ARDHI UNIVERSITY

THE GIS-BASED ASSESMENT OF LOCATION FOR PLACEMENT FIRE STATIONS

A Case Study of Dodoma Urban

MBOYA, GIFT M.

BSc Geoinformatics

Dissertation

Ardhi University, Dar es Salaam

July, 2023

THE GIS-BASED ASSESMENT OF LOCATION FOR PLACEMENT OF FIRE STATION.

A Case Study of Dodoma Urban

MBOYA, GIFT M.

A Dissertation Submitted to the Department of Geospatial Sciences and Technology in partially fulfilment of the requirements for the award of Bachelor of science in Geoinformatics (BSc. GI) of the Ardhi University.

CERTIFICATION

The undersigned certify that they have read and hereby recommended for acceptance by the Ardhi University a dissertation entitled: "**THE GIS-BASED ASSESMENT OF LOCATION FOR PLACEMENT OF FIRE STATION AT DODOMA URBAN"** in partial fulfillment of the requirements for the Award degree of Bachelor of Science in Geoinformatics at Ardhi University.

Signature ……

Mr. Michael Mavura.

(Supervisor)

Date……

DECLARATION AND COPYRIGHT

I, MBOYA, GIFT M, declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

……

MBOYA, GIFT M.

22719/T.2019

ACKNOWLEDGEMENT

The most important reason why I manage to accomplish this thesis is through the help and support from GIS expert at Ardhi university. I would like to express my sincerest gratitude to the following;

Firstly, I would like to express my sincerest thanks to my supervisor Mr. Michael Mavura from department of geospatial science, who support me during the whole process and give me the technical help and constructive suggestion for this research consistently. He also gave me many good suggestions regarding the structure of report and general writing techniques. Whenever I need help, he always there to help me solve those problem.

Meanwhile, I would like to give sincerest appreciation to my panel examiners Dr Atupele Komba, Dr Dorothy Deus, Dr Guido, Mr. Michael Mavura and Mr. Joseph Maziku from the department of geospatial science and technology: they give me many critical comments with great patience. During the revising the paper, their comments are very detailed and important they helped improve my thesis. All of their suggestions made my thesis paper more scientific and reasonable. From the revising work, my writing skills and my logic thinking improved.

Finally, I would like to thanking GOD for he has grant me a favor of being alive to this very moment and for his guidance and everlasting love since primary school to university. It could be hard perhaps impossible for me to be in university without the love and guidance from my parents and I do thank GOD again for keeping them alive up to now. Also, my friends William Erick and Jonas Kihalule for their cooperation and encouragement on my studies. Stay blessed with your endless love, advice and support during the whole period at Ardhi University.

DEDICATION

I dedicate this dissertation to my lovely parents (Mr. Joseph Mboya and Ms. Tamali Ramson), my uncle Mr. Khamis Mwatindi Mboya for their endless effort and financial support in insuring achievement of my education career and my whole family for their encouragement and best wishes on accomplishing of my study successfully.

ABSTRACT

The efficient placement of fire stations plays a crucial role in ensuring the safety and security of the urban areas. This research focuses on the GIS-based assessment of suitable location for placement the fire stations at Dodoma urban district. The study utilizes the multi-criteria decision analysis (MCDA) approach, specifically on the method of analytical hierarchy process (AHP), to determine the suitable location for fire station emplacement at Dodoma urban district.

The research considered on the only four criteria which are population density, slope, land use and the distance from the existing. GIS data, including the population data from national bureau of statistics (Tanzania census of 2022), Dodoma road network, coordinates of the existing fire stations and land use map are integrated within the analytical hierarchy process (AHP) method to evaluate and assign weights to these criteria and finally the result should overlaying through the weighted overlay in order to obtain the final output which is the map that shows the suitable area for locating fire stations at Dodoma urban. By employing the AHP method, the research enables the systematic comparison and prioritization of potential fire station locations. The process involves the pairwise comparison of the criteria, resulting with the consistency ratio of 0.029 (it is less than 0.1 so it is acceptable) and it ensures that the accuracy and reliability of the decision-making process. The findings of this research will provide valuable insights for urban planning authorities and the fire services administrator in Dodoma urban.

The research presents a comprehensive and objective methodology for assessment and selection of fire station locations. The integration of GIS technology and MCDA techniques enables a data driven approach to support informed decision making in urban fire station emplacement, ultimately enhancing emergency response capabilities, minimizing response time and ensuring the safety of the properties to be damage from fire

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

ACRONMYS AND SBBREVIATIONS

NFPA	National Fire Protection Association
GIS	Geographical Information System
AHP	Analytical Hierarchy Process
GNFS	Ghana National Fire Services
DEM	Digital Elevation Model
MCDA	Multi-criteria Decision Analysis
CI	Consistency Index
CR	Consistency Ratio
RI	Random Index
SRTM	Shuttle Radar Topography Mission
OSM	OpenStreetMap

CHAPTER ONE

INTRODUCTION

1.1 Background

Fire refers to uncontrolled burning which can easily be managed and controlled due to advanced technology in fire services. NFPA outlined that fire outbreaks lead to loss of property and people's life which is noted as a critical problem (G. Badger, 2019). Management of fire in the world differ from country to country depending on the level of technology as methods and response to fire approach are different despite that GIS has proven to be efficient at high rate in developed countries. Fire management include all fires such as wild fire and urban fires in cities.

Worldwide in wildfire many hectares are burned as about 75 to 820 hectares while wild life fire is to about 3 to 8 percent (Larsen, 2009). In developed countries medical calls for aid are less than 1 percent as management of fire is of high technology used different from developing countries. To developed countries fire incidents are managed by using GIS technology, remote sensing techniques and phone tracking technology (ESRI, 2006).

In Africa fire incidents are reported in bush burning where as to 70% occur in tropics, management of fire is hard in developing countries like Tanzania since the technology is not high and due to use of local ways in addressing fire issues. In Africa it has been reported that fire incidents are caused by accidental or alleged negligence, natural cause as well as own burning (SCFPA, 2009). In Tanzania fire disaster should be dealt stating with all member of house hold as well as fires services but most of high learning institution fail to prepare and manage fire (Yang, J. 2017). Also, fire may be caused by improper use of power line, poor installation of electric line, explosion of stoves that work with gas and oils. Firefighting and rescue services or fire stations are among the most crucial government services for protecting people, property, and the environment from fire and other emergencies.

Fire stations are one of the most essential and necessary land uses in urban area that guarantee the life and safety of urban residents. So, the location and number of the stations is very significant for the efficient coverage of the area which intended to be protected. Furthermore, the expanded of urbanization growth has multiplied the increase in population of urban area in the developing countries which the risk of hazardous fire area its impact of the city became more obvious Habibi et al., (2008). As a result, emergency response services are critical, especially in the case of fire disasters, to prevent the country from losing valuable resources Forkuo and Quaye-ballard., (2013). The success of emergency response depends on procedures, resources, and Employees. Services are required during the response, preparedness, and rehabilitation times and must be defined according to the responding agencies and the types of emergencies experienced. In addition, the right resource control processes, such as the implementation of an emergency response plan, an incident. As a result of being trained to use the tools and practice the systems in multiple emergency situations, the emergency management staff act as the link between the systems and resources. In other words, these professional workers are the ones that are on the site security problems and on the field at hand during crises. firemen and Ambulance staff are few examples of qualified emergency service personnel Subramaniam and Ali, (2012). Right now, in Dodoma urban have two (2) existing fire stations are found which provide a service for emergency response occurrence for the entry city. In order to determine the best location to the study area this study used GIS. Geographic information system (GIS) is one of the best techniques for determining the best location for a fire station, and it can integrate both spatial and non-spatial data Gokgoz, T. (2011).

The present study was carried out to solve the problem of inequality distribution of fire stations throughout the Dodoma city and develop a method of finding optimized routes for emergency response analysis. For that reason, an integrated method was used such as GIS techniques of Analytical Hierarchy Process (AHP) to propose additional candidate sites of fire stations to be added in the study area and network analysis techniques was conducted. Among of location

allocation analysis, Maximize Coverage has been utilized to determine the best optimum location of fire stations service in the Dodoma City.

1.2 Statement of the problem.

Dodoma is among the fast-growing cities in Tanzania since its promotion by the president many residential, industries and expansion of economic activities and trading centers have been observed growing in terms of population and material thing within the city.

In Dodoma there are only two fire station which operate in all city but due to its rapid growth population of Dodoma is increasing day to day. However, the criteria used to identify the locations of the fire stations are poorly understood. The methods used do not include spatial analysis of accessibility and the optimal path from the fire stations to the areas to be served. This has been attributed to locating fire stations which can hardly serve the intended areas. There is a need, therefore to establish a proper methodology for locating fire stations in the cities and towns to serve property and lives.

1.3 Research objectives

1.3.1 Main objectives

The main objective of the study is to determine the proper location of fire stations in Dodoma urban using GIS approach.

1.3.2 Specific objectives

- To map out existing locations of fire stations in Dodoma urban.
- To identify criteria to be used in locating fire stations.
- To determine weights and perform multi-criteria analysis for the identified criteria.
- To perform weighted overlay to identify the potential sites for fire stations.

1.4 Research questions

- Is there is any existing fire station in the study area?
- What are the criteria used for allocating fire station?

- How useful is multi-criteria decision analysis in locating suitable and potential area for allocating of fire stations?
- What are the suitable areas for allocation of fire stations?

1.5 Significance of the study

The importance of this study is not limited only for this paper but also the concerned stakeholders they look at will be beneficial. For example, the result of this study is very much useful for Dodoma city fire to assist in finding well thought-out locations for constructing new fire stations in the city. In connection with this the information generated by this study is also believed to provide useful information for Dodoma city government plan and development commission while designing public facilities and infrastructure in relation to population growth. In addition to this the methodology and procedures used in the study will be used as a reference to conduct further research in other places for the other researcher

1.6 Description of the study area

Dodoma urban is the one of the seven districts of the Dodoma region of Tanzania. Dodoma urban is located on the latitude 6º10′34″ and 6°9′33″ and the longitude of 35º44′21″ and 35°45′47″. According to census conducted at 2022 According to the 2022 Tanzania National Census, the population of Dodoma region was 3,085,625people and Dodoma urban district was 755,689 people., also with increase in population at current times the population is growing due to different push and pull factors such as political factors, migration especially rural to urban migration, provision of good social services.

The Dodoma Urban District, one of the seven districts in the Dodoma Region. Dodoma region is bounded with Manyara region to the North, Singida region to the West, Iringa region to the South, and Morogoro region to the East. Dodoma region has a dry Savanna type of climate, which is characterized by a long dry season lasting between late April to early December and a short single wet season during the remaining months. The average annual rainfall in this area is 152mm

(Weather Atlas, 2019). Dodoma experiences the greatest temperatures, which are on average 31°C in October, November, and December, and the lowest temperatures, which are on average 16°C in June and July. The figure below shows the location map of Dodoma urban;

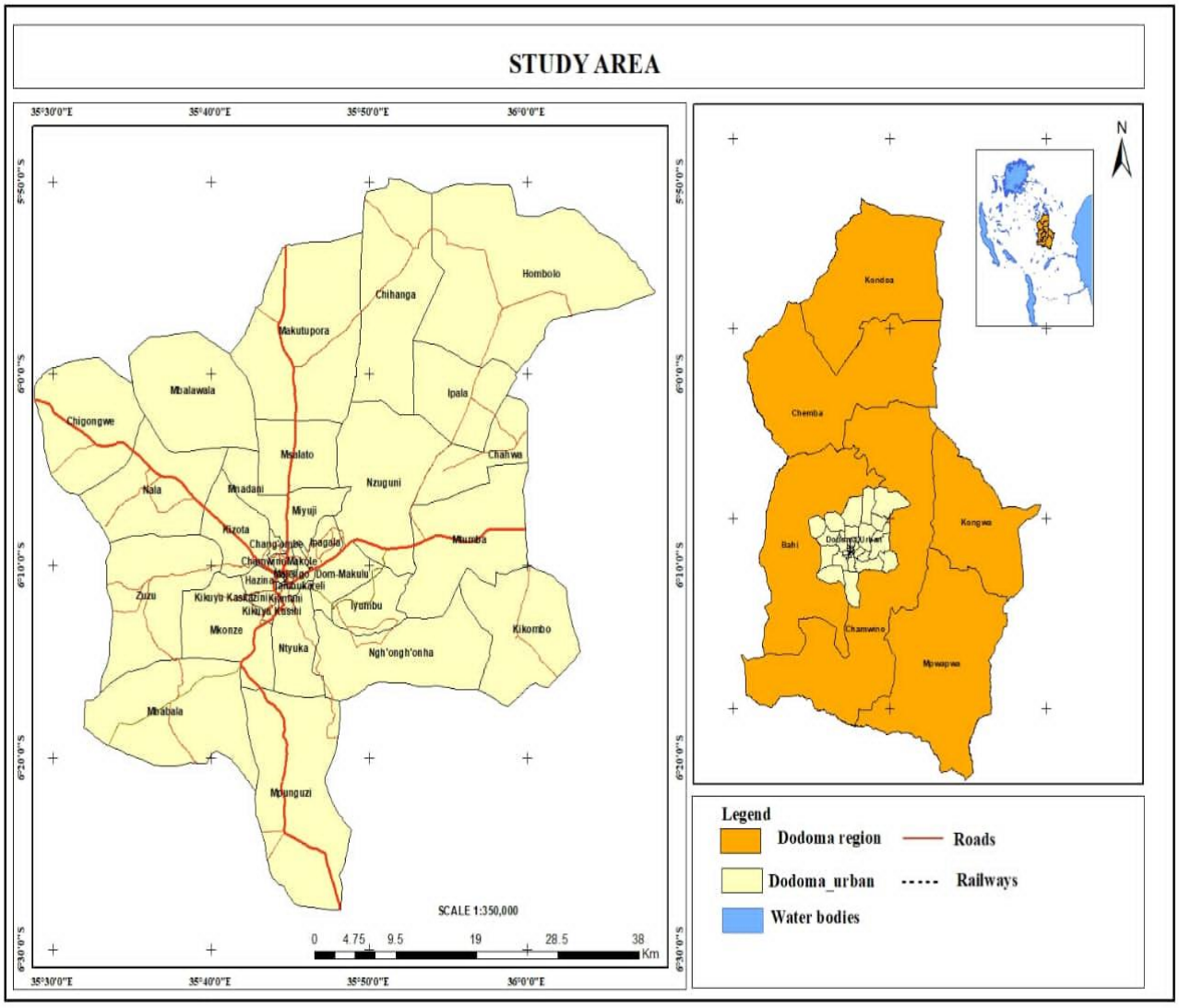

Figure 1.1: Location map of Dodoma urban

CHAPTER TWO

LITERATURE REVIEW

In this section the study reviews the previous literature related with the present study of GIS based network analysis for locating fire stations and emergency response analysis are reviewed and presented under the following sections in addition to this some standard practiced across world has been reviewed. This chapter attempts to highlight various applications of ArcGIS integrated with Analytical Hierarchy Process for finding optimum location for fire stations to the study area. Along with this the reason for doing this study is in the Dodoma city fire occurs frequently in order to save this event it is intended to establish a new fire station:

2.1 Definition of Terms and Concepts

2.1.1 Fire stations

Fire is among the causes of loss of life and property, therefore, to eliminate possible destructive outcomes there should be timely interventions. The fire service mission is to protect lives and property from fire. Therefore, emergency services in cities need to be planned in such a manner that they cater for all areas within their jurisdiction within the required response time. Traditionally, the purpose of the fire service departments has been to prevent fires and to respond to fires that do occur and to put them out. Although most fire departments are the primary providers of preventative fire protection, all fire departments are organized to react promptly to crisis situations such as road accidents and flooding (Drake et al., 1972)

Worldwide, fire stations play the most important role in case of any type of emergency. the fire service mission is to protect life, property and natural resources from fire and other emergencies with the help of their existing vehicles and equipment and manpower skill ESRI, (2007).

2.1.2 Fire incident

Fire incident is unexpected events can have its origin either in nature or in human activities. Whatever the case, it is a phenomenon that usually involves a process of occurrence, spreading,

human countermeasures and then disappearance, Haque, (2001). Fire usually occurs due to improper use of utilities or unaware human behavior. It can spread in any direction if inflammable materials are present, and it can last anywhere from a few minutes to days or weeks depending on the fire load and successful countermeasures Maniruzaman and Haque, (2007).

2.2 Emergency response using GIS

In Bhagat and Sharma, (2013) the authors develop a GIS desktop-based emergency response management system in Delhi, India. In this system, a detailed transportation network and Realtime traffic data were maintained and integrated. GIS capabilities, such as network analysis, Origin–Destination (OD) cost matrix, proximity analysis, and buffer analysis were also performed.

In Hoyos et al., (2015), the authors classify Emergency management activities can be classified into five phases; planning, mitigation, preparedness, response and recovery. Mitigation Phase associated with analytical modeling and reveals the natural spatial variation in hazard, prone and ultimately risk.

In (Nguyen, 2006), the authors states that creating the fire emergency response database, preparedness in emergency planning is a crucial factor that can impact the lives of people. When emergency preparedness is properly planned and executed, human lives can be saved and some of the economic losses in areas affected by fire can be mitigated. However, if not properly planned or implemented timeously, the consequences can be dire and could cost human lives

In Forkuo and Quaye-ballard, (2013), the authors introduced a GIS based fire emergency response service in Kumasi Metropolis, Ghana where the Ghana National Fire Service (GNFS) can select the best route from its location of any fire incident. The best route was modeled based on the travel time, travel distance, the slope of the roads and the delays in travel times.

In Bhagat and Sharma, (2013), the authors based on GIS in Delhi, India to develop a desktop-based emergency response management system. In this system, a detailed transportation network

and real-time traffic data were maintained and integrated. GIS capabilities, such as network analysis, Origin–Destination (OD) cost matrix, proximity analysis, and buffer analysis were also performed.

In Hay et al., (2019), the authors implemented the GIS-Based Fire Emergency Response System for Mandalay Road Network using the Dijkstra routing algorithm. The paper emphasizes the selection of the best route between two locations on the road network data and then finding the nearest emergency service providers and fire stations to an accident site based on traffic conditions.

In Sayed et al., (2017) the authors developed an enhanced GIS-based network analysis that was performed and applied to the Greater Cairo Road network. It focused on finding the best route between two locations on the road network and identifying the closest healthcare service providers to an incident location based on the response travel time and used historical traffic data in the analysis. It shows an improvement in the travel time with 20% to 22%, according to the travel distances. However, the system did not consider the other factors that cause a delay when traveling through the road network.

2.3 Fire response time

While it is important that fire stations are properly situated to maximize coverage, they must also be carefully placed to minimize response time fire scene Liu et al., (2006). A fire department's response time the length of time it takes a fire truck to arrive at a fire scene starting from the time the call was made to the fire department Flynn, (2009). Response time is important for firefighting. Changes in land use and urbanization request continual evaluation of the spatial spreading of fire stations and fire risk within the framework of costs/benefits. Since these issues have a spatial element, GIS systems are being utilized for solving and supporting them Martin Andre, (2008)

NFPA (National Fire Protection Association) 1710: requires countries to respond to fire incidents within an eight-minute response time (excluding call-processing time intervals) to 90% of incidents similarly provides essential benchmarks. Total response time, which is the time it takes

from the instant a call is received at the public safety answering point until the first unit reaches the scene of an emergency occurrences is a baseline for fire department. For all due units and effective response time should be measured and reported. Total response time is consisting of the following terms;

1**. Dispatch time:** The point at which the emergency alarm is received at the public safety answering point to the point where sufficient information is known to the dispatcher and applicable are notified of the emergency.

2. Turnout time: The time that begins when units acknowledge notification of the emergency to the beginning point of response time. One minute (80 seconds) for turn out time

3. Response time: The time that begins when units are in route to the emergency incident and ends when units arrive at the scene. The response time should be less than 240 seconds with less than 80 seconds of the turnout time. According to NFPA 1221 requires that 95 percent of alarms shall be answered in 15 seconds, 99 percent of alarms shall be answered in 40 seconds, and the dispatch of the emergency response agency shall be finalized within 60 seconds 95 percent of the time (ESRI, 2007). In accordance with the Standards for the Construction of Urban Fire Stations (2017) and the development situations of domestic and foreign cities, the standards for the construction of fire stations can be the site selection of fire stations should follow the principle that firefighters should be able to reach the margin of their jurisdictions within five minutes after receiving the set off instructions (the drive time of fire trucks should be within four minutes). Habibi et al. (2008) suggested a response time of 3 minutes to 5 minutes be applied in a region of high population density and residential land uses. The table 2.1 below shows the Different fire response time standards for different countries

Table 2.1 Different fire response time standards for different countries. Habibi et al. (2008)

Country name	Fire response times standards
United Kingdom	5,8,10 and 20 minutes (based on risk type)
Ghana	5 minutes
India	5minutes
Ethiopia	8 minutes
Tanzania	8 minutes

2.4 Digital elevation model

A digital elevation model refers to the presentation of bare ground topographic surface of the earth excluding the trees, buildings and any other objects (USGS, 2019). DEM can be presented into two formats i.e. a grid of squares (raster) or as vector based triangular irregular network (TIN) (Ronald, 1987). DEM acquired through techniques such as photogrammetry, lidar, ifSAR or inSAR etc. (Li 2005). They commonly built using data collected using remote sensing techniques but may also built from land surveying. From DEM users may explore variety of representation including elevation, aspect, slope, contours, hill shade etc. Elevation tinted hill shade, combined hill shade with color tint applied to the same terrain to represent elevation. Slope, a color visualization of the maximum rate for change in value from the cell to its neighbors, flat surface is gray, shallow slope are yellow and steep slopes are orange.

2.5 The role of GIS for fire stations

In Meyer., (2011), the author has described that Geographic Information Systems also plays a vital role for locating fire stations. In the area of urban cities, GIS can effectively assist in the design and operation of successful emergency response. Habibi et al., (2008) the authors stated that GIS is an important and efficient tool that can be used by local administrations to reduce the impact of natural disasters. Thus, GIS technologies have been used in fire analysis related to the optimum location of fire stations, the researcher has made spatial analysis of urban fire stations in Tehran, using an analytical hierarchy process and GIS. The authors stated that, using models and software

in urban planning has become prevalent in response to the complex dimension of the urban issues and the role of many different indicators in this field.

In Yang et al., (2004) also carried out studies concerning the selection of fire station locations using GIS. In Jasso et al., (2009), the author has carried out the location information of fires from 911 emergency calls that could not be identified accurately. By matching linking address information with coordinate information, GIS aids in determining the location of fires or accidents in the least amount of time. The literature reveals an increasing use of GIS in the fire service in the last decade Corcoran et al., (2007). GIS technology has become a powerful tool for improving all aspects of fire service delivery systems. With all the challenges confronting emergency crews today, effective response requires good planning, risk management, comprehensive training, and intelligent deployment through preparation ESRI, (2006).

2.6 Suitability analysis

Refer to the type of the analysis that mainly focused in determining appropriateness of a given area (land resources) for a certain specified use, example land suitability analysis, (Longley et el, 2011). Land suitability analysis within GIS classified into three groups (Collins et el, 2001).

- Computer assisted overlay.
- Multi-criteria decision analysis (MCDA)
- Artificial intelligence method.

2.6.1 Multi criteria decision analysis

MCDA refers to the systematic and scientific method for decision making which considering multiple factors derived from abundant geospatial data. It combines geospatial data and value judgement to solve spatial problems by considering geospatial data models, spatial dimensions of the evaluation criteria and decision alternatives in evaluating criteria to meet the specified objectives. (Longley et el, 2011). It involves the following steps:

- Define the problem or objective

- Determine the criteria
- Transforming the value into relative scale
- Weight the importance of each criterion
- Combine, synthesize and aggregate the layer
- Analyze and then validate the results

The multi-criteria decision analysis has six methods (Longley et el, 2011), which are the following:

- Boolean overlay
- Weighted linear combination
- Analytical hierarch process (AHP)
- Ordered weighted approach
- Artificial neural network
- Cellular Automata

2.6.2 Analytical hierarchy Process (AHP)

AHP refers to the priority-ranking technique that helps break down the complex problem into component parts. It involves arranging these parts or variables into hierarchic order and assigning numeric values to subjective judgements on the relative importance of variables (Saaty, 1980). In addition, the judgements synthesized to determine variables that have the highest priority and should acted upon to influence the outcome. It is pairwise comparison method used on the criteria on regard of the objectives: it carried out for all relevant factors within an analysis. It requires the decision maker to provide judgement about the relative importance of each criteria and then specifies a preference for each decision alternatives on each criterion. The output of AHP is the prioritizing ranking indicating the overall preference for each of the decision alternatives. (Saaty, 1980).

2.6.3 Pairwise comparison matrix

Pairwise comparison matrix is fundamental building block of AHP. The AHP employs an underlaying scale with values from 1 to 9 to rate the relative preferences for two items (Saaty, 1980). Pairwise comparison matrix element Ci, j of the matrix is the measure of preference of the item in row i when compared to the item in column j. AHP assigns 1 to all elements on the diagonal of the pairwise comparison matrix. AHP obtains the preference rating of Cj, i by computing the reciprocal (inverse) of Ci, j. according to the above rules, the number of entries actually filled in by decision makers is (n2-n)/2, where n is the number of elements to be compared.

Table 1.2 Table preference scale (Saaty, 1980)

Verbal judgement of preference	Numerical rating
Equally preferred	1
Equally to moderately preferred	2
Moderate preferred	3
Moderate to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strong to extreme preferred	8
Extreme preferred	9

2.6.3.1 Consistency

The AHP provides a method for measuring the degree of consistency among the pairwise judgement provided by the decision maker. If the degree of consistency is acceptable, the decision process can continue. If the degree of consistency is unacceptable, the decision maker should reconsider and possible revise comparison judgements before proceeding with the analysis. (Saaty, 1980)

2.6.3.2 Consistency ratio

The AHP provides the measure of the consistency of pairwise comparison judgement by computing the consistency ratio, the ratio designed in such a way that the values of ratio exceeding 0.1 are indicative of in consistent ratio judgements. Although the exact mathematical computation of the consistency ratio is beyond the scope of this text, an approximation of the ratio obtained. (Saaty, 1980)

Procedures for estimate the consistency ratio.

- Multiply each value in the first column of the pairwise comparison matrix by the relative priority of the first item considered. Same procedure for other items. Sum the values across the rows to obtain the vectors of the values labelled "weighted sum".
- Divide the element of the vector of weighted sums obtained in step 1 by the corresponding priority values.
- Compute the average of the values computed in this average denoted as "max".
- Compute the consistency index (CI)
- Compute the consistent ratio.

$$\mathrm{CR} = \frac{\mathrm{CI}}{RI}$$

2.6.4 Random index

Random index is the consistency index of a randomly generated pairwise comparison matrix (Saaty, 1980). Random index depends on the number of elements being compared (i.e. size of pairwise comparison matrix) and takes the following values in the table below;

Table 2.3 Random index.

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.3	1.4	1.45	1.49

2.6.5 Advantages of using AHP. (Saaty, 1980)

- The AHP organizes feelings, intuition, and logic in a structured approach to decision making.
- AHP allows for participation of both the experts and stakeholders in providing input.
- It is more systematic and in-depth analysis of the factors.
- It is more structured approach to measure suitability by breaking the problem down into hierarchical criteria.
- AHP combines deductive approach and inductive approach into one integrated logic framework.

CHAPTER THREE

METHODOLOGY

This part of based on the GIS-based Multi-criteria analysis. It involves the identification of data, their sources, tools and software used for processing and analyses as well as the procedures, methods and techniques used in order to meet the stated objectives and finally achieving the result of the study.

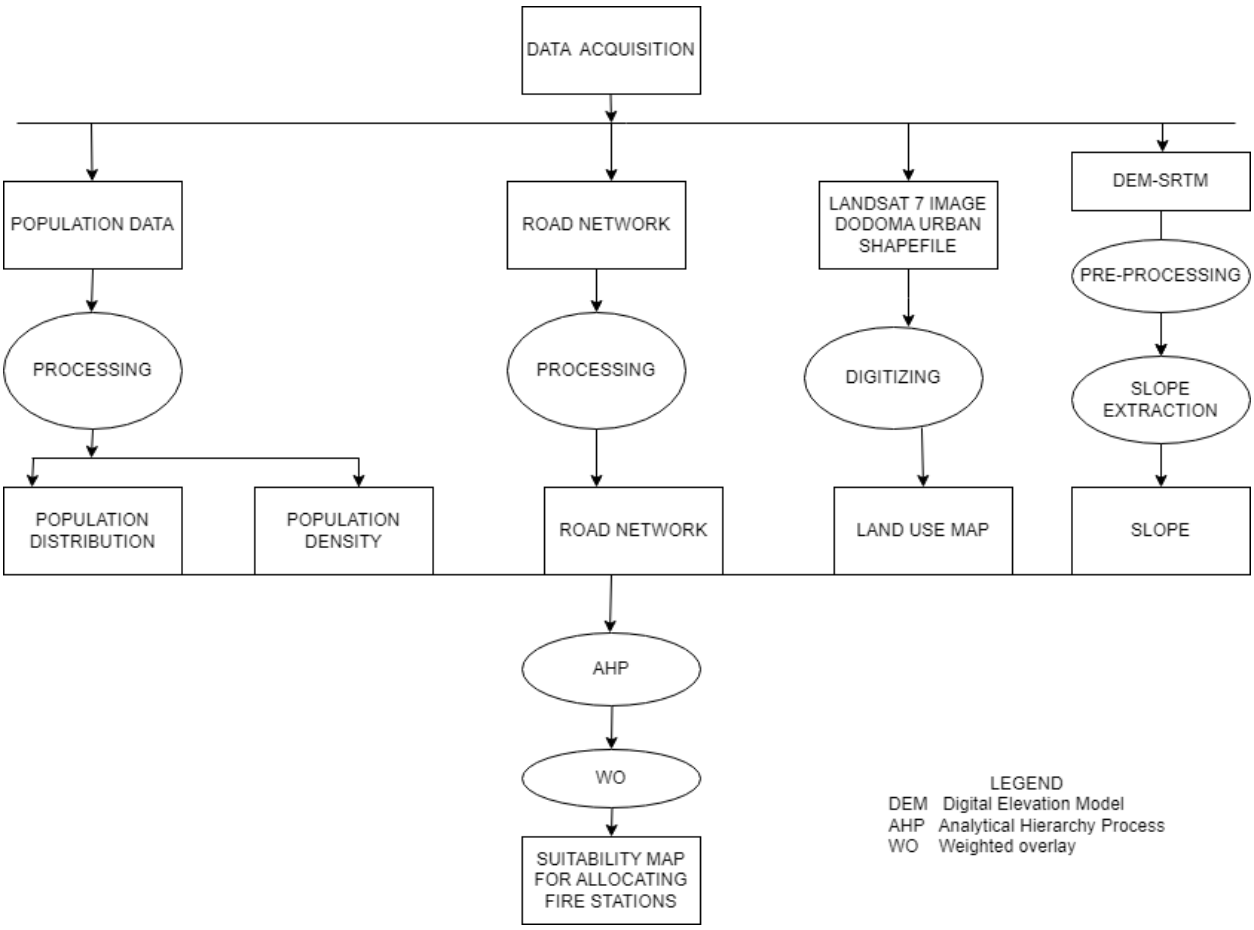

Figure 3.1: work flow

3.1 Data and Data Source

This part includes data sources, software used through the development of the research and methods used for analyses. Table 3.1 below indicates data type and data source that used in conducting a research:

Table 3.1 Data collection

S/N	LAYER/DATASET	FORMAT	RESOLUTION	SOURCE	USEFUL
1	Existing fire station	.csv		Google earth	To create a map that shows the distribution of fire station existing in the area of interest.
2	DEM	TIFF	30m	SRTM	To prepare the elevation and slope map of Dodoma urban.
3	Road networks	Shape file		OSM	To show the path way where the fire stations are accessible in Dodoma urban.
4	Population data	Pdf		NBS	To create a map population distribution and population density
5	Land use	Shapefile		Google earth	To show how the land of Dodoma urban used or covered

3.1.1 Road network

The road network consists of a system of interconnected paved/unpaved carriageways which are designed to carry buses, cars and goods vehicles; the road network generally forms the most basic level of transport infrastructure within urban areas, the function of a road network is to facilitate movement from one area to another. as such, it has an important role to play in the urban environment to facilitate mobility. For this study the road networks data was obtained from

OpenStreetMap. The figure below shows the road network of Dodoma urban that used for transportation of goods and services;

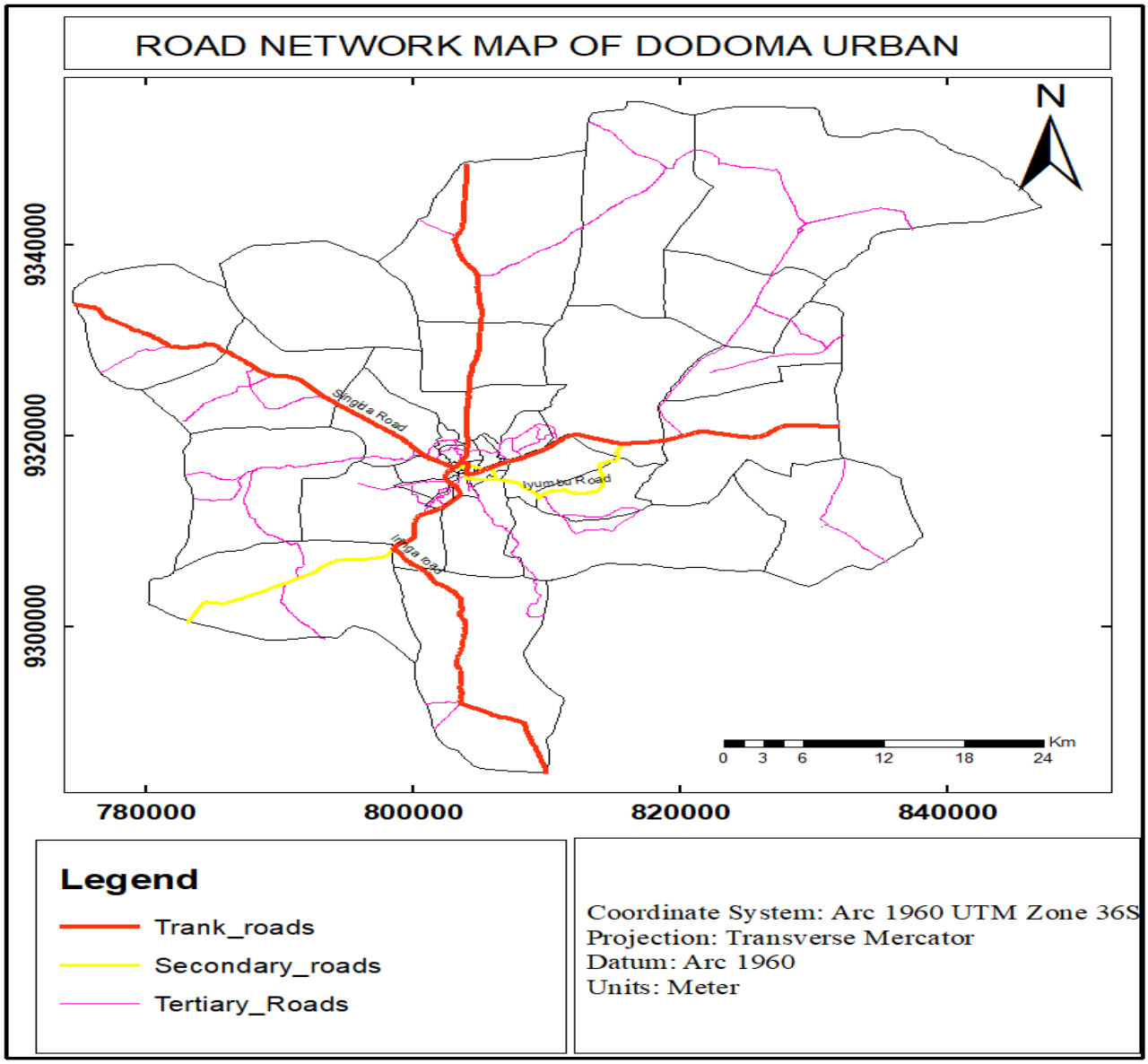

Figure 3.2: Dodoma urban road network

3.1.2 Existing fire station locations

At Dodoma urban there is only two fire stations named as Dodoma fire station and Tambukareli fire station which is located along the Dodoma airport. The coordinates of that fire station should be obtained from the google map with the reference of WGS 84 and then should be projected into Arc 1960 with the datum of 36S. This study applied this standard to find candidate sites for the study area. Moreover, new fire stations must be far from the existing fire stations existing, making sure that newly fire stations are situated in the area where there are no fire stations. The figure below shows the fire station that exist in Dodoma urban;

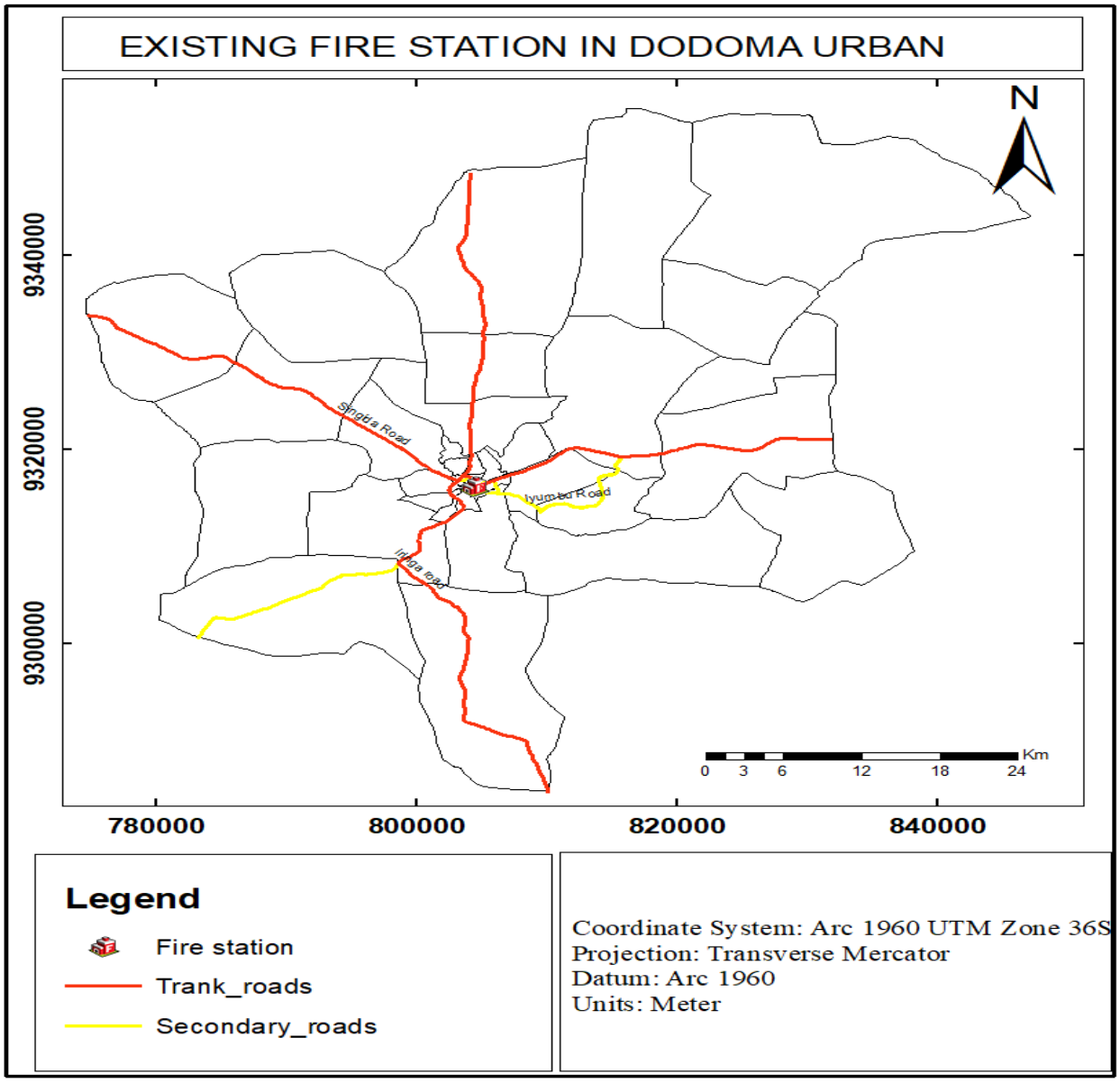

Figure 3.3: Dodoma urban existing fire station

3.2 GIS Multi-criteria analysis

The MCDA performed by considering all necessary criteria selected for the study and criteria ranked according to their influence, impact and importance to the fire stations. The analysis

involves the criteria to identify the suitable area to locate the fire stations and then the map of each criterion generated and reclassified into five classes and then should be overlay together in order to determine the suitable areas for locating the fire stations.

3.2.1 Factors for map generation

Factor criteria used to evaluate the area for the locating the fire stations should be done in ArcGIS software after conversion of all map into raster layer. The raster map should be reclassified through the reclassification tool. Four factors map were created by considering conditions and specifications concerned fire stations site selection. Reclassification was done in the scale of five i.e. (1 to 4) where by 4 represent the highest suitability and 1 represent less suitable, i.e. the suitability rated high in ascending order. Therefore, from each factor five classes created.

Population density and population distribution

Population density is the important factor for locating fire station. This study was need to consider the population density of the area of the site to be selected. The densely populated areas are usually housing on a relatively densely house area and close to each other which increases the probability of the occurrence of fire and the speed of its spread. The quick response to the area and ensures the delivery of fire department services to them has a great importance in order to avoid unwanted huge damages of firehouse incident. This study perfumed point density map using by dividing the total population collected from census data to existing residential housing. The NFPA release the standard for locating the fire station in a certain area but for our country the fire station should be located in the area with the population density above 350 people per 1-kilometer square. The figures below shows the population distribution and population density of Dodoma urban;

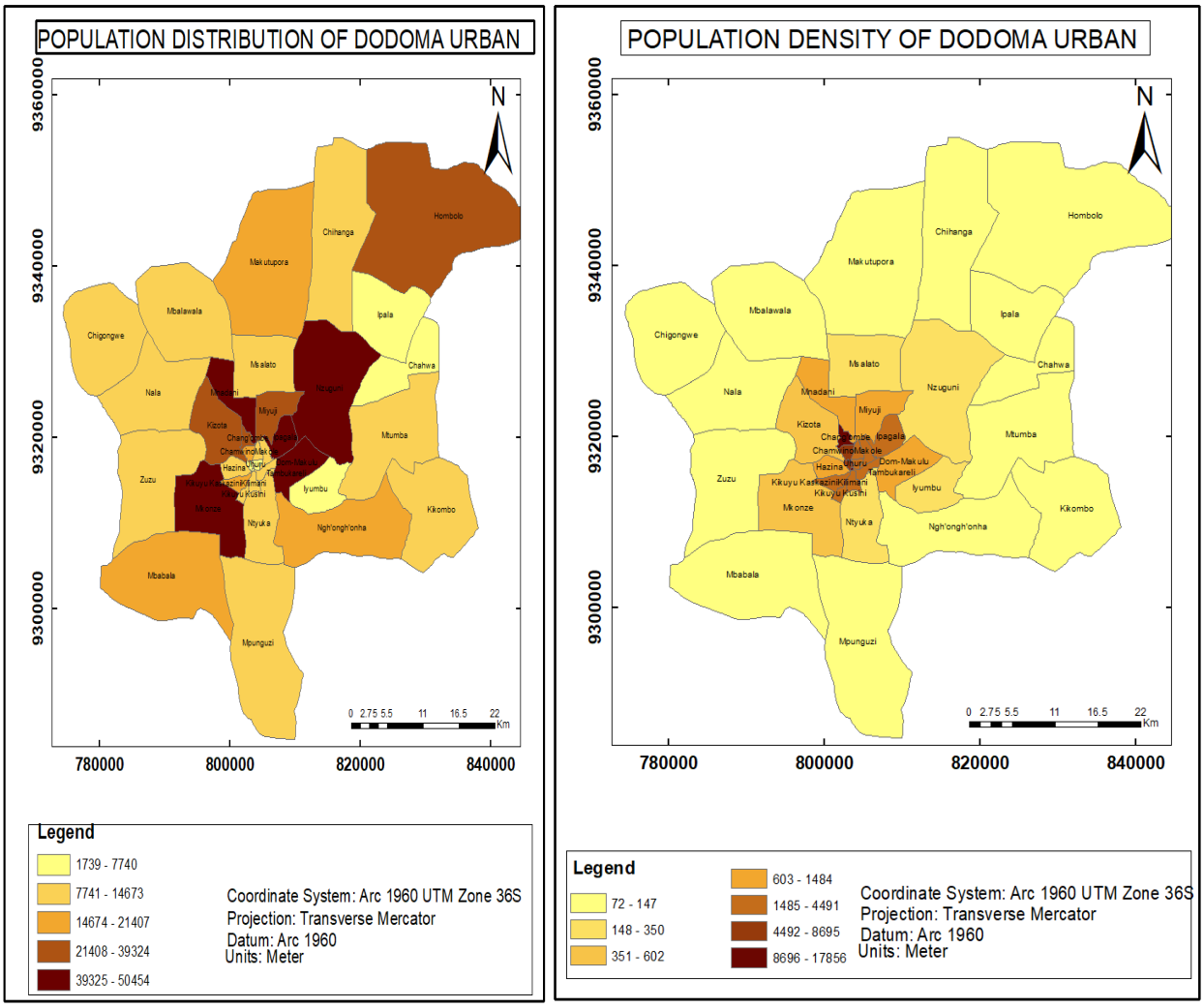

Figure 3.4: Population density and population distribution map

Land use

Land use maps are another important factor for locating the fire stations. Based on the land use map of Dodoma urban prepared through digitizing the satellite image connecting with the google earth engine and the shapefile of Dodoma urban should be added. For this study the land use classes of residential, trade area, undeveloped land and services areas are much preferred on locating the

fire stations (NFPA standards and codes). The figure below shows the land use map of Dodoma urban;

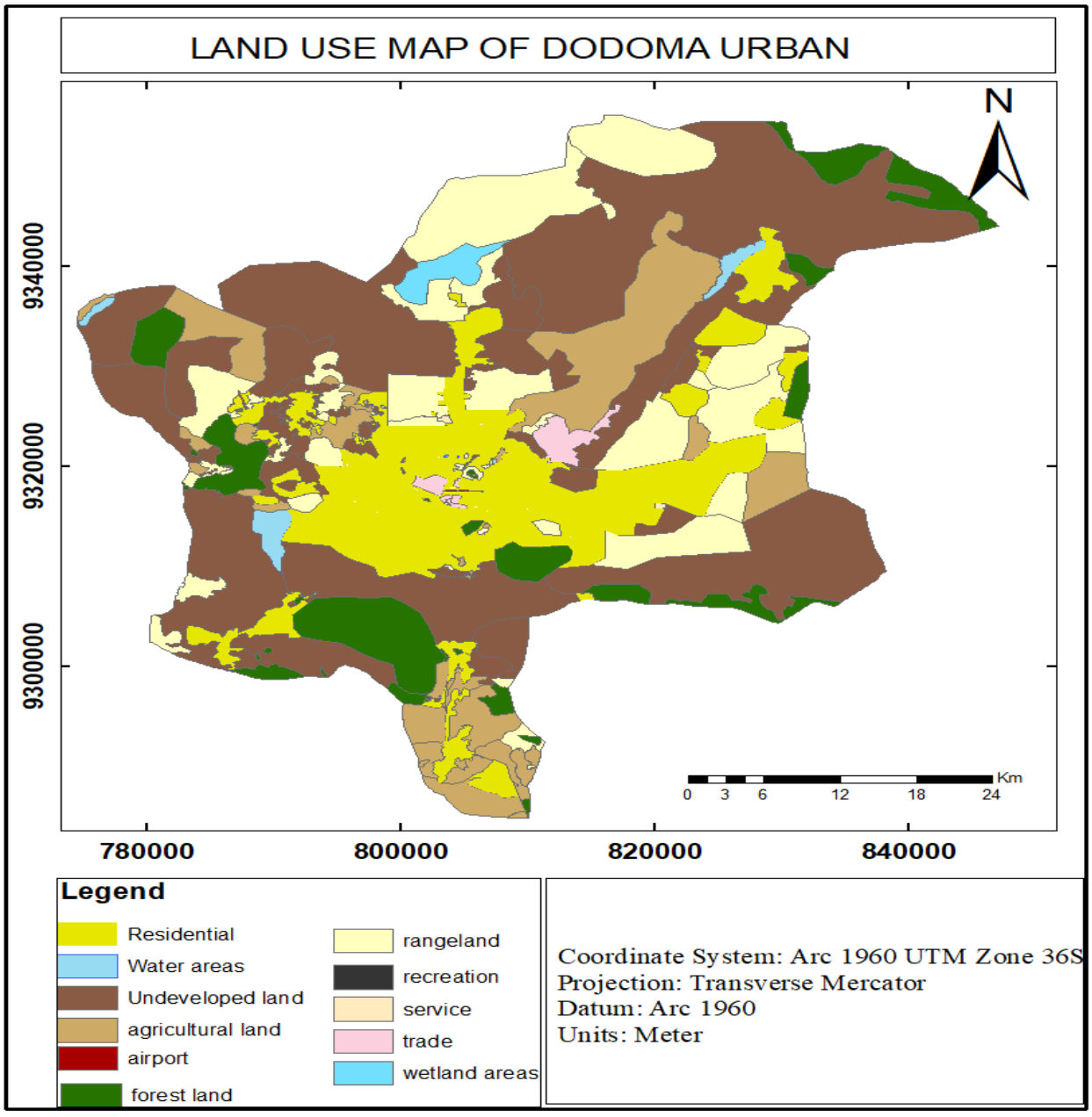

Figure 3.5: Land use factor map generation

Slope

After downloading the SRTM should be added into the ArcGIS software and then digital elevation model (DEM) should be created and then the slope should be extracted from the DEM and the slope should be projected into datum of UTM arc 1960 zone 36S. After obtain the slope map should be reclassified into five classes which is from unsuitable slope to most suitable slope for locating the fire station. According to the international fire protection association (NFPA) fire station should located to the area which have low elevation with the slope from 0 to 10 degree. The classified slope map should be created to locate that area. The figures below show the slope map of Dodoma urban and the classified slope of Dodoma urban;

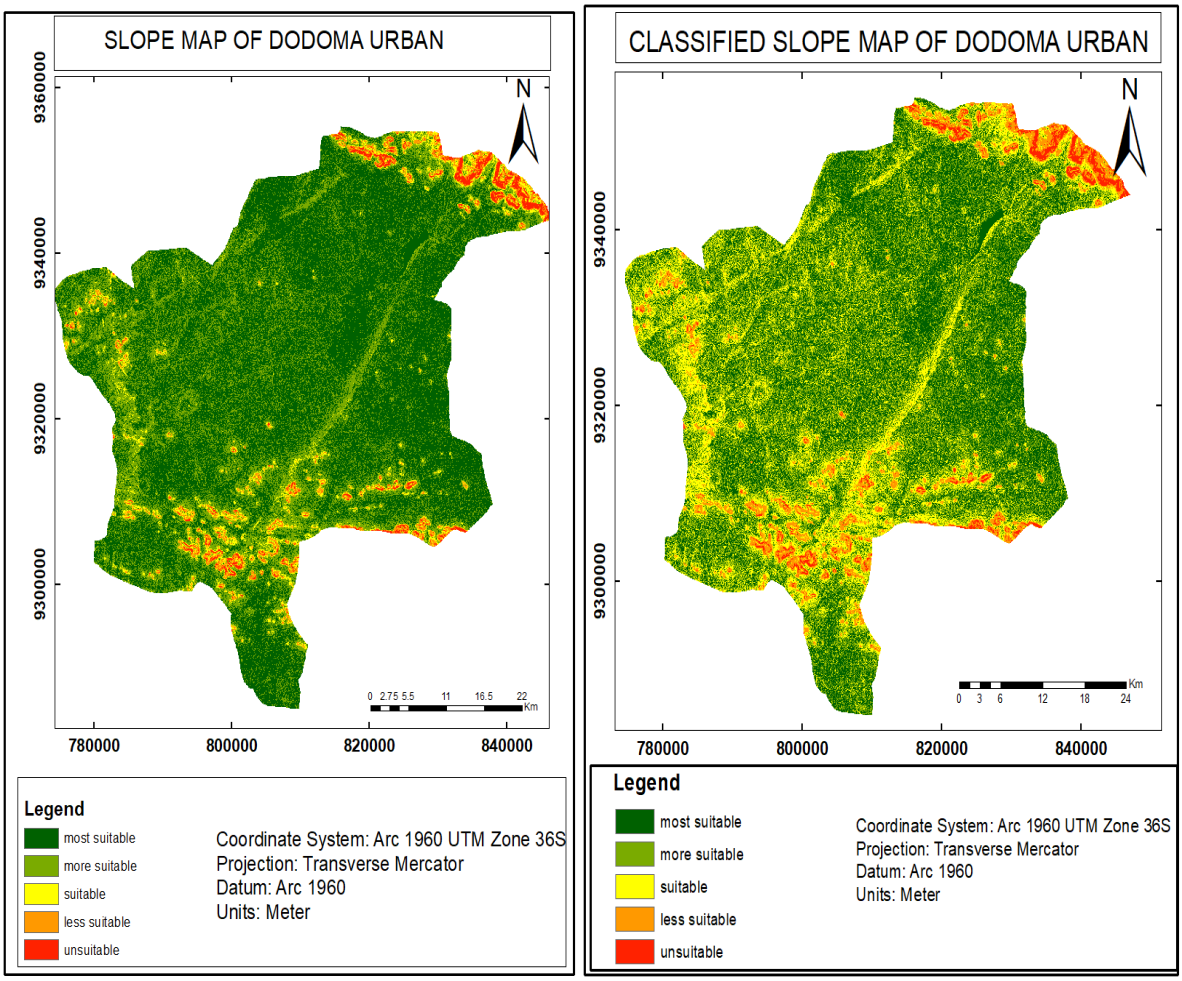

Figure 3.6: Slope factor map generation

Distance from the existing fire stations.

The existing fire stations were determined by Euclidean distance according to the international standard 5km are most suitable to propose additional new fire station. This study applied this standard to find the candidate sites for the study area. Moreover, new fire stations must be far from the existing, making sure that newly fire stations are situated in the area where there are no fire stations.

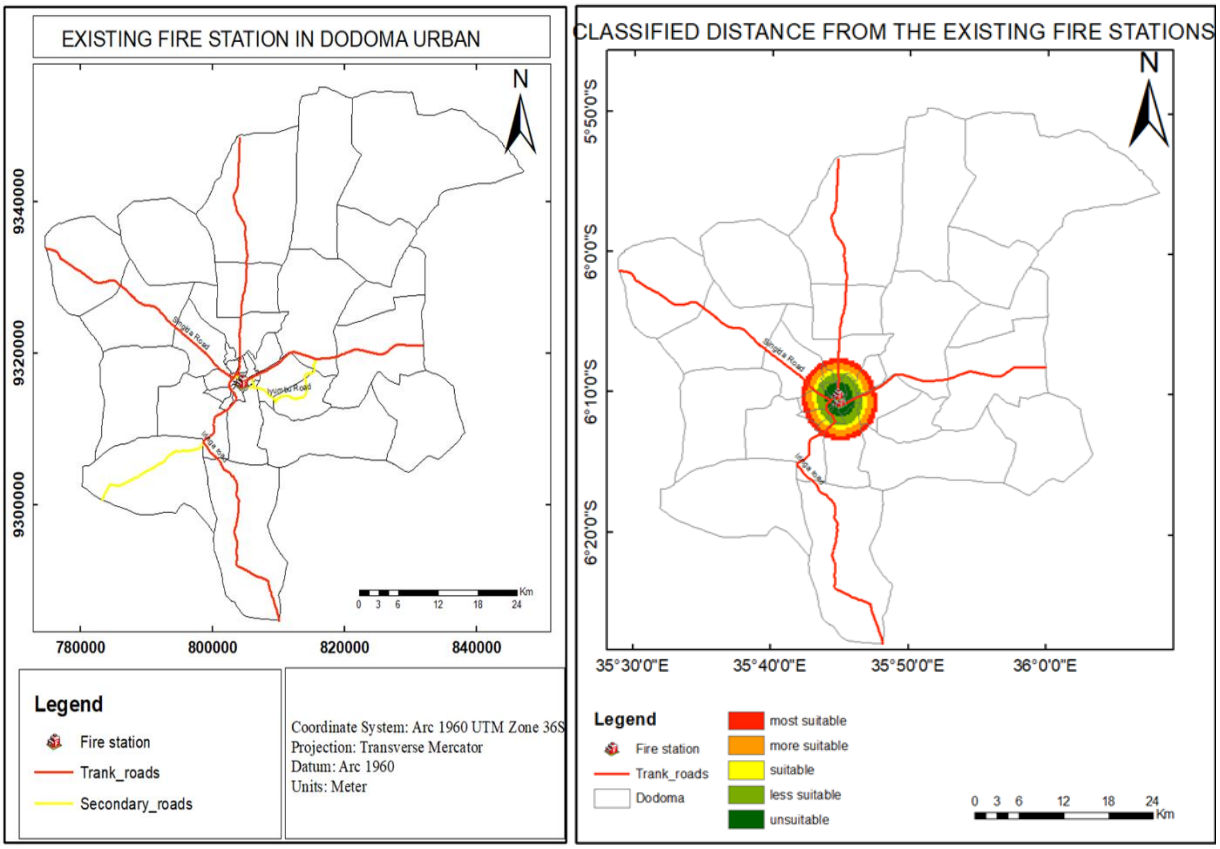

Figure 3.7: distance from existing fire station factor map generation

The final factor map generated by performing weighted overlay of factors involved therefore the weights for each factor had determined before generating of the final factor map.

3.2.2 Factors weight determination.

The weight for each factor determined by AHP method through the ArcGIS AHP extension in ArcGIS environment then the weighted linear combination obtained.

Step 1: From the Arc map tools window the added AHP extension tool and the designed decision problem window opened then the criteria hierarchy defined by adding required criteria listed on available criteria raster form

Step 2: After the required criteria added then the pairwise comparison matrix had designed by using the preference scale 1 to 9 (Saaty, 1980). Moreover, the consistency ratio checked to ensure requirement met. The process repeated five times until the allowable consistent ratio obtained. Consistency ratio should be less than 0.1.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

Where CI-consistency index, RI-random index

RI it is the consistency index of a randomly generated pairwise comparison matrix and it depends on the number of elements being compared i.e.

Table 3.2 showing random index

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.3	1.4	1.45	1.49

Moreover, for the case of this study RI=0.89 and N=4

Consistency index $CI = \frac{max-n}{n-1}$ where max -principle Eugen value

n-number of criteria.

Therefore, from AHP extension CR=0.029. It is allowable since it is less than 0.1. this implies that the decision judgement satisfied then the weights for the criteria computed. Then click on the create map and then the map for suitable locating of fire station should be created.

CHAPTER FOUR

RESULTS, DISCUSSION AND VALIDATION

4.1 Results

Suitability map for locating fire station shows the area resulted from the analytical hierarchy analysis (AHP) where by the suitable and unsuitable area within the Dodoma urban district presented by using different color codes whereby the color should be arranged in ascending from unsuitable to the most suitable areas for locating the fire stations at Dodoma urban district.

These areas identified through evaluation of four (4) factor criteria considered in the study to protect people and other properties from the damage and saves the life.

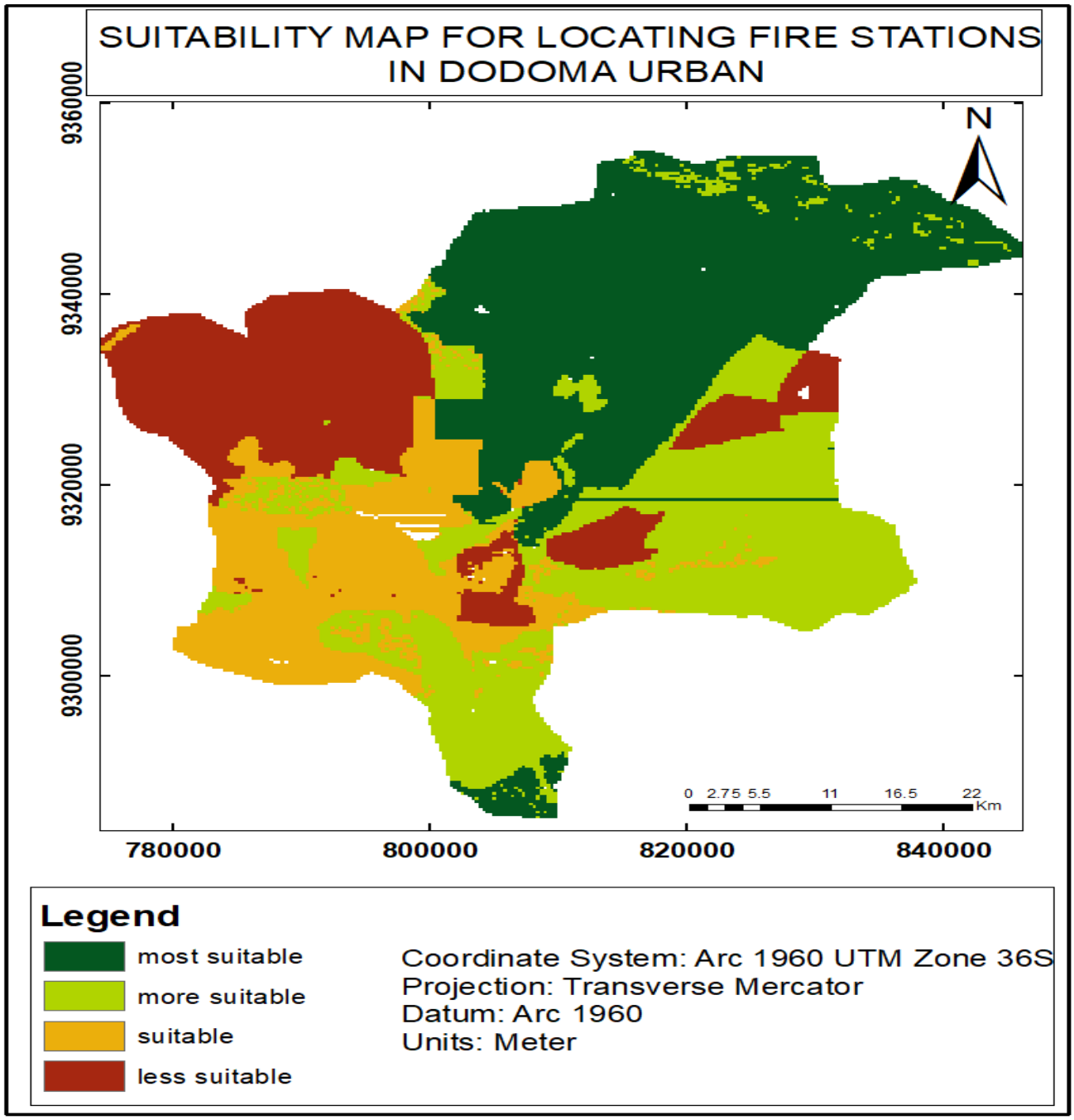

Figure 4.1: Suitability map for fire station locating in Dodoma urban

From the resulted map, the population density is considered as the superior criteria in locating the fire station followed by the slope, land use and distance from the existing in ascending order. It is shown with the percentage in the table below;

Table 4.1 criteria weight in percentage

Criteria	Weight in Percentage %
Population density	52.721
Slope	24.095
Land use	12.946
Distance from existing	10.238

And the weighted computed in the ArcGIS is shown below;

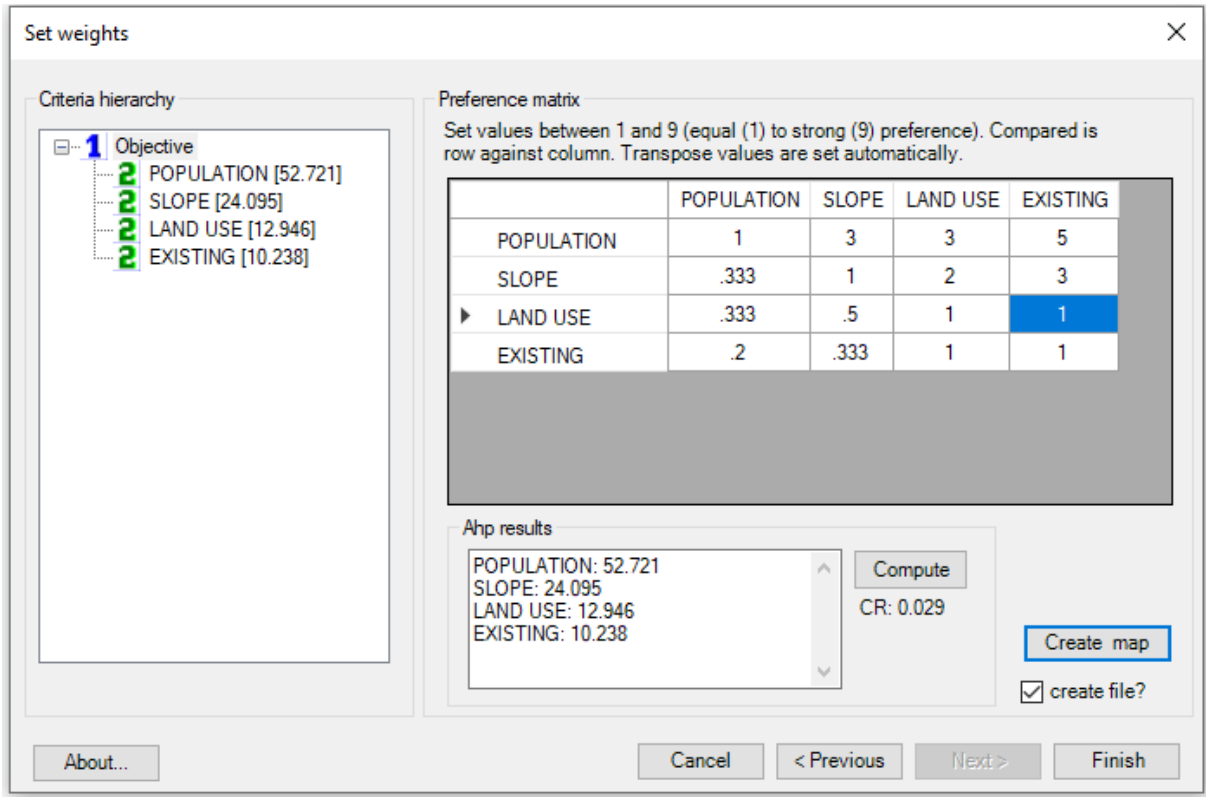

Figure 4.2: Weighted computation by AHP method

4.2 Result validation

Result validation involves the test the areas obtained for the suitable area for locating the fire station if the existing fire station followed on it. Through the criteria of population density land use and the distance from the main road (300m from the main road after buffering) the two existing fire station at Dodoma urban should follow on the required area.

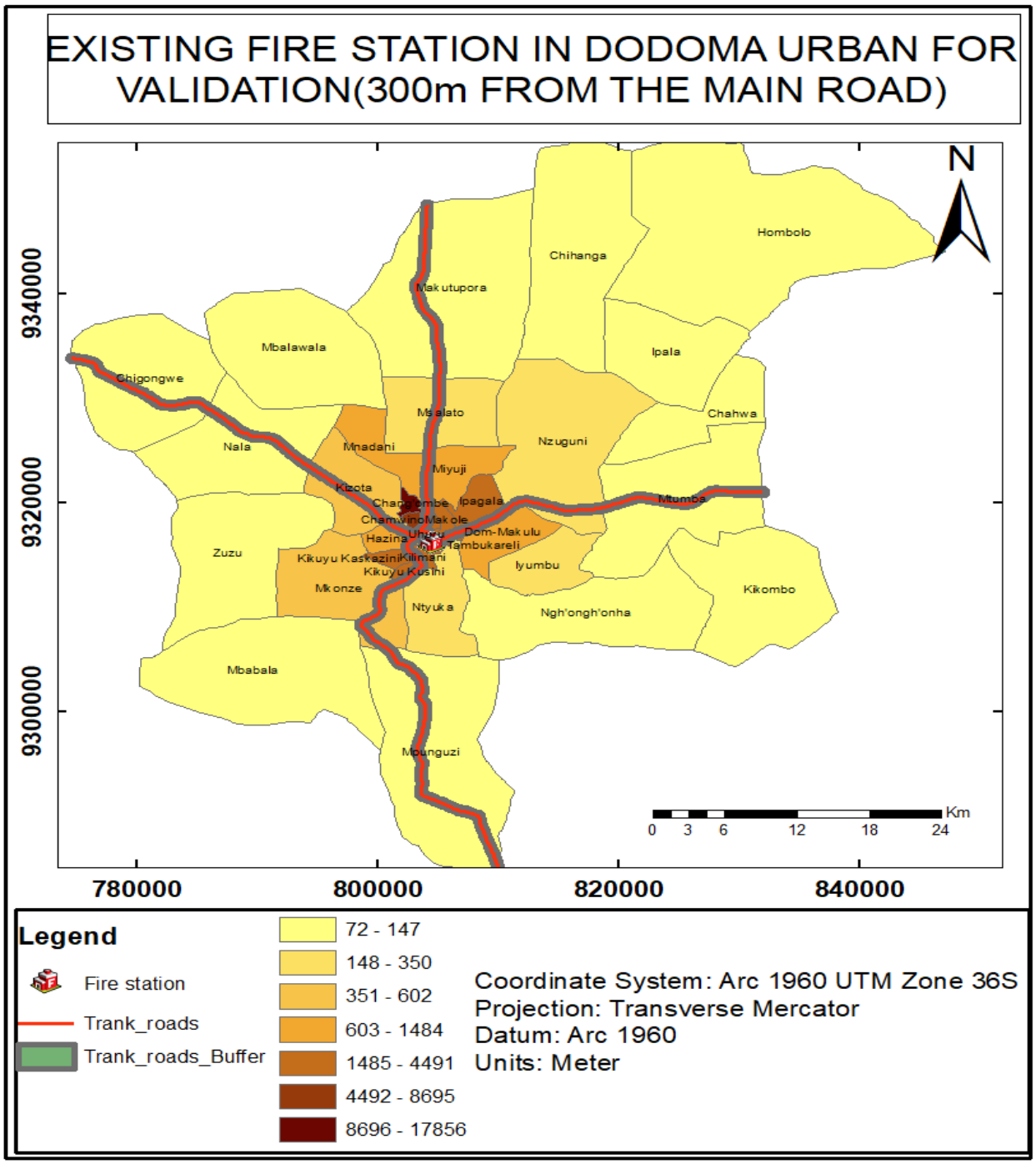

Figure 4.3: map for result validation

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Geographic information system (GIS) technologies has developed rapidly in the recent years and it is widely used in different fields specifically for solving certain spatial problem. The geographic information system (GIS) approach is useful for location decision making and has been applicable in different kinds of studies.

In this study, GIS play the greater role in determine the suitable areas for locating fire stations particularly through multi-criteria decision analysis (MCDA). It facilitates the generation of factors/criteria maps from the selected criteria for this study, and by using ArcGIS extension tool, AHP performed and the consistency ratio obtained was 0.029 which is less than 0.1 so the consistency ratio is accepted. Finally, the suitability map for locating the fire station at Dodoma urban generated and then the area for placement the fire stations and should be validated by using the existing fire station which after added to the suitability map for locating fire station it drops on the required/suitable areas and also validate by using the factor of placing fire station 300m from the main road. Therefore, the application of GIS and multi-criteria decision analysis (MCDA) for spatial decision making led to the identification of suitable areas for locating fire station at Dodoma urban district. Moreover, the use of criteria in MCDA resulted into suitable areas for locating of fire station but results has limited because some of the criteria such as distance from the main road, inaccessible area and incident rate were not included in this study.

5.2 Recommendation

Based on the finding of the study. This study has made the following recommendations for the study area.

- This study highly recommended that collecting and storing the spatial location of fire incidents at the time of emergency occurrences using handheld GPS is very important for the further interpretation and for researchers to do their study easily.
- This study highly recommended that as the number of criteria increased the consistency ratio also increased. So, there is need to increase the number of criteria for another researcher.
- Apart from AHP method also other methods of MCDA must be used in order to improve the efficient of the result.
- This study recommended that the future development of the city and the population growth has to be considered during the development of new fire stations. Since its obvious that increasing population will leads fire incident occurrence.

REFFERENCES

Bhagat, A., & Sharma, N. (2013a). *GIS-Based Application for Emergency Preparedness and Management Accelerating Response System through GIS*. http://en.wikipedia.org/wiki/Delhi

Chen, H. & Mao H. (2013). Application of GIS to site selection of municipal solid waste land fill. Environmental engineering , 31, Pp. 513-516.

Corcoran, J., Higgs, G., Brunsdon, C., Ware, A., & Norman, P. (2007). The use of spatial analytical techniques to explore patterns of fire incidence: A South Wales case study. *Computers, Environment and Urban Systems*, *31*(6), 623–647. https://doi.org/10.1016/j.compenvurbsys.2007.01.002

Drake, A. W., Ralph, L. K., & Philip, M. M. (1972). *Analysis of Public Systems*.

ESRI. (2006). *GIS Technology and Applications for the Fire Service*. 1–28. www.esri.com

ESRI. (2007). GIS for Fire Station Locations and Response Protocol GIS for Fire Station Locations and Response Protocol An ESRI White Paper

Forkuo, E. K., & Quaye-ballard, J. a. (2013). GIS Based Fire Emergency Response System. *International Journal of Remote Sensing and GIS*, *2*(1), 32–40

Green, C., Mans, G., Schmitz, P., Mckelly, D., & Water, M. (2014). Planning for emergency services using GIS-based geographic accessibility analysis. *Town and Regional Planning*, *64*(0), 53–64

Habibi, K. S.Lotifi, M. . K. (2008). Spatial Analysis of Urban Fire Station Location by Integerating AHP Model and IO Logic Using GIS (A Case Study of Zone 6 of Tehran). *Journal of Applied Sciences 8(9)*, 3302–3315.

Habibi, K., Lotfi, S., & Koohsari, M. J. (2008a). Spatial analysis of urban fire station locations by integrating AHP model and IO logic using GIS (A case study of zone 6 of Tehran). *Journal of Applied Sciences*, *8*(19), 3302–3315. https://doi.org/10.3923/JAS.2008.3302.3315

Habibi, K., Lotfi, S., & Koohsari, M. J. (2008b). Spatial analysis of urban fire station locations by

integrating AHP model and IO logic using GIS (A case study of zone 6 of Tehran). *Journal of Applied Sciences*, *8*(19), 3302–3315. https://doi.org/10.3923/JAS.2008.3302.3315

Hay, S., Shwe, M., & Oo, H. N. (2019). GIS Based Fire Emergency Response System for Mandalay. *International Journal of Open Information Technologies*, *7*(12), 39–45

Hoyos, M. C., Morales, R. S., & Akhavan-Tabatabaei, R. (2015). OR models with stochastic components in disaster operations management: A literature survey. *Computers and Industrial Engineering*, *82*, 183–197. https://doi.org/10.1016/j.cie.2014.11.025

Jasso, H., Hodgkiss, W., Baru, C., Fountain, T., Reich, D., & Warner, K. (2009). Using 9-1-1 call data and the space-time permutation scan statistic for emergency event detection. *Government Information Quarterly*, *26*(2), 265–274. https://doi.org/10.1016/j.giq.2008.12.005

Liu, N., Huang, B., & Chandramouli, M. (2006). Optimal Siting of Fire Stations Using GIS and ANT Algorithm. *Journal of Computing in Civil Engineering*, *20*(5), 361–369. https://doi.org/10.1061/(asce)0887-3801(2006)20:5(361)

Longley, P.A., Goodchild, M. F., Maguire, D. J., &Rhind, D. W. (2011). Geographic information system and science. Wiley, New York.

Meyer, E. (2011). *Performing Location Allocation Measures with a GIS for Fire Stations in Toledo, Ohio* (Issue December)

NFPA. (1710). *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. https://catalog.nfpa.org/NFPA-1710-Standard-for-the-Organization-and-Deployment-of-FireSuppression-Operations-Emergency-Medical-Operations-and-Special-Operations-to-the-Public-byCareer-Fire-Departments-P1441.aspx

Oh, J.-Y., Hessami, A., & Yang, H. J. (2019). Minimizing Response Time with Optimal Fire Station Allocation. *Studies in Engineering and Technology*, *6*(1), 47. https://doi.org/10.11114/set.v6i1.4187

Reveshti, M. A., Ahmadi, T., & Teymouri, R. (2015). *5 Identifying Areas outside the Response Range of Fire Stations Services Using Network Analysis (Case Study: Fire Stations in Tabriz)*

Saaty, T. L... (2000). *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process.*

Sayed, A., Romani, F. I., & Hesham, A. H. (2017). GIS-Based Network Analysis for the Roads Network of the Greater Cairo Area. *Proceedings of the International Conference on Applied Research in Computer Science and Engineering ICAR'17, Lebanon*

Şen, A., Önden, I., Gökgöz, T., & Şen, C. (2011). A GIS approach to fire station location selection. *Gi4DM 2011 - Geoinformation for Disaster Management*, *January 2015*. https://doi.org/10.13140/2.1.2568.4804

Subramaniam, C., & Ali, H. (2012). *Initial emergency response performance of fire fighters in Malaysia*. *January*. https://doi.org/10.1108/09513551211200294

Yang, J., & Lee, H. (1997). An AHP decision model for facility location selection. *Facilities*, *15*(9/10), 241–254. https://doi.org/10.1108/02632779710178785

Yang, J., & Lee, H. (2017). An AHP decision model for facility location selection. *Facilities*, *15*(9/10),241–254. https://doi.org/10.1108/02632779710178785