratio (CR) as given in eqn. 3.6 (Saaty, 1980).

$CR = \frac{CI}{RCI}$ ………………………………………………… Eqn 3.6

Where: the consistency index (CI) was determined by applying the primary eigen value (Saaty, 1980).

$CI = \frac{\lambda max - n}{n-1}$ ………………………………………………… Eqn 3.7

Where, λmax is denoted as the consistency vector and n as the quantity of layers utilized.

A consistency ratio of 0.088 was obtained. A consistency ratio smaller or equal to 0.1 is deemed as acceptable for more than 4x4 matrix whereas a CR greater than 0.1 is unacceptable and the process need to be revise. This indicates clearly that the weighs assigned were consistent, hence a valid result.

3.5 Computation of Groundwater Potential Index

The ground water potential index was obtained using GIS overlay analysis after all the theme maps were created. An area's groundwater potential zones can be predicted using GWPI, which is a dimensionless quantity. Research conducted by Shekhar and Pandey (2015) utilized a weighted linear combination approach (Table 3.2) to calculate the GWPI as given in given in equation 3.8:

$$GWPI = \sum_{j-1}^{m} \sum_{i-1}^{n} Wj * Xi \quad \text{.................................} \quad \text{Eqn 3.8}$$

Where:

GWPI- groundwater potential index

Wj -the normalized weight of the jth layer,

n - the total number of classes in each layer, and

m - the overall number of thematic layers and

Xi - the rank value for each class.

The Groundwater water potential zone was calculated using equation 3.9.

$$\mathrm{GWPZ} = \mathrm{GGw} * \mathrm{GGr} + \mathrm{RFw} * \mathrm{RFr} + \mathrm{TWIw} * \mathrm{TWIr} + \mathrm{LDw} * \mathrm{LDr} + \mathrm{LULCw} * \mathrm{LULCr} + \mathrm{DDw} * \mathrm{DDr} + \mathrm{ELw} * \mathrm{ELr} + \mathrm{SLw} * \mathrm{SLr} + \mathrm{SOw} * \mathrm{SOr} \quad \text{.................................. Eqn 3.9}$$

Where: GWPZ - Groundwater potential zone, w - weigh, r - rate, GG - geology, RF - rainfall, TWI - topographic wetness index, LD - lineament density, LULC - landuse landcover, DD - drainage density, EL - elevation, SL - slope and SO - soil.

Table 3.3 presents the groundwater potential index

Table 3.3 Groundwater Potential Index *(Adopted from Shekhar and Pandey, 2015)*

Value	Groundwater Potential Index Interpretation
4	Very high
3	High
2	Moderate
1	Low

3.6 Validation

3.6.1 Validation of Groundwater Potential Zones

Hydrogeological data such as static water level and the tube well water yield data for 40 tube wells were obtained from the Community Water and Sanitation Agency of Wa. This data was interpolated in the ArcMap 10.8 using the IDW tool. The static water level data, the well water yield and well depth data were employed for cross validation of the GWPZs (Nithya *et al*., 2019; Abdullateef *et al.*, 2021; Mustapha *et al*., 2023).

3.6.2 Analytic Hierarchy Process (AHP) Model Validation

Prediction accuracy was done using the receiver operating characteristic curve (ROC) and area under curve (AUC) value (Mustapha *et al*., 2023). Many researchers such as Dar *et al*. (2021); Makonyo and Msabi (2021); Alrawi *et al*. (2022); and Melese and Belay (2022) have employed the ROC in AHP model validation in recent groundwater studies.

3.7 Groundwater Quality Determination

Water quality data from 53 tube well samples were acquired from the Ghana Water Company Limited at Wa Municipality (GWCL-Wa, 2013). Physiochemical parameters such as electrical conductivity (EC), Ammonia (NH_4-N), potential hydrogen (pH), Turbidity, total iron, calcium hardness ($CaCO_3$), magnesium hardness (MH), total hardness (TH), Sodium, total dissolved solids (TDS), chlorine, Total iron (Fe), Nitrate (NO_3-N), Manganese (Mn) Nitrite (NO_2-N) and Fluoride were among the groundwater quality characteristics that were examined.

3.7.1 Geospatial Modelling of Groundwater Suitability for Irrigation

Groundwater suitability maps for agricultural use have been produced by a number of authors using a variety of interpolation techniques (Chaudhary and Satheeshkumar, 2018; Rawat *et al*., 2018; Tolche, 2020). Using ArcGIS 10.8, this research employed the kriging and Inverse Distance Weight (IDW) techniques.

In determining the groundwater suitability for irrigation purposes, the following parameters were overlaid by weight assignment according to their relevance using ArcMap 10.8: Sodium Absorption Ratio (SAR), Magnesium Hazard (MH), Total Dissolved Solids (TDS), Kelly ratio (KR) and Electrical Conductivity (EC). The sodium adsorption ratio (SAR), percent sodium (Na %), Kelly ratio (KR) and magnesium hazard (MH) were calculated using eqn 3.10, 3.11 and 3.12 respectively. These parameters were visualized, reclassified and overlaid using ArcMap 10.8. The weighted overlay methodology was used to integrate these irrigation suitability parameters to produce an irrigation suitability map. However, to use for the overlay analysis, all thematic maps were reclassified with same resolution into five equal intervals for them to be compactible. Then, by giving each layer a weight by way of ranking that accumulated all up to 100 %. The rationale of ranking is the weighing of the utmost important water quality indicator that determines the efficiency of a groundwater-based irrigable system.

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \text{ (Richards, 1954) .... Eqn 3.10}$$

$$Percent\ Sodium\ (Na\ \%) = \frac{Na^{2+}}{Na^{2+}+K^{+}Ca^{2+}+Mg^{2+}} x100 \text{ (Wilcox, 1955) .... Eqn 3.11}$$

$$Magnisium\ hazard\ (MH) = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \text{ (Szabolcs and Darab, 1964) .... Eqn 3.12}$$

$$Kelly\ Ratio\ (KR) = \frac{Na^{+}}{[Ca^{2+}+Mg^{2+}]} \text{ .... Eqn 3.13}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Factors Controlling Groundwater Occurrences

The factors controlling groundwater occurrences are discussed in the following sub-headings.

4.1.1 Influence of Geology on Groundwater Occurrence in the study area

Figure 4.1 presents the geological map of the study area. The classes of the geology present in the study area were Tamnean Plutonic suite (250 m^2), Birimian supergroup (231 km^2), Eburnean plutonic suite (86 km^2) and Mesozoic (11.6 km^2). Communities such as Busa, Biliboo, Kperisi, Jonga and Guli are underlain by the Tamnean plutonic suite. The Tamnean plutonic suite is consolidated and cannot hold water due to lack of secondary or primary porosity and permeability. The Birimian supergroup are underlying rocks in the Bamahu, Kpaguri, Piisi, Charia, Dobile and Sombo areas. The Birimian groups rocks of Ghana have high potential for groundwater because of their porous nature, and presence of fractures for water permeability and infiltration, (Yidana *et al*., 2012). According to a study by Abdul-Ganiyu and Kpiebaya (2020), the Birimain groups rock in Wa has a yield of 0.55 L/s and an average drilling success rate of 80 %. Geology was therefore ranked first with the highest normalize principal eigenvector of 19.94 % due to the magnitude of influence on groundwater occurrence in the research area. The recharge process, which is influenced by the geological features of a region, affects the presence and availability of groundwater (Zarate *et al*., 2021). Similarly, another study indicated that lithology plays a critical role in the occurrences of groundwater in a catchment (Bhuvaneswaran *et al*., 2015).

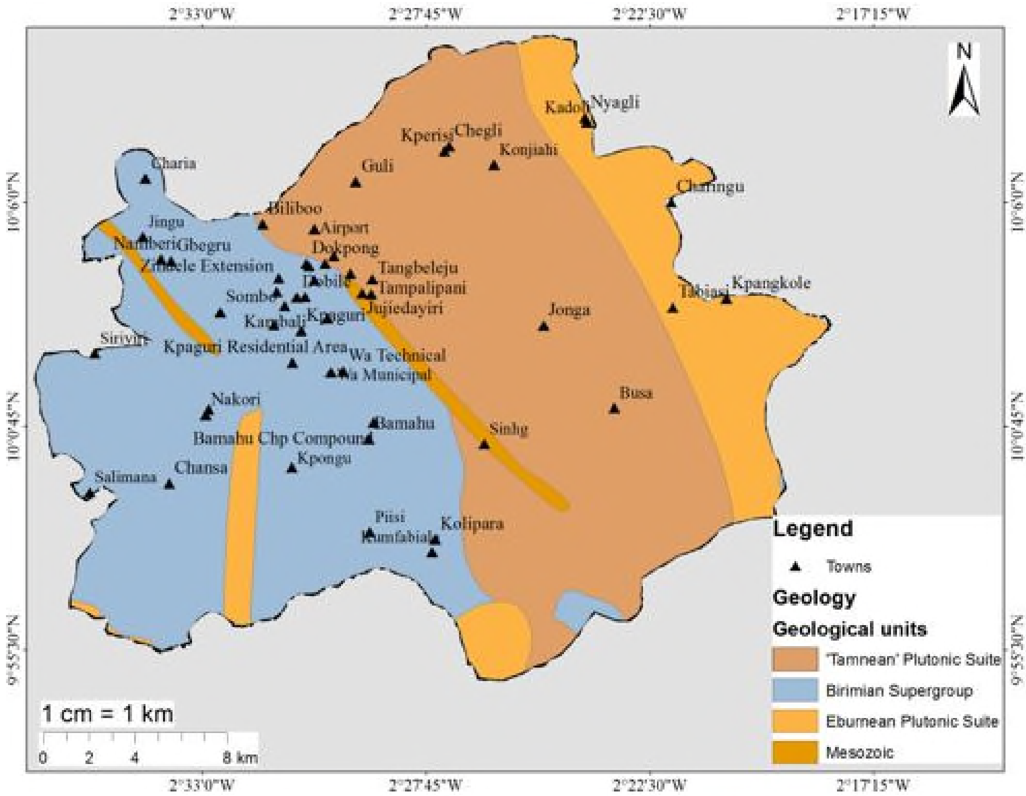

Figure 4.1: Geological Map of Wa Municipality

4.1.2 Influence of Landuse and Landcover on Groundwater Occurrence in the study area

The landuse and landcover (LULC) map of the study area is presented in figure 4.2. The percentage and area coverage of the various LULC classes are presented in Table 4.1. Agricultural land covers the larges area (44.96 %), followed by vegetation (28.89 %) and forest (12.97 %). The overall accuracy of the landuse and landcover map assessed was 84.72 % and Kappa coefficient of 0.96 (Appendix 10). The landuse and landcover has a good chance of having groundwater occurrence due to the impediment created by the general vegetation cover against runoff, making room for high infiltration. However, the water body was given the highest priority during ranking of the classes because there is more groundwater recharge in those areas. According to Das (2019), areas with a lot of habitation such as Dondoli, Dobile, Bamahu, Sombo may have low potential due to industrialization and urbanization, but areas with a lot of flora and deep forests suggest significant groundwater potential sites because of significant rainfall infiltration and percolation. Also, areas with bare land may also have low potential. The agriculture, forest and vegetative areas may have potential as vegetation and crops creates impediment against runoff. As noted by Abdelaziz *et al.* (2020), forest and agricultural land has impact on groundwater availability. The landuse and landcover of a region offers data on the environment and establishes groundwater dependency through water penetration (Elango, 2017; Abdelouhed *et al*., 2021). It was therefore imperative to consider the LULC in the groundwater assessment because of its effect in infiltration and runoff (Al-gburi, 2022).

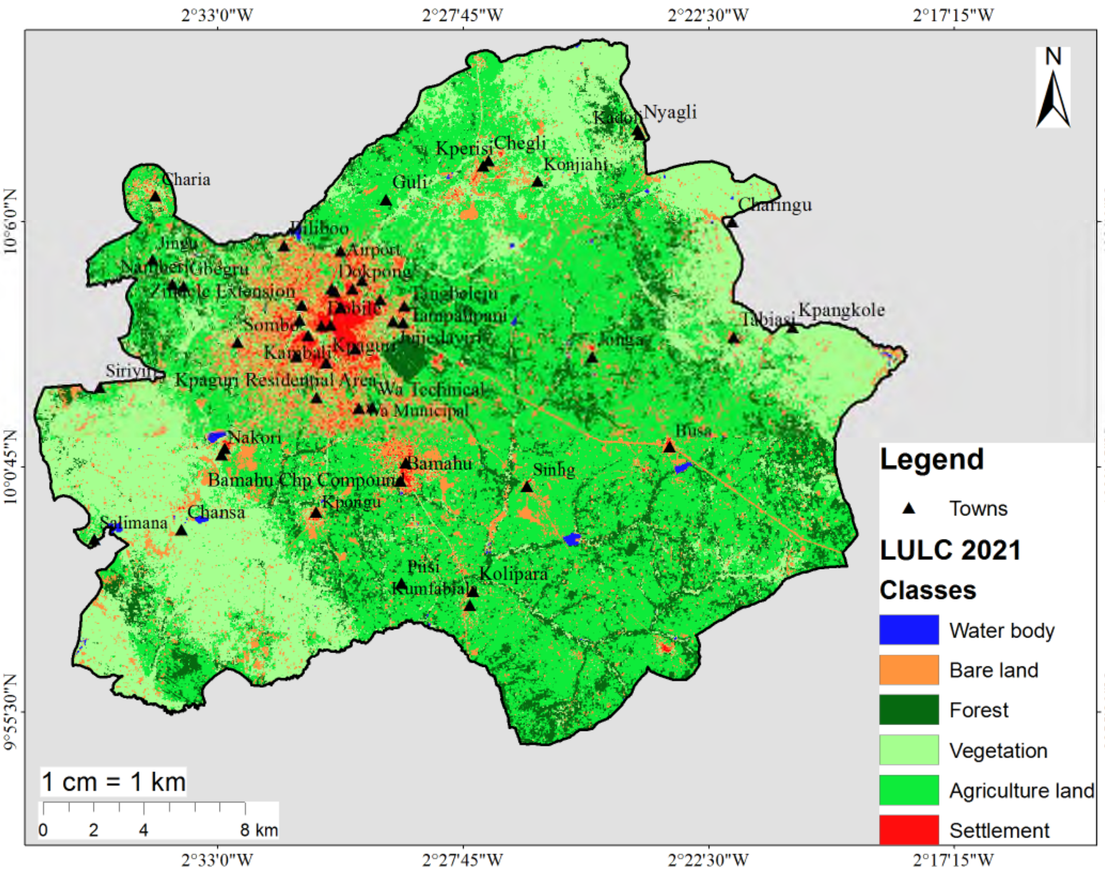

Figure 4.2: LULC Map of Wa Municipality

Table 4.1: Landuse and Landcover (LULC) Areal Coverage

S/N	Name	Area (km^2)	Percentage (%)
1	Waterbodies	1.64	0.28
2	Bare land	66.84	11.54
3	Forest	75.13	12.97
4	Vegetation	167.38	28.89
5	Agriculture land	260.46	44.96
6	Settlement	7.84	1.35
	Total	**579.29**	**100.00**

4.1.3 The Influence of Soil types on Groundwater Recharge in the Area

Presented in Figure 4.3 is the soil map of the study area. The soil type found in the study area are the ferric luvisols representing 96.5 % of the total study area and lithosols which makes up of 3.5 % of the study area. The ferric Luvisols is found in all the communities in the municipality except Tabiasi and Kpangkole. The ferric luvisols has a considerable drainage property which will possibly have influence in groundwater recharge due to the fact that there will be less runoff and more infiltration. The porosity of the soil type influences the rate of infiltration and groundwater recharge. The ferric luvisols therefore has a potential for groundwater. Lithosols soil is a coarse-grained textured with macro pore spaces which allows easy infiltration of water into the ground. The lithosols therefore have a good potential for groundwater. Infiltration and recharge of groundwater is also influenced by the soil type (Falah and Zeinivand, 2019). According to Ifediegwu (2022), lithosols is well drained in nature which has more influence in the groundwater potential occurrences.

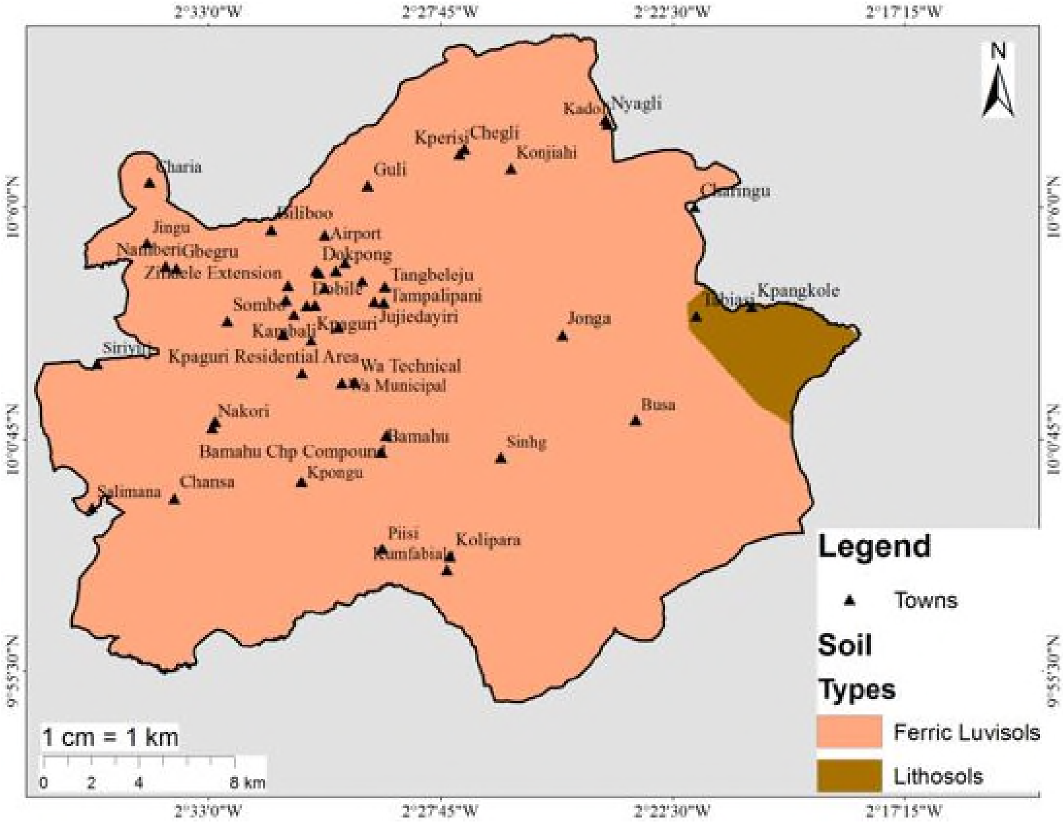

Figure 4.3: Soil Map of Wa Municipality

4.1.4 Influence of Lineament Density on Groundwater Occurrence in the Study Area

Figure 4.4 shows the lineament density map of the study area. The lineament density ranges from 0.00-0.32 km/km^2 (very low) 0.33-0.63 km/km^2 (low), 0.64-0.95 km/km^2 (moderate), 0.96-1.30 km/km^2 (high) and 1.40-1.60 km/km^2 (very high). The study area generally has a high lineament density. However, the very lineament density was found in areas such as Piisi, Biliboo, Nakori and Kpaguri which is an indication of fractures, joints and faults which allows infiltration and recharge of groundwater. The underlying rocks in these areas are the Birimian supergroup which has these characteristics of fractures, faults and joints. The availability of faults, joints and fractures on the basement rocks are typically an indication of occurrence groundwater storage in the area (Yidana *et al.*, 2015; Ahmed *et al.*, 2021). Lineaments can be utilized to distinguish between locations with pronounced weathered horizons. Hence, the basement rocks of the Wa Municipality have a high lineament density which suggest a very good ground for groundwater occurrences and storage (Steven *et al.*, 2022). The presence of groundwater is influenced by areas with increased lineament density because they make it easier for groundwater to infiltrate and recharge (Bhuvaneswaran *et al.*, 2015).

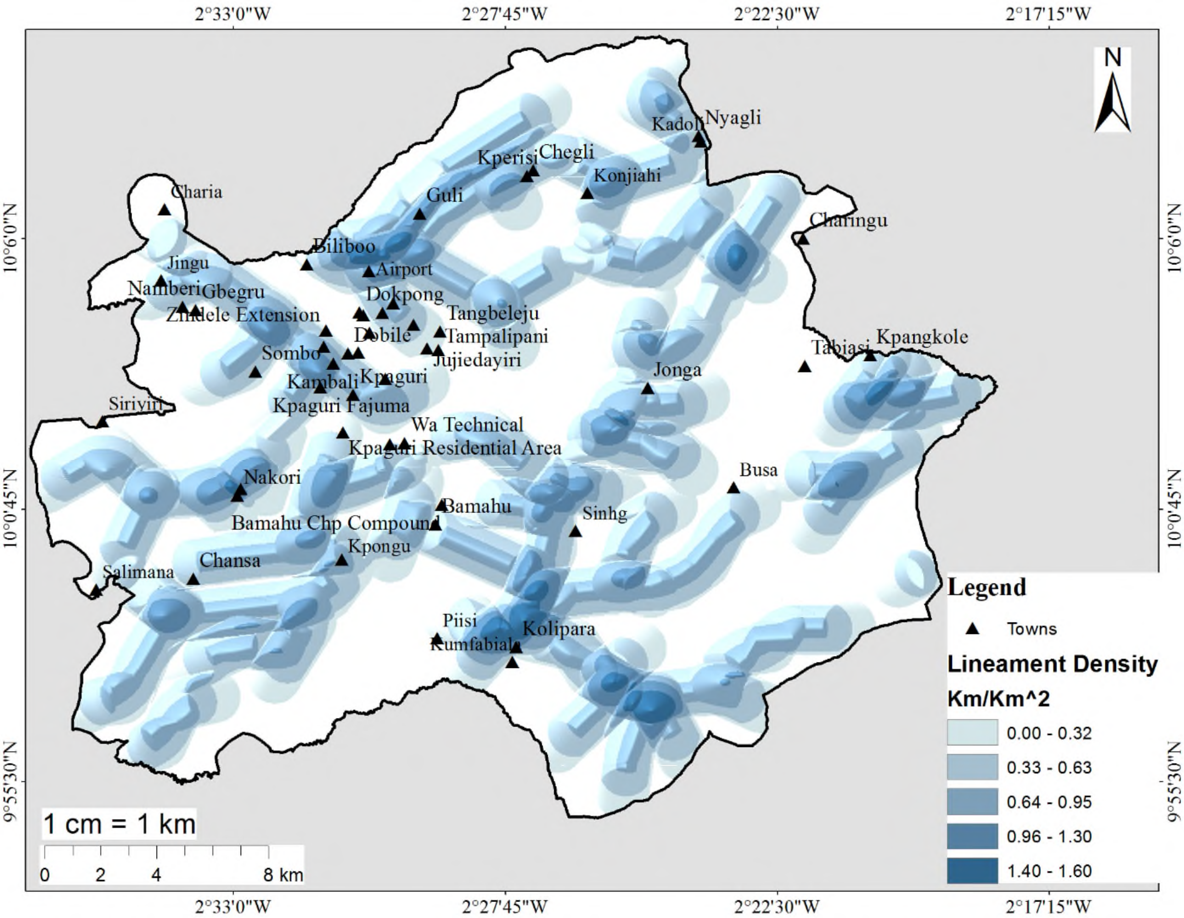

Figure 4.4: Lineament Density of Wa Municipality

4.1.5 Impact of Elevation on Groundwater Occurrence in the study area

Presented in figure 4.5 is the elevation map of the Wa Municipality. The elevation ranges from 248-283 m (very low), 283-301 m (low), 301-318 m (moderate), 318-335 m (high) and 335-369 m (very high). The very high elevated areas were found in Busa, Jonga, Tampalipani, Jujiedayiri, Kpaguri, Chegli, Kperisi and Konjiahi. While the very low elevated areas are found in Salimana, Piisi, Kumfabiala and Jingu. Runoff is high in areas of high elevation leading to low infiltration rate and the verse versa. Groundwater possibly occurred in areas of low elevation as a result of low runoff and high rate of infiltration. More weight was therefore assigned to the lowest elevation. Elevation plays an imperative role in the occurrence of groundwater due to its impact on runoff and infiltration (Al-gburi, 2022).

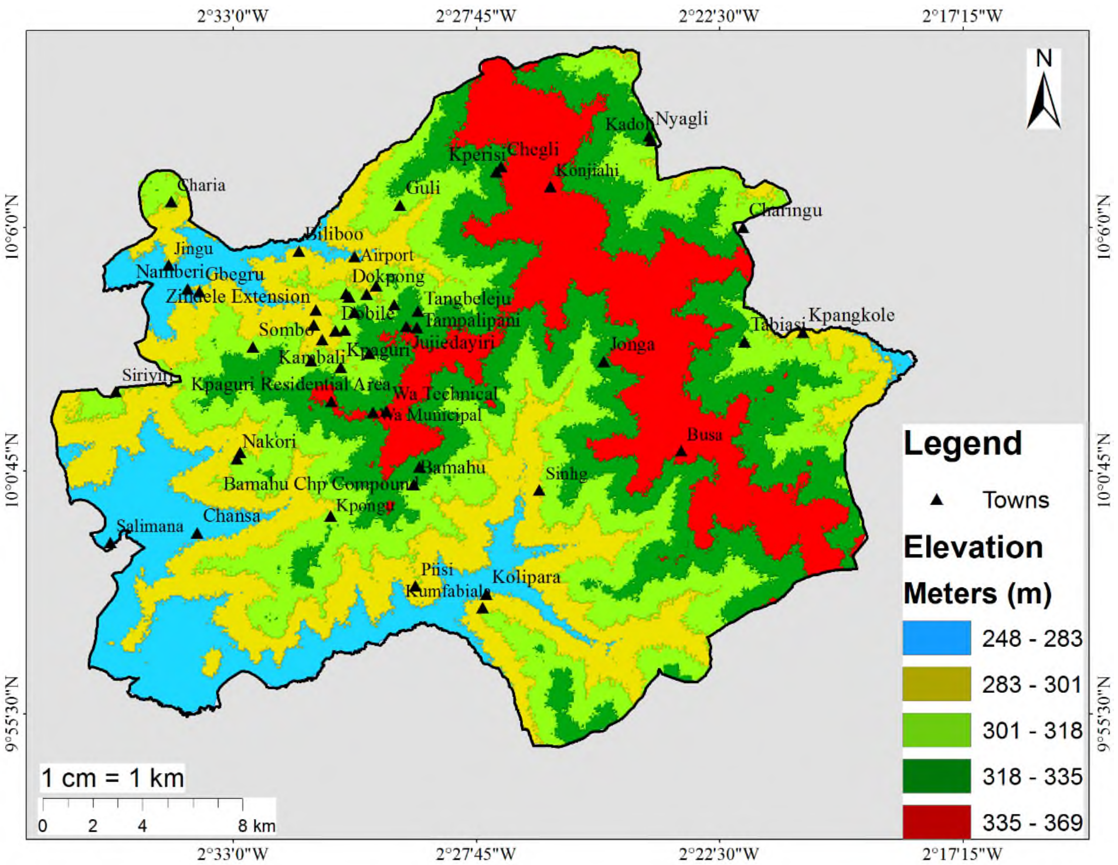

Figure 4.5: Elevation Map of Wa Municipality

4.1.6 Influence of Drainage Density on Groundwater Occurrence in the study area

Figure 4.6 presents the drainage density in the Wa Municipality. It ranges from 0.00 – 0.21, 0.22 – 0.54, 0.55 – 0.89, 0.90 – 1.30 and 1.40 – 2.00 km/km^2 representing very low, low, moderate, high, and very high drainage density respectively. It is observed that the Kperisi, Chegli, and Busa areas which are very high elevated areas have very low drainage density as compare to low elevated areas like Salimana. The very high drainage density is mostly found in low elevated areas like Kambali, Sinhg and Kolipara where there are valleys. The permeability nature of the Birimain and Eburnean rocks groups could be the contributing factor for low drainage density in areas such as Piisi, Biliboo, Kpongu and Bamahu. Shao *et al*., (2020) demonstrated that low drainage density is caused by the underneath rocks' high degree of permeability due to high penetration into the porous underlying rock. Groundwater zones are probable in locations with lower drainage densities, while higher drainage densities have lower potential for groundwater occurrence. Drainage density is an essential factor that affects the distribution and occurrence of groundwater. A high drainage density results in decreased infiltration and minor GWPZs, while a low drainage density result in high GWPZs. Typically, groundwater occurrence is inversely proportional to drainage density (Magesh *et al*., 2012; Shao *et al*., 2020; Saranya and Saravanan, 2020; Alrawi *et al*., 2022; Melese and Belay, 2022). However, a number of factors, including slope gradient, soil absorption capacity, rainfall, climate, vegetation cover, terrain, and subsurface properties, affect the drainage system (Mif *et al*., 2021).

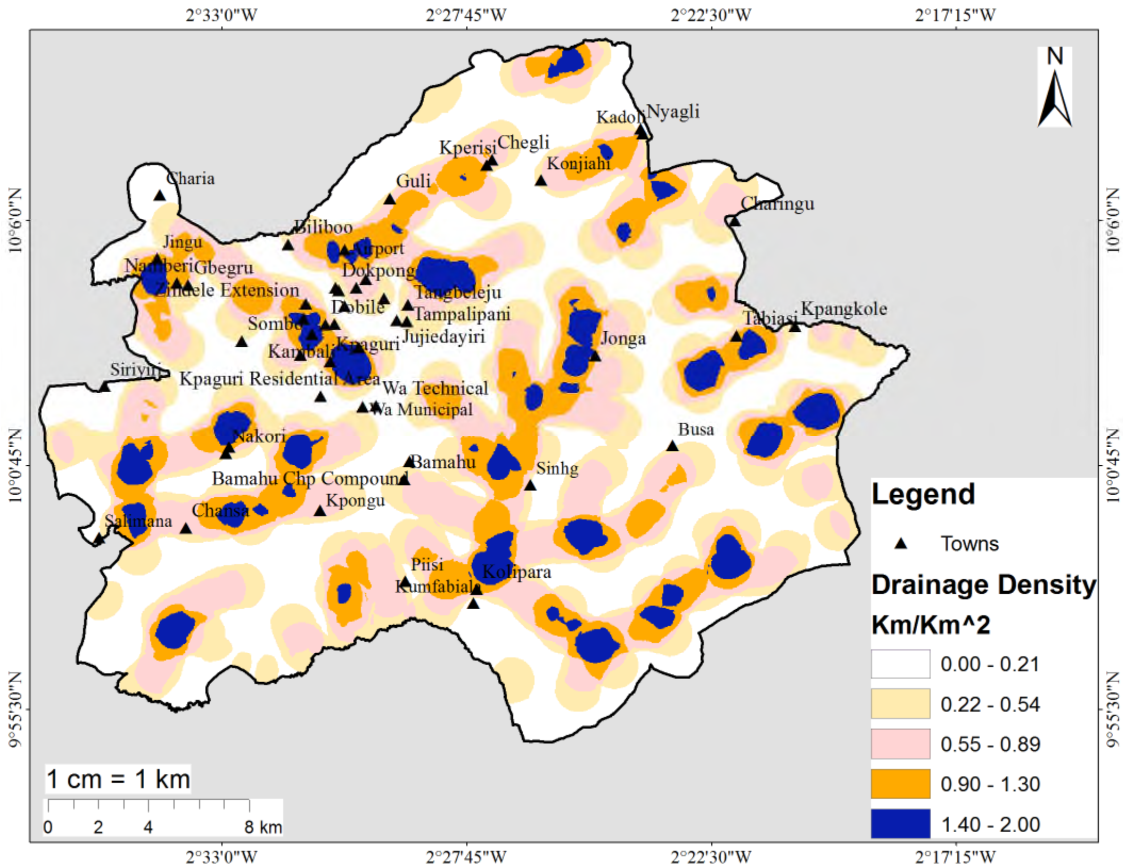

Figure 4.6: Drainage Density Map of Wa Municipality

4.1.7 Influence of Slope on Groundwater Occurrence in the study area

Presented in figure 4.8 is the slope of the Wa Municipality. The slope ranges from 0-1^0 (very low), 1-2^0 (low), 2-4^0 (moderate), 4-5^0 (high) and 5-18^0 (very high). The very high slope is found in areas such as Kpaguri, Chegli and generally at the eastern part of the municipality. The study area generally has a flat to a gentle slope and may not have much runoff than infiltration. There is an indirect relationship between slope and groundwater recharge potential.

High runoff is observed in steeply sloping areas as rainwater runs off rapidly on slope surfaces, with little or no infiltration or recharge. Groundwater potential is therefore low in these areas. However, flat and gently sloping areas have less runoff and high groundwater potential. Previous research which are consistent with this research had it that, gentle slopes have the affinity to hold rainfall longer to facilitate infiltration leading to groundwater recharge and possible occurrence (Abdullateef *et al*., 2021; Doke *et al*., 2021; Falowo *et al*., 2023). The nature of the topography directly influences rainfall infiltration and is considered and deemed as a cardinal factor in exploring groundwater occurrence (Manugula and Singh, 2022). The degree of the gradient of the slope in any area determines the amount of rainfall that is lost as runoff or that stays on the surface for some time to recharge the aquifers to determine the direction of groundwater recharge or flow in a particular basin *(*Al-Ruzouq *et al*., 2019; Tolche, 2020).

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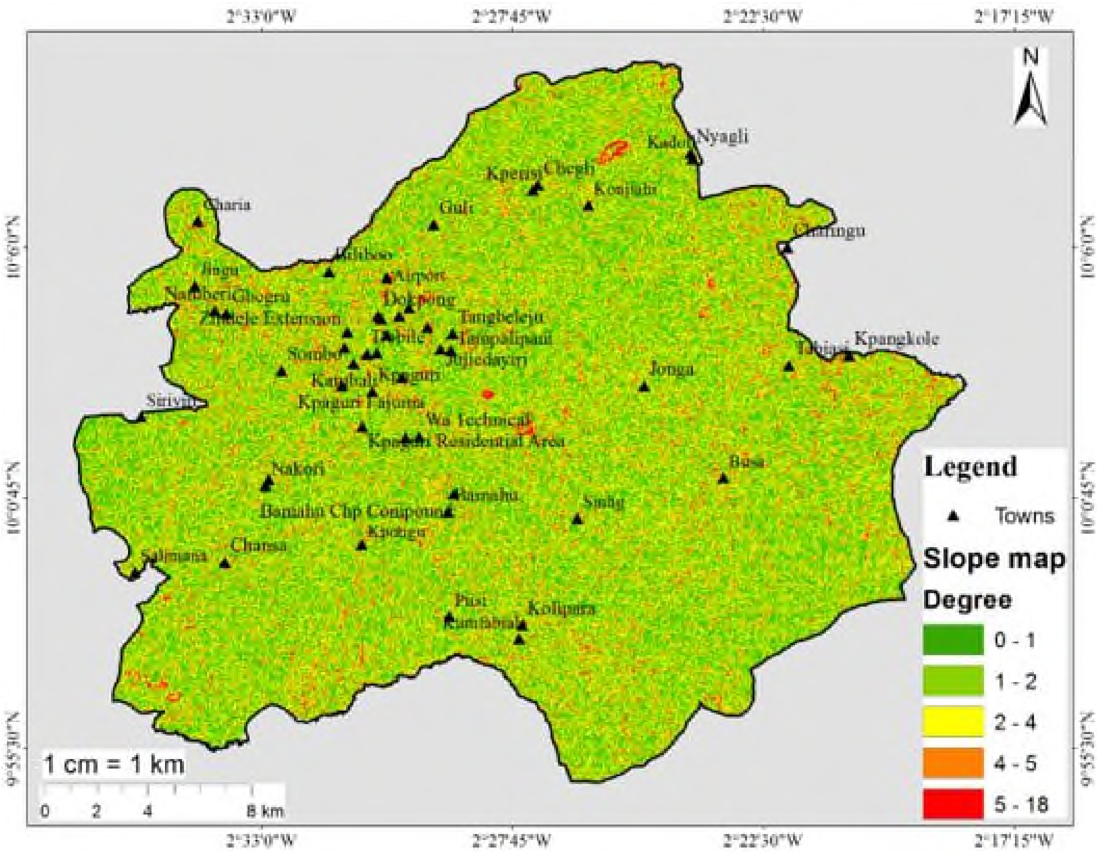

Figure 4.7: Slope Map of Wa Municipality

4.1.8 Influence of Topographic Wetness Index on Groundwater Occurrence in the study area

Figure 4.9 presents the TWI of the study area which ranges; 4.66-6.94 (Very low), 6.94-7.96 (Low), 7.96-9.31 (Moderate), 9.31-10.94 (High) and 10.94-16.51 (Very high). Generally, the topographic wetness index is evenly distributed from observation in the map. There is a positive relationship between TWI and groundwater because a higher TWI value indicates a high groundwater potential and vice versa (Arulbalaji *et al*., 2019; Yıldırım, 2021). Among the groundwater potential influencing factors is the Topographic Wetness Index (TWI). TWI has been extensively utilized to explain how topographic features affect the intensity and distribution of saturated zones that generate surface runoff (Razandi *et al.*, 2015; Razavi-termeh and Sadeghi-niaraki, 2019).

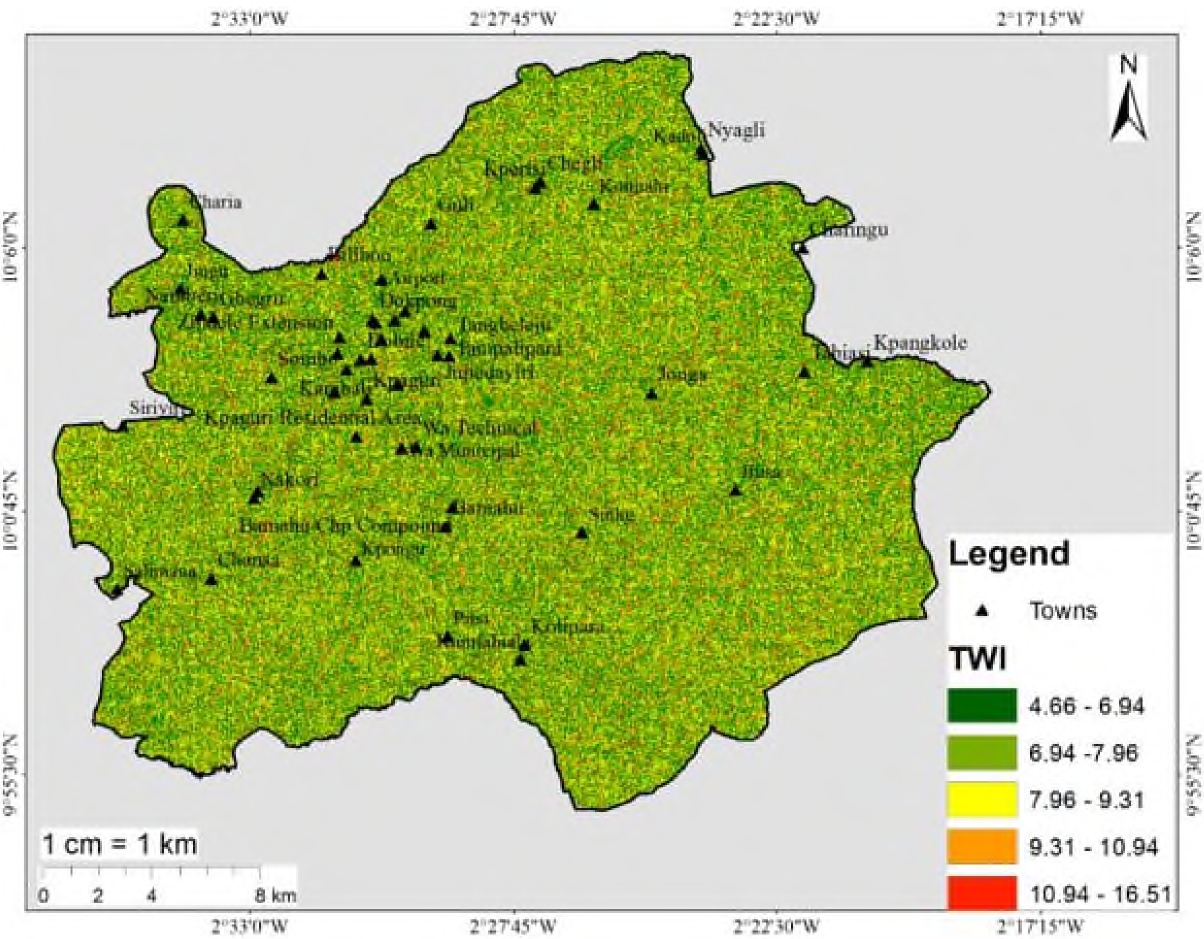

Figure 4.8: Topographic Wetness Index (TWI) of Wa Municipality

4.1.9 Influence of Rainfall on Groundwater Occurrence in the study area

Figure 4.9 presents the annual average rainfall in the municipality. The average annual rainfall ranged from 832-892 mm (very low), 892-938 mm (low), 938-990 mm (moderate), 990-1051 mm (high) and 990-1142 mm (very high). The average annual rainfall is found to have increased towards the western part of the municipality. The groundwater system is recharged by rainfall, which is one of the most significant sources of precipitation (Thapa *et al*., 2017; Models *et al*., 2021). This shows that areas with higher rainfall distribution have higher groundwater recharge provided there is less runoff. On the other hand, areas with lower annual rainfall distribution have less groundwater recharge. Rainfall is the major source of water for infiltration and percolation for groundwater recharge (Masroor *et al*., 2023).

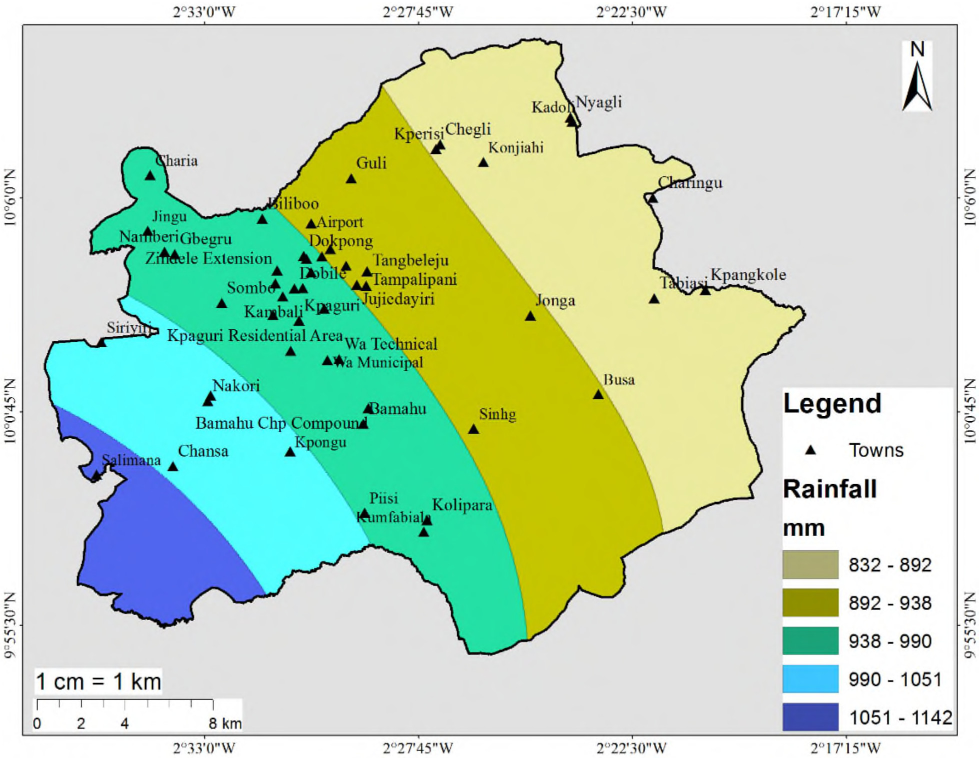

Figure 4.9: Rainfall of Wa Municipality

4.3 Mapping of Potential Zones for Groundwater

Table 4.2 presents the assigned normalized weight for the factors and their classes. Zones with potential groundwater were identified after integrating the various factors influencing groundwater water occurrence. The integration was done based on weigh assignment using the AHP established by Saaty, (1980). Table 4.3 presents the pairwise comparison matrix for the weight assignment. Geology was the most influential factor with a normalized principal eigenvector of 19.94 %. The second influential factor was lineament density with a normalized principal eigenvector of 18.92 %. Rainfall emerged as the third influential factor with a normalized principal eigenvector of 12.97 %. Drainage density, LULC, soil, TWI, slope and elevation had an influence with a normalized principal eigenvector of 10.25 %, 10.13 %, 9.98 %, 8.08 %, 5.85 % and 3.88 % respectively.

Table 4.2: Assigned Normalized Weight for the Factors and their Classes

Thematic Factor	Classes	Rank	Rate	Normalized weight of classes	Normalized weight of factors
Geology	Tamnean Plutonic suite	5	Poor	0.079	0.1994
	Birimian supergroup	9	Very good	0.716	
	Eburnean plutonic suite (Hornblende-biotite granitoid)	7	Good	0.145	
	Mesozoic (Mafic dyke, dolerite)	3	Very poor	0.06	
LULC	Agriculture land	3	Moderate	0.112	0.1013
	Bare land	1	Very poor	0.032	
	Forest	7	Good	0.288	
	Settlement	3	Poor	0.033	
	Vegetation	5	Good	0.143	
	Water body	9	Very good	0.391	
Soil	Ferric luvisols	5	Moderate	0.333	0.0980
	Lithosols	7	Very good	0.667	
Lineament density (km/km^2)	0.00-0.32	1	Very poor	0.513	0.1892
	0.33–0.63	3	Poor	0.261	
	0.64-0.95	5	Moderate	0.129	
	0.96-1.30	7	Good	0.063	
	1.40-1.60	9	Very good	0.033	
Elevation (m)	248-283	9	Very good	0.513	0.0388
	283-301	7	Good	0.261	
	301-318	5	Moderate	0.129	

	318-335	3	Poor	0.063	
	335-369	1	Very poor	0.033	
Drainage density (km/km^2)	0.00–0.21	9	Very good	0.507	0.1025
	0.22–0.54	7	Good	0.285	
	0.55–0.89	5	Moderate	0.124	
	0.90-1.30	3	Poor	0.046	
	1.40–2.00	1	Very poor	0.038	
Slope (^{0})	0-1	9	Very good	0.515	0.0585
	1-2	7	Good	0.264	
	2-4	5	Moderate	0.118	
	4-5	3	Poor	0.066	
	5-18	1	Very poor	0.037	
TWI	4.66-6.94	1	Very poor	0.09	0.0808
	6.94-7.96	3	Poor	0.114	
	7.96-9.31	5	Moderate	0.183	
	9.31-10.94	7	Good	0.271	
	10.94-16.51	9	Very good	0.342	
Rainfall (mm)	832-892	1	Very poor	0.079	0.1297
	892-938	3	Poor	0.112	
	938-990	5	Moderate	0.172	
	990-1,051	7	Good	0.267	
	1,051-1,142	9	Very good	0.366	

Table 4.3: Pairwise Comparison Matrix

Matrix		Geology 1	Rainfall 2	TWI 3	Lineament density 4	LULC 5	Drainage density 6	Elevation 7	Slope 8	Soil 9	0 10	normalized principal Eigenvector
Geology	1	1	3	3	1	3	2	5	3	1	-	19.94%
Rainfall	2	1/3	1	3	1/3	3	1	3	3	1	-	12.97%
TWI	3	1/3	1/3	1	1/3	1	1	5	1	1	-	8.08%
Lineament density	4	1	3	3	1	3	1	5	3	1	-	18.92%
LULC	5	1/3	1/3	1	1/3	1	3	5	1	1	-	10.13%
Drainage density	6	1/2	1	1	1	1/3	1	3	3	1	-	10.25%
Elevation	7	1/5	1/3	1/5	1/5	1/5	1/3	1	1	1	-	3.88%
Slope	8	1/3	1/3	1	1/3	1	1/3	1	1	1	-	5.85%
Soil	9	1	1	1	1	1	1	1	1	1	-	9.98%
0	10	-	-	-	-	-	-	-	-	-	1	0.00%

4.3.1 Groundwater Potential Zones, Distribution and Implications

Figure 4.11 shows the zones of potential groundwater delineated and table 4.4 presents the area and percentage coverage of the classes of potential zones. The very high groundwater potential zones represent 32.31 % (185.33 km^2) of the total municipality's area which is detected in areas such as Dondoli, Kpaguri, Nakori, Sombo, Kambali and Kolipara. A confirmation from a study carried out by Abdul-Ganiyu and Kpiebaya (2020) in the upper west region which clearly reported that communities such as Dondoli and Kpaguri have high potential for groundwater which could be tap for irrigation. However, this previous study used methods such as groundwater resistivity, overburden thickness, borehole success rate and groundwater pumping rate in their investigation, which is costly and takes time. Other areas such as Piisi and Kumfabiala are also very high potential areas which may be attributed to their very low elevation nature (Pande *et al.,* 2018) with very high lineament density and low drainage density. The very high potential area is generally underlain by the Birimian plutonic suite (Chegbeleh *et al*., 2020) with very high to average annual high rainfall (Masroor *et al*., 2023) and very high density of lineament manifesting fractures or faults with primary and secondary porosity. This confirms the findings of Danso and Ma (2023), which indicated that in zoning groundwater potential, high lineament density is a good prospect for high groundwater. The general vegetation cover of the area is an impediment for runoff, therefore contributing to recharge. Hence, the very high groundwater potential.

Also, the GWPZs map indicated 19.59 % (112.39 km^2) of the total area under study has a high groundwater potential. The high potential area is evenly distributed across the Wa Municipality. Except the far eastern part which is dominated by low potential due to the fact that there is a very low average annual rainfall at that area, high elevation, low density of lineament, Tamnean plutonic suite and high drainage density (Hagos and Andualem, 2021).

The moderate GWPZ occupies 22.69 % (130.15 km^2) of the Municipality's total area, and the low GWPZ represent 25.40 % (145.71 km^2). The far eastern part of the Municipality contains communities such as Nyagli, Tabiasi, Kpangkole, Kadoli, Konjiahi and Kperisi which are underlain by the Eburnean plutonic suite with very low rainfall of 832-892 mm and very high elevation of 335-369 m have low potential for groundwater which could be attributed to the high runoff with no or less infiltration.

The very low potential zones such Tampalipani and Namberi are underlain by Mesozoic which is a consolidated-impermeable rock with no primary and secondary porosity. Very low potential zones are also found in the municipal central such as Dobile, Dakpong and part of Kpaguri where there is dense settlement. This is due to the high runoff and less infiltration due to compaction and impediment created by housing roofs.

The outcome of the model exhibits a mirror image of the key elements that influence the prospective groundwater zone, such as geological formation, lineament density, rainfall, and elevation. This results clearly indicated that the physical and environmental factors have an impact on groundwater occurrence, movement and storage in the Wa Municipality.

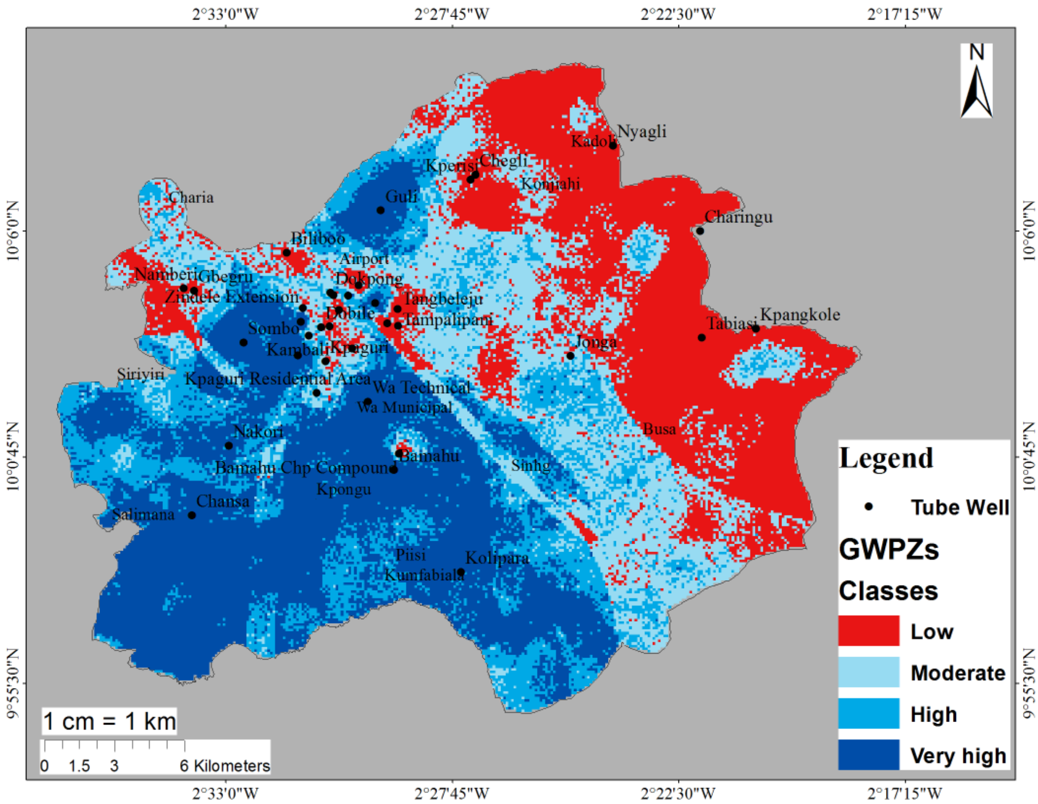

Figure 4.10: Groundwater Potential Zones in the Wa Municipality

Table 4.4: Areas and Percentages of GWPZs

Classes of GWPZs	**Area (Km^2)**	**Percentage (%)**
Low	145.71	25.40
Moderate	130.15	22.69
High	112.39	19.59
Very high	185.33	32.31

4.4 Validation of Zones of Potential Groundwater

4.4.1 Groundwater Yield

The yield of the sample wells is presented in figure 4.12. Tube wells at the eastern part of the Municipality such as Tabiasi, Nyagli, Kpangkole, Charingu, Kadoli and Jonga, has a low yield of 9 - 34 litres per minute (L/min) with an average well depth of 70 m which tallies with the groundwater potential zone map which indicated those areas have low and moderate GWP. The low GWP in those areas is also a reflection of the high elevation and a very low rainfall distribution of the area (figure 4.5 and 4.10). A very high (106 – 130 L/Min) yield is however found in the Wa Central to the western part in areas such as Kpongu, the Wa Technical, Dondoli, Kambali, Sombo and Bamahu which clearly reflect the GWP map which reveals these areas are very high potential areas for groundwater. Cross validation of the well yield classes with the groundwater potential classes reveals 7 wells of 8 in the very high yield (80-130 L/min) class were found in the zones of very high from the groundwater potential map. Only one (1) well was found in the high yielding (60-70 L/min) class which also conform with the resultant map. Also, 3 wells out of 5 in the moderate yield class correspond with the groundwater potential map. Finally, 19 wells out of 26 in the low yield class were found in the areas of low potential in the groundwater potential map. Averagely, 87 % of the sampled tube well yield data agrees with the delineated groundwater prospect map (Ifediegwu, 2022).

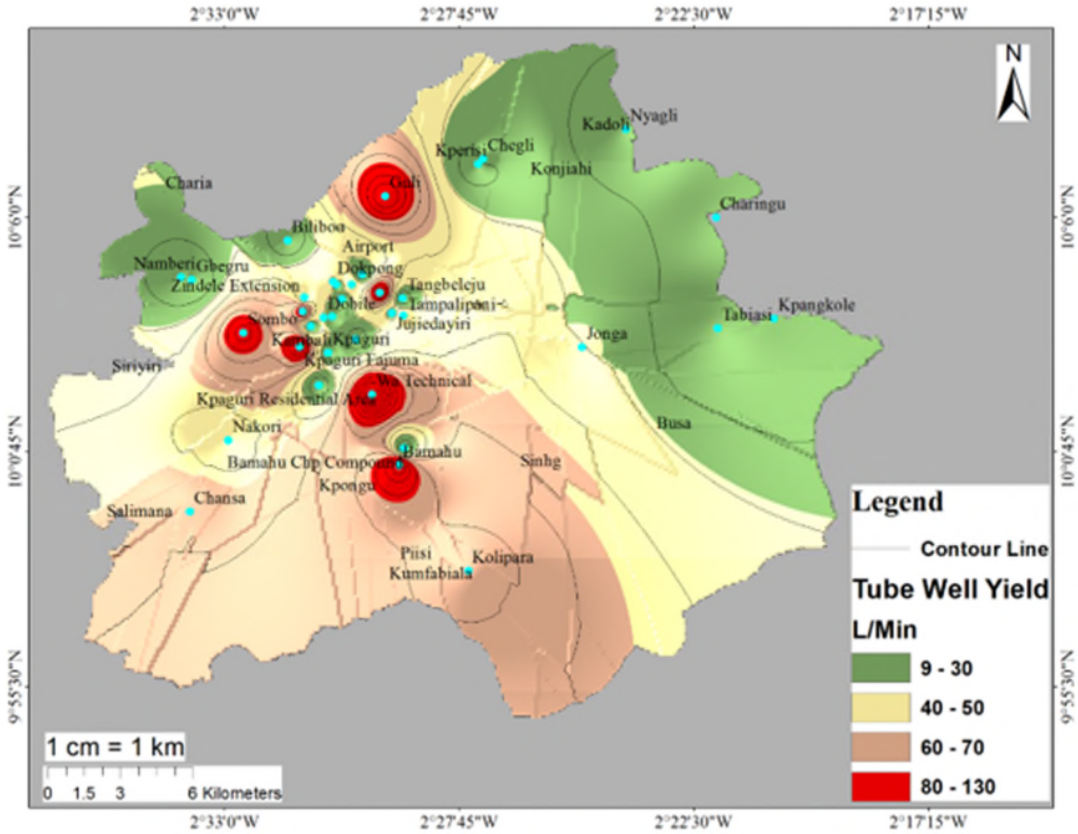

Figure 4.11: Groundwater Yield in Wa Municipality

4.4.2 Well Depth

Figure 4.13 and figure 4.14 shows the inventory well depth and static water level respectively in the municipality. Well depth is the final depth at which a tube well is drilled before striking water table in an aquifer. The drilling depth depends on the thickness of the regolith and the aquifer permeability of the area. The sample tube wells in the Wa Municipality have their depth classified into four which ranges from 33-59 m, 60-67 m, 68-74 m and 75-95 m. A very high yielding areas such as Piisi and Kumfabiala have very high drilling depth (75-95 m) contrary to other high yield areas. This conforms with the findings of Pudukkottai and Nadu (2023), which indicated that the water table in a catchment is influenced by the type or position of the aquifer system and that water table is closer to the surface in unconfined places and may have poor potential, but in confined aquifers the water table is lower but may possess substantial groundwater potential. It is therefore possible that those areas have a confined aquifer system. It is also possible the low yielding areas with higher water table have unconfined aquifers. Meanwhile, the static water level (3-9 m) at Piisi and Kumfabiala is very high confirming the area's excellent groundwater yield.

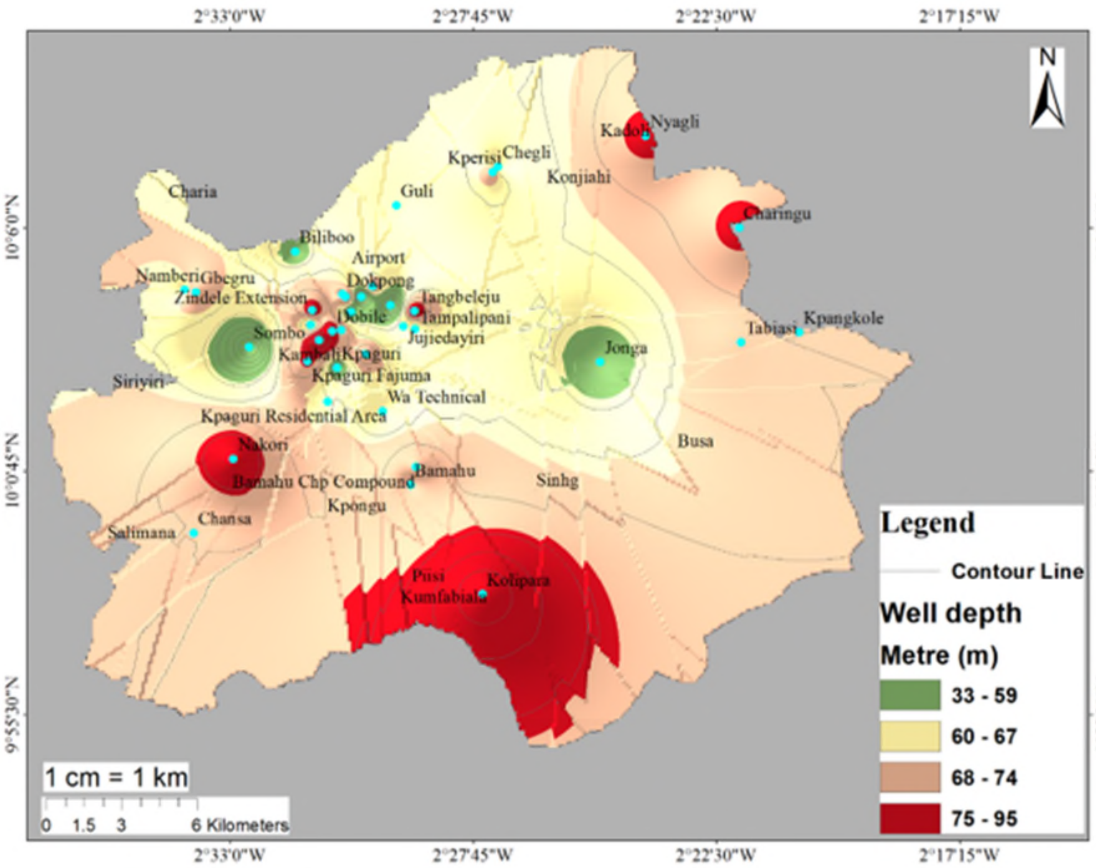

Figure 4.12: Well Depth in the Wa Municipality

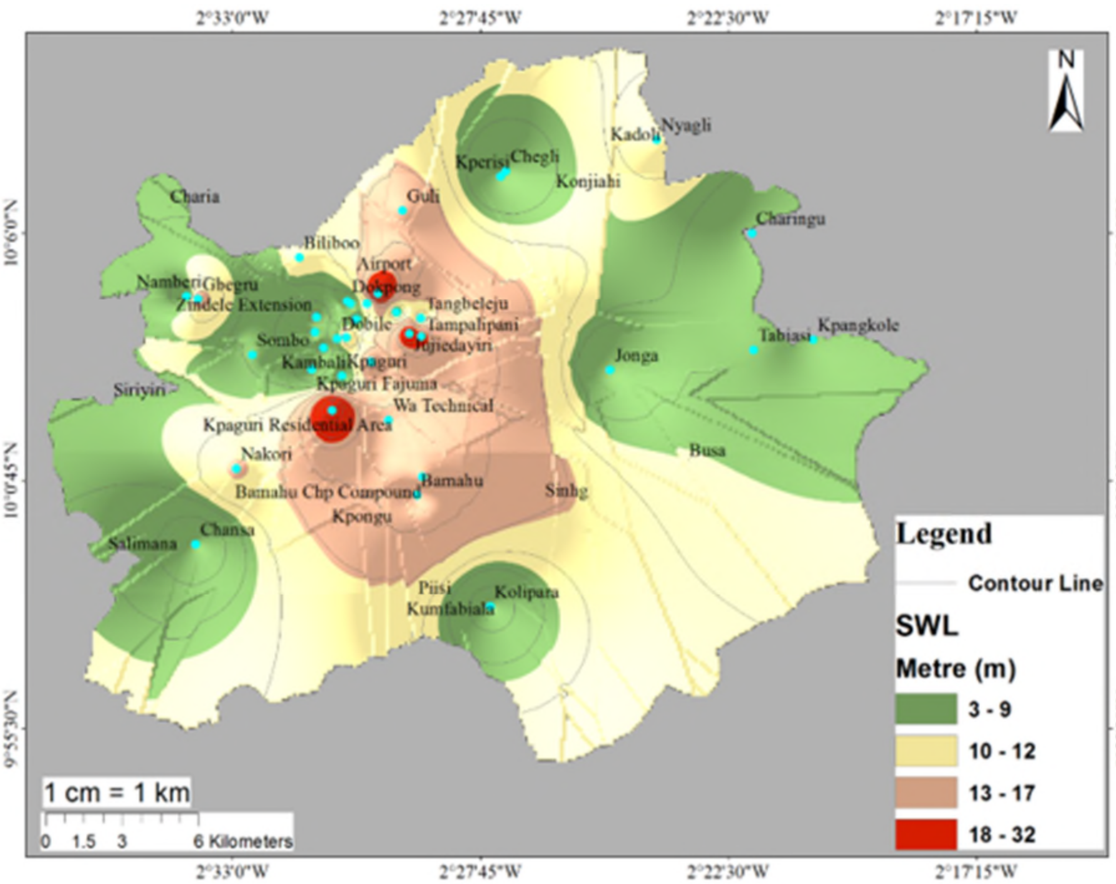

Figure 4.13: Static Water Level in Wa Municipality

4.4.3 Receiver Operating Characteristic (ROC)

As presented in Figure 4.13, the ROC displays a good AUC value of 0.703, which is between 0.70 and 0.80 and interpreted as satisfactory (Lee *et al.*, 2020). As a result, the implementation of the AHP model approach for the current investigation demonstrated a satisfactory accuracy of the spatial forecast of the groundwater potential.

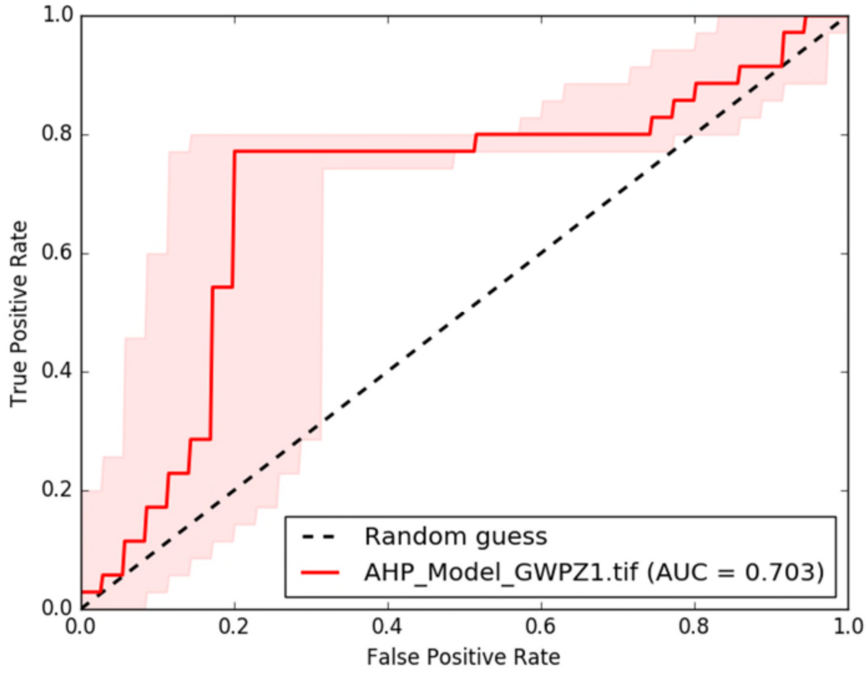

Figure 4.14: Receiver Operating Characteristic (ROC) Curve

4.5 Physiochemical Parameters of Groundwater

Table 4.5 presents the summary of the physio-chemical quality of groundwater in the municipality. The groundwater physio-chemical parameters of the Wa Municipality were assessed to determine its suitability for irrigation.

The range of sodium (Na) concentrations was found to be 9.1 to 199.9 (mg/L), the mean and standard deviation was arrived at 59.0 and 35.5 respectively (Table 4.7). These characteristics fell within the limits of the World Health Organization (WHO) Standard.

Calcium (Ca) concentrations vary from 4.8 to 68.9 (mg/L), the mean was 23.2 mg/L and standard deviation 6.2 mg/L (Table 4.7). The range of potassium (K) concentration was found to be 6 to 9.6 (mg/L) with a mean of 4.5 mg/L and standard deviation of 1.3 mg/L. This finding conforms with a similar study by Salifu *et al*. (2017), in the Upper West Region of Ghana with potassium (K) concentration ranging from 1.50 to 11.60 (mg/L) which is within the acceptable limit for irrigation.

The levels of magnesium (Mg) concentrations were found to range from 3.9 to 41.8 (mg/L), with 18.8 mg/L and 5.9 mg/L as the mean and standard deviation respectively (Table 4.7). Sulphate (SO_4) reduces the adsorption calcium by plants and increases potassium and sodium intake leading to cation instability in the crop (Salifu *et al*., 2017). The amount of SO_4 levels varied from 5.3 to 213 (mg/L) and the mean and standard deviation were arrived at 34.8 and 17.6 (mg/L) respectively (Table 4.7). The Sulphate (SO_4) concentration was found within the Food and Agriculture Organization (FAO) permissible limit for irrigation.

The alkalinity and acidity of a substance is a measure of pH. The spatial distribution of the pH is presented in appendix 6. The pH values ranged from 7.6 to 8.9 which is a little bit alkaline and did not fall within the permissible limit for irrigation. This could probably be caused by calcium carbonate leaching from the soil and rocks (Manu, *et al.*, 2023).

The nitrate (NO_3) level of concentration in the Municipality ranged from 0.2 to 5.2 (mg/L) and is recommended for irrigation by the Food and Agriculture Organization (FAO) standard. The total dissolve solid (TDS) was found to range from 4.4 to 627.9 (mg/L) falling within the Food and Agriculture Organization (FAO) standard of 2000 mg/L. This conforms with the findings of Sebiawu *et al*. (2014), in the Wa Municipality, who reported TDS values ranged from 100.1 to 304 (mg/L) which is within the FAO acceptable limit. This finding could be attributed to the fact that the Wa Municipality is mostly underlain by granite rock which takes time to decompose as reported by Salifu *et al*. (2017).

The spatial distribution of Iron (Fe) is presented in appendix 5. Iron (Fe) values range from 0.01 to 4.4 (mg/L) and mean and standard deviation of 0.4 mg/L and 0.2 mg/L respectively. The Fe concentrations were within the recommended standard for irrigation by the Food and Agriculture Organization (FAO). The presence of iron (Fe) could be as a result of peculation of deposit by water from the soil and geological formation (Ngah and Nwankwoala, 2013). Concentrations of ammonia ranged from 0.2 to 5.2 (mg/L), exceeding the recommended limit by the Food and Agriculture Organization (FAO). The concentrations of ammonia in this present study higher than geogenic values are a key sign of contamination from fecal matter (WHO, 2003). This could possibly be true due to leaching of fecal matter from open defecation and leaking septic tanks (Yahaya et al., 2021).

Table 4.5: Physio-Chemical Quality of Groundwater in the Municipality

S/N	Parameter	Units	Max	Min	Mean	Standard deviation	WHO Standard (WHO, 2011)	FAO Standard (FAO, 1985)
1	EC	µS/m	449.9	1.8	69.2	37.2	14.0	30
2	TH	mg/L	226	36	35.6	26.8	500.0	-
3	pH	-	8.9	7.6	8.0	0.2	6.5 - 8.5	6.5 - 8.5
4	Turbidity	NTU	87.3	1.1	12.8	8.2	5.0	25
5	TDS	mg/L	627.9	4.4	275.9	66.6	1000.0	2000

6	Ca^{2+}	mg/L	68.9	4.8	23.2	6.2	200.0	400
7	Mg^{2+}	mg/L	41.8	3.9	18.8	5.9	150.0	-
8	Na^{+}	mg/L	199.9	9.1	59.0	35.5	200.0	900
9	K^{+}	mg/L	9.7	6.0	4.5	1.3	30.0	-
10	F^{-}	mg/L	1.5	0.004	0.5	0.2	1.5	-
11	Cl^{-}	mg/L	174.8	4.0	14.6	9.8	250.0	1100
12	Mn	mg/L	0.06	0.005	0.02	0.01	0.4	0.2
13	SO_4	mg/L	213.8	5.3	34.8	17.6	250.0	1000
14	NO_3	mg/L	7.2	0.12	2.0	1.2	50.0	10
15	NH_3	mg/L	5.2	0.2	1.7	0.6	1.5	5
16	$CaCO_3$	mg/L	171.9	12	57.9	15.4	250.0	-
17	HCO_3	Mg/L	629.4	51.3	279.2	65.8	-	-
18	Fe	mg/L	4.4	0.01	0.4	0.2	0.3	5.0

4.5.1 Groundwater Suitability Mapping for Irrigation

Presented in Figure 4.14 is the irrigation water suitability map for study area. The variables evaluated as the key influencing elements in establishing the adequacy of the groundwater quality for irrigation were: Sodium Absorption Ratio (SAR), Magnesium Hazard (MH), Kelly's ratio (KR), Total Dissolved Solids (TDS), Percent Sodium (Na %) and Electrical Conductivity (EC). Sodium Absorption Ratio (SAR) values less than 26 (<26) is considered suitable and values greater than 26 (>26) are not permissible for irrigation. About 68.4 % of the samples were less than 26 (<26), which is desirable for irrigation. The remaining samples that were not desirable for irrigation represents 31.6 % of the total sample. SAR provides a better basis to determine the degree of hazard posed by sodium in irrigation water since it is directly related to the adsorption of sodium on surfaces of soils (Anim-Gyampo *et al.*, 2019).

In this study, 86 % of the samples had their percent sodium less than 80 % and it's regarded as desirable for irrigation. According to Wilcox (1955), values of percent Sodium (Na %) less than

80 % are suitable for crop growth. Anim-Gyampo *et al.* (2019), stated that high Na % causes compact and impervious soils obstructing crop growth. The remaining 14 % of the sampled area with percent sodium (Na %) greater than 80 % (>80 %) is therefore not permitted for irrigation. Magnesium Hazard (MH) values of the samples less than 50 (MH<50), is desirable for irrigation; if the values exceed 50 (MH>50), it is not desirable for irrigation. In the study area, 80.7 % of the samples were within the permissible limit (MH<50) for irrigation and the remaining 19.3 % which is greater than 50 is not desirable for irrigation (Szabolcs and Darab, 1964). High Mg ion has negative impact on the soil structure especially in high saline or sodic waters and may retard crop productivity (Srinivasamoorthy et al., 2013).

The suitable area mapped represents 77.41 % (448.43 km^2) of the study area. The less suitable area represents 20.74 % (120.12 km^2) of the study area and 1.85 % (10.74 km^2) representing the unsuitable area (Table 4.7). The ability of a crop to use nutrients is directly or indirectly affected by the chemical composition of irrigable water. The chemistry of irrigation water varies depending on the source and the geology of the area. For instance, soil water with a high salt content can be very harmful to crops since it alters their chemical reactions and slows down plant growth (Tekile, 2023). Knowing the quality of the irrigation water is important for determining what management strategies are required for continued efficiency (Jalali, 2011). Generally, the groundwater in the municipality is suitable for irrigation. However, turbidity, EC, pH, Fe and NH_3 were beyond WHO acceptable limits.

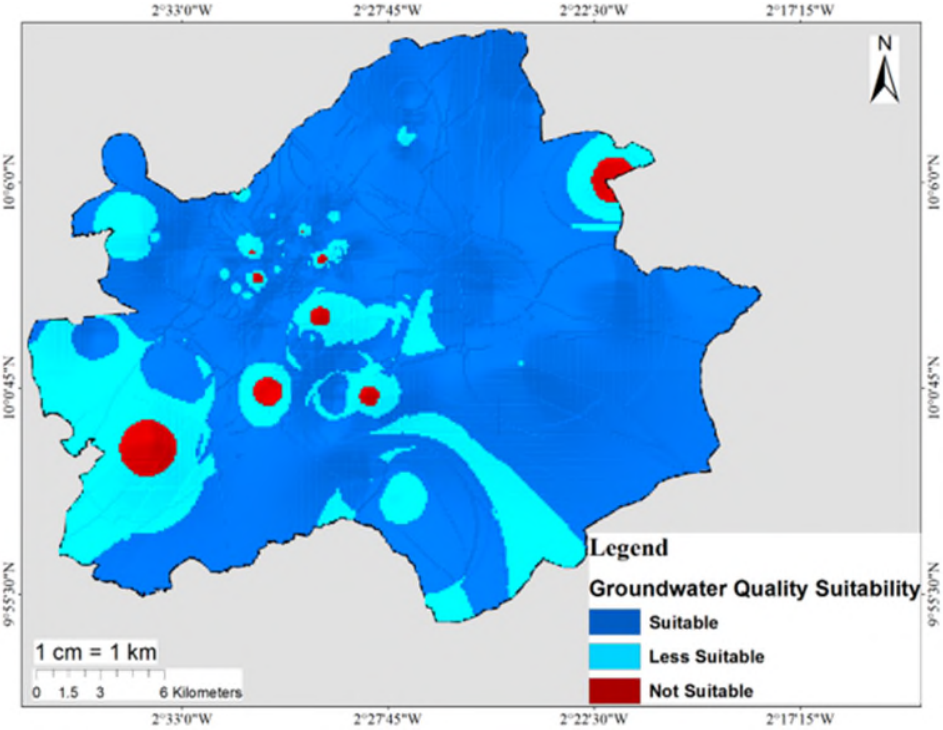

Figure 4.15: Groundwater Quality Suitability Map

Table 4.7: Area and Percentage Extent of Groundwater Quality Suitability for Irrigation in Wa Municipality

Classes	Area	Percent (%)
Not Suitable	10.74	1.85
Less Suitable	120.12	20.74
Suitable	448.43	77.41

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The study evaluated the significance of physical and environment factors on groundwater potential, delineate the groundwater potential zones and determine the water quality in the Wa Municipality of Ghana for irrigated agriculture. Geology, lineament density, rainfall, drainage density, soil, landuse and landcover (LULC), topographic wetness index (TWI), slope and elevation were used for modelling the groundwater potential. Using the analytic hierarchy process (AHP) at a consistency ratio of 0.088, Geology (19.9 %) was ranked the highest followed by lineament density (18.9 %), rainfall (12.8 %), drainage density (10.6 %), soil (10.1 %), LULC (9.9%), TWI (8.0 %), slope (5.8%) and elevation (3.9 %). By overlay analysis in ArcMap, the groundwater potential zones were delineated. The delineated groundwater potential zones were validated using 40 tube wells data for the study area. The irrigation suitability parameters such as Sodium Absorption Ratio (SAR), Magnesium Hazard (MH), Total Dissolved Solids (TDS), Kelly ratio (KR) and Electrical Conductivity (EC), were overlaid to produce a suitability map using ArcMap 10.8:

Based on the findings of the study the following conclusions were drawn:

- Environmental and physical factors have impact on the occurrence of groundwater in the Wa Municipality. Geology was the most influential factor followed by lineament density, rainfall, drainage density, LULC, soil, TWI, slope and elevation.
- About 145.71 km^2 (25.40 %) of the total study area had low potential for groundwater occurrence, 130.15 km^2 (22.69 %) had moderate potential for groundwater occurrence, 112.39 km^2 (19.59 %) had high potential for groundwater occurrence, and 185.33 km^2

(32.31 %) of the total area had very high potential for groundwater occurrence. The western part of the municipality has higher potential for groundwater as compared to the eastern part.

- About 448.43 km^2 representing 77.41 % of the total area of the municipality has suitable groundwater for irrigation. The less suitable area represents 20.74 % (120.12 km^2) of the study area and 1.85 % (10.74 km^2) representing the unsuitable area. However, it was discovered that the remaining 22.59 % of the total municipality have concentrations of ammonia (NH_3) (5.2 mg/L), electrical conductivity (EC) (449.9 µS/m), pH (8.9) and turbidity exceeding the acceptable limit of the FAO and WHO standard.
- Generally, the Wa Municipality have a very good potential groundwater quantity and quality for urban and peri-urban irrigated agriculture.

5.2 Recommendations

The following recommendations are made based on the findings of the study:

i. The results of this study can be used by farmers, policy makers and planners to make informed decisions.

ii. It is necessary to build groundwater recharge strategies such as injection wells, fish ponds and dugouts at areas with low groundwater potential.

iii. For the groundwater to be fully utilized for irrigation in the Municipality there is the need to treat and monitor the quality especially the turbidity, ammonia (NH_3), electrical conductivity (EC), turbidity and the pH concentration and level.

iv. It is essential to undertake additional research in the Wa Municipality to determine the heavy metals and biological parameters availability in groundwater for safe irrigated agriculture.

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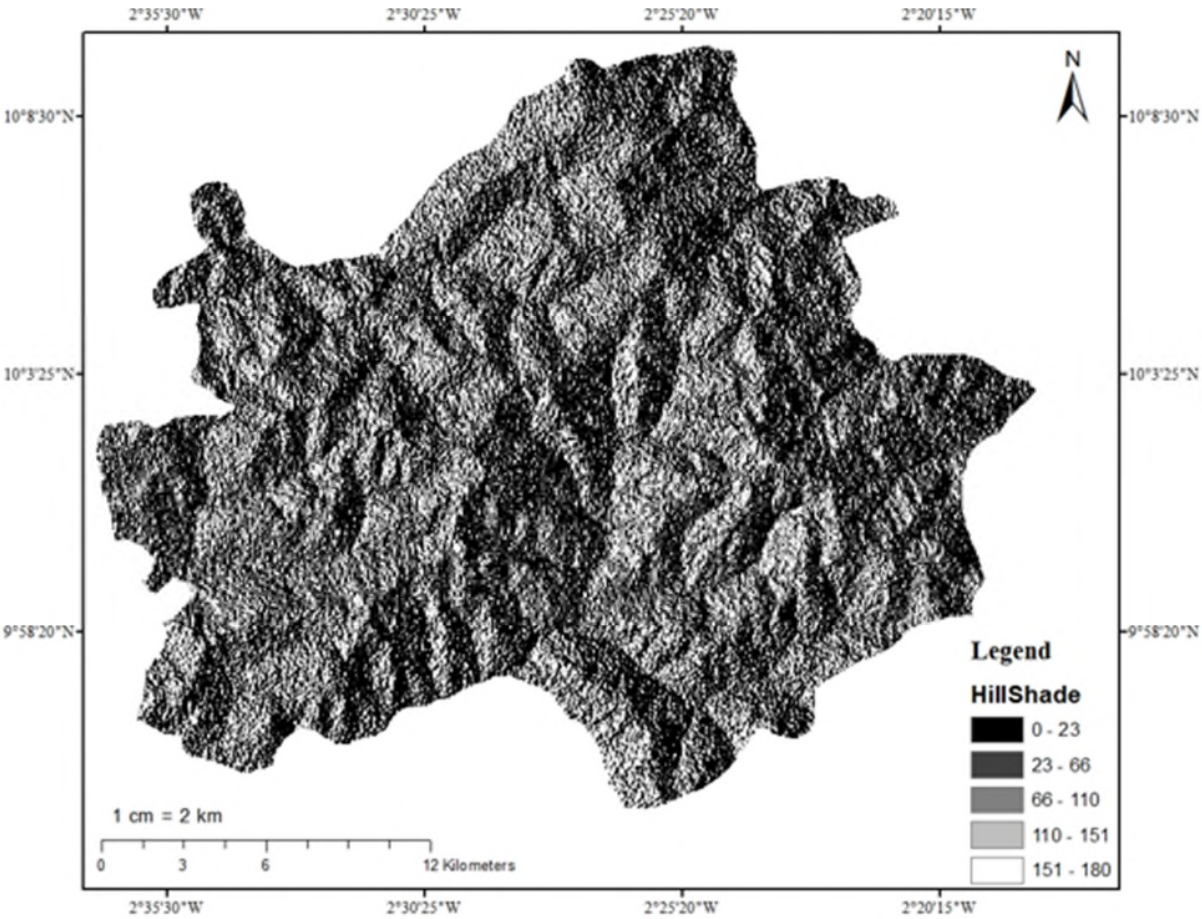
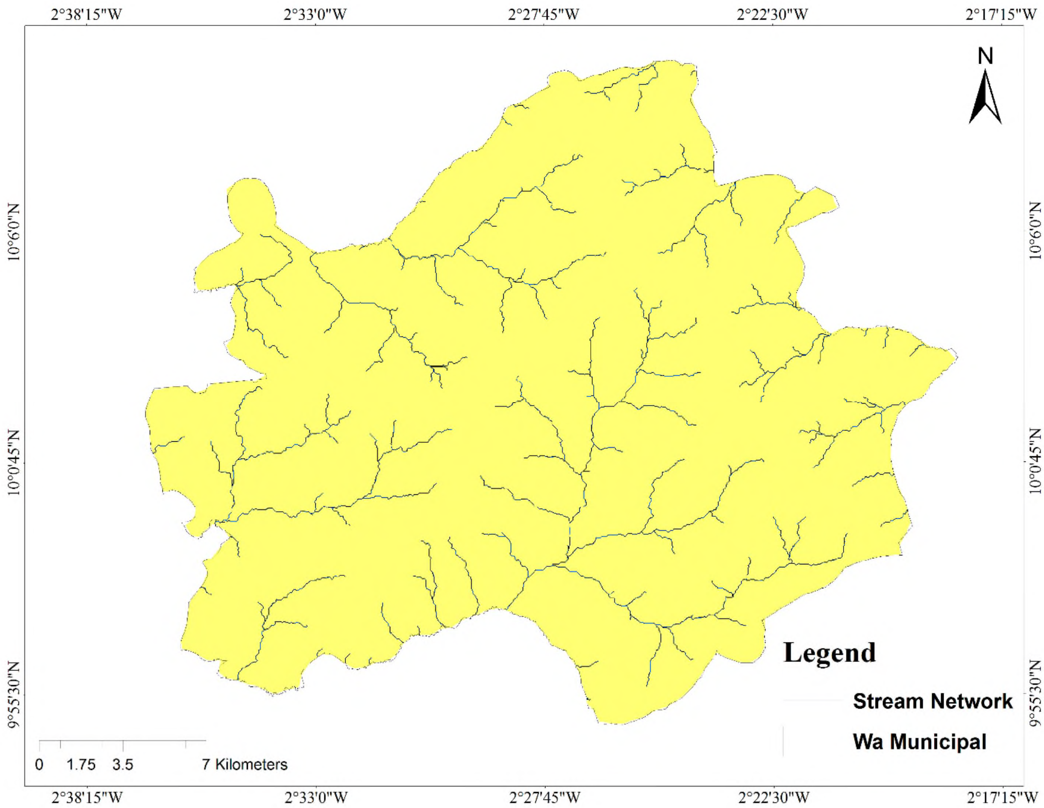
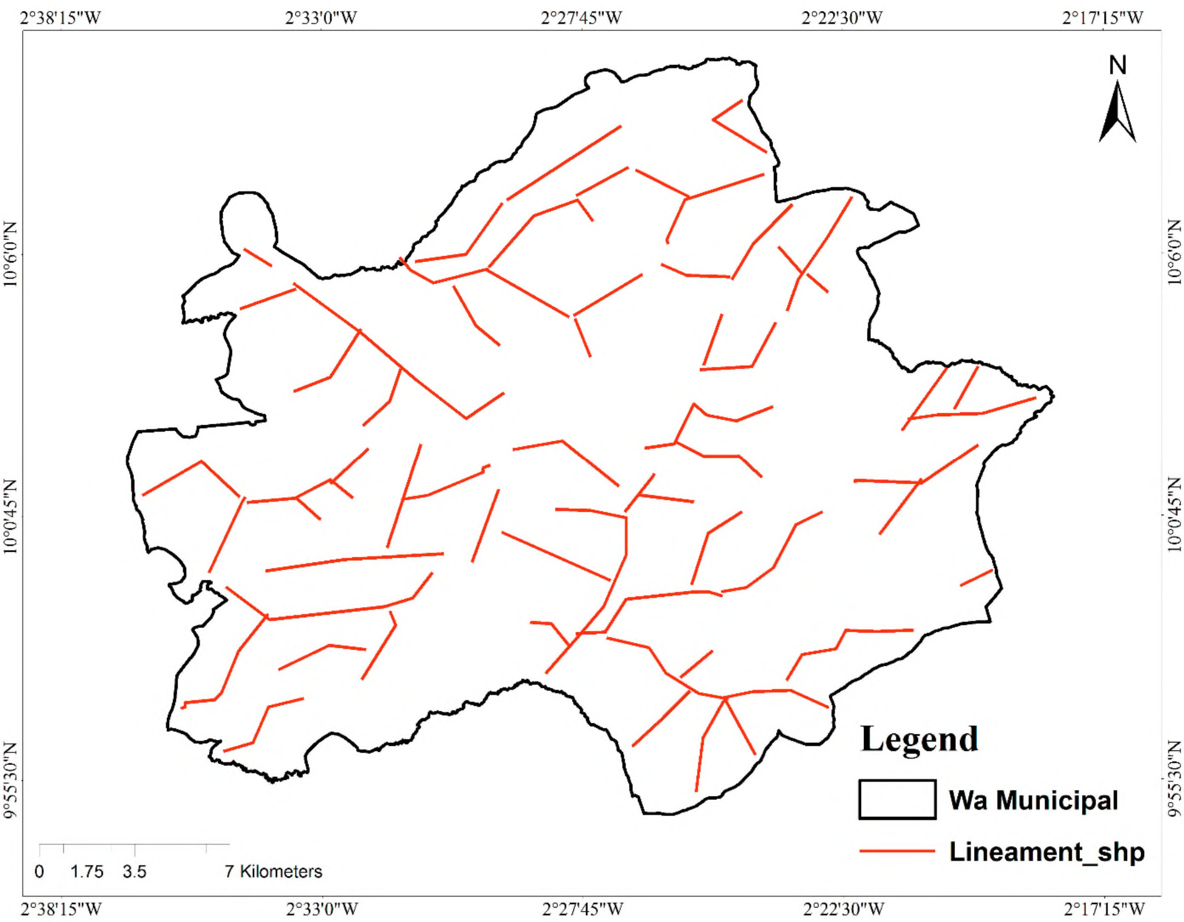
APPENDICES



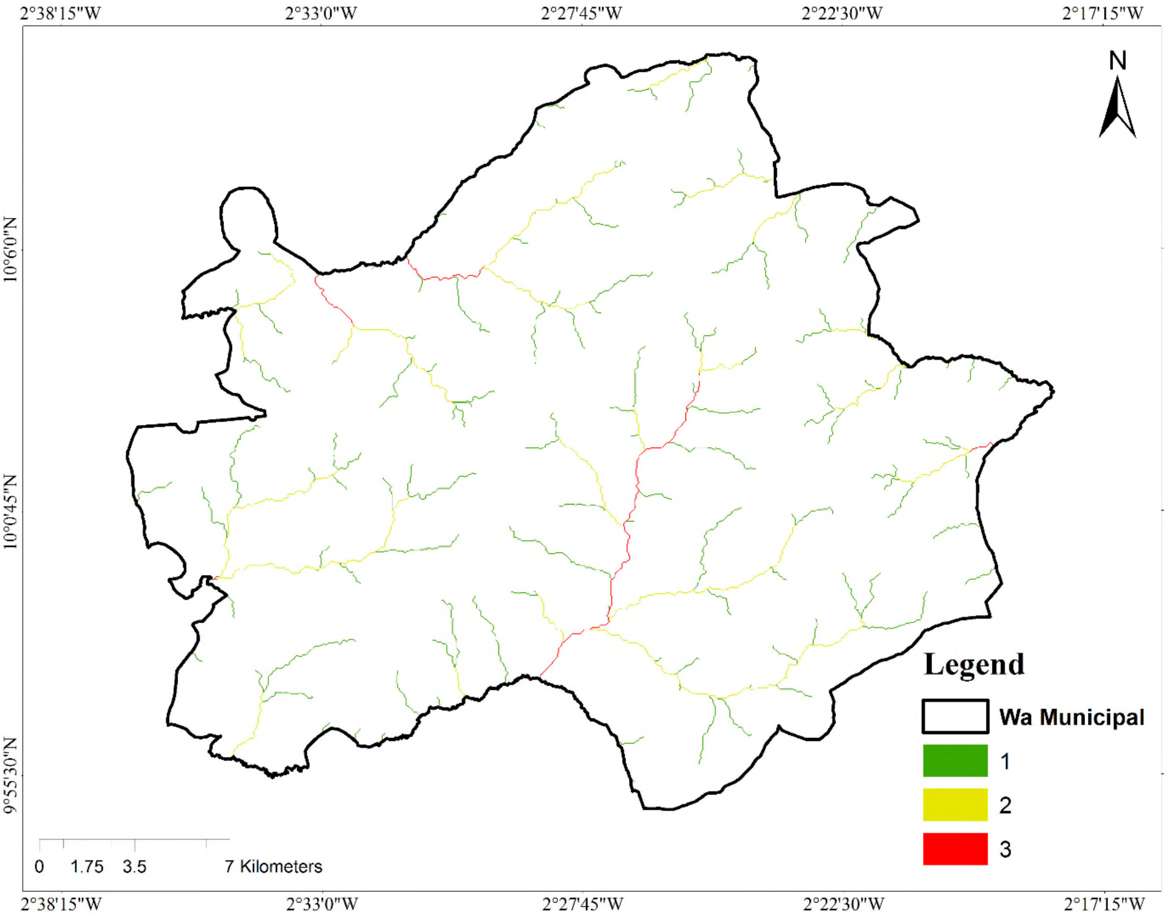
Appendix 1: Hillshade Map of Wa Municipality



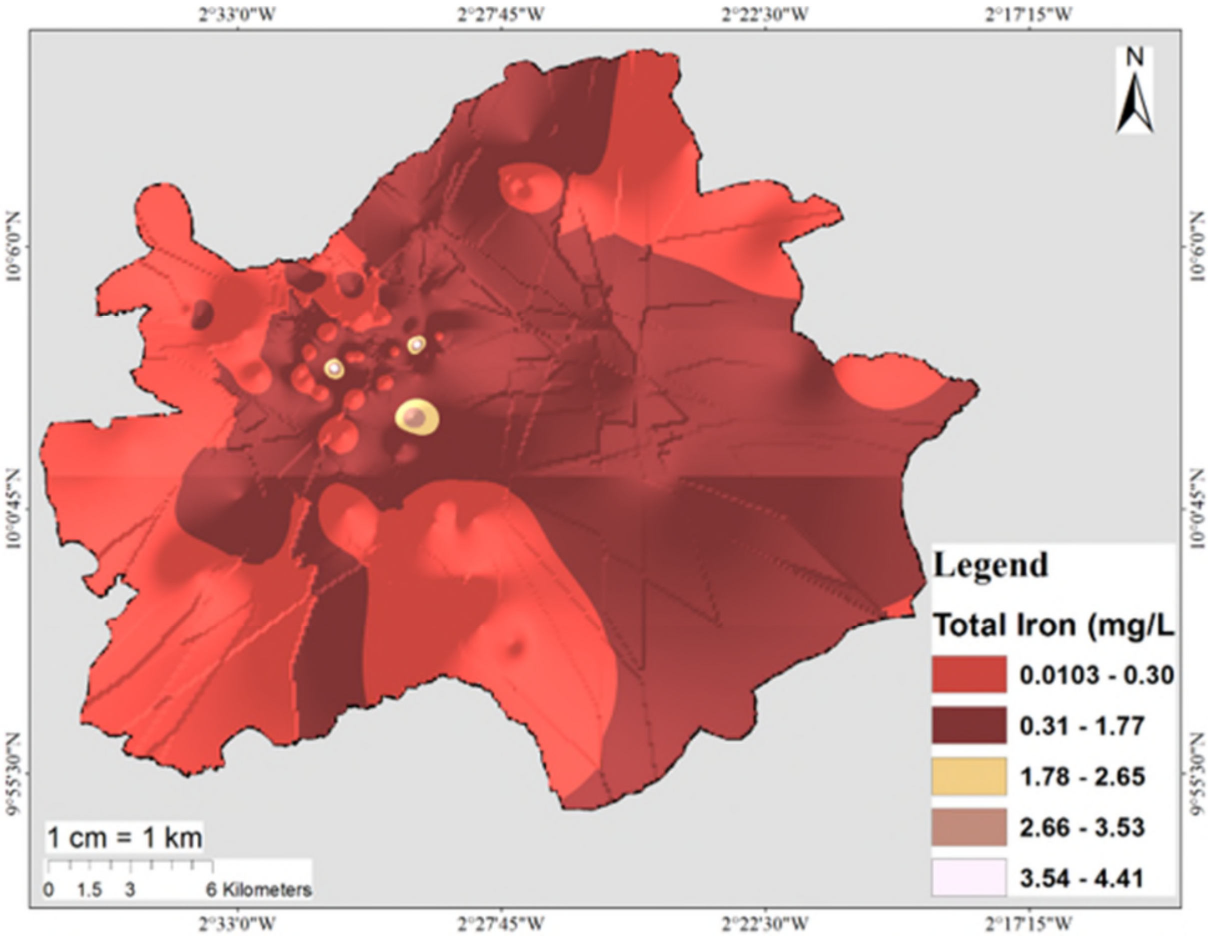
Appendix 2: Stream Network of Wa Municipality



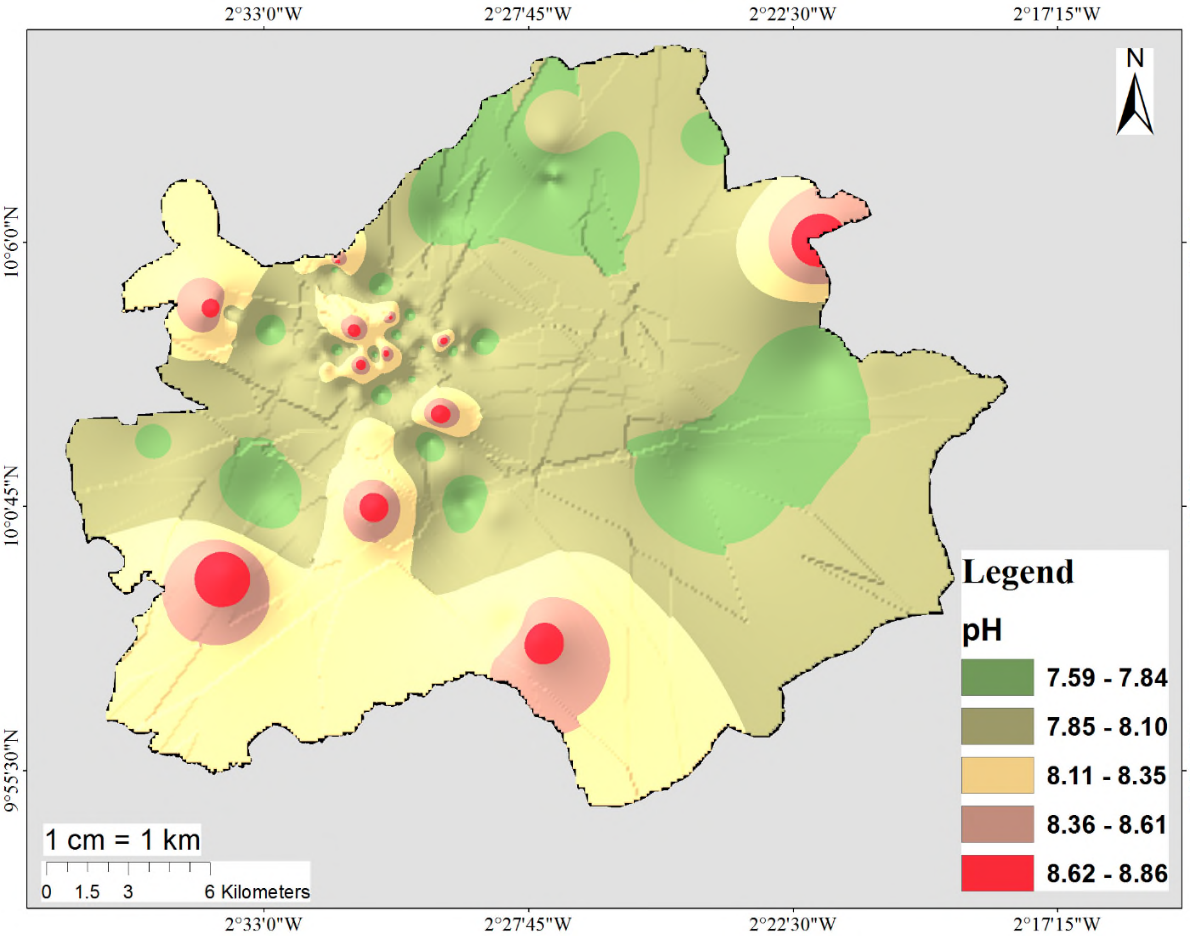
Appendix 3: Lineament of Wa Municipality



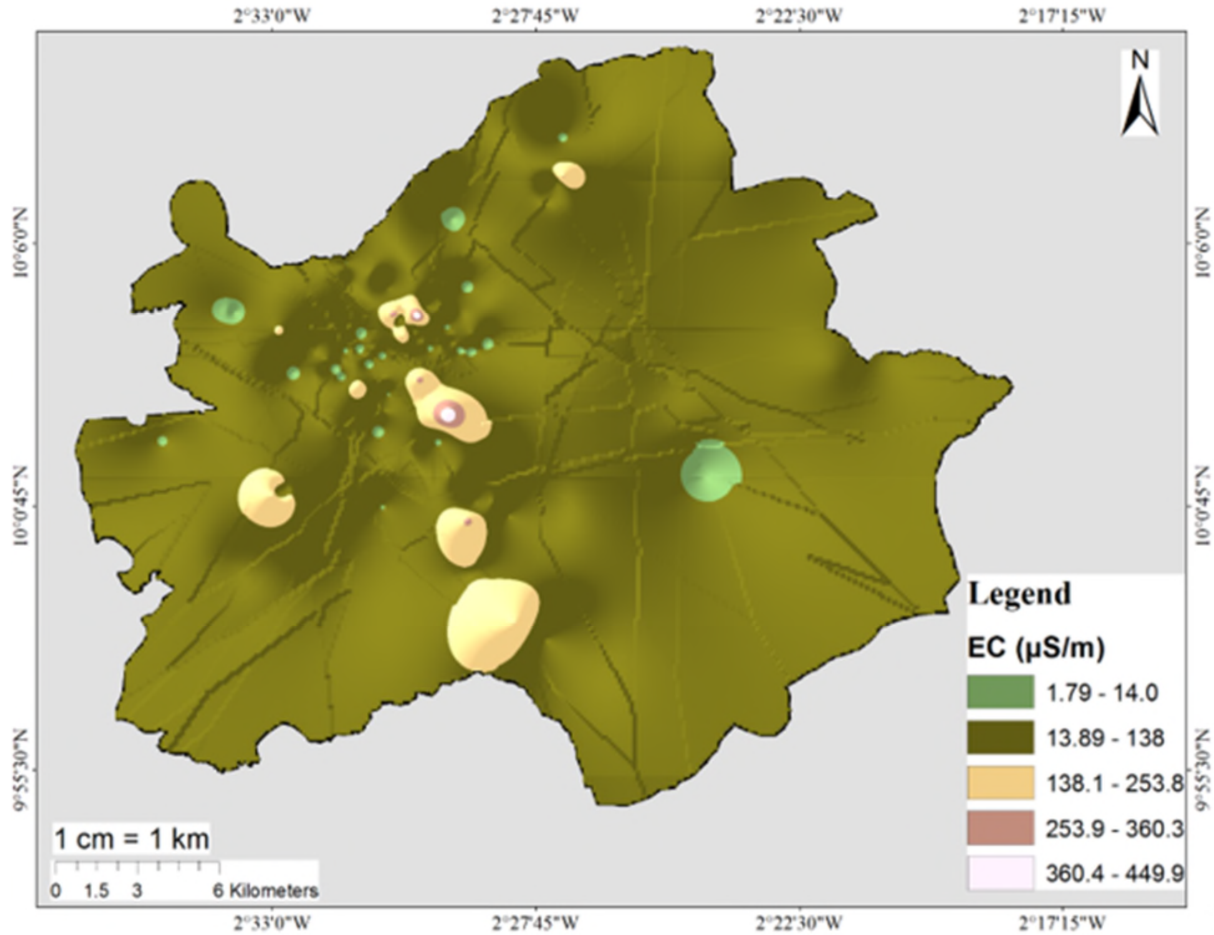
Appendix 4: Stream Order of Wa Municipality



Appendix 5: Total Iron of Wa Municipality



Appendix 6: pH of Wa Municipality



Appendix 7: EC of Wa Municipality

Appendix 8: Accuracy Assessment Confusion Matrix

Landuse/landcover class	Water	Bare land	Forest	Vegetation	Agriculture	Settlement	Total user	User accuracy (%)
Water	48	3	0	0	0	0	51	94
Bare land	0	44	0	2	1	3	50	88
Forest	0	0	32	11	7	0	50	64
Vegetation	0	2	9	39	0	0	50	78
Agriculture	0	0	0	0	50	0	50	100
Settlement	0	8	0	0	0	42	50	84
Total producer	48	57	41	52	67	45	301	
Producer accuracy (%)	100	77.2	78.0	75.0	74	93.3		
Overall accuracy								84.72%
Kappa coefficient								0.9645

Appendix 9: Geology of Wa Municipality

Code_ 1000	Geo_ symb ol	Stratigrap	Tectonic_d	Metamorpho	Legend_tex	Area (SqKm)	Percen tage (%)
1100	msd	Mesozoic		Non-metamorphic	Mafic dyke, dolerite (inferred from aeromagnetic data, may include pre-Mesozoic dykes, may be concealed by Voltaian cover)	7.95	1.37
3511	gvbp	Birimian Supergroup	Volcano - Plutonic Group ('Volcanic Belts')		Biotite granitoid, mostly granodioritic, peraluminous	0.10	0.02
3807	bmbt	Birimian Supergroup	Gneisses from Birimian Protoliths		Biotite schist	186.94	32.28
2510	gsh	Eburnean Plutonic Suite			Hornblende-biotite granitoid, undifferentiated	0.70	0.12
3800	bmgg	Birimian Supergroup	Gneisses from Birimian Protoliths	Upper Greenschist to amphibolite facies	Granitoid gneiss, leucocratic, locally dioritic	12.86	2.22
2502	gsmg	Eburnean Plutonic Suite	Plutonic Suite	Non-metamorphic	Two-mica or muscovite granite and minor granodiorite, locally leucogranite	8.41	1.45
3807	bmbt	Birimian Supergroup	Gneisses from Birimian Protoliths		Biotite schist	2.83	0.49
2512	gsht	Eburnean Plutonic Suite	Plutonic Suite		Hornblende-biotite tonalite, minor granodiorite, minor quartz diorite	66.45	11.47
3706	bs	Birimian Supergroup	Sedimentary - Volcano Sedimentary Group ('SedimentaryBasin')	Lower greenschist facies	Sediment/volcaniclastic sediment, undifferentiated, locally mica schist	28.56	4.93
2503	gsb	Eburnean Plutonic Suite	Plutonic Suite	Non-metamorphic	Biotite (+/- hornblende, +/- muscovite) granitoid, undifferentiated	10.44	1.80
1100	msd	Mesozoic		Non-metamorphic	Mafic dyke, dolerite (inferred from aeromagnetic data, may include pre-Mesozoic dykes, may be concealed by Voltaian cover)	3.64	0.63
3304	tmbz	'Tamnean' Plutonic Suite			Biotite-hornblende (monzo)granite, quartz monzodiorite and monzodiorite	250.27	43.21