

Morphometric and Change Detection Analysis for Prioritization of Sub Basin Conservation, Case Study of Taita Hills

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The study is aimed at analyzing the risk of Taita Hills region of harmful runoff and soil erosion by employing morphometric analysis and change detection in a GIS environment to prioritize the Taita Hills in Taita Taveta County. The objective of the study was to characterize and give hierarchy in which the region should be conserved. The methodology adopted hydrological modeling, morphometric computation, Weighted Sum Analysis (WSA) and change detection. Hydrological modeling was vital in delineating the sub-watersheds and stream network. Morphometric computation and WSA was applicable in coming up with parameters and weighting the parameters for each sub-watershed's prioritization. Change detection is related to how human activity is important for conservation as the effect of land forms and dimensions are compounded. Twenty-one fourth order streamed sub-watersheds were generated and prioritized using morphometry and change detection. Every sub-watershed is given a hierarchy based on the calculated compound parameter from the WSA equation developed and shows the risk of runoff and soil erosion. The morphometric prioritization shows 47% of the watersheds are in the high and very highly susceptible areas and there are two sub-watersheds with the highest land cover change. As well six sub-watersheds are risky with both land cover change and morphometry.

Keywords

Watershed Prioritization, Morphometric Analysis, GIS, Change Detection

1. Introduction

The level of urbanization and deforestation within and around Taita Hills has

led to continuous changes to destruction of the watershed environment within Taita Hills. The region surrounding Taita Hills is home to wild animals that depend on the river basin for continuous supply of food and water. As well the humans living around Wundanyi depend on the river basin for the environment's suitability to grow food and water. With increased population and thus deforestation for agriculture and urbanization there is a strain on the water tower (Taita Hills).

The ongoing reduction of the Taita Hills forest coverage affects the sustainable supply of the natural and conducive environment for water cycle regeneration and growth of food for humans and animals. The result is the drying of rivers and loss of biodiversity. According to [1], there is increased population growth and continuous demand for food production. For this reason, people have turned to forest and rangeland ecosystems that are water towers with favorable areas for agriculture thus increasing pressure on water resources and soil.

Considering the current levels of degradation of the river basins and its environs, there is a need for responsible and sustainable management within the spatial extents of the micro-environments. For sustainable management of the biodiversity, it is only imperative to show the trends of degradation of the river basins, analyze the factors and provide restoration measures.

Now in areas like Taita Hills that has 3 competing elements; urbanization, agriculture and wildlife, there is a need to discriminate the effects of the factors of degradation of the river basin environment. With known trends of degradation then it is possible to improve and provide conservation and restoration efforts where they are needed.

In this study, geographical information system (GIS) technology and Remote Sensing will be used to map, analyze using morphometry and land use and prioritize for conservation regions of river basin degradation in Taita Hills. Therefore, the main objective of this study research was to characterize and prioritize Taita Hills water catchment through in-depth terrain evaluation together with change detection to look into conservation goals.

2. Materials and Methods

2.1. Study Area

The Taita Hills catchment is located between 38°10'58"E to 38°33'29"E longitude and 3°14'51S to 3°31'6"S latitude in Taita Taveta County and the major river in the catchment is River Voi. The shape of Taita Hills watershed is nearly rectangular and has an area of 1391.45 km² with 483 m minimum and 2467 m maximum elevations. The catchment has the highest rainfall in months around April and November and lowest rainfall in months around July with average annual rainfall being about 1100 mm. The area has an annual average temperature of 23°. The area has previously been mostly forestland but with urbanization, agricultural and urban use has grown significantly.

2.2. Data and Methodology

The data used in this research was satellite data. Both the DEM and satellite images are satellite data. The DEM of 30 by 30 m of the SRTM archive was used to delineate watersheds and the stream network. The satellite images from Landsat 7 (2001) and Landsat 8 (2017) were used to do change detection. The study followed the following flow of steps (See Figure 1).

2.3. Morphometric Analysis and Prioritization

According to [2] degradation is the decrease of resource potential of the natural landscape by different processes. The resource potential includes plant life, soil and (or) water. Therefore, even the altering of the water cycle falls as degradation.

The processes that promote degradation are assumed to be by humans and animals through over-use and climate variability in accelerated loop process. The accelerated loop process is accelerated by the net removal of plant cover by humans, animals and (or) together with the climate [3].

Conservation efforts are mainly done by public institutions and NGOs to maintain the natural environment and attain sustainability from the resources of the environment.

According to the UN [4], natural and indigenous environments are under threat of destruction. More so, the areas affected are water catchment areas that provide 80% of earth's fresh water supply. In all efforts to protect such environments, parties have looked at human activities only with less concentration of the extensive terrain and its effects.

Forest areas in Kenya still serve a big contribution in the provision of clean water for use. As well there are effects of soil erosion and water runoff that contribute in the instability of such important environments. For efficient conservation minus human activities, morphometry is important in identifying region that requires extra protection.

Being the description of the land features and the terrain, hydrology analysis is the primary process. Hydrology analysis involves stream network and watersheds generation. From the stream network, stream ordering is the next process denoting the hierarchy and arrangement of rivers in a study area.





According to [5] the Arc Hydro tools are used in the hydrological analysis of the region. The study lists the following steps in the process of hydrology analysis:

1) Generation of a DEM without sinks.

2) Developing Flow Direction to give the direction of runoff flow.

3) Developing of Flow Accumulation to highlight the stream channels.

4) Flow Accumulation is then used to give pour points. Pour points are significant locations that show the highest flow accumulation within the region.

5) The pour points are then located and used to delineate sub watersheds served by the pour points.

6) From the Flow Accumulation streams are assigned orders using.

The Arc Hydro toolset is used as it is more objective and consistent as compared to the manual approaches. Now from this drainage generation process, we get sub watersheds, streams, and stream orders (using [6] ordering).

Morphometric analysis is performed by measurement of linear, areal and shape parameters. According to [7] and [8] they document that the various parameters have varying effects on soil erosion and water runoff.

In their various definitions the morphometric parameters are:

1) Bifurcation Ratio

The bifurcation ratio is the ratio of the number of the stream segments of given order to the number of streams in the next higher order [9]. The Bifurcation ratio can be used as an indicator of relief and dissection. A study by [6] shows that bifurcation ratio shows slight variations according to environment and regions. It is given by;

$$Rb = Nu/Nu + 1$$

2) Drainage Density

Drainage density is defined as the measure of the texture of the drainage basin. Drainage density is the ratio of the total stream length (Lu) cumulated to all orders in the basin to the total basin area (A).

Dd = Lu/A

Low density shows highly resistant subsoil material under dense vegetation and low relief or highly permeable whereas high density shows impermeable soft material or weak rock. Drainage density is important in the sense that it indicates linear scale of landform element in stream eroded topography, defines the total length of the stream and closeness of spacing.

3) Stream Frequency

The drainage frequency introduced by [10] is the stream frequency or channel frequency as the number of stream segments (Nu) per unit area (A). Given by;

$$Fs = Nu/A$$

Basically, stream frequency shows the correlation between stream population and drainage density and is affected by temperature and rainfall.

4) Drainage Texture

Given by;

$$Dt = Nu/F$$

Drainage texture (Dt) is the total number of stream segments of all orders per perimeter of that area [9]. It is a measure of relief aspect, rainfall, lithology, vegetation, infiltration capacity, of the terrain and closeness of channel spacing.

5) Form Factor

The form factor (Ff) is defined as the ratio of basin area to the square of the basin length and is a quantitative expression of drainage basin outline. It indicates the flow intensity of a basin of a defined area [9].

$$Ff = A/Lb^2$$

The value ranges from 0 - 1 for highly elongated basic to a highly circular basin respectively. Form factors form a good indicator to the management of flood flows.

6) Circulatory Ratio

Also known as the compactness ratio the circulatory ratio is defined as the ratio of the area of the basin (A) to the area of the circle having the same circumference as the perimeter (P) of the basin [11].

$$Rc = 12.57 \times A/P^2$$

The lithological characteristics of the basin have the most impact on the compactness ratio as compared to any other factor. It is important in staging of the streams as young, mature or old.

7) Elongation Ratio

Elongation ratio is defined as the ratio between the diameter of a circle of the same area as the drainage basin and the maximum length of the basin [12]. The elongation ratio is a pointer of the relief and the slope of the slope. It is calculated by;

$$Re = 2/Lb \times (A/\pi)0.5$$

8) Length of Over Land Flow

The length of overland flow is the length of water over the ground surface before it gets concentrated into definite stream channel [9].

The length is given by the formula;

$$Lg = A/2 \times L$$

The length of Over land flow is an important variable of physiographic development and hydrologic of drainage basin. The length of overland flow differentiates between sheet erosion and channel erosion as defined by [9].

9) Shape Factor

The shape of the basin can be described qualitatively or quantitatively. The qualitative description uses the terms rectangular, triangular, pear and circular to describe the shape. Quantitatively, the basin shape is described using the shape factor that is calculated by;

$$BSF = L^2/A = L/W$$

Shape determines peak discharge and arrival at the basin.

10) Relief Ratio

Relief ratio is a gradient measure depicting the mouth of a basin and its highest point [12].

$$Rh = Bh/Lb$$

11) Ruggedness Number

Ruggedness number indicates the structural complexity of the terrain. An extremely high value of ruggedness number occurs when both variables i.e. drainage density and relief are high and slope is not only steep but long as well [6].

$$Rn = Bh \times Dd$$

The number is a good indicator of soil erosion and intrinsic structural complexity in relation to relief and slope.

12) Compactness Constant

The term Compactness coefficient majorly used to describe the compactness constant. The compactness coefficient is the ratio of perimeter of sub-basin to circumference of circular area [13].

$$Cc = 0.2841 \times P/A0.5$$

The compactness constant is only dependent on slope and not the size. This means a perfectly circular sub-basin will give a constant of 1 regardless of the size [13].

13) Basin Relief

Total basin relief is the maximum vertical distance between the lowest and the highest points in a basin [9] [14]. It is a factor in determining the denudational characteristic of a basin.

$$Bh = H - h$$

The Morphometric analysis begins with computation of the parameters of all sub-watersheds using the already established formulas the parameters are computed as listed in **Table 1**.

From past studies, the parameters used occur as the major ones with significant effect on the surface flows and soil erosion. They are a number and it is a rigor to use all of them in the visualization of the surface characteristics. Thus, the need for selection of parameters is that best represent the others.

Looking at the number of morphometric parameters (13) that have been computed, some of them share characteristics and effects on soil erosion and runoff. Therefore, there's the need to remove redundant parameters and remain with parameters that exhibit the strongest characteristics required for prioritization.

The technique used for selection of parameters is Principal Component Analysis (PCA). As much as it has been used to process satellite images for a few bands, it is a statistical method used for various purposes. PCA as described by [1] is a method for exploratory analysis and in this study PCA was vital in evaluating the most valuable parameters from the 13 that still give the best representation of the dataset. Also, the 13 parameters share similar effects on runoff

Table	1. Mor	phometric	parameter	formulas.
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Parameter	Formula	Reference
Bifurcation Ratio (Rb)	Rb = Nu/Nu + 1 where, Nu = Total number of stream segment of order "u"; Nu + 1 = Number of segments of next higher order	[6] [9]
Drainage Density (Dd)	Dd = Lu/A where, Lu = Total length of streams; A = Area of watershed	[9]
Stream Frequency (Fs)	Fs = N/A where, $N = Total$ number of streams; A = Area of watershed	[10]
Drainage Texture (Dt)	T = Nu/P where, Nu= Total no of streams of order "u"; P = Perimeter of watershed	[9]
Form Factor (Rf)	$Rf = A/Lb^2$ where, $A = Area$ of watershed, Lb = Basin length	[9]
Circulatory Ratio (Rc) $Rc = 4\pi A/P^2$ where, A = Area of watershed, $\pi = 3.14$, P = Perimeter of watershed		[11]
Elongation Ratio (Re) Re = $2\sqrt{(A/\pi)^*Lb}$ where, A = Area of watershed, $\pi = 3.14$, Lb = Basin length		[12]
Length of Over Land Flow (Lof)	Lof = 1/2Dd where, Dd = Drainage density	[9]
Shape Factor (Bs)	$Bs = Lb^2/A$ where, $Lb = Basin length$, A = Area of basin	[11]
Relief Ratio (Rh)	Rh = Bh/Lb where, Bh = Basin relief, Lb = Basin length	[14]
Ruggedness Number (Rn)	Rn = Bh*Dd where, Bh = basin Relief, Dd = Drainage Density	[6]
Compactness Coefficient (Cc)	Cc = 0.2821 P/A 0.5 where, P = Perimeter of watershed, A = Area of watershed	[13]
Basin Relief (Bh)	Bh = H-h where H = Highest elevation, h = lowest elevation of the basin	[6]

and soil erosion, therefore there is the need to use the fewest possible parameters to evaluate the risk for ease in visualization. The PCA was run in an R environment and the computed morphometric parameters were loaded and the outputs were variances for all the principle components. From which only 6 components of the total are selected as they explain 99.4 (0.994) of the total data (**Table 2**) through the cumulative proportion variances. The PCA through the use of the variances and Eigen values (**Table 3**) selected the Bifurcation Ratio, Stream Frequency, Drainage Density, Drainage Texture, Length of Over Land Flow, and Circulatory Ratio as the best 6 parameters matching the principal components to represent all the parameters.

Table 2. PCA results for the influential 6 components.

	PC1	PC2	PC3	PC4	PC5	PC6
Standard deviation	2.177	1.874	1.435	1.082	0.931	0.759
Proportion of Variance	0.364	0.206	0.157	0.097	0.068	0.062
Cumulative Proportion	0.365	0.635	0.793	0.883	0.950	0.994

Table 3. PCA eigen values.

	PC1	PC2	PC3	PC4	PC5	PC6
Lof	0.1463	-0.0772	0.2066	0.1032	0.9304	-0.2137
Dt	-0.0938	-0.1439	0.2534	0.7413	-0.1824	-0.3620
Rc	-0.2038	0.3958	0.2187	0.1832	0.0962	0.4343
Rn	0.3719	-0.0676	0.1727	0.4260	-0.1935	0.0851
Re	-0.2033	0.3945	0.2212	0.1838	0.0992	0.4312
Cc	0.2985	-0.0748	-0.4326	0.2633	0.0950	0.3689
Rf	-0.4072	-0.0936	-0.2636	0.1503	0.0548	-0.0102
Rbm	0.4145	0.0744	0.2578	-0.1311	-0.0941	0.0340
Dd	-0.2987	0.1256	0.4466	-0.2087	-0.1184	-0.2681
Bs	0.4134	0.0790	0.2597	-0.1361	-0.0852	0.0280
Bh	0.2255	0.4252	-0.1767	-0.0150	-0.0424	-0.3000
Rh	-0.0157	0.4161	-0.3765	0.1229	0.0201	-0.3427
Fs	0.1032	0.5105	-0.0602	0.0668	0.0114	-0.1550

From the having the best parameters to use, then comes the need to visualize the combined effect of the parameters for use in prioritization. To achieve prioritization, Multi criteria Decision Making (MCDM) is important to make complex decisions that are special in nature like allocating varied efforts for conservation goals.

Several studies have used MCDM techniques to prioritize watersheds for conservation. Prioritization is an important process which highlights the hierarchy in which region is to receive varied treatment. According to [15] Weighted Sum Analysis (WSA) is highly suitable and efficient for MCDM as hard to obtain expert opinions are limited as required in AHP, a better MCDM technique.

Both [15] and [7] show the ranking of watersheds in the different selected parameters with already established patterns how the parameters affect soil erosion and runoff. In both studies geomorphometric parameters are ranked, correlation done, and weights generated to show their importance. Ranking looks at the relation of the individual parameters to the soil erosion and runoff. For instance, if

parameter A follows the general rule of being directly proportional to runoff, then the sub-watershed with the lowest will be assigned 1 increasing to the highest rank, or if parameter A follows the general rule of indirectly proportional to runoff, then the sub-watershed with the highest will be assigned 1 increasing to the highest rank. **Table 3** shows a correlation matrix developed to help in the weighting of the parameters.

The weights are important in coming up with a Compound parameter for each sub-watershed highlighting the risk. From Table 2 we obtain the equation:

$$CP = (0.1095 \times Rbm) + (0.2004 \times Fs) + (0.2540 \times Dd) + (0.0289 \times Dt) + (0.2540 \times Lof) + (0.1531 \times Rc)$$
(1)

where CP is the Compound Parameter

Rbm is the Bifurcation Ratio Fs is the Stream Frequency Dd is Drainage Density Dt is Drainage Texture

Lof is Length of Over Land Glow

Rc is Circulatory Ratio

2.4. Change Detection

The study of environmental degradation has often looked at the human activities that happen on the earth surface. As much as the human activities contribute significantly to loss of the natural biodiversity, there is a factor that has mostly been sidelined which is morphometry.

Landform processes and erosional characteristics that are statistically represented constitute morphometry and are substantial in describing the peculiarity of sub-watersheds through morphometric parameters. [16]

Even with the connection of morphometry and land use-land cover (LU/LC), [17] tries to give some better characterization of watershed by superimposing of the morphometric parameters and LU/LC layers.

The study followed through:

Image Processing: this process involved two satellite imagery; Landsat 7 (2001) and Landsat 8 (2017). ArcGIS was used in processing of the images.

Landsat 7 and 8: these are medium resolution multi-spectral sensors used mainly for land cover monitoring and environmental monitoring. Only one scene was downloaded and used from the respective sensors' archives. The true color composites were used by layer stacking the respective 3 bands out of the 12 spectral bands. Bands 1, 2, and 3 and bands 2, 3, and 4 were used for Landsat 7 and 8 respectively to obtain images of 30m spatial resolution. The images were pan-sharpened using the Pan band from the respective band set to obtain 2 images of 15 m resolution. A subset of the area of interest (AOI) *i.e.* Taita Hills Region was obtained from the pan-sharpened true composite images.

Classification: Supervised classification using Maximum Likelihood technique was carried out on the masked Landsat images where the following land cover classes were used; Forest, Cropland, Settlement, Shrub-Grassland and Rock Surface.

Change Detection: This was done to highlight the areas with the highest harmful land cover changes. The change detection was performed by converting the raster classified images into vector. Then the ArcGIS intersect tool was used to create overlapping land covers from the 2 images giving all the changes. The resulting vector data of change detection is then looked at from the point of forest and cropland to other land covers as vital cases for conservation.

3. Results

Hydrology analysis resulted in stream network making the study area a 4-order area and the 21 sub watersheds.

Table 4 shows all the 13 morphometric parameters with the basic ones that are inputs in the PCA and WSA.

Figure 2 is a Flow accumulation map which gives the highlight of the river network: from which sub-watersheds are also generated.

Figures 3-8 are maps for the six selected parameters that were used in prioritization and how they vary for the sub-watersheds:

Table 5 shows the Compound Parameters for the sub-watersheds highlighting the prioritization of the sub-watersheds.

Figure 9 is a spatial representation of the prioritization after WSA on the 6 selected parameters inclusive of the stream network and it's ordering.







Figure 3. Drainage densities.



Figure 4. Drainage textures.



Figure 5. Bifurcation ratios.



Figure 6. Length of over land flows.



Figure 7. Stream frequencies.



Figure 8. Circulatory ratios.

	Rbm	Fs	Dt		Dd	Cc	Bs
SW1	1.67	0.17	0.18		0.49	1.76	2.85
SW2	1.67	0.25	0.22		0.46	1.68	2.71
SW3	1.10	0.28	0.34		0.64	2.03	3.09
SW4	1.25	0.19	0.24		0.54	1.37	2.81
SW5	2.25	0.16	0.31		0.43	1.50	3.25
SW6	1.33	0.18	0.16		0.73	2.16	2.94
SW7	1.70	0.19	0.24		0.54	1.84	3.07
SW8	2.75	0.18	0.23		0.63	1.72	3.01
SW9	1.67	0.18	0.34		0.44	1.35	3.15
SW10	2.33	0.20	0.27		0.58	1.41	2.88
SW11	4.63	0.16	0.36		0.45	1.38	3.29
SW12	2.38	0.25	0.30		0.46	1.86	3.00
SW13	2.33	0.24	0.29		0.41	1.42	2.81
SW14	0.00	0.17	0.22		0.42	1.79	3.03
SW15	2.05	0.18	0.30		0.45	1.52	3.15
SW16	8.00	0.24	0.30		0.49	1.79	3.02
SW17	2.08	0.19	0.20		0.47	1.71	2.86
SW18	1.88	0.26	0.62		0.48	1.38	3.35
SW19	1.60	0.20	0.35		0.40	1.65	3.25
SW20	3.67	0.21	0.30		0.47	1.66	3.08
SW21	0.00	0.23	0.13		0.52	1.85	2.45
	Lof	Rc	Rf	Re	Bh	Rh	Rn
SW1	0.24	0.32	0.35	2.20	786.00	72.59	382.76
SW2	0.23	0.35	0.37	2.02	419.00	48.25	194.74
SW3	0.32	0.24	0.32	2.49	1250.00	82.82	800.30
SW4	0.27	0.53	0.36	2.14	1373.00	135.70	737.07
SW5	0.22	0.45	0.31	2.71	1167.00	62.31	506.07
SW6	0.36	0.21	0.34	2.30	1027.00	83.65	745.23
SW7	0.27	0.29	0.33	2.46	862.00	58.96	465.50
SW8	0.32	0.34	0.33	2.40	1984.00	145.88	1259.40
SW9	0.22	0.55	0.32	2.57	1303.00	79.69	579.36
SW10	0.29	0.50	0.35	2.24	684.00	60.34	394.83
SW11	0.23	0.52	0.30	2.75	1388.00	70.91	630.19
SW12	0.23	0.29	0.33	2.37	757.00	57.00	350.21
SW13	0.20	0.49	0.36	2.15	1048.00	103.06	425.87
SW14	0.21	0.31	0.33	2.42	1014.00	72.48	426.76
SW15	0.22	0.44	0.32	2.57	1377.00	83.93	613.82
SW16	0.24	0.31	0.33	2.41	629.00	45.63	306.60
SW17	0.23	0.34	0.35	2.20	449.00	41.11	209.28
SW18	0.24	0.52	0.30	2.84	947.00	44.55	454.63
SW19	0.20	0.37	0.31	2.70	1014.00	54.66	402.88
SW20	0.24	0.36	0.32	2.48	461.00	30.96	217.31
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Table 4. Shape and linear parameters

 Table 5. Morphometric parameter formulas.

	Compound Parameter
SW1	0.450
SW2	0.462
SW3	0.456
SW4	0.460
SW5	0.509
SW6	0.489
SW7	0.472
SW8	0.629
SW9	0.468
SW10	0.591
SW11	0.790
SW12	0.530
SW13	0.533
SW14	0.241
SW15	0.494
SW16	1.155
SW17	0.495
SW18	0.516
SW19	0.420
SW20	0.676
SW21	0.287





Table 6 shows the area statistics for the land covers for the two years.

Figure 10, **Figure 11** are maps showing the land covers for the years 2001 and 2017. From them, the study established the changes from forest and cropland to others and **Figure 12** is a result from differences of **Figure 10** and **Figure 11**.

Table 7_shows the change statistics per sub-watersheds.

Figure 13_shows the variation of efforts needed per sub-watershed according to morphometry and change detection analysis. The output further highlights that the whole area needs for environmental protection.

Table 6. Classification by land cover of 2001 and 2017.

Land Cover	2001 (km²)	2017 (km²)
Forest	192.2194	116.1953
Cropland	587.8997	498.3389
Settlement	103.1246	152.8757
Shrub-Grassland	374.9848	468.0485
Rock Surface	133.0503	115.1736

Table 7. Classification by land cover of 2001 and 2017.

	From Forest & Cropland to Others
SW15	31.173
SW5	31.128
SW11	29.779
SW19	28.480
SW17	20.621
SW9	17.692
SW7	14.731
SW13	14.179
SW12	13.444
SW8	13.033
SW14	12.587
SW10	10.188
SW20	9.385
SW18	8.844
SW3	7.985
SW4	7.498
SW2	7.136
SW21	6.995
SW1	5.664
SW16	5.334
SW6	5.251

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Figure 10. Land cover-land use 2001.



Figure 11. Land cover-land use 2017.



Figure 12. Land cover changes between 2001-2017.



Figure 13. Land cover changes between 2001-2017 and prioritization.

4. Discussion

The study involved hydrological analysis, morphometry, multi-criteria decision analysis and change detection with focus on highlighting river basins or catchments for conservation management.

According to [18] hydrological processes (peak flow, runoff, time to peak, overland flow and infiltration) are influenced by morphometric variables of the area of study. Therefore, it is important to look into morphometry to help evaluation in watershed management.

From hydrology analysis, we get a flow accumulation map that highlights the spread of rivers across the watershed and resulting sub-watersheds and as demonstrated by **Figure 2** there is a general spread of rivers in the watershed. Besides, further analysis leads to computation of the morphometric parameters for each watershed from basic parameters like stream lengths, stream orders, sub-watershed areas, perimeters, number of streams, highest points and lowest points.

Morphometry in this study was vital in documenting the effects of the terrain on the hydrological processes and further used to give hierarchy in efforts required to each sub-watershed for purposes of management and conservation. PCA and WSA were used in selection of parameters to be used and combination of the parameters' effects to identify areas where the potential for harmful runoff and soil erosion are highest so that efforts could be harnessed to limit them.

The 13 parameters were reduced to 6 through PCA's selection criteria and the 6 parameters for each sub watershed are demonstrated by **Figures 3-8**. And for ranking to occur a WSA was done to give an equation to determine compound parameters as in **Table 5** and spatially represented by **Figure 9** where the red and orange sub-watersheds (21, 19, 14, 9, 7, 6, 4, 3, 2, and 1) are more susceptible to degradation due to the landform and terrain.

The connection between land changes and morphometry has insignificantly been explored into but some studies like [17] [19] have tried to include the connection with the former using both morphometry and land use in prioritization. Land use change is a factor due to animal and human effects. Due to the LU-LC analysis as shown by **Figure 12**, the most changes for the period between 2001 and 2007 have happened centrally, expanding radially due to more urbanization in and around Wundanyi and surrounding towns. More forest land which is naturally the water catchment area has shifted to other land uses like cropland and settlement (**Table 6** and **Table 7**). Potentially, there has been disruption of rainfall weather patterns due to that change.

The combination of both morphometric analysis and LU-LC analysis (**Figure 13**) then requires the areas of the watershed (sub watershed 3, 4, 7, 9, 19, 21) to need more conservation efforts as the combined effect of morphometry and land use changes have significant effects.

Sub watershed 11 is not at risk morphometrically but at risk due to land use changes but sub watershed 14 is both at risk morphometrically and due to land

use changes (Figure 13).

5. Conclusions

This study analysed the Taita Hills river basin ecosystem using morphometry whereby. From the results it can be concluded that the region is a fourth order served by one major river (Voi) which flows from the centre of the region to the east with other smaller rivers flowing to different directions that serve the 21 sub-watersheds. Impervious surfaces are covering 62% of the area hence a lot of surface runoff is expected.

Morphometric Analysis, WSA and change detection results show 47% of the sub-watersheds are in high to very high risk areas with 21 and 14 as very highly risky due to morphometry and sub-watersheds 15 and 5 which are upstream that have the highest change to degraded vegetation (Shrub-Grassland, Settlement and Rock Surface).

With both morphometric analysis and change detection combined the results visually show sub-watersheds 3, 4, 7, 9, 19, and 21 as the risky areas with runoff and land cover change.

There is a need to establish detailed continuous monitoring of land use changes in detail together with any major changes in elevation within a region so that efforts of conservation are done when little damage has occurred or prediction and avert degradation.

Results of this study point towards the significant effects of landform on the river basin ecosystem and can be used to isolate regions for specific focus hence the governments and non-governmental bodies should consider setting aside funds for reliable water catchment management.

Further research on river basin management can still be done to automize the whole process of watershed prioritization considering both land use and morphometry.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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