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# GIS-Based Multi-Criteria Evaluation to Identify Areas for Soil and Water Conservation in Lower Lake Bogoria Landscapes, Baringo County, Kenya

**Mark Boitt[1]*, John Gathoni[2], Dickson Kaelo[3], Laurine Koech[4]**

[1]Institute of Geomatics, GIS and Remote Sensing, Dedan Kimathi University of Technology, Nyeri, Kenya
[2]Research and Development, Mapinfotek Geomatiks Ltd., Nairobi, Kenya
[3]Kenya Wildlife Conservancies Association (KWCA), Nairobi, Kenya
[4]Baringo County Conservancies Association (BCCA), Kabarnet, Kenya
Email: *mark.boitt@dkut.ac.ke, johnw@mapinfotek.co.ke, dkaelo@kwcakenya.com, laurinejemutai93@gmail.com

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## Abstract

This study was meant to ensure that there is proper and efficient conservation of soil and water using geospatial tools to enable us identify priority areas to carry out conservation. Over the past years, various fields of study have established how critical it is to conserve these natural resources in the ecosystem and to ensure sustainability in not only green livelihoods but also to enhance living conditions of the life on earth. The aim of this research was to generate high priority sites for establishing soil and water conservation techniques in the Lower Bogoria Landscapes in Baringo, Kenya using GIS-based multicriteria decision analysis. Various criteria were analyzed to generate the final conservation priority sites, such as land use land cover, rainfall runoff, soil erosion and slope. The criteria were assigned weights using the AHP technique and overlayed using the weighted overlay tools to produce the final outputs. Land use land cover maps were generated using supervised maximum likelihood technique, rainfall run-off maps were generated using the SCS-CN method and soil erosion maps were generated using RUSLE model. The final soil and water conservation maps showed that high and moderate priority areas requiring the establishment of techniques and mechanisms to control soil erosion and conserve water increased from 1990 to 2020. In 2020, more than 50% of the total study area was classified as moderate to high priority for water and soil conservation. Soil and water conservation structures such as water pans, percolation tanks, farm ponds and stop dams should be constructed in such areas.

**Keywords**

Conservation, Run-Off, Soil Erosion, Land Use Land Cover, Soil and Water Conservation

## 1. Introduction

Throughout the course of history, all the social improvement and economic development are deeply concerned with soil loss and ecological environmental protection. Poor soil and water conservation measures will lead to land degradation that are either natural or human induced. Natural hazards include land topography and climatic factors such as steep slopes, landslides from frequent floods, blowing of high velocity winds, rains of high intensity, strong leaching in humid regions and drought conditions in the dry regions. It is now common sense that soil and water conservation is the insurance for worldwide ecology and its development.

For a long period of time, soil and water loss has been recognized as number one killer to the ecological environment and Kenya is at critical conditions for its development with complicated geological conditions and accelerated human destruction and serious soil and water losses (Karuku, 2018).

United Nation Environmental Program reports that crop productivity on about 20 million hectares each year becomes unproductive because of soil erosion or soil-induced degradation (Tugizimana, 2015). The loss of soil production due to erosion is caused by deterioration in soil physical and chemical properties such as infiltration rate, water-holding capacity, loss of nutrients needed for crop production, and loss of soil carbon (Oldeman, 1992). In Kenya, the situation is not any different having had a history of near misses as far as soil conservation is concerned. The new policy traces this history starting with the soil and water conservation of the 1930s, introduced due to serious erosion problems in both the settlers and the African farms. This policy enforced contour farming, tree planting, terrace strip cropping and de-stocking among other measures.

The United Nations predicts that 1.8 billion people will experience absolute water scarcity in less than 5 years, and worry that by 2030, two out of three persons will be living in water stressed regions. Already every five persons worldwide cannot access their basic everyday water resource, a fact recently witnessed in Cape Town, South Africa which is in dire need of water with serious rationing of the commodity (Kulshreshtha, 1998). Poor management of resources such as unplanned land clearing for cultivation and deforestation of the water towers has led to serious environmental and ecological degradation as well as reduced water volumes as seen all across Africa.

Soil erosion is one of the major causes of ecosystem degradation which leads to a reduction in crop productivity. Soil erosion affects have various effects on soil resources such as: loss of fertile top soil, soil compaction, poor drainage, loss of nutrients, reduced soil depth and depletion of soil organic matter. On the other hand, soil erosion has the following effects on water resources: reduced water availability, sedimentation of water bodies, water pollution and water logging (Kumawat et al., 2020).

According to a study done in 2010 that was establishing the human aspects of Lake Baringo's siltation was able to determine that the livelihoods of communities around Lake Baringo depend on livestock rearing, charcoal burning and cultivation. Poor land-use systems together with resource user conflicts, political marginalization, poverty, weak institutions and policies are factors contributing to land and water degradation. Negative impacts of siltation identified include destruction of fish breeding areas, flooding, poor water quality affecting human and animal use and increased resource user conflicts. Strategies that various institutions are undertaking such as replanting indigenous vegetation, are showing little progress due to lack of co-ordination, the nature of the landscape, the lack of funding and political will (Lwenya & Yongo, 2010).

Soil and water are fundamental natural resources for the agricultural production system whose deterioration is caused by various degradation processes such as soil erosion. Holistic management of soil and water resources is crucial for the protection of the natural ecosystem and soil health (Kumawat et al., 2020). Identification of appropriate sites for water and soil conservation is an important step towards maximizing water availability and land production in arid and semi-arid lands (Varade et al., 2017).

Soil and water conservation practices should be formulated with a view to reduce amount and velocity of surface run-off, ensure good soil cover, ensure conservation and retention of soil moisture, minimize and stop the effects of raindrops impact on the soil, re-shape the slope to reduce its steepness and length, maintain and improve soil fertility and remove unwanted run-off safely and effectively. Run-off amount can be reduced by preventing run-off through diversion channels and interception ditches and increasing infiltration through terracing, contour bands, ridge tillage and broad beds while run-off velocity can be reduced by building porous barriers such as gabions, riprap, reno mattress and woven barriers and building concrete structures such as drop structures, chutes, check dams and stop dams (Khare et al., 2013).

There are two types of soil and water conservation structures; erosion control measures also referred to as mechanical measures which are permanent and semi-permanent structures that are established to divert, control and conserve surface run-off and preventative techniques also referred to as biological measures which are vegetative measures that improve the productivity of land without construction of structures. Mechanical measures include; terracing, bunding, trenching, check dams, gabions, stone barriers and percolation tanks while biological measures include; forestry, agroforestry, horticulture and contour farming (Kumawat et al., 2020).

The suitability of different soil and water conservation measures and structures is dependent on climate and the need to retain or discharge run-off, farm sizes, soil characteristics (texture, drainage and depth), availability of outlets and waterways, availability and cost of materials and labour and the adequacy of existing vegetative or biological measures (Mati, 2016).

The Lake Baringo region has also attracted the worlds eyes in the tourism sector with its unique land formations as seen in the areas such as those covered by the Sinibo Geopark Conservancy. The tourist destination brings a source of livelihood to the indigenous communities living in the areas as they are part of the ecological balance and thrive within it. However, the area is also prone to deep soil erosion and has been plagued by land degradation. Due to this, an assessment done by the Baringo County Conservancies Association (BCCA) termed land degradation as a major weakness in some of the conservancies which threatens the future of the region as a tourism hub as the situation is prone to worsen unless drastic changes to improve the ways of conservation are made.

The aim of this research was to generate high priority sites for establishing soil and water conservation techniques in the Lower Bogoria Landscapes in Baringo, Kenya using GIS-based multicriteria analysis. Specific objectives were:

- Perform land use land cover analysis of the area in 1990, 2000, 2010 and 2020,
- Analysis of soil loss estimation in the area in 1990, 2000, 2010 and 2020,
- Calculate annual rainfall run-off in the area,
- Identify priority sites for soil and water conservation.

GIS-based multicriteria decision analysis techniques such as weighted overlay could be used to produce a thematic map to show priority sites for soil and water conservation through assigning weights to land use land cover maps, soil loss maps, soil texture maps, slope maps and rainfall run-off maps (Varade et al., 2017). Although it is quite easy to term water and soil as renewable resources, this largely depends on how quick the resource can regenerate itself and how efficiently it is conserved. With the changing regimes in different unrelated sections such as climate change, land uses, economic development, which are connected in some way or another by land degradation; it is also important that we humans diversify using the current resources to better improve how we carry out conservation mechanisms to avert the combat crisis that bring about soil and water degradation.

## 2. Materials and Methods

### 2.1. Study Area

The study area as shown in **Figure 1** is found in Baringo County, Kenya between latitudes 0.0˚N and 2.0˚N and longitudes 35.5˚E and 36.5˚E with an area of approximately 7755.08 square kilometers. The annual average rainfall received in the area ranges between 700 mm and 2200 mm with different soil textures such as very clay, clay, loamy and sandy.

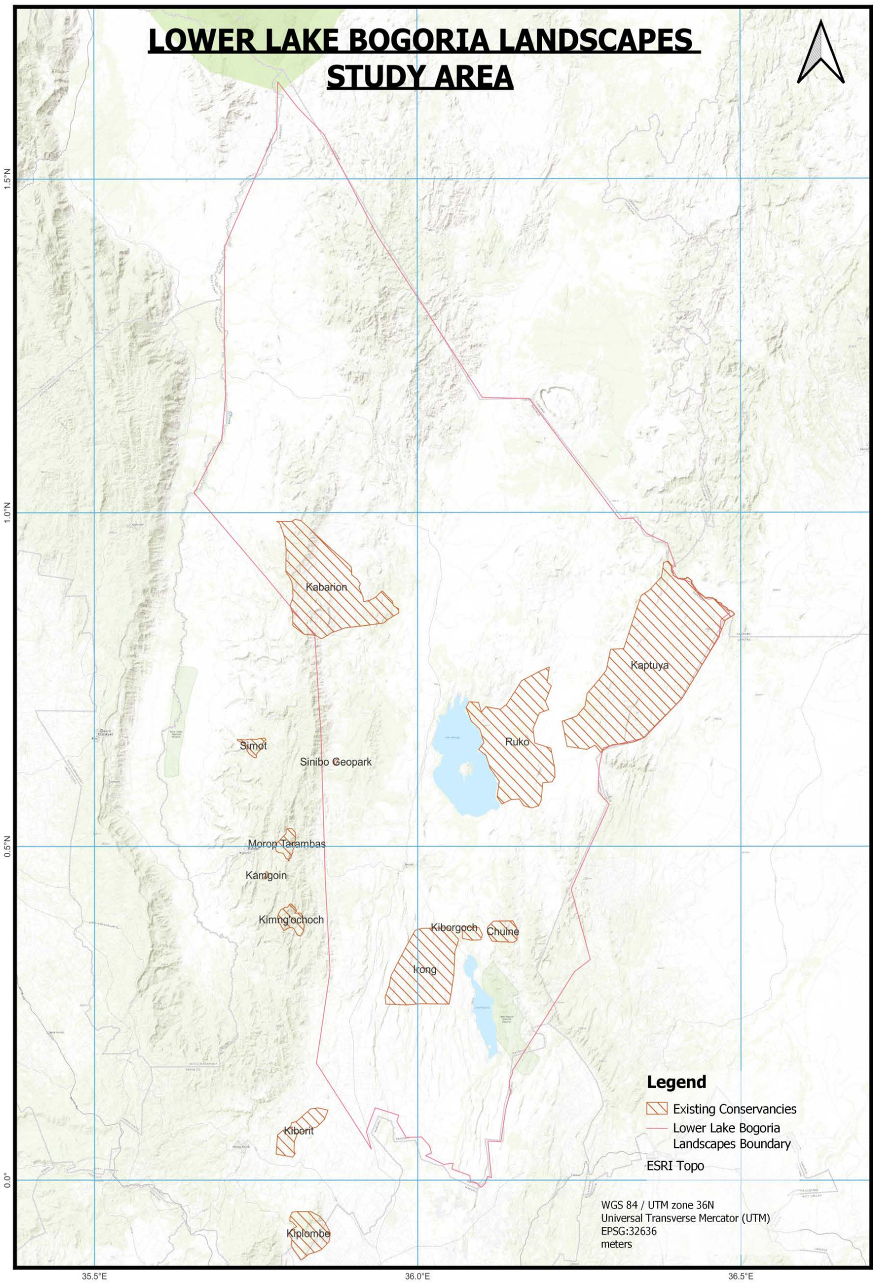


Figure 1. Lower Bogoria Landscapes study area.

## 2.2. Data and Software

The following data and software in Table 1 and Table 2 were used to undertake and complete this research.

## 2.3. Methodology

Figure 2 shows the summarized methods that were used to obtain the soil and water conservation priority maps.

**Land use land cover maps** were generated using Landsat 5, 7 and 8 images for the years 1990, 2000, 2010 and 2020. Landsat images were downloaded from the USGS website and preprocessed through reprojection, haze reduction, layer stacking bands, mosaicking of the respective layer stacked tiles and subset using the area of interest polygon as the masking layer.

Table 1. Data.

| Data | Source |
|---|---|
| Soil | ISRIC Data Hub |
| Satellite Imagery | USGS Earth Explorer |
| Digital Elevation Model | RCMRD Geoportal |
| Rainfall | CHIRPS |

Table 2. Software.

| Software | Use |
|---|---|
| ENVI | Land use land cover assessment |
| ArcGIS and QGIS | Soil Loss, Runoff estimation and Site Priority analysis |

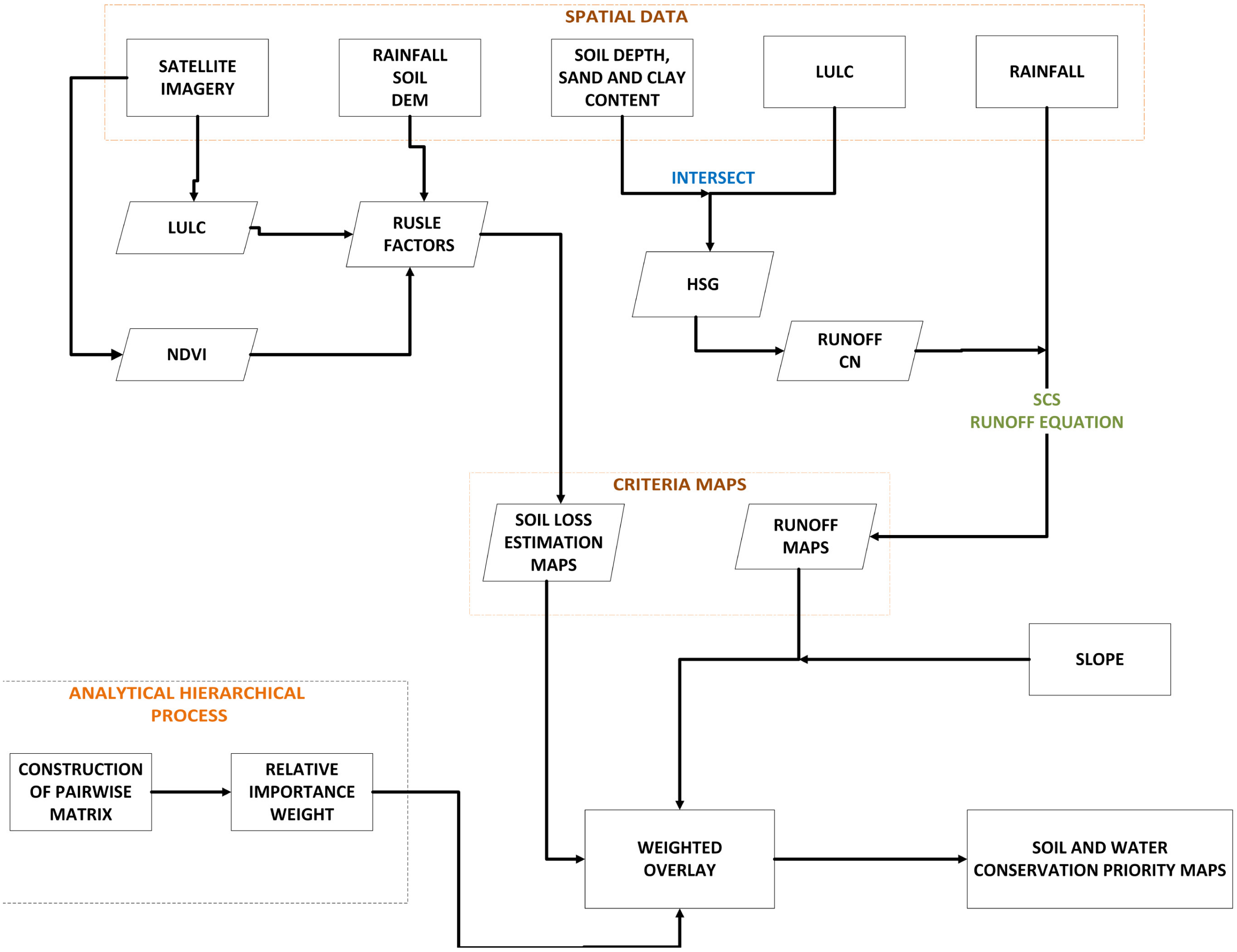


Figure 2. Methodology summary.

Subset images were then processed and classified using maximum likelihood algorithm in ENVI software. Each image was classified into five classes namely: forest, cropland, waterbody, bare land and built-up areas.

**The RUSLE model** developed by Wischmeier and Smith was used in this research to estimate soil loss in Lower Bogoria Landscapes. RUSLE model incorporates five parameters to estimate annual soil loss: rainfall and run-off erosivity factor, soil erodibility factor, slope length and steepness factor, cover management factor and support practice factor. The equation below illustrates the model.

$$A = R * K * LS * C * P \tag{1}$$

where $A$ is the computed annual soil loss, $R$ is the rainfall erosivity factor, $K$ is the soil erodibility factor, $LS$ is the slope length and steepness factor, $C$ is the cover management factor and $P$ is the support practice factor.

R-factor is the number of erosion-index units in a normal year's rain and estimates the erosive power of rainfall and surface runoff and can be calculated using the following equation developed by Kassam et al. (1992). According to Stone and Hilborn (2012), the greater the duration and intensity of rainstorm the higher rate of erosion.

$$R = 117.6\left(1.00105^{MAP}\right) \tag{2}$$

where $MAP$ is the mean annual precipitation received in the area.

K-factor is the erosion rate per unit of erosion index for a specific soil and is used to assess the susceptibility of soil to erosion based on its properties (USDA, 2016). Soil properties used to calculate k-factor in this research were; soil organic carbon content, soil sand content, soil clay content and soil silt content. The following equation was used to calculate the factor in a GIS environment (Kouli et al., 2009).

$$\begin{aligned} K = & \left[0.2 + 0.3\exp^{\left(-0.0256 SAND\left\{1-\frac{SILT}{100}\right\}\right)}\right] * \left[\frac{SILT}{CLAY + SILT}\right]^{0.3} \\ & * \left[1.0 - \frac{0.25 CARBON}{CARBON + \exp^{(3.72 - 2.95 CARBON)}}\right] \\ & * \left[1.0 - \frac{0.70\left(1 - \frac{SAND}{100}\right)}{\left(1 - \frac{SAND}{100}\right) + \exp^{\left(-5.51 + 22.9\left\{1 - \frac{SAND}{100}\right\}\right)}}\right] \end{aligned} \tag{3}$$

where $carbon$ is the soil organic carbon content, $silt$ is the soil silt content, $sand$ is the soil sand content and $clay$ is the soil clay content.

$LS$-factor is a product of slope length and slope steepness (Jiang et al., 2014). Slope length is the ratio of soil loss from the field slope length to that from a 72.6-foot length on the same soil type and gradient while slope steepness is the ratio of soil loss from the field gradient to that from a 9-percent slope. Slope length was obtained through calculation of the flow accumulation from elevation data using ArcHydro tools in ArcMap while slope steepness was obtained in percentage using the Slope tool in hydrology toolset. The $LS$ factor was then computed using the equation below (Stone & Hilborn, 2012).

$$LS = \sqrt{\frac{fac * 30}{22.1}} * \left(0.0065 + 0.045s + 0.0065s^2\right) \tag{4}$$

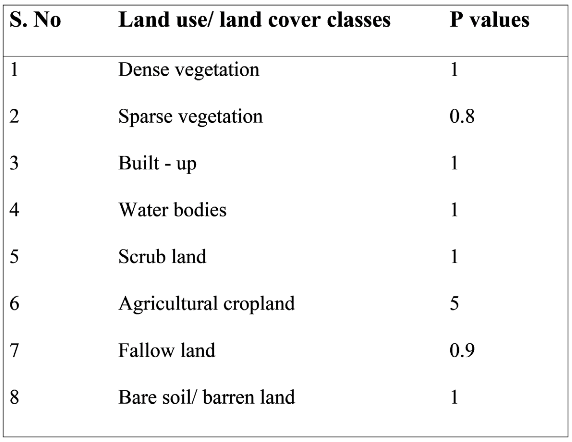
where $fac$ is the flow accumulation and $s$ is the slope.

$C$-factor is a ratio comparing the loss of soil from land under a specified cropping and management to that in untilled, bare and fallow land (Boitt & Gathoni, 2022) on which K-factor is evaluated. It is used to determine if soil and crop management systems and structures are effective in preventing soil loss (Stone & Hilborn, 2012). In this research, $C$ factor was calculated using the formula below developed by Durigon et al. (2014) and adopted by Colman (2018).

$$C = 0.1\left(\frac{-\text{NDVI} + 1}{2}\right) \quad \text{where NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{5}$$

P-factor is the ratio of soil loss with contouring, strip-cropping or terracing to that with straight row farming, up and down slope and it shows how different practices minimize soil erosion by reducing the rate and amount of rainfall runoff (Stone & Hilborn, 2012). United States Department of Agriculture (Wischmeier & Smith, 1981) provides manuals and tables for establishing p-factor values based on land use land use classes. As such, the table in **Figure 3** was used to determine the p-factor values in this research.

**Rainfall run-off** was modelled using the GIS-based Soil Conservation Service-Curve Number (SCS-CN) method for estimating runoff. In this approach, a single empirical formula and readily available tables and curves are used. According to Bonta (Bonta, 1997), the curve number (CN) is a critical factor in runoff estimation. High curve number value indicates high runoff and low rate of infiltration while a low curve number indicates a low runoff and high rate of infiltration (Zhan & Huang, 2004). Curve number was established as a function of land use land cover maps and Hydrologic Soil Group (Ara & Zakwan, 2018).



| S. No | Land use/ land cover classes | P values |
|---|---|---|
| 1 | Dense vegetation | 1 |
| 2 | Sparse vegetation | 0.8 |
| 3 | Built - up | 1 |
| 4 | Water bodies | 1 |
| 5 | Scrub land | 1 |
| 6 | Agricultural cropland | 5 |
| 7 | Fallow land | 0.9 |
| 8 | Bare soil/ barren land | 1 |

**Figure 3.** P-Factor values guide. Source: USDA Handbook No. 282 (1981).

The SCS run-off equation used in this research is;

$$Q=\frac{\left(P-I_a\right)^2}{\left(P-I_a\right)+S} \tag{6}$$

where;

$Q$ = run-off

$P$ = rainfall

$S$ = potential maximum retention after runoff begins

$I_a$ = initial abstraction

Initial abstraction is all the losses before run-off begins and it includes water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration (USDA, 1986). Through many studies, it was found to be approximated by the following empirical equation (Kumar et al., 2016):

$$I_a=0.2S \tag{7}$$

Substituting this in the run-off equation resulted in the following simplified equation:

$$Q=\frac{\left(P-0.2S\right)^2}{P+0.8S} \tag{8}$$

$S$ is obtained from CN values as shown in the following equation:

$$S=\frac{25400}{CN}-254 \tag{9}$$

Run-off calculations were done in Microsoft excel and the results obtained were plotted in QGIS and ArcMap software.

**Site priority analysis** is a GIS-based process used to determine the best place or site for something based on various factors (Patel et al., 2012). Analytical Hierarchical Process (AHP) tool was used to calculate weights of the different criteria since it allows breakdown of different and complex criteria into parts which are hierarchically related to each other. The AHP uses pairwise comparison and linear algebra to calculate different criteria weights where the higher the weight of criteria the more it is important in the end results of an analysis. In this research, water and soil conservation site priority was analyzed based on soil erosion estimation maps, rainfall runoff estimation maps and topography map. It was done using weighted overlay site selection since it supports raster data analysis. Relative weights were assigned to each layer using the AHP plugin in ArcMap since all factors are dependent on each other with respect to the study as shown in **Table 3** below.

Weighted overlay analysis was used to generate the site priority maps which were defined in four categories; High priority areas, moderate priority areas, least priority areas and no priority areas.

## 3. Results and Discussion

### 3.1. Land Use Land Cover

Using Landsat images land use land cover maps were generated for 1990, 2000, 2010 and 2020. The maps were classified into five classes, namely; forest, cropland, bare land, built-up and waterbody.

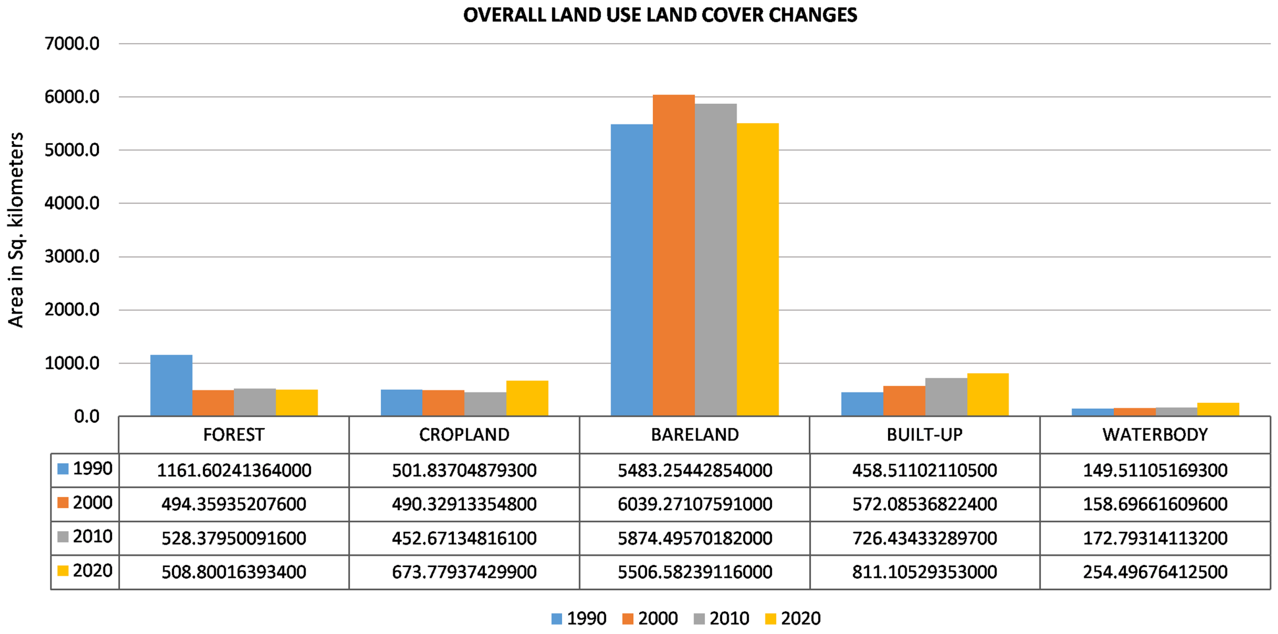
In 1990, approximately 14.98% of the area was covered in forest, 6.47% in cropland, 70.71% in bare land, 5.91% in built-up and 1.93% in waterbodies. Majority of the area was covered in bare land rocky areas while Lakes Baringo and Bogoria covered the least part in the area as shown in Figure 4.

In 2000, the forest cover reduced drastically from approximately 1161.60 sq·kilometers in 1990 to approximately 494.36 sq·kilometers while the bare land increased significantly to cover approximately 77.89% of the entire area. Built-up areas increased slightly to cover at least 7.38% of the area due to increased population while croplands decreased slightly from 1990 to 2000 as shown in Figure 5.

In 2010, forest cover increased slightly to cover approximately 6.81% of the total area while bare lands reduced to cover at least 75% of the total area. There was increased population in the area which led to increased build-up areas to about 9.37% of the total area while the croplands also reduced to cover about 452.67 sq kilometers. The waterbody coverage increased as Lake 94 was visible in

Table 3. Criteria weights.

| LAYER | WEIGHT | SOURCE |
|---|---|---|
| Slope/Topography | 20 | Generated from DEM obtained from RCMRD Geoportal |
| Soil loss estimation | 40 | Calculated from soil data obtained from ISRIC datahub |
| Rainfall run-off estimation | 40 | Calculated from Rainfall data obtained from CHIRPS |



| | FOREST | CROPLAND | BARELAND | BUILT-UP | WATERBODY |
|---|---|---|---|---|---|
| ■ 1990 | 1161.60241364000 | 501.83704879300 | 5483.25442854000 | 458.51102110500 | 149.51105169300 |
| ■ 2000 | 494.35935207600 | 490.32913354800 | 6039.27107591000 | 572.08536822400 | 158.69661609600 |
| ■ 2010 | 528.37950091600 | 452.67134816100 | 5874.49570182000 | 726.43433289700 | 172.79314113200 |
| ■ 2020 | 508.80016393400 | 673.77937429900 | 5506.58239116000 | 811.10529353000 | 254.49676412500 |

Figure 4. Overall land use land cover changes.

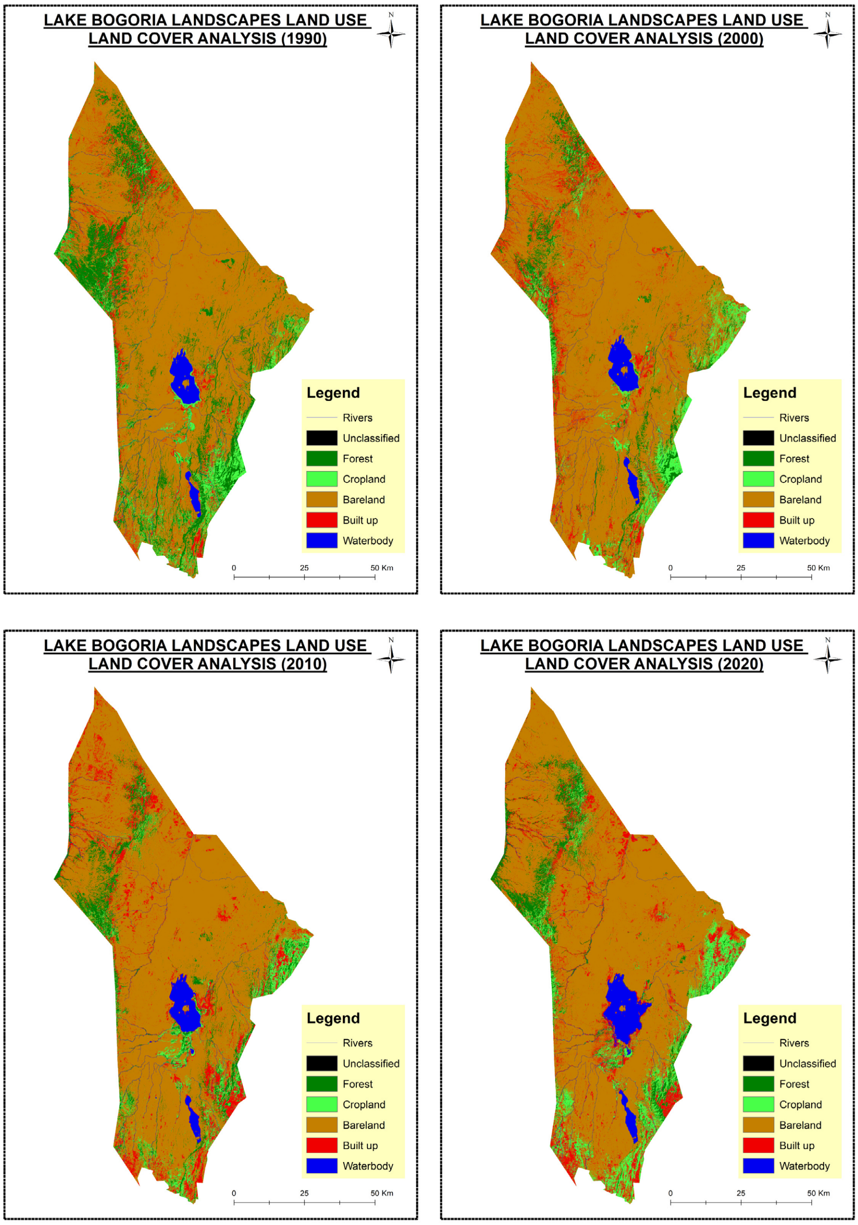


**Figure 5.** 1990-2020 land use land cover maps.

2010 thus increasing area of waterbodies to about 2.23 square kilometers as shown in Figure 5.

In 2020, increased rainfall led to the increase in size of Lakes Bogoria, 94 and Baringo thus leading to waterbody area coverage increasing in the land use land cover map. As a result of increased population and infrastructural development, built-up area increased in 2020 to cover approximately 10.46% of the total area as well as croplands which increased to approximately 6.56% of the area due to increased demand for agricultural products from the increased population. Increased built up, croplands and waterbody coverage resulted in reduction of bare lands to approximately 71% of the total area and forests from a coverage of approximately 528.38 sq·kilometers in 2010 to around 508 sq·kilometers in 2020 as shown in Figure 5.

### 3.2. Soil Loss Estimation

R-factor was generated using Equation (2) in raster calculator tool for 1990, 2000, 2010 and 2020. In 1990, the values ranged from 197 - 431 and from 162 - 524 in 2000. In 2010, the values ranged from 223 - 742 and from 271 - 1151 mj mm/ha/year in 2020 as shown in Figure 6.

K-factor was generated using Equation (3) in the raster calculator as shown in Figure 7.

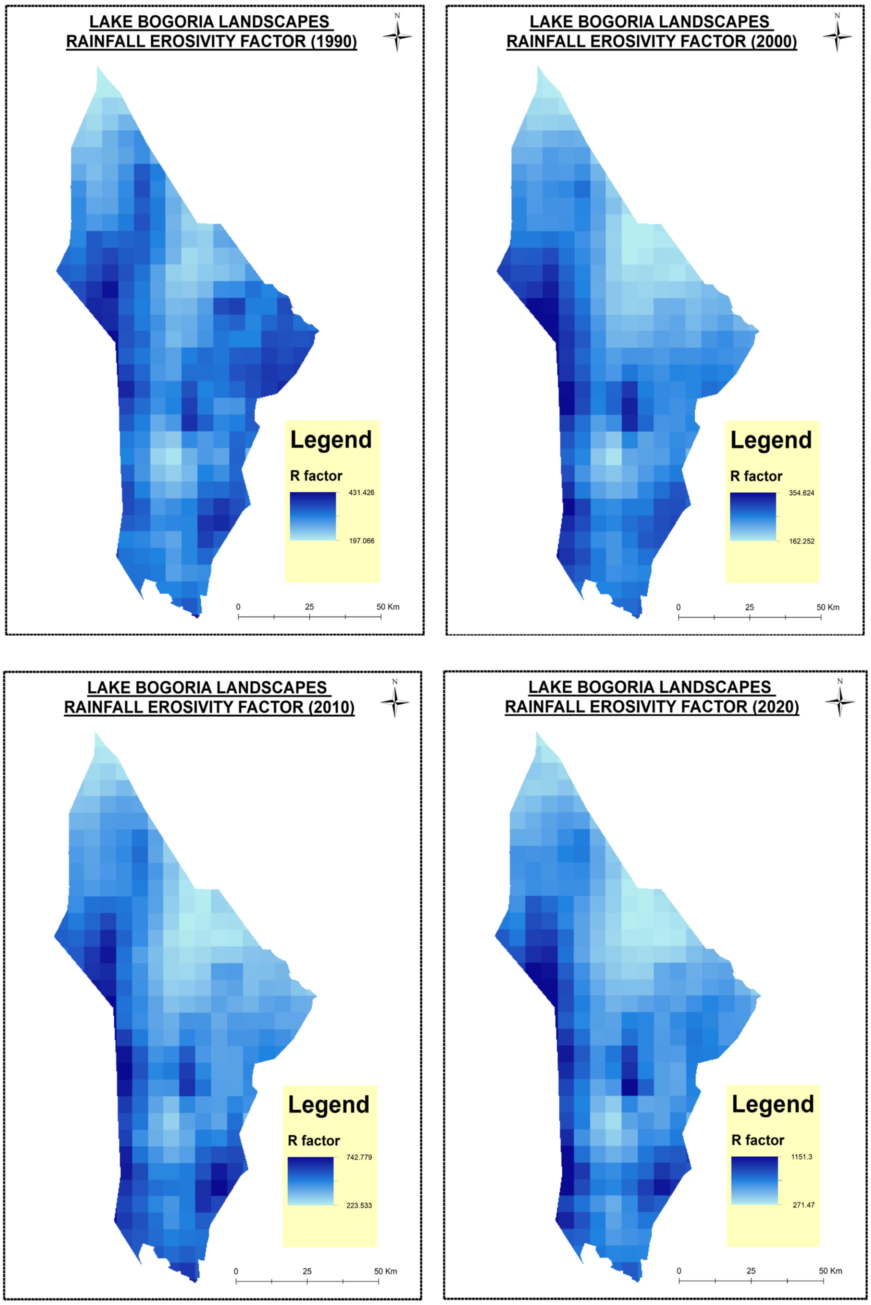


Figure 6. R-factor maps.

The LS factor was calculated after generating flow accumulation and slope using hydrology tools and the final output generated using Equation (4) in the raster calculator tool as in Figure 8.

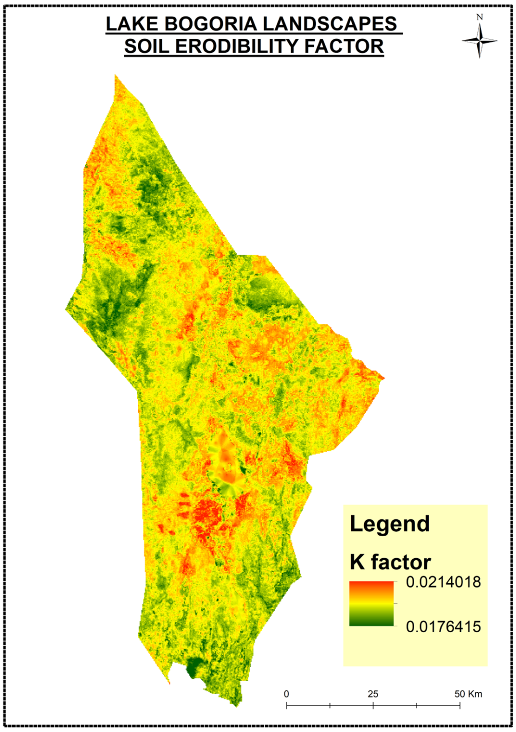


Figure 7. K-factor map.

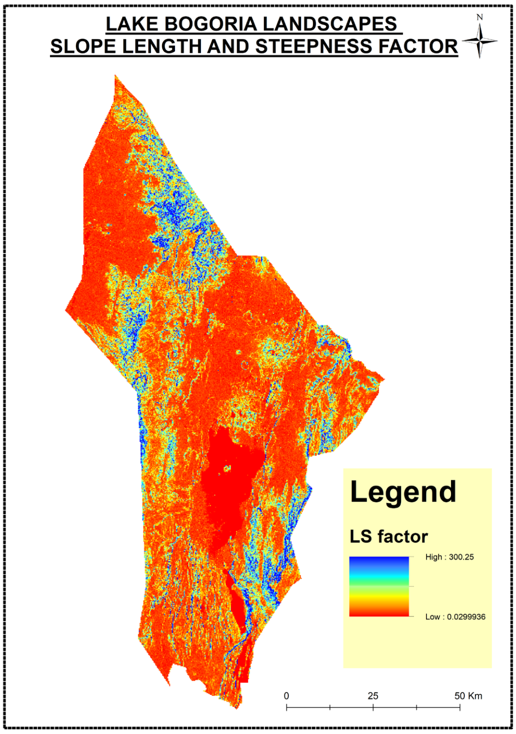


Figure 8. LS-factor map.

NDVI was calculated using the Near Infrared and Red bands using the raster calculator and used to generate the cover management factor using Equation (5) as shown in **Figure 9**.

P-factor values were obtained from land use land cover maps guided by **Figure 3**, where cropland was assigned a value of 0.5 and other classes were assigned a value of 1 resulting in maps showing in **Figure 10**.

Soil loss estimation was done using Equation (1) with the inputs being rainfall erosivity maps, soil erodibility map, slope length and steepness map, crop management maps and practice support maps. Soil loss maps were classified into five classes: severe, high, medium, low and no soil loss. Soil loss maps were classified as shown in **Table 4**.

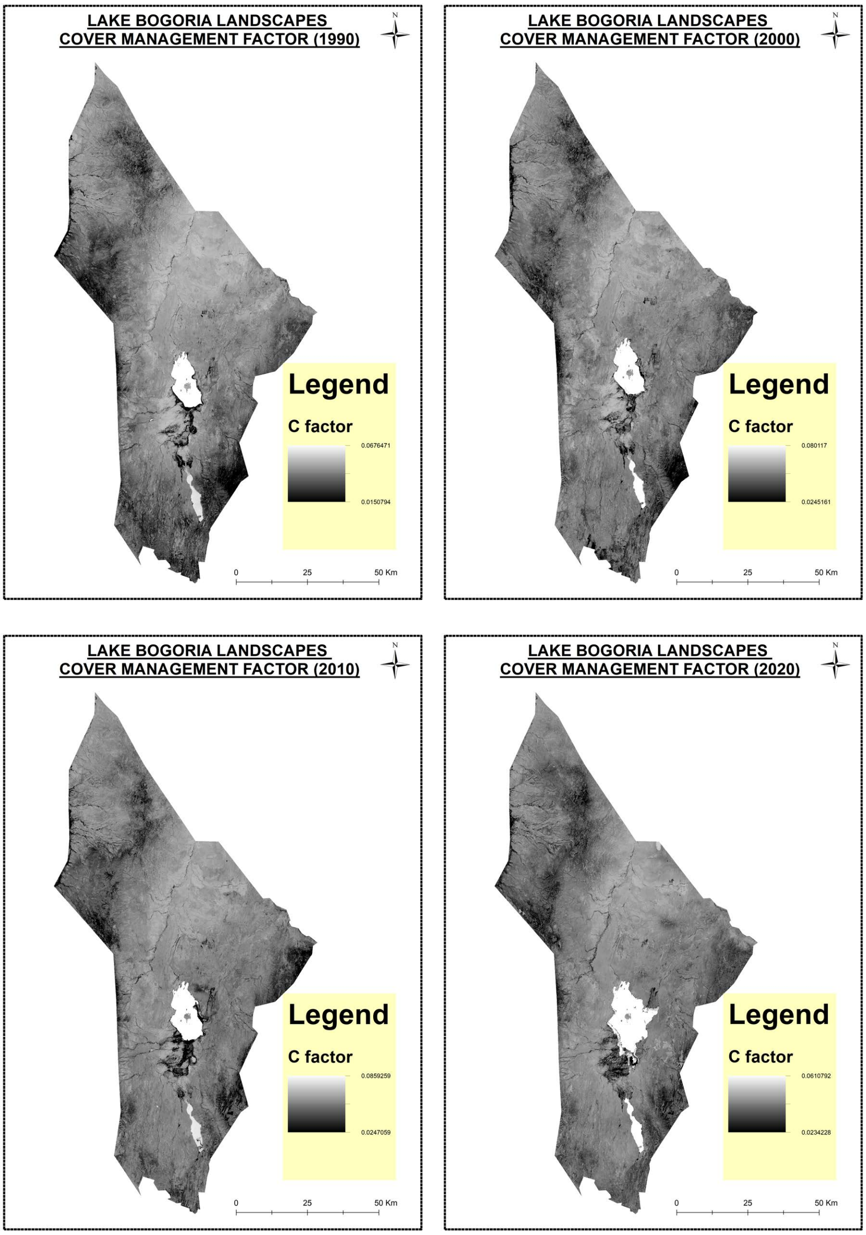


**Figure 9.** C-factor maps.

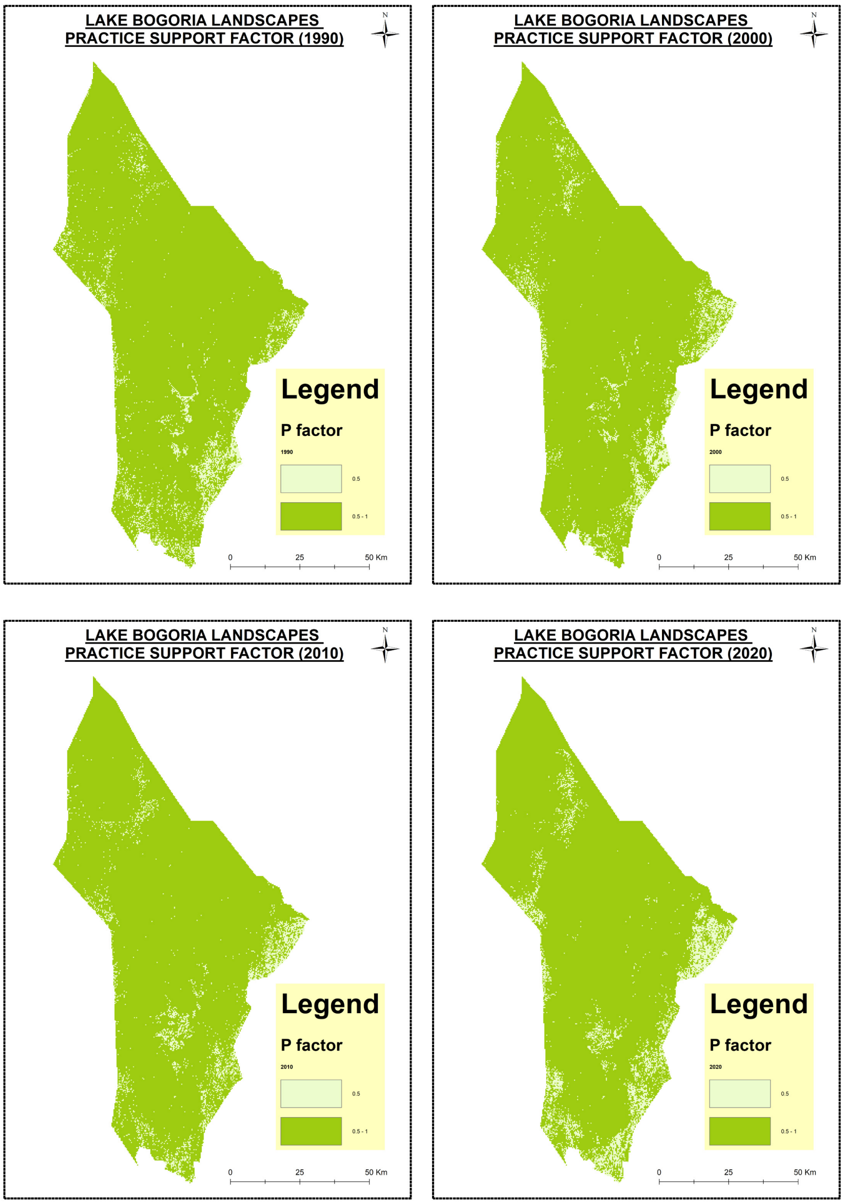


**Figure 10.** P-factor maps.

**Table 4.** Soil loss classes.

| SOIL LOSS (t/ha/yr) | CATEGORY |
|---|---|
| <1 | No loss |
| > 1 < 10 | Low |
| > 10 < 30 | Medium |
| > 30 < 50 | High |
| >50 | Severe |

In 1990, soil loss ranged between 0.001 - 55.424 t/ha/yr while in 2000 it ranged from 0.002 - 61.131 t/ha/yr. In 2010, it ranged from 0.003 - 82.512 t/ha/yr while in 2020 it ranged from 0.002 - 126.553 t/ha/yr as shown in **Figure 11**.

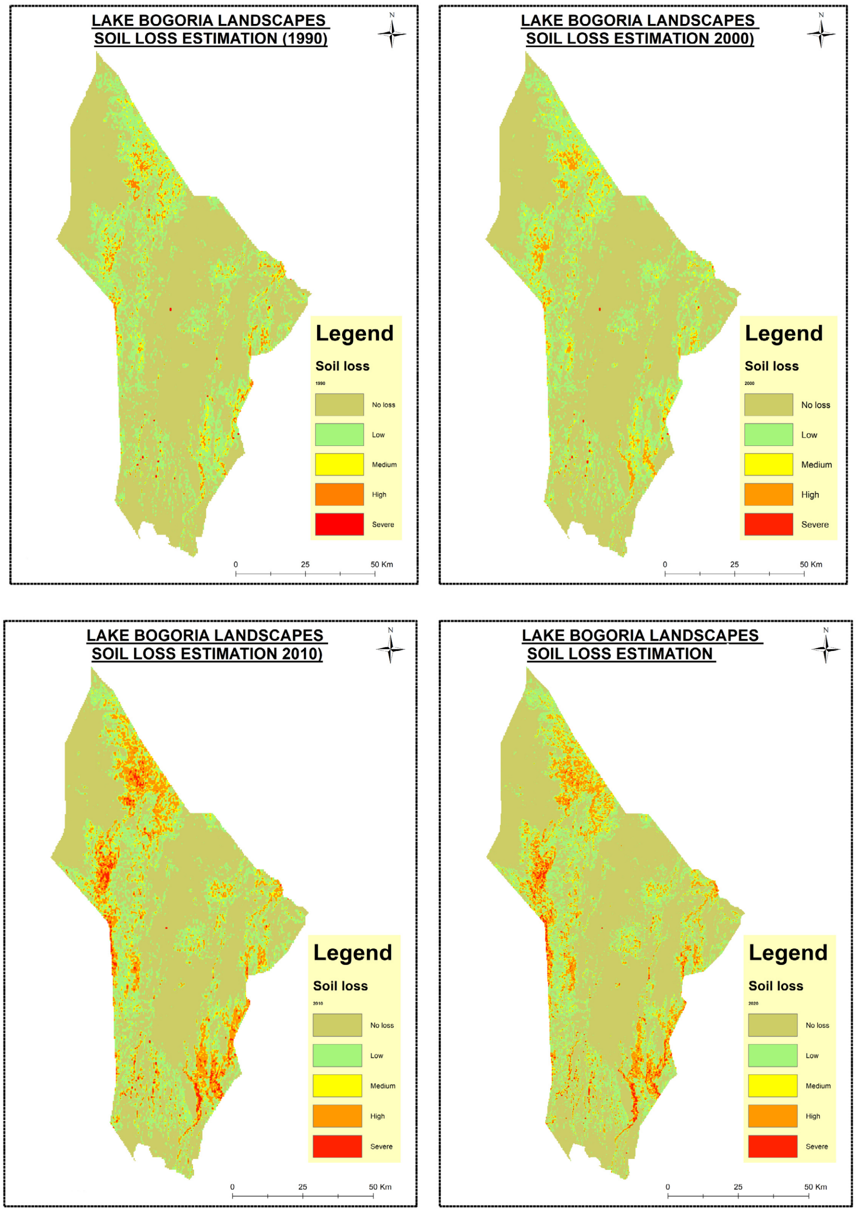


Figure 11. 1990-2020 soil loss maps.

### 3.3. Rainfall Run-Off Estimation

Using the SCS-CN model, curve numbers were a vital part of rainfall run-off estimation. Curve numbers were established from existing tables using the HSG and land use land cover of the area. HSG were generated from the soil layer in Figure 12 using the soil characteristics such as sand content, infiltration rate, clay content and soil depth.

The area was classified into four HSGs; A, B, C and D, based on the following:

- Infiltration and seepage of rainfall at maximum wetness
- Unfrozen soil state
- Bare soil surface

The four groups are described as follows (USDA, 2007):

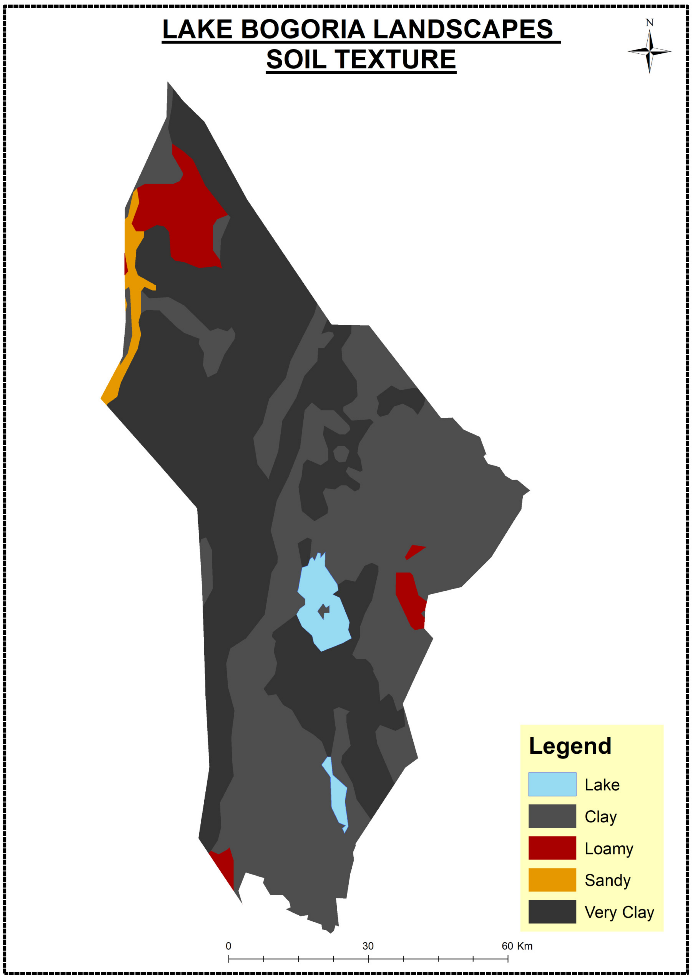


Figure 12. Soil texture map.

- **Group A**—soils have low run-off potential, less than 10% clay and more than 90% sand content. Some of the soils include loamy sand, sand soil and silt loamy with a gravel texture and greater that 60 cm depth to water table.
- **Group B**—soils have moderately low run-off potential, 10% - 20% clay and 50% - 90% sand content with a loamy sand texture. These soils should be well aggregated, have low bulk density and contain greater than 35% rock fragments.
- **Group C**—soils have moderately high run-off potential, between 20% - 40% clay content, less than 50% sand content with loam, silty loam, clay loam, sandy clay and silty clay loam textures.
- **Group D**—soils have high run-off potential, more than 40% clay content, less than 50% sand content with clayey texture and water movement is highly restricted in these soils.

The spatial distribution of Hydrologic Soil Groups in shown in Figure 13.

Using available tables from USDA (USDA, 2007), HSG map in Figure 13 and the land use land cover maps, the spatial distribution of Curve Numbers of the study area was determined as shown in Table 5.

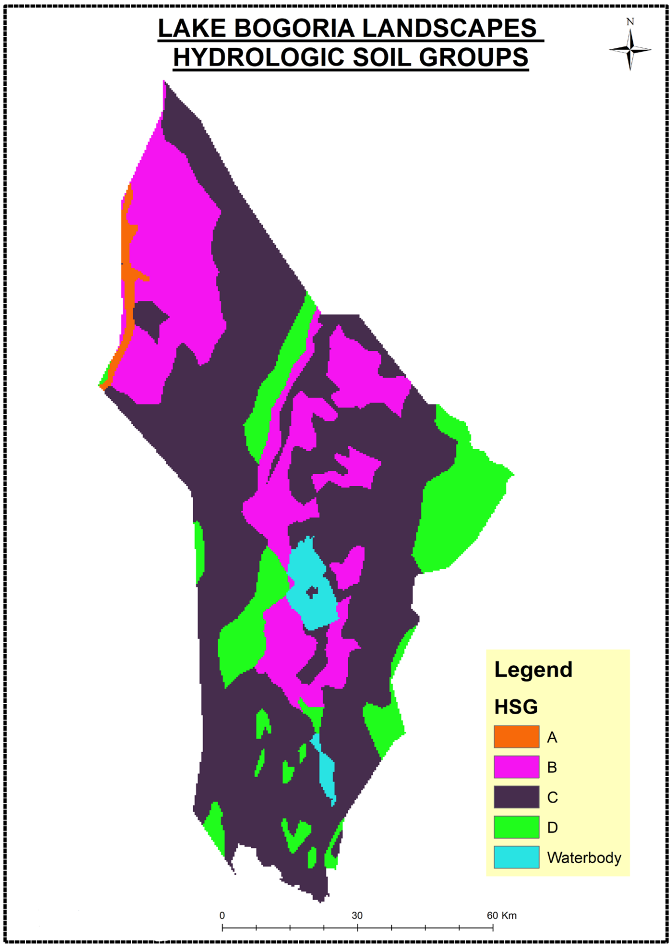


**Figure 13.** Hydrologic soil groups map.

**Table 5.** Curve numbers based on land use classes and HSG.

| Land use land cover classes | Hydrologic Soil Groups | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Forest | 36 | 60 | 73 | 79 |
| Cropland | 69 | 79 | 86 | 90 |
| Bare land | 77 | 86 | 91 | 94 |
| Built-up | 81 | 88 | 91 | 93 |
| Waterbody | 100 | 100 | 100 | 100 |

Curve numbers range between 1 - 100. High curve numbers such as 81, 88, 91 and 93 indicate a high run-off potential while low curve numbers such as 36 indicate a low run-off potential. There is 100% rainfall run-off on waterbodies thus having a curve number value of 100.

After all the factors were established, Equation (8) was used to calculate run-off numbers in Microsoft excel. **Figure 14** shows the percentage of total annual run-off against rainfall received in each land use land cover class in the

**Figure 14.** Graph showing changes in average runoff percentage in different classes.

area. In 1990, there was 70% run-off in forests, 88% run-off in croplands, 91% runoff in bare lands and 93% run-off in built-up areas as shown in Table 6. In 2000, there was 50% run-off in forests, 75% in croplands, 83% runoff in bare lands and 85% runoff in built-up areas. In 2010, there was 65% run-off in forests, 84% in croplands, 89% in bare lands and 91% in built-up areas while there was 70% runoff in forests, 88% in croplands, 92% in bare lands and 93% in built-up areas in 2020 as shown in Table 6. Figure 14 shows the summarized percentages of annual rainfall run-off estimations to total rainfall received in 1990, 2000, 2010 and 2020.

The estimated run-off values were then imported into GIS software to create average annual runoff maps as shown in Figure 15. Run-off was highest in waterbodies at 100% followed by urban and built-up areas, bare lands, croplands and forests sequentially in that order. Increased rainfall and built-up areas in 2020, resulted in high runoff in 2020 as shown in than in all the other years.

### 3.4. Slope

Slope in degrees was calculated using the slope tool in QGIS as shown in Figure 16 below. The map showed that most of the area ranged from medium flat slope to flat slope.

### 3.5. Soil and Water Conservation Analysis

Soil and water conservation priority analysis can be used to identify areas to construct conservation structures such as check dams, percolation tanks and rainwater harvesting structures. In this research, different criteria were used to analyze priority sites including slope data, soil erosion data and rainfall data. The different datasets were analyzed using multi-criteria analysis techniques; where AHP tool was used for construction of pairwise matrix and establishing relative

**Table 6.** Annual rainfall runoff estimates in 1990, 2000, 2010 and 2020.

| | 1990 | | |
|---|---|---|---|
| | Average annual rainfall | Average annual runoff | % Runoff |
| Forest | 1306.582 | 920.730 | 70.469 |
| Cropland | 1327.936 | 1167.868 | 87.946 |
| Bare land | 1286.653 | 1181.976 | 91.864 |
| Built-up | 1299.641 | 1206.668 | 92.846 |
| Waterbody | 1406.867 | 1406.867 | 100 |
| | 2000 | | |
| Forest | 575.040 | 287.289 | 49.959 |
| Cropland | 578.065 | 436.840 | 75.569 |
| Bare land | 560.076 | 464.118 | 82.867 |
| Built-up | 564.674 | 478.132 | 84.674 |
| Waterbody | 609.227 | 609.227 | 100 |
| | 2010 | | |
| Forest | 1016.342 | 660.646 | 65.002 |
| Cropland | 1015.890 | 860.857 | 84.739 |
| Bare land | 984.610 | 882.295 | 89.609 |
| Built-up | 993.908 | 902.587 | 90.812 |
| Waterbody | 1069.944 | 1069.944 | 100 |
| | 2020 | | |
| Forest | 1308.283 | 922.358 | 70.501 |
| Cropland | 1339.831 | 1179.568 | 88.039 |
| Bare land | 1291.266 | 1186.487 | 91.886 |
| Built-up | 1294.478 | 1201.512 | 92.818 |
| Waterbody | 1334.955 | 1334.955 | 100 |

importance weights. There after site priority analysis was done through GIS-based weighted overlay technique to generate site priority maps. Weighted overlay allows researchers to rank raster cells and assign a relative importance weight value to each layer.

In this research, potential sites were ranked from 1 to 4, in which sites with a value of 1 were the least priority areas and those with a value of 4 hold the highest priority. Table 7 shows how relative weights were assigned to different layers (Tushar et al., 2018).

The resulting maps were classified as high priority (4), moderate priority (3), least priority (2) and no priority (1) classes. This was done in all the years of analysis; 1990, 2000, 2010 and 2020. Figure 17 below shows the area coverages

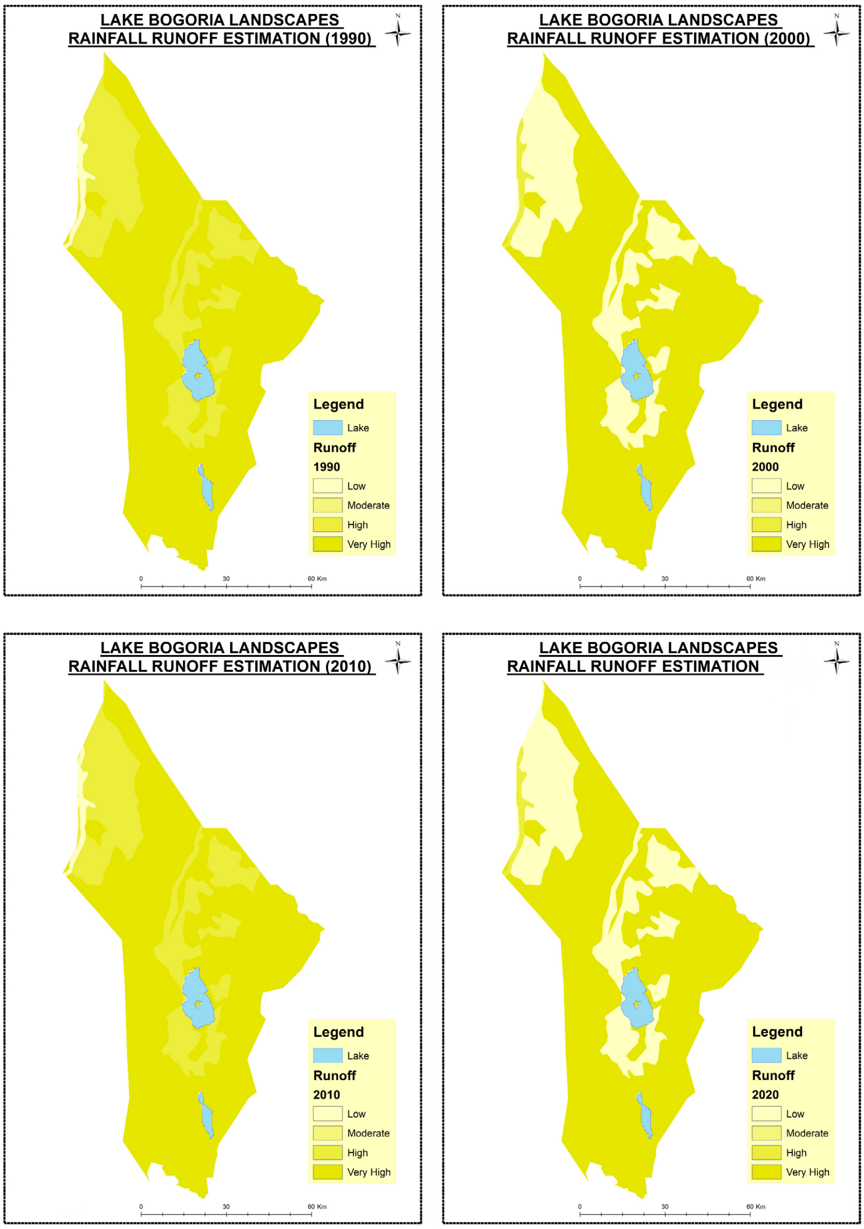


Figure 15. 1990-2020 rainfall runoff maps.

of different priority classes in the Lower Bogoria Landscapes region. The trend line shows the changes in the areas of the classes over time from 1990 to 2020.

Soil and water conservation priority site maps were produced using the weighted overlay tool as shown in Figures 18-21.

High priority areas are most favorable for soil and water conservation through various techniques. In 1990 as shown in Figure 18, high priority areas occupied approximately 13.63%, approximately 9.67% in 2000 as shown in Figure 19, approximately 12.33% in 2010 as shown in Figure 20 and approximately 22.22% in 2020 as shown in Figure 21. Increased areas requiring conservation is attributed to increased rainfall from 2000 to 2020 as well as increased soil loss in the area of study.

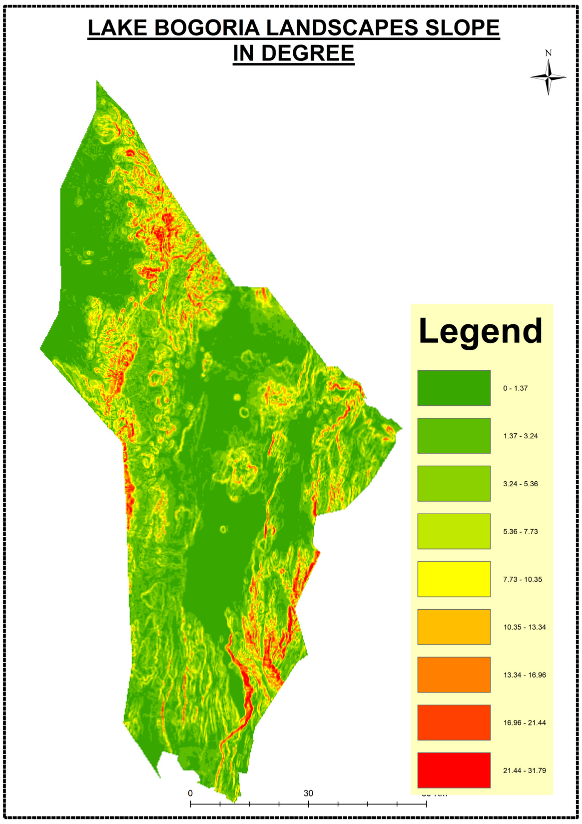


**Figure 16.** Slope map.

**Table 7.** Relative weights of criteria.

| LAYER | % INFLUENCE | LAYER CLASSES | WEIGHTS |
|---|---|---|---|
| SLOPE | 20 | <4 gentle slopes | 2 |
| | | 4 - 8 moderate slopes | 4 |
| | | 8 - 16 strongly sloping | 3 |
| | | 16 - 24 moderately steep | 2 |
| | | >24 very steep | 1 |
| RUNOFF in mm | 40 | <500 | 1 |
| | | 500 - 600 | 2 |
| | | 600 - 700 | 3 |
| | | 700 - 800 | 4 |
| | | >800 | 4 |
| SOIL EROSION | 40 | <1 | 1 |
| | | 1 - 10 | 2 |
| | | 10 - 30 | 3 |
| | | 30 - 50 | 3 |
| | | >50 | 4 |

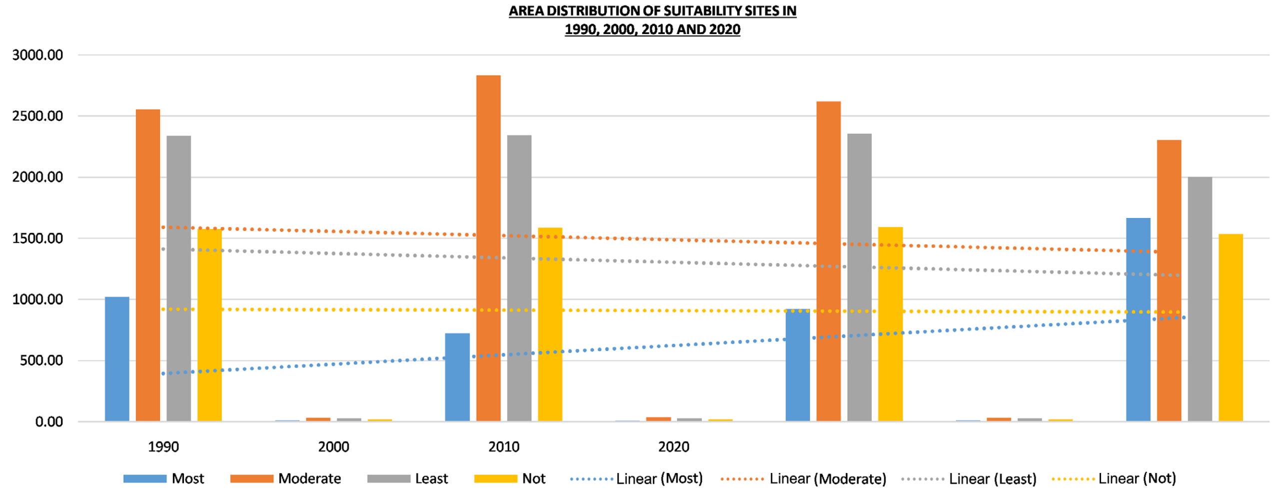


**Figure 17.** Area distribution of priority sites.

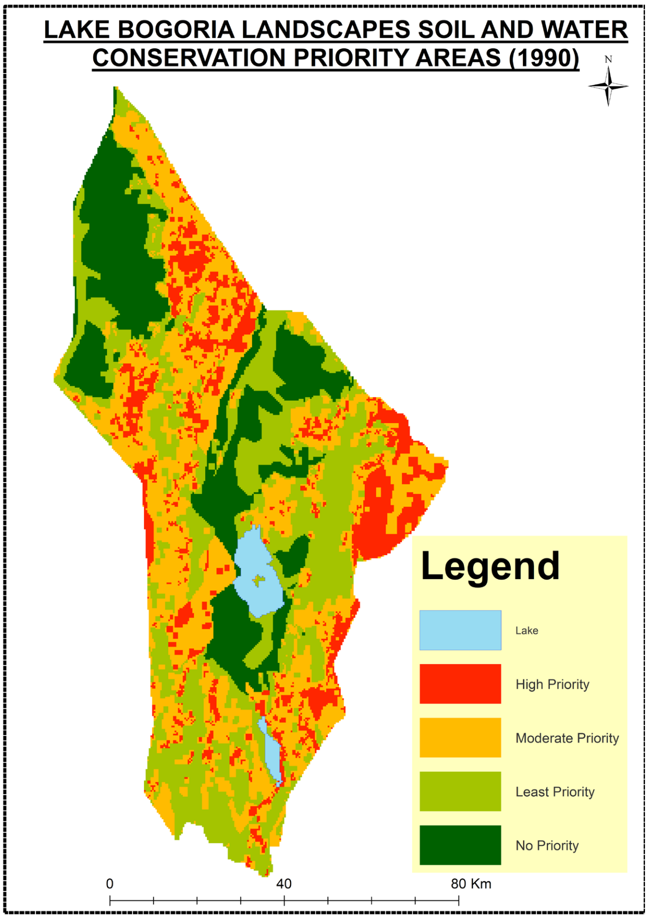


**Figure 18.** 1990 soil and water conservation priority map.

Moderate priority areas moderately favorable for setting up soil and water conservation techniques. In 1990, approximately 34.09% of the region had moderate priority for soil and water conservation, approximately 37.83% in 2000, approximately 34.99% in 2010 an approximately 30.69% in 2020.

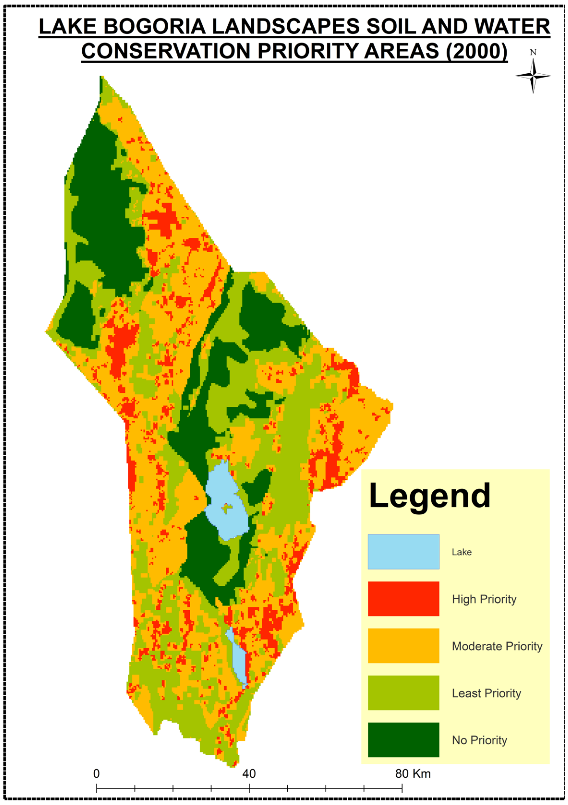


Figure 19. 2000 soil and water conservation priority map.

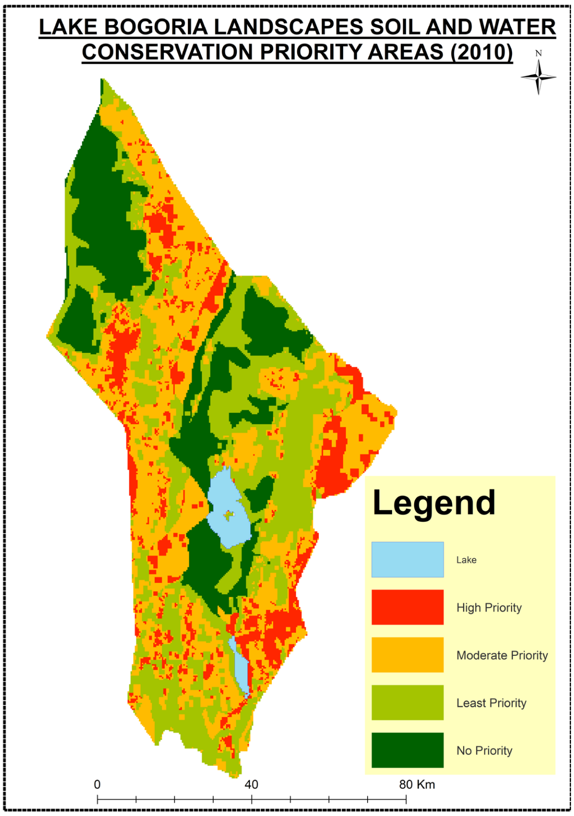


Figure 20. 2010 soil and water conservation priority map.

Least priority areas are least favorable for soil and water conservation especially due to flat slopes. Soil and water conservation techniques constructed in these areas are not very beneficial. In 1990, approximately 31.21% of the region had the least priority for soil and water conservation, approximately 31.30% in 2000, approximately 31.44% in 2010 and 26.64% in 2020.

No priority areas These are areas in which soil and water conservation techniques should not be considered since it will not be cost and time effective. Throughout the years the no priority areas remained relatively unchanged, covering approximately 21% of the total area as shown in Table 8.

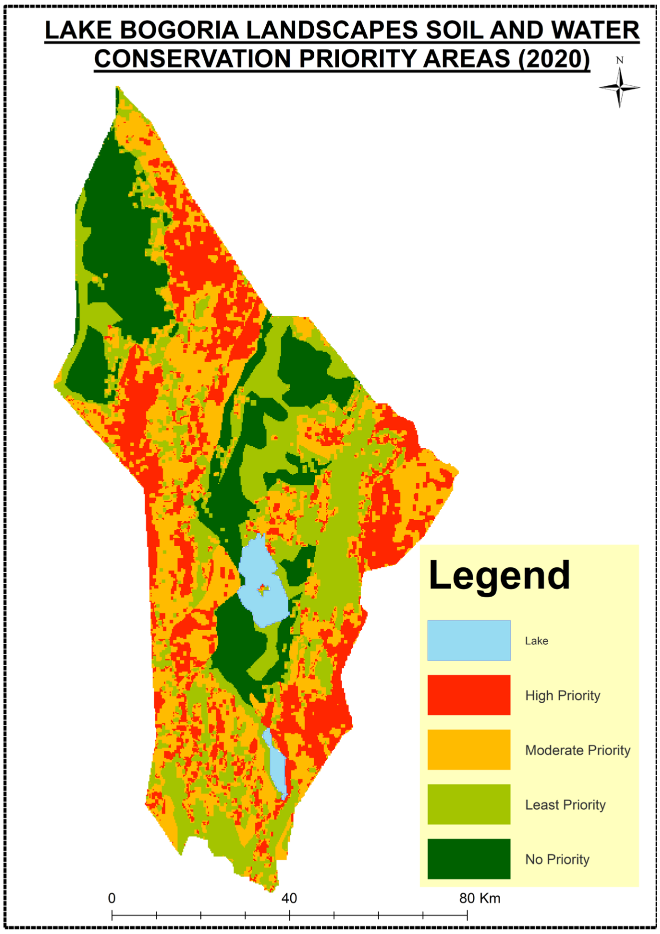


Figure 21. 2020 soil and water conservation priority map.

Table 8. Area distribution of soil and water priority sites.

| NAME | 1990 | | 2000 | | 2010 | | 2020 | |
|---|---|---|---|---|---|---|---|---|
| High | 1021.71 | 13.63 | 724.75 | 9.67 | 924.38 | 12.33 | 1669.21 | 22.22 |
| Moderate | 2554.76 | 34.09 | 2835.01 | 37.83 | 2622.03 | 34.98 | 2305.21 | 30.69 |
| Least | 2339.03 | 31.21 | 2345.77 | 31.30 | 2356.29 | 31.44 | 2001.17 | 26.64 |
| No | 1578.27 | 21.06 | 1589.11 | 21.20 | 1592.90 | 21.25 | 1535.83 | 20.45 |

## 4. Conclusions and Recommendations

For ideal and sustainable management of natural resources in a region, soil and water conservation techniques are required. Potential sites for water harvesting techniques are identified normally based on rainfall and subsequent runoff. Rainfall-run-off modeling was done based on the SCS-CN method which allows for GIS-based estimations.

The SCS-CN model was applied in this research using average annual rainfall for the years 1990, 2000, 2010 and 2020 to estimation annual run-off. The results show that significant run-off water can be harvested through water conservation structures.

Since the Bogoria Landscapes is a semi-arid region, it is essential to conserve soil and water resources appropriately. As such, rainfall runoff, soil loss and slope were used for site priority analysis to delineate potential zones for application soil and water conservation techniques.

Based on the analysis, priority sites were identified for the construction of soil and water conservation structures that are ecologically viable and will help sustain agricultural productivity of the region, thus improving food security in the larger Baringo County.

It was observed that increased built up and croplands due to population growth in 2020 resulted in an increase in the area classified as moderate to high priority sites.

Rainfall run-off estimation results showed that significant amounts of rainwater can be harvested in the entire study area and stored for livestock, domestic and agricultural use during the study area through structures such as water pans, stop dams, farm ponds and check dams as well as planting of vegetation cover in bare areas to minimize rainfall run-off and improve infiltration.

From the findings of this research, it is recommended that water and soil conservation structures such as check dams, stop dams, percolation tanks and farm ponds should be set up in the high priority zones and moderate priority zones in the area of study. All community members and stakeholders in the highlighted areas should be involved to ensure that there are no social implications which could lead to conflicts in the societies that would result in failure of the initiative.

The community members and other stakeholders should take measures to prevent damage of the soil and water conservation structures thus cutting on maintenance and repair costs. The community imitative such as the community conservancies in the area can prioritize soil and water conservations for sustainable and ecological balance between wildlife and the people around.

A favorable policy and legal framework should be set up in the areas requiring soil and water conservation structures under which farmers and other stakeholders will operate. Privatization of land tenure in Kenya has resulted in poor adoption of soil and water conservation techniques due to size of land as well as the cost and labour involved. Private land owners should be encouraged to gradually invest in soil and water conservation such as introduction of high value crops that would provide crop cover as well as provide economic benefits to the land owners. Zero grazing should also be encouraged to private land owners to prevent overgrazing that would result increased yields and promote adoption of soil and water conservation techniques thus providing social, economic and ecological benefits in the long run.

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## Author Contributions

Conceptualization, M.B.; methodology, J.G.; software, J.G.; validation, M.B.; formal analysis, J.G.; investigation, J.G.; resources, J.G; data curation, J.G.; writing—original draft preparation, J.G.; writing—review and editing, J.G; visualization, J.G.; supervision, M.B.; project administration, M.B.; funding acquisition, M.B. All authors have read and agreed to the published version of the manuscript.

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All data and resources are available in the text or sources cited in the text.

## Conflicts of Interest

The authors declare no conflict of interest.

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