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Site selection for rainwater harvesting: A case of KwaZulu-Natal, South Africa

By

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in the Faculty of Natural and Agricultural Sciences

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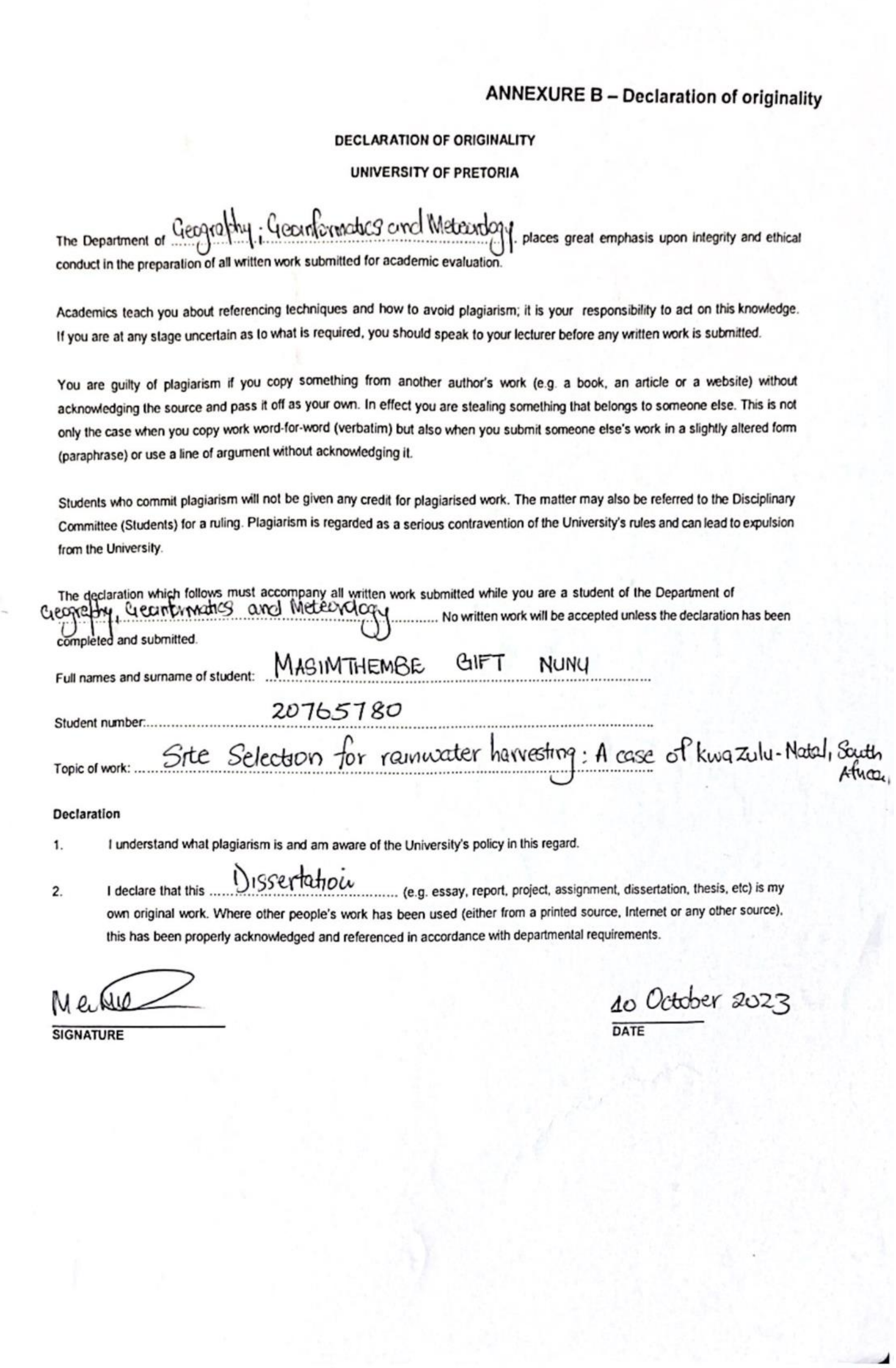
Declaration



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Abstract

The rapid growth of the world's population has placed an increased strain on water resources globally, particularly in sub-Saharan Africa, where communities rely on rainfall for their day to day activities. Water scarcity in KwaZulu-Natal, South Africa, is high because of unevenly distributed rainfall and limited water resources. There is a need for suitable site selection for rainwater harvesting structures in KwaZulu-Natal, which has the potential to address shortage of water currently experienced in the province. Access to adequate water supply and sanitation is crucial for poverty alleviation and addressing the problems faced by vulnerable groups, such as those affected by HIV/AIDS and other diseases. Rainwater collection is a procedure in which rainwater is gathered and stored for a multitude of objectives. This practice encompasses the capture of precipitation either at its point of descent or via the accumulation of runoff from various surfaces such as rooftops, roadways, or landmasses. By facilitating the optimal utilization of rainfall, rainwater collection endorses a diminished reliance on conventional water sources and the minimization of water dissipation. It contributes to the conservation of water resources and ensures their sustainable management. This study aimed to select suitable sites for rainwater harvesting using geographic information systems (GIS) and multi-criteria decision analysis (MCDA) techniques in the province of KwaZulu-Natal, South Africa. Geospatial data on precipitation, soil, slope, runoff curve number and land use were combined to develop a multi-criteria ranking system. Using the Analytical Hierarchical Process (AHP), weights were assigned with rainfall assigned (17), soil texture (39.1), slope (11.3), land cover (5.6) and Runoff curve number (27). The selection of these specific factors for this study areas was based on a review of literature. The study identified moderately to highly suitable sites for rainwater harvesting structures, covering 38% of the study area. Approximately 10% of the study area was considered to be less suitable for rainwater harvesting (RWH). The research findings could facilitate the wider adoption of rainwater harvesting in KwaZulu-Natal to meet irrigation demands and promote sustainable water resource management. The developed methodology can be implemented and adopted by any city or country. This study could be expanded by collecting and analysing various parameters (such as distance to roads, groundwater discharge, and geology and lineaments density, expertise and decision-makers preference value for pairwise matrix comparison). The development of a graphical user interface and improved approach in MCDA in relation to relative weight calculation while integrating the water balance model may also be considered for future research.

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Nomenclature

AHP Analytical Hierarchy Process

CN Curve Number

CI Consistency Index

CR Consistency Ratio

DEM Digital Elevation Map

ELECTRE Elimination and Choice Translating Reality

DSS Decision Support System

FAO Food and Agriculture Organisation

GIS Geographic Information System

IWRM Integrated Water Resources Management

MADM Multi-Attribute Decision Making

MAUT Multi-Attribute Utility Theory

MCDA Multi Criteria Decision Analysis

MODM Multi-Objective Decision Making

m Metre

mm Millimetre

PROMOTHEE Preference Ranking Organization Method for Enrichment Evaluation

RS Remote Sensing

RI Random Index

RWH Rainwater Harvesting

SCS-CN	Soil Conservation Services-Curve Number
USGS	United State Geology Survey
UTM	Universal Transverse Mercator

CHAPTER 1: Introduction

1.1 Background

The rapid growth of the world's population has placed an increased strain on water resources across the globe, and in Africa, which has resulted in an increased risk for communities that directly rely on rainfall to sustain their livelihoods through practices such as crop production, using water for drinking and domestic activities, and various other economic activities (i.e., commercial farming) (Andersson et al., 2023). These anthropogenic strains affect how ecosystems function and alter the balance of biodiversity and the functioning of the ecosystem (Andersson et al., 2023). Continuous overexploitation and inadequate use of natural resources such as water, land, and forest trees have caused a threat to the regional population of areas that are largely characterized by a humid subtropical climate along its coastal areas (Andersson et al., 2023). Hence, peculiarities such as the high rate of soil erosion, declining groundwater level, soil moisture storage, and shortage of drinking water have prevailed (Andersson et al., 2023). In this study, an attempt was made to select suitable sites for rainwater harvesting using geographic information systems (GIS) techniques to develop a rainwater harvesting (RWH) strategy for KwaZulu-Natal (KZN). This is critical to city planners, decision-makers, and non-governmental organizations when developing a long-term water harvesting strategy for water resource development that would improve the management of water resources in semi-arid areas, especially in the African continent (Andersson et al., 2023).

Various areas in Africa are currently experiencing an increase in temperature and intensification of precipitation and variability (Tamagnone et al., 2020). This has the potential to increase the duration of dry periods, which poses a threat to local agricultural practices (Tamagnone et al., 2020). The occurrence of extreme storms in the West African Sahel region has become more frequent, in addition to changes in land cover, leading to the occurrence of severe floods. To combat these hydrometeorological hazards and improve water availability, rainwater harvesting techniques (RWHTs) have been implemented in the Sahel region (Tamagnone et al., 2020). These techniques can retain up to 87% of the runoff and double the infiltration rate, thereby increasing the amount of water in the root zone and reducing water stress on crops (Tamagnone et al., 2020). Furthermore, rainwater harvesting techniques can extend the growing season by as much as 20 days, resulting in higher crop yields, reducing climate-related water stress, and preventing crop failure (Tamagnone et al., 2020). In South Africa, 9.7 million people do not have access to adequate water supply, and 16 million lack proper sanitation services (Rachidi, 2014). Domestic Rainwater Harvesting (DRWH) can supply water in rural and peri-urban areas that conventional technologies cannot reach. domestic rainwater harvesting is considered one of the most promising alternatives for supplying freshwater despite increasing water scarcity and escalating demand of freshwater (Kahinda et al., 2007). The South African government has committed to providing financial assistance to poor households for the capital cost of rainwater storage tanks and related works in rural areas (Rachidi, 2014). However, the legal status of the domestic rainwater harvesting remains unclear, and strict application of water legislation deems it illegal (Rachidi, 2014). Challenges to the sustainable implementation of domestic rainwater harvesting include the cost of installation, maintenance, proper use, and the risk of waterborne diseases (Rachidi, 2014). To ensure the success of domestic rainwater harvesting, an integrated system approach and a specific design and size of water storage tanks for different DRWH ecotopes are recommended. Access to adequate water supply and sanitation is crucial for poverty alleviation and addressing the problems faced by vulnerable groups, such as those affected by HIV/AIDS and other diseases (Kahinda et al., 2007).

Rainwater harvesting (RWH) is defined as the concentration, collection, and storage (which could be in different structures or the soil) of rainwater or water runoff that can be used either on-site or at a different site for immediate purposes or at a later stage (Mutekwa & Kusangaya, 2007). RWH aims to improve the efficient use of rainfall or water runoff through the process of capturing the rainfall in the place where it falls or by capturing the runoff that it generates and storing it for later use to supplement the plant water requirements (Mutekwa & Kusangaya, 2007). The advantage of RWH is that it reduces water supply costs and satisfies basic water needs for human consumption. Al Adamat (2010) stated that adjustments should be made in semi-arid regions because the amount of rainfall is inadequate for maintaining decent yields and field growth. Some parts of KwaZulu-Natal lack access to a consistent source of freshwater and are highly dependent on groundwater and rainwater for daily activities (Dhakate et al., 2013). The current situtation in some part of the province indicate the need to develop and adopt a water system that stores water after a rainfall event. This stored water can then be used by people as a supplemental source of water when experiencing dry conditions. The practice of rainwater harvesting in sub-tropical climate regions has become increasingly important because of global warming and the increasing depleting sources of freshwater (Dhakate et al., 2013). Water scarcity has resulted in the need to determine and use other sources of freshwater that can satisfy the growing global demand for water (Dhakate et al., 2013). The limit of RWH is in in-field or small-scale ex-situ catchments, and water is generally not available from the rainwater harvesting structures during the dry season (Rachidi, 2014). For crop production, RWH aims to decrease the amount of rainfall that is lost through the process of unproductive evaporation, which includes soil evaporation, litter, canopy interception, and runoff. This will increase the amount of water available to the plants for productive crop production, resulting in increased crop growth (Chikozho, 2010). Surface water harvesting promotes an alternative to the strategy of water supply to provide water security, assist in the safeguarding of the livelihoods of the people living in vulnerable communities, and help reduce anthropogenic-induced landscape degradation. Rainwater harvesting provides an adaptation strategy against climate change (Chikozho, 2010). RWH is an important component of storm water management and flood control in human settlements. It involves managing storm water with natural infiltration, retention, detention, and cleaning facilities, which allows the use of rainwater as a flood control measure (Zhang, 2018). The comprehensive utilization and management of urban rain and flood resources includes using rainwater while ensuring safety and controlling pollution.

The determination of suitable sites for rainwater harvesting structures can be performed using a weighted overlay process. The common factors considered in previous rainwater harvesting analysis studies include land use/cover, slope, run-off depth, rain surplus, lineaments, soil depth, lithology, and geomorphology (Qi, 2020). The study's identification of suitable sites for rainwater harvesting in KwaZulu-Natal aligns with SDG 6 (Clean Water and Sanitation) by promoting sustainable water resource management, and by enabling a wider adoption of rainwater harvesting for irrigation, the study contributes to SDG 2 (Zero Hunger) by supporting agricultural activities in water-scarce regions. Several studies have been conducted by various researchers regarding site selection of rainwater harvesting and the suitability of rainwater harvesting structures in many parts of the world (Kahinda et al.,2008; Mahmoud and Alazba, 2014; Tumbo et al., 2014; de Winnar et al., 2007, Qi 2020). However, none of the past investigations considered all of the recognized variables (namely, runoff curve number and hydrologic soil groups) that were accounted for in this investigation, and web mapping techniques were not employed, with desktop maps being the most prevalent mapping technique used. In this study, the majority of these variables were considered to identify potential locations for rainwater harvesting and the associated rainwater harvesting structures in KwaZulu-Natal using geospatial technologies.

1.2 Statement of the Problem

The province of KwaZulu-Natal experiences significant periods of dry seasons alleviated by unreliable and very low precipitation that is unevenly spatially distributed (Kahinda et al., 2007). This has resulted in a lack of freshwater availability and water for irrigation, e.g., subsistence farming. In addition, water resource management in the province experiences serious challenges, i.e., lack of scientific and technical decision support tools that sustainably guide the monitoring of existing water resource management policies (Kahinda et al., 2007). Rainwater harvesting is a vital method for collecting rainwater and providing safe and clean usable water for human consumption, especially in sub-tropical climate regions. Therefore, there is a need to create alternative and comprehensive strategies informed by effective management tools to address water scarcity issues, and to efficiently assess and identify locations for RWH potential to achieve maximum use of the unevenly distributed rainfall in the province.

1.3 Research questions

Rainwater harvesting (RWH) captures and stores rainwater or surface water runoff for immediate or future use while improving water efficiency and supplementing plant water requirements. The selection of suitable sites for RWH is crucial for sustainable water resource management, especially in sub-tropical climate areas. In selecting suitable sites for RWH in KwaZulu-Natal, some important questions should be considered, which include:

- What are the primary factors responsible for selecting suitable sites for rainwater harvesting?
- Where are the suitable locations for rainwater harvesting in KwaZulu-Natal?

1.4 Research objectives

The main aim of this study was to use GIS with MCDA to identify potential rainwater harvesting sites in KwaZulu-Natal, South Africa. The research objectives include providing insights into the spatial distribution of suitable RWH sites in KwaZulu-Natal and enabling a wider adoption of rainwater harvesting for irrigation and sustainable water resource management in the province. The developed methodology can be implemented and adopted by other cities or countries.

To achieve this aim, the following objectives were pursued.

- To identify factors that affect RWH sites in areas with similar climatic condition with KwaZulu-Natal from literature.
- To determine suitable locations for rainwater harvesting in KwaZulu-Natal.

1.5 Significance of the study

The study addresses the pressing issue of water scarcity in KwaZulu-Natal, South Africa, and provides a solution through the selection of suitable sites for rainwater harvesting (RWH) structures using GIS with spatial MCDA where rainwater harvesting can be a mitigation strategy in addressing the shortage of water in the area in consideration of the spatial and temporal distribution of rainfall in order to better understand the management of water supply for the purposes of adaptation and mitigation of the scarcity of freshwater in the area. This study contribute towards sustainable development goal 2 (which promotes ending hunger, achieving food security, and improving nutrition through promoting sustainable agriculture) (UNDP, 2011) and sustainable development goal 6 (which involves ensuring the availability and sustainability of water and sanitation) will be achieved using harvested water, which is also a renewable natural resource (UNDP, 2011).

The process of assessing and identifying the sites that can harvest rainwater is aimed at increasing the efficient use of rainfall where it falls and helping promote the practice of sustainable development and implementation and promotion of rainwater harvesting initiatives and community projects. This will help ensure the availability of water and control the occurrences of flooding and soil erosion in these susceptible areas. This will ultimately lead to an improvement of land productivity and the overall sustainability of the province by informing decision makers and policy makers with scientific information for the purposes of better planning and decision-making processes to develop better impact strategies for future use.

1.6 Scope of the study

The study focuses on the site selection for rainwater harvesting (RWH) structures in KwaZulu-Natal, South Africa, using a multi-criteria decision analysis (MCDA) method based on geographical information systems (GIS). The research methodology includes the use of soil conservation services curve number (SCS-CN) method to determine runoff depth and assess the suitability of different sites. The study integrates geospatial data on precipitation, soil, digital elevation model (DEM), and land use to develop a multi-criterion ranking system for identifying potential RWH sites.

1.7 Thesis Outline

The remainder of the dissertation is structured as follows:

Chapter Two presents literature review on the importance of site selection analysis, significance of the study and the application of multi-criteria analysis integrated with GIS and MCDA. This chapter presents a comprehensive review of the theoretical framework of MCDA and the geospatial techniques used to support decision-making problems. This chapter also reviews and discusses various factors directly related to rainwater harvesting, and thus determining factors responsible for identifying suitable RWH sites.

Chapter three presents the research methodology used in this study. This section describes the geospatial datasets (with their relevant data sources) and software used in this study, the research methodology procedure, and the implementation of the MCDA technique in assigning the weight of the criteria. It also describes the study area, data preparation, and data processing.

The fourth chapter demonstrates analytical hierarchy process (AHP), reclassification, and combining geospatial datasets using the weighted overlay analysis tool. This chapter presents the key findings of the study and their explanations using evidence from the study.

Finally, Chapter 5 provides an overall summary of the study. It also provides suggestions and recommendations for future research purposes.

CHAPTER 2: Literature Review

The previous chapter introduces the study, highlighting the use and importance of rainwater harvesting (RWH) in addressing water scarcity issues, promoting sustainable water resource management, and adapting to climate change. Chapter 2 reviews and discusses various factors directly related to rainwater harvesting, and ensures that the research findings are based on a comprehensive understanding of the existing literature, enhancing the credibility and validity of the study. The chapter also mentions the use of GIS and multi-criteria decision analysis (MCDA) to assess the suitability of potential RWH sites based on factors such as precipitation, soil, land use, and runoff characteristics. This chapter provides a comprehensive review of the relevant literature and the methodology used in this study.

2.1 Context of the RWH

Strategies for the adoption and development of rainwater harvesting for the efficient use of water and to sustain human livelihood have evolved over the years for both domestic and agricultural purposes (Chikozho, 2010). The limitations of RWH are in-field or at small-scale ex situ catchments, where the availability of water is limited throughout the dry season. The difference comes from conventional irrigation, in which water is generally not available during the dry season (Mbilinyi et al., 2005). For crop production, the aim of water harvesting is to decrease the amount of rainfall that is lost during the process of unproductive evaporation and to increase the availability of water for processes such as productive crop transpiration, which will lead to increased crop growth and crop production.

According to Lutta et al. (2020), there is an intention to increase the amount of domestic water that is provided through rainwater harvesting systems in Africa to approximately 15%, and comprehensive efforts are being made to expand the usage of small-scale systems in the areas which are not suitable for conventional irrigation development. In modern times, RWH systems have changed and evolved from traditional or indigenous systems, and when coupled with an improvement in agricultural practices, there is an indication of enhancement in crop production (Mbilinyi et al., 2005). The recommendation on which RWH system is better suited for a potential harvesting site (between the traditional system and indigenous system) requires the analysis of an existing successful water harvesting system.

The methods of rainwater harvesting are divided into two groups: in situ and ex-situ. The in-situ method involves the capture of runoff generated in the fields or in the cultivation sites where crops are grown. The ex-situ method involves the collection of water runoff from a larger site and storage of the runoff in a site that is not adjacent to the runoff generation site. The resulting water can then be transported through channels or ducts to the cultivation area (Rachidi, 2014). Examples of these water harvesting methods include dead-level terraces, checked dams, runoff storage tanks, and terraces (Chikozho, 2010).

2.2 Application of GIS and RS for identification of RWH sites

According to Qi (2020), solving complex challenges related to water resources requires both spatial representation of water resource systems and insights into water resource problems. In recent times, the application of GIS and RS technologies has received much-needed support and has managed to close the gap of poor management of water resources (Forkuob et al., 2013). GIS and hydrological model integration has provided unique advantages for sustainable water resource management because they provide functions such as spatial representation, comprehensive database, and modeling capability (Forkuob et al., 2013).

Various studies conducted by different researchers have adopted GIS and RS technologies to identify suitable rainwater harvesting sites in many semi-arid regions where data availability is limited (Giupponi and Sgobbi, 2011). The similarities that are distinguished in the use of these methods are the generation of different thematic maps from remotely sensed data (i.e., satellite images and aerial photographs) overlaid in a GIS environment for the assessment and investigation of site selection for rainwater harvesting sites (Mbilinyi and Tumbo, 2013). In many studies, GIS has been applied as both a data management and modeling tool for the analysis of spatial and non-spatial data.

In previous studies conducted for catchment rainwater harvesting, researchers such as Ramakrishnan et al. (2009) used spatial parameters such as runoff potential, fracture pattern, and microcatchments. The soil conservation services curve number (SCS-CN) method was used to derive the runoff potential, which was expressed as the runoff coefficient. Food and Agriculture

Organization (FAO) specifications for recharge structure parameters, such as storage rock mass permeability, were also included to augment effective storage. After identifying potential RWH sites, the researchers conducted a field survey to verify and assess the suitability of the area of interest. Various researchers, such as Mbilinyi et al. (2006), have used baseline thematic maps such as topographic maps, precipitation, soil depth and texture, and population density to create composite maps that indicate attributes that will have functions that will act as indicators of suitable sites for specific rainwater harvesting projects.

Researchers such as Kadam et al. (2012) considered factors such as geology and hydrogeomorphology for sustainable development specifications in the determination of harvesting structures. In addition, they used biophysical parameters such as drainage networks. Significant recognition must also be given to researchers such as Kahinda et al. (2008) who used socioeconomic factors in their studies. For the methodology, they used GIS with MCDA, which enabled the researchers and water resource managers to assess which sites were suitable for rainwater harvesting, which other studies excluded.

2.3 Factors affecting the identification of potential rainwater harvesting sites

FAO (2003) outlined six key factors that should be considered when identifying sites that are suitable for rainwater harvesting, which will have to be overlaid in a GIS environment to successfully develop a suitability model. These factors include slope (or topography), rainfall (or climate), land use/land cover (LU/LC), hydrology (rainfall-runoff relationship), and the socioeconomic components (which include population density, water laws, related project implementation cost, people’s priority, and land use) of the area of interest.

The following section will discuss in detail some key factors that should be considered when selecting sites for rainwater harvesting.

2.3.1 Slope

According to Mfitumukiza et al. (2020), the slope gradient and relief factors play a major role in the assessment of the rainwater harvesting system method, especially regarding the generation of water runoff, because they influence the recharge and rate of infiltration of a given area. Hence, different rainwater harvesting methods depend on the slope of the area. Catchment areas with steep slopes are better suited to ensure higher runoff efficiency. However, catchment areas with slopes greater than 5% are more vulnerable to soil erosion. Mfitumukiza et al. (2020) recommended that catchment areas with steeper slopes should be considered for soil erosion control measures.

2.3.2 Land Use/Land Cover

The influence of land use/land cover (LU/LC) on surface water runoff is a critical aspect that merits attention as change in land use/land cover influences the runoff characteristics of a drainage basin to a large extent, which in turn, affects the surface and groundwater availability of the area. Vegetated areas enhance water infiltration rates due to the presence of organic materials. Built-up areas and bare ground exhibit higher runoff rates, affecting water retention. Land use and cover influence surface water runoff after rainfall events (Mbilinyi and Tumbo, 2013). An undeniable correlation exists between the runoff generated and land use/land cover after a rainfall event, as noted by Mbilinyi and Tumbo (2013). Therefore, optimal surface water harvesting is undertaken in regions with minimal infrastructure and natural cover.

2.3.3 Rainfall

The climate factor helps determine the amount of soil moisture available and understand the relationship between rainfall and runoff processes. The magnitude of rainfall plays a crucial role in assessing the feasibility of rainwater harvesting in each area (FAO, 2003). In some areas of arid to semi-arid regions, for example, Botswana, Zimbabwe, and even South Africa, the occurrence of a rainfall event is of short duration, unevenly distributed spatially, and the intensity is relatively high, resulting in flash floods. Therefore, the FAO (2003) does not recommend adopting and practicing rainwater harvesting in regions that receive low average rainfall per year.

2.3.4 Soil

Lekshmi et al. (2014) states that soil acts as a pervious medium that provides various passageways for water to penetrate the surface. Soil depth and soil texture are the main soil physical properties that are used when dealing with rainwater harvesting. According to USDA (2007), the soil’s ability to pass water through a drainage channel is dependent on the arrangement and degree between them and on the size of the particles. Excessively deep-drained soils with low clay content can generate low water runoff when the soil profile has no limiting restrictions such as an impermeable layer. Poorly drained soils with high clay content are prone to surface crusting and have a higher potential of generating high runoff (Lekshmi et al., 2014). In-situ rainwater harvesting systems are the most suitable for soils with a deeper soil depth (FAO, 2003).

2.4 Rainwater harvesting suitability model framework

The application of combining multi-criteria decision-making methods with GIS has proven to be efficient and has gained noticeable confidence from researchers in recent times and has advanced from being used for convectional map overlay methods in land use (Mbilinyi and Tumbo, 2013). The advantages of spatial decision support systems are that they can perform functions such as spatial representation, modeling capability, and a comprehensive database for sustainable water resource management (Mbilinyi and Tumbo, 2013). The suitability model framework adopted in the Analytical Hierarchical Process (AHP) can be integrated and used in a GIS environment using multi-criteria evaluation as a spatial support decision system (Mbilinyi and Tumbo, 2013).

The analysis of site selection for RWH clearly distinguishes between the process of the location selection problem and the location search problem. The main objective of the location selection analysis process is to identify the most suitable site for RWH from a group of potential sites. The analysis can be characterized using known physical factors in the pre-identified site (Malczewski, 2004).

2.5 Decision - making and selection of potential RWH sites

The application of GIS-based and RS methods for site selection analysis has been used for over decades for the identification of areas that are suitable for various uses, i.e., in the ecological approach, where it is used to identify habitat sites for plant and animal species and for land suitability analysis for agricultural activities (Qi, 2020).

There is a clear distinction between the problem of site search and that of site selection. For site selection analysis, the properties of the potential sites for RWH are established and the best suitable site is chosen from a group of potential sites. The challenge of selecting the best suitable rainwater harvesting sites is ranking the alternative sites based on their characteristics (Qi, 2020). Site search analysis is defined as a situation in which there is no pre-determined set of candidate sites, and the characteristics of the sites must be set to solve the problem (Qi, 2020).

2.6 Rainfall– Runoff Coefficient Modeling in a GIS Environment

The main purpose of the surface rainwater harvesting method is to increase the efficiency of rainwater collection by concentrating it through the runoff, and it is best to show it through the rainfall– runoff model assisted by GIS (Mbilinyi and Tumbo, 2013). The integration of GIS will enable the methodology to show flow direction, runoff, and areas of runoff concentration (Mbilinyi and Tumbo, 2013). The application of GIS and RS technologies has proven to be useful for overcoming this problem by using conventional methods for the estimation of runoff, such as the soil conservation services method (SCS-CN) (Mbilinyi and Tumbo, 2013).

Various researchers have widely used this method in rainwater harvesting studies to estimate runoff, and it has been used in many areas located on the rural outskirts of South Africa (de Winnar et al., 2007). The SCS-CN model (refer to figure 2.1) uses many hydrological factors that affect the generation of runoff (i.e., soil type, land use/land cover and soil moisture condition) and can incorporate these hydrological factors into a single CN parameter. The model creates an empirical relationship for calculating initial abstraction and runoff as functions of soil type and land use (Singh et al., 2015).

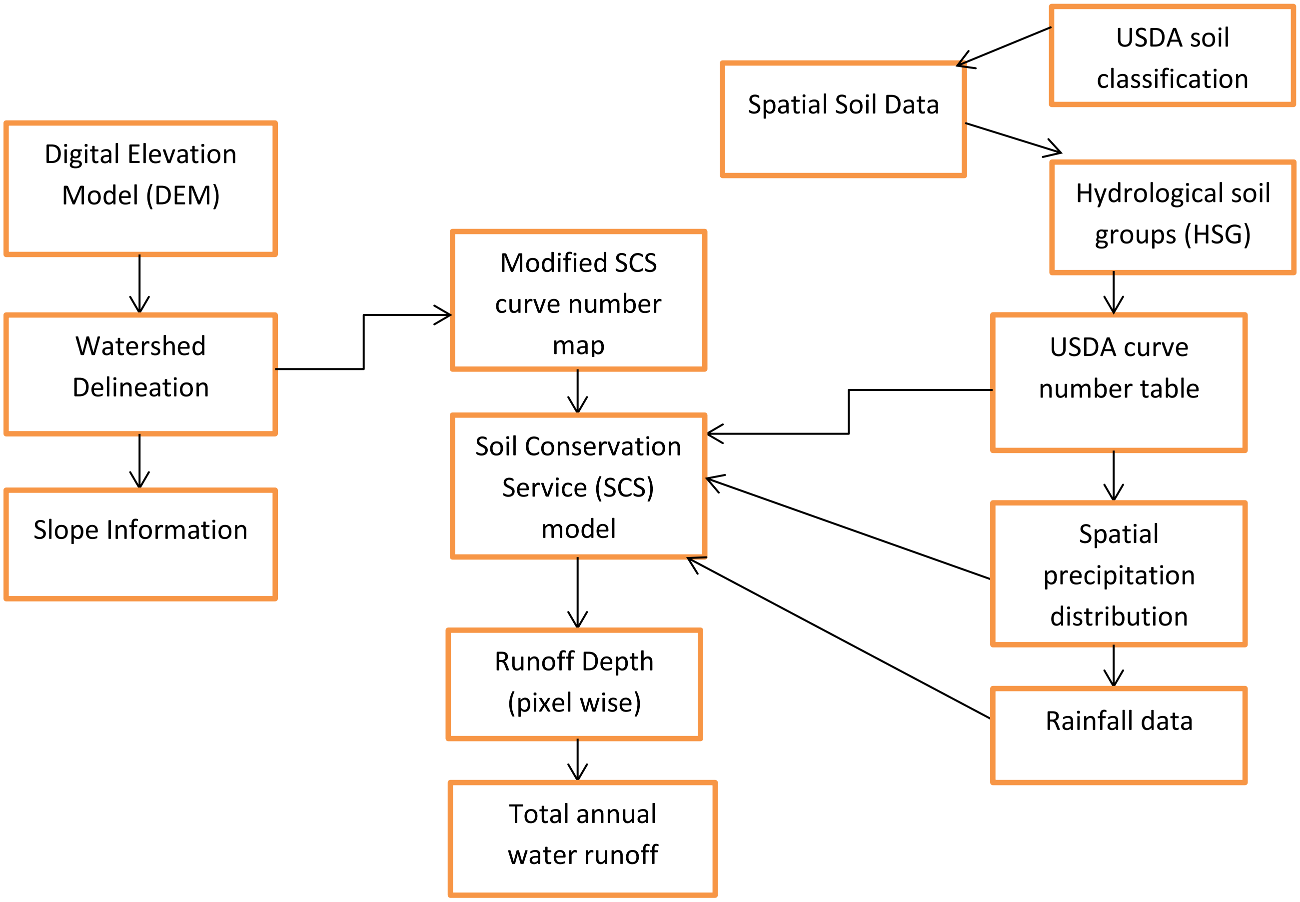

Figure 2.1: Framework for SCS-CN method to estimate potential runoff (Source: Adapted after Muthu and Santhi, 2015).

Muthu and Santhi (2015) applied the SCS-CN method in the Wadi su'd watershed to estimate the runoff generated in the region. Other researchers, such as Liu and Jiang (2019), have used this method to generate SCS curve numbers using raster GIS. In addition, Liu and Jiang (2019) used the SCS-CN model to investigate the impact of seasonal and monthly effects on the curve number and created a curve number for some basins in India, which was the study area.

2.7 Overview of the different rainwater harvesting methods

Kahinda et al. (2008) stated that rainwater harvesting methods can be grouped into two classes, micro-catchment and macro-catchment, depending on the catchment area. Micro-catchment rainwater harvesting involves collecting runoff from a small catchment area whereby the sheet flow prevails over a shorter distance (Kahinda et al., 2008). In macro-catchment rainwater harvesting, runoff is collected from a larger natural catchment such as mountains or hills. Figure 2.2 below clearly demonstrates the distinction between the micro- and macro-catchment rainwater harvesting methods.

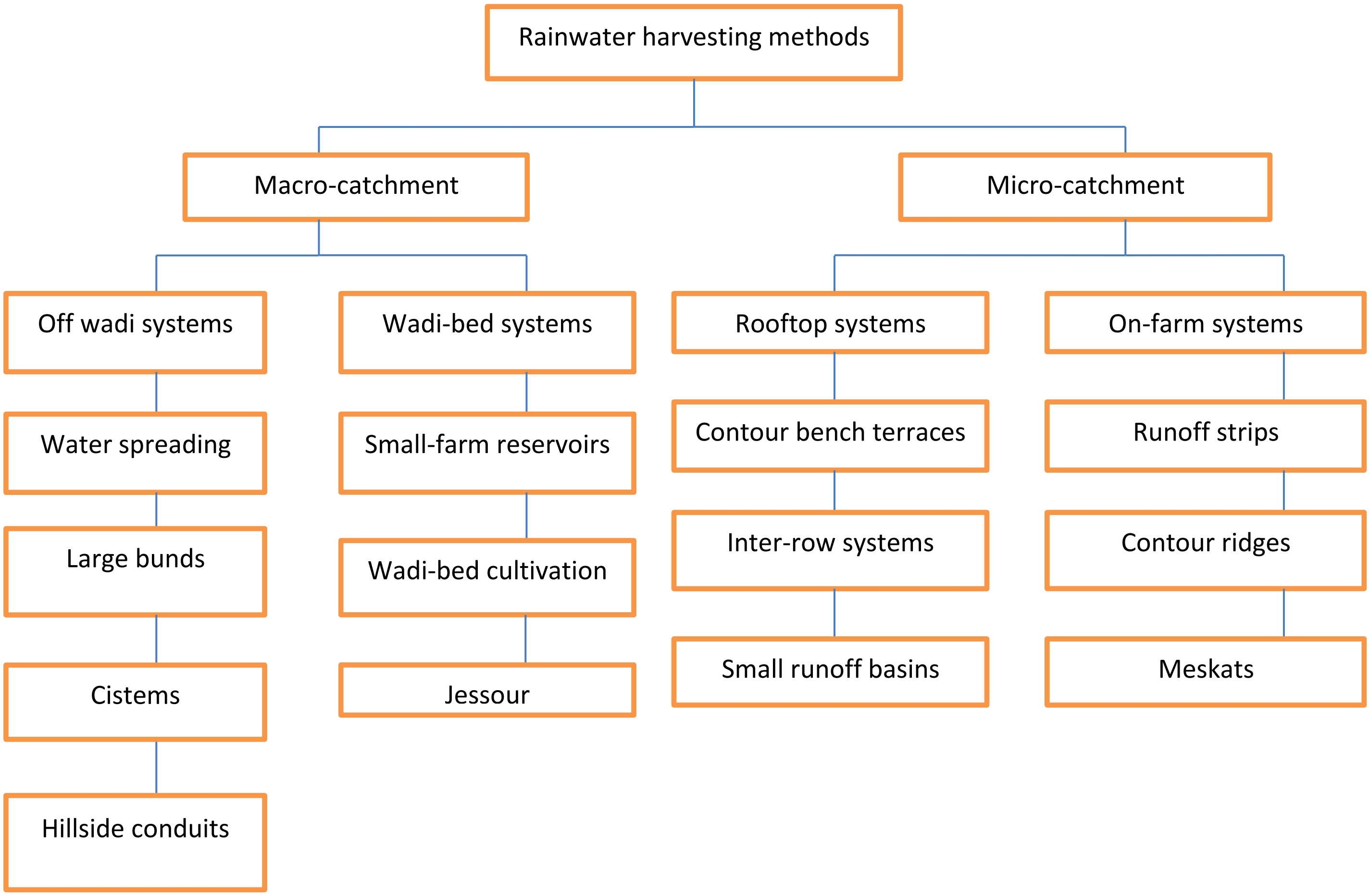

Figure 2.2: Different rainwater harvesting techniques (Ziadat et al., 2006)

As shown in Figure 2.3, microcatchment rainwater harvesting can be divided into rooftop and on-farm systems. The methods of rainwater harvesting that are possible under the on-farm system are contour ridges, runoff strips, meskat, and small pits. Macro-catchment RWH and floodwater techniques can be subdivided into two groups: wadi-bed systems and off-wadi systems.

The following section will discuss in detail some methods shown in Figure 2.3.

2.7.1 Micro-catchment rainwater harvesting

In the macro-catchment RWH system, the methods included are runoff strips and contour ridges, as indicated in Figure 2.3. These methods generate small amounts of runoff (Mutekwa & Kusangaya, 2007). In the microcatchment RWH system, the cropped area is adjacent to the catchment area (which is located right above the cropped area) and is far away from vegetation to increase runoff generation. This process then results in the availability of excess water for crop uptake, thereby increasing the availability of water and reducing water stress during dry conditions (Liu and Jiang, 2019). The micro-catchment RWH system is suitable for practice under arid to semi-arid conditions for crop production for activities such as subsistence and commercial farming. The microcatchment RWH system is divided into two groups: rooftop and on-farm systems. The rooftop system is known as domestic rainwater harvesting (Kahinda et al., 2008). The rooftop system involves collecting water from building roofs and then storing the generated water in water tanks, as shown in Figure 2.3. This system is generally practiced in cities and villages for small-scale use in gardens or for household use. The on-farm system is different in that water runoff is collected in a catchment area and then later used for agricultural activities.

(a) (b)

Figure 2.3: Rooftop (a) and on-farm (b) rainwater harvesting (Kahinda et al., 2008)

2.7.2 Macro-catchment rainwater harvesting

Macro-catchment (or external catchment) rainwater harvesting involves the collection of water runoff from larger catchment areas that are at a greater distance from where they are used (Mupangwa et al., 2006). This method of rainwater harvesting involves harvesting runoff from catchment areas with a range of 0.1 to thousands of hectares (ha). These catchment areas can be found near the cropped area or further away (Liu and Jiang, 2019). Harvested water runoff is used on cropped areas for terrace bunds or flat lands (Ren et al., 2008). Water runoff is conveyed using distribution networks and diversion structures when the catchment is large and located further from the cropped area. In this system, the rate of flow and runoff volume is much higher than those of the micro-catchment RWH system because the macro-catchment RWH system has difficulties managing the very demanding peak flows, which then results in soil erosion and sediment deposition (Mzirai and Tumbo, 2010). Therefore, it is critical that substantial channels and control structures are constructed. When the macro-catchment RWH system produces very high volumes of runoff that cannot be stored in the soil profile, the harvested water is stored in water holes or dams. Hence, small dams are built across the rolling topography where creeks are located (Mzirai and Tumbo, 2010).

The limitation of adopting and implementing a macro-catchment RWH system is the risk posed by the biophysical constraints associated with the design of the system (Mzirai and Tumbo, 2010).

This is because it is not an easy process to estimate the runoff amount, which is probably received annually. In some cases, the system will receive high volumes of runoff and flow rates, which will lead to soil loss (Mzirai and Tumbo, 2010).

2.8 Challenges and Opportunities for Rainwater Harvesting in South Africa

The Republic of South Africa has not fully adopted and implemented rainwater harvesting methods because of their high costs, which are required for the construction of RWH storage structures. Farmers in rural areas do not have the necessary skills to successfully implement these technologies (Jiang et al., 2013). Jiang et al. (2013) suggested that the main limitation of the adoption of rainwater harvesting is the inability of not being able to identify suitable sites for rainwater harvesting. Also, another limitation is that there is a lack of literature on rainwater harvesting that will relate its function and purpose for domestic and agricultural purposes (Kahinda et al., 2008). Farmers who are constrained by resources cannot afford to pay high costs for skilled personnel who will ensure the correct adoption and implementation of RWH methods. The practice of RWH methods requires a high labor input to be adopted initially and for maintenance thereafter. The lack of required machinery plays a vital role in the uncommon practice of rainwater harvesting in South Africa (Jiang et al.,2013). According to Kahinda et al. (2008), socio-economic studies of micro-basin tillage in the Free State indicated that the adoption of rainwater harvesting is a hands-on process that demands a very high labor input. Because households in rural areas cannot afford to pay high costs for skilled personnel, they fail to adopt and sustain RWH methods.

The other challenge regarding the implementation of rainwater harvesting in various countries (including South Africa) is that it is excluded from their water policies (Xiaolong et al., 2008). The management of water is usually based on renewable water (which is surface water and groundwater with little consideration for rainwater). This then results in very low quantities of water available for people and reaching the ecosystems situated downstream, resulting in conflict. The last limitation of the sustainable implementation of rainwater harvesting methods is the lack of institutional support (Xiaolong et al., 2008). Kahinda et al. (2008) suggested that policymakers and stakeholders should consider creating a governing body to coordinate the adoption of rainwater harvesting strategies. The established governing body will ensure that the RWH methods are expanded and provide guidelines on how they can be practiced for sustainable development.

2.9 Level of adoption for rainwater harvesting in South Africa

Rainwater harvesting as a practice is mostly adopted in regions with high populations, such as the Republic of China, where the cost of developing surface water or groundwater reserves is restricted (Baiyegunhi, 2015). Rainwater harvesting has been mainly adopted in many arid and semi-arid regions. In contrast, the adoption of rainwater harvesting in South Africa has been very low due to the high costs and skill requirements for this technology (Baiyegunhi, 2015). The only method of RWH that is common in South Africa is the rooftop system, which traps rainwater for domestic use (Baiyegunhi, 2015). Approximately 1% of South Africa's rural households currently rely on domestic rainwater harvesting as the main source of water for household use (Kahinda et al., 2008). The Department of Agriculture Land Reform and Rural Development has also adopted and supported the use of RWH by providing water tanks to small-scale farmers in rural settlements experiencing drought (Kahinda et al., 2008). The basic education department has adopted and implemented this method by providing schools with tanks to curb rainfall variability and water shortages that are experienced throughout the country (Kahinda et al., 2008).

Methods of in-field rainwater harvesting, such as contour ridges, are being implemented at the household level, whereas methods of ex-field rainwater harvesting, such as contour terracing, are not common practice (Kahinda et al., 2008). The Eastern Cape Province has considered implementing contour ridges in homestead gardens (Kahinda et al., 2008). In KwaZulu-Natal province, various rural farmers have used contour bunds to harvest rainwater in their gardens (Baiyegunhi, 2015). According to Kahinda et al. (2008), the Agricultural Research Council of South Africa started a program of in-field rainwater harvesting in the Taba Nchu region for over 10 years. The method has not been practiced beyond small plots around the homestead gardens because of the high costs required to scale it out. Therefore, it can be concluded that the adoption and practice of rainwater harvesting as a method to ensure the availability of water is still very uncommon in South Africa, despite the practice having a positive impact on the agricultural landscape and food security (Kahinda et al., 2008).

2.10 Application of multi-criteria decision analysis with GIS

There are available techniques to help solve decision-making problems, and multi-criteria decision analysis (MCDA) is one of the approaches that can be used for evaluating existing alternatives in considering different measurement units and incompatible criterion characteristics in achieving a certain objective (Baiyegunhi, 2015). The MCDA technique has become more relevantly used in many various fields because it is capable of supporting judgments made by skilled personnel, decision-makers, and relevant stakeholders considering all factors simultaneously (Szurek et al., 2014). The use of GIS allows the capability of enabling functions such as combining, manipulating, converting, retrieving, and displaying different criteria map layers to the process of decision–making (Szurek et al., 2014).

Kahinda (2008) stated that MCDA problems usually have five segments: available options, the decision-maker's judgment for criteria, factor criteria, results, and objectives. Various studies have shown that MCDA has two classes: multi-attribute decision-making (MADM) and multi-objective decision-making (MODM). The application of these methods depends on the type of problem. Therefore, in the instance of site selection, land use suitability, and the evaluation of environmental impact problems, MADM is the suitable approach to be used, and it has the advantage of quantifying quantitative and qualitative data (Szurek et al., 2014). According to Qi (2020), the MODM approach is more suitable for assessing infinite alternatives based on defined factors in the form of a statistical and mathematical formula for location-allocation scenarios.

The process of integrating MCDA with GIS allows the merging of geospatial data and decision-makers' criteria preferences for the assessment of available options concerning the factor criteria (Szurek et al., 2014). This method is extensively used worldwide and is very suitable for solving multi-criteria problems related to site selection and land use suitability (Szurek et al., 2014).

The role of GIS technology is to handle geospatial data in the process of allocating an economical and safe place for selection (Szurek et al., 2014). The advantages of this technology are that it is precise, useful, worthwhile, and can eliminate human bias. All criteria must be standardized into comparable units to proceed with site selection/site search using MCDA integrated with the GIS approach (Szurek et al., 2014). A study conducted in Mukim Batu, Malaysia, used the MCDA integrated with the GIS approach for organizing the chosen criterion in hierarchical form and assigning the decision-makers' preference in determining the potential feature site. In this study, the constraint and factor maps were overlaid to produce the potential site for building a school in the study area (Szurek et al., 2014).

A study conducted by González and Enríquez-de-Salamanca (2018) indicated that the integration of MCDA with GIS as a method helps the judgments made by experts to be precise and allows the selection of optimal alternatives based on different criteria. Richard and Ogba (2016) conducted a study in Andoni, Nigeria, to select potential sites suitable for building a secondary school for children from lower-class families. In this investigation, three datasets were selected: land use/land cover, settlement data, and existing secondary datasets to produce a suitability map. The weight overlay tool was used to create the suitability map.

Another research study conducted by Mugo and Odera (2019) indicated that the implementation of the MCDA technique with GIS was applied to investigate site selection for rainwater harvesting structures in the case study area of Kiambu County in Kenya. The investigation highlighted that the application of this method can support the decisions made by experts on site selection analysis. In this study, five datasets were used, namely slope, drainage density, land use/land cover, runoff depth, and soil, to yield a suitability map. The weight overlay tool was used to create the suitability map.

2.11 MCDA methods and theoretical principles

The multi-criteria decision making (MCDM) approach is valuable for evaluating alternatives to the available choices with the aim of identifying or ranking, using different qualitative and quantitative criteria that have varying measurement units (Richard and Ogba, 2016). The advantage of MCDM is its exclusive qualities, i.e., the existence of different clashing criteria and the presence of various alternatives (Richard and Ogba, 2016).

There are 3 phases when using the decision-making approach for identifying and selecting alternatives, namely:

- To identify and select suitable standards and alternatives
- The assigning of numerical values for standards because of the effects of alternatives on the standards

- The handling of the numerical esteems for deciding on a ranking for every option

2.11.1 Classification of multi-criteria decision-making problems

Liou and Tzeng (2012) state that the classification of multi-criteria decision-making problems is based on the character of the alternatives, which could either be discrete or continuous.

- Discrete: it contains a defined attribute; these are multi-attribute decision making (MADM)
- Continuous: It consists of an infinite number of alternatives, which are multi-objective decision making (MODM)

In MADM problems, there is a finite number of alternatives that are known from the start and are applied for solving issues that require selection from a defined set of alternatives (Liou and Tzeng, 2012). In MODM problems, the alternatives are undefined and can be determined by solving a mathematical model. The number of alternatives is infinite (Liou and Tzeng, 2012).

2.11.2 Summary on MCDA methods

The following section provides brief explanations of the different types of MCDA methods and the data required to perform the technique. The necessary theoretical procedures of the methods and the area of application are described on the basis of various research studies as follows (Kumar et al., 2017, Triantaphyllou and Mann, 1989, Velazquez and Hester, 2013).

Table 2.1: Summary on multi-criteria decision analysis techniques (modified after Liou and Tzeng, 2012)

Methods	**Explanation**	**Theoretical principle**	**Advantage**	**Disadvantage**	**Area of application**	**Initial data needed**
Weighted Sum Model (WSM)	It is the most commonly used method, especially for one-	Additive assumption	It's performed efficiently without any difficulty at the Layman level. It	It can only be used for single-dimensional problems	Evaluation of the business environment, energy development,	Defined criteria, criteria weights, and criteria score values

	dimensional problems		is suitable for use in one-dimensional problems.		and server selection	
Weighted Product Model (WPM)	It is the same as the WSM. The notable difference between the two methods is that rather than addition in the model, such as WSM, multiplication	Alternatives compared through the multiplication of the number of ratios one for each criterion	It can be used for both single- and multidimensional problems	It does not have a method for assigning weights to criteria	Used for the allocation of labor based on many criteria	Possible alternatives, defined criteria, weights of criteria, and criterion score values
Analytical hierarchy Model (AHP)	It is the most used MADM method. Every element in the hierarchy can be measured quantitatively or qualitatively	Decomposes a problem into several problems at a hierarchy level, and pairwise comparison can be applied for each hierarchy level	Ease of use. Provides a pairwise comparison method for assigning criteria weights	Inconsistency may occur because of biased judgment on the pairwise comparison due to the inability of not allowing the score criteria individually	Development of political strategies and planning, site selection, and land use suitability	Possible alternatives, defined criteria, weights of criteria, and criterion score values
TOPSIS	The technique is widely used in many complex	The core principle is to identify the best alternative that is near,	Simple process. Ability to obtain a full ranking of alternatives	Euclidean distance does not consider the mutual	Supply chain management, logistics, and water	Possible alternatives, defined criteria, weights of criteria, and

	decision problems because of its simplicity	positive, and far from negative		relationship between the two criteria	resource management	criterion score values
PROMOTHE E	It is one of the outranking methods developed by Brans in 1982 The technique uses a pair of alternative’s differences under every criterion	The rank of alternatives is obtained based on the difference value of positive and negative outranking flow which is known as net flow	It allows for comparability between the criterion	Do not have a method to assign weights for criterion	Environmental management, logistics and transportation	A possible alternative, a defined criterion, weights for criteria, and criterion score value
ELECTRE	This is one of the outranking methods developed in 1960 by B. Ray and it is used to support many decision problems for allocating the best alternatives	The core principle of this method is to identify and rank the best possible alternatives on the basis of a pair of alternatives being compared and ranked under each criterion	It considers uncertainty and vagueness	It is unable to detect alternative weakness and strength directly	Applied to water management and transportation	Possible alternatives, defined criteria, weights of criteria, and criterion score values

This section provides brief information about the MCDA methods. Table 2.1 summarizes the MCDA methods based on theoretical principles, advantages and disadvantages, area of application, and initial data required. All the approaches require criteria weight values and preference scores, and the other techniques cannot assign a relative weight for the chosen criterion and the best possible alternative, except for AHP. Hence, AHP is a more promising approach for this research study than the other methods because of its ease of use, ability to structure a complex and assign a relative weight score for the criterion through pairwise comparison, and suitability for decision-making processes with limited information. In addition, the AHP approach can be used to check comparison consistency (Kahinda et al., 2008).

2.12 Multi-criteria decision analysis with analytical hierarchy process (AHP)

In the process of analyzing the suitability of a location for rainwater harvesting, the MCDA approach provides a logical framework to tackle the complex criteria used to reach a particular decision (Zhang et al., 2020). The MCDA-GIS method yields criterion maps from geospatially referenced datasets, which can be in vector or raster format. The role played by GIS technology in identifying suitable sites for RWH is discussed by Mugo and Odera (2019) and highlights different techniques, i.e., the raster-based approach. GIS technology plays an important role in site selection because it stores and processes geospatial data, performs analysis and calculation, and visualizes the geolocation for rainwater harvesting, which helps in deciding whether to establish rainwater harvesting structures.

The AHP approach was established in the 1970s by Thomas Saaty and is a multi-criteria decision-making model. The AHP approach prioritizes multiple factors that are considered in the decision-making process into a hierarchy (Saaty, 1990). The valuable role played by AHP is to gather various opinions from experts about the selected criterion and after comparisons are made for two criteria at a time. The methodology requires human judgments, which are then translated into a quantitative interpretation.

The AHP is very valuable for application in structuring conflicting and complex multi-criteria scenarios into a hierarchy that gives each criterion a weight based on its relative importance against an alternative criterion (Zhang et al., 2020). The AHP, as discovered by Saaty (1990), uses a scale called the Saaty scale, which ranges from 1 to 9. The Saaty scale explains the relative importance of one alternative to another in numeric form. The scores help in structuring a pairwise matrix that is used to calculate the individual weights of the criterion.

Table 2.2: Saaty (1990) Relative scale of importance

Intensity of importance	**Definition**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocals	If criterion x has one of the values above given to it in comparison to criterion y, then criterion y has the reciprocal value when compared to criterion x

The AHP method is commonly used for criterion weight calculations, especially in site selection for RWH. The ranking of the factors used was determined by the judgments made by experts, which were based on the relative importance of each criterion as expressed in words. The Saaty scale (1990) was used to translate human judgments into a numerical form from 1 to 9. A pairwise matrix is developed on the basis of the criterion scores, which result in an n x n matrix.

2.13 Systematic review

A systematic review was conducted for the study using inclusion and exclusion criteria whereby keywords were utilised (with the aid of Boolean operators) to extract relevant works of literature from open-source and trusted scholarly databases e.g. Web of Science, Scopus etc. The inclusion criteria included keywords such as ‘site selection’ or ‘optimum search’, ‘site suitability’, ‘spatial model’ or ‘geospatial approach’, and ‘rainwater’ or’ storm water’ (see appendix B). The exclusion criteria included keywords such as ‘geological approach’, ‘recharge wells’, ‘land assessment’, and ‘artificial groundwater recharge’. The inclusion and exclusion criteria were based on keywords derived from the titles of similar studies. Appendix A presents the summaries extracted from the literature resulting from the systematic review.

This review aimed to identify the importance of site selection, analyze the application of multi-criteria analysis integrated with GIS, and identify the types of MCDA techniques used for decision-making problems. This study also justified the selection of a specific MCDA method and explored the weighted overlay analysis technique used to determine suitable locations for rainwater harvesting. The systematic review ensured that the research findings were based on a comprehensive understanding of the existing literature and established a strong theoretical framework for the study.

2.14 Summary

Chapter 2 provides an overview of previous studies and research related to rainwater harvesting (RWH) and the use of GIS in site selection. This chapter discusses the importance of RWH in addressing water scarcity and promoting sustainable water resource management. This study highlights the use of multi-criteria decision analysis (MCDA) and GIS in site selection for RWH structures, emphasizing the integration of geospatial data on precipitation, soil, land use, and DEM. The chapter also mentions the Soil Conservation Service curve number (SCS-CN) method used to determine runoff depth by integrating land use/land cover, rainfall, and soil type layers. In addition, the chapter suggests the need for web-based suitability maps and provides recommendations for future research on rainwater modeling using GIS and MCDA

Chapter 3: Methodology

The previous chapter provided a comprehensive review of the literature related to rainwater harvesting (RWH) and the use of geographical information systems (GIS) and multi-criteria decision analysis (MCDA) in site selection for RWH structures. It discusses the importance of RWH in addressing water scarcity and promoting sustainable water resource management. This chapter highlights the application of GIS techniques in identifying suitable RWH sites based on factors such as precipitation, soil, land use, and runoff characteristics. This chapter outlines the methodology used in the study to select suitable sites for RWH in KwaZulu-Natal. This involves the integration of geospatial data on precipitation, soil, digital elevation model (DEM), and land use/land cover in GIS layers. This study used the soil conservation services curve number (SCS-CN) method to determine runoff depth and integrated it with land use/land cover, rainfall, and soil type layers. A multi-criterion ranking system was developed to assess the suitability of potential RWH sites for different structures.

3.1 Introduction

The selection of suitable sites for rainwater harvesting is a multi-criteria and multi-objective problem. This research is empirical because of its basis on measurable and observed data; therefore, it is a quantitative empirical study. The relationship between multivariables is observed, e.g., environmental factors, socioeconomic factors, and ecological considerations of KwaZulu-Natal, which are the independent variables in this investigation, and suitability, which is the dependent variable. These factors have an indirect/direct impact on the suitability of the sites for rainwater harvesting. First, the runoff coefficient for different land-use/land cover classes and different soil textures along with the runoff depth for KwaZulu-Natal was produced using a geospatial approach. Then, a map of rainwater harvesting availability was generated. This map will enable city managers and decision-makers in KwaZulu-Natal province to plan and develop RWH structures such as building dams or recharge wells in suitable sites so that urban flooding in areas experiencing heavy rainfall will be reduced. Therefore, it will also assist in maintaining a sustainable water environment in areas experiencing water scarcity.

The methodology used in this study involved the following major steps:

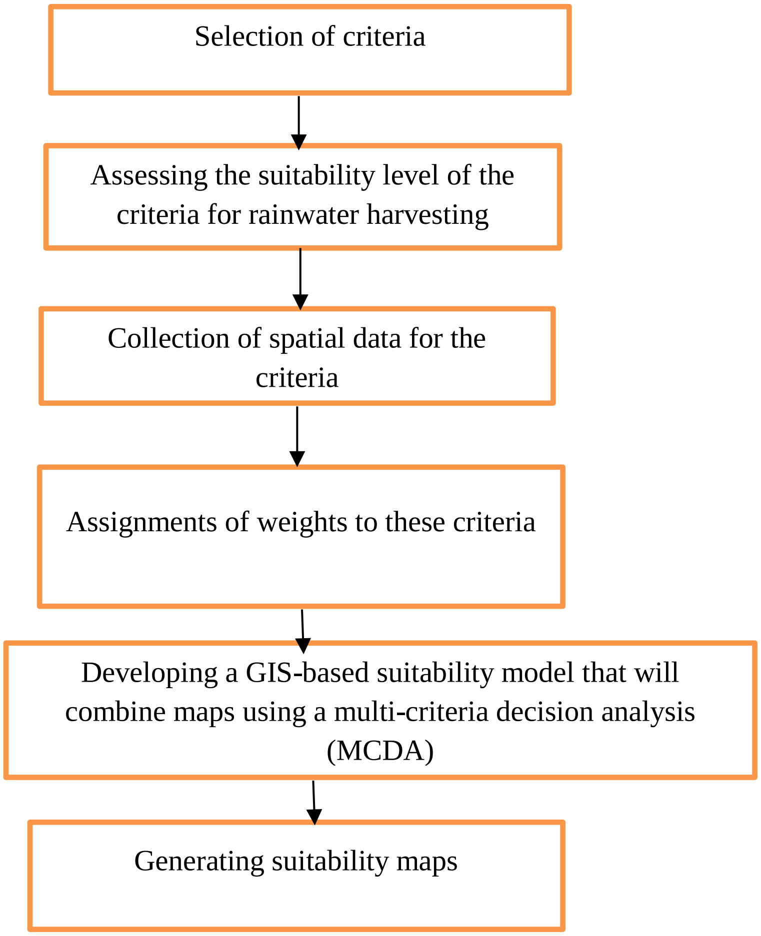

Figure 3.1: Methodology Flowchart for Rainwater Harvesting Suitability Assessment

To select suitable sites for rainwater harvesting, the following five criteria were selected to determine suitable sites for RWH:

- Soil maps (soil texture, soil type and hydrologic soil groups)
- Land Use/ Land cover
- Slope
- Rainfall
- Runoff curve number (CN)

3.2 Study area

The study area of this investigation is the KwaZulu-Natal province, which is a coastal South African province that consists of an area of approximately 94 361 km^2 and a population of approximately 11, 1 million people (Statistics, 2014). KwaZulu-Natal (KZN) is very mountainous and hilly, especially around the western border area. The land in the area rises to more than 3,000 m from the coastal region along the Drakensburg escarpment on the western border. The topography in KZN is not flat, and different rocky outcrops in most of the province render the terrain into steps of undulating lands that ascend from an elevation of about 150 m along the coastal plain to areas of about 600 m, and then to about 1200 meters in the center of KZN in a region called the Midlands (Statistics, 2014).

The climate of KZN varies from subtropical to temperate. Rainfall surplus in the area decreases from more than 1270 mm in a year along the coast to approximately 1020 mm inland (Statistics, 2014). Temperatures can decrease in frost-free coastal regions, but they remain warmer (Statistics, 2014). The summer is hot and experiences occasional rainfall. Because the area experiences inconsistent precipitation annually, there is a need to diversify the water sources to meet the high demand for water in the area.

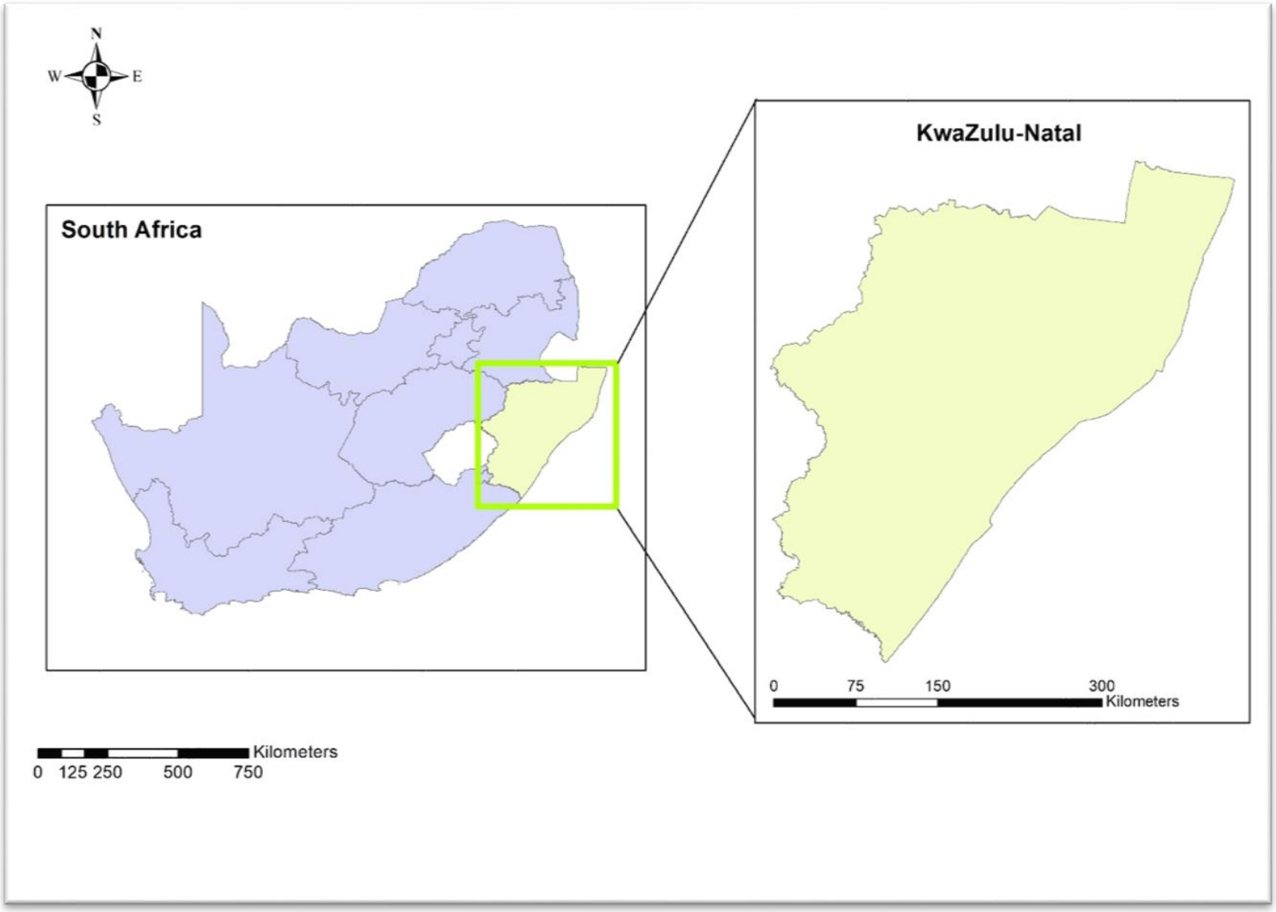

Figure 3.2: Map of the study area

3.3 Research Design

The overall process of identifying the RWH sites is illustrated in Figure 3.3. The study area's slope was extracted using 30 m SRTM DEM as it is considered more accurate due to radar beam penetrating into the tree canopy to obtain accurate topographic measurement (Zhang et al., 2018). Using satellite image data from Sentinel-2, a Land use/Land cover (LULC) cover map of the study area was generated. This map was then combined with the soil map to create the curve number (CN) layer. Subsequently, the CN layer was employed to estimate the runoff depth within the study area. Finally, the weights from relevant literature were combined with all the aforementioned layers to produce the RWH potential suitability map. The RWH suitability map was used to create and publish the web map using ArcGIS online.

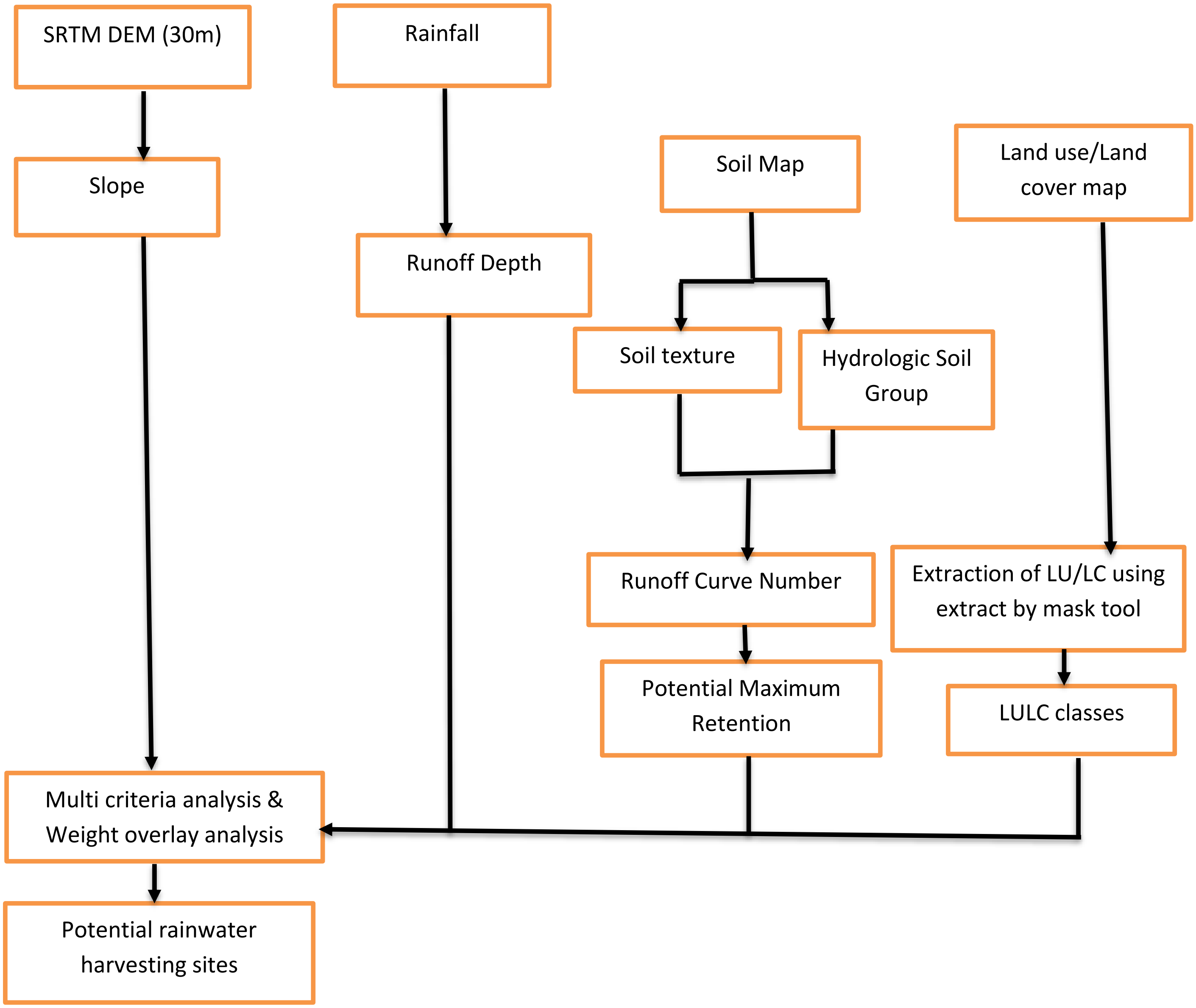

Figure 3.3: Overall process for identifying potential RWH zones

3.3.1 Data

Since the general objective of this research study was to select the potential rainwater harvesting, the results of this study were based on the application of the representations of spatial variations in landscape characteristics, i.e., slope, land use/land cover, soil, runoff depth, and rainfall, which were collected from various websites and governmental departments. The spatial data were collected in raster and vector formats from various sources on the Internet, which are mainly open-access. The spatial datasets are categorized as secondary data.

Table 3.1: Data collected for the study area

Data	**Type**	**Source**	**License/Permission**	**Use**
DEM (resolution: 30m)	Raster	USGS	Open access published	Used to generate slope map
Land cover - Sentinel – 2 (resolution 10 m)	Raster	ESRI	Open access published	Input into RWH site suitability framework and SCS-CN for generating runoff depth layer
Soil	Vector	Digital Soil Map of the World (DSMW)	Open access published	Input into RWH site suitability framework and SCS-CN for generating runoff depth layer
Rainfall	Raster	Worldclim.org (version 3)	Open access published	Input into the SCS-CN model to estimate potential runoff depth

3.4 Data Processing

This section presents the structure of the research methodology that addresses the fundamental questions in this investigation. This study describes the implementation and application of MCDA with GIS to assign criterion weights, the generation of thematic maps for the selected criteria, and the use of weighted overlay analysis for combining the criterion's map based on their relative importance.

The software used for data analysis in this investigation was ESRI's ArcGIS Desktop 10.7.1. The software allows the user to create, manipulate, model, and analyze spatial data (Chen et al., 2023). Five criteria were selected for the determination of potential RWH sites: slope, land use/land cover, soil, rainfall, and runoff coefficient or runoff depth. The coordinate system used for this investigation is universal transverse mercator zone 35 South (UTM 35S) as it covers KZN, which is meter-based. This ensured that all geospatial data were in the same coordinate reference system. Other data preparation of the geospatial data will include resampling all the data to a resolution of 30 m.

The soil depth and texture maps were generated from the soil data shape file, and the slope map was generated from the 30m*30m DEM. The land use/land cover was downloaded from ArcGIS and clipped to the extent of the study area using the clip tool. After generating all the required thematic layers, each thematic layer was re-classified using the reclassification tool into five comparable units of levels one to five according to their suitability level (refer to Table 3.3).

Since the spatial datasets were collected for different sources and different organizations at varying scales, to ensure consistency and account for the difference in resolutions, a cell size of 30m*30m was adopted when resampling the re-classified vector layers into a raster format for further analysis.

3.4.1 Slope

Kia et al. (2012) defined the topographic slope as the angle between the surface and the horizontal datum. The slope has an impact on the amount and velocity of water runoff on the surface, and adopting rainwater harvesting in areas with suitable slope gradients can increase the amount of water runoff that will be available to be harvested for RWH structures, i.e., dams and water tanks. The DEM (refer to figure 3.4) was processed in the ArcGIS spatial analyst environment. The slope tool was used to generate the slope layer from the 30 m DEM. The slope layer was re-classified into fives classes relative to water runoff generation and rentention capacity based on Table 3.4 and as further discussed in Section 3.5.1.

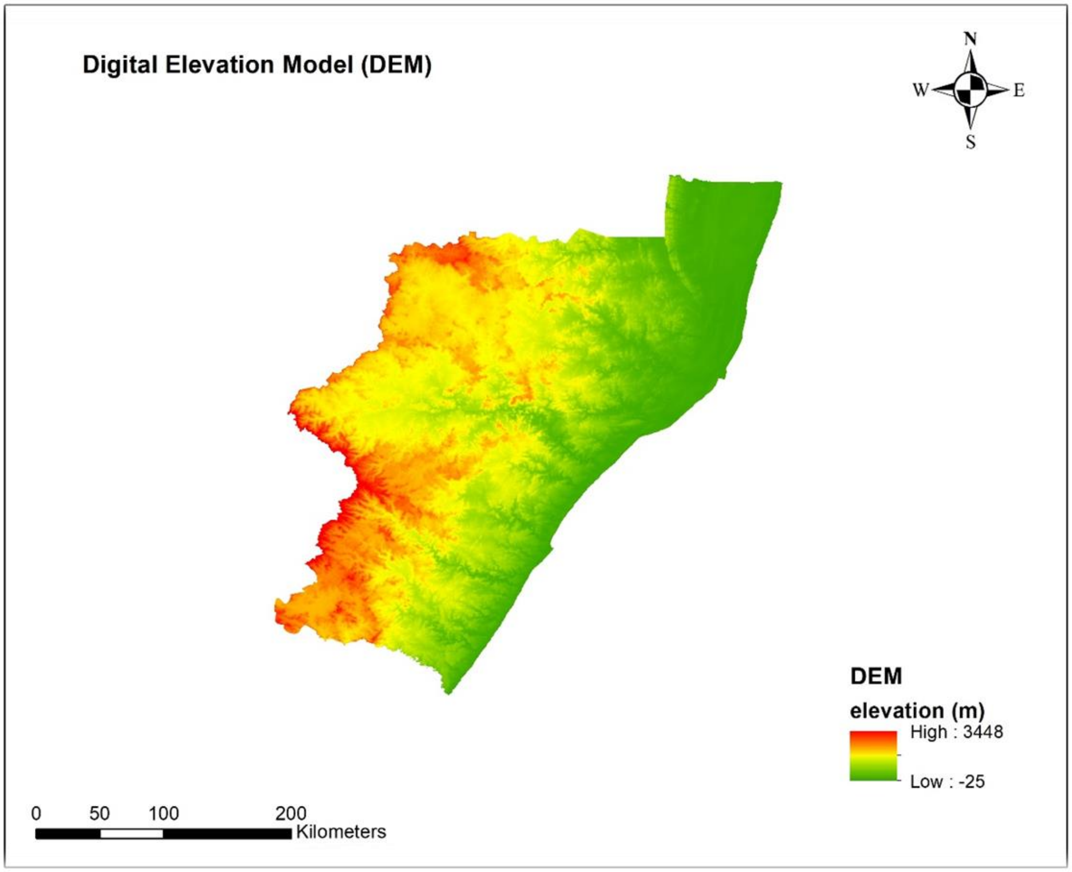

Figure 3.4: DEM of the study area

3.4.2 Land Use/ Land cover

The land use/land cover of the study area consists of 16 main elements, most of which cover most of the area: commercial agriculture (grassland and cultivation) and urban/built environments and settlements (rural and urban areas). As most of the land in the area is generally not in its natural state (due to agricultural, industrial, and domestic activities occurring in the area), the land has reduced precipitation retention, which results in increased generation of surface water runoff, making some parts of the regions in KZN suitable for adopting rainwater harvesting. The LU/LC layer was clipped to the extent of the study area using the clip tool and then reclassified into five classes (refer to Table 3.3).

3.4.3 Soils

Digital soil data with metadata were obtained from the Agricultural Geographic Information System (AGIS) database. The study area was clipped out of the whole country soil data using the clip tool in ArcGIS and projected to UTM Zone 35S for further analysis. The clipped soil layer was used to generate soil texture and hydrological soil group maps. Soils with high clay content and low infiltration rate have higher runoff generation. Soils with sandy content have a higher infiltration rate and thus low runoff generation. The US Soil Conservation Service (SCS) has identified four soil groups that provide information for determining water runoff coefficients. The four hydrological soil groups are identified as soil types A, B, C, and D. The following information on the four soil groups was modified after USDA (2007).

Table 3.2: Hydrological soil groups and their corresponding texture classes

Hydrological Soil Group (HSG)	**Description**	**Textural Class**
A	Low overland flow potential. Minimum infiltration capacity when it’s wet. Deep to excessively drained sand and gravel	Sandy loam
B	Moderate minimum infiltration capacity when wet. Moderately deep to deep, moderately to well drained	Silty loam and loamy
C	Low infiltration rate, high to moderate runoff potential	Sandy clay loam
D	High runoff potential with a low infiltration rate	Sandy clay, Clay

The agricultural geographic information system data indicated that most of the soil in the study area is very poorly drained, and a thin soil development means that the soil will take up a small amount of precipitation before it becomes saturated. Thus, most of the precipitation will be converted into surface water runoff (Liu et al., 2017).

3.4.4 Rainfall

Rainfall is a major factor in the determination of potential RWH sites because rainfall events indicate where it is suitable to adopt and implement RWH structures. The climate of the study area is described as a subtropical climate whereby a dry and cold winter season is experienced from April to August, whereas a hot and humid summer season is experienced from September to March. During the summer season, the average temperatures frequently rise above 25 degrees Celsius and in the winter season, the average temperature often drops to an average of approximately 20 degrees Celsius. The coastal areas situated around Richards Bay and Durban receive annual mean precipitation of approximately 1193 and 964 mm/year, respectively (Liu et al., 2017). The midlands of KZN, located in the northwestern part of the province, receive an annual mean precipitation of approximately 813 and 847 mm/year. The southeastern parts of the province receive an annual mean precipitation of approximately 1382 mm/year. According to Ndovu and Demlie (2020), the main sources of moisture in the KZN province are the southwestern and western tropical Indian Ocean.

The pre-processing of rainfall data included performing a quality check using the double mass curve method. The annual average rainfall value was interpolated to estimate rainfall for areas not having rainfall point measurements (Abdullah, 2021). The mean annual precipitation layer was re-classed into five classes relative to the suitability of potential RWH sites.

3.4.5 Runoff Curve Number

The runoff coefficient (RC) or runoff curve number (CN) is a hydrological parameter used to describe the water runoff potential for drainage areas. CN is a function of soil type, soil texture, and land use/land cover. The SCS-CN technique was applied to determine the CN map based on the study area’s hydrological soil groups (HSGs), land use/land cover, and slope. The soil map for KZN was used to generate an HSG map. The LU/LC map for KZN was re-classified into five main classes (refer to Figure 4.5). The previously mentioned thematic maps (slope, LU/LC, and soil maps) were combined using GIS technique (Mugo and Odera, 2019)

The runoff coefficient can be generated as an event runoff co-efficient or an annual runoff co-efficient. The event runoff co-efficient is referred to as the rainfall portion that has become a direct runoff after a precipitation event. In the context of hydrological modeling, it shows the lumped effect of several hydrological processes in a catchment, such as evaporation, rainfall intensity, interception, initial abstraction, and water runoff (Abdullah, 2021). The annual runoff coefficient was derived for this study, as opposed to the event runoff coefficient, because the annual runoff co-efficient enables determining the amount of runoff that could be available for harvesting through RWH structures. The harvested water in the RWH structures can be used for agricultural and domestic purposes. The annual runoff co-efficient is generated using the annual rainfall surplus and runoff CN maps. This is an indicator of rainfall percentage that is transformed into surface-water runoff.

3.5 Main processing and suitability model development

3.5.1 Assessment of the suitability level of the criteria for RWH

Mahmoud and Alazba (2014) stated that areas with a larger rainfall surplus have a higher suitability ranking because rainfall surplus ensures the availability of runoff for RWH. Rainwater harvesting is generally more suitable in flat areas with gentle slopes. However, a mild slope is required for better capture of surface water runoff. Therefore, locations with slopes of 2-8 % (or class value of 5) have a higher suitability ranking. The runoff index for CN>50 (or class value of 4 to 5) is an indicator of potential sites for rainwater harvesting (refer to Table 6) (Mahmoud and Alazba, 2014).

Mugo and Odera (2019) conducted a detailed analysis of suitability rankings. The value for each category of suitability was scaled from 1 to 5. This approach is robust and reliable; hence, it was adopted for this study. Table 3.4 presents the suitability ranking values for these factors.

Table 3.3: RWH suitability classes (modified after Mugo and Odera, 2019)

Comparable units	**Suitability class**
1	Unsuitable
2	Low suitability
3	Medium suitability
4	High suitability
5	Very high suitability

Table 3.4: Suitability ranking for the different factors in selecting potential sites for RWH (Source: modified after Mugo and Odera, 2019)

Suitability Values and Criteria	**5 – Very high suitability**	**4 (High suitability)**	**3 (Medium suitability)**	**2 (Low suitability)**	**1(Unsuitable)**
Soil texture	Clay	Clay loam	Sandy clay loam	Sandy loam	others
Rainfall	Large surplus (984 – 1 108)	Small surplus (895 – 983)	Medium deficit (821 – 894)	Large deficit (750 – 820)	Very large deficit (615 – 749)
Slope (%)	0-5	6-11	12-18	19-28	29-77
Land cover	Intensively cultivated	Moderately cultivated	Forest, exposed surface	Mountain	Water body, urban areas
CN	70-100	50-70	40-50	30-40	0-30

3.5.2 Assignments of weights to the criteria

The relative importance weight of each criterion is a crucial component for decision makers because each factor has varying significance. The decision-making process in multi-criteria evaluation is based on the relative importance of the weight of each criterion. Several approaches are available for determining these weights. The pairwise comparison matrix method, which is commonly known as AHP, is the most used method, especially for RWH site selection, because of its robust nature; hence, it has been adopted for this study. This method involves evaluating each criterion against another criterion and occurs in pairs to decide on a criterion that is more significant than the other for a specific aim (Abdullah, 2021). Under the AHP, the pairwise matrix methodology has many advantages, such as the pairwise ratings being independent of any specific measurement and the methodology that promotes discussions, which lead to a consensus for the criteria weights that has been used (Abdullah, 2021). Table 2.2 shows the scaling used to compare the two criteria on a 9-point continuous scale. The Saaty scale score values are generally used to structure the pairwise comparison matrix used for calculating the individual weights of the factors. Normally, these criterion score values are linguistic judgments as assigned by experts.

The pairwise matrix calculation method is employed in the GIS-based suitability model to allocate weights to various criteria based on their relative importance. These weights are determined by comparing criteria against one another, resulting in the assignment of values that encapsulate their respective levels of significance. The process of pairwise matrix calculation involves the comparison of criteria in pairs, in which each criterion is assessed in relation to every other criterion with regard to its importance(Ayodele et al., 2018). This comparative analysis is typically conducted using a scale that can take the form of either a numerical or verbal scale to indicate the relative importance of each criterion. The outcomes of these pairwise comparisons are subsequently used to create a matrix, commonly referred to as the pairwise comparison matrix, which conveys the relative weights of the criteria. The pairwise comparison matrix is subsequently applied in the weighted overlay analysis to allocate weights to the criteria and determine the suitability of different areas for the implementation of rainwater harvesting structures (Ayodele et al., 2018).

The consistency of the calculated pairwise comparison matrix was then evaluated by using the consistency ratio (CR) to check if the evaluation that exists between the selected criteria falls within acceptable limits. The CR must be below 10% or else that calls for a re-evaluation of comparing the criteria again. The following mathematical formula was used for calculating CR (Algarin et al., 2017)**:**

$$CR = CI/RI, \text{ whereby:}$$

CI = consistency index

RI = random index

Table 3.5: Random consistency index (source: modified after Algarin et al., 2017)

n	**RI**
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

If the consistency index is less than or equal to 0.10, then the judgements should be considered inconsistent and must be reviewed by the researcher before proceeding to the calculation of the criteria weights (Algarin et al., 2017).

3.5.3 Extraction of criterion scores

The Saaty scores were used to structure a pairwise matrix to calculate the individual weights of the criteria. Normally, these scores of linguistic judgments are provided by a panel of experts. However, a different methodology is presented in this study. Two criteria are compared at a time, e.g., rainfall versus slope. A reverse methodology was applied, where 10 or more pairwise matrices were used to extract the scores of two comparable criteria. Therefore, the score comparisons extracted are determined by the order of importance of the criteria. Criteria weights from an average of ten studies were used to determine the hierarchy. This was achieved by listing the weight hierarchy of all authors. For example, if soil texture has the highest weight in 11 out of the 11 articles, then it is listed first in the criterion extraction and will have some importance over the remaining criteria. If the slope has 8/11 authors in agreement as the second highest weighted criterion, it is listed second in the extraction. Therefore, the order of the criterion extraction was soil texture > runoff curve number > rainfall > slope, while the land cover was the least weighted, and it has no importance over any other criteria. To obtain the final scores for each criterion comparison that will populate the pairwise matrix, the average of each score was calculated.

Table 3.6: Criterion weight extraction order

Soil texture	**Runoff Curve Number**	**Rainfall**	**Slope**
1. soil texture/runoff CN 2. soil texture/ rainfall 3. soil texture/ slope 4. soil texture/land cover	5. runoff CN/rainfall 6. runoff CN/ slope 7. runoff CN/ land cover	8. rainfall/slope 9. rainfall/land cover	10. slope/land cover

Literature used to extract the scores was based on two factors: an inclusion of a pairwise matrix and citation credibility. The articles are peer-reviewed and collected from trusted scholarly databases e.g., Google Scholar, Web of Science, Science Direct, and Scopus.

3.6 Suitability Model

3.6.1 Criteria for determining the suitability of RWH sites

Site search/site selection analysis is the most important step in planning and implementing a successful strategy for an RWH initiative. The process should be adequate on both social and physical grounds. Because of its status as a hydrological intervention, the identification of appropriate criteria for determining potential rainwater harvesting (RWH) sites necessitates a geospatial approach. This approach entails the use of information derived from the physical catchment data to comprehend the hydrological response of the catchments. This method proves to be efficient with respect to time and conservation of resources that would otherwise be used for manually identifying RWH sites. However, its effectiveness is contingent on the availability of reliable data.

Various researchers have developed several biophysical factors that are useful in the selection of potential RWH sites, i.e., soil suitability, slope, land use/land cover, and upstream catchment harvesting potential. The steepness of the area is an important factor in the determination and implementation of water runoff harvesting interventions (Ziadat et al., 2006). Schmidt and Schulze (1987) suggested that soil type is a determinant factor in the selection of potential RWH sites because of the soil's capacity to soak up, store, and discharge water.

3.6.2 Development of a GIS-based suitability model

Weighted overlay is a frequently employed technique within geographical information systems (GIS) for the purposes of site selection and decision-making procedures. This method assigns weights to distinct thematic layers based on their ability to infiltrate and their runoff characteristics. The assigned weights indicate the relative significance of each criterion within the decision-making process. This approach allows for the integration of multiple spatial datasets that encompass factors such as precipitation, soil composition, land usage, and slope, thereby facilitating the assessment of different areas in terms of their appropriateness for a specific objective. The weighted overlay technique proves exceedingly beneficial in the realm of rainwater harvesting, as it aids in the identification of suitable locations for the construction of structures such as percolation tanks, check dams, and farm ponds. The analysis encompasses a range of factors, including land use/cover, slope, runoff curve number, rain surplus, and soil texture. The ultimate suitability map delineates regions classified as most suitable, suitable, moderately suitable, less suitable, and not suitable for the support of water harvesting structures. These layers are subsequently superimposed to generate a map indicating suitability. By combining and analyzing various criteria, weighted overlay provides a systematic method for site selection, empowering decision makers to prioritize areas exhibiting the highest potential for rainwater harvesting.

The ArcGIS model builder was used to generate RWH suitability maps for the study area. The ArcGIS spatial analyst tool was applied in this model to solve geospatial problems in the process of selecting suitable sites for rainwater harvesting. The model creates suitability maps for rainwater harvesting by integrating different input criterion maps by applying the weighted overlay analysis tool and using vector and raster datasets. With the weighted linear combination, the criteria are combined by assigning a weight to each criterion, and the summation of the results yields the RWH suitability map. The final weights are shown in Table 4.7. The spatial extents of suitable RWH sites were selected using multi-criteria decision analysis (MCDA).

To finally select potential RWH sites, the re-classed thematic layers from 1 to 5 are overlaid using the weight overlay tool. The aim of the weight overlay sum is to apply a common scale of values when standardizing diversified and dissimilar data inputs for an easily integrated analysis.

3.7 Summary

In Chapter 3 of the research paper, the methodology used to achieve the objectives of the study is outlined. The first objective is to select criteria for assessing the suitability level of the criteria for rainwater harvesting. This objective is achieved using a multi-criteria decision analysis (MCDA) method, which involves assigning weights to the criteria based on their importance. The second objective was to identify and evaluate potential sites for rainwater harvesting structures. This objective is accomplished through the integration of geospatial data on precipitation, soil, land use, and DEM using GIS techniques. The third objective is to develop a multi-criterion ranking system to determine the suitability of sites for rainwater harvesting. This is achieved by combining the thematic layers generated from the geospatial data and using the Soil Conservation Service curve number (SCS-CN) method to determine the runoff depth. Overall, the methodology in Chapter 3 aligns with the objectives of the study, using MCDA and GIS techniques to assess suitability, identify potential sites, and rank them for rainwater harvesting structures.

In this chapter, the structure of the research methodology and procedure is explicitly described. The AHP method can decompose the decision problems at the hierarchy level and perform pairwise comparisons at each level. The methodology used in this study involves a multi-criteria decision analysis (MCDA) approach based on Geographical Information Systems (GIS). The methodology incorporates the selection of criteria, assessment of suitability levels, and use of a GIS-based decision support system to delineate potential rainwater harvesting areas. The methodology uses geospatial data on precipitation, soil, digital elevation model (DEM), and land use, which are stored in GIS layers and combined to develop a multi-criterion ranking system for site selection. Moreover, different software and tools that have been used to analyse the criteria datasets are concisely described, such as AHP and weight overlay. The soil conservation services curve number (SCS-CN) method is employed to integrate land use/land cover, rainfall, and soil type layers to determine runoff depth. The methodology provides a systematic approach for identifying suitable sites for rainwater harvesting structures, which can be applied in any city or country to address water scarcity and promote sustainable water resource management.

Chapter 4: Results and Discussion

Chapter 4 presents the key findings of the investigation regarding the identification of suitable sites for rainwater harvesting in KwaZulu-Natal using multi criteria decision analysis (MCDA), and GIS. The results from the AHP, reclassification, and weighted overlay analysis are presented and discussed separately. The analysis highlights a finer-level classification for site selection, and the identified potential RWH zones can be utilized for domestic and agricultural activities.

4.1 Overview

In this chapter, the key findings of the research study are presented and discussed with regard to the research objective of the study, which was to identify suitable sites for rainwater harvesting in KwaZulu-Natal province using GIS with MCDA. Results from AHP, reclassification, and weighted overlay analysis are presented in separate sections

GIS technology provides city planners, decision-makers, and various stakeholders with a powerful collection of tools that enable the processing and analysis of geospatial information. Multi-criteria decision analysis (MCDA) is the most commonly used decision support system (DSS) model for complex choice scenarios such as site suitability analysis and land suitability evaluation. Integration of the DSS with GIS allows GIS users to evaluate various alternatives with a focus on multiple conflicting scenarios (Mahmoud and Tang, 2015). A typical DSS model comprises three main elements: (a) a database management system, (b) a graphical user interface, and (c) a group of potential analytical models used to simulate scenarios. The DSS plays a crucial role in providing users with unique optimal solutions for complex choice situations throughout the database management system.

4.2 Criterion Scores and Weights

The results of the criterion scores, which were extracted from different studies, are presented in Tables 4.1 – 4.4. All the literature listed indicated that soil texture is the most important criterion and was assigned the highest score in the pairwise matrices. The comparison of score values of criterion weights in various literature indicated that the order of importance for the criterion was soil texture, runoff curve number, rainfall, slope, and land use/land cover. The analysis conducted in this study was substantiated by the findings obtained from the calculation of criterion weight (refer to Table 4.6). The results of the criterion were further validated for consistency by conducting a consistency check, as explained in (3.5.2). An outlier detection analysis was performed to evaluate data consistency within the data extraction process from various studies. The importance of outlier detection analysis is to find patterns in the data that do not conform to the expected behavior.

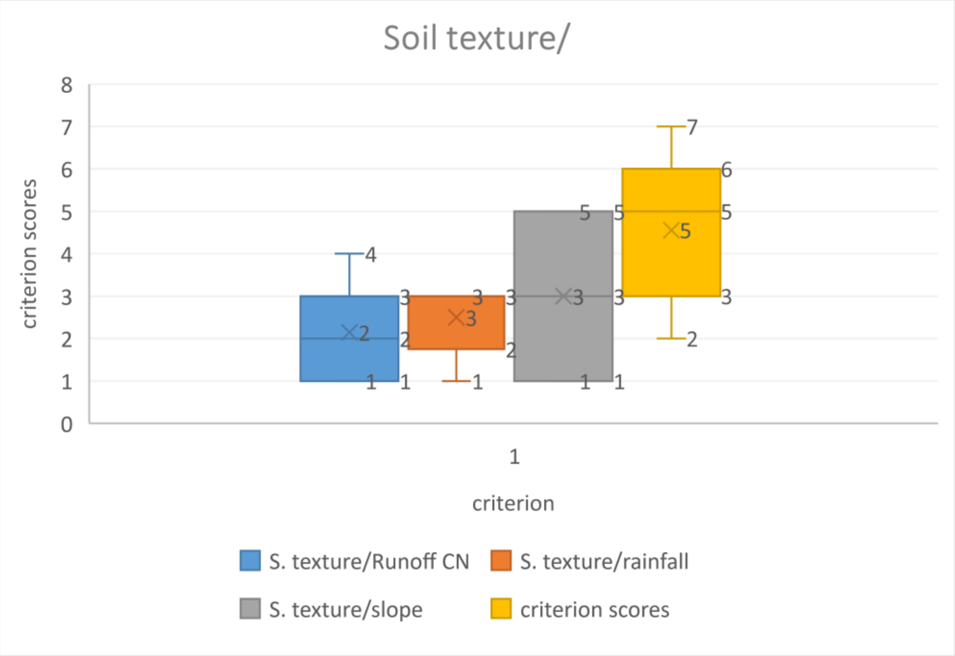

Figure 4.1: Soil texture criterion outliers

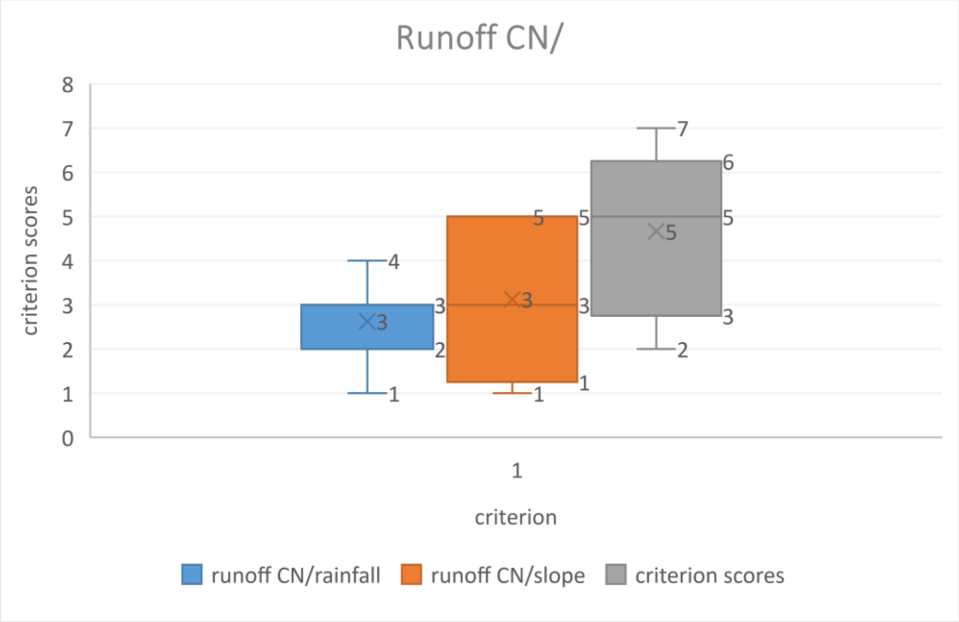

Figure 4.2: Runoff CN criterion outliers

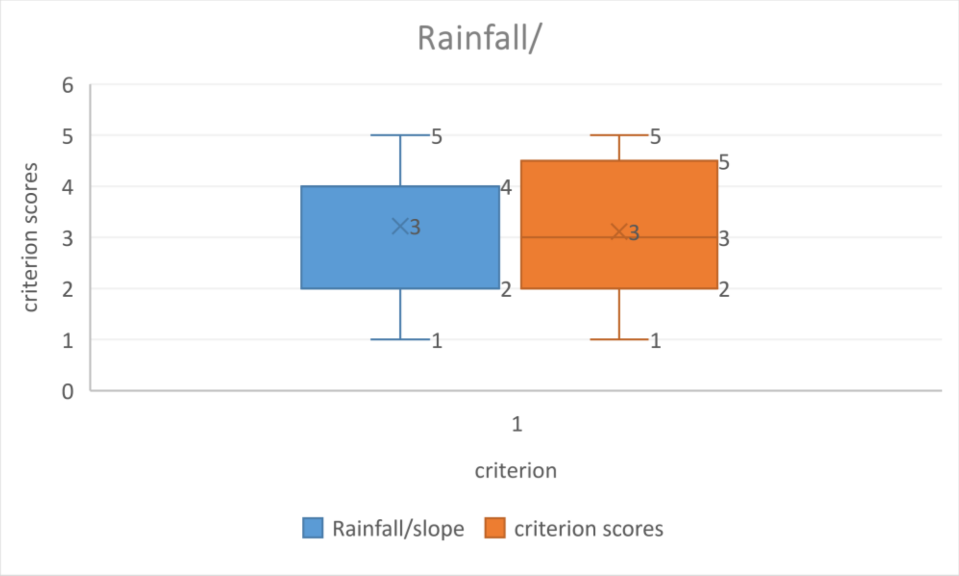

Figure 4.3: Rainfall criterion outliers

Table 4.1: Criterion scores for soil texture against remaining criteria as extracted from literature

Criteria Comparison	Sayl, Mohammed and Ahmed (2020)	El Ghezali et al. (2021)	Buraihi and Shariff (2015)	Saxena, Jat and Kumar (2018)	Shashikumar, Garg and Nikam (2018)	Duaij Al-Rukaibi (2017)	Altansukh Ochir (2017)	Prasad, Bhalla and S Palria (2014)	Wondimu and Jote (2020)	Al-shabeeb (2016)	Average	Rounded average
soil texture/runoff CN	2	2	2	1	1			3	4		2.14	2
soil texture/ rainfall		3	3	3	3	1				2	2.50	3
soil texture/ slope	1	4	5	5	1	5		2	3	1	3	3
soil texture/ land cover	2	7	6	6		5	6	3	3	3	4.56	5

Table 4.2: Criterion scores for runoff curve number against remaining criteria as extracted from literature

Criteria Comparison	Sayl, Mohammed and Ahmed (2020)	El Ghezali et al. (2021)	Buraihi and Shariff (2015)	Saxena, Jat and Kumar (2018)	Shashikumar, Garg and B Nikam (2018)	Duaij Al-Rukaibi (2017)	Altansukh Ochir (2017)	Prasad, Bhalla and Palria (2014)	Wondimu and Jote (2020)	Al-shabeeb (2016)	Average	Rounded average
runoff CN/rainfall	2	3	3	3	4	3	2	1			2.63	3
runoff CN/ slope	5	1	2	4	1		5	5	2		3.12	3
runoff CN/ land cover	3	2	5	7				6	5		4.67	5

Table 4.3: Criterion scores for rainfall against remaining criteria as extracted from literature

Criteria Comparison	Sayl, Mohammed and Ahmed (2020)	El Ghezali et al. (2021)	Buraihi and Shariff (2015)	Saxena, Jat and Kumar (2018)	Shashikumar, Garg and Nikam (2018)	Duaij Al-Rukaibi (2017)	Altansukh Ochir (2017)	Prasad, Bhalla and Palria (2014)	Wondimu and Jote (2020)	Al-shabeeb (2016)	Average	Rounded average
rainfall/slope	3	5	4	4	4	2	4	2		1	3.11	3
rainfall/land cover	3	1	5	4	2	3	3	5		2	3.11	3

Table 4.4: Criterion scores for slope against remaining criteria as extracted from literature

Criteria Comparison	Sayl, Mohammed and Ahmed (2020)	El Ghezali et al. (2021)	Buraihi and Shariff (2015)	Saxena, Jat and Kumar (2018)	Shashikumar, Garg and Nikam (2018)	Duaij Al-Rukaibi (2017)	Altansukh Ochir (2017)	Prasad, Bhalla and Palria (2014)	Wondimu and Jote (2020)	Al-shabeeb (2016)	Average	Rounded average
slope/land cover	3	4	4	2	3	3	4	4	4	1	3.2	3

Table 4.5: Pairwise Comparison Matrix

Criteria	**Soil texture**	**Runoff Curve Number**	**Rainfall**	**Slope**	**Land Use/ Land Cover**	**Total**
Soil texture	1	2	3	3	5	14
Runoff Curve Number	1/2	1	3	3	5	10.5
Rainfall	1/3	1/3	1	3	3	7.67
Slope	1/3	1/3	1/3	1	3	5
Land Use/Land Cover (LU/LC)	1/5	1/5	1/3	1/3	1	2.07
Sum	2.37	3.87	7.67	10.33	15	39.24

Table 4.6: Normalized pairwise comparison matrix

Criteria	**Soil texture**	**Runoff curve number**	**Rainfall**	**Slope**	**Land Use/Land Cover**	**Criterion Weight**
Soil texture	0.423	0.517	0.391	0.290	0.3	0.391
Runoff curve number	0.211	0.258	0.391	0.290	0.2	0.27
Rainfall	0.141	0.086	0.130	0.290	0.2	0.17
Slope	0.141	0.086	0.043	0.097	0.2	0.113
Land Use/Land Cover (LU/LC)	0.084	0.052	0.043	0.032	0.087	0.056
Sum	1	1	1	1	1	1

The calculation below represents, CI ratio calculation and value:

The priority vector (PV) representing the weights of each criterion is - PV = [0.423, 0.258, 0.130, 0.097, 0.087]

Next phase is to determine the principal eigenvalue (λ_max). The sum of each row in the normalized matrix represents the weighted sum of each criterion. Therefore, it was required to compute the weighted sum of the PV:

Weighted sum=(0.423×2.37)+(0.258×3.87)+(0.130×7.67)+(0.097×10.33)+(0.087×15)=3.6094+1.0008+1.0008+1.0003+1.305= 7.9163

And then, CI is calculated:

$$CI = \lambda max - n / n - 1 = 7.9163 - 5 / 5 - 1 = 0.6$$

Therefore, the consistency index (CI) is 0.6

Table 4.7: Weight (percent of influence)

No.	**Criteria**	**Weight**	**Weight (%)**
1	Soil texture	0.391	39.1
2	Runoff CN	0.27	27
3	Rainfall	0.17	17
4	Slope	0,113	11.3
5	Land cover	0,056	5.6
	Sum	1	100

4.3 Factor maps

The criterion thematic layers used in this study should be on the same scale and cell sizes as those used for the weighted overlay analysis. Further categorization in the study requires performing data conversion (from vector to raster) for layers such as soil texture and land use/land cover, as shown below.

The re-classified factor maps indicate the degree of suitability (refer to Table 3.3) for each criterion. The results show that site selection for RWH is not entirely dependent on one factor.

4.3.1 Slope

The slope of the region and the reclassified suitability maps are shown in Figure 4.4. The slope map was created using the spatial analyst tool in the ArcMap environment. The study region comprises a wide variety of slopes, ranging from mild to high steep slopes. In this study, five classes of slope percentages are distinguished: flat (0-5%), mild (6 – 11), moderate (12-18%), steep (19-28%), and mountainous (29 -77%). The slope exerts a significant impact on the generation of runoff, the rate of flow, and its recharge and is a determinant factor when selecting sites for rainwater harvesting structures. The very mountainous steep areas (29-77%) cover the least area in the region. The area covered in (0-5) slope percentage is as high as 45% coverage, which indicates the flat and mildly flat areas having slope of less than 5%. The gently sloping areas covered by 6-11% slope are suitable for adopting and implementing RWH structures to meet irrigation demand in KwaZulu-Natal. Table 4.7 shows the distribution of the slope suitability classes.

Table 4.8: Distribution of slope suitability classes (modified after Mugo and Odera, 2019)

Factor	Interval	Rate	Suitability
Slope (%)	29-77	1	Unsuitable
	19-28	2	Low suitability
	12-18	3	Medium suitability
	6-11	4	High suitability
	0-5	5	Very high suitability

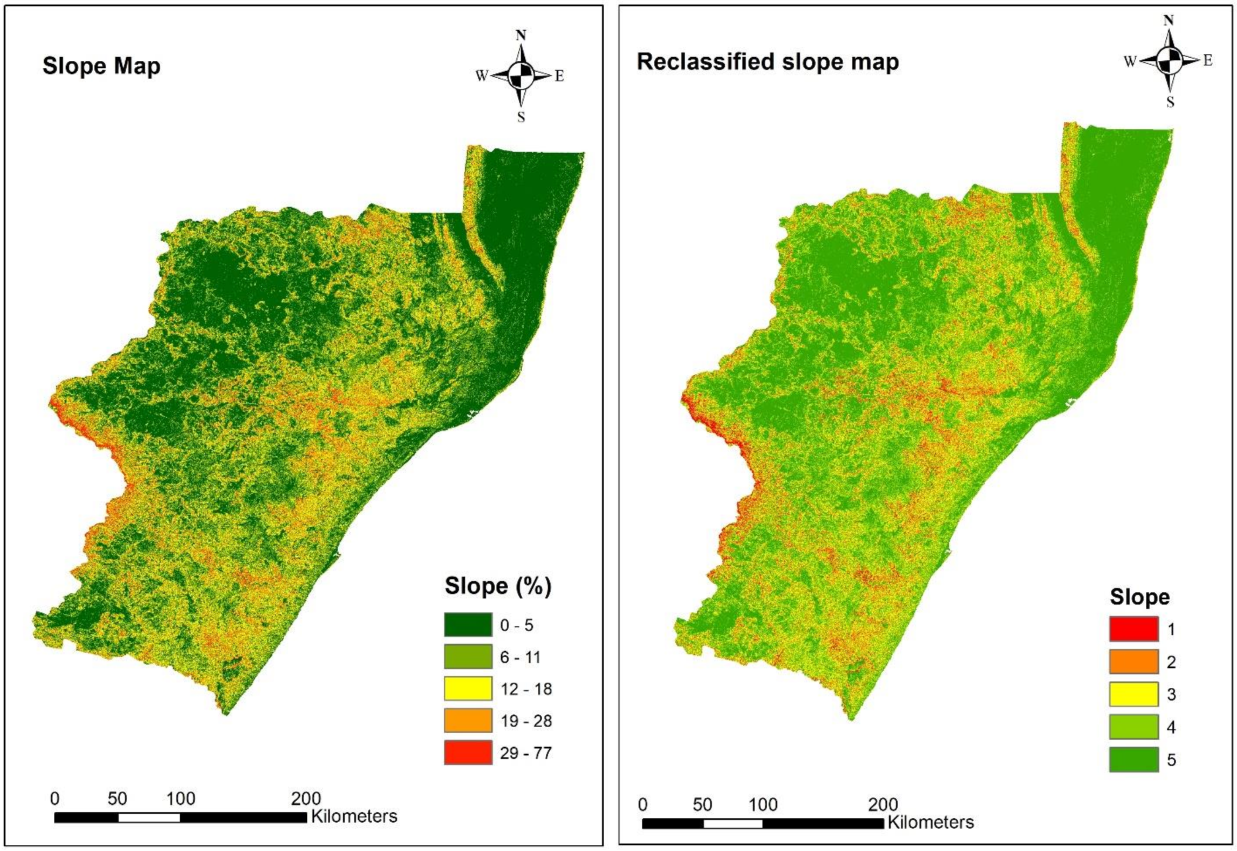

Figure 4.4: Study area's slope map (left); reclassified slope map (right).

4.3.2 Land use/Land cover

Figure 4.5 shows the land use/land cover distribution within the study area and identifies 8 main categories: waterbodies, trees, flood vegetation, crops, built areas, barren-ground, snow/ice, and rangelands (which has sub-categories such as shrublands, woodlands and grasslands). All these categories are then divided into 5 LU/LC suitability classes as indicated in the LU/LC reclassified map. Shrublands and woodlands (collectively known as rangeland) cover the most area with > 56% coverage then followed by trees, croplands, and flooded vegetation with about 24% coverage. Waterbodies and built areas account for approximately 17% of the coverage, with barren land having the least area coverage. To successfully adopt and implement rainwater harvesting structures and select suitable sites for RWH, it is often advisable to use LU/LC types such as barren ground and croplands. Table 4.9 shows LU/LC suitability classes. Conversely, built areas and waterbodies are unsuitable for rainwater harvesting structures because they may result in flash floods if poorly maintained, causing loss of life and infrastructure. Therefore, rangelands, which have the most coverage in the region, are the most favorable areas when selecting and implementing RWH sites and structures, i.e., check dams, contour bunds, and percolation tanks.

Table 4.9: Distribution of land use/land cover suitability classes (modified after Mugo and Odera, 2019)

Factor	Type	Rate	Suitability
Land use /Land cover	Waterbodies, Built areas	1	unsuitable
	Flooded vegetation, trees	2	Low suitability
	Bare ground	3	Medium suitability
	Croplands	4	High suitability
	Rangelands (shrub lands & woodlands)	5	Very high suitability

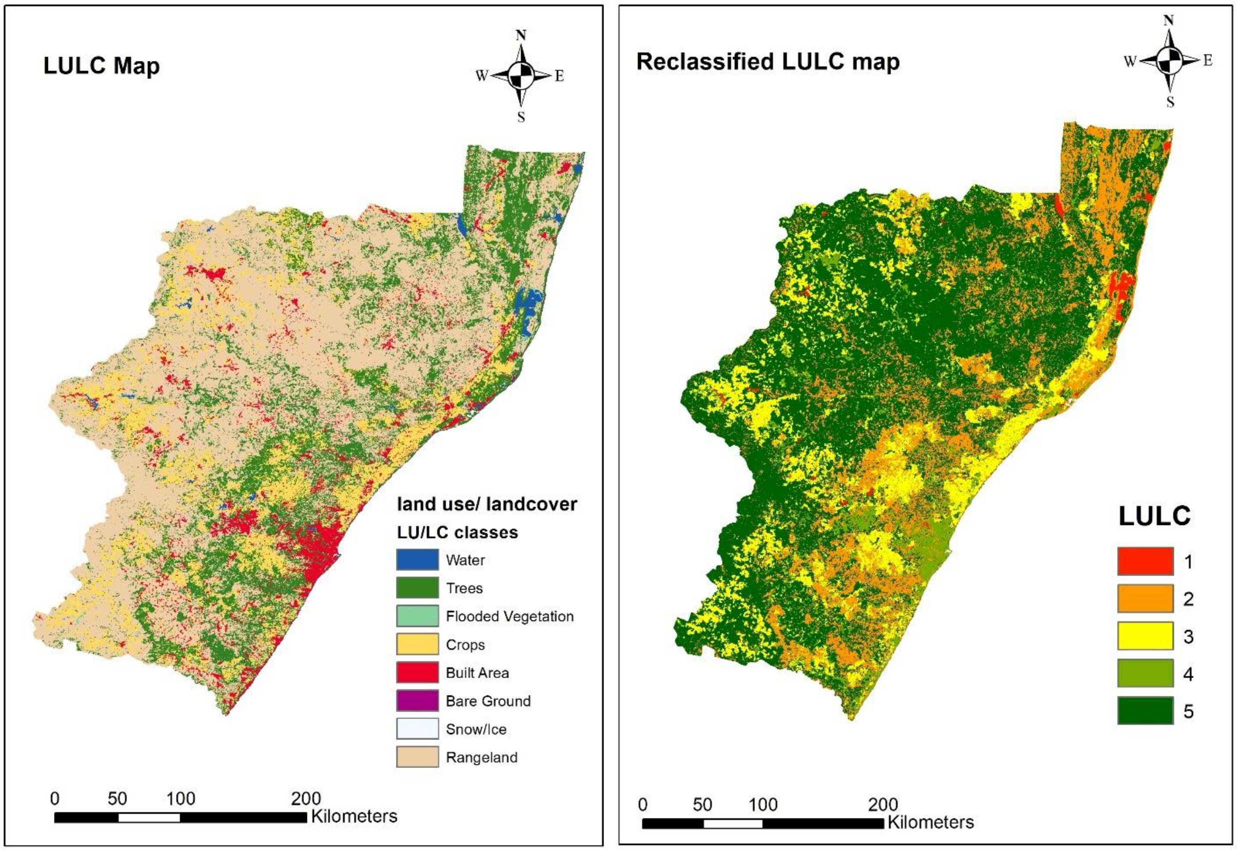

Figure 4.5: Study area’s LULC map (left); reclassified LULC map (right).

4.3.3 Rainfall Surplus

Figure 4.6 shows the mean annual rainfall distribution, and the reclassified map of the study region. The rainfall map indicates how rainfall amounts are spatially distributed throughout KwaZulu-Natal annually. However, a high rainfall concentration does not imply that a particular region is highly suitable for rainwater harvesting. The coastal areas receive the highest rainfall throughout the year compared with the inland areas. The mean annual precipitation ranges from 615 mm/year to 1108 mm/year. The areas toward the south and southwest of the region receive the lowest annual rainfall. The area is characterized by flat to relatively flat slopes and terrains, and the areas are largely used for grazing and hunting for animals. The inland areas in the province also receive moderate to low annual mean precipitation, as shown in figure 4.6. Table 4.10 represents the spatial distribution of the mean annual rainfall suitability classes.

Table 4.10: Distribution of rainfall suitability classes (modified after Mugo and Odera, 2019)

Factor	Interval	Rate	Suitability
Mean annual rainfall (mm/year)	Very large deficit (615 – 749)	1	unsuitable
	Large deficit (750 – 820)	2	Low suitability
	Medium deficit (821 – 894)	3	Medium suitability
	Small surplus (895 – 983)	4	High suitability
	Large surplus (984 – 1 108)	5	Very high suitability

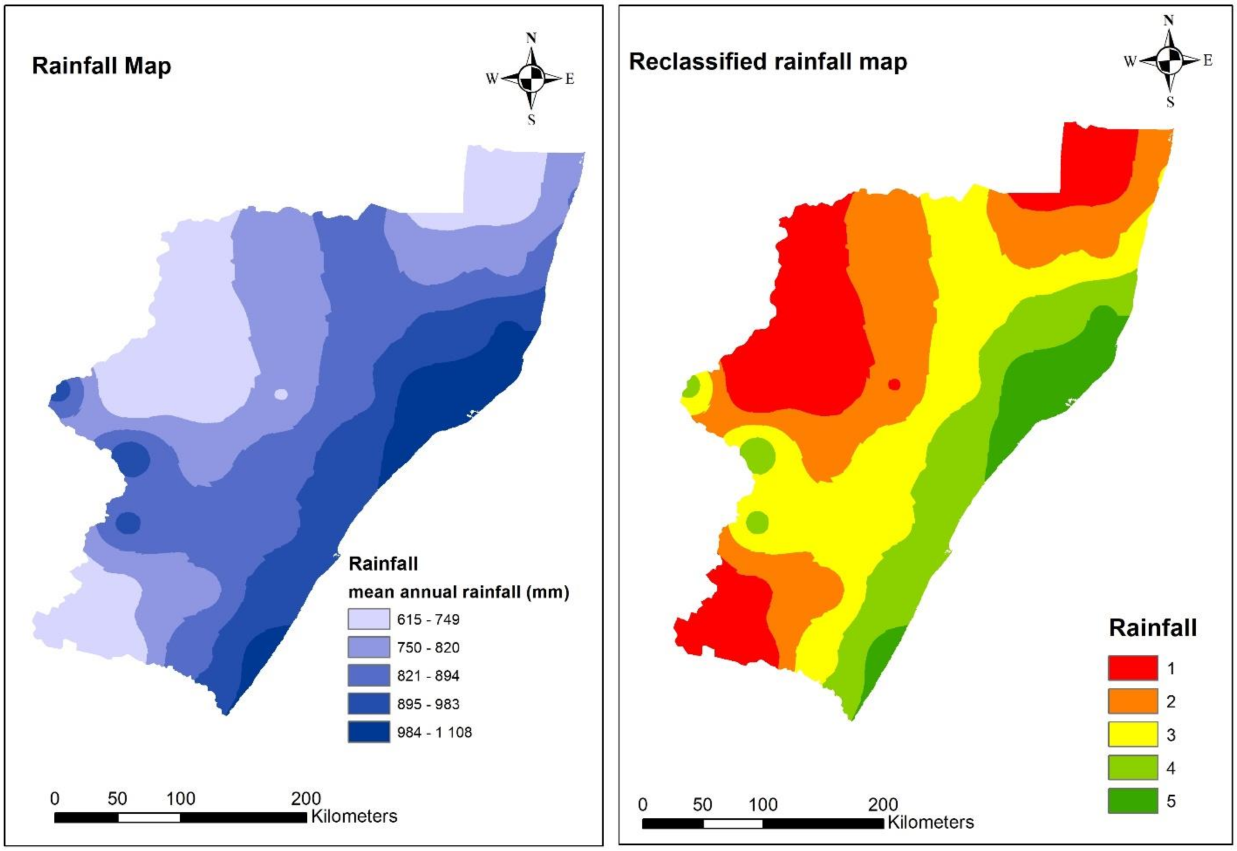

Figure 4.6: Study areas mean annual rainfall map (left); reclassified rainfall map (right).

4.3.4 Soil texture

Figure 4.7 depicts the spatial distribution of soil classes in the region and the reclassified soil map based on the soil texture suitability classes. The clip tool was applied to clip and digitize the soil map to the extent of the study area, and a final reclassified raster map was generated. The soil type representation for KwaZulu-Natal is provided in Figure 4.7. Ferrosols (which are the dominant soil type alongside Luvisols) are the deeply weathered yellow or red soils from the humid tropics, which are characterized by mostly clayey soil texture and strong water retention at a permanent wilting point, which makes the Ferrosols more suitable for water storage and RWH structures. Planosols are typical of an alluvial horizon dominated mostly by loamy and coarser textures. Planosols are subjected to water saturation during wetter periods because of stagnant rainwater. Hence, planosols are not suitable for rainwater harvesting. Vertisols are dominated by clayey soil textures.

The hydrologic soil group representation for the region is shown in Figure 4.7. The hydrologic soil group (HSG) C is a mixture of both loamy and clayey soils and has the most spatial coverage in the study region. HSG C is moderately suitable for RWH because it has adequate water retention but has a lesser scope than HSG D. HSG D is characteristic of clayey soils and is mostly suited for rainwater harvesting structures because of its high-water retention. This indicates that a lesser spatial extent of the study region is highly suitable for RWH based on the infiltration rate.

The soil texture representation for this region is shown in Figure 4.8. The study region’s soil texture map indicates various soils such as sandy loam, clay, sandy clay loam, and clay loam. All these soil texture classes are then classified into five suitability classes: very high suitability (clay), high suitability (clay loam), medium suitability (sandy clay loam), low suitability (sandy loam), and unsuitable (others). The major portion of the study region is clay, which indicates that most of the spatial extent of the region is highly suitable for RWH structures because clayey soils allow higher runoff generation and water runoff retention.

Table 4.11: Distribution of soil texture suitability classes (modified after Mugo and Odera, 2019)

Factor	Type	Rate	Suitability
Soil texture	others	1	unsuitable
	Sandy loam	2	Low suitability
	Sandy clay loam	3	Medium suitability
	Clay loam	4	High suitability
	Clay	5	Very high suitability

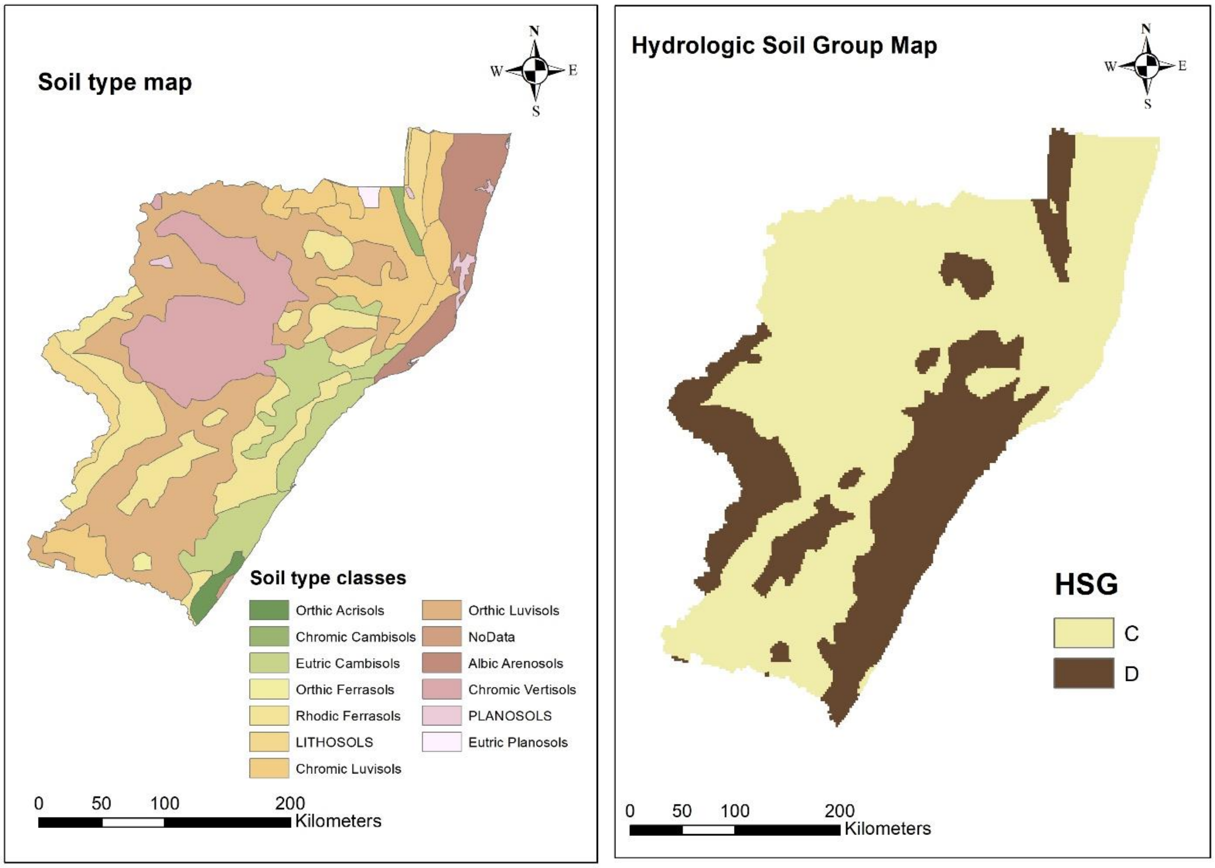

Figure 4.7: Soil type map (left) and hydrologic soil group map (right)

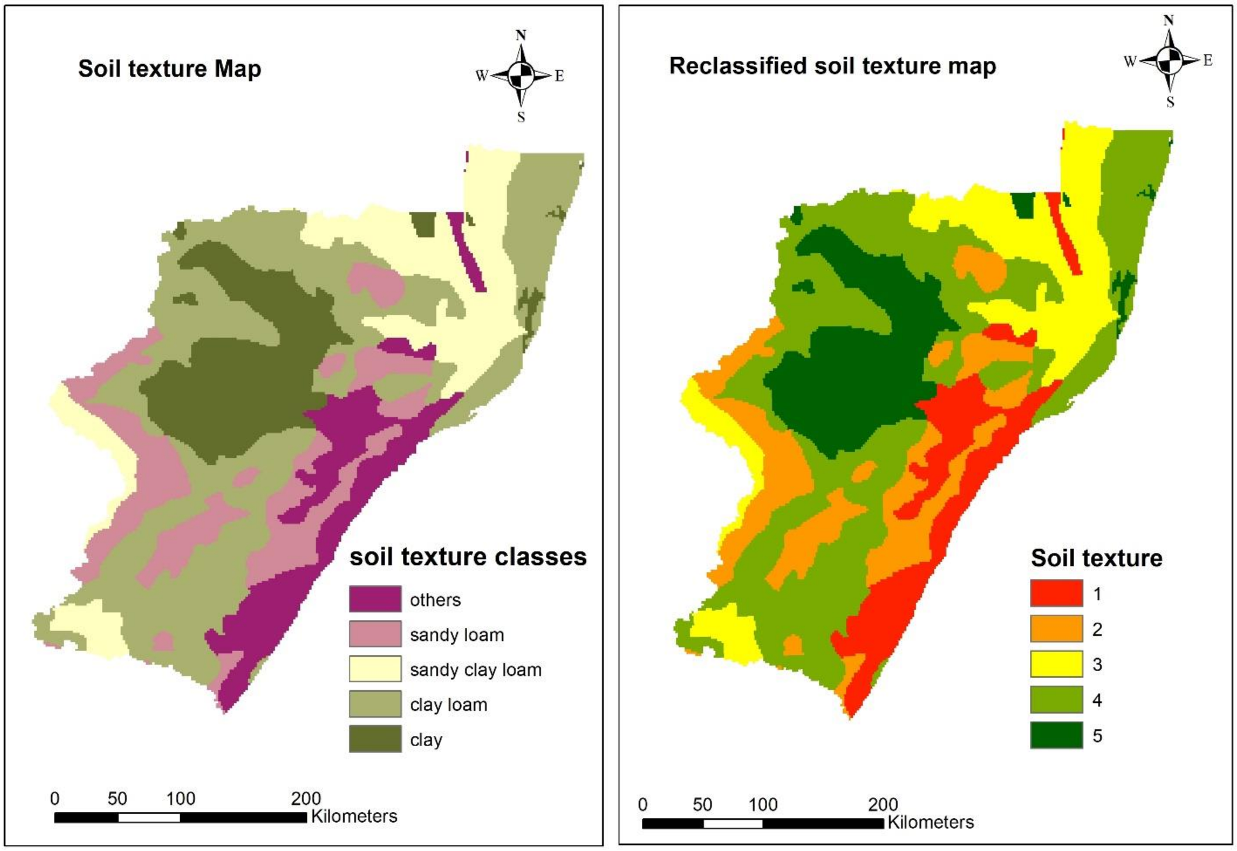

Figure 4.8: Study area’s soil texture map (left); reclassified soil texture map (right)

4.3.5 Runoff curve number variations

The runoff process is governed by three environmental factors: soil type, rainfall, and land use/land cover. When considering the given conditions, land cover may display minor variations, whereas the soil type remains constant. Consequently, rainfall assumes a significant role as the primary catalyst for runoff generation. The distribution, volume, and intensity of rainfall serve as the decisive elements influencing runoff. The corresponding runoff CN values for the hydrologic soil groups were assigned according to the standard NCRS curve number table (refer to Table 4.11). It was observed that the maximum CN value assigned was 100 for rivers/water bodies, while the minimum CN value was 58 for forests/trees. Employing the natural break classification system, the region's runoff CN distribution was categorized into five classes: very low (26 – 58), low (59–77), medium (78-85), high (56-91), and very high (92 – 100) (Dai et al., 2010).

The results obtained from the ArcGIS environment reveal that there is considerable variation in the runoff curve number (CN) across the entire province, as depicted in Figure 4.9. The rangelands, flooded vegetation, and tree lands exhibit lower CN values in their spatial coverages on the map. Conversely, forested and cultivated areas display lower CN values, which can be attributed to the presence of vegetated materials from trees and crops. These organic materials enhance water infiltration rates, enabling longer water retention and facilitating gradual infiltration. On the other hand, built-up areas, surface water regions, and bare ground areas tend to exhibit higher CN values. Among the study regions, the highest CN value recorded during the long rainy seasons was 100.

Table 4.12: Curve number distribution with respect to HSG and land uses (Source: modified after Dai et al., 2010)

HSG	A	B	C	D
LULC	**Curve Number**			
Croplands	95	95	95	95
Trees and Rangelands	26	40	58	61
Built-up areas	77	86	91	93
Waterbodies	100	100	100	100
Bare ground	71	80	85	88

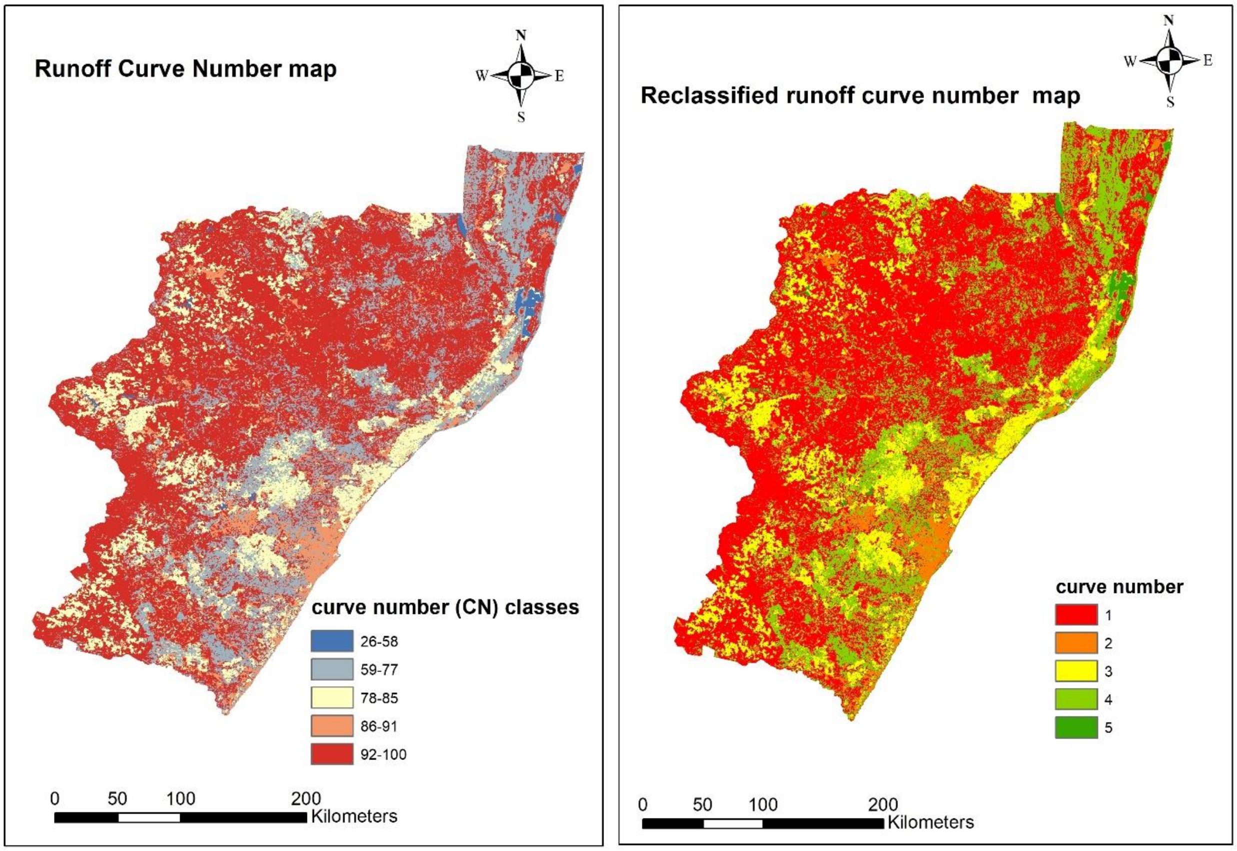

Figure 4.9: Curve number distribution in the study area

4.4 Final RWH suitability map

Identification and selection of potential zones for RWH are critical for maximization of water availability, recharge, and land productivity in semi-arid to arid areas. Therefore, rainwater harvesting can be used as a strategy for water provision to people for domestic and agricultural use in sub-tropical climate regions (where there is a lack of surface water availability). The agricultural sector in KwaZulu-Natal is almost dependent on groundwater for irrigation, which is a costly process and difficult to access. With such limitations in the availability of water resources in KwaZulu-Natal, it is necessary to develop alternative supplementary water resource structures for domestic, agricultural, and economic use. Therefore, the rainwater harvesting technique is considered an important tool for water resource sustainability.

The selected areas indicating RWH suitability and potential zones for RWH structures were classified into sub-areas based on their relative suitability classes. The suitability classes were grouped on the basis of their rankings as follows: 1- unsuitable, 2-low suitability, 3-medium suitability, 4-high suitability, and 5-very high suitability, as presented in Figure 4.10. The suitability rankings consist of a 1-5 range with 1 denoting unsuitable/restricted sites and 5 denoting the most suitable sites. According to Figure 4.10, the study region was mostly represented by moderately suitable sites, which comprised 38% of the study area. Approximately 10% of the study area was at the lowest scale and was a less suitable zone for RWH. Most of the spatial coverage within the study area was given the greatest attention because it had greater potential for RWH structure development in terms of slope, land use/land cover, rainfall, soil texture, and runoff curve number. Figure 4.10 illustrates the final RWH site suitability map of the study area.

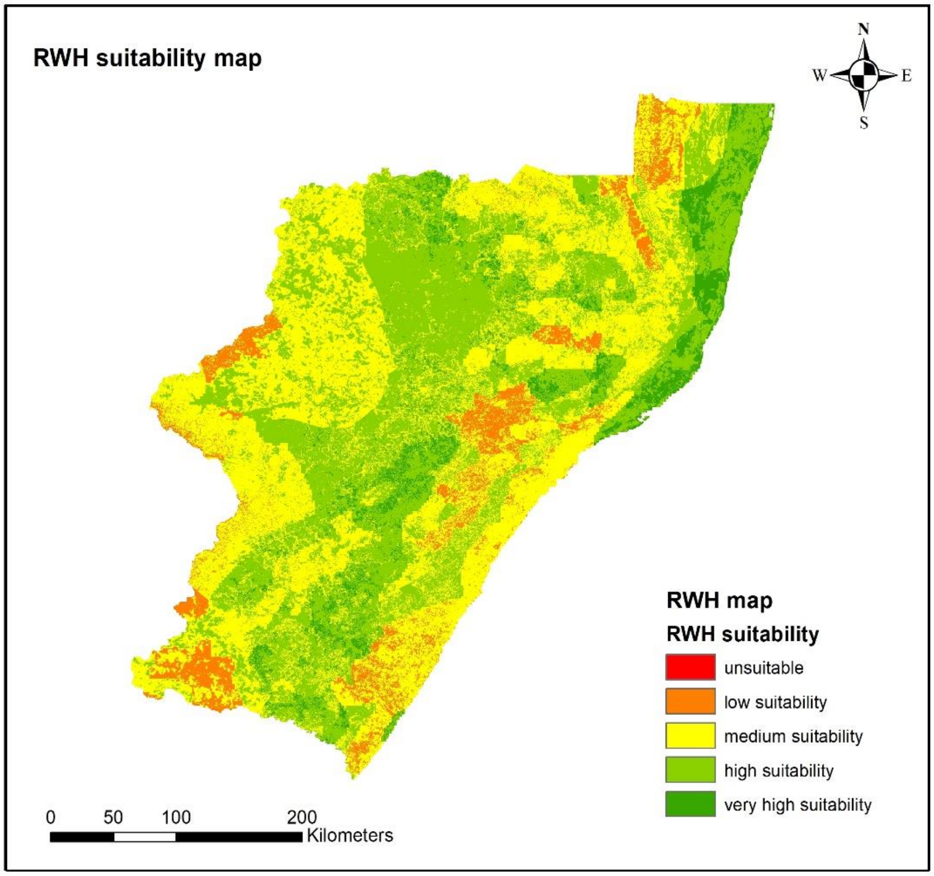

Figure 4.10: Rainwater harvesting site suitability map

4.5 Discussion

The results of the study have significant implications for addressing water scarcity and management challenges in KwaZulu-Natal, South Africa. The identification of suitable sites for rainwater harvesting structures using GIS and MCDA techniques can contribute to the wider adoption of rainwater harvesting in the region. The developed methodology can be implemented and adopted by other cities or countries facing similar water scarcity issues. The study highlights the potential of rainwater harvesting as an alternative strategy for water supply, promoting water security, safeguarding livelihoods, and mitigating landscape degradation. The identified potential rainwater harvesting zones can be utilized for domestic and agricultural activities, supporting sustainable water resource management. The integration of geospatial data and decision-making approaches can aid in the effective utilization and management of rain and flood resources, ensuring safety and controlling pollution. The study identified suitable sites for rainwater harvesting structures, including bench terraces, check dams, percolation tanks, and contour ridges, in KwaZulu-Natal.

The suitability of farming areas for rainwater harvesting depends on factors such as land-use/cover, hydrologic soil group, slope, and soil characteristics. The study considered the distribution of soil classes within the province, with a significant percentage coverage by Ferrosols, which are deep, well-drained, and have satisfactory moisture retention capacity. Farming areas with forested and cultivated regions may have lower curve number (CN) values, indicating higher infiltration rates due to vegetative material from trees and crops. Suitable farming areas for rainwater harvesting structures can be determined by integrating various factors, including land-use/cover, soil type, and slope, to optimize runoff capture and storage.

4.6 Summary

Chapter 4 presents the key findings of the study on identifying suitable sites for rainwater harvesting in KwaZulu-Natal using multi-criteria decision analysis (MCDA) and GIS. The results of AHP, reclassification, and weighted overlay analysis are presented in separate sections. The study identifies moderately suitable sites for rainwater harvesting structures, covering 38% of the study area, with the highest attention given to areas with high potential based on slope, land use, rainfall, soil texture, and runoff curve number. The research findings align with the objectives set out in the first chapter, providing a systematic approach for site selection and promoting the adoption of rainwater harvesting to address water scarcity in KwaZulu-Natal. The study's methodology, which combines GIS and MCDA, can be implemented and adopted by other cities or countries facing similar water scarcity challenges. Therefore, in this study, a suitability model was successfully developed to allocate optimum sites for rainwater harvesting in KwaZulu-Natal, South Africa.

5. Conclusion and Recommendations

Chapter 5 provides a summary and conclusion of the study. It highlights the relative contribution of the study to the field and discusses its limitations. Suggestions are made for future research perspectives on the application of GIS with MCDA for rainwater modeling. This study emphasizes the significance of rainwater harvesting as an alternative strategy for water supply, promoting water security, safeguarding livelihoods, and mitigating anthropogenic-induced landscape degradation.

5.1 Conclusion

The motivation for this study was to address water scarcity and management challenges in the study area of KwaZulu-Natal, South Africa. The rapid growth of the world's population and the increasing strain on water resources have resulted in an increased risk of communities reliant on rainfall for their livelihoods. The practice of rainwater harvesting is seen as a solution to the shortage of water in semi-arid and arid regions, especially in areas with limited and costly access to water resources.

The aim of this study was to use GIS with MCDA to identify potential rainwater harvesting sites in KwaZulu-Natal, South Africa. This was achieved by following the laid out objectives, which helped answered the research questions posed. A systematic review of relevant literature in the field of rainwater harvest site suitability helped identified all factors required to identify RWH sites, thereby answering the first question about the primary factors responsible for selecting suitable sites for rainwater harvesting. These relevant weights were obtained with rainfall having (17), soil texture (39.1), slope (11.3), land cover (5.6) and Runoff curve number (27). The selection of these specific factors for this study areas was based on a review of literature. The second objective seeking to identify a geospatial technique for determining potential sites for rainwater harvesting was achieved by adapting the MCDA technique to assign weights to the identified criteria, the importance of each criterion was deduced from literature by adopting the average of the scores. The map in Figure 4.10 resulted from the third objective, thus answering the question of where are the suitable locations for rainwater harvesting in the province of KwaZulu-Natal. The fourth objective seeking to develop web-based suitability mapping system that integrates geospatial data and allow real time analysis was achieved by using web-mapping techniques, such as ArcGIS online, to develop and publish web-based suitability map. The map in Figure 4.11 resulted from the fourth objective, thus answering the research question of how can web-mapping techniques be applied to enhance site selection for rainwater harvesting.

Site suitability analysis for identifying potential RWH sites using GIS with MCDA provides an advantage over conventional survey methods. This is because this methodology can produce a multi-layer integration of relevant parameters, i.e., land use/land cover, drainage density, proximity to residential areas, slope, soil texture, and rainfall, which provides smaller suitability units as a composite layer. The application of the SCS-CN technique for runoff mapping provided a unique analysis of the study area’s runoff, providing acceptable results for the study area’s runoff depth using rainfall, soil texture, and land use/land cover parameters.

RWH is a viable technique for water management deficiency issues because it effectively increases the availability of water for a sustainable period. In this study, a GIS-based MCDA method was used to address this issue and to develop an effective, feasible, and reliable method for optimal RWH sites. Based on the study findings, potential zones for RWH are spatially distributed in the southwest and northeast regions within the spatial extent of the study area. Approximately 10% of the region is classified as unsuitable for water harvesting. The analysis in this study highlights a finer-level classification for site selection analysis. The harvested rainwater from the identified potential RWH zones can be used for domestic and agricultural purposes.

This study proved that the use of GIS with MCDA as a methodology is a valuable tool for selecting suitable sites for rainwater harvesting structures through the overlaying of various thematic layers and is also a very flexible and cost-effective tool for larger geographic areas. The results provided by the RWH suitability map will help KwaZulu-Natal town planners, city managers, and relevant stakeholders make informed decisions and quickly identify areas in need of rainwater harvesting structures. The method that has been developed to identify suitable locations for rainwater harvesting (RWH) for the purpose of irrigation necessitates minimal effort and has the potential to be utilized in other regions that suffer from water scarcity. However, prior to the implementation of the RWH system, additional research is required, such as conducting comprehensive assessments of the designated sites, analyzing socioeconomic activities, and conducting a thorough evaluation of the proposed RWH locations.

The practical implications of this study are as follows:

This study provides a methodology for selecting appropriate locations for rainwater harvesting (RWH) structures using Geographic Information Systems (GIS). This methodology can be implemented in other urban areas or nations confronted with water scarcity concerns. The developed RWH strategy can meet the requirements for irrigation and foster sustainable management of water resources in KwaZulu-Natal province. The findings of this study can assist urban planners, municipal administrators, and pertinent stakeholders in making well-informed choices and swiftly identifying areas in need of RWH structures. The collected rainwater from the potential RWH zones identified can be utilized for domestic and agricultural purposes. This study emphasizes the significance of RWH in augmenting groundwater storage, encouraging sustainable management of water resources, and mitigating landscape degradation. The use of GIS methodology is a valuable instrument for selecting appropriate locations for RWH structures with diverse thematic layers, and it represents a flexible and cost-effective approach for larger geographical areas.

5.2 Recommendations and Future research scope

The analytical methodology used in this study is a flexible and comprehensive approach for the site selection analysis of RWH structures. Hence, it can change the present criterion and its corresponding criterion weight (CW) values. The considered criteria for the site suitability model should be different based on the geographic background of that particular region of interest. Other new parameters specific to the study area could be implemented for a robust analysis, i.e., population density, stream discharge, lineament density, and other new parameters that were not considered in this study. Therefore, using study area-specific criteria for site selection analysis, and changing parameters provides multiple benefits for future development of the site suitability model. The South African Ministry of Water and Sanitation has not identified a standard criterion for RWH site selection. Therefore, this research investigation will enable policymakers to introduce and implement new scientific analysis techniques for RWH site suitability analysis to ensure sustainable land planning and water resource management.

Based on the outcomes of this study, it is recommended that:

- For better and more accurate site selection analysis of RWH structures, spatial data with high resolution and fine scale should be used.
- This research framework/findings of this study could be adopted by the Ministry of Water and Sanitation and the eThekwini local municipality to manage future water development projects and sustainably preserve water resources in the province, as the study indicates the full potential zones with higher surface water generation.

This investigation has the potential for expansion through the acquisition and examination of diverse parameters (e.g., proximity to roadways, discharge of groundwater, geological characteristics, density of lineaments, expertise, and the value of preferences of decision-makers for pairwise matrix comparison). Prospective research may also take into account the creation of a user interface with graphical representation and an enhanced approach to MCDA (Multi-Criteria Decision Analysis), specifically in relation to the calculation of relative weights, while simultaneously integrating the water balance model. On the whole, this study offers valuable insights into the process of selecting suitable sites for rainwater harvesting structures in the region of KwaZulu-Natal, South Africa. Additionally, it provides recommendations for the effective implementation of such structures to optimize the management of water resources.

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APPENDICES

Appendix A: summaries from various literature

Author(s)	Year	Title	Summary
El Ghezali et al.	2021	Enhancing the success of new dams implantation under semi-arid climate, based on a multi-criteria analysis approach: Case of Marrakech region (Central Morocco)	This study is centered around the identification of appropriate dam sites within the Marrakech region of Central Morocco, which experiences a semi-arid climate. Two primary methodologies were employed for this purpose: Geographic Information System and Remote Sensing (GIS/RS) and Multi-criteria Analysis (MCA) integrated with GIS/RS. The selection of dam sites entailed the consideration of various criteria, including slope, rainfall, land use land cover, soil type, lithology, lineament density, and hydrographic typology. To validate the efficacy of the MCA approach, an existing dam within the study area was utilized. The findings of this study indicate that areas deemed unsuitable for surface water harvesting and dam projects may, in fact, be suitable for groundwater recharge. Consequently, the methodology employed herein can be applied globally to identify potential locations for dam construction. Additionally, the Tensift region in Morocco was examined, and appropriate dam sites were determined based on environmental conditions and the primary purpose of the dams, which is irrigation water supply. Qualitative and quantitative criteria were employed, and a model incorporating Geographic Information System (GIS) and Remote Sensing (RS) was implemented. The methodology involved assigning weights to various factors and calculating an accumulation index to ascertain the water storage potential of each site. Furthermore, soil characteristics, such as grain size and arrangement, were taken into consideration during the site selection process.

Ramakrishnan, Bandyopadhyay and Kusuma	2009	SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India	This research study is centered on the identification of potential water harvesting locations within the Kali Watershed in the Mahi River Basin of India. The Kali sub-watershed regularly experiences drought-like conditions from December to June as a result of elevated runoff potential, evapotranspiration, and inadequate infiltration. To enhance water resources, this study proposes the establishment of runoff harvesting structures such as check dams, percolation ponds, farm ponds, wells, and subsurface dykes. The suitability of various water harvesting structures is determined by considering spatially varying parameters including runoff potential, slope, fracture pattern, and micro-watershed area. The utilization of Geographic Information System (GIS) is employed as a tool to store, analyze, and integrate both spatial and attribute information. The SCS-CN method is utilized in this study to calculate the runoff potential, which is then classified into three categories: high, moderate, and low. Through the application of overlay and decision tree concepts within the GIS, potential water harvesting sites are identified. The accuracy of site selection during the implementation phase ranges from 80% to 100%.
Karani et al.	2019	Optimization of Rainwater Harvesting Sites using GIS	This research presents a conceptual framework for the optimization of reservoir site selection by means of rainwater harvesting, utilizing Geographic Information System (GIS) technology. The framework integrates stream networks, digital elevation data, and soil quality data to identify the most feasible reservoir sites. The study is specifically focused on the arid Beed district in Maharashtra, India, serving as a proof of concept. The framework is user-friendly and scalable, yielding consistent outcomes that align with manual inferences drawn from the data. The study also highlights the process of hydrological conditioning, which involves the creation of a depression-less Digital Elevation Model (DEM), the computation of flow direction and accumulation, and the utilization of pour points derived from the perennial stream network. The results obtained through hydrological conditioning are employed to demarcate watersheds. The proposed methodology can be applied to any location within the country, utilizing the available data for the entire nation.
Shashikumar, Garg and Nikam	2018	ANALYTICAL HIERARCHY PROCESS FOR IDENTIFICATION OF SUITABLE WATER HARVESTING SITE IN GEOSPATIAL ENVIRONMENT	This investigation centers on the identification of appropriate locations for the establishment of check dams through the utilization of the analytical hierarchy process (AHP) within the Hatni watershed in Madhya Pradesh, India. The determination of suitable sites relies on parameters such as soil composition,

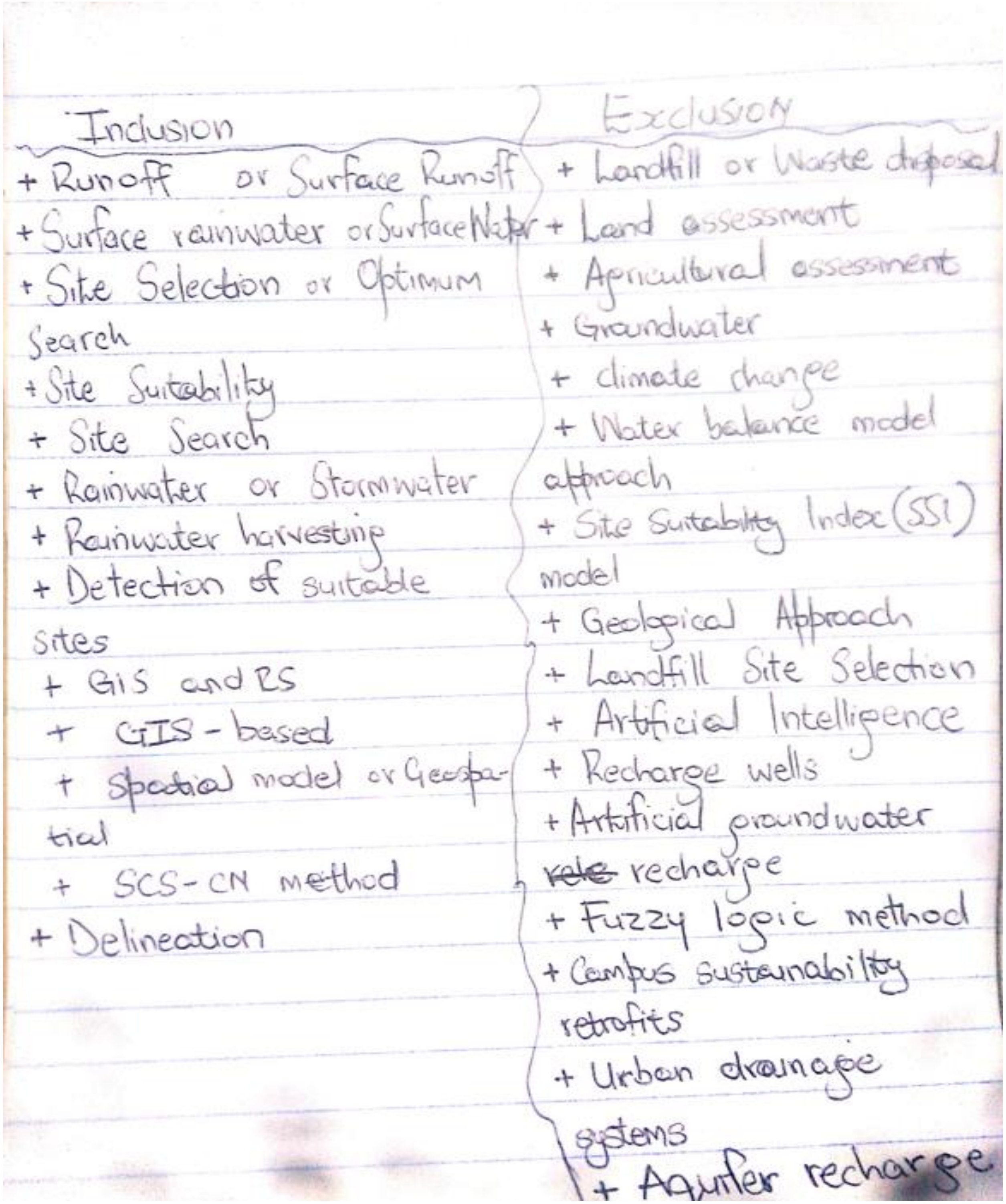
			incline, water availability, land utilization, and land coverage. These parameters were obtained from remote sensing data and subsequently examined. The research employed geospatial technology and remote sensing to evaluate the influence of water retention structures on the surrounding plant life. It was observed that the vegetation cover experienced an increase subsequent to the implementation of water conservation measures. Factors such as soil texture, incline, stream order, and curve number were taken into consideration during the AHP procedure. The layers were allocated weights based on pairwise comparison, and overlay analysis was performed to generate the ultimate site suitability map. Additionally, the investigation examined alterations in land utilization and land coverage both prior to and following the implementation of water conservation measures. The research locale boasts a fourth-order stream, and appropriate locations for check dams were chosen up to second- and third-order streams in accordance with the guidelines set forth by the Integrated Mission for Sustainable Development (IMSD).
Harish Chand Prasad, Parul Bhalla and Sarvesh Palria	2014	Site Suitability Analysis of Water Harvesting Structures Using Remote Sensing and GIS – A Case Study of Pisangan Watershed, Ajmer District, Rajasthan	This study aims to identify suitable zones for water harvesting structures in the Pisangan watershed of Ajmer district, Rajasthan, using a Geographic Information System (GIS) and Multi Criteria Evaluation (MSE). The study utilizes different layers such as soil texture, slope, rainfall data, land use/cover, geomorphology, lithology, lineaments, and drainage network for multi-criteria evaluation. The soil conservation service model was used to estimate the runoff depth in the study area Analytical Hierarchy Processes (AHP) are used to find suitable water harvesting structures based on rainfall. This study produces a suitability map to aid in the selection of water harvesting structures such as percolation tanks, storage tanks, check dams, and stop dams. The study also suggests sites for water structures in a planned manner to promote conservation and better utilization of water. This study adopts an equal weightage approach for relative importance in

			GIS analysis. Geomorphological units in the study area include denudation hills, structural hills, pediments, and pediplains. Lineaments are defined as linear features on the surface that differ from adjacent features and reflect subsurface phenomena.
Sayl, Muhammad and El-Shafie	2017	Robust approach for optimal positioning and ranking potential rainwater harvesting structure (RWH): a case study of Iraq	This study presents a robust approach for the determination of the optimal location for rainwater harvesting (RWH) structures in dry regions utilizing geographical information systems (GIS) and remote sensing (RS) in conjunction with multi-criteria decision techniques. The approach involves the derivation of thematic maps such as vegetation coverage, soil classification, slope, land utilization, and digital elevation. The RWH sites are prioritized based on four key indices: evaporation, cost-benefit analysis, sedimentation, and hydrological assessment. Sensitivity analysis demonstrates that the proposed methodology encompasses all relevant indices that influence the ranking process, rendering it suitable for the selection of RWH sites in arid regions. The study also underscores the significance of land utilization patterns, vegetation indices, and hydrological assessments in the estimation of runoff and the identification of suitable RWH sites.
Saxena, Jat and Kumar	2018	APPLICATION OF GIS AND MCE TECHNIQUES FOR OPTIMUM SITE SELECTION FOR WATER HARVESTING STRUCTURES	This study focuses on the application of GIS (Geographic Information System) and multi-criteria evaluation (MCE) techniques for optimum site selection for water harvesting structures. Water resource management at a watershed scale requires both water supply and demand management, including water conservation through rainwater harvesting, groundwater recharge, and recycling. This study uses consistency index (CI) and consistency ratio (CR) to assess the efficiency and sustainability of water resources in rural areas. Rainfall data from a span of 16 years (2000-2016) is considered for the analysis. Toposheets with a scale of 1:25000 and the SRTM Digital Elevation Model (DEM) with a resolution of 30 m were used as data sources. The objective of this study

			was to make rural areas water sustainable and promote efficient use of available water resources.
Singh et. al	2018	Rainfall Probability Distribution Analysis in Selected Lateral Command Area of Upper Krishna Project (Karnataka), India	This study focuses on the application of GIS (Geographic Information System) and multi-criteria evaluation (MCE) techniques for optimum site selection for water harvesting structures. Water resource management at a watershed scale requires both water supply and demand management, including water conservation through rainwater harvesting, groundwater recharge, and recycling. This study uses consistency index (CI) and consistency ratio (CR) to assess the efficiency and sustainability of water resources in rural areas. Rainfall data from a span of 16 years (2000-2016) is considered for the analysis. Toposheets with a scale of 1:25000 and the SRTM Digital Elevation Model (DEM) with a resolution of 30 m were used as data sources. The objective of this study was to make rural areas water sustainable and promote efficient use of available water resources.
Shalamzari et al.	2019	Runoff Harvesting Site Suitability Analysis for Wildlife in Sub-Desert Regions	This study focuses on site suitability analysis for runoff harvesting in sub-desert regions, specifically in the Kavir National Park of Iran.The researchers used a combination of Geographic Information System (GIS) and multi-criteria techniques to estimate runoff coefficient and volume based on climatic, topographic, and soil parameters. The main challenges addressed in this research include the large area of the park, the need for quick and reliable site evaluation, and the lack of discharge volume data from water streams. The study evaluated site suitability for two important wildlife species in the park, Gazella dorcas and Ovis orientalis, which are food sources for the endangered Persian Cheetah. The Analytic Hierarchical Process (AHP) and fuzzy membership functions were used to assign weights and integrate thematic layers for the final suitability map. The results showed that 38% of the area is suitable for runoff harvesting, whereas 62% has a very low potential. Based on the population of wildlife species and their water requirements, only 4% of the total water demand can be collected from all runoff harvesting structures.

Sayl , Muhammad and El-Shafie	2019	Identification of potential sites for runoff water harvesting	This study focused on the identification of potential sites for runoff water harvesting (RWH) in areas suffering from water scarcity, such as the western desert of Iraq. The researchers employed a combination of watershed modeling, geographic information systems (GIS), and remote sensing techniques to generate thematic maps pertaining to various factors such as the volume of floods, the area and length of basins, the maximum distance of flow, the density of drainage frequency, the density of lineament frequency, the slope of basins, and the order of streams. These maps were subsequently utilized to rank and categorize likely sites based on an equal weight and statistical weight approach, resulting in the classification of selected sites into four distinct categories: very high, high, moderate, and low potential for runoff water harvesting. The proposed methodology yields considerable benefits in the identification of potential sites for runoff water harvesting and can significantly contribute to the enhancement of water resource management and the promotion of sustainable development in arid regions.

Appendix B: Inclusion and exclusion criteria list



Inclusion

+ Runoff or Surface Runoff
+ Surface rainwater or Surface Water
+ Site Selection or Optimum Search
+ Site Suitability
+ Site Search
+ Rainwater or Stormwater
+ Rainwater harvesting
+ Detection of suitable sites
+ GIS and RS
+ GIS - based
+ Spatial model or Geospatial
+ SCS-CN method
+ Delineation

Exclusion

+ Landfill or Waste disposal
+ Land assessment
+ Agricultural assessment
+ Groundwater
+ climate change
+ Water balance model approach
+ Site Suitability Index (SSI) model
+ Geological Approach
+ Landfill Site Selection
+ Artificial Intelligence
+ Recharge wells
+ Artificial groundwater ~~rele~~ recharge
+ Fuzzy logic method
+ Campus sustainability retrofits
+ Urban drainage systems
+ Aquifer recharge