University of Nairobi

School of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

A GEOSPATIAL APPROACH FOR ESTIMATING OPTIMAL (ROOFTOP) SITES FOR OFF –GRID CONNECTED PHOTOVOLTAIC (PV) CELLS IN PART OF NAIROBI CENTRAL AND NGARA, NAIROBI

By

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A Project submitted in partial fulfillment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi.

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DECLARATION OF ORIGINALITY

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DEDICATION

I dedicate this project to my mother, who has always taught me that Education is the most powerful weapon that one can ever have and for her unwavering support and encouragement in pursuit of my Master's degree.

This dedication also goes to my lovely daughter, Zariah. You are my biggest cheer leader. May this be an inspiration to relentlessly pursue knowledge, become a person of value and achieve the fullness of your destiny.

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ABSTRACT

Solar energy is the cleanest source of renewable energy and has good prospects for future sustainable development. More also photovoltaic (PV) systems have become less costly and building rooftops have become attractive for local power production. Identifying rooftops suitable for solar energy systems over large geographic areas is needed for countries to obtain more accurate assessments of production potential and likely patterns of development.

This project presents a method of estimating the optimal rooftop sites for off grid - connected solar panel cells in Nairobi using LIDAR data and high resolution satellite imagery. Roof aspect and slope was examined using ArcGIS. The methodology is semi-automatic since it was implemented as an ArcGIS model in Model Builder. In order to show its validity the model was applied in Parts of Ngara ward in Nairobi County with the criteria of slope and aspect used to locate suitable areas for installation of Photovoltaic system.

The resultant suitable cells that met the conditions were combined to determine the most suitable rooftop to mount PV solar panels. Within my study area it was found that 53% of rooftop areas had suitable aspect, 31% of roof areas had suitable slope and overall 48% rooftop areas are suitable for PV systems. The result presented is a map showing the most suitable rooftop locations within the study area for solar panels installations. Other key factors to determine a suitable rooftop to mount photovoltaic solar panels i.e. shadow analysis and solar radiation were not considered in this study. It is therefore recommended that in a future study they could be incorporated.

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List of Abbreviations

ALS-	Airborne Laser Scanning
AOI-	Area of Interest
CSP –	Concentrating Solar Power
DSM –	Digital Surface Model
DTM –	Digital Terrain Model
ERC-	Energy Regulatory Commission
GIS –	Geospatial Information Systems
GPS –	Global Positioning System
GHGs –	Global Greenhouse Gas
IEA -	International Energy Agency
JICA –	Japanese International Cooperation Agency
LAS-	LASer (file Format)
LIDAR-	Light Detection and Ranging
PV –	Photovoltaic
RES –	Renewable Energy Sources
RCMRD –	Regional Centre for Mapping of Resources for Development
UNFCC –	United Nations Frameworks Convention on Climate Change

1 INTRODUCTION

Over time, discussions about climate change have been of high concern one of the reasons being; the sources of energy used are harmful to the environment and human life. Renewable sources of energy have been found to be efficient and energy saving compared to the non-renewable sources. For a period of time, it has been observed that fossil energy sources are finite and on the verge of extinction. Therefore, different governments and private energy providers have shown a keen interest in renewable energy sources and other possible energy models.

Global energy consumption has rebounded as renewable energy consumption continues to grow strongly in all end user sectors, i.e. power, heat and transport. The capacity of many renewable energy technologies including the wind power, solar water heating systems, biofuels, concentrating solar thermal power (CSP) and solar PV cells has increased at a high rate with wind and hydropower adding the newest capacities. Though minor to notice, technological cost reduction in the solar PV, wind turbines and biofuels processing technology, has contributed to the growth in renewable energy production and its utilization. Renewable energy policies and developments are potential factors propelling the creation of new industries and as such, generation of new jobs (Lanig et al., 2009).

Restriction for the installation of solar PV cells location should be taken into account for it is not each of the rooftop areas that are suitable for photovoltaic or thermal solar panels. In order therefore to determine such desirable conducive rooftops and guarantee the competitive ability of renewable energies, geospatial analysts demonstrate and provide knowledge since the global community dedication is to ensure there is sustainable energy growth and low greenhouse gas emission. With the ever-increasing consumption and need for energy in relation to the global environmental concern, new technologies and science knowledge are opening and exploring all the avenues in renewable energy.

Developing countries especially in Africa, have enormous potential in energy resources, but investments in renewable sources of energy is hampered by insufficient data and information to support policies for planning and decision making. Without reliable and quantifiable resources of information, prospective investors may tend to avoid the danger of solar project development activities.

Renewable energy has generated economic growth thereby reducing poverty, improving intra and inter generation of equity in remote areas, maintaining and improving the countries per capita well-being and as a result, sustainable environment and energy. In rural areas, renewable energy increases access to basic energy services including lighting, communication and water pumping. PV household systems, solar pumps, wind turbines and biomass-based systems are employed in homes, schools, agricultural farms, hospitals and small industries in rural areas as an off-grid power supply for development.

1.1 Background to the project

The increase of renewable form of energy is a means of making sustainable energy supply possible. The UN report on climate change stated that the biggest polluter to the environment is the burning of non-renewable energy sources such as coal, gas and oil and the consequence release of carbon dioxide gas into the atmosphere(Ludwig et al., 2008) .In addition to the global issue of climatic changes, Kenya is a country without fossil energy until recently when some was discovered in Turkana. Kenya's energy sector is predominantly constituted of the traditional biomass energy and imported petroleum to fulfil the energy needs of the rural homes. Consequently, the country faces problems associated with the use of traditional forms of biomass and exposure to unstable oil import prices.

In the year 2004,the Kenyan government introduced Sessional Paper no.4 of 2004 in the energy sector which was aimed at expanding energy sources and supporting the development of renewable energy technology in the country (Ministry of Energy, 2004). The Energy Regulation Commission (ERC) was also formed as the body responsible for regulatory stewardship of the sub-sectors of electricity, petroleum and renewable energy in Kenya through the Energy Act NO.12 of December 2006. The goal of the law was to encourage the growth of renewable energy technology and international cooperation on renewable energy related programs.

In addition, the Act was intended to facilitate mainstreaming of the exploitation of renewable energy resources use in electricity generation and transportation (GOK, 2012; Oloo et al., 2015).In the year 2010, Kenya adopted a feed-in tariff, based on the awareness that renewable energy sources (RES) can be used as a source of income and employment creation, over and above contributing to the supply and expansion of electricity generation sources (Oloo et al., 2015).

1.2 Statement of the problem

Solar technology is based on the modality of the usage of solar energy. Efficiency of a solar energy collection system is determined by the robustness of solar radiation. The difference between photovoltaic and solar thermal technology is that photovoltaic module enables direct transformation of solar radiation into electricity whereas the solar thermal technology exploits the inherent thermal energy of solar radiation, and they are mainly used for heating water and central heating (Lanig et al., 2009).

The existing methods of fossil energy exploration using geophysical and geo-electrical techniques and its consumption are expensive, time consuming and pollutant to the environment and biodiversity, hence there is a need to exploit new technologies of remote sensing and GIS in the exploration of renewable solar energy using the photovoltaic cells. Solar energy should be harnessed using solar panels in places with suitable elevation, aspect, slope and high solar radiation, the goal being to find rooftops that are flat and have a slope that is not too steep for installing solar panels (Ludwig et al., 2008). This will supplement the highly erratic and unreliable fossil energy for domestic, industrial and agricultural use.

In Kenya the energy demand rate supersedes the productions rate hence Kenya Power and Lighting Company in many occasions ought to regulate and ration power consumption to its customers. This has however had impacts on to the production companies that are entirely dependent on such energy sources in order to meet their customers' demands. Energy is the driving factor to improve any country's economic status and therefore by rationing such important basic commodity towards the development of a country, implies that development is hampered.

A country being in a state of darkness for long durations of time due to maintenance and repair, retards' their production rate and thus the country's economy is deemed not to rise. With the availability of immense solar energy potential, technological know-how and reduced cost in acquiring photovoltaic solar panel cells, citizen's standards of living can be improved and the country's economy boosted as there will be enough power energy to drive industrialization at a lower cost while conserving the environment. This is in relation to the reduced amount of carbon dioxide gas emitted to the atmosphere compared to the current trend of using non-renewable energy sources.

1.3 Objectives of the study

Main objective

The main objective of the study was to develop a criteria for locating suitable existing rooftop sites for installation of photovoltaic cells.

Specific objectives

a) To identify the best factors to be considered in selection of suitable existing rooftops for photovoltaic cells installation
b) To assess the suitability of a rooftop for solar installation.
c) To create a model that can be used to determine the best rooftops to mount the PV panels, given their characteristics.

1.4 Justification of the study

The cost of implementing photovoltaic (PV) technology is decreasing and at the same time, the efficiency of photovoltaic technology is improving. With this in mind, it follows that there may be an increased interest in investment into solar technology installations. Siting of these installations is typically informed by spatial data. With stereo satellite imagery and LIDAR data allowing for the broad-scale acquisition of detailed elevation and surface models, decision makers considering these solar options may want to know if it is worth investing satellite image acquisition. While this may not be practical for individuals curious about their home's potential, private and government entities will be interested to learn about the return on the investment of acquiring high resolution data and its impact on solar site suitability surveys.

In Kenya, attempts have been made to evaluate the potential of solar energy generation. (Schillings et al., (2004) used data from geostationary satellite to model Global Horizontal Irradiation and Direct Normal Irradiation at a spatial resolution of 10km for the years 2000-2002. Their results were however not compared to ground measurements for validation and the resolution of the satellite images used was low. This study therefore aimed at using high resolution satellite imagery and LIDAR data to estimate optimal rooftop sites for off –grid connected photovoltaic cells in

Ngara and bearing in mind that different factors have an impact on solar energy potential. Ngara area was chosen because it contains single houses and block buildings, with different roof types.

1.5 Scope of work

The study was conducted in Nairobi which is the capital city of the Republic of Kenya. This location was chosen because of its accessibility to the researcher and availability of data needed to successfully carry out the research. In this study both radiation data and energy production were not determined. Shading analysis was also not performed as it is expensive to acquire LIDAR datasets for different times of the year.

2 LITERATURE REVIEW

2.1 Introduction

The Kenyan energy supply and demand is rapidly changing, and the local resources that are being exploited are becoming more costly. Moreover, the government and the local investing companies are reluctant in exploring the renewable sources of energy as they perceive risks in utilizing such sources as solar PV which is inexhaustible but expensive to developing countries. Globally, emphasis to replace the unclean source of energy such as fossil fuels in order to limit the emission of greenhouse gases into the atmosphere are underway as solar and wind power energy is becoming the fuel of choice.

Kenya is situated a stride the equator and extending four degrees either sides and as thus receiving a considerable high irradiance of solar radiation mostly in the northern and north eastern parts of the country. Such areas are normally known as the hotspots. Generally, the immense and abundant solar power is used for photosynthetic conversion whereas a significant amount is used for drying and heating of cereals, coffee and biomass. Assessment by Ministry of Energy indicates that the country receives on average 4.5 kwh per square meter per day thus the country is exposed to high radiation moderated by climatology and altitudinal differences (Gichungi, 2012).

Nguyen (2017) argues that understanding the rooftop photovoltaic energy potential is an essential criterion and of importance to utility planning, accommodating grid capacity, deploying financing schemes and formulating future adaptive policies. The involvement of electricity utility sector in the development of rooftop photovoltaic solar panels is of an important constraint. Such utility companies will therefore take responsibility and involvement in the conservation of the environment and its participation in important topics such as the carbon dioxide reduction (Solangi et al., 2011).

PV is perceived as a long-term energy option with enormous impacts on the present energy production and important environmental advantages. In many of the developing countries and more specifically to the sub- Saharan Africa – the hub of potential and inexhaustible solar energy, maximum energy potential if the PV cells are installed on every suitable rooftop in a region still remain unknown because data about rooftops in most areas does not exist as Ter Horst, (1994) stated in his findings. Therefore, in order to overcome these challenges, different techniques have been applied to combine the capabilities of geographical information systems and object specific recognition to determine the suitable rooftop area for photovoltaic solar panels installation. Wiginton (2010) suggested that by applying the ArcGIS extension, feature analysis it is possible to perform advanced feature classification algorithms for extracting rooftop features from many high resolution digital orthophotos. Spatial feature analyst is an extension in the geographical information systems software, ArcGIS which has been widely used in the assessment of the buildings potentiality to install PV solar panels and in land use. Spatial feature analyst was used in Greece to determine the building condition changes and suitability to install solar panels.

2.2 The photovoltaic (PV) system

Photovoltaic (PV) cells are the building block of all the PV systems, they are devices that convert sunlight to electricity. The PV cells are made in many different sizes and are often connected together to form a PV module that may be up to several feet long and a few feet wide. Modules in turn can be combined and connected to for PV arrays of different sizes and power output (Träder, 1986) . By themselves, the modules or arrays do not represent the entire PV system and as such, the system is complete when the components that take the direct current electricity produced by the modules and the balance of system (BOS) components such as batteries are incorporated into the system.

When light shines on a PV cell, it may be reflected, absorbed or pass through, but it is only the absorbed light that is used to generate electricity. The energy of the absorbed light is transferred to electrons in the atoms of the PV cell semiconductor material; the electrons thereby escape from their normal positions in the atom and become part of the electrical flow in an electrical circuit. The photovoltaic cells have a built-in electric field property that provides the force or voltage needed to drive the current through an external load such as a bulb (Tsai & Chen, 2012). Figure 2.1 shows the photovoltaic system and the relationship of its individual components.

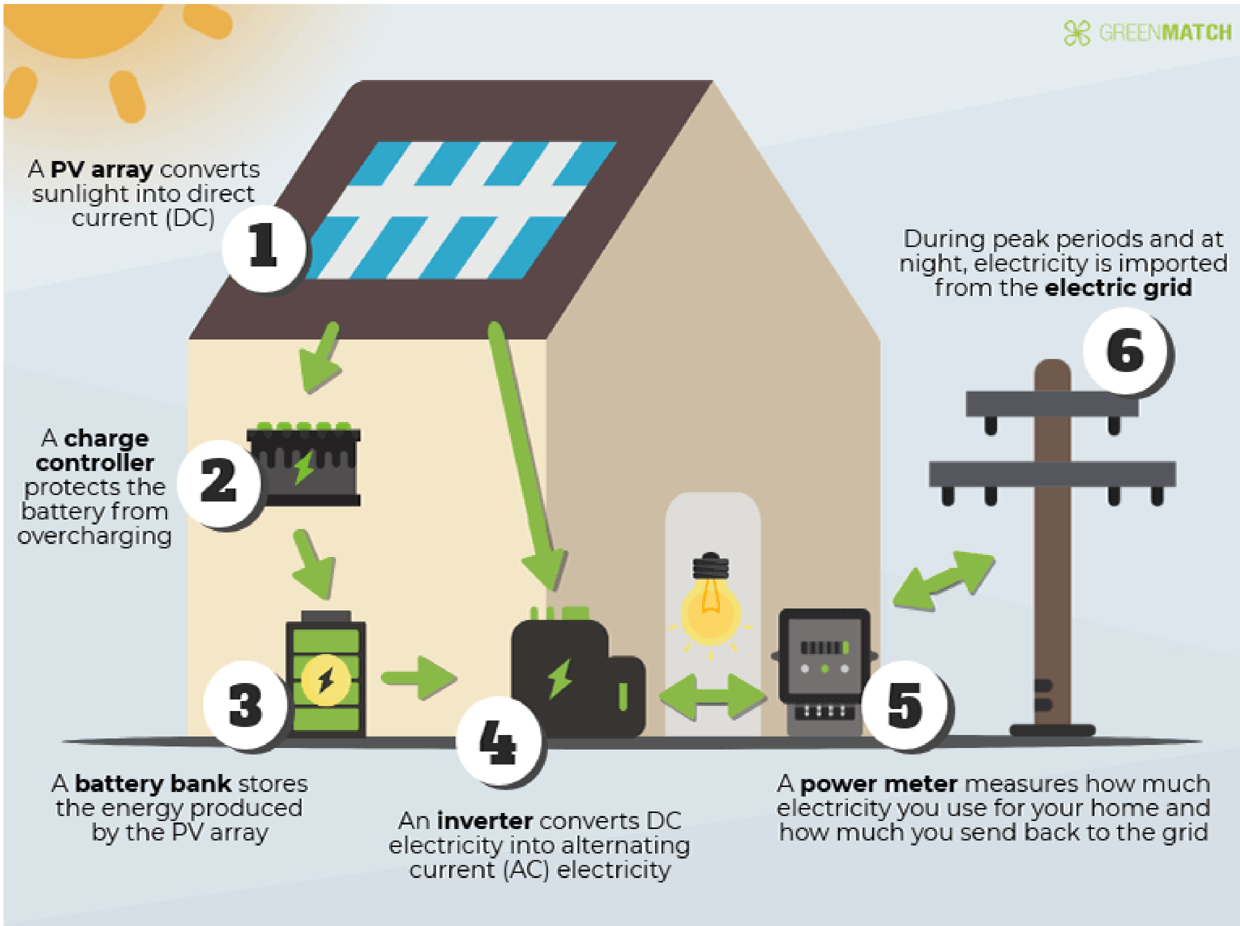

Figure 2.1: The photovoltaic system and the relationship of its individual components (Vekony, 2019)

2.3 Requirement for rooftop PV site selection process

Characterization of the rooftop geometry is the fundamental requirement for rooftop PV site selection process. According to (Mahide & Özgür, 2016) the slope and the aspect (azimuth) of the building roofs are determined together with the shading factor regarding surrounding features. An ArcGIS model was developed by (Bayrakci Boz et al., 2015) and it automates the procedure for identifying rooftop sites that are best for PV installation. Slope, aspect, and shading were the parameters considered. According to (Ludwig et al., 2008) five variables must be considered to determine the suitability of a roof for a solar installation., it is important to consider radiation, shadow and the required roof size and not only the slope and orientation of the roof . Therefore, key factors to be considered in selection of suitable rooftops are slope, aspect, shadow analysis and solar radiation.

2.3.1 Creation of a Digital Surface Model

Digital surface model (DSM) provides the height information of the surrounding vegetation and the buildings (Kassner et al., 2008). (Bayrakci Boz et al., 2015) performed an analysis from a digital surface model (DSM) with a cell size of one meter generated using the highest value within the cell. The highest value was used because it is best for adjusting the result to higher elevations when making a DSM. The DSM was then processed so as to zero in on rooftops only. The first step was to apply a one -meter buffer to the masked building data. This assisted in removing noise in the data, as LIDAR data is not reliable near the roof edges and a more suitable surface was also delineated since roof edges do not support PV panels.

2.3.2 Creation of masks and building detection

Mask layers are desirable to use since the analysis process of any data manipulation is limited only to that area of interest. The mask files contain values “1” in pixels that are to be included in the analysis process and values “0” in pixels that are not to be used in the analysis. For points that carry elevation, aspect and slope of the building’s rooftops data to be identified, the data has to be masked by the buildings outlines (Nguyen, 2017).

It is possible to detect buildings on both 3D point cloud and on resampled 2.5D grid data in airborne laser scanner data. Buildings are identified after the generation of a normalized digital surface model by subtracting the digital terrain model (DTM) from the digital surface model (DSM). Roughness, as defined by local height variance, curvature and height variations, are the most common characteristics used to distinguish buildings from other objects.

In addition, buildings can be detected in gridded ALS data by first eliminating the terrain pixels through smooth interpolation and then using a region growing algorithm to group elevated regions. Classes of the pixels in each region as roof shapes, ridges and buildings outlines are used to extract roofs (Jochem et al., 2009). Moreover, the performance of photogrammetric and laser scanner based were compared, and focusing on the determination of the buildings outline, lengths and roofs inclination, it was confirmed that laser scanner are most accurate for obtaining building heights, extracting planer roof faces and ridges of the roofs whereas photogrammetric methods yield better results in building outlines and length determination.

To detect buildings from the images, classification on height of difference between the DSM and DTM, the textural characteristic of the DSM, the image intensity and the shape of the segment can be used. The DSM of the area of study can be segmented into homogeneous areas using a regional segmentation based on the bottom up region merging and a local optimization process. The segments can be classified as buildings, trees and ground surfaces.

2.3.3 Aspect

Almost all the energy that powers the atmosphere and oceanic circulations, which generate the geological processes of weathering, erosion, transportation of materials and decomposition, supporting and sustaining life and growth is provided by the sun energy. With the earth's elliptical orbit around the sun and rotating at an inclined axis, inclination of the earth's axis of rotation brings about the issue of aspect to which every part of the earth faces the sun. Aspect has a strong influence on temperature thus affecting the angle of the sun rays when they come in contact to the ground and concentration of the sun's rays on the earth (Cummins, 2020).

Aspect can be termed as the direction in which the slope faces with respect to the sun and its influences is mostly felt in the mid-latitudes, while at the equatorial latitudes; the sun shines almost straight overhead**.** Aspect defines the downward slope direction of the maximum rate of change in value from each cell to its neighbor's, which is thought as a direction of slope. In the output raster the values of each cell represent the direction of the compass that the surface faces at that position .It is calculated in degrees, and in a clockwise manner from 0 to 360. Therefore, zero value is classified as north, east as 90, 180 as south and west as 270. If a given rooftop is flat, the value of -1 is classified as aspect because flat roofs do not have a downward slope (Mahide & Özgür, 2016).

An automated model for evaluating rooftop PV systems in ArcGIS using LIDAR was developed by (Bayrakci Boz et al., 2015). To obtain aspect values from DSM, the Spatial Analyst Toolbox aspect tool in ArcGIS was used. Afterwards, the resulting aspect file was reclassified into 5 classes, as shown in Figure 2.2.The majority filter was used after classification to eliminate noise, so a single value was generated for a given roof section. Based on the classifications, a polygon layer was created. The resultant area that was less than 10 square meters, was merged with the neighboring polygon.

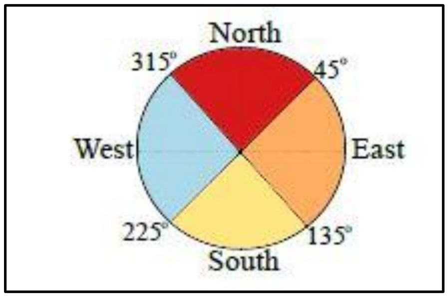

Figure 2.2:Reclassification of aspect values (Bayrakci Boz et al., 2015)

2.3.4 Slope

Slope refers to a surface's steepness. A 0 degrees value means no slope i.e. flat, whereas a value of 90 degrees implies an absolutely vertical surface. The surface slope is determined using the maximum change in elevation from a given cell and eight of its adjoining cells (Bairiki Boz et al., 2015). A classification system can be designed after the slope calculation in the Spatial Analyst toolbox to arrange the results according to their suitability for the implementation of the PV system. Optimal slope value of the rooftop is considered as 30° for an efficient energy supply by the use of solar PVs (Latif et al., 2012).However according to (Kassner et al., 2008) a roof inclination between 10° and 60° is acceptable.

2.3.5 Shadow analysis

The performance of a solar photovoltaic cell may be hindered by shade, if the shade falls on the sub range of the solar PV panel, the efficiency of the entire cell within a panel is lowered. It is therefore very important to consider the possible sources and causes of shade to a region or rooftop onto which the PV cells are to be mounted for the shading analysis. According to Lanig (2009) it is very important to study the self-shadowing of the roof area with constructional systems in addition to the possible shade caused from the vegetation in the neighboring environment of the building .

A research project called SUN – AREA was carried out by the University Of Applied Science Of Osnabrück whereby a shading model was carried out by calculating the sun's position for the whole year for both the daily and the yearly variations of the sun. For each point on the DEM, a shading analysis took place in the annual variability and diurnal variation depending on the corresponding location of the sun. The findings were weighted and encapsulated based on the strength of the solar irradiation and presumed directly for the assessment of the suitability of the individual roof areas with respect to their solar suitability (Lanig et al., 2009).

Scholars and researchers have suggested a detailed and mathematical precise account of different shading algorithm analysis methods. According to Nguyen & Pearce (2012), a shading algorithm analysis starts by fixing of coordinate systems at a point of interest on the surface of the earth and then defining the position of the sun using the hour angle (ω), site latitude (Φ) and solar declination (δ). Thus the relationship of the expression of the sun's position in a spherical coordinate system of the local tilted plane undergoes two transformations;

- Transformation to the horizontal plane from the spherical coordinate system of the local tilted plane.
- Transformation to the equator from the spherical coordinate system of the horizontal plane.

Panchromatic aerial images can be used for shadow correction and to generate large scale true ortho-photo and therefore, in order to be able to correct for the illumination differences around the shadowed areas, a buffer zone can be created around such shadowed areas. Therefore, image enhancement techniques can applied around the building area and rooftops excluded from both the shadow areas and buffer zone. For correction using high resolution remote sensing images, quantitative analysis can be done using different values between the shadow pixel and their surrounding pixels (Zhan et al., 2012).

2.4 The current trends

In their research paper Kenny (2010); Nguyen & Pearce,(2012) observed a paradigm shift in energy policies and the use of dynamic carbon life cycle analysis to guide on energy choices. They also mentioned the increasing technology as the main contributor of competitiveness of solar PV, amongst other kind of renewable energy sources. Consequently, there has been minimal research work done on the regional and urban impacts on the utility and the changing environmental characteristics. With the most affected continent being Africa, since its development, there has been a decline in PV equipment and technological costs, though slightly.

The urban roof areas, solar exposures and the ability to stimulate solar availability given the topology, is important for planning, grid efficiency and policy making (Wiginton et al., 2010).In order to understand current energy needs and consumption trends, various algorithms have been developed to calculate solar photovoltaic (PV) potential on 2.5D raster data. A study conducted by (Nguyen & Pearce, 2012) suggested a new algorithm that incorporated both terrain and near surface shadowing effects on the beam components. It Scales down the diffuse portion of global irradiation, and makes us of free and open source GRASS and the module Solar irradiance and irradiation model in modeling irradiation.

2.5 Summary of related work

The first phase towards reliable solar potential calculations for the rooftops of buildings in urban areas is the use of geographic data for automated solar potential estimation. Many distinct model s have been proposed. (Ruiz-Arias et al., 2009) performed a detailed comparison of the best-known models for the estimation of solar potential and reported the Solar Irradiance and Irradiation (r.sun) model by (Šúri & Hofierka, 2004) as being one of the most reliable. The solar potential on rooftops in urban areas was analyzed by Voegtle et al., (2012). In order to estimate solar potential with the aid of masked roof segments (Kassner et al., 2008) represented LiDAR as 2.5D point-cloud.

The method for automatic plane detection of roofs in the 3D point cloud was introduced by (Jochem et al., 2009) using a solar potential estimation implementation based on the r.sun model. The clear-sky index (CSI) was used in their process. Transparent shadowing caused by vegetation when measuring the solar potential was introduced by Jochem et al., (2009). The ratio between the first and last echoes of the laser pulses was considered for the calculation of transparency. Such vegetation shadowing can be used only during the particular seasons when scanning is done. In order to predict the effect of rooftop shading and solar irradiance Levinson et al., (2009) used a more precise approach with the use of high resolution orthophotos and LiDAR, along with the vegetation growth model. For precise simulation of the vegetation growth, the authors had manually surveyed and classified the data. Therefore, it was only possible to study smaller metropolitan areas within a reasonable period.

3 METHODOLOGY

3.1 Study area

The study area for this project was part of Ngara Ward and part of Nairobi Central District in Nairobi County as shown in figure 3.1.

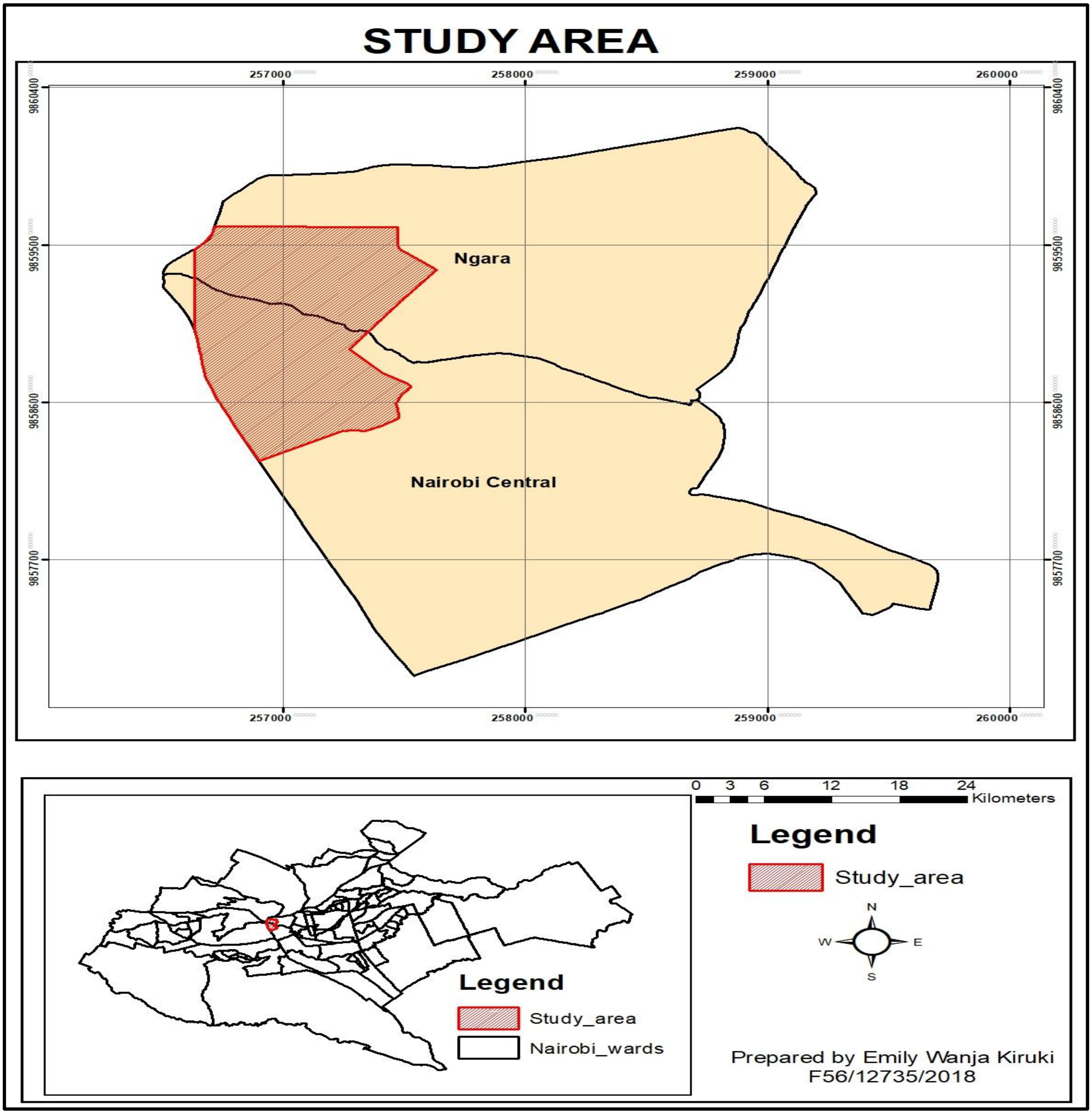

Figure 3.1: Study Area

3.2 Data and Data sources

In order to use the GIS software for optimal rooftop selection, data was collected from the sources shown in Table 3.1, processed and stored in the GIS system for analysis.

Table 3.1: The Geospatial data types used in the study.

Data	Description	Format	Sources
Satellite Imagery	Data depicting the areal coverage of the study area.	Raster	RCMRD.
AOI Shapefile	It shows and describes the AOI perimeter outline.	Vector	Survey Of Kenya
Lidar Data	Point clouds	Raster	Geomaps Africa

3.2.1 Software Requirement

The software used in this project include: -

- Erdas Imagine.
- ArcGIS software
- MS office

3.3 Work flow and Methodology

The methodology used to undertake the project was based on the overall scope of the project objective which was to develop a criteria for location of suitable existing rooftop sites for installation of photovoltaic cells. The scope involved data acquisition, creation of a DSM, aspect and slope layer generation and finally coming up with optimal homogeneous roof areas and an ArcGIS Model. Figure 3.2 shows the steps followed to achieve the objectives of the research.

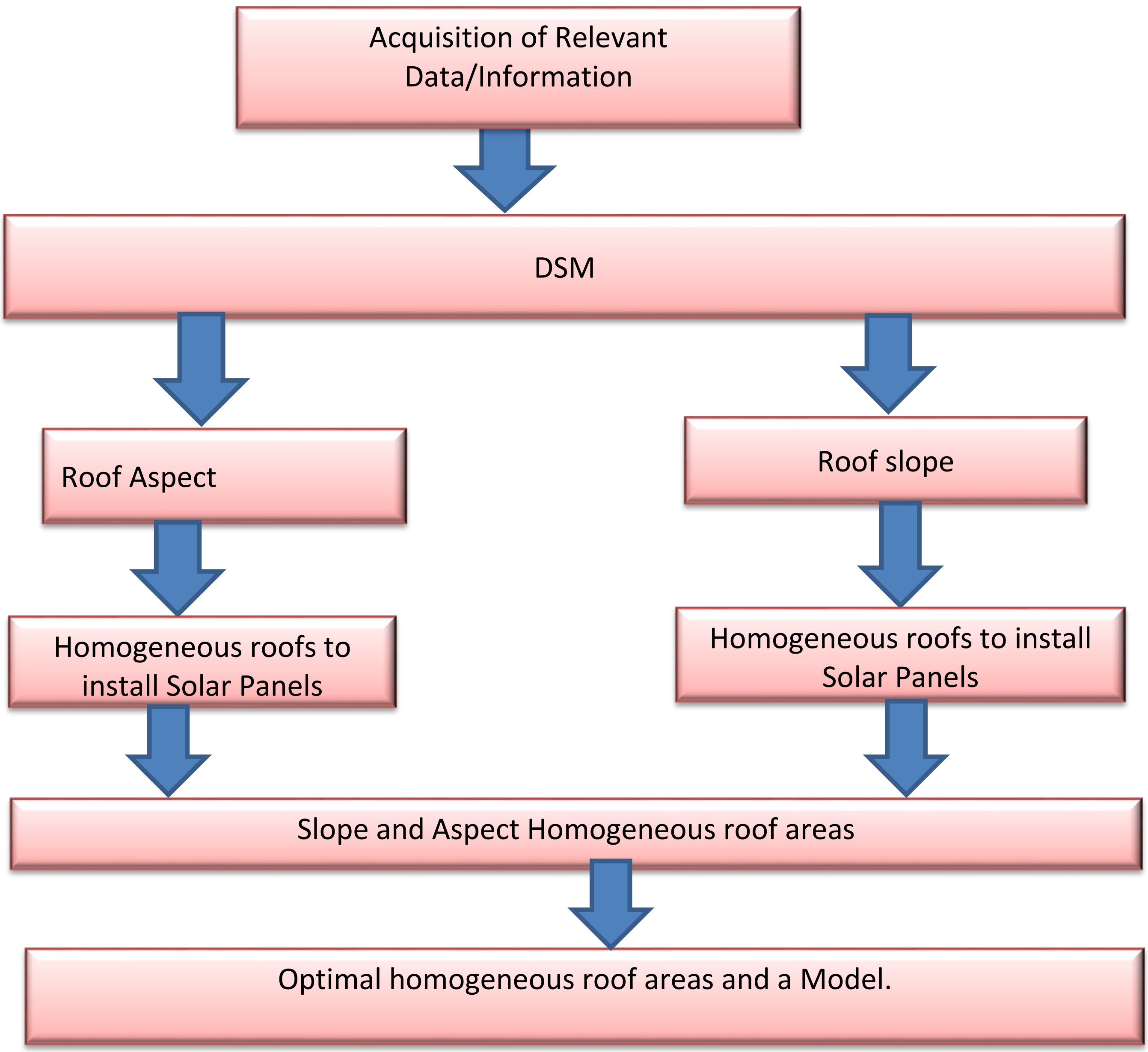

Figure 3.2: Methodology flow chart

3.4 Creation of a Digital Surface Model

The analysis was based on a digital surface model (DSM) derived from LIDAR data (see figure 3.3) and by using maximum value within the cell as shown in figure 3.4. The highest value was used because it is best for biasing the result to higher elevations when making a DSM. Building masks were generated using the resulting DSM.

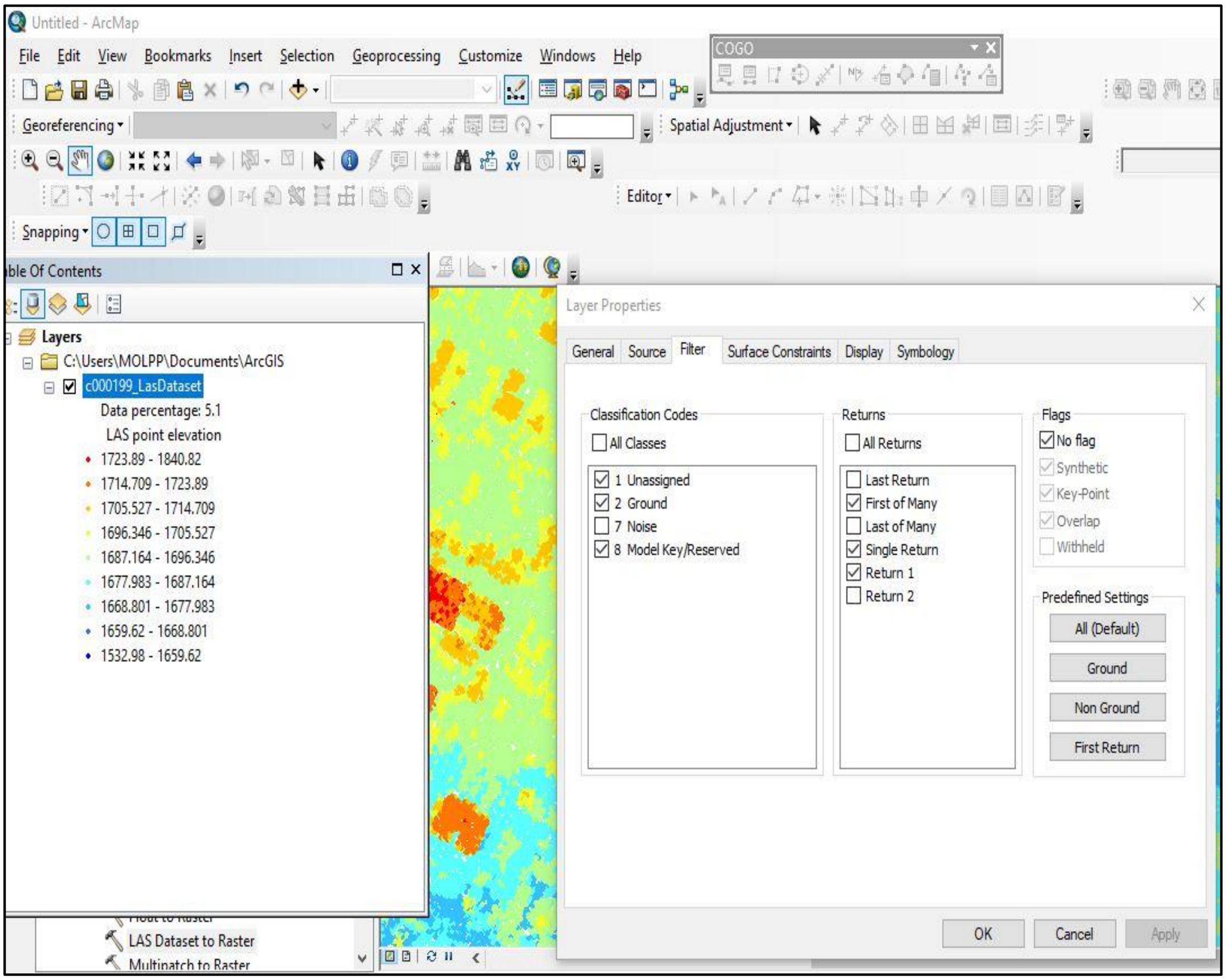

Figure 3.3: DSM creation using LIDAR data

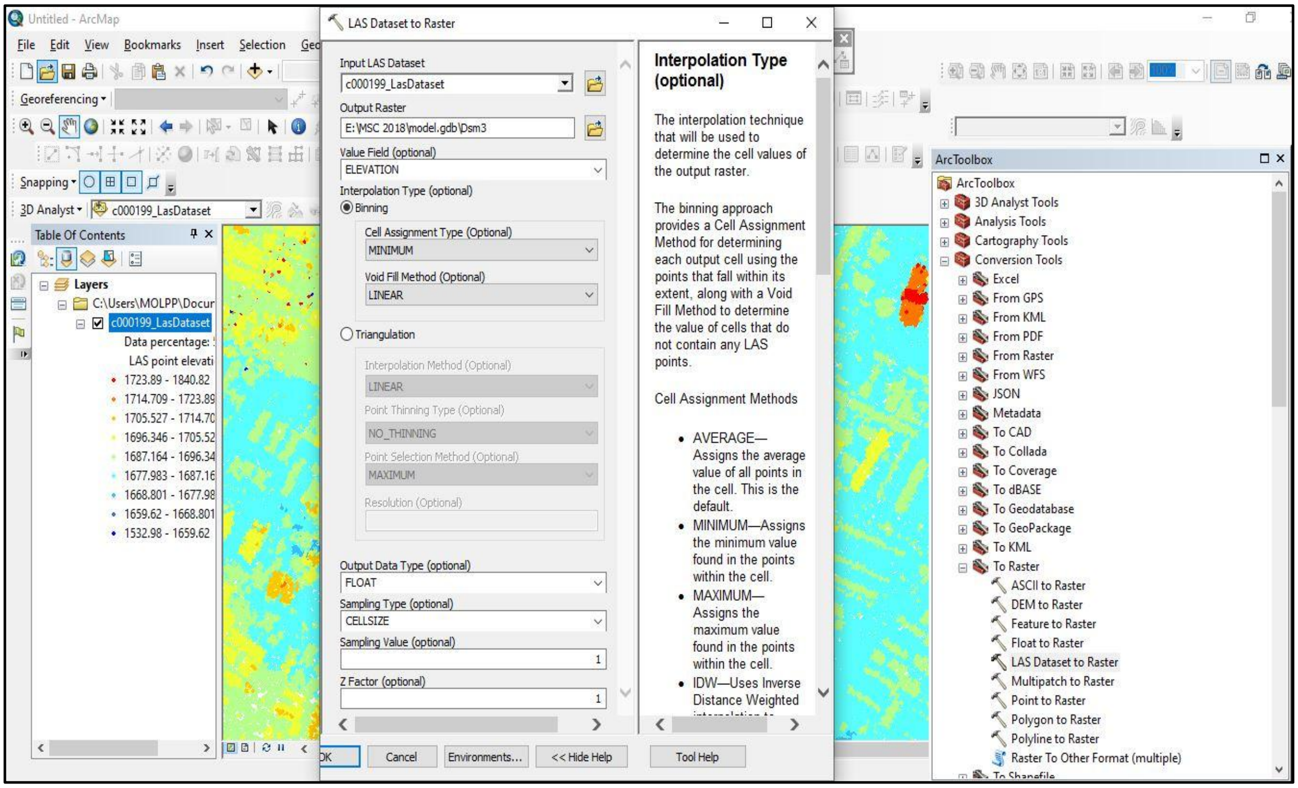

Figure 3.4: DSM creation using LIDAR data

3.5 Aspect

To find rooftops that were facing north, an aspect layer was created from the DSM. Aspect is calculated in degrees clockwise from 0, due north, to 360, due north again, coming full circle. The aspect tool in ArcGIS Spatial analyst tools was used to obtain aspect values from DSM. Figure 3.5 shows the resulting aspect file after reclassification into 10 classes i.e. Flat, north, north east, east southeast, south, southwest, west and northwest. In order therefore to select the most feasible roof aspect for photovoltaic solar cells installation, a constant raster was created to represent both the changing range in angles of north, north east, and north west directions and then a logical operation was applied to determine the feasible roof aspect.

Cells with North, Northeast, Northwest, were assigned the value of 1.If a rooftop is flat, it was given a value of -1.values between 0 to 67.5 and 292.5 to 360 degrees were used to zero in on the north facing rooftops. Since Nairobi is located in the Southern Hemisphere, the North facing aspect layer was considered because solar panels located on North-facing slopes will have a higher solar power output than those located on South-facing slopes.

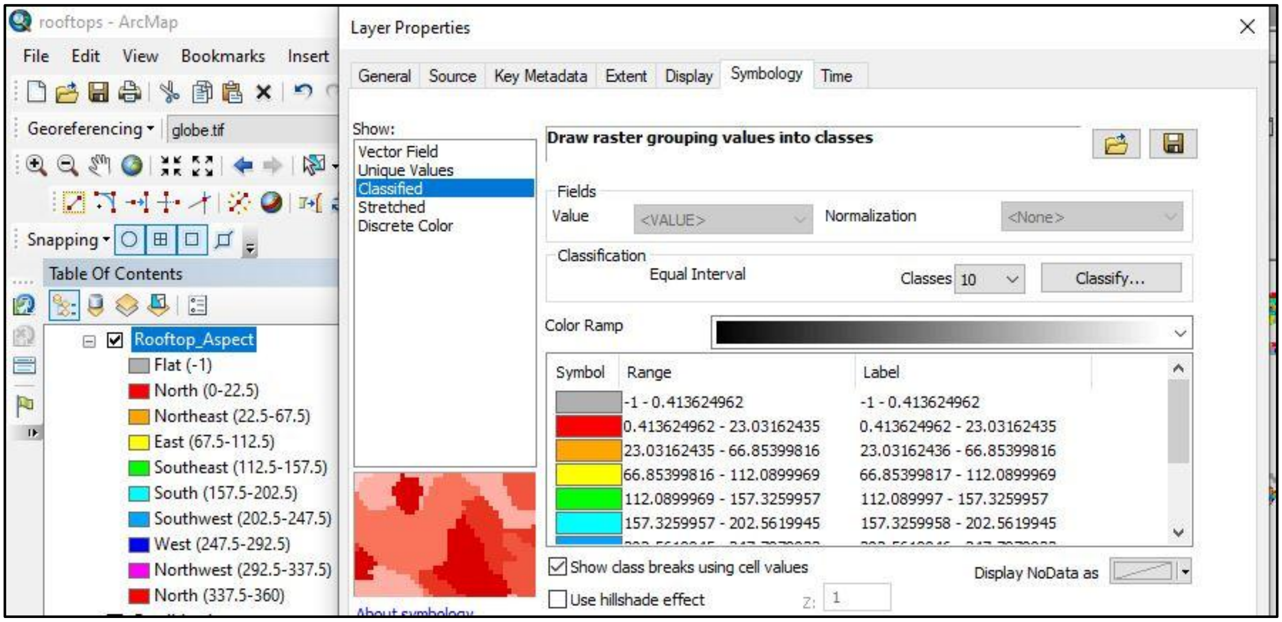

Figure 3.5: Aspect classification

3.6 Slope

The slope mask was generated in a manner similar to the aspect mask. The gradient or rate of maximum change in Z-value from each cell of a raster surface identifies the rooftop slope. For each cell, the slope tool module in ArcGIS extension spatial analyst, calculates the maximum rate of change in value from that cell to it neighbors. The output slope raster was in degrees, moreover, it can be calculated in two types of units i.e. percentage rise or in degrees.

It is therefore of importance to consider the location and characteristics of the area of study before determining the suitable slope angle. Moreover it would be unrealistic to mount a PV solar panel at a small angle, therefore neither a stepper nor gentler slope is conducive. In regard to the study area; a slope angle of between 30 to 45 degrees was used. See figure 3.6.

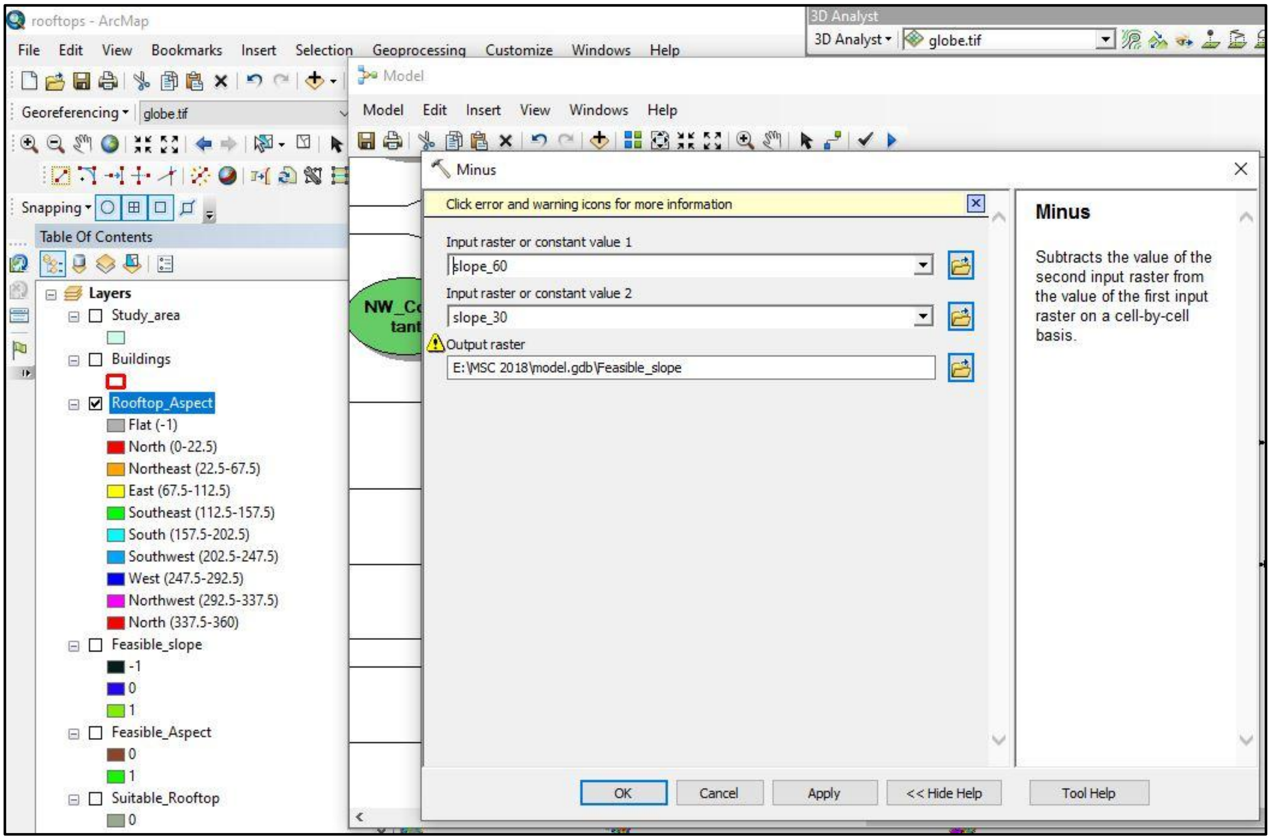

Figure 3.6: Slope calculation

3.7 Finding suitable locations

In order to be able to eliminate the unwanted rooftops based on slope and aspect, a model that selected the rooftops that had the desired characteristics while eliminating those that did not meet such was generated. Since the project main objective was to find feasible suitable locations for the photovoltaic solar panels, to attain that, all the binary raster of different characteristic conditions that were to be considered, were combined together into a final raster that took a value of 1 for rooftop sites that meet all conditions and value 0 for those that did not.

4 RESULTS AND DISCUSSION

4.1 Creation of DSM from LIDAR data

Figure 4.1 shows the results of the DSM that was created using the LAS dataset tools in ArcGIS. In order to gather information, the LiDAR sensor is mounted below an aircraft where it emits short infrared laser pulses towards the surface of the earth which fan-shaped across the flight path. The result of each pulse is multiple echoes or 'returns'. Usually, the first return will be received from the top of trees, buildings and vegetation and the last return is received from the surface of the ground.

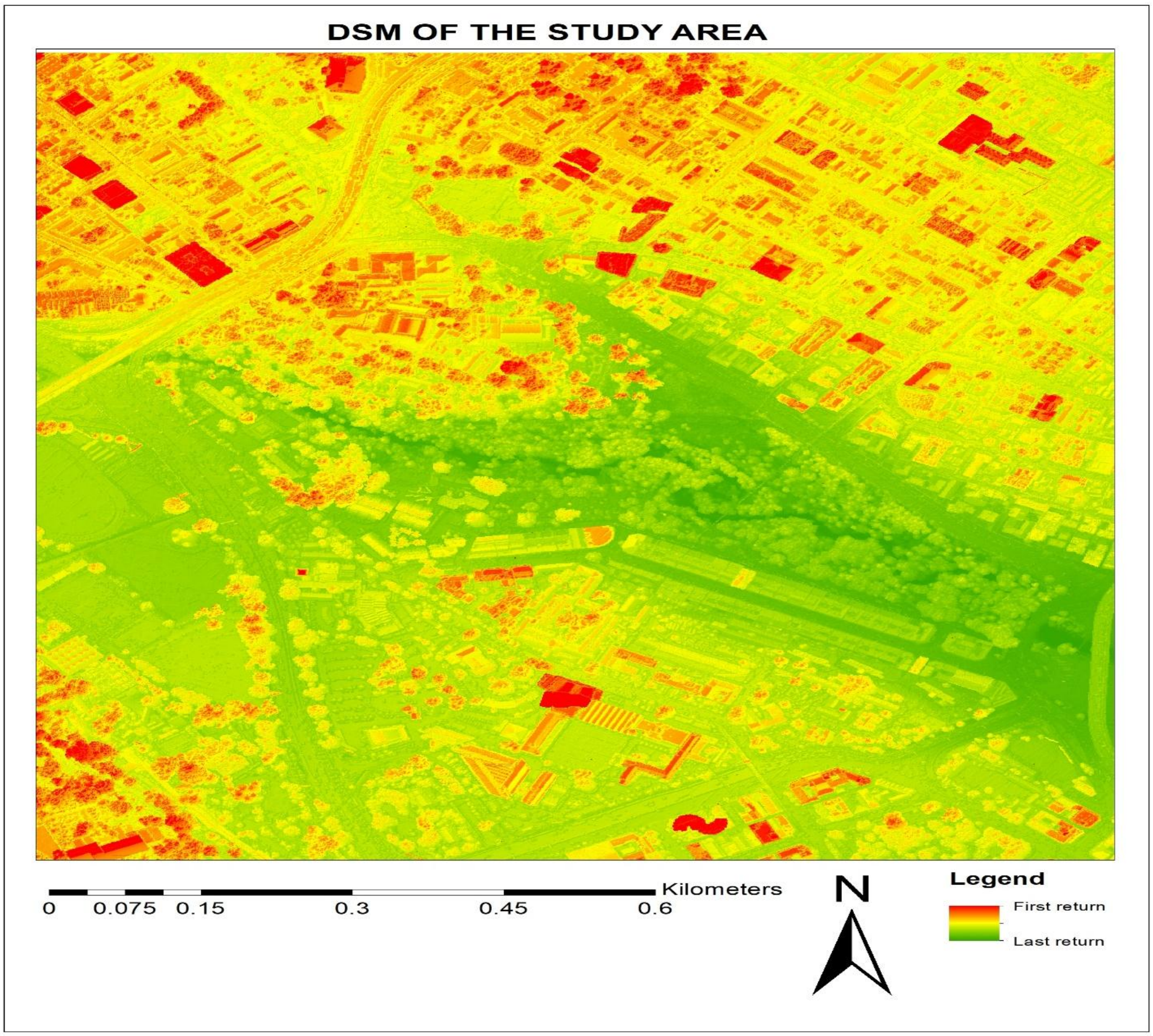

Figure 4.1: DSM of the study area

4.2 Masked rooftops

Extraction by mask is whereby cells of a raster that correspond to the area defined by a mask are extracted. The mask in this case was the digitized buildings and the raster was the digital surface model. The results of the masking are as shown in figure 4.2.

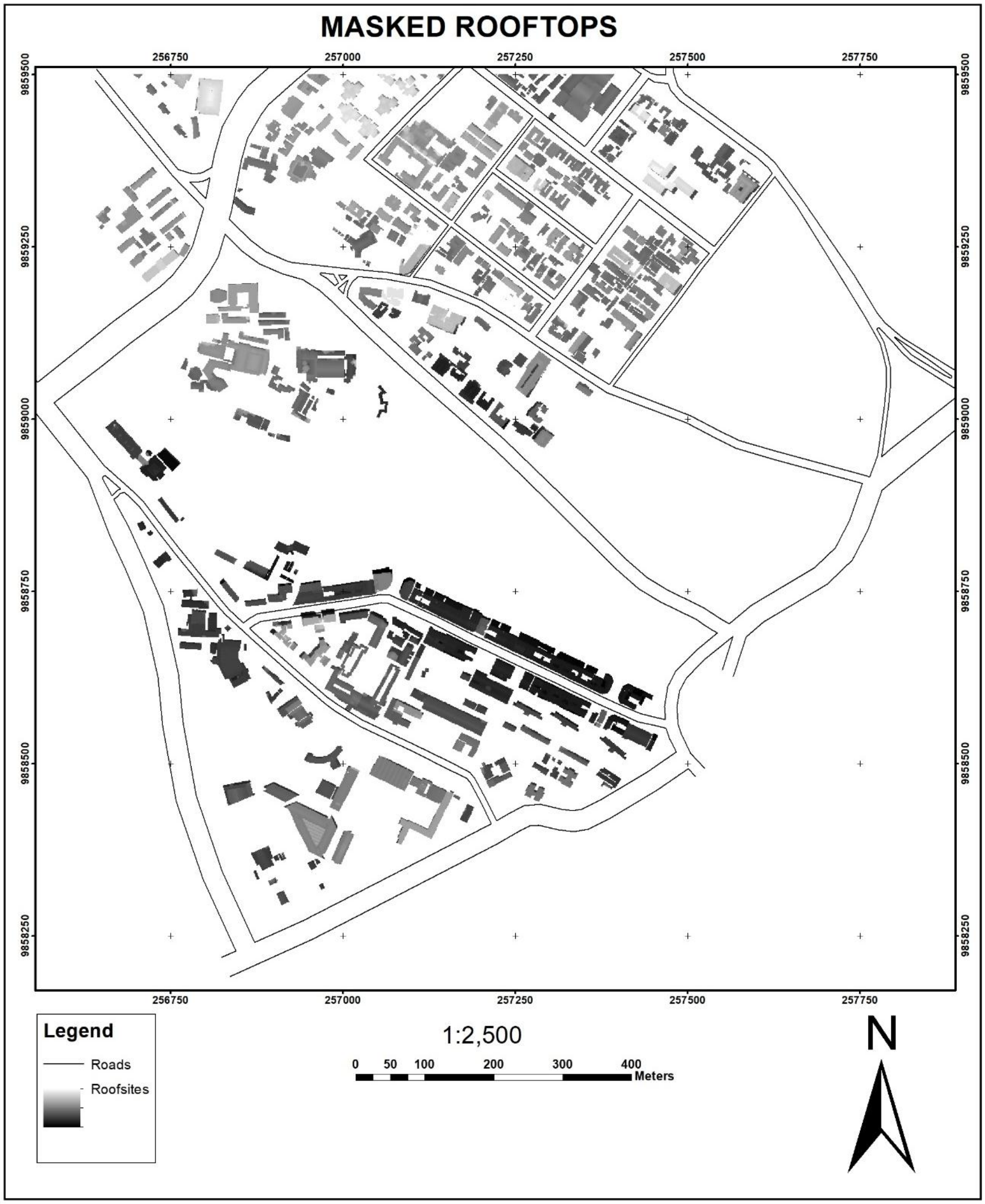

Figure 4.2: masked Rooftops

4.3 Aspect

Figure 4.3 shows the rooftop aspect from North to East to South all the way to West and then back to North again.

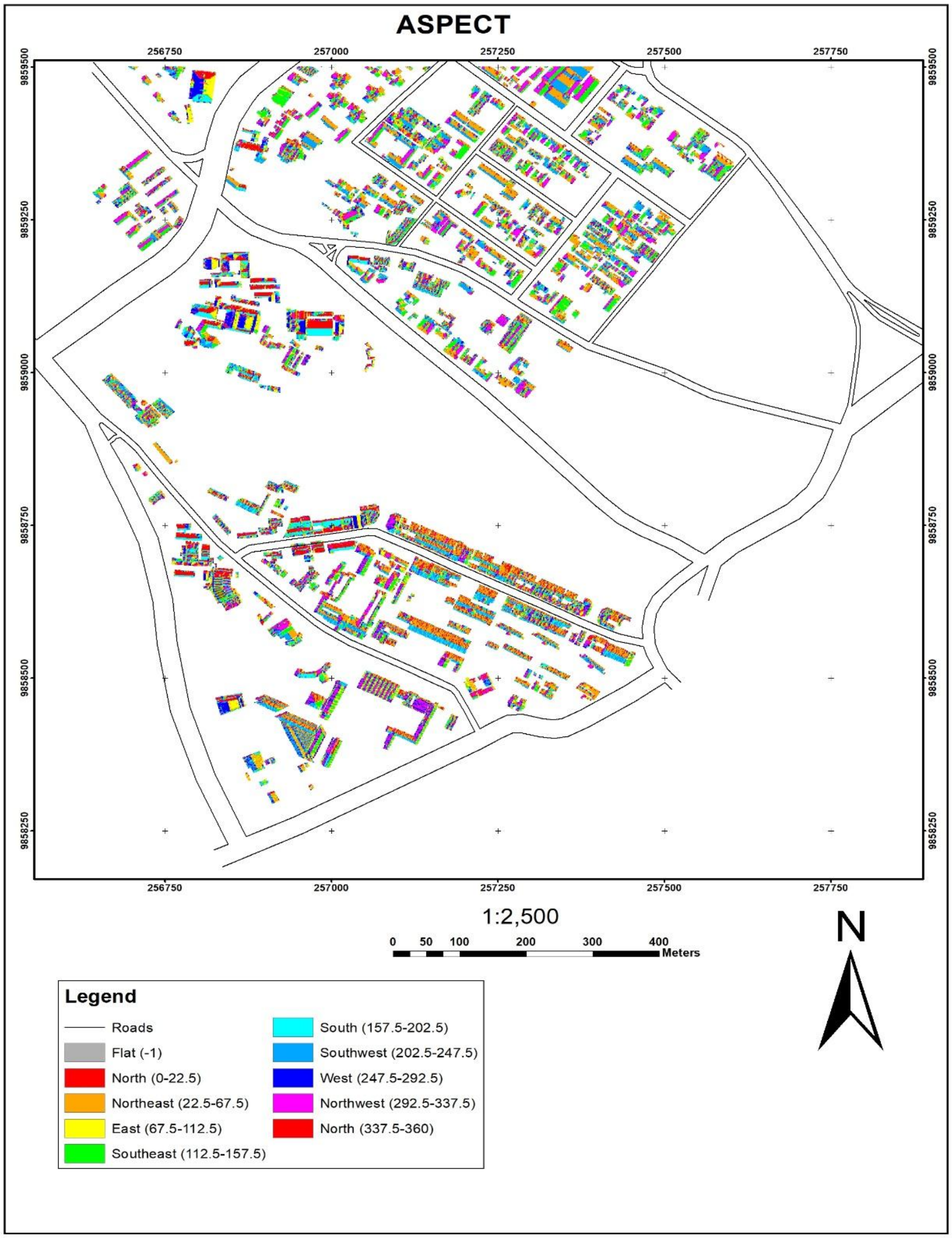

Figure 4.3: Aspect of the Study area

Since the main aim was to focus on north facing rooftops, classification of aspect results in figure 4.3 was done. Aspect identifies the downslope direction in which the slope faces and it is measured clockwise in degrees, moving from 0 to 360 degrees, hence north facing roofs lie between 0 to 67.5 degrees and 292.5 to 360 degrees. That range of values is what was used to classify results shown in figure 4.3 and results of that can be seen in figure 4.4. Color green represents north facing roofs while blue represents roofs that are facing all other directions but north.

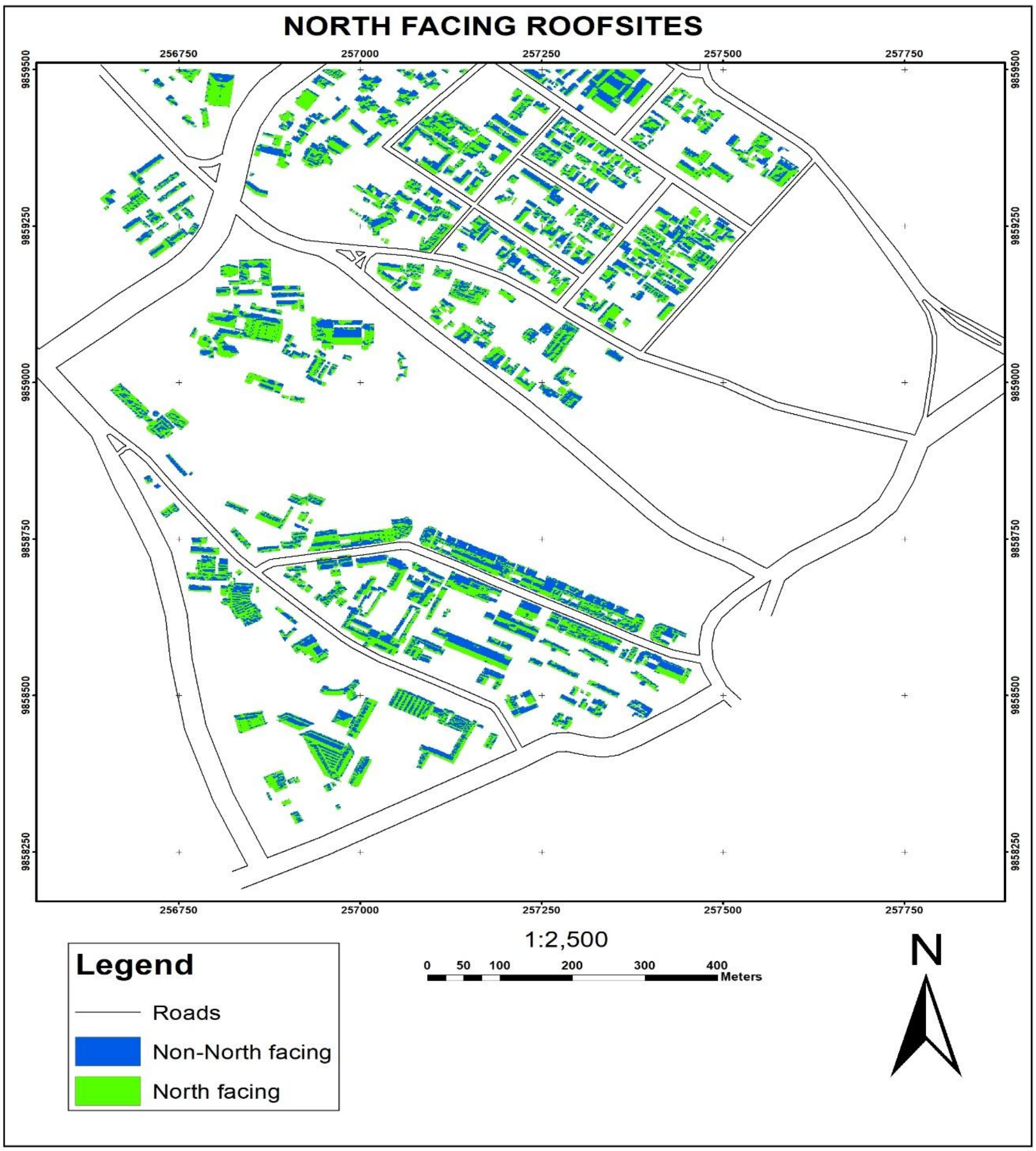

Figure 4.4: North facing rooftops

It is important to consider the roofs direction in relation to the sunshine while constructing to optimize the performance of the photovoltaic solar panels. Therefore the flat roofs and the North facing roofs were combined to come up with feasible aspect as shown in figure 4.5. Color green represents feasible aspect while color red represents non feasible aspect. This is to mean the color blue is a combination of the flat and north facing roofs.

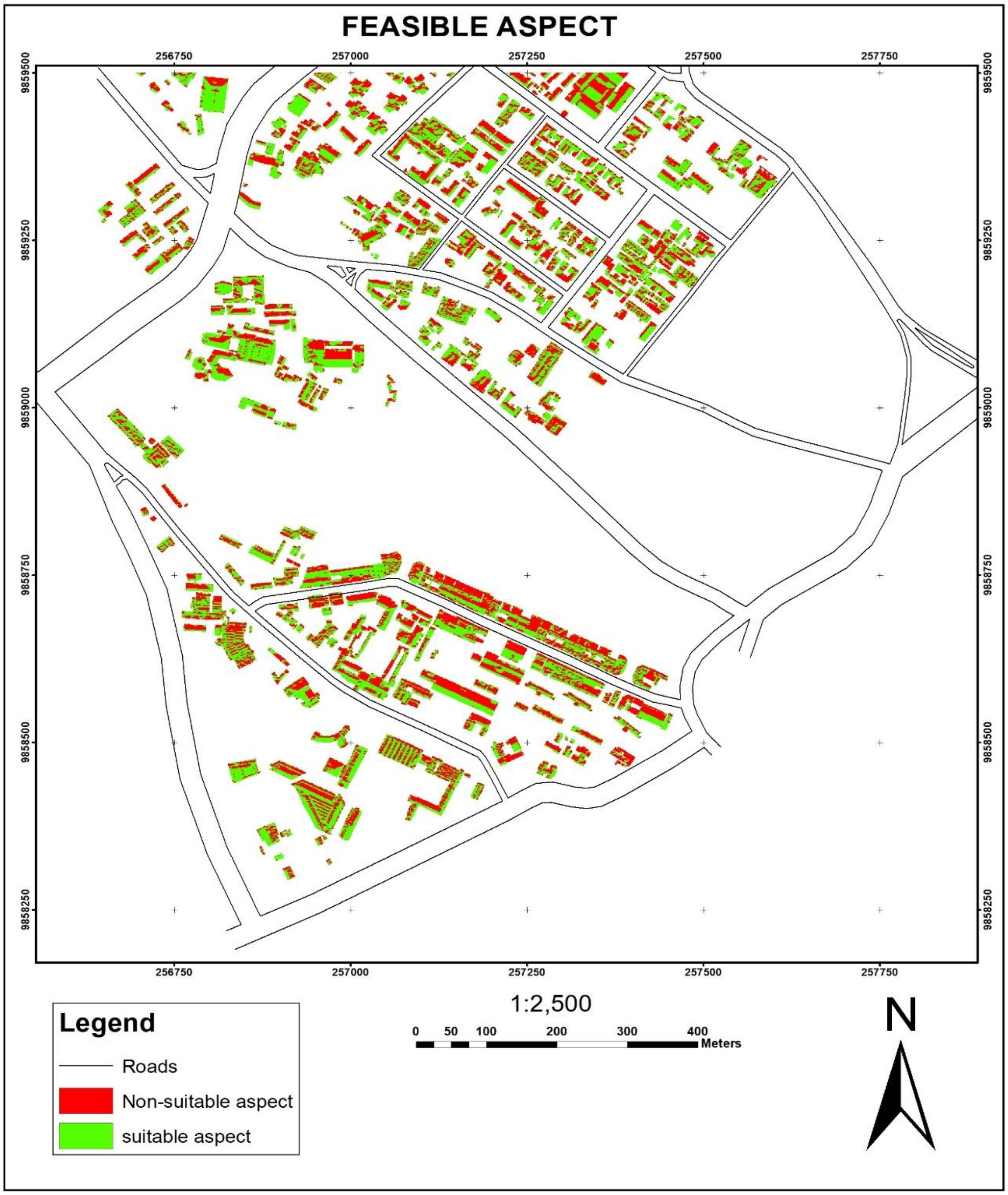

Figure 4.5: Feasible aspect

Out of the 171906 pixels analyzed, 91664 had feasible slope while 80242 pixels had a slope that is not suitable for installation of solar PV cells. It can therefore be noted that 53% of the rooftop sites as represented with color blue in chart 4.6 have a suitable aspect for installation of PV cells. This means they are north facing and flat. 47% however are not flat and are East, west or south facing.

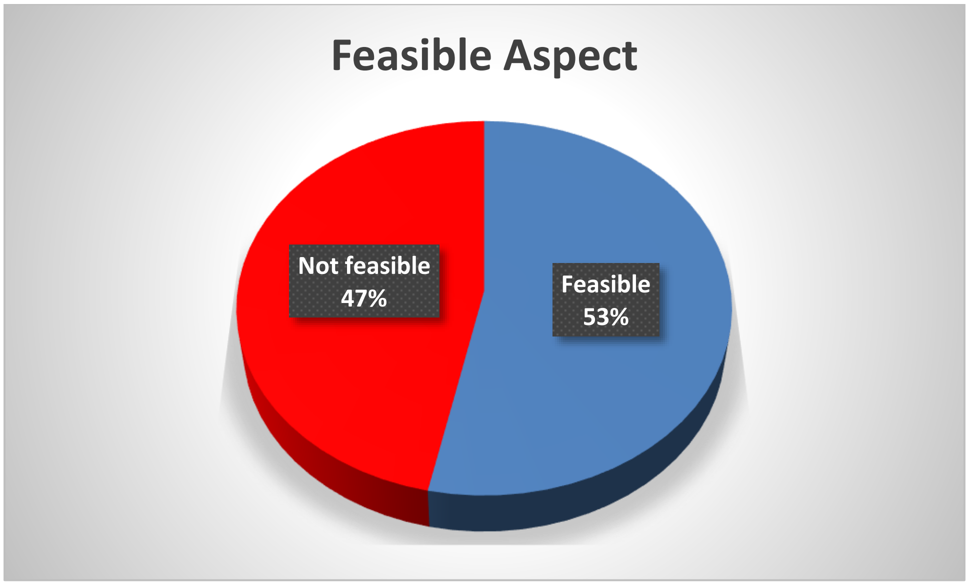

Figure 4.6 Feasible aspect chart

4.4 Slope

Results from slope calculation are as shown in figure 4.7. Red means very steep slope while green means a gentler slope. A Slope of between 30 to 45 degrees was considered to produce results as shown in figure 4.8

Figure 4.7: Rooftop slope

Figure 4.8 shows rooftops sites that have feasible slope that is 30-45 degrees in this case. Green represents the most suitable slope, pink shows the least suitable slopes while blue shows the unsuitable roof sites.

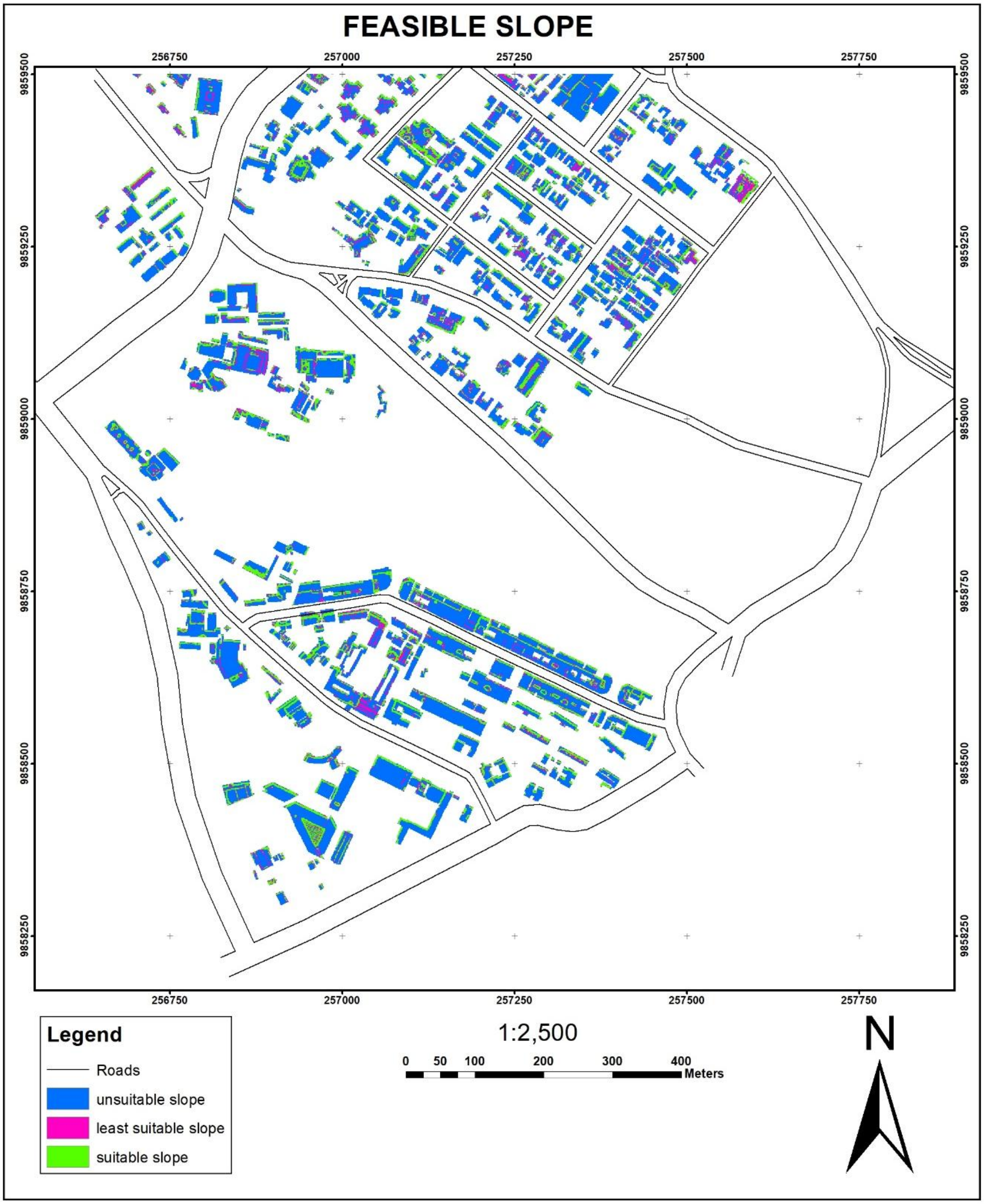

Figure 4.8: Feasible rooftop slope

Out of the 171906 pixels analyzed, 117326 were unsuitable while 18683 were least suitable and 35897 were suitable. From chart 4.9, 68 % of the roof sites as shown using color blue did not meet the threshold of 30 degrees to 45 degrees required for installation of pv cells.11% as shown using color red are least suitable while 21% are most suitable.

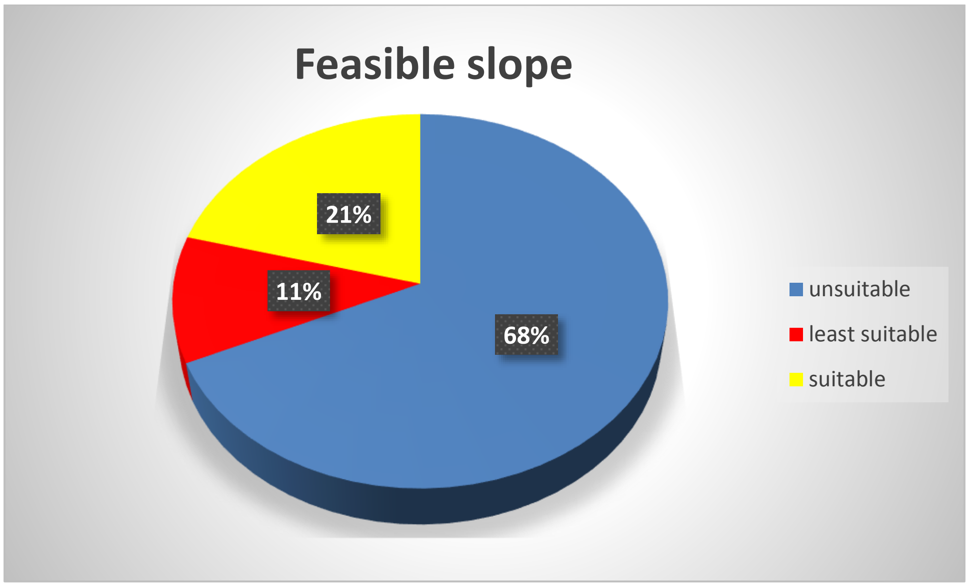

Figure 4.9 feasible slope chart

4.5 Suitable rooftops

Feasible aspect as shown in figure 4.5 was combined with feasible slope as shown in figure 4.8 so as to come up with suitable rooftops for installation of solar PV cells as shown in figure4.10 .Green shows the suitable locations , blue shows the most suitable rooftop locations while pink shows the unsuitable locations.

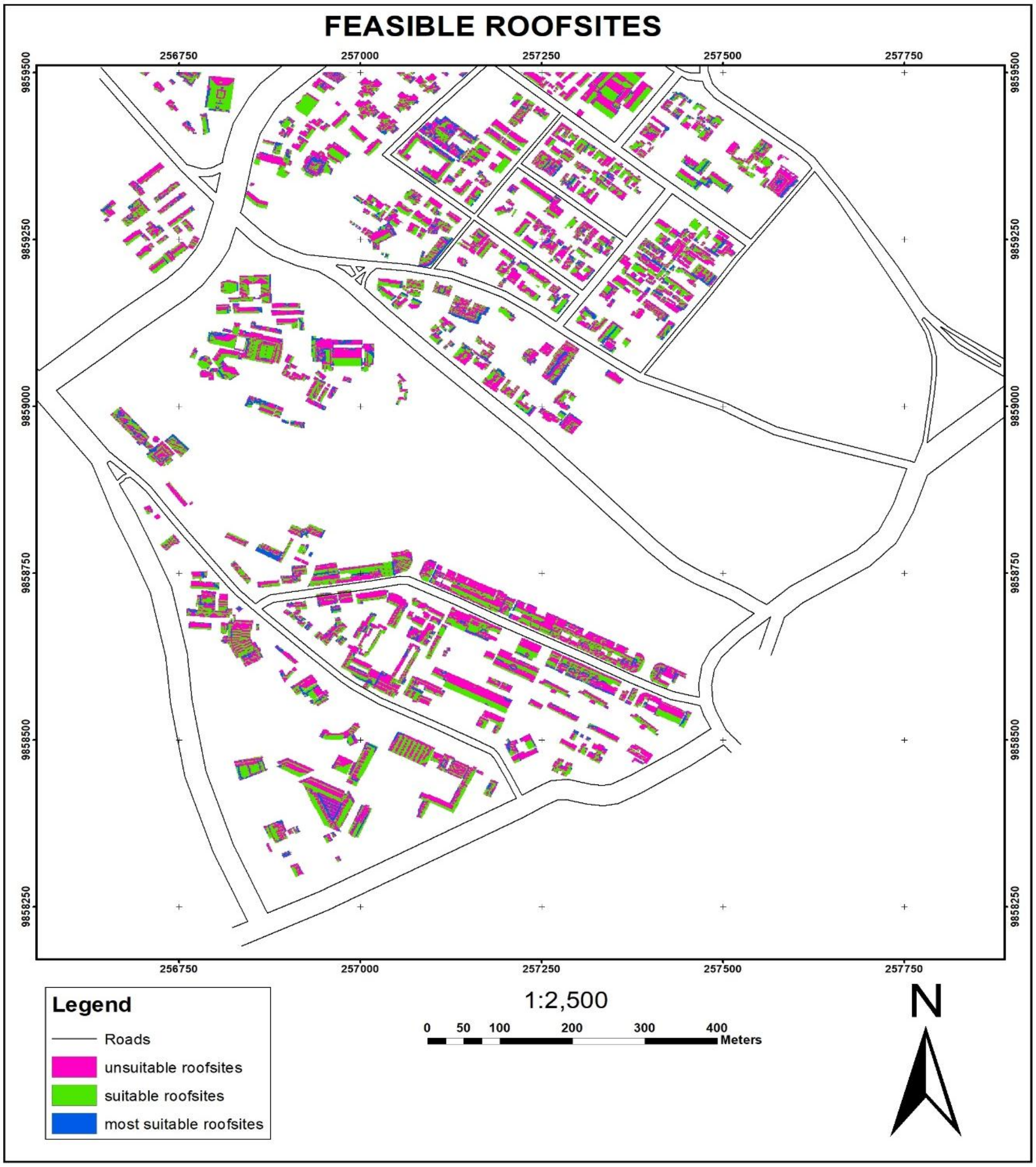

Figure 4.10: Suitable rooftop sites

Chart 4.11 shows the suitability of roof sites for solar PV installation in the study area was at 48% percent. 171906 pixels were analyzed and 89972 pixels were unsuitable while 65844 were suitable and 16090 were most suitable.

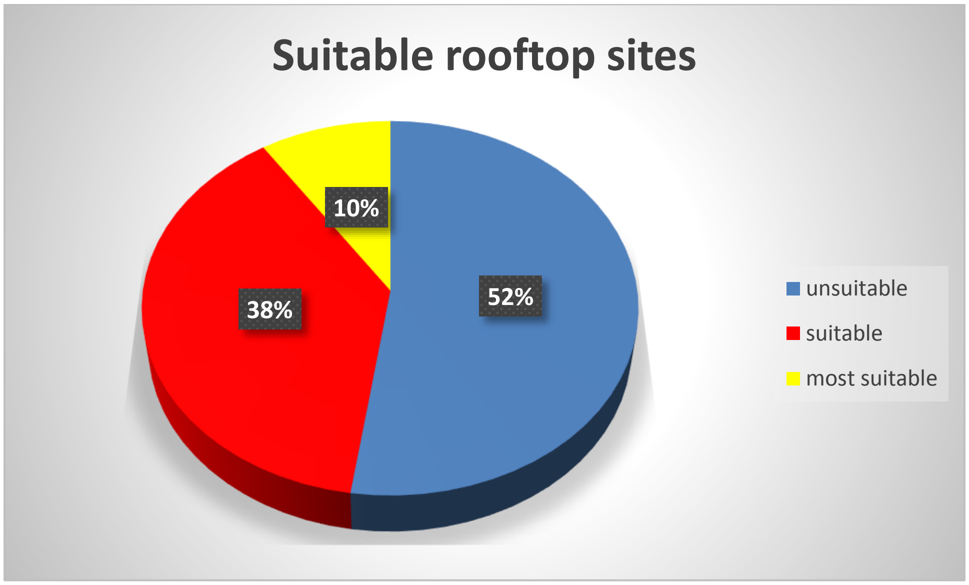

Figure 4.11: suitable rooftops chart

4.6 Model

Figure 4.12 below shows the model generated for determining a roof's suitability to mount a photovoltaic solar panel.

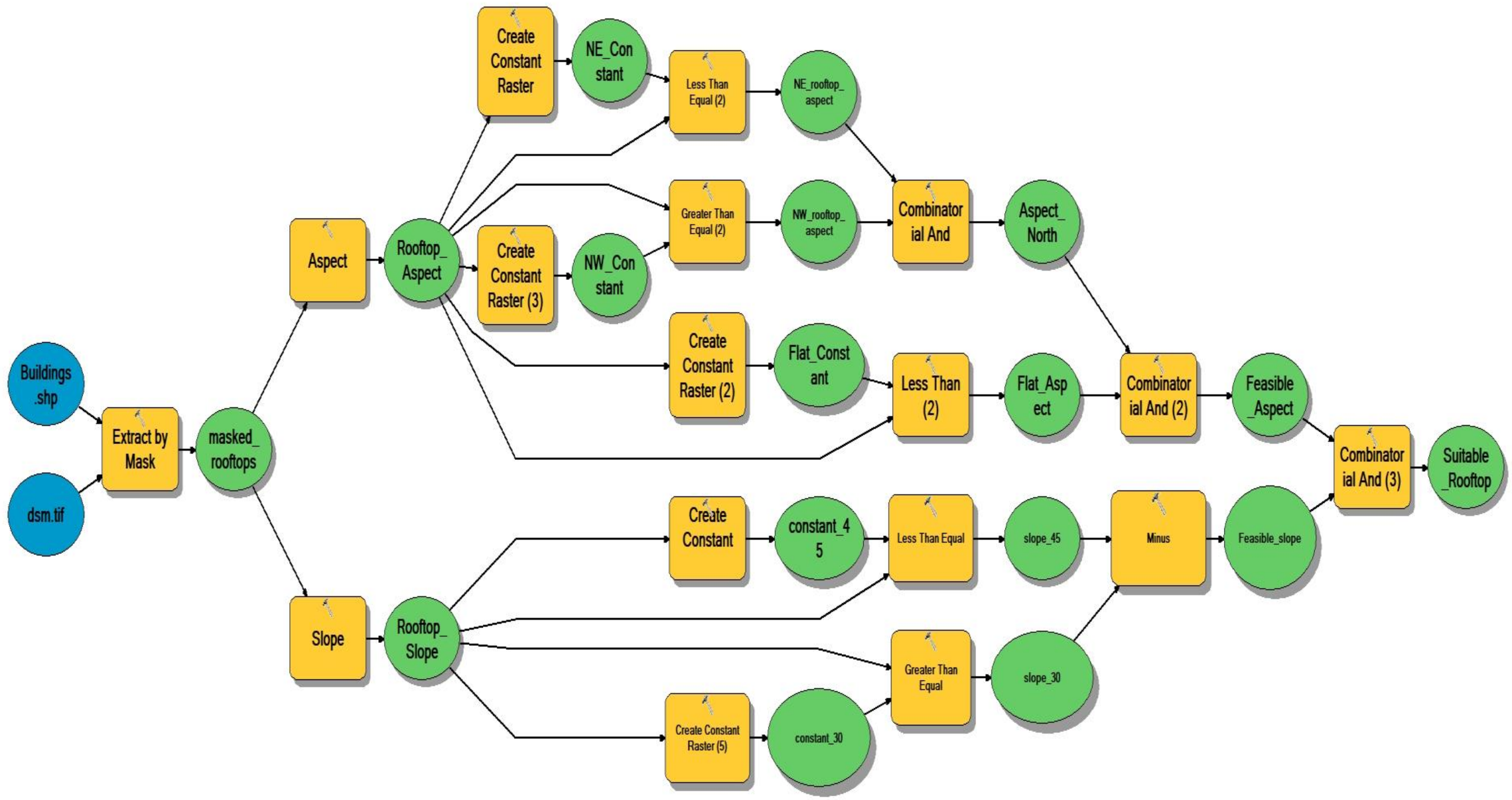

Figure 4.12: Suitability model

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In conclusion this study successfully integrated LiDAR data, high resolution satellite image and GIS in order to locate suitable existing roof sections for the installation of solar photovoltaic panels. The integration of LiDAR and GIS can lead to the development of the greatest innovation that supports green technology applications. This study identifies suitable existing roofs using a multi-criteria spatial analysis for PV systems for Ngara area in Nairobi. In order to identify suitable areas, slope and aspect were used. It was found that 53% of rooftop areas had suitable aspect, 31% of roof areas had suitable slope and 48% rooftop areas are ideal for PV systems

Assessment of rooftop PV potential is a vital step for electricity service providers, policy makers, and landlords who wish to install PV systems on their roof tops. By evaluating rooftop PV potential, electricity operators and planners have tools that can help them to predict future electricity generation. Finally, building owners can avoid high energy costs by installing PV systems on the right side of their roofs. This study developed a method for informing each of these stakeholder groups.

5.2 Recommendations

Energy is an important component for every human activity as it is the driving force or power needed to effectively and adequately accomplish such activities. Moreover, when it’s clean, renewable and free from pollutant, it reduces health hazard risks to both flora and fauna. It’s therefore important to invest and incorporate new technologies in efficient harnessing of renewable clean sources of energy. Since all the suitable factors to determine a suitable rooftop to mount photovoltaic solar panels i.e. potential electricity to be generated, shading, and radiation were not considered in this study, it is therefore recommended that in a future study they could be incorporated. Moreover, it’s not only the rooftops that can be used to mount the panels but also the buildings walls can be considered as an option.

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