APPLICATION OF GEOSPATIAL TECHNIQUES IN SITES SELECTION FOR COMMUNITY SMALL EARTH DAMS IN KAJIADO COUNTY, KENYA

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ABSTRACT

The study was carried out along Ol Kejuado River basin, which is an ephemeral river that traverses the middle part of Kajiado County in Kenya. There are no rainwater harvesting structures along the reiver's course. The study applied geospatial techniques to select sites for community small earth dams. The objectives of the study were to identify suitable criteria for the site location and to apply them to map potential sites. Eight variables which included stream order, slope, precipitation, Net Difference Vegetative Index (NDVI), Topographic Wetness Index (TWI), soil texture, road network and market centres were identified for the site selection analysis. From the analysis, 15 potential sites were generated but four of the sixteen communities identified which included Maparasha in the middle part of the basin, and Emotoroki, Lolakel and Lengisim on the lowest part of the basin did not get any suitable site. Four of the potential sites were further evaluated to establish if they met some important dam design characteristics. Their selection was based on their central position to support maximal sharing by communities. The dam characteristics evaluated included size category, site suitability based on area-volume-dam elevation relationship, dam reliability based on precipitation-runoff ratio and challenges of dam siltation. The community water demand which was projected for a 20 years design period fell above the initially proposed capacity for small earth dams. The annual water demand volume of 201,185m^3 placed the dams in the category of Class B (Middle Hazard Dams) where a dam failure would result in damage to isolated infrastructure and interruption of important utilities downstream. The dam sites were subjected to reservoir Area-Volume-Elevation (AVE) analysis where the four dam sites had capacities ranging from 1.1 to 5.5 Mm^3 (Million cubic metres) at between 7metres and 9metres depths. Results of analysis of precipitation to runoff ratio of the basin between the years 2011 and 2020 indicated that 88.6% of the precipitation was converted to runoff and were sufficient to fill the reservoirs. It was established that soil erosion was high (11.75 to 34.29 tons/Ha) which could compromise the life of reservoir through siltation. The application of geospatial techniques were found to be faster and more economical than the traditionally applied methods. They were also found to be important in aiding decision-making towards site selection for community earth dams.

INTRODUCTION

Water is among the most important and valuable natural resources in the world. Unfortunately, of all the world waters, only less than 1% is potable water for human consumption (UNDP, 2006). More than 1.42 billion people globally live in regions with high to extreme water vulnerability, unimproved sources or where the location of the water would take them more than 30 minutes to collect (Alhattab, 2021). Kenya is regarded as a water-scarce country (Omondi *et al.,* 2014) with prolonged droughts constraining the availability of drinking water, rain-fed agricultural production and pastoralism. The areas hit most are Arid and Semi-Arid Lands (ASALs) which form about 89% of the country (KNBS, 2019) and host 70% of the national livestock herd with an estimated value of Ksh.70 billion. On the other hand, domestic, agricultural and livestock water demand continue to rise whereas the population growth has pushed people to settle in low potential areas. Search for water in ASAL regions is a reserve of women and children whereas men walk long distances with their livestock in search of pasture and water for the animals (Kisiangani, 2015).

Rainwater harvesting (RWH) can supplement and recharge other water resources to overcome the imbalance between water supply and demand under changing climate conditions. Sustainability in RWH development and management requires the participation of the local community as one of the stakeholders. Their input in decision making, and material or labour provision instils ownership during the project life. Legislation is also

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important in executing rainwater harvesting policies. In 2020, a positive move was undertaken by Kajiado County Government by enacting a bill to compel any residential property development to include a rainwater harvesting system to supplement on municipal water supply.

Kajiado County is one of the counties in Kenya that are located in ASALs where the residents travel long distances in search of drinking water. The county has no perennial rivers save for River Ngong and River Ewaso Nyiro which are located at the edges of the County and are therefore only accessible to a few residents. With a population of more than one million residents, Kajiado County has 604 boreholes, 384 water pans, 3 sand dams, 3 small earth dams and 2 large dams (Verde Engineering C., 2019). The County has 6000 acres of land under irrigation in 80 small-scale and two large-scale irrigation schemes (Kajiado-CIDP, 2018) but they are not sustainable due to lack of sufficient water (Tapatayia, 2020).

The main County water operator, Ol Kejuado Water and Sewerage Company (OWASCO) supply water to four main towns, Kajiado, Ilbisil, Isinya, and Kitengela. Though they have invested in boreholes only, the water is only accessible to those living within the towns. This leaves out exploitation of all other potential water resources in the county which could address the other reported challenges in the county which include drought, famine, flash floods and environmental pollution (Kajiado-CIDP, 2018). The trend of extensive exploitation of groundwater, which is prevalent in the county, could have long-term negative environmental effects among them lowering of groundwater table, aquifer salinization and contamination.

Reservoir characteristics

When a dam is constructed across a suitable location of a river basin, a reservoir is created behind the dam by the water retained. Assessment of the characteristics of the reservoir created is important to ensure proposed water demand is met, reservoir safety precautions are taken care of considering the dam hazard category and establishing that the dam depth has a direct influence on the reservoir's surface area and volume. The shape of the reservoir also affects the evaporation losses where deep narrow reservoirs have lower evaporation losses than broad shallow reservoirs (Sayl. et al., 2017)

Classification of dams

Small earth dams fall under the Class A (low hazard) dams (Table I). Errors created by human miscalculations in design can be the source of disasters such as dam failure which place the development downstream of the dam at risk. In carrying out the site study, it is necessary to evaluate if the proposed sites meet the conditions of a low hazard dam. Low hazard dams should not have a height exceeding 5m, their volume should not exceed 10,000m^3 of water and the area of catchment should not exceed 100km^2.

Application of water demand parameter to establish the suitable dam category

Investment in small earth dams is aimed at improving water access and security to communities in the rural set-up to meet the domestic, livestock, irrigation, commercial, tourism and wildlife demands. The water supply design manual stipulates the water consumption rate for each category of consumers (MWI, 2005). The design of a water project requires population projection for 20 years. The present population estimate was based on the latest census but cross-checking with other sources such as local administration is important. Future population forecast is difficult but all possible information should be collected and evaluated. Application of a suitable population projection formula is necessary.

$$P(i+n) = Pi(1+r)^n$$

Equation 1. The exponential equation on Population

TABLE I - DAM HAZARD CLASSIFICATION

Class of Dam	Maximum Depth of Water at NWL (m)	Impoundment and NWL (m^3)	Catchment Area (km^2)
A (Low Hazard)	0 - 4.99	<100,000	<100
B (Medium Hazard)	5.00 – 14.99	100,000 to 1,000,000	100 – 1,000
C (High Hazard)	> 15.00	>1,000,000	>1,000

NWL =Normal Water Level.
Source: MWI (2015)

projection Source: (MWI, 2005)

Where P(i+n) =Population in n years

Pi=Initial Population

r=Rate of growth

n=number of years

In estimating the livestock water demand, the livestock numbers are converted to livestock units (LU); which is equivalent to one grade cow, three indigenous cows, 15 sheep or goats, five donkeys or two camels. Institutional water demand such as schools assumes that 30% of the population attend school (both primary and secondary). The design manual does not include irrigation in domestic water projects. For this project, it is important to consider small scale irrigation in the water demand. The paternalistic community require to be encouraged to develop kitchen gardens for vegetable provision. The same can be used to introduce tree nurseries for environmental conservation.

Application of Reservoir Area-Volume-Elevation Curve (AVE)

The property of the relationship between area, capacity and elevation of a reservoir is important in planning sustainable withdrawal rates and considering reservoir sedimentation rates (Sayl. *et al*., 2017). The water balance (inflow-outflow) determines the volume of water that can be stored by a reservoir. The calculation of reservoir capacity is based on the formula

$$V_{1-2} = ((A_1 + A_2)/2) * (E_2 - E_1)$$

Equation 2. The trapezoidal equation for reservoir volume calculation

Where; V1-2 is the sectional storage capacity (m^3)

A1 is lower contour flooded area (m^2)

A2 is the upper contour flooded area (m^2)

E2 is the upper contour elevation (m)

E1 is the lower contour elevation (m)

When harvesting flood water, the AVE curve is fundamental in planning and modelling considering it establishes the optimum surface area, capacity and depth of the reservoir (Mahmoud. *et al*., 2015). The curve provides key design criteria and essential rules for reservoir operations (minimum and maximum reservoir operating level). Different methods to establish AVE are available which include the application of topographical maps and direct dam survey methods but they are more expensive considering the labour costs and time. However,

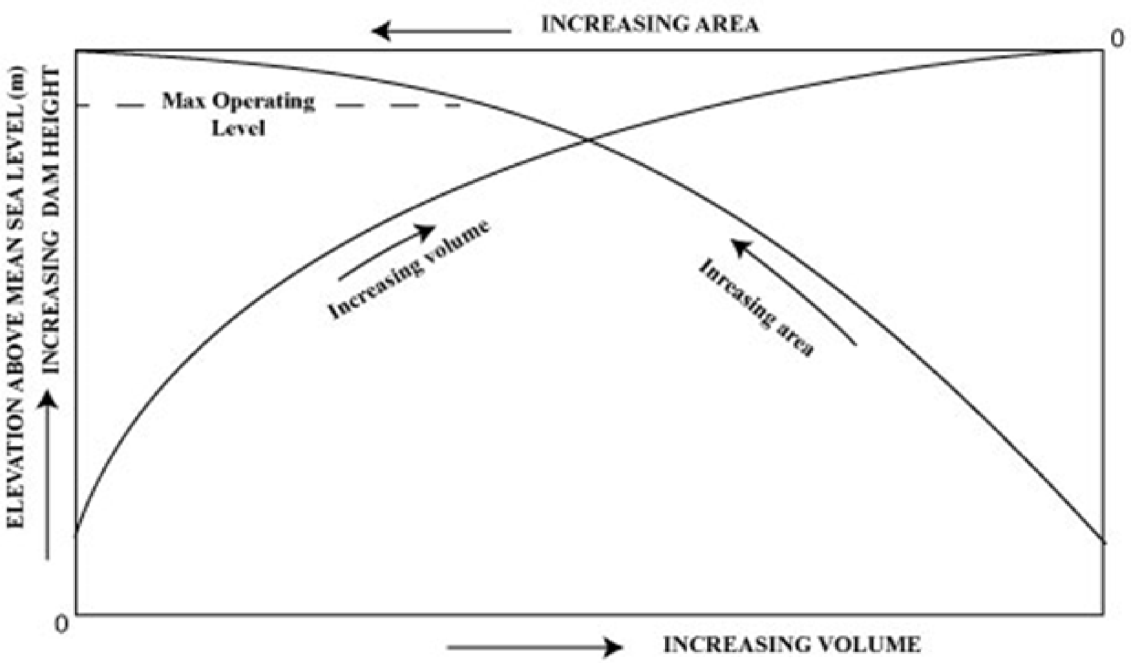


Figure 1. Typical reservoir Area-Volume-Elevation curve (AVE) (Mahmoud. *et al.* (2017)

the application of geospatial technology is economical, reliable, and more efficient and the AVE curves have a relative error that falls below 20% (Mahmoud. *et al*., 2015).

MATERIALS AND METHODS

Study Area

The study area was Ol Kejuado River Basin in Kajiado County which lies between Longitudes 36^0 30' East and 37^0 20' East and Latitudes 1^0 45' South and 2^0 15' South. The river basin has an area of about 2,461km2 and represents about 11.2% of the County. The estimated population in the basin is 125,511 based on the population density of 51 persons per square kilometre (KNBS, 2019). It was noted that the watershed boundaries do not follow administrative boundaries.

Methodology, Analysis and Presentation

This study applied geospatial technology in generating maps of suitable sites for the establishment of small earth dams. The Multi-Criteria Decision Analysis (MCDA) process was adopted to support the complex decision-making criteria. The Multi-Criteria Evaluation (MCE) analysis was used to combine different criteria layers to generate the most suitable decision option. The main advantage of MCE is that it can be done quickly utilizing the data processing and capabilities of Geographic Information Systems (GIS) and Remote Sensing (RS) in the RWH location decision-making process (Liaghat *et al.,* 2013). The MCE process applied in this analysis is expressed in Figure 3.

Generation of Criteria Maps using Geospatial Technology

The Ol Kejuado River Basin was delineated using the pour point method contained in ArcGIS 10.8.1 hydrology toolbox. The Digital Elevation Model (DEM) used was obtained from NASA Space Shuttle Topographic Mission (SRTM-GDEM) open-source website. The DEM was used to generate important topographic features of the study

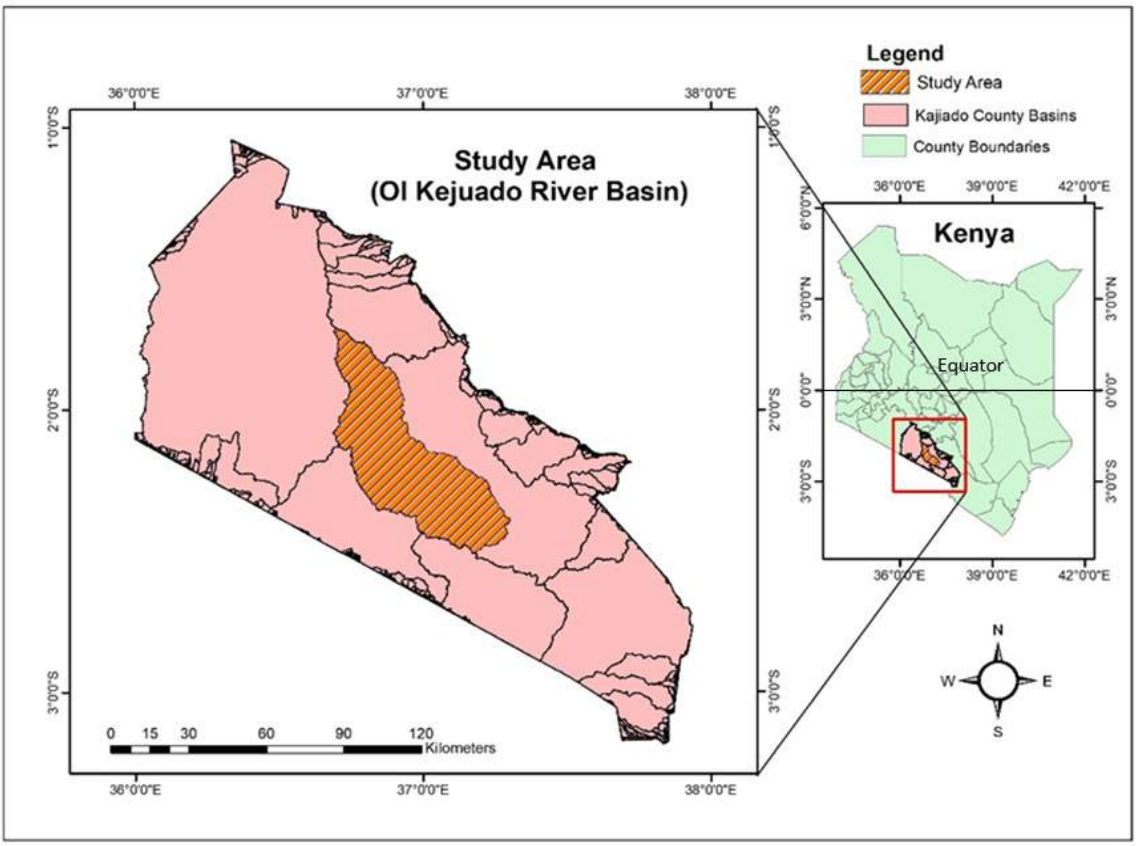


Figure 2. Ol Kejuado River Basin in Kajiado County, Kenya

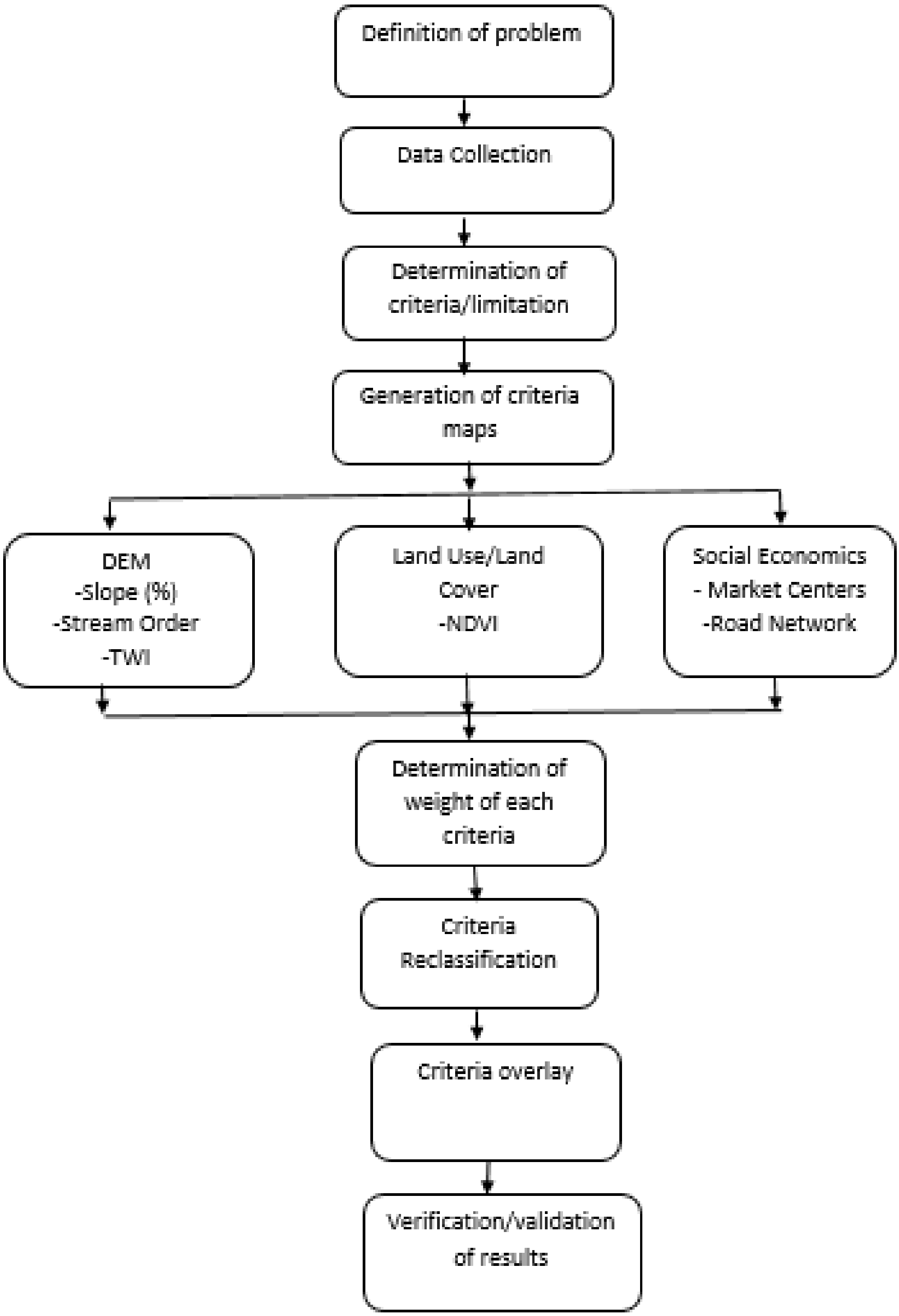


Figure 3. Site selection model using multi-criteria evaluation. Source: Alwan *et al*. (2020)

area which include delineated watershed, stream order, slope and topographic wetness index (TWI) calculation.

Stream order: This is a hydrology tool in ArcGIS that applies the Strahler method to assign the stream numbers (Strahler, 1957). Stream order goes with stream density where the higher the stream order, the higher the stream density. Areas with higher stream order are ranked higher in dam site suitability compared to areas of lower stream order (Mbilinyi *et al.,* 2014).

Slope: This can be described as the incline or gradient of a surface commonly expressed in percentage. Slope influences runoff velocity, drainage and rate of erosion. The DEM of the study area was used to generate a slope map of the drainage basin. From the slope raster, it is possible to determine the suitable position of a dam structure. Suitable slopes range from 0 to 5% (Alwan *et al.,* 2020).

Precipitation: Since Kajiado County does not have sufficient and reliable rain gauging stations, a 10-year high-resolution monthly precipitation data was downloaded from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) website using Google Earth and Climate Engine App. This data had been calibrated to some extent using actual data from ground stations. The rainfall distribution was carried out using Thiessen's Polygon method in ArcGIS and a rainfall distribution map was generated (Figure 7). Annual average precipitation in the 10year period ranged from 614mm to 789mm increasing uniformly from the highest elevation to the lowest elevation. If this map was applied in the overlay, the uniformity of precipitation changes from one edge to the other would mean that if a certain range was set as most suitable for RWH, the other region with different precipitation depths would automatically be eliminated. Since lower rainfall depths than that of the study area (504 mm) have been considered for setting up dams across the river courses, (Alwan et al., 2020b), the whole study area was assumed to meet the threshold and it was logical to exclude rainfall criteria map in the final overlay.

Evaporation: This contributes to water loss from RWH structures. Regions with very high evaporation rates (Chimoyi, 2009), may be limited in choices of RWH systems. A 20-year monthly potential evapotranspiration (PET) rate was obtained from NASA's Global Land Data Assimilation System (GLDAS) Noah Model website mean daily PET rates ranged from 1.5 to 5mm/day.

Land cover: This is used to refer to the surface cover on the ground which could be vegetation, urban infrastructure, water or bare soil. Land use refers to the purpose the land serves such as parking lot, agriculture, road reserve, and military camp among other uses. The Normalized Difference Vegetative Index (NDVI) is an indicator of the vegetation greenness and is widely used as a change detection method providing detailed information for detecting and monitoring changes in land use and land cover (LULC). The NDVI was calculated using spatial analyst tools in ArcGIS 10.8.1 applying the formula (Equation 1). Landsat 8 images were obtained from NASA open-source website.

$$NDVI = \frac{NIR - R}{NIR + R}$$

Equation 1. Normalized Difference Vegetative Index Equation

NDVI values obtained from the spatial calculator ranged from -1.12 to +0.51. This indicated that the study area had large areas with no vegetation to few patches of grasslands and light vegetation.

Soil types: Soil characteristics influence the location of an RWH system (MWI, 2015). Description of soil characteristics which include texture, drainage properties, perviousness and plasticity determine the choice of dam construction material and foundation conditions. The soil datasets were obtained from the Soil and Terrain Database for Kenya (KENSOTER) available at Kenya Soil Survey (Ngeno, 2016). The study area had four categories of soil texture. Clay soils dominated the study area covering 48.8%, loam soils with 35.5% and sandy clay loam with 15.7%. Since clays and loam soils with infiltration of rates of 1 and 5mm/hr constituted 81% of the study area, the soil thematic map was not included in the final overlay.

Road network: Accessibility of community dams from public roads is very important. This allows free movement of people and livestock to the dams without trespassing through private property. It may not be prudent to site an earth dam too close or across a road infrastructure to minimize security risks related to drowning and conflict of interest. The Open Street Map (OSM) was used to generate a road network map.

Market centres: Community small earth dams require to be sited close to the communities they serve to help reduce the travel distance and time spent in search of water (Mugo and Odera, 2019). Since the rural parts of the county are sparsely populated with an average population of 51 persons per square kilometre (KNBS, 2019), it was not possible to consider every household in the study. Since most of the market centres were not visible on Google map, a physical tour of the study area was conducted where 16 small towns and market centres were captured with a GPS and mapped.

Topographic wetness index: Topography is a first-order control of the spatial variation of hydrological conditions which affects the distribution of soil moisture. The topographic wetness index (TWI) combines local upslope contributing area and slope. TWI is commonly used to quantify topographic control on hydrological processes. Groundwater flow often follows surface topography (Burt and Butcher, 1986). The formula is expressed in equation 2:

$$TWI = \ln\left(\frac{a}{\tan\beta}\right)$$

Equation 3. Topographic Wetness Index formula

Where: a is the local up-slope area draining through a certain point per unit contour length.

$\tan\beta$ is the local slope.

In ArcGIS 10.8.1, the TWI map was generated from an SRTM DEM. To ensure the values are positive, the DEM was transformed to Universal Transverse Mercator (UTM) projections. Applying the map algebra spatial calculator, the formula [ln (a /tan β)] was used to generate the TWI map.

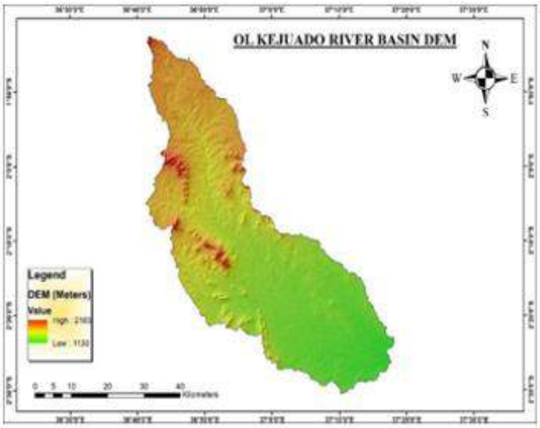
Standardization of criteria maps

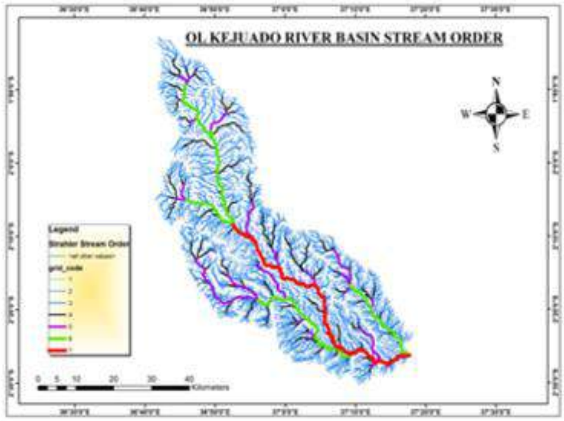
Standardization makes measurement units uniform to enable weighted overlay since the criteria maps are in different units. The vector layers were converted to raster layers during standardization where the reclassification tool contained in the spatial analyst of ArcGIS was applied. The Euclidean distance function in ArcGIS 10.8.1 was applied in converting the market and road vector layers to raster layers to enable reclassification.

After standardization was carried out to covert the units to a uniform state, the datasets were reclassified into four categories of suitability: Not suitable (Rank 1), Marginally suitable (Rank 2), Moderately suitable (Rank 3), and Highly suitable (Rank 4). Six criteria layers were qualified for reclassification. The maps generated after standardization are shown in Figure 5.

TABLE II - THEMATIC LAYERS WEIGHTS, CLASSES AND RANKS

Thematic layer	Thematic layer weight (%)	Classes	Rank
Stream Order (Strahler Order)		Order 1,2,7	1
	20	Order 3	2
		Order 4	3
		Order 5, 6	4
Slope		6 -59%	1
	15	5 - 6%	2
		4 - 5%	3
		0 - 4%	4
Land Use (NDVI)		-0.12 - 0.0	1
	15	0.0 - 0.15	2
		0.15 - 0.2	3
		0.2 - 0.5	4
Distance from Roads (Metres)		0 - 200	1
	15	5,000 -11,600	2
		2,500 - 5,000	3
		200 - 2,500	4
Distance from Markets (Metres)		0-1,000	1
	15	6,000-17,400	2
		3,000-6,000	3
		1,000-3,000	4
TWI		2.9 - 4	1
	20	4 - 6	2
		6 - 8	3
		8 - 11	4


OL KEJUADO RIVER BASIN DEM
Legend
DEM (Meters)
Value
N
W
E
S


OL KEJUADO RIVER BASIN STREAM ORDER
N
W
E
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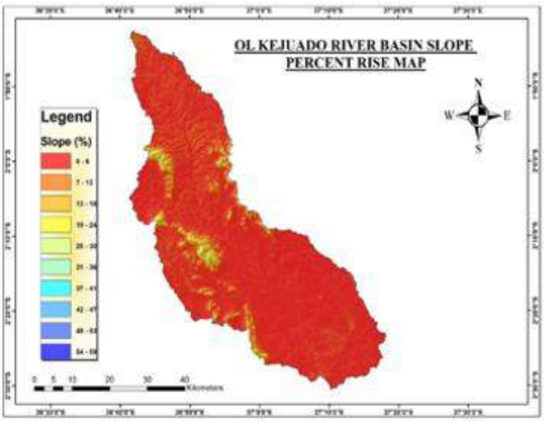
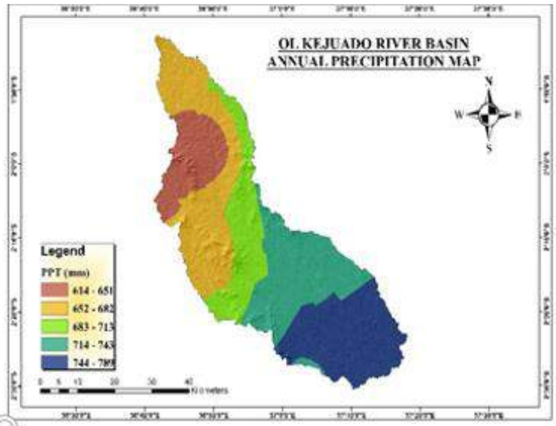
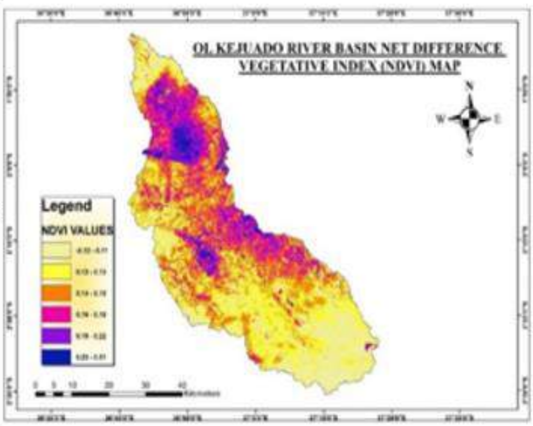
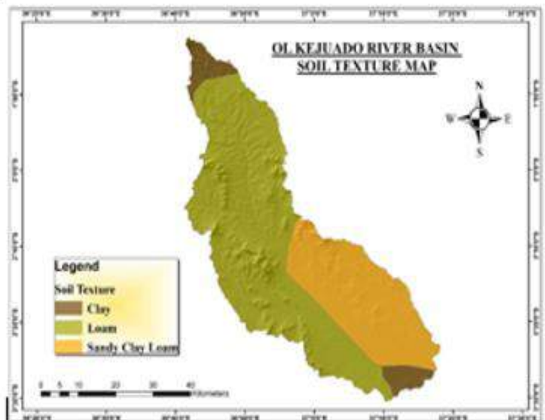
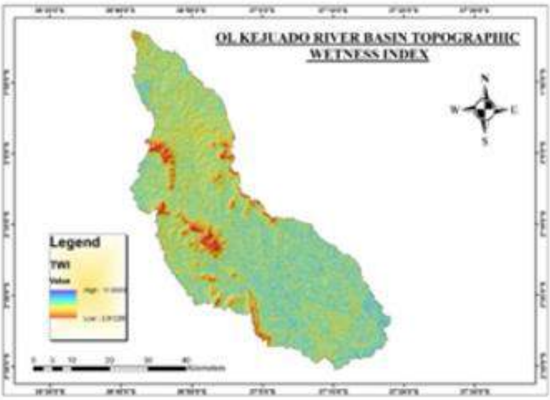
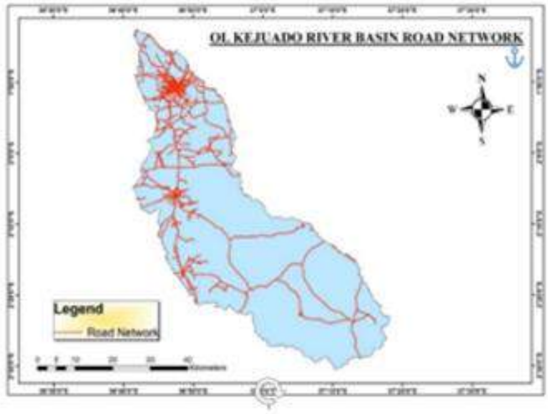

OL KEJUADO RIVER BASIN SLOPE PERCENT RISE MAP
Legend
Slope (%)
N
W
E
S


OL KEJUADO RIVER BASIN ANNUAL PRECIPITATION MAP
Legend
PPT (mm)
614 - 651
652 - 682
683 - 713
714 - 743
N
W
E
S


OL KEJUADO RIVER BASIN NET DIFFERENCE VEGETATIVE INDEX (NDVI) MAP
Legend
NDVI VALUES
N
W
E
S


OL KEJUADO RIVER BASIN SOIL TEXTURE MAP
Legend
Soil Texture
Clay
Loam
Sandy Clay Loam
N
W
E
S





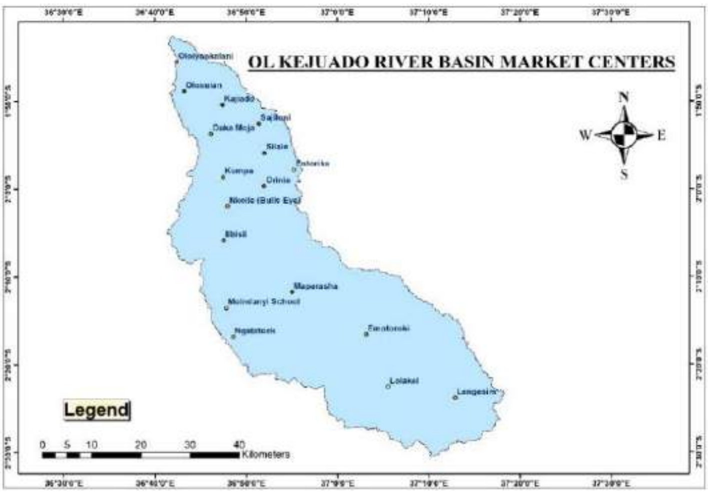


Figure 4. Maps of the Digital Elevation Model (DEM) and thematic layers selected for the Multi-Criteria Evaluation (MCE) dam siting approach: Stream order, Slope, Precipitation, Normalized Difference Vegetative Index (NDVI), Soils texture. Topographic Wetness Index (TWI), Road network and Market Centres

Datasets overlay

The reclassified datasets which were set to a common measurement scale were then combined using the spatial calculator tool in ArcGIS 10.8.1. Datasets included stream order, slope, land use/land cover, road networks, market centres and topographic wetness index. Selected suitable points were picked and stacked with individual reclassified layers where they fell within the most suitable area of each layer.

RESULTS

To reduce the distance travelled by the community in search of domestic and livestock water in the study area, the geospatial technology approach was utilized to identify potential sites for setting up small earth dams. Using the technology, 15 sites were identified as suitable for setting up small earth dams (Figure 6). Four of the sixteen identified communities which included Oloiyankalani at the highest part of the study area, Maparasha in the middle, Emotoroki and Lengesim at the lowest part of the study area were not favoured by the analysis. The suitable dam site locations were further presented based on their location on the stream network of the study area (Figure 7). A table bearing the coordinates of the suitable sites was prepared (Table III).

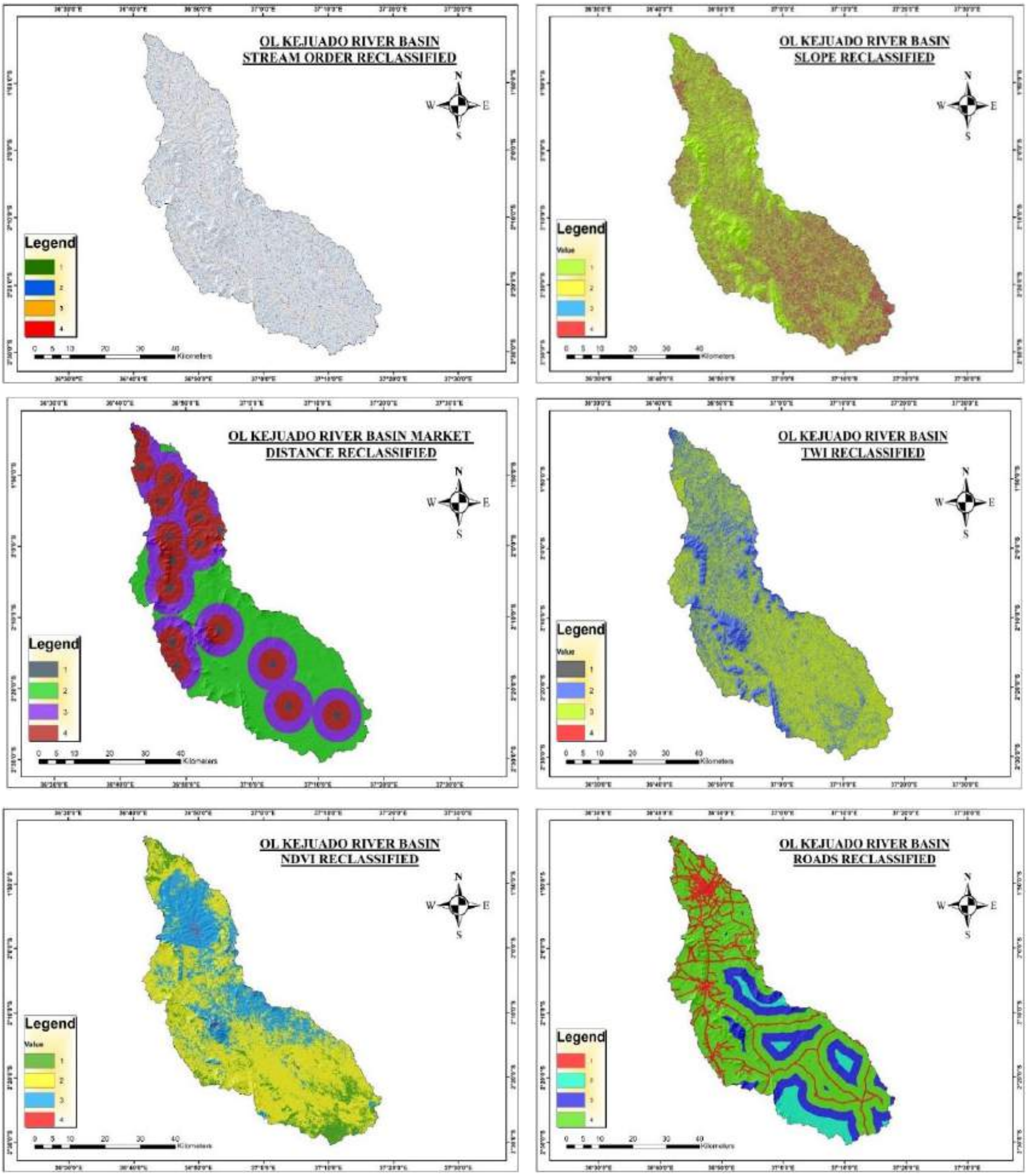


Figure 5. Maps of the reclassified thematic layers selected for the Multi-Criteria Evaluation (MCE) dam siting approach: Stream order, slope, Distance to market, Topographic Wetness Index, Normalized Difference Vegetative Index (NDVI) and Road network

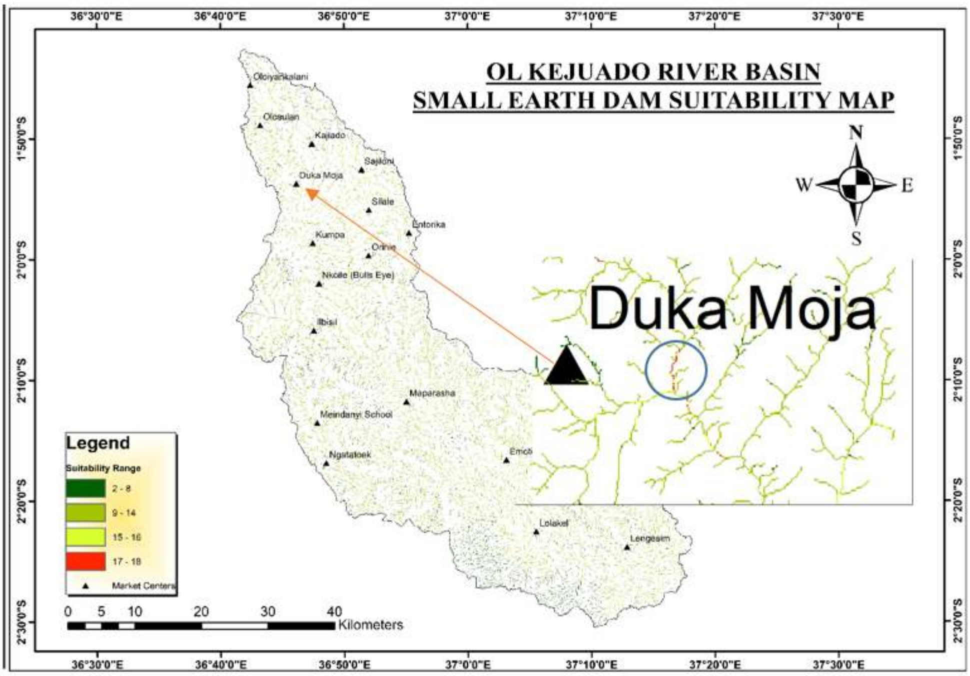


Figure 6. Final overlay with most suitable dam spots indicated in red colour as circled in the magnified part of the map

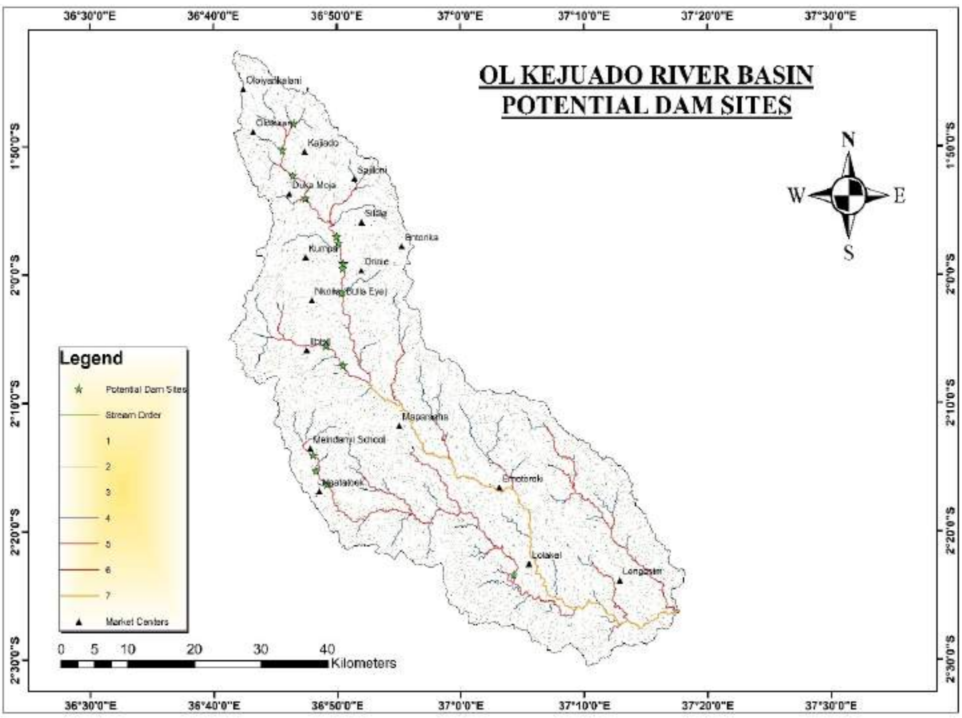


Figure 7. Generated map of potential sites within the stream order

TABLE III - LOCATIONS OF POTENTIAL SITES AND THE FAVOURED COMMUNITIES

Point Location	Metres (Eastings)	Metres (Northings)	Degrees (East)	Degrees (South)	Favoured Markets
1	250791.0	9796644.0	36.75984963	-1.838404633	Kajiado
2	252508.0	9800451.0	36.7753182	-1.804007407	Olosuiyan, Kajiado
3	252340.5	9792994.5	36.7737298	-1.871414893	Duka Moja
4	254240.0	9789752.0	36.79075931	-1.900750255	Duka Moja
5	258949.0	9784247.0	36.83300707	-1.950573249	Silale
6	259229.5	9783353.0	36.83551713	-1.958658907	Kumpa, Orinie
7	259938.5	9780362.0	36.84185302	-1.985708046	Orinie
8	259847.0	9779711.5	36.84102318	-1.991587966	Orinie
9	259689.6	9776149.0	36.83956652	-2.023793696	Nkoile
10	257342.0	9768578.0	36.81837834	-2.092211628	Il Bisil
11	259933.5	9765763.0	36.84163108	-2.117693692	Il Bisl
12	255400.6	9752888.0	36.80072838	-2.234032188	Meidany
13	255860.0	9750613.0	36.80482626	-2.254605515	Meidany
14	257556.0	9748640.0	36.82004166	-2.272465622	Ngatatoek
15	285555.0	9735687.0	37.07153577	-2.389946768	Lolakel

Important Site Suitability Checks

The map overlay is not a complete site suitability identification method. More geospatial checks are required to confirm if the suitable sites conform to important dam design characteristics. Checks that were carried out in some of the identified sites included dam hazard classification, dam size classification in terms of Area-Volume-Elevation Curves, chances of filling the dam based on annual average precipitation and chances of dam siltation. From the generated potential sites, four sites were identified for further analysis (Table IV). These sites were selected for a reason that if developed, they could be shared by more than one community. It would be more economical to construct one large dam than two small separate dams. Since the analysis required a projected community water demand, combined market centres would generate a more realistic demand considering the low population density documented in rural Kajiado County.

TABLE IV- SELECTED SUITABLE DAM SITES FOR EXTENDED EVALUATION

Site No	**Coordinates** (East)	(South)	**Shared Markets**
1	36.77531820	36.75984963	Olosuiyan and Kajiado
2	36.83300707	1.950573249	Silale and Sajiloni
3	36.84102318	1.991587966	Orinie and Nkoile
4	36.82004166	2.272465622	Meidany and Ngatatoek

Reservoir Hazard Category

To identify the dam category, the water demand for the target community was required to be established. The community water demand was projected for a 20 years design period. In the study area, the main water demand was for domestic and livestock use. There were very few agricultural practices which were more concentrated in the upper part of the study area at Loiyankalani, Olosuiyan and Kajiado Town where crops were rain-fed. Lower parts of the study area that included Lengisim, Lolakel and Emotoroki had small to large volumes of wildlife sharing the pastureland with the livestock. In these areas, there were many incidents of wildlife destroying water infrastructure, especially at the borehole sites while searching for water. However, the design manual for small dams and water pans does not consider sharing of community water resources with wildlife (MWIS, 2015). Water demand for the population covering a radius of 5,000 metres from the suitable site defined as moderately suitable in the ranking was projected to 20 years ultimate design period. In estimating the livestock water demand, the livestock numbers were converted to livestock units (LSU) where an equivalent of a livestock unit is one grade cow that consumes 50l/head/day. Though the design manual does not consider sharing domestic water resources with irrigation, it was found an opportunity for the pastoralist community to engage in small scale irrigation where 50% of the total water demand was suggested to be added for irrigation and environmental management. Kajiado Central where the larger part of the study area falls covers an area of 4,212 km^2 and population a density of 53 persons per square kilometre. This population density was applied where an area around a community earth dam with a radius of 5,000m was used for the population projection.

The ultimate annual water demand volume of 201,185m^3 realized (Table V) placed the dams in the category of Class B known as Middle Hazard Dams which have water capacity ranging from 100,000 to 1,000,000m^3. This class of dams is described to have the potential to make a significant impact on a resource where a dam failure would result in damage to isolated infrastructure and interruption of important utilities downstream. Since there was no water resources infrastructure constructed across the river downstream, there would be no major impact expected.

Dam size classification in terms of Area-Volume-Elevation Curves

The dam sites were further subjected to reservoir Area-Volume-Elevation (AVE) analysis considering they are intended to harvest flood water. The AVE curves provide key design criteria and essential rules for reservoir operations considering they establish the optimum surface area, capacity and depth of the reservoir. The 30m DEM was used to evaluate and generate AVE curves where contours in the range of 2 metres rise were extracted using ArcGIS. The coordinates of the dam were considered as the dam axis. Area polygons at each elevation were created upstream of the axis. Analysis of the reservoir volume and area at each contour was carried out using the ArcGIS program where AVE curves values generated (Table VI to IX) were drawn using the excel program (Figures 8 to 11).

TABLE V - POPULATION PROJECTION (2022 TO 2042)

Item description	Present population (2022)	Growth rate	Population in 20yrs (2042)	Demand rate per day	Total Annual Demand (Mm^3)
Human	4,003	5.5%	11,680	10 l/h/d	42,632
Livestock Units	1,626	5%	4,312	50 l/h/d	78,694
Institutions	1,200	5.5%	3,501	10 l/h/d	12,779
Sub Total					134,105
Irrigation 50% of total demand					67,053
Total					**201,185**

TABLE VI - DAM 1. GENERATED AREA-VOLUME-ELEVATION TABLE

Dam 1 Elevation (M)	Reservoir Area (M^2)	Reservoir Volume (Mm^3)
1,664	0	0
1,666	99,031	101,888
1,668	396,125	669,414
1,670	585,618	1,751,141
1,672	796,060	3,219,471
1,674	1,229,322	5,474,339
1,676	1,700,673	8,617,632

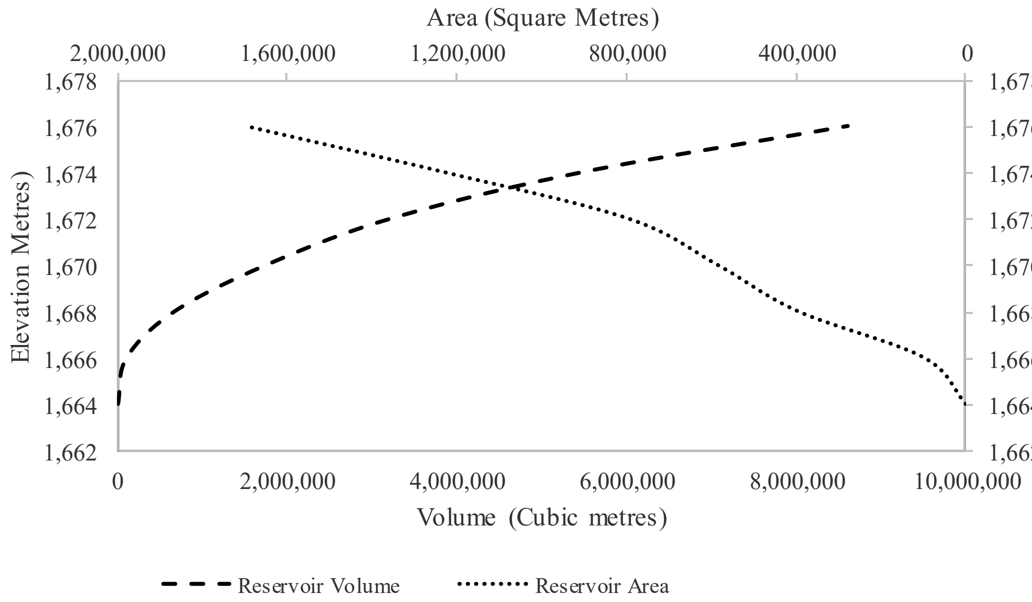


Figure 8. Dam 1. Reservoir area-storage capacity-elevation curve

TABLE VII - GENERATED DAM 2. AREA-VOLUME-ELEVATION TABLE

Dam 2 Elevation (m)	Reservoir Area (m^2)	Reservoir Volume (m^3)
1547	0	0
1549	15,235.6	39,041.2
1551	69,512.4	125,693.6
1553	142,833.7	348,514.2
1555	185,683.8	698,932.8
1557	231,390.6	1,139,812.8
1559	404,695.4	1,898,735.7

TABLE VIII - DAM 3. GENERATED AREA-VOLUME-ELEVATION TABLE

Dam 3 Elevation (m)	Reservoir Area (m^2)	Reservoir Volume (m^3)
1530	0	0
1532	335,183.0	643,703.8
1534	482,777.8	1,543,556.0
1536	722,738.4	2,843,342.5
1538	977,934.6	4,653,521.3
1540	1,255,984.2	6,991,232.6
1542	1,595,928.3	10,019,306.6

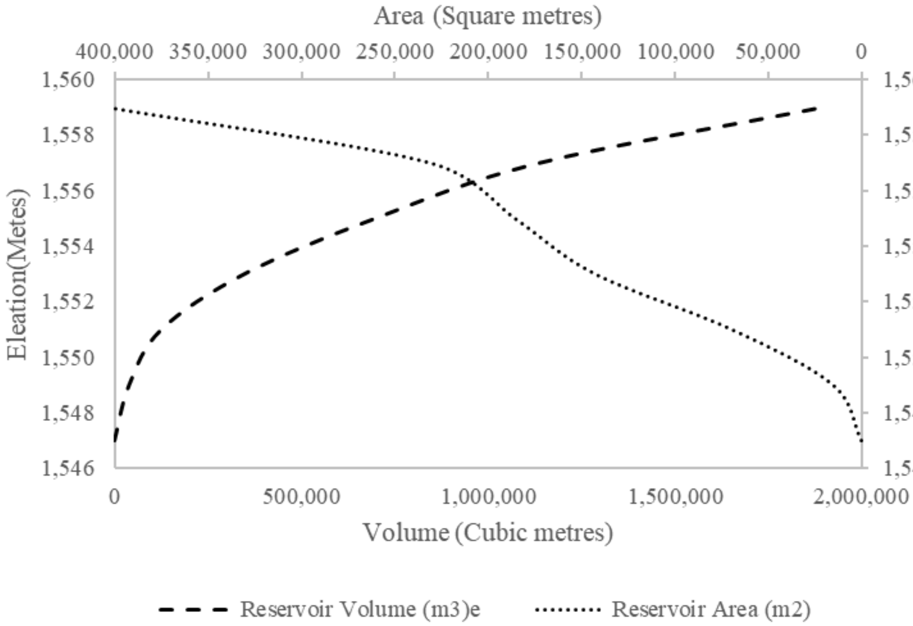


Figure 9. Dam 2. Reservoir area-storage capacity-elevation curve

TABLE IX - GENERATED DAM 4. AREA-VOLUME-ELEVATION TABLE

Dam 4 **Elevation (Metres)**	**Area (M²)**	**Volume (M³)**
1465	12,379	17,140
1467	56,181	101,888
1469	161,878	338,040
1471	258,053	813,200
1473	454,211	1,593,072
1475	632,277	2,780,496

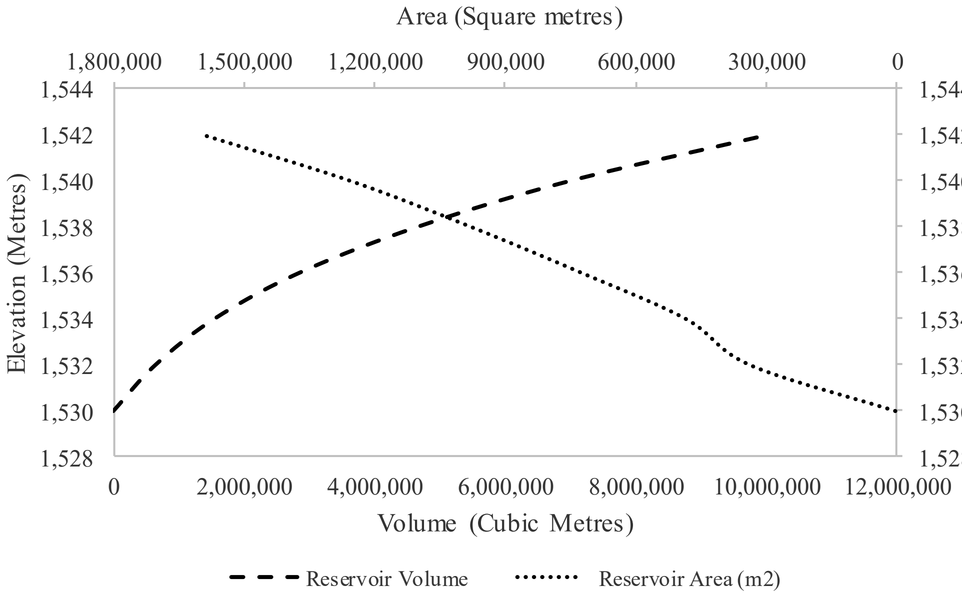


Figure 10. Dam 3. Reservoir area-storage capacity-elevation curve

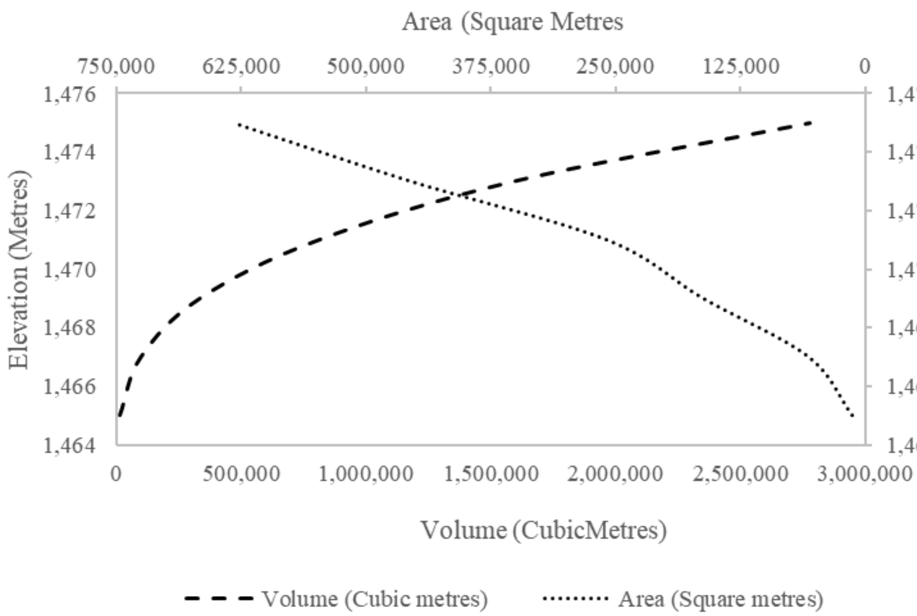


Figure 11. Dam 4. Reservoir area-storage capacity-elevation curve

From the AVE analysis, the 4 dams performed as follows: Dam 1 generated 4.8Mm^3 at 9m depth; Dam 2 generated 1.1Mm^3 at 8m depth; Dam 3 generated 5.5Mm^3 at 7m depth, and Dam 4 generated 1.3Mm^3 at 7.5m depth respectively. Dam 1 and 3 performed best with very large volumes of water at low depths. One of the considerations when carrying out a site investigation of a dam of any size includes safety, environment and economy. The established results already confirm the economic value of the two sites in constructing high-capacity reservoirs at low embankments. The contours and reservoir top area of the four dams were generated for the visual expression of the reservoir created when the dams are constructed (Figure 12). The AVE of all the four dams placed the sites in the category of middle hazard and intermediate dams. The dam sizes suggested carrying out an environmental and social impact assessment (ESIA) before their construction.

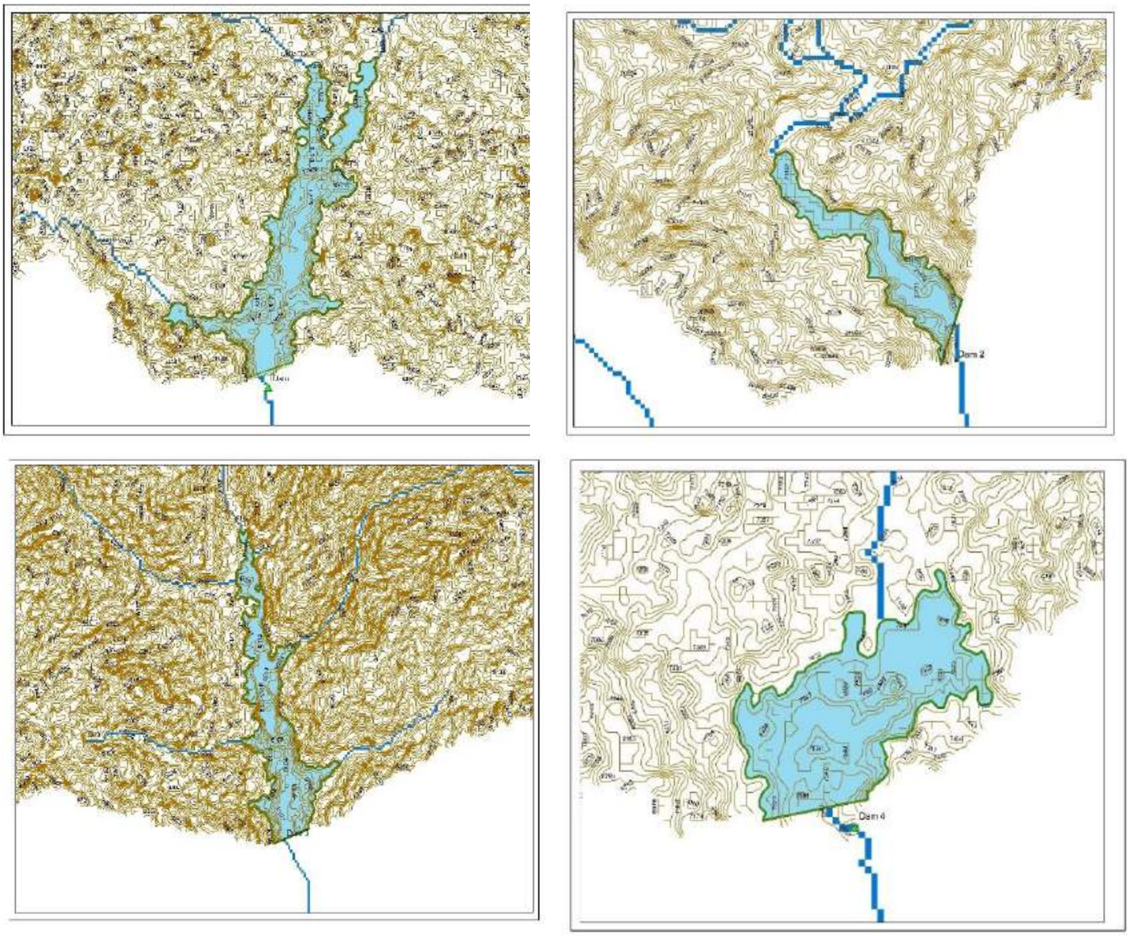


Figure 12. Illustration of the contours and the reservoir top area at the four selected potential sites named Dam 1, Dam 2, Dam 3 and Dam 4.

Dam suitability based on dam width

Dam construction is laborious based on the huge volumes of material required to construct the wall. Before constructing the wall (dam) it is necessary to consider the volumes of water which will be harvested and stored behind the wall. The cross-sections of the four reservoirs at the dam sites were calculated and their profiles were generated (Figure 13) where a provision of a 1-metre freeboard was included. All the dams had generally the same depth ranging from 8 to 10 metres and width ranging from 350 to 435 metres (Table X). However, their volumes differed by a big margin where Dam 3 was the most suitable (economical) based on the volume generated behind the wall while Dam 4 was the least suitable.

TABLE X - COMPARATIVE TABLE OF THE DAM WIDTH, DEPTH AND VOLUME OF WATER GENERATED OF DAMS 1, 2, 3 AND 4.

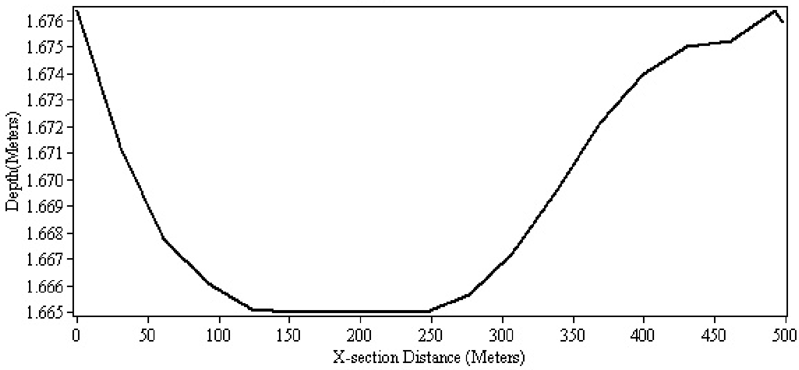
Dam number	Dam width with 1m freeboard (m)	Dam depth with 1 m freeboard (m)	Reservoir volume (Mm^3)	Comparative suitability
1	400	10	4.8	Very suitable
2	350	9	1.1	Suitable
3	435	8	5.5	Most suitable
4	400	8.5	1.3	Least suitable

Dam suitability based on Annual Surface Runoff Volume

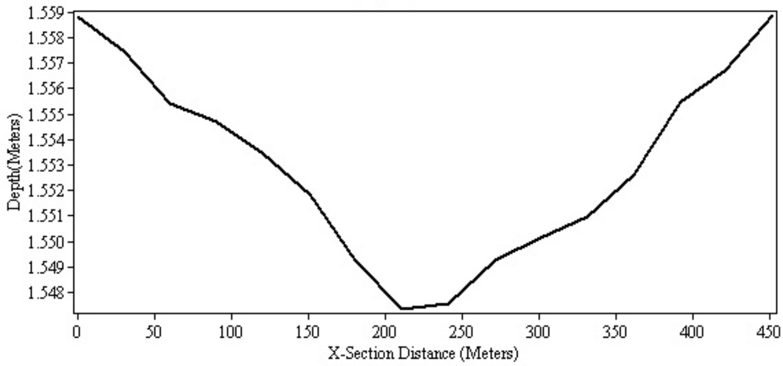
The sustainability of a reservoir would be futile if the volume of surface runoff expected to reach the dam site was not evaluated. Estimation of the surface runoff was carried out using Soil Conservation Service Curve Number (SCS-CN) integrated with geospatial technology. The SCS-CN approach is a commonly used empirical method to estimate surface runoff from a river basin (USDA, 1972). To obtain the surface runoff, parameters applied included precipitation, soil map and land use/ land cover map. Since all the dam sites are located in the same river basin, only one dam site was evaluated. A 10-year high-resolution monthly precipitation data was downloaded from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) website using Google Earth and Climate Engine App. This data had been calibrated to some extent using actual data from ground stations. The Google Earth and the study area shapefile were both loaded to the Climate Engine App where the CHIRPS monthly precipitation data (2011-2020) was extracted and presented in the form of an excel worksheet (Table XI). From the FAO world soil database, the study area had three dominant soil textures; sandy clay loam, loam and clay which fell under Hydrological Soil Group (HSG) Class C concerning infiltration capacity of the soil groups A, B, C and D (Table XII).

TABLE XI - AVERAGE ANNUAL PRECIPITATION DEPTHS IN THE OL KEJUADO RIVER BASIN FROM THE CHIRPS WEBSITE

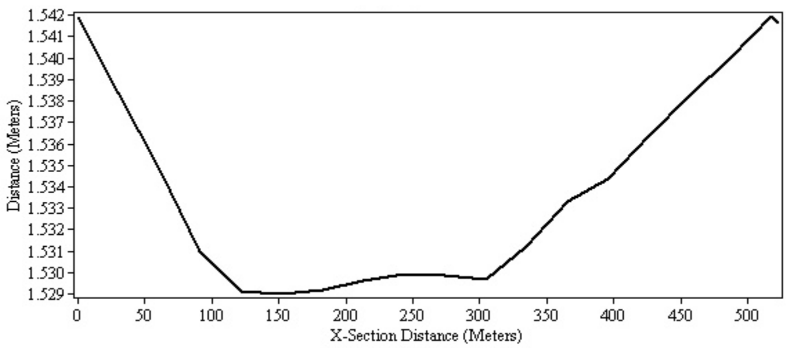
		Precipitation depths (2011-2020) in mm								
Months	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	16.53	29.67	37.13	32.53	50.17	119.07	50.13	124.30	114.23	193.63
2	51.53	37.23	19.87	68.97	44.10	40.43	39.50	62.47	60.47	44.33
3	75.20	13.20	106.77	91.67	67.73	48.07	35.83	68.10	87.73	68.37
4	62.77	150.90	175.97	43.70	153.97	171.97	154.33	154.33	146.17	154.30
5	43.13	59.80	29.93	32.70	66.00	58.33	49.23	95.97	66.03	41.20
6	2.83	7.30	8.63	21.27	14.67	11.43	11.43	14.33	13.33	11.50
7	0.67	2.90	1.93	2.77	4.63	2.30	9.50	4.00	3.60	13.20
8	0.43	7.73	3.27	3.67	3.67	2.33	4.20	10.13	4.63	1.33
9	10.27	8.07	10.13	12.47	10.80	5.60	12.57	24.83	12.33	21.93
10	48.23	17.00	4.53	22.33	27.13	14.07	53.20	23.70	87.37	22.17
11	123.90	137.00	68.63	105.63	210.77	130.57	185.60	42.67	193.13	87.03
12	30.77	136.90	111.37	72.33	96.47	130.27	68.93	91.70	169.97	40.07
Total	**466.26**	**607.70**	**578.16**	**510.03**	**750.10**	**734.43**	**674.47**	**716.53**	**959.00**	**699.07**



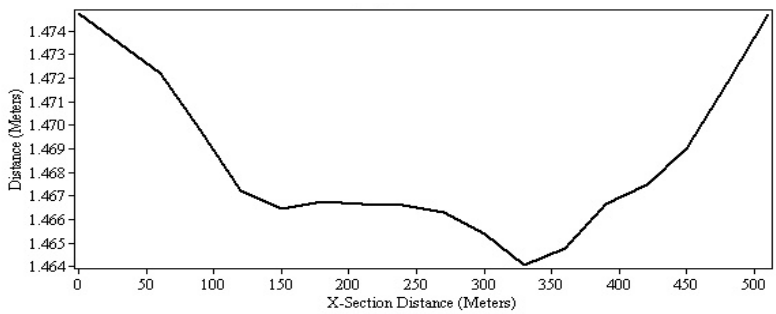
Dam 1



Dam 2



Dam 3



Dam 4

Figure 13. Cross-section dam profiles of Dam 1, 2, 3 and 4

The land use and land cover map for the study area were obtained from the FAO Space Agency Initiative (SAI) GlobCover database (USDA, 1972). To calculate the surface runoff volume (S), several hydrological equations are applied which include curve number (CN), Potential Maximum Storage (S) and Surface Run-off depth (Q).

Potential Maximum Storage

Potential maximum storage also called potential maximum retention represents infiltration occurring after runoff has commenced. The infiltration is guided by the infiltration rate at the soil's surface or infiltration rate through the soil profile or the water holding capacity of the soil profile.

TABLE XII - SOIL CONSERVATION SERVICE CLASSIFICATION TABLE

Hydrologic Soil Group (HSG)	Soil Textures	Runoff Potential	Water Transmission	Final Infiltration
Group A	Deep, well-drained sand and gravel	Low	High rate	>7.5
Group B	Moderately deep, well-drained with moderate	Moderate	Moderate rate	3.8-7.5
Group C	Clay loams, shallow sandy loams, soils with moderate to fine textures	Moderate	Moderate	1.3-3.8
Group D	Clay soils and swell significantly when wet	High	Low	<1.3

Courtesy USDA (1972)

Curve Number

The land use land cover map for 2006 was overlaid with the HSG map of 2006. The land cover was found to fall in the HEC-HMS Manual under runoff curves for other agricultural lands The study area had three major hydrologic conditions; Pasture, grassland and range continuous rated as a poor hydrologic condition with a CN value of 74, forage for graving rated as fair with a CN value of 79 and ground cover not heavily grazed rated as good with a CN value of 86. To get the weighted curve number, the three curve numbers for each land use are multiplied by the area under the land use and divided by the total area of the watershed.

$$CN_\omega = \frac{\sum CN_i * A_i}{A}$$

Equation 4. Derivation of Weighted curve number

Where:

CN_w Weighted Curve Number

CN_i Curve Number from 1 to any number N

A_i Area with Curve Number CN_i

A The total area of the watershed.

The Weighted Curve number obtained using a spatial calculator generated a figure of 78.5.

The potential Maximum storage (S) was computed using

$$S = \frac{25400}{CN} - 254$$

Equation 5. Derivation of Potential maximum storage formula

With the CN as 78.5, then S was calculated to be 69.6

Surface Runoff depth

The surface runoff depth (Q) is calculated using the formula

$$= \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad Q$$

Equation 6. Derivation of surface runoff depth formula

Where P is the average annual precipitation in mm (Table XIII).

To get surface runoff depth (Q), each of the annual precipitation (P) from 2011 to 2020 was calculated with

$$V = (A * 10^6) * (\frac{Q}{1000})$$

Equation 7. Surface runoff equation

Where:

V Runoff volume in cubic metres

A Catchment area experiencing the respective runoff depth in square metres.

Q Annual runoff depth in millimetres

The runoff volume of the selected catchment of Dam 2 was calculated using the runoff depth layer using excel (Table XIII) where the area of the dam catchment was 367,250,982m^2.

percentage of in-flowing sediments retained in a reservoir that determines its lifespan. The sediment efficiency of a reservoir decreases with age as more sediments are accumulated in the reservoir rendering it uneconomical. The Practice Manual for Small Dams (MWIS, 2015) has developed and categorized representative figures for sediment yields of catchments in Kenya and their class of severity (Table XIV).

The Dam 3 catchment was evaluated to forecast if the soil erosion rate and sediment yield would jeopardize the life of the reservoir. It had been identified through the questionnaires that the community in the study area do not know about environmental management. The harsh environmental conditions and poor land management would most likely cause substantial erosion rates that would affect the reservoir capacity. The Soil and Water Analysis Tool (SWAT) (Arnold *et al.*, 1998) was used to predict the rate of soil erosion and sediment yields in the Dam 3 catchment area. Inputs into the analysis included soil type, topography, land-use and climate data. The DEM was used to generate the catchment of Dam 3 and develop the slope map. From the slope, land use/land cover and soil map, 96 Hydraulic Response Units (HRU) were realized using SWAT. These are portions of a sub-basin which possess unique and land–use/ management and soil attributes.

TABLE XIII - ANNUAL PRECIPITATION-RUNOFF VOLUME RATIO

Year	**Annual PPT P (mm)**	**Runoff Q (mm)**	**Volume V (Cubic Metres)**	**Runoff-PPT Ratio (%)**
2011	466.27	392.03	85,524,324,563,657.00	84.1
2012	607.70	531.48	51,520,249,724,865.00	87.5
2013	578.17	502.29	37,704,822,282,772.00	86.9
2014	510.03	435.08	05,896,793,015,703.00	85.3
2015	750.10	672.59	18,299,344,642,897.00	89.7
2016	734.43	657.04	10,941,616,557,610.00	89.5
2017	674.47	597.58	82,801,105,314,240.00	88.6
2018	716.53	639.29	02,537,822,546,006.00	89.2
2019	959.00	880.25	16,574,079,951,665.00	91.8
2020	699.07	621.96	294,340,547,576,824.00	89.0
Average	**669.58**	**592.96**	**280,614,070,617,624.00**	**88.6**

The runoff volume generated annually was averaged for 20 years. The calculation realized a runoff volume of 280.6x10^{12} m^3. Compared with the reservoir capacity of 5.5Mm^3 (5.5x10^6 M^3), it was very small compared to the runoff generated in the study area which confirmed that the reservoir would be filled in one year. Although not all the runoff reaches the control area due to other natural breaks, it is recommended a sufficient spillway be incorporated to evacuate the excess runoff.

Dam suitability based on catchment sediment generation

The rate of erosion in the reservoir catchment area and the flow conditions determine the quantities of sediments that reach it. The trap efficiency of a reservoir is defined as a

TABLE XIV - THE DISTRIBUTION OF ESTIMATED SOIL EROSION RATES PER DIFFERENT SEVERITY CLASSES.

Erosion Severity Class	**Erosion Class(t/ha/y)**
Slight	0-5
Moderate	5-10
High	10-20
Very High	20-40
Severe	40-80
Very Severe	>80

Courtesy of *Were et al.* (2013)

Climate data which included precipitation, relative humidity, temperature, wind and solar radiation were sourced from the SWAT world database structured for SWAT Models for the period 2000 to 2014. The catchment yielded 7 basins from which the mean annual sediment yields were analyzed using an excel worksheet (Table XV) and mapped using ArcGIS (Figure 14).

The catchment yielded sediments in the range of 11.75 and 34.29 Tons/Hectare. According to the estimated soil erosion distribution rates against severity classes, the catchment sediment yield ranged from high to very high (Table XIV). Chances are that the sediment yield potential in the study area could be higher since the trend in the study area show that the sediment generation continues increasing from the top towards the lower part of the watershed (Figure 14). The sediment generation rate can have negative effects on the reservoir capacity. Since the community did not have tangible knowledge about environmental management, as established from the interviews, it was recommended that capacity building be initiated but in the meantime, construct soil and water conservation structures such as check dams upstream of the proposed dam sites to reduce the sediment entry into the reservoirs

TABLE XV. AVERAGE SEDIMENT YIELD IN THE 7 HRU IN DAM 3 CATCHMENT BETWEEN THE YEARS 2000 AND 2014

	Annual average sediment yields (Tons/Ha)															
HRU	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Mean
1	1.3	0.8	9.5	6.8	11.8	26.4	15.4	12.7	13.5	8.0	27.8	25.5	6.0	5.4	5.5	11.8
2	1.3	0.3	10.9	8.8	12.8	26.7	18.6	12.9	15.0	8.0	29.2	26.6	5.8	6.6	5.8	12.6
3	1.5	0.4	13.3	11.9	15.6	31.5	24.7	15.0	18.8	9.2	35.3	32.1	6.6	8.9	7.0	15.4
4	1.3	0.5	11.6	10.6	13.6	28.2	22.1	13.3	16.7	8.2	31.4	28.5	5.9	7.8	6.4	13.8
5	1.9	0.5	16.5	14.8	19.4	39.4	30.9	18.7	23.4	11.5	44.3	40.2	8.2	11.0	8.6	19.3
6	3.4	0.7	30.0	26.0	34.7	69.9	54.9	33.9	41.3	20.2	80.6	71.6	13.9	18.8	14.5	34.3
7	3.0	0.8	25.5	22.3	29.8	59.3	46.6	28.9	35.3	17.3	67.9	60.6	12.0	16.4	12.7	29.2

CONCLUSION AND RECOMMENDATIONS

Identification of potential community small earth dam sites is a critical step towards alleviating the intermittent water problems experienced by the communities living

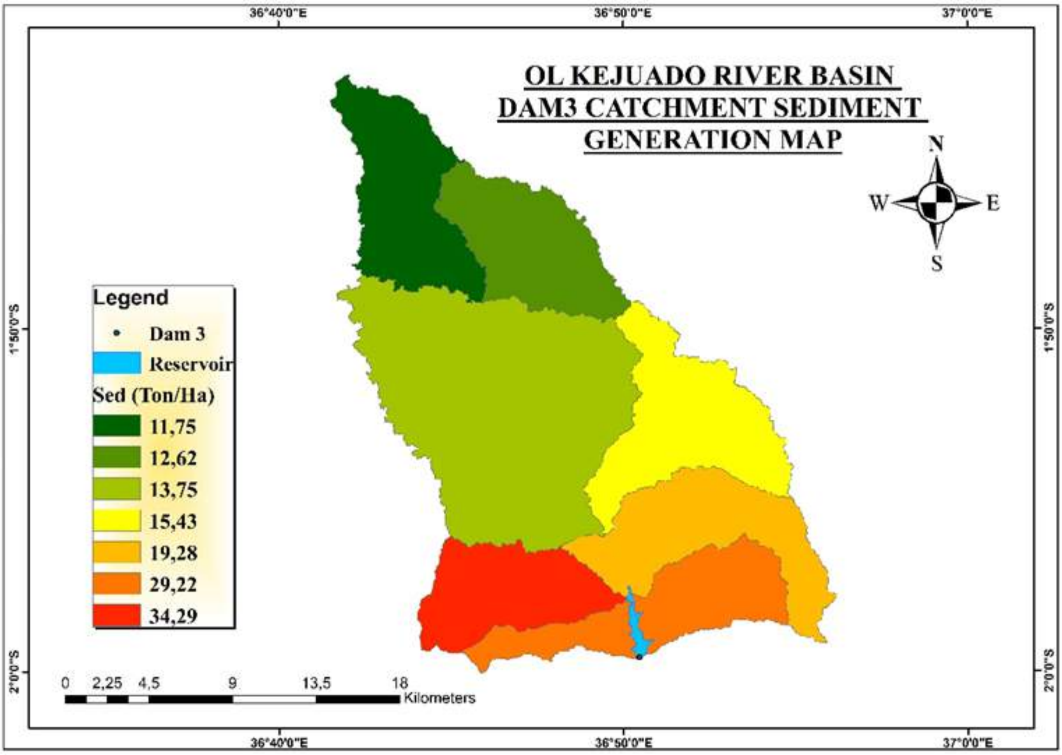


Figure 14. Dam 3 catchment Sediment yield map

in Kajiado County and similar ASAL areas of Kenya. This study demonstrated the application of geospatial technology as a flexible, time-saving and cost-effective decision-making method in the identification of potential sites for the construction of community small earth dams in the Ol Kejuado River basin. The communities in the study area currently depend on boreholes which are concentrated in market centres and small towns where there are large populations who can meet the costs of operation and maintenance of the pumps. When seven maps were overlaid using geospatial technology, they generated 15 suitable community dam sites. Further analysis of four of the sites found that the sites had a potential of storing between 1.1 and 5.5Mm^3, at dam heights between 7 and 9metres. The dam site with 5.5Mm^3 was more economical since it had almost the same dam length and depth as the other three analyzed but the largest capacity. Average annual rainfall-runoff volumes of 20 years were evaluated and found sufficient to fill the largest of the proposed dams. However, the catchment annual sediment yield rate was between high and very high which would jeopardise the life of the reservoirs through siltation. This called upon the need to train the community on environmental management. This included controlled grazing, reduced livestock numbers, re-introduce diminishing native grasses and vegetation which acts as a good soil cover and also growing fodder for the livestock. Construction of check dams upstream of the proposed dam sites would also offer short term control of silts entry into the reservoirs.

From this study, it was evident that RWH was not prioritized by both the Kajiado County Government and donor agencies who had financed most of the borehole projects. River Ol Kejuado and its tributaries did not have any dam constructed across them. The Dam 1 site which was close to the Kajiado Town had a potential of 4.5 million m^3 at a normal water depth level of 9 metres, which should challenge the government to consider the untapped potential of the river. Since the communities in the study area were able to manage the generally expensive boreholes, they also had the potential to manage productively the earth dams. Availability of water would also expand their productivity from livestock to other projects which include irrigation and apiary.

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