CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled "**: Identification of Potential Areas for Rainwater Harvesting Using GIS and Remote Sensing"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geographical Information Systems and Remote Sensing at Ardhi University.

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(Main Supervisor)   (Second Supervisor)

Date ………………………   Date ………………………

DECLARATION AND COPYRIGHT

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

………………………………..

YUSUFU, MWAJUMA R

25513/T.2020

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DEDICATION

I dedicate this study to my lovely parents Mr. and Mrs. Ridhiwani Yusufu who put a lot of efforts, encouragement, love, care and support for me to reach at this level. I am very grateful and humbled may Allah (SW) bless them abundantly.

ABSTRACT

Water scarcity is a growing concern, particularly in urban areas like Dar es Salaam, Tanzania. This research aims to address the water scarcity challenge by identifying and mapping potential catchment areas for rainwater harvesting using geographic information system (GIS) and remote sensing (RS) techniques. The study area, Kinondoni district, was selected for analysis due to its rapid population growth and reliance on piped water systems. The research objectives were to select appropriate criteria for locating potential catchment areas, perform suitability analysis, and generate a map of identified catchment areas. The data used for the study were rainfall data, land sat 8 image, SRTM DEM and soil data, which were captured and analyzed through using geographic information system and remote sensing approaches. Also, the factors that were considered in this study were Rainfall, slope, soil and land cover. Suitability analysis was conducted using the Analytic Hierarchy Process (AHP) a technique in multi-criteria analysis technique used for pairwise comparison of the criterion to determine its influence or weight over one another, weighted overlay analysis also was performed purposively for multiplying each criterion map to its weight so as to obtaining suitability map. The intermediate results obtained were rainfall map, soil map, slope map and land cover map. The resulting suitability map depicts that ,categorized areas as very high suitable amount to (0.47%) of Kinondoni district, high suitable areas amount to (21.42%), moderate suitable areas amounts to (28.18%), low suitable areas with low rated of suitability amounts to (26.69%), and areas that are not suitable for rainwater harvesting were amount to (23.24%), from obtained consistency ratio of 0.04, it indicates that the factors or criteria can be used in the whole processes of identifying potential catchment areas for rain water harvesting. The study findings indicate that rainwater harvesting can be a viable solution to mitigate water scarcity challenges in the Kinondoni district. Recommendations include raising public awareness about rainwater harvesting and conducting similar studies in other areas, considering additional criteria for more accurate results. This research contributes to sustainable water management and offers a practical approach for identifying suitable areas for rainwater harvesting using GIS and RS techniques.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AHP……………… Analytic Hierarchy Process

DEM……………… Digital Elevation Model

GIS…………………Geographic Information System

IDW………………...Inverse Distance Weighting

ISRIC……………….International Soil Reference Information Centre

MCDA……………...Multi-criteria Decision Analysis

RS…………………. Remote Sensing

RWH………………. Rainwater Harvesting

USGS………………. United States Geological Survey

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Water is the most essential and crucial for all living things, it is also the most noteworthy natural resources which support human needs and economic development; hence it should be used precisely for tomorrow's use (Gavit et al., 2018). Tanzania country is being characterized by a number of water resources such as from rivers, ponds, reservoirs and wetlands. Most of urban areas uses piped water supply system from rivers and underground water (Dismass et al., 2018) . Both the rivers water and ground water are climate dependants thus they may not be the reliable sources in areas like Dar es Salaam where population is increasing rapidly. Alternative to these sources, rainfall water can be harvested for current and future use especially at the time when the other two main sources do not perform well. And particularly in urban regions, where shortages of quality water supply can often occur, this practice offers a sustainable alternative in terms of cost and maintenance (Knan et al., 2022). Efficient rainwater harvesting relies on the proper identification and delineation of rainwater catchment areas through using suitability analysis.

Spatial techniques such as Geographical information system (GIS) and Remote sensing (RS) are vastly used in suitability evaluation (Al-Adamat et al., 2010), were they proven to be good for reconnaissance survey of any land assessment and their results could then be used as a guideline for pinpointing areas that could be targeted (Mosase et al., 2017). Also, RS can be used to deliver real data with high temporal resolution and spatial resolution whereas GIS is a device for gathering, storing and examining spatial and non-spatial data (Mati, et al., 2006). GISs and Remote sensing offer a data-reviewing capability that supports both quality control and identification of errors, also they provide a good opportunity to gain a better understanding of any patterns make a query, update criteria, posters and produce easy-to-read/use information through maps, posters, and the internet. The maps can also be converted into pictures to enable access by non-GIS users (Adham et al., 2016). Satellite remote sensing data provides fast and useful baseline information of parameters such as soil type, land use/landcover such as remote sensing data have been useful in the determination of landcover thematic mapping, providing valuable information for delineating the extent of land-cover classes and GIS technique is used to integrate all these thematic layers

(Tiwari et al., 2018). The accuracy of remote sensing and GIS tools significantly depends on the quality (spatial, spectral and temporal resolution) and availability of the data (Adham et al., 2016). Also, using GIS for site selection is based more on the application of deterministic rules guiding the integration of set of parameter maps, so that alternative location gets arranged according to several settings on evaluation criteria (Malczewski, 2004). GIS and RS are valuable and time-saving approaches in identifying optimal water harvesting sites (Harka et al., 2020).

Due to less studies being conducted concerning on using suitability analysis for identification of potential rainwater harvesting areas especially in Dar es salaam region, thus there is still unpredictable water scarcity challenge that experience Dar es salaam region caused by being much depends on water piped systems. Therefore, this study aims in identifying potential areas for harvesting rainwater in Dar es salaam region especially in Kinondoni District which will try to ensure enough availability of water and reduce the water scarcity challenge that might be experienced in Dar es salaam region. As, RWH offers a flexible solution which can effectively meet small- and large-scale demands (Abdulla & AL-Shareef, 2009) .

1.1.1 The study area

Kinondoni is the one among the five-district found in the northwest Dar es salaam region were to the East is bounded by Indian ocean, it is located in a geographic coordinate of latitude 6º 47´12´´S and longitude 39º 16´ 11´´E and it has coverage area of approximate 537 km^2. Kinondoni is located at the elevation of none meters (0 feet) above sea level it has a tropical wet and dry or savanna climate, it has a yearly temperature of 28.04ºC (82.47ºF) and it is 3.82 % higher than Tanzanian averages and typically experiences a modified type of equatorial climate. There are two rain seasons in Kinondoni district, short rain from October to December and long rain season between March and May. The average annual rainfall is 1300mm. Humidity is around 96% in the mornings and 67% in the afternoons. The climate is also influenced by the Southwest monsoon winds from April to October and Northeast monsoon winds between November and March. It is economy of the Kinondoni District depends on the small scale and large-scale businesses being operated within the district. The figure 1.1 illustrate the location of the study area,

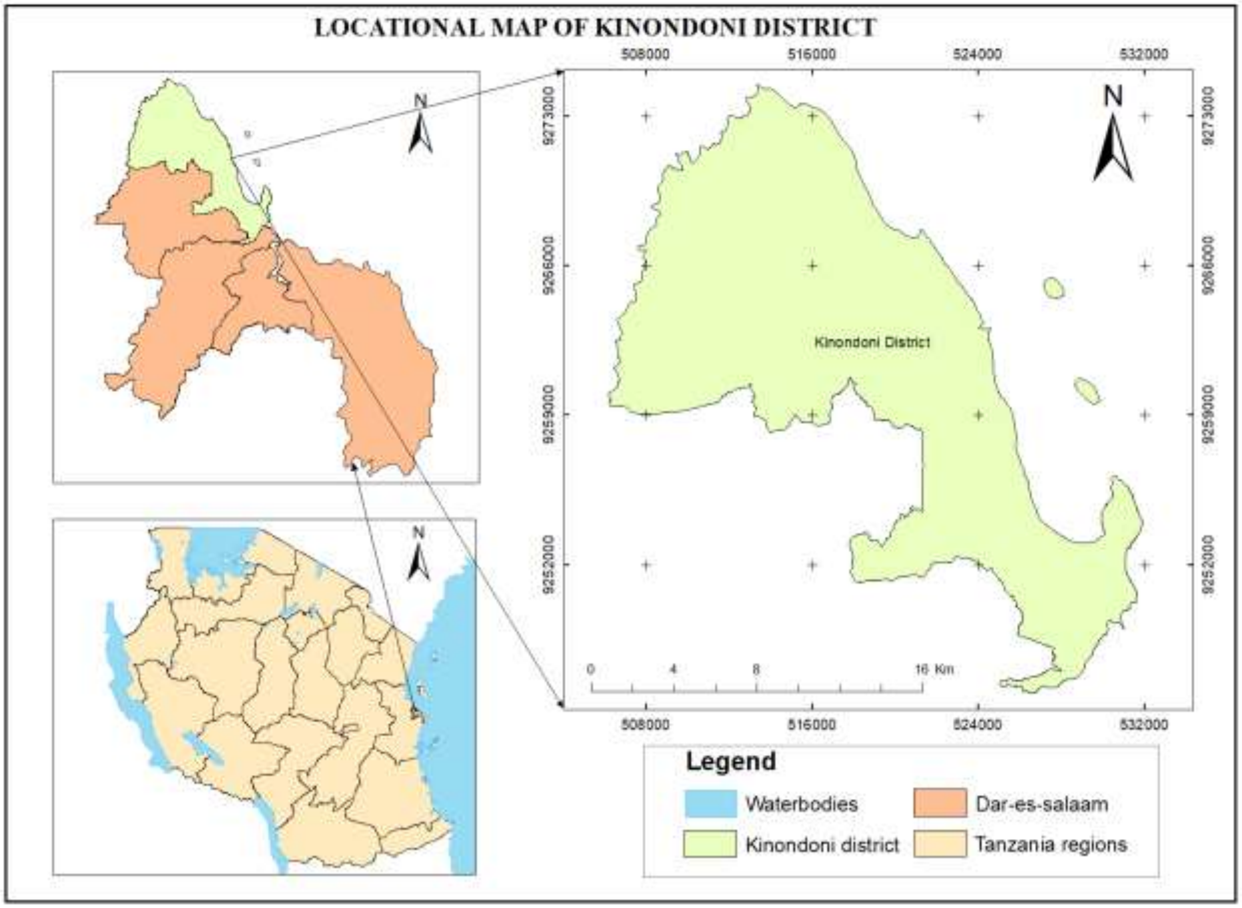

Figure 1.1: Study area locational map

1.2 Statement of the research problem

Due to rapid increase in population within Dar es salaam region it leads to overuse of the available water resources and results to its shortages, thus the available water sources may not be enough for sustaining the present population. Rainwater harvest has been proposed as an alternative for water sources in a highly populated urban areas such as Dar es Salaam

However, there is still an in adequate or limited information or knowledge on proper location for collecting the rainwater, as only few studied have been conducted to explore areas which are potential for rainwater harvest in Dar es salaam.

1.3 Objectives of the research

1.3.1 Main objective

To identify and map potential areas for rainwater harvesting using GIS and remote sensing

1.3.2 Specific objective

i. To perform suitability analysis for identifying the potential areas for rainwater harvesting in the study area

1.3.3 Research questions

After the completion of this research will answer the following questions;

i. Where are the possible potential areas for rainwater harvesting within the study area?

1.5 Significance of the research

The research results will be able to identify the potential catchment areas for rainwater harvesting (conserving the rainwater) that will enhance proper allocation of the dams for harvested water which will be trying to reduce the water shortages problem that faces the urban region especially in Dar es salaam, also being able to reduce the risk of flooding by decreasing the amount of runoff. Finally, the research outcomes being able to raise social awareness (awareness to the society) on the benefits of harvested rain water and encouraging its management for long-term uses.

1.6 Beneficiaries of the research

The expected users of this research results will include;

i. The water supply authorities

The research could be used by the water supply authorities or being considered by government through ministry of water as a reference to identify other areas (other regions) that experiences water shortages different from Dar es salaam region. Also, the ministry and generally water authorities will be able to identify potential areas were catchment surfaces such as dams could be constructed for harvesting the rainwater and investing funds for its construction.

ii. The researchers

Also, the research could be used by other researchers as a reference study to learn more on the concepts of rainwater harvesting and be able to develop more new ideas that could be added for their study.

iii. The community

Through the study or the research will try to raise awareness to the community on the benefits of harvesting rainwater and even encouraging the management of the available harvested rainwater.

1.7 Scope and Limitation of the Research

The study will apply the use of the GIS and remote sensing purposively for identifying potentially catchment areas that could be used for rain water harvest, thus will use criteria's such as slope, rainfall, surface area (type of soil) and slope for dealing with the ground catchment method thus, the other method such as roof catchment method will Lesly or not even much being considered.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter pinpoint different literatures and materials that are related on identifying potential areas for rainwater harvesting in aspect such as on the data and concepts used, methodology or techniques applied. As it highlights different literature or findings that were related and useful for this research, where different research and literature that has particular theme or objective as the study will be discussed and highlighted in this chapter.

2.2 The concept of Rainwater Harvesting

Rainwater harvesting is defined as the collection, storage, distribution, and use of rainwater. RWH includes techniques for collecting and storing runoff from rainwater for domestic and agricultural use in the wider sense (Naseef & Thomas, 2016), thus is the collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural as well as ecosystem sustenance (Mekdaschi Studer & Liniger, 2013). Also, Rainwater harvesting practice is defined as harvesting and storing rainwater during rainy season(s) (Biswas & Mandal, 2014). In urban areas, RWH consists of the concentration, collection, storage and treatment of rainwater from rooftops, terraces, enclosures, and other impervious building surfaces for on-site use (Ghaffarian Hoseini, et al., 2016).

The main role of RWH is to increase the amount of available water by capturing rainwater in one area for local use or for transfer to another area. Most of Rainwater harvesting systems consist of the following components (Oweis et al., 2012):

- A catchment: the part of an area from which some of the rainfall is harvested. It is also known as a runoff area. This area can be a few square meters to several square kilometers in size and may be agricultural, rocky, a paved road, or a rooftop.
- A storage facility: the area that holds the harvested runoff water until used for crops, animals, or people. Water can be stored above ground (example, reservoirs or ponds), in the soil profile, and in underground storage containers (example, cisterns).

- A target: the endpoint of a water harvesting system, where the harvested water is used for crop production or domestic use

2.2.1 A catchment area

A catchment area represents the land area where precipitation such as rainfall is collected and eventually funneled into a specific water system. Also, a catchment is a land area from which all rainfall would drain by gravity into a common outlet point (Hatibu, et al., 2000), and a catchment can be the area where rain in the form of run off is harvested and may be small or large area in square kilometers as paved area like a terrace of a building or a unpaved area like a lawn or open ground. And for the study the open ground type of a catchment will be considered.

Generally, Gould & Nissen-Petersen,(1999) categorized rainwater harvesting systems according to the types of catchment surface used. These types are roof catchment systems, rock catchment systems, ground catchment systems, and check or earth dams, but for the study the ground catchment (surface runoff) harvesting will be much considered. The catchment area of already harvested water can be illustrated in figure 2.1,

Figure 2.1: A rainwater harvested catchment area

2.2.2 Benefits of rainwater harvesting

The harvested rainwater can be used for potable and non-potable uses. The potable uses include drinking, bathing, and cooking and dish wash. Usually, the rainwater used this purpose must be treated to remove the contaminants and non-potable uses include flushing toilets, watering garden and washing floor and treatment of rainwater is not required for this purpose. RWH benefits include decreased runoff, flood protection in upstream areas, soil moisture improvement, and soil conservation (Singh, Singh, & Litoria, 2009)

2.3 The Remote sensing and GIS application in Rainwater harvesting

Diverse research methodologies using RS and GIS have been applied by different authors to identify potential rainwater harvestings in remote and data scarce areas, in most of these methods thematic maps are derived from remote sensing data and integrated in GIS to evaluate suitable sites for rainwater harvesting (Munyayo, 2010).

Remote sensing is of immense use for natural resources mapping and generating necessary spatial database required as an input for GIS analysis. GIS is a tool for collecting, storing and analyzing spatial and non - spatial data, and developing a model based on local factors can be used to evaluate appropriate natural resources development and management action plans, also GISs are very useful tools, especially in areas where very little information is available which is often the case in developing countries (Mahmoud, 2014). As various thematic layers can be generated by applying spatial analysis with GIS software. These layers can then be integrated for identifying suitable sites for RWH (Adham et al., 2016). Both these techniques can complement each other to be used as an effective tool for selecting suitable sites for water harvesting structures (ICRAF, 2005). Integration of Remote sensing and Geographic Information Systems (GIS) help to facilitate and identify suitable site and permit rapid and cost-effective sites survey. Remote sensing and GIS techniques provide accurate, reliable and update on land, soil, water resources, which is a prerequisite for and integrated approach in identifying suitable sites for water harvesting structures (Lillesand & Kiefer, 2000)

Remote sensing and GIS technology was used to prepare various thematic maps of other related features which are directly or indirectly influence water harvesting site identification such as land use/land cover, soil, drainage, and slope (Wondimu & Jote, 2020).

2.4 Suitability analysis

Land Suitability Analysis (LSA) is a GIS-based process applied to determine the suitability of a specific area for considered use, where it reveals the suitability of an area regarding its intrinsic characteristics (suitable or unsuitable) (Jafari & Zaredar, 2010). Also, can be refers to the geospatial analysis process that aims to identify most suitable and appropriate locations for a specific purpose based on a certain criteria or factors, as it uses the available criteria or factors to determine suitable locations that maximizes water collection and storage efficiency as it minimizes potential risks.

2.4.1 Multi-criteria Decision Analysis

Multi-criteria Decision Analysis is a commonly used method of analysis that combines data for various criteria, one of the main rules of MCA is to estimate a relative weight for each criterion, rather than assuming the same weight for all criteria and then compare two or more alternatives (Adham et al., 2016).

Some spatial planning or spatial problems like site selection can be considered as a multiple criteria decision making or multiple MCDM problems involve a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria (Malczewski, 1999).

Multi-criteria analysis was regarded as the most convenient method of suitability selection. The pros of using this method are that it is flexible, effective, updating criteria is easy and can be applied in differently sized areas (Adham et al., 2016).

2.4.1.1 Analytic Hierarchy Process(AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria analysis technique, selected as the most viable decision method to identify suitable sites for RWH with GIS platform, as a wide use of AHP has been done in many research studies for the identification of potential RWH sites (Krois & Schulte, 2014).The AHP is a multi-criteria decision-making method, providing a structured technique for organizing and analyzing complex decisions (Adamcsek, 2008), based on mathematics and expert knowledge. It was developed by Thomas Saaty in the 1970s and, since then, has been applied extensively in different disciplines.

The main principle of AHP is representing the elements of any problem hierarchically to show the relationships between each level. The uppermost level is the main goal(objective) for resolving a problem and the lower levels are made up of the most important criteria that are related to the main objective. Pairwise comparison matrixes are constructed and scaled in preference from 1to 9 for each level as shown in table 2.1. Then, the consistency of each matrix is checked through the calculation of a consistency ratio (CR) which is used to determine whether the inconsistency is acceptable or not. The CR should be smaller or equal to 10% (Ying, et al., 2007). Generally, in the AHP approach, the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding CR is less than 10% or (0.1), If CR exceeds 0.1, based on expert knowledge and experience, recommends a revision of the pairwise comparison matrix with different values (Wondimu & Jote, 2020). The weight for each criterion and the CR is determined, then all matrices are solved, for the study the value of CR of 0.043 was obtained which lies under allowable range of consistency ratio. To determine the consistency of weights allocated to each thematic layer and its characteristics, the consistency ratio was calculated using equation below (Saaty & Kearns, 1985);

$$\text{Consistency Ratio (CR)} = \frac{CI}{RCI} \quad \text{.........................Eqn (2.1)}$$

where RCI is the random consistency index, and CI is the consistency index given as:

$$CI = \frac{\lambda max - n}{n - 1} \quad \text{....................................... Eqn (2.2)}$$

where λmax is the principal eigenvalue computed by the eigenvector technique, and n is the number of criteria (factors), and the values for random index are indicated in table 2.2.

Table 2.1: The scales for pairwise comparison

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more importance	Experience and judgement slightly favor one factor over another
5	Much more importance	Experience and judgement strongly favor one factor over another
7	Very much more importance	Experience and judgement very strongly favor one factor over the other. Its importance is demonstrated in practice
9	Absolutely more importance	The evidence favoring one factor over the other is of highest possible validity
2,4,6,8	Intermediate values between two adjacent judgements	When compromise is needed

Table 2.2: The Random index value

Matrix size(n)	1,2	3	4	5	6	7	8	9	10
Random index (RI)	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

2.5 Criteria selection

Identifying optimal RWH areas depends on many factors including biophysical and socio-economic conditions, the biophysical factors are as rainfall, drainage system, slope, land use land cover, soil type and the socio-economic factors may include land tenure, distance to settlement/streams/roads/agricultural area, population density, related cost (Wu et al., 2018). But for the study only biophysical factors such as slope type, soil texture, rainfall and land cover will be considered. Relating to the revised literatures, we have identified the criteria to consider are rainfall, land slope, land cover and soil texture (Tahera et al., 2022),and summarized description of the criteria are described in table 2.3,

Table 2.3: Factors and their criteria description

Factors	Criteria
Rainfall	>325mm of the annual rainfall
Soil texture	Soil enriched with clay is highly suitable (clay soil)
Slope type	<2^{o} is suitable
Land cover	Bare land area is more suitable

CHAPTER THREE

METHODOLOGY

3.0 Overview

This is the major chapter that contains or explains in details all the tasks that was performed during the research. Describes all the stages from data collection or acquisition and the sources used to acquire them, the criteria used in assessing the data, methods used to process the data purposively for achieving the desired research objectives.

The summaries of the systematic procedures which were considered during performing the research are shown in figure 3.1.

3.1 Data collection

Due to the criteria that will be used for performing the research the collected data are rainfall data, satellite image, DEM, soil data, administrative boundaries and road network data. The data were obtained using different methods and were being acquired from different sources as shown in table 3.1.

3.2 Tools used

In the study computer, and the software such as QGIS and ArcGIS and internet facility were used, such that the QGIS software was being used during the pre-processing and ArcGIS was being used in processing the collected data and producing the required output.

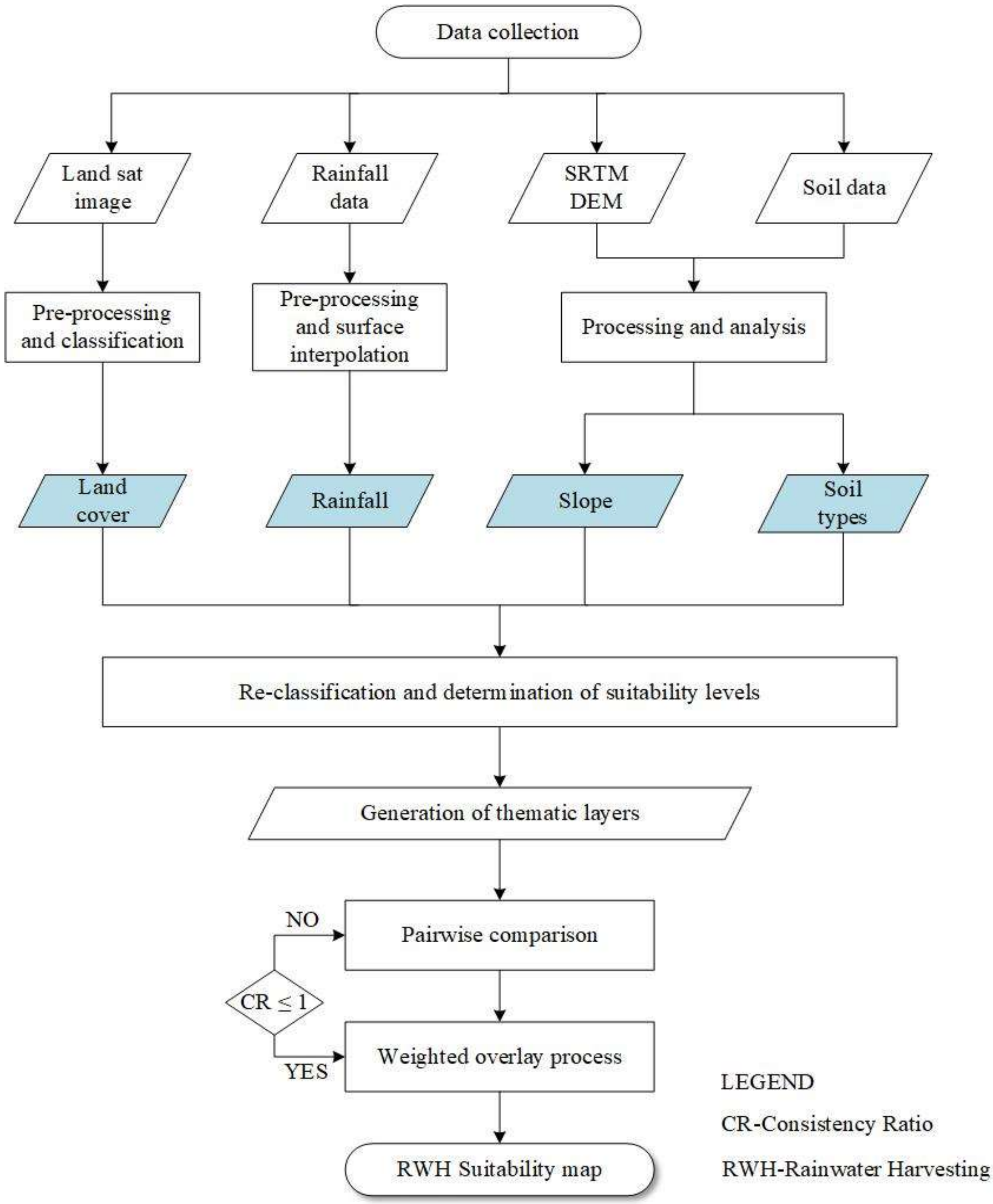

Figure 3.1: Research work flow

Table 3.1: Data types and their sources

Dataset	Format	Resolution	Source	Uses
Landsat 8 image	TIFF	30m	USGS (https://earthexplorer.usgs.gov)	Determine landcover for spatial and spectral observation
DEM SRTM	TIFF	30m	USGS (https://earthexplorer.usgs.gov)	Determines slope and modelling water flow movements
Soil data	shapefile		ISRIC (https://files.isric.org/public/soter/SAF-SOTER.zip)	Soil texture and soil types determination
Rainfall data	Netcdf file	4km	Climatology lab (https://www.climatologylab.org/terraclimate.html)	Determining average amount of rainfall in an area
Administrative boundaries	shapefile		DIVA GIS (https://www.diva-gis.org/gdata)	For extracting area of interest

3.3 Data Pre-processing

It involves all the initial procedures(preparation) that were done to the acquired data, so as to make the data be useful for the further processing. And the procedures are as follows,

3.3.1 Image correction and reprojection

The downloaded image was initially being atmospherically corrected as a radiometric correction stage using the semi-automatic classification (SCP) plugin in QGIS software. And the output obtained after being corrected was being reprojected from WGS84 which is the normal projection for downloaded image to WGS84 zone 37 in Southern hemisphere which corresponds to UTM projection of the study area, and was done using ArcGIS 10.8 software.

3.3.2 Layer stacking

The projected bands of Landsat 8 images were stacked so as to combine them together, band 1 up to 7 band were stacked using the band composite under raster processing found in data management toolbox in ArcGIS software leaving band 10 which is thermal infrared band whose information are not needed for land cover preparation.

3.3.3 Image clipping

Image clipping is the process of extracting the part of interest from the large image dataset. Thus, the stacked image, the DEM, rainfall and soil data were imported in ArcMap software in which the boundary of the study area (Kinondoni district) was also imported. By using the Extract by Mask under the Extraction tool found in spatial analyst toolbox the stacked image was clipped, also the other data such as rainfall, DEM and soil data using the same procedure was clipped to remain with only the area of interest (Kinondoni district).

3.3.4 Interpolation

The rainfall data was being interpolated after being downloaded, rasterized, clipped to cover the area of interest and band combined for the pixels and later was converted to points using tools in ArcMap environment and being interpolated using IDW method of interpolation.

3.4 Data processing

In the study the four thematic layers for each identified criterion were created which are land cover, slope, soil and rainfall, and the identified layers at the end were used for pair wise comparison and weighting overlay associated with the criteria so as to identify suitable catchment areas for harvesting rainwater.

3.4.1 Image Classification

The Landsat 8 image of 2022 covering the study area was classified using maximum likelihood technique(algorithm) for supervised classification into three classes (which are bare land, built up areas and vegetation). The classification was done using ArcGIS software.

3.4.2 Accuracy assessment

The accuracy assessment was done after classification of an image, and the kappa index of agreement method was used. The kappa index of agreement is defined as the measure of classification accuracy (Congalton et al., 1982), as is the measure of how well the land sat classification agrees wiyth the reference data.And is obtained using the following formula,

$$K = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r} (X_{i+} * X_{+i})} \quad \text{......................................Eqn (3.1)}$$

Where:

r is the number of rows in the error matrix

X_{ii} is the number of observations in row i and column i

X_{i+} total observations in row

X_{+i} total observations in column

N is the total number of observations(cells)

3.4.3 Slope extraction and mapping

The slope layer was being created or extracted from the SRTM DEM which were downloaded using SRTM downloader plugin in QGIS, as slope was being extracted from the SRTM DEM using surface tool found in spatial analysis toolbox in ArcGIS software as it was expressed in degree(radians), and slope plays a vital role in runoff and sedimentation quantity. Finally, the slope layer was being mapped in ArcMap environment.

3.4.4 Soil mapping

Soil mapping it involves the whole process of representing the classified soil basing on its type or texture according to the study area (Kinondoni district). As the downloaded soil data was being clipped using clip tool in ArcMap environment and being rasterized as converted to raster using the polygon to raster tool found in conversion toolbox in ArcMap software and the output was being projected using the project tool and mapping also was done using the ArcGIS software. The process of classifying soil satisfies in identifying the infiltration rate and holding capacity of the particular soil type.

3.4.5 Rainfall mapping

The rainfall data which were interpolated was exported according to study area referring the spatial reference to be the same as the data frame so as to fit to the projection of the study area in ArcMap environment, and mapping of the rainfall layer was also done in ArcMap. As rainfall being the major factor in assessing suitability in a given study area.

3.5 Data reclassification

Reclassification is the process that involves reassigning each criterion's respective score so that it can be used for selecting the suitable(appropriate) site. In reclassifying all data were set into raster format using the polygon to raster tool found in conversion toolbox in ArcMap software, also the data were reclassified using the reclassify tool in spatial analysis toolbox in ArcGIS software depending on the nature of the criterion. The criteria have varying scale thus they were reclassified to obtain a common scale before they are combined for the analysis. The following tables shows the reclassification of layers basing on their scores, in which the layers were reclassified into three classes.

Table 3.2: Slope reclassification

slope values(degree)	Suitability levels	Scores
0-2.87(gentle)	High suitable	7
2.87-6.04(moderate)	Medium suitable	5
6.04-26.10(very steep)	Low suitable	2

Table 3.3: Rainfall Reclassification

Rainfall values(mm)	Suitability levels	Scores
882-938	Low suitable	3
938-984	Medium suitable	5
984-1082	High suitable	7

Table 3.4: Soil type reclassification

Soil type	Suitability level	score
AR (Hypoluvic Arenosols)	Low suitable	4
FR (Haplic Ferralsols)	High suitable	7

Table 3.5: Land cover reclassification

Land cover type	Suitability level	Score
Bare land	High suitable	7
Vegetation	Medium suitable	3
Built up area	Low suitable	2

3.6 Weighted overlay

Suitability analysis for identifying potential catchment areas for rainwater harvesting was analyzed using weight overlay analysis based on the criterion layers (factors). The weight was assigned for each criteria layer according to its importance by using Analytic Hierarchy Process (AHP) from Multi-criteria decision analysis (MCDA), and the weighted overlay was used to identify the suitable areas for rainwater harvesting. As in this technique the overlay analysis was performed by multiplying each criterion map with its relative weight so as to get a suitability map.

In order to determine the weight assigned for each criterion, pair wise comparison was performed by considering the Saaty scale of importance ranging from most important factor to least important factor as indicated in table 3.7. The pairwise comparison process was done using the AHP extension tool in ArcMap, in which the weight for each criterion was computed, and normalization for the scores was performed as indicated in table 3.7, also the consistency ratio was also obtained as shown in table 3.7.

Table 3.6: Pairwise comparison matrix table

Criteria	Rainfall	Land Cover	Slope	Soil
Rainfall	1.00	3.00	5.00	7.00
Land Cover	0.33	1.00	3.00	5.00
Slope	0.20	0.33	1.00	3.00
Soil	0.14	0.20	0.33	1.00
SUM	1.67	4.53	9.33	16.00

Table 3.7: Computed weight table

Criteria	Rainfall	Land Cover	Slope	Soil	Weight	Weight (%)
Rainfall	0.60	0.66	0.54	0.44	0.57	57
Land Cover	0.20	0.22	0.32	0.31	0.26	26
Slope	0.12	0.07	0.10	0.19	0.12	12
Soil	0.08	0.05	0.04	0.06	0.05	5
SUM	1.00	1.00	1.00	1.00	1.00	100
CR	0.043	-	-	-	-	-

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter describes, displays, analyzing and interpreting all the obtained results from data processing and reclassification of the given data proposed for obtaining potential catchment areas for rainwater harvesting.

4.1 Criteria maps

4.1.1 Rainfall map

The Rainfall map was obtained after pre-processing and interpolation of the rainfall data, the values of parts of Kinondoni district were obtained. The rainfall map produced showed the average annual rainfall in Kinondoni district from 882 mm to 1082 mm, as the rainfall amounts per annual affects to the selection of potential site for rainwater harvesting thus the amount of annually rainfall distribution ranging from 984-1082 is highly contributing and was given much of contribution depending on the objective of the study. The rainfall map showing different rainfall value is shown in figure 4.1.

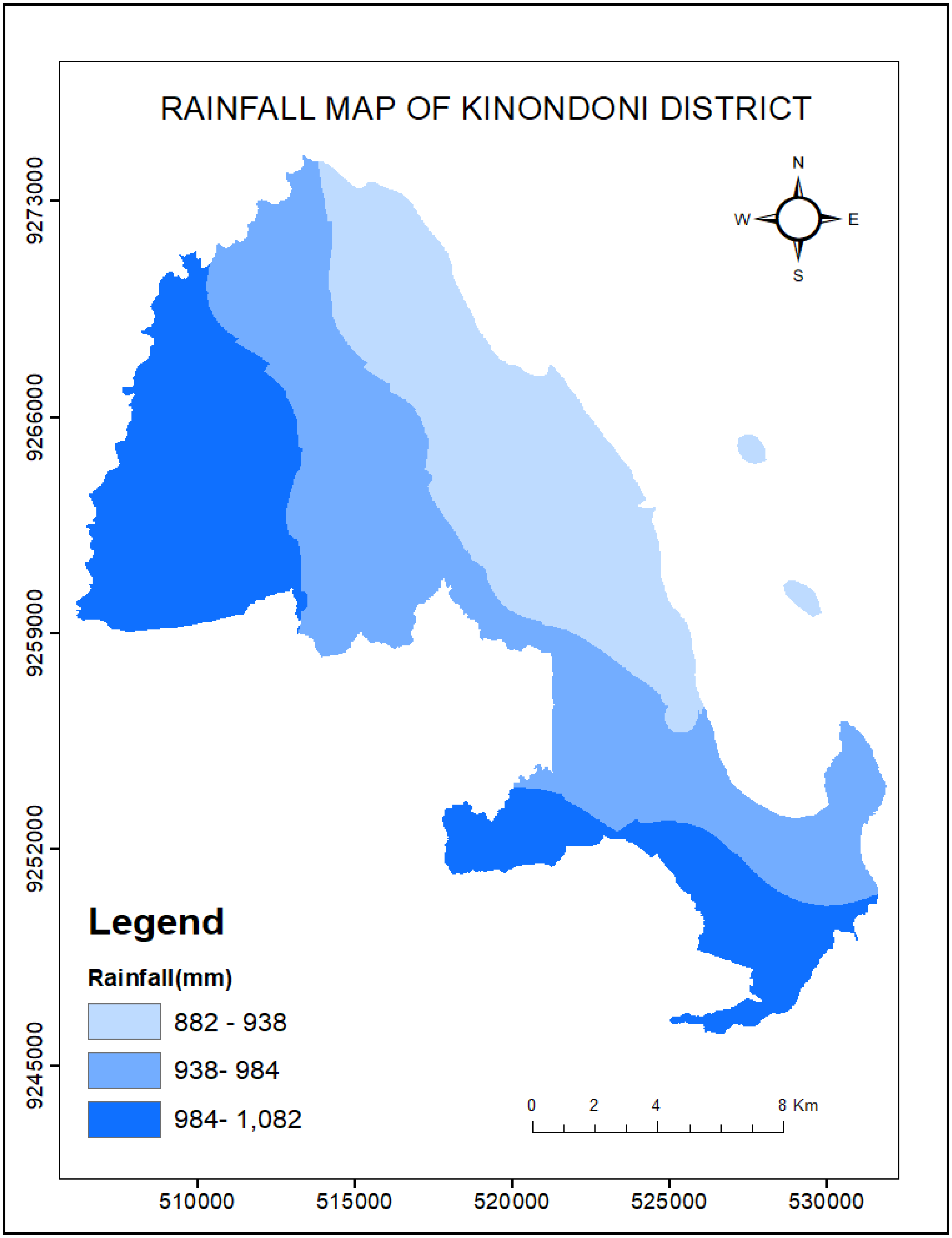

Figure 4.1: Average annual rainfall map

4.1.2 Slope map

The slope was obtained after performing surface analysis on DEM dataset, and slope analysis is useful in identifying potential catchment areas for water harvesting as is important for determining water runoff speed. And slope map was produced and categorized into three classes from 0-2.87 to 6.04-26.10 degree of radians, as it affects the infiltration and recharge of water in the catchment the slope ranging from (0-2.87) degree was highly considered as it influences on identifying potential area for harvesting rainwater. The slope map is displayed in figure 4.2.

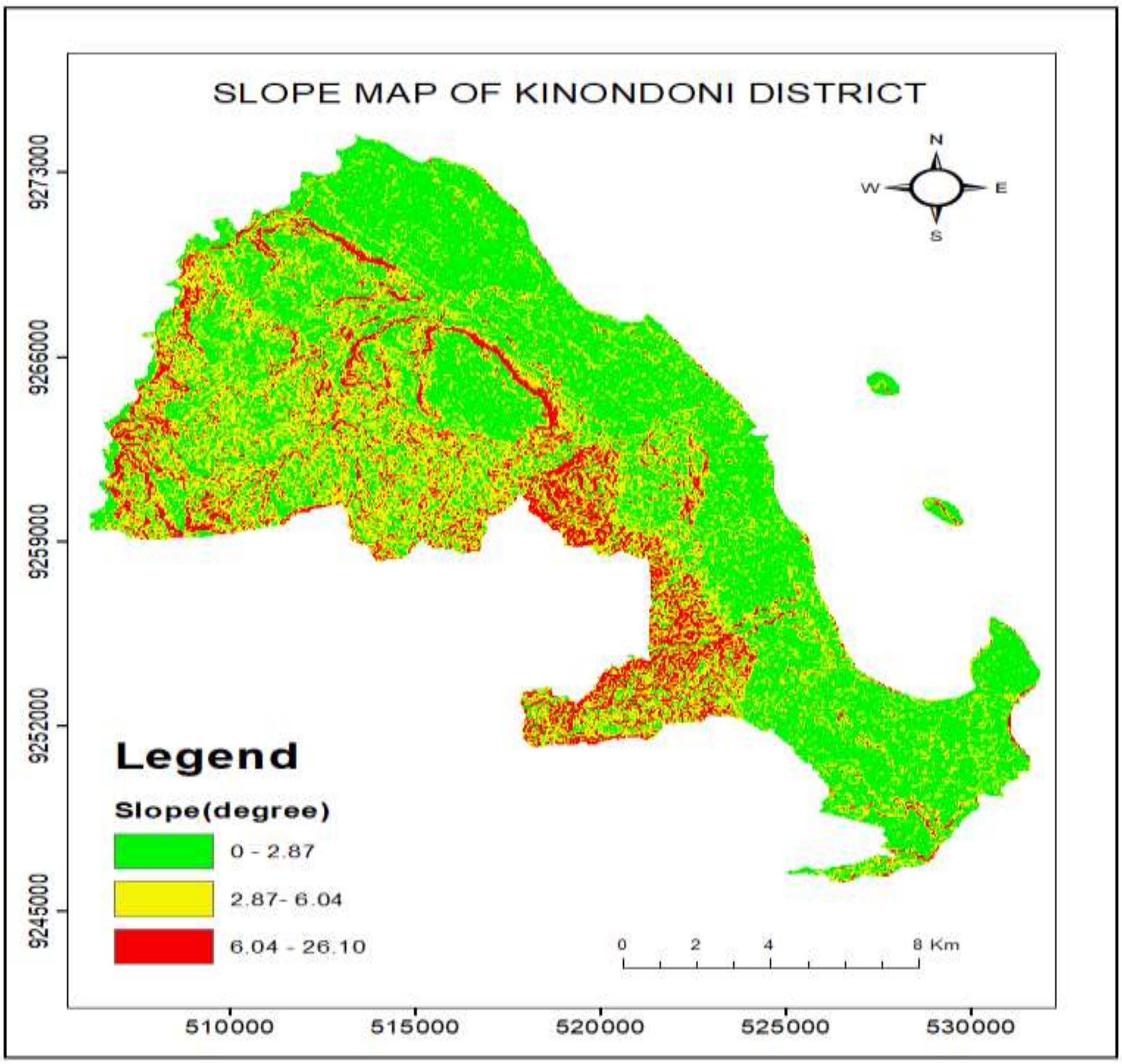

Figure 4.2: Slope map

4.1.3 Soil map

The soil is considered as the vital input or criteria in the identification of potential catchment area, from the produced map of the study area (Kinondoni district) only two categories of soil were found around the study area which are AR (Hypoluvic Arenosols) which is enrich of sandy soil and FR (Haplic Ferralsols) which has clay contents. As Soil texture affects both infiltration and surface runoff rate the soil type which is enriched with clay was be much considered and given high priority because it has high water-holding capacities and are suitable for harvesting rainwater (Adham et al., 2016) compared to the soil which is enriched in sandy it has high infiltration rate thus is not favorable for harvesting rainwater, the slope map is depicted in figure 4.3.

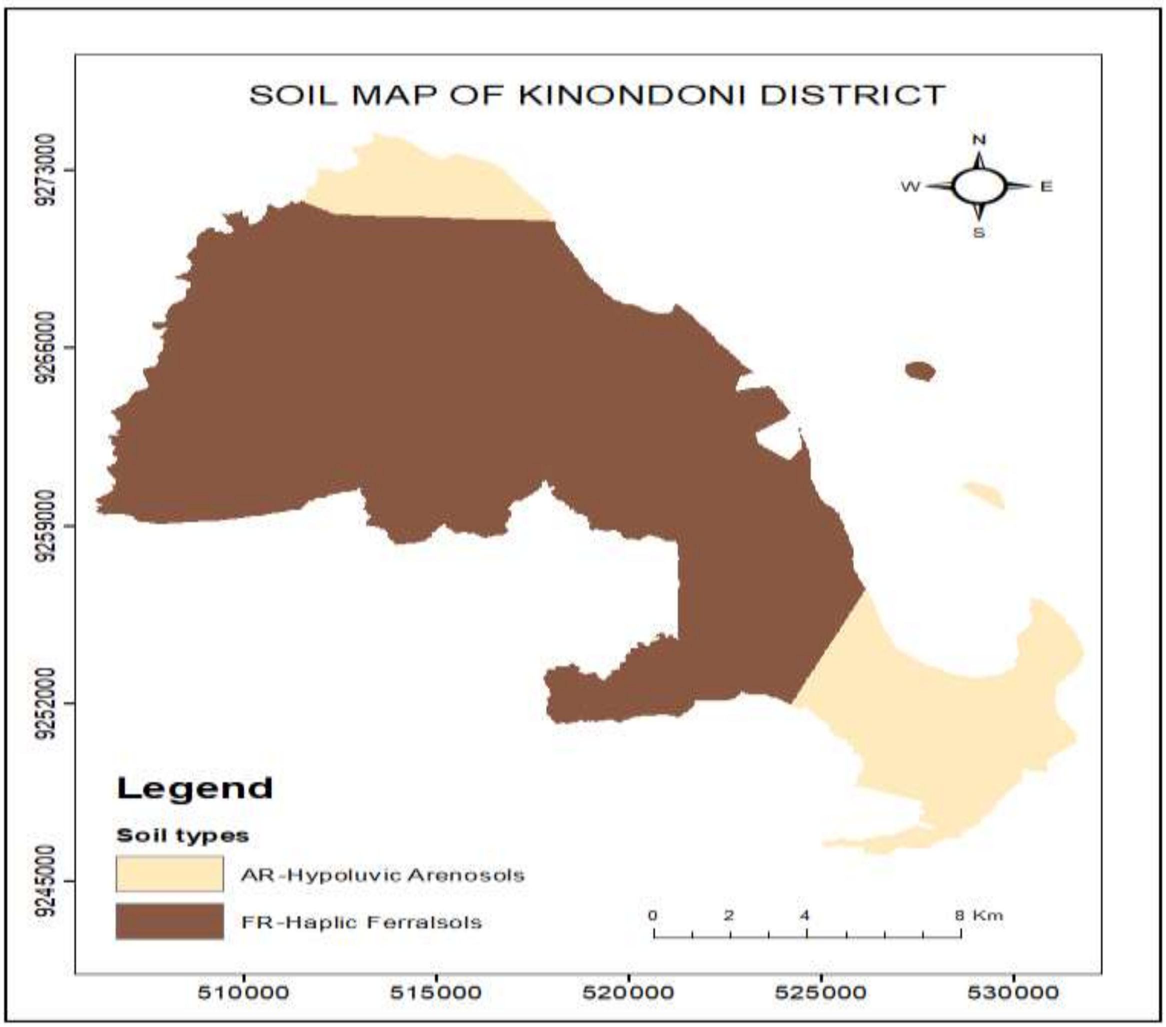

Figure 4.3: Soil map

4.1.4 Land cover map

Land cover is used to show what is covered on the ground from the given study area. After performing classification, during accuracy assessment of a classified image of the study area the overall allowable accuracy value of 80% was obtained, the land cover map having three classes of Bare land, Built-up areas and Vegetation was produced, the Bare land class was given much of consideration for the study area as it contributes to the catchment of the harvested rainwater. The land cover map is shown in figure 4.4, and the error matrix table for the classified image is indicated in table 4.1.

Table 4.1: Error matrix table

CLASSIFIED/REFERENCE	Bare land	Built-up area	Vegetation	Total Reference
Bare land	11	1	1	13
Built-up area	3	11	2	16
Vegetation	2	1	18	21
Total Classified	16	13	21	50
Total Correct Reference Points	40			
Total True Reference Points	50			
Total Accuracy	80%			
Kappa	0.6957			
User's Accuracy			Producer Accuracy	
Bare land	84.70%		Bare land	68.80%
Built-up area	68.80%		Built-up area	84.70%
Vegetation	85.70%		Vegetation	85.70%

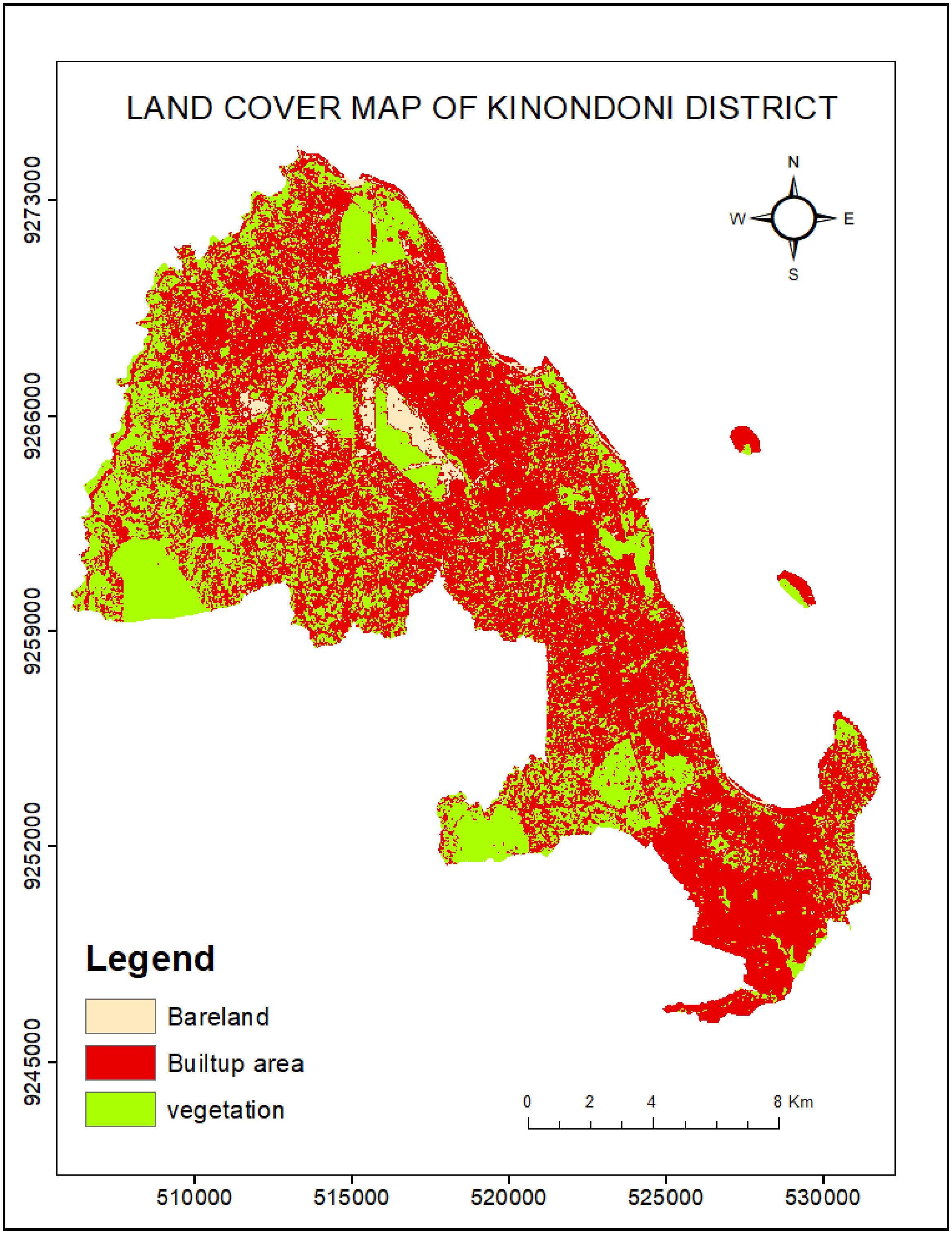

Figure 4.4: Land cover map

4.2 Reclassified maps (thematic layers)

The criteria maps were reclassified depending on the weight or influence of each criterion on suitability site selection. The layers were reclassified into three classes of Low suitable, Medium suitable and High suitable as shown in the following reclassified maps.

4.2.1: Reclassified Rainfall map

The map was obtained after reclassification of rainfall map, as areas that receives high amount of rainfall was indicated as highly suitable compared to the area receives the minimum amount of rainfall which was reclassified as low suitability in influencing of RWH. As reclassified rainfall map is indicated in figure 4.5.

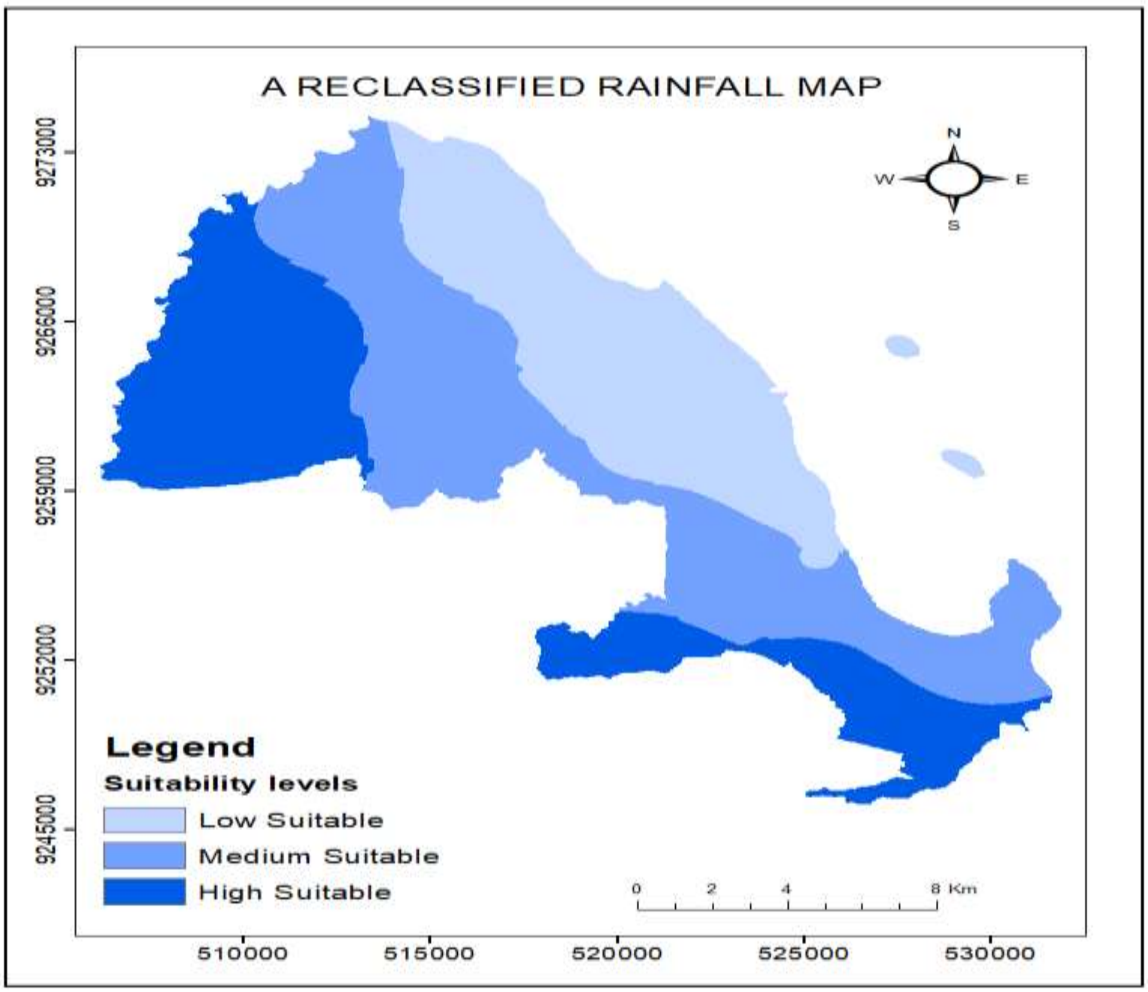

Figure 4.5: Reclassified Rainfall map

4.2.2 Reclassified Slope map

It is the map indicating the reclassified slope map as according to criteria the steeper the slope the higher the catchment as classes from 0-2.87º assigned as low suitability, 2.87-6.04º was assigned as Medium Suitability and 6.04-26.10º was assigned as high suitability in influencing RWH as depicted in figure 4.6.

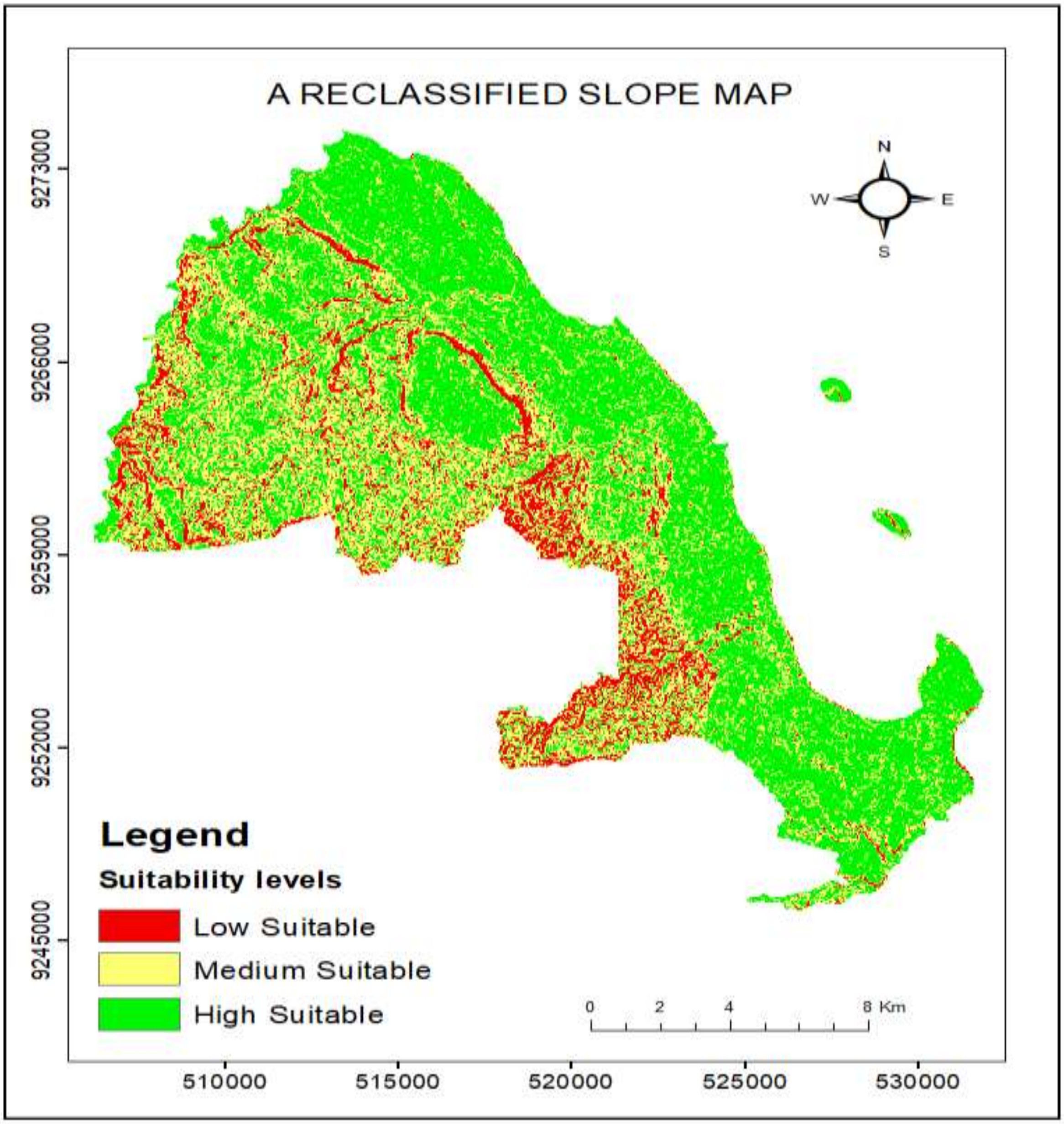

Figure 4.6: Reclassified Slope map

4.2.3 Reclassified Soil map

For the soil map having only two classes were reclassified into low suitability for the soil enriched with sandy soil and High suitability to soil characterized with clay soil as depicted in figure 4.7.

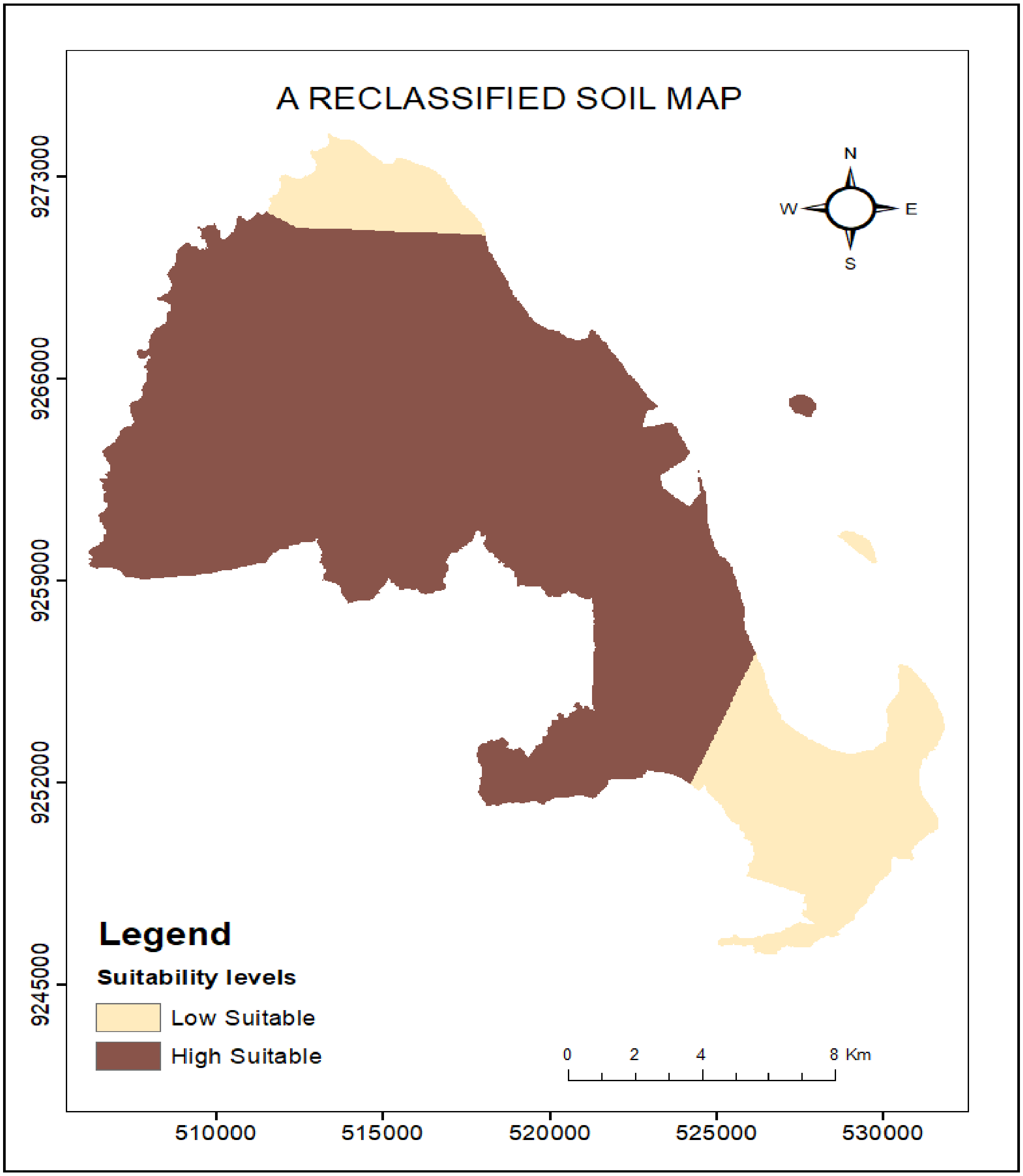

Figure 4.7: Reclassified Soil map

4.2.4 Reclassified land cover map

The land cover map was reclassified to low suitability for built-up area, medium suitability for vegetative area and high suitability for bare land area as shown in figure 4.8.

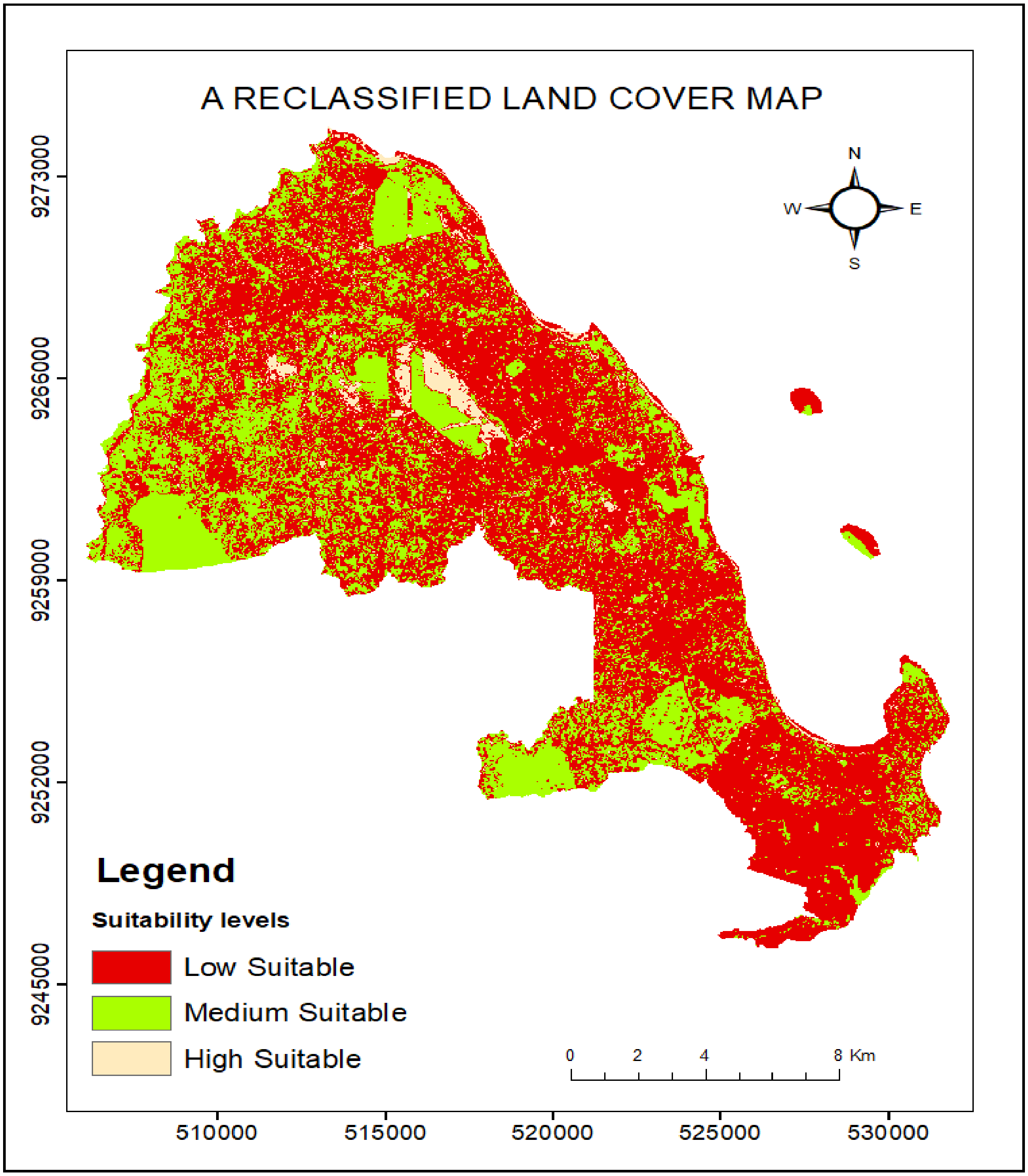

Figure 4.8: Reclassified Land cover map

4.3 Rainwater harvesting suitability map

The suitability map is the map that shows the potential areas for rainwater harvesting found in the study area (Kinondoni district), The suitability map is depicted in figure 4.9, and in table 4.2 depicts the percentage and area coverage for suitability levels or area, were suitability map has levels ranges from not suitable, low suitable, moderate suitable to very high suitable levels. Also, on the suitability map the area-colored colored green indicates very high suitable areas, the area with pale green color indicates the high suitable areas, the area-colored pale yellow indicates the moderate suitable area, also area colored as orange depicts low suitable areas, and area colored as red depicts the areas which are not suitable for rain water harvesting, as large part of the area (Kinondoni district) falls under moderate suitable category.

Also, from the suitability graph in figure 4.10 it indicates that only 0.47% of the area lies under very high suitability class, the 21.42% lies under highly suitable area, 28.18% of the area lies under moderately suitable area, 26.69% falls on the low suitable areas and 23.24% of the area were indicated as not suitable areas for rain water harvesting in Kinondoni district. The explanations are illustrated as follows,

Table 4.2: Area and percentage coverage for suitability levels

Suitability levels	**Area coverage (Ha)**	**Area coverage (%)**
Not Suitable	5956.29	23.24
Low Suitable	6841.35	26.69
Moderate Suitable	7224.03	28.18
High Suitable	5489.19	21.42
Very High Suitable	121.05	0.47

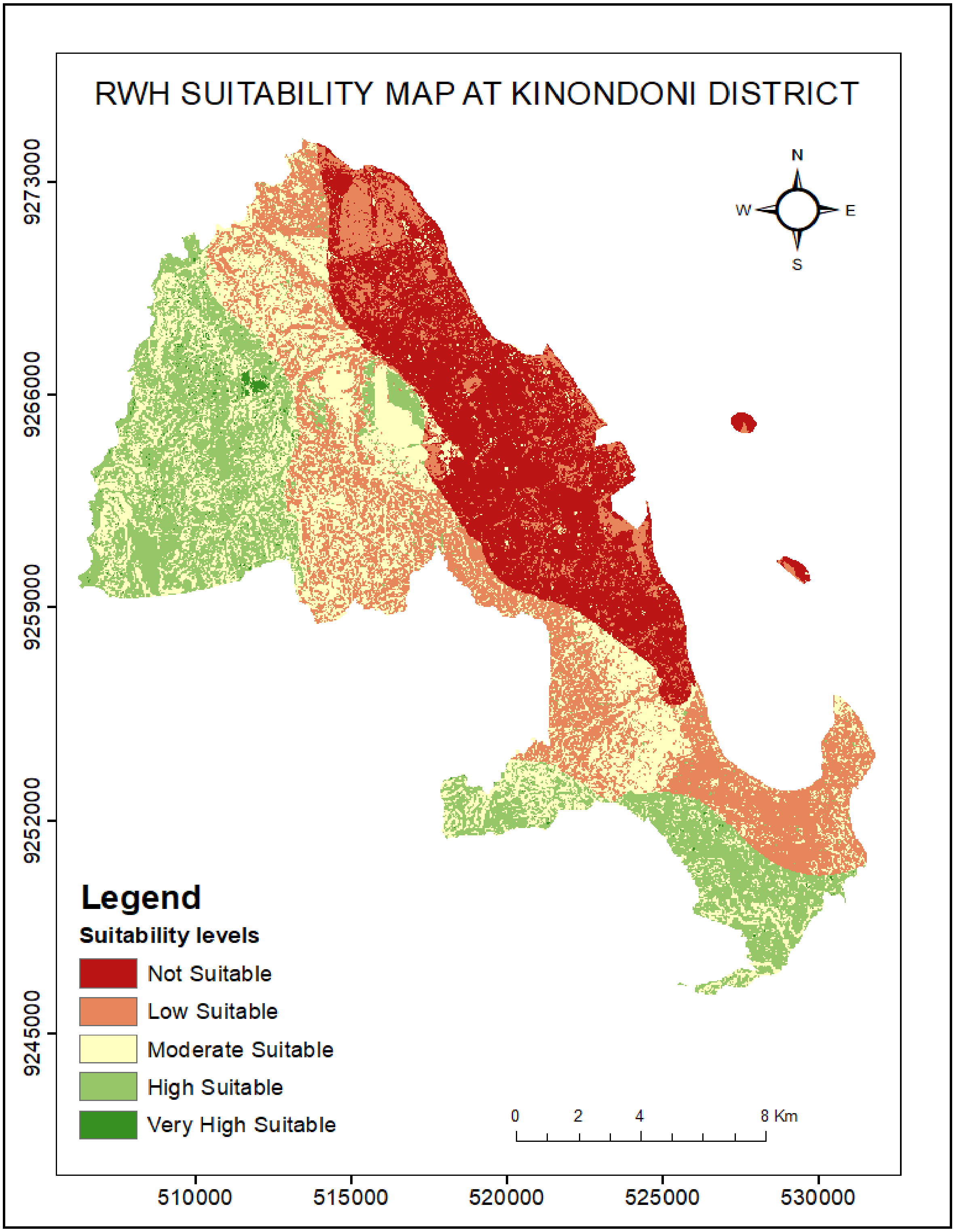

Figure 4.9: The Rainwater harvesting suitability map

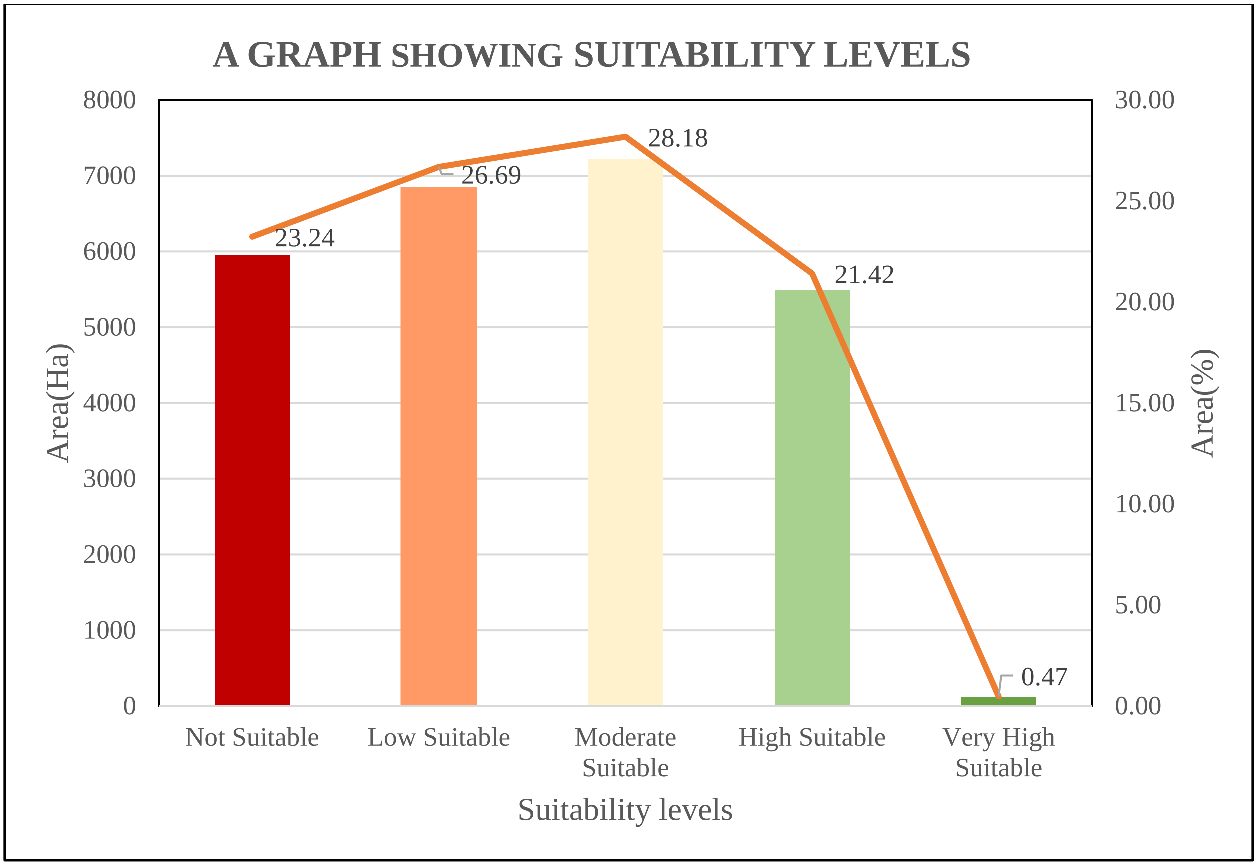

Figure 4.10: Graph showing area coverage in hectares (Ha) and percentage for suitability

4.4 Discussion

For the criteria or factor used such as soil, slope rainfall and land cover proved to be appropriate in weighting due to the value of consistency ratio (CR) to be 0.043 which is the allowable value for the given criteria, thus it obeys the rule that the value of consistency ratio should be less than 10% (0.1) that were proposed by Saaty. The moderately contributing factors slope (12%) and soil (5%) were factors that has moderately contribution to the identification of potential areas for rainwater harvesting similar to (Faisal & Abdaki, 2021). Also, the most contributing factor according to the results of the study are Rainfall (56%) and Land cover (26%), as the enough amount of rainfall is needed for facilitating harvesting rainwater and the area which is bare is more contributing to the harvesting of the rainwater and for slope the area which is gentle to flat areas are suitable for rainwater harvesting, while the soil which is reach in clay is more suitable as it has high water holding capacity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed to identify and map potential areas for rainwater harvesting in the Kinondoni district of Dar es Salaam region using GIS and remote sensing techniques. In the study, a multi-criteria decision analysis integrated with GIS and RS was being used as the method in identifying potential areas for rainwater harvesting in Kinondoni district. The criteria used was land cover, slope, soil and rainfall in doing analysis and performing weight overlay for obtaining suitability map. The GIS and RS techniques were applied in obtain the layers and doing analysis and for multi-criteria analysis and weighting overlay was used in performing pairwise comparison of the criteria and integrating with its weight to get the suitability map.

From the study indicates that only 0.47% of the Kinondoni district were very high suitable, 21.42% were high suitable, 28.18% were moderately suitable, 26.69% were low in suitability and 23.24% of the area was not suitable. The findings of this study indicate that rainwater harvesting can be a viable solution to mitigate water scarcity challenges in the Kinondoni district.

5.2 Recommendations

Based on the study the following recommendation can be considered

- To raise public awareness on the importance of rainwater harvesting especially for ground catchment system for both rural and urban areas.
- Other studies similar to the study should be conducted in other areas for both urban and rural and it should consider more criteria, especially integrating the biophysical and social economic factors which are considered in suitability analysis for more appropriate results.

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