INVESTIGATING GIS APPROACH IN SITE SELECTION FOR RAINWATER HARVESTING

A CASE OF T/A TENGANI, NSANJE

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ABSTRACT

The main obstacle to development in arid areas is the scarce and intermittent rainfall. Rainfall is a key source to diminish the problem of water scarcity in the arid and semi-arid regions. Rainwater harvesting is considered an imperious tool for rainwater conservation. Locating the appropriate location for rainwater harvesting structure plays an important role to increase water availability and improve water resources planning. The main goal of the paper is to recognize appropriate site for the allocation of rainwater harvesting structures using GIS and remote sensing which was generated using ArcGIS PRO and ArcGIS 10.8.Many thematic maps were extracted such as soil map, slope map, drainage map, rainfall map, temperature map, land use map and sedimentation map. The result shows that 3% represent the suitable sites for rainwater harvesting of the total study area, 97% represents the medium suitable area and 0% represents not suitable areas to implement rainwater harvesting structure. The proposed method is relatively supportive in analyzing geospatial data to determine and select the optimal site for rainwater harvesting for mitigation dry spells and floods.

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ABBREVIATIONS AND ACRONYMS

RWH…… Rainwater harvesting

MGDS……Malawi Growth and Development Strategy

RHAM…… Rainwater association of Malawi

AHP……..Analytical hierarchal process

FAHP……Fuzzy analytical hierarchal process

MCA…… Multi criteria analysis

WLC……Weighted Linear combination

EPA…… Extension Planning Area

SCS…… Soil conservation Service

USGC…… United State Geological Survey Earth Explorer

DEM…… Digital Elevation Model

IDW…… Inverse distance weighted

MUSTREC……Malawi university of science and Technology Research Ethics Committee

GDP…… Gross Domestic Production

TA…… ……..Traditional Authority

GOM…… Government of Malawi

RS…… Remote Sensing

FAO…… Food and Agriculture Organization

LST……..... Land Surface Temperature

CHRS…… Centre for Hydrometeorology and Remote Sensing

MCDA…….... Multi Criteria Analysis

RWHT…….....Rainwater Harvesting Technology

MUST…… Malawi University of Science and Technology

SWAT……. Soil and Water Assessment Tool

UTM……Universal Transverse Mercator

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CHAPTER 1: INTRODUCTION

1.1 Background

Water is one of the most essential natural resources, which is needed for survival of both humans and animals, as well as for economic growth and development (Preeti et al., 2022a). In semiarid and dry sub-humid Africa, water has become a limiting factor for crop growth and sustainability developments in smallholder farming systems (Barron, 2004).This is because the amount of water demands has increased compared to the amount of water available to meet all needs.

Malawi is one of the nations in Southeast Africa that depends on agriculture for both its national economy and domestic food security (Kadammanja, 2021). According to Government of Malawi (2021) ,70% of Malawi's workforce is involved in agriculture directly or indirectly and it continues to be the nation's economic pill (Kadammanja, 2021). Since most of Malawi's agricultural production depends on rain, droughts cause the majority of the crops to wither or wilt, which lowers productivity and causes food shortages, hunger, and malnutrition(Kasungu, n.d.)

Nsanje is one of the districts in southern Malawi that is highly affected each and every year by dry spells. This climatic effect has resulted in shortage of water for agriculture production. Agriculture is their main source of survival for the people in this area. As such this situation has forced the government to explore other alternative sources of water for both domestic and agricultural use (Kalowekamo, n.d.).

However, to solve the issue of water scarcity, researchers from all over the world have employed a variety of alternate strategies and Rain Water Harvesting (RWH) has been regarded as one of the most economically and environmentally advantageous water preservation techniques, addressing issues of water scarcity while also lowering the risk of flash floods and dry spells. RWH has resolved the issue of groundwater over-extraction and has become a common practice in many water-stressed region (Preeti et al., 2022b).Nsanje has tried adopting this system but the efficiency of operation has not been so effective. RWH implementation in Nsanje has encountered a number of

difficulties, including considerable water loss caused by high rates of evaporation and sedimentation. This has primarily been due to RWH technology' ineffective placement (Mhizha & Gumindoga, 2016),most areas are randomly chosen without considering the suitability conditions of the area. In order to correct this challenge this study has looked at GIS approach in the site selection for rain water harvesting. This study has incorporated runoff, slope, soil type, land use, temperature and drainage to choose the best area that can store efficient water which can be used when a dry spell occurs. The use of GIS for RWH has few documentations and has not been implemented recently, so this study aimed at being like a guide line for those who want to practice RWH in Malawi particularly Nsanje. Most studies have only looked at the factors mentioned above when using GIS approach in site selection for RWH but this study has also looked at sedimentation risk of the area. Most areas in Nsanje are affected by sedimentation as such the implementation of RWH meets a lot of challenges. So, it's the aim of this study to use GIS in mapping low sedimentation area which can favor the implementation of RWH.

1.2 Problem statement

Although the rain water association of Malawi and the government enhance the implementation of rainwater harvesting technique to improve food security and adapt dry spells, the implementation has faced a lot of limitations resulting to low adoption. Most of the implementation of these RWH is not successful in meeting the main objective of providing enough water for crop production and mitigating dry spell. This is because most technologies for water harvesting are planned without knowledge of the condition of the site ,which has resulted into many challenges such as waterlogging ,siltation , sedimentation and insufficient water collection(Nyirenda et al., 2021).According to research it has been indicated that the main reason for the failure and low adoption RWH technologies is due to poor site selection and matching between the technical and social economic requirements. Therefore, there is a need for a specific criterion that enable suitable site for water harvesting. This study investigated the use of GIS approach in identifying suitable site for implementation of Rain water harvesting technologies.

1.3. Main objective

To develop a GIS approach for identifying suitable site for Rain Water Harvesting technologies in TA Tengani in Nsanje.

1.3.1. Specific objective

I. To analyze factors for allocating suitable site for Rainwater harvesting.

ii. To perform sedimentation risk.

iii. To generate a suitability map of RWH for TA Tengani.

1.4. Research question

I. How to analyze factors for allocating suitable site for Rainwater harvesting?

ii. How to perform sedimentation risk?

iii. How to generate a suitable map of RWH for TA Tengani ?

1.5. Significance

The major reason why Malawi's agriculture industry and food security are vulnerable to the effects of climate change is that precipitation patterns and the frequency of extreme weather events, such as dry spells and floods, are becoming more unpredictable. Dry spells and flooding are occurring more frequently, reducing the production of staple crops and adversely affecting nutrition, health, and food security(Lewis, 2004). Dry spells will negatively impact other sectors of the economy by disrupting downstream food processing, which will have an impact on Malawi's export revenues (Lewis, 2004).This issue has been evidence enough by the Nsanje case of Malemia village where the villagers where hit by dry spell in 2021 and the harvest they got could barely sustain them. The government gave them some seed to replant but due to lack on enough rains the crops didn't grow (Mwale, 2021).

In addition to this, the climate change adaptation of Malawi has recorded a reduction of Malawi's economy by 1.7% GDP each year due to dry spells and floods. This only shows how serious a solution is needed for the problem at hand (Lewis, 2004).According to Jennie Barron (2004) ,Rain water harvesting can help mitigate dry spells and floods (Barron, 2004).Hence this study has shown the potential of the technique in ensuring the mitigation of flood and dry spells in TA Tengani in Nsanje. Even if a dry spell strikes in the area the harvested water will be able to sustain the people during this period and plants will have enough until they are ready for harvesting (Wang & Cai, 2015).Water will also be diverted from rivers to dams.

There is limited documentation and no practice of using GIS in Malawi to identify ideal areas for RWH (Mhizha & Gumindoga, 2016).Henceforth the establishment of this research has added value on how possible and effective GIS approach is in RWH. This research has also looked at sedimentation mapping of an area which so far has not been documented in most GIS approach of RWH research. This has thereby allowed potential areas to be selected to achieve high adoption.

This research has acted as an answer to the call by Malawi Growth and Development Strategy iii(MGDS) for RWH as a way of mitigating water shortage (Malawi Government, 2017).Lastly through the data analysis that the research has provided, future researchers may explore other capabilities of site selection for rainwater harvesting for mitigating food security.

CHAPTER 2: LITERATURE REVIEW

This section below reviews literature on RWH in general and use of Remote Sensing and Geographic Information Systems in identifying suitable sites for RWH in particular.

2.1 Rainwater harvesting technologies

2.1.1 Definitions of rainwater harvesting

Rain water harvesting is a global term which is defined differently worldwide. According to(Cuffari & Sc, 2019) Rainwater harvesting (RWH) is the process by which rain is collected and stored for future use. Rainwater harvesting, in simple terms, involves the collection of water directly from rainfall and runoff, by the construction of collection, conveyance and storage structures, from which it is directed for various uses ranging from domestic, watering animals (livestock and wildlife) and irrigation as well as landscaping (Adham , Riksen, Quessar, & Ritsema, 2016).And it can also be defined as the collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance(Hindersah et al., 2018).

When humans first began to plow the land and needed to develop new methods of irrigating crops, they discovered ways to collect and store rainwater. This practice dates back thousands of years. Catching that sporadic rainfall might make the difference between life and death for inhabitants in hotter climates. As the necessity for water conservation diminished over the past thousand years as urbanization grew, we are again going back to this essential aspect of living more sustainably.

It is obviously hard to pinpoint which culture originally employed the technique of rainwater collecting, but evidence suggests that various kinds of rainwater collection devices were in use in India, Mesopotamia, China, and modern-day Israel circa 2000 BC (water, 2018).

These systems' fundamental layout frequently required shaping a sizable boulder into a basin and sealing it with clay and other rocks to prevent leaks. Water would then be stored and used for drinking, washing, agriculture, and other purposes after being diverted using various strategies (*History-of-Rainwater-Harvesting*, n.d.). In Africa it is traced that

Botswana, Kenya, Mali, Tanzania and Togo are one of the first countries that practiced RWH(Lee & Visscher, 1990).

Though Malawi wasn't one of the earliest countries to participate in RWH but according to history ,RWH dates back to the colonial error ,where a number of small and medium size dams were built across the country for various purposes including drinking water supply, agriculture, fisheries, livestock watering and soil conservation(Oceanic & Service, 1995).Due to lack of maintenance RWH died out and was later reformed again by the department of meteorology and boosted in the country with the formation of rain water association of Malawi (RHAM) in 2003.

2.2 Reasons for rainwater harvesting

According to Preeti and Yuri(2022), RWH is essential in increase water availability and land productivity in dry places while protecting water resources(Preeti et al., 2022a).As for Sayl and Ahmed , in order to improve the quality of life in areas and boost access to freshwater, rainwater harvesting structures are thought to be one of the finest solutions. They guarantee a continuous supply all year long and Water sustainability for home, agricultural, and even industrial use (Sayl et al., 2020).Rainwater harvesting reduces the effects of mid-season dry spells and drought which reduces crop yields(Hindersah et al., 2018).

As rainwater is a renewable resource, harvesting it has a little impact on the environment, and the majority of the labor and supplies are available locally. Malawi as a country has considered rainwater harvesting as a practical solution to the country's water shortage (Adham , Riksen, Quessar, & Ritsema, 2016).

According to Macpherson Nthara, Rainwater harvesting in Malawi is one of the technology that has proven to be more viable to complement conventional method for water supply. As land degradation and climate change have negatively affected water resource, RWH has imparted stability in crop production during these sub-normal years. This technique has helped in minimizing soil-water availability to crops and enhanced crop yield per unit of available soil water.

2.3 Types of rainwater harvesting technologies

According to different researchers RWH has been classified into macro RWH and micro RWH which also known as ex-situ RWH and in- situ RWH.

Macro RWH systems area systems that are designed to collect and store large amount of water from large catchments areas such as rooftops or large open area. These systems are typically used for irrigation and other agriculture purposes (Tolossa, Abebe, & Girma, 2020).

While as for micro RWH systems are normally within cropped land, which generate small quantities of runoff for a single group, groups of crops or rows of crops (Adham , Riksen, Quessar, & Ritsema, 2016).

2.4 Experience of rainwater harvesting in the world

Different parts of the world are practicing rainwater harvesting due to water in availabilities. Some of the experiences are as discussed below.

Yemen is one of the countries that practices rainwater harvesting, this country is to the southern wester of the southern end of the Arabian Peninsula. This area has experienced a lot of groundwater problems due to the frequent conflicts and climate change effects. This has impacted greatly their economy because it is an agriculture rain dependent country. By the help of the World bank Yemen started practicing rainwater harvesting to mitigate the problem of water scarcity. Yemen has used roof rainwater harvesting and has also built cisterns from stones to capture water for use. This implementation of RWH has solved the country's biggest challenge of providing water access to rural areas. It has also relieved women of the burden of getting water someway far (Munir, 2002).Below is an example of roof rainwater harvesting.



Figure 1 Rooftop RWH

Japan is also one of the leading countries in practicing rainwater harvesting in the world. Due to the increased population and industrial development the pressure on the limited water resources has arisen in the country. To combat water scarcity, the country has resorted into rainwater harvesting. It has built in Sumida City in 1985, the Ryogoku Kokugikan Sumo-wrestling Arena is a well-known structure that makes extensive use of rainfall. In Tokyo, numerous new public facilities have started implementing rainwater utilization systems after the lead of Kokugikan. Japan has also adapted rainwater harvesting

for safety purposes. Urban flooding, which includes sewer backups and the flooding of small to medium-sized rivers during heavy rains, has been devastating to Japan in recent years. In one instance, water overflowed into an underground commercial area, causing a people to drown. Japan has used rainwater harvesting implementation as sustainable solution (Rainwater harvesting around the word, 2023). And more interesting is the rain harvesting in Singapore where despite being a small country with limited area it is able to supply all the water demands for the increasing population. This area also practices roof water harvesting to implement for the scarce water (Borsi, 2022).Below is a picture of Japans unique facility for rainwater harvesting.

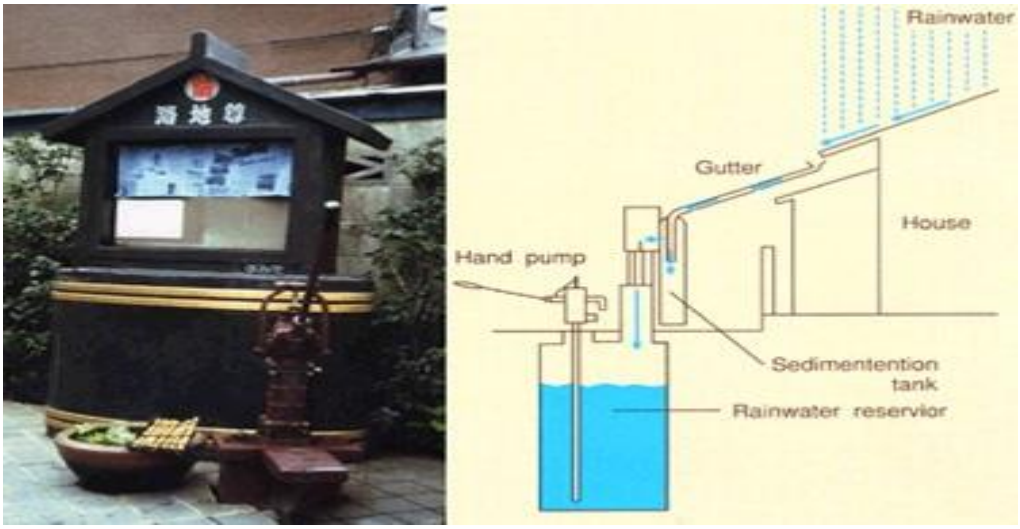


Figure 2 Ryogoku Kokugikan Sumo-Wrestling Arena

2.5 Rainwater harvesting in Malawi

The history of rainwater harvesting in Malawi dates back to the colonial era under the Nyasaland Government, when a number of small and medium size dams were built across the country for various purposes including drinking water supply, agriculture, fisheries, livestock watering and soil conservation (Oceanic & Service, 1995).These dams were constructed by the British government to address problems such as drought.

The majority of the dam infrastructure constructed during the colonial era started to erode and disintegrate over time. Many of them were in this condition as a result of poor

maintenance and severe environmental damage to the dam catchments. Despite that rain harvesting degraded, in the late 80's it was implemented again by the department of meteorology and boosted in the country with the formation of rain water association of Malawi (RHAM) in 2003.This association was launched as a development partner towards integrated water resource management initiative of the government of Malawi (GoM) and other stakeholders.

The promotion of this rainwater harvesting is in line with the government development agenda to mitigate water shortage and augmenting current supplies as outlined in the Malawi Growth and Development Strategy III.

2.5.1 Rainwater Structures in Malawi

Malawi has engaged in above tank rainwater harvesting. The above ground tanks for domestic application has been the most popular technique for rainwater harvesting in Malawi. These are popular in Malawi because it is ease to collect water from them, the water is usually of good quality and the impacts they have on reducing drudgery of water collection over long distances. The first tanks were normally constructed using bricks and mortar but in the last three years Ferro cement and plastic tanks have been in use.



Figure 3 A brick and plastic above ground tanks

To date over 500 above ground tanks have been constructed for roof-top water harvesting across the country but there is low adoption due to their high cost.

Malawi also practices lined underground tanks, concrete lined underground tanks have mostly been built to collect runoff from ground surfaces e.g., school grounds, hill sides and road runoff. The water from underground tanks is mostly used for cleaning, watering livestock and tree nurseries for afforestation. The Irrigation Rural Livelihood and Agriculture Development Programme facilitated the construction of over 50 Underground tanks in the early 2000 which were used for agriculture production using Drip Irrigation.

These underground tanks have been popular in Malawi since they are able to collect huge volumes of water compared with the above ground tanks. The water is cooler making it suitable for irrigation. There disadvantages include; large amount of sediment that is collected in the tank and since the water is stored under the ground, withdrawing water cannot be done using gravity.



Figure 4 Underground tank in Kasungu



Figure 5 Underground tank in Karonga

During the 90's earth dams, farm ponds, water pots and water tanks were piloted in Kasungu, Blantyre, Chikwawa, Machinga and Nsanje districts (Nthara, 2020). This practice ages back to the colonial time.



Figure 6 Water harvesting in Senzani Ntcheu

Malawi has also engaged in-situ rainwater harvesting to mitigate erratic rains and dry spells. Some examples are such as swales, infiltration pits, percolation ponds, conservation agriculture, box ridges, marker ridges and mulching.



Figure 7 Percolation ponds in Neno



Figure 8 Filtration pit in Karonga

In Nsanje flood -based farming system is the common rain water harvesting technique that is practiced. This is a system where flood water is channeled through diversions to bunded basins on cropped land (Mekdaschi & Liniger, 2013).In Nsanje flood farming is used for better management of flood water for crop and animal production. Flood plain systems like flood plain, spate irrigation, use of residual moisture and inundation canals have been practiced in Nsanje (Nthara, 2020).Though these practices have been practiced their

effectiveness has been very small due to lack of sufficient knowledge of the area of establishment.



Figure 9 Flooded field

Rain water harvesting technique to be consideres in this study

This study looked at potential site for water storage dams such as earth dams using GIS.Earth dams consist of raised dam walls formed by compacted earth that retain water in a reservior upstream.Water stored in earth dams can be used for flood control,industrial use ,dry spell mitigation and domestic storage.



Figure 10 Earth dams

2.6. GIS and Remote Sensing approach in site selection for rainwater harvesting

Several methods have been used for rainwater harvesting but are not efficient enough since large areas of different characteristics are considered. In this section we will look at different countries that took part in GIS approach in site selection for Rainwater harvesting and the factors they considered.

In Tanzania the area that was considered is Zanzibar. The vector and raster (gridded) databases that were readily available were used to create the GIS database of Zanzibar's RWH potential using the Arc GIS and Arc view tools. Rainfall, terrain, soils, appropriateness of the land for human habitation, and population density were the main factors found for RWH prioritization in the GIS (RGF, 2007) .

Also, in Iraq a studies of GIS approach in site selection for rainwater harvesting was undertaken. Using GIS and Remote Sensing (RS) methods, this study sought to identify prospective locations for rainwater collection in the Garmian region of Kurdistan-Iraq. Analytical hierarchal process (AHP) and fuzzy analytical hierarchal process (FAHP), two multi criteria analysis (MCA) methodologies, were compared to find viable RWH sites. The weighted linear combination (WLC) and fuzzy gamma approaches were then used to create a map of possible RWH systems' applicability.

The results demonstrated that a minimum agreed-upon rainfall depth should be utilized as a baseline when classifying rainfall in order to produce realistic results, in contrast to most recent research that relied on the minimum and maximum local rainfall data (Aziz, Abdulrahman, Ali, & Karakouziana, 2023).

In Ethiopia Eleven layers of the research area's physical characteristics were selected to integrate the multi-criteria decision analysis, which employs fuzzy logic, analytical hierarchy processes, and geographic information systems. The research area's runoff depth layer was estimated using a model for soil conservation. Based on the research area's environmental, socioeconomic, and hydro-geological factors as well as the literature that was available, weighting decisions were determined (Haile & Suryabhagavan, 2019).

In Malawi, GIS approach in site selection for water harvesting has also been researched but little documentation is there and it hasn't been fully implemented. One research was done in Kasungu where they were identifying and assessing the efficiency of current RWH initiatives and creating criteria for identifying appropriate RWH locations. Field surveys were carried out in the villages of the Chipala Extension Planning Area (EPA). Performance of RWH technologies was evaluated based on the moisture content of the soil. To map probable runoff areas for RWH, the GIS-based Soil Conservation Service (SCS) Curve Number approach was employed. 87% of the land in the research region was shown on a map of RWH potential as being suitable for RWH. The model was verified by comparing the locations of current RWH technologies to the suitability map, which revealed that 79% of RWH technologies were situated in high and moderate suitability areas, 17% in low suitability areas, and just 4% in extremely low suitability areas. So, the model can be used to accurately identify regions that would benefit from RWH technologies(Nyirenda et al., 2021).Another research was taken in Salima where GIS approach was also used (Kadammanja, 2021).

Based on the literature review it shows that most factors were considered in site selection but the sedimentation of an area was neglected in most of this research so it was the aim of this research to look at how GIS approach can incorporate it for RWH.

CHAPTER 3: METHODOLOGY

3.1. Research design

The study was qualitative in nature, it used the application of remote sensing and GIS techniques whereby satellites images were used and analyzed using GIS software (ArcGIS, ArcGIS PRO) to obtain the results.

3.2. Study area

This study was carried out at TA Tengani in Nsanje district in the southern region of Malawi at a latitude of 16°'43°'59°S and 35°'16°'0°E. The district covers an area of 1942square kilometers and has a population of about 1,063. The area is 131Km from Blantyre. This area has a larger population than other areas in Nsanje and it's highly affected by climatic impacts such as floods and droughts every year. Most areas in Nsanje experience rapid droughts and floods as such the government has tried encouraging people to take part in RWH to minimize the impacts. Though people have taken up this initiative it has not been so efficient due to sufficient knowledge in its implementation. This project has stood as an outstanding way in which effective rainwater harvesting can be implemented in an area. It has managed to find the suitable site for rainwater harvesting which are free from sedimentation risks.

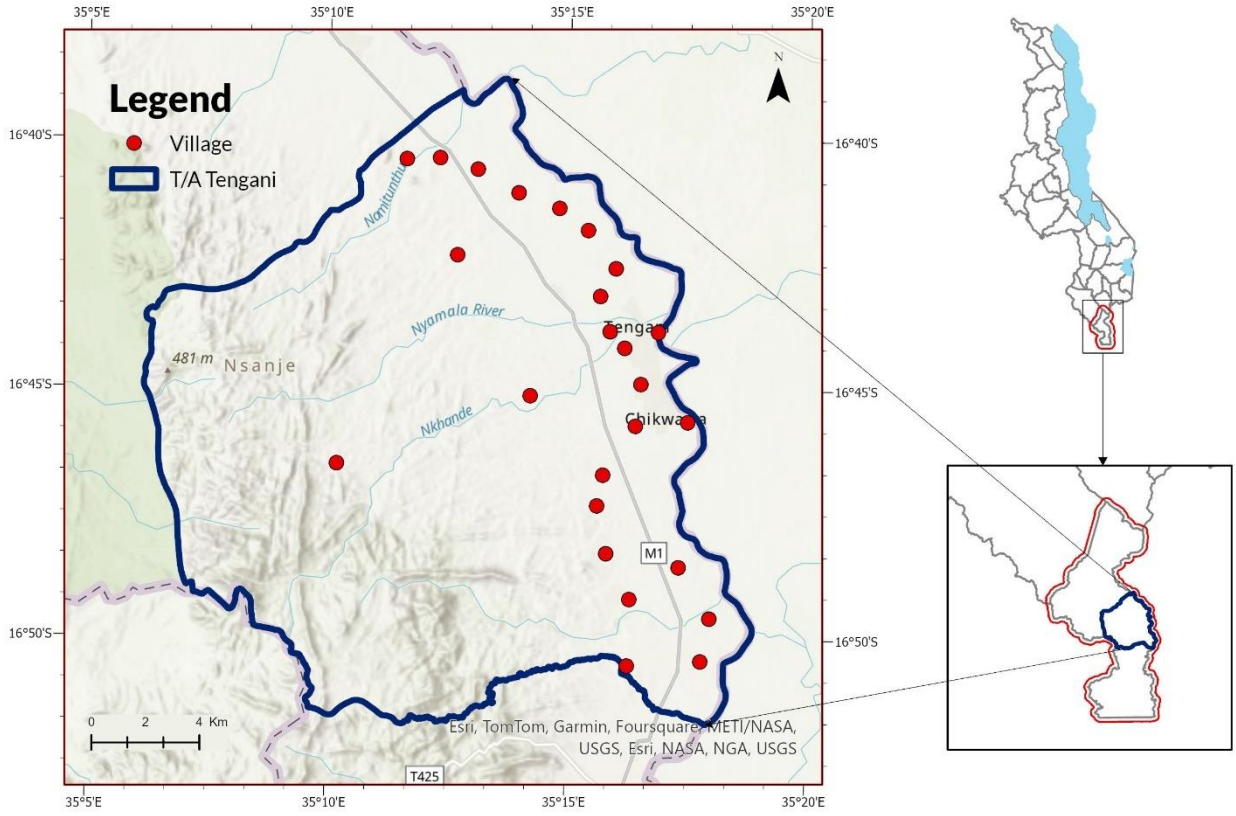


Figure 11 Study area map (TA Tengani)

3.3. Data collection and analysis

3.3.1 Data collection.

This section contains methods that were used to collect and process data for the study. This study used data sets from a DEM, sentinel-2 land cover, Google search engine and FAO data. Most of the data was annually based to get more efficient results. This study has used two software's namely ArcGIS and ArcGIS PRO.

3.3.1.1 Digital Elevation Model (DEM)

A DEM is an illustration of the topographic surface of the Earth known as "bare ground," devoid of any trees, structures, or other surface items. A common array of elevation data from geographic maps and aerophoto is used to create DEMs(Preeti et al., 2022a). The DEM contains information about basin's topographical features such as slope, aspect, perspective three-dimensional view, hill shading, flow direction, flow accumulation,

stream order. The Nsanje DEM was used in this study and was downloaded using USGS earth explorer (https://earthexplorer.usgs.gov/) .The DEM was acquired on the 25th of November 2022 and it had a resolution of 30m.This data was used to come up with the slope and the drainage density map of the study.

3.3.1.2 Sentinel-2 Land cover

Sentinel-2 land cover images were downloaded using http://livingatlas.arcgis.com. This platform provides a more detailed, accurate and timely LULC map of the world. It is a Landsat 2 level 2 data that contains an annual data set with a 10m resolution. This data was chosen because it is annually based, so to avoid biasness Landsat were not used since there are monthly data which means the study could have assigned the result of a month to a year. This data set was downloaded and then processed using ArcGIS. The living Atlas was used to identify the land use of that area.

Sentinel-2 land cover	Spatial resolution(m)	Season
Landsat 2 level 2	10	Yearly (2022)

Table 1 Sentinel-2 landcover

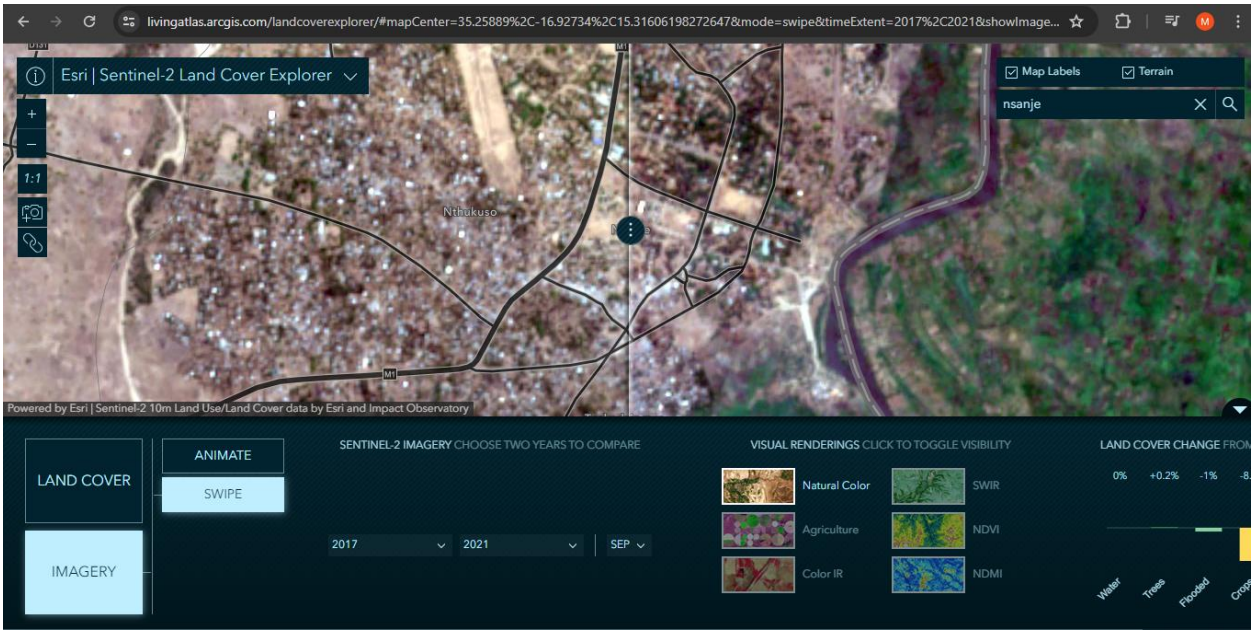


Figure 12 Sentinel-2 Land cover website

3.3.1.3 Food and Agriculture Organization (FAO)

This database refers to data and maps obtained using field surveys backed up by remote sensing and other environmental data, expert opinion and laboratory analysis. This soil information is essential for monitoring progress on the Agenda 2030 and national development plans. It was created in 2012 in Latin America(https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/). The FAO data was used to create soil maps.

3.3.1.4 Google Search Engine

This platform was used to acquire MODIS Land surface temperature (LST) and Emissivity (MOD11).This dataset contains a resolution of 1km (https://modis.gsfc.nasa.gov)

The data was acquired though coding and the code is as shown in the appendix.

3.3.1.5 Center for Hydrometeorology and Remote Sensing (CHRS)

This data set is for precipitation. It's a 4km resolution data and it contains data for hours, 3hours, 6-hours, daily, monthly and yearly. It was downloaded using https://chrsdata.eng.uci.edu/

3.3.2 Data pre-processing

In this section we will look at how the datasets was processed to produce a suitability map.

3.3.2.1 DEM Data

The DEM was used to process a slope map and a drainage density map.

(i) Slope pre-processing

In the processing of a slope map a DEM from USGS was used and it was in the form of Geo TIFF. The DEM was first imported in ArcGIS and the coordinate system of the layers were checked. It was then followed by projection. Projections main theme is that all the layers should be in one coordinate system. It was then turned into a polygon using extraction by mask tool. Lastly it was analyzed using the slope 3D tool and reclassified. The slope values can either be in degrees or percentage.

(ii) Drainage density

To produce a density drainage map the Nsanje DEM was also used. During processing the spatial analysis tools were used, were the following steps were taken, (i) fill, (ii) flow direction tool, (iii) flow accumulation, (iv) stream order (which comprised of flow direction and flow accumulation), Lastly stream order to feature then a drainage density map was generated.

3.3.2.2 Land use pre-processing

The land use map was produced using the sentinel-2 land cover data set of 10m resolution. This Landsat 2level 2 contains already classified datasets. This dataset was chosen because it contains annual information. This helped to get a clear picture rather than using a satellite image that would give monthly information. Firstly, once it was downloaded it was imported into ArcGIS and the study area map was added. The area of interest was clipped and all the other things were unchecked. Properties was chosen where symbology and then unique values was used. As shown in figure 14 below using the ArcGIS living Atlas of the world the number of where it is written label was changed and replaced with the number that corresponds to the number that is on the heading written value. As shown in the figure

14, the number which are on the heading value are contained in the ArcGIS Atlas and they stand for a specific land use. Therefore, the number obtained from the value heading was looked at in the ArcGIS Living Atlas (Table 2) and the land use name was written on the heading written label and a land use map was then produced.

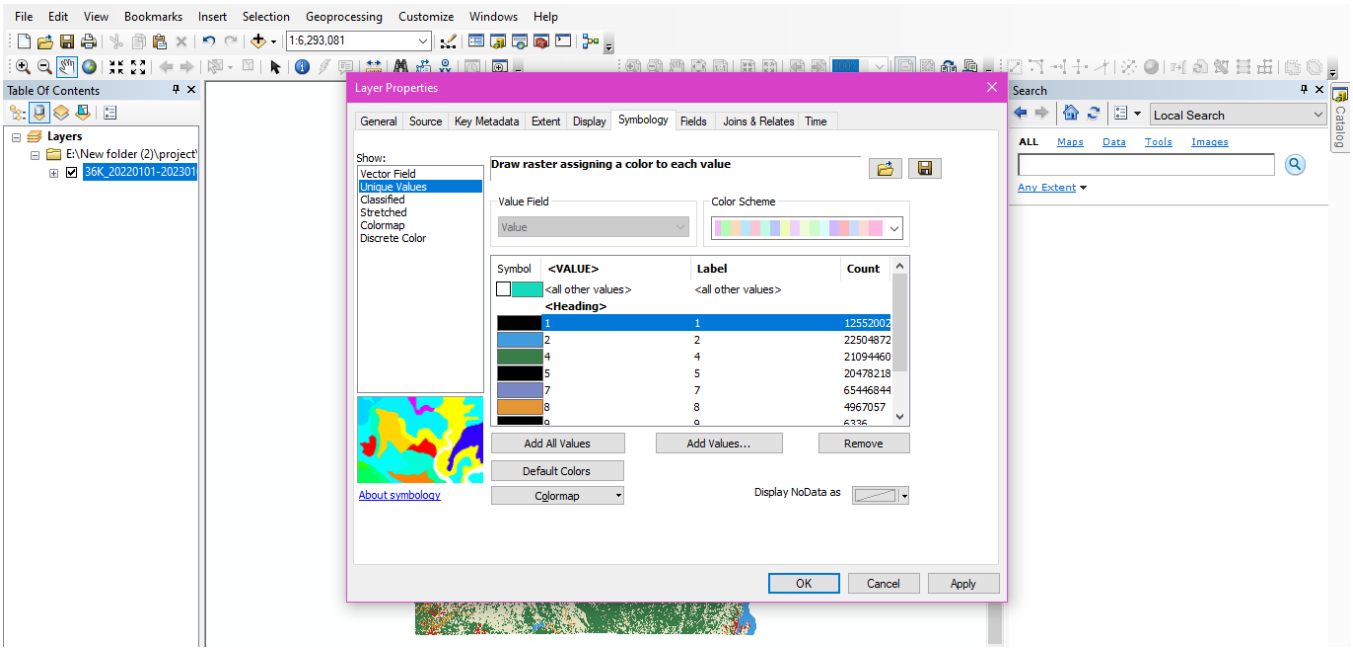


Figure 13 Replacing values in ArcGIS

Number of class ID	Micro classes	Description
1	Water	Places where water was present through the year e.g. rivers, ponds, lakes, oceans and flooded salt plains
2	Trees	Clustering of tall dense vegetation (approximately 15 feet or higher)
4	Flooded vegetation	Area where vegetation is mixed with water
5	Crops	These can be human planted, grasses, plotted cereals or any crop not the height of a tree
7	Built area	Human made structures e.g. houses, cities and roads
8	Bare Ground	Areas of rocks or soil with sparsed to no vegetation fort the entire year
9	Snow/ice	Area of permanent snow or ice
10	Clouds	No land cover information due to persistent cloud cover
11	Rangeland	Open areas covered in homogenous grasses with little to no taller vegetation

Table 2 ArcGIS Living Atlas

3.3.2.3 Soil FAO Data

The soil map was made using soil data that was downloaded from FAO. The following steps were taken ,(i)Firstly it was imported in ArcGIS,(ii) attribute table was opened and the 3rd option from the left was chosen,(iii)selection of the country of interest (a tab popped then a country was chosen, then unique value, add an equal sign and choose Malawi on country),(iv)Addition of study area shape file and clipping (done through geo-processing tool)the area of interest,(v) properties, symbology, category then select SNUM (Different colors will appear on the map and the colors will have a number corresponding to it),(vi)classification (using those numbers then classification was undertaken using the soil SWAT 2012.SWAT 2012 is a soil user Manuel which is downloaded together when downloading the soil data),Lastly referring the ArcGIS SNUM to the user Manuel(this is done by getting the SNUM and search it on the table SEQN in the user soil Manuel. The corresponding soil was the soil available in the area.

3.3.2.4 Rainfall map

This rainfall map was made using the CHRS data. This data was downloaded as a tiff and was loaded in ArcGIS PRO. The multidimensional tool was used to change the data set to raster. Followed by clipping of the study area and transformation of the data set from raster to point using conversion tool. These points were used to create a surface for the rainfall. Lastly it was interpolated using the Inverse Distance weighting (IDW). Interpolation was used because we had point rainfall data which made resampling to 30m resolution a problem since the pixel were huge.

3.3.2.5 Temperature

A temperature map was made from MODIS 1km data set. Similarly, to rainfall it was change from raster to point to create a surface for the temperature. Interpolation using Inverse Distance Weighting (IDW) was performed to lastly produce a temperature map.

3.3.2.6 Sedimentation map

In order to find the risk of the area to sedimentation we considered the parameter of soil erosion. The high the soil erosion risk the high the risk of accumulation of the sediments in

the RWH structures which can affect effectiveness of the structures implemented. Soil erosion was tested using a formula called soil erosion index(Rohrer & Madurapperuma, 2016).parameters such as rainfall, land use and slope were used . Using a formula below((Rohrer & Madurapperuma, 2016) parameters which have already been processed above were imputed in the raster calculator to produce a soil erosion map. The formula;

$$Erosion\ Index\ Model = Preciptation * \frac{1}{3} + Soil\ type * \frac{1}{3} + Land\ use * \frac{1}{3}$$

Equation 1 Soil Erosion index model

3.3.3 Identification of Area Suitable for rainwater Harvesting

A GIS-based multi criteria decision analysis (MCDA) modelling approach was used in this study to standardize different data layers. In the location of suitable site for rainwater harvesting certain important factors have to be put into consideration for instance, the kind of soil having sufficient clay to retain water and limit seepage; a flat terrain that allows for economic construction; and adequate amount of runoff that can be stored in dams (Preeti et al., 2022a).Therefore in order to carry out this multi-objective and multi-criteria analysis, the following steps were taken; (i) Selection of factors, (ii) assessment of suitability levels for the factors, (iii) assignment of weights to the factors(resampled to 30m resolution and reclassified before the assigning of weights) (iv) performance of a soil erosion index test to account for sedimentation risk of the area, (v) developing a GIS-based model that combines all maps layers through MCE process (weighted overlay) and (vi) Generation of suitability map(Mhizha & Gumindoga, 2016)

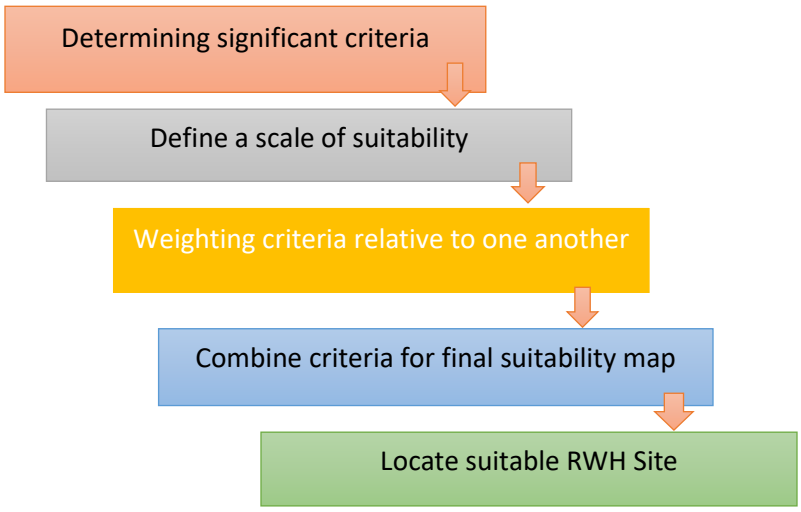


Figure 14 Main steps used in RWH site selection data process

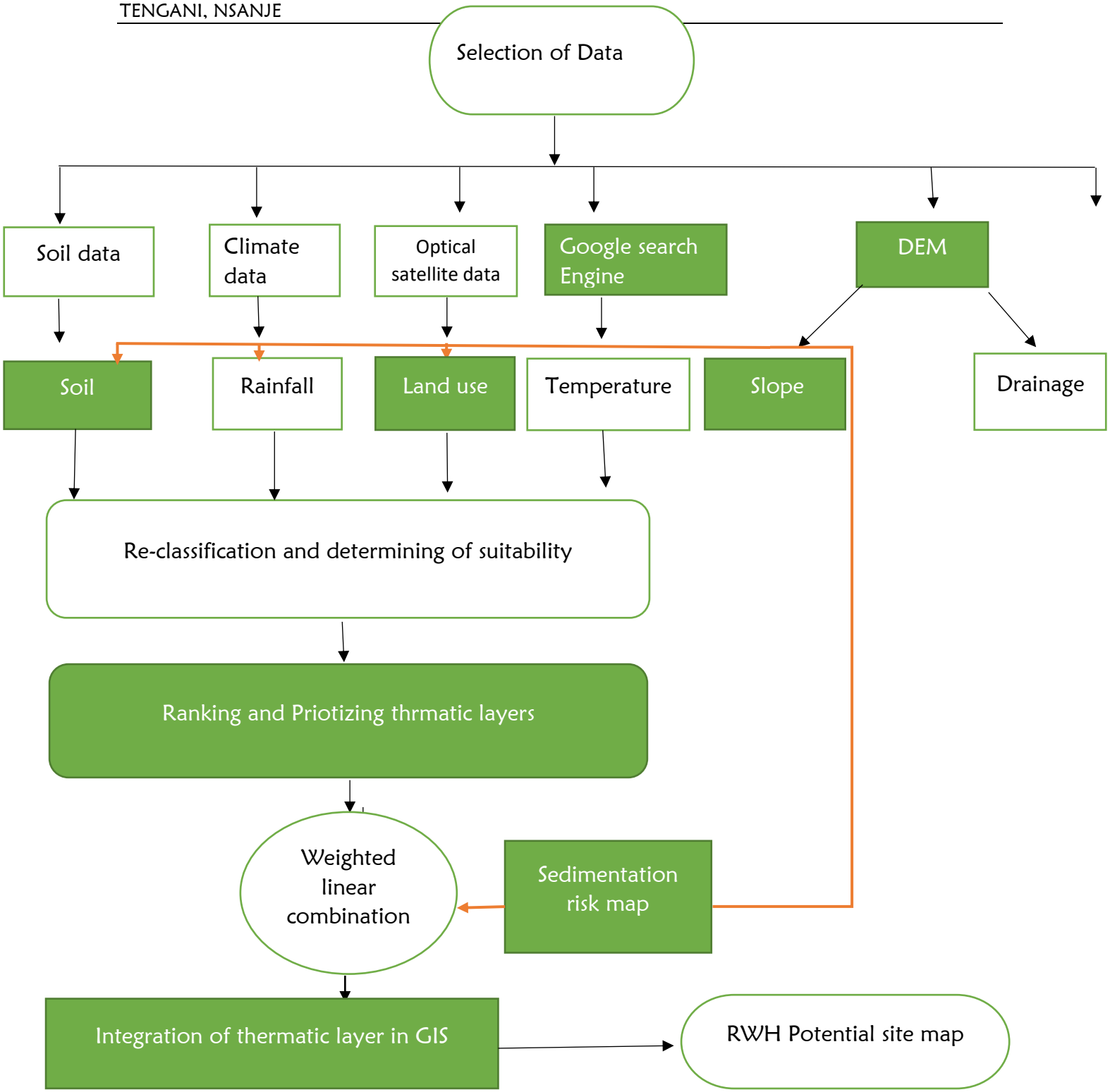


Figure 15 Methodology

3.3.4 Site Selection Criteria

RWH appropriateness was determined by a number of parameters, including environmental, socioeconomic, and physical. To facilitate integration, these factors were divided into five suitability scores: 1, 2, and 3.

(i)Soil

Soil is one of the most important factors to be considered when choosing a suitable site for rain water harvesting as it affects the runoff and rate of infiltration (Priti, 2023).Soil texture indicates the comparative content of various particle sizes, such as clay, silt and sand soil. Medium and fine - textured soil are more desired for rainwater harvesting(Khudhair et al., 2020).Clay soils are the most suitable soils for rainwater harvesting because of its high water retention capacity and low permeability. This low permeability allows it to store and hold the harvested water(Sayl et al., 2020).

(ii)Land use

During rainfall different land use result into different runoff generation as such it was very important to look at the land use of the study area in RWH site selection(Nyirenda et al., 2021).The study area was divided into categories of land use namely; water, agriculture ,flooded vegetation,crops,trees,rangeland,bare land and built areas. Although variations of land use affect infiltration and evapotranspiration trees, water, flooded vegetation and crops are more favorable land cover types for rainwater harvesting(Suni et al., 2023).Based on socioeconomic and environmental issues built up areas and areas with little vegetation are not suitable for rainwater harvesting(Ibrahim et al., 2019).

(iii)Slope

It is very important to consider the slope of an area when choosing RWH site since it affects the size of the harvesting structures and the water storage amount. High slope lands might not be appropriate if a lot of water is needed to meet irrigation demand because the cost of the storage facility (such as a farm dam) could increase in these situations. It is more practicable to use areas with medium to low slopes to lower the construction cost of

storage structures(Preeti et al., 2022a).Slope can affect runoff, sedimentation ratio, recharge and number of material used in dam construction(Ibrahim et al., 2019).A slope of less than 5% is required because of uneven distribution of run-off and large quantities of earthwork required which is not economical(Mhizha & Gumindoga, 2016).

(iv)Drainage density

When determining the quantity of surface runoff that originates from rainfall, the catchment's stream network features are crucial(Khudhair et al., 2020). Drainage density has a fundamental impact on recharge, groundwater transport, and hydrogeological processes. The drainage density determines the amount of runoff loss by infiltration; the lower the drainage density, the lower the RWH potential(Preeti et al., 2022b).

(v)Rainfall

The most significant factor, with the largest weight, is rainfall(Preeti et al., 2022a). FAO advises using rainwater harvesting technology (RWHT) in regions that receive at least 100 mm of rainfall up to 1,000 mm of rain per year. In regions where the yearly rainfall is less than 100 mm√year-1, there is hardly any productive water-based activity, while in locations where the annual rainfall exceeds 1 000 mm√year-1, there is no motivation to apply RWHT(Nyirenda et al., 2021).

(vi)Temperature

The aspect of temperature was incorporated in this study to achieve accuracy. The area has very high temperatures which can cause high evaporation rate. As such area of low temperatures will be more efficient for rainwater harvesting.

(vii)Soil erosion modelling

Soil erosion is one of the important aspects to consider for efficient rainwater harvesting. Most areas are at risk to sedimentation hindering the construction of RWH. To avoid soil building in RWH construction the sedimentation risk of the area has to be accountable. Slope, rainfall and land use was used to carry out soil erosion index(Rohrer & Madurapperuma, 2016).

3.3.5 Data presentation

The results were summarized and presented inform of maps and tables.

3.3.6 Ethical Considerations

This study will be approved by the Malawi University of Science and Technology (MUST), department of Ndata School of Climate and Earth Sciences.

3.3.6 Limitations

The major challenge that was faced when conducting this study was missing of annual rainfall data sets. The meteorological department gave me annual rainfall data for the whole Nsanje not TA Tengani specifically. So the study area had to use satellite rainfall data to achieve accuracy.

CHARPTER 4: RESULTS AND DISCUSSION

4.1. RESULTS

4.1.1 Rainfall

This is the very first important factor that is put into consideration before performing rainwater harvesting. The rainfall map was divided further into three classes based on the suitability presented in the table below and a classified map was produced as stated below.

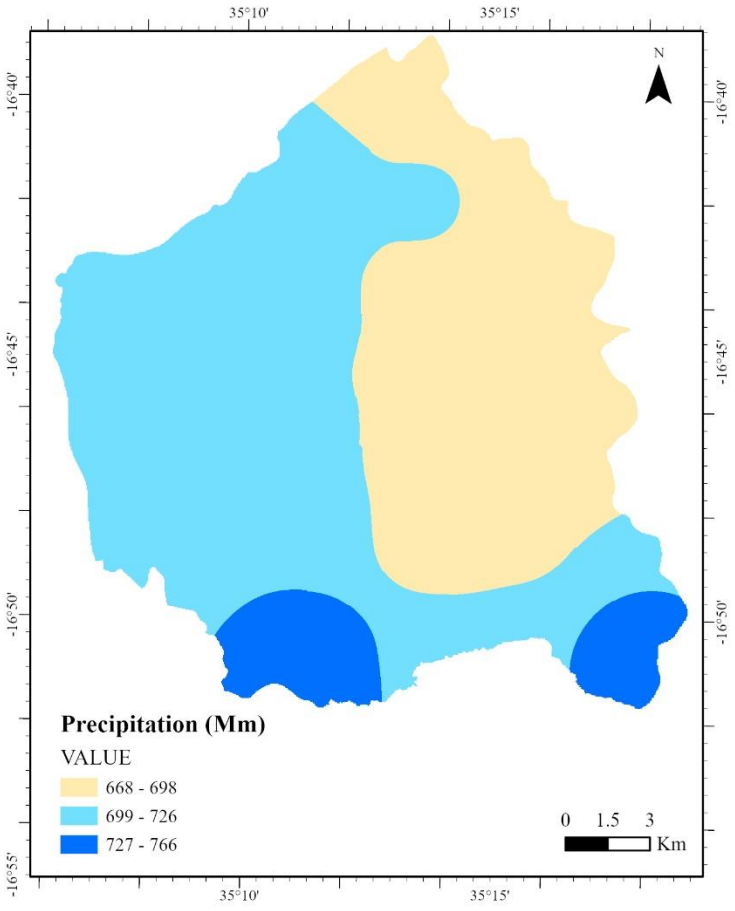


Figure 16 Rainfall map

Rainfall amount(mm/year)	Rank
725.001 – 766	3
686.001 – 725	2
667.00.1 – 686	1

Table 3 Rainfall Classes

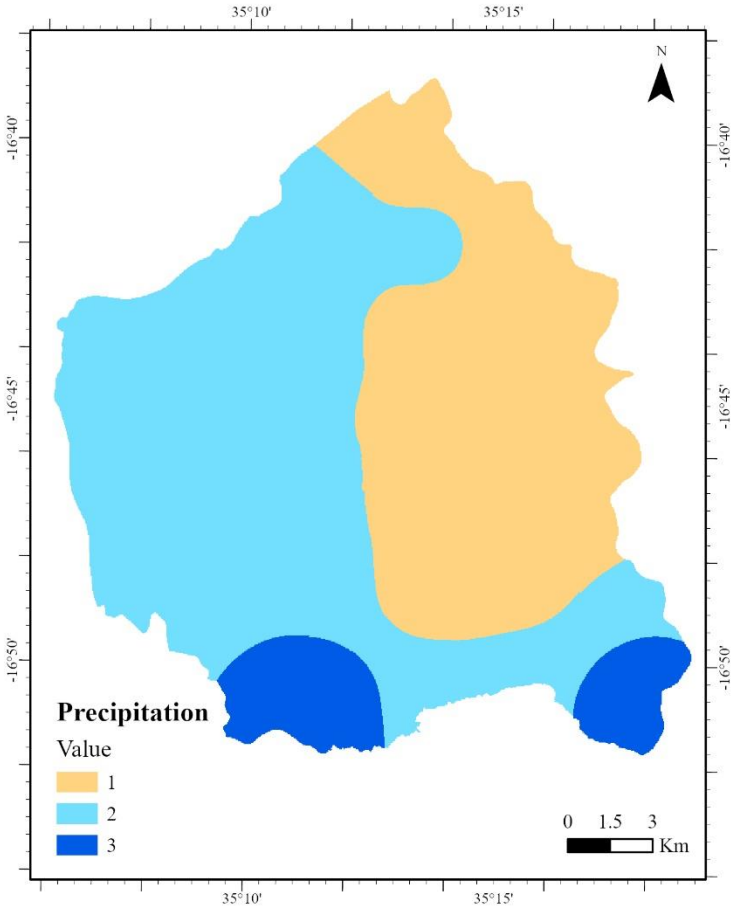


Figure 17 Classified rainfall map

4.1.2 Land use map

The study area had 7 categories namely water bodies, flooded vegetation, crops, trees, Rangeland, Bare land and Built areas as shown in the land use map below. These categories

were then divided into 3 classes based on their suitability as shown in the reclassification map.

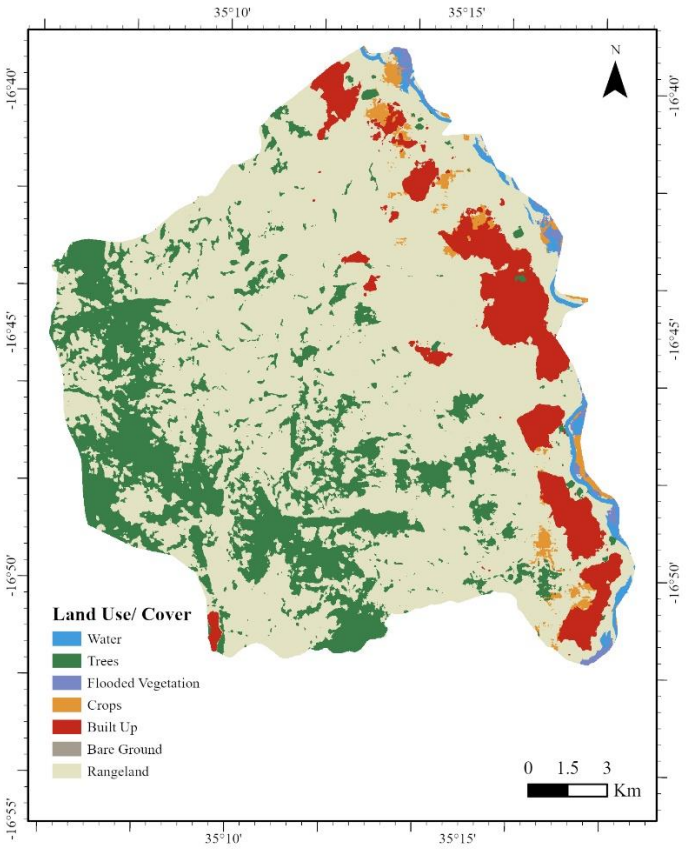


Figure 18 Land use map

Land use	Rank
Water	3
Flooded vegetation	3
Crops	3
Trees	2

Rangeland	2
Bare land	1
Built areas	1

Table 4 Land use classes

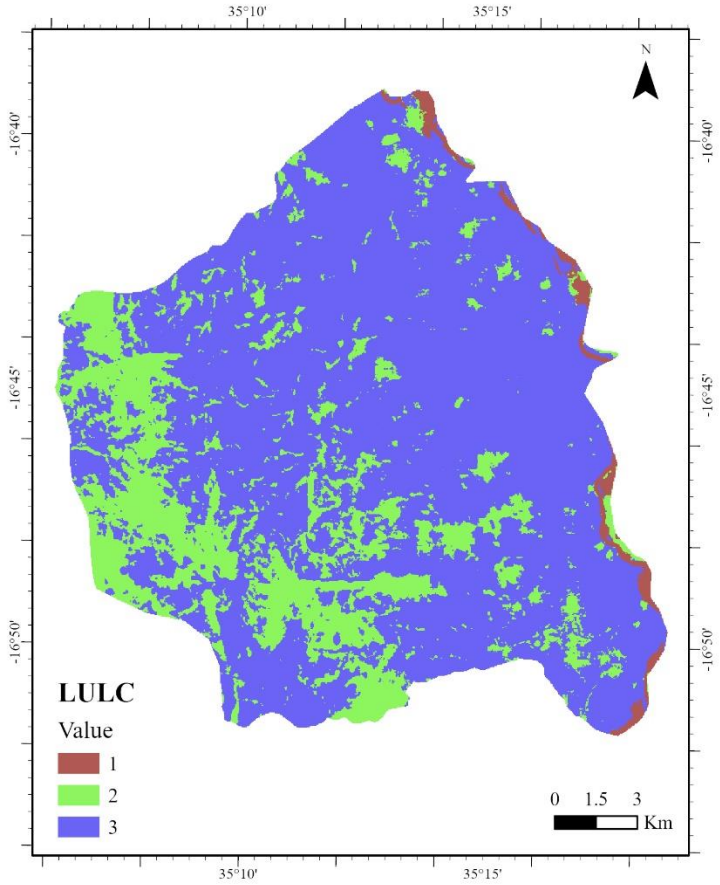


Figure 19 Classified land use map

4.1.3. Slope

Slope is one of the important factors that must be considered as it influences recharge and infiltration. The study area slope map had a range of slopes from 0.001 – 5.929,5.93 – 14.737 and 14.738 – 43.196 as shown below, which were later on reclassified into three classes based on their suitability. The table below shows how slope was classified based on high, medium and low suitability.

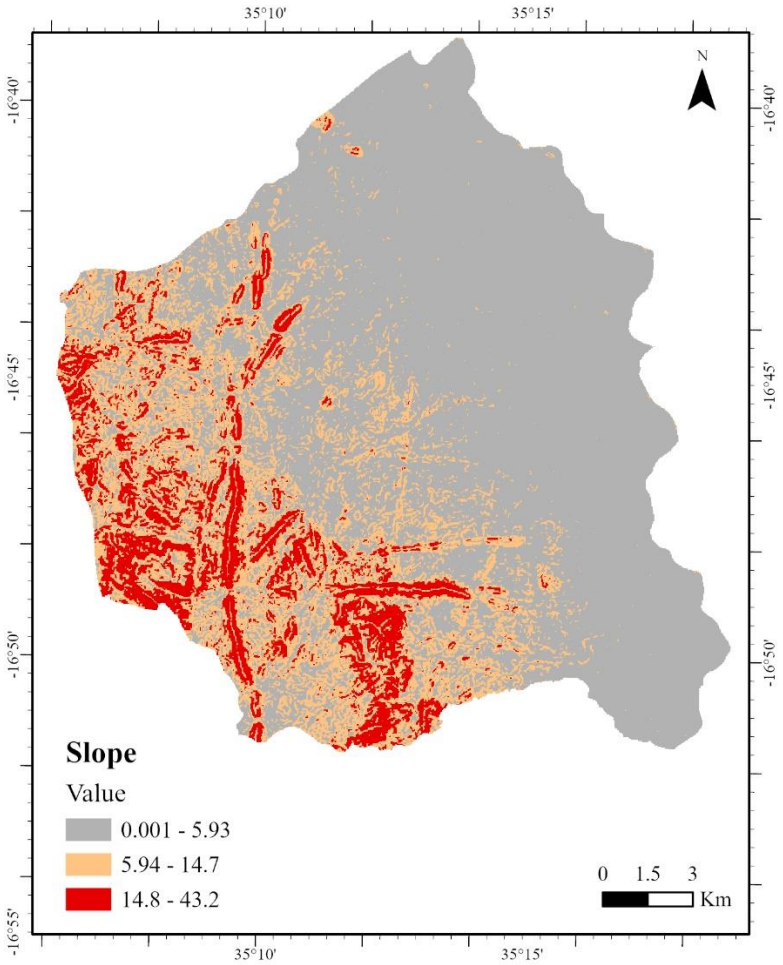


Figure 20 Slope map

Actual slope	Rank
0.001 – 5.929	3
5.93 – 14.737	1
14.738 – 43.196	1

Table 5 Slope classes

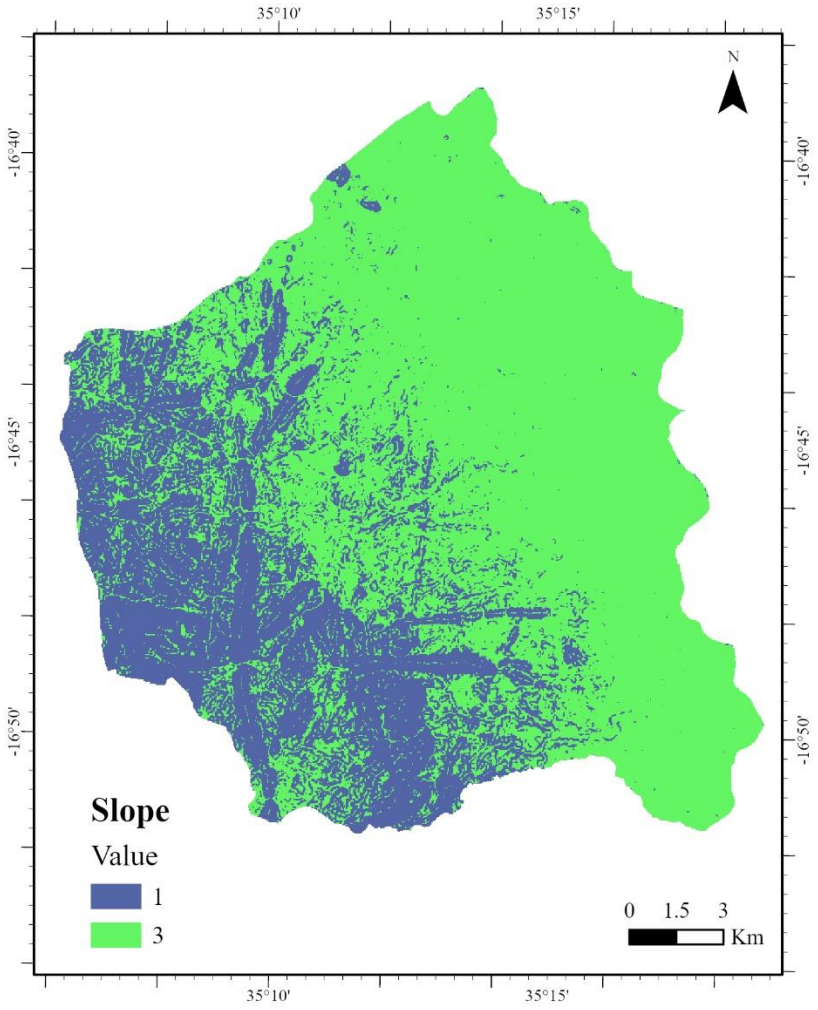


Figure 21 Classified slope map

4.1.4. Drainage density

The measure of the length of stream channel per unit area of drainage basin is shown in the map which was reclassified three classes. As shown on the map the drainage density was ranging from 1660.631 – 2490.946, 830.316 – 166063 and 0.001 – 830.315.

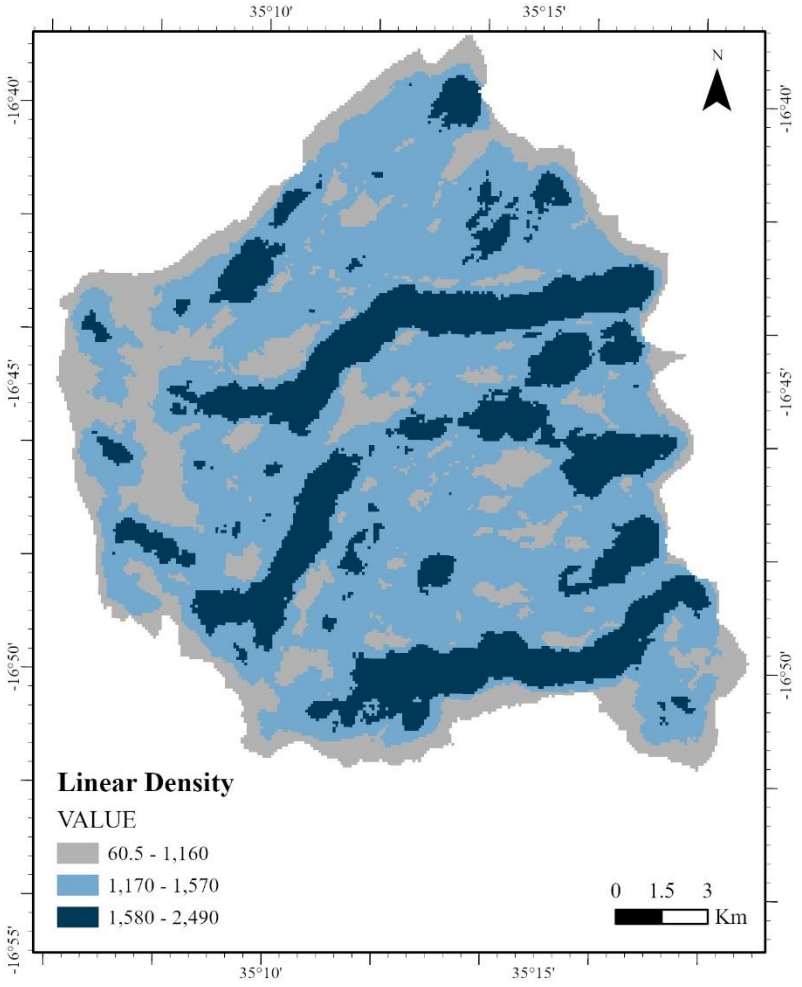


Figure 22 Drainage density map

Density	Ranks
1660.631 – 2490.946	3
830.316 – 166063	2
0.001 – 830.315	1

Figure 23 Drainage density classes

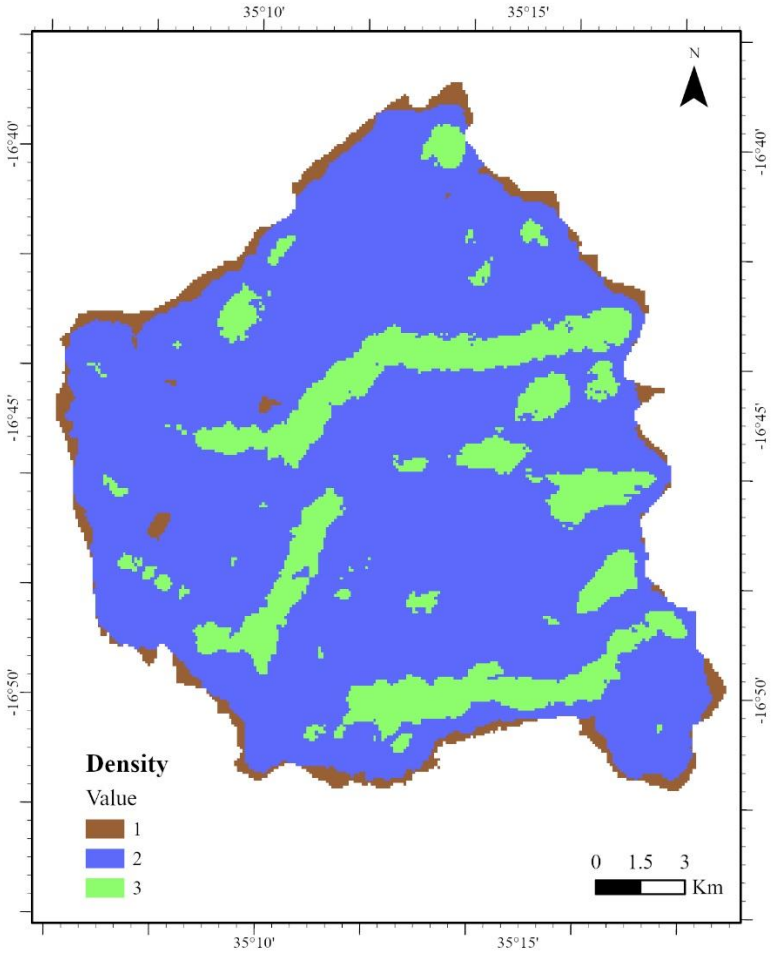


Figure 24 Classified density drainage map

4.1.5. Soil

The area had 4 types of soils as shown in the map namely; clay, clay, clay loam and loam soil which were classified into three classes based on their suitability of high, medium and low.

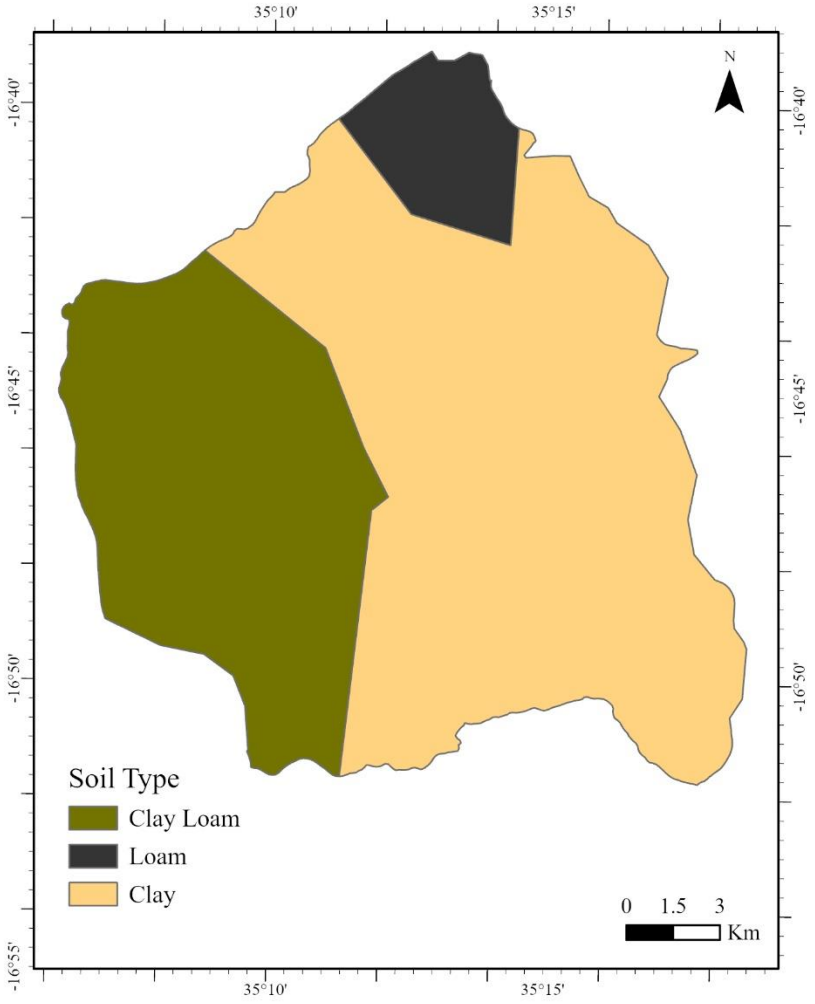


Figure 25 Soil type map

Soil type	Rank
Clay	1
Clay	1
Clay loam	2
Loam	3

Table 6 Soil type classes

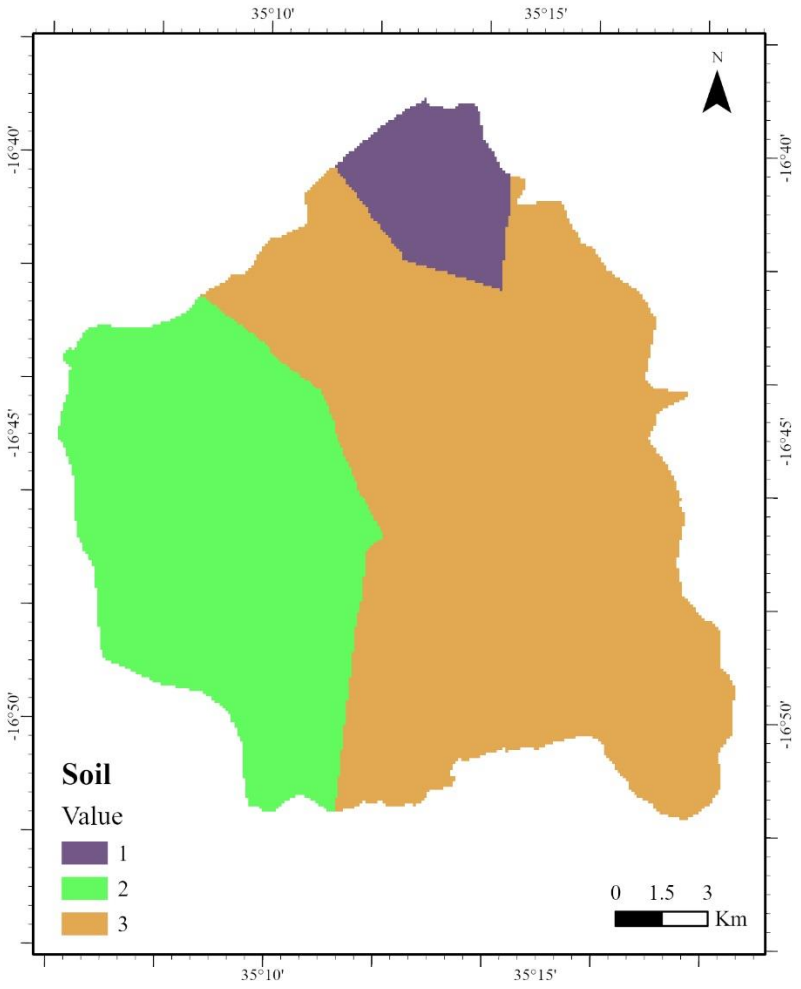


Figure 26 Classified soil map

4.1.6. Temperature

The temperature map was produced which ranged from 27.205 – 29.497, 29.498 – 31.678 and 31.679 – 34. 246. These temperatures were reclassified into high suitability, medium suitability and low suitability as shown by the classified map.

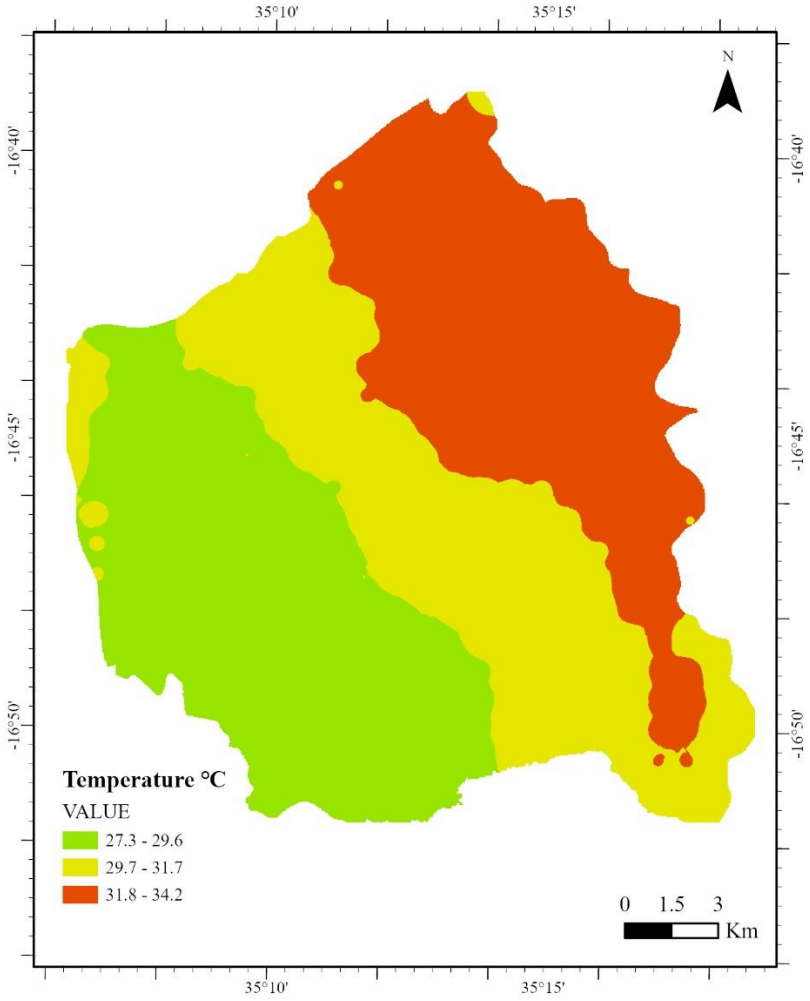


Figure 27 Temperature map

Temperature	Rank
27.205 – 29.497	3
29.498 – 31.678	2
31.679 – 34.246	1

Table 7 Temperature classes

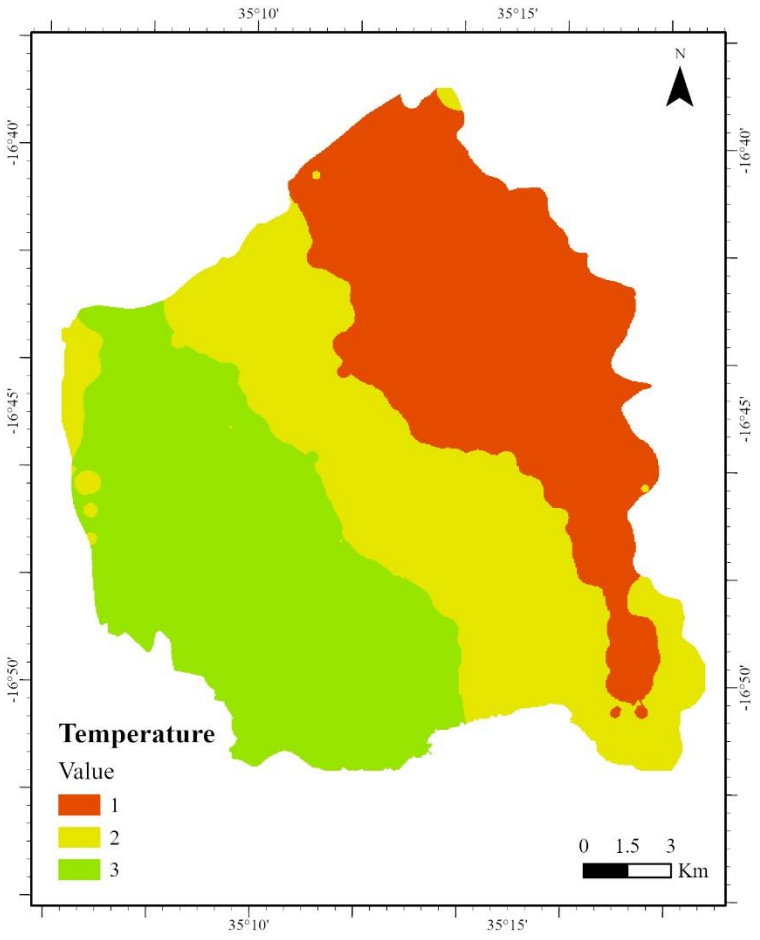


Figure 28 Classified temperature map

4.1.7. Soil Erosion index

The soil erosion index comprised of classes such as 1.001.61 – 1.667,1.668 -2 and 2.001 -3. These were classified into three classes.

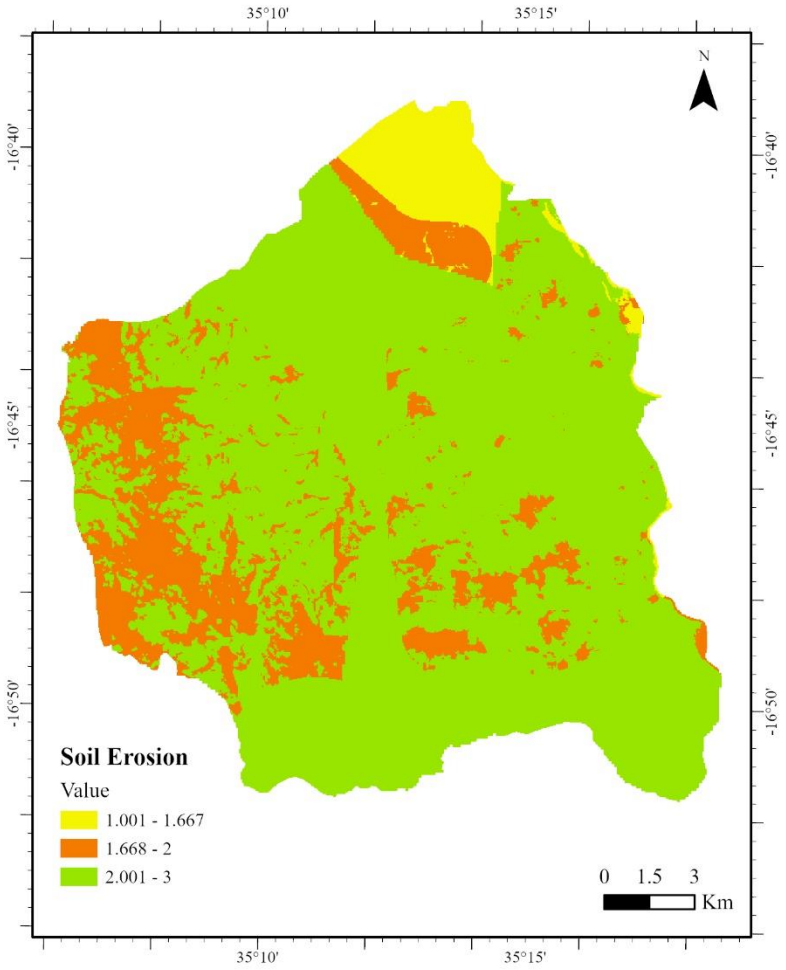


Figure 29 Soil erosion map

Erosion	Rank
1.001 -1.667	3
1.668 -2	2
2.001 -3	1

Table 8 Erosion Classes

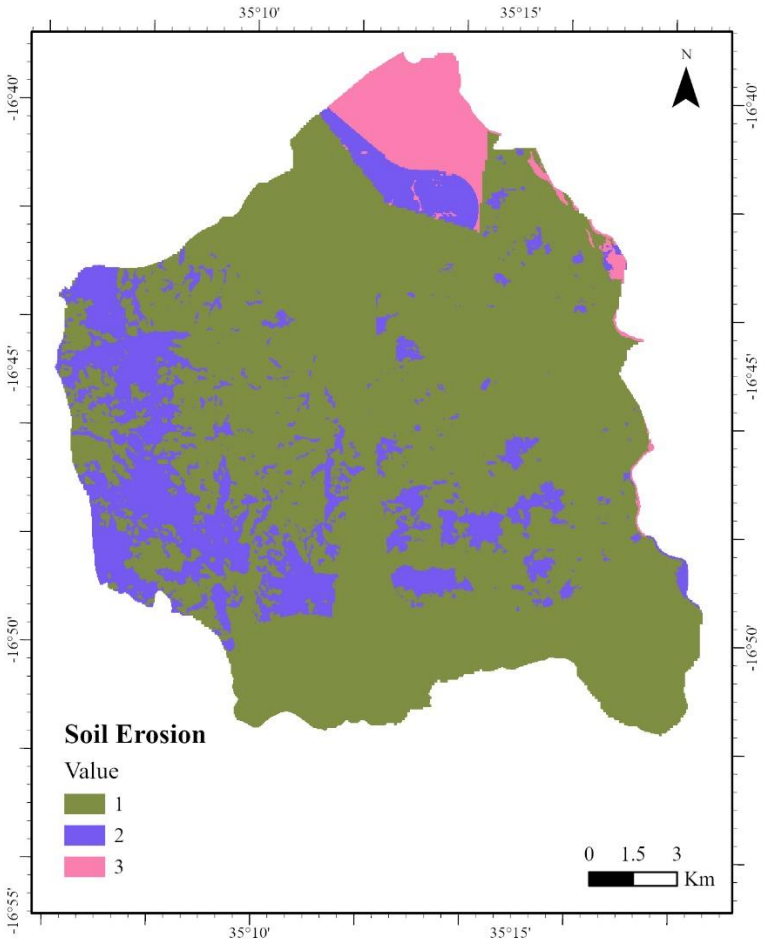


Figure 30 Classified soil erosion map

4.1.8. Potential site for rainwater harvesting

All the maps which were created were resampled to a resolution on 30m resolution and spatial reference of WGS 1984 UTM zone 36s and then reclassified to be used by the weighted overlay. Each area was divided based on their suitability. Three ranks were chosen base on the weight which was assigned to it. Each weight was assigned based on the importance of the factor to rain water harvesting.

Factor	Weight assigned
Rainfall	20
Slope	15
Soil	15
land use	14
Drainage density	12
Erosion index	12
Temperature	12

Figure 31 Overlay weights

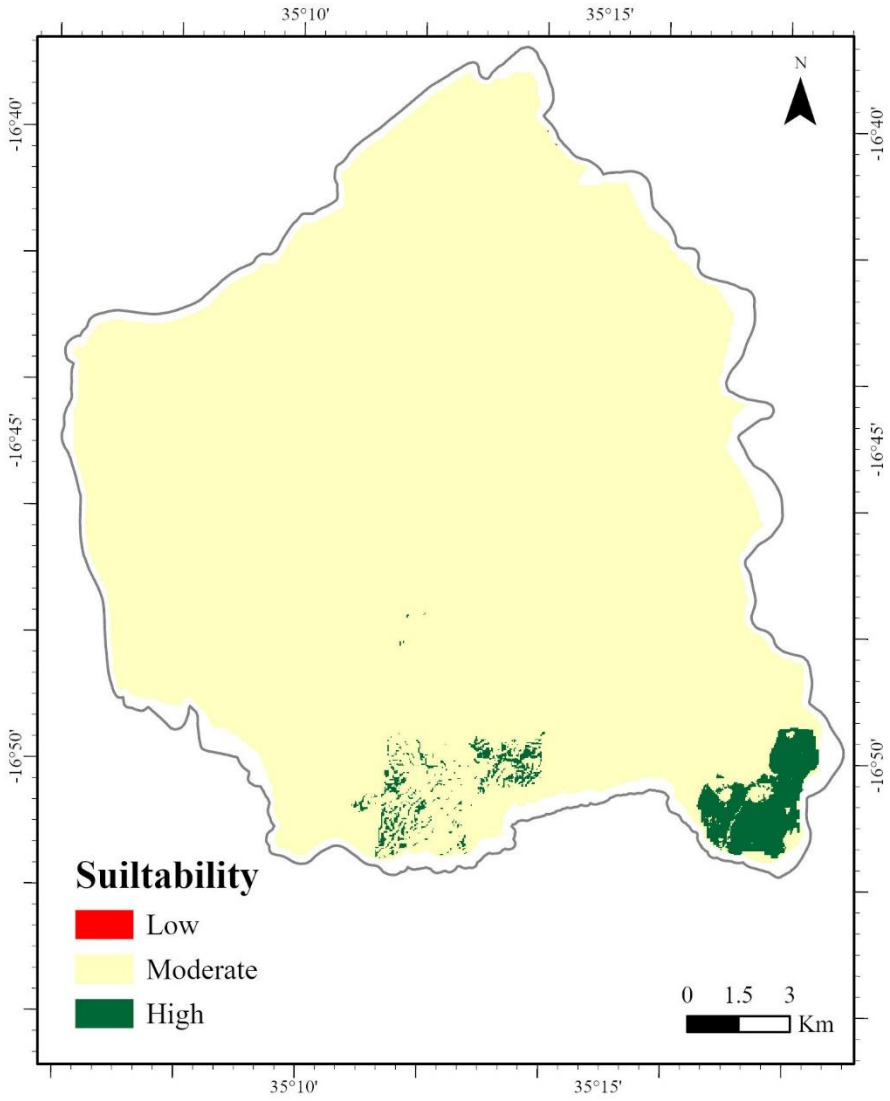


Figure 32 Final Rainwater suitable map

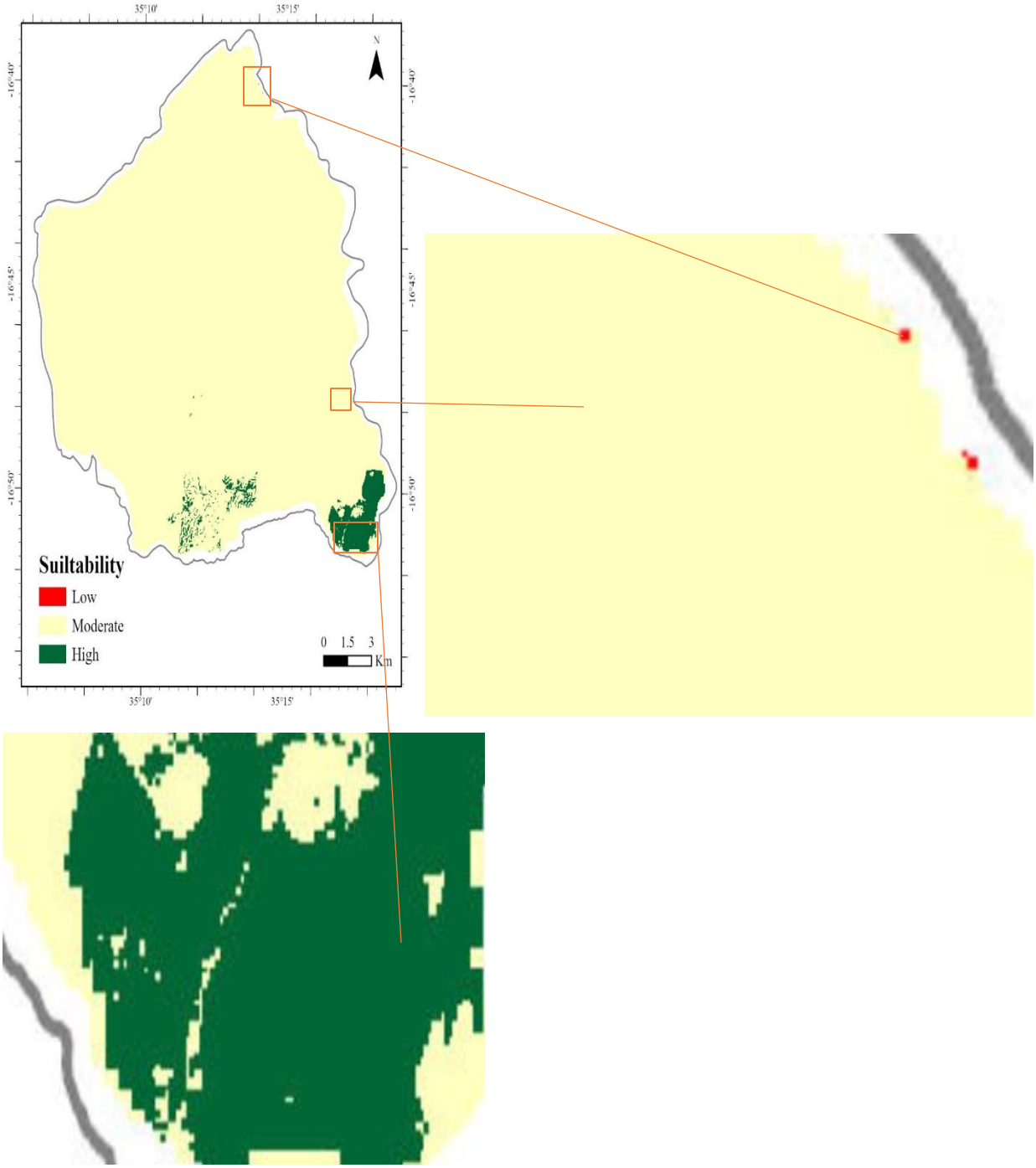


Figure 33 Potion of suitable RWH places

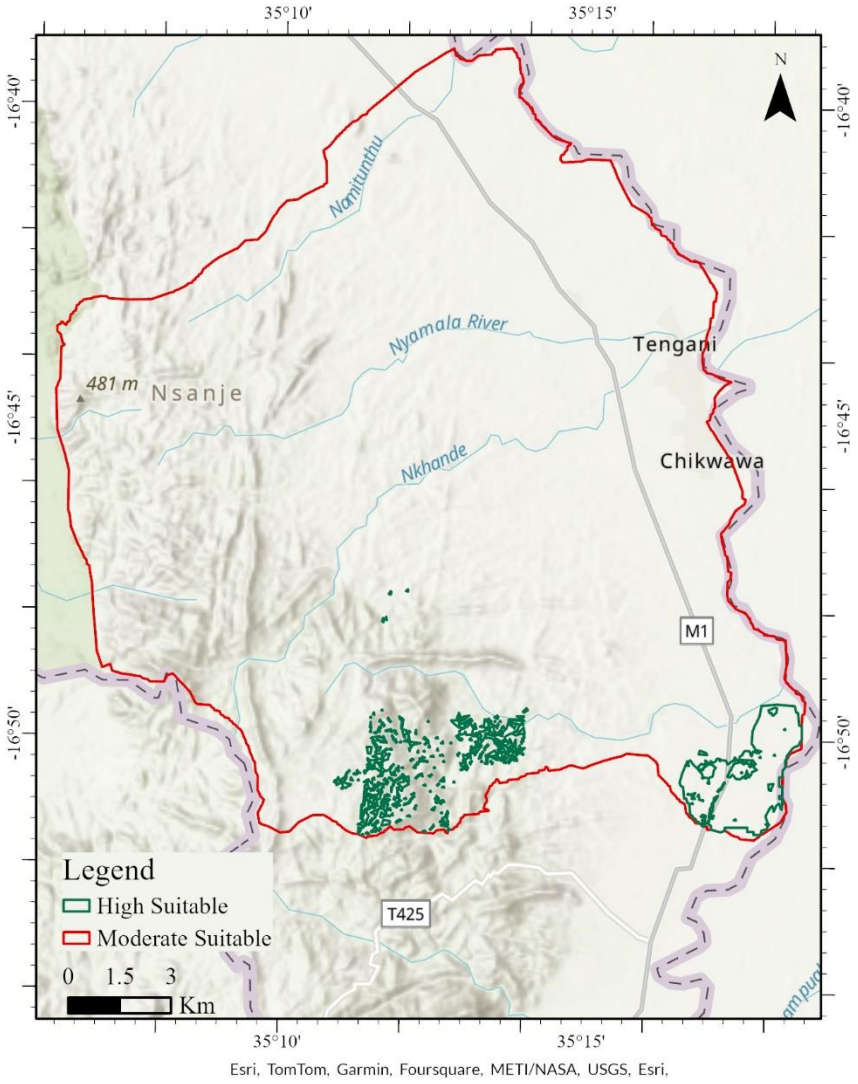


Figure 34 Finale suitability map

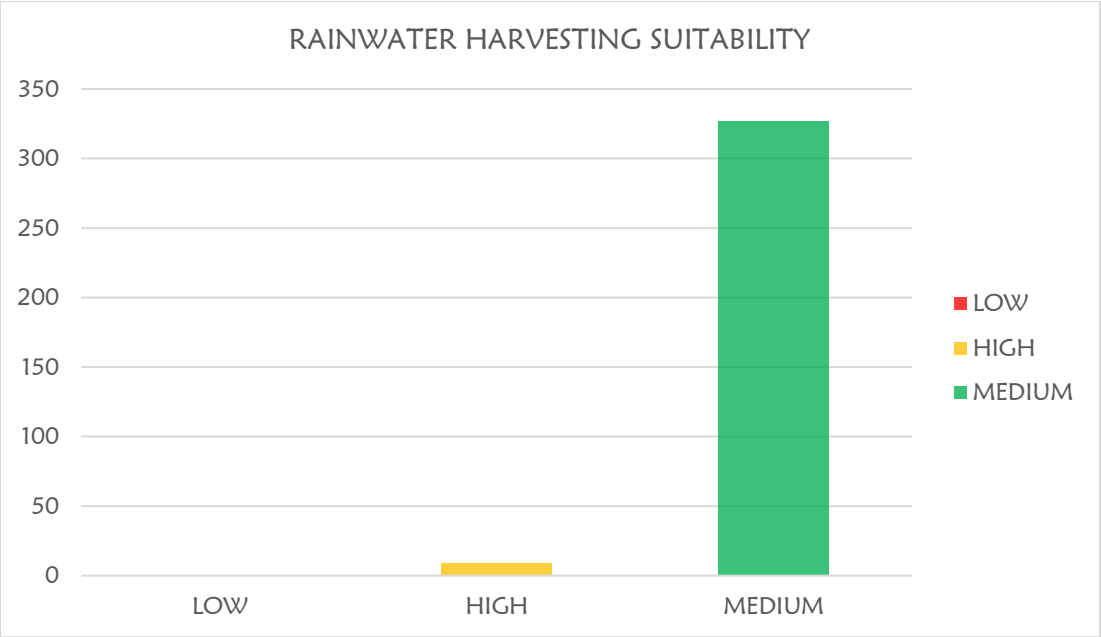


Figure 35 Bar chart for Final rainwater harvesting suitability map

4.2. DISCUSSION

The main reasons for the analyzing different types of factors in the area was to find suitable characteristic in the area that can support rainwater harvesting. This is very important because RWH structures can be implemented in areas where no efficiency can be achieved.

The first parameter that was look at was rainfall amount in the area. This factor was very important because the amount of rain an area receives helps in deciding whether the water can be harvested or not. Based on FAO, rains can be harvested if there is an amount ranging from 100mm to 1000mm.As shown on the rainfall map (*Figure 36 Rainfall map*

) the area received annual rainfall of 667mm, 686mm, 725mm and 766mm.These results show that RWH can be possible in the area and the most favorable place for construction is where the amount of 766- 725 of rainfall was received. The place that received 686.001 – 725mm of rainfall stood a medium chance of suitability while as the last class that has 667.00.1 – 686 was the less suitable for RWH.

The slope of the area is very important as it determines the infiltration and recharge rate. It is recommended that a slope of less than 5% should be found in the area where RWH can be constructed. According to the slope map, the slope ranged from 0.001, 5.929, 14.737 and 43. 196. This only indicates that the slope from 0.001-5.929 were the only one suitable for implementation of rainwater harvesting.

The soil type of the area matters the most as it influences how much water can be stored without being infiltrated. RWH dam construction supports the clay type of soil due to its water holding capacity and low permeability property. As seen in the soil map most areas in TA Tengani have clay, clay loam and lastly loam. This is to conclude that all the areas that have clay soil are the potential areas for rainwater harvesting. All areas which consist of loam soil are less suitable as loam soil has low water holding capacity.

The land use of an area plays a major role in the amount of runoff generation. Based on literature variations of land use ,affect infiltration and evapotranspiration as such trees, water, flooded vegetation and crops are more favorable land cover types for rainwater harvesting(Suni et al., 2023).Based on socioeconomic and environmental issues built up areas and areas with little vegetation are not suitable for rainwater harvesting(Ibrahim et al., 2019).The land use map show how a lot of area were dominated by water bodies, flooded vegetation, crops, trees, Rangeland, Bare land and Built areas .Based on the land use classified map Water ,Flooded vegetation, Crops are highly recommended for RWH seconded by Trees, Rangeland. While as for bare land and Built areas are not suitable for RWH implementation.

Drainage density also influences the amount of runoff generation. The greater the drainage density the greater the potential the area is for rainwater harvesting. As shown by the map the drainage density ranged from 1660.631, 2490.946, 830.316 and 0.001. This only shows that the areas that contained 2490.946 and 1660.631 contained a more potential for rainwater harvesting compared to the one that contained 0.001 – 830.315.

The levels of temperatures that an area experiences has to be taken into consideration. Areas with very high temperatures will cause evaporation of the harvested water than the

areas with low temperatures. According to the map temperatures ranged from 27.205, 29.497 and 31.679. This is to say the areas that experience 27.205 are more suitable rainwater harvesting as evaporation rate will be minimized while as for area of 31.679 are unsuitable as the will facilitate the loss of the stored water.

Sedimentation risk test

This study also looked at how much the area was prone to sedimentation. A sediment risk places will result in accumulation of sediments in the RWH equipment's as such a low sedimentation risk area was required for efficient implementation of RWH. This was modelled using a soil erosion index model. Area with high soil erosion will result into low potential for rainwater harvesting while as for those areas with low erosion will result into high potential sites for rainwater harvesting. As shown on the map soil erosion ranged from 1.001.61 – 1.667, 1.668 -2 and 2.001 - 3. Areas with high erosion such as 2-3 are not suitable for rainwater harvesting compare to area ranging from 1.001.61 to 1.667.

Reclassification and Ranking

All the maps were sampled to a resolution of 30m resolution, reclassified and ranked into three classes. As shown below, areas were ranked from 1-3 where 1 represented low suitability, 2 represented medium suitability and 3 represents highest suitability.

Potential site for Rainwater Harvesting

The reclassified and ranked maps for all the factors were all combined using the weighted overlay too. Each factors were assigned weight based on its importance as shown in the table (*Figure 37 Overlay weights)*.weighting helped in choosing the best areas that had most of the suitable characteristics for rainwater harvesting. As shown on the map all the area represented by 3 indicated highest efficiency for rainwater harvesting, as on 2, moderate efficiency and lastly 1 represented places which were not suitable for rainwater harvesting.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

The overall aim of this study was to identify potential site for Rainwater harvesting in TA Tengani using GIS and Remote Sensing. A sequence of data collection and analysis were conducted to achieve the study objectives.

5.1.1 Summary Conclusion

In chapter two of this research, a literature review identified key knowledge gap on site selection for rainwater harvesting. This led to this studying looking at using GIS and Remote Sensing in site selection in rainwater harvesting. The following are general conclusions based on the specific objectives of this study.

5.1.2 To analyze factors for allocating suitable site for RWH

This objective was formulated to identify all the factors that can be used in choosing a suitable site for rainwater harvesting using GIS. Based on literature the study incorporated factors such as rainfall, slope, soil type, land use, drainage density and temperature to allocate a suitable site. These classes were grouped into three class based on literature which were namely high suitability, medium suitability and low suitability. Area of high rainfall, clay type of soil, flat terrain, water to forested areas, high drainage density and low temperature we best in allocating of Rainwater harvesting.

5.1.3 To perform sedimentation risk

This objective was formed to check areas that contained all the required criteria's for RWH were free from sedimentation accumulation. This was very important to be investigated because sedimentation risk areas will result in them accumulating in the RWH structures hence leading to their damage. The soil erosion index model helped in modelling the sedimentation risk in the area, and it was found out that area of high risk were those with high erosion index and those will low erosion index were at low risk. This helped to conclude that low erosion index areas were more suitable for rainwater harvesting.

5.1.4 To generate a suitability map of RWH for TA Tengani

This objective was formulated so that it incorporates all the maps developed in the selection process and produce one finale map. This finale map was produced by weighting and areas which were highly suitable to low suitable were identify. This map was able to allocate all the places which contained all the requirement for an efficient running of the rainwater harvesting structures. The most suitable place for rainwater harvesting was identify and it was supposed to comprise of rainfall amount of 766mm, clay type of soil, flat terrain, water to forested areas, high drainage density, low temperatures and low soil erosion index.

5.2 Recommendation

Based on the findings of this study and other literature, the study recommends that;

- There is high rainwater harvesting potential in TA Tengani if optimally harvested, enough to mitigate dry spells and floods.
- The framework can be used in other studies and rainwater harvesting practices.
- Based on the results a further study should be conducted before implementation because the sedimentation risk is very high in the area of high suitability.

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7.0 APPENDICIES

Google search engine Temperature data

```
// Define the Region of Interest (ROI) - Malawi

var countries = ee.FeatureCollection("USDOS/LSIB_SIMPLE/2017");

var roi = countries.filter(ee.Filter.eq('country_na', 'Malawi'));

Map.addLayer(roi, {}, 'Malawi');

Map.centerObject(roi);



var modisLSTday = ee.ImageCollection('MODIS/MOD11A2').select('LST_Day_1km');

var modisLSTnight = ee.ImageCollection('MODIS/MOD11A2').select('LST_Night_1km');

var modLSTday = modisLSTday.map(function(img) {

  return
img.multiply(0.02).subtract(273.15).copyProperties(img,['system:time_start','system:time_
end']);

});

var modLSTnight = modisLSTnight.map(function(img) {

  return
img.multiply(0.02).subtract(273.15).copyProperties(img,['system:time_start','system:time_
end']);

});
```

```
var collection01night = ee.ImageCollection(modLSTnight.filterDate('2015-01-01', '2015-12-31'));

var collection01day = ee.ImageCollection(modLSTday.filterDate('2015-01-01', '2015-12-31'));



var clipped01night = collection01night.mean().clip(roi);

var clipped01day = collection01day.mean().clip(roi);



Map.addLayer(clipped01night, {min: 0, max: 40, palette: "0000ff,32cd32,ffff00,ff8c00,ff0000"}, 'LST Night Clip');

Map.addLayer(clipped01day, {min: 0, max: 40, palette: "0000ff,32cd32,ffff00,ff8c00,ff0000"}, 'LST Day Clip');


// Export the clipped images to Google Drive

Export.image.toDrive({

  image: clipped01night.toFloat(),

  description: 'Malawi_LST_Night_2015',

  scale: 1000,

  region: roi.geometry(),

  maxPixels: 1e13
```

```
});


Export.image.toDrive({
  image: clipped01day.toFloat(),
  description: 'Malawi_LST_Day_2015',
  scale: 1000,
  region: roi.geometry(),
  maxPixels: 1e13
});
```

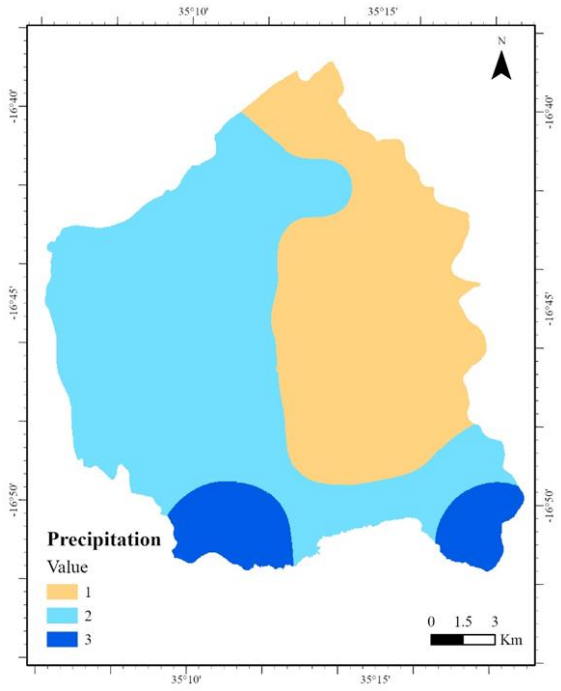


Figure 38 Classified rainfall map

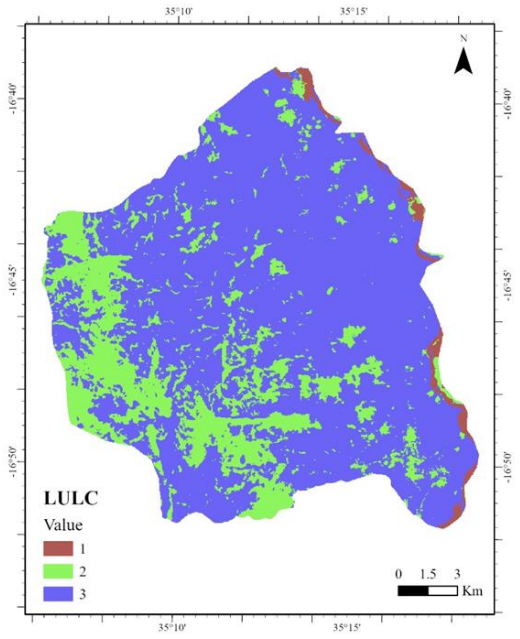


Figure 39 Classified land use map

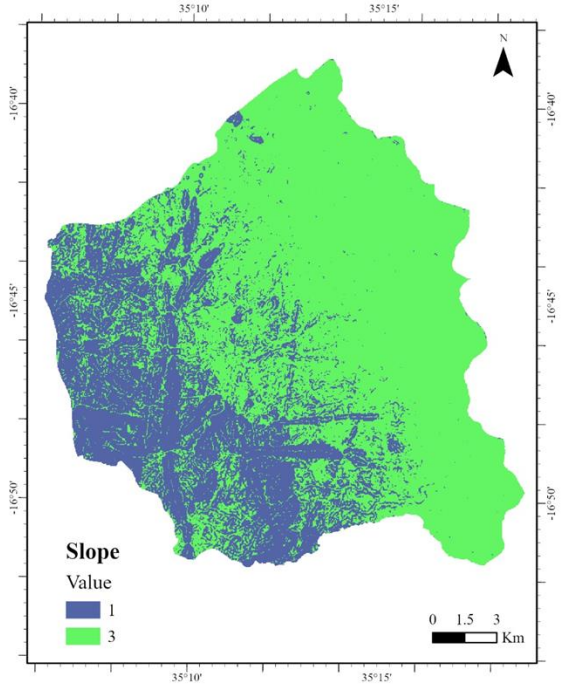


Figure 40 Classified slope map

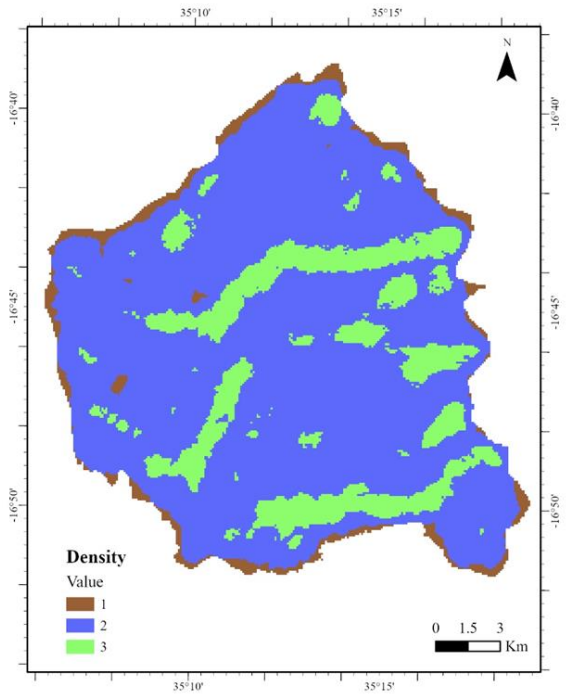


Figure 41 Classified drainage density

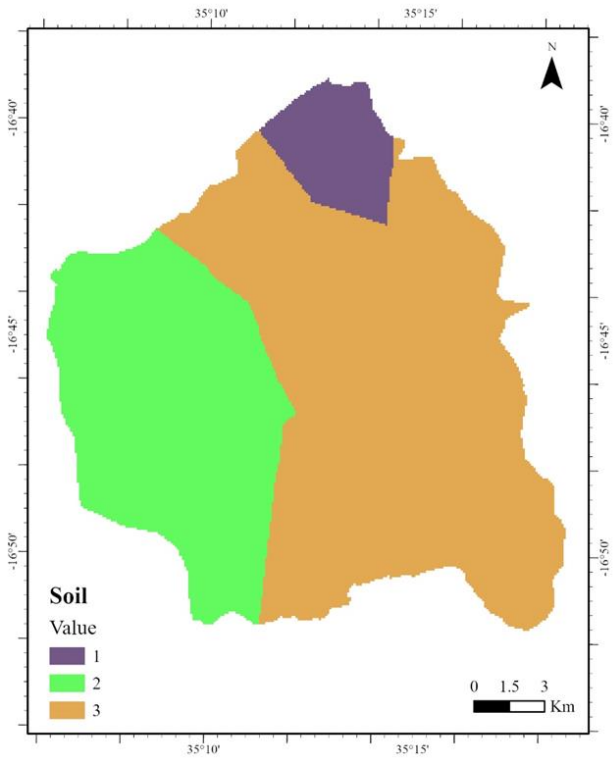


Figure 42 Classified soil map

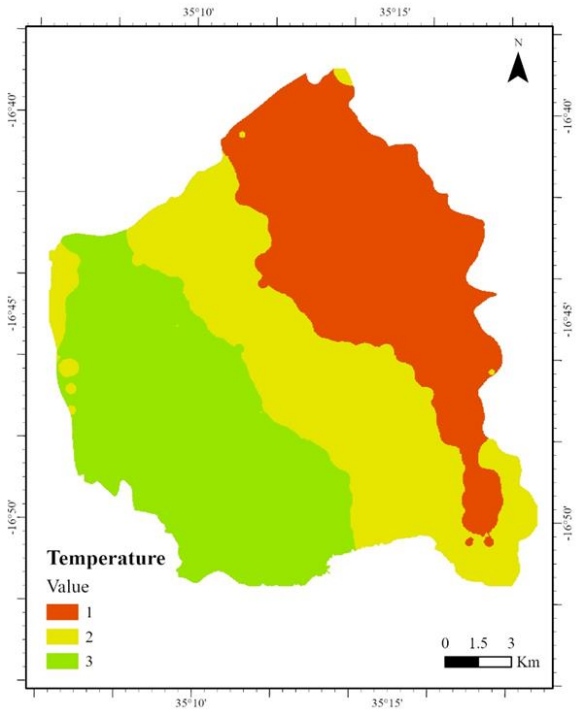


Figure 43 Classified temperature map

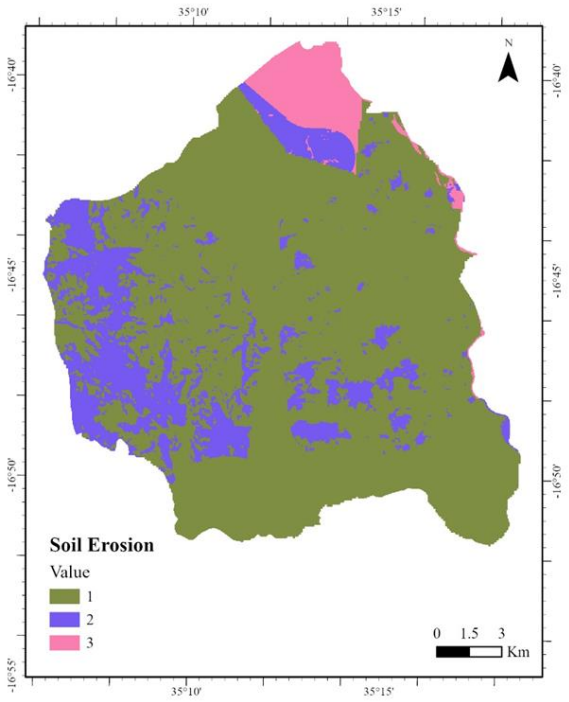


Figure 44 Classified soil erosion map

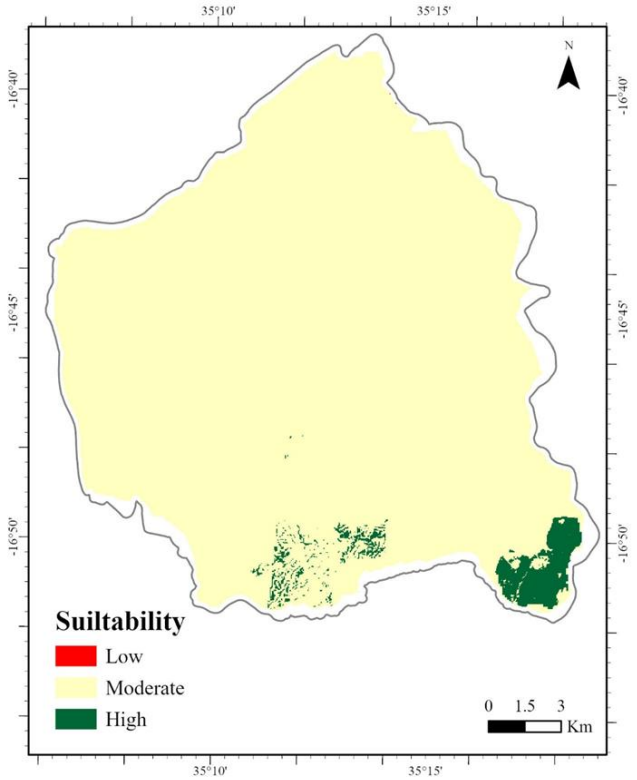


Figure 45 Final Rainwater suitable map

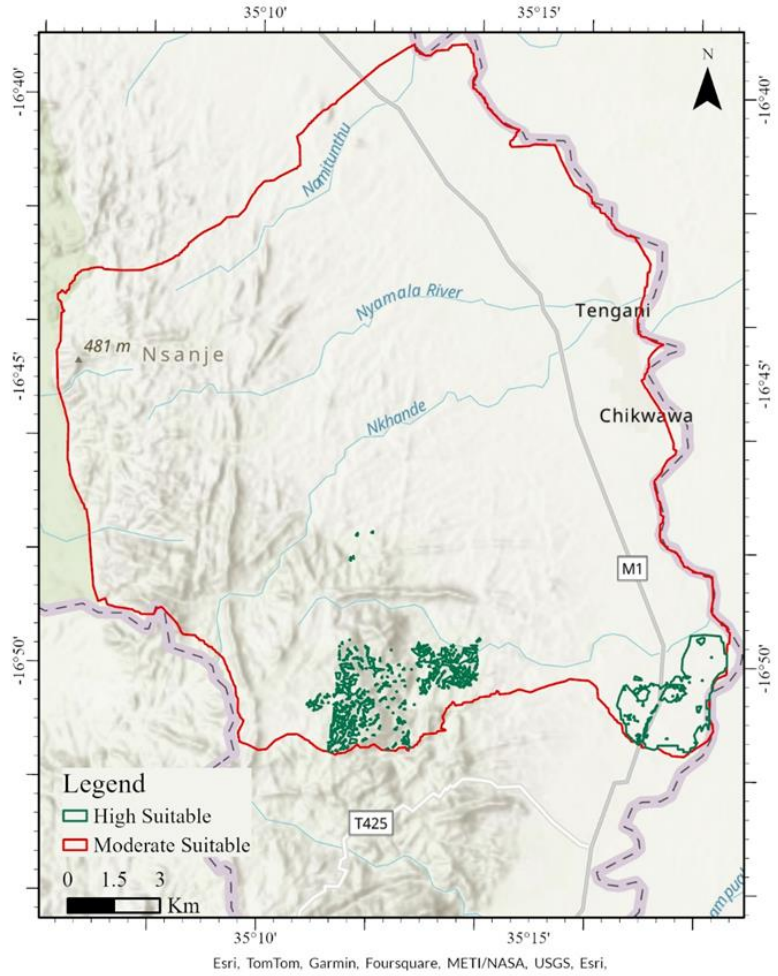


Figure 46 Finale suitability map