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GIS-based network analysis of public transport accessibility in Temeke municipality.

By

DOMINIC, DANFORD D.

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DISSERTATION

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GIS-BASED NETWORK ANALYSIS OF PUBLIC TRANSPORT ACCESSIBILITY IN TEMEKE MUNICIPALITY.

DOMINIC,DANFORD D

A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geographic Information Systems

(GIS & RS) of Ardhi University

CERTIFICATION AND COPYRIGHT

The undersigned certify that he has proof read and hereby recommend for acceptance of Dissertation entitled “**GIS-based network analysis of public transport accessibility in Temeke municipality**” for University Examination.

…………………...   ……………………

Dr Zakaria Ngereja   Mr. Nelson Ochieng

(Main Supervisor)   (Second Supervisor)

…………………….   …………………….

DECLARATION AND COPYRIGHT

Dominic, Danford D. declare that this Research is my own original work and that to the best of my knowledge, it has not been presented to any other university for a similar or any other degree award except where due acknowledgements have been made in the text.

Dominic, Danford David

Reg No. 25471/T.2020

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ABSTRACT

Public transport accessibility plays a crucial role in urban mobility, providing convenient and affordable transportation options for residents. It offers numerous benefits, including enhanced mobility, reduced congestion, economic opportunities, social equity, and environmental sustainability. However, there are many challenges that hinders the accessibility and connectivity of public transport infrastructure, such as limited coverage, inadequate infrastructure, affordability issues, and limited integration. This study had focused on analyzing the accessibility of public transport in Temeke Municipality, a region within Dar es Salaam city. The research objectives include identifying areas with limited or no access to public transport and assessing the quality and affordability of the existing infrastructure. The methodology involved data acquisition from various sources, such as satellite images and road networks. Preprocessing and processing techniques, including image classification and network analysis, are applied to generate outputs like service area coverage based on travel time and distance impedance. The results have provided insights into households' travel distance and travel time to public transport networks, as well as the age group's accessibility to public transport. This research contributes to the understanding of public transport accessibility and its significance in promoting commuting efficiency, employment opportunities, education access, business and commerce, social interaction, reduced transportation costs, environmental sustainability, and health and well-being.

TABLE CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Public transport systems around the world have undergone significant advancements in recent years, aiming to enhance accessibility, sustainability, and efficiency. Many countries have embraced innovative technologies and strategies to improve their public transportation networks(Corporate Partnership Board, 2019). Advanced systems, such as high-speed trains, automated metros, and Bus Rapid Transit (BRT) systems, have emerged as key components of modern public transport. In developed regions like Europe and North America, countries have invested heavily in high-speed rail networks, connecting major cities and reducing travel times. For instance, countries like France, Germany, and Japan have successfully implemented high-speed rail systems that offer fast, reliable, and comfortable transportation options for both domestic and international travel. Additionally, automated metro systems have gained popularity in cities like Singapore, Dubai, and London, providing efficient and convenient transportation within urban areas(Kamarudeen et al., 2020). In terms of Bus Rapid Transit (BRT) systems, several cities worldwide have implemented these networks to improve public transport accessibility. BRT combines dedicated bus lanes, efficient boarding systems, and modern vehicles to provide fast and reliable services. Cities like Bogotá (Colombia), Curitiba (Brazil), and Guangzhou (China) have established successful BRT systems, offering cost-effective and sustainable transportation solutions.

The development of public transport systems in Africa, particularly in sub-Saharan Africa, is an ongoing process. While the region faces various challenges, such as limited infrastructure, funding constraints, and rapid urbanization, efforts are being made to improve public transport accessibility and efficiency. Several African cities have introduced Bus Rapid Transit systems to address the growing demand for public transport. For example, Johannesburg (South Africa) implemented the Rea Vaya BRT system, which has enhanced mobility and reduced congestion(Parliament, 2017). Dar es Salaam (Tanzania) introduced the Dar Rapid Transit (DART) system, which has significantly improved transportation options for residents. Furthermore, light rail systems have been implemented in some African cities(Kalugendo, 2020). Addis Ababa (Ethiopia) launched Africa's first light rail system, providing a reliable and affordable mode of transportation for its growing population(Mintesnot et al., 2022). Nairobi (Kenya) also introduced a light rail system, aiming to alleviate traffic congestion and improve connectivity(Tanaka et al., 2014).

Public transport systems have significant benefits for environmental sustainability, land use efficiency, and health and well-being. They improve mobility for residents, reduce traffic congestion, lower fuel consumption and greenhouse gas emissions, enhance economic opportunities, ensure social equity, promote a greener environment, influence urban development patterns, and encourage active lifestyles, leading to improved public health.

In Tanzania, the government has recognized the importance of developing a robust and efficient public transport system. One notable initiative is the implementation of the Dar Rapid Transit (DART) system in Dar es Salaam. The DART system consists of dedicated bus lanes, modern buses, and efficient fare collection systems, providing residents with a reliable and affordable mode of transportation. Tanzania has also focused on improving intercity connectivity through various infrastructure projects. For instance, the Standard Gauge Railway (SGR) project aims to connect major cities and enhance freight and passenger transportation. These initiatives align with Tanzania's broader transport policies, which emphasize the development of sustainable and integrated transportation networks to support economic growth and social development. This study aims to analyze the accessibility and infrastructure connectivity of public transport in Dar es Salaam, identifying areas where it is inadequate or poorly connected, with the goal of informing comprehensive strategies and investments to address coverage gaps, improve infrastructure, enhance affordability, and promote better integration in the city's public transport systems.

1.2 Statement of the problem

The population of Dar es Salaam city encounters various challenges in accessing safe, reliable, and affordable public transport options, including limited coverage in low-density suburbs and unplanned settlements, inadequate infrastructure, affordability concerns, and a lack of integration between different modes of transportation. These challenges hinder accessibility, limit mobility, and negatively impact socio-economic opportunities.

1.3 Research objectives

1.3.1 Main objective

The general objective of this research is to analyze the accessibility of public transport in Temeke Municipality

1.3.2 Specific objectives

Specifically, the study aims to

- **i.** Identify areas with limited or no access to public transport.
- **ii.** Assess the quality and affordability of public transport.

1.3.3 Research Questions

- i. Which parts in the city have limited or does not have access to public transport
- ii. What is the quality and affordability of public transport

1.4 Organization of Report

The report consists of five chapters. Chapter one introduces the research, highlighting the problem of limited accessibility and connectivity of public transport in Temeke Municipality. It presents the main and specific objectives of the study, the study area being Temeke Municipality, and provides information about the research duration, instrumentation, and software used. Chapter two discusses the conceptual and empirical framework, focusing on key tasks and related terms essential for the research. Chapter three outlines the methodology employed, including image classification, network analysis, and catchment area analysis. Chapter four presents the obtained results, specifically households' travel distance and travel time to the public transport network. Finally, chapter five discusses the implications of the results, providing a comprehensive analysis of the research findings.

1.5 Description of Study Area

Temeke Municipal is one of the municipals in Dar es salaam city, located at 39.0000000 central meridian, extent of 9245363.719m, 9227130.140200m, 538936.796700m, 521290.875700m, top, bottom, Right, and left respectively. According to 2012 population censor it has a total population of 982580, male 493705 and female 488875. Currently municipal has total length of 306.65 kilometers road network used for public transportation.

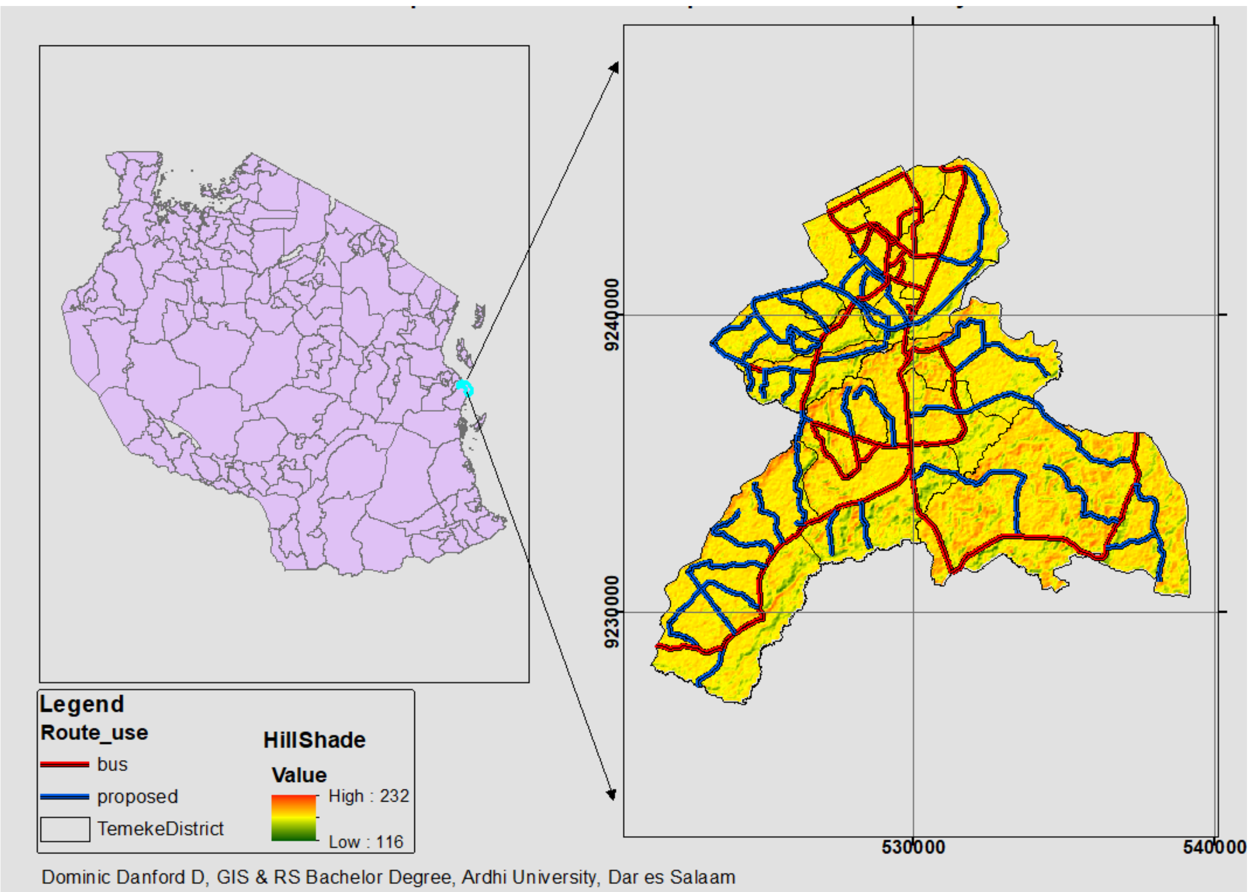

Figure 1.1 Study Area

1.6 Significance and contribution of the study

The research on public transport accessibility in Temeke Municipal, a municipal within Dar es Salaam city, holds significant importance in understanding the challenges faced by residents in accessing convenient and affordable transportation options. By identifying areas with limited or no access to public transport and assessing the quality and affordability of existing infrastructure, my study provides valuable insights into the barriers that hinder accessibility. Through the utilization of diverse data sources such as satellite images, demographic data, and road networks, I employed a comprehensive methodology to analyze public transport accessibility. The outcomes obtained, including service area coverage based on travel time and distance impedance, offer crucial information on households' travel distance and time to public transport networks. This research holds great significance as it sheds light on the various benefits of public transport accessibility, such as promoting commuting efficiency, employment opportunities, education access, business and commerce, social interaction, reduced transportation costs, environmental sustainability, and the overall well-being of residents. By addressing these issues, my research contributes to the development of informed policies and decision-making processes, aiming to enhance public transport accessibility, improve socio-economic opportunities, and create a more sustainable and inclusive urban environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter provides a background on public transport and explores the concept of public transport accessibility. It highlights the significance of combining different characteristics to study the impact of accessibility on individuals and how it can potentially hinder socio-economic activities. Public transport plays a crucial role in urban areas, providing convenient and affordable transportation options for residents. However, the accessibility of public transport is a critical factor that determines its effectiveness in facilitating daily activities and promoting socio-economic opportunities. By examining various characteristics such as coverage, infrastructure, affordability, and integration, researchers can gain a comprehensive understanding of how accessibility, or lack thereof, affects people's ability to engage in social and economic activities. Understanding these factors is essential for policymakers and urban planners to address the challenges and barriers that limit public transport accessibility, ultimately creating a more inclusive and efficient transportation system.

2.2 Public Transport Accessibility

Public transport accessibility and connectivity play crucial roles in urban planning and transportation systems. Geographic Information Systems (GIS)-based network analysis provides a powerful tool for evaluating and enhancing these aspects. In this explanation, we will delve into the concept of public transport accessibility, connectivity, and how GIS-based network analysis can be applied to analyze and improve them (Curtin, 2007)

Public Transport Accessibility: Public transport accessibility refers to the ease with which people can reach public transportation facilities, such as bus stops, train stations, and subway entrances. It is a measure of how well public transport services are integrated into the urban fabric and how easily they can be accessed by the population. Public transport accessibility is influenced by factors such as the distribution of transport infrastructure, the layout of road networks, and the proximity of public transport stops to residential and commercial areas. Commonly referenced benchmark for public transport accessibility for a one-way trip is 60 minutes' drive time and 400 meters drive distance around stop or stations.(Scheurer, 2010)

Public Transport Connectivity: Public transport connectivity focuses on the quality and efficiency of connections between different public transport modes and services. It involves analysing the network of routes, schedules, and transfers to ensure smooth and convenient travel for passengers. High-quality connectivity minimizes travel times, reduces waiting times, and provides seamless transfers between different modes of transportation. It is an essential aspect of creating an efficient and attractive public transport system.

GIS-based Network Analysis: GIS-based network analysis involves utilizing geospatial data and specialized software tools to analyse transportation networks and evaluate various aspects of accessibility and connectivity(Ford et al., 2015). Here are some key components and techniques used in this process:

a. **Network Data**: The first step is to gather accurate network data, including road networks, public transport routes, stops, and stations. These data are typically collected through surveys, GPS tracking, and official transportation authority records.
b. **Network Representation**: The network data is then digitized and represented as a graph, where nodes represent points of interest (e.g., bus stops, train stations) and edges represent connections between them (e.g., roads, rail lines). This graph-based representation enables efficient analysis and optimization of the network.
c. **Routing Analysis**: Routing algorithms are applied to calculate the optimal paths and travel times between different network nodes. These algorithms take into account factors such as road conditions, speed limits, and public transport schedules to determine the most efficient routes.
d. **Accessibility Measures**: GIS-based network analysis allows the computation of various accessibility measures, such as travel time to the nearest public transport stop or the number of transfers required to reach a destination. These measures help identify areas with limited access to public transport services and guide the planning of new infrastructure or service improvements.
e. **Connectivity Analysis**: Connectivity analysis involves examining the connections between different public transport modes, identifying transfer points, and assessing the frequency and reliability of services. This analysis helps pinpoint bottlenecks and areas where connectivity can be improved, such as adding new routes or adjusting schedules.
f. **Scenario Evaluation**: GIS-based network analysis also enables scenario evaluation, where different planning scenarios and interventions can be simulated and assessed. For example, the impact of adding new bus routes, modifying road layouts, or changing the locations of transit hubs can be evaluated to optimize public transport accessibility and connectivity.

2.3 Relationship between service area coverage to public transport accessibility may be measured using factors as

1. **Determining Coverage**: Service area network analysis helps identify the geographic coverage of public transportation services based on time or distance. By applying impedance measures (such as travel time or distance), it is possible to determine the areas that can be reached within a certain threshold from public transport stops or stations. This analysis helps in understanding the extent of the service area and the accessibility it provides to different locations(Levinson & Krizek, 2008).
2. **Catchment Area Delineation**: Service area network analysis can be used to delineate catchment areas around public transport stops or stations. Catchment areas represent the geographic zones from which people can reasonably access the public transportation system within a specified time or distance. These delineated catchment areas define the accessibility boundaries and help in evaluating the level of service provided by the public transport network.
3. **Evaluating Accessibility**: Service area network analysis allows for evaluating the accessibility of public transportation to different areas. By examining the extent of the service area, it becomes possible to assess how many people or destinations are within a certain travel time or distance from public transport facilities. This analysis helps in understanding the accessibility levels across the network and identifying areas that may have limited access(Delmelle & Casas, 2011).
4. **Mode Choice and Connectivity**: Service area network analysis can also aid in mode choice decisions and improving connectivity. By examining the service areas of different modes of public transportation (such as buses, trains, or trams), it becomes possible to identify areas with overlapping or complementary coverage. This analysis can help in optimizing transfer points, integrating different modes, and enhancing the overall connectivity of the public transport system.
5. **Equity and Planning**: Service area network analysis plays a crucial role in promoting equity and informing transport planning decisions. By evaluating the accessibility provided by the public transport network, planners can identify areas with inadequate coverage or limited access. This information helps in prioritizing resources, improving service provision in underserved areas, and ensuring equitable access to public transportation for all segments of the population(Robert, 2002).
6. **Performance Evaluation**: Service area network analysis allows for the evaluation of public transportation performance. By comparing the actual service area with the desired

or expected service area, it becomes possible to assess the effectiveness of the network in providing accessible transport options. This analysis can aid in identifying gaps, areas for improvement, and informing decision-making for service enhancements.

2.4 Image Classification

Image classification is the process of assigning pixels to nominal, which results to the thematic classes(Mather & Koch, 2011).The principle of image classification is that a pixel is assigned to a class based on its feature vector by comparing it to the predefined clusters in the feature space whereby doing so all image pixels results in a classified image. This is also a process in which the (human) operator instructs the computer to perform an interpretation according to certain conditions. Image classification is based on the different spectral characteristics of different materials on the earth's surface. Spectral pattern is a set of radiance measurements from various wavelength bands for each pixel. Classification procedures can be based on Spectral pattern (spectral pattern recognition), Spatial patterns (spatial pattern recognition), Temporal patterns (temporal pattern recognition). Spectral pattern recognition uses pixel-by-pixel spectral information as a basis for automated classification(Rehna & Natya, 2016).The principle behind classification is that Pixel is assigned to a class based on its feature vector, by comparing it to predefined clusters in the feature space. Doing this for all image pixels results in a classified image. The crux of image classification in comparing it to predefined clusters, which require definition of clusters and methods of comparison Definition of clusters is an interactive process and is carried out during the training process. Comparison of individual pixels with the clusters take place using classifier algorithms(Rehna & Natya, 2016). General steps in classifying satellite image the process of satellite image classifications typically involves five steps which are.

- Selection and preparation of the image data depending on the cover types to be classified, the most appropriate sensor, the most appropriate dates of acquisition and the most appropriate wavelength bands should be selected.
- Definition of the clusters in the feature space where two approaches are used which is supervised and unsupervised classification.
- Selection of classification algorithms where the operators need to decide on how the pixels (based on their DN) are assigned to the classes.
- Running the actual classification which is done once the training data have been established and the classifier algorithm is selected. This means that based on its DN values, each pixel in the image is assigned to one of the predefined classes.

- Validation of the result which is done once the classified image has been produced its quality is assessed by comparing it to reference data (ground truth). This requires selection of sampling technique of a sampling technique, generation of an error matrix and the calculation of error parameters(Rehna & Natya, 2016).

Classification methods Computer assisted classification is one among the classification methods, the other ones be manual and object-oriented method(Rehna & Natya, 2016). Depending on the interaction between the analyst and the computer during the classification, there are two types of classification which are supervised classification and unsupervised classification.

i. Supervised classifications in supervised classification the operator defines the spectral characteristics of the classes by identifying sample areas (training areas). Supervised classification requires that the operator to be familiar with the area of interest. The operator needs to know where to find the classes of interest in the area covered by the image. This information can be derived from the general area knowledge of from dedicated fields of observations.

General stages in performing supervised classification

- **Training stage**. The analyst identifies representative training sites and develops a numerical description of the spectral attributes of each feature imaged (Rehna & Natya, 2016). The training effort is both an art and a science. It requires close interaction between the image analyst and the image data. It requires substantial reference data and a thorough knowledge of the geographic area represented by the data. The training stage is important as it determines the quality of the information generated through classification. It helps to yield quality classification results; training data must be representative and complete but also to include all spectral classes and to include all information classes to be discriminated. In the training stage were,
    i. The number of classes are identified.
    ii. The Training sample per each class
    iii. The selecting and identifying validation samples and training samples. The validation samples are the samples that are used to qualify the performance. The training samples are the samples used to create the model. Training samples are always 70% of all samples while the validation samples are 30% of all samples.
    iv. Class separability. This is the statistical measure between two signatures and can be calculated by Euclidean distance, Divergence, Transform divergence and Jeffries (Rehna & Natya, 2016).
- **Classification stage**.

Training sites are used to categorize each pixel in the image data into the land feature class it most closely resembles. A number of mathematical approaches exist for this purpose i.e., spectral pattern recognition. Select appropriate classification algorithm Example Minimum Distance to means classifier, Parallelepiped classifier, and Maximum Likelihood classifier. The actual classification is done here. A computer program that implements a set of procedures for image classification. There are different methods/strategies to image classification. Example ML classification, composed of various sets of procedures. A proper selection of a classifier is required for good accurate results. The classifier selected was Random Forest classifier. The operator provides class limits by means of class mean and covariance matrix (Rehna & Natya, 2016). It considers variability within a cluster but also considers the shape, the size, and the orientation of clusters. Among the disadvantages of this is that it takes more time to compute.

- **Output stage**.

In this stage Presentation of the results of the categorization process. The output must effectively convey the interpreted information to its end user. The output might be in the form of Graphic files, Tabular data, and Digital information file. It is in this place where Accuracy assessment is done. Accuracy assessment determines the correctness of a classified image based on pixel groupings. Example the categories of real-world features presented. The results of classification are assessed using a confusion matrix. User accuracy Probability that a certain reference class has also been labelled as that class. In other words, it tells us the likelihood that pixel classified as a certain class represents that class. Producer accuracy. Probability that a sample point on a map is that class. It indicates how well the training pixels for that class have been classified (Rehna & Natya, 2016).

Unsupervised Classification. In unsupervised classification, grouping of pixels with common characteristics are based on the software analysis of an image without the user providing sample classes.

2.1 Existing Research about public Transport Accessibility in Dar es salaam city including Temeke Municipality

Research on public transport accessibility done so far for Dar es salaam city which Temeke is one of its Municipals. According to the Dar es Salaam City Master Plan 2016-2036, transportation planning aims to align transportation supply with travel demand, which represents the actual need for transportation services. To determine the demand for transportation, various methodologies were employed. First, a household survey was conducted to understand travel patterns in different Traffic Analysis Zones (TAZ). This survey provided valuable insights into the commuting habits and transportation needs of residents.

Additionally, traffic volume and composition were determined through manual traffic counting conducted at different road sections and junctions. This data collection method helped in analyzing the flow of vehicles and understanding the overall traffic patterns within the city. Furthermore, roadside interviews were conducted to gather information on main entry and exit roads, as well as purpose surveys in fast-growing centers and industrial areas. These interviews provided valuable data on the specific travel purposes and destinations of commuters in key areas of the city.

(Olvera et al., 2002)_assessed varying accessibility of public transport in the city. It focused on different types of residential zones (planned and unplanned wards). Approach shows variation of road characteristics (paved and unpaved roads), access roads sized for four-wheel motor vehicles are paved for only 46% of homes, as compared to 55% in planned wards and 60% in affluent wards. Access to public transport is satisfactory in planned wards (77% of homes) and is paradoxically similar in the unplanned (62%) and the affluent wards (64%). Data used collected by The Human Resources Development (HDR) in 1993, by the Department of Economics of The University of Dar es salaam, the Government of Tanzania and The World Bank, and was funded by the World Bank, The Government of Japan and British Overseas Development Agency, it included sub-sample of 1128 households representing the population of Dar es salaam.

2.2 Knowledge gap

In previous studies on public transport accessibility, various methodologies, data collection approaches, and plans have been suggested to analyze and improve accessibility. These include the collection of data through household surveys to understand travel patterns in different Traffic Analysis Zones and obtain a representative household sample. Manual traffic counting on different road sections and junctions has been used to determine traffic volume and composition, while roadside interviews have been conducted to gather information on main entry and exit roads and the purpose of travel, particularly in fast-growing centers and industrial areas.

In the context of improving public transport in Dar es Salaam, the city's master plan emphasizes the enhancement of current road routes and the implementation of several Bus Rapid Transit (BRT) phases to replace traditional daladala operations. To assess the accessibility of public transport in Temeke municipal, this study employed GIS-based Network Analysis. It utilized the most up-to-date high-resolution multispectral images acquired from CNES/Airbus and Maxar Technologies Satellites and road network data,

Given the rapid urban growth in the area, effective sampling procedures were crucial for household selection. Therefore, the study maximized the extraction of households (facilities) by utilizing the most recent available higher-resolution images (40cm). The population growth in the outskirts of the current center, characterized by rugged terrain, has posed challenges to the accessibility of public transport, particularly for those residing in areas with limited or no access. The study examined the current coverage of public transport across different service area levels based on time and distance, and it proposed additional road segments that could be incorporated into the existing public transport network to expand coverage to a wider range of service areas.

CHAPTER THREE

METHODOLOGY

This chapter presents the systematic procedures applied towards achieving the main objective. It includes the data collection, data processing, processing techniques and analysis methods that were used in this study.

3.1 Flow Chart

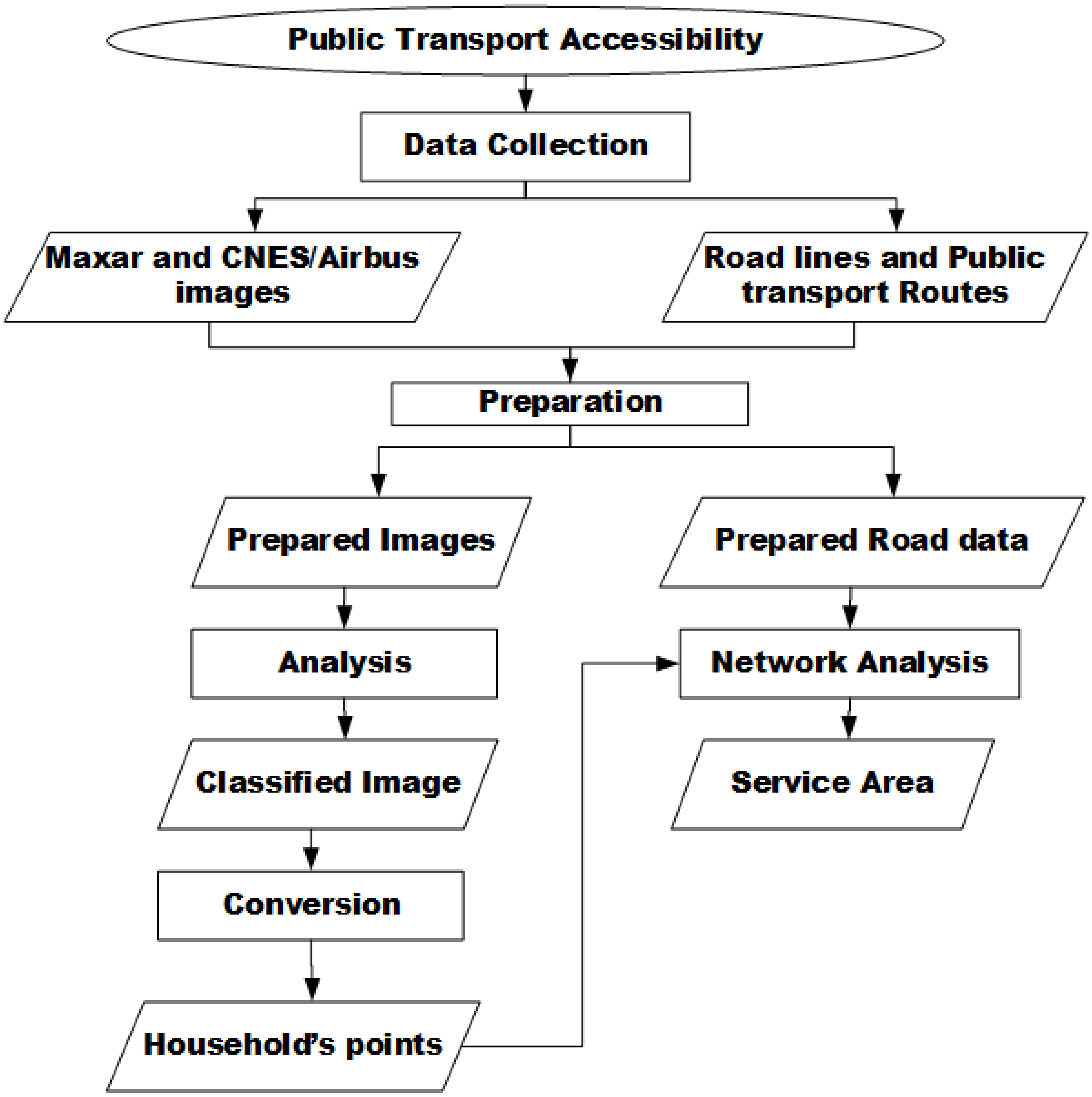

Figure 3.1 Flow Chart

3.2 Data collection

This study involved the collection of data required from web archives and from government agencies. The dataset collected satellite images, Road lines and public transport routes.

Table 3.1 Data acquired

No.	Data Source	Data	Date
1	Maxar Technologies Satellite (From Google Earth Map Platform)	Multispectral image (14cm resolution)	08/27/2021
2	CNES/Airbus (From Google Earth Map Platform)	Multispectral image (14cm resolution)	08/27/2021
3	LATRA	Public Transport Routes	2023
4	Google Maps	Road Lines	

3.3 Processing Techniques

3.3.1 Image classification

In this study, the images and Ground truthing were,

i. Initially split into training and testing datasets.
ii. The training dataset was used to train a random forest classifier, while the testing dataset was utilized to evaluate the accuracy of the classification.
iii. Feature extraction was performed by extracting features based on the pixel values of the images. The study focused on two classes: one class represented households' pixels, and the other class represented the pixel values that remained after assigning households' pixels. For this representation, a value of 1 was assigned to represent households, while 2 represented the pixel values of other features.
iv. The random forest classifier was trained using the training dataset, with 50 trees, 1000 features considered for each class, and a maximum tree depth of 30 pixels. Once the classifier was trained, it was applied to the entire image, classifying each pixel into the assigned classes.
v. To assess the accuracy of the classification, an accuracy assessment was conducted using the testing dataset, comparing the classified image with the known classifications.

Figure 3.2 Extracted Household

Figure 3.3 Extracted non-household feature

3.3.2 Network Analysis.

In the study, a network analysis was conducted through following steps,

i. Firstly, a network dataset was created using road network data, with appropriate configuration of distance and time attributes. This dataset served as the foundation for further analysis. The households extracted from the image were used as the origin points for the service area analysis. To assess accessibility, the analysis considered a range of distances 0-400 and 400-1000 meter. Additionally, drive time impedance was taken into account, ranging from 0-60 and 60-120 minutes.

ii. Next, the network analysis was performed, specifically focusing on service area analysis. This analysis generated polygons that represented the travel distance and travel time from households to the road network, providing a visual representation of areas reachable within specific distance or time constraints.

CHAPTER FOUR

RESULTS AND ANALYSIS

OVERVIEW

This section consists of the outputs, which were obtained, in both steps, project and the discussion of those outputs, results are explained in each part. This chapter involves data presentation, interpretation, and analysis of the products results. Consists outputs obtained in image classification, Network Analysis, Catchment Area Calculation and Demographic Characteristics of Temeke Municipal.

4.1 Image Classification

4.1.1 Accuracy Assessment of classified image

Accuracy of classified image based on Error matrix or a **confusion matrix**. A table that compares the reference and classified values representing features extracted basing on their spectral characteristics.

Overall accuracy was 90%,

Producer's accuracy was as;

Households correctly classified was 72% and None-Households was 83%.

User's accuracy

Households correctly classified was 93% and None-Households was 84%.

As overall accuracy was 90%, suggest that the classification algorithm (Random Forest) performed well in correctly assigning pixels to their respective classes, this indicates a reliability of classified image. Table 4.1 shows more about accuracy assessment report.

Table 4.1 Accuracy Assessment

CLASSIFIED/REFERENCE	Households	Non-Households	Total Reference	
Households	1785	141	1926	
Non-Households	133	700	833	
Total Classified	1918	841	2759	
Total Correct Reference Points	2485			
Total True Reference Points	2759			
Percent Accuracy	90			
User's Accuracy			Producer's Accuracy	
Households	93		Households	72
Non-Households	84		Non-Households	83

Total Accuracy Percentage = (2485/2759) *100

= 90%

Total classified = 1785 + 133

= 1918

Total Correct Reference Points = 1785 + 700

= 2485

User's Accuracy

Households = (1785/1926) *100

= 93%

Non households = (700/833) *100

= 84%

Producer's Accuracy

Households = (1785/1918) *100

= 72%

Non-Households = (700/841) *100

= 83%

Overall accuracy = ((Total number of correct classified) / (total number of reference)) * 100

4.1.2 Temeke Municipal Households

Methodology used to obtain household's coverage was using **Random Forest classifier**. Random forest classifier used with input data or image and features trained from the image. Random forest algorithm has higher ability to handle complex datasets, handle a large number of input variables, and provide accurate results.

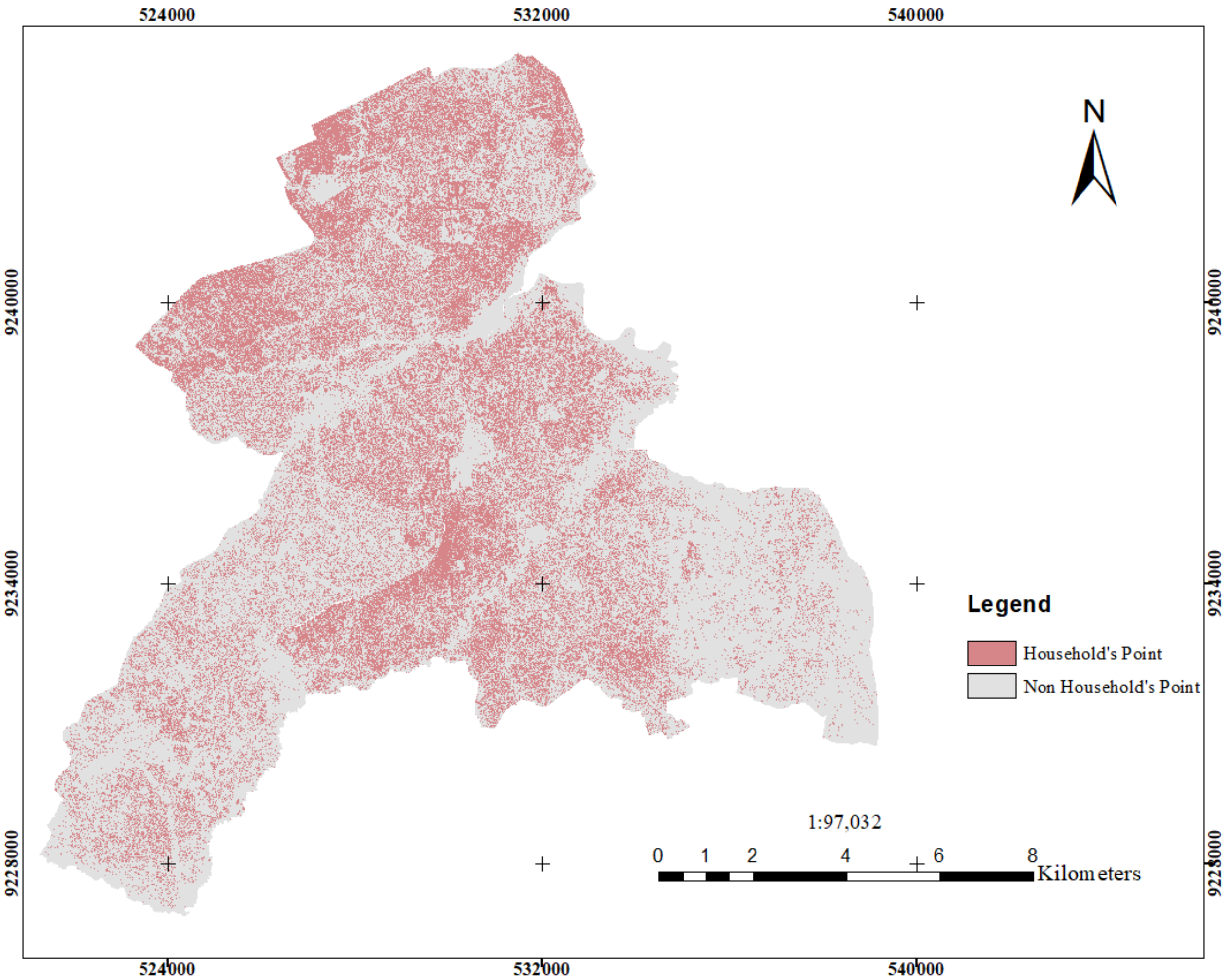

Figure 4.1 Temeke Municipal Households

4.1.3 Extracted Households

The process employed to obtain Household's points involved two key steps. Firstly, image classification was conducted using a random forest classification algorithm. This technique assigned pixels to specific classes based on their spectral characteristics, allowing for the identification of households within the image data. Secondly, vectorization was employed to convert the classified pixels into multipart polygons, facilitating the extraction of the table's contents. Overall, a total of 95,527 households were extracted using this approach.

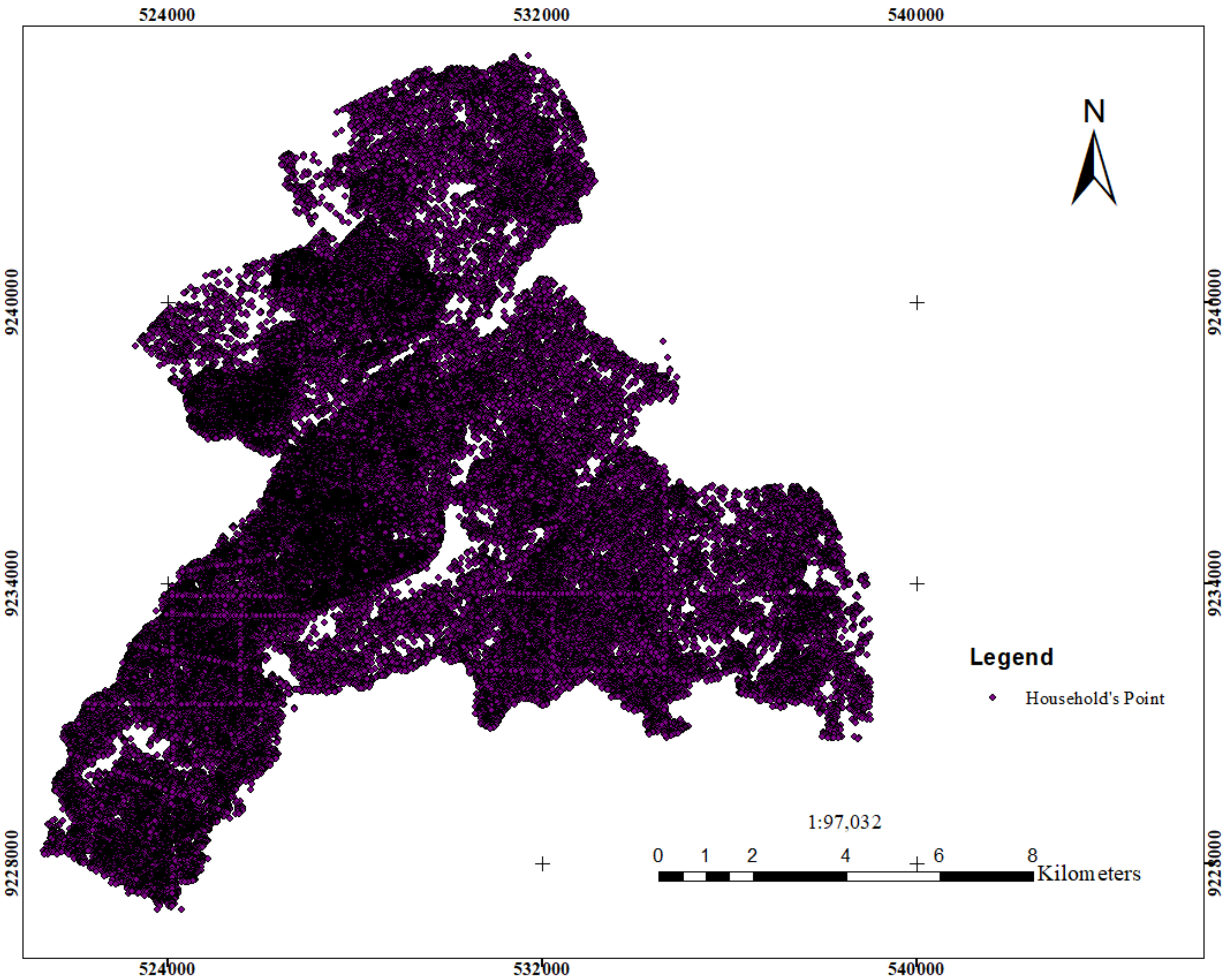

Figure 4.2 Extracted Households

4.2 Service Area Analysis

The network datasets utilized for analyzing accessibility encompassed road networks and public transit routes. The process employed in creating the network dataset involved several key steps. Firstly, data collection was carried out to gather the necessary information. Subsequently, data preparation was conducted, which involved cleaning the data to ensure spatial accuracy and address any errors that may have been present.

The creation of the network dataset was accomplished using the ArcGIS Network Analyst tool. This tool provides a range of functionalities and workflows that allow for the definition of network attributes, connectivity rules, travel restrictions, and other important parameters.

In order to facilitate the analysis, attributes such as the speed and length of roads were assigned to the network dataset. These attributes were crucial for assessing travel time and travel distance accurately.

Validation and calibration were then performed to ensure the network dataset's accuracy and performance. This involved comparing the network dataset with real-world travel observations data, allowing for adjustments to be made to fine-tune the network's performance and improve the accuracy of the accessibility analysis.

Creating a robust and accurate network dataset is a critical aspect of analyzing accessibility. It provides a solid foundation for conducting various analyses and evaluations related to transportation planning, public transit optimization, and assessing the overall accessibility of an area. By incorporating reliable and up-to-date data, the network dataset becomes a valuable tool for decision-makers and planners in improving transportation systems and enhancing accessibility for the public.

4.2.1 Network dataset

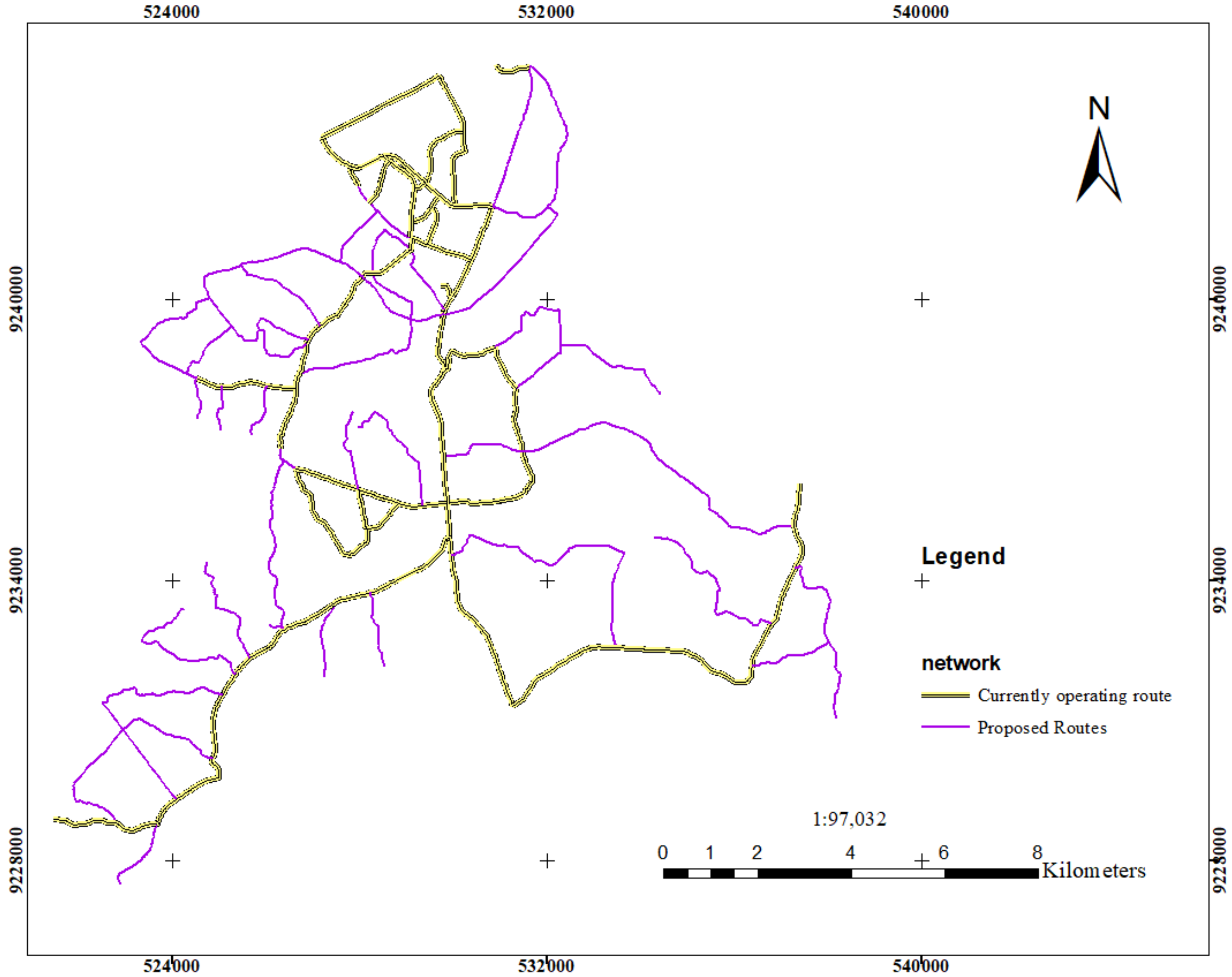

Figure 4.3 Network Dataset

4.2.2 Drive distance for currently operating routes

Figure 4.4 below shows results of travel distance which calculated basing on currently operating road network for public transport, and found that Household's points location in Chamazi which are <400m constitute 4% and <1000m 49% of 22244 total observed points, Toangoma <400m constitutes 3% and <1000m 48% of 20481 while Yombo Vituka <400m constitutes 2% and <1000m 27% of 992 observed points. Chamazi, Toangoma and Yombo Vituka considered as they have very few locations which are able to access public transport within drive distance below 400 meter, which means that accessibility to public transport is poor compare to other wards in Temeke municipality.

In figure 4.5, Drive distance below 400 meter presented by values below 1, while for drive distance above 400 meter represented by values greater than one.

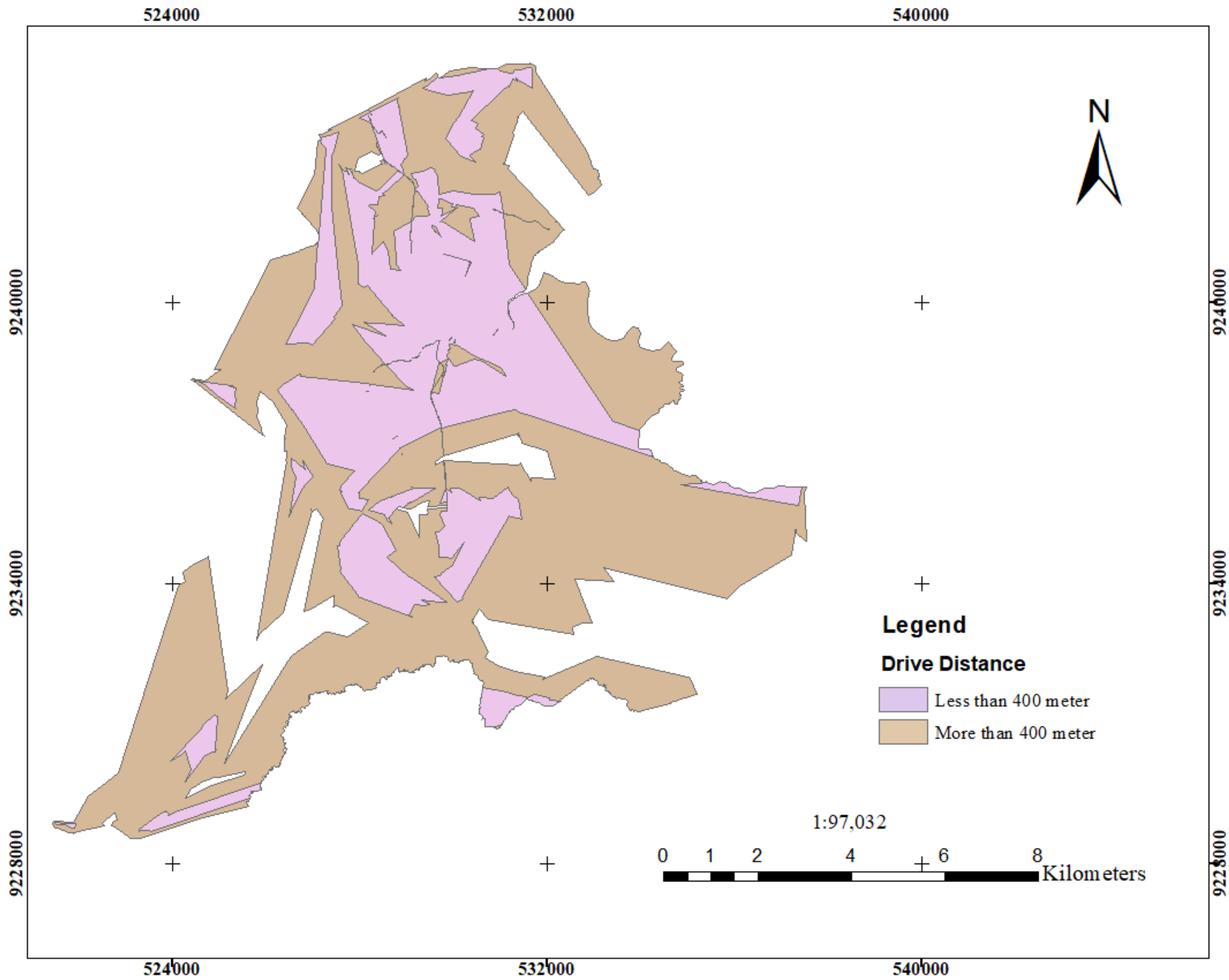

Figure 4.4 Drive Distance for currently operating routes

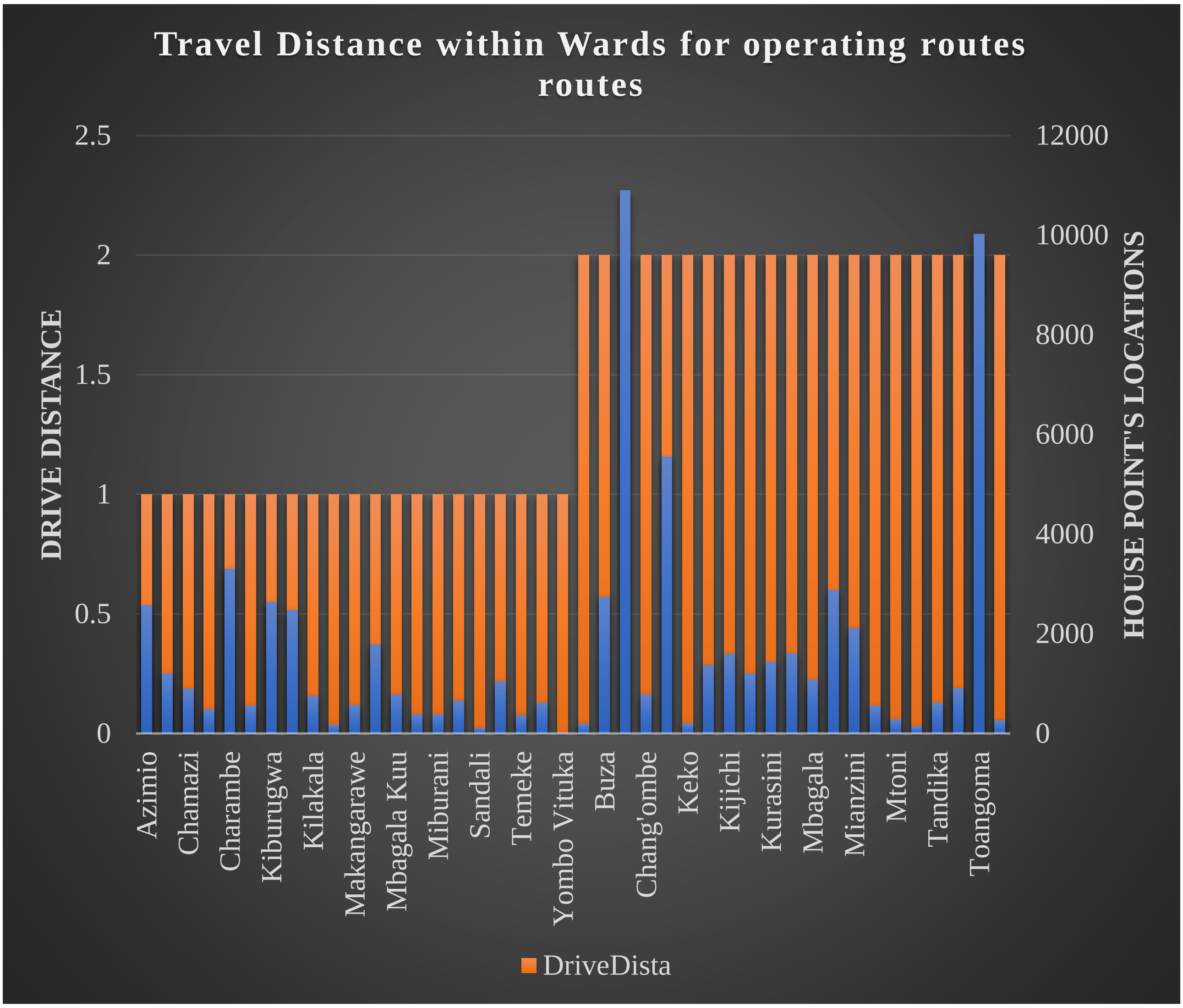

Figure 4.5 Graph showing travel distance within wards accessible by household's points for operating routes

4.2.3 Drive time for currently operating routes

Figure 4.6 below shows results of drive time which calculated basing on currently operating road network for public transport, and found that Household's points location in Chamazi which are <60 minutes constitutes 22% and <120min 55% of 22244,Toangoma <60 minutes constitutes 19% and <120 minutes 52% of 20481 while Yombo Vituka <60 minutes constitutes 6% and <120 minutes 23% of 992. In figure 4.7 drive time below 60 minutes presented with values below 1, and for drive time above 60 minutes represented with values above 1.

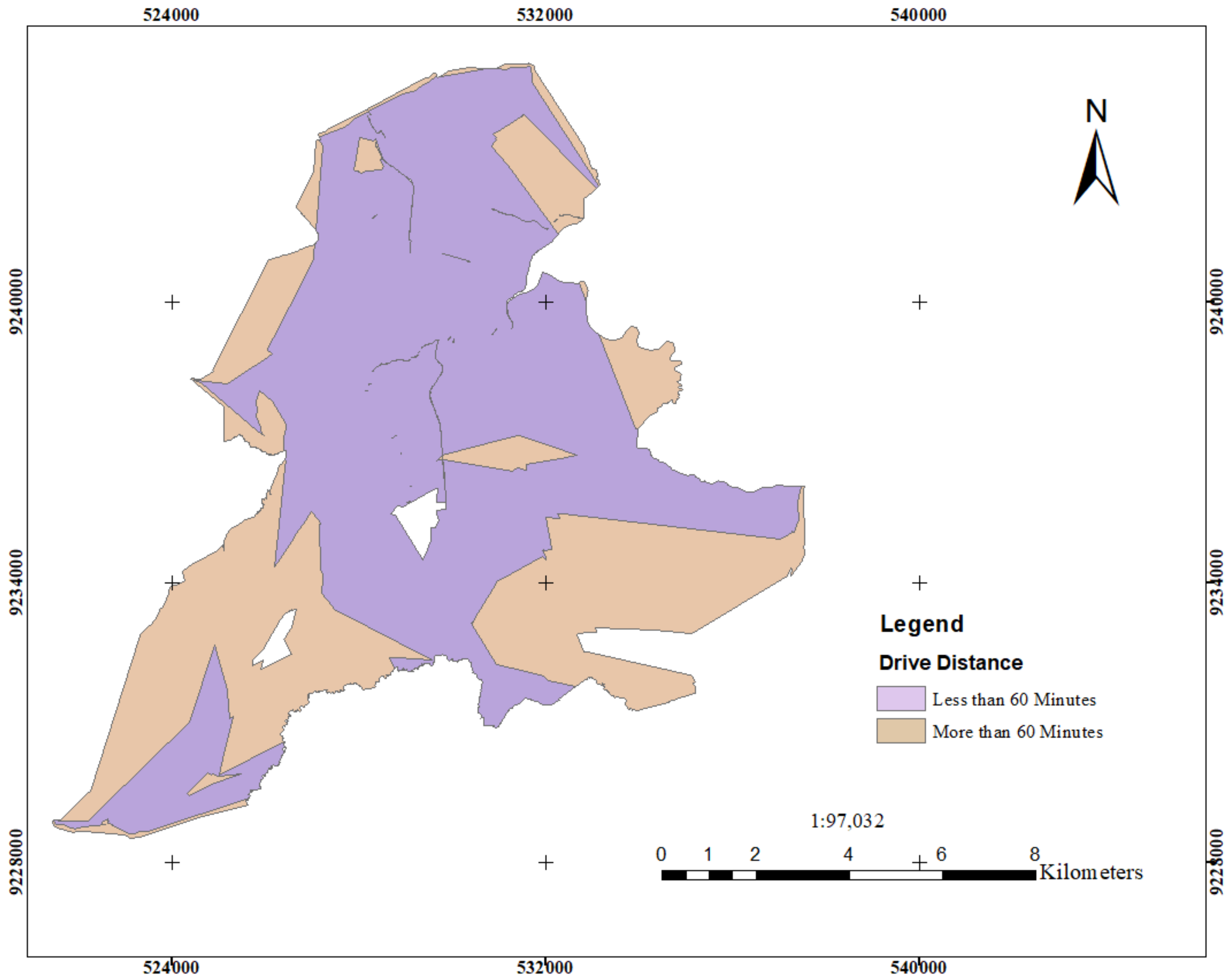

Figure 4.6 Drive Time for currently operating routes

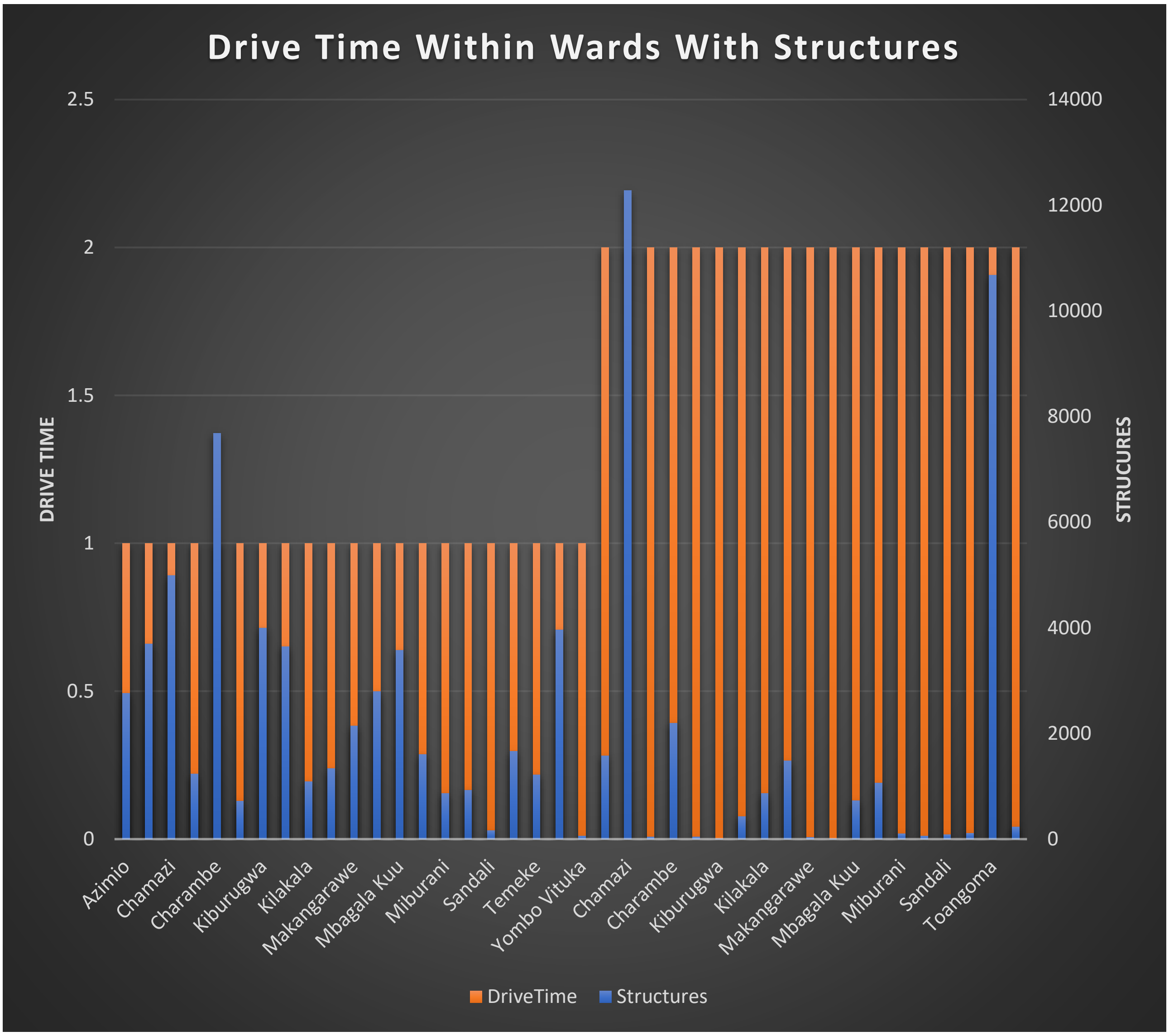

Figure 4.7 Graph showing drive time within wards accessible by household's points for currently operating routes

4.2.4 Drive distance for proposed routes

Figure 4.8 below shows results of travel distance which calculated basing on proposed road network for public transport, and found that Household's points location in Chamazi which are <400m constitutes 13% and <1000m 45% of 22244, Toangoma <400m constitutes 9% and <1000m 51% of 20481 while Yombo Vituka <400m constitutes 23% and <1000m 42% of 992.

Figure 4.9, values below 1 represents drive distance which is below 400 meter, while 1 and above represents drive distance above 400 meter.

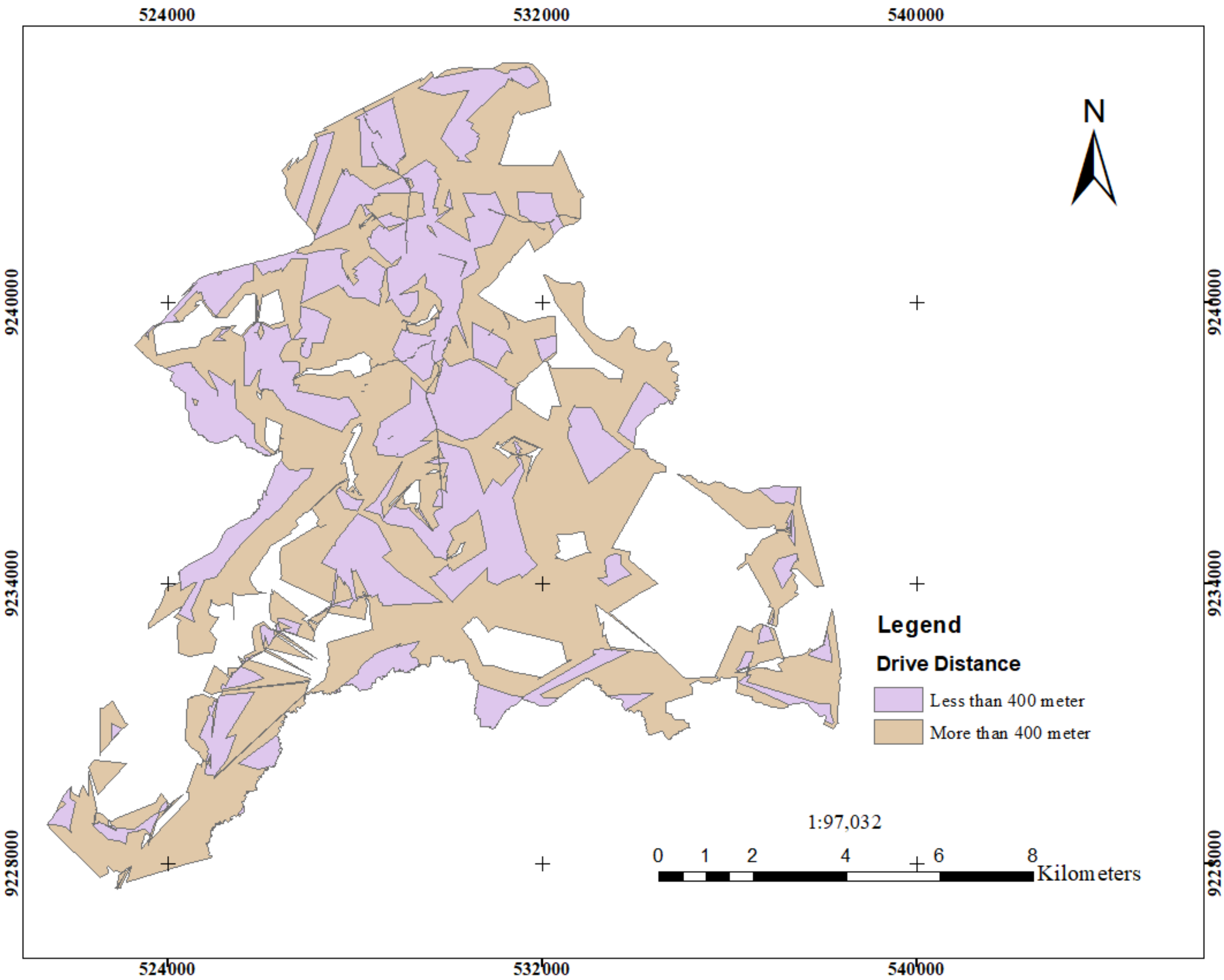

Figure 4.8 Drive Distance for Proposed Routes

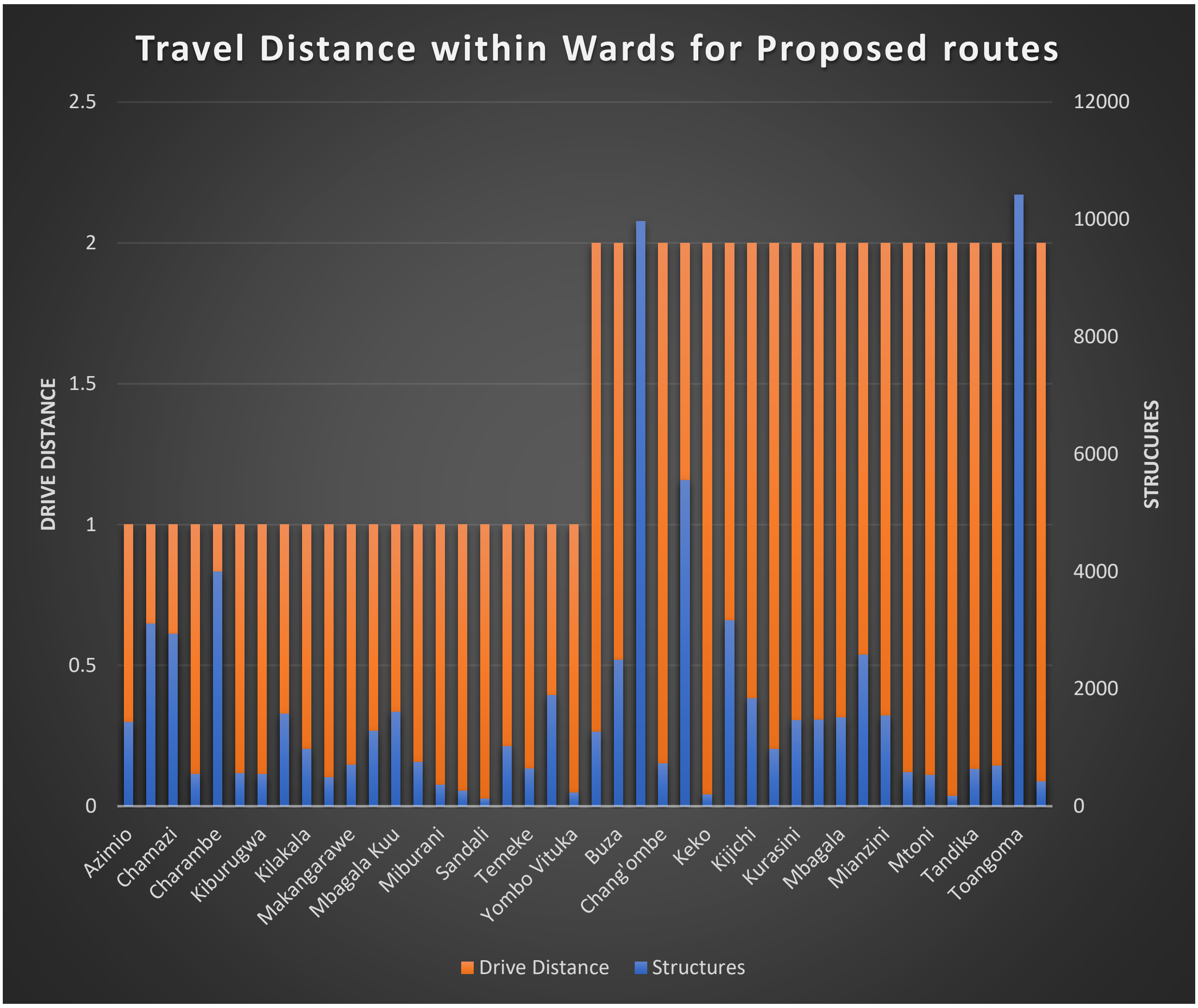

Figure 4.9 Graph showing travel distance within wards accessible by household's points for proposed routes

4.2.5 Drive time for proposed routes

Figure 4.10 below shows results of drive time which calculated basing on proposed road network for public transport, and found that Household's points location in Chamazi which are Chamazi <60 minutes constitutes 52% and <120 minutes 31% of 22244, Toangoma <60 minutes constitutes 55% and <120 minutes 31% of 20481 while Yombo Vituka <60 minutes constitutes 68% and <120 minutes 24% of 992. In figure 4.11 drive time below 60 minutes presented with values below 1, and for drive time above 60 minutes represented with values above 1.

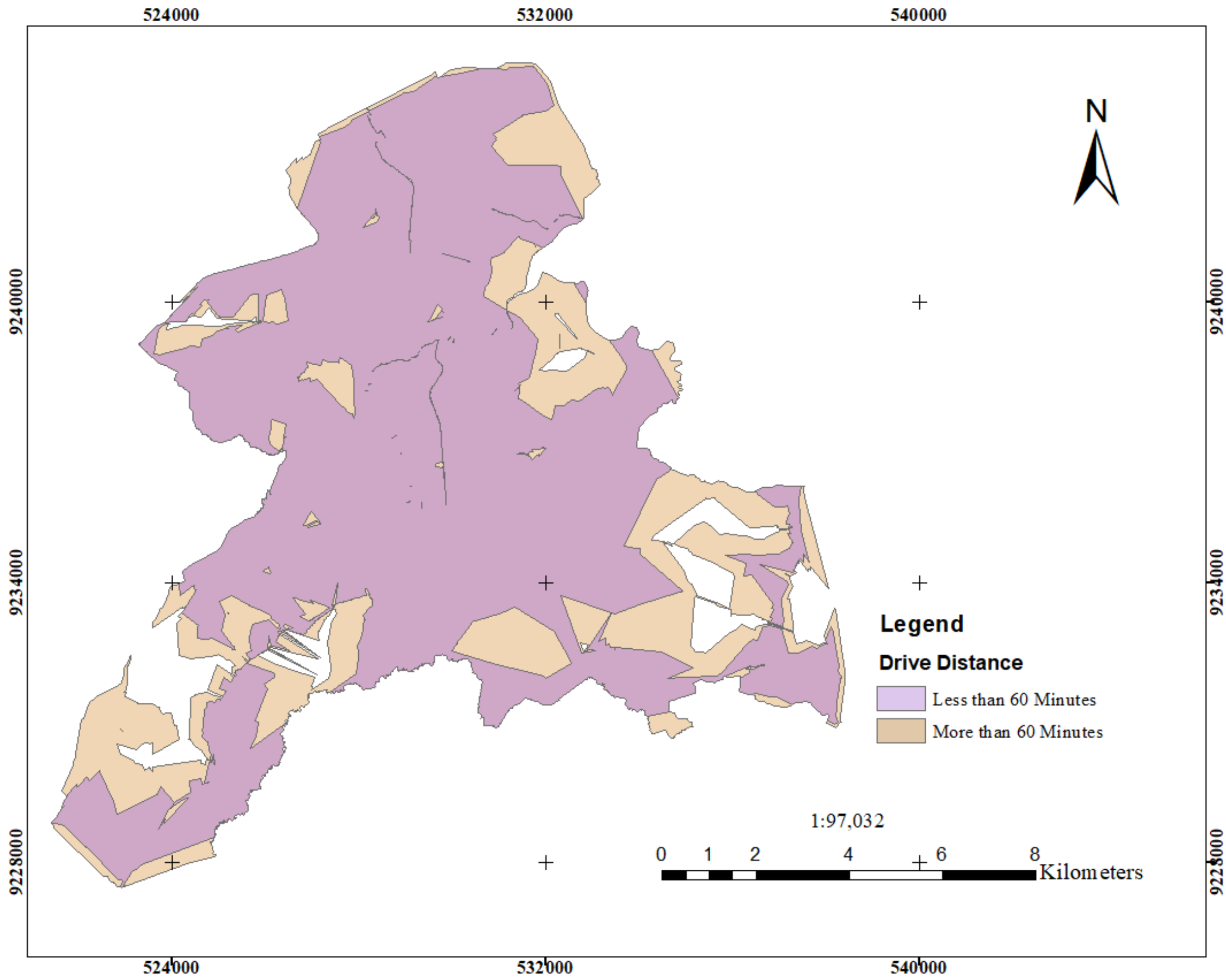

Figure 4.10 Drive time for proposed routes

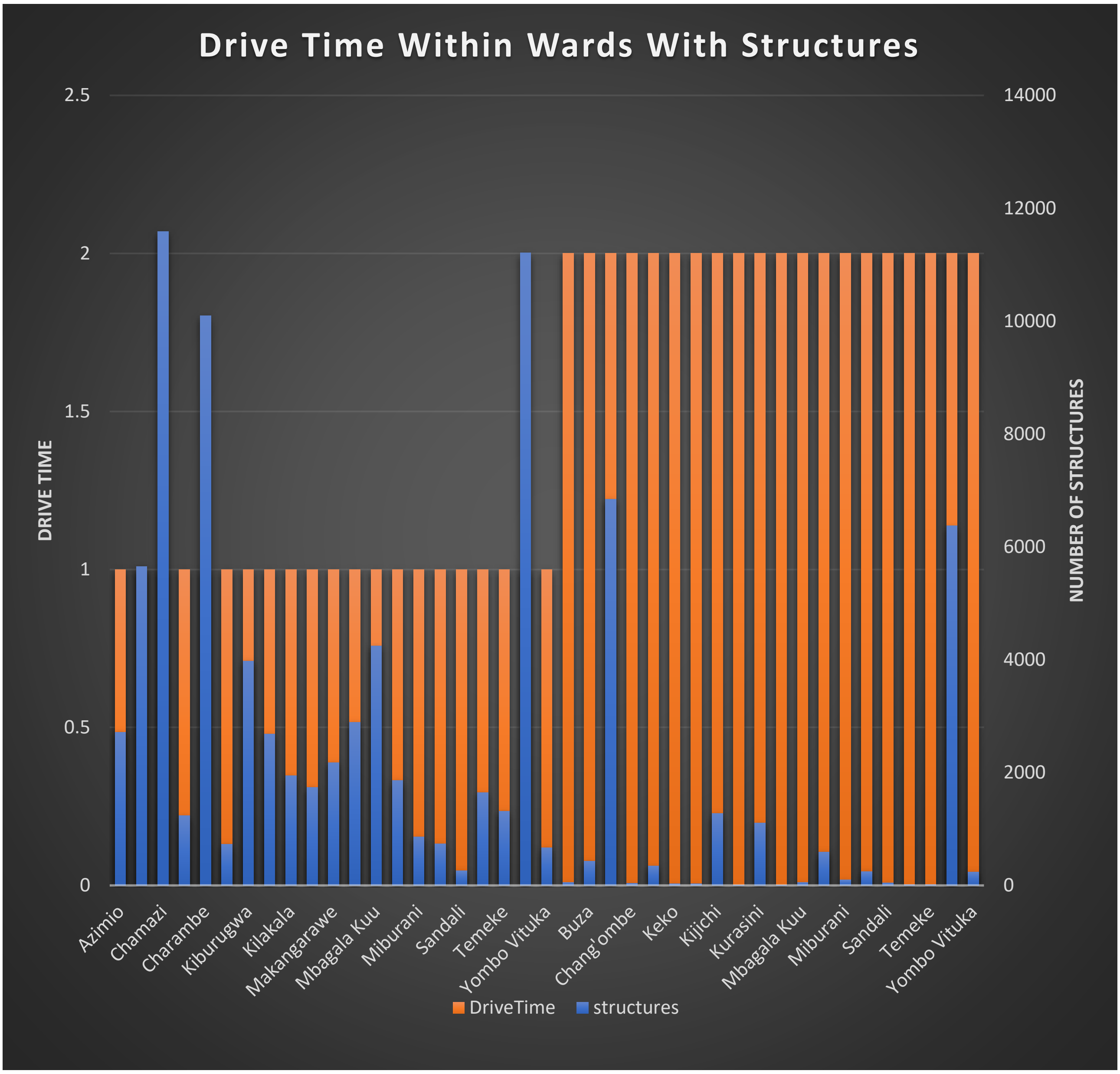

Figure 4.11 Graph showing drive time within wards accessible by household's points for proposed routes

CHAPTER FIVE

DISCUSSION AND CONCLUSION

5.1 Households' points

Utilizing the Household approach for assessing public transport accessibility offers several noteworthy advantages. Firstly, it enables targeted service planning by identifying areas with high concentrations of households. This information is invaluable for public transport planners and policymakers as it helps prioritize service planning and resource allocation in an efficient manner. By focusing on areas where households require improved or expanded transportation infrastructure and services, accessibility can be enhanced effectively.

Secondly, mapping households contributes to equity and social inclusion. Analyzing public transport accessibility across different neighborhoods allows for the identification of areas with lower accessibility. Consequently, efforts can be concentrated on improving service provision in underserved or disadvantaged communities, thereby promoting equity and social inclusion.

Thirdly, the Household approach provides valuable insights into demand assessment for public transport. Through the analysis of population density and household distribution, transportation planners can estimate the potential number of passengers in a given area. This information aids in evaluating service demand and optimizing routes and frequencies to meet the needs of the population.

Lastly, mapping households facilitates policy evaluation. By comparing accessibility metrics before and after the implementation of public transport policies and interventions, policymakers can monitor and assess their effectiveness. This enables informed decision-making for future improvements to public transport systems.

Despite these advantages, there are also limitations associated with the Household approach. Firstly, challenges arise from the availability and accuracy of household data. Census data, for instance, may have limited temporal resolution, providing information that may be outdated by up to 10 years. On the other hand, household surveys can be resource-intensive and may not cover large areas for analysis. Additionally, while image classification methods provide more frequent updates depending on the availability of images acquired over the study area, they may have lower accuracy compared to other approaches.

Secondly, the spatial resolution of household data can impact the precision of the analysis. Coarser resolution data may fail to capture fine-scale variations in accessibility within neighborhoods, potentially leading to generalized findings that overlook specific localized issues.

Lastly, it is important to note that static household data may not account for temporal variations in travel patterns and accessibility. Factors such as peak/off-peak travel times, seasonal variations, or changes in household composition can influence accessibility levels, which may not be adequately captured in static household datasets.

5.2 Accessibility of Public Transport

Table 5.1 Household’s Points to public transport accessibility

	Density	525.5172	1421.497	285.8961	248.1959	393.314	657.4924
	Area	1.45	7.35	9.43	3.88	3.44	6.54
	Proposed	200	5557	1544	578	726	2579
400-1000	Operating	199	5557	2111	556	782	2873
	Proposed	560	3992	750	365	549	1609
0-400	Operating	557	3298	382	387	487	782
	Proposed	32	348	589	100	39	55
60-120	Operating	39	2197	1060	100	40	729
	Proposed	728	10100	1859	863	1235	4245
0-60	Operating	717	7680	1606	863	1230	3571
	Household’ s points	762	10448	2696	963	1353	4300
	Ward Name	Keko	Charambe	Mianzini	Miburani	Chang'ombe	Mbagala kuu

872.0721	820.2065	918.1435	535.3464	1059.756	1279.085	977.0588	464.726	546.5973	178.7387	345.9643
3.33	27.12	2.37	5.63	5.74	1.53	1.70	2.92	37.47	5.55	11.77
1512	9970	1469	1460	2488	971	634	686	10422	421	1836
1079	10895	1607	1434	2742	1202	616	910	10021	266	1597
1285	2837	707	489	3132	973	1023	644	1890	230	1570
1783	896	569	176	1204	755	1045	366	617	15	2474
11	6845	0	1109	432	10	18	13	6376	241	1278
5	12277	32	1483	1573	866	0	115	10674	233	424
2893	11589	2176	1737	5651	1947	1643	1317	11208	671	2682
2794	4988	2144	1333	3699	1091	1661	1214	3962	62	3648
2904	22244	2176	3014	6083	1957	1661	1357	20481	992	4072
Mbagala	Chamazi	Makangarawe	Kurasini	Buza	Kilakala	Tandika	Temeke	Toangoma	Yombo Vituka	Kijichi

121.978	1146.888	1023.785	250.2538		
2.73	2.41	3.91	3.94	150.21	
175	1264	3166	527	48185	50
140	191	1366	281	46425	49
126	1433	543	257	24964	26
109	2573	2654	662	21791	23
48	52	27	249	17872	19
87	0	2	61	31997	33
258	2712	3976	737	70227	73
166	2764	3996	925	50114	52
333	2764	4003	986	95549	
Sandali	Azimio	Kiburungwa	Mtoni	**Total**	**Percentage**

5.3 Summary of findings

A total of 95,549 households underwent assessment to determine their accessibility to public transport from their respective locations. The study evaluated accessibility based on drive time, categorized into 0-60 minutes and 60-120 minutes, as well as drive distance, divided into 0-400 meters and 400-1000 meters.

Regarding currently operating routes, the analysis revealed that within the 0–60-minute drive time range in Temeke municipal, 50,114 households, accounting for 52%, had access to public transport. Additionally, 31,997 households, representing 33% of the total, were able to access public transport within the 60–120-minute range. The remaining households, totaling 13,438 or 15%, required more than 120 minutes to access public transport. In terms of drive distance, 21,791 households (23%) could access public transport within 0-400 meters, while 46,125 households (49%) were able to access it within 400-1000 meters. The remaining 27,333 households (28%) had access to public transport at distances exceeding 1000 meters.

The proposed routes, based on their connectivity, showed some improvement in accessibility if effectively implemented. The analysis indicated that within the 0–60-minute drive time range in

Temeke municipal, 70,227 households (73%) could access public transport. Additionally, 17,872 households (19%) were able to access public transport within the 60–120-minute range. The remaining households, constituting 7,450 or 8%, required more than 120 minutes to access public transport. In terms of drive distance, 24,964 households (26%) could access public transport within 0-400 meters, while 48,185 households (50%) were able to access it within 400-1000 meters. The remaining 22,400 households (24%) had access to public transport at distances exceeding 1000 meters.

In general, the findings indicate that a significant number of households still need to travel more than 1000 meters to reach public transport nodes, accounting for 24% for proposed routes and 28% for currently operating routes. Furthermore, a considerable number of points spend over 120 minutes accessing public transport, comprising 15% for currently operating routes and 8% for proposed routes. According to the theory of service area, which calculates drive distance and time within a community, a well-connected road network leads to reduced travel time and distance for improved accessibility(Niedzielski et al., 2014). However, Temeke municipality lacks a well-connected road network in some areas, resulting in several limitations. These limitations have various impacts, including inequitable access to social services, challenges in emergency response and disaster planning, increased transportation costs, limited integration and interconnectivity, and reduced community efficiency.

5.4 Conclusion

The accessibility of public transport needed to be significantly enhanced, ensuring that a larger proportion of households have convenient and reliable access to essential services, promoting sustainable urban mobility, and improving overall quality of life. Regular monitoring and evaluation of the implemented measures will be crucial to measure their effectiveness and make further adjustments as needed.

CHAPTER SIX

RECOMMENDATIONS

6.1 Recommendations for improving research on accessibility of public transport.

Enhance Data Collection and Quality: Collaboration with relevant transportation authorities and organizations to establish a data-sharing mechanism. There is an need for standardized data formats and frequent updates to ensure the availability of accurate and current datasets. Also considering to incorporate real-time data feeds to enhance the precision of accessibility assessments.

Refine Assumptions and Simplifications: In order to obtain reasonable results from this kind of analysis there is a need to conduct sensitivity analyses by systematically varying the assumptions and simplifications made during the analysis. And documenting the range of outcomes for different scenarios, highlighting the potential impacts of each assumption. This will provide a clearer understanding of the uncertainty associated with the model results.

Incorporate Comprehensive Transport Modes: There is a need to expand the scope of the analysis to include a wider array of transport modes. Collaborate with local transport authorities to gather data on walking, cycling, and ridesharing options. Incorporate these modes into the accessibility analysis to provide a more holistic view of mobility patterns.

Capture Travel Behavior and Demand Dynamics: Implementing a combination of surveys, focus groups, and interviews to gather qualitative insights into travel behavior and demand dynamics. Collect information on preferred travel modes, peak travel times, and reasons for mode choices. Incorporate this qualitative data to refine the model and enhance its accuracy. By doing this can be useful to answer about affordability and quality of public transport which was one of the objective of this study, but have not addressed.

Address Spatial and Temporal Scale Challenges: Other studies needed to conduct accessibility analyses at multiple spatial scales, such as city-wide, neighborhood-level, and even individual street segments. Similarly, analyze accessibility over different time periods to understand daily, weekly, and seasonal variations. Document how the results change with varying scales and timeframes to provide a comprehensive understanding.

Conduct Robust Sensitivity Analyses: Systematically vary model parameters and settings within reasonable ranges to assess their impact on the results. Analyze how changes in parameters influence accessibility scores and identify critical factors that significantly affect outcomes. This will provide insights into the stability and reliability of the model.

Promote Model Validation and Calibration: Gather real-world data on travel times, routes, and accessibility measures. Compare the model predictions with actual observed data to validate its accuracy. Additionally, calibrate the model by adjusting parameters to ensure that the predictions closely match real-world observations.

Collaborate with Stakeholders: Establish partnerships with transportation agencies, urban planners, and local communities. Engage in regular discussions and workshops to understand their perspectives and gather feedback on the analysis. By involving stakeholders, you can ensure that your research aligns with practical needs and concerns.

Continued Research and Innovation: This study encourage future researchers to build upon your work by addressing the identified limitations. Advocate for cross-disciplinary collaboration, promoting the integration of emerging technologies and methodologies. This will help advance the field of GIS-based network analysis and contribute to more robust and accurate accessibility assessments.

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