International Journal of Plant & Soil Science

30(1): 1-20, 2019; Article no.IJPSS.51079
ISSN: 2320-7035

Application of GIS on the Identification of Suitable Areas for Water Conservation Technologies in the Upper Tana Watershed of the Central Highlands of Kenya

B. W. Nganga[1*], K. O. Nge'tich[2], N. Adamtey[3], K. Milka[1] and K. F. Ngetich[1]

[1]Department of Land and Water Management, University of Embu, P.O.Box 6-60100, Embu, Kenya.
[2]Department of Agricultural Resource Management, University of Embu, P.O.Box 6-60100, Embu, Kenya.
[3]Department of Soil Sciences, Research Institute of Organic Agriculture (FiBL), Ackerstrasse, 113, 5070 Frick, Switzerland.

Authors' contributions

This work was carried out in collaboration among all authors. Author BWN Investigation, Writing-Original draft preparation. Author KON Supervision, Writing-Reviewing and Editing. Author KM Formal analysis, Writing-Reviewing and Editing. Author NA Methodology, Supervision, Funding Acquisition. Author KFN Supervision. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2019/v30i130166
Editor(s):
(1) Dr. Abhishek Naik, Acsen Hyveg Pvt.Ltd. Vegetable Seed Division, India.
Reviewers:
(1) Mandadapu.S.V.K.V.Prasad, Jawaharlal Nehru Technological University, India.
(2) Qingfeng Zhang, Northwest A&F University, China.
Complete Peer review History: https://sdiarticle4.com/review-history/51079

Original Research Article

Received 17 June 2019
Accepted 31 August 2019
Published 02 October 2019

ABSTRACT

Low adoption of soil water conservation technologies has been one of the main causes for decreased agricultural productivity in the Upper Tana Catchment of Kenya. Proper identification of locations to scale-out the individual technologies necessary to improve water conservation is a key determinant for the rate of adoption. Our main aim was to identify the suitable sites for water conservation technologies using the suitability model created by the model builder function in ArcGIS 10.5®. The model combined the thematic layers of soil texture, slope, rainfall, and stream order, which were acquired from assorted online sources. The factors were converted to raster format and reclassified based on their suitability and were assigned fixed scores and weights by

**Corresponding author: E-mail: beatienganga@gmail.com;*

use of multi influencing factor (MIF) method. The suitability evaluation was carried out by use of weighted overlay to produce suitability classes for each of the water conservation technique. The delineated suitability maps indicated that check dams are highly suitable in 50% of the study area. Mulching, on the other hand, is highly suitable for 49% of the study area. Zai pits are highly suitable in 43% of the study area. Majority of the study area is moderately suitable for the use of terraces, covering 41% of the study area. The highly suitable areas for the Checkdams are Machakos, Kitui, Tharaka-Nithi and lower parts of Embu. The highly suitable areas for mulching are Kirinyaga, Murang'a, Nyandarua and Nyeri. The highly suitable areas for the Zai pits are Kitui, lower parts of Tharaka-Nithi and the highly suitable areas for the terraces are Murang'a, Nyeri and Kirinyaga. Furthermore, the results demonstrated the effectiveness of GIS in delineating the suitable areas for the use of water conservation technologies.

Keywords: Agriculture zai pits; mulching; terraces; check dams; Geographical Information System (GIS); weighted overlay; suitability map.

1. INTRODUCTION

Rain fed agriculture contributes to around 60% of the world's agricultural productivity [1]. In Sub-Saharan Africa (SSA), the per capita food availability has decreased over time and consequently led to food insecurity [2]. Rain-fed agriculture is the source of staple food production among the poor people in Sub Saharan Africa. The frequent dry spells in SSA have made water the main limiting factor in agriculture posing a threat to the livelihood of the smallholder farmers [3,4]. In Kenya, agriculture is the backbone of the economy, and more than 75% of people make a living from agriculture [5]. However, agricultural productivity has continued to decline despite the growing population. The Arid and Semi-Arid areas of Kenya occupy 80%of the total Kenyan land, and the people occupying these areas are generally poor and depend on food handouts to survive [6]. The low levels of moisture in Arid and Semi-Arid Areas of Kenya make the water conservation technologies an important intervention in water supply and food production [7].

Over 80% of agriculture in the Upper Tana Watershed of the Central Highlands of Kenya is rain-fed, and sufficient soil moisture retention is therefore important [8]. The farmers in the Upper Tana region have, however, been facing challenges of decreased agricultural productivity, which are linked to the degradation of natural resources due to excessive runoff leading to excessive nutrients depletion. One of the main reasons for the decreased agricultural productivity is the low or non-adoption of soil water conservation practices by the smallholder farmers. Therefore, part of the solution to the challenge of inadequate food availability would be the adoption of soil water conservation techniques. Some regions of the Upper Tana Region Watershed face frequent dry spells droughts [9]. There is a need to increase water availability to the crop grown in these areas through soil water conservation. Some water conservation practices have been developed, tested, adopted by some farmers, and seen to increase soil water availability and retention [10].

Water conservation technologies have continued to gain recognition in the world with an emphasis on erosion control [11]. The soil water conservation technologies mostly used in in the Upper Tana Catchment of Kenya are mulching, Zai pits, Terraces, and Check-dams. Despite the positive impacts arrived from using these technologies, the farmers in the Upper Tana region have not fully adopted these technologies. One of the main reasons for the low adoption of the technologies is the poor scaling out of the on-station developed technologies. Therefore, there is a need to conduct a site evaluation to identify the most suitable sites for the use of water conservation technologies.

Mulching prevents soil erosion by reducing the rate of runoff [12]. When mulches are spread over the soil, they slow down the rainwater runoff increasing the amount of water retained by the soil. As the mulches decompose, they provide organic matter which keeps the soil loose [13]. Zai pits are water conservation technologies that deal with the issue of land degradation, soil fertility, and soil moisture instead of the water being lost to runoff it is trapped inside the pits close to the crop roots. The Zai pits can provide for growth of water demanding crops and also reduce the chances of crop failure during dry spells [14]. The pits are about 0.6m in diameter and 0.3m in depth in which seeds are planted in the pits. The Zai pits gained popularity in Kenya and especially the dry areas [15] The Zai pits are especially relevant in areas receiving low rainfall of between 300mm to 800mm [16]. Terraces reduce the slope steepness as they divide the slope into small, gently sloping sections. The terraces reduce runoff by encouraging it to infiltrate, evaporate, or is directed to a safe predetermined outlet at a controlled velocity to avoid soil erosion [17] Check-dams are devices made of rock, gravel bags, sandbags, and fibre rolls that are placed on natural or manmade ditches. Check dams reduce soil erosion as they reduce the flow velocity and encourage sediment settlement [18].

The factors necessary for the identification of suitable sites according to the Food and Agriculture Organization (FAO) are climate, soils, hydrology, topography, and agronomy [19]. Clay soils are prone to waterlogging; hence, the soil texture is an important factor in determining the suitability of soil water conservation technologies. In the drier areas (e.g., rainfall less than 750 mm per annum) it is usually desirable to keep rainwater in situ and to prevent runoff. Other factors that must be considered in reaching a decision, besides the availability of a discharge area or waterway, include the soil texture, slope, land use, and the risk, if any, of retaining water in situ. Soils in higher rainfall areas that are prone to waterlogging because they are shallow or because of the clay content, such as the grey soil (planosols) or black cotton soils (vertisols) in other areas, normally require structures that will drain water [20]. Some soil on steep slopes, such as the areas with Andosols, it is better to drain water. Also, areas prone to landslides become unstable if they are very wet, and conservation structures should be designed to drain the water away.

Traditional methods such as field visits in determining the most suitable sites for the use of water conservation are tedious and time-consuming [21]. GIS-based techniques are fast and most effective in conducting suitability analysis and can be used in preparing a map showing potential zones for water conservation structures and their appropriate measures [22]. Therefore, the main objective of the study was to identify the suitable sites for the use of water conservation technologies by use of a geospatial approach in the Upper Tana region of Kenya. For this purpose, the necessary biophysical and meteorological factors were identified, evaluated, and mapped by use of the GIS for proper zoning out of the suitable areas for the use of the water conservation technologies.

2. MATERIALS AND METHODS

The methodology adopted is illustrated in Fig. 1. The first step was the generation of the spatial database. The data used in this study was slope, Land use/Land Cover, Soil texture, and rainfall. The data was projected into a common coordinate system. The data were reclassified into five classes based on their suitability. Scores were assigned to each data set to bring them into comparable units. The thematic maps of each dataset were combined through weighted overlay obtaining the suitability maps for each of the water conservation technology.

2.1 Data Acquisition

Digital Elevation Model (DEM), rainfall, soil texture, and land use data was needed for this study. Rainfall was used as a climate parameter; slope represented topography, the streamflow order represented hydrology, land cover represented agronomy while the soil texture was used as a parameter for soil. DEM was used to generate the slope and the stream order layers. The DEM was downloaded from http://earthexplorer.usgs.gov (Site of United States of Geographical Survey). The rainfall data were obtained from the National Aeronautical Space Administration (NASA) https://power.larc.nasa.gov/common/php/POWER_AboutPOWER.php. The soil texture was obtained from ISRIC (International Soil Reference and Information Centre) database of Kenya https://data2.isric.org/geonetwork/srv/search?keyword=Kenya. The land Use/ Cover was obtained from the Kenya GIS data/World Research Institute https://www.wri.org/resources/data-sets/kenya-gis-data.

2.1.1 Slope

Slope affects the suitability of water conservation technologies as the surface runoff depends on the slope of an area. The position of a slope determines the moisture availability since it determines the amount of runoff. Topography affects vegetable establishment hence affecting water conservation. Linear profiles have widespread plant cover on the topsoils compared to the concave profiles with which plant cover is much widespread at the bottom of the slopes [23]. The slope layer was generated from DEM through the surface option on the spatial analyst tool (Fig. 2).

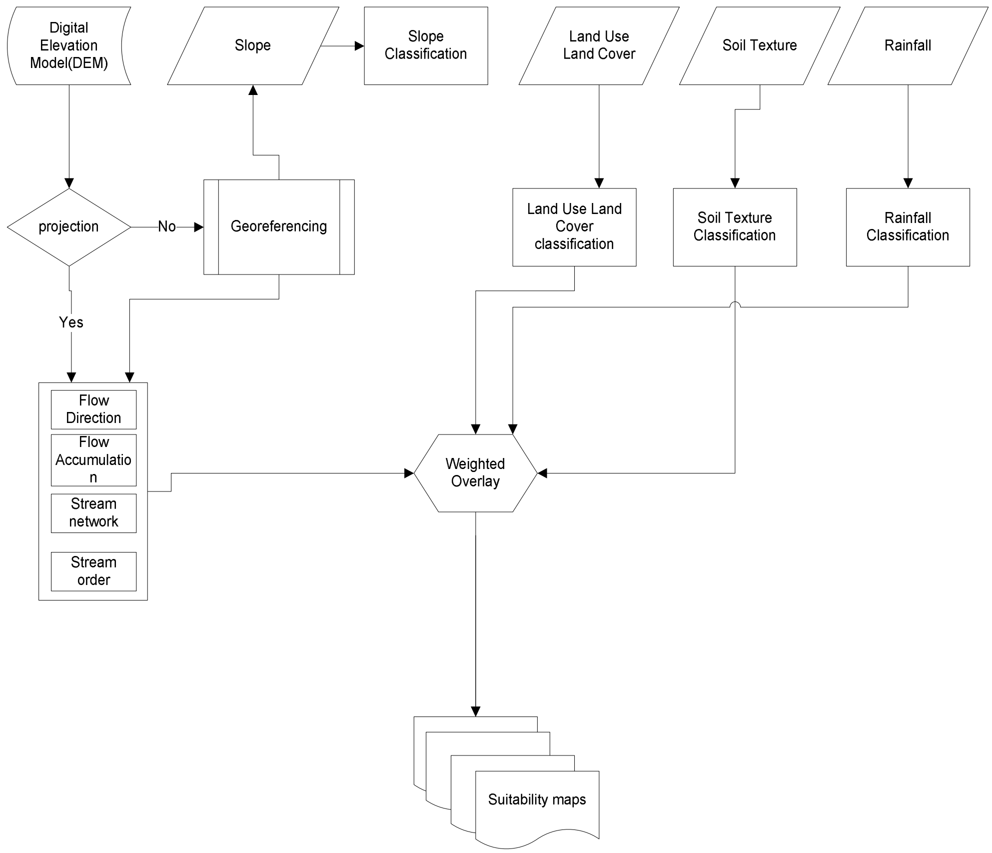

Fig. 1. Methodology framework

The slope layer was classified based on the slope degree based on the IMSD (Integrated Mission for Sustainable Development) guidelines. Slope percentage of 35 and above is considered very steep while slope of less than 3% is considered to be gentle sloping. The moderate slope of 5-10% is considered suitable. Fig. 2b illustrates the classification of slope based on its suitability. The least suitable areas were represented by 1, the Marginally suitable areas were represented by 2, the moderately suitable areas were represented by 3, the medium highly suitable areas were represented by 4 while 5 represented the very highly suitable areas.

2.1.2 Stream order

The stream order is determined by the tributaries connection. The stream order is based on the hierarchical connection of the tributaries, which helps in the classification of drainage basins based on their size. Low stream orders have high permeability as compared to the high stream orders. The low stream orders also have high infiltration rates as compared to the high stream orders [24]. Stream orders are essential in the planning of conservation measures in terms of storage and capacity [25].

The Stream order map was generated from the DEM data through the hydrology function in the spatial analyst tool. The flow direction map was determined, and the flow accumulation map was prepared by eliminating values less than 200 through the raster calculator tool under math algebra function. The results obtained from the flow accumulation tool were used to create a stream network where the cells that had more than 200 cells flowing into them were used to identify the stream network. The set null tool created a stream network where the flow accumulations of 200 or more went to one, and the remainder was put into no data. The resultant stream network was used to generate the stream order of the sub-basins. The stream order map is illustrated in Fig. 3.

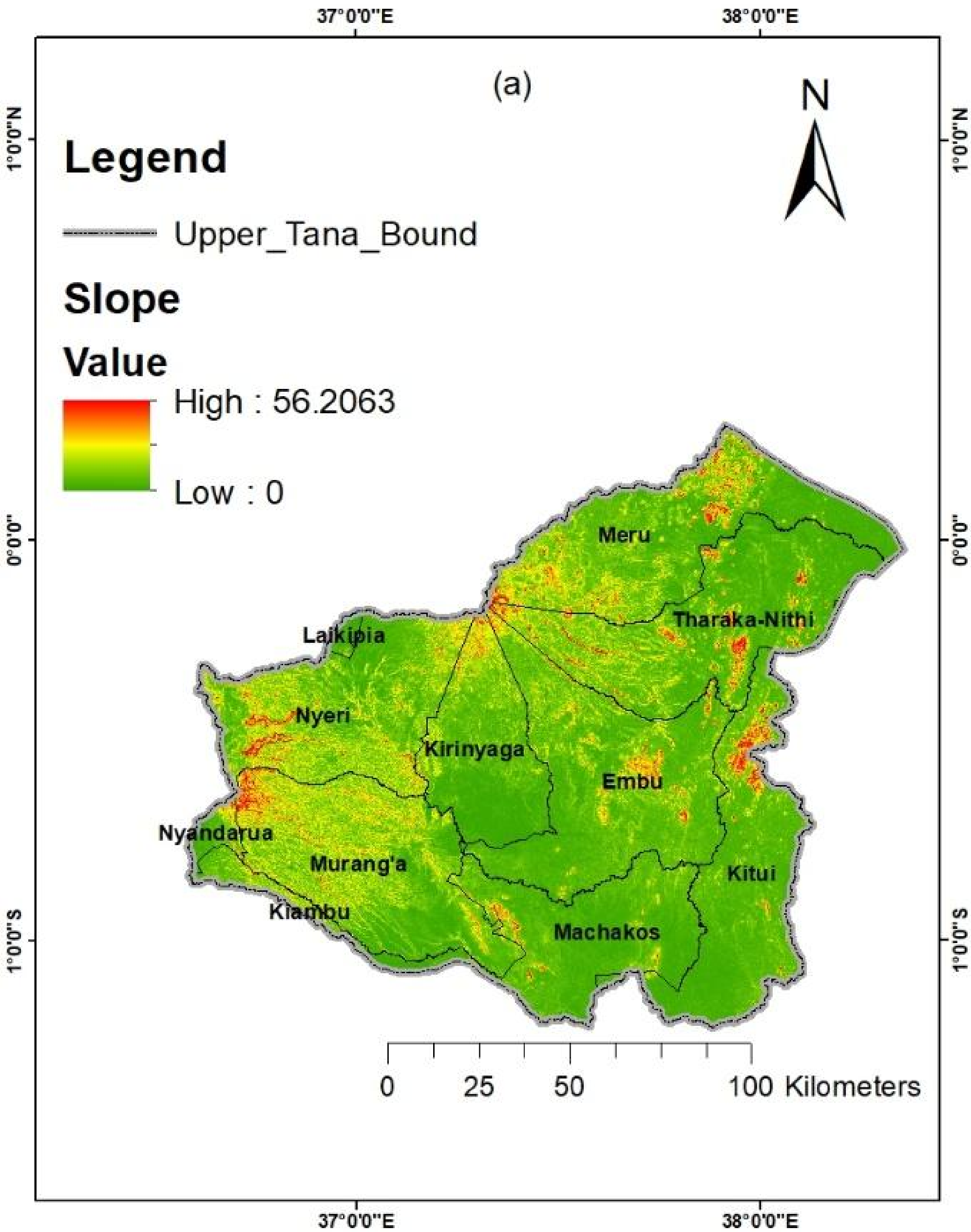

Fig. 2. Slope map of the upper Tana catchment of Kenya

2.1.3 Land Use/Land Cover (LULC)

Land cover is important in determining the suitability of the water conservation technologies as it determines the runoff of an area. The denser the vegetation, the higher the interception and infiltration, and the lower the run-off. Data on Kenya's land cover was obtained from the Kenya GIS data/World Research Institute https://www.wri.org/resources/data-sets/kenya-gis-data. Upper Tana region comprises of the Agricultural lands, Bushlands, Barren land, towns, Forests, Swampy areas, woodlands, Plantations, and water bodies. Fig. 4 shows the LULC (Land Use Land Cover) map.

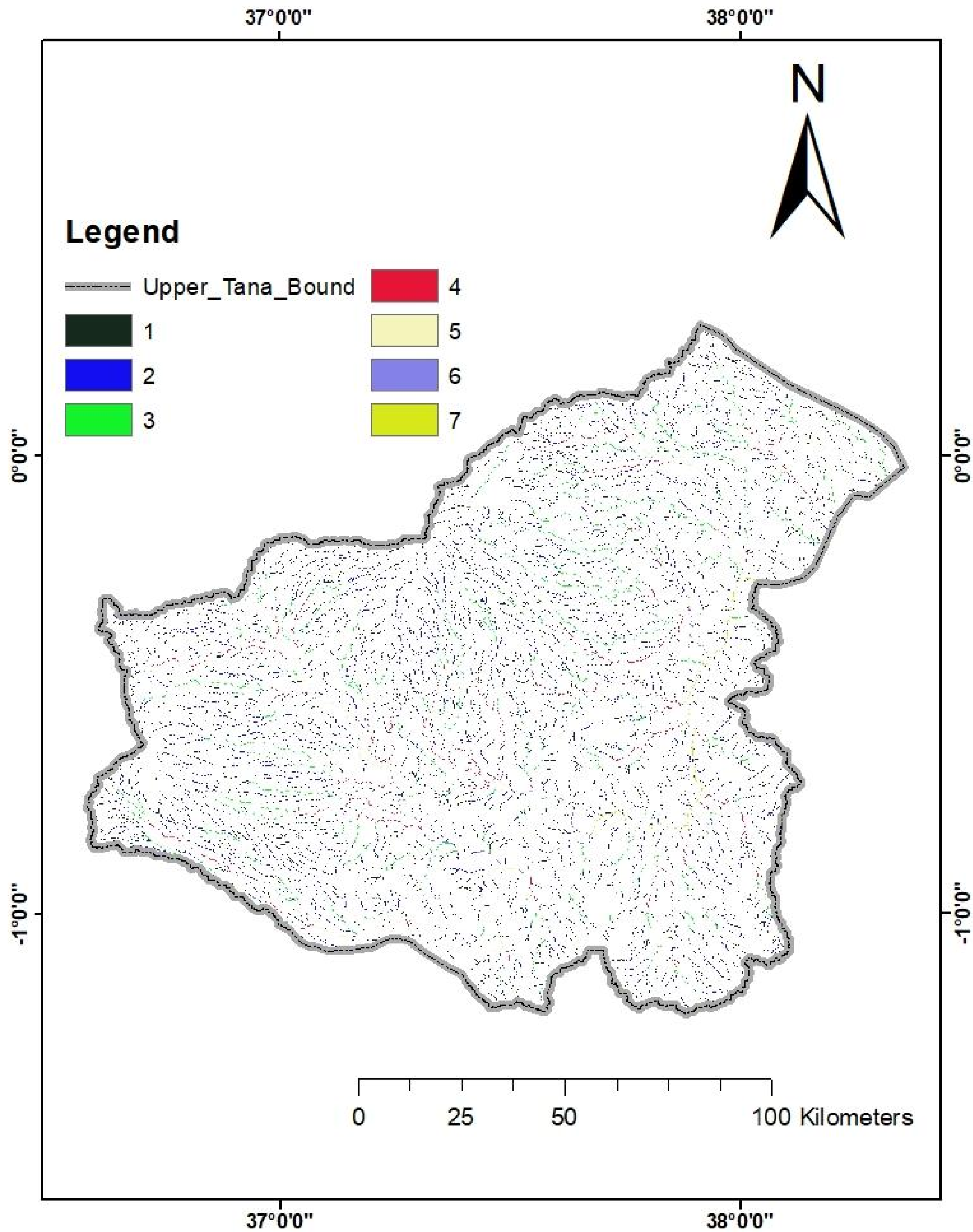

Fig. 3. Stream order map of the upper Tana catchment of Kenya

2.1.4 Rainfall

Rainfall is also an important factor to consider as it is a big determinant of runoff. For instance, dry areas are much prone to erosion as the prolonged dry spells destroy the vegetation making the soils prone to erosion [26]. In the drier areas, it is usually desirable to keep rainwater in situ and to prevent runoff. Fig. 5 illustrates the rainfall map distribution map.

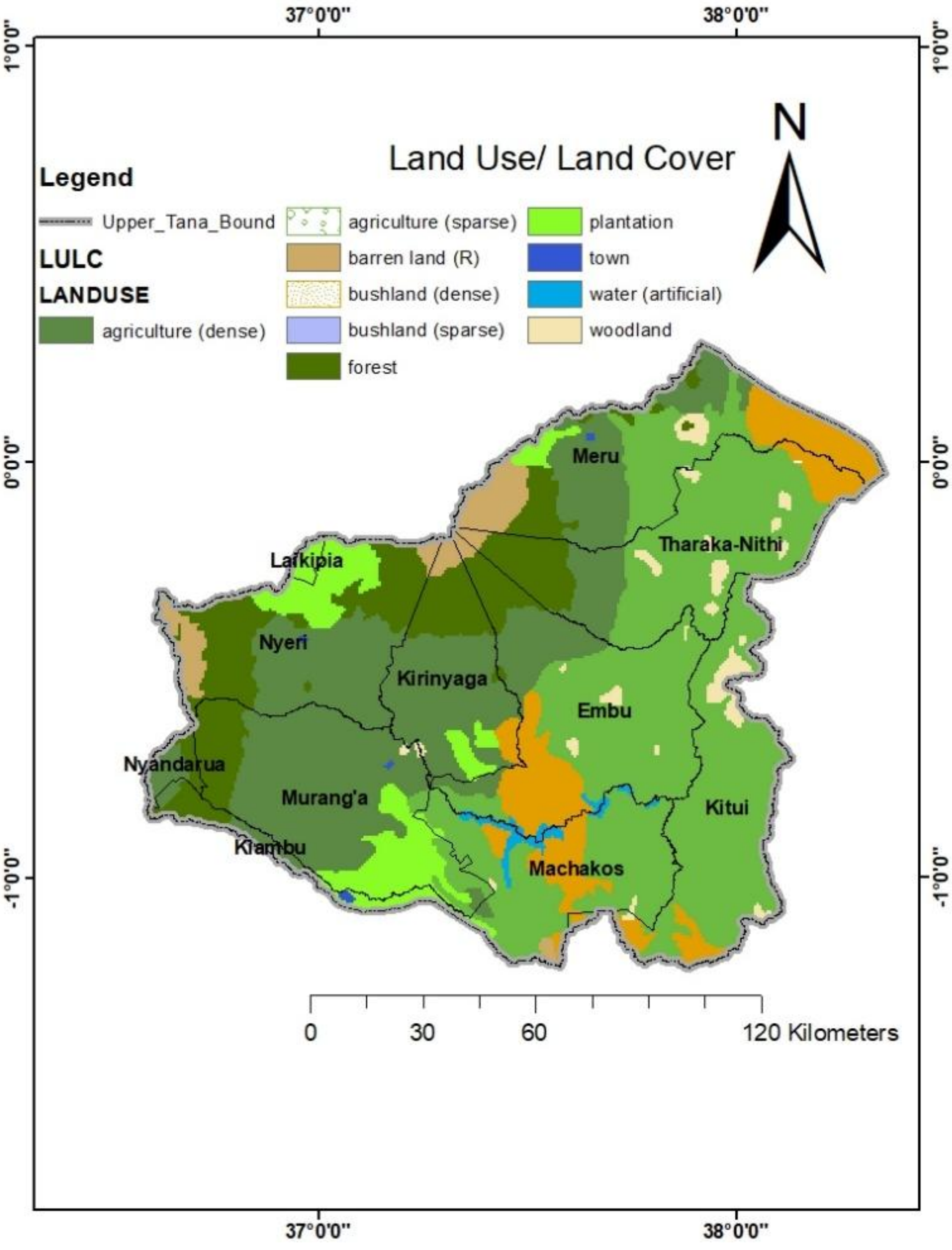

Fig. 4. Land Use/Land Cover map of the upper Tana catchment of Kenya

2.1.5 Soil texture

Soil texture affects the rate of runoff and infiltration [27]. Soils with fine textures are suitable for water conservation technologies such the check dams and the water pans due to their high retention capacities while the medium textured soils are more suitable for technologies such as Mulching and the Zai pits. The soil texture map is illustrated in Fig. 6.

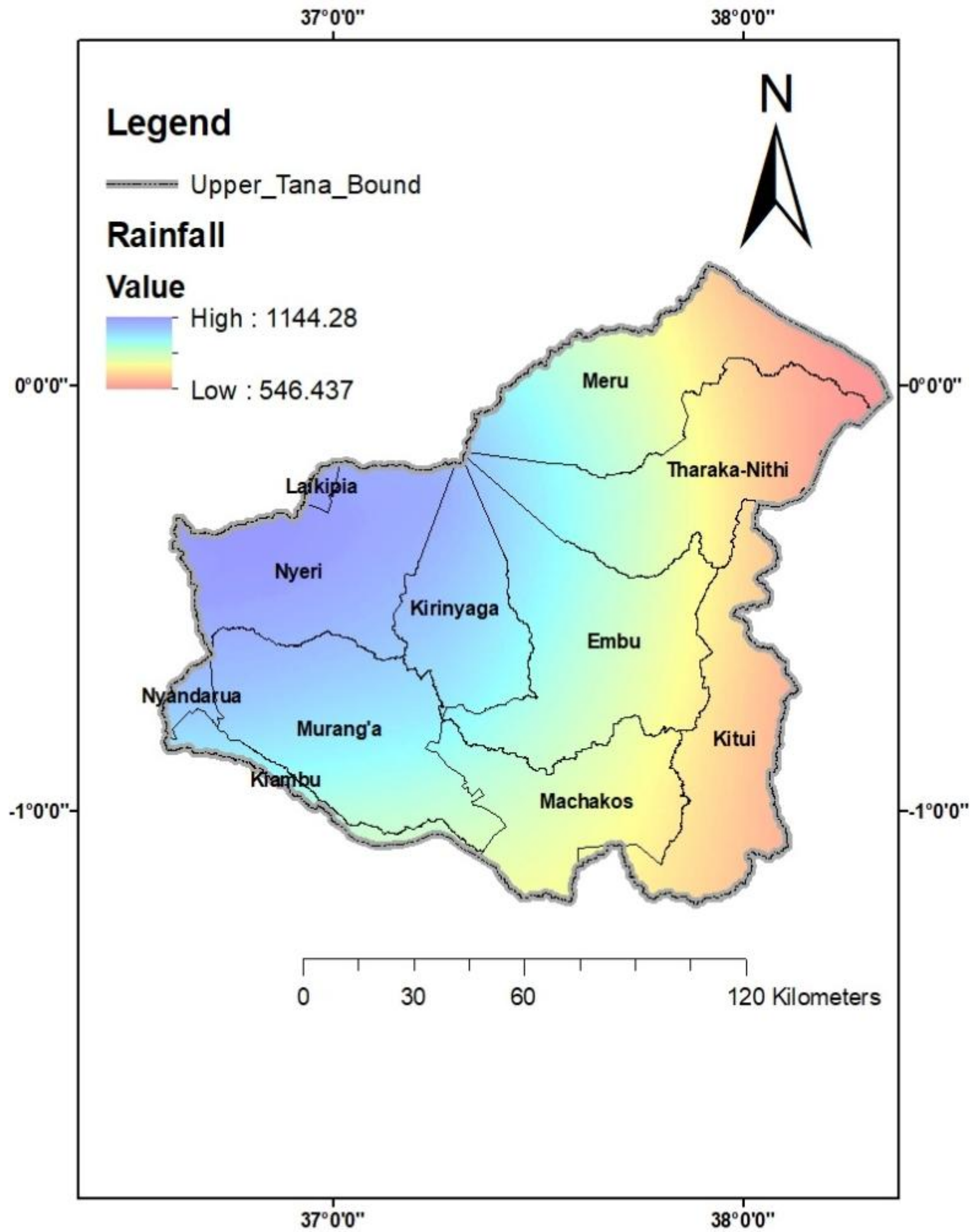

Fig. 5. Annual Average rainfall map of the upper Tana catchment of Kenya

Each water conservation technology has its peculiarities, and therefore the proposal for the suitable areas was made judiciously. For instance, check dams are suitable in areas with defined straight stream channels, soils with high water retention capacity, and gently sloping areas. Terraces, on the other hand, are suitable in medium textured soils and in slopy areas. Zai pits are suitable in areas receiving 300-800 mm of rain, medium-textured soils, and gently sloping areas. Mulches are suitable in gently sloping areas and in medium-textured soils.

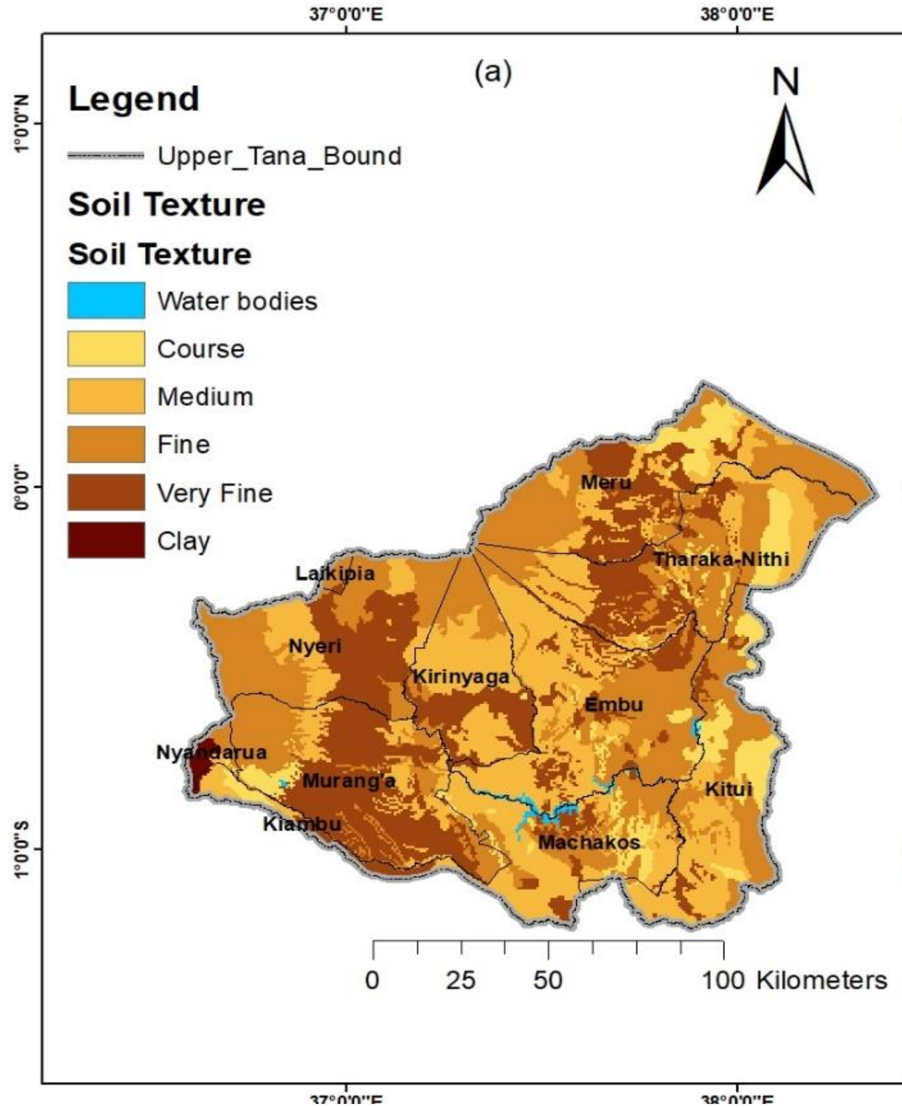

Fig. 6. Soil Texture map of the upper Tana catchment of Kenya

2. 2 Data Analysis

The data layers were converted to raster format under the conversion tool. Each data set was reclassified under the spatial analyst tool where they were assigned values ranging from 1-5 based on their suitability. The very low suitable areas were represented by 1 while 5 represented the very highly suitable areas. Each data was reclassified based on the suitability of each of the water conservation technologies. The weights were assigned depending on the weight of each factor. The Multi-Influencing Factor (MIF) method was used to calculate the weights of each of the factors based on their influence in determining the suitability of the water conservation technologies. The four influencing factors in the study (slope, soil structure, stream order, and land-use) were delineated to determine the suitability of each the water conservation technology. Each factor was evaluated against the other factors to determine the significance of the factors in determining suitability as all the factors are interdependent.

The relationship between the factors is indicated in Fig. 8. Each relationship was weighed according to its strength. The major influencing factors were assigned a score of 1.0 while the minor influencing factors were assigned the score of 0.5, whereby the total score for each of the factors was used in calculating the weights. The factor with the highest weight value was the factor with the largest impact, while the factor with the lowest weight value had the least impact, as shown in tables 1 and 2. The factors were then integrated by use of weighted overlay, which was carried out in a suitability model created under the model builder function in Arc GIS 10.5. The restrictions were then set like a mask, and all the restrictions were excluded. The towns, urban centres, and the forests were used as restrictions, and a buffer was provided for each of the restrictions. The towns and the urban centres were given a buffer of 300 meters while the forests were given a buffer of 50 meters. The buffer was provided under proximity in the spatial analyst tool. The restrictions were set as null and given a score of 0. All the factors were then combined through the raster calculator under math algebra, and the suitability maps for each of the factors were obtained.

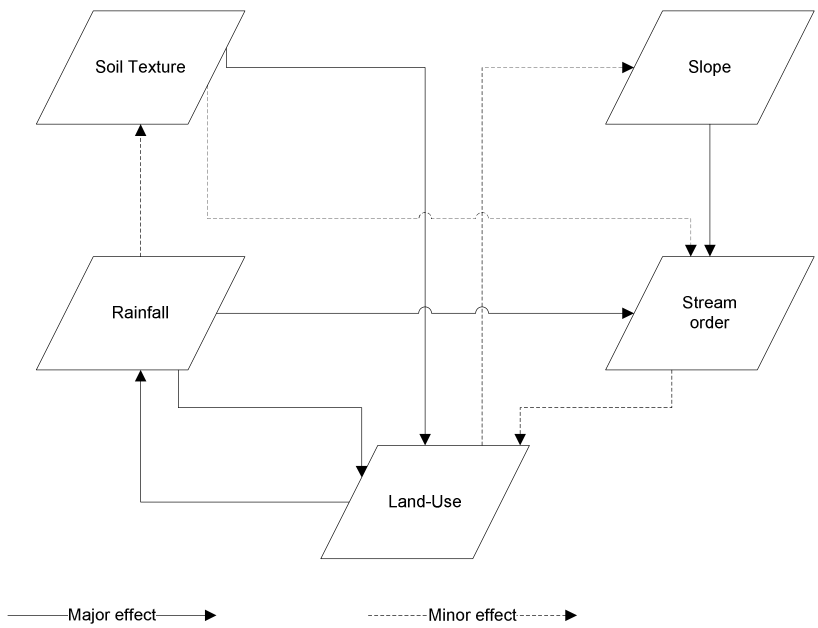

Fig. 7. The interrelationship between the influencing factors determining the suitability of water conservation technologies

Table 1. Factor weights for the check dams

Factor	Stream order	Slope	Land Use	Soil Texture	Total Scores	Weightages
Stream Order	0	0	0.5	0	0.5	8
Slope	1	0	1	0	2	31
Land Use	0.5	0	0.5	0	1	15
Rainfall	1	0	1	0	2	31
Soil Texture	0.5	0	0.5	0	1	15
Total					**6.5**	**100**

Table 2. Factor weights for the Mulches, Terraces and Zai Pits

	Slope	Rainfall	Texture	Land Use	Total Scores	Weightages
Slope	0	0	0	1	1	33
Rainfall	0	0	0	1	1	33
Texture	0	0	0	0.5	0.5	17
Land Use	0	0	0.5	0	0.5	17
Total					3	100

3. RESULTS AND DISCUSSION

The suitability model generated suitability maps for each of the water conservation technology divided into five classes; Restrictions (0), very high suitability (5), high suitability(4), moderate suitability(3), low suitability (2) and very low suitability (1) (Figs. 8, 9, 10 and 11). The percentages of the suitable areas are indicated in (Table 3). Results should be clearly described in a concise manner. Results for different parameters should be described under subheadings or in a separate paragraph. Table or figure numbers should be mentioned in parentheses for better understanding.

3.1 Check-Dams

The results indicated that check dams are highly suitable in Machakos, Kitui, Tharaka-Nithi, lower parts of Embu, and the upper parts of Meru (Fig. 8). The very highly suitable areas occupied Kirinyaga and the upper parts of Embu and Kirinyaga. The low and very low suitable areas occupied Murang'a Nyeri, Laikipia, and Nyandarua.

The high suitability of the Check-dams was attributed to the dense hydrological networks, and the low rainfall received in these areas. [28] reported that Check-dams are suitable in dry areas receiving less than 700mm of rainfall and areas with defined straight stream channels. They also reported that the Check-dams are suitable in areas with a slope of less than 2%. Their results were in line with our results as the very highly suitable areas lie in the gently sloping areas (Fig. 2). The soils in the highly suitable areas are fine-textured, as described in (Fig. 6).

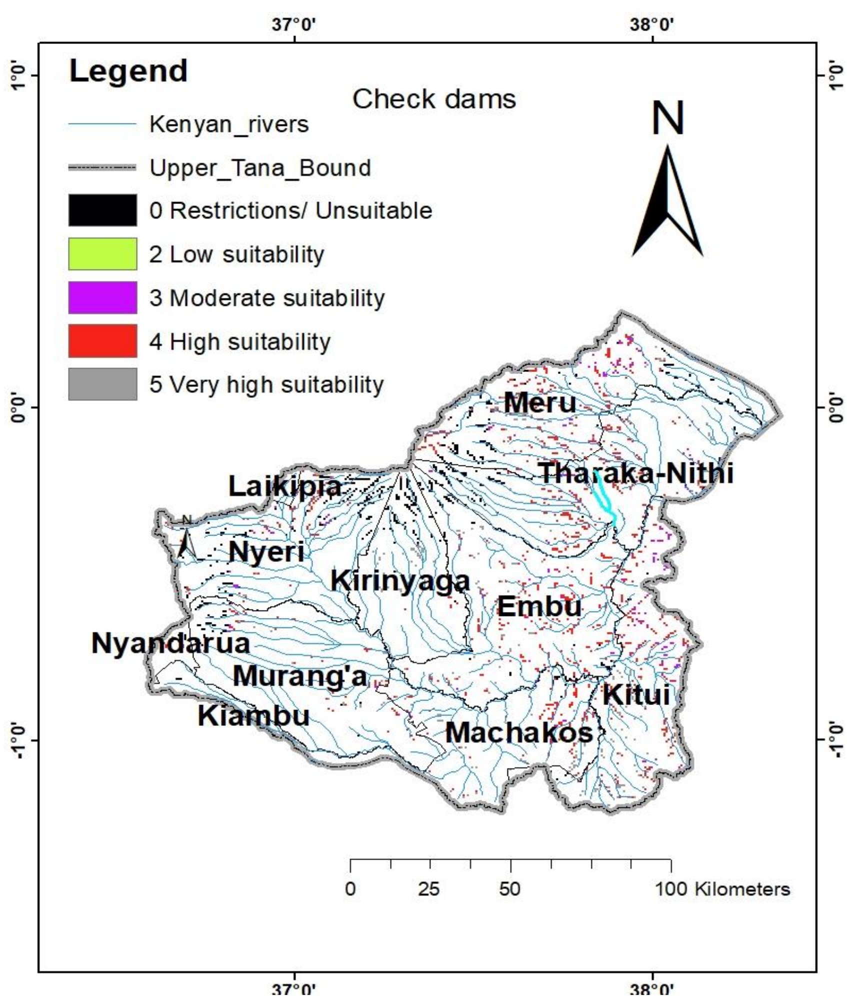

Fig. 8. Checkdams suitability map

Table 3. Summary results for the water conservation technologies

Technologies	Suitability value	Area(ha)	Area %
Mulching	0	3408	22
	1	12	0.08
	2	191	1
	3	3229	21
	4	7551	49
	5	1033	6.70
Total		**15424**	**100**
Zai pits	0	3408	22
	1	1	0.01
	2	357	2
	3	4022	26
	4	6606	43
	5	1030	7
Total		**15424**	**100**
Terraces	0	3408	22
	1	33	0.21
	2	3230	21
	3	6269	41
	4	2361	15
	5	121	0.78
Total		**15424**	**100**

[29] also indicated that check-dams are suitable in areas receiving <1000mm of rainfall. Our results were also in line with, [30] who reported that the Check-dams are suitable in areas with fine textures due to their high retention capacities. The low suitable areas were the areas that received a high amount of rainfall, as indicated in the rainfall map of the Upper Tana watershed (Fig. 5). The low suitability can also be attributed to the steep slopes in these areas, as indicated in the slope map of the Upper Tana watershed (Fig. 2).

3.2 Mulching

The results from the mulching suitability map indicated that the restricted areas occupy 22% of the areas. The restricted areas used in this study were the forest ecosystems, wetlands, and urban centres. These areas were considered unsuitable and were given a score of zero. The very high suitable areas for mulching were distributed in Kirinyaga, Murang'a, Nyandarua, and Nyeri (Fig. 9). Mulching was highly suitable in 49% of the areas (Table 3). The highly suitable areas are distributed in the study region. The moderately suitable areas occupied 21% of the areas. The moderately suitable areas were also distributed across the study area. The low suitable areas were in Embu and Tharaka-Nithi (Fig. 9). The low suitable areas covered 191 hectares, which were 1% of the study region.

The very high suitability of the mulches was attributed to the fact the areas suit the selection criteria for the use of mulches . For instance, these areas are gently sloping, have medium textured soils, and the major type of land use is agriculture. Mulching is applied in agricultural areas to reduce the rate of runoff [31]. The very high suitable areas receive an average annual rainfall of above 1000mm. [32] reported that mulches are suitable in areas receiving high rainfall as for the mulches to decompose, there needs to be sufficient moisture in the soil. They also indicated that the best time to apply mulches is during the beginning and end of the rainy season. [33] reported that the mulches are suitable in areas receiving low rainfall and in well-drained soils. The high percentage of the highly suitable areas means that mulching can be applied across areas with different kinds of soils and areas receiving different amounts of rainfall. The largest percentage of the areas in the Upper Tana region of Kenya are moderately slopy (5-10%), with medium-textured soils and the largest form of land use is agriculture which suits the suitability criteria for the mulches. This makes mulching the most suitable water conservation technology in the upper Tana watershed.

3.3 Zai Pits

The very highly suitable areas covered Kitui and lower parts of Tharaka-Nithi (Fig. 10). The very high suitable areas covered 1030 hectares of the study area, which was 21% of the total area. The low and the very low suitable areas, on the other hand, covered Nyeri, Laikipia and Murang'a which are high rainfall areas. These areas covered 358 hectares of the study area, which was 2% of the study area. These areas also have steep slopes making them less suitable for the use of Zai pits. The highly suitable areas occupied 6606 hectares, which were 43% of the study area (Fig. 10).

The very high suitability of the Zai pits was attributed to the low rainfall received in the areas. [34] reported that Zai pits are highly suitable areas receiving an average rainfall of 300-800mm. These areas have medium textured soils and are moderately sloping, which make them more suitable for the use of Zai pits. According to Mati et al[35], Zai pits are suitable in areas with a slope of 1-15%. The highly suitable areas were distributed across the study area. The wide distribution of suitable areas means that the Zai pits are highly suitable across areas with different biophysical characteristics.

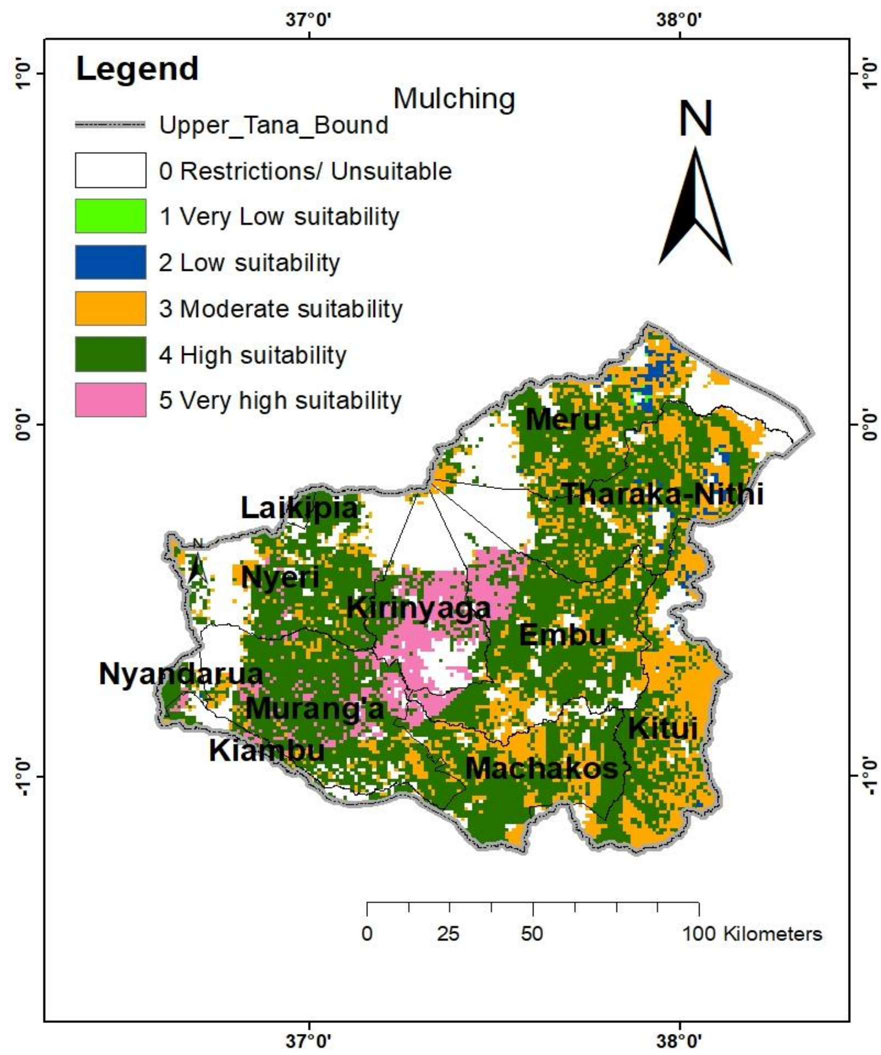

Fig. 9. Mulching suitability map

The distribution of the highly suitable areas across the study area can also be attributed by the fact that a large percentage of the Upper Tana region has medium textured soils and is moderately sloping. It can also be attributed to the fact the large percentage of the areas in the Upper Tana region are agricultural areas, and Zai pits are suited in agricultural areas. [36] reported that Zai pits are most suited in dryland areas receiving rainfall of less than 700mm per year. According to Namirembe et al. [37], Zai pits are suitable in arid to Semi-Arid areas, and moderately sloping areas which were in line with our results.

3.4 Terraces

The very highly suitable and highly suitable areas covered Murang'a Nyeri and Kirinyaga (Fig. 11). The moderately suitable areas were distributed across the study area and covered an area of 6269 hectares, which is 41% of the study area (Table 3). From the Terraces suitability map, the terraces are highly suitable in Kirinyaga, Murang'a, Nyandarua, Nyeri, and upper parts of Tharaka-Nithi. The highly suitable areas covered 2361 hectares, which are 15% of the study area. The low and very low suitable areas covered Machakos, Tharaka-Nithi, and Kitui. The low suitable areas covered 3263 hectares, which are 0.21 and 21 respectively of the study area. These areas occupy the lowlands of Kenya. The moderately suitable areas were distributed across the study region and covered 41% of the study area.

The very highly suitability was attributed to the fact that Terraces are mostly suitable in steep areas, with medium-textured soils and also areas receiving high rainfall. The high suitability was attributed to the fact the highly suitable areas are highly slopy (Fig. 2).

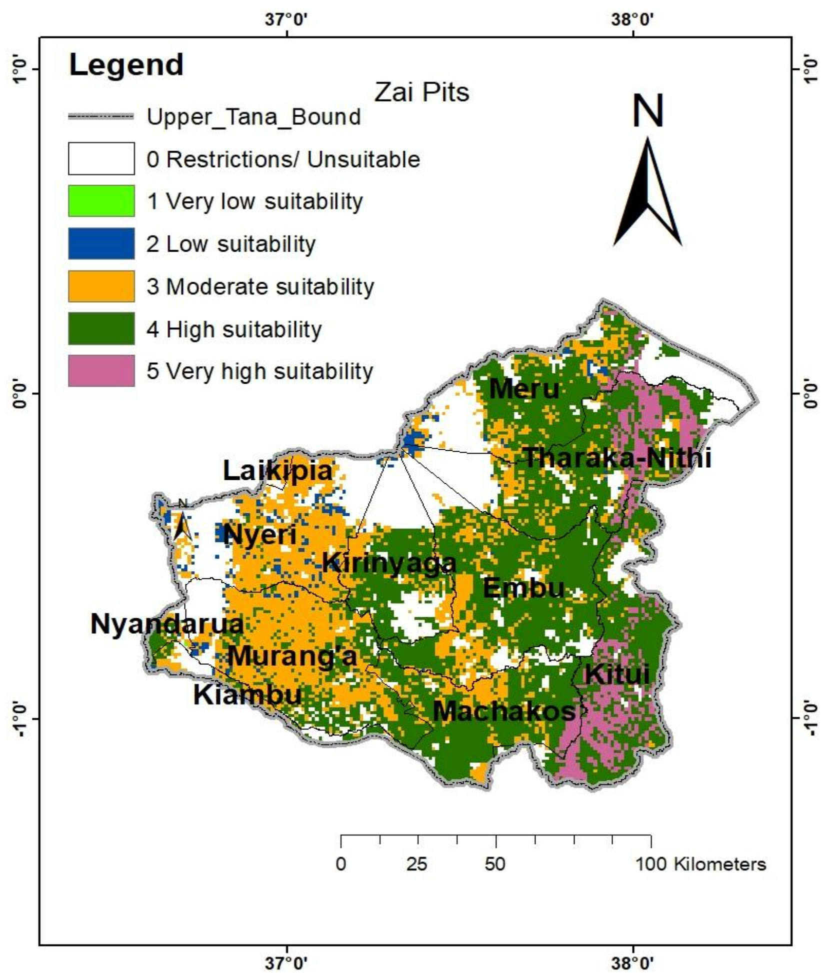

Fig. 10. Zai pits suitability map

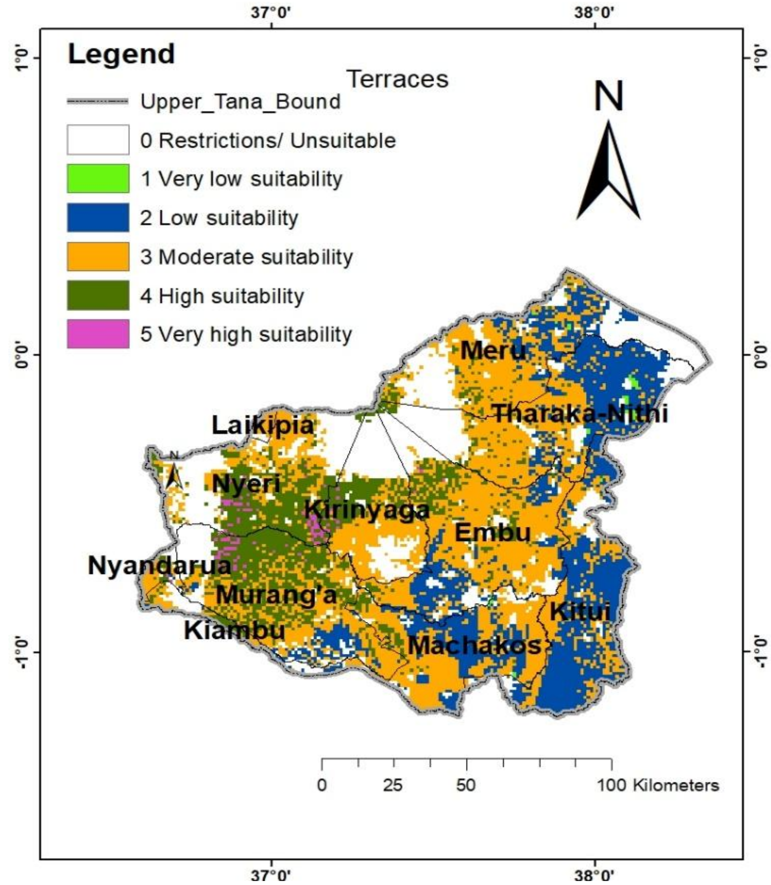

Fig. 11. Terraces suitability map

Meru is proximal to the highest mountain in Kenya, Mt. Kenya and the Nyambene hills while Nyandarua and Nyeri have the Aberdare ranges. The results were in line with [38,39] who reported that terraces are suitable in areas receiving more than 700mm of rainfall per annum and with slopes higher than 12%. Report from [40] indicated that terraces are suitable in an area with a slope percentage of above 10%. Murang'a Nyeri and Kirinyaga receive a high amount of rainfall as indicated in Fig. 5. The low suitability of these areas can be attributed to the fact these areas range from moderately sloping to gently sloping, and very few of sections in these areas have a slope percentage of 12 and above. The high percentage of the moderately sloping areas that are widely distributed across the Upper Tana region means that the terraces can be constructed in areas with varied biophysical characteristics. [41] reported that the terraces are suitable in semi-arid to humid regions, and in medium to steep slopes of 12-47%.

4. CONCLUSION

From the findings of the study, the highly suitable areas for the Checkdams are Machakos, Kitui, Tharaka-Nithi and lower parts of Embu. These are areas with defined straight channels, and have soils with high retention capacity and are gently sloping The highly suitable areas for mulching are Kirinyaga, Murang'a, Nyandarua and Nyeri as they are gently sloping and have medium-textured soils. The highly suitable areas for the Zai pits are Kitui, lower parts of Tharaka-Nithi which receive rainfall of 300-800mm and are gently sloping and the highly suitable areas for the terraces are Murang'a, Nyeri and Kirinyaga as they have a higher slope percentage. The results also demonstrated the effectiveness of GIS in delineating the suitable areas for the use of water conservation technologies. Therefore, it is recommended to scale out the technologies to the different areas in the Upper Tana watershed based on the suitability maps provided.

ACKNOWLEDGEMENTS

We acknowledge the Swiss Agency for Development and Cooperation (SDC) and Swiss National Science Foundation (SNSF) in the Swiss Programme for Research on Global Issues for Development (r4d programme) and Research Institute of Organic Agriculture (FiBL), Switzerland for the support provided through the Organic Resource Management for Soil Fertility project. All the datasets used in this study were freely available from the world Research Institute World soil information and NASA.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. Rapid Assessment of Aid Flows for Agricultural Development in Sub-Saharan Africa. Investment Div. Discuss. 2009:1–18.
2. Okeyo AI, Mucheru-Muna M, Mugwe J, Ngetich KF. Effects of selected soil and water conservation technologies on nutrient losses and maize yields in the central highlands of Kenya. Agric. Water Manag. 2014;137:52–58.
   Available:https://doi.org/10.1016/j.agwat.2014.01.014.
3. Cooper PJM, Dimes J, Rao KPC, Shapiro B, Shiferaw B, Twomlow S. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? Agric. Ecosyst. Environ. 2008;126:24–35.
   Available:https://doi.org/10.1016/j.agee.2008.01.007
4. Kiboi MN, Ngetich KF, Diels J, Mucheru-Muna M, Mugwe J, Mugendi DN. Minimum tillage, tied ridging, and mulching for better maize yield and yield stability in the Central Highlands of Kenya. Soil Tillage Res. 2017;170:157–166.
   Available:https://doi.org/10.1016/j.still.2017.04.001
5. FAO 2018. The State of Food and Agriculture. Migration, agriculture, and rural development; 2018.
6. Mutunga K. Water Conservation, Harvesting, and Management (WCHM) - Kenyan Experience. Sel. Pap. from 10th Int. Soil Conserv. Organ. Meet. Purdue Univ. held May 24-29, 1999 Purdue Univ. USDA-ARS Natl. Soil Eros. Res. Lab. 20011;139–1143.
7. Muriu-Ng'ang'a FW, Mucheru-Muna M, Waswa F, Mairura FS. Socio-economic factors influencing utilization of rainwater harvesting and saving technologies in Tharaka South, Eastern Kenya. Agric. Water Manag. 2017;194:150–159. Available:https://doi.org/10.1016/j.agwat.2017.09.005
8. Wilschut LI. Baseline Review of the Upper Tana, Kenya; 2015.
9. Nzuve B, Mulei S. Effects of soil erosion on sediment dynamics, food security, and rural poverty in Makueni District, Eastern Kenya. 2014;4:101–107.
10. Ouma EN, Rop S, Okoba B. Status review of the adopted soil and water management technologies in Kenya as a critical component of the environment; 2013
11. Mutunga K. Water Conservation, Harvesting, and Management (WCHM) - Kenyan Experience. Sel. Pap. from 10th Int. Soil Conserv. Organ. Meet. Purdue Univ. held May 24-29, 1999 Purdue Univ. USDA-ARS Natl. Soil Eros. Res. Lab. 2001:1139–1143.
12. Nyamekye C, Thiel M, Schönbrodt-Stitt S, Zoungrana BJ, Amekudzi LK. Soil and Water Conservation in Burkina Faso, West Africa. 2018:1–24.
    Available:https://doi.org/10.3390/su10093182.
13. Telkar S, Kant K. Types of Mulching and their uses for dryland condition;2017.
14. Mati B, Bock T. De. Mapping the potential of rainwater harvesting technologies in Africa. A GIS Overview; 2006.
15. Joshua Black, Maimbo Malesu, Alex Oduor KC, MN. Rainwater harvesting inventory of Kenya, Icraf; 2012.
16. Mati B. Overview of Water and Soil Nutrient Management under Smallholder Rain-fed Agriculture in East Africa; 2018.
17. Dorren L. A review of the effect of terracing on erosion. Soil Conserv. Prot. Eur. 2014:97–108.
18. Prasad HC, Bhalla P, Palria S. Site Suitability Analysis of Water Harvesting Structures Using Remote Sensing and GIS

– A Case Study of Pisangan Watershed, Ajmer District, Rajasthan XL. 2014:9–12.
Available:https://doi.org/10.5194/isprsarchives-XL-8-1471-2014

19. FAO. Climate Change, water, and food security. 2008:92–94.
20. Han Y, Feng G, Ouyang Y. Effects of soil and water conservation practices on runoff, sediment, and nutrient losses. Water (Switzerland). 2018;10:1–13.
Available:https://doi.org/10.3390/w10101333.
21. Ouma EN, Rop S, Okoba B. Status review of the adopted soil and water management technologies in Kenya as a critical component of the environment; 2013.
22. Saima I. Site Suitability Analysis for Small Multipurpose Dams Using Geospatial Technologies. J. Remote Sens. GIS 2016:5.
Available:https://doi.org/10.4172/2469-4134.1000162.
23. Martín-Moreno C, Martín Duque JF, Nicolau Ibarra JM, Hernando Rodríguez, N, Sanz Santos MÁ, Sánchez Castillo L. Effects of topography and surface soil cover on erosion for mining reclamation: The Experimental Spoil Heap at El Machorro Mine (Central Spain). L. Degrad. Dev. 2016;27:145–159.
Available:https://doi.org/10.1002/ldr.2232
24. Adham A, Naba K, Abed R, Arbi M, Wesseling JG, Riksen M, Fleskens L, Karim U, Ritsema CJ. International Soil and Water Conservation Research A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq. Int. Soil Water Conserv. Res. 2018;6:297–304. Available:https://doi.org/10.1016/j.iswcr.2018.07.003
25. Kolekar S, Chauhan S, Raavi H, Gupta D. Site Selection of Water Conservation Measures by Using RS and GIS : A Review 2017;10:805–813.
26. Bancy. Design of soil and water conservation structures for smallholder agriculture training notes by prof. Bancy M. Mati. 2014;0–7.
27. Haghnazari F, Shahgholi H, Feizi M. Factors affecting the infiltration of agricultural soils : A review. Factors Affect. infiltration Agric. soils Rev. 2015;6:21–35.
28. Namirembe S, Nzyoka JM, Gathenya JM. A guide for selecting the right soil and water conservation practices for smallholder farming in Africa; 2009.
29. Mugo GM, Odera PA. Site selection for rainwater harvesting structures in Kiambu County-Kenya. Egypt. J. Remote Sens. Sp.Sci;2018.
Available:https://doi.org/10.1016/j.ejrs.2018.05.003.
30. Adham A, Naba K, Abed R, Arbi M, Wesseling JG, Riksen M, Fleskens L, Karim U, Ritsema CJ. International soil and water conservation research a gis-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq. Int. Soil Water Conserv. Res. 2018;6:297–304. Available:https://doi.org/10.1016/j.iswcr.2018.07.003
31. Sharma R, Bhardwaj S. Effect of mulching on soil and water conservation -A review. Agric. Rev. 2017;38. Available:https://doi.org/10.18805/ag.r-1732.
32. Ranjan P, Patel GT, Prem M, Solanke KR. Organic mulching- a water saving technique to Increase the Production of Fruits and Vegetables. Curr. Agric. Res. J. 2017;5:371–380. Available:https://doi.org/10.12944/carj.5.3.17.
33. Namirembe S, Nzyoka JM, Gathenya JM. A guide for selecting the right soil and water conservation practices for smallholder farming in Africa; 2009.
34. Mati B. Overview of water and soil nutrient management under smallholder Rain-fed Agriculture in East Africa; 2018.
35. Mati B, Bock T. De. Mapping the potential of rainwater harvesting technologies in Africa. A GIS Overv; 2006.
36. Danjuma MN, Mohammed S. Zai pits system: A catalyst for restoration in the dry lands. 2015;8:1–04.
Available:https://doi.org/10.9790/2380-08210104.
37. Namirembe S, Nzyoka JM, Gathenya JM. A guide for selecting the right soil and water conservation practices for smallholder farming in Africa; 2009.
38. Dorren L. A review of the effect of terracing on erosion. Soil Conserv. Prot. Eur. 2014;97–108.

39. Sheng TC. Bench terrace design made simple. Proc. 12th Int. Soil Conserv. Organ. Conf. 2002;500–504.
40. Baryła A, Pierzgalski E. Ridged Terraces - Functions, Construction and Use/Kraiginės Terasos – Funkcijos, Konstrukcijos Ir Naudojimas/Гребневые Террасы – Функции, Конструкции И Использование. J. Environ. Eng. Landsc. Manag. 2008;16:3–20. Available:https://doi.org/10.3846/1648-6897.2008.16.104-109.
41. Namirembe S, Nzyoka JM, Gathenya JM. A guide for selecting the right soil and water conservation practices for smallholder farming in Africa; 2009.

APPENDIX

Appendix 1. Selection criteria for the check dams

Criterion	Class	Score
Stream order	1	5
	2	4
	3	3
Soil Texture	Clay	5
	Silty Clay	4
	Sandy Clay	3
	Sandy Loam	2
	Sandy	1
Slope	Level (0-1)	2
	Gentle Slope(3-5)	4
	Moderate Slope (5-10)	5
	Very Steep (10-50)	3
	Extremely Steep(>50)	1
Rainfall	0-500	5
	500-1000	4
	1000-1500	3
	1500-2000	2
	>2000	1

1= Very low suitability 2=Low suitability 3= Moderate suitability 4= High suitability 5=Very high suitability

Appendix 2. Selection criteria for mulching

Criterion	Class	Score
Slope (%)	Level (0-1)	2
	Gentle Slope(3-5)	4
	Moderate Slope (5-10)	5
	Very Steep (10-50)	3
	Extremely Steep(>50)	1
Rainfall	0-500	1
	500-1000	2
	1000-1500	3
	1500-2000	4
	>2000	5
Soil Texture	Clay	1
	Silty Clay	3
	Sandy Clay	4
	Sandy Loam	5
	Sandy	2
Land Use	Agricultural	5
	Barren Land	3
	Bush Land	2
	Plantation	4
	Woodland/Forests/towns	Restricted

Appendix 3. Selection criteria for the zai pits

Criterion	Class	Score
Slope	Level (0-1)	2
	Gentle Slope(3-5)	4
	Moderate Slope (5-10)	5
	Very Steep (10-50)	3
	Extremely Steep(>50)	1
Soil Texture	Clay	1
	Silty Clay	3
	Sandy Clay	4
	Sandy Loam	5
	Sandy	2
Rainfall	0-500	5
	500-1000	4
	1000-1500	3
	1500-2000	2
	>2000	1
Land Use	Agricultural	5
	Barren Land	3
	Bush Land	2
	Plantation	4
	Woodland/Forests/towns	Restricted

Appendix 4. Selection criteria for the terraces

Criterion	Class	Score
Rainfall	0-500	1
	500-1000	2
	1000-1500	3
	1500-2000	4
	>2000	5
Slope	Level (0-1)	1
	Gentle Slope(3-5)	2
	Moderate Slope (5-10)	3
	Very Steep (10-50)	4
	Extremely Steep(>50)	5
Soil Texture	Clay	1
	Silty Clay	3
	Sandy Clay	4
	Sandy Loam	5
	Sandy	2
Land Use	Agricultural Lands	5
	Barren land	3
	Bush Land	2
	Plantation	4
	Woodlands/Forests/towns	Restricted

Peer-review history:
The peer review history for this paper can be accessed here:
https://sdiarticle4.com/review-history/51079