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Identification of Suitable Dam Site Location and Reservoir Characteristics; A Case Study of Nanyuki River in the Upper Ewaso N'giro Basin

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Abstract: Identification of potential sites for dams is a critical strategic initiative for water resources management, in particular, the highland-lowland system such as the Ewaso-N'giro River Basin. In this research, we adopted an integrated GIS and AHP Multi-Criteria Decision Analysis with an overlay of thematic attributes to identify suitable locations for the small dams along the Nanyuki River. Six thematic attributes were considered: Stream Order (Strahler Classification), Elevation, Slope, Curve Number, Lithology and Land use/Landcover. Two suitable sites were identified in the downstream of the catchment. The result has demonstrated the potential of GIS and RS in affordable and quick approach towards selecting suitable dam sites. However, it is vital to note that the approaches should be utilized together with other traditional approaches to ascertain and ground truth the cited location. Geospatial data are fundamental in the modern-day water resources management. The AVE curve is a vital and pivotal decision-making tool for reservoir development. GIS techniques and remote sensing are important approaches in reservoir characteristics estimation and provide reliable AVE curves. The entire process was considerably faster and consumed less time and thus results are visualized immediately.

Keywords: Nanyuki River, Thematic Attributes, GIS, AHP MCDA, AVE Curves.

1. INTRODUCTION

Water storage and in particular floods is a fundamental viable water management option that can potentially reduce demand on river flows and hence dry season over-abstractions. In this case, flood and excess runoff is captured and stored for use during the low-flow periods. The most common method of harvesting excess runoff is through construction of in-stream dams where runoff is captured during the peak flows. By definition, a dam is a structure constructed along the river reach to hold water back thus creating impoundment commonly referred to as a reservoir. Identifying suitable sites for dams and reservoirs is a fundamental process in dam development as it is always vital to establish the stability of the foundation to sustain the weight of impounded volume as well as the materials used in the construction [7]. Well sited dams will ensure optimum benefits including improving the aesthetic value of the area around the dam for recreational purposes. On the other hand, poorly sited dam locations are a key threat to the life downstream of the impoundment [10]. For instance, an occurrence of a dam breach/break may result in huge damages and losses of life and economy. Therefore, the process of selecting suitable locations for new dams is of critical importance. Besides the focus on structural stability and integrity of the intended dams, dam siting also takes into consideration other important factors such as proximity to intended users, accessibility among others that ensures maximum economic benefits of the intended impoundment/reservoir.

Dams present a primary asset of flood storage in the Ewaso Ngiro Catchment where unsustainable water abstraction in the upstream has drastically modified the downstream natural flows particularly during the dry periods. The basin experiences water scarcity problems that result in social-economic and ecological effects. River water is abstracted upstream of the basin leaving little or no water for the downstream users. There is a need therefore to store flood waters to mitigate the social-economic effects which are extremely felt during the dry season especially when the river is experiencing low flows. [12] reported that there is a lack of adequate surface water storage investment in the upper Ewaso Ng'iro basin and therefore this could have had a positive result in reducing upstream-downstream conflicts. In this contribution, we seek to identify suitable dam sites and determine reservoir characteristics in the

Nanyuki River Catchment of the upper Ewaso Ng'iro Basin. Thereafter, we test whether establishing such small reservoirs along the river is a sustainable approach that can ensure equitable allocation and in particular even distribution of dry weather discharges across all demand sectors.

Dam site selection is a critical component of reservoir development since it influences, as well as influenced by, a myriad of factors that include both anthropogenic or human societal and environmental factors [23]. There is a range of parameters considered for dam suitability siting as well as design; topography, soil properties, slope, land-use, present and planned development including the dam site seismicity [28]. Topography is one of the major factors considered in the construction of earth reservoirs; it exerts a dominant control on flow routing through upstream catchment, which provides a bare land representation of terrain or surface. Its characterization represents the ground surface, hydrological boundaries and terrain attributes such as slope and terrain aspects [4]. Well-drained, gently sloping site is preferable 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. Geological foundation within a site often influences the type of reservoir suitable for that particular location. Competent rock foundations have relatively high resistance to erosion, filtration and pressure [20]. The land cover of an area 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. 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. A suitable reservoir site should have a catchment area that is not so small such that the water is not sufficient enough to fill the reservoir, neither should it be so big such that it may require an expensive spillway. The reservoir site should be easily accessible, so that it can be economically connected to the required population [28]. Is the highland-lowland system unique when considering conventional procedures to siting of a dam whose fundamental purpose is to maintain dry season flows?

Selection of suitable locations for dams is usually a complex issue and is primarily an out-door field exercise conducted using traditional approaches [23]. The process is usually conducted using traditional approaches that include conventional decision-making approaches at times leaning towards political interests [5]. However, aerial photographs, maps and remotely sensed data provide a vital avenue for accurate dam sitting with the pre-assessment of the topography and hydrological conditions before actual field investigations. This is most importantly essential for larger sites and watershed in which time can be saved by eliminating sites that are not feasible. In particular, Remote sensing and Geographical Information System (GIS) are vital tools that provide management actions for decision makers by allowing easy access and generation including handling and manipulation of data. For instance, [6] highlights that GIS enables setting of priorities for efficient data acquisition and use through multi-criteria approaches. The tools are highly adaptable in merging the spatial information with various existing factual and numerical decision-making approaches and strategies such as multi-criteria evaluation, weighted overlay analysis, artificial intelligence process among others [17,23]. Among these strategies, GIS and Multi-Criteria Decision Analysis (MCDA) are widely used. Usually, decision analysis involves systematic procedures employed in assessing complex decision problems with regard to siting. GIS is adopted to analyze the decision in the spatial context while MCDA compares alternatives. MCDA adopts a given restricted set of attributes and depends on specific distinctive alternatives [5,24]. Therefore, the approach requires that concerned decisions have clear objectivated information with a focus on the key outcomes. MCDA required knowledge on the relative weights of the individual layers/attribute and the contribution of each attribute on the assessment of the alternatives [9].

Several studies have been undertaken on suitable sites selection using GIS, Remote Sensing and MCDA approach [8,17,24,25]. [23] conducted suitable dam sites selection using AHP and fuzzy logic in the Greater Zan Region of Northern Iraq by considering spatial attributes such as geology, soil and lithology, lineaments (fault lines), hydrometeorological characteristics, land cover among others and identified for sites. [9] also assessed the spatial multi-criteria evaluation when sitting underground dams in Alborz Province of Iran and noted that the approach illustrated reasonable results providing opportunities for upscaling the approach to other regions. Further, [5] mapped suitable dam sites using machine learning and GIS and identified three major sites in Sharjah, United Arab Emirates illustrating that the adopted approach could be applied to other locations to identify potential sites for dam's construction. All these studies have adopted a diverse combination of approaches including of parameters depending on the size an intended purpose of the reservoir. [26] adopted a four-criterion – catchment slope, lithology, soil type and land cover type - approach to select the most suitable site for a dam in Northwest Saudi Arabia. On the other hand, he used a combination of 18 criteria – Cost, yield, health impacts, topographic conditions, accessibility, contribution to economic development, water quality, flow regime, reservoir volume, sediment yield and loadings into the reservoir, intended water diversions and transfers, probability of a dam breach, evaporative losses, probable maximum flood and impacts (environmental, political and societal) – to determine the suitability of dam locations.

In general, defining the right criterion for selection of best sites for dams is a difficult and tainting task that requires a clear understanding of the intended purposes for the proposed dams/reservoirs [5,9,25]. However, of critical importance, are the parameters such as slope, hydrological conditions that are related to the environment and the ultimate safety of the dam infrastructure. In this paper, the proposed dams are mainly for maintaining dry season flows and thus we have focused on the key biophysical factors that include elevation and the vital derivatives of slope and stream density, soils land use and land cover and Soil Conservation Service Curve Number layer.

Once a suitable location for a dam construction is identified, it is necessary to assess the characteristics of the proposed dam which usually depended on the height of the dam [27]. Dam construction particularly in the Highland-Lowland System like the Ewaso-Ng'iro have the potential of storing significant volumes of water that can sustain downstream flows in the dry period. However, planning and management of the development process is often insufficient. Quantifying available storage volume for such reservoirs beforehand enables water resource planners to ensure that all demand sectors are satisfied [1]. One important characteristic of a dam is the optimal dam height that will ensure excellent reservoir properties are maintained. Reservoir shape naturally affects evaporation losses in such a way that shallow broad reservoirs have higher evaporative losses than deep narrow reservoirs. [5,27] established that the depth of a dam has a direct influence on the reservoir surface area and volume. Key critical feature of dam characteristics is usually the property of the storage volume commonly referred to as the Area-Storage-Elevation curve (AVE - Figure 1). It is therefore more practical to obtain this relationship so as to ensure that sustainable withdrawal rates are applied and have a clear understanding of reservoir sedimentation rate [22]. Importantly, the volume of water to be harnessed by a reservoir commonly referred to as storage capacity is dependent on the reservoir water balance i.e., inflows and outflows from the reservoir. [27] notes that the AVE curve is thus fundamental for water resource planning, modelling and management when considering reservoirs for flood storage as it plays an essential role in establishing optimum surface area, suitable depth and highest capacity [19].

Available techniques to estimate reservoir storage volume include indirect (using topographical maps) and direct (dam surveys) methods [3]. Field surveys are usually laborious and time consuming and hence require more financial and human resources. Proper water resource planning approaches, in particular the highland-lowland systems with many challenges on water allocation, have become increasingly essential and vital. For instance, accurate assessment of reservoir properties with minimal cost implication is crucial. Geographical information system (GIS) provides an opportunity to efficiently estimate reservoir properties therefore enhancing decision making in terms of efficiency and reliability [14,15]. GIS has functionalities such as interpretation and transformation of spatial data which makes it vital in supporting the decision-making process. A common technique used to determine the storage characteristics of a reservoir is the mass balance approach or generally the mass curve approach. A myriad of studies has adopted GIS to estimate and assess the potential of rainwater harvesting infrastructure such as dams [1,13,16,19,22] notes that the GIS based approach is less time consuming and produces reliable AVE curves with a relative error below 20%. In this study. We have adopted GIS to manipulate 30 m resolution Digital Elevation Model (DEM) to estimate and extract the AVE properties for the two selected dams. Geospatial data (DEM) coupled with GIS have proved to be powerful and cost-effective tools for estimating reservoir characteristics important for dam planning and operational management.

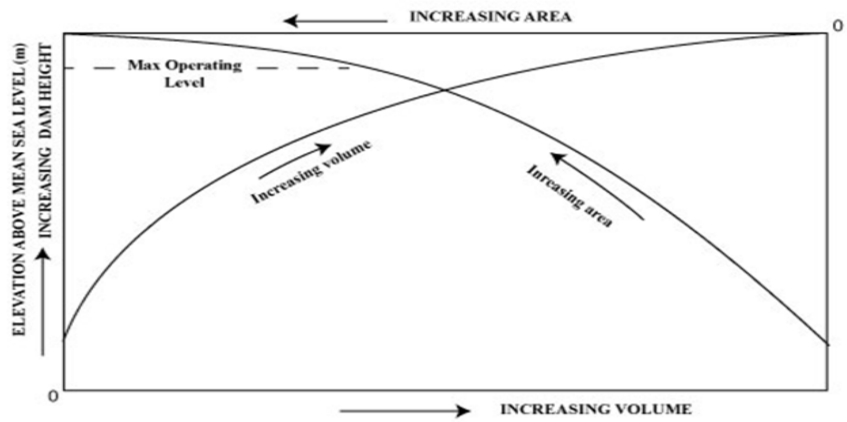

Figure 1: Typical reservoir elevation-area-volume relationship curve (AVE). The curve provides key design criteria and essential rules for reservoir operations (minimum and maximum operating reservoir level).

The aim of this contribution is to find suitable sites for dams in the Nanyuki watershed of the upper Ewaso Ng'iro Catchment area for the purposes of investigating their potential to maintain dry season flows. The dams' sites are generated mainly based on the physical and environmental conditions. Specific objectives of the study are; to identify suitable dam locations according to a selected criterion and generate a suitability map; to select two key dam sites with relatively high suitability and to determine the reservoir characteristics, including volume-Area-Height Curve for the selected sites.

2. MATERIALS AND METHODS

2.1. DESCRIPTION OF THE STUDY AREA

The Nanyuki river Catchment is situated between 0° 18.5'N, 36° 54.5'E and 0° 9'S, 37° 21.5'E at the upper region of Ewaso Ng'iro North Catchment in central Kenya (see Figure 2). The larger Ewaso Ng'iro basin is the largest of the six water catchment areas in Kenya [21]. The Nanyuki River originates from the slopes of Mt. Kenya which receives substantial amounts of rainfall giving rise to multiple perennial streams. These streams that flow all-year-round are a critical source of freshwater for the semi-arid Laikipia Plateau and the other lowland areas [11]. The Nanyuki River flows into Ewaso Ng'iro River, before which numerous water abstractions have taken place for irrigation and domestic use. This has drastically reduced flow of water in the river to alarming levels. In general, the Nanyuki Basin experiences varying climatic conditions ranging from arid (semi) to humid resulting from a large difference in the elevations. The annual precipitation patterns indicate high variation in both space and time ranging from 300 mm in the southern sections of the watershed to 1500 mm in the Mt. Kenya region [2,18]. The long rains occur from March to May while the short rains are in October and November. The annual mean temperature of the county ranges between 16° C and 26° C. The study area as illustrated in figure 2.

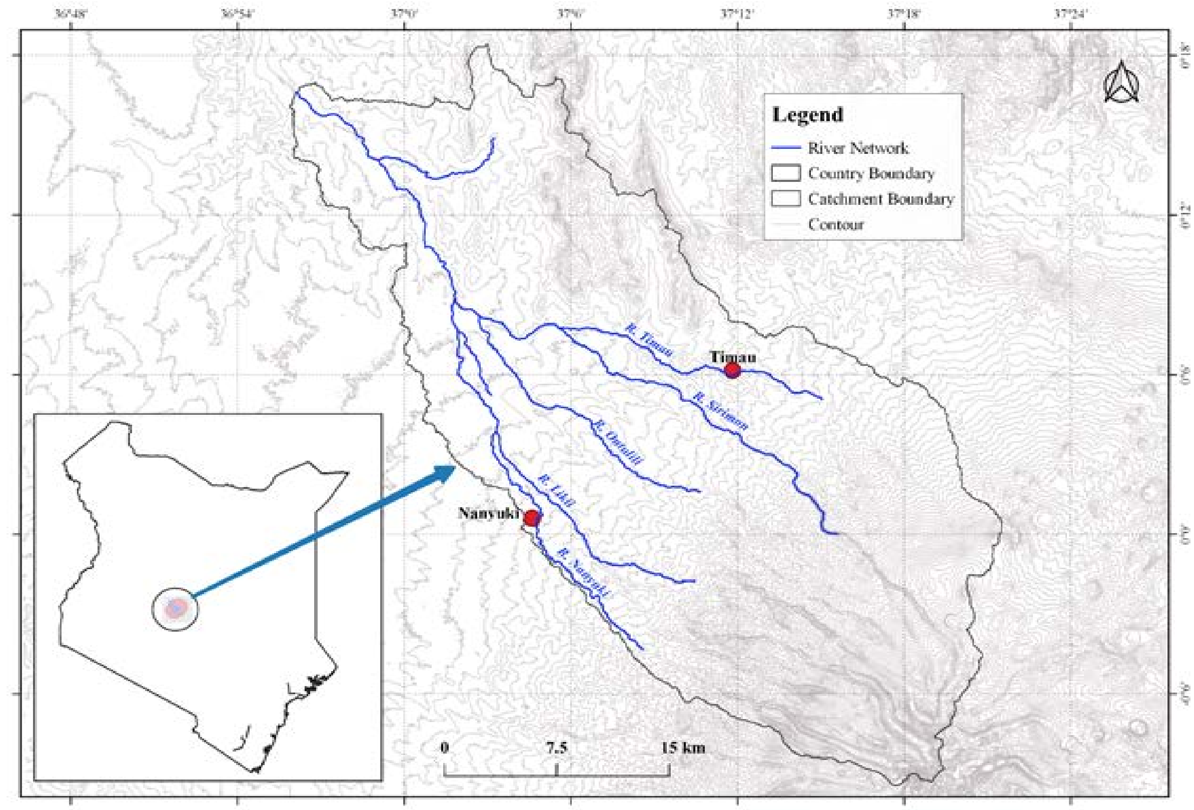

Figure 2: The Nanyuki Drainage Basin. The Basin is drained by five major streams originating from the slopes of Mt. Kenya.

2.2. METHODOLOGY

2.2.1. DAM SITING

The study adopted a AHP Multi-Criteria Decision Analysis (MCDA) integrated with the GIS Environment to determine and identify suitable dam sites. The adopted approach was implemented in four main steps: 1) data collection/acquisition based on the number of criteria to be used in the site selection, 2) processing of the data to generate thematic layers, 3) establish attribute for each thematic layer and assign constraints and weighting factors corresponding to the individual layer influence on dam location for generation of dam suitability map, 4) and validation and suitable site selection. The key output from the process is the suitability map resulting from a combination of the organized thematic layers combined by performance of a weighted overlay analysis. Figure 3 below illustrates the methodology adopted to generate a site suitability map and further selection of the two most suitable dams ‘sites.

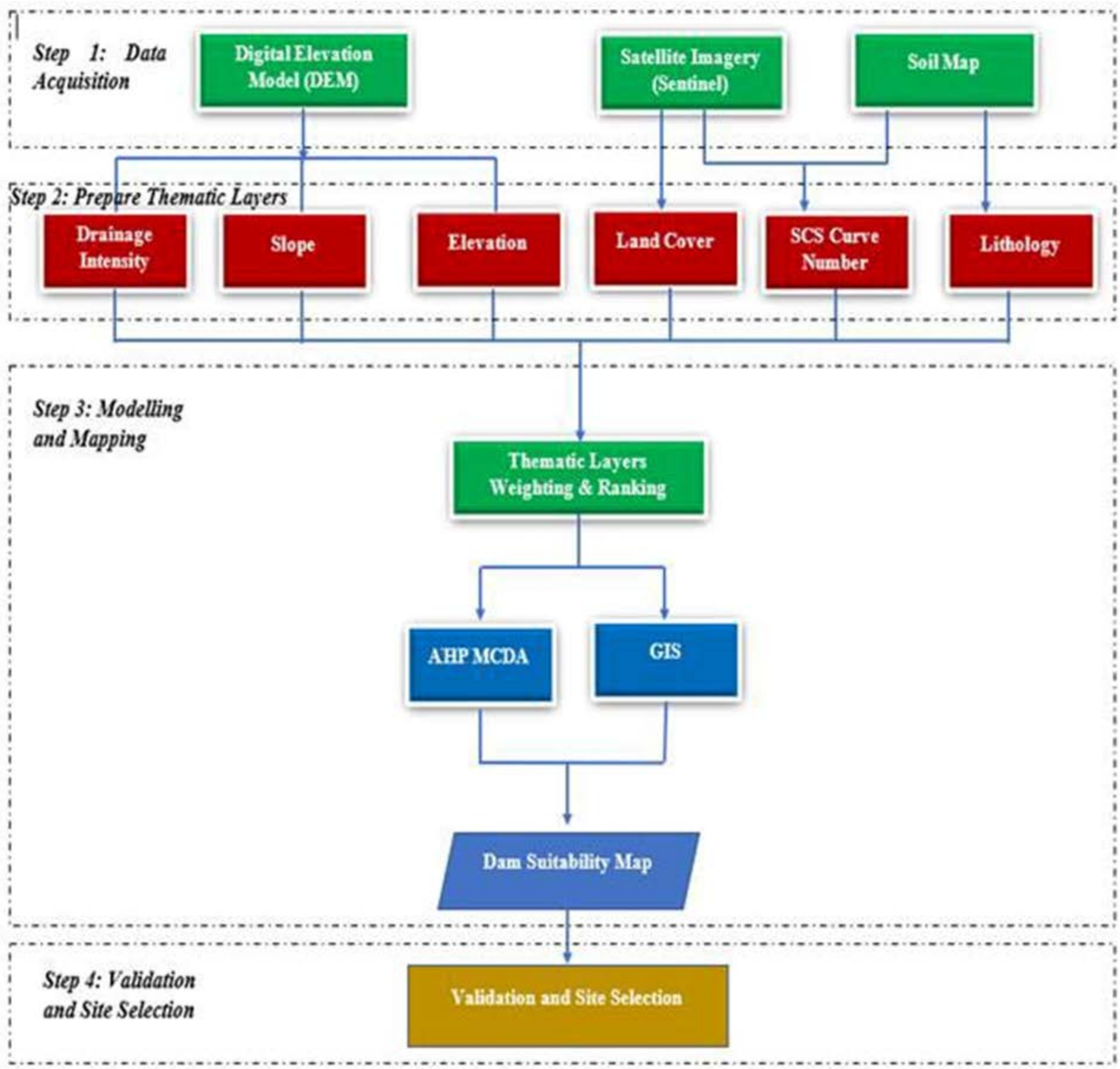

Figure 3: Step-by-step methodology selecting suitable sites for the dams. The approach is phased in four stages: Data Acquisition, Preparation of Thematic Layers, Modelling & Mapping, and Validation & Site Selection.

Step 1 – Data Acquisition: For the purpose of this study, we collected three main sets of data. Raw data was acquired for different sources for the development of thematic layers. Data sets obtained for this purpose included the following:

Digital Elevation Model: Catchment boundary and stream network were extracted from 30 m Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) using a combination Geographical Information System software and tools (Kim et al., 2020). The DEM was downloaded from the USGS earth explorer website (https://earthexplorer.usgs.gov/). Elevation, Slope and Stream Density are generated from DEM.

Land-use: Land cover data was downloaded from the Regional Centre for Mapping of Resource geoportal (RCMRD). The classification of the land cover was based on the Sentinel 2 imagery of 2016 with ten different land cover classes defined. The ten classes were later re-classified by combining classes with similar characteristics resulting in four major land-use categories. Landcover is combined with Soil to generate the SCS Curve Number.

Soil data: Soil data was obtained from the IGAD Climate Prediction and Applications Centre Geoportal (http://geoportal.icpac.net/labbbbbbbbbbbbbbtehyers/geonode%3Asoils). The coverage illustrates the soil's physical and chemical properties. The soil was originally prepared by the Kenya soil survey (KSS) in 1982 and later revised in 1997. The soil data was converted to the hydrologic soil groups based on the provided texture description and later combined with land cover to generate the Curve Number for separation of excess rainfall from infiltration.

Step 2 – Preparation of thematic layers: The obtained raw data was processed to generate thematic layers. Six thematic layers were developed for the study area. Factors for dam siting include slope, elevation, soil, stream order, geology and land use. Hydrological parameters that include slope, flow accumulation, stream density and network, and altitude were extracted from the 30 m Digital Elevation Model (DEM). Six thematic layers were extracted from the three sets of data sets obtained (Figure 4).

A digital elevation model (DEM) obtained was used as an elevation raster with heights above sea level ranging between 1678 and 4898 m. The DEM influences water accumulation and movement. Low elevation areas are considered as suitable for dam siting due to the possibility of accumulating substantial volumes from large catchment areas. Low elevation also provides wider areas to accumulate sufficient run-off volumes. Suitable site for dam construction ought to be gently sloping and well drained. The slope parameter generally affects water velocity in that lower slopes provide a possibility of water accumulation. Slope further influences the safety of dams since large degrees of slope has a higher risk of landslide and gives more pressure on foundations. Similar to elevation, slope was extracted from the obtained 30 m resolution DEM.

Landcover on the other hand constituting of plant biomass is more resistant to both winds as well as water soil erosion thus experiencing limited erosion activities. In this regard, Wooded\Grassland has the highest score. Landcover layer is generated from a satellite derived data. Fine particle soils such as clay experience low infiltration rate. The dam site should be characterized by minimum water losses through seepage, a feature of clay soils. Therefore, clayey soil was given the highest scale. The CN predicts direct runoff retention and further provides a proxy definition of the magnitude of infiltration/seepage losses. CN is dependent on the soil type and land use/cover as well as the hydrogeological condition of the study area. A low CN indicates low suitability for locating dam sites. Suitable sites for dams are generally located along streams of higher orders. Higher order streams have features of larger catchment areas and are located in low elevation. Inclusion of stream factor in the siting process ensures that dams are only sited along the water courses.

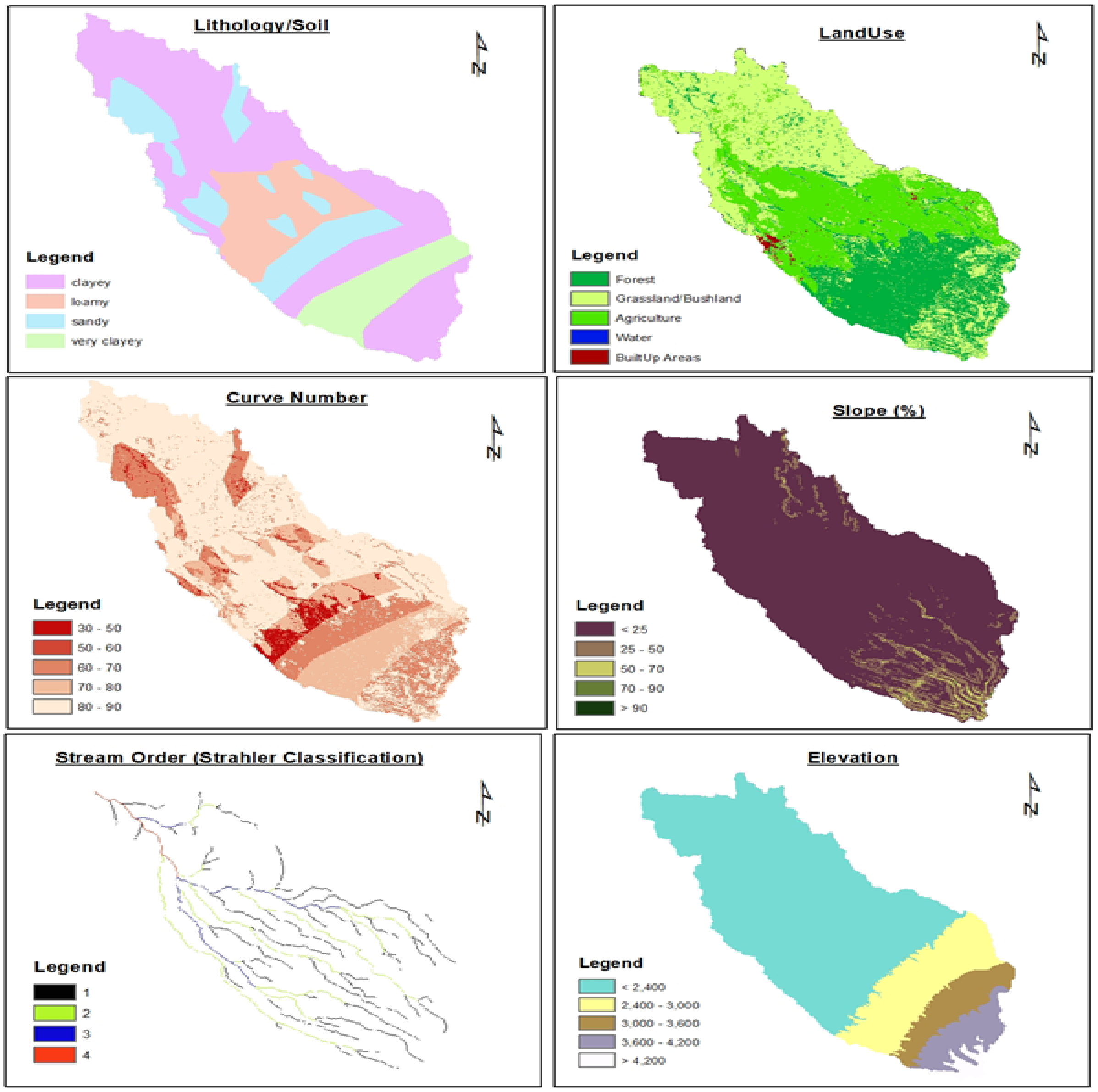

Figure 4: Maps of the thematic layers selected for AHP MCDA dam siting approach: Lithology and Soil, Land-use, curve number, slope, stream order and elevation.

Step 3 – Modelling and Mapping: The thematic layers were processed to model and further map the most suitable sites. Table 1 indicates the weights of the respective thematic layers. The research followed the FAO recommendations and adopted the following parameters to select suitable dam locations: Curve number representing runoff retention properties, stream order representing hydrology, slope and elevation as a topographic parameter, land use/cover indicating the parameter to help exclude highly populated areas, soil texture as a parameter defining infiltration and seepage losses. We adopted the scale of values from 1 to 5 to assign and rate relative importance of the selected layers. The parameters were also weighted using a square framework by assigning a value of 1 to the diagonal element. The weightage of these parameters was then decided from the eigenvalue and the corresponding right eigenvector of the AHP correlation grid. Each parameter was assigned weights based on the constraints set in Table 1. The Hierarchical Process was adopted as an aid to multi-criteria decision analysis (MCDA) and guided the process of determination of the importance of the selected layers.

Table 1: Ranks and weights for thematic layers and their subclasses

Thematic Layer	Thematic Layer Weight	Classes	Ranks	Buffering
Stream Order (Strahler Classification)	20%	Order 1	1	Excludes Order 1
		Order 2	2	
		Order 3	3	
		Order 4	4	
Elevation	10%	< 2400	5	
		2400 – 3000	4	
		3000 – 3600	3	
		3600 – 4200	2	
		> 4200	1	Exclude higher elevation
Slope	20%	<25	5	
		25 – 50	4	
		50 – 70	3	
		70 – 90	2	
		< 90	1	
Curve Number	20%	30 – 50	1	
		50 – 60	2	
		60 – 70	3	
		70 – 80	4	
		80 - 100	5	
Lithology	20%	Very Clayey	4	
		Clayey	3	
		Loamy	2	
		Sandy	1	
Land use/Landcover	10%	Forest	4	
		Bushland/Grassland	5	
		Agriculture	2	
		Open Water	1	Exclude Open Water
		Built Up Areas	1	Exclude Built Up Areas

Step 4- Validation and Site Selection: Subsequently, the output was validated and the weighting fine-tuned to achieve the desired accuracy. The drainage streamlines (vector format) were finally overlaid on the sited dams to select the best locations for siting dams to capture runoff for release during the dry period.

2.2.2. RESERVOIR CHARACTERISTICS

Similar to dam siting, the main primary data for establishing reservoir characteristics is the Digital Elevation Model. Therefore, contours were extracted from a 30 m Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) using a combination Geographical Information System software and tools. The key properties established were area and elevation since these are critical in planning for an optimal storage size that meets the desired water demand. The optimal depth of the dam crest was established to ensure that highest reservoir storage capacity with an optimum surface area was achieved. The proposed location of the small dams is in the semi-arid zones of the catchment with high potential evapotranspiration and hence open water evaporation. In order to evaluate the surface area and reservoir volume, contours were generated for each 2 m rise from a digital elevation model 30 m resolution using GIS. The established dam location was considered as the dam axis and a polygon created considering the contours in the upstream direction. The Cut-and fill tool was used to calculate the volume of storage at each elevation. For each of the cut/fill pixels at the dam location, the volume was calculated. For a single pixel cell, the formula for the volume is as illustrated below:

$$\text{Volume} = (\text{Pixel area}) * \Delta Z$$

where:

ΔZ = Z Before – Z after and Z is the elevation above sea level (m).

The value considered in the net-gain volume the pixels for the dem used had a uniform area of 900 m^2 since it had a 30 m resolution. Polygons were therefore created at different elevation and areas calculated. The elevation at each contour considered was noted as well. Expected inundation areas upstream of the dam location were extracted, the storage volume at the respective contour elevation was estimated using the automated cut and fill tool in ArcGIS 10.3. Figure 8 illustrates the contours and the dams' top area at the two best selected locations.

3. RESULTS AND DISCUSSIONS

Attached below in figure 5 is the dam suitability map. Upstream of the river are sites suitable for the dam sites however because of the steep slope and the need to have dams for downstream inhabitants, it was found that the most suitable sites are two sites as shown in the map.

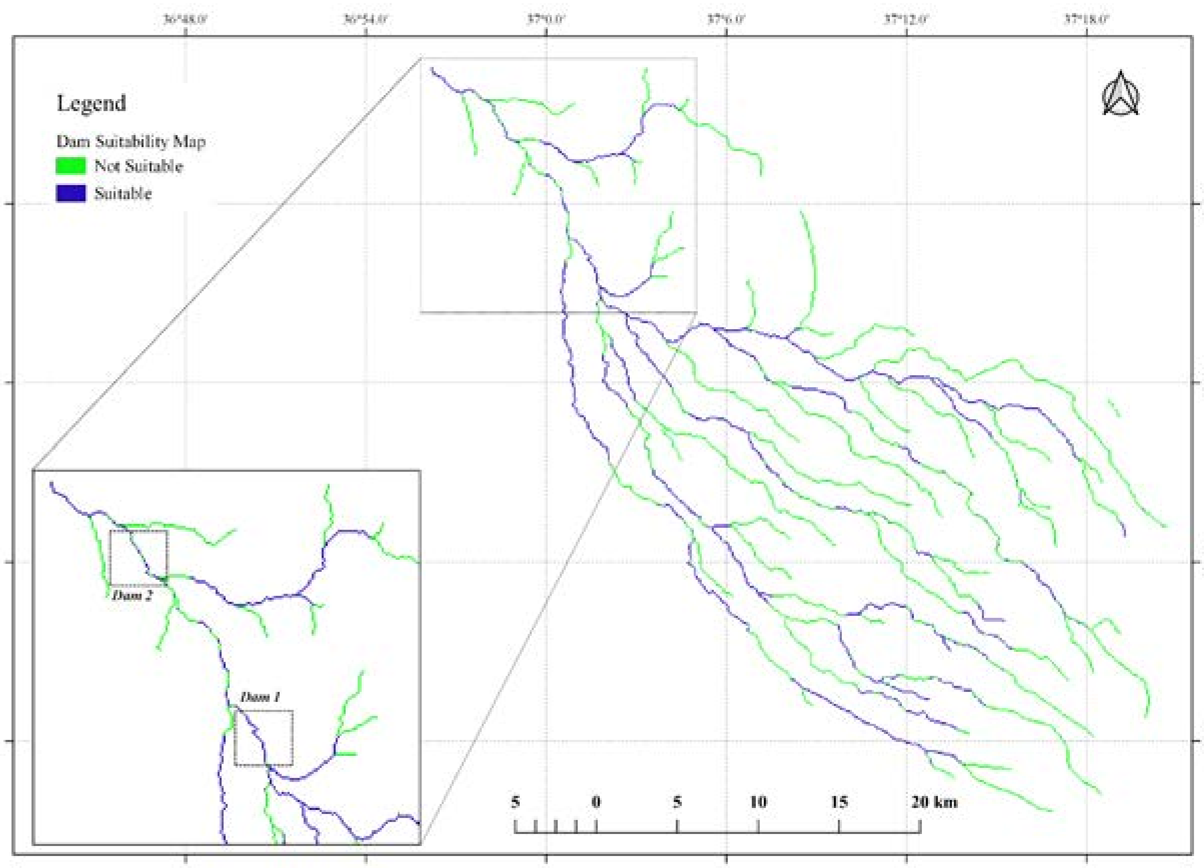

Figure 5: Dam Suitability Map

Among the dams sited along the main river reach, two dams were considered in the assessment as indicated in Figure 5. Figures 6 and 7 illustrate the cross-section of the dam axis at the two selected locations. The main consideration when siting a dam of any size includes safety, environment and economy. Thus, criteria for siting any dam should be sensitive to environmental, physical and economical settings. Geographical Information System and remote sensing have proved to be useful tools for manipulating, handling and generating spatial data relevant to rapid identification of optimum reservoir sites that is vital for planning and decision-making processes. In general, the selected potential sites satisfy, the constraints set in the criteria as the relevant sites selected were in the close proximity to the target water users (lowlands/grazing lands) and outside the settlements and active all-year round agricultural area and thus ensuring that conflicts between the pastoralists and the farmers in the upstream of the catchment. Thus, selected dam locations are buffers that prevent migration/movement of the pastoralists further upstream thereby acting as a vital nature-based tool for conflict prevention in the water scarce Ewaso-Ngiro Watershed.

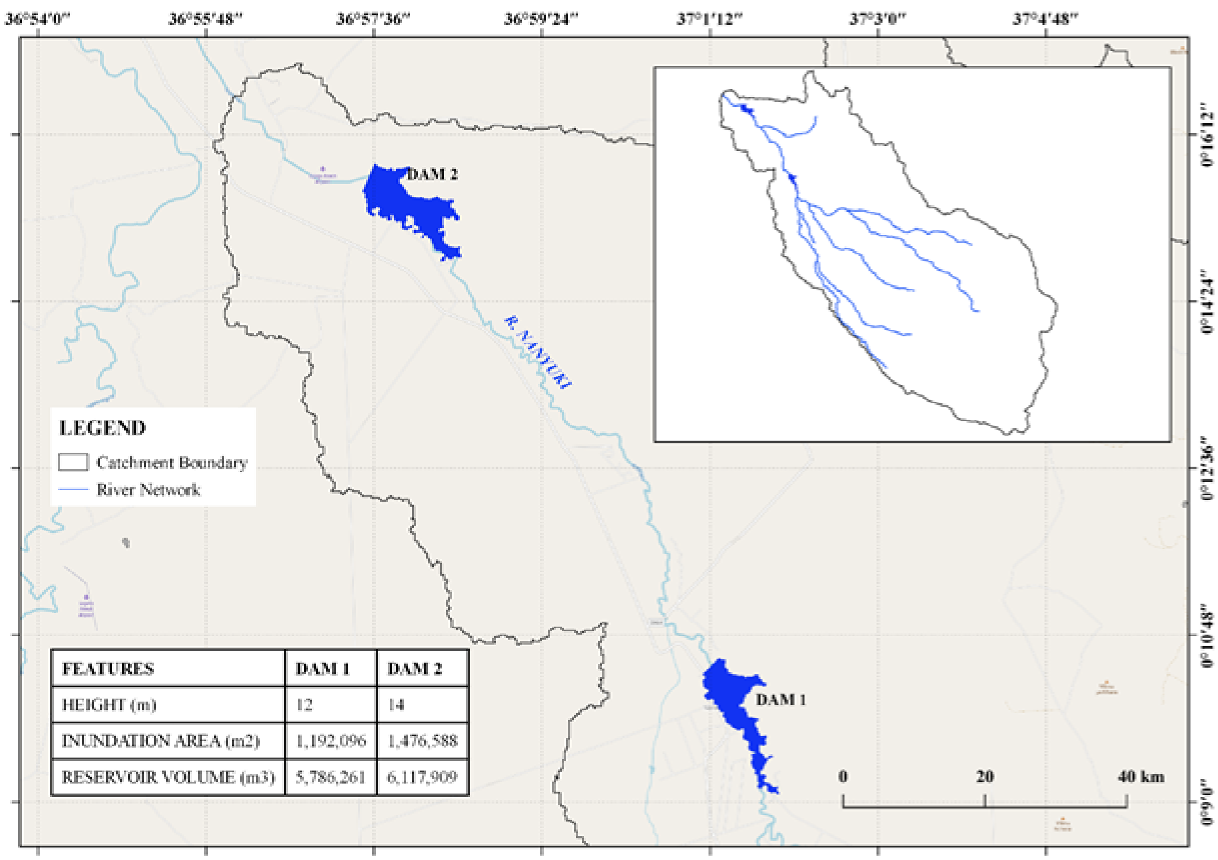

Figure 6: Location of the maps considered for simulating impact of small dams on the downstream flows.

Although GIS and RS based methodology allows for a rapid decision-making process that is more objective, there lies an element of subjectivity associated with assigning weights and scaling layers. With sufficient time, the outcome of the MCDA process of siting dams should be supported by ground truthing to check whether the outcome conforms with the actual site reality.

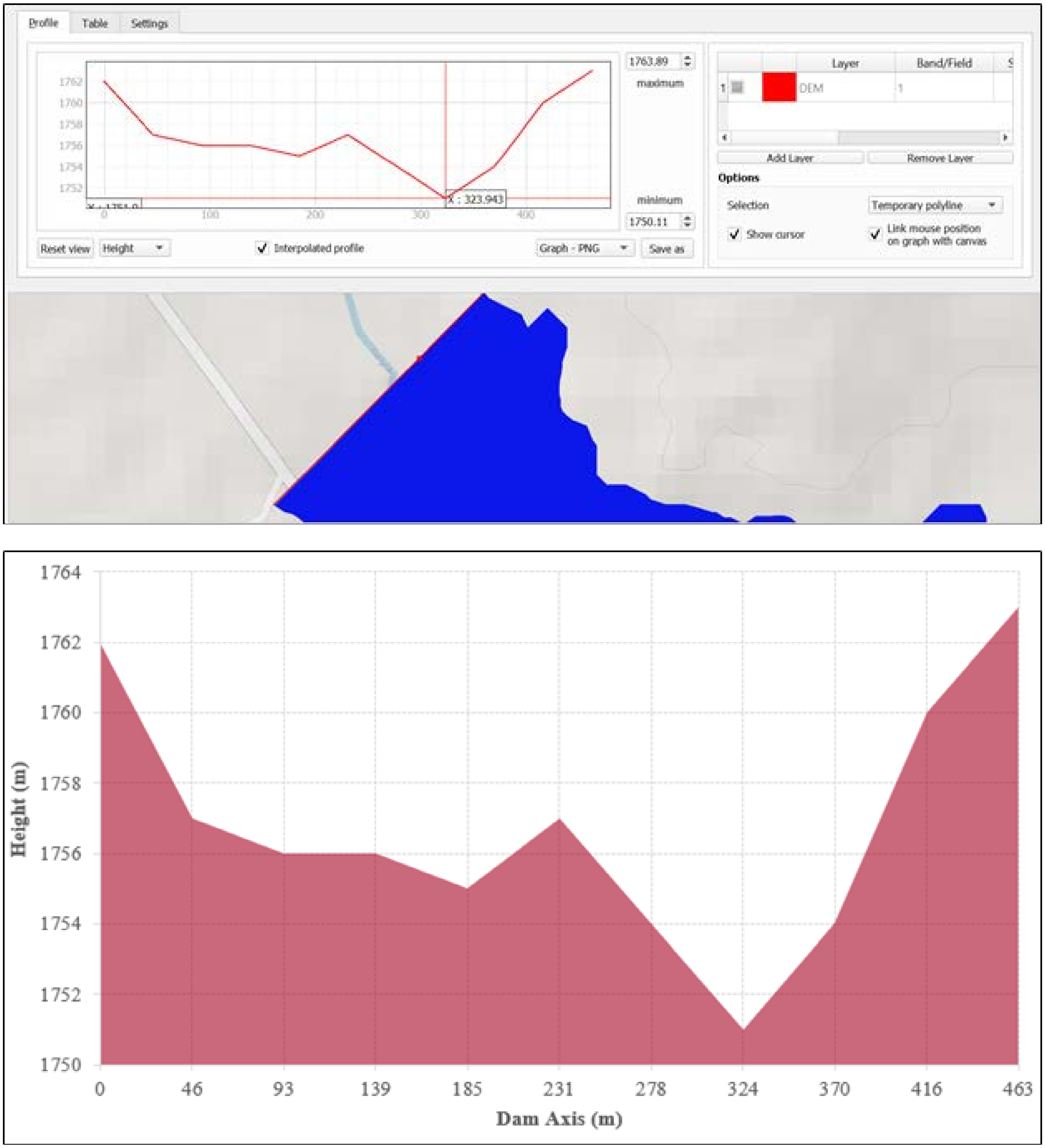

Figure 7: a) Profile of the Dam axis at dam location 1 extracted using the profile tool in QGIS from a Digital Elevation Model (DEM). b) Profile plot for dam 1 axis in excel.

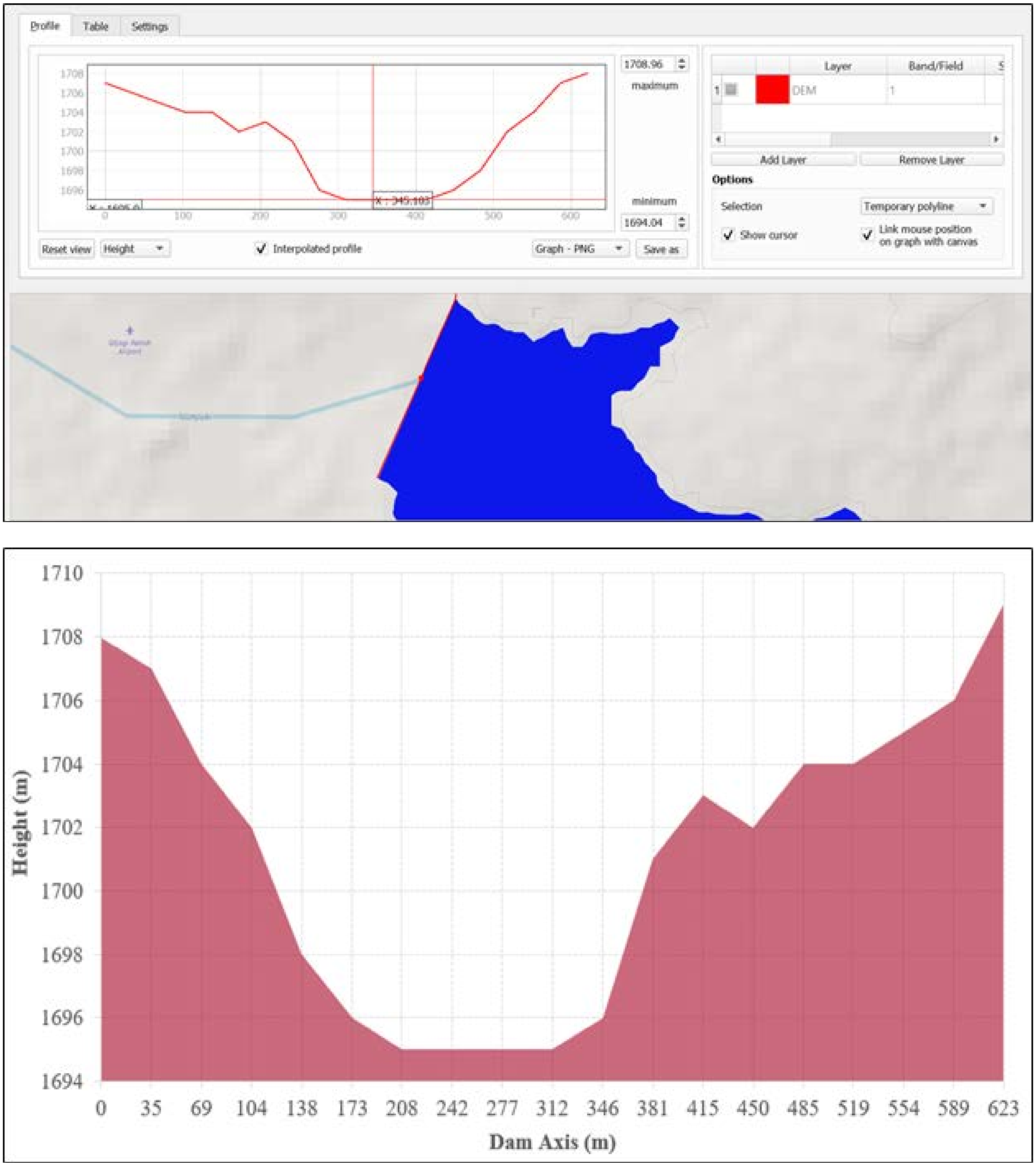

Figure 8: a) Profile of the Dam axis at dam location 2 extracted using the profile tool in QGIS from a Digital Elevation Model (DEM). b) Profile plot for dam 2 axis in excel.

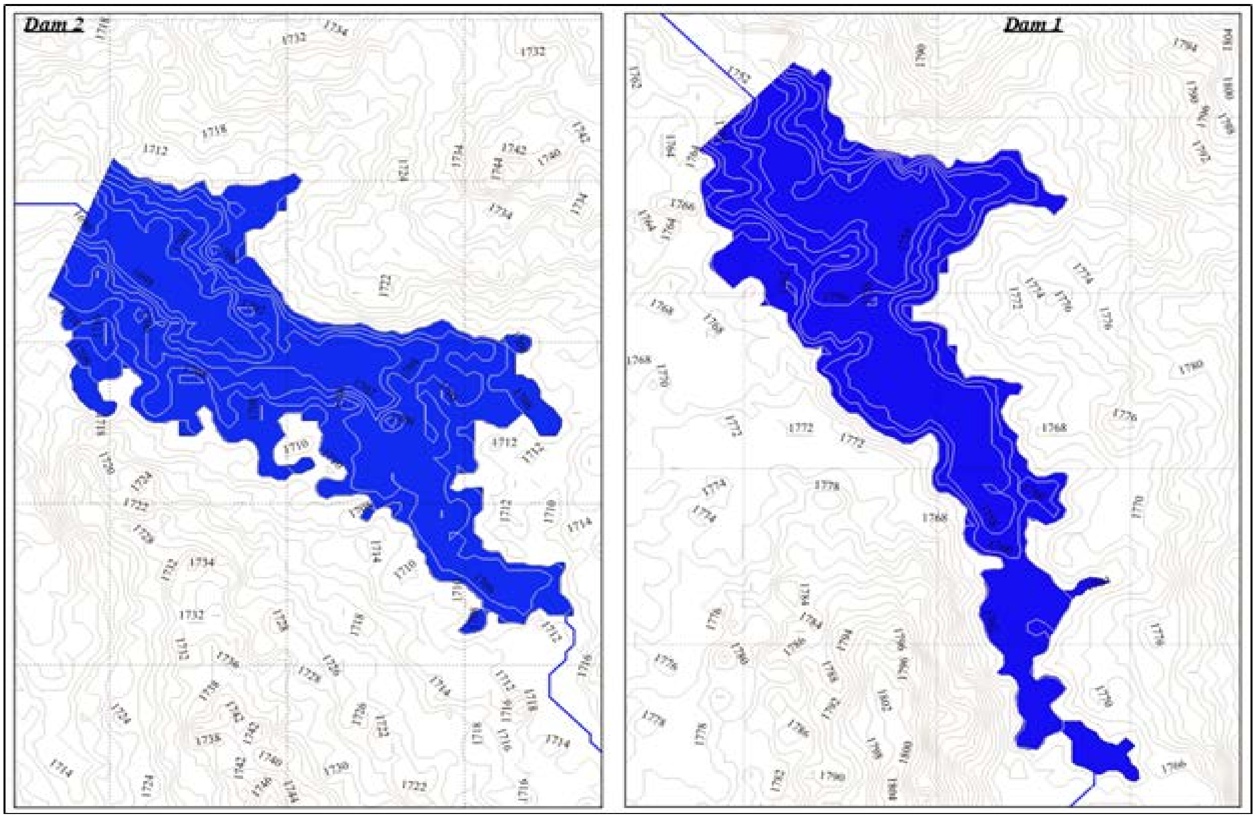

Figure 9: Illustration of the contours and the dams' top area at the two best selected locations. Note the numbers indicate the contour elevations.

The dam axis for Dam 1 is at elevation of 1750 m and that of Dam 2 is approximately 1694. The estimated water storage volumes for Dams 1 and 2 are approximately 5.8 and 6.1 Mm^3 respectively. The top water level for Dam 1 is at 1762 m translating to a dam elevation of more than 12 m high with the free board. Height to the water top water level for Dam 2 is 14 m at an elevation of 1708 m. The focus of this research is mainly on the impact of small dams on downstream flows. Therefore, the dam selected should not be in the category of Large dams as defined by the International Commission on Large Dams (ICOLD). According to ICOLD, a large dam should satisfy the following: a height of 15 m or higher or a height of between 10 and 15 m with a crest not less than 500 m, a spillway of potential minimum discharge of 2000 m/s and a reservoir volume of 15 Mm3. Considering the guidelines set-out by ICOLD, the two dams are outside the category of large dams. In addition, dams are also classified by the Federal Emergency Management Agency (FEMA) in terms of effective height and storage as illustrated in Table 2 below.

Table 2: Dam size classification in terms of effective height and storage (NDNR)

Size	Effective Height (feet) X Effective Storage (acre-feet)	Effective Height
Small	≤3000 acre-feet2	and ≤35 feet
Intermediate	>acre-feet2 and <30000 acre-feet2	or >35 feet
Large	≥30000 acre-feet2	Regardless of height

Source: MDNR

Therefore, the sited dams fall in the category of intermediate dams based on the above classification. Figure 12 and 13, Tables 3 and 4 indicated the storage-elevation-area relationships for the two dams.

Table 3: Elevation-Area-Volume Curve for the Proposed Dam No. 1

Elevation	Reservoir Area (sq. m)	Reservoir Area (cubic m)
1,750	0	0
1,752	16,570	24,707
1,754	197,217	410,521
1,756	421,183	907,518
1,758	626,354	2,200,851
1,760	877,100	3,612,968
1,762	1,192,096	5,786,261

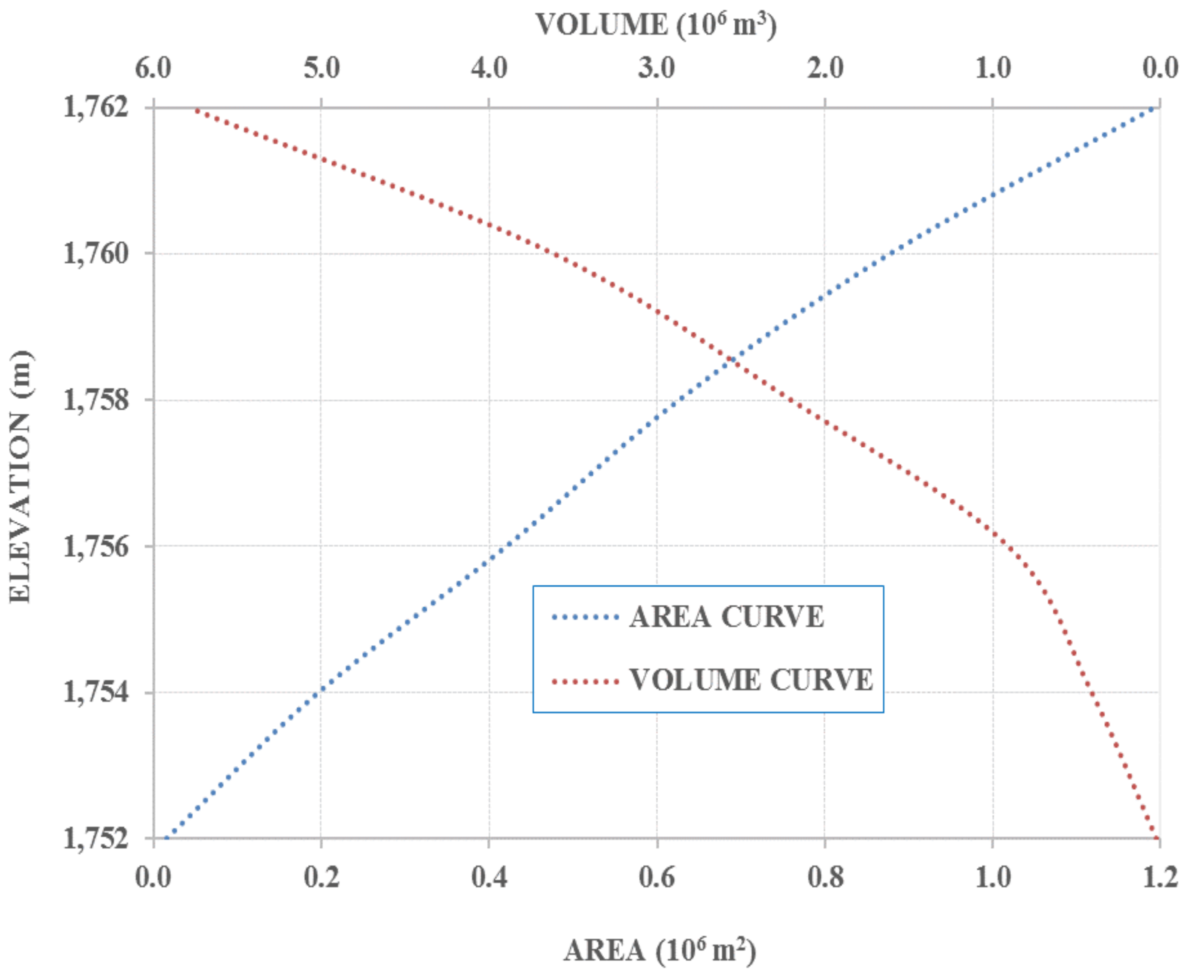

Figure 10: Elevation-Area-Volume Curve for the Proposed Dam No. 1

Table 4: Elevation-Area-Volume Curve for the Proposed Dam No. 1

Elevation	Reservoir Area (sq. m)	Reservoir Area (cubic m)
1,694	0	0
1,696	48,249	33,260
1,698	142,599	268,930
1,700	208,603	607,230
1,702	384,743	1,285,730
1,704	563,938	2,170,442
1,706	965,052	3,717,499
1708	1476588	6,117,909

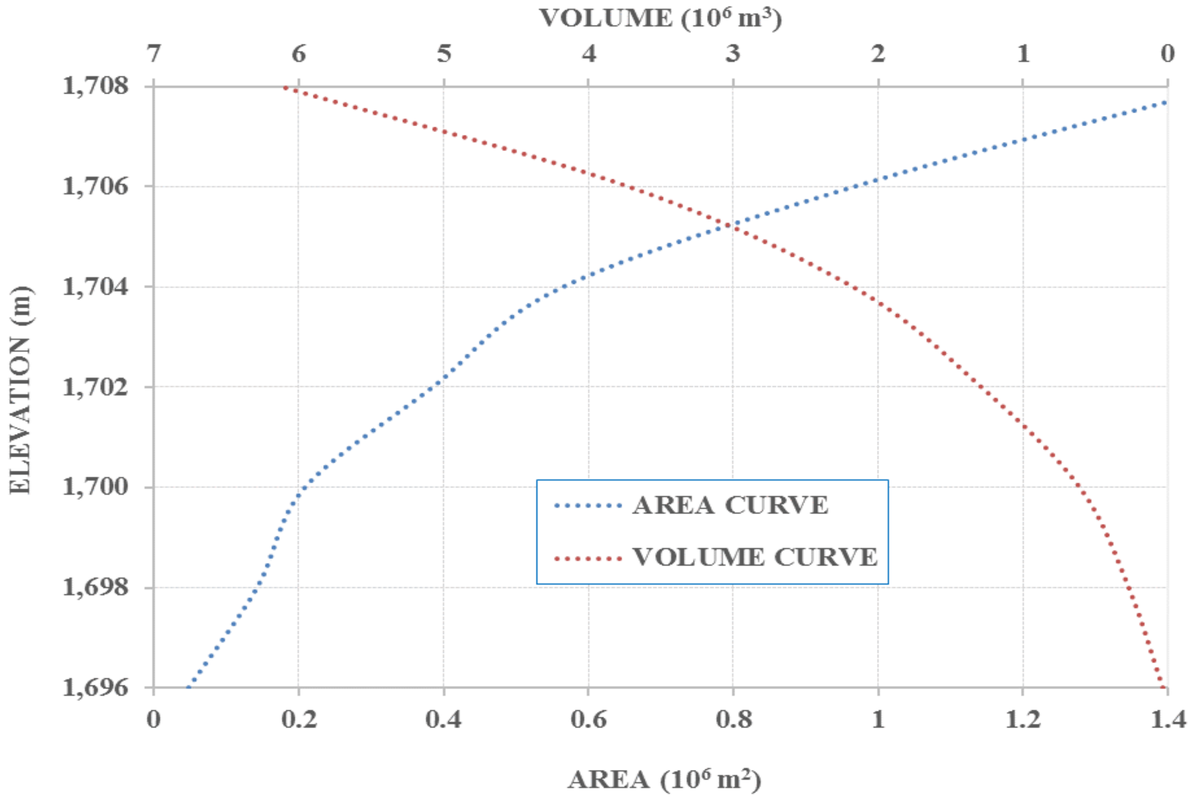

Figure 11: Elevation-Area-Volume Curve for the Proposed Dam No. 1

4. CONCLUSION AND RECOMMENDATIONS

From the results, it is clear that integrated GIS and MCDA with an overlay of thematic attributes to identify suitable locations for the small dams along the Nanyuki River has been successful.

The results further indicates that the integrated GIS and AHP multi-criteria decision analysis is practical, productive, affordable and quick approach towards selecting suitable dam sites. Geospatial data are fundamental in the present-day water resources management.

The AVE curve is a vigorous and important decision-making method for reservoir development. GIS techniques and remote sensing are effective approaches in reservoir characteristics estimation and provide accurate AVE curves. The whole procedure took a lot less time and was much quicker, so the results were visible right away.

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6. REFERENCES

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