*IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*
*e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 11, Issue 4 Ser. I (July. – Aug. 2023), 13-23*
*www.iosrjournals.org*

# Identification Of Critical Sub-Watersheds Prone To Soil Erosion Using Remote Sensing Data And Geospatial Techniques In Thiririka Watershed, Kenya

Juliet Inyele[1], Shadrack Murimi[2] , Raphael Kweyu[3]
[123]*(Geography Department, Kenyatta University, Kenya)*

***Abstract***
*Morphometric Studies And Land Use/Land Cover Analysis Play A Key Role In Integrated Watershed Management. Sustainable Resource Utilization At A Watershed Level Requires An In-Depth Understanding Of Land Use, Drainage, And Hydrological Patterns Of The Watershed. In Developing Countries, Poverty Has Led To Unsuitable Land Management Practices (E.G. Deforestation, Continuous Tillage), Contributing To Increased Soil Erosion In Watersheds. To Reduce Soil Erosion At The Watershed Level, Watershed Managers Need To Make Informed Decisions Such As Developing Vegetative Cover And Agroforestry. However, This Is Limited Due To A Lack Of Readily Available Data To Guide The Process. This Study Explores The Potential Use Of Basin Morphometry And Land Use /Land Cover Parameters With Geographic Information Systems (GIS) And Remote Sensing (RS) Tools To Identify Areas Susceptible To Soil Erosion In Thiririka Watershed In Kenya. Five Sub-Watersheds Were Delineated And Assigned A Code From SW1 To SW5 Using The Shuttle Radar Topographic Mission (SRTM) 30-Meter Resolution Digital Elevation Model (DEM) In Arcgis Software, Followed By Morphometric Analysis Of Linear, Aerial, And Relief Aspects Of The Watershed. Land Use/Land Cover Classes Were Generated From A Median Composite Of Sentinel-2 2020 Image. A Supervised Classification Scheme Was Used To Develop A Random Forest Classifier To Perform The Classification. Finally, The Effects Of Each Morphometric And Land Use/Land Cover Parameters On Soil Erosion Were Assessed And Assigned Ranks 1 To 5. These Ranks Were Averaged To Get The Compound Priority (CP) In GIS Tabular Database. Results Showed That Sub-Watershed 5 Is Highly Susceptible To Soil Erosion Needing Immediate Management Actions, While Sub-Watershed 4 (SW4) Shows Less Susceptibility To Soil Erosion. The Study Recommends The Use Of Remote Sensing And GIS In Watershed Prioritization Management.*

***Keywords****: Soil Erosion, Land Use / Land Cover, Morphometric Analysis, GIS, Watersheds, Prioritization.*

---

Date of Submission: 24-06-2023 Date of Acceptance: 04-07-2023

---

## I. Introduction

Over the years, increased food demand has been a major problem particularly under the current global changes such as population growth, climate change and variability (EU, 2015). The increasing population results in more land being converted into agricultural production at the expense of forest. In developing countries, the issue is escalated by the lack of financial and skilled human resources to support sustainable agricultural intensification. Consequently, inefficient land use has contributed to increased land degradation. The impacts of these problems are more felt in developing countries where poor farm management have worsened the issue, leading to poverty-population-land degradation cycle.

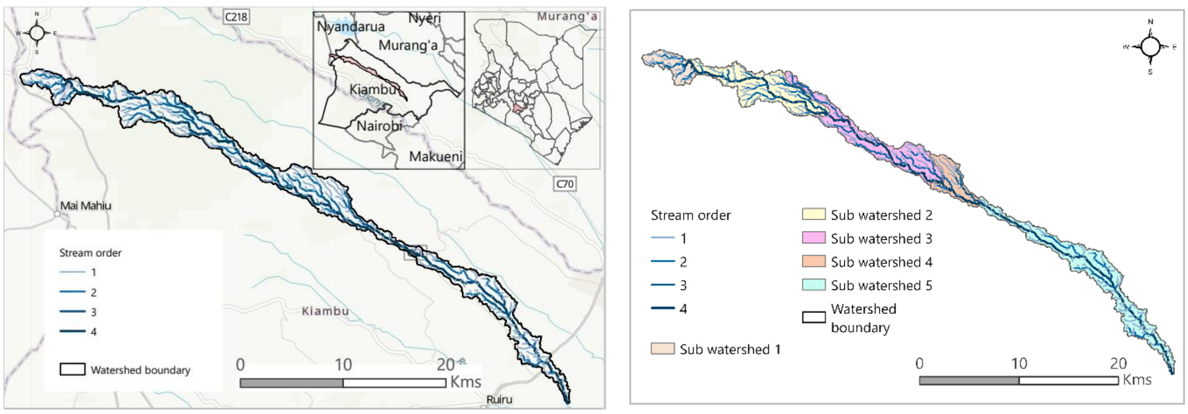
In Kenya the annual cost of land degradation is estimated at 1.5 billion USD and has been associated with increased soil erosion (Egede & Donatus, 2013). This is particularly important in the hilly regions and floodplains areas where natural factors (e.g. high-intensity rainfall, steep slopes), often coupled with unsuitable land management practices (e.g. deforestation, continuous tillage), contribute to increased runoff and soil erosion. In Thiririka watershed, for instance, increasing demand for forest products and agricultural land due to high population pressure has led to increasing deforestation (Kiio & Achola, 2015). Therefore, conservation of the limited resources, especially top fertile soils, should be given high priority at the watershed level. Factors such as Land Use Land Cover (LULC) parameters are drivers to soil erosion (Tamma Rao et al., 2012). Therefore, to establish soil erosion management plans at a watershed level, it is important to assess these parameters. Mapping the soil erosion areas at the watershed level will help identify sub-watersheds prone to soil erosion, provide management and conservation measures and ultimately reduce environmental degradation (e.g. erosion of agricultural land, pollution of water).

Many researchers have attempted to study soil erosion using models formulated to predict and provide rough estimates of soil erosion to guide control. The applicability or the performance of such models vary with location based on the prevailing conditions such as soil types, climatic condition, topography, hydrological properties and LULC. Examples of such models include: The Revised Universal Soil Loss Equation (RUSLE), Coordination of Information on the Environment (CORINE), Kinematic Runoff and Erosion Model (KINEROS), Water Erosion Prediction Project (WEPP) and Pan-European Soil Erosion Risk Assessment (PESERA) (Igwe et al., 2017). The major limitation of most of these models is lack of data to fit or accurately study soil erosion in some areas.

Nevertheless, combining the LULC and morphometric parameters has proven to assess soil and hydrological patterns of the watershed. Morphometric analysis is a method developed by (Horton, 1945) to quantitatively study watersheds. The analysis uses the elevation model to generate drainage characteristics that help depict the behavior of the river. The geo-morphometric parameters are derived from the Digital Elevation Models (DEMs) representing the topography of the earth surface without ground surface features such as buildings (Moore et al., 1991). These parameters provide a guide for informed decisions in understanding the drainage characteristics and ranking of the sub-watersheds for efficient resource distribution (Malik et al., 2019). The study explores the potential use of DEM and satellite images to identify sub-watersheds exposed to soil erosion in Thiririka watershed.

## II. Material and Methods

**Study Location**: Thiririka watershed is located in Kiambu County in Kenya (Figure 1). The River originates from the southern slopes of the Aberdare Ranges in the Kikuyu Escarpment forest and drains to Ruiru River a tributary of the Athi River. The watershed is on the Eastern slopes of the Aberdare Mountain and is approximately 120 km$^2$. Rainfall exhibits a bimodal distribution in the catchment, with the wet season from mid-March to April and the short wet season from November to December. The annual rainfall ranges from 700 mm to 1800 mm. The watershed is within the humid to semi-humid agro-climatic zones of Kenya.




**A** **B**

**Figure 1: (A) Thiririka watershed and stream network (B) Delineated sub watersheds**

**Table 1: Summary of the Datasets used for the study**

| Dataset | Description | Source | Purpose |
|---|---|---|---|
| Sentinel-2 satellite image | 2020 annual median composite | https://scihub.copernicus.eu/dhus/#/home | LULC Classification |
| SRTM-DEM | 30 meter spatial resolution | http://www.earthexplorer.usgs.gov/ | Delineation of watershed Morphometric analysis |
| Training data | Ground thruthing polygons | Field Survey | Training the classification algorithm and validation |

**Delineating the watersheds using DEM and computing the morphometric parameters**

The 30 m SRTM-DEM was utilized in ArcGIS environment to delineate the sub-watersheds (

Table **1**). The procedure for delineating watershed and streams was systematically followed using the hydrology tools in ArcGIS 10.8. Although several approaches are used to study the drainage of an area, the DEM elevation grids was preferred because of their wide availability (Seemuller, 1989).

From the DEM, the pit removal algorithm was applied to raise pixel values surrounded by high elevation values. This procedure allows for adequate flow routing during the computation (Moore et al., 1991). Filling sinks is an iteration process that occurs in every grid cell by comparing the cell value to the neighboring cells of the DEM, achieved using the fill-DEM function in hydrology tools. The depression less DEM layer was used to generate the flow direction per grid cell, showing the direction of the steepest descent from the cell. Flow direction was generated using the D8 algorithm, the method proposed by (Tarboton, 1997). In any grid cell, water flows to any of the eight (8) surrounding directions whereby it is assigned a value corresponding to the orientation of one of the eight cells surrounding the cell as described by (Jenson & Domingue, 1998). These cell numbers correspond to a binary and each flow direction value is encoded with a unique color (Figure 2). The third step is generating the flow accumulation layer defining the grid cells containing the accumulated water from the upstream cells. The flow accumulation is calculated by combining the flow direction and counting the number of cells flowing downslope to a particular cell (Gumma et al., 2016). The higher the values of the cells, the lower the drainage network whereby, grid cells with zero values represent ridges. Upon finishing DEM reconditioning (obtaining depression less DEM, flow direction, and flow accumulation) steps. The watershed and sub-watersheds boundaries were delineated by defining an outlet point from the drainage network. The flow accumulation layer was used to generate the stream network raster. The raster layer of the stream network were vectorized to create streams shapefile lines for analysis. Stream orders were derived using (Strahler, 1957) stream ordering method. Five sub-watersheds were derived from the main watershed using watershed tool and coded as follows: SW1, SW2, SW3, SW4, and SW5 (Figure 1). Each sub-watersheds morphometric parameters were computed using the standard formula in (Table 2). These parameters are categorized to three (3) namely, linear, areal, and relief parameters.

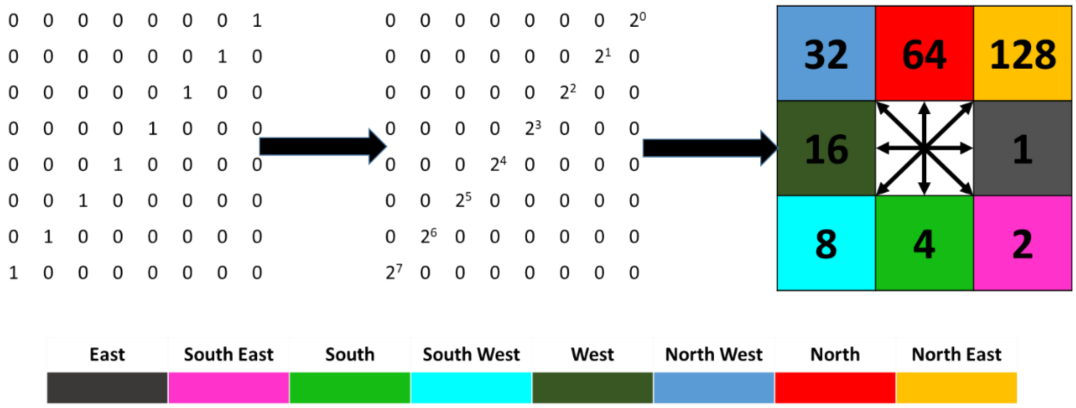



**Figure 2: Pour point flow direction model**

**Table 2: Morphometric parameters standard methods and formula adopted in the study**

| **Morphometric parameter** | **Formula** | **References** |
|---|---|---|
| Stream order | Ordering of stream segment based on the hierarchy | Strahler (1964) |
| Stream length ($L_u$) | Length of the streams (km) | Horton (1945) |
| Basin area (A) | Area of watershed ($km^2$) | |
| Basin perimeter | Perimeter of watershed (km) | |
| Stream number | The number of stream segments of various orders in a sub-watershed | Horton (1945) |
| Basin length ($L_b$) | The line along the flow path of the longest stream from the basin inlet to the outlet point | |
| Drainage density ($D_d$) | $Dd = \frac{Lu}{A}$<br>Where, $D_d$ = Drainage density<br>$L_u$ = total stream length of all orders (km)<br>A =area of the basin ($km^2$) | Horton (1945) |
| Stream frequency ($F_s$) | $Fs = Nu/A$<br>Where, $F_s$ =Stream frequency<br>$N_u$ =Total number of streams of all orders<br>A =Area of the basin ($km^2$) | Horton (1945) |
| Length of overland flow ($L_g$) | $Lg = 1/2Dd$<br>Where, $L_g$ =Length of overland flow (km)<br>$D_d$ =Drainage density | Horton (1945) |
| Elongation Ratio ($R_e$) | $Re = \left(\frac{2}{Lb}\right) \times (\sqrt{A}/\pi)^{\wedge}0.5$<br>Where, $R_e$ =Elongation ratio<br>A =Area of the basin<br>$L_{b.}$=Length of the basin while $\pi$ =3.14 | Schumm (1956) |
| Form factor ($R_f$) | $Rf = \frac{A}{Lb2}$<br>Where, $R_f$ =Form factor<br>A =Area of the basin ($km^2$)<br>$L_b$ =Length of the basin (km) | Schumm (1956) |
| Circulatory ratio ($R_c$) | $Rc = 4\pi A/P^2$ | Miller (1953) |

| | | |
|---|---|---|
| | Where, $R_c$ =Circularity ratio<br>A =Area of the basin, P =Perimeter | |
| Bifurcation ratio ($R_b$) | $\mathbf{R_b=N_u/N_u+1}$<br>Where, $N_u$ =Total number. of stream segment of order 'u'<br>$N_u+1$ =Number of segment of the next higher order | Schumm (1956) |
| Watershed Relief | Vertical difference between the highest and the lowest point | Schumm (1956) |
| Relief ratio ($R_h$) | $Rh = \frac{H}{Lb}$<br>Where, $R_h$ =Relief ratio<br>H =Watershed relief (km), $L_b$ =Basin length | Schumm (1956) |
| Ruggedness number ($R_n$) | $Rn = H \times Dd$<br>Where, $R_n$ =Ruggedness number<br>H =Watershed relief (km)<br>$D_d$ =Drainage density (km/km$^2$) | Schumm (1956) |

**Methodology for land use / land cover classification**

The image used for classification was a cloudless median composite of all the Sentinel-2 images from 1 January 2020 to 31 December 2020. The annual composite is considered to capture LULC variation of different seasons all year round. The Google Earth Engine (GEE) was used to process the multi temporal images. In addition to the spectral bands, the Normalized Difference Vegetation Index (NDVI) band (Tucker, 1979) and the SRTM-DEM band were incorporated to increase the classification accuracy. Advanced processing of Sentinel-2 images developed by Justin (2020) was adopted to get the cloudless image of the watershed. The median composite for 2020 images was obtained for LULC classification. The median was preferred because it is closer to the majority of values and is insensitive to extreme/noise values (Rumora et al., 2020). All the image bands were then resampled to a 10 m spatial resolution using the nearest neighbor method and clipped using a bounding box of the watershed boundary. For classification, the training and validation data were collected from the field using the handheld GPS. Seven LULC classes (i.e. water bodies, built up, closed forest, open forest, croplands, crop and vegetation mosaic, and shrublands) were sampled (

Table **3**). The LULC classes were defined based on the standard International Geosphere Biosphere Programme (IGBP) and FAO LULC classification scheme (FAO-FRA, 2000). A supervised classification was used with a random forest algorithm to perform LULC classification.

**Table 3: Categories of land use and land cover used for an image classification in Thiririka watershed.**

| Land use/Land cover | Description | Name on the map |
|---|---|---|
| Water bodies | Streams, dams, canals rivers, wetland and water pans. | Water |
| Built up/ developed | Residential, industrial, commercial areas and roads. | Built up |
| Croplands | Perennial and annual crops lands followed by harvest and a bare soil period. | Croplands |
| Crop and vegetation mosaic | Lands covered with crops, trees and grass, mostly perennial crops including coffee and tea plantations. | Mosaics |
| Dense forest | Land covered with tall strands of trees, purely evergreen with 70% land coverage. | Closed forest |
| Open forest | Land covered with trees below 60% and above 30% | Open forest |
| Shrublands | Extended lands with little grass, bare soil and bushes | Shrublands |

**Identification of critical sub-watersheds prone to soil erosion**

Watershed susceptible to soil erosion based on LULC were determined by looking at the LULC class abundance and their effects on soil erosion in each sub-watersheds. High priority (1) was assigned to the sub-watersheds with less vegetation cover, large cropland, large water coverage and built up areas (Gumma et al., 2016). Whereas, sub-watersheds with less cropland, more forest cover, more shrubland and more mosaics were given low ranking (5). The LULC ranks in each sub-watershed were averaged to get the compound priority (CP) of each sub-watershed.

The morphometric parameters are sometimes referred to the erosion risk assessment parameters (Avinash et al., 2011) and have been used as a basis to select critical watersheds for integrated watershed management approaches implementation. This method is proven to be significant with no considerations of soil properties (Biswas et al., 1999). Linear parameters e.g. bifurcation ratio have a direct effect on soil erodibility whereby high values of linear parameters show more risk of erodibility. The length of overland flow is a unique linear factor that has an inverse relationship to soil erosion (Puno & Puno, 2019). Aerial parameters such as circulatory ratio, form factor and elongation ratio have an inverse relationship to soil erosion hence lower values of this parameter indicate a high susceptibility of watershed to soil erosion. Other aerial parameters such as stream frequency and drainage density have a direct relationship with soil erosion (Puno & Puno, 2019). Relief parameters such as basin relief, relief ratio and ruggedness number have a direct influence on soil erodibility (Tolessa & Rao, 2013). Therefore, sub-watersheds with higher values of relief parameters were given value rank of 1, while the lowest value were assigned a value of 5. Later the morphometric parameter ranks for each SW were averaged to get compound priority (CP). The sub-watersheds with the least CP was assigned high priority (1) and vice versa. Then the values were categorized into five ranks corresponding to very high (1), high (2), moderate (3), low (4), and very low (5) priority.

## III. Results and Discussion

**Morphometric analysis**

**Stream order, Watershed perimeter (P), Watershed area (A) and watershed length ($L_b$)**

These study implemented an approach according to (Strahler, 1957) stream ordering system. According to Strahler (1957), stream order is the ranking of the streams of the basin following the hierarchical position of the rivers tributaries. The smallest stream segment without tributaries is the first-order stream. Second-order streams is formed after two streams of the first order join and so forth. The entire Thiririka watershed is a 4$^{th}$ order type with 284 streams and a total stream length of 290.18 km shown in (Figure 1). SW5 is the largest with a perimeter of 91.13 km followed by SW3 with a perimeter of 65.2 km. The smallest sub basin is SW1 with a perimeter of 23.01 km. The drainage area of the entire Thiririka watershed is approximately 119.8 km$^2$. SW1 covers a smaller area of 9.64 km$^2$ while SW5 has a large area coverage of 39.34 km$^2$ . Basin length ($L_b$) is the line along the flow path of the longest stream from the basin inlet to the outlet point. SW1 with the $L_b$ of 4.75 km was the lowest while SW5 recorded the highest $L_b$ of 10.56 km.

**Linear aspects**

Stream length, mean stream length, birfurcation ratio, length of the overland flow are the linear parameters shown in (Table 2). According to Horton (1945), stream length ($L_u$) is the length of individual stream segment in the watershed obtained by counting the number of streams in each order and measuring their length. $L_u$ indicates the amount of surface runoff whereby a high value of $L_u$ shows that the watershed is characterized by gentle slopes while shorter stream lengths shows steep slopes with high amount of runoff and low discharge (Tamma Rao *et al.*, 2012). In Thiririka watershed, SW2 recorded the highest $L_u$ value of 44.97 km representing gentle slopes with reduced runoff while SW1 had a shorter $L_u$ value of 16.4 km, indicating steep slopes with more surface runoff. Mean Stream Length ($L_{sm}$) is the total length of the streams of a specific order to the number of streams in the same order (Horton, 1945). According to Ahirwar et al.,(2019) $L_{sm}$ is linked to the catchment surface and the drainage pattern. $L_{sm}$ value were higher in SW4 (0.76) SW2 and SW3 (0.69) and lower in SW1 (0.43).

Bifurcation ratio ($R_b$) as defined by Schumm (1956) is the ratio between the total numbers of stream channels of one order to that of the next higher order in a catchment. Strahler (1957) suggested that lower $R_b$ values represent more first and second order streams segments with plain terrain, lowlands, and permeable sub surface watersheds while higher $R_b$ is associated with mountainous region with high runoff. As indicated in (Table 2), $R_b$ of the study area ranges from 3.2 in SW1 to 4.65 in SW5.

Length of overland flow $L_g$ is described as the length of water flowing in the surface before reaching to the main streams Suji et al., (2015),. $L_g$ affects the physiographic properties of the watershed (Horton, 1945) whereby during rain, water seeps into the ground while the excess water flows to the streams and rivers. Higher values of $L_g$ indicate that the basin is highly exposed to soil erosion (Suji et al., 2015). $L_g$ values for Thiririka sub-watersheds ranges from 0.29 for SW1 and SW4 to 0.45 in SW5.

**Areal aspects**

Areal parameters such as circulatory ratio, form factor, elongation ratio, stream frequency and drainage density are presented in (Table 2). Drainage density (Dd) as described by Horton (1945) is the total length of all the stream channels of all orders within the watershed per basin area. Watersheds with high Dd experience high surface runoff because they are less permeable, have less vegetation cover and steep slopes, areas of low Dd are more permeable allowing for high infiltration with reduced runoff, characterized by dense vegetation cover with gentle slopes (Puno & Puno, 2019). SW5 recorded the lowest Dd value of with 1.11km/km$^2$ while SW4 recorded Dd of 1.72 km/km$^2$ suggesting that the sub-watershed are vegetated with little runoff and high infiltration rates.

The stream frequency of a watershed is the ratio between the total number of stream channels within the basin to the catchment unit area (Horton, 1945). $F_s$ determines the surface runoff and the rate of infiltration of the drainage area i.e., higher $F_s$ values watersheds have lower infiltration rates and reduced runoff. In Thiririka sub-watersheds, SW1 recorded the highest $F_s$ value of 3.94, while SW3 had the lowest $F_s$ value of 2.07. Sub-watersheds with a higher $F_s$ values indicate high relief with low surface permeability hence high run off (Ikbal & Ali, 2017).

Elongation ratio is the ratio between the diameters of a circle having a similar area as that of the basin to the maximum length of the basin, used to show the shape of the catchment (Schumm, 1956). According to Sarkar et al., (2020) basins with $R_e$ close to 1.0 have low relief and gentle slope while those with $R_e$ between 0.6 to 0.8 represent high relief and steep slopes. $R_e$ is used to show how the basin is stretching with respect to the area whereby the lower value of $R_e$ means that the basin is elongated while high $R_e$ values represent circular shaped watersheds which tend to have less runoff as compared to the elongated watersheds. $R_e$ of SW1 is 0.74, which is the highest while SW5 recorded the lowest $R_e$ of 0.63.

Circulatory ratio is the ratio of the area of a watershed to the area of a circle with similar diameter as the perimeter of the catchment. Low values of Rc indicate that the watershed is at a young stage while high values indicate the catchment is at maturity stage (Choudhari et al., 2018). In Thiririka sub-watersheds, Rc values range from 0.06 for SW5 to 0.23 in SW1.

According to Horton (1945), $R_f$ is defined as the ratio of catchment area to square of the maximum catchment length which ranges from zero to one (1). Watersheds with higher form factor are circular with high peak flows for shorter duration, whereas watersheds with lower values of form factor are elongated with low peak flowing for longer duration (Ahirwar et al., 2019). In Thiririka sub-watersheds, the $R_f$ values range from 0.43 for SW1 to 0.35 for SW5 indicating that they are highly elongated with flat peak flows for longer duration.

**Relief Aspects**

Relief parameters basin relief, relief ratio and ruggedness number are shown in (Table 2). The basin relief shows the elevation of the watershed i.e., the difference between the peak of the basin and the mouth of the basin (Choudhari et al., 2018). The Bh value of Thiririka sub-watersheds range between 96 m in SW1 to 332 m in SW5 (Table 4.5). Basin relief parameter influences the amount of basin denudation, surface runoff and sediments yield. Relief ratio (Rh) is the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Tamene et al., 2017). In the present study, the relief ratio varies from 0.07 in SW3 to 0.02 in SW2. The relief ratio of the sub-watershed was high in SW3 and lower in SW2. It shows that SW3 has steep slopes indicating high intensity of soil erosion as described by (Tamene et al., 2017). Ruggedness number (Rn) is the value derived by assessing the drainage density and the relief of the basinFrom the analysis, the Rn value of the present study varies from a maximum of 13.49 in SW3 to a minimum value of 8.08 in SW1. When Rn value is low, it indicates that the particular watershed is not susceptible to erosion. Ruggedness number assessment is useful to determine the steepness of the drainage network. Lower values of ruggedness number indicate that the basin is more resistant to erosion (Puno & Puno, 2019).

**Table 4: Thiririka watershed morphometric parameters values**

**Linear Parameters**

| SW | Basin Length ($L_b$) Km | Total No. of Streams ($N_u$) | Total Stream Length ($L_u$) | Mean Stream Length ($L_{sm}$) | Mean bifurcation ratio ($R_b$) | Length of Overland Flow ($L_g$) |
|---|---|---|---|---|---|---|
| SW1 | 4.75 | 38 | 16.4 | 0.43 | 3.2 | 0.29 |
| SW2 | 9.11 | 65 | 44.97 | 0.69 | 4.09 | 0.34 |
| SW3 | 8.98 | 61 | 41.89 | 0.69 | 4.26 | 0.35 |
| SW4 | 5.14 | 25 | 18.99 | 0.76 | 3.25 | 0.29 |
| SW5 | 10.56 | 95 | 43.8 | 0.46 | 4.65 | 0.45 |

**Aerial Parameters**

| SW | Perimeter (P) Km | Area (A) $Km^2$ | Drainage density ($D_d$) ($Km/Km^2$) | Stream frequency ($F_s$) | Form factor ($R_f$) | Circulator y ratio ($R_c$) | Elongation ratio ($R_e$) |
|---|---|---|---|---|---|---|---|
| SW1 | 23.01 | 9.64 | 1.70 | 3.94 | 0.43 | 0.23 | 0.74 |
| SW2 | 52.19 | 30.33 | 1.48 | 2.14 | 0.37 | 0.14 | 0.68 |
| SW3 | 65.2 | 29.53 | 1.42 | 2.07 | 0.37 | 0.09 | 0.68 |
| SW4 | 26.76 | 11.05 | 1.72 | 2.26 | 0.42 | 0.19 | 0.73 |
| SW5 | 91.13 | 39.34 | 1.11 | 2.41 | 0.35 | 0.06 | 0.67 |

**Relief Parameters**

| SW | Maximum elevation(m) | Minimum elevation(m) | Basin relief($B_h$)(km) | Relief ratio($R_h$) | Ruggedness number($R_n$) |
|---|---|---|---|---|---|
| SW1 | 2755 | 2659 | 0.1 | 0.02 | 8.08 |
| SW2 | 2683 | 2210 | 0.47 | 0.05 | 13.49 |
| SW3 | 2515 | 1843 | 0.67 | 0.07 | 12.74 |
| SW4 | 1981 | 1753 | 0.23 | 0.04 | 8.83 |
| SW5 | 1814 | 1482 | 0.33 | 0.03 | 11.73 |

**Stream orders and numbers**

| Stream order | SW1 | SW2 | SW3 | SW4 | SW5 |
|---|---|---|---|---|---|
| 1st | 28 | 49 | 51 | 19 | 80 |

| | | | | | |
|---|---|---|---|---|---|
| 2nd | 6 | 13 | 7 | 4 | 11 |
| 3rd | 3 | 2 | 2 | 1 | 3 |
| 4th | 1 | 1 | 1 | 1 | 1 |
| **Total streams** | **38** | **65** | **61** | **25** | **95** |

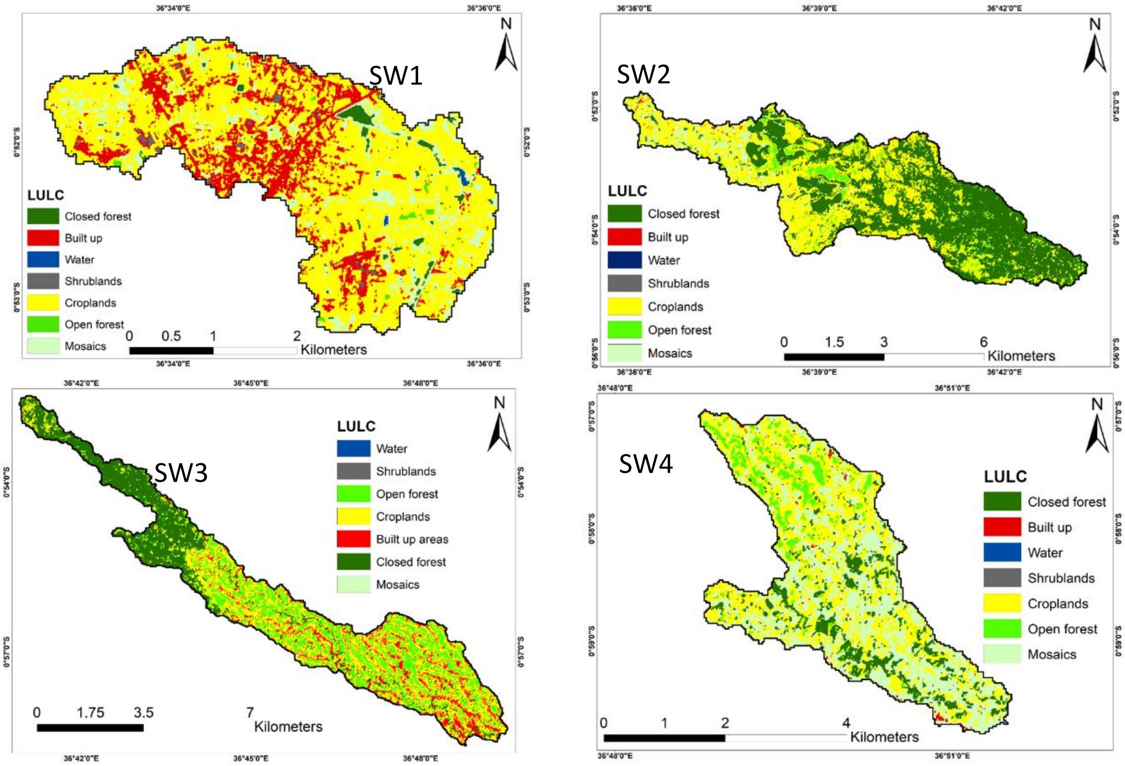
**Thiririka sub-watersheds land use and land cover parameters**
**Land use/ land cover Classification Accuracy Assessment**

The identified classes of the watersheds were validated through accuracy assessment with ground truth data collected from the field. About 100 polygons were collected for each LULC across the watershed. Out of the collected samples, 70% was used for training the model while 30% was used for validation using the random forest classifier with a maximum number of 30 trees. The overall accuracy for the classification was 0.88, with the overall kappa statistics of 0.86. Producer accuracy for the classes ranges from 0.74 to 1, while consumer accuracy value ranges from 0.78 to 1 (

Table **5**).

**Table 5: Statistical accuracy assessment for land use / land cover classifications of Thiririka watershed**

| LULC | Producer accuracy | Consumers accuracy |
|---|---|---|
| Closed forest | 1.00 | 0.92 |
| Built up areas | 0.89 | 0.85 |
| Water bodies | 0.93 | 1.00 |
| Shrublands | 0.93 | 0.93 |
| Croplands | 0.74 | 0.78 |
| Open forest | 0.90 | 0.79 |
| Mosaics | 0.86 | 0.97 |
| **Overall Accuracy** | **0.88** | |
| **Overall Kappa Statistics** | **0.86** | |



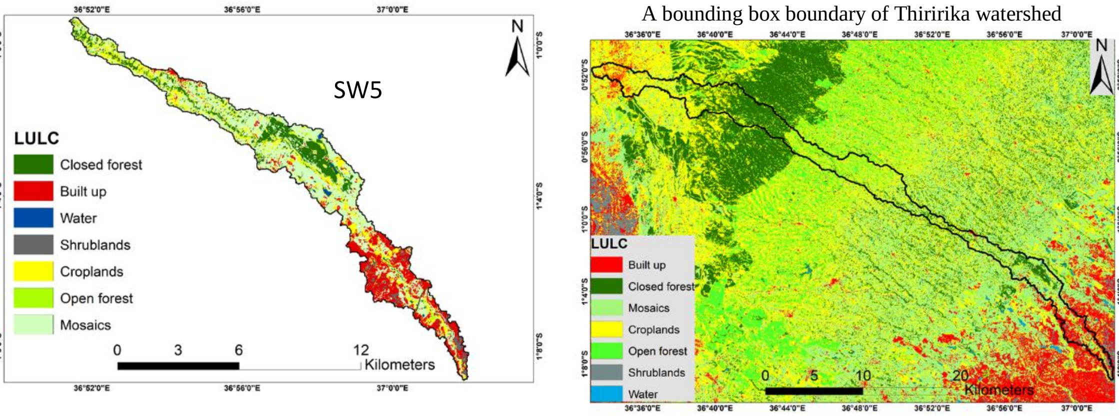



**Figure 3: Thiririka sub-watersheds land use and land cover classification maps**

Most waterbodies in the Thiririka watershed are mainly for irrigation and commercial farming. SW5 had the highest waterbodies area of 0.23 km$^2$ (Table 6). During prioritization sub-watersheds with more water were given high priority, whereas, sub-watersheds with less water were given little priority because water is considered an agent of soil erosion and runoff through seepage erosion (Vijith & Dodge-Wan, 2019). Built up areas are concentrated in SW5 with an estimated area extent of 7.68 km$^2$ while fewer developments were recorded in SW2 (0.08 km$^2$) (Table 6). High built up areas are given high priority and vice versa. Built-up areas have a high population exerting pressure on land resources causing land degradation and soil erosion. This happens especially in communities with underdeveloped social and economic domains *(*Rumora et al., 2020), though not the case with sustained and developed communities whereby increased populations leads to increased technological innovations leading to efficient land resource utilization (Boserup, 2013). Closed forests were highest in SW2 (14.39 km$^2$) and lowest in SW4 (1.31 km$^2$) (Figure 3). The sub-watersheds with less closed forests were given high ranks and vice versa. In general, vegetation tends to slow water movement hence reducing soil erosion, while fewer trees cover exposes the soil to agents of erosion. In addition, tree canopies enhance infiltration as well as reduce surface runoff in watersheds. Higher open forest cover was recorded in SW3 (7.13 km$^2$) while less forest cover were recorded in SW5 (0.32 km$^2$) (Table 6). For prioritization, areas with less open forest cover were assigned high priority due to an increase in rainfall erosivity as compared to areas with less open forest cover

**Table 6: Thiririka sub-watersheds land use / land cover areal coverage in km$^2$**

| SW | Closed forest | Built up areas | Water bodies | Shrub lands | Croplands | Open forest | Mosaics |
|---|---|---|---|---|---|---|---|
| SW1 | 0.18 | 1.78 | 0.02 | 0.1 | 6.44 | 0.06 | 1.12 |
| SW2 | 14.39 | 0.08 | 0.01 | 0.02 | 12.64 | 1.5 | 1.91 |
| SW3 | 7.53 | 3.29 | 0 | 0 | 11.68 | 7.13 | 0.1 |
| SW4 | 1.31 | 0.07 | 0 | 0 | 4.72 | 0.77 | 4.27 |
| SW5 | 5.68 | 7.68 | 0.23 | 1.1 | 6.95 | 0.32 | 17.65 |

The total area covered with shrublands is approximately 1.2 km$^2$, concentrated in SW5 with an area of 1.1 km$^2$. When giving priority, low priority was given to sub-watersheds with less shrublands while, high priority was assigned to sub-watersheds with more shrublands. SW2 (12.64 km$^2$) and SW3 (11.68 km$^2$) have the largest area of croplands. SW4 recorded the lowest area of 4.72 km$^2$ of croplands (Table 6). The sub-watersheds with more cultivated land was given a higher priority, as compared to sub-watersheds with less cultivated area. Generally, continuous and intensive tillage practices tend to affect the soil structure hence increasing surface runoff and sediments delivery (Seitz et al., 2019). From field observation, most occurring mosaics include coffee, Persea Americano (avocado), maize, bananas, Napier grass, beans and potatoes. In Thiririka sub-watersheds, SW5 (17.65 km$^2$) was highly dominant of mosaics while SW1 (1.12 km$^2$) had fewer mosaics. Sub-watershed with less coverage of mosaics was given high priority because the soil is exposed to agents of erosion as compared to lands with more crops and vegetation mosaic. Besides, trees and grass in cropland fields may imply soil conservation and management practices are in place.

**Sub-watersheds Prioritization**

Based on the LULC, results in (Table 7 and Figure 4) show that sub-watershed 5 (SW5) was highly exposed to erosion. This can be attributed to the watershed having less forest and more commercial farming. Despite most land of SW5 having more crop and vegetation mosaics, the area is undergoing high urban sprawl in the lower section and the upper section is experiencing an increase in croplands. SW4 has the lowest susceptibility

to soil erosion, which can be attributed to its larger area being covered by crop and vegetation that tend to reduce soil erosion.
Prioritization based on morphometric analysis indicated that SW5 is highly susceptible to soil erosion. The sub-watershed is characterized by high length of overland flow subjecting it to high surface runoff. The sub-watershed also has a lower form factor, low circulatory ratio and low elongation ratio indicating that it is highly elongated in shape with low infiltration capacity causing a continuous soil erosion activity. The mean bifurcation ratio of SW5 indicate that it experiences flash floods during heavy rains. Again, SW5 has more first and second order stream, which exhibits the soil erosion by surface runoff.

Generally, SW5 has the highest priority (1) with mean compound value of 2.05 indicating high susceptibility to soil erosion from the effect of critical basin morphometry and LULC. On the other hand, SW4 recorded less priority (5) with a mean CP value of 3.61. Therefore, suitable watershed conservation measures need to be adopted for soil and water resources sustainability in SW5.

**Table 7: Susceptibility of Thiririka sub-watersheds to soil erosion based on land use / land cover and basin morphometry.**

**Prioritization based on land use / land cover**

| SW | Closed forest | Builtup | Waterbodies | Shrublands | Croplands | Open forest | Mosaics | Compound value CP) | Priority rank |
|---|---|---|---|---|---|---|---|---|---|
| SW1 | 1 | 2 | 2 | 2 | 4 | 1 | 5 | 2.43 | 2 |
| SW2 | 5 | 4 | 3 | 3 | 1 | 4 | 4 | 3.43 | 3 |
| SW3 | 4 | 3 | 4 | 4 | 2 | 5 | 3 | 3.57 | 4 |
| SW4 | 2 | 5 | 4 | 4 | 5 | 3 | 2 | 3.58 | 5 |
| SW5 | 3 | 1 | 1 | 1 | 3 | 2 | 1 | 1.71 | 1 |

**Prioritization based on morphometric parameters compound values.**

| SW | Bifurcation ratio | Drainage density | Stream frequency | Form factor | Circulatory ratio | Elongation ratio | Length of overland flow | Relief ratio | Ruggedness number | Compound value | Priority ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SW 1 | 5 | 2 | 1 | 4 | 5 | 4 | 4 | 5 | 5 | 4.38 | 5 |
| SW 2 | 3 | 3 | 4 | 2 | 3 | 2 | 3 | 2 | 1 | 2.88 | 3 |
| SW 3 | 2 | 4 | 5 | 2 | 2 | 2 | 2 | 1 | 2 | 2.75 | 2 |
| SW 4 | 4 | 1 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 3.63 | 4 |
| SW 5 | 1 | 5 | 2 | 1 | 1 | 1 | 1 | 4 | 3 | 2.38 | 1 |

**Final priority ranks of Thiririka sub-watersheds.**

| Sub-watershed | Land use / land cover CP | Morphometric parameters CP | Mean Compound Priority | Final rank |
|---|---|---|---|---|
| **SW1** | 2.43 | 4.38 | 3.41 | 3 |
| **SW2** | 3.43 | 2.88 | 3.16 | 2 |
| **SW3** | 3.57 | 2.75 | 3.16 | 2 |
| **SW4** | 3.58 | 3.63 | 3.61 | 4 |
| **SW5** | 1.71 | 2.38 | 2.05 | 1 |

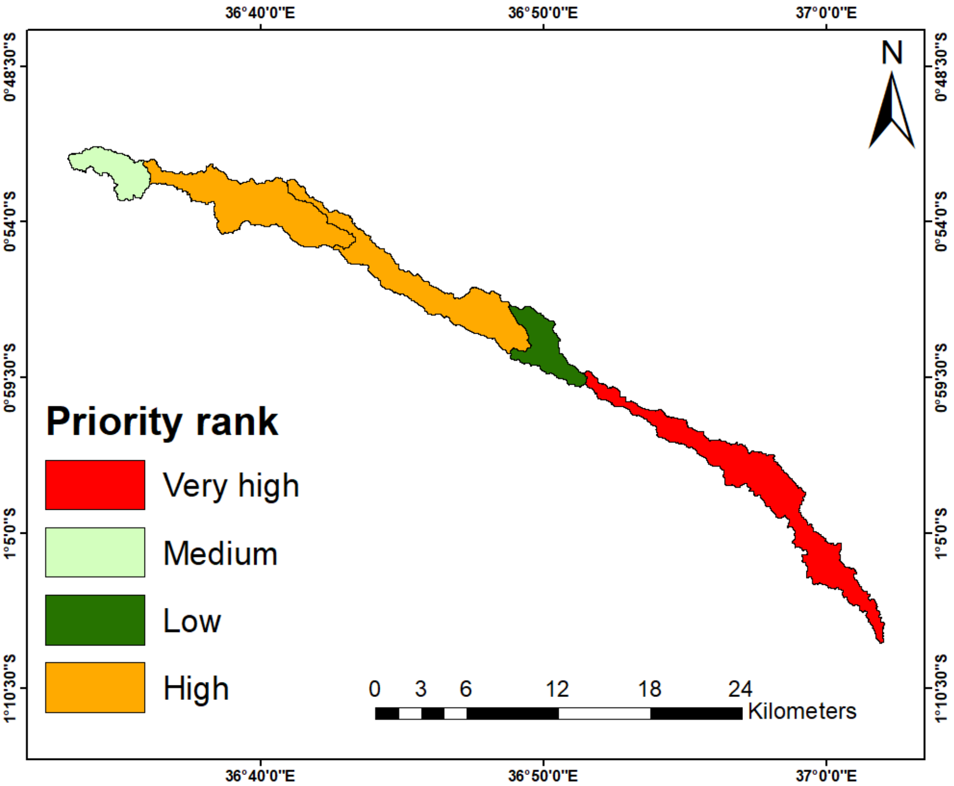



**Figure 4: Thiririka sub-watersheds soil erosion susceptibility map, the ranks were derived from mean compound value of basin morphometric parameters and land use / land cover.**

## IV. Conclusion

For effective and sustainable utilization of watershed resources, identifying areas that need attention is crucial. The present study shows the steps in delineating watersheds and sub-watersheds, quantifying LULC and computing the basin morphometric parameters. For prioritization of the Thiririka sub-watershed relative to soil and water resources conservation, five sub-watersheds were delineated and their LULC and basin morphometry, effects to soil erosion assessed. The standard methods of identifying soil erosion prone areas require a lot of resources, they are time consuming coupled with data unavailability such as sediments yields, précised soil characteristics etc., but with the use of RS and GIS these problems have been reduced. The study shows that remote sensing data and GIS can be utilized to assess the drainage characteristics and LULC. Mapping watersheds characteristics for prioritization is the first step in implementation of integrated watershed management for sustainable livelihoods. Therefore, identifying critical watersheds gives insights to various stakeholders to come up with sustainable measures for conservation and management of soil and water resources within the watersheds. In designing the integrated watershed management plans for managing watersheds, the analysis of LULC characteristics and morphometry has produced useful information.

## References

[1]. Ahirwar, R., Malik, M. S., & Shukla, J. P. (2019). Prioritization Of Sub-Watersheds For Soil And Water Conservation In Parts Of Narmada River Through Morphometric Analysis Using Remote Sensing And GIS. Journal Of The Geological Society Of India, 94(5), 515–524. Https://Doi.Org/10.1007/S12594-019-1349-8

[2]. Avinash, K., Jayappa, K. S., & Deepika, B. (2011). Prioritization Of Sub-Basins Based On Geomorphology And Morphometric Analysis Using Remote Sensing And Geographic Information System (GIS) Techniques. Geocarto International, 26(7), 569–592. Https://Doi.Org/10.1080/10106049.2011.606925

[3]. Biswas, S., Sudhakar, S., & Desai, V. R. (1999). Prioritisation Of Subwatersheds Based On Morphometric Analysis Of Drainage Basin: A Remote Sensing And GIS Approach. Journal Of The Indian Society Of Remote Sensing, 27(3), 155–166. Https://Doi.Org/10.1007/BF02991569

[4]. Boserup, E. (2013). The Conditions Of Agricultural Growth: The Economics Of Agrarian Change Under Population Pressure. In G. A. & U. LTD & R. H. M. STREET (Eds.), Routledge (1st Ed.). Https://Doi.Org/10.4324/9781315016320

[5]. Choudhari, P. P., Nigam, G. K., Singh, S. K., & Thakur, S. (2018). Morphometric Based Prioritization Of Watershed For Groundwater Potential Of Mula River Basin, Maharashtra, India. Geology, Ecology, And Landscapes, 2(4), 256–267. Https://Doi.Org/10.1080/24749508.2018.1452482

[6]. Egede, E. A., & Donatus, U. (2013). Threats And Mitigation Of Soil Erosion And Land Degradation In South East Nigeria. Journal Of Environment And Earth Science, 3(13), 95–103.

[7]. EU. (2015). World Food Consumption Patterns – Trends And Drivers. EU Agricultural Markets Briefs, 6, 11. Http://Ec.Europa.Eu/Agriculture/Markets-And-Prices/Market-Briefs/Index_En.Htm

[8]. FAO-FRA. (2000). FRA 2000 Forest Cover Mapping & Monitoring With NOAA - AVHRR & Other Coarse Spatial Resolution Sensors (Vol. 29). Http://Www.Fao.Org/Forestry/4031-0b6287f13b0c2adb3352c5ded18e491fd.Pdf

[9]. Gumma, M. K., Birhanu, B. Z., Mohammed, I. A., Tabo, R., & Whitbread, A. M. (2016). Prioritization Of Watersheds Across Mali Using Remote Sensing Data And GIS Techniques For Agricultural Development Planning. Water (Switzerland), 8(6), 1–17. Https://Doi.Org/10.3390/W8060260

[10]. Horton, R. F. (1945). Erosional Development Of Streams And Their Drainage Basins; Hydrophysical Approach To Quantitative Morphology. Nihon Ringakkai Shi/Journal Of The Japanese Forestry Society, 37(12), 555–558. Https://Doi.Org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

[11]. Igwe, P. U., Onuigbo, A. A., Chinedu, O. C., Ezeaku, I. I., & Muoneke, M. M. (2017). Soil Erosion: A Review Of Models And Applications. International Journal Of Advanced Engineering Research And Science, 4(12), 138–150. Https://Doi.Org/10.22161/Ijaers.4.12.22

[12]. Ikbal, J., & Ali, S. A. (2017). Site Selection For Soil Conservation By Geometric Analysis Of Watershed In The Southeastern Part Of Aravalli Mountain Range Using Remote Sensing And GIS. International Journal Of Scientific Research In Science And Technology, 3(8), 369–378.

[13]. Jenson, S. K., & Domingue, J. O. (1998). Extracting Topographic Structure From Digital Elevation Data For Geographic Information System Analysis. American Society For Photogrammetry And Remote Sensing, 54(11), 1593–1600. Https://Pubs.Er.Usgs.Gov/Publication/70142175

[14]. Justin Braaten. (2020). Earthengine-Community/Index.Ipynb At Master · Google/Earthengine-Community · Github. Https://Github.Com/Google/Earthengine-Community/Blob/Master/Tutorials/Sentinel-2-S2cloudless/Index.Ipynb

[15]. Kiio, M. M., & Achola, O. P. (2015). Land Use Land Cover Changes And Their Effects On Agricultural Land: A Case Study Of Kiambu County-Kenya. Kabarak Journal Of Research & Innovation, 3(1), 74–86. Http://Eserver.Kabarak.Ac.Ke/Ojs/

[16]. Malik, A., Kumar, A., & Kandpal, H. (2019). Morphometric Analysis And Prioritization Of Sub-Watersheds In A Hilly Watershed Using Weighted Sum Approach. Arabian Journal Of Geosciences, 12(4). Https://Doi.Org/10.1007/S12517-019-4310-7

[17]. Miller, V. . (1953). A Quantitative Geomorphologic Study Of Drainage Basin Characteristics In The Clinch Mountain Area. Technical Report, 3, 271–300. Https://Www.Journals.Uchicago.Edu/Doi/Epdf/10.1086/626413

[18]. Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital Terrain Modelling: A Review Of Hydrological, Geomorphological, And Biological Applications. Hydrological Processes, 5(1), 3–30. Https://Doi.Org/10.1002/Hyp.3360050103

[19]. Puno, G. R., & Puno, R. C. C. (2019). Watershed Conservation Prioritization Using Geomorphometric And Land Use-Land Cover Parameters. Global Journal Of Environmental Science And Management, 5(3), 279–294. Https://Doi.Org/10.22034/Gjesm.2019.03.02

[20]. Rumora, L., Miler, M., & Medak, D. (2020). Impact Of Various Atmospheric Corrections On Sentinel-2 Land Cover Classification Accuracy Using Machine Learning Classifiers. ISPRS International Journal Of Geo-Information, 9(4). Https://Doi.Org/10.3390/Ijgi9040277

[21]. Sarkar, D., Mondal, P., Sutradhar, S., & Sarkar, P. (2020). Morphometric Analysis Using SRTM-DEM And GIS Of Nagar River Basin, Indo-Bangladesh Barind Tract. Journal Of The Indian Society Of Remote Sensing, 48(4), 597–614. Https://Doi.Org/10.1007/S12524-020-01106-7

[22]. Schumm, S. A. (1956). Evolution Of Drainage Systems And Slopes In Badlands At Perth Amboy, New Jersey. Bulletin Of The Geological Society Of America, 67(5), 597–646. Https://Doi.Org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

[23]. Seemuller, W. W. (1989). The Extraction Of Ordered Vector Drainage Networks From Elevation Data. Computer Vision, Graphics And Image Processing, 47(1), 45–58. Https://Doi.Org/10.1016/0734-189X(89)90053-4

[24]. Seitz, S., Goebes, P., Puerta, V. L., Pereira, E. I. P., Wittwer, R., Six, J., Van Der Heijden, M. G. A., & Scholten, T. (2019). Conservation Tillage And Organic Farming Reduce Soil Erosion. Agronomy For Sustainable Development, 39(1). Https://Doi.Org/10.1007/S13593-018-0545-Z

[25]. Strahler, A. N. (1957). Quantitative Analysis Of Watershed Geomorphology,. Transactions, American Geophysical Union, 38(6), 913–920. Https://Doi.Org/10.1029/TR038i006p00913

[26]. Suji, V. R., Sheeja, R. V., & Karuppasamy, S. (2015). Prioritization Using Morphometric Analysis And Land Use/Land Cover Parameters For Vazhichal Watershed Using Remote Sensing And GIS Techniques. International Journal For Innovative Research In Science & Technology, 2(1), 61–68. Www.Ijirst.Org

[27]. Tamene, L., Adimassu, Z., Ellison, J., Yaekob, T., Woldearegay, K., Mekonnen, K., Thorne, P., & Le, Q. B. (2017). Mapping Soil Erosion Hotspots And Assessing The Potential Impacts Of Land Management Practices In The Highlands Of Ethiopia. Journal Of Indian Society Remote Sensing, 292(2), 153–163. Https://Doi.Org/10.1016/J.Geomorph.2017.04.038

[28]. Tamma Rao, G. T., Gurunadha Rao, V. V. S., Dakate, R., Allikharjuna Rao, S. T. M., & Raja Rao, B. M. (2012). Remote Sensing And GIS Based Comparative Morphometric Study Of Two Sub-Watershed Of Different Physiographic Conditions, West Godavari District, A.P. Journal Of The Geological Society Of India, 79(4), 383–390. Https://Doi.Org/10.1007/S12594-012-0059-2

[29]. Tarboton, D. G. (1997). A New Method For The Determination Of Flow Directions And Upslope Areas In Grid Digital Elevation Models. Water Resources Research, 33(2), 309–319. Https://Doi.Org/10.1029/96WR03137

[30]. Tolessa, G. A., & Rao, P. J. (2013). Watershed Development Prioritization Of Tandava River Basin , Andhra Pradesh , India – GIS Approach. International Journal Of Engineering Science Invention, 2(2).

[31]. Tucker, C. J. (1979). Red And Photographic Infrared Linear Combinations For Monitoring Vegetation. Remote Sensing Of Environment, 8(2), 127–150. Https://Doi.Org/10.1016/0034-4257(79)90013-0

[32]. Vijith, H., & Dodge-Wan, D. (2019). Modelling Terrain Erosion Susceptibility Of Logged And Regenerated Forested Region In Northern Borneo Through The Analytical Hierarchy Process (AHP) And GIS Techniques. Geoenvironmental Disasters, 6(1). Https://Doi.Org/10.1186/S40677-019-0124-X