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Hydrological information for Dam site selection by Integrating Geographic Information System (GIS) and Analytical Hierarchical Process (AHP)

BY

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DECLARATION

I, Fausta Mbura Njiru, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

.....
Name of student

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Sign

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Date

This project has been submitted for examination with our approval as university supervisor(s).

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Name of supervisor

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Sign

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Date

DEDICATION

This project is dedicated to my loving husband David; and to our three children Grace, Gladwell and Gladwin. They accorded me great love, support, encouragement and co-operation during this study.

ACKNOWLEDGEMENT

Above all, I would like to thank the Almighty God for granting me the opportunity and the ability to progress effectively. With the faith I have in you, you have provided sufficient power to strengthen me in pursuing my passions and dreams.

Special thanks to the chairman, Geomaps Africa, Hon. L. Kivuti for granting me an opportunity to further my studies as I continue to be a dedicated employee of Geomaps Africa. He has offered me a favourable environment throughout my study period. I sincerely appreciate.

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ABSTRACT

Over time, dams have provided substantial amount of benefits to mankind for they constitute an effective and sensible method if constructed on a suitable site, for sustainable growth and managing of groundwater resources.

It's a tradition that dam selection in Kenya is done manually whereby engineers only use contour and topographic maps, without taking into consideration some watershed properties and characteristics which are mostly discovered through automated techniques and procedures of GIS analysis on a Digital Terrain Model (DTM). This study aims to investigate and demonstrate Hydrological information for dam site selection by integrating Geographic Information System (GIS) with Multi-Criteria Decision Analysis (MCDA).

Hydrological layers of water accumulation through catchments and basins were generated from the DEM using Arc Hydro tools. These tools are fully dependent on ArcGIS and are used to calculate, delineate and derive hydrologic thematic layers to describe various characteristics of the catchment area. The main software used for this study was ArcGIS. Global Mapper was also used for manipulating the Digital Elevation Model (DEM).

Seven criteria were considered for this study which included topographic factors (slope), geological factors, soil type, catchment size, land cover, proximity to river and proximity to roads. By using Analytic Hierarchy Process (AHP) Pair-wise comparisons, each criterion was assigned a weight with slope being considered as the most important factor. Weighted overlay analysis was performed in ArcGIS and determination of suitable dam site was done from the summation of weight of each contributing factor. A final suitability map was generated which indicated that 10% of the total study area showed that the area was highly suitable, 14% was suitable, 45% was moderately suitable, 23% was low suitable, while 8% was not suitable for dam construction. The highly suitable classification had four possible sites of 2.8, 3.5, 8.0 and 37.8 km². The larger site was the most recommended. The formation of contours within this site is not very wide and therefore allows for various dam options with considerable weir length.

From the results, it is evident that integrating GIS with AHP Multi-Criteria Decision Analysis has been successful in arriving at a suitable locations for a dam site selection. Therefore both are proficient and supportive decision-making tools.

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ACRONYMS

GIS	Geographic Information System
DEM	Digital Elevation Model
GDEM	Global Digital Elevation Model
EGM96	Earth Gravitation Model 1996
DTM	Digital Terrain Model
NASA	National Aeronautics and Space Administration
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
LiDAR	Light Detection And Ranging
SRTM	Shuttle Radar Topography Mission
ILRI	International Livestock Research Institute
TWSB	Tana Water Service Board
NIB	National Irrigation Board
MCDA	Multi-Criteria Decision Analysis
AHP	Analytic Hierarchy Process
PCM	Pair-wise Comparison Matrices
JPEG	Joint Photographic Experts Group
WGS 84	World Geodetic System 1984
CR	Consistency Ratio
CI	Consistency Index

1. INTRODUCTION

1.1. Background

Mbeere North Sub-County is one of the semi-arid regions of Embu County. However, low and unpredictable amount of rainfall remains a major obstacle in the Sub-County, making it one of the regions in Kenya where food insecurity and water scarcity is on the rise due to crop failures and droughts. Most rivers in Mbeere North are seasonal apart from River Tana, Thuci and Ena, making the whole area dry most of the time. This situation therefore necessitate construction of a dam as a possible solution to boost agriculture through irrigation and at the same time provide water for domestic use to Mbeere North residents.

A suitable dam site location involves sensible decision making process comprising of various considerations of factors and criteria (Boateng, Stemn, & Sibil, 2016). At the same time dam construction in their various stages, require up to date and complete information about terrain characteristics (Thanoon & Ahmed, 2013). It is evident that the factors considered for dam site selection and also the physical appearances of the area are fundamentally geospatial in nature. This necessitates the use of GIS tools, concepts, and technology in managing this data (Boateng, Stemn, & Sibil, 2016).

In this study, the use of GIS and Analytic Hierarchical Process (AHP), a Multi-Criteria Decision Analysis (MCDA) techniques has been preferred as a possible way of making optimal decisions in selecting a suitable site for dam construction. AHP approach is based on human intellectual analysis for complex issues and therefore one of the most suitable methods for spatial and non-spatial Multi-Criteria analysis and evaluation (Kheirkhah, Sharifi, & Azizi, No Date). The major considerations involves the GIS capabilities to acquire, store, retrieve, manipulate and analyze data while the MCDA capabilities combines the geographic data with decision maker's preferences into alternative judgments of one-dimensional values (Munyao, 2010).

Geospatial data from Remote Sensing sources and GIS databases are suitable for addressing factors on the best sites for dam selection (Manugula, Veeranna, & Patel, 2015). Analysis and quantification of different elements of hydrological processes within an area of study must be done in order to tackle water management issues (Ghoraba, 2015). With support from GIS, DEM plays a significant role in hydrological modeling (Li, 2014). Through integration of water resource

management, ideas for good governance are gathered through combination of our understanding of water from various fields, therefore the principle measure of any empowering environment is providing knowledge, facts, realities, evidences and information (Mcdonnell, 2008). For a successive dam site selection, information such as DEM, land cover and drainage pattern for the catchment area plays an important role. Of most important is the slope analysis for the data extracted from DEM, which is very useful for hydrological studies during dam site selection (Manugula, Veeranna, & Patel, 2015).

Extensive use of computers in hydrological analysis has provided principal source of data for decision making by many hydrologic engineers (Bruce & Alren, 1993). All together GIS technology plays a powerful role in all dimensions of drainage basin management, ranging from evaluating drainage basin characteristics all the way to modeling of human activities impacts (Tim & Mallavaram, 2003). Initial steps in performing any form of hydrologic modeling comprises of delineation of streams and drainage basins, followed by determining crucial watershed properties which includes slope, length of flow, density of stream network among others. Customarily, this was done and is currently being done manually with the help of information from topographic and contour maps. Today, with the availability of DEM powered by GIS tools, various automated procedures are used to extract watershed properties (Merwade, 2012).

Assessing and managing water resources are essentially geographical activities which require handling of spatial data of different formats. Integration of various GIS and simulation models is essential to improve knowledge in these areas. As described by Djokic (2012), water resources concerns occurs when water is inadequate and leads to droughts, excessive and causes flooding, of poor quality, in a wrong place and at the wrong time among others. The role of GIS in water resource management is to provide core GIS tools for surface water analysis in order to determine these and many other issues.

1.2. Problem Statement

Constructing a dam for Mbeere North residents is an important solution to curbing water problem for both domestic and irrigation purposes, which mostly occur due to poor rainfall and prolonged dry seasons which leads to droughts. For this effort to be achieved successfully, it should be primarily centered on finding a suitable site for the dam. The main problem is the use of an effective, efficient and accurate method of dam site selection that will provide accurate terrain

investigation and provide adequate information on the selected site for proper planning and design. This will be solved through application of capabilities of GIS technologies in spatial analytical and hydrological modeling, combined with Multi-Criteria Decision Analysis.

1.3. Objectives

1.3.1. Main Objective

To investigate and demonstrate the integration of Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) in the location of a good dam site.

1.3.2. Specific objectives

1. To determine a selection criteria for dam site selection and establish respective weights
2. To perform overlay analysis by applying the resulting weights to the contributing factors and determine suitable dam sites from the summation of weight of each contributing factor
3. To evaluate the results and draw appropriate conclusions and recommendations

1.4. Justification of the Study

It is critical to consider watershed properties and ground characteristics of the area of study before dam site selection. These properties are mostly discovered through automated techniques and procedures of GIS analysis on a Digital Elevation Model (DEM), which are unlikely to be discovered through manual methods used by most engineers, where they only use contour and topographic maps for dam site selection.

The intent of this study is to provide a comprehensive watershed analysis and ground characteristics for the study area by integrating Geographic Information System and Multi-Criteria Decision Analysis to identify potential sites for a dam construction. While GIS will provide approaches and procedures for processing the geographic data to acquire relevant information for decision making, integration with MCDA will enhance GIS capabilities by providing a methodology for assisting decision makers in the process of expounding evaluation criteria and defining values that are appropriate to the decision situation.

1.5. Scope

Ground investigation is crucial in order to reveal properties and other physical characteristics for any engineering work. The scope of the work entails undertaking hydrological analysis of the study area, analyzing factors that influence dam site selection in GIS and apply AHP Pair-wise

comparison, a Multi-Criteria Decision Analysis, to come up with suitable locations. It includes a detailed report highlighting work execution, data collection, data processing, data analysis and all relevant information on each tasks undertaken.

The study area covers approximately 514 km² stretch along Ena River which intersects major segments of three Wards in Mbeere North Sub-County; Evurore, Nthawa and Muminji.. Ena River originates from Mt. Kenya and passes through the steep slopes of Runyenjes constituency as it crosses Mbeere north to drain its water to River Tana (the largest river in Mbeere North). This will be the main source of water for the proposed Dam. Figure 1 and 2 below shows the overview and the detailed view of the study area respectively.

The geology of the study area is dominated by granitoid gneisses and magmatic gneisses rocks (BEAR, 1952). The Permeability of gneisses and granite rock is originally very low and serves as a good reservoir for ground water (Marinos, Koukis, Tsiambaos, & Stournaras, 1997). In the aspect of climate, Mbeere North Sub-County is considered one of the semi-arid areas in Embu County. Rainfall in Embu County occurs in two main seasons; from March to May and again from October to December and varies with altitude, ranging from 600 to 1,800 mm (MoALF, 2016). Upper areas bordering Mt. Kenya (Runyenjes and Manyatta Sub-Counties) receives more rainfall than the lower parts of Mbeere North and Mbeere South Sub-Counties.

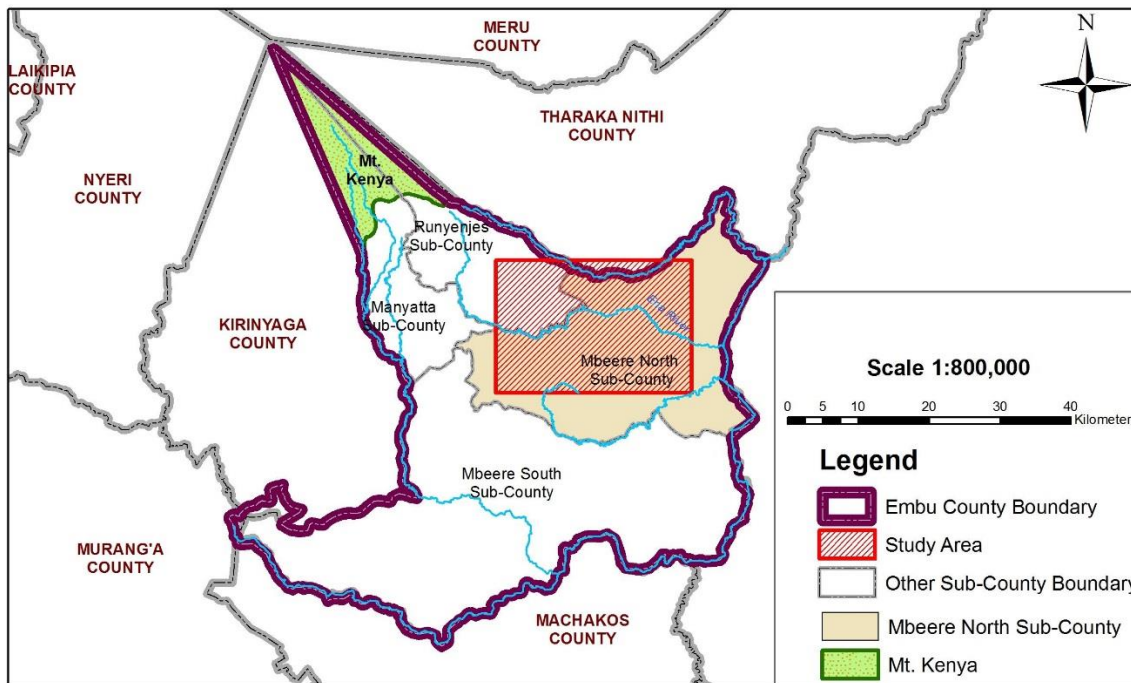


Figure 1: Study area (Overview)

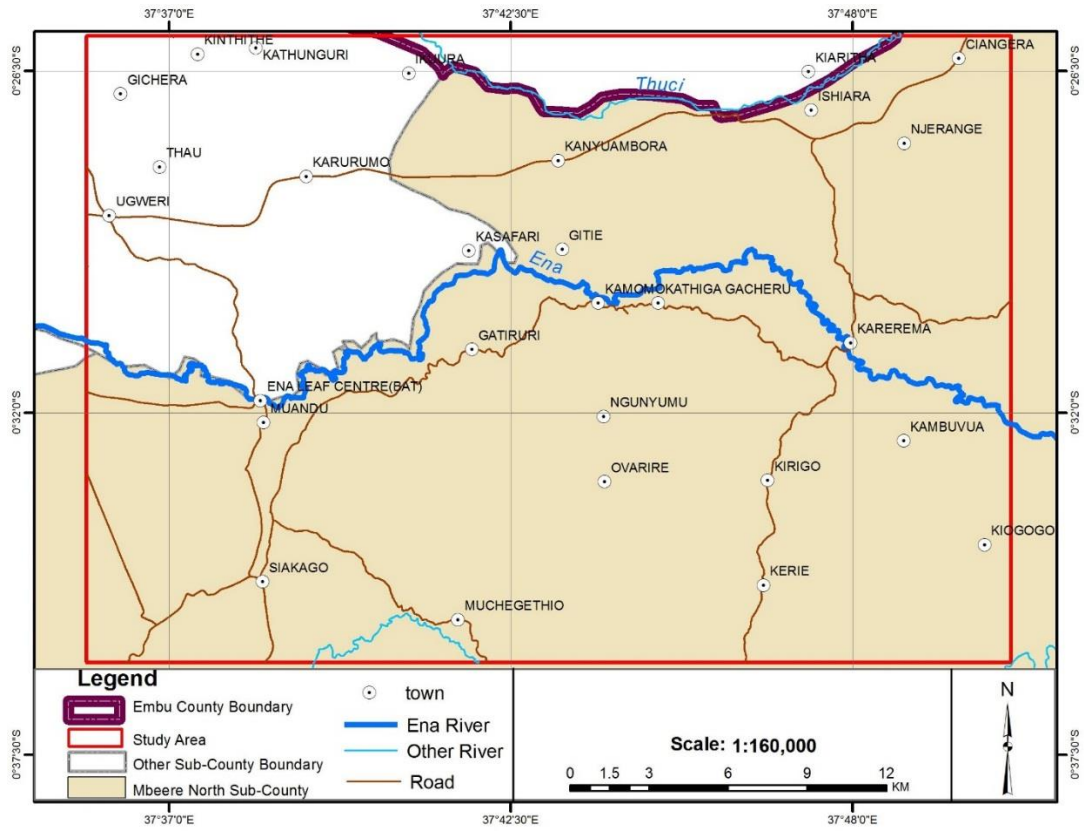


Figure 2: Study Area (Detailed)

2. LITERATURE REVIEW

2.1. Existing Situation

The principal source of food in Embu County greatly depends on the agricultural sector. In spite of this, an estimated 20% of households are considered food insecure mostly in the hot and dry semi-arid zones of Mbeere North and South Sub-Counties (MoALF, 2016). According to a report by Jeremiah, Obondo & CSG (2013), on Mbeere food security assessment, the situation is deteriorating due to low amount of rains received, which are also poorly distributed. Figure 3 below was captured in August 2016 and illustrates the situation in most parts of Mbeere North.



Figure 3: Existing Situation in Some Parts Mbeere North

As a remedy to the situation, constructing a dam for Mbeere North Residents is an essential solution for boosting food security in the Sub-County through irrigation, as well as providing them with water for domestic use. The seven folks dams (Masinga, Kamburu, Gitaru, Kindaruma and

Kiambere), located in both Mbeere North and Mbeere South were initially built for hydro-electric power generation and therefore cannot be used by residents for farming activities.

2.2. Locating the best Dam Site

The success of constructing a dam is primarily centered on locating the best site for the dam. As revealed by Dorfeshan, Heidarnejad & Bo (2014), selecting a suitable site calls for thorough consideration of several factors which includes the physical characteristics of the site and economic factors among others. Abushandi & Alatawi (2015), describes terrain surface, land cover and catchment delineations as crucial for selecting a suitable dam site. In particular, slope data and the physical characteristics of the area are the most influential factors as they determines the inundation behaviour of the area in study. As seen by Beavers Advisory Committee for England (2017), slope constitutes a major control on whether dam construction is essential to creating an appropriate habitat and at the same time, it dictates the river energy and velocity, hence closely connected with flood plain extent and bank materials.

As described by Abushandi & Alatawi (2015), prior to planning to construct an earth dam, ground examination is significant particularly for site selection and deliberations of earthworks. On the other hand, remote sensing and GIS techniques application in hydrology is currently one of the utmost effective methodologies as justified by Ghazal & Salman (2015), in their research on determining the optimum site of small dams using remote sensing techniques and GIS. Today, remote sensing provides valuable datasets for examining hydrological variables and morphological changes for small, medium and large regions at different scales both spatial and temporal (Abushandi & Alatawi, 2015).

Generation and analysis of DEM facilitates automatic accomplishment of tasks such as planning, designing, constructing and monitoring of reservoirs, which serves as a substitute to using topographic maps as seen by Ouma (2016).

Earlier investigations as described by Thanoon & Ahmed (2013), demonstrated that application of GIS significantly enhances the value of spatial analysis in land use administration as well as automatic delineation of drainage systems and fundamental catchments from DEMs. Based on these investigations, it was concluded that automating the method for obtaining the spatial representation of drainage systems and fundamental catchments is important since these entities are terrain objects which connects different aggregation level of hydrographic information.

2.3. Hydrological Modelling for Dam site Selection

As described by Hosseinzadeh (2011), drainage network extraction and watershed delineation are algorithms which are developed from a DEM to derive basic topographic characteristics.

For years, DEM has been commonly used for extraction of drainage patterns and other properties of a drainage basin required for hydrological modeling. Hanuphab, Suwanprasit, & Srichai (2012), cites poor quality of DEM as one of the reasons why numerous hydrologic studies have failed to deliver reliable results. For this reason, there is a need to use high quality DEM for hydrological model studies in order to present a continuously varying topographic surface of the Earth. In his investigation on the role of resolution and accuracy of a DEM on flood mapping, Saksena (2014), noted that a DEM of higher resolution provides more cells per unit area and therefore represents the landscape more truthfully as compared to a DEM of coarser resolution.

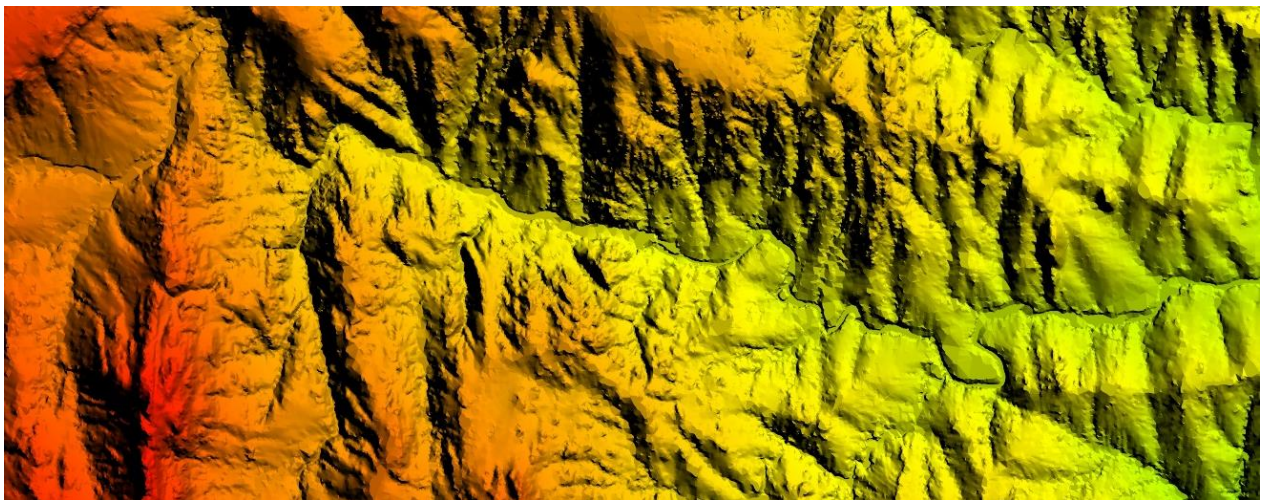


Figure 4: Sample LiDAR Digital Elevation Model (Source: Geomaps Africa)

Investigations by Walczak et al (2016) concluded that LiDAR generated DEMs, (See figure 4) are much more accurate for deriving terrain models. DEM accuracy as well as DEM resolution, affects the quality of output hydrological features, resulting in measurable differences between high resolution and coarse resolution DEM-derived layers (Vaze & Teng, 2007) as shown in figure 5.

From my work experience in Geomaps Africa (a progressive and well established consultancy, providing professional and comprehensive service in all Geomatics and Geo-Information solutions), the company has embraced LiDAR Technology for the acquisition of high density LiDAR products, where the accuracy of the height ranges between 3-20 cm and the Point density

is between 3-4 points per m² resulting in a high resolution DEM suitable for performing various analysis for GIS and Engineering projects among others.

Considering that LiDAR data was not available for this study area, a 30m resolution ASTER GDEM was used. Both ASTER and SRTM offers a 30m resolution DEM which is fairly reasonable for a medium scale study area for a dam site selection. However ASTER GDEM was more preferred for this study. According to NASA (2017), some tiles in SRTM contains voids and in most cases, these voids are filled with ASTER DEM elevation data, the reason which informed the use of ASTER GDEM.

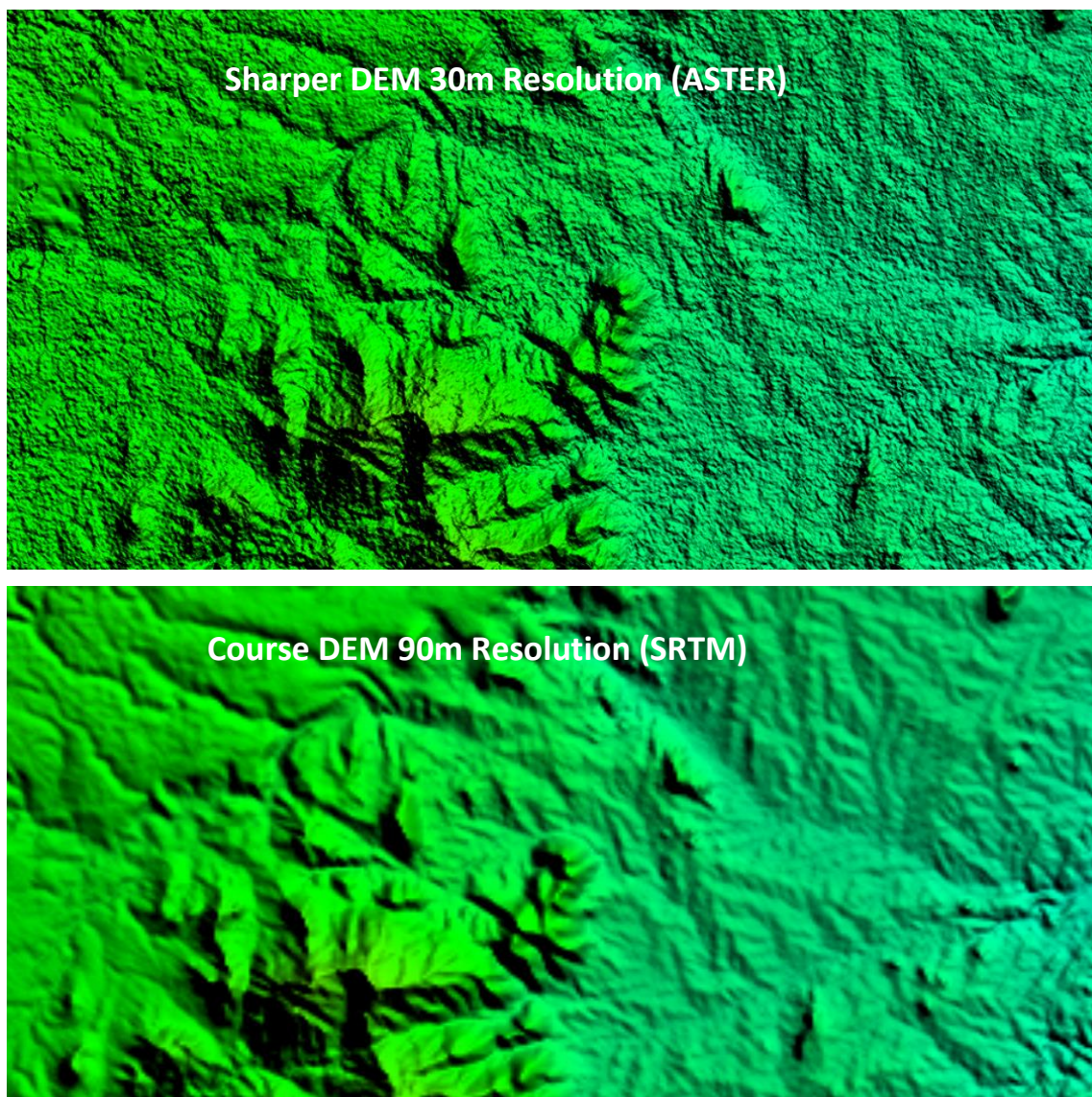


Figure 5: Different DEM resolution depicts different Ground Characteristics

For terrain processing, Arc Hydro tools are very crucial. As provided by Esri Water Resources Team (2011), Arc Hydro, an ArcGIS-based extension is designed to support and offer basic database design and set of tools to aide in the analyses usually performed in the water resources applications. It provides preliminary functionalities that can then be extended by adding structures and functions of a database which are required by a specific task or application. Final results of DEM processing with Arc Hydro are similar to the ones found in ESRI (2011), Arc Hydro Tools Tutorial, in which several data sets that collectively describes a catchment's drainage patterns are derived .These datasets includes flow direction, flow accumulation, watersheds and stream networks among others. These functionalities forms the primary layers which are then integrated with other contributing factors in a GIS environment to derive suitable dam sites.

2.4. Integration of AHP and GIS

According to Srdjevic et al (2010), scientific literature argues that it's not satisfactory enough to use only GIS and spatial data to evaluate land suitability for complex problems such as dam site selection. GIS alone doesn't have capabilities to include all decision elements related to land suitability assessment, even though it's powerful in spatial analysis. Therefore it should be integrated with additional evaluation and assessment tools, specifically the MCDA methods combining GIS and AHP. As described by Vahidnia et al (2008), AHP is just one of the approaches of Multi-Criteria Decision Making for problems of different nature but does not depend on GIS. According to Saaty (2008), AHP has been applied in various context, ranging from a problem of a simple selection of a school to challenging problems of designing alternatives for a country's future outcomes. This approach of AHP will be utilized in this study by combining GIS and AHP, which is a popular MCDA tool to evaluate suitability for a good dam site.

According to Gayatri & Chetan (2013), five MCDA methods that are regularly used includes Simple Additive Method, Weighted Product Method, Analytical Hierarchy Process, Techniques for Order Preference by Similarity to Identical Solution and Compromise ranking method. Of these methods, Analytical Hierarchy Process is mostly preferred due its functionality and characteristics which make it a suitable approach, as described by Triantaphyllou (2000), and these characteristics includes the capability to tackle decision situations which involves subjective judgments, several decision makers and most importantly, the capability to offer consistency measures of preference.

To accomplish this, a layer is dedicated for each factor in which weighting is done in AHP and overlay done in ArcGIS. Suitable dam site is then selected from the results of the overlay. This method is similar to that used by Shamsai & Ahmadi (2009), whereby it incorporates all criteria for selecting and prioritizing sites into the priority list and can identify areas of critical ecological importance that may have gone unnoticed by the conventional decision approaches. According to Thomas Saaty (2008), the development of AHP was to optimize decision making process after someone has encountered a mixture of qualitative and quantitative factors as well as conflicting factors that are taken into consideration. It has been an effective way of making complex and sometimes irremediable decisions. Dorfeshan, Heidarnejad, & Bo (2014), describes AHP as a technique which is based on three principles of analysis, binary comparison, summarizing, prioritizing and selection among other alternatives.

As described by Vahidniaa, Alesheikhb, Alimohammadic & Bassiri (2008), GIS-based multi-criteria analysis has been used in a wide-ranging decision and management circumstances like hydrology and water resources among others. According to Al-shabeeb (2016), the AHP is applied within GIS to define the weights for the selected criteria, and has the ability to deal with inconsistent judgements. Lee, Chen & Chang (2008), defines six essential AHP procedures:

- Problem definition by clearly stating the objectives and the outcomes
- Decomposing the problem into a hierarchical structure by the use of decision elements such as criteria, detailed criteria and alternatives
- Employing pair-wise comparison
- Estimating the relative weights of decision elements
- Checking the consistency property of matrices to ensure consistency of decision makers' judgments
- Obtaining an overall rating for the alternatives

As seen by Al-shabeeb (2016), the AHP method is centered upon the construction of a sequence of Pair-wise Comparison Matrices (PCMs), which all the criteria are compared to one another. For PCM elements, Saaty (2008) suggested a scale of numbers 1 to 9. These numbers Indicates the number of times more or less important one element is above the other. Saaty (2008), illustrated these scales as in table 1.

Table 1: Intensity of Importance Scale

Intensity of Importance	Definition
1	Equal Importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very, very strong
9	Extreme importance
Reciprocals of the above numbers(e.g. 1/9)	If first factor has one of the above non-zero numbers assigned to it when compared with the second factor, then the second factor is assigned the reciprocal of the first e.g. if slope compared to land cover has a factor of 9, then the land cover will have a factor of 1/9.

Calculation of weight estimate is then done which is used for derivation of a consistency ratio (CR) of the pair-wise comparisons. As described by Al-shabeeb (2016), PCM comprises of a consistency check in which judgment errors are identified and a consistency ratio is calculated. If CR is greater than 0.10, then some pair-wise values requires some review & the procedure is repeated until the preferred value of CR of less than 0.10 is gotten.

Integration of GIS and AHP has been widely applied in land suitability and the results are similar to those that were founded by Srdjevic et al (2010) whereby they Combined GIS and AHP process for evaluating land suitability for irrigation. Dai (2016), terms integration of AHP with GIS as an efficient and user friendly method of solving complex problems, due to its combination of decision making support method and tools which have powerful capabilities of bulk data computation, visualization and mapping.

2.5. Similar Efforts

Effort to curb water shortage in Embu County, and three other neighbouring counties; Parts of Kirinyaga, Tharaka Nithi and Kitui, are underway as the Government is set to build four Mega Dams in Embu County. This was reported in the Daily Nation 10th march 2016. The four, proposed dams includes Thuci, Kamumu, Thambana and Rupingazi. The dams upon completion are expected to provide water for domestic use and irrigation to the four counties. Information gathered from a representative of Tana Water Services Board, Eng. J. Wagereka indicated that three dams (Thambana, Rupingazi and Kamumu) will be handled by Tana Water Services Board while Thuci dam will be handled by National Irrigation Board (NIB).

Report by Tana Water Services Board on the Development of three multipurpose dams in Embu County indicated that initial identification of these three dams was done by Tana Water Services Board in conjunction with the leaders of Embu County (See Appendix A1 Source: Tana Water Services Board). Location co-ordinates of these proposed dams are indicated in the report. These co-ordinates were plotted and overlaid in a map of Embu County and their positions are as shown in figure 6 below. An interview with one of Tana Water Service Board (TWSB) Engineer, Mr. James Wagereka confirmed that the leaders usually propose a dam to serve a certain area that has shortages then TWSB comes in and use topographic maps, DEMs and site visits to identify the most feasible sites. One of the proposed dams lies within my study area and therefore will be useful in discussions on whether their choice of dam site was worth.

From the ongoing efforts to construct Embu mega dams, research and records for determining the locations of these dams is very limited and shows no efforts whatsoever to determine topographic characteristics of the area through hydrological analysis using GIS. Ouma (2016), described the generation and analysis of DEM as a substitute to using topographic maps while planning, designing, constructing and monitoring of reservoirs.

As the report indicates, preliminary design has been done and the Ministry of Water and Irrigation has already directed Tana Water Services Board to proceed with sourcing for funds for Kamumu, Thambana and Rupingazi Multipurpose. Thanoon & Ahmed (2013) explains that dam site selection require up to date and complete information about terrain characteristics which was not the case with the selection of these dams. Vaze & Teng (2007), describes topography as a significant ground characteristic that affects major aspects of water balance within a drainage

basin, and therefore should be put into consideration before dam site selection. Boateng, Stemn, & Sibil (2016), recommends the use of GIS tools, concepts, and technology, an approach which has been used in this study.

Many other efforts including construction of earth dams are alternatives proposed by the Embu County Government. (Kenya News Agency, 2017), but so far no efforts have been put to apply GIS and AHP methodology for locating suitable sites for constructing these proposed dams.

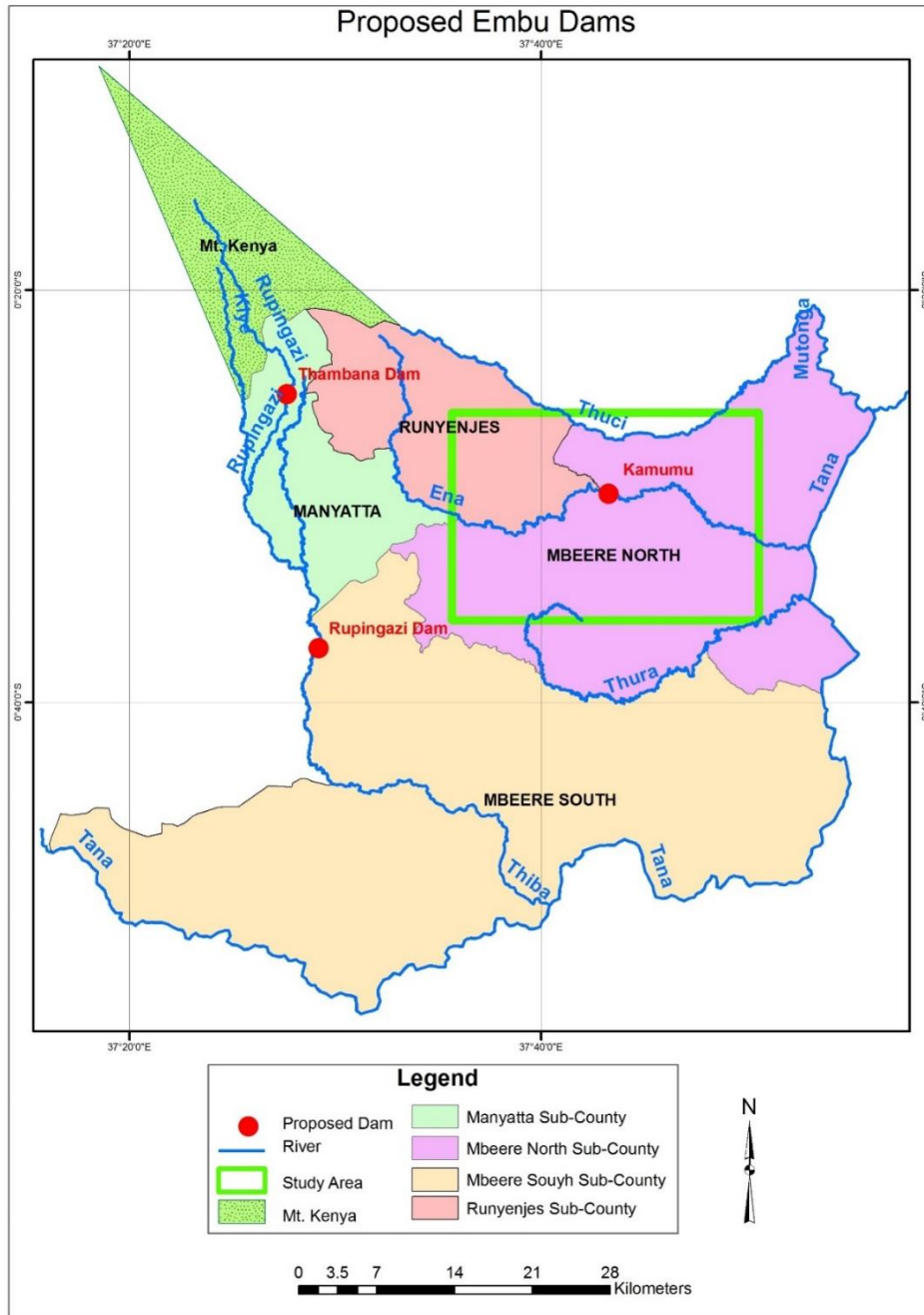


Figure 6: Proposed Embu Dams

3. MATERIALS AND METHODS

3.1. Materials

This study involved use of various datasets. These datasets included both vector and raster data of different scales and resolutions. See table 3 for the list of datasets acquired for this study. Data was obtained from different sources which included downloads from websites such as International Livestock Research Institute (ILRI) and National Aeronautics and Space Administration (NASA); Institutions such as Geomaps Africa, Regional Centre for Mapping of Resources for Development (RCMRD) and Kenya Department of Mines.

3.2. Method

The study used MCDA integrated in a GIS environment to determine suitable sites for dam construction. The methodology was implemented in 4 phases. Phase one involved planning and other necessary logistics prior to project implementation which included determination of criteria that affect dam site selection in order to govern the required data. In Phase two all necessary data was collected governed by the number of criteria determined. Appropriate attributes for each criterion were established in phase three, and influence of each criterion was also determined using AHP. In the final Phase the weighted criteria was overlaid by performing a weighted overlay analysis to produce a suitability map combining all criteria.

Throughout the project implementation stages, the following approach was adopted:

- Data collected from various sources was integrated into a common UTM projection system based on WGS84
- Both vector and raster layers were generated according to the required accuracy such that the pixel size of the rasters generated was not more than 30m. During vectorization, proper zoom ratio was done to ensure accurate outputs.
- This project has been carried out in consultation with the relevant experts in the fields of civil engineering, lithology, hydrology, groundwater and Geographic Information System among others. Consultation was mostly on civil engineering, and lithology issues.
- The work has been undertaken to the specifications contained in this report and improved on the accuracy and quality of outputs by using the technical skills experienced during this course and at my career field.

3.3. Determination of criteria

Preceding the initiation of every GIS project, preliminary data is required in order to provide information which leads to attainment of the project goal; finding a suitable site for a dam construction (Dorfeshan, Heidarnejad , & Bo, 2014). The data required was governed by a number of criteria that affect dam site selection. Of most important is to select a site with impermeable dam foundation and without leakage, while it provides ease of construction as well as a guaranteed firm structure (Prof. Nancy Mati, 2017).

Different criteria were determined for this project. During this process, I received incredible support from Engineer George Murithi (Senior Engineer) and his team in Howard Humphreys who have been involved in the design of several dams both locally, regionally and internationally. Howard Humphreys is among the Eastern Africa’s leading consulting engineering companies in engineering design and construction, water supply and sewerage projects among others. They gave me opinion about the criteria based on their previous work experience on dam site location. Based on their opinion, the criteria considered for this project are shown in Table 2.

Table 2: Selected Criteria

	Element	Way of Influence	Explanation (Experts opinion)
1	Slope (Topography)	Factor	The gentle the slope the better
2	Geology	Factor	Stronger foundations are preferred for dam construction
3	Soil type	Factor	The lower the soil infiltration rate , the better
4	Catchment size	Factor	The bigger the catchment size , the more water it can provide for the dam
5	Land Cover	Factor	Land cover prone to soil erosion are less conducive for dam construction
6	Proximity to River Centerline	Factor	The nearer the dam to the river centerline i.e. $\leq 1000\text{m}$, the better
7	Proximity to roads	Factor	The nearer the dam to the major roads buffer i.e. $\leq 1000\text{m}$, the better

From both the expert's opinion and the existing literature, these criteria are discussed in details as follows:

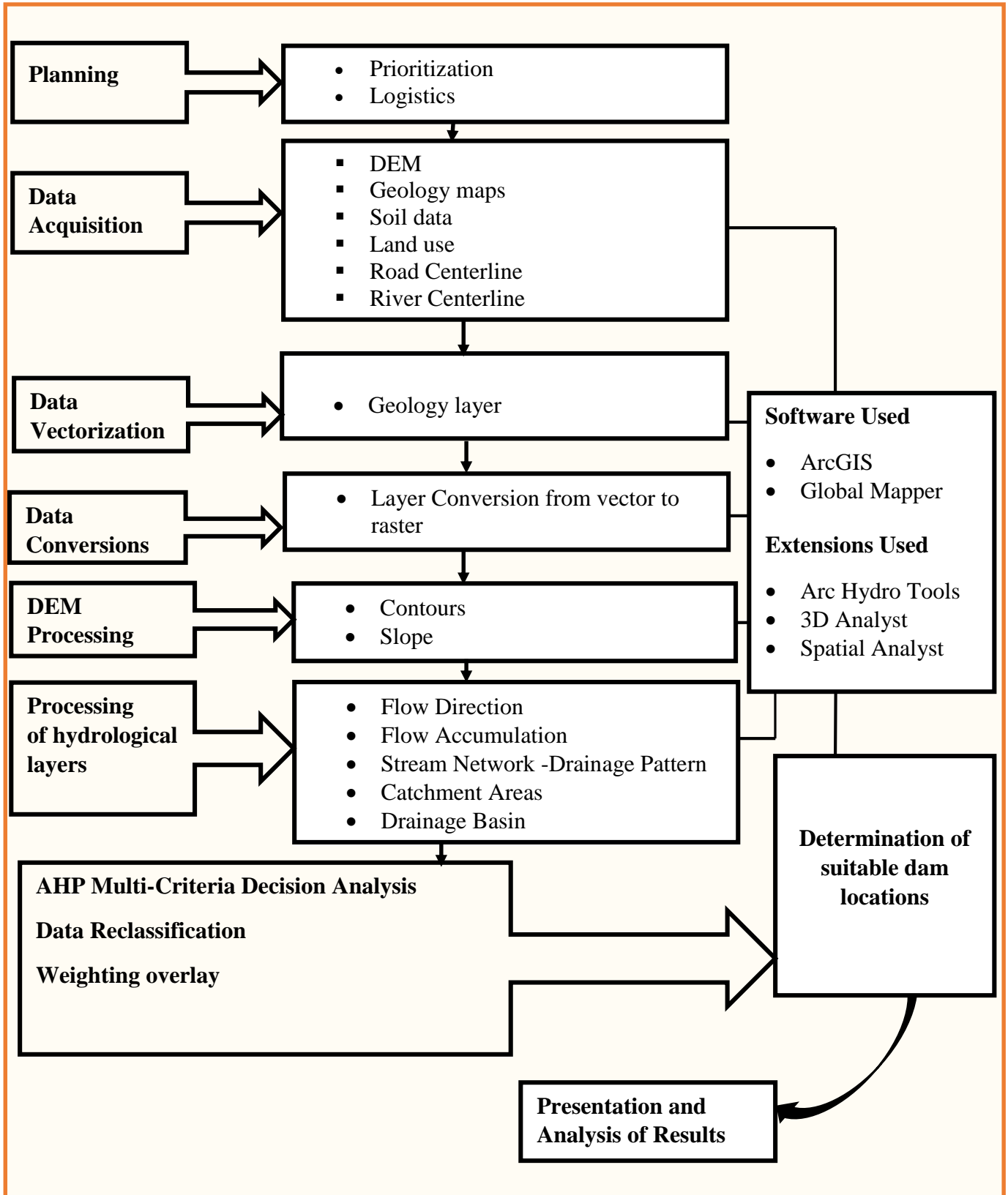
- Topography, as stated by Dorfeshan, Heidarnejad & Bo (2014), is one of the major factors to be considered for the construction of underground dams with an appropriate reservoir. Topography exerts a dominant control on flow routing through upland catchment (Xu, 2002). DEM provides a bare land representation of terrain or surface topography (Lalhmimgliana & Saha, 2016). In particular DEMs are very crucial for topographic characterization as they represent the ground surface, hydrological boundaries and terrain attributes which includes slope and aspect (Manugula, Veeranna, & Patel, 2015). A well-drained, gently sloping site is best as it minimizes construction costs. Slope also influences the safety of dams since large degrees of slope has a higher risk of landslide and gives more pressure on foundations (Dai, 2016).
In addition to terrain characteristics, use of aerial images offer a direct portrayal of the physical scenery of an area at a given time (APDER, 2016). Use of aerial photographs provides a useful assessment of the local topography and hydrological conditions of the area (Stephens, 2010). Information acquired from Aerial imagery in combination with GIS mapping and techniques is utilized for various analysis, strategic planning and evaluation among others (Haseena & Kiran, 2013).
- Geological conditions. Geology foundation within a dam site often recommends the type of dam suitable for that particular site (EMIROGLU, 2008). Geological conditions not only regulate the character of formations, but also directs the available materials for dam construction (Lashkaripour & Ghafoori, 2002). Competent rock foundations have relatively high resistance to erosion, filtration and pressure, which includes igneous rocks such as granite among others (Dai, 2016).
- Land cover. The land cover of an area is a principal concern as it is one the factors which reflects the current use of the land and pattern as well as the importance of its use in relation to the population and its connection with the prevailing development (Ajin, Krishnamurthy, Jayaprakash, & Vinod, 2013). Changes in land use and vegetation usually affect the water cycle and its influence is a function of the density of plant cover and morphology of plant species (Ghoraba, 2015).

- Soil data. Soil type affects the volume of water that the soil can infiltrate. EMIROGLU (2008), has described the foundations of fine-grained soils such as clay, which are water-resistant enough as being recommended for a dam construction. Clay soils and their combinations are appropriate for dam construction (Stephens, 2010).
- Catchment size. A suitable dam site should have a catchment area that is not so small such that the water is not sufficient enough to fill the dam, neither should it be so big such that it may require an expensive spillway (Stephens, 2010). This is guided by the catchment areas or the size of the drainage basin within the area.
- Roads. The dam site should be easily accessible, so that it can be economically connected to the required population (Engineering Articles, 2017).

NB: Fault line is an important factor to consider. However the nearest fault line from the study area was 25 km (Source: Archived data from Geomaps Africa) and therefore was not considered as it was too far to have any effect within the study area.

3.4. Methodology

The methodology used for data collection as well as data analysis is presented in the chart below:



3.5. Planning

The planning process incorporated the prioritization and logistics necessary for the project at commencement. Project tasks were grouped in the observance of time frame, logical sequence of performing the work and the possibility of concurrency of tasks in the interest of saving time. The following were addressed during the planning stage:

Needs Assessment

- Data acquisition needs (where, when will I get the data, will the data be free or at a fee)
- Data formats to be used (Which data formats am I likely to use during the project execution and do I have the necessary tools and equipment for data conversion from one format to another)
- Logistics. How will I be travelling from one point to another during the project execution

Data acquisition

- Hard copy Maps
- DEM
- Digital maps

Equipment required

- A computer installed with ArcGIS and Global Mapper software

The Procedures required and how they will be done

- Data digitization
- Data conversion
- Data manipulation
- Multi-Criteria Decision Analysis with AHP
- Data analysis
- Presentation of results

The resources to be used

- Contact Persons (Supervisor and the experts)
- Planning wisely for the money to be used to avoid failure in terms of the budget

3.6. Data Acquisition

3.6.1. DEM

The DEM used was downloaded from National Aeronautics and Space Administration website (NASA). It was downloaded as an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GDEM, with pixel size of 1 arc-second. The output format was a 16-bit GeoTIFF, which is referenced to WGS84, EGM96 geoid.

3.6.2. Geology Map

The two geology maps shown in figure 7, were acquired from Kenya Department of Mines in the form of a scanned JPEG image. The study is dominated by granitoid gneisses, undifferentiated predominantly irregularly banded magmatic gneisses, kenyte lava, agglomerate and tuff rocks (BEAR, 1952). According to Marinos et al (1997), the Permeability of gneisses and granite is originally very low but orogeny-related deep-seated fracture or shear zone in these rocks serves as good pass way or reservoir of ground water, therefore making the geology of the area suitable for dam construction. The area was covered by two sheets at a scale of 1:125,000 as follows:

Sheet 1: Geological Map of the area South East of Embu

Sheet 2: Geology of the Country between Embu and Meru

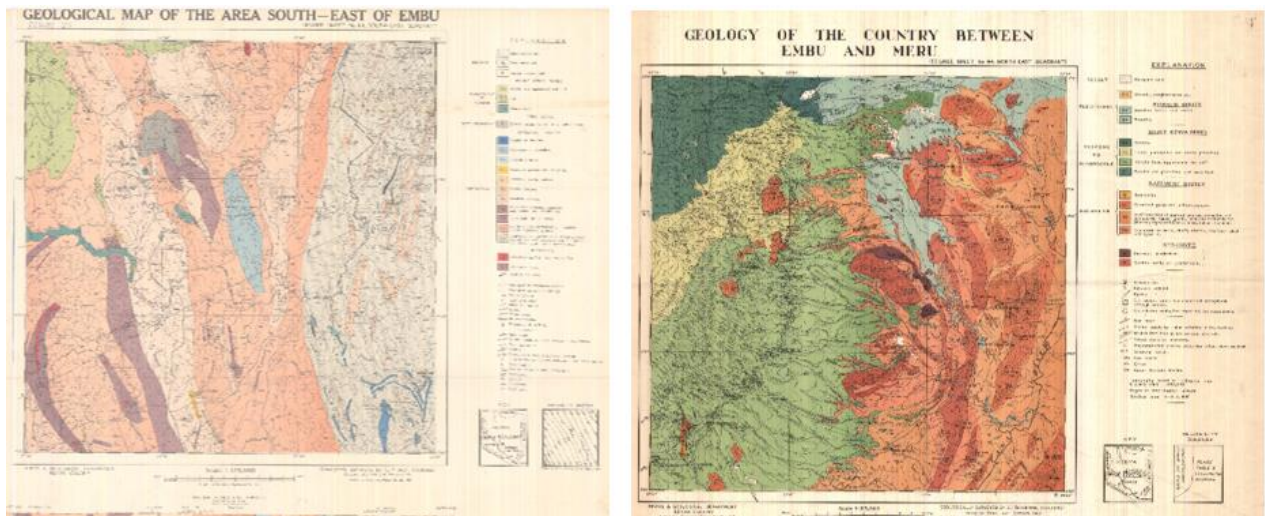


Figure 7: Geological Maps

3.6.3. Soil data

The soil data used was downloaded from IRLI GIS services website (ILRI, 2017). This data had all the soil attributes required for the purpose of this study. It consists of four different classes i.e. Clayey, loamy, sandy and very clayey as illustrated in figure 8.

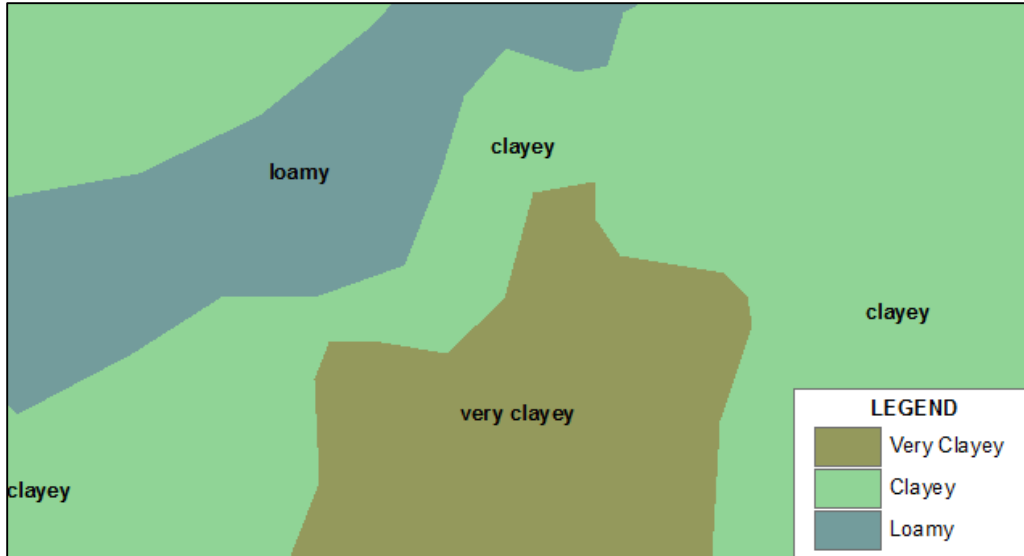


Figure 8: Soil map

3.6.4. Land Cover data

The land cover data was sourced from Regional Centre for Mapping of Resources for Development (RCMRD). This data was already classified, considering six different types of land cover i.e. Dense Forest, Wooded Grassland, Open Grassland, Open Water, Perennial Cropland and Annual Cropland as illustrated in figure 9.

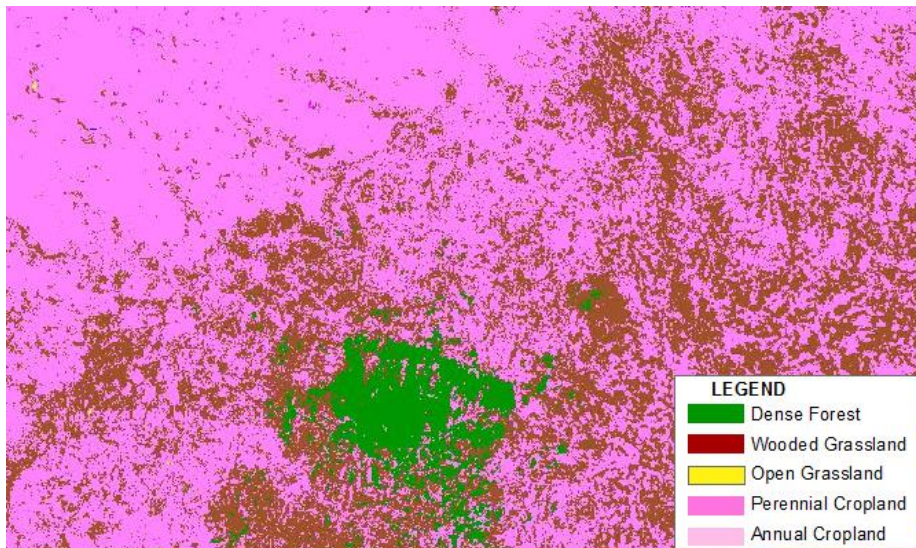


Figure 9: Land Cover map

3.6.5. River and Road Centerline

The data for river and road centerlines was acquired from Geomaps Africa in a shapefile format as shown in figure 10.

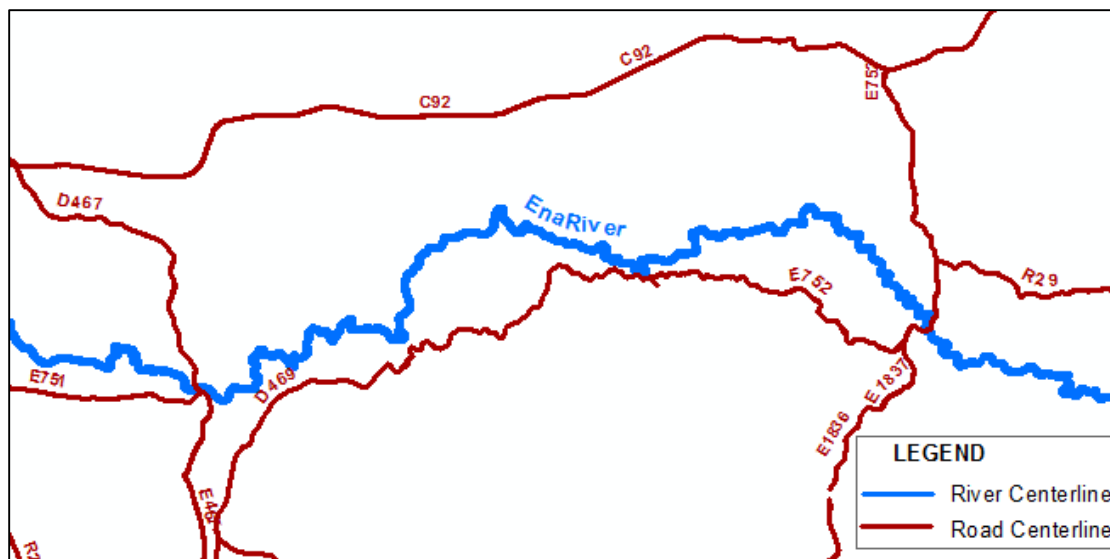


Figure 10: Road and river centerline

Table 3: Summary of the Data Used

NO.	DATA	Explanation	Source
1.	DEM	Dataset used for generating DEM, slope and hydrological layers	Downloaded from NASA website
2.	River Centerline	The main source of water for the proposed Dam	Geomaps Africa
3.	Road Centerline	This was used to calculate proximity of the dam to the existing main roads	Geomaps Africa
4.	Soil data	This dataset illustrated the distribution of the various soil categories within the study area	Downloaded from ILRI website
5.	Land Cover	This showed the current pattern and use of the land within the study area	Regional Centre for Mapping of Resources for Development (RCMRD).
6.	Geological maps	Maps depicting rock formation/ structure of the study area	Kenya Department of Mines

3.7. Data Vectorization

3.7.1. Geology map vectorization

Prior to digitizing, the scanned JPEG image was georeferenced to provide spatial reference information and align it with the coordinate system in use for the project. The four corner coordinates of the image were used for georeferencing. After georeferencing, the image was vectorized with respect to the available geological layers. Each layer was given its attribute depending on the type of rocks represented. Both georeferencing and digitizing was done in ArcGIS software. The output from this vectorization was a shapefile of geology layer as illustrated in figure 11.

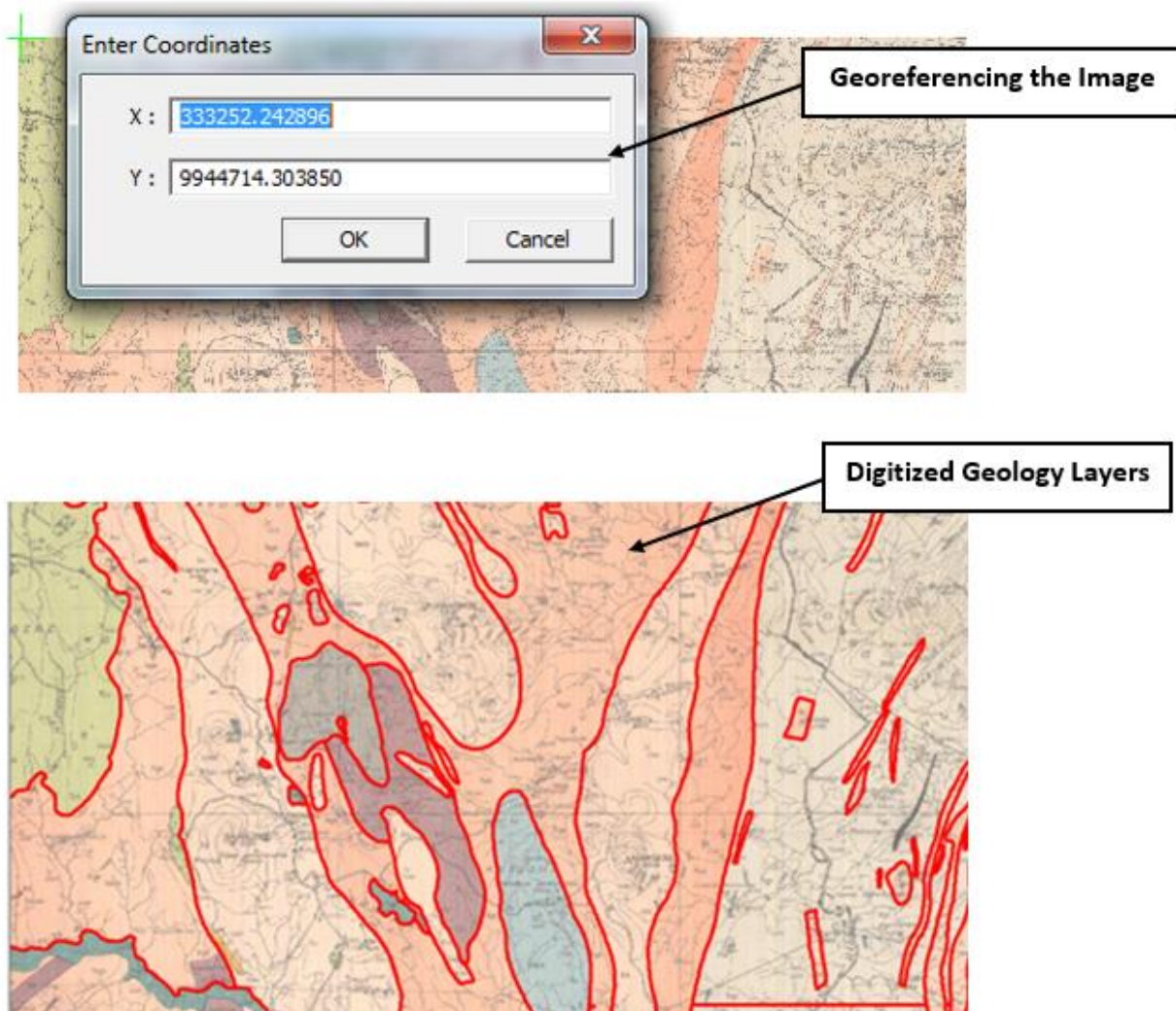


Figure 11: Digitized Geological Map

All necessary Quality control and quality checks were carried out during the vectorization process.

This included among other checks:

- Layer topology building and topology checks to ensure correct relationship between data feature and layers. It involved ensuring that intersecting lines have common nodes and Contiguous polygons have common boundaries
- Edge matching of the vectorized data was done to ensure that data from different sources is continuous by snapping vertices.
- Attribute data consistency check included spellings and other attribute associated errors.
- Duplicate data records checks and removal. The checks ensured that records or features were not duplicated allowing for accurate analysis.

3.8. Conversion of data to Raster

The conversion of vector layer to raster was done with the help of conversion tool in ArcGIS. This was done since hydrological analysis are perfectly carried out by overlaying raster layers. During this process, all the datasets in vector format were converted into raster. Figure 12 shows the geology and soil layers converted from vector to raster.

3.8.1. Geology and Soil Layers Conversion

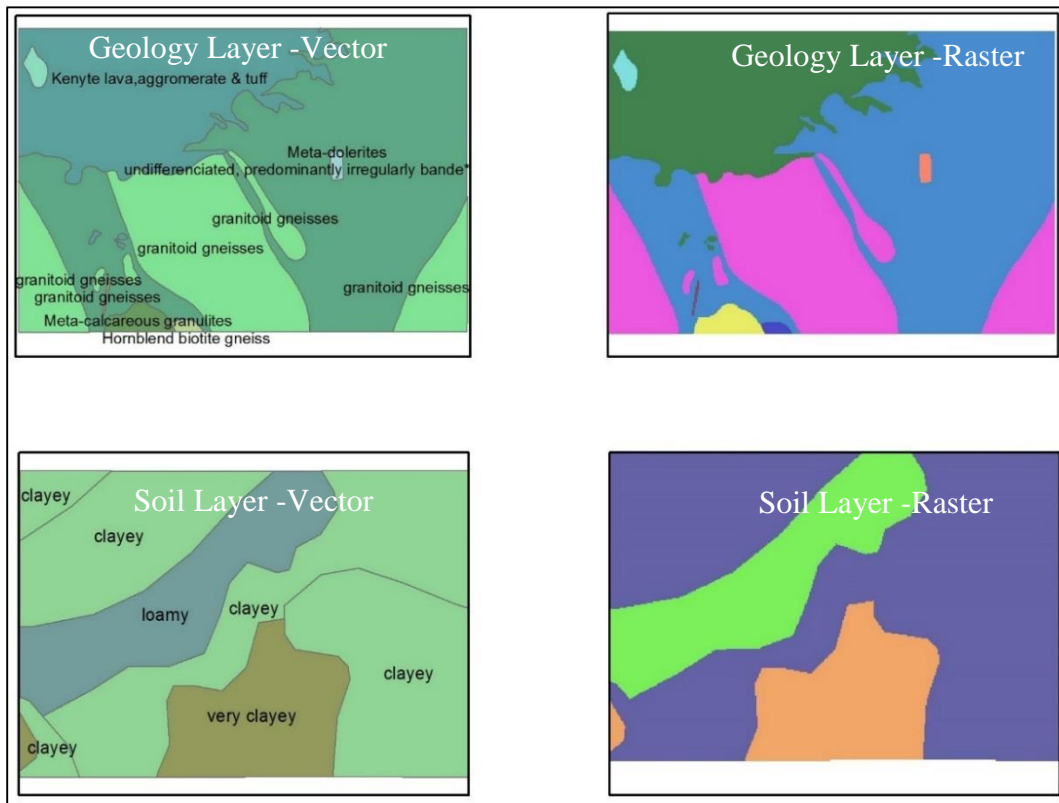


Figure 12: Converted Data Outputs

3.8.2. Proximity from the river centerline

This was done by creating Euclidean distances by using spatial analyst tool in ArcGIS. A suitable dam site should be within one kilometer corridor from the river centerline. More than one kilometer may result in several challenges which would include financial. Figure 13 shows the output results from river proximity analysis.

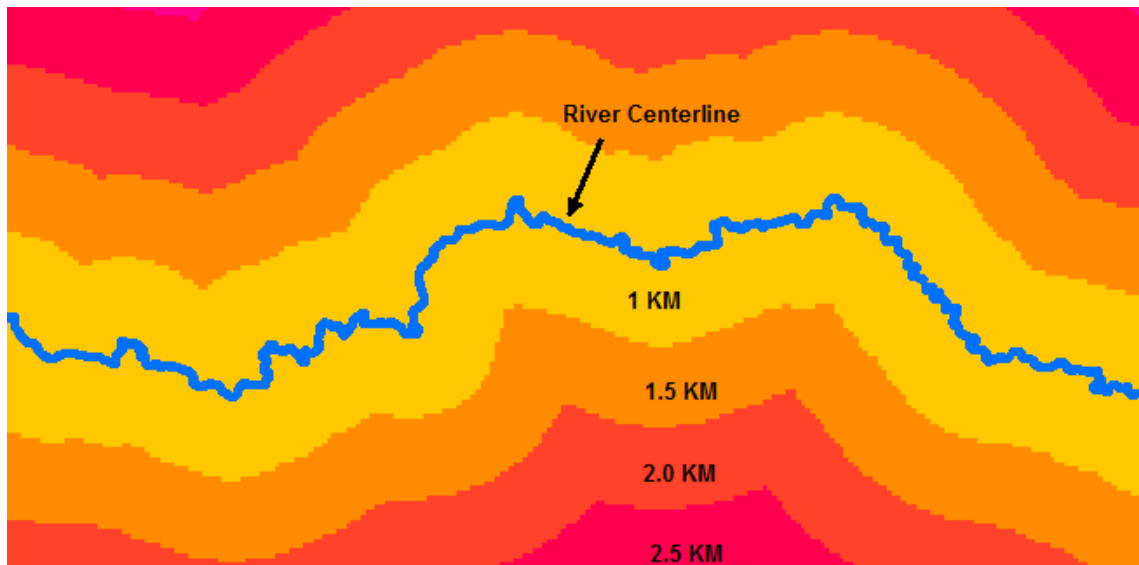


Figure 13: River Proximity

3.8.3. Proximity to the existing roads

This was done by using spatial analyst tool in ArcGIS to create Euclidean distance. The dam should be as near as possible to the existing roads. Existing literature reveals that a distance of a kilometer to the main road is recommended. Figure 14 shows the output results from road proximity analysis.

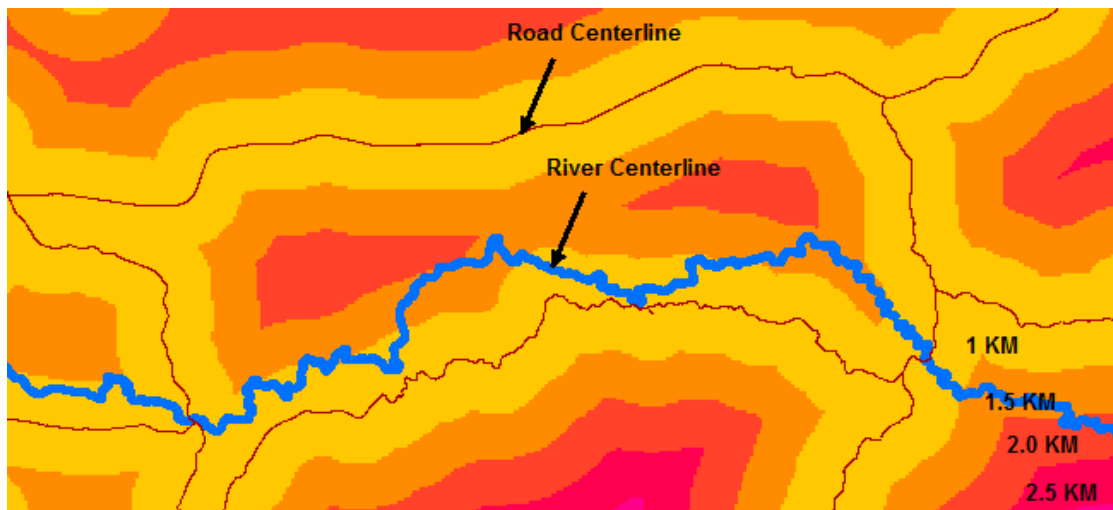


Figure 14: Road Proximity

3.9. DEM Processing

Layers generated from the DEM included Elevation, Slope and contours as shown in figure 15 &16 respectively. The elevation layer was generated from ASTER DEM in Global Mapper .With elevation as the input, the slope tool in ArcGIS 3D analyst extension was used to calculate the maximum gradient between a cell and its adjacent cells. The output raster was calculated as a slope percentage. Contours were also generated from the ASTER DEM in Global Mapper.

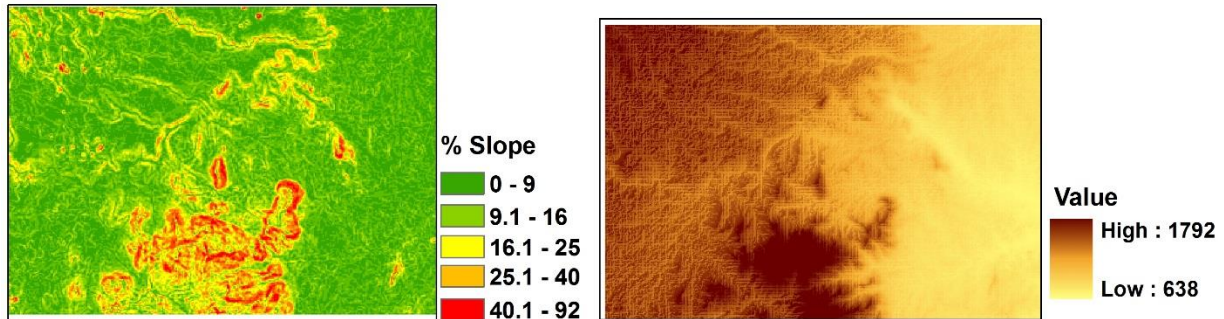


Figure 15: Generated Slope and Elevation

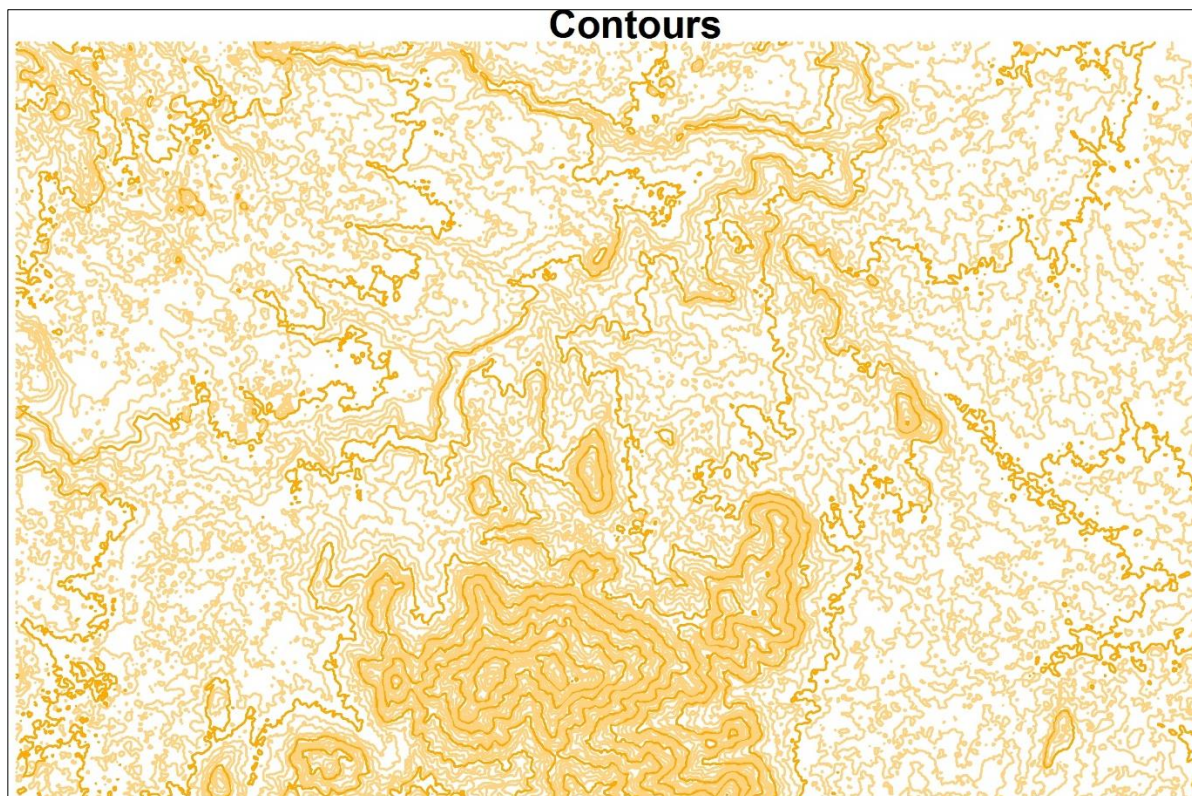


Figure 16: Generated Contours

3.10. Terrain processing of hydrological layers

DEM is used for Terrain Preprocessing in order to ascertain the drainage system of the area (Berolo, 2008). The Arc Hydro extension within ArcGIS was used for terrain processing. Final processed DEM and its end product were then used for delineation of watershed and generation of stream network. The procedures in DEM processing are sequential and must start from the first and end with the last as indicated in figure 17 below.

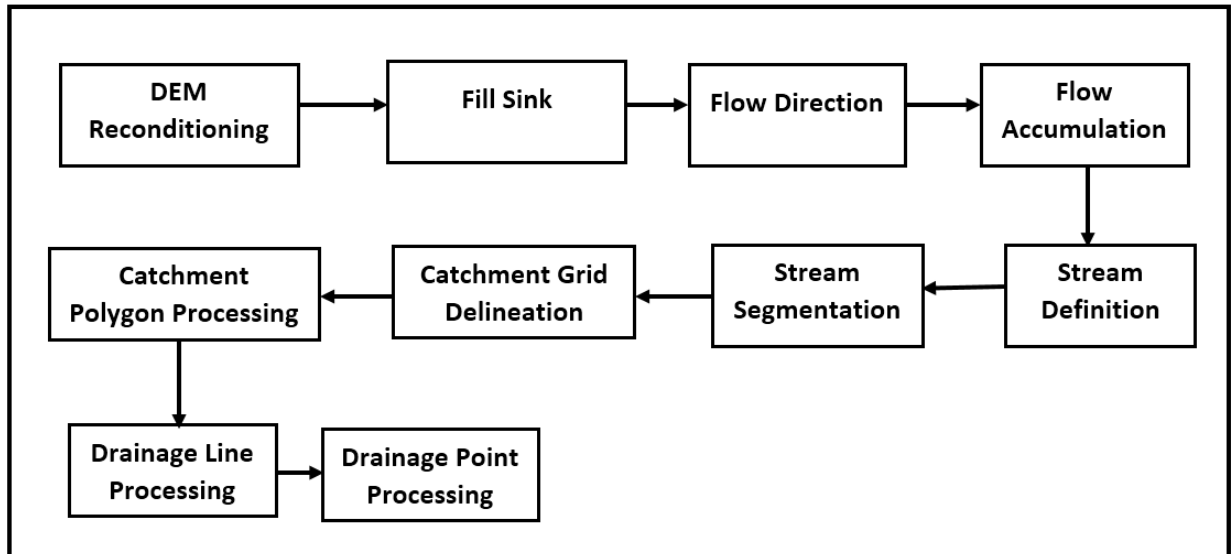
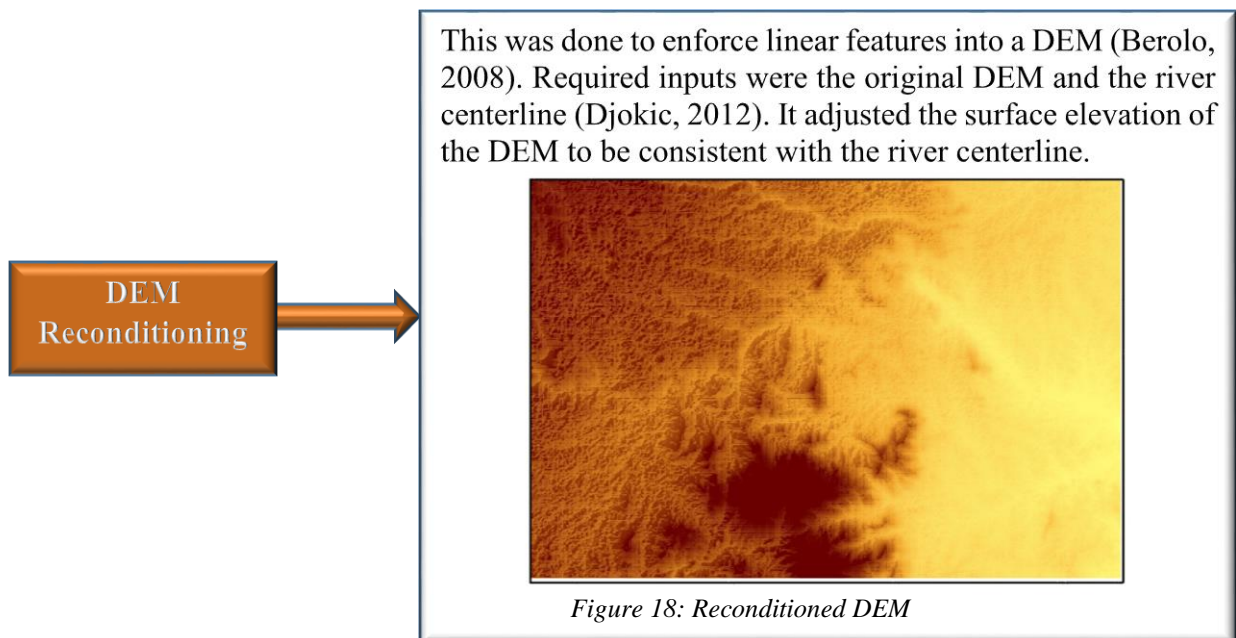


Figure 17: Terrain Processing Flow Chart

3.10.1. Hydrological Layers



Fill Sink →

This was done to modify the elevation value in order to get rid of problems of the water being trapped where a cell is surrounded by cells with higher elevation values (Berolo, 2008). If there were any sinks, they were filled and this resulted in a depressionless DEM (Djokic, 2012).

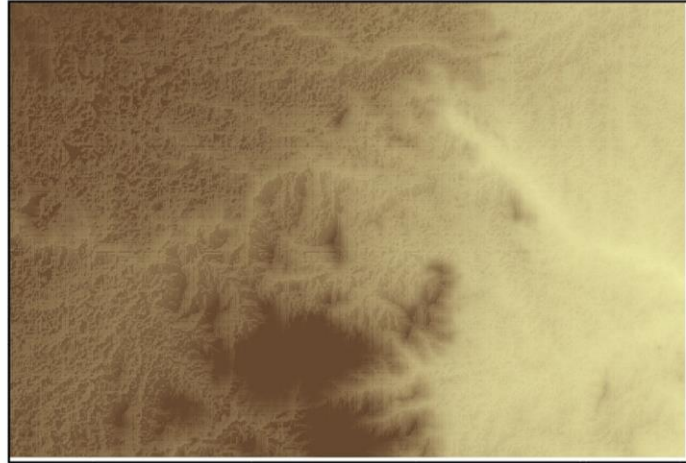


Figure 19: Fill Sink DEM

Flow Direction →

This was done to compute the flow direction of the resulting grid from the fill sink. Final result were a flow direction grid with its cell values, indicating the steepest descent direction (ESRI, 2011).

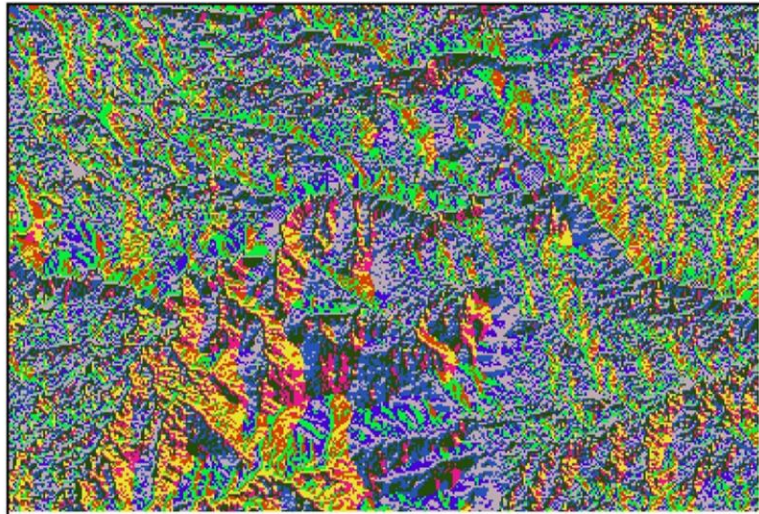


Figure 20: Flow Direction

Flow Accumulation

The input grid for this process was the flow direction grid. This was done to compute a flow accumulation grid comprising of the accumulated number of cells upstream. (ESRI, 2011). Resulting grid illustrated the increasing flow accumulations as it go downhill into the flow network (Berolo, 2008).

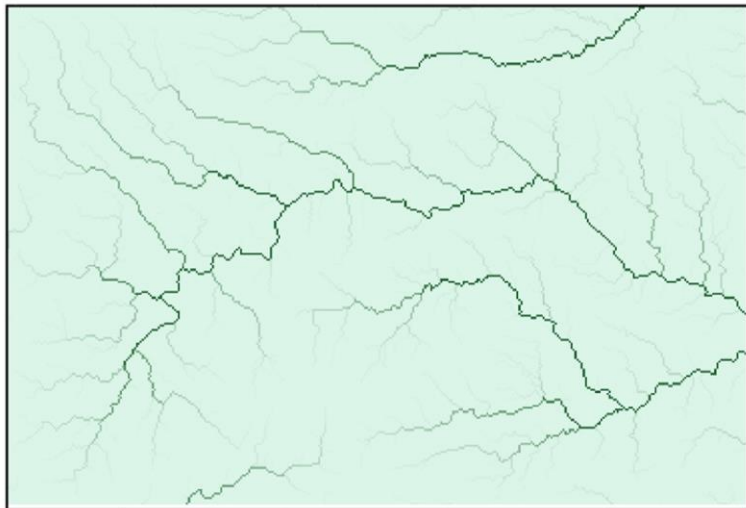


Figure 21: Flow Accumulation

Stream Definition

The input for this process was the flow accumulation grid and the output was a Stream grid. The grid contained a value of 'one' for every cells in the input grid with a value greater than the given threshold while no data was contained in the rest of the cells in the stream grid (Berolo, 2008).

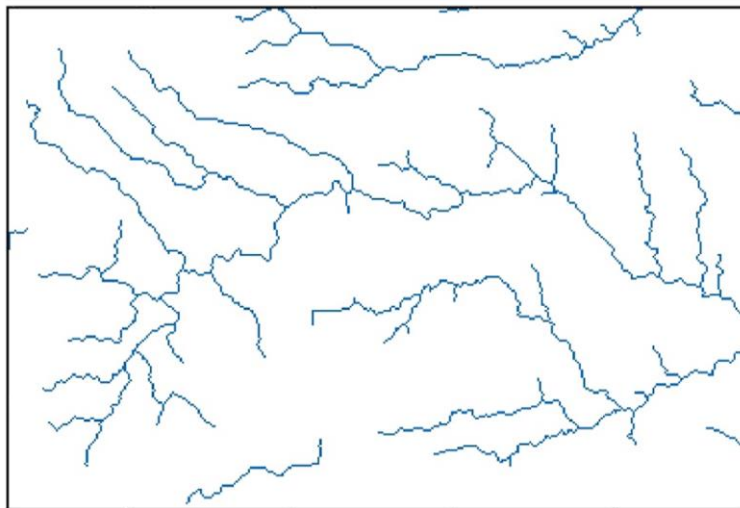


Figure 22: Stream Definition

Stream Segmentation

This created a grid of stream segments containing a unique identification. It is created in such a way that cells within a certain segment comprises of similar grid code which is specific to that particular segment (ESRI, 2011).

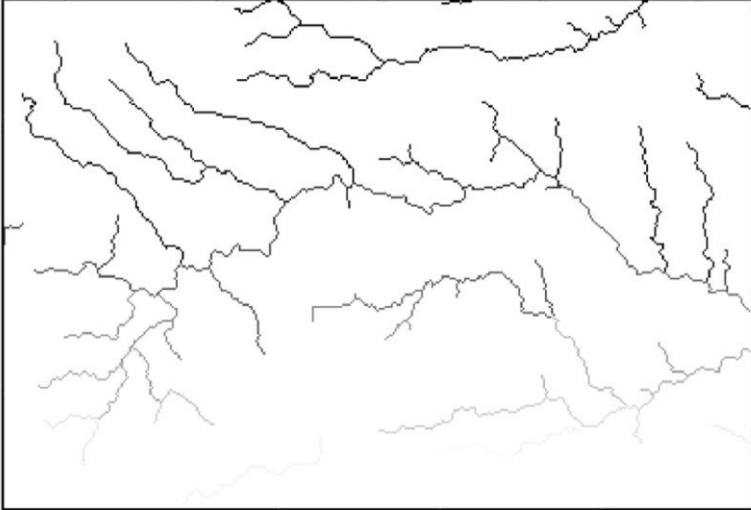


Figure 23: Stream Segmentation

Catchment Grid Delineation

This was done to create a grid where each cell has a value which indicating the catchment to which the cell belongs. The value are same as the value carried by the stream segment that drains the area (Berolo, 2008).

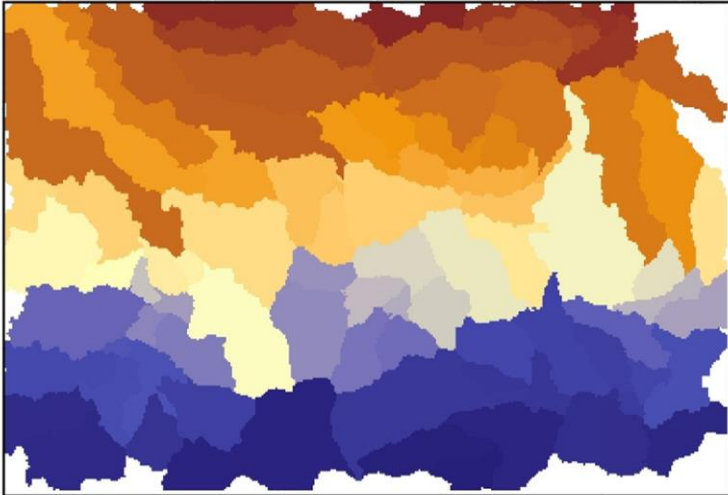


Figure 24: Catchment Grid Delineation

**Catchment
Polygon
Processing**



This converts the input catchment grid from raster to vector (Berolo, 2008).

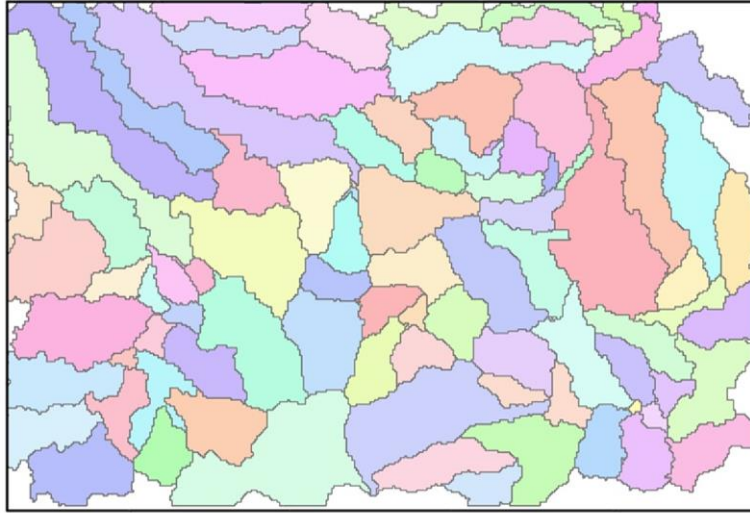


Figure 25: Catchment Areas

**Drainage Line
Processing**



This is a drainage line feature class, created from stream segmentation, in which each line in the feature class is identified with the catchment in which it belongs (ESRI, 2011).

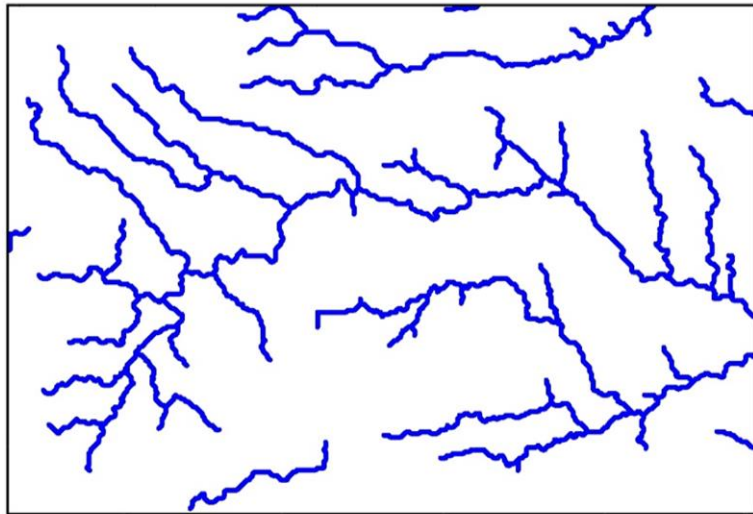
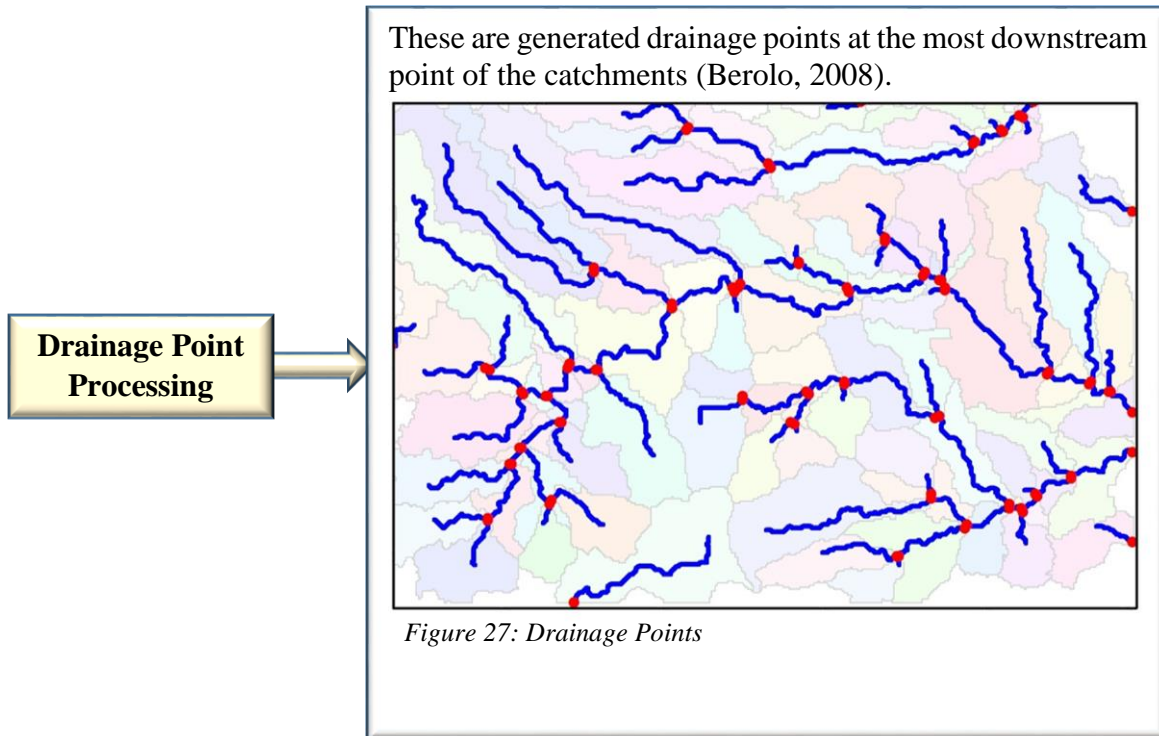


Figure 26: Drainage lines



3.10.2. Drainage Basin

Drainage basin as shown in figure 28, was created using the derived datasets during terrain processing. It was created to show the drainage basin of the area under study. This is very crucial as it delineates the entire area flowing to a given channel. This demonstrated the area which is most likely to be flooded with water incase water is blocked (or overflow) at the pour point, hence very crucial for dam site location. As stated by ESRI (2017), a pour point is a point at which water goes out of an area. This point was created at the lowest point of the river within the generated catchments. This ensured a huge watershed as described by Jackson (2017), in which the larger the drainage basin the more water it will collect hence increased volume of water sufficient for feeding a dam. The Spatial Analyst Tools in ArcGIS was used for creating the basin.

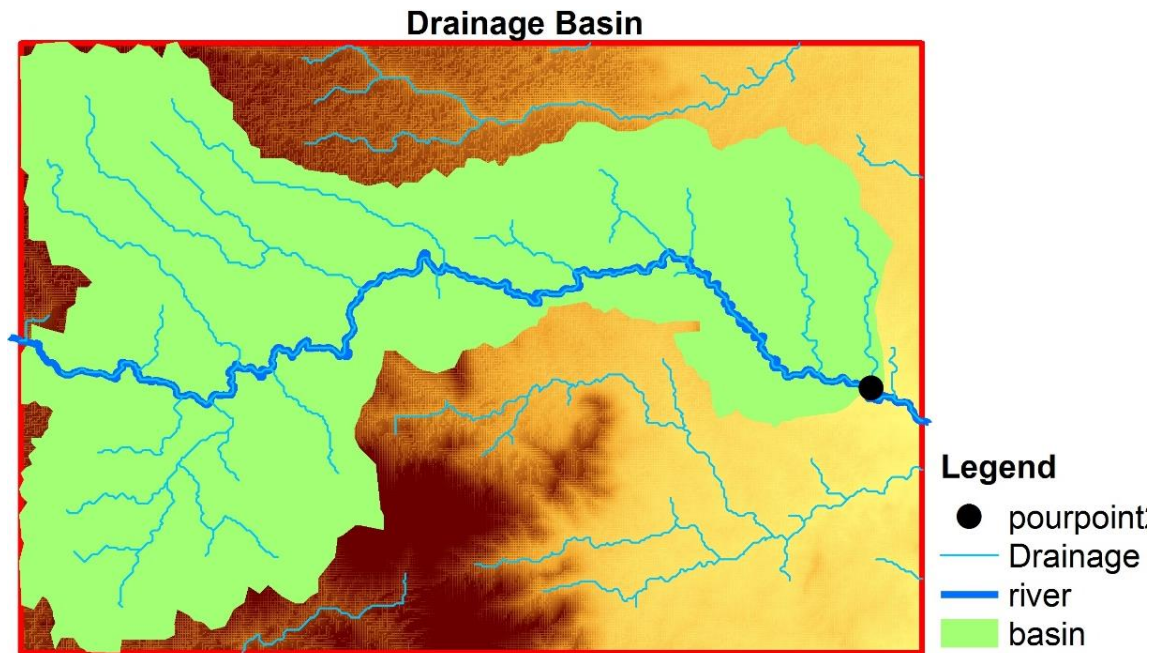


Figure 28: Drainage Basin

3.11. Weighting of factors Using AHP Multi-Criteria Decision Analysis

Weighting was an important part of this study. Each factor was assigned a weights which determined their significance to the project. The weights displayed the way the study was conducted in view of economic factors which minimizes the production cost, project viability based on physical factors of the study areas as well as the overall benefits it will accrue to Mbeere North residents.

Several methods are applied for weight determination of each contributing factor. See section 2.4 for details on other methods of weight determination. Among widely used, is the pair-wise comparison method, AHP by Saaty (1977), where in the basis of their significance, factors are weighted and compared against each other. Hence this study applied AHP pair-wise comparison method.

Several online programs are available for calculating AHP priority weights which includes Microsoft Excel, BPMSG AHP Online System (BPMS, 2017) among others. The program used for this study was Microsoft Excel as described by Bunruamkaew (2012).

According to Saaty, (2008), a matrix is constructed, in which relative to its importance, every criterion is compared with each other, on a scale of 1 to 9. Calculated weight estimate is then used to derive a Consistency Ratio (CR) of the pair-wise comparisons. If CR is greater than 0.10, then

some pair-wise values need to be reviewed. The procedure is repeated until the acceptable value of CR less than 0.10 is achieved. Three main stages were involved as follows:

- Determination of the structure of AHP decision making tree.
- The evaluation of the relative importance of each criterion with one another.
- The assessment of consistency done with pair-wise comparisons to assign the Consistency Ratio. This included
 - Computing the Principal Eigenvalue i.e. λ_{max}
 - Consistency index (CI) Computation
 - Calculating CR.

3.11.1. Determination of the structure of AHP decision making tree

From the literature review of previous studies, specific conditions of Mbeere north region and availability of data, the analysis utilizes seven different map layers as inputs in the suitability; Slope, Geology, Soil type, Catchment size, Land Cover, Proximity to river centerline and Proximity to roads. For a start the decision making tree was constructed as described by Dorfeshan, Heidarnejad & Bo (2014). This formed the structure of Multi-Criteria Decision Analysis. The problem was decomposed into a level of hierarchy consisting crucial elements of the decision problem (Vahidnia, Alesheikhb, Alimohammadic , & Bassiri, 2008). The first layer indicating the goal of decisions making, the second layer containing the criterion to be used and the third level showing the decisions making attributes as shown in figure 29 below.

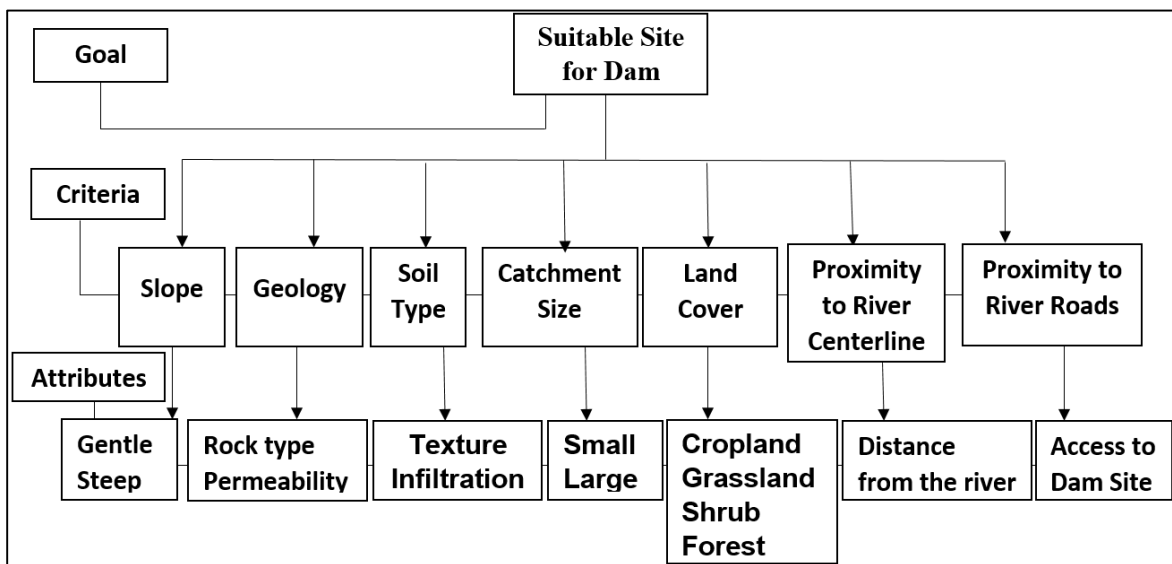


Figure 29: AHP Decision-Making Tree Structure used for the study area

3.11.2. Assessment of the relative importance of each criteria with one another

During this process, significant technical aspects were considered centered on the criteria. A scale of 1 to 9, which allows for the equitable comparison of intensities of suitability was used (Saaty, 2008), with 1 being factors of equal preference and 9 being the factors with extreme preference over the other as shown in table 4.

Table 4: Intensity of Importance

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	The judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	The judgment strongly favor one activity over another
6	Strong plus	
7	Very strong	An activity is favored very strongly over another
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of weight
Reciprocals of the above numbers(e.g. 1/9)	If first factor has one of the above non-zero numbers assigned to it when compared with the second factor, then the	This is a reasonable assumption

	<p>second factor is assigned the reciprocal of the first e.g. if slope compared to land cover has a factor of 9, then the land cover will have a factor of 1/9.</p>	
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From previous studies on dam site selection, incorporated with the experts opinion on factors affecting dam site selection, the order of importance of each criterion was stated as indicated in table5.

Table 5: Order of Importance

Factor	Order of Importance	Argument
Slope	1	Slope influences dam safety since higher slopes have more risks of landslides and usually give pressure to the foundation of the dam (Dai, 2016)
Geology	2	The rock type within a certain region influences permeability of the dam (Marinos, Koukis, Tsiambaos, & Stournaras, 1997) which includes the capability of holding water for the dam
Soil type	3	Different soil types have different infiltration rate which usually influence the runoff flowing to the dam (Djokic, 2012)
Catchment Size	4	A Large catchment will provide sufficient water for the dam (Government of Western Australia, 2014)
Land Cover	5	This is useful for examination of land that have different economical cost depending

Factor	Order of Importance	Argument
		on the land cover type and at the same time land cover influences soil erosion which usually creates a weak foundation for constructing a dam (Dai, 2016)
Proximity to River	6	A suitable dam site should be within a buffer of one kilometer from the river centerline. This was considered an economically sustainable distance from the river centerline (Experts opinion)
Proximity to Roads	7	The dam site should be easily accessible, so that it can be economically connected to the required population (Engineering Articles, 2017).

3.11.3. Calculating Priority weight using Pair-wise Comparison.

The weight was based on a scale of 1 to 9 as indicated in the table 4 above. To determine the weight of each factor, Pair-wise Comparison was used as illustrated in table 6. A matrix was constructed as recommended by Saaty (1977), in which relative to its importance, a criterion was compared with the other criteria on a scale from 1 to 9.

Where 1 = Two factors of Equal preference

9 = Extremely favored factor over the other

3.11.4. Complete Matrix

Table 6: Pair-wise Comparison

Factors	Slope	Geology	Soil type	Catchment Size	Land Cover	Proximity to River	Proximity to Road
Slope	1	2	5	3	7	9	9
Geology	1/2	1	2	7	7	9	9
Soil type	1/5	1/2	1	2	3	5	7
Catchment Size	1/3	1/7	1/2	1	3	5	5
Land Cover	1/7	1/7	1/3	1/3	1	2	2
Proximity to River	1/9	1/9	1/7	1/5	1/2	1	2
Proximity to Roads	1/9	1/9	1/5	1/5	1/2	1/2	1
Total	2 2/5	4	9 1/6	13 3/4	22	31 1/2	35

While the intensity of importance is allocated to criteria *i* when compared to criteria *j*, the reciprocal value is assigned to criteria *j* as intensity of importance. For example, from the above matrix, *i* (slope) =9 while *j* (Proximity to Road) =1/9. After comparison between all possible criteria pairs is complete, the Weight (W) of criteria *i* is calculated using equation 1 (Dai, 2016). See table 7 below for the calculated weight (W).

$$W_i = \frac{\sum_{j=1}^n P_{ij}}{(\sum_{i=1}^n \sum_{j=1}^n P_{ij})} \dots\dots\dots (1)$$

Equation 1: Calculation of weight (source (Dai, 2016))

Where P_{ij} = Relative importance in pair-wise comparison of criterion *i* compared to criterion *j*

n = Number of factors

i & *j* = Criterion

W = Priority Weight

3.11.5. Normalization and weight determination

Table 7: Normalization and Weight determination

	Slope	Geology	Soil type	Catchment Size	Land Cover	Proximity to River	Proximity to Road	Priority Weight (W)
Slope	0.4169	0.4990	0.5449	0.2184	0.3182	0.2857	0.2571	0.3629
Geology	0.2085	0.2495	0.2180	0.5097	0.3182	0.2857	0.2571	0.2924
Soil type	0.0834	0.1248	0.1090	0.1456	0.1364	0.1587	0.2000	0.1368
Catchment Size	0.1390	0.0356	0.0545	0.0728	0.1364	0.1587	0.1429	0.1057
Land Cover	0.0596	0.0356	0.0363	0.0243	0.0455	0.0635	0.0571	0.0460
Proximity to River	0.0463	0.0277	0.0156	0.0146	0.0227	0.0317	0.0571	0.0308
Proximity to Road	0.0463	0.0277	0.0218	0.0146	0.0227	0.0159	0.0286	0.0254
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

NB: according to Saaty (1977)

- Another name for Priority weight is normalized principal Eigen Value
- The cell is divided by its column total in order to normalize the values
- Priority weight is calculated by determining the mean value of the rows

3.11.6. Assessment of consistency

As expressed by Dai (2016), the values used for pair-wise comparison usually relies on subjective judgement which could lead to arbitrary results with bias. To evaluate the consistency of pair-wise comapprison matrix , a numerical index called Consistency Ratio(CR) is used. CR shows the ratio of the Consistency Index (CI) to the average consistency index, known as Radom Index(RI) as shown in equation 2.

$$CR = CI/RI \dots\dots\dots(2)$$

Equation 2: Calculation of Consistency Ratio

Calculation of CI is shown in equation 3

$$CI = (\lambda_{max} - n)/n - 1 \dots\dots\dots (3)$$

Equation 3: Calculation of Consistency Index

Where

n is the number of factors = 7

λ_{max} is the Principal Eigen Value

$\lambda_{max} = \Sigma$ of the products between each element of the priority vector and column totals.

$$\lambda_{max} = (2 \frac{2}{5} * 0.3629) + (4 * 0.2924) + (9 \frac{1}{6} * 0.1368) + (13 \frac{3}{4} * 0.1057) + (22 * 0.0460) + (31 \frac{1}{2} * 0.0308) + (35 * 0.0254) = 7.6201$$

$$CI = (7.6201 - 7) / (7 - 1) \quad CI = 0.6201 / 6 \quad CI = \mathbf{0.1033}$$

3.11.7. Determination of Random Consistency Index (RI)

As proposed by Saaty (1977), the RI used depends on the number of criteria. This study has seven criteria hence the RI used was 1.32 as indicated in table 8 below.

Table 8: Random Index Values (Source: Saaty (1977))

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = CI/RI$$

$$CR = 0.1033/1.32$$

$$= 0.07$$

According to Saaty (1977), the value of CR is compared to 0.1 which is the maximum CR value for an acceptable pair-wise comparison. The resulting CR for this analysis is 0.07 which is less than the acceptable maximum CR value recommended in AHP and therefore this consistency is accepted.

3.12. Data Reclassification

Decision on features to include or exclude for analysis usually require a quite measurable field knowledge combined with modeling experiences (Forkuo, 2011). Further assistance should also be gotten from experts of various fields such as geological experts as they play a big role in providing assistance especially in telling which geological and topographical conditions are favorable for dam site selection.

Values must be prioritized even within a single raster. This is because values in a particular raster may be fit for your purpose while others may be undesirable (ESRI, 2017). For example a slope of 0-9 % is ideal for dam site selection. Hence the reason behind data classification.

Classification was done with the help of Spatial Analyst Tools in ArcGIS. During the classification, the rank for each criterion was given based on its estimated implication in site selection. Each input layer has potential different ranges of values as well as diverse styles of numbering systems, which necessitates reclassification or transformation into a common ratio scale before they are combined for analysis (ESRI, 2017). To perform the reclassification, each raster dataset was reclassified into a common scale of 1 to 5, With 5 being more favorable hence has the highest influence for dam site selection and 1 with the lowest influence.

Classification of geological factors mainly depended on the permeability, thickness and strength of rocks foundations at the area of interest (Ghafoori, Lashkaripour, & Azali, 2011). Stronger foundation was given the highest scale of 5 while weaker was given the lowest scale of 1.

Dam site construction requires a topography of a well-drained, gently sloping site. This is best as it minimizes construction costs as described by (Queensland, 2017). Gentle slope was given the highest scale of 5 steep slope was given the lowest scale of 1.

The choice of the dam site should provide a large area for water storage and this is determined by the size of the water catchment areas around the selected area. Catchment size determines what water is available within a catchment (Government of Western Australia, 2014). A large catchment was given the highest scale of 5 while a small catchments was given the lowest scale of 1.

According to Pimentel & Burgess(2013), the land covered by plant biomass are more resistant to both wind and water soil erosion and therefore usually experience moderately little erosion. In this regard, Wooded Grassland was given a highest scale of 5.

The ranking of soil was done bases on the soil infiltration rate. As described by Djokic (2012), the smaller the soil particles, the slower the water infiltration rate. To ensure minimum loss of water through seepage soils must be impermeable, with more than 20% clay (Queensland, 2017). Therefore clayey soil was given the highest scale of 5 and the sandy soil was given the lowest scale of 1.

The closer the dam to the river, the better for economical purposes. The closest distance of 500m buffer from the river centerline was given the highest scale of 5 while distances beyond 3 kilometers were given a lower scale of 1.

The near the dam to transport networks, the better the accessibility (Dorfeshan, Heidarnejad , & Bo, 2014). Therefore short distances were given the highest scale of 5 and longer distances were given the lowers scale of 1. Table 9 shows the summary of the selected ranks.

Table 9: Summary of the Selected Ranks

Factors	High Rank(5)	Low Rank(1)	Reason (Experts opinion and the existing literature)
1. Geological factors	Stronger Foundation	Weaker Foundation	The stronger the foundation the more it can sustain water
2. Soil Type	Low Infiltration Rate	High Infiltration Rate	The lower the infiltration rate , the better the soil type
3. Topographic factors	Well-drained, gently sloping site	Steep and flat land	Gentle slopes minimizes construction costs

Factors	High Rank(5)	Low Rank(1)	Reason (Experts opinion and the existing literature)
4. Land Cover	Low soil erosion area	High soil erosion area	Land cover prone to soil erosion are less conducive for dam construction.
5. Water storage factors	large catchment	small catchments	A large catchment provides a large area for water storage
6. Transport networks factors	Near Distance	Far Distance	The closer the dam to the existing roads ensures easier accessibility
7. Proximity to river	Lower distance	Higher distance	The shorter the distance the better

Slope (%)	Rank
0-9	5
9.1-16	4
16.1-25	3
25.1-40	2
40.1-92	1

Geology (Rock type)	Rank
irregularly banded migmatitic gneiss	5
Kenyanite lava, agglomerate and tuff	4
Granitoid gneiss	3

Soil type	Rank
Very Clayey	5
Clayey	4
Loamy	3
Sandy	2
Very Sandy	1

Catchment Size (km sq.)	Rank
1.87 - 2.11	5
1.03 - 1.86	4
0.726 - 1.02	3
0.451 - 0.725	2
0.02 - 0.45	1

Land Cover	Rank
Wooded Grassland	5
Open Grassland	4
Annual Cropland	3
Perennial Cropland	2
Forested area	1

Proximity to River (km)	Rank
0 - 0.5	5
0.5 - 1.0	4
1.1 - 1.5	3
1.51 - 2.0	2
2.01 and above	1

Proximity to Roads (km)	Rank
0 - 1.0	5
1.1 - 2.0	4
2.1 - 3.0	3
3.1 - 4.0	2
4.1 and above	1

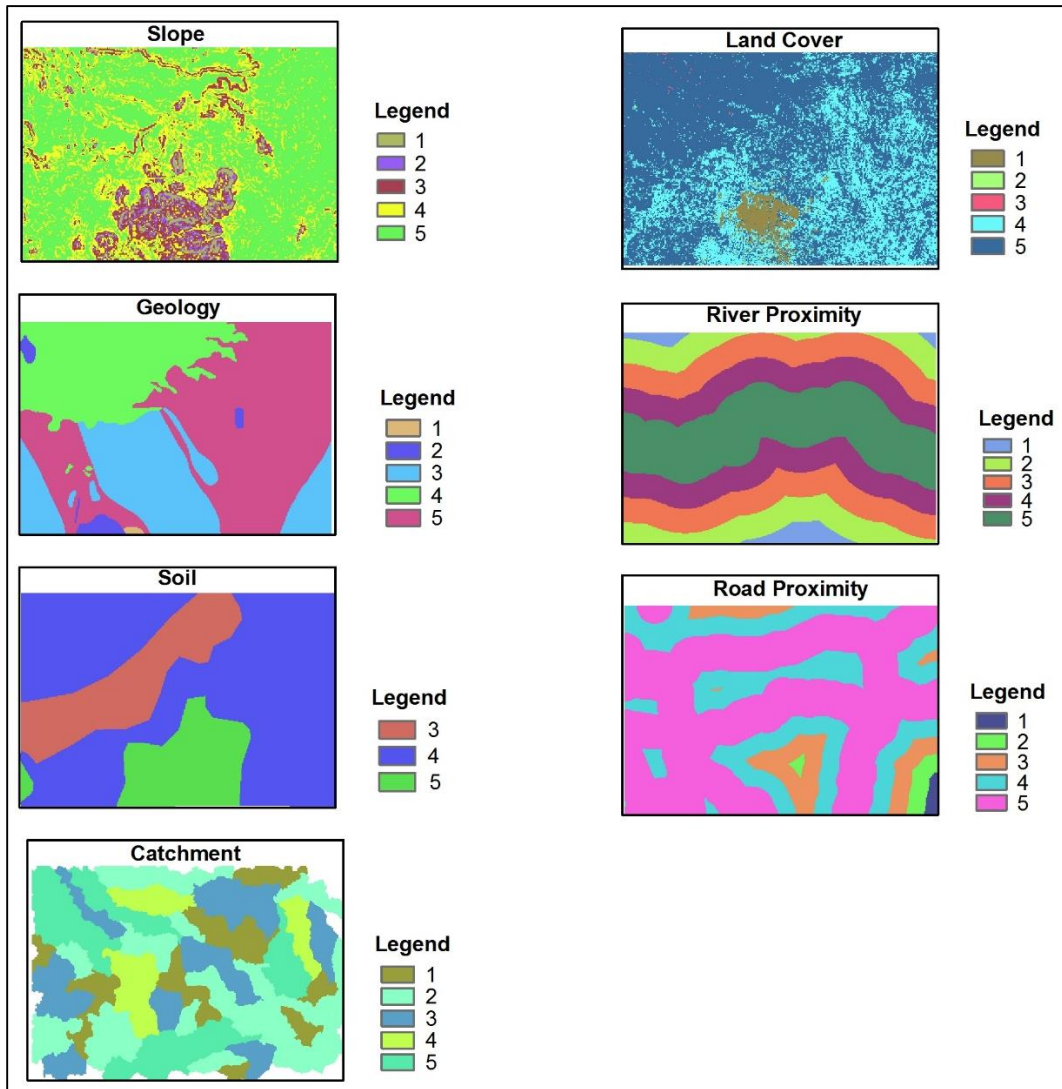


Figure 30: Integrated Ranked Layers

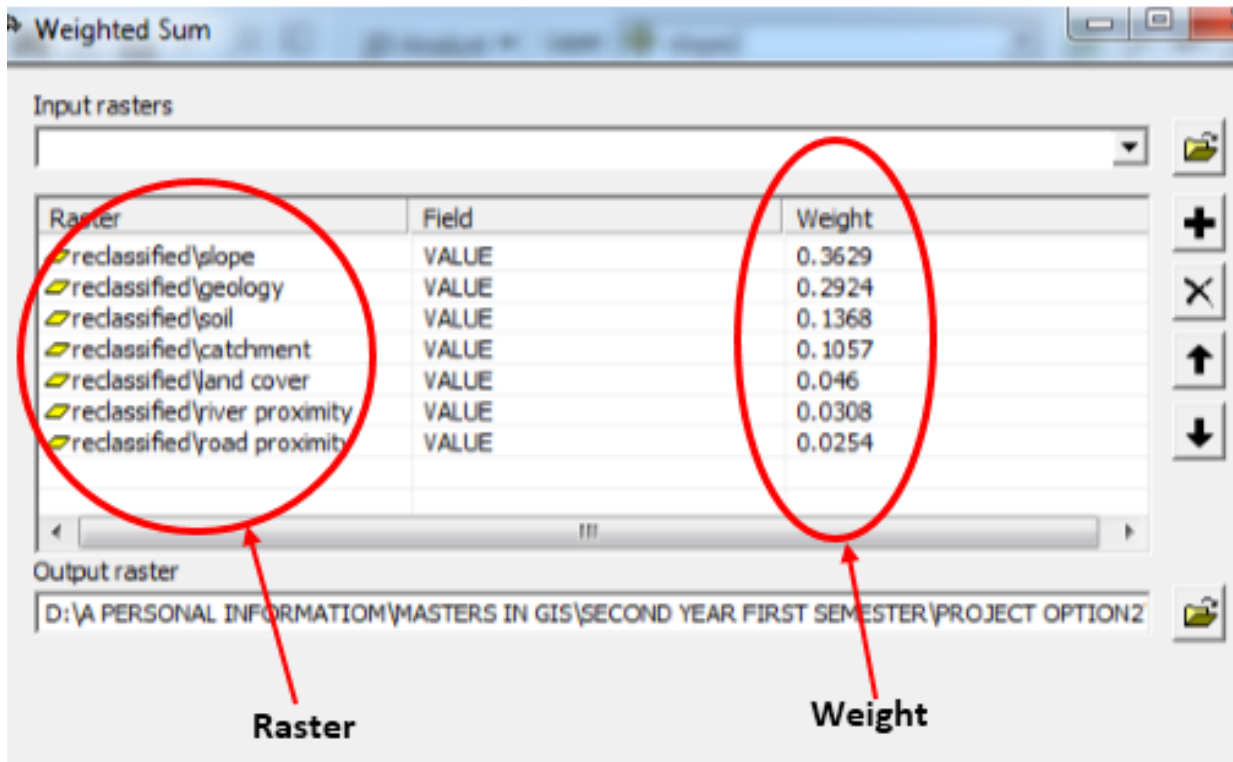
3.13. Weighting Overlay

This included weighting of factor multiplied by their respective weights as shown in table 10 below. This was done using ArcGIS Raster Calculator, available in Spatial Analyst Extension. The purpose was to get the overall summation of the weight of every contributing factor, to produce

the suitability map. The overlay inputs were all the layers reclassified into a common scale of 1 to 5, with 5 being the most favorable as shown in figure 30 above. By using the Weighted Sum tool in the ArcGIS Spatial Analyst, each input raster is multiplied by the specified weight. It then adds all input rasters together to obtain the final suitability map.

Table 10: Generated Weights for Each Factor

Factor	Weight (As calculated in AHP)
Slope	0.362904
Geology	0.292383
Soil type	0.136835
Catchment size	0.105697
Land Cover	0.045985
Proximity to River Centreline	0.030828
Proximity to roads	0.025369



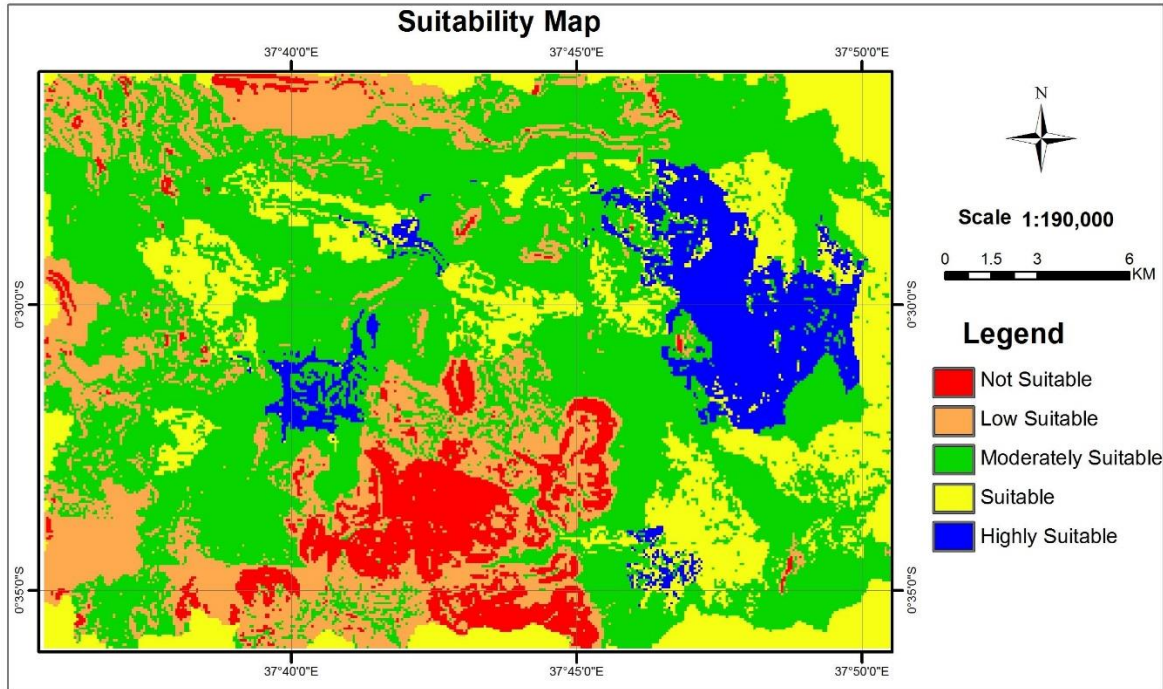


Figure 31: Suitability Map

Figure 32 below demonstrates the overall process used during the overlay analysis

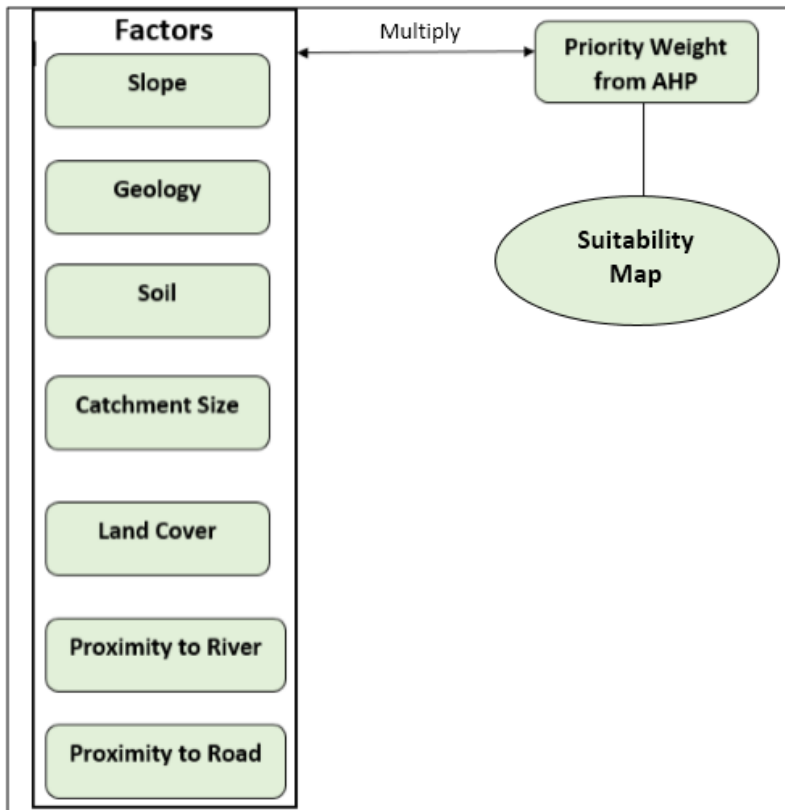


Figure 32: Flow Chart of the Overall Weighting Process

4. RESULTS AND DISCUSSIONS

4.1. Analysis of results

A suitability map specifying suitable locations for a dam construction in Mbeere North Sub-County was produced as shown in figure 31. Likewise, a bar graph showing area in kilometers and percentages for various suitability levels was also produced (see figure 33). The maps was reclassified into five classes of different colours. Blue colour represented the land which is the most suitable for dam construction with respect to the considered criteria (Slope, geology, soil, catchment size, river proximity and proximity to major roads), yellow represented the land which is suitable, green represented the land which is moderately suitable, orange represented the land which is of low suitability while red represented areas not suitable for dam construction. Extents of highly suitable and suitable area are as highlighted in figure 34 and 35 respectively.

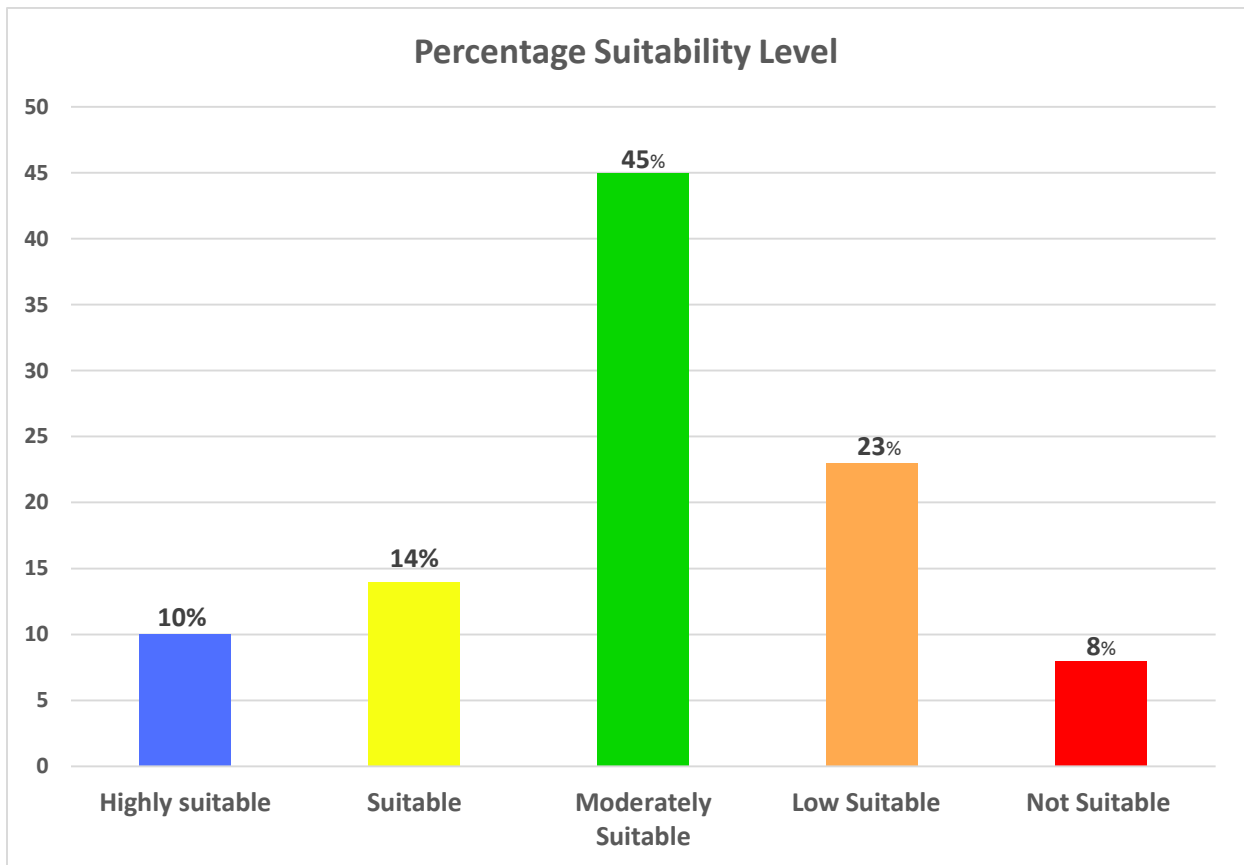


Figure 33: A Graph of Suitability Levels

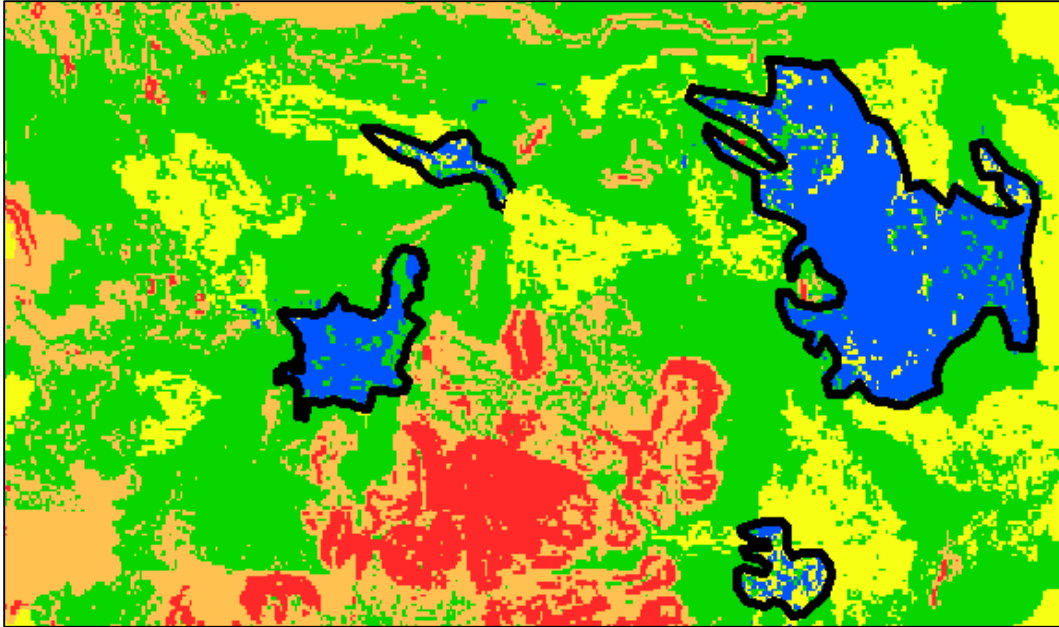


Figure 34: Highly Suitable Areas Highlights

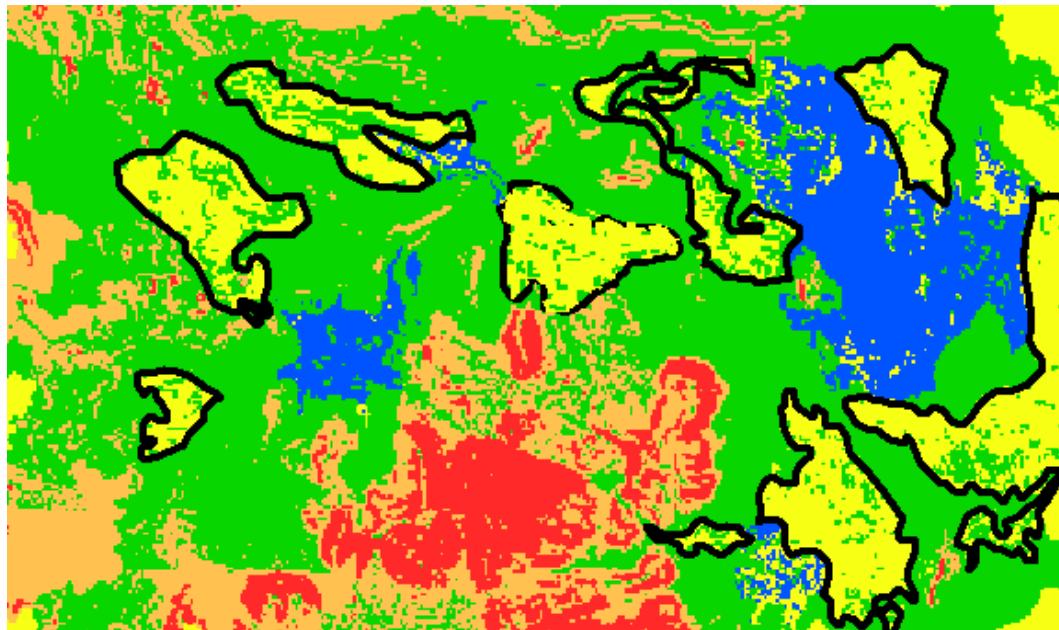


Figure 35: Suitable Areas Highlights

Suitability sites were chosen based on the integration of all considered factors. As the map shows, the northern area towards Mt. Kenya highlands is showing mixed levels of low suitability. This is probably because of changes in slope as steep slopes are dominant as we approach Mt. Kenya.

Suitability increases as we move towards the interior of Mbeere North Sub-County. This is probably favored by flat slopes within the area.

10% of the total study area showed that the area was highly suitable, 14% was suitable, 45% was moderately suitable, 23% was low suitable while 8% was not suitable for dam construction. The highly suitable classification had four possible sites of 2.8, 3.5, 8.0 and 37.8 km².

The larger site was the most recommended. Due to its size, there is a choice on all possible sizes of the dam required unlike other three sites which are limited in size and irregular in formation and therefore no possible expansion or reduction can be done within these sites. At the same time the formation of contours within the large site is not very wide and therefore allows for various dam options with considerable weir length. Wide contours mostly leads to a very big dam which is not economical in most cases as demonstrated on figure 36.

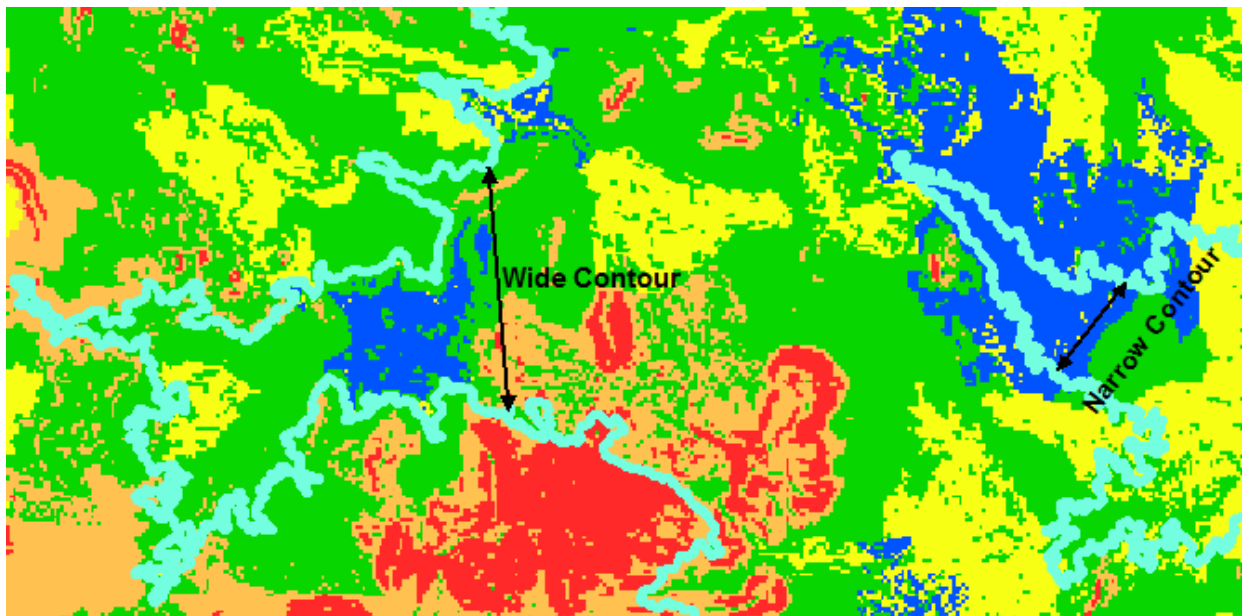


Figure 36: Formation of Contours

4.2. Discussions

The elevation within the study area ranges between 638 to 1798m above sea level. After comparing the suitability map with the elevation map, the high suitability areas lies within fairly flat elevation of between 850 to 950 m as well as within areas of gentle slope of between 2 to 9%. The suitable areas also lies within the drainage basin meaning the dam will be able to get water from all possible catchments within the available drainage basin. All unsuitable areas were the areas around

Kiang'ombe Hills, depicting steep slopes within the area which are not suitable for dam construction.

Coordinates provided by Tana Water Services Board (TWSB) in their report on the development of three dams in Embu County (See Appendix A1), were added on the suitability map. One of the three TWSB points fell on the suitable site of the study area as illustrated in figure 37. Further analysis were done on which possible reservoirs from site A (Proposed Kamumu Dam) and Site B (Highly Suitable area) were created to determine the surface area and volumes of water from each. Site A had less surface area and volume than site B (See figure 38). In reality, site B would provide more water for the residents than site B, one of the reason in which site B would be preferred to site A.

On the other hand, site B is more preferred as the area is large enough such that there is enough site for weir length adjustment in case of enlargement or reduction of the reservoir size. This is not the case with the proposed site. Suitability of the proposed site is within a small area and the surroundings are low suitable areas and therefore cannot provide enough room for adjustments or alternatives if need be.

From the available documents and research on the proposed Embu dams, it is evident that GIS analysis were not applied during site selection. Even though the location was on a suitable site, GIS analysis would have resulted on a highly suitable location.

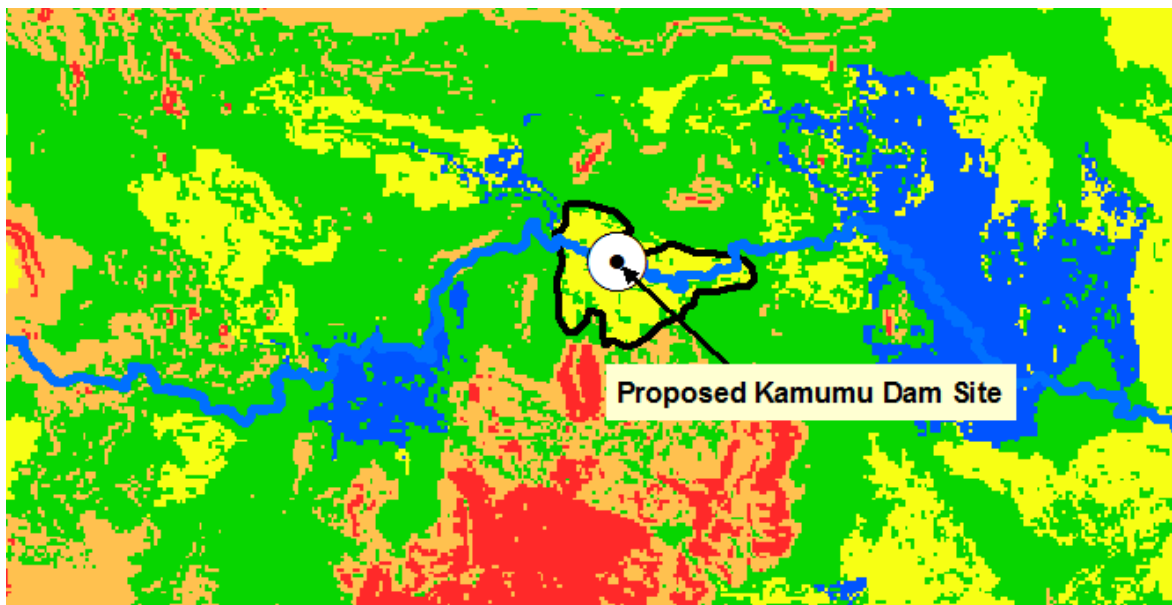


Figure 37: Proposed Kamumu Dam Site

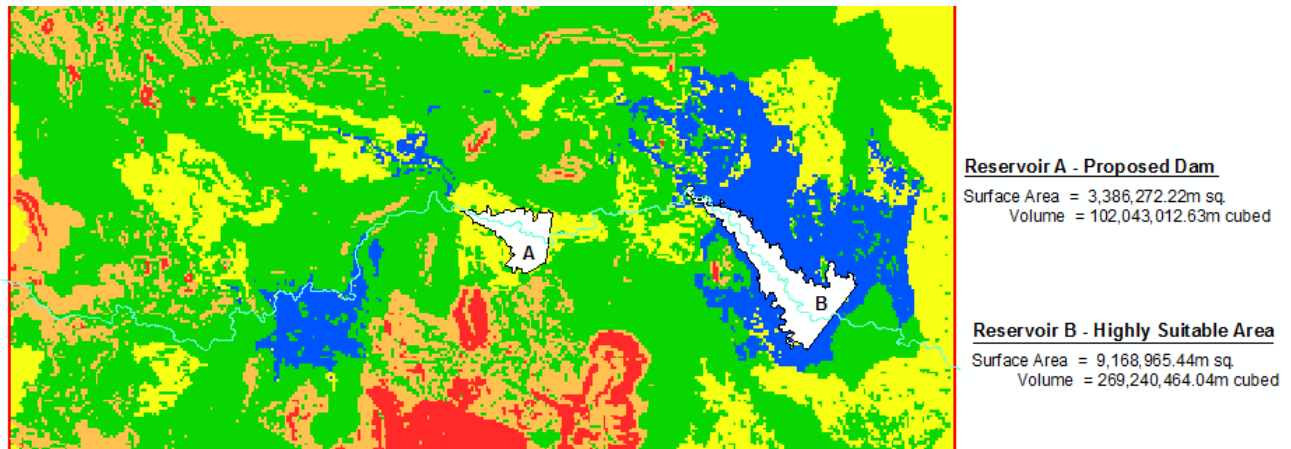


Figure 38: Possible Reservoirs

The main objective of this study has been achieved in such that suitable sites for dam site location have been analyzed. The integration GIS and AHP has been successful and a final suitability map has been produced. The success of the final results mainly depended on the accuracy of the DEM used since this was the main dataset. ASTER DEM was used with a horizontal accuracy of 1 arc-seconds equivalent to 30m resolution. This was detailed enough to meet the requirements for a medium scale study such as this study, whose area was approximately 514 km². Nonetheless, even though suitable areas have been selected, there are areas of limitations which need to be pointed out such as:

- Bearing in mind that weight assignment affects the overall results, determining which weights to be given to a certain factor is an individual judgment which is subjective and therefore may be bias.
- There were no similar studies done within the study area and therefore there was no validation of the resulting suitability map.
- Data for this study has been collected from various sources and therefore, the quality and accuracy of the datasets used for this study and their corresponding information depended on how they were collected, created and processed. Quality of data is vital in providing more accurate, reliable and sufficient information useful for decision making.

In general integration of GIS with AHP has been helpful in arriving at a suitable locations for a dam site selection. Therefore both are proficient and supportive tools for decision-making process.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In the view to support policy makers to come up with conclusive and dependable decision on a suitable location to construct a dam for Mbeere North residents, I selected a methodology of integrating GIS and AHP, one of the popular Multi-Criteria Decision Analysis tool. Having determined the criteria and their respective weights, ArcGIS extensions; 3D Analyst, Spatial Analyst and Arc Hydro, were used to obtain a final suitability map. The entire process demonstrates that this is a reliable and precise method of dam site selection, even though it has some few limitations which requires future improvements.

The result indicates that integration of GIS with AHP Multi-Criteria Decision Analysis for a dam site selection is feasible and effective. Powered by GIS analytical capabilities and Geospatial technologies, dam site selection and planning can be done in a more effective and scientific way. This is contrary to manual methods of dam site selection using topographic maps and contours, without consideration of terrain properties which can only be discovered by GIS analysis. Therefore this study provides a reference for future GIS based dam site selection especially in areas where integration of GIS with Multi-Criteria Decision Analysis for a dam site selection is yet to be implemented. There is hope that future projects for dam selection will be done using this approach.

5.2. Recommendations

Based on the limitation of this study as well as the future perspective, there are parts of the study which requires improvement in future studies of the same nature.

- In the AHP weight determination, there is no standard for the rank order of criteria. As a first time user of GIS and AHP for dam site selection, I was assisted by an experienced experts from Howard Humphreys who gave me suggestions on rank order and weighting of factors. In the future, more GIS research can be done to develop a standard way of ranking criteria.
- High Resolution DEM especially the LiDAR DEM should be used in future to increase the accuracy of the results. LiDAR DEM can be of as high resolution as one meter and as high point density as 3 to 4 points per meter squared.

- Future studies should have comprehensive GIS analysis which includes the calculation of surface runoff in order to determine how much water is expected in the dam.
- Future studies should be validated even if it means looking for a different location away from the study area where a dam exists, and similar analysis done in order to validate the suitability map produced.

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APPENDIX A

A1 Report on the Development of Three Multipurpose Dams in Embu County



TANA WATER SERVICES BOARD

DEVELOPMENT OF THREE MULTIPURPOSE DAMS
IN
EMBU COUNTY

JANUARY 2017

1. Introduction

Embu County is located in Eastern Kenya and borders Tharaka-Nithi, Kitui, Machakos, Muranga, and Kirinyaga Counties.

The County measures 2,818 km² in area, broken down into Embu (726 km²) and Mbeere (2,092km²). Hence, Mbeere though drier than Embu constitutes 74% of the County's land resource.

As per the census of 2009 the total population of Embu County was 516,212 and is projected to be 577,390 in 2017. About 84% of the population resides in rural areas and rely on agriculture as a source of their income. Although the County is ranked as the 14th richest among the forty seven Counties (data released by the Commission on Revenue Allocation), 42% percent of the population is classified as poor, or unable to meet their daily nutritional requirements. Hence, there is an urgent need for interventions to be undertaken in order to reduce poverty levels to an acceptable minimum.

Considering that most of the population live in the rural areas improving agriculture would be one of the key activities that would catalyze poverty reduction. Agricultural activities in the county are mainly rain-fed. However, rainfall in 76% of the county is highly unpredictable and most places receive less than 500mm making agriculture extremely vulnerable to low rainfalls and its variability.

To avail clean and safe water in adequate quantities to the whole of the population in the county now and in the long term extensive infrastructure for domestic water is required. To grow food-crops and agricultural products in large quantities to feed the growing population and create jobs with higher incomes leading to a better standard of living, extensive irrigation is necessary.

For this to be realized, the leaders of Embu County proposed to the Ministry of Water and Irrigation the development of four Dams to harness enough and adequate water for domestic, industrial, and irrigation in order to stimulate social and economic development of the entire Embu County.

Tana Water Services Board in conjunction with the leaders of Embu County identified four sites to facilitate the delivery of water through gravity to all areas of the county which have been experiencing serious water shortages. The rivers targeted are Rupingazi, Thuci and Ena.

The proposed dams are:

- 1.Kamumu Dam on Ena River
- 2.Thuci Dam on Thuci River

3.Thambana Dam on Rupingazi River

4.Rupingazi Dam on Rupingazi River

The Ministry of Water and Irrigation further directed Tana Water Services Board to proceed with sourcing for funds for Kamumu, Thambana and Rupingazi Multipurpose dams while Thuci Multipurpose dam is to be undertaken by the National Irrigation Board.

2. Briefs on the Dams

2.1. Kamumu Dam.

The proposed Dam is in Mbeere North Constituency on Ena River coordinates 9945271mS, 357631mE. The Dam whose designs are at preliminary stage has the following particulars associated with it:

2.1.1. Scope

- A 60m high zoned Rock fill dam to create a reservoir with gross storage capacity of 24 million cubic metres
- A 650m long side channel spillway
- A intake tower with bridge access to the dam embankment
- Off take pipes to accommodate 4,400 m³/day of water for domestic
- Off take pipes to accommodate 160,000 m³/day of water for irrigation purposes
- A small hydro power station with capacity of 400KW
- Water treatment plant with a capacity of 4,400 m³/day for Domestic Water Supply

Beneficiary Population

Year 2020 = 61,919

Year 2030 = 77,730

Year 2420 = 97,576

- Transmission mains, Storage tanks and Distribution Pipelines for domestic water supply.
- Transmission pipelines and ancillary works for an irrigation system
Irrigation Water - 157,911m³/day
Irrigation area - 13,795 Ha

2.2. Rupingazi Dam.

Rupingazi Multipurpose Dam is located in Mbeere South. It is situated at Latitude 0°37'22''S and Longitude 37°29'13'' E. It is 10km south of Embu Town on the Rupingazi River and near to Rwika Trading Centre.

The proposed Rupingazi multipurpose dam is expected to provide water for human consumption, livestock consumption and irrigation requirements for parts of Mbeere North and Mbeere South sub counties in Embu County and Mwea East Sub County in Kirinyaga County. It is expected that the proposed Rupingazi Dam will provide long-term solution for water and irrigation programs in these sub counties.

2.2.1. Scope

The proposed dam axis is located across Rupingazi River approximately 5km west of Gachoka trading centre on the Embu - Kiritiri road and 20km south of Embu Town. The GPS coordinates (UTM Zone 37M) of the proposed dam axis are 328752 mE, 9953889 mS. Data gathered at this stage is not sufficiently detailed to perform a relevant preliminary design of the dam.

The dam type envisaged is a zoned rock/earth fill embankment with a central impervious core or concrete faced rock fill dam depending on the materials available at the site. The proposed height of the embankment will be around 40m. The general layout of the reservoir consists of the following main elements:

- A 40m high zoned earth/rock fill dam;
- A side channel spillway
- free standing intake tower with bridge access to the dam embankment
- Multiple off take pipes to accommodate domestic and irrigation water
- Low level compensation pipes

A Water treatment plant with a capacity of 20,000 m³/day for Domestic Water Supply for a population of 198,082 people is also to be built close to the dam but such a location as to supply the project area by gravity.

2.3. Thambana Dam.

Thambana Multipurpose Dam is located in Embu North. It is situated at Latitude 0°25'2''S and Longitude 37°27'40'' E. It is 15km north of Embu Town on the Rupingazi River just around its confluence with Thambana River. The proposed Thambana multipurpose dam is expected to provide water for human consumption, livestock consumption and irrigation requirements for Embu North sub county and parts of Mbeere North and Mbeere South sub counties in Embu County and Mwea East Sub County in Kirinyaga County. It is expected that the proposed Thambana Dam will provide long-term solution for water and irrigation programmes in Embu North Sub County and other adjoining sub counties.

2.3.1. Scope

The proposed dam axis is located across Rupingazi River approximately 700m upstream from where road E637 starts from road D459. The GPS coordinates (UTM Zone 37M) of the proposed dam axis are 328752 mE, 9953889 mS. The data gathered at this stage is not sufficiently detailed to perform a relevant preliminary design of the dam.

The dam type envisaged is a zoned rock/earth fill embankment with a central impervious core owing to the materials available at the site. The proposed height of the embankment will be around 40m. The general layout of the reservoir consists of the following main elements:

- A 40m high zoned earth/rock fill dam;
- A side channel spillway
- free standing intake tower with bridge access to the dam embankment
- Multiple off take pipes to accommodate domestic and irrigation water
- Low level compensation pipes

A Water treatment plant with a capacity of 25,000 m³/day for Domestic Water Supply for a population of 536,423 is also to be built close to the dam but such a location as to supply the project area by gravity.