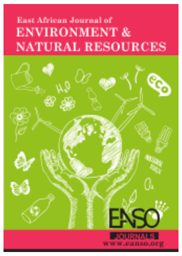

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Original Article

Dam Sites Identification using Multi-Criteria Analysis and Spatial Weighted Overlay. The Case of Kapseret Sub-County, Kenya

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ABSTRACT

Water shortage is a common phenomenon in many parts of Kenya in the dry season, including the Kapseret Sub-County. However, water harvesting has seldom been practised, despite its high potential to alleviate water shortages in the dry season. This is largely influenced by a lack of access to dams and pans. The objective of this study was to identify potential dam sites for water harvesting in Kapseret Sub County, Uasin Gishu County, Kenya. Multiple criteria analysis and weighted overlay were performed on ArcGIS to map suitable sites for the location of dams. The multiple criteria considered in site suitability analysis were land use and land cover (LULC), slope, and proximity to streams, institutions, roads, and airports. Digital Elevation Model (DEM) of 30 m resolution was downloaded from the USGS website and used to process stream network, slope, and contours. Landsat 8 satellite imagery taken on January 2022 were downloaded from the USGS website and used to generate LULC data. It was established that the Kapseret basin has moderate to highly suitable zones for dam siting, covering 74.66% of the area with only 25.34% of the land being unsuitable. Further analysis using contours identified four potential dam sites with a combined capacity of 3,436,500 m3. The study concluded that the potential for water harvesting is high in the area as significant portions of the land are generally suitable for dam siting. It was recommended that action be taken by the county and other stakeholders to develop dams in suitable zones so as to increase access to water, particularly in the dry season when there are shortages.

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INTRODUCTION

Dams are an important infrastructure for water harvesting and storage. Baba et al. (2018) noted that water harvesting is essential particularly in regions with uneven rainfall distribution, so as to provide water in the dry season and justified the need for dams in such environments. Although the Kapseret region receives sufficient rainfall of >1000 mm annually, the rainfall is confined to a rainy season between March and September. The rainy season is then followed by a lengthy dry season, where households are faced with water shortages due to the absence of reliable water supply, especially in rural areas (UGC, 2018). To avert this, there is a need for better management of water resources. Salehi (2022), Anwar (2019) and Pathak et al. (2019) observed that because current freshwater availability is impacted by climate change, rapid urbanisation, and an increase in population, alternative water resources need to be explored. The new era of water management involves a search for untapped water sources, one of which is stormwater harvesting (UNESCO/UN-Water, 2020; Dandy et al., 2019; NASEM, 2016). Among all alternatives, stormwater has been found as among the most promising for reuse and recycling (Anwar, 2019; Cousins, 2018). Stormwater harvesting (SWH) refers to the collection, storage, treatment, and use of runoff from surfaces such as roads and drains that would otherwise drain to a water body (Akram et al., 2014; O'Connor et al., 2007). SWH is one of the ways that man tries to avert water shortages (Gallo et al., 2020; Okedi & Armitage, 2019; Luthy et al., 2020; Kimani et al., 2015). Thus, the development of dams for SWH is suggested as an important strategy towards reducing water shortages in future in Kapseret Sub-County.

Dam siting, on its part, involves the identification of the most suitable sites for the location of water harvesting infrastructure. There are three main techniques used in dam siting, including GIS/RS methods, Multicriteria Decision Making and Machine Learning Methods. Setiawan & Nandini (2022) critically evaluated the application of each method. Although GIS/RS methods have the ability to analyse and capture data with significant accuracy, all factors are weighed equally, which is not realistic. Multicriteria Decision Making, on the other hand, addresses the shortcoming of GIS/RS methods by weighing the influence of multiple factors differently while still utilising the GIS/RS geospatial techniques in siting. In addition, they are a cost-effective approach (Wondimu & Jote, 2020; Buraihi & Shariff, 2015). Zamarrón-Mieza et al. (2017) noted that the Multi-criteria Decicion Analysis technique is currently being adopted for the comprehensive management of dams at all levels. Machine Learning Methods in divergence are suitable when dealing with complex data.

Setiawan & Nandini (2022) noted that dam siting is usually site-specific due to a region's unique

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characteristics. As a result, factors to consider while identifying suitable sites are dependent on the purposes of the dam. Sayl et al. (2020) and Mbilinyi et al. (2007) observed that important factors to consider while sitting in a stormwater reservoir include topographical, geological, hydrological, socioeconomic, environmental and water quality. Wondimu & Jote (2020), Buraihi Shariff (2015) and Critchley & Siegert (1991) observed that gently sloping areas of not more than 5% are good sites for the location of dams. The LULC is similarly considered when selecting suitable sites for dam construction. Wondimu & Jote (2020) and Mbilinyi et al. (2007) noted that bare land that generates high volumes of runoff is ranked highly for siting water reservoirs. They recommended that water harvesting dams should be located in areas with significant runoff as opposed to areas with little runoff, such as forested areas. Setiawan & Nandini (2022) concurred, noting that land use types and spatial extent of vegetation influence runoff velocity and yield. Soil type and proximity to roads are also important factors to consider when selecting suitable dam sites. Wondimu & Jote (2020) and Mbilinyi et al. (2007) concluded that sites with clay soils are best for the location of dams because of the inherent capacity of clay soils to hold harvested water. Wondimu & Jote (2020) and Sayl et al. (2020) further observed that stormwater harvesting dams should be located in close proximity to the stream network so as to capture runoff within the stream/river network. On socioeconomic factors, Setiawan & Nandini (2022) proposed that dams should be situated away from roads and settlements because of conflict of interests amongst users, as well as safety considerations.

The importance of dam site suitability analysis before actual dam construction is undertaken cannot be overemphasised. The purpose of this study was to identify suitable sites for dam siting in Kapseret Sub-County, Uasin Gishu County, and hence provide valuable information for water resource developers.

MATERIALS AND METHODS

Study Area

Kapseret Sub-County (KSC) is one of the administrative units in Uasin Gishu County covering an area of 299.3 km^2 with a population density of 663 persons per km^2 (KNBS, 2019). In 2019, it had a population of 198,499 persons and 59,746 households. The study area has a relatively cool climate with mean annual temperatures across the county being predominantly below 21 °C, a factor attributed to its location on a plateau that rises gently from 1500 m above sea level to 2,700 m above sea level. Rainfall in the county is relatively high with the northern and central parts receiving between 1000 and 1250 mm of rainfall annually, the southern parts receiving 1250-1500 mm annually, and the western tip receiving above 1500 mm. The rainy season lasts from March to September followed by a dry spell lasting from November to February (UGC, 2018).

The Soils in the county are red loam soils, red clay soils, brown clay soils, and brown loam soils (MoALF, 2017). The two soil types in KSC are orthic ferrasols and humic nitosols. Orthic ferralsols are well-drained soils, mainly composed of sandy clay, while humic nitosols are composed mainly of silty clay. There is evidence of a gentle slope in KSC. The largest area (262.68 km^2) has a gentle slope of <5%, 3.66 km^2 has a slope of 10-15%, while only 0.6 km^2 has a slope of >15%. *Figure 2* shows the degree of slope in the study area. The DEM revealed a stream network exhibiting a dendritic pattern with numerous ephemeral streams, shown in *Figure 1*.

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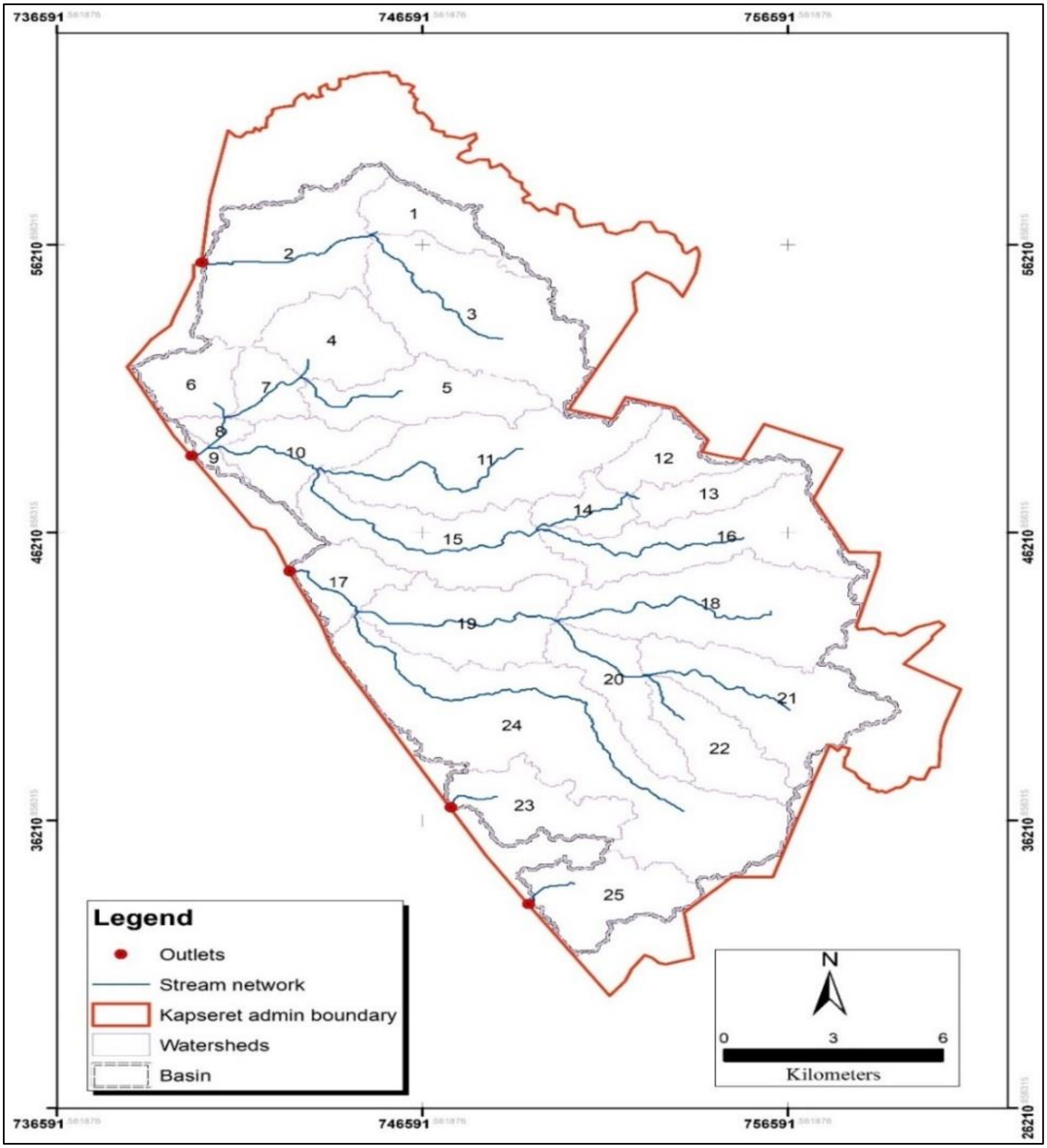
Figure 1: Kapseret Sub-County administrative boundary, boundaries of Kapseret basin, watersheds (sub-basins), stream network and the outlets



Source: Author

Data Collection, Processing and Analysis

The KSC shapefile obtained from Independent Electoral and Boundaries Commission (IEBC) was used to guide where to collect roads, institutions, and airport data. It was further used to sub-setting the spatial soil and satellite imagery data. The data were obtained in spatial format from different sources. The soil data was sourced from the FAO website and processed in ArcGIS to produce a soil

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map for the study area. The slope data was processed from a 30 m resolution. DEM was downloaded from https://earthexplorer.usgs.gov/. The land uses land cover data was prepared from Landsat 8 satellite imagery downloaded from https://earthexplorer.usgs.gov/._Other spatial data comprising institutions, roads and airports were sourced from Google Earth Pro and exported to the ArcGIS format._The data capture and processing were done in ArcGIS version 10.5 and restricted to the watersheds within the sub-county.

Criteria Classification and Ranking

Criteria Classification

Criteria classification was conducted to enable standardisation of the factors, hence allowing uniform consideration when performing overlay analysis. Ranking enabled segregation of classes based on their considered importance in dam siting. Five ranks were considered ranging from a scale of 1 representing the least preferred to 5 representing the most preferred. This was done for each criterion based on the expert assessment, as shown in *Table 1*.

Table 1: Criteria Classification and Ranking

Criterion	High rank	Low rank	Reason
Slope	Well-drained, gentle sloping	Steep and flat land	The gentle slope is cost-effective and less prone to landslides (Wondimu & Jote, 2020; Buraihi & Shariff, 2015; Critchley & Siegert, 1991)
Proximity to streams	Near	Far	The shorter the distance, the better (Wondimu & Jote, 2020; Sayl et al., 2020, Buraihi & Shariff, 2015)
Road network	Far	Near	May lead to a conflict of interest between road users and development (Setiawan & Nandini, 2022)
Airport proximity	Far	Near	The dam might attract waterfowl posing risks to aeroplanes (Setiawan & Nandini, 2022)
Institutions	Far	Near	Economic considerations in the event of relocation and safety concerns (Setiawan & Nandini, 2022)
LULC	Wetlands and low soil erosion areas	Forest	Land use types and vegetation coverage influence the generation of runoff volume and velocity. Areas with high runoff potential are more suitable sites for water harvesting. (Setiawan & Nandini, 2022; Wondimu & Jote, 2020; Buraihi & Shariff, 2015)

To identify suitable dam sites, the following criteria were considered; slope, proximity to roads, proximity to the airport, proximity to schools and institutions, proximity to stream network and LULC. Their layers were prepared separately before weighed overlay operation. The soil data was not used in the analysis as it was deemed to be a constant. There are two soil types in the area, namely orthic ferrasols and humic nitosols, both of which are highly suitable for dam sitting as they are clayey.

Criteria Ranking

Criteria considered in mapping suitable dam sites in KSC included slope and proximity to streams, institutions, roads, and airports. For the purpose of ranking, the criterion was first grouped into classes.

Firstly, the slope was reclassified into five classes 0-10, 10-20, 20-30, 30-40 and over 40%. The most suitable location for dam siting were areas with gentle slopes and were ranked 5, while the least suitable areas with steep slopes were ranked 1.

Secondly, proximity to institutions was reclassified into two classes. The farthest distance from any

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institutions was 11,838 m. Areas within 1000 m of institutions were considered least suitable for dam siting and were ranked 1, while areas beyond 1000 m from institutions were ranked 5.

Thirdly, the classification of proximity to streams and rivers was done at intervals of 500 m. Areas closest to the streams or rivers were considered most suitable for dam siting hence ranked highest compared to areas located farthest from the stream network, which were ranked 1.

In addition, areas on roads and road reserves were considered unsuitable for the location of dams, hence ranked lowest. Roads were reclassified into two classes at intervals of 0-500 m and over 500 m. Areas away from roads, over 500 m, were ranked 5.

Proximity to the airport was subdivided into two classes of 0-1000 and 1000-14,036.7 m. Areas closest to the airport (0-1000 m) represented the unsuitable areas and were ranked lowest, while areas beyond 1000 m from the airport were ranked 5.

Finally, LULC was reclassified into five classes, namely built, combined water and swamp, bare land, cropland, and trees combined with grass. LULC with the generation of the highest runoff like built environments was ranked highest, while those areas with minimal runoff like forest were ranked lowest, as shown in *Table 2*.

Table 2: Ranking of various criteria.

Criteria	Classification	Categories				
Slope	Class	0-10	10-20	20-30	30-40	40-46.67
	Rank	5	4	3	2	1
Proximity to institutions	Class	0-1000				1000-11,838
	Rank	1				5
Proximity to streams and rivers	Class	0-500	500-1000	1000-1500	1500 - 2000	2000-3308.7
	Rank	5	4	3	2	1
Proximity to roads	Class	0-100				100-3814.13
	Rank	1				5
Proximity to airport	Class	0-1000				1000-14,036.7
	Rank	1				5
LULC	Class	Wetland/swamp	Built	Bare land	Cropland	Trees/Grass
	Rank	5	4	3	2	1

Based on the ranks assigned, the different map layers were processed on ArcGIS. *Figure 2* shows the various layer suitability maps used for siting dams in the Kapseret basin.

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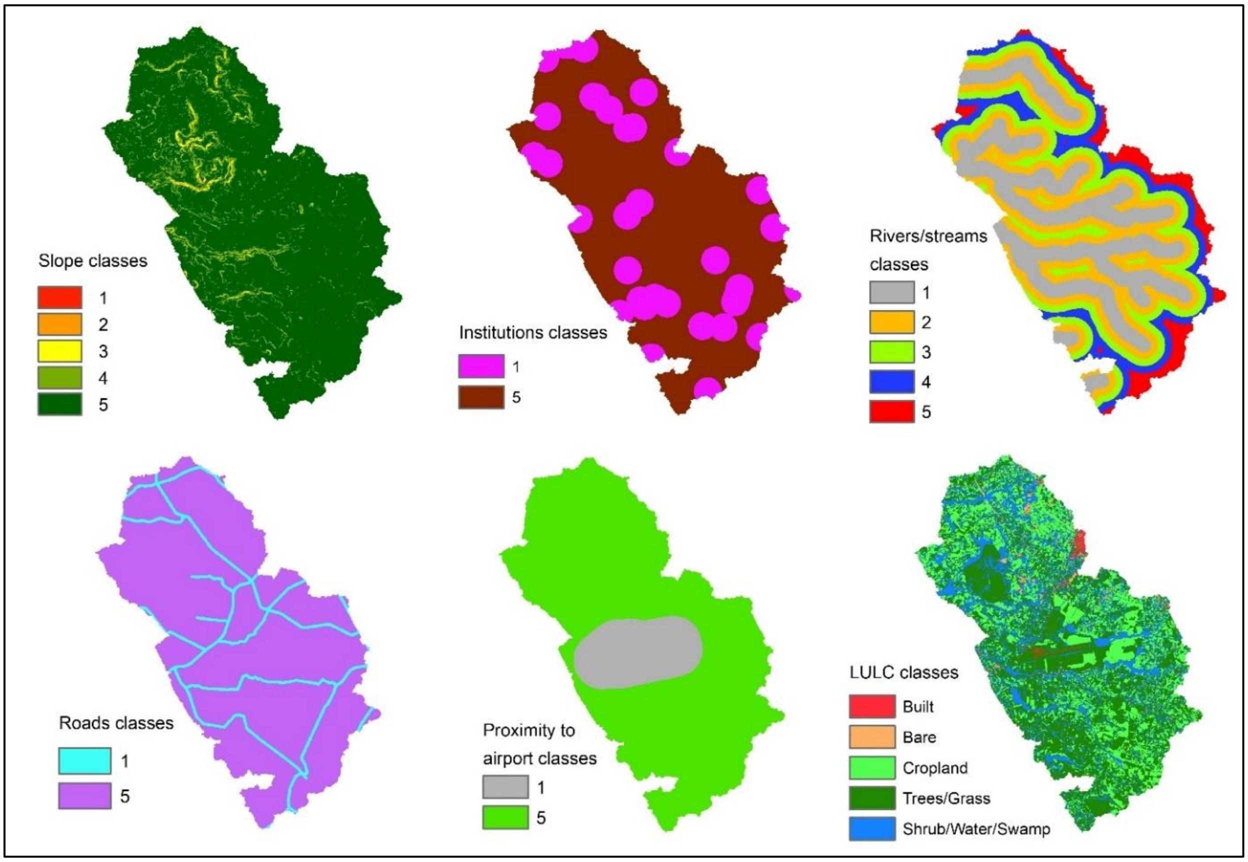
Figure 2: Suitability layer maps for dam siting.



Source: Author

Based on their importance in dam siting, criteria were allocated weights adding up to 100%. Slope and proximity to the stream network were given the highest weights of 30%, while proximity to the airport had the least weight of 5%. *Table 3* shows the weight assigned to each criterion.

Table 3: Assigned criterion weights

Criterion	Weight (%)
Slope	30
Proximity to river	30
LULC	15
Road network	10
Institutions	10
Airport proximity	5
Total	100

The overlay inputs were all the criteria layers with identical geospatial characteristics of 702 columns, 917 rows, pixel size of 30 meters and spatial extent of 59039.4346329, 738576.044595, 759636.044595 and 31529.4346329 at the top, left, right and bottom respectively. The Weighted Overlay tool used the common measurement scale, 1-5, and the different allocated weights based on the importance to generate the dam suitability map. The generalised methodology used in data processing and analysis involved overlaying the spatial data.

The Weighted Overlay tool in ArcGIS was then used to overlay the criterion layers including slope,

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proximity to roads, proximity to the airport, proximity to institutions, proximity to stream network and LULC, while adopting the weighting criteria so as to generate the dam site suitability map.

RESULTS AND DISCUSSION

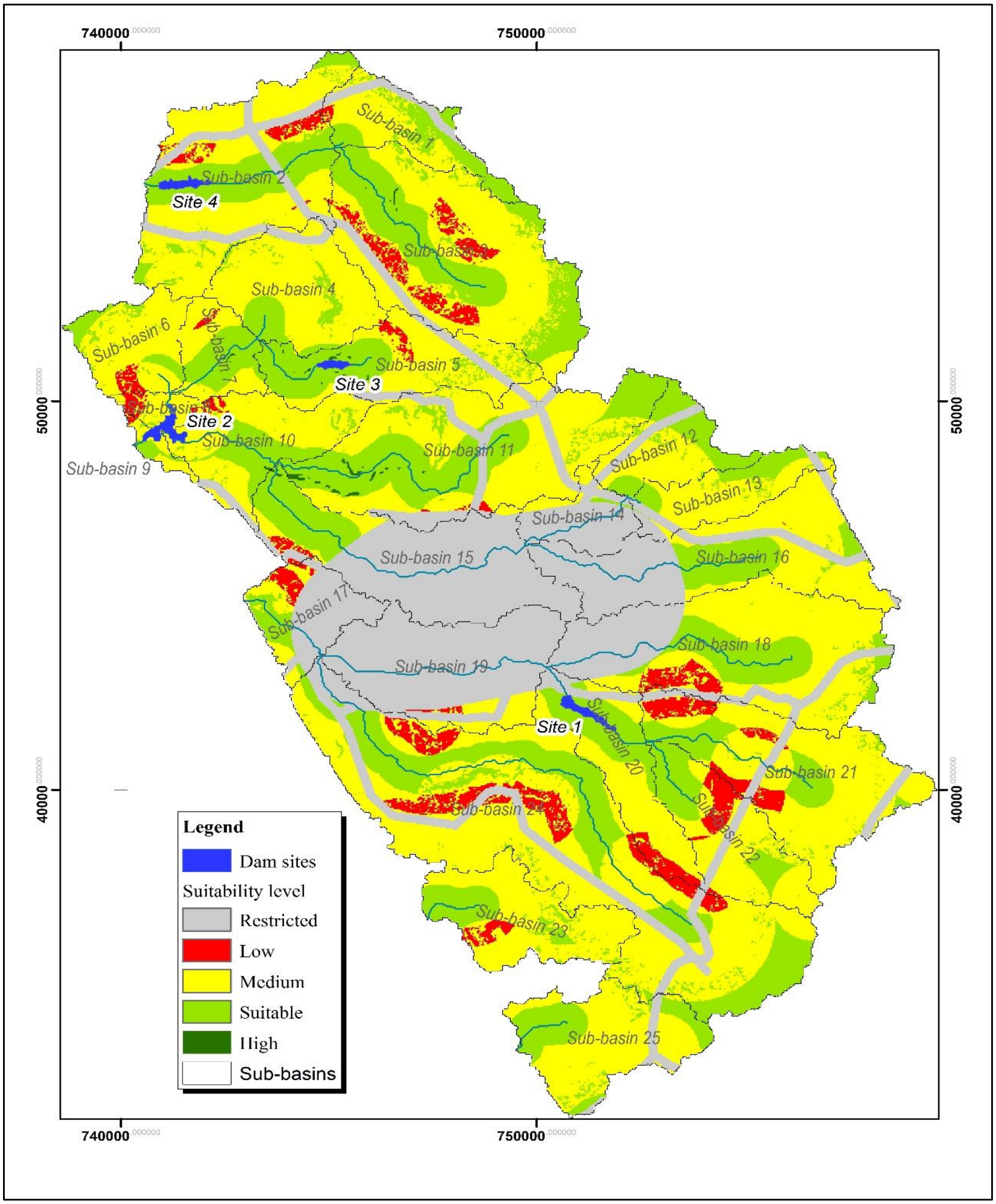
The suitability level for dam siting differed based on the prevailing criteria and the allocated weight. The moderate to highly suitable areas for dam siting covers 74.66% of the land surface. However, 21.37% of the area is restricted, while 3.96% has low suitability. These two areas are therefore, unsuitable for siting dams. This is shown in *Table 4*.

Table 4: Suitability level for stormwater harvesting in Kapseret Basin

Suitability level	Area in km^2	Percentage of Area
Restricted	60.5052	21.37
Low	11.2185	3.96
Moderate	138.1284	48.79
Suitable	72.9729	25.77
Highly suitable	0.297	0.10
Total	283.122	100.00

From the identified suitable and highly suitable zones for stormwater harvesting, the analysis of contours identified four sites with natural depressions in the area as the most suitable sites. The location of each site within the basin is shown in *Figure 3*.

Figure 3: Dam suitability map of Kapseret Basin



Source: Author

Further analysis of the identified sites considered the length of the dam barriers guided by the elevation of the contours. This narrowed down to four sites. Site 1 has the largest capacity of 1,422,300 m^3 and the longest dam barrier length of 205 meters. Site 2 is on the lowest contour of 1900 meters. It has the shortest dam barrier length of 35 meters, with a capacity of 637,575 m^3. Site 3 is on the 1980-meter contour, with a dam barrier length of 100 meters and a capacity of 684,450 m^3. Site 4 lies on the 1920 contours with a dam barrier length of 160 meters and a capacity of 692,175 m^3. The

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four sites combined have a capacity of 3,436,500 m^3, which is equivalent to 3.44 billion litres. *Table 5* indicates the location, dam barrier lengths, area, and capacities of the identified dam sites.

Table 5: Suitable dam sites and their capacities

Site	Contour	Dam barrier coordinates	Dam barrier Length (m)	Area (m^2)	Volume (m^3)
1	2100	750736.6, 42427.5	205	206,100	1,422,300
2	1900	740727.9, 48965.6	35	274,500	637,575
3	1980	744722.8, 50911.5	100	100,800	684,450
4	1920	740913.6, 55536.7	160	176,400	692,175
Total				**757,800**	**3,436,500**

CONCLUSION

Suitable zones and sites for stormwater harvesting in the Kapseret basin were identified. The criterion considered in siting dams included slope, proximity to streams, roads, airports, institutions and LULC. It was established that significant portions of the Kapseret basin (74.66%) are categorised as moderate to highly suitable for dam siting. Thus, dams can be constructed at various locations to harvest the high volumes of runoff generated each year during the rainy seasons within the Kapseret basin. Specifically, four suitable dam sites, with a total holding capacity of 3.43 billion litres were mapped. This implies that the potential for water harvesting is huge but remains untapped.

Cognizant of the fact that water demand is constantly increasing, there is a need to expand the water supply by including all the untapped water sources so as to augment the existing sources. Stormwater harvesting provides an opportunity to alleviate seasonal water shortages, given the huge volumes of runoff generated during rainfall events in the rainy season. The Uasin Gishu government in conjunction with the National Water Harvesting and Storage Authority, needs to plan, budget for, develop and maintain SWM infrastructure. This should include collection, storage, treatment of stormwater and eventual distribution of water to households.

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