SUITABILITY ANALYSIS FOR LOCATION OF FIRE TOWERS AT SAO HILL FOREST PLANTATION USING GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geographical Information Systems and Remote Sensing (BSc. GIS and RS) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Suitability analysis for location of fire towers at Sao Hill Forest Plantation using Geographic Information System and Remote Sensing"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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DECLARATION AND COPYRIGHT

I, ERNEST C ERNEST hereby 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.

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DEDICATION

I dedicate this dissertation to my beloved father Charles Ernest Akida, my mother Theresia Irneous Ndunguru, my aunt Agnes Ernest Akida and my brother Japhet Patrick Ngussa. And all my relative who support me to accomplish this dissertation God bless you.

ABSTRACT

Sao Hill Forest Plantation is the one of the most important forest plantations in Tanzania useful for timber production and contribute as source of water for Great Ruaha river. Trees found in Sao Hill Plantation have economic and ecological value and functions in the society. Wildfire is one of the threats for unsustainable use of resources found at Sao Hill Plantation. Government have increased efforts in protection of Sao Hill Plantation from wildfire disaster by providing education to the society on how to avoid wildfire, increase tools and equipment for firefighting unit. Forest management requires spatial reference data to identify location of fire incidence. Visibility analysis for existing fire towers was done by using spatial analyst tool in ArcMap 10.8 and found that available fire towers in Sao Hill Plantation cannot view total area in plantation. Analysis results shows that existing fire towers are capable to view 34,325.15ha (25.26%) out of 135,903ha of total forest area. That means 101,577.85ha (74.74%) of the plantation, is not visible by the current fire towers.

Suitability analysis using Analytic Hierarchy Process (AHP) using GIS and Remote Sensing techniques was performed to determine suitable locations to install new fire towers. AHP involved multicriteria decision making approach derived from ground elevation, ground slope, land cover map, distance from roads, distance from existing fire towers and distance from existing fire line. Desirable elevation and slope were derived from Digital Elevation Model (DEM). Sentinel 2A image was used to generate landcover map. Roads network was used for proximity analysis, existing fire towers and fire lines indicated in compartment map. Suitability analysis for this study involved data preprocessing, data processing, identification of criteria, reclassification of each criteria, weight determination for each criterion, weight overlay and suitable area are found.

Suitability analysis results shows that, areas that are highly elevated and consist of no fire station around are high suitable areas to install new fire towers. Sufficient and properly located towers can help in surveillance of the whole plantation. These stations can provide data or information which can support decisions and in developing planning and management strategies for fire activities in plantations.

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ACRONYMS AND ABBREVIATIONS

GIS	Geographic Information System
AFIS	Advanced Fire Information System
MODIS	Moderate Resolution Image Spectro Radiometer
TFS	Tanzania Forest Service Agency
UTM	Universal Transverse Mercator
m.s.l	mean sea level
QGIS	Quantum Geographic Information System
IT	Information Technology
AHP	Analytic Hierarchy Process
DEM	Digital Elevation Model
WGS	World Geodetic System
TIFF	Tagged Image File Format
GPS	Global Positioning System
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
UAV	Unmanned Aerial Vehicle
.shp	Shapefile
.jpeg	joint photograph expert group
Cm/m/km	Centimeter/meter/kilometer
Ha	Hectare

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Forest fire is one among the major problems at Sao Hill Forest Plantation, forest fire at Sao Hill is caused by human activities such as burning of bushes during the time of farms preparation and careless disposal of burning piece of cigarettes. Forest fire at Sao Hill causes Loss of government revenue, decrease amount of rainfall and loss of biodiversity. Forest fire can be categorized into three types which are ground fire, surface fire and crown fire (Delatorre, 2021). Ground fire burns beneath the earth surface were by it affect much the roots of the trees. Ground fire is not seen by naked eyes but can be identified due to increase of surface temperature. Surface fire burns grasses on the earth surface, it easily seen and can be controlled easily. Crown fire is the large fire which burn branches and top of the trees. Crown fire is hard to control and can cause high burn severity. Within the Year 2022 thirteen (13) incidences occurred in Sao Hill Plantation.

Site selection is one of the GIS analysis which is used to determine the best location for provision of services in the identified area. Site selection requires analysis of different criteria in GIS environment. Mostly site selection analysis uses raster data although site selection can be done by using both vector data and raster data. "When performing site selection analysis users must set various criteria from which the GIS software can rate the best or ideal sites" (Briney, 2014). This analysis can be used to identify a location to place dumping site, hospitals, schools and markets. This study aim to identify best site to install new fire towers at Sao Hill.

Fire tower is the building structure which used by a trained fire officer to watch out the occurrence of fire in the plantation. Common method used here at Sao Hill Forest Plantation since it allows easy provision of information of the current situation. Fire towers play a key role in forest fire observation, main function of fire tower is to view if there is incident of fire in the forest and take quick measure to extinguish the fire (Norden & Clotworthy, 2007). Instead of using ground based techniques remote sensing techniques can be used.

Remote sensing technique is another method used to detect wildfire. Remote sensing techniques uses satellite sensors to detect active fire on the earth surface. Example of the system used is Advanced Fire Information System (AFIS), this system uses Moderate Resolution Image Spectro Radiometer (MODIS) sensor which are mounted in Terra and Aqua Satellite. This sensor has the spatial resolution of 1000 meter (Frost & Scholes, 2007). This system has advantages such as, detecting fire even for inaccessible areas and it provide daily information on the active fire. Despite of these advantages this system faces a challenge of network which lead to delay of information to reach firefighter and led to increase fire incidence. Therefore, there is a need to perform suitability analysis for location of fire towers so as to have ground-based system which will ensure the security constantly.

The use of GIS tools and Remote Sensing techniques can help represent real life phenomena and to interpret spatial data and non spatial data. GIS can be used to integrate multi data to identify criteria and identify suitable sites which increase service provision and efficient in forest management. This study aims to identify a suitable location to build new fire tower.

1.2 Statement of The Research Problem

Sao Hill forest have insufficient number of fire towers to accommodate whole plantation for both planted area and extension areas (unplanted). This insufficient was determined because other parts of the plantation are not visible by current fire towers, to justify this statement visibility analysis performed for existing fire towers. Insufficient fire towers led to high damage when fire start on non visible areas because it can take much time to identify incidence area. Delay to extinguish fire led to high fire intensity and high burn severity which can cause to loss of properties (trees), decrease of government revenue, loss of biodiversity, decrease amount of rainfall. This study entails suitability analysis to locate new fire towers to serve the whole Sao Hill Plantation.

1.3 Objectives of The Research

1.3.1 Main Objective

To investigate and identify suitable places to locate new fire towers at Sao Hill forest Plantation so as to increase visibility of the plantation.

1.3.2 Specific Objectives

i. To determine visibility capacity of existing fire towers.
ii. To perform suitability analysis for location of new fire towers.
iii. To map suitable place to locate new fire towers at Sao Hill Forest Plantation

1.4 Research Questions

i. What is the percentage of visible area by using existing fire towers?
ii. What are the criteria used for site selection for fire tower?
iii. Where are the suitable sites to locate new fire towers at Sao Hill Plantation?

1.5 Significance of Research

i. This study will identify suitable areas for fire towers location in the Plantation
ii. This study will help society to be aware on how we can use GIS and remote sensing to solve real life problem

1.6 Beneficiaries of Research

Outputs produced in this study will be useful to Management of the Sao Hill Plantation in department of Forest Resource Assessment and Development. Tanzania Forest Service (TFS) Agency will benefits from this study since they can apply these tools and techniques in another area and give the useful outputs. GIS tools and techniques used in this study will benefits other individual person who will use this research. will benefits to understand the use of GIS and Remote Sensing in solving the real life problems.

1.7 Description of the Study Area

Study area was Sao Hill Forest Plantation located in Mufindi district at Iringa region, United Republic of Tanzania. Sao Hill located within southern highland in Arc 1960 UTM Zone 36 South (731296,9081924) to (756843,9054120) and (755247,9033107) to (790580,9031989) see figure 1.1. It has average elevation of 1634 m.s.l. (TFS, 2023). Because of this elevation it has the average temperature of 14 degree Celsius to 22 degree Celsius, this climatic condition is very supportive for growth of trees such as Pinus Partula which are used mostly for timber and wood purpose.

Sao Hill forest plantation is located in Mufindi District at Iringa Region for its large part and small area is within Kilombero District in Morogoro Region. Sao Hill was established since 1939 to 1951 by experiment and official planting was conducted in 1968 by the government of Tanzania. Sao Hill Forest Plantation divided and operate in four division as Ilundi, Ihefu, Ihalimba and Mgololo. Sao Hill Forest Plantation it also gives the product such as Honey, raw materials to manufacture glue and shoe polish. Sao hill plantation has large contribution in Government revenue through the Ministry of Natural Resources and Tourism (Mwakalukwa, 2021).

The Sao Hill Forest plantation covers a total area of 135,903 ha, out of which 54,070 ha are planted with Pines and 3,500 ha with Cypress and Eucalyptus spp. This makes the Sao Hill Forest Plantation to be the largest plantation in Tanzania. 48,200 ha are natural forests and river valleys managed as water catchment areas, 31,933 ha are extension areas and 1,700 ha are areas for other uses including residential (TFS, 2023).

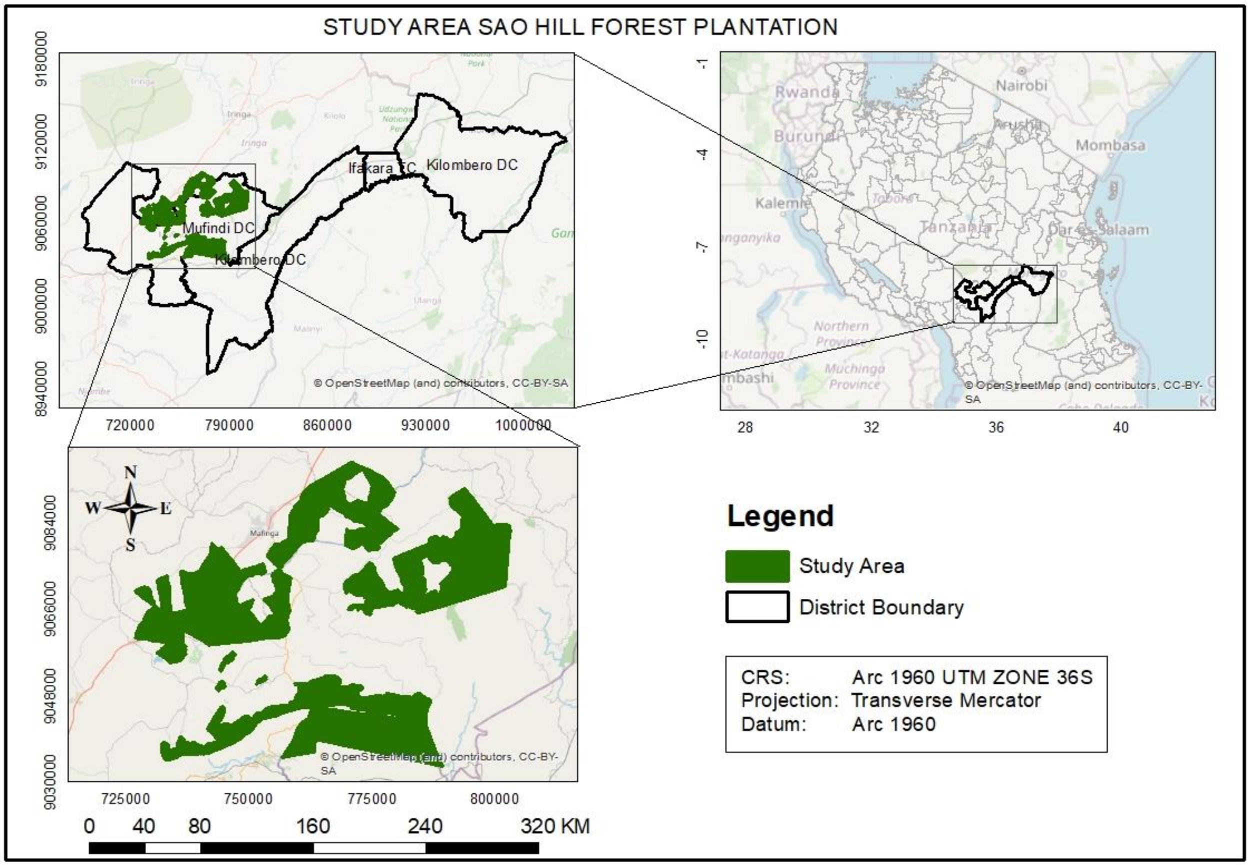

Figure 1. 1: Location map of study area

From the figure 1.1 shown above, top right is a map of Tanzania which show administrative boundaries. Top left is Mufindi district which is the study area. Bottom left is a map showing boundary of my study area Sao Hill Forest Plantation.

CHAPTER TWO
LITERATURE REVIEW

2.1 Suitability Analysis

Suitability analysis is the process of identify location which is mostly useful for a certain purpose by considering the criteria for establishment of that action. Suitability analysis is the process of determining the fitness or the appropriateness of a given tract of land for a specific use (Steiner, 1991). Suitability analysis or selection process is appropriate means which can be used in a project to quantify constraints and opportunities for planners and decision makers for project development. Suitability analysis depend on the criteria which are identified by the user, site selection can be for dumping site, market location, fire station location, or health service center location. In this study suitability analysis will help to show suitable location for fire tower at Sao Hill forest plantation.

2.2 Overview of Wildfire

Wildfire refers to accidentally happening large burning fire in the rural areas specific in the forest, bush land, national parks or game reserve in which it become hard to control and cause loss of flora and fauna and destruction of ecosystem. Wildfire can be caused by human activities such as smoking, burning of bushes during farming preparations, or intention burning of bush land. Wildfire can be caused by natural factors such as lighting and volcanic activities. Wildfire it causes burn severity as the effect of fire intensity. Fire intensity refers to the energy of combustion of active fire, high fire intensity it led to high burn severity and low fire intensity led to low burn severity. Effects of wildfire can be as follows

i. Climatic changes, trees are one of the sources of rainfall. Forest it contributes in the formation of rainfall through the process of transpirations, therefore the decrease of trees it led to decrease of amount of rainfall hence climate change. Furthermore, trees reduce carbon gas on the atmosphere and increase oxygen gas on the atmosphere. Shortage of trees it can lead to destruction of ozone layer and cause global warming.

ii. Loss of revenue, other species of trees are used to produce timber for commercial purpose (Mwakalukwa, 2021). Trees of this type when are burn it become loss to the government since they cannot used for timber purpose or electric pole. Therefore, wildfire can cause loss of revenue.

At Sao hill forest plantation accident of fire happen mostly in dry season between month of August and November. This is the season where farmers start to prepare farms for cultivation of crops when the wet season begins. When they prepare farms by burning the bushes sometimes the fail to consider the wind direction so burning fire catches the forest and wildfire happen.

2.3 Overview of Fire Tower

Fire tower is high building structure constructed for purpose to observe for the occurrence of fire accident in surrounding areas. It is normal constructed on the areas with high elevation. Fire tower is constructed by using wood or steel poles, heights are varies depending on the design of the fire tower. Height start from 15 meters and above, at the top of the tower it allows a person to stand and observe the situation in the forest. Fire towers also served for other activities such as spotter posts for aircraft identification (Norden & Clotworthy, 2007). Fire watch personnel may use a binocular in order to have more clear view of the long distance, and uses of radio call to communicate with another person in the control center to report the situation in the forest. Figure 2.1 show different design structure of fire towers, figure 2.2 show fire tower used at Sao Hill Plantation.

Figure 2. 2:Existing fire tower at Sao Hill forest Plantation (photo by Murya, June 2023)

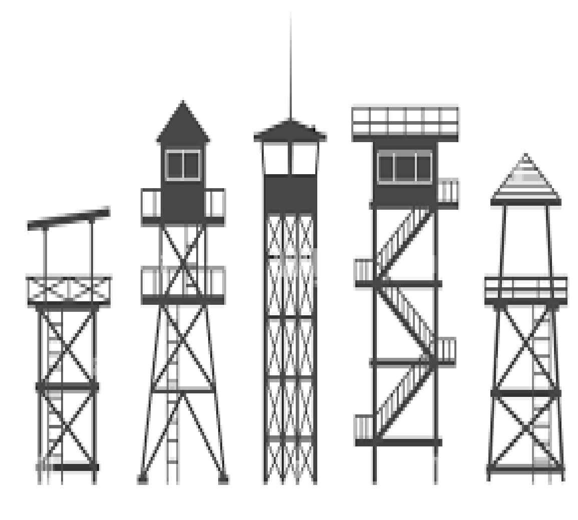

Figure 2. 1: Different building structures of fire towers (photo by www.shutterstock.com)

2.4 Fire Control

Fire control refers to the means used to avoid or reduce damages caused by wildfire. There are methods implemented in order to minimize damage which can be caused by fire, wildfire is unpredicted event and cannot be stopped to happen therefore, different measures introduced in order to reduce number of events and reduce damage whenever accident happen. One of the measures used to reduce fire damage when accident happen is by using fire line or fire break. Also, Government and non-government organization increases effort in providing education to the society on proper ways to prepare farms for crop cultivation and to consider wind direction if there is a need to burn the bushes

2.4.1 Fire Line

A linear bare land having a width size of fifteen meters to fifty meters established between plantation compartments for aim to avoid wildfire move from one compartment to another compartment. This feature is established and maintained by fire fighter personnel of the plantation manager. Main function of fire line is to block fire to move from one compartment to another and it act as a boundary from civilian’s farms and government farms. Fire line it used to provide accessibility of the plantation for maintenance activities.

2.4.2 Wind Direction

Wind is the main agent of transportation of fire in the forest, it can move light burning particles from one place to another. These small particles can cause high damage when it catches in the forest especially in dry season were there is low moisture content on the grass. To avoid effect of wind to cause damage in forest wind direction should be considered before starting fire. Starting a fire when preparation of farms for crop cultivation or during maintenance of fire line. Wind direction is measured by using wind vane or windsock tools, these are tools designed to identify the direction of the wind. Local method to identify wind direction is by using a wet finger and let it on air to dry the first side to dry is where wind come from and the later side to dry is where wind move, although this method is not much accuracy and applicable. There are other methods to check for find direction it depends on the understanding of the person.

2.4.3 Mop-up

This is the action of extinguish fire which is already under control. This action is taken by firefighting officers to make sure that there is no continuation of burning fire after put out wildfire, mop-up it makes sure that any fuel around fire incidence area is eliminated or removed from the area so as to make sure it cannot burn. For a small burn area mopping is done by starting from fire lines toward center of the area, and for large burnt area mopping is done in enough area adjacent to the fire line to make sure that fire do not start again. Mopping crew should have enough resources and equipment to monitor re-ignition of fire (Geldenhuys, n.d.).

2.5 Role of GIS in Suitability Analysis

GIS it is not only applicable for producing maps, but also GIS is capable to integrate multiple sources of datasets and different types of dataset to perform analysis which can be used to solve the real life problems. GIS can deal with vector data and raster data at the same time in performing different analysis, it can integrate data such as elevation, land cover, transportation network, public infrastructure and climate data. The idea of using multiple data for analysis is for reason of having multi criteria decision making problem, such problem can be land use suitability analysis.

2.6 GIS Application for Fire Services

The main objective for fire fighter is to protect life of living things, to reduce damage caused by fire in property and natural resources. The large area of service it demands fire fighter to use best tools, techniques and more advanced methods in order to meet public expectation. One of the tools used for planning and response for fire accident is GIS. GIS can answer the question about information of where, when and how when dealing with accidence of fire (Mahenge, 2019).

GIS can perform the following functions for planning and analysis for fire services:

i. GIS can show administrative boundaries that fire fighter officers will be required to visit to provide services. This function can be done by preparing maps and present it in either softcopy as web map or hard copy in a paper work. Web map can be used in mobile devices such as smartphones and tables devices.
ii. GIS can be used to show roads network, roads network refers to the interconnectedness of the one road of another in which it allows flow of goods and services. In order for firefighting team to reach the incident area they must have accessibility. Through network

analysis GIS will help to identify the best route and shortest path to reach the incidence area. Network analysis will determine the closest facility that can help quickly other than depending on the facility which is located far distance.

iii. GIS perform multi criteria analysis in order to identify site to locate fire stations that will maximize service provision. Suitability analysis can be performed by using GIS tool such as AHP, to identify suitable areas will help in proper allocation of resources and minimize operation costs. Suitability analysis also it helps to increase service area and meet the public demand.

iv. GIS can perform trend analysis of incidence of fire, by doing such analysis analyst can be able to assess the damage caused by fire incidence and to identify areas which are more affected. This analysis can be presented in a table which show location of incidence occur, date, time, causes of incidence, victims and total damage caused by fire incident.

2.7 Proximity analysis Function

Proximity analysis identifies the feature within a specified distance, attribute information and based on the location. Proximity can be used to identify the closest facility in term of length or travel distance measure by time using measurement unit. Proximity analysis tools in GIS uses both spatial data and non spatial data to provide results which answer real world problems. Spatial data are data related to location of geographic phenomena, data such as ground coordinate, aerial photographs and satellite images. Non spatial data shows the description about the spatial data, explain all about data concern, these are metadata and attribute data. This study deals with analysis tools which are proximity analysis within buffering.

types point features, linear features or polygon features. Digitized features can be saved as shapefile file format used by esri software, shapefile store shape, attribute data and location of geographic feature created.

2.8 Image Classification

Image classification refers to the assigning pixels of an image in a single group depending on the characteristic and Digital Number value of the pixel after detection, recognition and identification of features on image. Classification is done by using GIS software in computer environment and can be through crowd sources and online mapping application such as Google Earth Engine. Classification process require interaction between computer environment and human knowledge.

Human knowledge concerning the study area it is necessary in classification since human will be able to train computer which pixel to assign in which class. More knowledge of analyst will simplify the classification process and get more accurate results. Knowledge of study area can be obtained by doing reconnaissance, reconnaissance can be done through site visit, using produced materials such as large scale maps, large scale aerial photographs and large scale satellite images. Interaction of human and computer can be in different level depend on the method of classification used, such as unsupervised classification or supervised classification.

2.8.1 Supervised Classification

This image classification method which require analyst to specify the training sample of different types of land cover to computer algorithm. This training sample are data collected from site when analyst conduct reconnaissance, using topographical maps, land use maps, satellite images or aerial photographs. By doing supervised classification analyst required to do spectral separability analysis in order to ensure classes created do not overlay one to another. Supervised classification is more superior and preferable because development of characteristics signature of known specific feature or contiguous cover type it can lead to have more accurate classification.

2.8.2 Unsupervised Classification

Unsupervised classification applies "the classification system, or classifier, uses statistical means and covariance matrices to iteratively assign each pixel to a designated output class based on how spectrally separate each group of clustered pixels are". (Stacy & Siamak, 2000). Unsupervised classification method is useful for an area which lack enough training sample and analyst is not much familiar to the study area. Also unsupervised classification can be used for quick determination of spectral characteristics of the study area.

2.8.3 Accuracy Assessment

This is the procedure which is done after doing image classification were by analyst check out the output obtained it is correct with the ground situation for how much percent. Accuracy assessment check for error matrix calculate errors in each individual class assigned, overall map accuracy combines producer's accuracy, user's accuracy and kappa statistics.

i. Producer’s accuracy it is known to show the errors of omission, were by it shows the probability that the area classified in one single class (class vegetation) it is correctly identified in a specific class. It defines total number used for verification in the classification.

ii. User’s accuracy it shows the errors of commission, identify the probabilities of the area classified as class vegetation actually is in class vegetation. These types of errors define total number of verification train sample used committed to the true class.

iii. Kappa statistics consider random assigned labels should have a certain degree of accuracy. Kappa statistics allows to detect if two datasets have a statistically different accuracy.

2.9 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is the tool which is more useful to deal with complex problem that have more than one criterion, from the criteria identified AHP will solve the problem by considering the priorities of the decision maker. AHP use pairwise comparison method to reduce problem from complex decision to simple decision. AHP incorporate a useful technique for checking the consistency of the decision maker’s evaluations thus reducing the bias in the decision making process (Saaty, 1980).

2.9.1 How AHP Works

AHP it deals with the identified criteria together with a set of alternative solutions available for the problem need to be solved. Weight of each criteria is generated according to the pairwise comparison created by analyst. The higher weight increase importance to the criteria and less weight give small important for the criteria. After assigning the weight AHP assign score to every alternative preferred by a decision maker from pairwise comparison based on the criteria. When the score is higher it means that alternative is more favorable to solve the problem by using specified criteria. Lastly, AHP combine all criteria weight and the alternative scores to determine global score for each alternative and ranking the results. Obtained global score for a given alternative is a weighted sum of the scores it obtained with respect to all criteria (Saaty, 1980).

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter explain the procedures, methods, tools and techniques used to determine the suitable location for fire towers using GIS technique. It describes the research design and method used from data collection, data pre processing and data processing. The methodology of this research is shown in the figure 3.1.

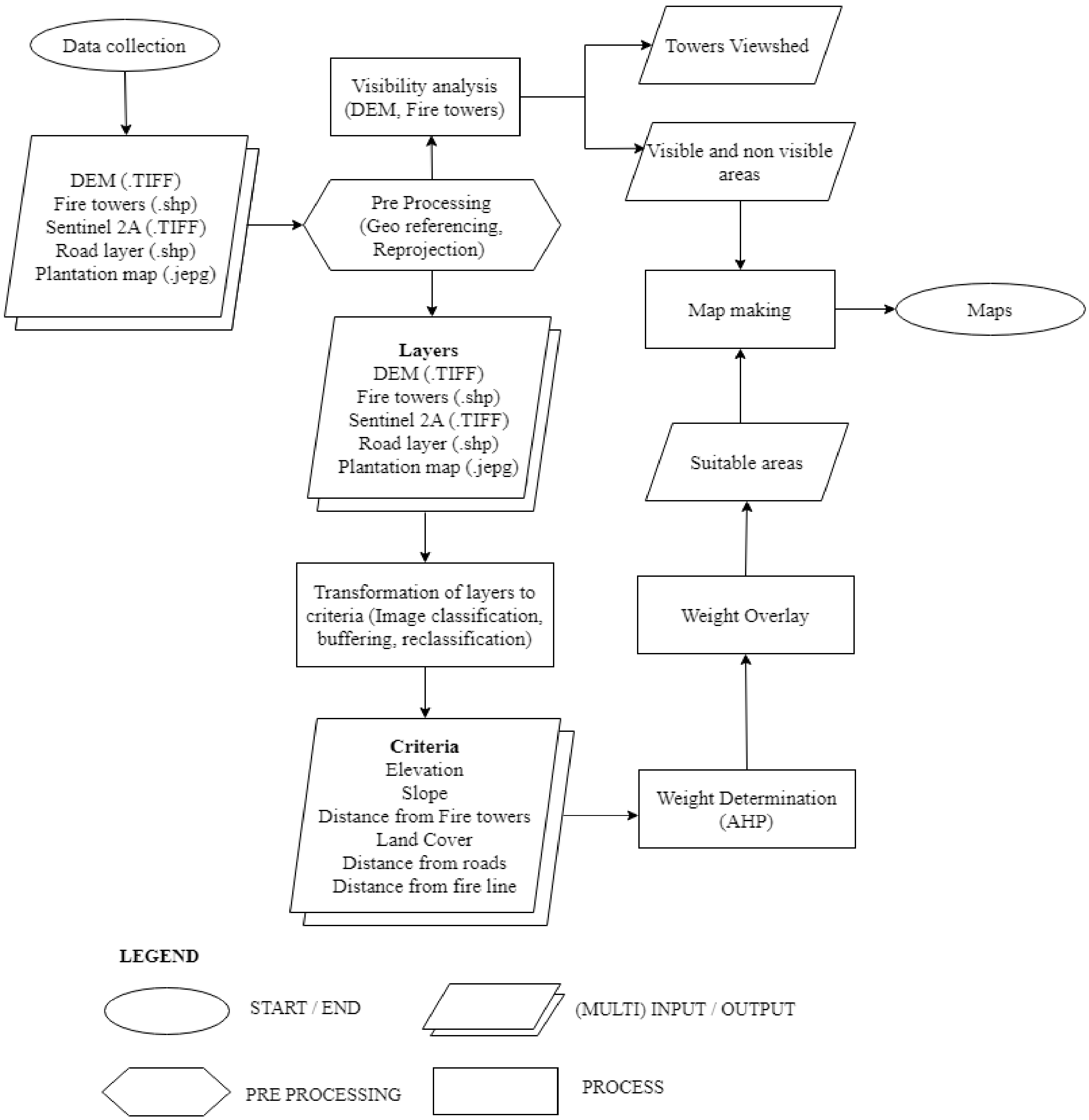

Figure 3. 1: Methodology Flow Chart

3.2 Data Collection

Data which have been used in this research were both primary data and secondary data. Data used in this research are summarized in table 3.1.

i. Primary data are collected direct from the field by using handheld GPS (Garmin), data collected are ground coordinates for existing fire towers. GPS was set to datum Arc 1960 and data were collected in form of UTM by recording Eastings, Northings and Elevation for each point of existing fire towers.

ii. Secondary data was collected through public domain, secondary data collected are Sentinel image, existing topographic map of Sao Hill forest Plantation, Digital Elevation Model and roads data layer from open street map.

Table 3. 1: Characteristics of the Research data

No	DATA	SPATIAL RESOLUTION	SOURCE OF DATA	USES
1	DEM	30 m	Africa Geoportal	Elevation and slope
2	Satellite Image (Sentinel 2A)	10 m	Copernicus Hub	Land cover map
3	Roads Data		Open Street Map and Digitization	Accessibility in plantation
4	Fire Tower	3 m	Hand Held GPS	Show available fire control measures
5	Plantation Map (Compartment register)	1:10000	Plantation management	Show boundary of plantation and fire line

3.3 Data Preparation

Data collected was stored in a single folder named “**Dissertation data**” in desktop of computer, this is to make sure that there is easy and quick access of the data whenever it needed for processing. Then preprocessing of the data is follow, preprocessing it include performing reprojection of layers and georeferencing. These actions were taken in order to remove geometric errors from the collected data.

3.3.1 Georeferencing

Georeferencing is the process of align coordinate of aerial photographs or scanned maps with ground coordinate reference system. The topographic maps sheets of the plantation were georeferenced in ArcMap software assigned to Arc 1960 UTM zone 36S.

3.3.2 Creating Shapefiles

A shapefile is esri file format for vector data used to store the geometric location and attribute information of geographic features. Shapefile is created in Arc Catalog by selecting a folder location of the created shapefile should be stored. Name of shapefile was specified, specify feature data type (point, line or polygon) and you will have to specify the coordinate reference system for shapefile (Arc 1960 UTM Zone 36S). Shapefile of fire line was created by using the georeferenced topographic map of plantation.

3.3.3 On Screen Digitization

This is the process of generating a spatial feature from the existing data such as scanned maps and satellite images. This process it follows after creating shapefile now we start editing the shapefile and add features by tracing and follow the topographic map of the plantation. Digitization process was done in Arc Map software after loading the topographic map of plantation and Sentinel 2A image which show existing situation on the land cover of the forest. Fire line was digitized as polyline features.

3.3.4 Reprojection

This is the preprocessing stage were by a layer is transformed from one coordinate system to another coordinate system. This stage was done in order to make sure that each data it in actual position in the ground. Data collected were in WGS 1984 coordinate system which is geographic coordinate system and it used to map a large area (area cover more than one zone). Study area of is located within one zone so that is needed to be projected to Arc 1960 UTM Zone 36S to have more precise accuracy.

3.4 Visibility Analysis

Visibility analysis aim to determine capability of existing fire tower to view the forest area. In this study visibility analysis for existing fire towers done by using "Observer Points" method in ArcGIS software. Observer Points tools requires point features (fire towers) with attribute information as summarized in table 3.2 and elevation raster data (DEM) (Akay et al., 2020). Observer tool was used input data was DEM and point feature (fire towers), all tower was processed at once and output was raster data with two classes; visible area and non visible area.

Table 3. 2: Attribute Information of Existing Fire Towers

Tower location	Tower name	Location elevation	Tower height (m)	Smoke visibility height (m)	Horizontal view angle	Vertical view angle	Viewshed (km)
Irundi mlimani	FT 1	1975	15	100	150	90	6
Irundi mlimani	FT 2	1993	15	100	210	90	7
Nzivi	FT 3	1922	15	100	360	90	5
Matanana	FT 4	1937	15	100	360	90	6
Itimbo	FT 5	1941	15	100	360	90	5
Ilasa	FT 6	1885	15	100	360	90	5
Wami	FT 7	1894	15	100	360	90	6
Kisilu	FT 8	1720	15	100	150	90	4
Mgololo	FT 9	1516	15	100	360	90	2
Kitete	FT 10	1274	15	100	360	90	3

Attribute information from table 3.1 obtained from Head of Forest protection unit - Sao Hill forest plantation. Observer Point tool were used to analyze the attribute information of fire tower. Observer point tool use points data and elevation raster dataset to show portion of forestlands that were visible and nonvisible from the fire towers in the study area. Visible areas were measured to have a statistic results shows how much part of the plantation is observed. Observer points tools shown in figure 3.2

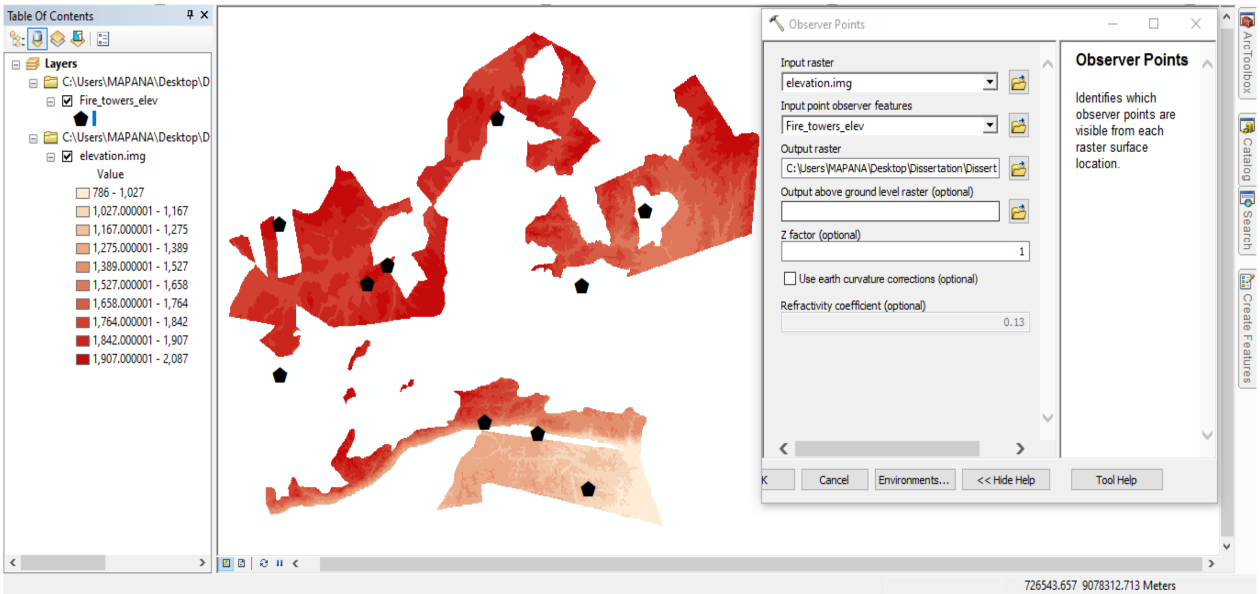

Figure 3. 2: Observer Points Tool in ArcMap 10.8

3.5 Clipping

This is geoprocessing tool which is used to minimize large dataset in small area of interest specified by the user. All secondary datasets downloaded were in a large area covers the whole Tanzania, therefore clipping was done to minimize the data in only study area. Datasets which are clipped are Digital Elevation Model (DEM), Sentinel 2A image and Roads data. Figure 3.3 show the tool used to clip vector datasets.

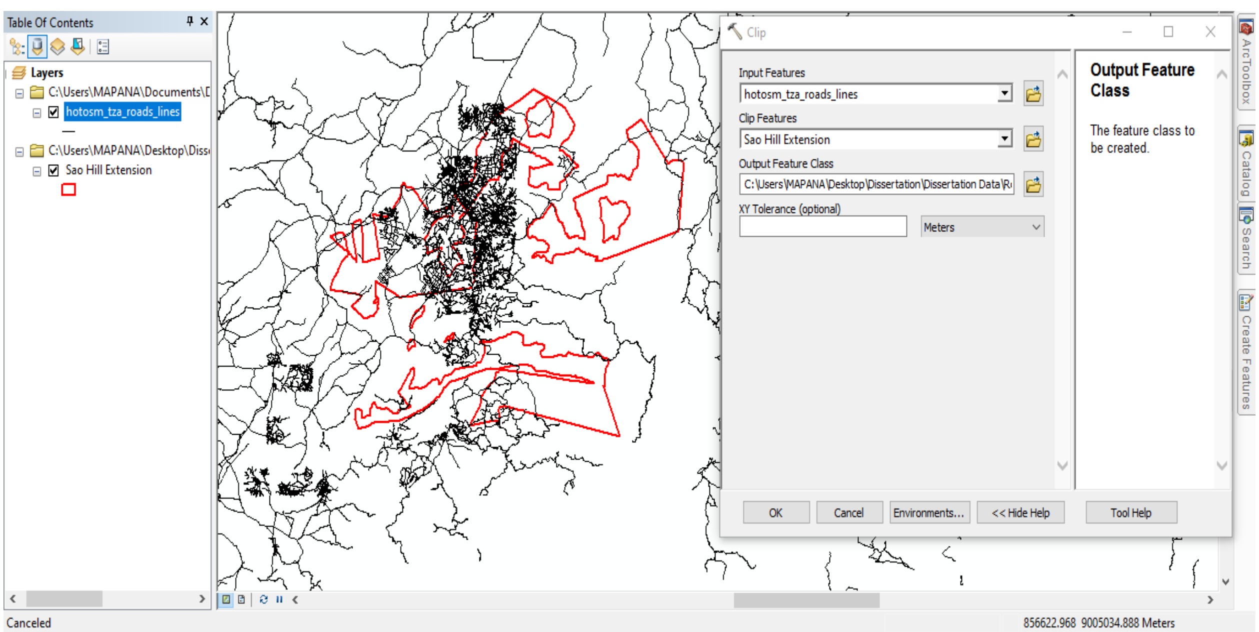

Figure 3. 3: Clip Tool in ArcMap 10.8

3.6 Image Classification

Sentinel 2A image was classified in order to have land cover image that will be used as one of the criteria for site selection. Method used to classify image was supervised classification were by three classes created which are planted area, unplanted area and civilian area. Algorithm used to classify image was maximum likelihood were by classifier used was nearest neighbor. Procedures used to perform image classification are as follows:

i. Open raster layer of the study area

This is the first step were Sentinel 2A image of the study area was added in working environment of software, image was in format of IMAGINE Image (.img) this is because classification was done using ERDAS software which is capable to read this (.img) files.

ii. Select the training samples of the images

After display the image on the working space, signature editor tool was used to create training sample by taking different sample of pixel values for planted area class and unplanted area class. Planted area it covers the pixel values with trees and unplanted area class it combines pixels of bare land, built up and grassland area. The process performed as shown in figure 3.4.

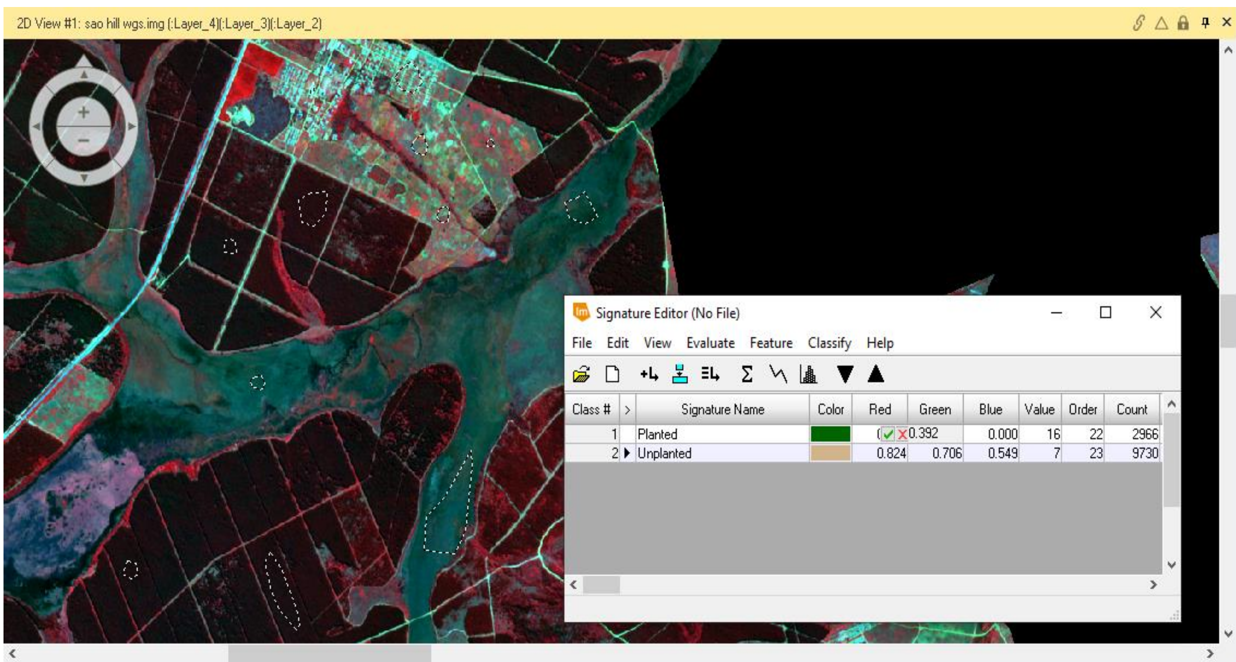

Figure 3. 4: Select Training Samples for Classification

iii. Select method to classify the image

There are various methods to classify image such as supervised classification, unsupervised classification and vector support machine. In this study supervised classification method was used to get the required output. Supervised classification it is interactive methods which require skills of the user/ expert to cooperate with computer because of this it will lead to provide output which is accurate and similar to the actual environment.

iv. Select algorithm for classification

Algorithm used in this classification was maximum likelihood which uses the pixel reflectance values of selected training samples to group all remaining pixels according to the identified training samples. This algorithm used to classify an image since the land cover map required do not have many classes to distinguish from one to another. Maximum likelihood algorithm used as shown in figure 3.5.

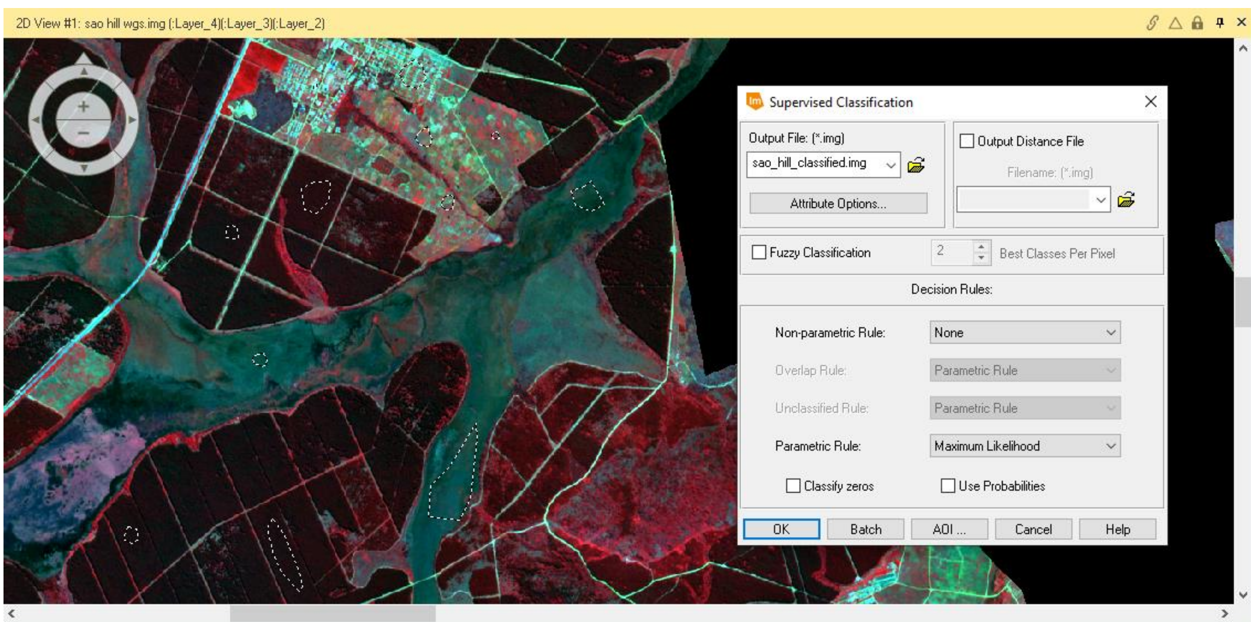

Figure 3. 5: Select Classification Algorithm in ERDAS Imagine Software

v. Perform image classification

After set all the required information in the classification tool then you click OK button to allow the software to classify image by using your inputs. Output obtained was one band image (Thematic layer) with identified classes and other classes which happen as default.

vi. Recode the classified mage

In order to remove the unwanted classes and arrange the required classes recode tool was used. Recode tool found in ERDAS Imagine software from thematic in Raster GIS group, by using this tool thematic layer of land cover was obtained with only three classes Planted areas, Unplanted areas and Civilian area that is extent of Sao Hill Boundary. Figure 3.6 show how recode was done.

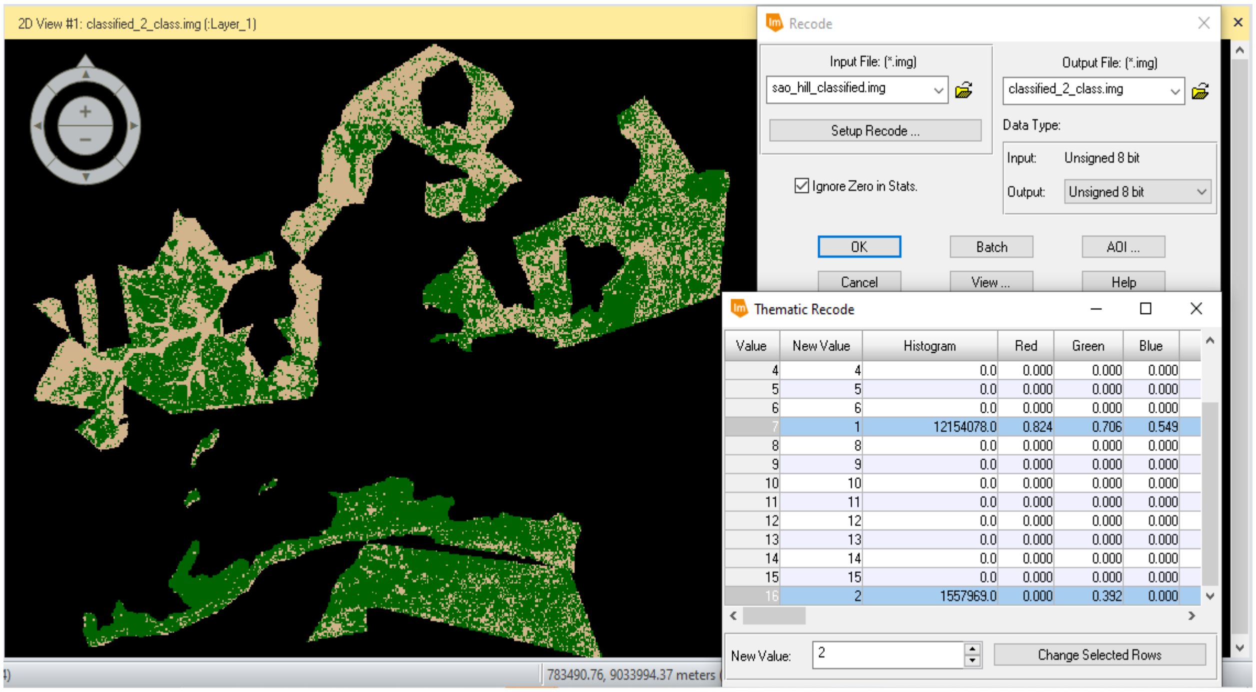

Figure 3. 6: Removing Unwanted Classes by Recode

3.7 Accuracy Assessment

After doing image classification land cover map obtained it was assessed to determine in what percent it resembles to the real world situation. Accuracy assessment uses of random points to compared classified image with another data as references. In this study comparison was done between land cover classified image and google earth satellite image from google earth pro application as shown in figure 3.7. In this study sample of 150 random points were used to check the accuracy of the classified land cover. After doing accuracy assessment it was found that land cover classified image has accuracy of 80.67%. From this result it means that classified image is useful, since the reasonable accuracy is supposed to be above 78%.

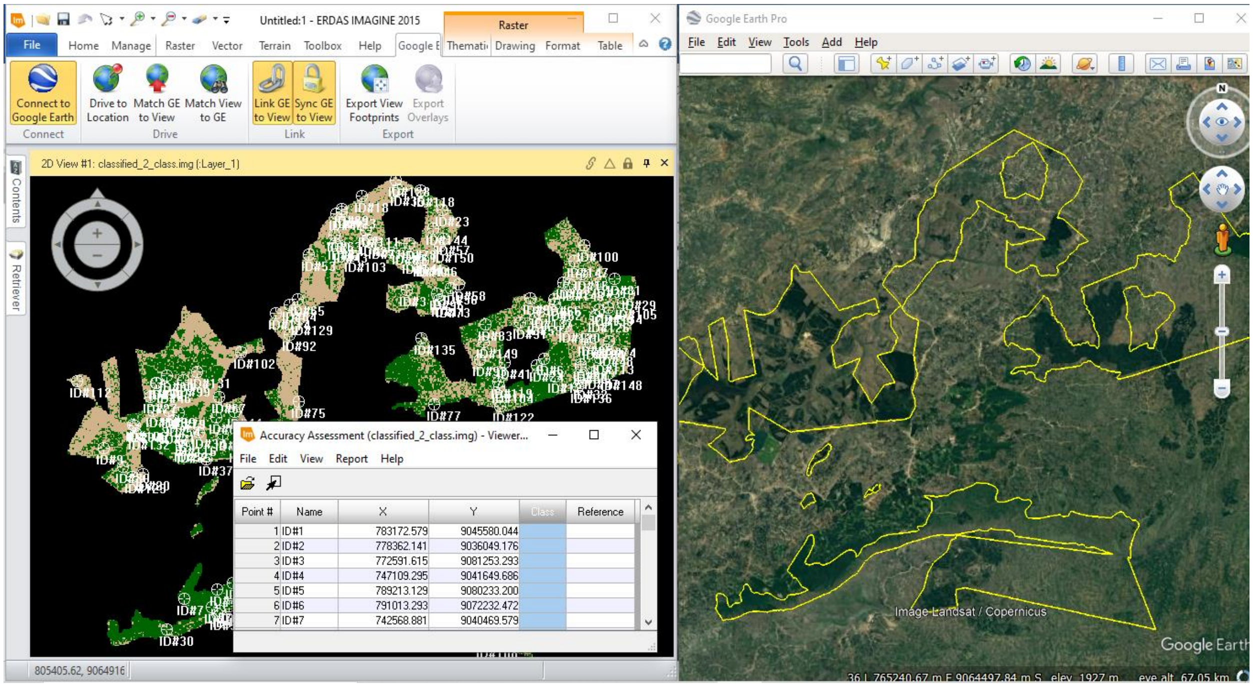

Figure 3. 7: Comparison Classified image with Google Earth Satellite Imagery

3.8 Topology Error Correction

Spatial relationship between features, can be connectivity, adjacency and containment. Connectivity shows how one linear feature is connected to another linear feature, adjacency shows polygon features which share boundary and containment show the relationship between a polygon feature which is within another polygon feature. “Topology focuses on connectivity, it calculated to determine if all polygons are closed, lines connected by nodes, and nodes connected to lines. This allows for the determination of errors in digitized or scanned vector data” (Harvey, 2008). Topology error correction of roads layer was performed in ArcMap software. Steps for topology correction are as follows

i. Create file geodatabase

All layers which are supposed to participate in topology correction should be stored in a single database file. Geodatabase created with name “**Sao Hill**”.

ii. Create new feature dataset

Within geodatabase should create a feature dataset which used to store feature class of the same location in a same coordinate system. Feature dataset were named “**Data**”

iii. Import feature class

Feature class is the file format which used to store vector data with the same characteristics, it can be point feature, line feature or polygon feature that have a specified coordinate system. Shapefile of roads and shapefile of Sao Hill boundary were imported as feature class.

iv. Create new topology from the feature datasets

After all datasets located in one geodatabase new topology created to show the relation of the features and to correct errors. After open the topology tool the steps were followed.

a. Identify name of topology and cluster tolerance, topology was named "**Roads topology**" and cluster tolerance were specified to five (5) meters
b. Select dataset (feature class will be used in topology), datasets which have been used to create topology relationship were roads data and Sao Hill boundary.
c. Enter number of ranks for the feature class, number of ranks for both data decided to be 1 since these are downloaded data which are secondary data.
d. Select the rules to be used in topology correction, rule used to show relationship are roads Must Not Have Dangles, roads Must Not Self-Overlap, roads Must Be Inside Sao Hill boundary
e. Finish to run the topology checker
f. Validate the created topology, after running topology tool validation was done so as to see the error appears from the selected rules.
g. Add topology on working environment and correct errors appear on dataset, from the appeared errors editing mode activated together with topology editing toolbar to correct the errors.

3.9 Creating Slope and Elevation Map

Elevation is one of the criteria used in this study, in order to have suitable area elevation and slope should be considered (Prasanth DK et al., 2009). High elevation it better because it enables large viewshed. Also, slope is considered in order to make sure stability of building structure, and during construction activities provide easy movement of materials to the site and work to be performed well. Elevation and slope were derived from Digital Elevation Model dataset. Slope were derived in units of percentage rise see figure 3.8, were by high suitable area is recommended slope below 5%.

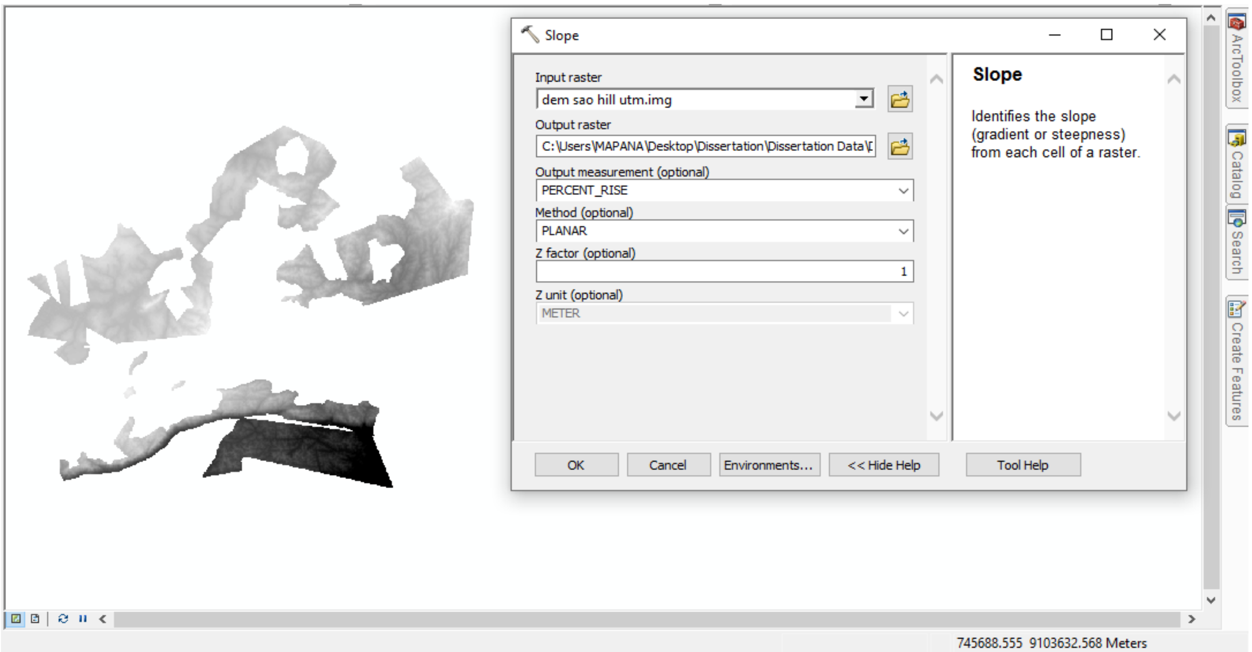

Figure 3. 8: Slope Creation Tool in ArcMap 10.8

3.10 Buffer

Buffer "it determines the zone around the objects using one or more distances" (Harvey, 2008). Multiple buffering was performed for vector layers to create zones which shows the classes for the criteria. Buffer created for three zones which identify High suitable region, moderate suitable region and less suitable region. Layers used for buffering are existing fire tower, roads layer and fire line layer. ArcGIS tool used to create buffer shown in figure 3.9. Multiple buffering of these vector layer conversion from vector to raster was done by feature to raster tool in ArcGIS software.

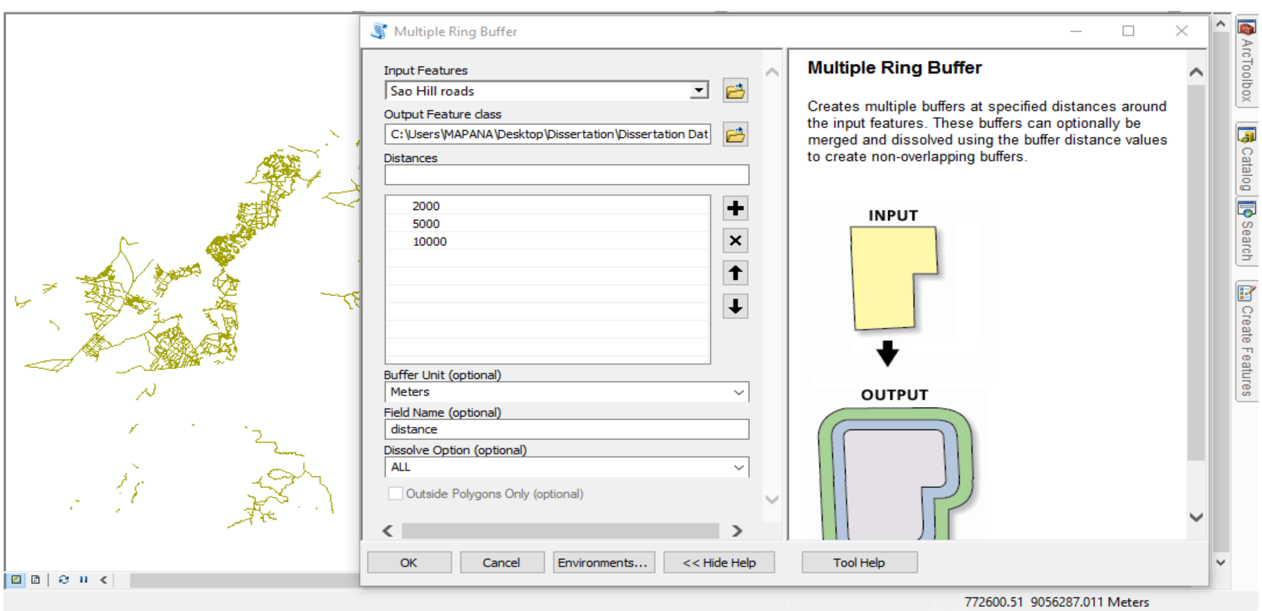

Figure 3. 9: Multiple Ring Buffer Tool in ArcMap 10.8

3.11 Reclassification

In this study data used were both vector data and raster data, method used to identify suitable location is AHP. AHP method it deals with raster data with the same classes; therefore, vector data were converted to raster data format. All raster layer used to determine the suitable location for fire tower were reclassified into three classes termed as High suitable, moderate suitable and less suitable. Reclassified criteria are elevation, slope, land cover, roads layer, fire line and existing fire tower layer. Tool used to reclassify raster dataset is shown in figure 3.10.

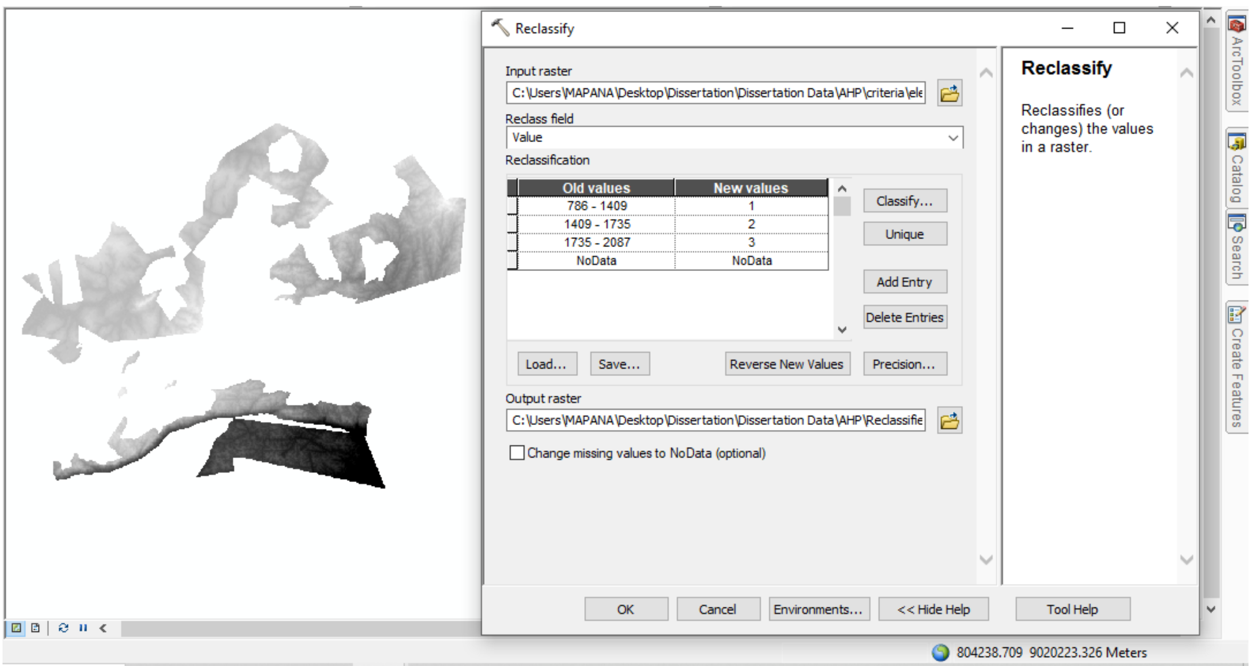

Figure 3.10: Reclassify Tool in ArcMap 10.8

3.12 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is the common tool and mostly used for multi criteria decision making technique. This technique is working by evaluating the relative weights of the multiple alternatives available against given criteria in a intuitive manner (Saaty, 1990). Multicriteria decision analysis means it have uncertainties, it complex and it have many alternative solutions (Quinta-Nova et al., 2017). AHP technique convert the pairwise comparison between the standards into weights and numbers that show relative importance of these criteria (Saaty, 1980, 1990).

3.12.1 Identification of Criteria

In this study criteria used are elevation, slope, proximity to existing fire towers, proximity to roads, distance from fire lines and land cover. Elevation criteria because in order to view long distance area you have to be in high elevated area, slope criteria should be considered in order to have easy access during construction and stability of building structure. Distance from roads to have accessibility of the tower, and it should have long distance from existing fire tower and fire line in order to cover large area which is not visible. Table 3.3 shows the criteria classes and scores for each of the class. Information presented in table 3.3 criteria and values were derived based on published literature, slope criteria and distance from roads based on (Akay et al., 2020), land cover criteria based on (Korale et al., 2009), elevation criteria based on (Pompa-Garcia, 2010), distance from existing fire towers and distance from fire line based on preference from forest protection unit – Sao Hill forest Plantation.

Table 3. 1: Classes, Value and Score of the Criteria Used in This Study

No:	CRITERIA	CLASSES	VALUE	SCORE
1	Distance from Fire tower (meter)	High suitable Moderate suitable Less suitable	10000 – 17000 5000 – 10000 0 – 5000	3 2 1
2	Elevation (meter)	High suitable Moderate suitable Less suitable	1735 – 2087 1409 – 1735 786 – 1409	3 2 1
3	Slope (% rise)	High suitable Moderate suitable Less suitable	0 – 5 5 – 10 10+	3 2 1
4	Land Cover	High suitable Moderate suitable Less suitable	Unplanted Planted Civilian	3 2 1
5	Distance from fire line (meter)	High suitable Moderate suitable Less suitable	5000 – 10000 2000 – 5000 0 – 2000	3 2 1
6	Distance from roads (meter)	High suitable Moderate suitable Less suitable	0 – 2000 2000 – 5000 5000 – 10000	3 2 1

3.12.2 Pairwise Comparison Between the Criteria and Weight

By doing this comparison importance between alternatives is identified, importance of the choice is given a degree ranging in interval of (1 – 9) from equal importance to the medium importance, strong and very strong importance. It important considered the consistency ratio value to make sure pairwise comparison has no divergence and biases between the comparison and choices. The consistency ratio should not be greater than 0.1, consistency ratio in this study was 0.079. Table 3.4 shows the Intensity of importance of each criterion to be used, their definition and their explanations

Table 3. 2: Intensity of Importance

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or equal importance	Experience and judgement strongly favor one activity over another
7	Demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent Judgement	When compromise is needed
Reciprocals of above non-zero	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

3.12.3 Pairwise Comparison Matrix

Pairwise is done by using the intensity of importance from table 3.4. The criteria used were arranged from high priority to low priority criteria. Those criteria are distance from existing fire tower, elevation, slope, land cover, distance from fire line and distance from roads. Table 3.5 shows comparison matrix done in AHP tool.

Table 3. 3: Pairwise Comparison Matrix Created by AHP Tool

Criteria	Distance from Fire tower	Elevation	Slope	Land Cover	Distance from fire line	Distance from roads
Distance from Fire tower	1	2	5	3	4	5
Elevation	0.5	1	2	4	3	5
Slope	0.2	0.5	1	2	3	4
Land Cover	0.333	0.25	0.5	1	2	4
Distance from fire line	0.25	0.333	0.333	0.5	1	5
Distance from roads	0.2	0.2	0.25	0.25	0.2	1

After formation of pairwise comparison matrix by AHP tool, also it provides the value of consistency ration and weight value for each criterion. Consistency Ratio from pairwise comparison matrix was 0.079. Table 3.6 shows weight value for each of the criteria.

Table 3. 4: Weight of Criteria in Percent

Criteria	Distance from Fire tower	Elevation	Slope	Land Cover	Distance from fire line	Distance from roads
Weight (%)	37	25	15	11	8	4

Despite of using AHP tool to calculate weight and Consistency Ratio (CR) automatically, these values can be calculated manually. Below are the formulas and procedures to calculate for weight of the criteria and Consistency Ratio (CR)

Calculation of weight values

Weight value for available criteria is calculated by using the N^{th} root of product, N^{th} root of product is obtained by multiplying the entries of each row in pairwise comparison matrix in table 3.5. Weight value of each criteria is obtained by taking the n^{th} root of each criteria divide by total n^{th} root value. Value of n^{th} root and weight are summarized in table 3.7.

N^{th} root = $\sqrt[6]{(Product\ of\ the\ entries\ in\ each\ row)}$ ..………………………………. (i)

Example n^{th} root for elevation is shown below:

$\sqrt[6]{(0.5 * 1 * 2 * 4 * 3 * 5)}$ = 1.979

Weight value = $\frac{nth\ root\ of\ product\ value}{total\ nth\ root\ of\ the\ product\ values}$ …..………………………………….. (ii)

Weight for elevation criteria is calculated below:

Weight = $\frac{1.979}{7.796}$ = 0.2538

Table 3. 5: Nth Root and Weight of Each Criteria Calculated Manually

Criteria	N^{th} root of the product	Weight
Distance from Fire tower	2.904	0.37
Elevation	1.979	0.25
Slope	1.157	0.15
Land Cover	0.833	0.11
Distance from fire line	0.641	0.08
Distance from roads	0.282	0.04
Total	7.796	1

Eigen vector and eigenvalue

These are used in calculating the Consistency Index and Consistency Ratio, vector value for elevation was calculated as follows:

Eigen vector = $\sum(Entries\ in\ each\ row * Weight)$ …………………………………. (iii)

Eigen vector (elevation) = [(0.5*0.37) +(1*0.25) +(2*0.15) +(4*0.11) +(3*0.08) +(5*0.04)] = 1.61

Eigen vector for other criteria are 2.47, 0.97, 0.69, 0.56 and 0.25 for distance from fire tower, slope, land cover, distance from fire line and distance from roads respectively.

From the calculated vector value were used to estimate the eigenvalue (λmax) by using formula:

Eigenvalue (λmax) = $\frac{Eigen\ vector}{Weight}$ ……………..…………………..……………. (iv)

Eigenvalue (elevation) = $\frac{1.61}{0.25}$ = 6.4465

Other eigenvalues are 6.64, 6.44, 6.24, 6.97 and 6.22 for distance from fire tower, slope, land cover, distance from fire line and distance from roads respectively. Then we have to calculate the mean for the eigenvalues which is 6.49 estimated for eigenvalue (λmax). Since (λmax) is not less than 6 number of criteria means that there is no error in the calculation.

Consistency Index for a matrix

Consistency index of comparison matrix is obtained by using the formula below:

Consistency Index (CI) = $\frac{(\lambda \max - n)}{(n-1)}$ ……………………………………….………. (v)

Where λmax refers to eigenvalue

n refers to the number of criteria

Consistency Index = $\frac{(6.49 - 6)}{(6 - 1)}$ = 0.098

Therefore, Consistency index for comparison matrix is 0.098

Consistency ratio calculation

This is the value that show there is no divergence and bias between comparison and choices. Consistency Ratio (CR) is calculated as follows:

Consistency Ratio (CR) = $\frac{Consistency\ Index\ (CI)}{Random\ Index\ (RI)}$ ……………………..……………..(vi)

Where RI is the corresponding values from large samples of matrix as shows in table 3.8 derived from (Saaty, 1980). In this study number of criteria used is 6.

Consistency Ratio (CR) = $\frac{0.098}{1.24}$ = 0.079

Condition for Consistency Ratio it should CR<0.1, means the pairwise comparison it is acceptable since there is no bias between the choices. If the CR $\geq$ 0.1 then it shows the decision are not reliable, therefore needed to change the comparison matrix value to have more reliable solutions.

Table 3. 6: Random Index values corresponding to number of criteria

Number of criteria	**RI values**
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

3.13 Weighted Overlay

Weights calculated by AHP tool for each criterion supposed to multiply together to have the final output which show suitable areas. All reclassified layers are combined together in weighted overlay operation tool. In order for this tool to process and provide outputs, summation of weight must be hundred percent. Scale values for each criterion were assigned followed by weights of the input raster as were determined using AHP method. See figure 3.11

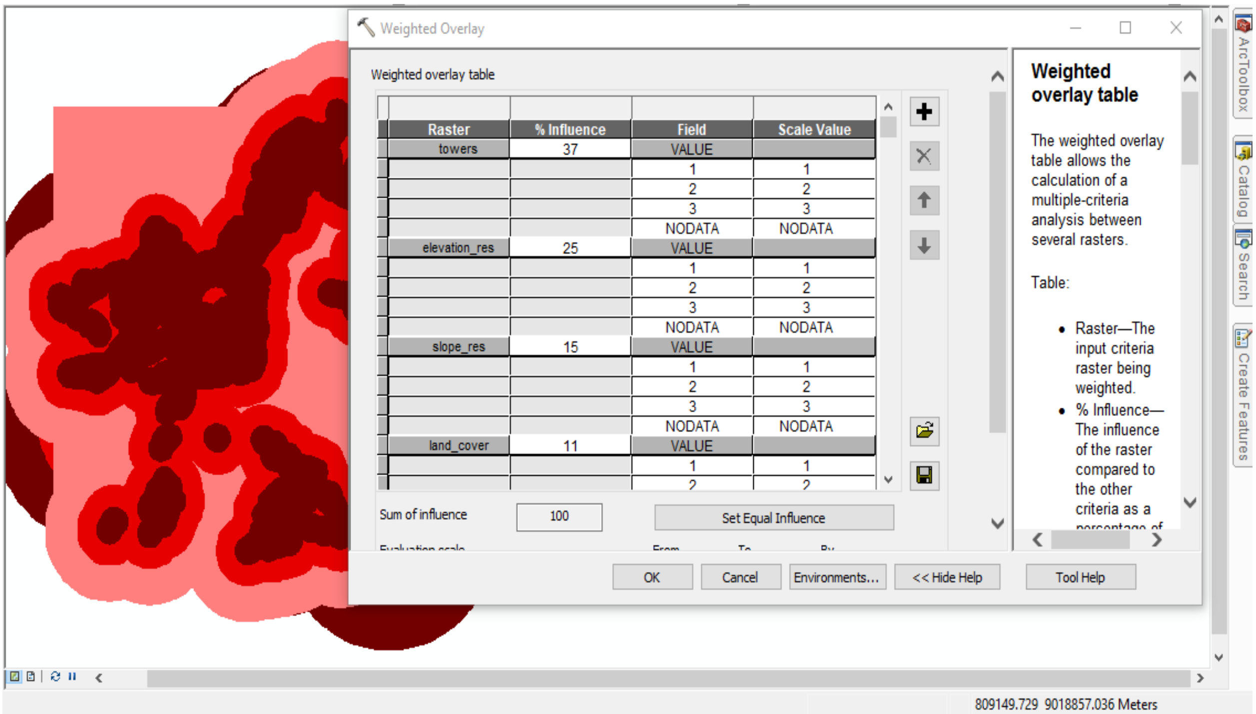

Figure 3.11: Weight overlay tool in ArcMap 10.8

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter explain the findings obtained from the processed data and discussion of the research results. The findings and outputs are presented in maps and graphical representation, in discussion section explain the findings of the study and shows how much fulfill the identified objectives and solve the problem.

4.2 Results

Spatial and non spatial analysis performed in this research produces the followings results

i. Visibility map for existing fire stations
ii. Viewshed coverage of existing fire tower
iii. Reclassified map distance from existing fire towers
iv. Reclassified elevation map
v. Reclassified slope map
vi. Reclassified land cover map
vii. Reclassified map of distance from fire line
viii. Reclassified map of distance from roads
ix. Suitability map for location of fire towers at Sao Hill forest planta

4.3 Analysis

Table 4.1 show the attribute information of each existing fire tower and viewshed coverage identified from visibility analysis. Figure 4.1 show a map of visible region and non visible region of the forest land, Figure 4.2 show graphical representation of viewshed of existing fire tower. Figures 4.3 to Figure 4.8 are reclassified layers of distance from fire tower, elevation, slope, land cover map, distance from fire line and distance from roads respectively. Figure 4.9 is suitability map for fire tower location at Sao Hill Forest Plantation.

Visibility analysis for all fire towers performed in one run by considering the criteria provided in table 3.1. From visibility analysis shows that total forest area visible by current fire towers is 34,325.15 ha out of 135,903 ha of total forest area. Visible area is equal to 25.26% percent of the total area of the plantation, this means that there is 74.74% of Sao Hill Forest Plantation is not visible by the current fire towers. Figure 4.2 shows the visible area and non visible area.

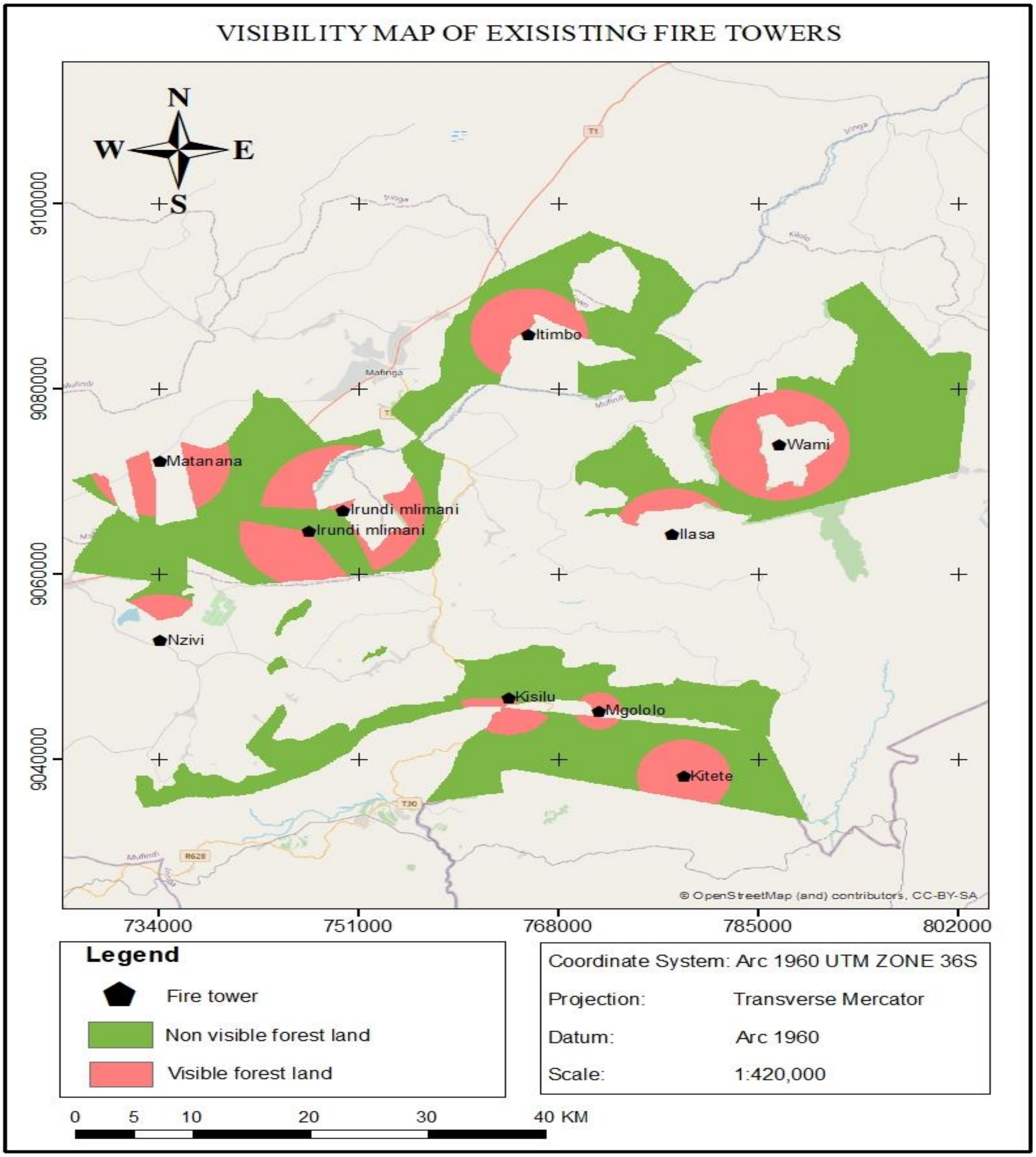

Figure 4. 1: Area visible by existing fire towers and non visible areas

Table 4.1 shows viewshed area of each fire tower. Maximum viewshed is obtained by fire tower located at Wami village which cover 7903.45 ha of the forest land, and minimum viewshed is covered by fire tower located in Mgololo cover 861.69 ha of the forest land.

Table 4. 1: Viewshed for existing fire towers

Tower Number	**Place Name**	**Eastings**	**Northings**	**Elevation**	**Viewshed (Ha)**
FT 1	Irundi mlimani	746836	9064615	1975	3933.79
FT 2	Irundi mlimani	749696	9066871	1993	5182.45
FT 3	Nzivi	734179	9052829	1922	988.06
FT 4	Matanana	734147	9072170	1937	3587.76
FT 5	Itimbo	765517	9085818	1941	4563.94
FT 6	Kisilu	763778	9046640	1720	1520.52
FT 7	Ilasa	777715	9064234	1885	1505.12
FT 8	Wami	786859	9073917	1894	7903.45
FT 9	Mgololo	771442	9045218	1516	861.69
FT 10	Kitete	778673	9038140	1274	4278.37

Existing fire towers viewshed are presented in bar graph as shown in figure 4.2 simplify the distribution of each tower viewshed and can be able to identify the maximum viewshed and minimum viewshed from the graph.

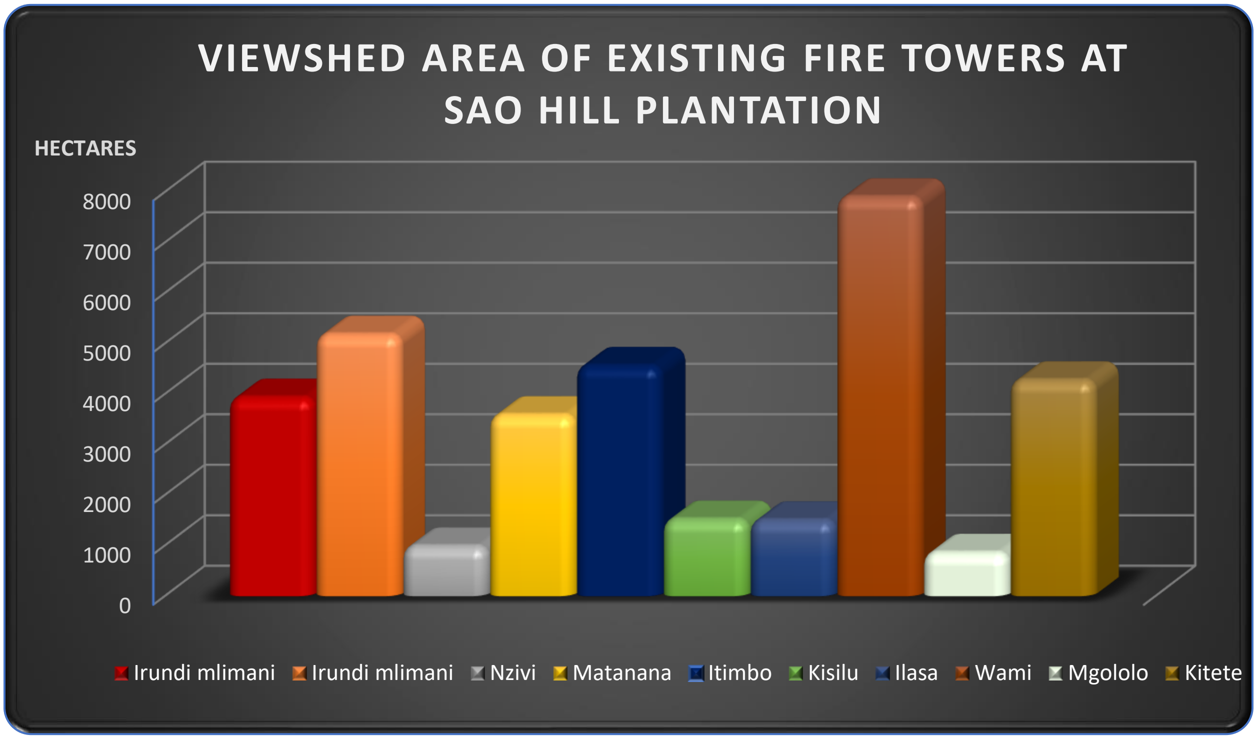

Figure 4.2: Show the maximum and minimum viewshed for existing fire towers

To locate new fire tower should consider the proximity from the existing fire towers so as to have proper allocation of resources. Figure 4.3 show suitable distance to locate new fire towers by considering distance from existing fire towers.

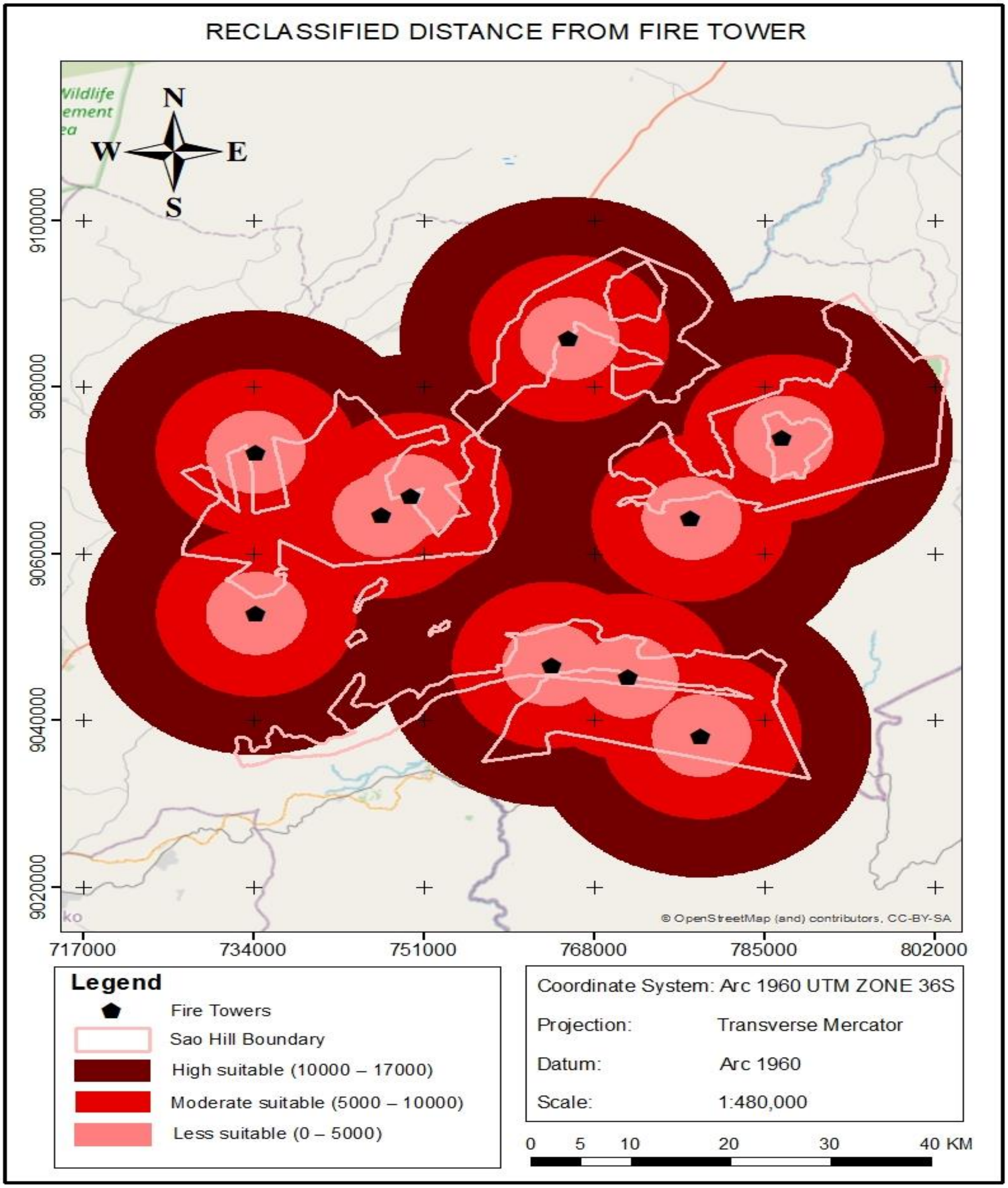

Figure 4. 1: Shows longer distance from existing fire tower more suitable to locate new tower

DEM downloaded was processed to have slope criteria but also elevation as it is used as criteria, figure 4.4 shows that high elevation is high suitable to locate new fire towers rather than low elevation areas are low suitable.

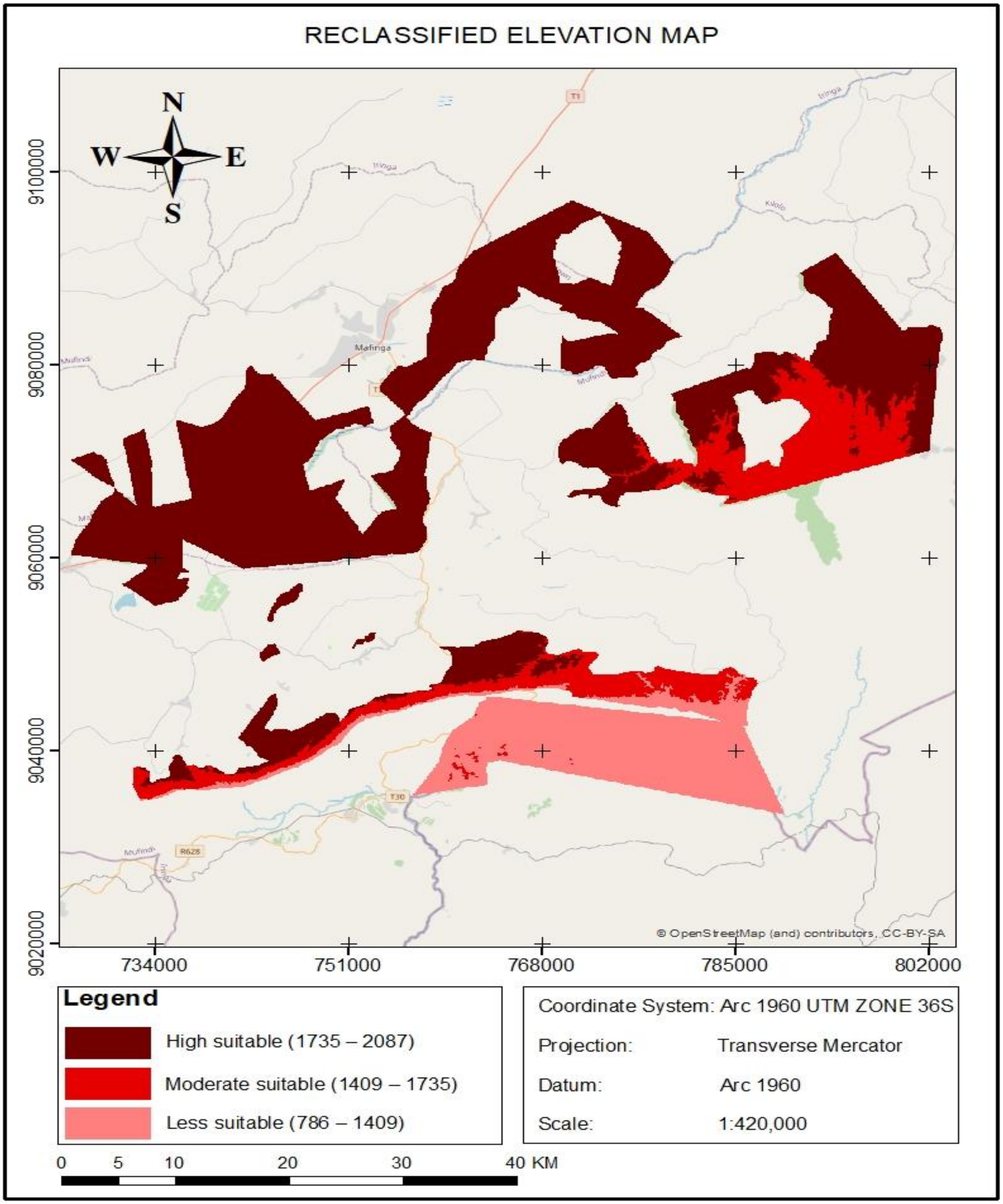

Figure 4. 2: High elevated areas fit for location of new tower than low elevated areas

Building will be more stable when constructed in a gentle slope rather than in steep slope. Gentle slope it enables easy movement of building materials during construction period. Therefore, slope was used as one of the criteria, gentle slope of percentage rise below 5% it is more suitable to locate new fire tower as shown in figure 4.5.

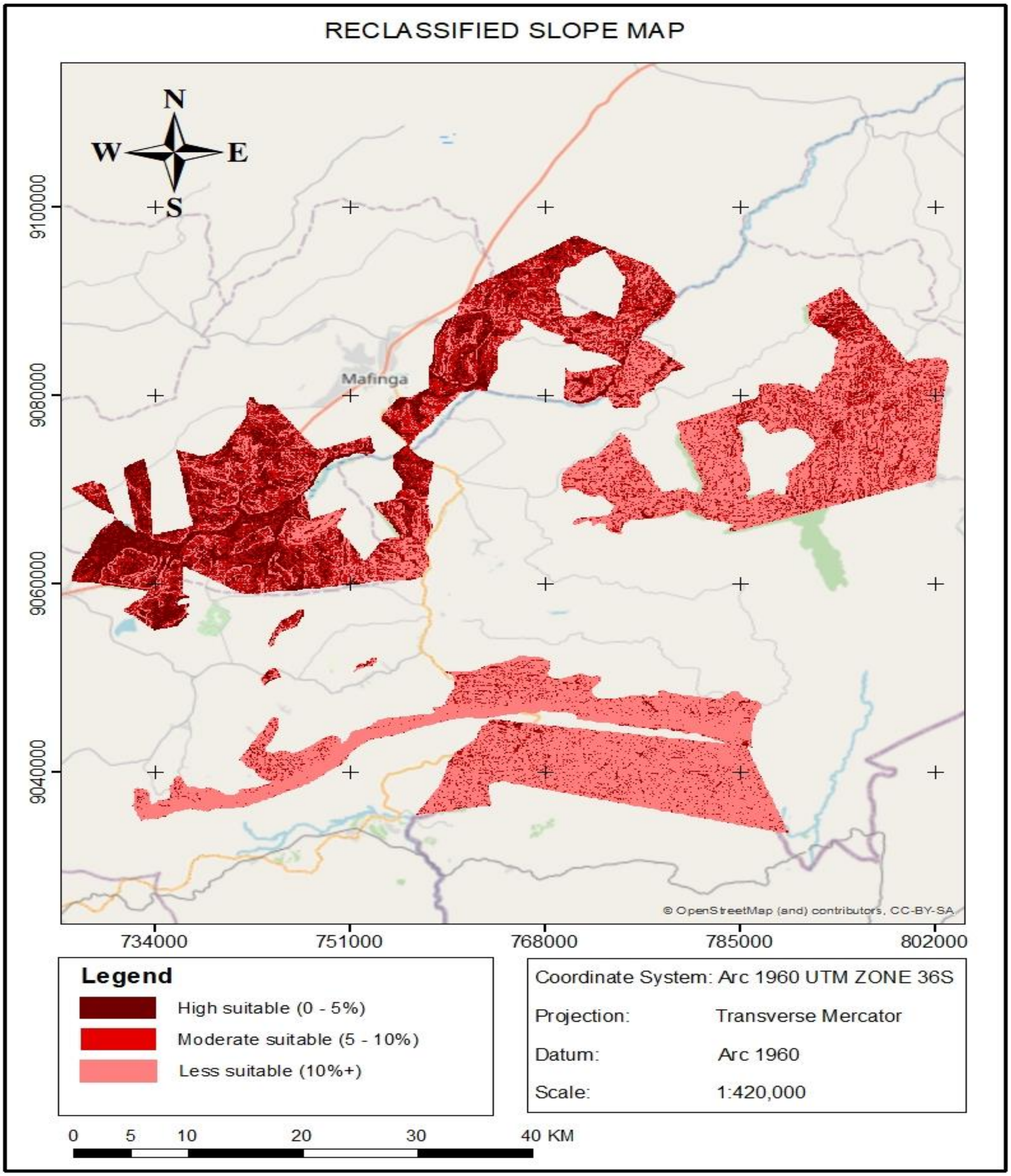

Figure 4. 3: Gentle slope is high suitable for construction of fire tower

Remote sensing data (Sentinel 2A) image used to create land cover map, from land cover map criteria show that unplanted area is high suitable to locate new fire tower as shown in figure 4.6.

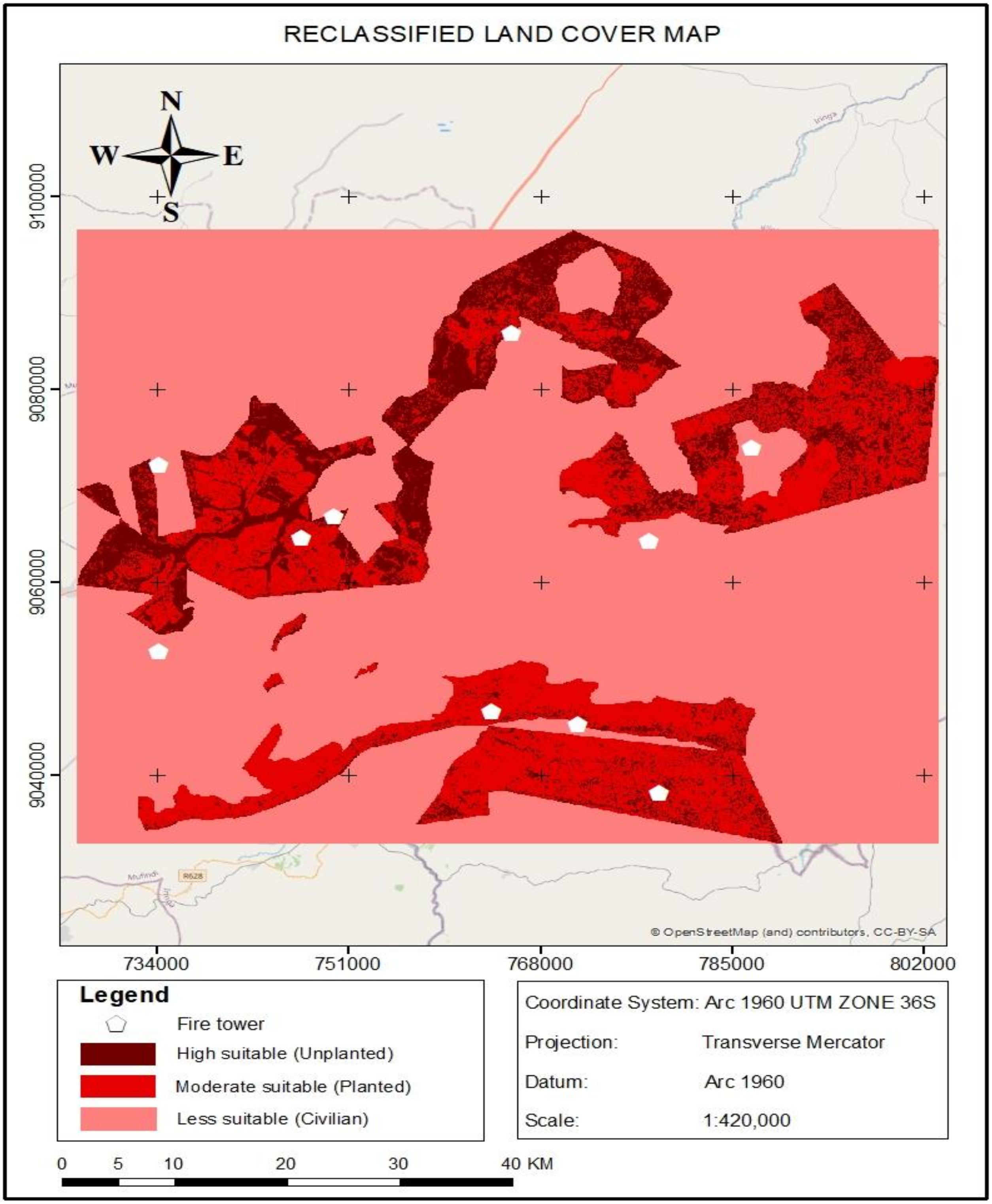

Figure 4. 4: Shows forest lad covered with trees and land without trees

Fire line data obtained from plantation maps, this feature used to block burning fire movement from one farm to another. From the processes have been done fire line criteria should be high suitable to locate new fire towers far from fire line see figure 4.7.

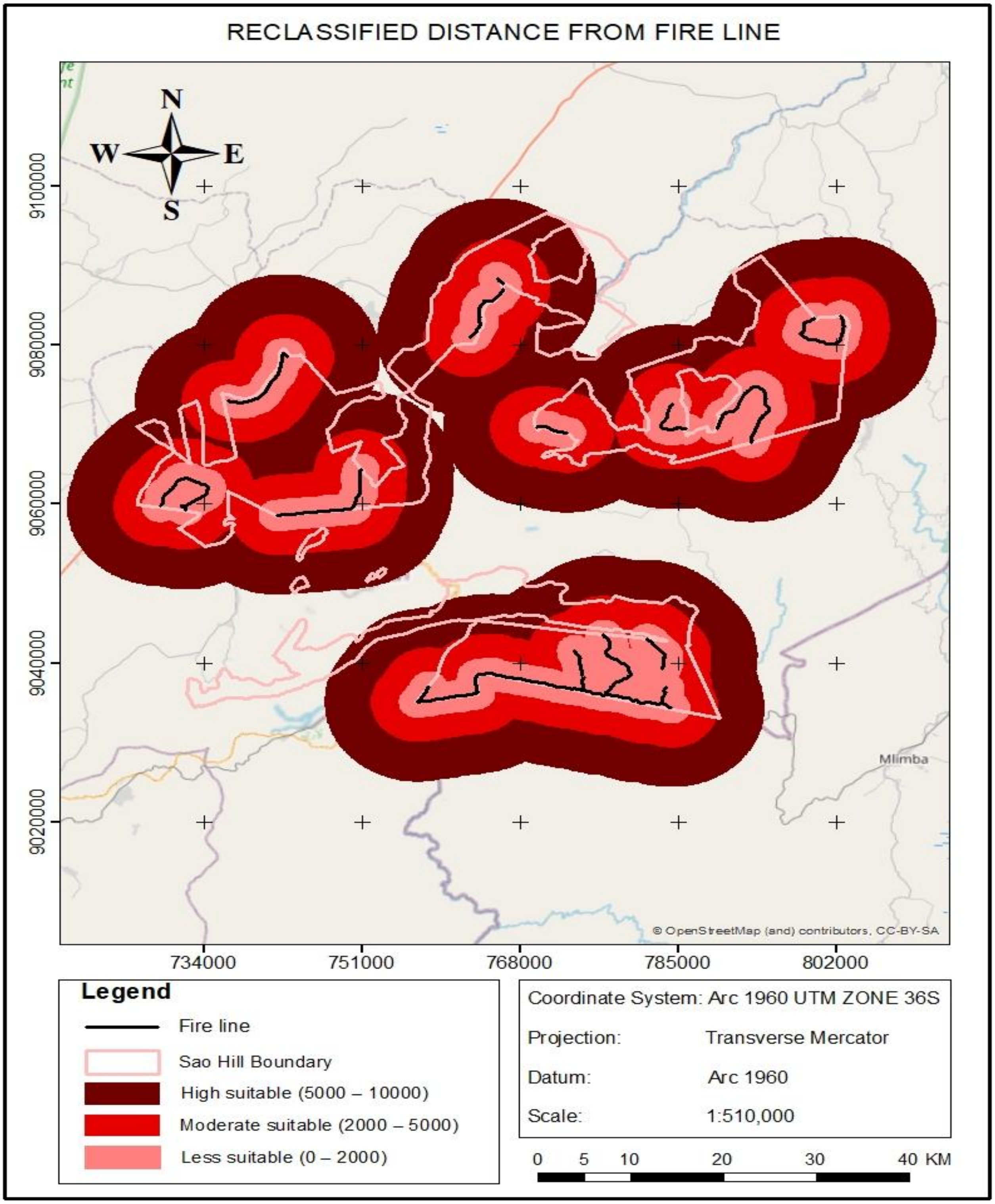

Figure 4. 5: Shows far distance from fire line high suitable and near distance is low suitable

Processing of roads data from openstreet show that areas near the roads are high suitable since it facilitates easy accessibility of movement in and out of the plantation. See figure 4.8 short distance from road high suitable than far distance from roads.

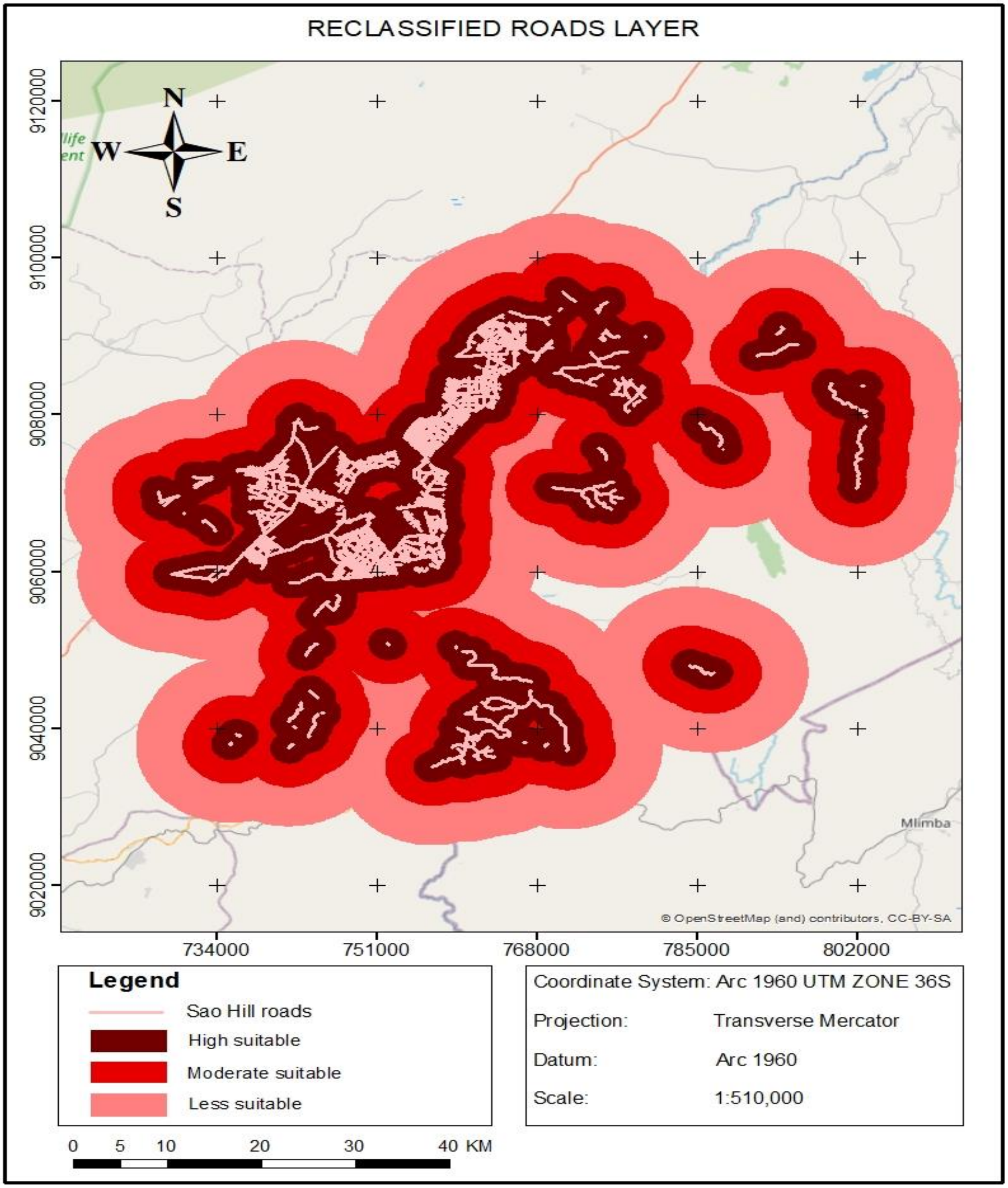

Figure 4. 6: Roads layer for accessibility within plantation

Suitability map is classified in three classes with different value and are differentiated by colors as shown in figure 4.9. Suitability map shows high suitable area to locate fire tower is at the edge of the boundary of Sao Hill Plantation.

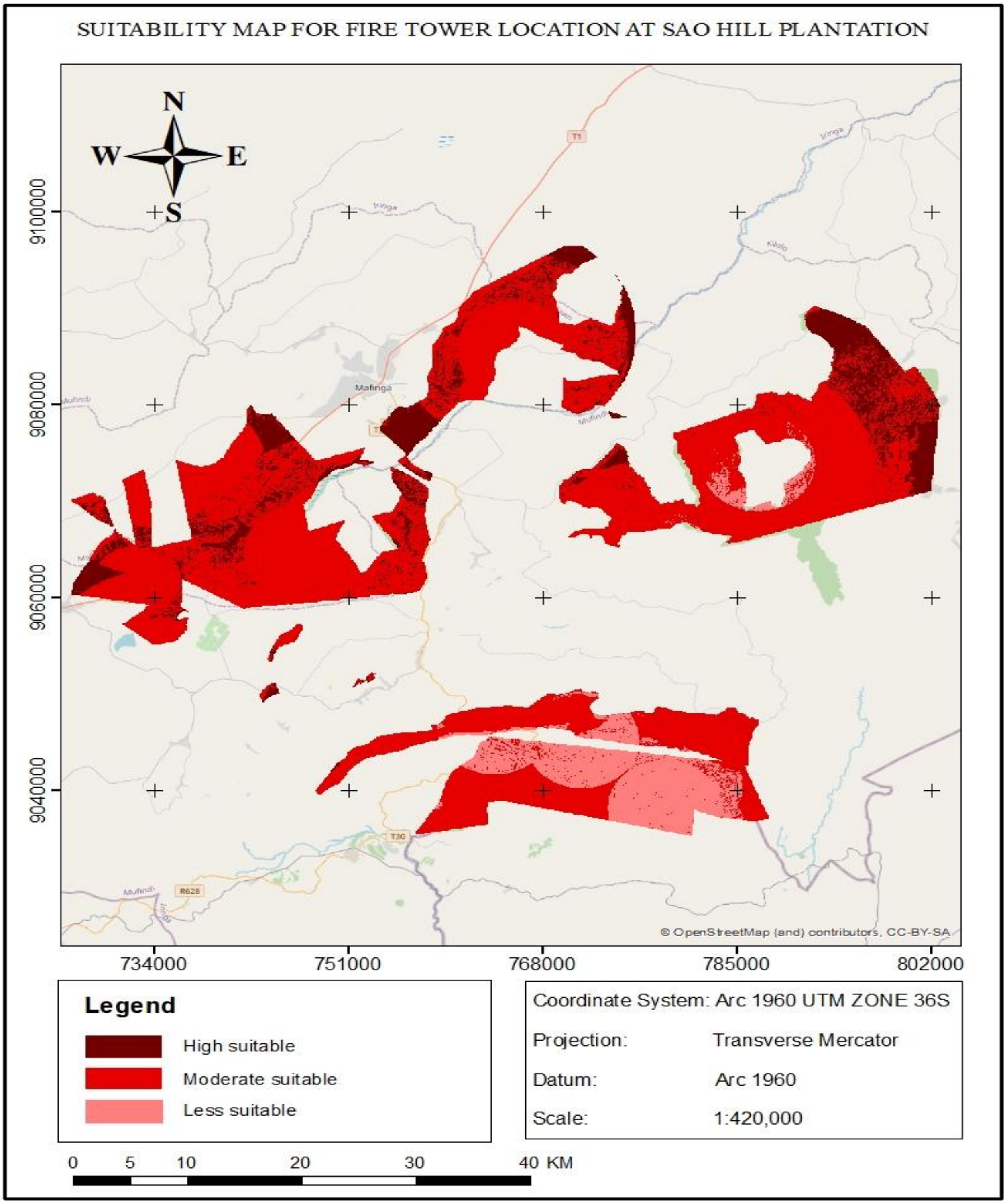

Figure 4. 7: Suitability map for location of new fire towers

4.4 Discussion of Results

Generally, the final output of this study is suitability map that show sites to locate fire towers. Suitability analysis performed and suitability map was produced because results of visibility analysis for existing fire tower shows that more than half of the forest land is not visible by existing fire tower. This means that there is insufficient of fire towers to accommodate the plantation.

Visibility analysis of all fire towers was performed in one run by considering the criteria provided in table 3.1. Visibility analysis shows that total forest area visible by current fire towers is 34,325.15 ha out of 135,903 ha of total forest area. Visible area is equal to 25.26% percent of the total area of the plantation, this means that there is 74.74% is not visible by the current fire towers. The forest area observed by Irundi mlimani, Irundi mlimani, Nzivi, Matanana, Itimbo, Kisilu, Ilasa, Wami, Mgololo and Kitete was 3933.79ha, 5182.45ha, 988.06ha, 3587.76ha, 4563.94ha, 1520.52ha, 1505.12ha, 7903.45ha, 861.69ha and 4278.37ha respectively. This research intended to perform suitability analysis in order to increase visible area to at least 70% of the total area as recommended in the study done (Akay et al., 2020). The results of this study indicate suitable area for fire stations to be in highly elevated locations similar to the study by (ibid) to facilitate proper monitoring.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Generally, from analysis it shows that existing fire towers are capable to view 34,325.15ha out of 135,903ha of the whole plantation. Therefore, this study addresses the objective to determine visibility capacity of existing fire towers. Existing fire tower visibility is not enough to accommodate whole plantation and there is a need to add new fire towers. Increase of number of fire towers it will also increase efficiency in monitoring forest land.

To increase efficiency for location of fire towers suitability analysis was performed by considering the following criteria elevation, slope, roads network, fire lines and land cover. This study addresses second objective by identifying the potential sites to construct new fire towers using AHP method as multi criteria decision making process, GIS and Remote Sensing techniques.

Suitability analysis results shows that high suitable location to install fire towers are high elevated areas that does not have fire towers. Addition of fire towers at these areas will increase the efficiency in plantation surveillance and monitoring. Monitoring will help in prevention of wildfire and post fire recovery.

5.2 Recommendations

One of the criteria used to identify suitable areas is land cover, this criterion is derived from satellite imagery (Sentinel 2A) remote sensing data. This remote sensing data have a challenge of clouds cover and resolution characteristics. In order to have high resolution data and free from clouds it is recommended to use Unmanned Aerial Vehicle (UAV) aerial image. Uses of aerial images from UAV it recommended since it provides high spatial resolution data with resolution in centimeter (cm) level. From these UAV data we can be able to derive more accurate data such roads data and fire line through digitization process.

In order to reduce incidence of fire and ensure sustainability development of the forest and natural resources, it is recommended to increase number of fire towers in the plantation.

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APPENDICES

APPENDIX 1: Accuracy Assessment Report

```
                 CLASSIFICATION ACCURACY ASSESSMENT REPORT
                 -----------------------------------------
Image File : c:/users/mapana/desktop/dissertation/dissertation data/image data/classified_2_class.img
User Name  : MAPANA
Date       : Fri May 19 01:25:42 2023


ACCURACY TOTALS
----------------

     Class   Reference      Classified      Number  Producers       Users
      Name      Totals          Totals     Correct   Accuracy       Accuracy
----------  ----------      ----------     -------  ---------       -----
   Class 0           0               0           0        ---         ---
   Class 1          73              60          52     71.23%      86.67%
   Class 2          77              90          69     89.61%      76.67%


    Totals         150             150         121

Overall Classification Accuracy =     80.67%

                 ----- End of Accuracy Totals -----



KAPPA (K^) STATISTICS
---------------------

Overall Kappa Statistics = 0.6113

Conditional Kappa for each Category.
------------------------------------

                              Class Name           Kappa
                              ----------           -----
                                 Class 0          0.0000
                                 Class 1          0.7403
                                 Class 2          0.5205


            ----- End of Kappa Statistics -----
```

APPENDIX 2: Fire Incidence 2022

Date	Location	Comp no.	Total area (ha)	Burnt Area (ha)	Tree Specie	Age (year)
20/08/2022	Nzivi			Less than 1	Pines	10
31/08/2022	Nzivi	1/R/12a1A	30.13	3.45	Pine	10
4/9/2022	Nzivi	1/NZ/8a9	37.84	1.03	Pine	3
14/09/2022	Nzivi			Less than 1	Pine	10
7/10/2022	Gulusilo	1/G2/29B	7.27	2.3	Pine	5
3/9/2022	Itimbo West	3/ITW1/21A	34.96	1.2	Pine	11
29/10/2022	Usokami	3/USO/10	15.22	2.02	Pine	10
31/08/2022	Saohill			Less than 1	Pine	4
27/10/2022	Kipapulanyeki	4/KP/11	36.6	35.3	Pine	10
27/10/2022	Kipapulanyeki	4/KP/12	2	2	Pine	10
27/10/2022	Kipapulanyeki	4/KP/13	24.9	23.4	Pine	10
27/10/2022	Kipapulanyeki	4/KP/14	25.7	23.6	Pine	10
27/10/2022	Kipapulanyeki	4/KP/15	16.8	11.7	Pine	10