UNIVERSITY OF NAIROBI

FACULTY OF ENGINEERING

ASSESSING HEALTHCARE ACCESSIBILITY FOR MALARIA PATIENTS USING GEOSPATIAL TECHNIQUES IN RARIEDA SUB-COUNTY

WANINA SYLVESTER ONYANGO

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Abstract

Malaria remains one of the leading public health concerns in Kenya, particularly in malaria-endemic regions such as Rarieda Constituency, Siaya County. Despite national efforts to reduce the burden of malaria, limited access to healthcare facilities continues to hinder effective prevention and treatment. This study assesses the spatial accessibility of healthcare services for malaria patients in Rarieda Constituency using Geographic Information System (GIS)-based methods. The analysis integrates spatial data on health facility locations, malaria incidence, population distribution, and road networks to identify underserved areas and evaluate travel distances to the nearest treatment centers. Inverse Distance Weighting (IDW) interpolation was employed to visualize malaria risk zones, while network analysis determined the shortest travel paths from population centers to health facilities. The results reveal disparities in service provision, with some wards lacking adequate access to higher-level healthcare centers. The study highlights the importance of spatial analysis in health planning and proposes data-driven recommendations to improve healthcare accessibility and reduce malaria-related morbidity and mortality in the region.

Declaration

I, Sylvester Onyango Wanina, hereby declare that this project report titled, Assessing Healthcare Accessibility for Malaria Patients using Geospatial Techniques in Rarieda Sub-County, is my original work and has not been presented for a research project in any other university.

Mr. Sylvester Onyango Wanina

Student Signature .... Date 30/5/2025 ....

This project has been submitted for examination with my approval as the university supervisor.

Prof. Faith N. Karanja

Supervisor Signature .... Date 29.05.2025 ....

Dedication

This project is dedicated with love and deep gratitude to my parents, Mr. Joseph Ochola Wanina and Mrs. Caroline Atieno Ogutu, whose unwavering support, sacrifices, and encouragement have been the foundation of my journey. Your belief in the power of education and your constant presence in my life have made this accomplishment possible. To my siblings, Daniel, Esther, and Anthony, thank you for your love, patience and continuous inspiration. Your support has meant more than words can express.

I would also like to dedicate this work to the residents of Rarieda Constituency and all communities affected by malaria. May this research contribute meaningfully to improving healthcare accessibility and enhancing health outcomes in underserved regions.

Acknowledgement

First and foremost, I thank God Almighty for His unwavering guidance, strength and grace that carried me through every stage of this project. Without His divine wisdom and provision, this journey would not have been possible.

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I am especially thankful to my mum, Mrs. Caroline Ogutu, for your unwavering financial support and sacrifices that made this project possible. Your love and commitment have been my foundation and motivation. To my family, thank you for being my anchor. Your prayers, understanding, and uplifting words kept me going even in the most challenging moments. Your unwavering belief in me has been a constant source of motivation.

I also extend heartfelt thanks to my friends, whose encouragement, assistance, and belief in my vision have meant more than words can express. To each of you, thank you sincerely for walking this journey with me.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AMMA – African Monsoon Multidisciplinary Analysis

CDC – Centers for Disease Control and Prevention

CHAI – Clinton Health Access Initiative

DHS – Demographic and Health Surveys

FAO – Food and Agricultural Organization

GIS – Geographic Information System

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

HMIS – Health Management Information System

HIV/AIDS – Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome

IDW – Inverse Distance Weighting

IEBC – Independent Electoral and Boundaries Commission

IPCC – Intergovernmental Panel on Climate Change

ITNs – Insecticide-Treated Nets

KEMRI – Kenya Medical Research Institute

KMHFL – Kenya Master Health Facility List

KMIS – Kenya Malaria Indicator Survey

KNBS – Kenya National Bureau of Statistics

LLIN – Long-Lasting Insecticidal Nets

MARA – Mapping Malaria Risks in Africa

MoALF – Ministry of Agriculture, Livestock, Fisheries and Co-operatives

MoH – Ministry of Health

MoPHS – Ministry of Public Health and Sanitation

NASA – National Aeronautics and Space Administration

NCCRS – National Climate Change Response Strategy

NMCP – National Malaria Control Programme

PGIS – Participatory Geographic Information System

QGIS – Quantum Geographic Information System

RS – Remote Sensing

SMC – Seasonal Malaria Chemoprevention

UHC – Universal Health Coverage

UN – United Nations

UTM – Universal Transverse Mercator

WHO – World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Background to the study

Malaria is a parasitic disease caused by *Plasmodium* species and transmitted to humans through the bites of infected female *Anopheles* mosquitoes (WHO, 2022). Four species are primarily responsible for human malaria: *Plasmodium vivax*, *Plasmodium ovale*, *Plasmodium falciparum*, and *Plasmodium malariae*. Among these, *P. falciparum* is the most prevalent and deadly, accounting for the majority of cases in high-burden regions such as Kenya (WHO, 2022). Malaria is fundamentally an environmental disease, as vector survival and abundance are heavily influenced by a range of ecological and socio-economic conditions. These include physical factors such as elevation, rainfall, humidity, slope, temperature, soil type, and proximity to water bodies; social factors such as human migration patterns; economic conditions such as housing quality and poverty; and political considerations, including regional collaboration efforts (Tatem et al., 2013). Globally, malaria remains a critical public health challenge, with an estimated 249 million cases reported across 85 endemic countries and territories in 2022. Approximately 608,000 deaths were recorded that year, with children under five years of age comprising the most vulnerable group (WHO, 2023). Sub-Saharan Africa continues to bear the highest burden, accounting for 94% of all malaria cases. This region faces compounded challenges, including increasing resistance to insecticides, insufficient healthcare infrastructure, and the effects of climate change on mosquito breeding patterns (WHO, 2023). As part of SDG 3, the United Nations has targeted the elimination of malaria by 2030. To this end, WHO has outlined objectives such as reducing global malaria incidence and mortality by 90%, eliminating malaria in at least 35 countries, and preventing its resurgence in malaria-free regions by the year 2030 (WHO, 2023).

Kenya's Malaria Burden

Kenya is one of the 11 high-burden malaria countries, where the disease remains a leading cause of morbidity and mortality. It contributes to 1.4% of global malaria cases (WHO, 2022). Key challenges in addressing malaria in Kenya include limited access to healthcare, frequent stockouts of essential malaria medications, and the growing issue of insecticide and treatment resistance (MoH Kenya, 2021). Kenya is divided into four malaria epidemiological zones: the endemic zone around Lake Victoria and the Coast, the seasonal transmission zone in arid and semi-arid regions, the epidemic-prone areas in the western highlands, and the low-risk zone in the Central Highlands and Nairobi. All 47 counties in Kenya are classified into one of these zones based on malaria transmission patterns (MoH Kenya, 2021).

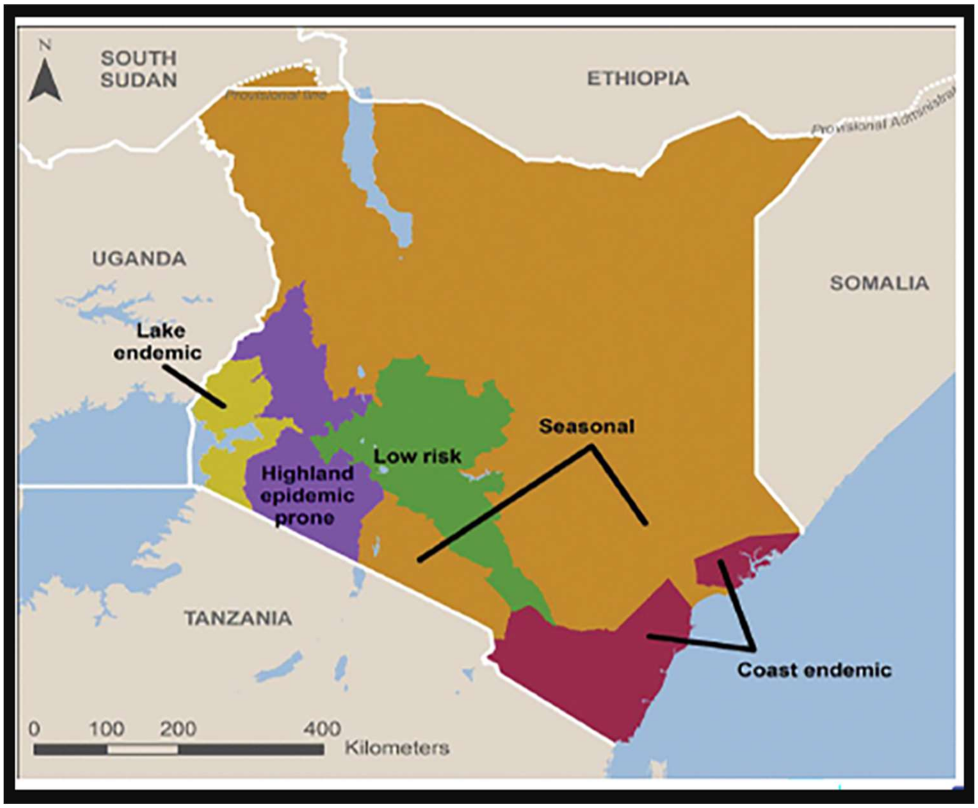


Figure 1.1 – Malaria Epidemiological zones in Kenya (PLOS Global Public Health 2023)

Figure 1.1 above shows how malaria zones in Kenya are categorized based on transmission intensity. The endemic zones, which include the Lake Victoria and Coastal regions, experience high malaria transmission throughout the year due to favorable environmental conditions such as high temperatures, humidity, and stagnant water bodies that provide ideal breeding habitats for *Anopheles* mosquitoes, the primary vectors of malaria (MoH Kenya, 2021). These endemic zones include the Lake Victoria region (comprising Siaya, Kisumu, Homabay, Migori, and Busia counties) and the Coastal region (including Kwale, Kilifi, Mombasa, Tana River, and Lamu counties). Table 1.1 below highlights the malaria prevalence statistics for these zones.

Malaria zones	Estimation of prevalence	Counties
Lake Endemic	27%	Siaya, Kisumu, Migori, Homa Bay, Busia, Kakamega, Bungoma
Coast Endemic	8%	Mombasa, Kwale, Kilifi, Lamu, Taita Taveta
Highland epidemic prone	3%	Kisii, Nyamira, Trans Nzoia, Uasin Gishu, Nandi, Narok, Kericho, Bomet,
Semi-arid Seasonal	1%	Tana River, Marsabit, Isiolo, Garissa, Wajir, Mandera, Turkana, Samburu, Baringo, Kajiado
Low risk	1%	Nairobi, Nyandarua, Nyeri, Kirinyaga, Murang'a, Kiambu, Machakos, Makueni, Laikipia, Nakuru

Table 1.1: Malaria zones in Kenya, source Kenya Malaria Indicator Survey 2020

Rarieda Constituency Context

Rarieda, located in Siaya County, is within Kenya's Lake Victoria malaria-endemic zone, where transmission rates remain one of the highest in the country. The study will focus on assessing spatial access to malaria treatment centers and the gaps in healthcare delivery. Figure 1.2 is a map showing hydrographic features within Rarieda.

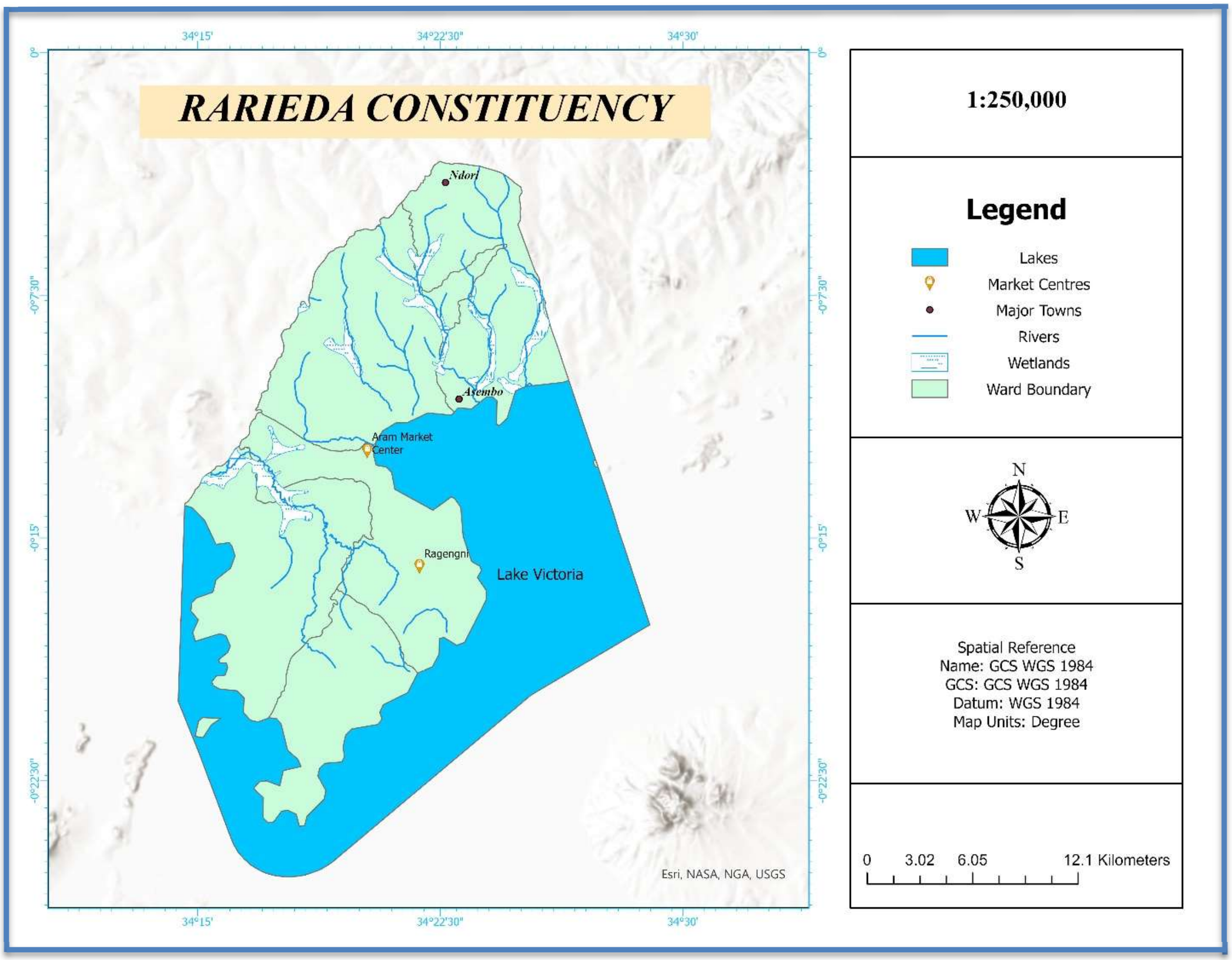


Figure 1.1 Rarieda Constituency

1.2 Problem Statement

Several studies have explored the relationship between healthcare accessibility and malaria outcomes in high-burden regions. For example, USAID in 2020 examined public health determinants of child malaria mortality in Siaya County reporting a prevalence rate of 546 per 1,000 people. The study found that distances to health facilities significantly influenced malaria-related mortality among children under the age of five. These findings emphasize the need to address spatial healthcare disparities to reduce child mortality. Other investigations have applied spatial tools to assess healthcare access. In Kisumu County, Macharia et al. (2017) used a geographic information system (GIS)-based network analysis to evaluate spatial accessibility to malaria treatment centers. The study found that individuals residing more than 5 kilometers from a health facility were significantly less likely to seek prompt treatment. Similarly, Mboera et al. (2019) conducted a spatial modeling study in western Uganda using malaria incidence data, health facility locations, and road network information. Their findings highlighted how poor infrastructure and uneven distribution of facilities hindered malaria service delivery and led to the reallocation of mobile clinics to underserved areas. While these studies provide important insights, they primarily focus on specific populations such as children or pregnant women and often utilize limited methods, such as cross-sectional surveys or qualitative assessments. To date, no comprehensive GIS-based study has been conducted for Rarieda Constituency, an area with high malaria prevalence and uneven access to healthcare. This study addresses the gap by employing advanced spatial analysis and mapping techniques to assess healthcare accessibility for all malaria patients in the constituency. The outcomes are expected to inform policy decisions, enhance resource allocation and improve healthcare delivery strategies in malaria-endemic regions.

1.3. Objectives of the study

1.3.1. Main Objective

The overall objective of this study was to assess healthcare accessibility for malaria patients in Rarieda constituency.

1.3.2. Specific Objectives

The specific objectives for this study were namely to:

1) Map healthcare facilities in Rarieda constituency.
2) Analyze spatial distribution of malaria cases in Rarieda constituency.
3) Access travel time & accessibility.
4) Identify underserved areas.

1.4. Justification for the study.

Malaria remains a major public health challenge in Rarieda Constituency, Siaya County—an area located within Kenya’s Lake Victoria basin where malaria transmission is endemic and persistent. Assessing healthcare accessibility for malaria patients in this region is both timely and relevant due to the ongoing need for targeted, data-driven interventions that can reduce disease burden and improve treatment outcomes. Despite efforts by the Ministry of Health and development partners to expand malaria control programs, access to healthcare facilities remains uneven, especially in rural and hard-to-reach areas.

The findings from this study will benefit:

- National and County-level health planner – in identifying areas with inadequate healthcare access for malaria patients. This information can guide the design and implementation of targeted health programs, resource allocation and infrastructure development. Health planners may use this data to ensure that malaria control interventions reach the most vulnerable populations and to evaluate the effectiveness of existing programs.
- Local healthcare providers – to understand spatial healthcare needs in their communities. By identifying areas with limited access, healthcare providers can work to optimize their services whether by increasing outreach in underserved areas, adjusting their service delivery models or coordinating with other stakeholders for improved coverage.
- Community health workers – to better understand where their services are needed the most. This will help them plan their outreach efforts and improve their communication with local populations about available health services particularly about malaria prevention and treatment.
- Residents of Rarieda constituency – particularly those living in hard-to-reach areas will benefit from more equitable healthcare access. If the findings are used to prioritize areas for new health facilities, mobile clinics or better transportation networks, the residents will have more timely access to malaria treatment and preventive measures. Improved healthcare access can significantly reduce malaria related morbidity and mortality.

By identifying geographic disparities and access barriers, this research will help in prioritizing locations for new health facilities, mobile clinics and improved transportation infrastructure. While several studies have documented malaria prevalence in western Kenya, there is a notable gap in the integration of spatial analysis and network-based approaches to evaluate healthcare accessibility specifically for malaria patients. This study aims to fill that gap by leveraging GIS techniques to provide visual and analytical insights that are currently lacking in health planning documents. The results will support more equitable healthcare delivery by informing resource allocation and enabling policy-makers to design interventions that are responsive to the spatial needs of vulnerable populations. Furthermore, this study is feasible due to the availability of secondary data on malaria incidence, health facility locations, road networks and proficiency in GIS tools such as QGIS and ArcGIS Pro.

1.5 Scope & limitations of the study

This study focuses on assessing spatial healthcare accessibility for malaria patients in Rarieda Constituency (Siaya County) using GIS-based tools such as ArcGIS Pro. It analyzes how distance to health facilities and road networks affect access to malaria treatment, relying entirely on secondary data, including malaria case records, health facility locations and road network data. The study mainly targets vulnerable groups such as children under five and pregnant women. However, the study is limited by the availability and accuracy of secondary data, as no primary data collection was carried out. It focuses only on physical accessibility and does not consider other important factors like affordability, quality of care, or availability of medical supplies. Additionally, the results may not be generalizable beyond Rarieda due to regional differences and technical limitations of the GIS tools and datasets used may slightly affect the precision of the findings.

1.6 Report organization

Chapter One: Introduction

This chapter gives background information on the study, focusing on the current state of air pollution. It includes the problem statement, study objectives, justification, scope, and limitations.

Chapter Two: Literature Review

This chapter explores the concept of air quality, starting from a global perspective and narrowing down to Kenya and specifically Kiambu County. It reviews past studies and highlights the role of geospatial technologies in air quality analysis.

Chapter Three: Materials and Methods

Here, the study area is described in detail, along with the data used and their sources. The chapter explains the methods used for data collection, preprocessing, and analysis. It forms the core of the project.

Chapter Four: Results and Discussions

This chapter presents the outputs of the analysis using maps, charts, and tables. It includes a detailed discussion and interpretation of the results.

Chapter Five: Conclusions and Recommendations

The final chapter summarizes the main findings and provides recommendations based on the study results.

CHAPTER 2: LITERATURE REVIEW

2.1 Healthcare Accessibility

Healthcare accessibility refers to the ease with which individuals can obtain necessary health services. It includes several factors, such as physical distance to healthcare facilities, the availability of services, affordability, acceptability, and the appropriateness of the care provided. This concept is essential in ensuring equitable health outcomes across various populations (Levesque et al., 2013).

2.1.1 Concepts of Healthcare Accessibility

In the context of malaria healthcare access in rural Kenya, healthcare accessibility refers to the physical, economic, and systemic ease with which malaria patients can reach and utilize treatment services. It is a critical determinant of health outcomes, particularly in resource-constrained areas such as Rarieda Constituency. Levesque et al. (2013) define healthcare accessibility as the interaction between healthcare systems and populations across five dimensions.

The most relevant dimensions to this study include:

- ✓ Availability and Accommodation: This refers to the presence and capacity of healthcare facilities to provide malaria-related services such as diagnosis, treatment, and follow-up. In rural areas, limited facility density and operational hours significantly affect access to care.
- ✓ Affordability: Economic barriers, including the cost of transportation to distant healthcare facilities and out-of-pocket expenses for treatment, are significant challenges faced by many households in malaria-endemic regions.
- ✓ Ability to Reach: Physical distance and poor road infrastructure are major access barriers for rural populations. Geographic Information System (GIS) network analysis is particularly valuable for modeling travel times and identifying underserved areas.

This study adopts a spatial accessibility approach to identify gaps in healthcare coverage for malaria patients by evaluating proximity to healthcare facilities, facility availability and transportation networks in Rarieda.

2.1.2 Determinants of Healthcare Access

The determinants of healthcare access are the structural, spatial, and socioeconomic factors that influence an individual's ability to seek and receive timely and appropriate care. In the context of malaria in rural Kenya, these determinants directly affect how quickly and effectively patients can receive treatment, which is crucial for reducing complications and transmission of the disease.

Key determinants relevant to this study include:

- Geographical location: Distance from a patient's residence to the nearest health facility is a major determinant. In Rarieda, many communities are dispersed and located far from formal health centers. Long travel distances discourage early care-seeking behavior especially for febrile illnesses like malaria.
- Road Infrastructure and Transportation: Poor Road conditions and limited access to affordable transport options severely limit mobility. During rainy seasons, some roads may be impassable cutting off entire communities from essential health services.
- Health Facility Density and Distribution: Malaria-endemic areas often suffer from unequal distribution of healthcare facilities, with most centers concentrated in urban wards. This imbalance creates spatial inequities in access, which this study investigates using GIS-based network analysis.
- Socioeconomic Status: Poverty limits the ability to pay for services, medication, and transport. Households may also prioritize basic needs over health expenses, especially when malaria symptoms appear mild at onset.
- Availability of malaria services: Some facilities may lack diagnostics, antimalarial drugs, or trained personnel. Even when physically accessible, if services are inadequate, effective access is still compromised.

These factors form the basis for assessing spatial healthcare accessibility using GIS tools to identify underserved populations and inform more equitable health service planning in Rarieda.

2.1.3 Indicators of Access and Equity

To assess healthcare accessibility and equity, researchers and policymakers rely on quantifiable indicators that reflect the population's ability to obtain necessary health services. In the context of malaria treatment in Rarieda, these indicators help evaluate spatial disparities, identify underserved areas, and guide interventions. Relevant indicators of access and equity in this study include:

- ✓ Distance to Nearest Health Facility: A core spatial indicator measured either as straight-line (Euclidean) distance or actual travel distance along roads. This study uses network analysis to derive accurate accessibility metrics.
- ✓ Proportion of Population within 5 km of a Facility: Recommended by the WHO as a standard benchmark for physical access. Populations residing beyond this threshold are considered underserved.
- ✓ Travel Time to Facility: Combines distance with road conditions and available transport options to reflect real-world access challenges. This metric is particularly relevant in rural Rarieda, where infrastructure is often poor.
- ✓ Malaria Case Burden per Facility: Evaluates service equity by examining the ratio of malaria cases to available treatment capacity. Overloaded facilities may struggle to provide timely care.
- ✓ Utilization Rates of Malaria Services: Where available, data on outpatient visits and confirmed malaria treatments can indicate whether accessible services are being used, or if hidden barriers remain

By analyzing these indicators through a GIS framework, this study aims to spatially visualize inequities and support targeted health system improvements for malaria control in the constituency.

2.2 The Burden of Malaria

Malaria remains one of the most significant public health challenges in sub-Saharan Africa, particularly in rural and low-lying regions such as western Kenya. The disease is caused by *Plasmodium* parasites, which are transmitted through the bites of infected female *Anopheles* mosquitoes. Although malaria is both preventable and treatable, it continues to result in high rates of morbidity and mortality due to environmental, socioeconomic, and health system barriers. In Kenya, malaria accounts for approximately 30% of outpatient visits and 19% of hospital admissions (Kenya Malaria Indicator Survey, 2020). Figure 2.1 shows the malaria zones in Kenya.

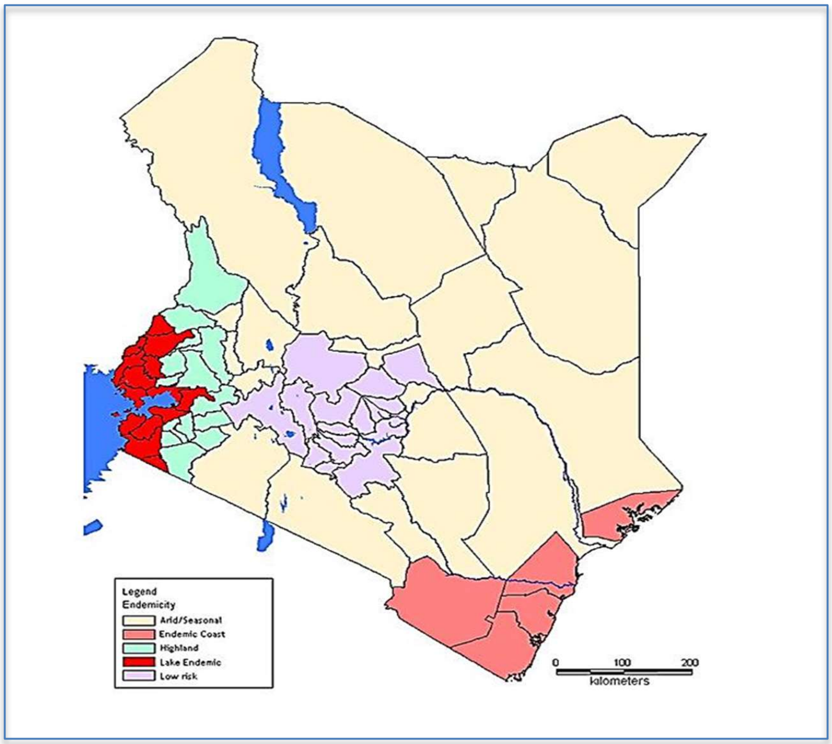


Figure 2.1 – Malaria Endemic Zones in Kenya, Source: Ministry of Health

The most vulnerable populations include children under five years of age and pregnant women. Malaria is endemic in areas with favorable climatic conditions for mosquito breeding, especially around lakes, rivers, and swampy lowlands. Siaya County, where Rarieda Constituency is located, falls within one of the high-transmission zones.

Rarieda's proximity to Lake Victoria and its tropical climate make it a persistent malaria hotspot. Seasonal rainfall contributes to stagnant water accumulation, thereby increasing mosquito habitats and raising the risk of infection. Combined with limited access to healthcare facilities and essential malaria services, these environmental factors significantly exacerbate the malaria burden in the area

Key contributing factors to malaria burden in Rarieda include:

- High mosquito breeding potential due to poor drainage and proximity to water bodies. The presence of stagnant water, especially near Lake Victoria and during the rainy season, creates ideal breeding conditions for *Anopheles* mosquito which are responsible for malaria transmission (Githeko et al., 2000; Mogeni et al., 2016).
- Low household incomes, which affect access to preventive tools like insecticide-treated nets (ITNs) and prompt treatment. Many families in Rarieda struggle with the cost of healthcare and transport, which delays care-seeking and increases vulnerability to severe malaria (Kariuki et al., 2018; World Health Organization [WHO], 2023).
- Uneven distribution of health facilities across the constituency. Some areas are located far from health centers, making it harder for residents to get diagnosed and treated early. This has been linked to poor health outcomes in malaria-endemic regions like western Kenya (Noor et al., 2009; Gething et al., 2012).

This study focuses on the spatial aspects of malaria burden, identifying where confirmed and suspected cases are concentrated and how well these areas are served by existing healthcare infrastructure.

2.2.1 Malaria Epidemiology in Sub-Saharan Africa

Malaria remains one of the most significant public health challenges in sub-Saharan Africa, contributing to the highest global burden of the disease. According to the World Health Organization (WHO, 2022), the region accounts for approximately 95% of global malaria cases and 96% of malaria-related deaths, with children under five years of age and pregnant women being the most vulnerable groups. The disease is primarily caused by the *Plasmodium falciparum* parasite, which is transmitted through the bites of infected female *Anopheles* mosquitoes that thrive in the warm, humid climates typical of the region.

Despite various national and regional malaria control programs, such as the use of insecticide-treated nets (ITNs), indoor residual spraying (IRS), and improved access to diagnosis and treatment, malaria continues to have a significant impact on health systems and economic development. Contributing factors include poverty, inadequate healthcare infrastructure, limited access to health services, and climate-related conditions, such as rainfall patterns, which support malaria transmission in many parts of sub-Saharan Africa. In recent years, the use of geospatial technologies to map malaria transmission patterns has increased, allowing health planners to identify high-risk areas and implement targeted interventions. However, disparities in healthcare accessibility, particularly in rural and remote regions, remain a major barrier to achieving malaria elimination goals in the region.

2.2.2 Malaria in Kenya: Trends and Risk Zone

Malaria remains a major public health concern in Kenya with approximately 70% of the population at risk of infection and an estimated 14 million cases reported annually (Division of National Malaria Programme, 2021). The disease significantly contributes to outpatient visits and hospital admissions, particularly among children under five and pregnant women. Although malaria is endemic in many regions, its transmission patterns vary widely due to geographical and ecological factors such as altitude, rainfall, temperature and land use. Kenya is divided into 5 malaria epidemiological zone each with distinct transmission profiles (Kenya National Bureau of Statistics & ICF, 2021)

1. ***Lake Endemic Zone*** – This region surrounding Lake Victoria, experiences intense and perennial malaria transmission due to favorable climatic conditions. According to the 2020 Kenya Malaria Indicator Survey (KMIS), this zone has the highest malaria prevalence reaching up to 19% among children under five years.
2. ***Coast Endemic Zone*** – Malaria is endemic along the coast belt with transmissions occurring all year-round. The warm and humid environment creates the ideal breeding zones for *Anopheles* mosquitoes.
3. ***Highland Epidemic-prone Zone* –** Located in the Western highlands above 1,500 meters, this area experiences seasonal malaria transmission. Outbreaks typically occur when temperatures rise, allowing mosquito vectors to survive and breed.
4. ***Semi-Arid Seasonal Transmission Zone*** – Found in the Northern and South-Eastern regions, malaria in this zone is primarily seasonal and influenced by rainfall. Transmission is generally low but unstable with occasional epidemics during rainy periods.

5. ***Low-Risk Zone*** **–** Areas with high altitudes and cool climates such as Nairobi, Central Kenya report very low malaria transmission due to environmental conditions that are unfavorable for mosquito breeding.

These zones inform Kenya's malaria control strategies including the distribution of insecticide-treated nets (ITNs). Indoor residual spraying (IRS) and case management with artemisinin-based combination therapy (ACT)

2.2.3 Accessibility Challenges in Malaria Control

One of the most persistent barriers to effective malaria control in Kenya and across Sub-Saharan Africa is limited access to healthcare services, particularly in rural, remote, and marginalized communities. Healthcare accessibility not only impacts the ability to receive timely diagnosis and treatment but also affects the consistent delivery and use of preventive measures such as insecticide-treated nets (ITNs) and indoor residual spraying (IRS). In areas with inadequate road networks or sparse distribution of health facilities, individuals may have to travel long distances, often on foot, to reach the nearest clinic. This results in delays in seeking care, particularly among vulnerable groups such as children under five and pregnant women, who are at a higher risk of severe malaria (Noor et al., 2006; Gething et al., 2012). Additionally, economic barriers exacerbate physical inaccessibility. Many families in low-income areas cannot afford transportation to health centers or the opportunity cost of taking time off work. Even when healthcare services are geographically accessible, stock-outs of antimalarial drugs, limited diagnostic tools, and inadequate healthcare personnel can restrict service availability and quality (World Health Organization [WHO], 2023). This challenge is further intensified in semi-arid and conflict-affected regions, where seasonal malaria epidemics occur but healthcare infrastructure is particularly weak. Mobile populations, such as nomadic communities or informal urban settlements like Kibera in Nairobi, are often underserved by national malaria control programs. Addressing these barriers requires integrating spatial analysis into public health planning. Geospatial tools can identify underserved areas and optimize the placement of health facilities, community health workers, and intervention campaigns to reach populations most in need.

2.2.3.1 Environmental and Climatic Factors Influencing Malaria Transmission

Environmental and climatic conditions play a critical role in determining the spatial and temporal distribution of malaria. The availability of suitable breeding habitats for *Anopheles* mosquitoes, the primary vectors of malaria, is largely influenced by factors such as temperature, rainfall, humidity and land cover types. In Kenya and much of Sub- Saharan Africa, seasonal rainfall creates stagnant water pools that serve as ideal breeding grounds for mosquitoes. Areas prone to flooding or poor drainage such as informal settlements like Kibera are particularly vulnerable (Mogeni et al., 2016). Furthermore, temperature fluctuations directly impact the lifecycle of mosquitoes and the development of

Plasmodium parasite within the vector. Optimal malaria transmission occurs at temperatures between 18°C and 32°C making lowland regions more conducive to year-round transmission compared to highland areas (Githeko et al., 2000). Vegetation cover and land use patterns also influence mosquito habitats. Deforestation, irrigation schemes, and urban sprawl can alter natural ecosystems, creating environments that support mosquito breeding. For example, rice paddies and poorly managed waste sites near human settlements often serve as breeding grounds for mosquito larvae.

Climatic anomalies, such as El Niño events, have been linked to increased malaria outbreaks due to higher rainfall and humidity. The effects of climate change are further shifting malaria-endemic zones, sometimes into areas that were previously non-endemic, such as the Kenyan highlands (World Health Organization, 2023). Understanding these environmental dynamics is essential for targeting malaria control interventions more effectively. The integration of remote sensing and geographic information systems (GIS) allows for the mapping of ecological risk zones and helps predict malaria hotspots based on environmental variables.

2.2.3.2 Infrastructure and Socioeconomic Factors

In addition to environmental factors, infrastructure and socioeconomic conditions significantly influence malaria control efforts in Kenya and Sub-Saharan Africa. The effectiveness of malaria prevention and treatment depends not only on the availability of health services but also on the broader economic and social environment that supports or hinders access to these services. Infrastructure challenges, such as limited transportation networks, poor road conditions, and inadequate health facilities, remain significant barriers in remote and rural areas. In regions like rural Kenya, the long distances individuals must travel to reach health facilities—combined with poor road conditions and limited transportation options—delay timely diagnosis and treatment, contributing to higher morbidity and mortality rates from malaria (Kisumu County Malaria Control Programme, 2020). Additionally, underfunded health systems are often ill-equipped to handle malaria effectively, leading to stock-outs of essential medicines, inadequate diagnostic capacity, and overworked healthcare staff (World Health Organization [WHO], 2023). Socioeconomic factors also play a central role in malaria outcomes. Poverty, lack of education, and limited health awareness are critical barriers to effective malaria control. Poorer communities often reside in high-risk areas and may lack the financial resources to afford preventive measures, such as insecticide-treated nets (ITNs) or indoor residual spraying (IRS). Furthermore, informal settlements, such as those found in Nairobi, often lack proper sanitation, drainage systems, and waste management, contributing to favorable breeding grounds for mosquitoes (Karanja et al., 2017).

Moreover, gender disparities exacerbate malaria risks, with women and children, particularly in rural areas, facing higher levels of vulnerability due to limited access to resources and healthcare (Noor et al., 2006). These social inequalities affect the ability of populations to adopt preventive health behaviors and seek timely treatment. To address these challenges, improving health infrastructure through community health initiatives, better distribution of healthcare services, and enhanced public health education is essential. Approaches that integrate social determinants of health, including economic empowerment and education, will be crucial in achieving sustainable malaria control.

2.3 Previous Studies on Healthcare Accessibility and Malaria

Numerous studies have examined the intersection of healthcare accessibility and malaria control, particularly in regions where the disease burden is high, such as Sub-Saharan Africa. Accessibility to healthcare services is a critical factor in reducing the morbidity and mortality associated with malaria, yet challenges remain, particularly in remote and resource-poor settings.

1. Healthcare Access and Timely Treatment:

One study by Mmbaga et al. (2019) examined the timing of malaria treatment and its association with clinical outcomes in rural Tanzania. The research found that delays in seeking treatment due to long distances to health facilities, poor road infrastructure, and the absence of local healthcare workers resulted in higher fatality rates. Similarly, Githeko et al. (2006) emphasized that delayed diagnosis and treatment initiation significantly increase malaria-related morbidity, especially in remote areas where healthcare infrastructure is often inadequate.

2. Malaria Prevention and Access to Resources:

A study by Noor et al. (2009) analyzed the use of insecticide-treated nets (ITNs) in Kenya and demonstrated a strong correlation between accessibility of health services and preventive interventions. They found that in rural areas, where malaria control programs were either underfunded or poorly implemented, ITN usage was substantially lower compared to urban areas. Limited access to malaria prevention tools exacerbates the disease burden, especially among vulnerable populations such as children under five and pregnant women.

3. Health System Barriers and Malaria Control in Low-Income Settings:

A research study by Yahaya et al. (2020) focused on Nigeria and analyzed how health system barriers hinder the effectiveness of malaria interventions. The study revealed that health system deficiencies, such as poor infrastructure, limited staff capacity, and stock-outs of antimalarial drugs, severely restrict the ability of healthcare systems to provide timely and effective malaria treatment and prevention. The lack of accessible and functional healthcare infrastructure meant that many individuals delayed treatment, which contributed to the persistence of high malaria incidence.

4. Socioeconomic Factors and Access to Healthcare:

Several studies have also highlighted how socioeconomic status influences access to malaria treatment. Kariuki et al. (2018) conducted research in Kenya, showing that household income and education levels were significant predictors of healthcare access. People from lower-income households were less likely to afford transport to health facilities or purchase malaria medications and bed nets. Furthermore, gender disparities were noted, as women in certain regions experienced additional barriers to accessing healthcare due to social and cultural norms.

5. The Role of Community Health Workers (CHWs):

In some studies, the role of Community Health Workers (CHWs) in improving healthcare accessibility has been a focal point. Molyneux et al. (2009) explored the impact of CHWs in malaria control in Kenya, finding that these workers helped bridge the gap in remote and underserved areas. They provided basic healthcare services, delivered antimalarial treatments, and educated communities on prevention. The study showed that CHWs increased the uptake of malaria prevention and treatment services, thereby improving healthcare access in malaria-endemic areas.

6. Urban vs. Rural Disparities in Healthcare Accessibility:

Studies have also demonstrated a significant urban-rural divide in terms of healthcare accessibility and malaria control. According to Ghebreyesus et al. (2000), people living in rural areas were more likely to face barriers to healthcare, such as long distances to health facilities, poor transport infrastructure, and inconsistent availability of medical supplies, which often delayed their access to malaria treatment. In contrast, urban areas typically have better access to health facilities, which contributes to faster treatment and lower disease burden.

2.3.1 Data Used in Spatial Health Research

Spatial health research, particularly in the context of malaria and healthcare accessibility, relies on a variety of data types to analyze the relationship between geographic factors and health outcomes. The data used can be broadly categorized into spatial data, health data, and socioeconomic data, each playing a vital role in understanding how healthcare accessibility affects malaria transmission and control.

1. Spatial Data:

Spatial data is crucial in mapping healthcare access, malaria distribution, and environmental factors that influence disease transmission. This type of data includes:

- ***Geospatial Data:*** Information derived from satellite imagery, remote sensing, and Geographic Information Systems (GIS). This data can show the location of healthcare facilities, road networks, elevation, and land use/land cover, all of which are important for assessing the accessibility of healthcare services in relation to malaria risk zones. For example, in Kenya, GIS has been used to map the distribution of malaria cases and the proximity of these cases to healthcare facilities (Kariuki et al., 2018). Remote sensing data is also used to identify mosquito breeding sites, which are influenced by factors like standing water bodies and vegetation (Ghebreyesus et al., 2000).
- ***Proximity Data:*** Data on the distance between populations and the nearest healthcare centers or malaria treatment centers is often used to evaluate access to medical services. This data can be combined with network analysis tools to determine how long it takes to reach health services by foot or by vehicle, particularly in rural or remote areas.

2. Health Data:

Health data is fundamental in understanding the burden of malaria and the relationship between healthcare access and disease outcomes. Common health data sources include:

- ***Malaria Incidence Data:*** Information on the number of suspected and confirmed malaria cases, often obtained from health facilities or community health workers. This data is used to analyze the spatial distribution of malaria cases and identify malaria hotspots. In many studies, health facility records are utilized to track the prevalence of malaria over time. These records are also used to measure the effectiveness of malaria control interventions, such as the distribution of insecticide-treated nets (ITNs) and seasonal malaria chemoprevention (SMC).
- ***Demographic Health Surveys (DHS)****:* These surveys often provide important data on population characteristics, access to healthcare, and malaria control behaviors. The data

can be used to analyze disparities in healthcare access among different demographic groups and its impact on malaria control efforts.

3. Socioeconomic and Demographic Data:

Socioeconomic and demographic data play a critical role in understanding the broader context in which malaria prevention and treatment are taking place. These data include:

- ✓ ***Socioeconomic Status****:* Information on household income, education levels, and employment status helps to understand how economic barriers influence access to healthcare services. Studies have shown that lower-income populations often face greater barriers to healthcare access (Kariuki et al., 2018).
- ✓ ***Population Density:*** Information on population density and distribution is used to understand how malaria spreads within different communities and how population movement may impact malaria transmission. In some studies, mobility data is used to track migration patterns and how they correlate with disease outbreaks (Mmbaga et al., 2019).
- ✓ ***Cultural Factors:*** In some studies, data on cultural practices and gender roles is collected to understand how local customs affect the uptake of malaria prevention strategies. For example, in some areas, women may have limited decision-making power regarding the use of insecticide-treated nets, affecting the success of prevention programs.

4. Transportation and Infrastructure Data:

In order to assess accessibility, transportation and infrastructure data is essential. This includes:

- Road Network Data: Information on the quality, availability, and density of transport networks plays a key role in determining how easily populations can access healthcare facilities. Poorly maintained roads, limited public transport, and long distances to the nearest health facility are major barriers to healthcare access in many malaria-endemic regions (Yahaya et al., 2020).
- Transportation time and costs: Data on travel times and costs helps to assess the economic accessibility of healthcare services. In remote areas, high transportation costs can deter people from seeking timely medical attention for malaria (Molyneux et al., 2009).

5. Climate and Environmental Data:

Climate and environmental data are particularly important in studies that investigate the relationship between environmental factors and malaria transmission. These data include:

- Temperature and Rainfall Data: As malaria is transmitted by mosquitoes, climatic conditions such as temperature, humidity, and rainfall are crucial for understanding the breeding patterns of malaria-carrying mosquitoes. These data can be obtained through weather stations and satellite-based monitoring systems.
- Land Use and Land Cover Data: Studies on malaria distribution often use land use data to examine how land changes, such as deforestation, urbanization, or agricultural practices, influence mosquito breeding sites. This data can be gathered through remote sensing and GIS tools to analyze ecosystem changes and their effect on malaria transmission patterns (Ghebreyesus et al., 2000).

2.3.2 Geographic Focus of Studies

The geographic focus of studies on healthcare accessibility and malaria varies widely depending on the region, disease burden, and available data. Many studies focus on **malaria-endemic regions**, particularly in Sub-Saharan Africa, where malaria remains one of the leading causes of morbidity and mortality. This section reviews the key geographic areas that have been frequently studied in terms of healthcare access and its impact on malaria control.

1. Sub-Saharan Africa: The Epicenter of Malaria

Most studies on malaria and healthcare accessibility are conducted in Sub-Saharan Africa, the region most heavily impacted by malaria. Several countries in this region experience high transmission rates, with rural and remote areas facing particular challenges in accessing healthcare services. Countries such as Kenya, Tanzania, Uganda, Nigeria, and Mozambique have been the focus of many studies due to their high malaria burden and the difficulties populations face in accessing treatment and prevention services. For instance, studies in Kenya have mapped the distribution of malaria cases, identifying high-risk areas in regions like Nyanza and Western Kenya (Kariuki et al., 2018). These studies have used GIS to assess healthcare facility accessibility and its relationship to malaria prevalence. Similarly, research in Tanzania and Uganda has highlighted how distance to healthcare facilities and poor transportation infrastructure contribute to delayed treatment and poor malaria outcomes (Mmbaga et al., 2019).

2. Rural vs. Urban Areas

A significant portion of spatial health research focuses on rural areas, where healthcare infrastructure is often inadequate, and access to malaria treatment is limited. In many rural areas, communities face longer travel times, higher costs, and limited transportation options to reach health facilities (Molyneux et al., 2009). Studies have compared malaria outcomes in rural and urban areas, revealing that urban populations generally have better access to healthcare services, including malaria treatment, due to better infrastructure and more healthcare facilities (Ghebreyesus et al., 2000). For example, a study in Kenya found that malaria transmission rates were significantly higher in rural regions like Western Kenya due to limited access to healthcare, while urban areas like Nairobi had more healthcare facilities and greater access to timely treatment (Kariuki et al., 2018).

3. Border Regions and Migration Hotspots

Studies have also focused on border regions and migration hotspots, where cross-border movements and refugee populations often create unique challenges for malaria control. In areas where people frequently cross borders, such as between Kenya and Uganda or Ethiopia and Sudan, healthcare access is often fragmented, and disease control measures are complicated by the mobility of populations (Molyneux et al., 2009). Migrants and refugees may also face language barriers, legal obstacles, and lack of documentation, preventing them from accessing health services (Yahaya et al., 2020). Research in these areas focuses on how healthcare policies and international cooperation can improve malaria control in mobile populations. In Kenya, studies have examined how refugee camps in Dadaab and Kakuma deal with malaria outbreaks and healthcare accessibility, with findings suggesting that limited healthcare infrastructure and poor sanitation exacerbate malaria transmission in these settings (Ghebreyesus et al., 2000).

4. High-Transmission Zones

Some studies focus on high-transmission malaria zones, where the intensity of transmission is highest, and healthcare access is critical in preventing widespread outbreaks. Areas like the Lake

Victoria region in Kenya, which experiences intense malaria transmission, have been the subject of various studies. These regions require effective healthcare access, preventive measures, and prompt treatment to reduce malaria's impact. In these areas, studies often focus on how timely access to malaria interventions such as insecticide-treated nets (ITNs), seasonal malaria chemoprevention (SMC), and early diagnosis and treatment can significantly reduce the disease burden (Kariuki et al., 2018).

5. Global Focus on Malaria Elimination

While Sub-Saharan Africa remains the primary focus, studies are also emerging in Asia and Latin America, where malaria transmission is endemic but less intense compared to Africa. In countries like India, Myanmar, and Brazil, studies focus on malaria control strategies and healthcare accessibility in areas with a lower but persistent malaria burden. These regions often face unique challenges such as seasonal malaria transmission, health system fragmentation, and migration from malaria-endemic zones. Research in India and Myanmar has focused on how health system strengthening and community health workers can improve healthcare access in remote malaria-endemic areas, while studies in Brazil explore indigenous populations and healthcare delivery in the Amazon (Mmbaga et al., 2019).

2.3.3 Methodologies in GIS-Based Healthcare Accessibility Studies

Geographic Information Systems (GIS) have become a pivotal tool in healthcare accessibility studies, particularly in understanding spatial factors that affect the distribution of diseases such as malaria. By analyzing geographic data, GIS helps in mapping healthcare facility locations, population density, travel time, and other infrastructural factors that influence access to medical services. This section discusses the various methodologies used in GIS-based studies related to healthcare accessibility and malaria control.

1. Mapping Healthcare Facilities and Malaria Incidence

One of the primary methods in GIS-based healthcare accessibility studies is mapping healthcare facilities and correlating them with malaria incidence. These studies typically involve georeferencing healthcare facilities (e.g., clinics, hospitals, community health posts) and overlaying them with malaria prevalence data from hospitals or health surveillance systems. By using spatial analysis techniques, researchers can identify areas with limited access to malaria treatment services and examine how accessibility relates to malaria hotspots. In Kenya, for example, studies have used buffer zones around healthcare facilities to assess the distance between communities and healthcare centers. Areas with greater distances to health facilities often experience higher malaria burden due to delayed diagnosis and treatment (Kariuki et al., 2018). Kernel density estimation (KDE) is often used to identify areas with high malaria incidence, which can help in targeting healthcare interventions and resource allocation.

2. Network Analysis for Accessibility

Network analysis is another common GIS methodology used to evaluate healthcare accessibility. This approach considers the transportation network and travel time between healthcare facilities and population centers. Travel time estimation is based on road networks, distance calculations, and average travel speeds, which can be affected by factors such as road conditions, terrain, and traffic. Network analysis allows researchers to create service areas that show which populations are within a reasonable travel distance (e.g., 30 minutes) from a healthcare facility. This method is particularly useful in rural or remote areas where transportation infrastructure may be lacking or difficult to navigate. For example, spatial accessibility models have been applied in malaria-endemic regions in Sub-Saharan Africa, including Kenya, to identify regions where healthcare services are too far for timely malaria treatment, thus increasing vulnerability to the disease (Mmbaga et al., 2019).

3. Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA) is often combined with GIS to evaluate and prioritize areas for healthcare interventions based on multiple factors such as distance to healthcare facilities, population density, malaria prevalence, transportation access, and socioeconomic variables. This method enables decision-makers to identify the most critical areas requiring intervention based on various criteria, helping allocate limited resources effectively. For instance, studies in Tanzania and Uganda have employed MCDA to prioritize areas for the distribution of insecticide-treated nets (ITNs) and malaria treatment programs by considering healthcare access alongside other factors like climate conditions, which influence malaria transmission patterns (Molyneux et al., 2009).

4. Spatial Interpolation for Disease Mapping

Spatial interpolation methods, such as kriging and inverse distance weighting (IDW), are often applied in GIS-based healthcare studies to estimate the distribution of malaria cases in areas without sufficient data points. These techniques use existing data from malaria surveys and health facilities to predict malaria incidence in unsampled areas. By applying spatial interpolation, researchers can create continuous surfaces of malaria risk, which can be compared with healthcare accessibility data to identify areas with both high malaria risk and poor healthcare access. For example, in Kenya, kriging has been used to predict malaria prevalence across regions with sparse data, allowing researchers to highlight areas where healthcare access improvements are most urgently needed (Kariuki et al., 2018).

5. Participatory GIS (PGIS)

Participatory GIS (PGIS) involves engaging local communities in the data collection and mapping process. In malaria studies, PGIS can be used to gather community-based data on healthcare accessibility, malaria hotspots, and barriers to seeking care. This method is particularly valuable in rural or marginalized areas, where local knowledge is essential to understanding real-world barriers to healthcare access. For instance, community mapping using mobile apps like Survey123 allows residents to report healthcare facility locations, accessibility challenges, and malaria risks, which can then be mapped in real time. This approach has been applied in studies in Kenya and Tanzania, helping bridge the gap between official data and local experiences of healthcare accessibility (Molyneux et al., 2009).

6. Temporal Analysis for Seasonal Variability

Malaria transmission is seasonal, with peaks occurring during the rainy season. Temporal GIS analysis helps to assess how accessibility issues evolve over time in relation to changes in malaria incidence. By analyzing seasonal variations in healthcare accessibility and disease prevalence, researchers can identify periods when access to healthcare services becomes more critical due to increased malaria transmission. In Kenya, GIS-based studies have shown that during the rainy season, the burden of malaria increases, and the need for timely healthcare access becomes more urgent. Spatial models that account for seasonal factors such as rainfall patterns, temperature, and healthcare access provide valuable insights into how to optimize healthcare delivery during malaria outbreaks (Mmbaga et al., 2019).

2.4 The Role of Geospatial Technologies in Public Health

Geospatial technologies, including Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS), have revolutionized the way public health challenges, including the control of malaria, are understood and addressed. By combining spatial data with health-related information, these technologies help improve decision-making, resource allocation, and the effectiveness of interventions aimed at enhancing healthcare accessibility and disease control.

1. GIS in Public Health

Geographic Information Systems (GIS) have become essential tools in public health research, especially in the field of disease epidemiology. GIS allows for the visualization, analysis, and interpretation of spatial data related to healthcare facilities, disease incidence, population distribution, and environmental factors. In malaria control, GIS is widely used to map malaria hotspots, track disease outbreaks, and identify areas with limited healthcare access. For instance, GIS is used to map malaria prevalence in relation to the location of healthcare facilities, allowing public health authorities to determine which communities are underserved and need better access to treatment. Proximity analysis can identify areas where people are too far from healthcare services, resulting in delayed diagnoses and increased morbidity. GIS also enables the monitoring of healthcare facilities' performance by analyzing data related to patient visits, treatment outcomes, and service delivery. By overlaying this data with malaria incidence maps, health officials can determine which areas need more resources or infrastructure improvements to meet the demand for malaria treatment.

2. Remote Sensing and Disease Mapping

Remote Sensing (RS) technology involves collecting data from satellite imagery, drones, and airborne sensors to study environmental factors that affect disease transmission, including malaria. Satellite imagery provides valuable information about land use, vegetation, water bodies, and climatic conditions that influence the breeding habitats of malaria vectors (Anopheles mosquitoes). For example, flooded areas and stagnant water bodies are key breeding grounds for mosquitoes. Remote sensing data allows public health officials to monitor seasonal changes in these environmental conditions, track mosquito habitat expansion, and predict malaria outbreaks. Additionally, climate change and temperature variations are important factors in the transmission dynamics of malaria. Remote sensing technologies can help in monitoring temperature, rainfall patterns, and humidity levels, which are critical in assessing the suitability of regions for malaria transmission. By integrating remote sensing data with GIS, researchers can create disease forecasting models that predict malaria outbreaks based on environmental and climatic variables.

3. GPS for Healthcare Service Delivery

Global Positioning System (GPS) technology is widely used in healthcare service delivery to improve the coordination and logistics of medical interventions. In malaria-endemic areas, GPS can be used to map the locations of mobile clinics, health workers, and medicine distribution points. By tracking the movement and activities of healthcare providers, health officials can ensure that malaria prevention tools, such as insecticide-treated nets (ITNs) and antimalarial drugs, reach the communities that need them most.

Moreover, GPS can assist in monitoring healthcare access by identifying remote or underserved areas where malaria prevention and treatment programs need to be intensified. It can also help improve emergency response times for malaria treatment by enabling the tracking of patients' locations and travel times to the nearest health facilities.

4. Data Integration for Decision Making

The integration of geospatial data with health datasets is one of the most powerful aspects of geospatial technologies in public health. By combining malaria incidence data with geographic location data (e.g., the location of households, healthcare facilities, water bodies), health authorities can conduct spatial analysis to identify key factors contributing to malaria transmission and healthcare accessibility. For example, spatial statistical models can be used to assess the correlation between malaria prevalence and factors such as distance to healthcare facilities, land use, weather patterns, and socioeconomic status. This approach enables public health agencies to make informed decisions on where to allocate resources, improve healthcare access, and design targeted malaria control interventions. Moreover, GIS tools such as spatial analysis and modeling can be used to predict where malaria transmission is likely to increase, allowing for proactive measures to be put in place, such as increased surveillance or mosquito control programs.

5. Public Health Campaigns and Community Engagement

Geospatial technologies are also instrumental in community engagement and health awareness campaigns. Mapping tools can help visualize malaria prevention strategies, such as the distribution of ITNs, and make it easier for communities to understand where and how to access services. This is especially important in remote areas where people may not be aware of available healthcare resources. Through the use of story maps or web-based applications, public health campaigns can be designed to show the impact of malaria and the benefits of prevention measures. These visualizations can be shared widely through social media, community meetings, and local radio broadcasts, helping to reach large populations with malaria education messages. In addition, Participatory GIS (PGIS) allows communities to engage in mapping and identifying local healthcare needs, malaria hotspots, and barriers to healthcare access. PGIS gives local populations a voice in the decision-making process, fostering community empowerment and ownership of malaria control efforts.

2.4.1 GIS in Disease Mapping and Surveillance

Geographic Information Systems (GIS) play a pivotal role in mapping diseases, analyzing their spread, and strengthening surveillance efforts, especially for infectious diseases like malaria. By integrating spatial data with health information, GIS enables public health officials to visualize disease patterns, monitor outbreaks, and optimize resource allocation. For malaria control, GIS tools have become indispensable in creating malaria prevalence maps, identifying high-risk areas, and improving the timeliness of interventions.

1. Mapping Malaria Prevalence

GIS is essential in creating detailed malaria prevalence maps that allow health authorities to pinpoint areas of high malaria transmission risk. By layering malaria incidence data over geographic maps, public health officials can identify regions with higher transmission rates and target them with specific control measures. These maps are particularly useful for identifying malaria hotspots, where resources like mosquito nets, insecticides, and medications should be prioritized. GIS allows for real-time mapping, which can provide up-to-date information on the spread of malaria cases, thereby facilitating rapid response actions during outbreaks. By visualizing trends in malaria transmission over time, GIS helps identify seasonal patterns, geographical hotspots, and vulnerable communities, which are critical in designing malaria prevention and control strategies.

2. Malaria Surveillance and Early Warning Systems

GIS enhances disease surveillance by integrating health data from various sources, such as hospitals, clinics, and mobile health units, and combining it with geospatial data like climate, environmental factors, and population density. This integrated data allows for the tracking of malaria trends and the identification of emerging risk zones. Surveillance systems can be set up to monitor cases over time, enabling health agencies to respond to new outbreaks quickly. A key aspect of GIS-based surveillance systems is the creation of early warning systems for malaria outbreaks. By analyzing trends in malaria incidence along with environmental factors (e.g., temperature, rainfall), GIS can help predict malaria outbreaks before they occur. For example, GIS models can identify regions where mosquito populations are likely to increase due to changing environmental conditions, such as higher rainfall, creating ideal conditions for malaria transmission.

3. Spatial Analysis and Risk Assessment

GIS provides powerful tools for spatial analysis, which helps assess malaria risk based on a range of factors. By integrating data on environmental conditions, human movement, and health infrastructure, GIS allows for multi-layered analysis that reveals the spatial relationships between disease and risk factors. For example, GIS can analyze the relationship between distance to healthcare facilities and malaria prevalence, highlighting areas where poor healthcare access may contribute to higher disease transmission. Furthermore, GIS can be used to assess the effectiveness of malaria control interventions, such as the distribution of insecticide-treated nets (ITNs) and spraying programs, by comparing spatial data before and after interventions. By examining areas with persistent high malaria rates, public health officials can refine their targeting strategies, ensuring that malaria prevention measures are deployed where they will have the greatest impact.

4. Case Study Examples

- In Kenya, GIS has been used to map malaria hotspots in regions like Rift Valley and Coast Province. These maps help target malaria control efforts to the most affected areas and allow for more efficient distribution of mosquito nets and antimalarial treatments.
- In Uganda, GIS was used in malaria control programs to track the spread of malaria cases, especially in rural areas, where access to healthcare is limited. The integration of GIS with mobile health systems allowed health workers to track patient locations and provide more timely interventions.

5. Enhancing Collaboration and Data Sharing

GIS also fosters collaboration between different sectors involved in malaria control, such as healthcare, environmental agencies, and community organizations. By making malaria-related data accessible in a visual format, GIS facilitates data sharing and coordination, which are critical for comprehensive disease control. In many regions, government agencies, non-governmental organizations (NGOs), and community health workers use GIS to plan and execute malaria control strategies together. The ability to share real-time data across various levels of government and healthcare networks is especially important for rapid response efforts during malaria outbreaks.

This information sharing is essential for ensuring that resources, such as medications and mosquito control measures, are distributed efficiently.

2.4.2 Network Analysis for Healthcare Accessibility

Network analysis is a powerful tool in Geographic Information Systems (GIS) that is used to evaluate healthcare accessibility, particularly in regions with high malaria prevalence. By analyzing transportation networks, such as roads, rivers, and footpaths, network analysis helps to assess the time and distance required for individuals to access healthcare facilities. This is particularly important in remote or rural areas, where access to healthcare services may be limited by poor infrastructure.

1. Understanding Healthcare Accessibility

Healthcare accessibility refers to the ability of individuals to reach medical services when needed. In areas with malaria transmission, this is crucial because timely treatment is essential to prevent severe illness and death. Distance to healthcare facilities, combined with transportation availability, significantly impacts access to malaria diagnosis and treatment. In many malaria-endemic regions, especially in sub-Saharan Africa, healthcare access is often limited by poor infrastructure, long travel times, and high costs. Network analysis in GIS evaluates how healthcare services are distributed across a region and how easy it is for people to access these services based on existing transportation networks. By factoring in the location of healthcare centers and the availability of roads or other means of transport, network analysis can reveal areas with poor healthcare access, which are often at higher risk for diseases like malaria.

2. Identifying Gaps in Healthcare Access

Network analysis helps to identify gaps in healthcare access, especially in remote areas that are far from healthcare facilities. For example, by mapping the distance to the nearest healthcare center from malaria-affected communities, network analysis can show which populations are underserved and may not receive timely malaria treatment. This is critical in areas where malaria-related deaths are high due to delayed diagnosis or lack of treatment facilities. Network analysis can also highlight areas where transportation networks are inadequate, making it difficult for patients to reach healthcare facilities. For example, it can identify regions with limited road access or poorly connected villages where people may need to walk long distances to seek medical help. These analyses provide insight into healthcare system inefficiencies and areas where improvements are needed to enhance malaria control efforts.

3. Optimizing Healthcare Delivery

One of the key applications of network analysis is optimizing healthcare delivery to ensure that resources are allocated efficiently. By analyzing the proximity of healthcare centers to populations at risk of malaria, network analysis can help identify priority areas for investment in healthcare infrastructure. This could include building new health facilities, improving road networks, or providing mobile clinics in underserved areas. Network analysis also helps in evaluating the efficiency of existing healthcare delivery models. For example, it can assess how quickly healthcare workers can reach remote communities to deliver malaria treatments or prevention programs like insecticide-treated nets (ITNs). By identifying bottlenecks in the healthcare system, such as slow transportation routes or insufficient healthcare staff, network analysis can inform strategies to improve access to timely malaria interventions.

4. Case Study Examples

- Malaria Control in Rural Tanzania: A GIS network analysis conducted in rural Tanzania examined the travel times to the nearest healthcare facilities from malaria-affected areas. The study found that more than 50% of households were located over 10 km away from the nearest health facility, highlighting the need for improved road networks and mobile clinics to reach remote populations (Misinzo et al., 2014).
- Kenya's Malaria Control Program: In Kenya, network analysis has been used to assess the spatial distribution of healthcare facilities in malaria-endemic regions. The analysis found that rural communities in the Coast Province had limited access to healthcare services, contributing to delays in treatment and higher malaria-related morbidity and mortality (Ndungu et al., 2018). This prompted the government to focus on improving transportation access and expanding healthcare infrastructure in high-risk areas.

5. Enhancing Health Equity through Network Analysis

Network analysis in GIS is not only a tool for improving healthcare access but also for promoting health equity. By identifying regions with poor access to healthcare services, network analysis ensures that vulnerable populations, such as those living in poverty, the elderly, or people with disabilities, receive the attention and resources they need. This approach aligns with the United Nations Sustainable Development Goal 3 (Good Health and Well-Being), which calls for universal health coverage and access to quality healthcare services for all. By focusing on accessibility, network analysis helps to eliminate barriers that prevent people from reaching healthcare services, particularly in malaria-endemic areas where early diagnosis and treatment are essential to reducing the burden of the disease.

2.5 Summary and Research Gaps

The literature on malaria and healthcare accessibility highlights the complex relationship between disease incidence and access to healthcare services. Malaria remains a major public health concern in Sub-Saharan Africa, including Kenya, where regional disparities in healthcare access contribute significantly to the high burden of the disease. Various factors—such as infrastructure, socioeconomic conditions, and environmental influences—affect the accessibility of healthcare services for malaria patients. Studies have shown that rural areas, in particular, face challenges in reaching healthcare facilities due to poor road networks, lack of transportation options, and financial barriers. Geographic Information Systems (GIS) and spatial analysis have proven to be valuable tools in mapping healthcare accessibility and identifying high-risk zones for malaria transmission, facilitating targeted interventions and resource allocation.

However, despite the substantial body of research on malaria epidemiology and healthcare accessibility, there remain significant research gaps in the context of Kenya, particularly in understanding the finer details of how spatial factors impact access to care at the household level. Existing studies often focus on broad regional data but lack granular analysis that can help policymakers understand local disparities in healthcare access and malaria risk. Furthermore, while network analysis and GIS techniques are widely used, there is limited research on how these methods can be integrated with real-time data from health facilities and communities to improve healthcare delivery for malaria patients.

This study aims to address these gaps by conducting a spatial analysis of healthcare accessibility for malaria patients in Rarieda Constituency. By focusing on local-level accessibility and leveraging GIS tools, the study will provide a more nuanced understanding of the factors influencing healthcare access, ultimately supporting the development of targeted interventions to reduce malaria morbidity and mortality.

CHAPTER 3: MATERIALS AND METHODS

3.1. Introduction

This chapter focuses on the methodology used to conduct the study. It provides a description of the study area, data sources, tools used and the step-by-step approach for data collection, preprocessing, spatial analysis, and mapping. The methodology is guided by the specific objectives of the study and is designed to utilize spatial data and GIS-based tools to generate insights into healthcare accessibility.

3.2. The study Area

Rarieda constituency, situated in Siaya county, is located in the western part of Kenya, along the southern shores of the vast and scenic Lake Victoria. The constituency is bordered by several neighboring constituencies, including Bondo to the west, Seme to the east, Gem to the North and Mbita to the south. Figure 3.1 is the area of study map of Rarieda constituency providing context and geographic reference of its locality.

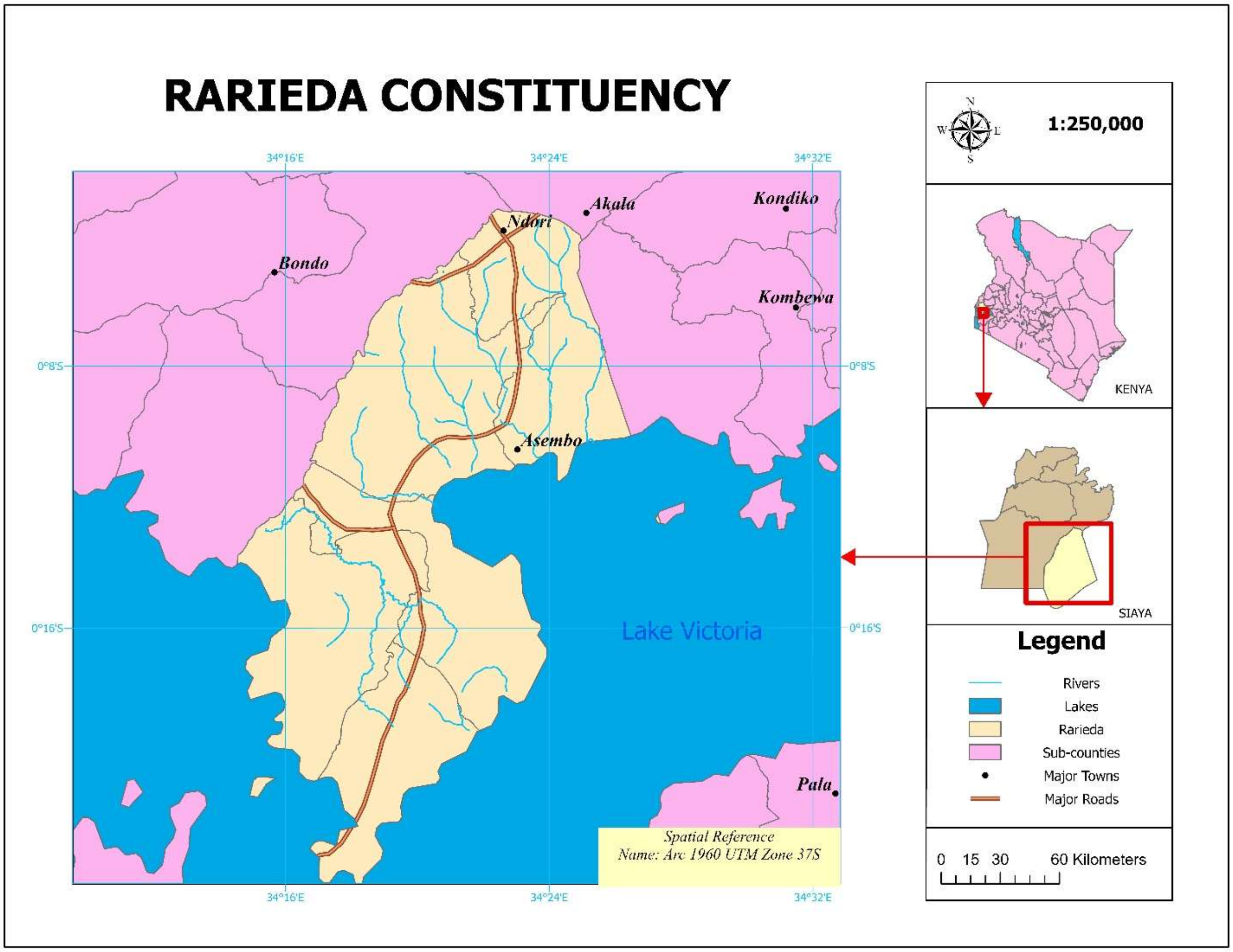


Figure 3.1 – Area of study map

Rarieda Constituency, located in Siaya County, covers an estimated area of 644 square kilometers, of which 62% is land and 38% is water, primarily due to its proximity to Lake Victoria. According to the 2019 Kenya Population and Housing Census, the constituency has a population of 124,938. This results in a population density of approximately 194 people per square kilometer. Rarieda is one of six constituencies in Siaya County and comprises several wards that represent the local administrative units. Table 3.1 details the five wards in Rarieda constituency and their description.

Table 3.1 – Rarieda Wards

Rarieda Wards	Description
East Asembo	Located in the eastern part of the constituency, East Asembo is one of the most populated wards. It is known for its agricultural activities, particularly farming and fishing due to its proximity to Lake Victoria.
West Asembo	Situated to the west of Rarieda, West Asembo borders other constituencies within Siaya County. This ward is also involved in farming, with a mix of crops and livestock farming.
North Uyoma	Covering the northern part of Rarieda, North Uyoma has a large population engaged in both agriculture and fishing, benefiting from the fertile land and proximity to the lake. This ward has a substantial number of residents relying on small-scale farming for their livelihoods.
South Uyoma	Located in the southern part of Rarieda, South Uyoma is known for its rural setting, with a focus on subsistence farming.
West Uyoma	Positioned in the western part of the constituency, West Uyoma shares socio-economic characteristics with the other wards. It has a population engaged in farming.

The constituency has a diverse population that largely relies on fishing, agriculture, and small-scale trading for its livelihood. The area experiences a tropical climate with the heaviest rainfall occurring between March and May, and it faces environmental challenges such as water pollution, soil erosion, and limited access to clean water. Rarieda is served by both public and private healthcare facilities, including dispensaries, health centers, and private hospitals, many of which are located in urban areas while others serve rural communities. Malaria is endemic in the region, particularly in areas near Lake Victoria, where stagnant water creates favorable breeding grounds for mosquitoes. The prevalence of malaria is high, which makes the accessibility to healthcare facilities especially critical in managing the disease. The constituency faces significant challenges in healthcare access due to the distance to healthcare facilities, poor road infrastructure, and the rural nature of many areas. Inadequate healthcare access is compounded by long travel times to the nearest health centers and inconsistent healthcare service delivery in some regions. These factors make Rarieda an ideal location for studying healthcare accessibility for malaria patients, as the population is at significant risk due to these barriers.

3.3. Sources and Tools

This section outlines the various datasets and tools used in conducting the spatial analysis of healthcare accessibility in Rarieda Constituency. The study relied on secondary data sources and geospatial tools to analyze healthcare facility distribution, malaria incidence, and population access to medical services.

3.3.1. Data sources

This study majorly uses secondary data which is already existing data. The table 3.2 shows the various data sets that were used for the study. Table 3.2 shows the data used in this research, their sources, file formats and specifications.

Table 3.2 - Data sources

Data	Source	Format	Specifications	Availability
Administrative Boundary 1. Kenya counties 2. Siaya Sub-counties 3. Rarieda Wards	IEBC – Humanitarian Data Exchange (https://data.humdata.org/dataset/cod-ab-ken)	Shapefiles (.shp)	WGS 84	Yes

Kenya Population Density	Kenya National Bureau of Statistics (www.knbs.or.ke/2019-kenya-population-and-housing-census-reports/	Raster (.tiff)	WGS 84, Population count, Density (people/km^2), Year, Resolution (30m)	Yes
Health facilities	Kenya Master Health Facility List (KMHFL) (https://kmhfr.health.go.ke/public/facilities)	Shapefile (.shp) / CSV	WGS 84, Facility name, Type (hospital, dispensary) and Coordinates	Yes
Road Networks	OpenStreetMap (OSM), Ministry of Roads	Shapefile (.shp)	Road name and Type	Yes
Malaria incidence data	Clinton Health Access Initiative (CHAI), provided upon request	Excel (.xlsx) / CSV	Facility name Ward, Suspected Confirmed cases and period	Yes

3.3.2. Tools

Hardware and software tools used in this research are highlighted in tables 3.3 & 3.4 respectively.

Table 3.3 – Hardware tools

Hardware Tools	**Description**	**Use**
Lenovo ThinkPad X1 Yoga	Core i7 @ 1.80GHz 2.30 GHz, 16GB RAM, 64-bit Operating System	Provides robust computing power for efficient data processing, analysis, and GIS operations.
Mouse and mouse pad	Standard USB wired mouse with mouse pad	Ensures precise control and comfort during data navigation and GIS analysis tasks.

Table 3.4 – Software Tools

Software Tool	**Description**	**Use**
Microsoft office word	Word processing software for creating and editing documents	Used for drafting, formatting, and finalizing the project report.
ArcGIS	A powerful GIS platform by Esri for spatial analysis and mapping	Used to compile and manage data, perform various kinds of spatial analysis, visualization of data through the generation of maps and sharing of findings.
Microsoft Excel	Spreadsheet application for data organization and analysis	Helps to organize, clean, and analyze malaria case data and related population information.
World Wide Web	Information System that allows access through the Internet.	Allows for accessing of online resources useful for research purposes.

3.4 An overview of the methodology

This study utilizes a combination of spatial analysis, data preprocessing, and network-based approaches to assess healthcare accessibility for malaria patients in Rarieda Constituency. The methodology integrates population density, health facility data, malaria case data, and the road network to identify underserved areas and prioritize intervention strategies. The first step involves collecting relevant spatial data, including the locations of health facilities, malaria cases, road networks, and administrative boundaries. These datasets are imported into GIS software, such as ArcGIS or QGIS, where they undergo preprocessing to ensure compatibility with the analysis tools. Preprocessing ensures the data is accurate and appropriately formatted for the subsequent analysis. Health facility data will be classified and symbolized to represent the different types of healthcare services available in the study area. A final map will visually display the locations and types of health facilities, which will aid in identifying gaps in healthcare service delivery. This classification is essential for understanding the distribution and accessibility of healthcare services within the region. Additionally, malaria case data will be imported into ArcGIS to visualize and analyze the spatial distribution of both confirmed and suspected malaria cases. Inverse Distance Weighting (IDW) interpolation will be applied to generate a continuous surface representing the spatial distribution of confirmed malaria cases, highlighting areas with higher malaria incidences. This will help identify regions that may require more intensive healthcare intervention.

The road network data will be imported into a newly created geodatabase and used to build a network dataset for route analysis. This dataset will enable the identification of the nearest healthcare facility to each population center or malaria case using the closest facility approach. Network analysis will help assess the accessibility of healthcare services for malaria patients based on the existing road infrastructure, aiming to identify transportation barriers that could impede access to necessary care. Finally, the study will involve generating routes from population centers to health facilities, identifying underserved areas that face significant barriers to healthcare access. These areas will be mapped and analyzed to inform future healthcare interventions, such as the establishment of new health facilities, mobile clinics, or improvements in transportation infrastructure. Identifying underserved areas is crucial for optimizing healthcare delivery and ensuring equitable access for all residents.

This comprehensive approach will provide valuable insights into the accessibility of healthcare services for malaria patients in Rarieda Constituency, supporting the development of targeted and effective healthcare interventions. Figure 3.2 shows the methodology workflow.

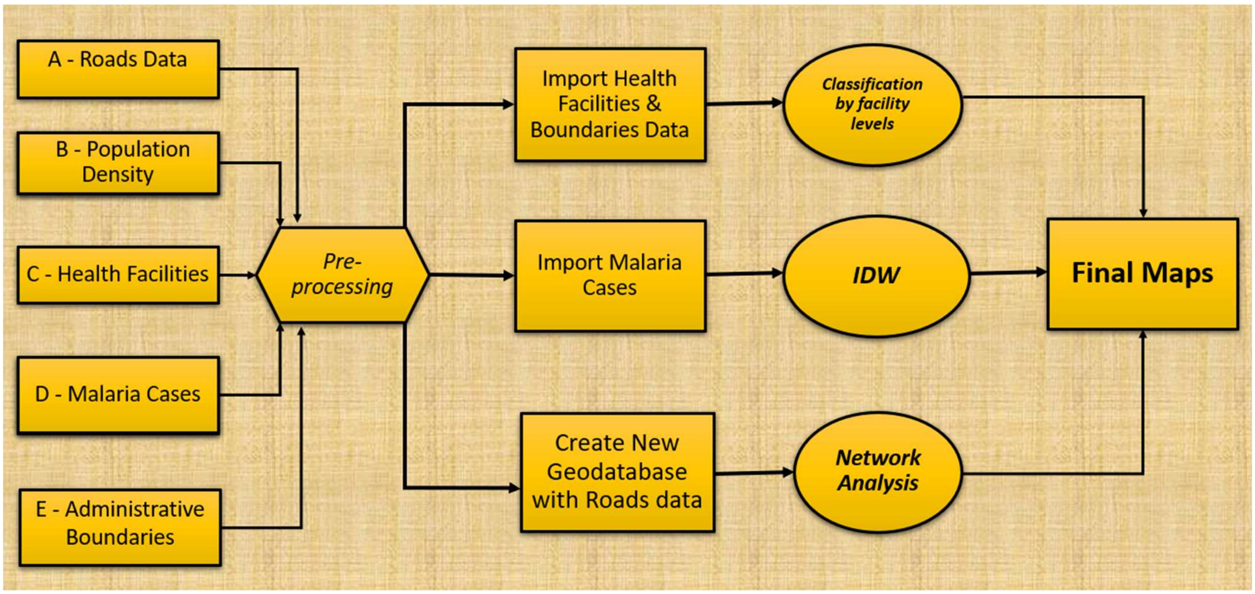
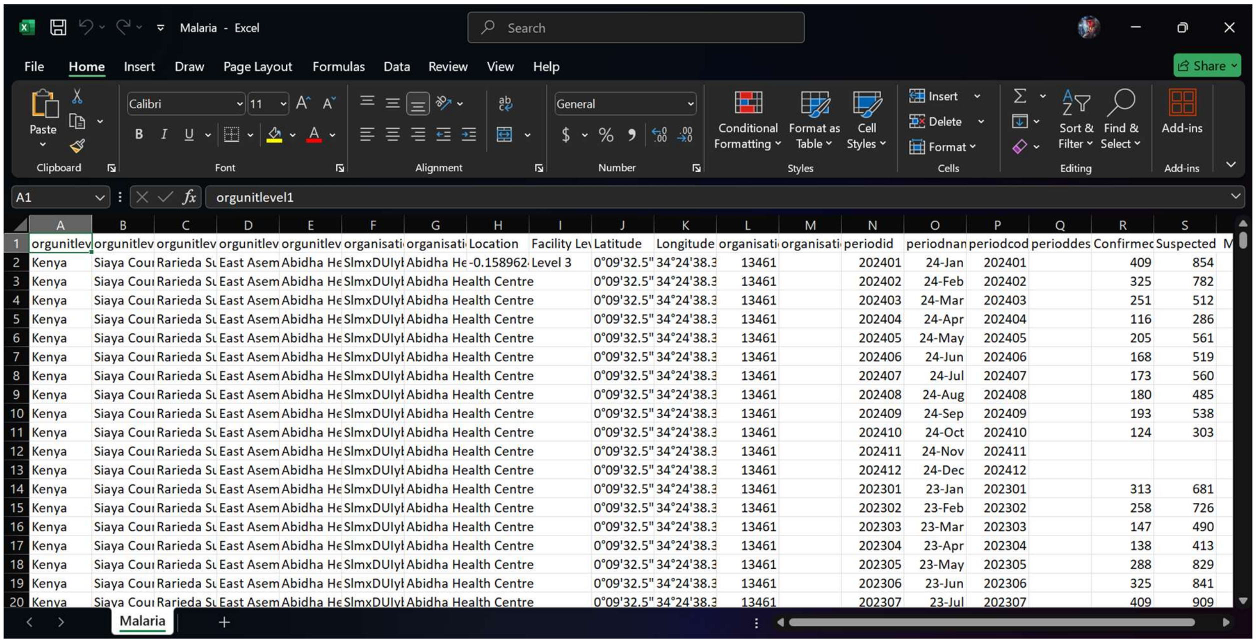


Figure 3.2 – Methodology Work flow

3.5. Data preprocessing

Data preprocessing involved several steps to ensure spatial accuracy, consistency, and analytical readiness. All spatial datasets were reprojected to a uniform coordinate system, Universal Transverse Mercator (UTM) Zone 37S, which is appropriate for the geographic extent of Rarieda Constituency. This projection was selected to maintain spatial accuracy during distance-based network analysis. Shapefiles for administrative boundaries, healthcare facilities, and road networks were clipped to the Rarieda Constituency extent using the "Clip" tool in ArcGIS Pro.

Attribute fields were standardized, and null or erroneous entries corrected to ensure consistency across datasets. Duplicate points in the healthcare facility layer were removed after verification, and facility names were harmonized to match official government listings from the Kenya Master Health Facility List (KMHFL). Malaria case data reported by health facilities were cleaned in Microsoft Excel. Only confirmed malaria cases were used in the spatial analysis to avoid bias introduced by suspected or unverified cases. Facility-based case data were geocoded using facility coordinates to enable spatial visualization and interpolation. Figure 3.3 shows a snapshot of the malaria cases data including the facility name, location, period, suspected and confirmed cases.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	orgunitlev	orgunitlev	orgunitlev	orgunitlev	orgunitlev	organisati	organisati	Location	Facility Lev	Latitude	Longitude	organisati	organisati	periodid	periodnan	periodcod	perioddes	Confirmec	Suspected	M
2	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha He	-0.158962	Level 3	0°09'32.5"	34°24'38.3	13461		202401	24-Jan	202401		409	854	
3	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202402	24-Feb	202402		325	782	
4	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202403	24-Mar	202403		251	512	
5	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202404	24-Apr	202404		116	286	
6	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202405	24-May	202405		205	561	
7	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202406	24-Jun	202406		168	519	
8	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202407	24-Jul	202407		173	560	
9	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202408	24-Aug	202408		180	485	
10	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202409	24-Sep	202409		193	538	
11	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202410	24-Oct	202410		124	303	
12	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202411	24-Nov	202411				
13	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202412	24-Dec	202412				
14	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202301	23-Jan	202301		313	681	
15	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202302	23-Feb	202302		258	726	
16	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202303	23-Mar	202303		147	490	
17	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202304	23-Apr	202304		138	413	
18	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202305	23-May	202305		288	829	
19	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202306	23-Jun	202306		325	841	
20	Kenya	Siaya Cou	Rarieda Su	East Asem	Abidha He	SlmxDUlyl	Abidha Health Centre			0°09'32.5"	34°24'38.3	13461		202307	23-Jul	202307		409	909	

Figure 3.3 – Malaria cases data

Raster datasets such as the population raster dataset were resampled to 30-meter resolution to match the scale of other datasets used in the accessibility and interpolation models. All layers were verified for spatial alignment using the "Check Geometry" and "Repair Geometry" tools before being integrated into the geodatabase for analysis.

3.6. Mapping healthcare facilities in Rarieda

Healthcare facilities within Rarieda Constituency were mapped to visualize their spatial distribution and support accessibility analysis. The facility data were obtained from the Kenya Master Health Facility List (KMHFL), which provides official records of healthcare institutions across Kenya. Each facility was geocoded using its coordinates and categorized based on the Kenya Essential Package for Health (KEPH) levels namely, Level 2 (dispensaries and clinics), Level 3 (health centers), and Level 4 (sub-county hospitals). To distinguish between the different facility levels, the "Select by Attributes" tool was employed. This tool enabled the selection and extraction of features based on attribute criteria corresponding to each KEPH level. Separate layers were then created for Level 2, Level 3, and Level 4 facilities to facilitate clear classification and spatial analysis. Figure 3.4 is an SQL query window in ArcGIS pro used to select features by attributes.

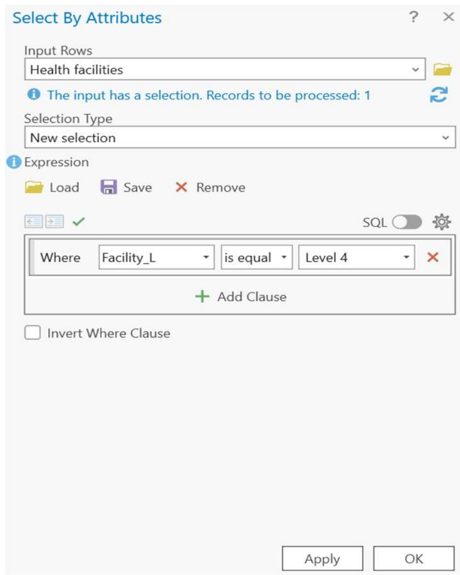


Figure 3.4 – SQL query

These facility layers were subsequently overlaid onto the constituency's administrative boundary. The "Symbology" function was used to apply distinct symbols to each facility level, allowing for visual differentiation and better interpretation of healthcare service coverage.

Map elements such as a legend, north arrow, scale bar, and labels were added to enhance the overall readability and interpretation of the map. These cartographic elements ensured that the map could effectively communicate the distribution and classification of healthcare facilities to a broad audience.3.6. Analyze spatial distribution of malaria cases

3.7. Analyze spatial distribution of Malaria cases

To analyze the spatial distribution of malaria cases in Rarieda Constituency, secondary data were obtained from the Clinton Health Access Initiative (CHAI). The dataset included reported monthly malaria cases per health facility distinguishing between suspected and confirmed cases. Each record was already georeferenced and linked to its respective healthcare facility, simplifying integration into the GIS environment. Confirmed malaria cases were used for spatial analysis to ensure a more accurate representation of the disease burden. Graduated symbols were applied in ArcGIS pro to map the variation in malaria cases across facilities. Facilities with higher confirmed cases were represented with proportionally larger symbols enabling easy identification of clusters and hotspots. This visualization revealed that malaria cases were spatially clustered rather than evenly distributed, with certain facilities, particularly higher-tier centers, reporting disproportionately high caseloads. To estimate continuous malaria risk across the constituency, Inverse Distance Weighting (IDW) interpolation was employed. IDW, a spatial interpolation method that assigns greater weight to nearby points, was used to generate a malaria risk surface. The resulting raster highlighted high-risk zones, especially those near Lake Victoria, indicating the possible influence of environmental conditions such as proximity to water bodies on malaria transmission. This spatial analysis provided critical insight into localized malaria burden, serving as a foundation for subsequent accessibility assessments and intervention planning.

3.8. Assess Distance to Closest Facility

To evaluate healthcare accessibility for malaria patients, a network analysis was conducted in ArcMap using a closest facility analysis. Initially, new geodatabases and feature datasets were created to organize and manage the data. OpenStreetMap (OSM) road data was then incorporated to build a network dataset, which facilitated the calculation of optimal routes. Figure 3.5 below shows the created Roads geodatabase with the roads data inside it.

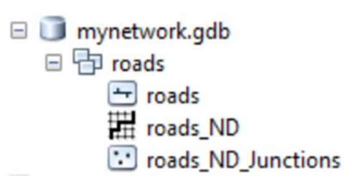


Figure 3.5 – Network geodatabase

The health facility data was added to the network as the 'facilities' layer, while point-population data was included in the incidents section. A closest facility analysis was performed to determine the nearest healthcare facility for each population point as shown in figure 3.6. This analysis computed the shortest distance in meters between each population point and the closest health facility, generating routes that reflected the most efficient paths along the road network.

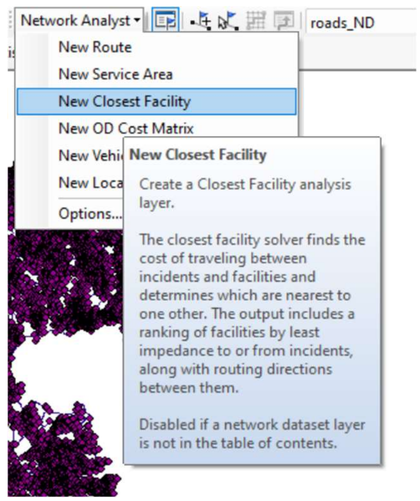


Figure 3.6 – Closest facility analysis

The output provided a detailed assessment of spatial healthcare accessibility, with distances to the nearest health facilities for populations in the study area. This analysis was essential for identifying underserved regions and planning targeted healthcare interventions for malaria patients.

3.9. Identify underserved areas

To identify underserved areas, the results from the closest facility analysis were further examined to highlight spatial disparities in healthcare accessibility. The generated routes, which represented the shortest travel distances from population points to the nearest health facilities, were analyzed to determine areas with limited access. Distance thresholds were established based on public health literature and contextual travel considerations to categorize service levels. Population points with travel distances exceeding these thresholds were flagged as underserved. These areas were then visualized using graduated symbology to distinguish between well-served, moderately served, and poorly served regions. Identifying these underserved areas provided critical input for planning targeted health interventions and infrastructure improvements aimed at reducing malaria-related health disparities.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the results derived from the spatial analysis of healthcare accessibility for malaria patients in Rarieda Constituency. The analysis focused on mapping healthcare facilities, examining the spatial distribution of malaria cases, assessing travel times to the nearest health facilities, and identifying underserved areas. The outputs include maps, spatial statistics, and descriptive summaries that highlight patterns of service provision and areas in need of improved healthcare access. These results form the basis for the discussions and recommendations in the subsequent chapter.

4.2 Healthcare Facilities

This section presents the results of mapping healthcare facilities within Rarieda Constituency. The facilities were mapped based on their geographic locations and classified according to the levels of services they provide. The spatial distribution of these facilities provides insight into the accessibility of healthcare services across different areas of the constituency.

4.2.1 Total number of facilities

In this study, an in-depth mapping and analysis of healthcare facilities across Rarieda Constituency were conducted using ArcGIS Pro, a sophisticated and versatile Geographic Information System (GIS) tool. This robust tool enabled accurate visualization and spatial representation of healthcare resources, capturing both their geolocations and classifications. As a result of this analysis, a total of 42 healthcare facilities were identified, geocoded, and mapped as shown in figure 4.1. These facilities represented a diverse range of sizes, capacities, and levels of service provision, encompassing a spectrum from smaller dispensaries classified as Level 2, to intermediate health centers categorized as Level 3, and finally one advanced facility, a Level 4 sub-county hospital, offering a referral level of care as shown in figure 4.2 Each identified facility was meticulously categorized based on its operational level to allow for a comprehensive understanding of the healthcare landscape within the constituency. Level 2 facilities, which accounted for the majority, were primarily dispensaries offering basic outpatient services aimed at addressing common ailments, including initial care for malaria patients. Level 3 facilities, such as health centers, provided more advanced diagnostic and treatment services, contributing to enhanced accessibility for residents. The single Level 4 facility, Madiany Sub- County Hospital, was a critical resource offering a wider range of specialized services and serving as a referral center for the surrounding wards.

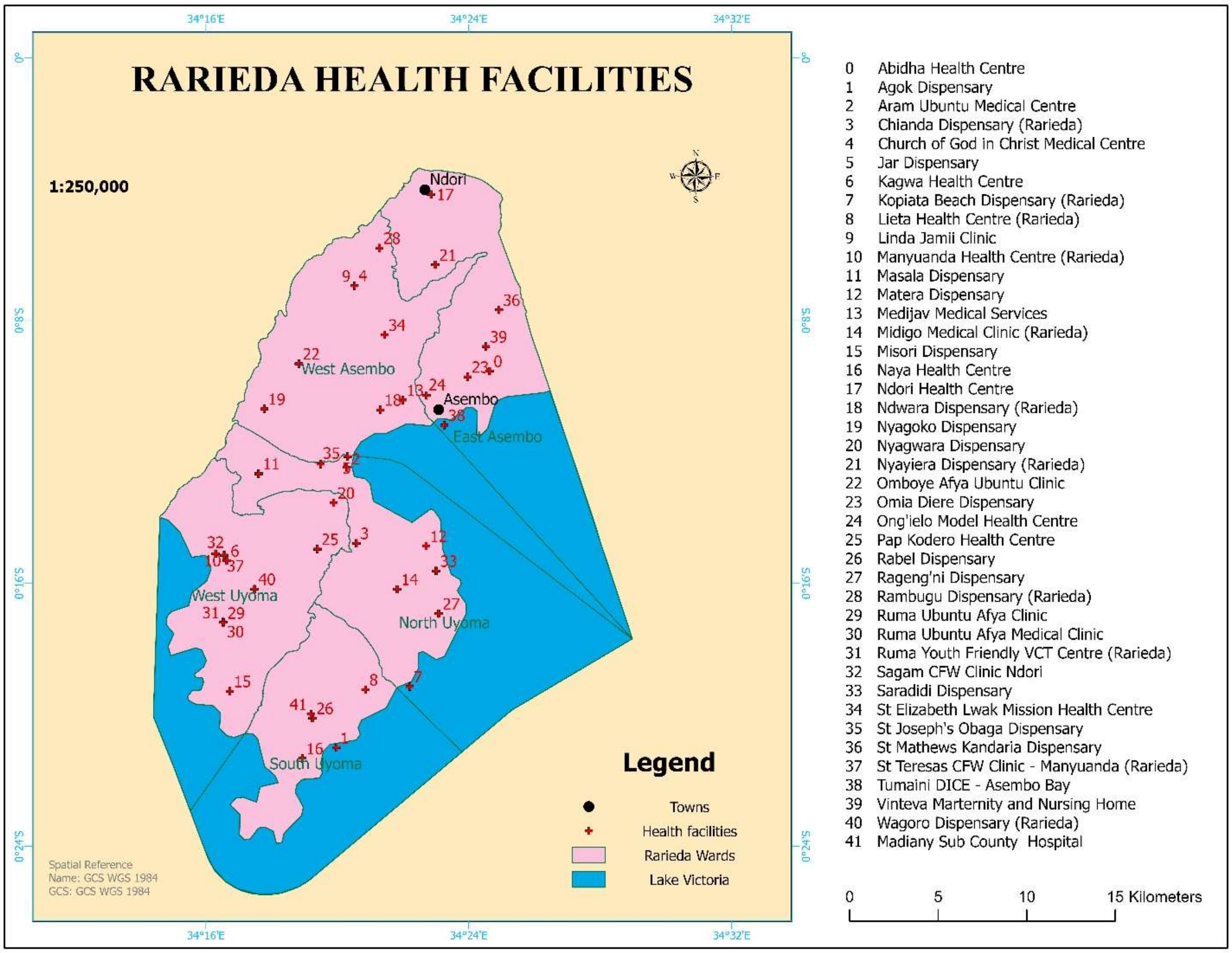


Figure 4.1 – Rarieda Health facilities

The analysis further revealed a heterogeneous distribution pattern, characterized by densely clustered facilities in some wards and a sparser distribution in others. For instance, wards like North Uyoma and West Uyoma were found to have a relatively higher concentration of facilities, including Level 3 and 4 centers, whereas wards such as South Uyoma had fewer facilities, leaving certain regions underserved. This uneven distribution underscored the existing geographic disparities in healthcare accessibility, with some residents enjoying shorter distances to healthcare services while others faced significant travel challenges. ArcGIS Pro played a key role in creating detailed maps and models that shed light on how healthcare facilities are distributed and accessible in Rarieda constituency. Through the geospatial analysis, it became clear where the gaps in healthcare resources exist, making it easier to identify areas that urgently need more investment. By utilizing these advanced tools, the study provided a solid basis for making informed decisions and crafting targeted strategies to address disparities in access to healthcare, particularly for malaria patients. These insights are not just helpful for understanding the current situation but also serve as a critical guide for future planning, emphasizing the need for equitable distribution of healthcare services to close the gaps and improve overall health outcomes in the region.

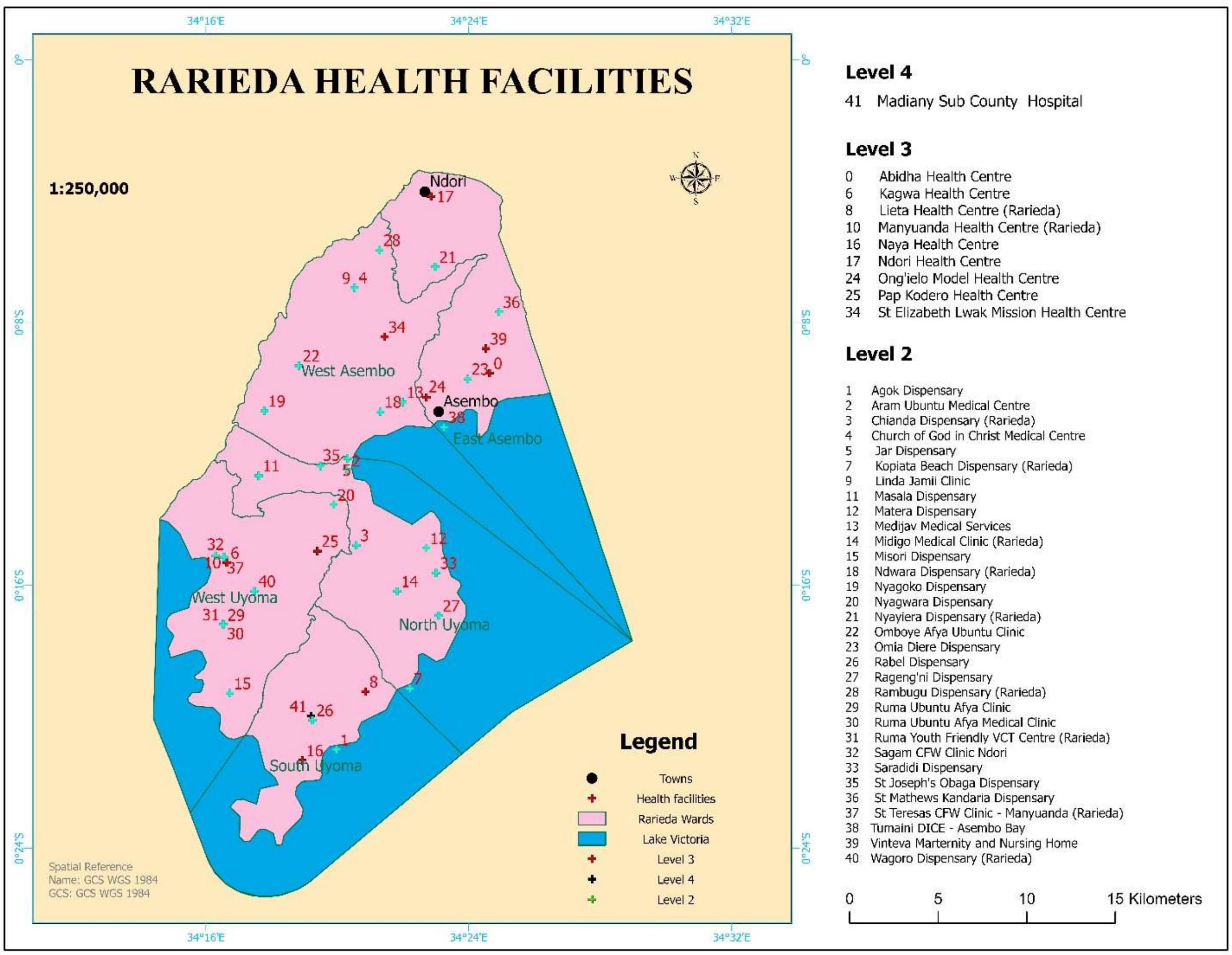


Figure 4.2 – Health facilities distribution by levels

- **Level 2 (Dispensaries and Clinics):** 32 facilities

The majority of facilities, predominantly classified as Level 2, fell into this category and primarily comprised dispensaries scattered throughout Rarieda constituency as shown in figure 4.3. These facilities offered widespread coverage, ensuring that basic outpatient healthcare services were accessible to many residents, particularly in more rural or less densely populated areas. However, the services provided were relatively limited in scope, focusing on initial diagnosis and basic treatment, with minimal capacity for specialized care or advanced medical interventions. Their presence was instrumental in bridging healthcare gaps in underserved regions, acting as vital points of contact for malaria patients who might otherwise face significant challenges in reaching higher-level facilities. Despite their widespread distribution, the need for enhanced capacity and resources within these facilities remains critical to addressing more complex healthcare demands in the constituency.

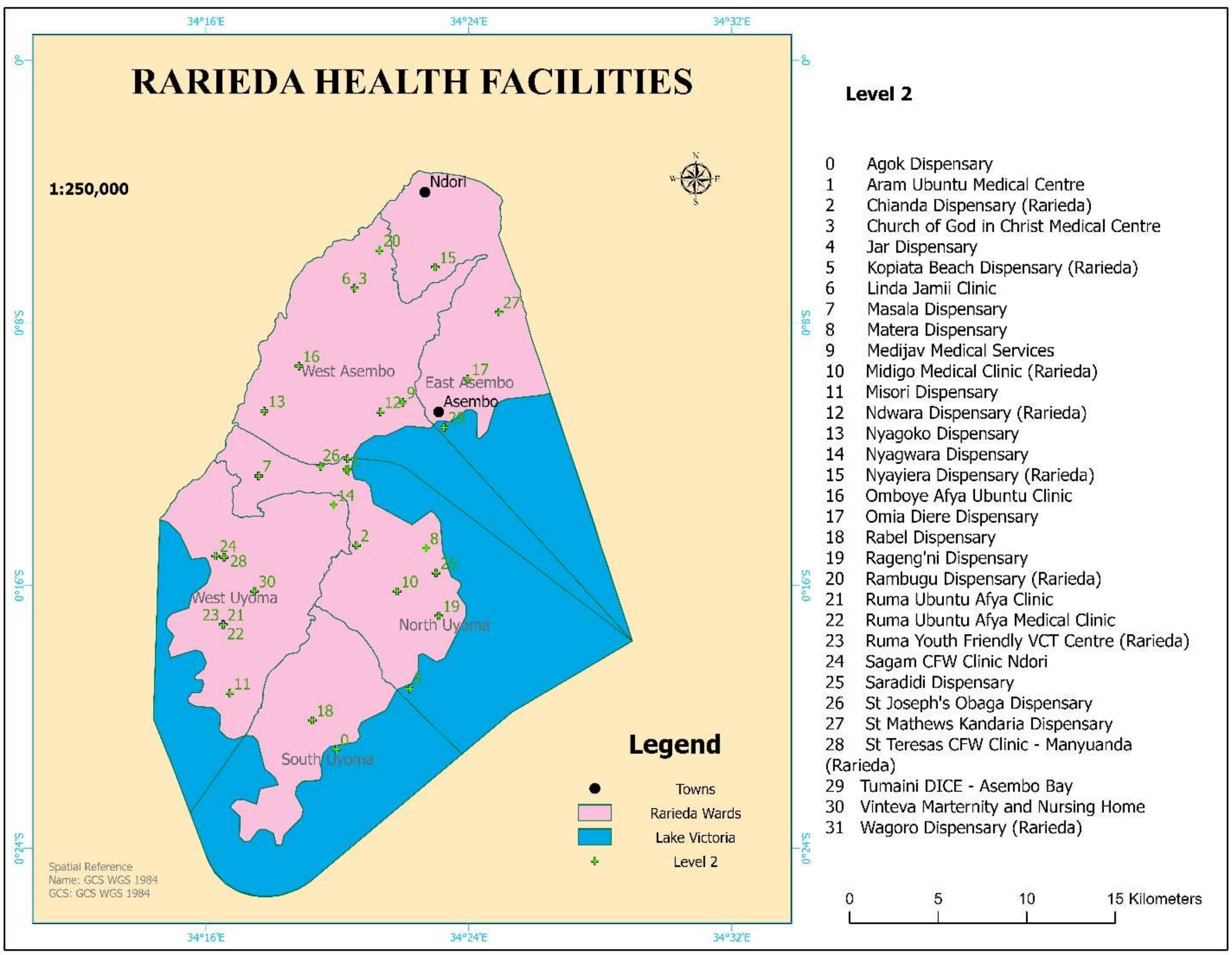


Figure 4.3 – Level 2 Health Facilities

- **Level 3 (Health Centers):** 9 facilities

The Rarieda constituency boasts a total of nine Level 3 healthcare facilities all mapped in figure 4.4, which play a crucial role in providing mid-level healthcare services to residents. These facilities include Abidha Health Centre, Kagwa Health Centre, Lieta Health Centre (Rarieda), Manyuanda Health Centre (Rarieda), Naya Health Centre, Ndori Health Centre, Ong'ielo Model Health Centre, Pap Kodiero Health Centre, and St Elizabeth Lwak Mission Health Centre. Each of these centers offers more advanced diagnostic and treatment services compared to Level 2 facilities, forming an essential part of the healthcare framework in the region. Key facilities like Ndori Health Centre and Naya Health Centre stand out for their strategic placement and functionality, as they are well-distributed across several wards. Their central locations make them highly accessible to a large portion of the population, thus improving healthcare delivery in their catchment areas. These centers not only handle outpatient services but also support community health initiatives, such as maternal health programs, immunization drives, and the management of chronic and infectious diseases like malaria.

On the other hand, wards such as West Uyoma and sections of East and West Asembo enjoy the advantage of having multiple Level 3 health facilities, providing comparatively better access to mid-level healthcare services for residents in these areas. South Uyoma, despite having some health facilities, continues to face significant challenges, particularly due to the longer distances residents must travel to reach higher-level healthcare services. This uneven distribution of the nine facilities underscores the urgent need for thoughtful strategic planning and equitable resource allocation. Addressing gaps like the complete absence of a Level 3 health facility in North Uyoma is critical to ensuring that all wards within the constituency have access to quality healthcare services, regardless of location.

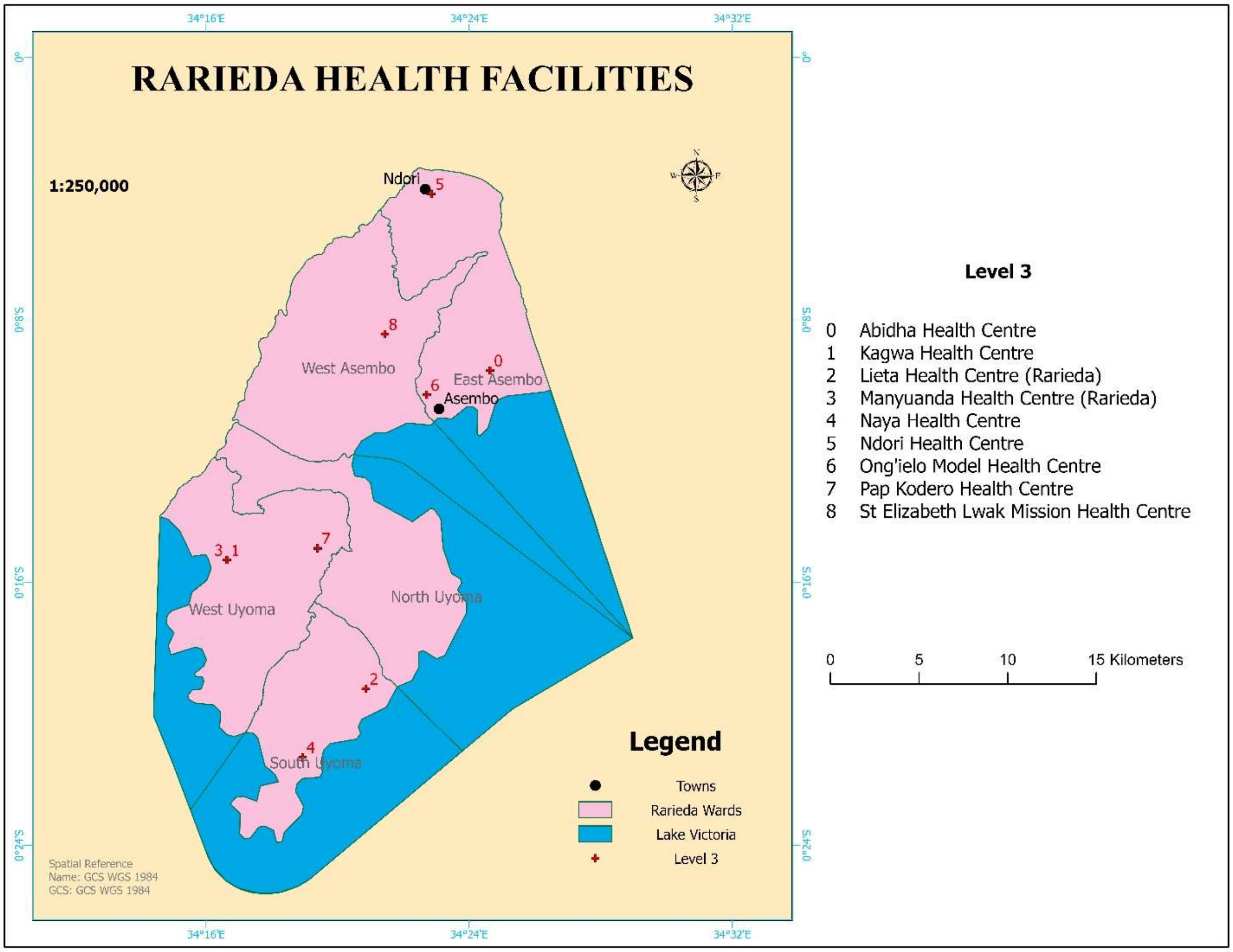


Figure 4.4 – Level 3 Health Facilities

- **Level 4 (Sub-County Hospitals):** 1 facility

In Rarieda constituency, the Madiany Sub- County Hospital, located in South Uyoma ward, stands as the only Level 4 healthcare facility as shown in figure 4.5. As the highest-tier facility in the region, it serves as the primary referral center, offering advanced medical care that is beyond the scope of the Level 2 and Level 3 facilities scattered across the constituency. While Level 2 facilities mostly provide outpatient services and Level 3 facilities offer a broader range of diagnostic and treatment options, Madiany Sub- County Hospital is equipped to handle specialized treatments, manage critical health emergencies, and treat complex medical conditions.

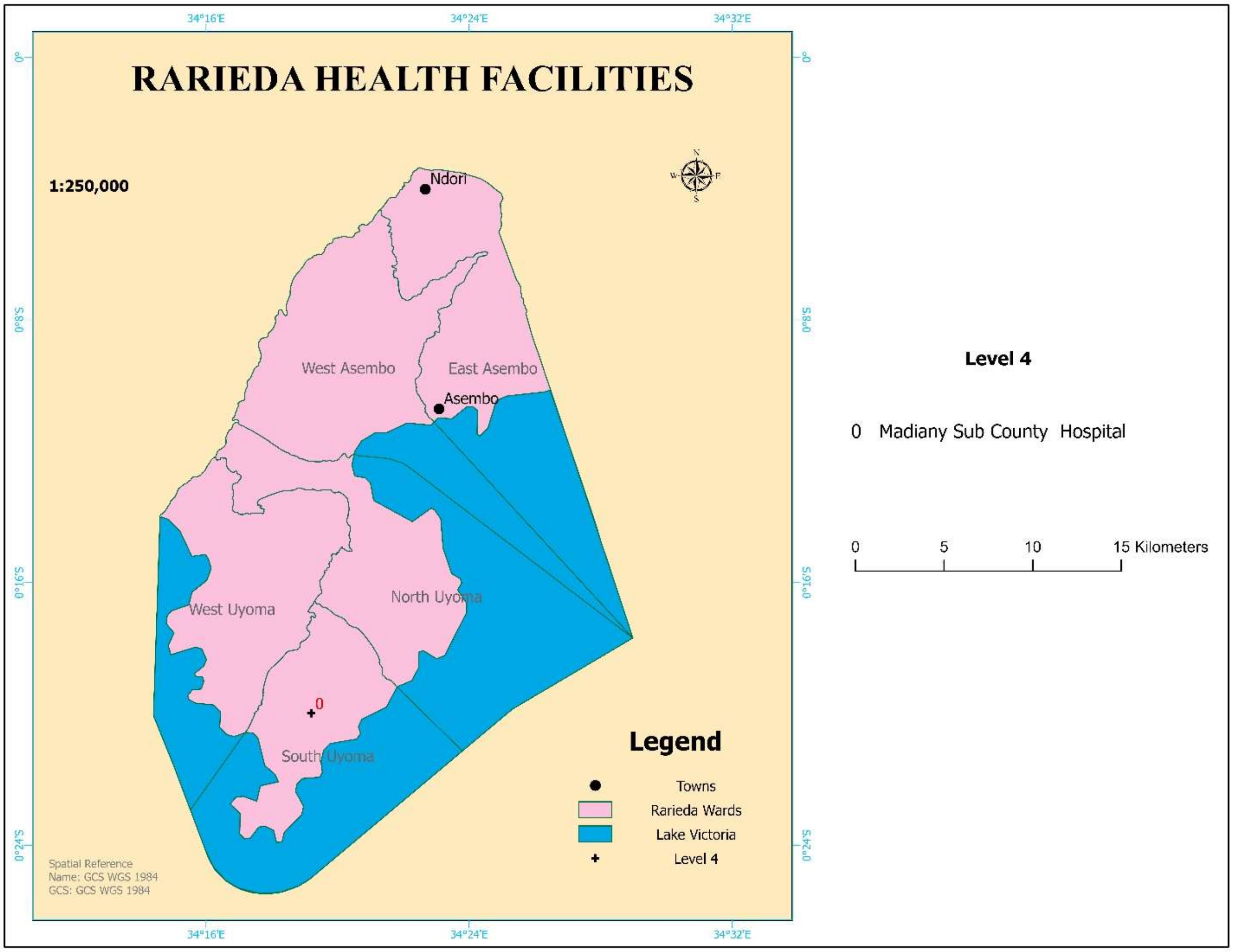


Figure 4.5 – Level 4 Health Facility

As the sole Level 4 facility, its significance in the healthcare system of Rarieda cannot be overstated. It serves as a lifeline for residents requiring specialized care, particularly those with severe malaria cases or other conditions that demand higher-level expertise. Moreover, it plays a crucial role in accommodating patient referrals from the lower-tier health centers and dispensaries within the constituency. For many residents, Madiany Sub- County Hospital is their only option for accessing advanced healthcare without traveling far beyond the region.

However, being the only facility of its kind creates significant challenges for healthcare delivery in Rarieda. The hospital is often under immense pressure to meet the needs of the entire population, resulting in resource strain and an overburdened system. This single-point dependency also highlights inequities in healthcare access, especially for residents of remote wards, who face long travel distances to reach the hospital. Such disparities in accessibility further emphasize the urgent need for infrastructure improvements. Addressing this situation requires targeted investment in healthcare infrastructure. Expanding the number of Level 4 facilities in Rarieda or upgrading select Level 3 facilities to handle more advanced medical care could alleviate the strain on Madiany Sub-County Hospital. These measures would not only reduce the burden on the hospital but also create a more equitable healthcare system that ensures every resident has access to comprehensive and timely medical care, regardless of their location within the constituency. Such improvements are essential for fostering better health outcomes and closing gaps in healthcare accessibility.

4.2.2 Spatial distribution and classification (Level 2, 3, 4)

Healthcare facilities in Rarieda Constituency vary significantly in distribution based on their classification levels. Level 2 dispensaries are the most numerous and widely spread, providing basic outpatient services but with limited capacity, leaving some areas like South Uyoma underserved. Level 3 health centers, offering mid-level care, are fewer, with nine facilities concentrated in areas like West Uyoma and East Asembo, while North Uyoma lacks any such facility. The sole Level 4 facility, Madiany Sub- County Hospital in South Uyoma, serves as the primary referral center but struggles to meet the needs of the entire constituency, especially in remote areas. This uneven distribution highlights disparities in healthcare access and the need for strategic planning to address gaps and ensure equitable healthcare delivery. Figure 4.6 below shows the distribution of these facilities per ward.

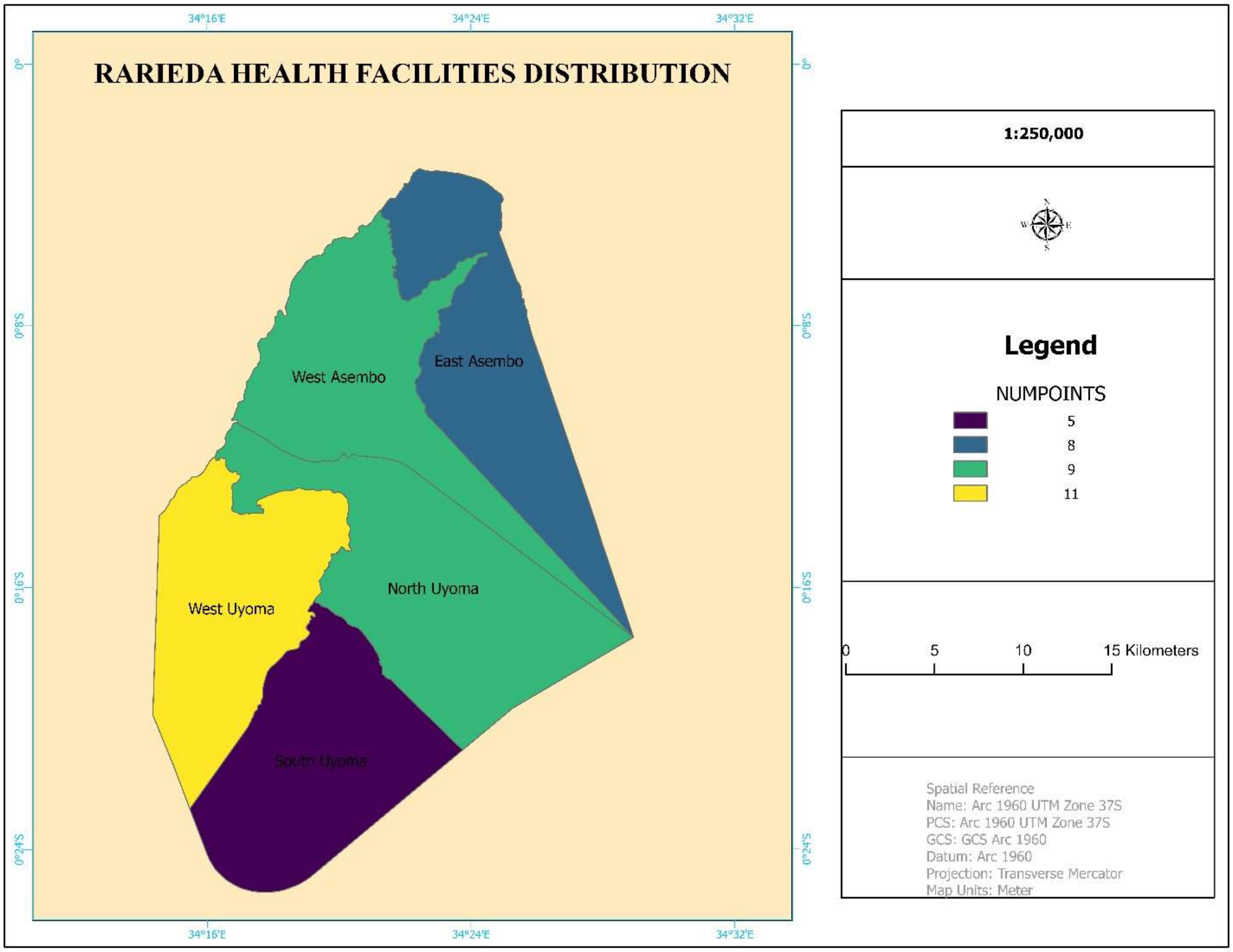


Figure 4.6 – Health Facilities Distribution

Figure 4.7 below provides a clear and comprehensive visualization of the spatial distribution and classification of healthcare facilities across the constituency. It effectively highlights the concentration of Level 2 dispensaries and the comparatively fewer Level 3 and Level 4 facilities. The chart also illustrates the clustering of health facilities in specific wards, such as West Uyoma, East Asembo, and South Uyoma, while drawing attention to underrepresented areas, such as North Uyoma, which lacks a Level 3 facility.

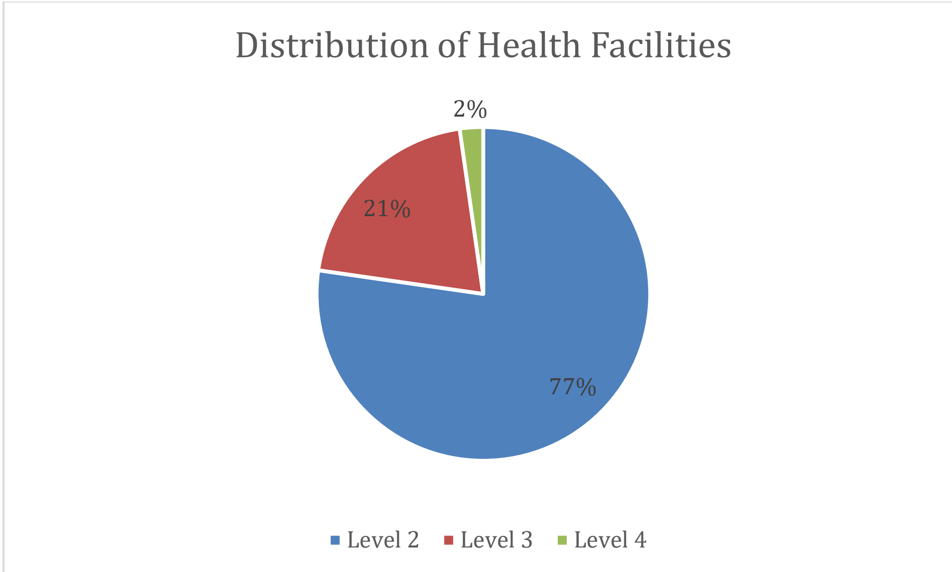


Figure 4.7 – Health facilities distribution pie chart

By analyzing the chart, we can better understand the disparities in healthcare accessibility, as seen in both the mapped distribution and the accompanying classification statistics.

Figure 4.8 is a bar graph representing the distribution in terms of statistics of health facilities per ward.

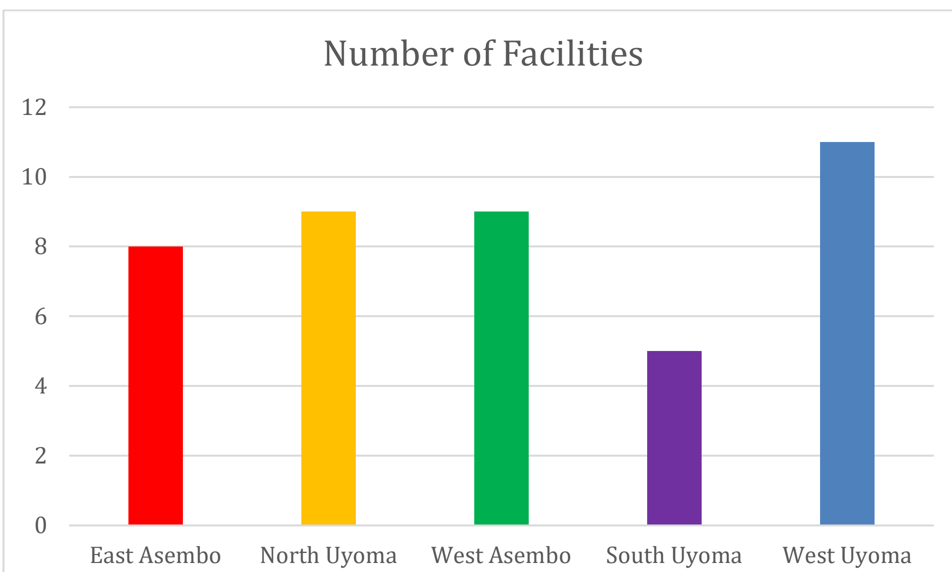


Figure 4.8 – Number of facilities per ward

Level 2 facilities, consisting of dispensaries and clinics, were the most widespread. They were mainly concentrated around densely populated settlements and trading centers, ensuring that basic outpatient services were accessible to a large portion of the population. However, some remote areas had relatively few or no Level 2 facilities, indicating potential service gaps.

Level 3 facilities, which include health centers, were fewer in number and strategically distributed to serve broader catchment areas. These facilities were typically located at central points within wards, allowing them to provide inpatient care and maternal health services to surrounding populations.

Level 4 facilities, representing sub-county hospitals, were the least numerous and primarily located near major towns and transport corridors. Their spatial placement was intended to offer specialized medical services that could not be handled at lower-level facilities.

Overall, the spatial classification revealed a pyramidal healthcare structure, with basic services being widely accessible through Level 2 facilities, while advanced services at Level 4 facilities required longer travel for residents, particularly in remote parts of the constituency.

4.2.3 Observations from the facility map

The results showed that Level 2 facilities were the most common across the constituency, providing basic outpatient services to the majority of the population. Level 3 facilities, offering a broader range of services including inpatient care, were fewer in number but strategically located to serve larger population clusters. Level 4 facilities were the least represented and mainly located near major towns, providing specialized care for more severe cases.

This distribution reflects the tiered healthcare delivery system in Kenya, where lower-level facilities are more widely distributed to enhance community-level access to basic health services.

4.3 Spatial Distribution of Malaria cases

Malaria remains a significant public health challenge in Rarieda Constituency, with varying case distributions across healthcare facilities. Understanding the spatial patterns of confirmed and suspected cases provides insights into accessibility, prevalence, and potential intervention strategies.

4.3.1 Summary of malaria case data

The analysis of malaria data from health facilities in Rarieda Constituency reveals disparities in the number of reported cases. The data includes both confirmed and suspected malaria cases recorded across different health centers, dispensaries, and hospitals.

A visual representation using a bar chart (Figure 4.9) highlights the comparative burden of malaria cases in various healthcare facilities. Facilities such as St. Elizabeth Lwak Mission Health Centre and Manyuanda Health Centre reported the highest number of confirmed cases, while other facilities, such as Abidha Health Centre and Ndori Health Centre, also recorded substantial case numbers. Conversely, several dispensaries, such as Chianda Dispensary and Jar Dispensary, showed relatively lower confirmed cases but still had a considerable number of suspected cases.

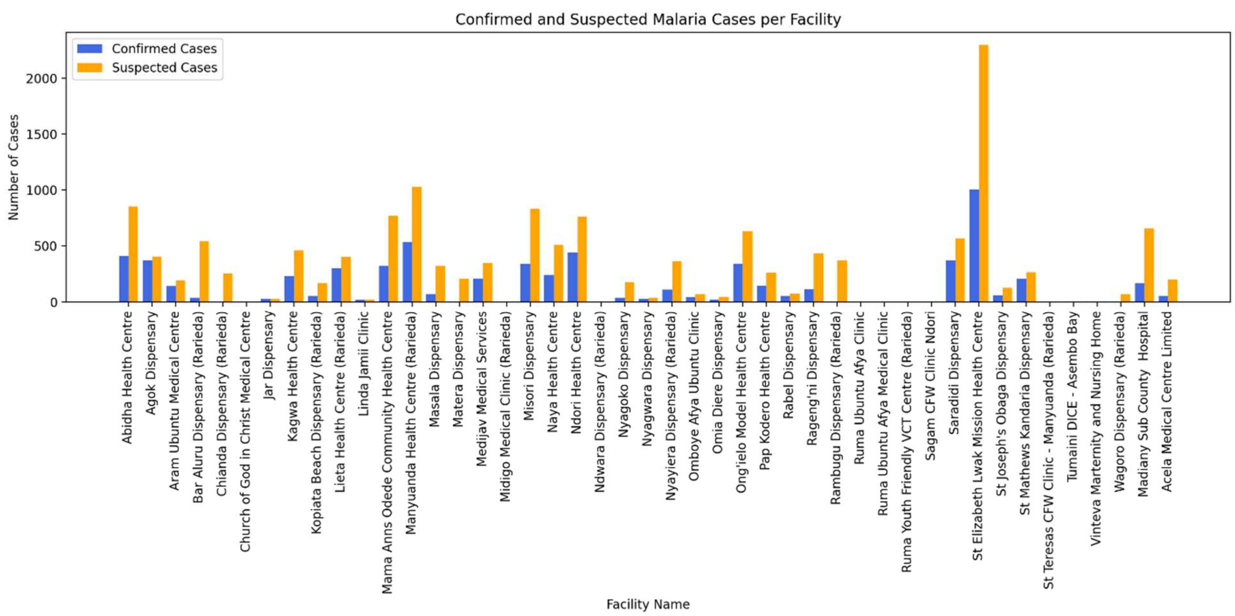


Figure 4.9: Malaria Cases per Facility

From the analysis, it is evident that malaria prevalence varies significantly across different locations. The disparities could be influenced by factors such as population density, proximity to water sources (which serve as mosquito breeding grounds), and accessibility to healthcare services. Further spatial analysis, including heatmaps and geographical mapping, will provide deeper insights into the distribution of malaria cases and help identify high-risk zones that require targeted intervention.

4.3.2 Visualization using graduated symbols

The malaria burden in Rarieda was visualized using graduated symbols to effectively represent the distribution of suspected and confirmed cases across different locations. The graduated pie charts were used to denote variations in case numbers, ensuring that spatial differences were easily distinguishable. Figure 4.10 shown below, presents the spatial distribution of malaria cases in the study area. Larger pie charts indicate locations with a higher disease burden, while smaller symbols represent areas with fewer cases. This graduated approach enables a quick visual assessment of disease hotspots and potential intervention priorities. Moreover, the proportion of suspected versus confirmed cases varied among locations, as seen in the relative sizes of the red and blue segments within the pie charts. This differentiation allows for a more nuanced understanding of diagnostic trends in different regions. The spatial distribution suggests correlations with environmental factors, accessibility to healthcare, and population density, which may influence malaria prevalence. The visualization underscores the importance of spatial mapping techniques in epidemiological studies by providing a clear, data-driven representation of disease trends. By integrating spatial analysis, this approach supports informed decision-making for targeted malaria interventions, guiding resource allocation to areas most in need.

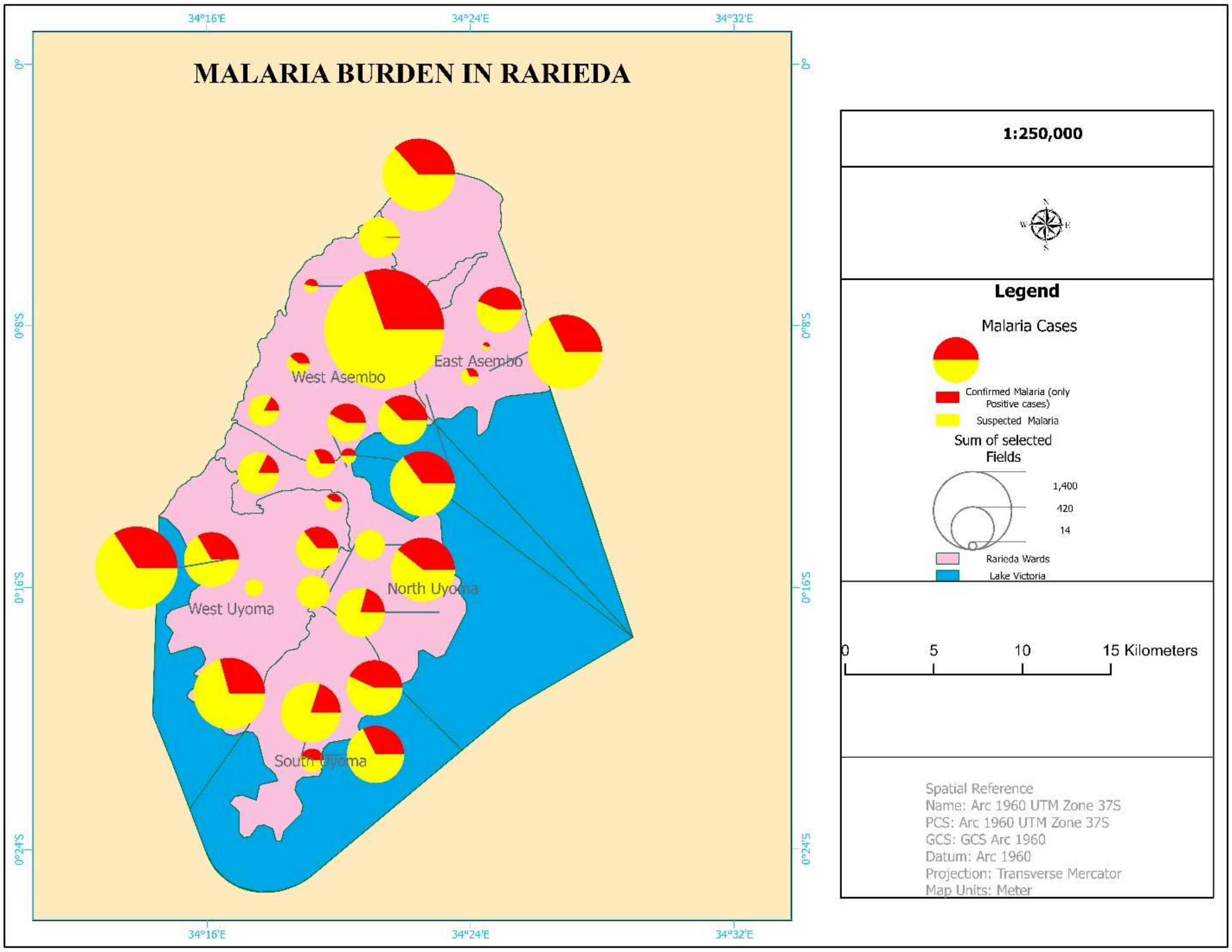


Figure 4.10: Malaria Burden in Rarieda Using Graduated Pie Charts

4.3.3 IDW interpolation to show malaria spread

The spatial distribution of confirmed malaria cases in Rarieda was analyzed using Inverse Distance Weighting (IDW) interpolation, a technique that estimates disease risk across the study area based on known case locations. Figure X below illustrates the malaria spread, categorizing the region into three distinct risk zones: low risk (green), moderate risk (yellow), and high risk (red). From the visualization shown in figure 4.11, it is evident that malaria risk varies geographically, with a small percentage (1.80%) of the area classified as high risk and concentrated in specific locations. The moderate-risk zone covers 33.46% of the area, while the majority (64.74%) remains in the low-risk category. The placement of health facilities (green dots) offers insight into accessibility to healthcare services in relation to malaria prevalence.

The proximity of malaria hotspots to Lake Victoria suggests potential environmental influences, such as mosquito breeding habitats, contributing to disease transmission. Additionally, the interpolated map serves as a crucial tool for identifying areas requiring targeted interventions, guiding malaria control strategies such as vector management and resource allocation.

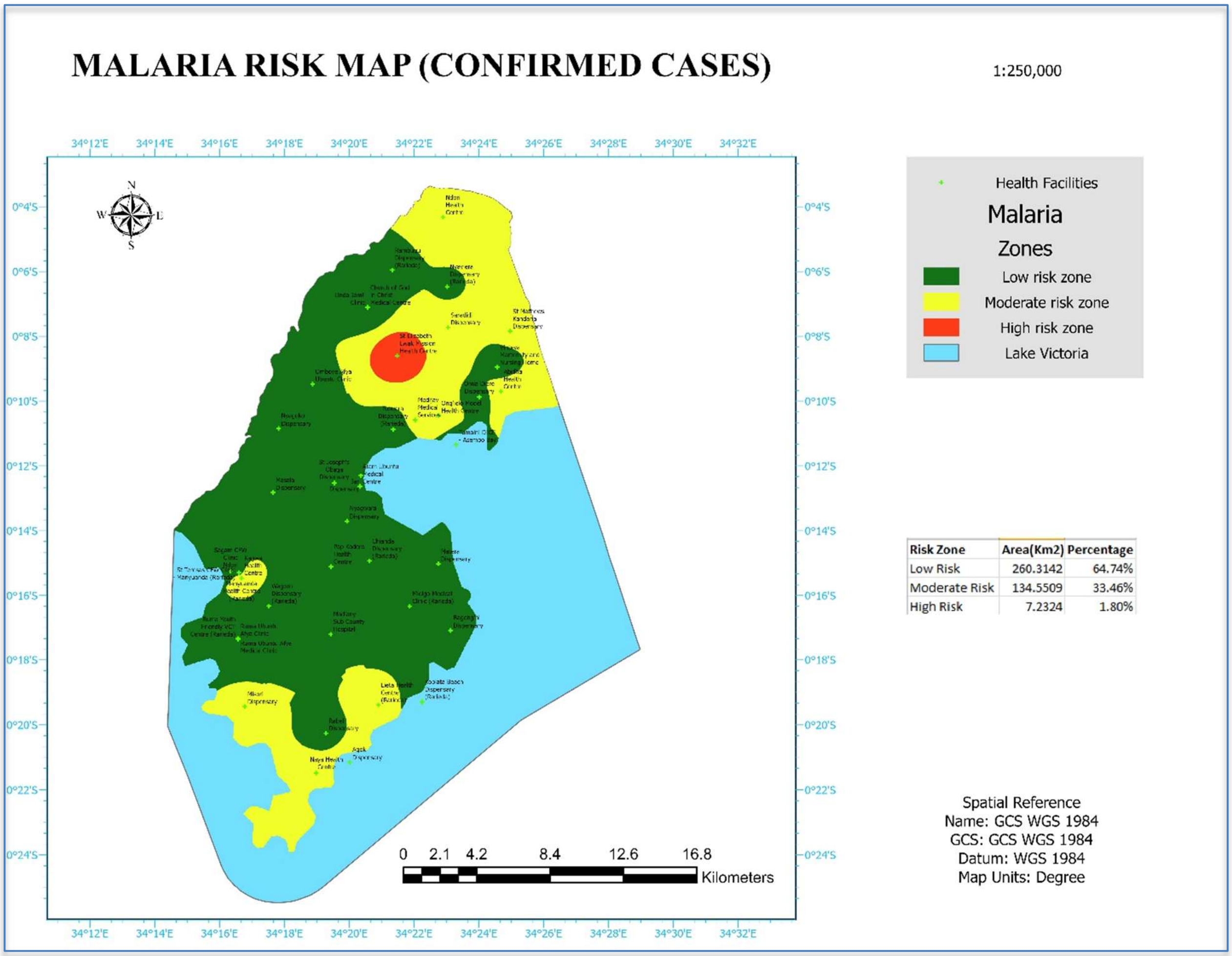


Figure 4.11: Malaria Risk Map Using IDW Interpolation

4.3.4 Identification of malaria hotspots

Based on the findings from graduated symbol mapping and IDW interpolation, specific areas exhibit a disproportionately higher burden of malaria cases. The graduated symbol visualization highlighted significant variations in the distribution of confirmed and suspected malaria cases. Larger pie charts in certain locations indicated high malaria prevalence, suggesting areas where transmission rates are consistently elevated. These concentrations align with known environmental and infrastructural factors that influence disease spread, such as population density and proximity to water bodies. Furthermore, the IDW interpolation provided a smoothed spatial representation of malaria risk across Rarieda, revealing distinct zones of high, moderate, and low transmission risk. The analysis demonstrated that malaria cases are clustered, rather than randomly dispersed, with notable high-risk zones situated near key geographical features. The proximity of these high-risk regions to Lake Victoria supports the hypothesis that environmental factors, particularly mosquito breeding habitats, play a role in sustaining transmission.

Although a dedicated hotspot map was not created, the integration of these two visual approaches allows for an inferred identification of high-burden areas. These findings emphasize the importance of spatial epidemiology in malaria control and underscore the need for targeted interventions such as vector control measures, healthcare accessibility improvements, and community-based awareness programs in identified high-risk zones.

4.4 Accessibility Analysis

4.4.1 Observations about accessibility patterns

The accessibility analysis conducted in Rarieda Constituency reveals significant disparities in healthcare access, primarily shaped by the distribution of health facilities, the quality of road infrastructure, and population density. A total of 44 healthcare facilities were identified in the study, including Level 2 dispensaries, Level 3 health centers, and one Level 4 facility—Madiany Sub-County Hospital. Despite the presence of these facilities, access to healthcare remains uneven, with some wards enjoying relatively short travel times, while others experience substantial delays due to long distances and poorly developed road networks. Using ArcMap's closest facility tool, a network analysis was conducted to generate travel routes and assess the distance to the nearest healthcare center. The results show that travel distances range from 0 kilometers—indicating households located adjacent to health facilities—to a maximum of 6.8 kilometers. Approximately 65% of the population resides within 5 kilometers of a healthcare facility, whereas the remaining 35% live beyond this threshold, placing them in underserved zones with limited access to timely medical care. Accessibility declines noticeably toward the outer wards, particularly in South

Uyoma and parts of North Uyoma, where the sparse distribution of facilities and inadequate transport infrastructure contribute to healthcare access challenges and delays in malaria treatment.

4.4.2 Which areas have quick vs. delayed access

Zones were categorized based on the results of a distance-to-nearest-facility raster analysis and network modeling. Areas with quick access (0–1.04 km) include West Uyoma, East Asembo, and parts of North Uyoma, where residents are located close to healthcare centers, particularly along major roads and near town centers. These well-served areas allow for timely malaria diagnosis and treatment, reducing the likelihood of severe disease outcomes. Moderate access areas (1.04–2.93 km) are found in parts of North Uyoma and West Asembo, where residents must travel slightly longer distances to access care. However, treatment remains relatively accessible depending on the quality of roads and the availability of transportation. In contrast, delayed access areas (2.93–6.80 km) are concentrated in South Uyoma and interior sections of North Uyoma. These underserved regions experience the greatest access barriers, with some locations requiring travel distances exceeding 4 kilometers to reach the nearest facility. Limited road infrastructure and sparse facility distribution further exacerbate delays in seeking treatment, increasing the risk of untreated malaria cases and related complications. In these areas, community-based health interventions and alternative service delivery mechanisms are especially critical.

4.5 Identification of Underserved Areas

4.5.1 Definition of underserved based on travel distance + malaria burden

In the context of healthcare accessibility for malaria patients in Rarieda Constituency, underserved areas are defined as regions where populations face significant barriers in reaching the nearest healthcare facilities within a reasonable travel distance. Using distance to the closest facility raster analysis, areas with long travel times were identified, revealing zones where residents experience delayed access to malaria diagnosis and treatment.

Key Criteria for Identifying Underserved Areas:

1. Travel Distance Thresholds
   - Areas where residents must travel more than 4 km to access the nearest healthcare facility are classified as underserved.
   - Optimal travel distance for timely malaria treatment should be less than 2 km.
2. Impact on Malaria Treatment
   - Long travel distances lead to delays in seeking treatment, increasing disease severity and mortality risk, especially for children under five and pregnant women.
   - Patients in underserved areas may opt for self-medication, which can lead to improper treatment and drug resistance.

By integrating raster-based travel distance analysis with malaria prevalence mapping, this study systematically identifies areas that require urgent healthcare interventions, including facility expansion, mobile clinics, and improved transportation networks.

4.5.2 Maps showing underserved zones

Figure 4.12 highlights key patterns across Rarieda Constituency, providing insights into the distribution of healthcare services and the varying ease of access among residents. The well-served areas, shown in green and located within 0 to 1.04 kilometers of healthcare facilities, indicate zones where healthcare services are readily available. Residents in these areas can access medical services quickly, ensuring timely treatment for malaria and other illnesses. These regions are typically near major health centers and dispensaries, benefiting from close proximity and better infrastructure.

The moderately accessible areas, depicted in yellow to orange and spanning 1.04 to 2.93 kilometers, represent locations where healthcare services are available within a reasonable distance, though accessibility is not as immediate. In these areas, travel time to the nearest healthcare facility may still influence care-seeking behavior, potentially delaying diagnosis and treatment for malaria cases. Factors such as road conditions, availability of transportation, and geographic obstacles, such as rivers or uneven terrain, can further impact accessibility in these zones. The poorly accessible areas, marked in red to dark red and covering distances between 2.93

and 6.80 kilometers, highlight the most underserved communities where long travel distances significantly hinder access to healthcare services. Residents in these zones often face severe challenges in reaching healthcare facilities, leading to delays in malaria diagnosis and treatment. Limited road infrastructure, remote settlements, and the lack of nearby healthcare centers contribute to these accessibility gaps, increasing vulnerability to health risks. These underserved regions, particularly those located further inland or near Lake Victoria, require urgent interventions such as mobile health clinics, improved road networks, and the establishment of additional health facilities to enhance accessibility and healthcare outcomes.

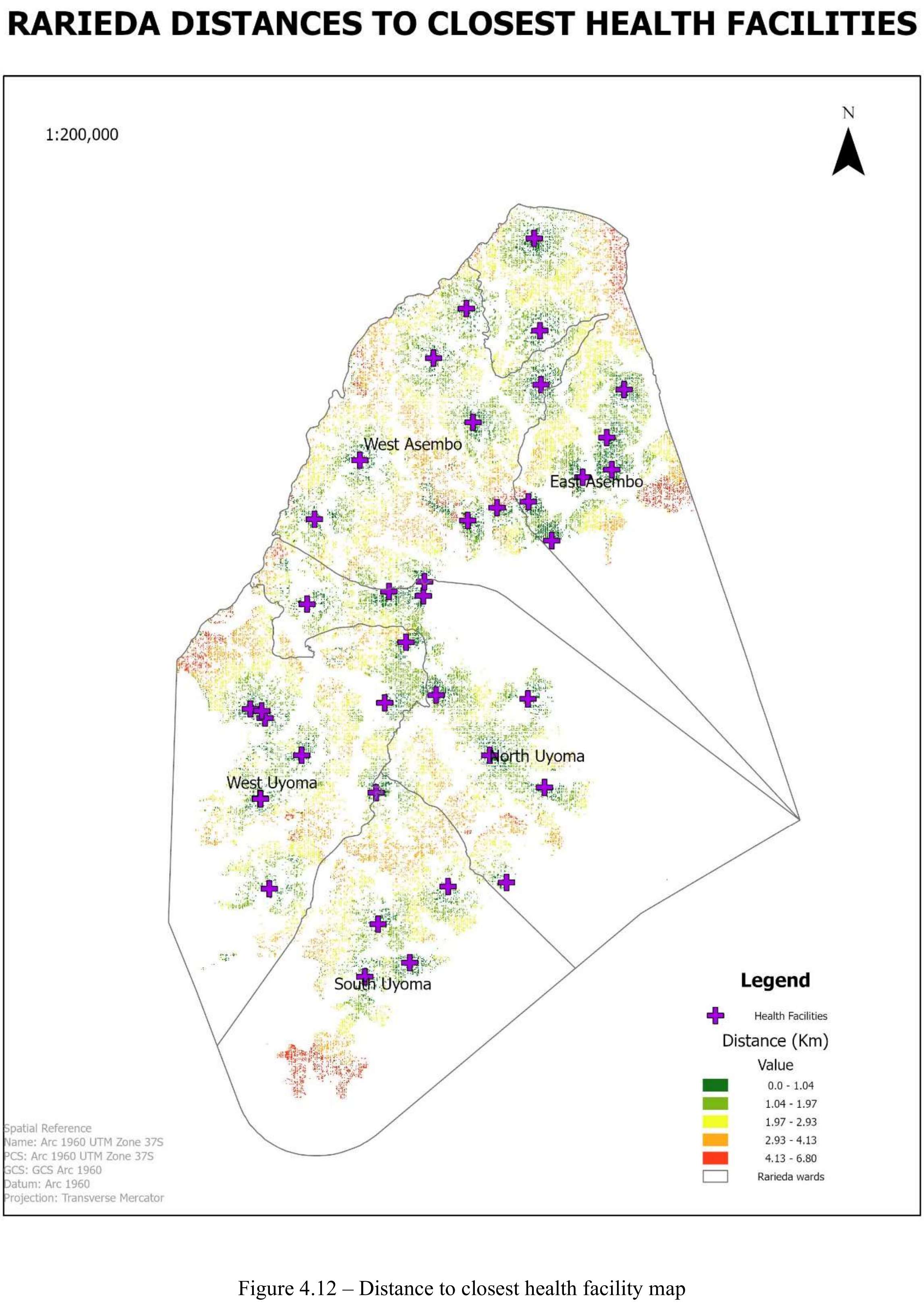


Figure 4.12 – Distance to closest health facility map

4.5.3 Key locations lacking sufficient healthcare access

Based on an accessibility analysis that combined the distance to the nearest healthcare facility with the spatial distribution of malaria cases, several locations within Rarieda Constituency have been identified as critically underserved. These areas are characterized by both long travel distances to healthcare services and a high burden of malaria, thereby increasing health risks for local populations. Notably, South Uyoma Ward presents significant healthcare access challenges, with residents in its southern and inland regions traveling over 4 kilometers to reach the nearest health facility. The malaria burden in this ward is also substantial, making it a high-priority area for intervention. Poor road infrastructure, particularly during the rainy season, further limits timely access to treatment. Similarly, parts of North Uyoma Ward remain underserved, especially in the northern areas where healthcare facilities are sparse. While the central region of this ward shows some service coverage, peripheral villages continue to face access barriers, compounded by overlapping high-risk malaria zones. Additionally, remote settlements near Lake Victoria, especially along South Uyoma's lakeshore, suffer from severe accessibility issues due to inadequate infrastructure. Despite recording high malaria transmission rates, these lakeside communities encounter substantial challenges in reaching treatment centers. The combination of long travel distances and high disease burden in these locations elevates the risk of severe malaria outcomes and mortality, particularly among vulnerable groups such as children under five and pregnant women. These findings underscore the urgent need for targeted healthcare planning and infrastructure development to improve service delivery and promote health equity across Rarieda Constituency.

4.6 Summary of Results

The spatial analysis of healthcare accessibility for malaria patients in Rarieda Constituency offers critical insights into the distribution of health facilities, malaria burden, travel-time challenges, and the identification of underserved areas. A total of 42 healthcare facilities were mapped and categorized into Level 2 (dispensaries and clinics), Level 3 (health centers), and Level 4 (sub-county hospital) facilities. While Level 2 facilities are relatively widespread, Level 3 and Level 4 centers are limited, with Madiany Sub-County Hospital serving as the only Level 4 facility in the area. This uneven distribution contributes to significant disparities in access to healthcare, especially in South Uyoma and parts of North Uyoma, where residents face long travel distances to reach medical services. Analysis of malaria incidence revealed spatial variation in the disease burden, with larger and more equipped health centers reporting higher numbers of confirmed cases. Graduated symbol mapping illustrated that malaria cases are clustered rather than uniformly spread, and inverse distance weighting (IDW) interpolation pinpointed high-risk zones, particularly around Lake Victoria, suggesting that proximity to water bodies and environmental conditions play a role in transmission dynamics. A travel-time analysis using a distance-to-closest-facility raster categorized accessibility levels into well-served (0–1.04 km), moderately accessible (1.04–2.93 km), and poorly accessible areas (beyond 2.93 km). Results indicated that South Uyoma and sections of North Uyoma are poorly served, with distance significantly limiting access to malaria treatment. By overlaying the malaria burden map with accessibility analysis, critical underserved areas were identified—locations where high malaria prevalence coincides with poor access to healthcare infrastructure. These include communities near Lake Victoria, South Uyoma, and outlying parts of North Uyoma. Based on these findings, key recommendations include expanding healthcare infrastructure in underserved areas, deploying mobile clinics to reduce travel time for remote populations, improving road networks to enhance physical access, and strengthening community-based malaria interventions to promote early detection and treatment. Collectively, these strategies provide a data-informed foundation for targeted healthcare planning and malaria control efforts within Rarieda Constituency.

4.7 Discussion of Results

The findings from this study clearly demonstrate spatial disparities in healthcare accessibility for malaria patients across Rarieda Constituency. Through facility mapping, malaria case distribution analysis, network-based travel modeling, and identification of underserved areas, several critical observations were made. First, the distribution of healthcare facilities is uneven, with Level 2 dispensaries being the most common, followed by a smaller number of Level 3 health centers and only one Level 4 sub-county hospital located in South Uyoma. This pyramidal structure, while intended to provide community-level access, reveals gaps—particularly in remote areas where specialized care remains out of reach. For example, North Uyoma lacks a Level 3 facility entirely, and the sole Level 4 facility, Madiany Sub-County Hospital, is overburdened and far from some settlements. Second, analysis of malaria case data showed a non-uniform distribution, with some facilities like St. Elizabeth Lwak Mission Health Centre and Manyuanda Health Centre reporting disproportionately high numbers of confirmed cases. Graduated symbol mapping and IDW interpolation confirmed that malaria risk is not randomly distributed. High-risk zones are primarily concentrated around Lake Victoria, suggesting a strong environmental influence, particularly mosquito breeding habitats, which contribute to sustained transmission in lakeside communities. The accessibility analysis, using both network-based routing and raster distance modeling, further revealed that a significant portion of the population—around 35%—resides beyond 5 kilometers from the nearest health facility. These individuals face long travel times, with delays worsened by poor road infrastructure, especially during the rainy season. South Uyoma and parts of North Uyoma emerged as the most underserved areas. These zones not only require long travel distances to reach healthcare services but also correspond to high malaria burden regions, compounding the risk for residents.

By overlaying spatial malaria risk and accessibility data, this study identified critical underserved hotspots—places where delayed access coincides with high transmission. These findings highlight the need for context-specific interventions, such as upgrading select Level 2 or 3 facilities, introducing mobile clinics, and improving transportation networks to reduce access barriers. These strategies are especially important for vulnerable groups like children under five and pregnant women, who are at greater risk of severe malaria outcomes.

In conclusion, this spatial analysis provides a clear understanding of where healthcare services are lacking and where the malaria burden is greatest. The results support the urgent need for more equitable healthcare planning in Rarieda Constituency and offer a strong geospatial foundation for targeting future malaria control and treatment programs.

CHAPTER 5: CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study set out to assess healthcare accessibility for malaria patients in Rarieda Constituency using a spatial analysis approach. By mapping the locations of health facilities, analyzing the spatial distribution of malaria cases, evaluating travel distance and time to the nearest facility, and identifying underserved areas, the study has provided a detailed view of the healthcare landscape for malaria treatment. The results showed that although 42 health facilities exist in the constituency, they are unevenly distributed, with most of them being Level 2 dispensaries. Only one Level 4 facility, Madiany Sub-County Hospital, serves as a referral center, and Level 3 facilities are limited to a few wards. Areas such as North Uyoma lack mid-level facilities altogether, revealing inequities in healthcare access. Malaria cases are spatially clustered, with higher incidences recorded in facilities near Lake Victoria. Interpolation results confirmed that East Asembo and parts of South Uyoma are high-risk zones. This clustering indicates that environmental factors continue to drive malaria transmission in lakeside regions.

Network analysis revealed that about 35% of the population in Rarieda Constituency lives beyond the recommended 5 km distance from a healthcare facility. These underserved populations face longer travel times, often on poor road networks. Importantly, several of these underserved zones also correspond with areas of high malaria burden, compounding health risks and treatment delays.

In conclusion, the study has confirmed that geographic disparities in healthcare access significantly influence malaria outcomes in Rarieda. The findings provide evidence for targeted interventions that can reduce access barriers, especially for populations living in high-burden and underserved areas.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Upgrade Existing Facilities in Underserved Wards
   Wards such as North Uyoma and South Uyoma should be prioritized for facility upgrades. Upgrading select Level 2 dispensaries to Level 3 health centers would improve diagnostic and treatment capacity in areas that are both underserved and malaria-prone.

2. Introduce Mobile Health Services
   In the short term, deploying mobile clinics in areas with poor facility access and high malaria burden would help bridge service gaps and ensure timely treatment, especially during peak transmission seasons.
3. Improve Road Infrastructure in Remote Areas
   Long travel times and poor roads hinder access to care. Improving road connectivity, especially in interior parts of South and North Uyoma, would reduce delays in accessing malaria treatment and improve emergency response.
4. Prioritize Facility Siting Using GIS Tools
   The county health department should adopt GIS tools in future planning to site new health facilities in a data-driven manner. This would ensure equitable distribution and optimal coverage based on population distribution and disease burden.
5. Integrate Spatial Data into Health Planning Frameworks
   GIS-based spatial data should be integrated into routine planning by the Ministry of Health at both the national and county levels. This would enhance evidence-based decision-making, particularly in identifying and addressing healthcare access gaps.

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