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MORPHOMETRIC ANALYSIS OF KAGUNUZI SUB-BASIN IN KIBIRA NATIONAL PARK NORTH-WESTERN PART OF BURUNDI USING GEOSPATIAL TECHNIQUES

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ABSTRACT

In the present study, an attempt has been made to understand the importance of Digital Elevation Model for the analyses of drainage network and to extract the relative attributes for the Kagunuzi sub-basin. With geospatial techniquesof Remote Sensing and GIS, several morphometric parameters have been determined to understand the hydrological and geomorphological characteristics of Kagunuzi sub-basin. The morphometric parameters considered for the analysis includes the linear, areal and relief aspects which were carried out to illustrate the drainage characteristics and morphology of Kagunuzi sab-basin.The bifurcation ratio (Rbm) is 2.050 which suggest moderate structural disturbance. Rho Coefficient value for Kagunuzi river basin span from 0.0073 to 2.388, the largest value suggesting higher storage during floods and attenuation of effects of erosion during elevated discharge. The elongated nature of the Kagunuzi sub-basin can be determined by the value of form factor ratio, which is 0.124. The high gradient ratio Rg of 14.348 of Kagunuzi sab-basin reflects the mountainous nature of the terrain. The elongation ratio of the Kagunuzi sab-basin is 0.397. Hence, it is clear that the watershed basin is elongated. The study has highlighted the significance of ASTER G DEM; RS&GIS based approach inthe evaluation of drainage morphometric parameters and their influence on drainage characteristics.These results will be useful in effective basin management and hydrological studies in Kagunuzi sub-basin in particularly to estimate hydropower potential in downstream of Rwegura and for irrigation scheme in Bubanza district.

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INTRODUCTION

Burundi is attracting the researchers due to its morphology, plenty of hills and abundant rainfall. It has alargetheoretical hydropower potential. However, the development of hydropower is a challenging task and even the existing is overexploited due to increased demand. Currently, the country is facing significant energy challenge, economic and social development. In addition to this, Kagunuzi sub-basin is facing acute shortage of surface water for irrigation and drinking purpose. In the downstream, the management of Kagunuzi sub-basin can contribute to new hydropower scheme.

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The input parameters required for soil erosion modeling, flood water, hydropower potential, and irrigation scheme can be generated by the morphometric survey of basin modeling by geospatial techniques of RS and GIS. It helps to understand the hydrological characters and the results will be useful input for a comprehensive water resource management plan (Jawahar raj *et al.,* 1998; Kumaraswami *et al.,* 1998 and Sreedevi *et al.,* 2001). Specifically, the analysis has helped to elaborate hydrological diagnostic, to identify opportunity for hydropower potential and irrigation scheme of Kagunuzi sab-basin in Kibira National Park, North-Western part of Burundi.

Study area: The Kagunuzi sub-basin is located in north-western part of Burundi (Figure1). It drains its water within an area of 424.694 km^2 to Ruzizi River before it reaches the Lake

Tanganyika. Its altitude varies from 2661 m to 788 m; precipitation varies between 74mm to 137mm, the monthly precipitation of Kagunuzi sub-basin is provided below (source: IGEBU-Burundi).

MATERIALS AND METHODS

Data, Material and Methodology: In the present study, the morphometric analysis of Kagunuzi sub-basin has been carried out by the integrated approach of remote sensing and geographical information system techniques. The morphometric characterization and basin delineation was made using ASTER G DEM data with a spatial resolution of 30m. Morphometric parameters of drainage networks such as the bifurcation ratio, drainage density, stream frequency, texture ratio, basin relief, ruggedness number were evaluated with established mathematical equations. Various parameters like the number and lengths of streams of the different order, drainage area, basin perimeter and maximum basin lengths were calculated after cleaning and topology building of the drainage layer in GIS software. The ASTER G DEM data available at USGS Earth Explorer was used for delineating slope, relief and aspect maps of the basin. The different morphometric parameters have been determined are shown in the workflow (Figure 2).

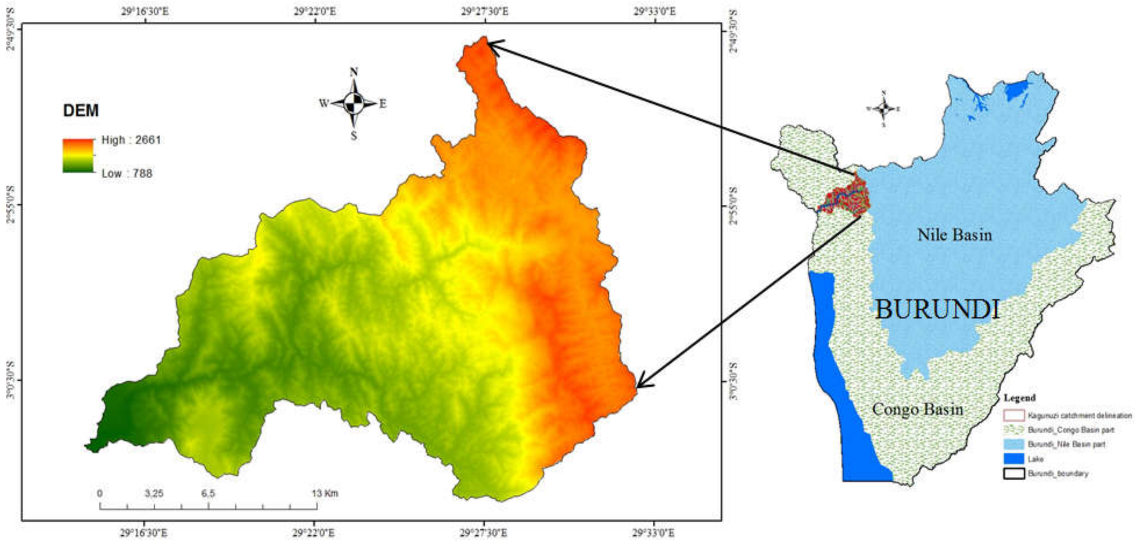

Fig.1. Location of study area

Workflow

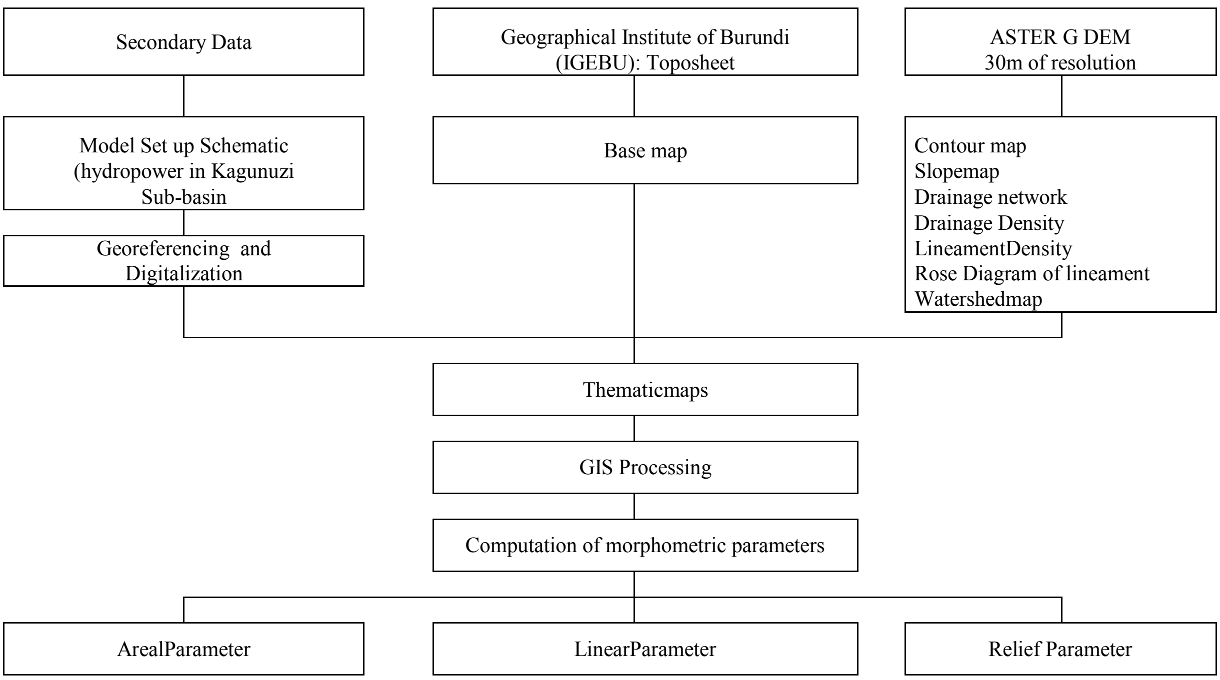

Fig.2. Work flow

Table 1. Methodology adopted for computation of morphometric parameters

Characteristics of the Drainage Sub-basin	Formula	Reference
Stream order	Hierarchical Rank	Strahler (1952)
Total Stream order	Sum of Stream order	
Stream number : Nu	Nu=N1+N2+…+Nn	Horton (1945)
Stream length [L] : Lu	Length of stream	Strahler (1964)
Total Stream length [L]	Lu=L1+L2+…Ln	Strahler (1964)
Mean stream length [L] : (Lsm)	Lsm = Lu/Nu	Strahler (1964)
Stream length ratio : Lur	Lur =Lu/(Lu-1)	Strahler (1964)
Bifurcation ratio : Rb	Rb= Nu/Nu+1	Strahler (1964)
Rho Coefficient :ρ	ρ = Lur / Rb	Horton (1945)
Mean bifurcation ratio:Rsm	Average of bifurcation	Strahler (1957)
Perimeter [L] : P	GIS Software	Strahler (1964)
Basin length [L] : Lb	GIS Software	Schumm (1956)
Basin area [L^2] : A	GIS Software	Schumm (1956)
Mean Basin Width [L] : Wb	Wb = A / Lb	Horton (1932)
Relative Perimeter [L]: Pr	Pr = A / P	Schumm (1956)
Length Area Relation : Lar	Lar= 1.4 * $A^{0.6}$	Hack (1957)
Lemniscate's : k	k = Lb^2/ A	Chorley (1957)
Form Factor Ratio : Rf	Rf= A / Lb^2	Horton (1932)
Shape Factor Ratio : Rs	Rs = Lb^2/ A	Horton (1932)
Elongation ratio:Re	Re=2*(A/Pi)$^{(1/2)}$/Lb	Schumm (1956)
Drainage Texture Analysis		
Drainage Density : Dd	Dd =Lu / A	Horton (1932)
Stream Frequency : Fs	Fs = Nu / A	Horton (1932)
Drainage Texture : Dt	Dt = Nu / P	Horton (1945)
Circularity Ratio : Rc	Rc = 12.57 * (A / P^2) =4*π*A/P^2	Miller (1953)
Length of Overland Flow : Lg	Lg = A / 2 * Lu =1/(Dd*2)	Horton (1945)
Drainage Intensity : Di	Di = Fs / Dd	Faniran (1968)
Constant of Channel Maintenance: C	C=1 / Dd =A/Lu	Schumm (1956)
Infiltration Number : If	If= Fs * Dd	Faniran (1968)
Time of concentration (Tc)	Tc=0.0078 ($L^{0.77}$*$Bh^{0.385}$)	Kirpich (1940)
Relief Characterization		
Height of basin mouth [L] : z	GIS Analysis / DEM	
Maximum height of the basin [L] : Z	GIS Analysis / DEM	
Total Basin relief[L] : H	H = Z - z	Strahler (1952)
Relief ratio : Rhl	Rhl = H / Lb	Schumm (1956)
Relative Relief Ratio : Rhp	Rhp = H * 100 / P	Melton (1957)
Gradient Ratio : Rg	Rg = (Z - z) / Lb	Sreedevi (2004)
Ruggedness Number : Rn	Rn = Dd * (H /1000)	Patton & Baker 1976)
MaeltonRuggedness Number:MRn	MRn = H / $A^{0.5}$	Melton (1965)
Watershed Slope : Sw	Sw = H / Lb	
Slope Analysis (Sa) (deg)	GIS Analysis / DEM	
Average Slope [%] : (S)	S = (Z * (Ctl/H)) / (10 * A)	Wenthworth's (1930)

Regional settings

Meteorological datahavebeen collected from Burundian Authority for Meteorology (IGEBU) for five stations (Bujumbura, Imbo: Bubanza, Mparambo: Cibitoke, Rwegura: Kayanza, and Teza: Muramvya) for the period from 1970 to 2016.The rainfall data show that in 20 years, out of 46 years of data recording, there were rainstorms equal to or higher than 79 mm.

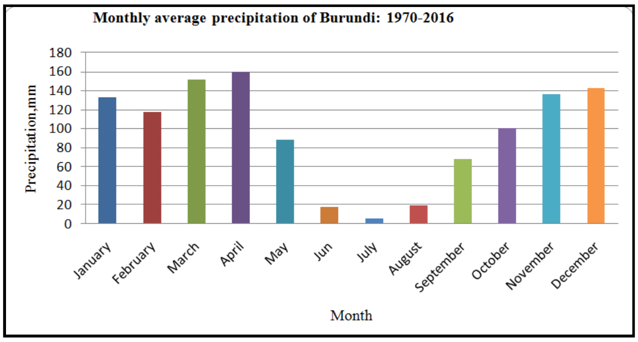

Fig.3. Monthly average precipitation of Burundi: 1970-2016

RESULTS AND DISCUSSION

Linear Characteristics of the Drainage network

Table 2. Monthlyaverage precipitation of Kagunuzi sub-basin: 1970-2016, class, area [km^2]

Average precipitation range, mm	Area, km^2	Area,%
74-79	41.96	9.9%
79-84	65.89	15.5%
84-90	48.67	11.5%
90-96	39.49	9.3%
96-103	39.00	9.2%
103-111	32.08	7.6%
111-118	35.96	8.5%
118-125	34.69	8.2%
125-131	40.32	9.5%
131-137	45.84	10.8%

Stream order (u)

The streams of the Kagunuzi river basin have been ranked according to Strahler's (1964) stream ordering system and the number of streams of each segment (Nu) of the order (U) is presented in table (I,II,III,IV and V). The variation in order and size of the tributary basins is largely due to physiographic and structural conditions of the region.

Stream number (Nu)

It is obvious that the total number of streams gradually decrease as the stream order increases except for V^{th} order.

The number of streams of each order and the total number of streams was computed using GIS tools. High values of first-order streams indicate that there is a possibility of sudden flash floods after heavy rainfall in the downstream where the slope is lowest: 0-9.62.

Stream length (Lu)

It is clear that the length of stream segments is maximum in case of first order streams. In almost all cases, the basin length decreases as the order increases except in for Vth order. This is due to the variation in relief over which the segments occur.

Mean Stream Length (Lsm)

The mean stream length (Lsm) has been calculated by dividing the total stream length of order by the number of streams. The mean stream length increases with the increase of the order except for the 5th order.

Table 3. Stream information for the Kagunuzi river basin

Stream order (u)	Stream number: (Nu)	Total streamnumber(∑Nu)	Stream length: (km) (Lu)	Total Stream length : (km)	Mean stream length: (km) (Lsm)
I	608		335.257		0.501
II	274		167.768		0.251
III	195	1208	97.434	669.542	0.146
IV	49		28.463		0.043
V	82		40.619		0.061

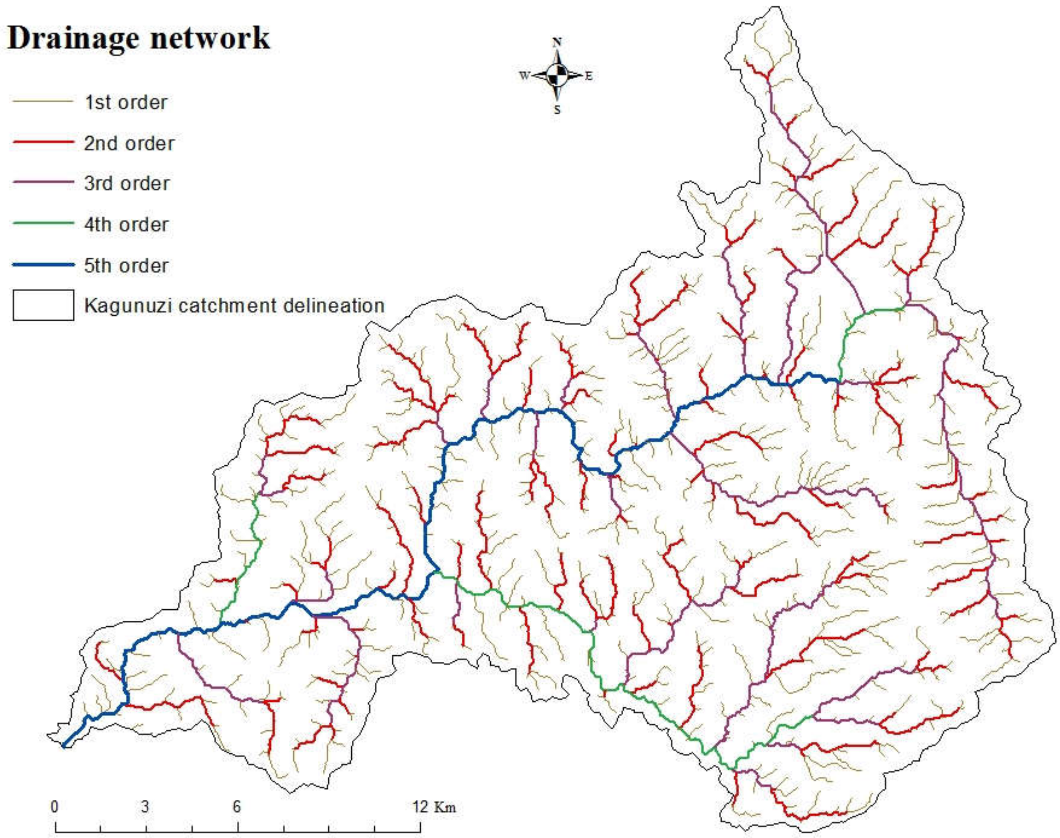

Fig.4. Drainage/stream network of Kagunuzi sub-basin

Table 4. Morphometric parameters calculated for Kagunuzi river basin

Stream length ratio (Lur)		Bifurcation ratio (Rb)		Rho Coef (ρ)	Mean bifurcation ratio (Rbm)	Form Factor Ratio (Rf)	Shape Factor Ratio (Rs)
II/I	0.500	I/II	2.219	0.226	2.050	0.124	8.089
III/II	0.581	II/III	1.405	0.413			
IV/III	0.292	III/IV	3.980	0.073			
V/IV	1.427	IV/V	0.598	2.388			

Table 5. Basin Geometry calculated for Kagunuzi River basin

Perimeter (P) (km)	Basin length (Lb) (km)	Basin area (km^2) (A)	Mean Basin Width (Wb)	Relative Perimeter (Pr)	Length Area Relation (Lar)	Lemniscate's (k)	Elongation ratio:Re
130.359	58.613	424.694	7.246	3.258	52.841	0.124	0.397

Table 6. Drainage Texture calculated for Kagunuzi river basin

Drainage Density (Dd)	Stream Frequency (Fs)	Drainage Texture (Dt)	Circularity Ratio (Rc)	Length of Overland Flow (Lg)	Drainage Intensity (Di)	Constant of Channel Maintenance	Infiltration Number (If)
1.577	2.844	9.267	0.314	0.317	1.804	0.634	4.484

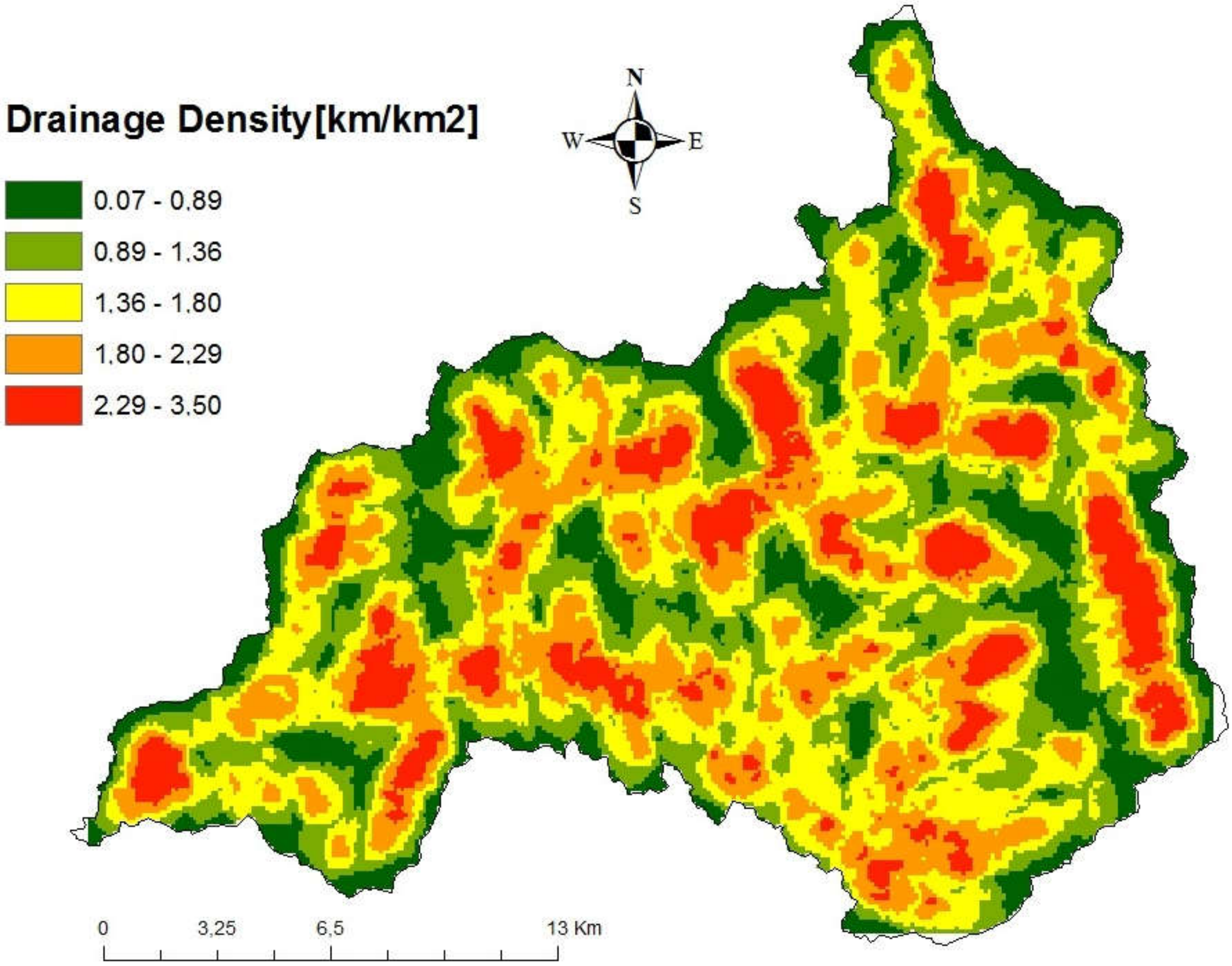

Fig.5. Drainage density of Kagunuzi sub-basin

Table 7. Drainage density, area

Class	Area,km^2	Area,%
0.07-0.89	106.769	25.8%
0.89-1.36	85.823	20.8%
1.36-1.80	106.343	25.7%
1.80-2.29	82.677	20.0%
2.29-3.50	31.825	7.7%

Table 8. Relief characterization for Kagunuzi river basin

Height of basin mouth (z)	Maximum height of the basin (Z)	Total Basin relief (H) (m)	Relief ratio(Rhl) m	Relative Relief Ratio (Rhp)	Gradient Ratio (Rg)	Ruggedness Number (Rn)	MaeltonRuggedness Number (MRn)
788	2661	1873	31.955	1436.801	14.368	2.953	90.887

Table 9. Slope Characteristics of Kagunuzi sub-basin

WatershedSlope (Sw)	SlopeAnalysis(Sa) (deg)	AverageSlope(S) %	Total Contour Length(Ctl)km	Contour Interval(Cin) m
31.955	0-55º34'12"	2.653	7930.53	20

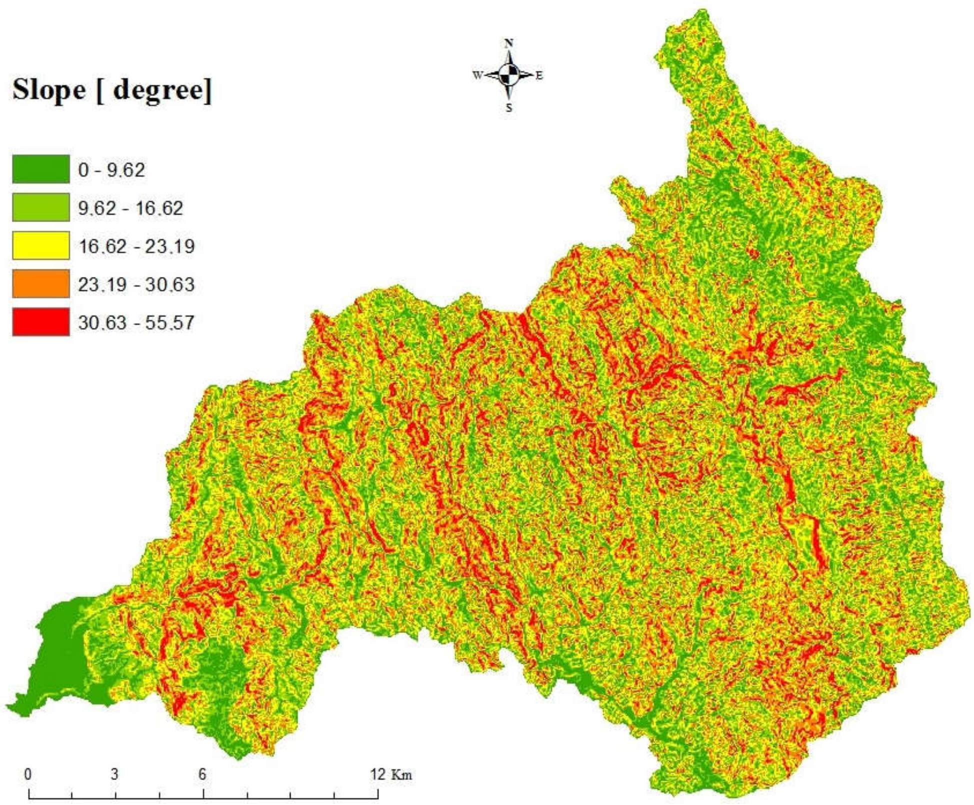

Fig.6. Slope map of Kagunuzi sub-basin

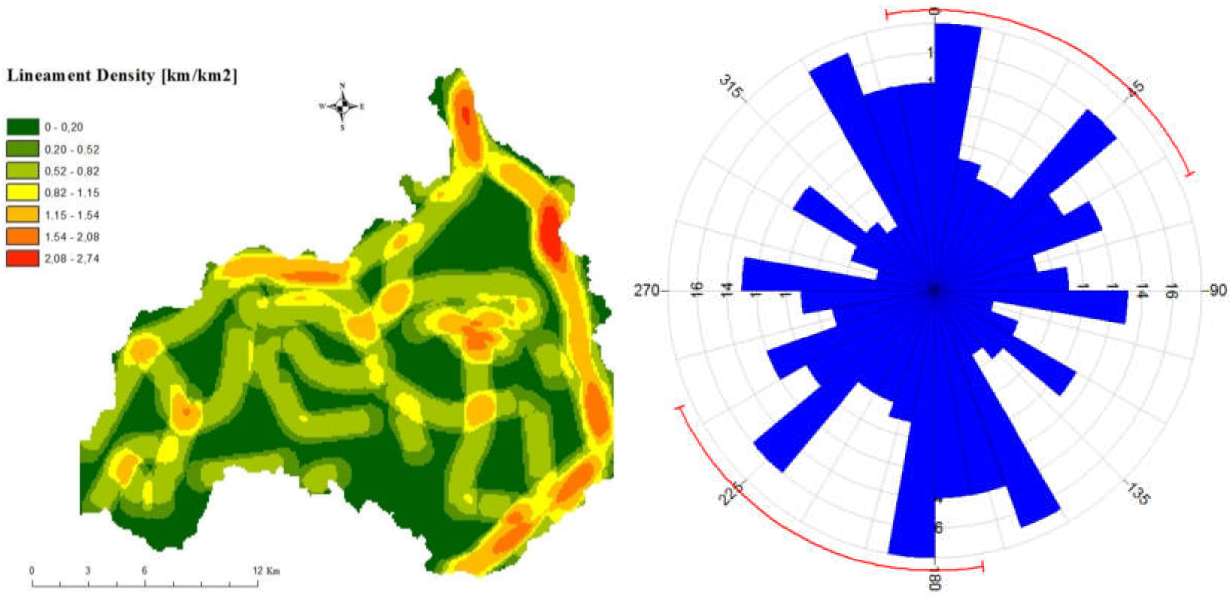

Fig.7. Lineament density and rose diagram of lineament of Kagunuzi sub-basin

Table 10. Lineament density, area

Class	Area, km^2	Area,%
0.00-0.20	121.74	29.5%
0.20-0.52	68.29	16.6%
0.52-0.82	121.57	29.5%
0.82-1.15	43.39	10.5%
1.15-1.54	40.40	9.8%
1.54-2.08	14.34	3.5%
2.08-2.74	2.78	0.7%

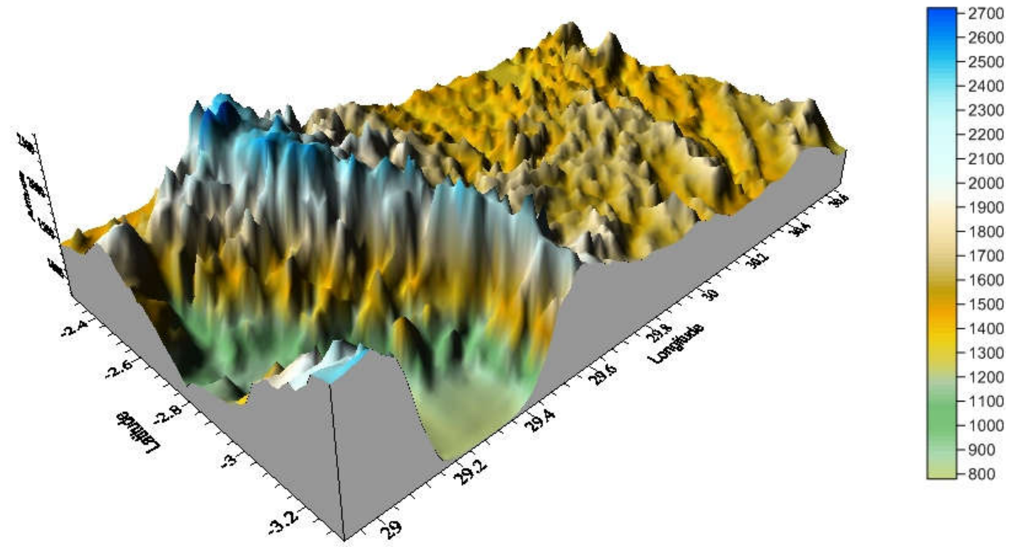

Fig.8. Physical morphology of north part of Burundi

Stream length ratio (Lur)

Stream length ratio (Lur) is defined as the ratio of mean stream length (Lu) of the segment of order u, to mean stream segment length (Lu-1) of the next lower order u-1 (Horton, 1932). The Lur varies between 0.5-1.427, the variability in Lur, among successive stream orders, is a reflection of differences between slope and topography (Sreedevi *et al.,* 2005; Magesh *et al.,* 2011) and hence it has an important control on discharge and erosional stage of the watershed (Sreedevi *et al.,* 2009). More specifically, variation indicates if there is a major change in the hydrological characteristics of the underlying rock-surface over the areas of consecutive stream orders. Variation from one order to another order indicates the late youth stage of geomorphic development (Singh and Singh, 1997). This change might be attributed to variation in slope and topography.

Bifurcation Ratio (Rb)

Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Chow (1964) stated that Rb range of '3 to 5' for watersheds indicates that geologic structure does not exercise a dominant influence on the drainage pattern. The Rb between first and second order streams may be considerably higher than the Rb of higher order streams. This is indicative of a state of accelerated erosion (Verstappen, 1983).In the study means area bifurcation ratio (Rbm) is 2.050 which suggest moderate structural disturbance.

Rho coefficient (ρ)

This parameter was defined by Horton (1945) as the ratio between the stream length ratio and the bifurcation ratio. It is influenced by climatic, geologic, biologic, geomorphologic and anthropogenic factors. Rho values for Kagunuzi river basin span from 0.0073 to 2.388, the largest value suggesting higher storage during floods and attenuation of effects of erosion during elevated discharge.

Form Factor ratio (Rf)

The form factor may be defined as the ratio of basin area to thesquare of the basin length. The elongated watershed basins have the small value of form factor while the higher value indicates a basin which is nearly circular. The form factor should always less than 0.13 it indicates the basin has elongated and lower peak flows of longer duration. The elongated nature of the Kagunuzi sub-basin can be determined by the value of form factor ratio, which is 0.124.

Shape factor ratio (Rs)

Shape factor ratio is the square of basin length (Lb) to the area of basin (A). Kagunuzi catchment has a Shape Factor of 8.089. This indicates that the basin is elongated. Hence the basin has the moderate time concentration of flood waters.

Basin Perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area. It may be used as an indicator of watershed size and shape. The perimeter of Kagunuzi catchment is 130.359 Km.

Basin length (Lb): The basin length is the longest part of the basin parallel to the principal drainage line defined by Schumm (1956). The length of the Kagunuzi sab-basin arrives as 58.613km.

Basin Area (A): The area of the watershed is another important parameter like the length of the stream drainage. The area of a given order is defined as the total area projected on a horizontal plane and contribution of overland flow to the channel segments of the given order, which includes all tributaries of the lower order. Total drainage area of the Kagunuzi sub-basin, is 424.694km^2

Lemniscate's (k): The lemniscate (k) value for the Kagunuzi sab-basin is 0.124 which shows that maximum area is occupied in its region of inception with a large number of streams of the higher order.

Elongation ratio (Re): According to Pareta and Pareta (2011), elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length and have classified the watershed with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<

0.5). The elongation ratio of the Kagunuzi sab-basin is 0.397. Hence, it is clear that the watershed basin is elongated.

Drainage Density (Dd)

Drainage density is defined as the cumulative length of all streams in a basin divided by the area of the basin. In general low drainage, density is favored in regions of highly permeable subsoil materials, under dense vegetation cover and where relief is low. In the Study area, average drainage density is 1.577 km/km^2.

Stream frequency (Fs)

Stream frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932). Reddy *et al.* According to Kale [6], flooding is more likely in the basins with a high drainage and stream frequency. The stream frequency value of the Kagunuzi sab-basin is 2.844stream/km^2. The high value indicates flooding is more likely in the basin.

Drainage texture (Dt)

Drainage texture is defined by Horton (1945) as the total number of streams divided by the perimeter. The drainage texture of Kagunuzi sab-basin is 9.267 which indicate that the texture is very fine.

Circularity ratio Rc: Catchments with low circularity ratios are elongated in shape and controlled primarily by the geologic structure (Fryirs and Brierley, 2013). The circularity ratio of the study area is 0.314, which indicates that the basin is not circular.

Length of Overland Flow (Lg):

Overland area is defined as half of the reciprocal of drainage density. It is one of the most important independent variables, affecting both the hydrological and physiographical development of the drainage basin (Horton 1945). The calculated length of overland flow of the study area is 0.317.

Drainage intensity (Di): The high value of drainage intensity indicates that together the drainage density and stream frequency have more effect on the surface denudation. This study shows a moderate drainage intensity of 1.804 for the basin.

Constant of channel maintenance (C): The constant of channel maintenance (C) is the inverse of the drainage density. (Schumm, 1956).Generally, the higher the constant C of a basin, the greater the permeability of the rocks of that basin. The low value of C indicates the high density of drainage network and less area required to sustain 1 km of drainage and vice versa. The value of constant C in the Kagunuzi sab-basin is 0.634.

Infiltration Number (If): The Infiltration number of the Kagunuzi sab-basin is 4.484. Higher the value of infiltration number indicates lower the infiltration capacity and higher runoff. There is also a correlation between hydrological characteristics and the relief ratio of a drainage basin. There is a correlation between hydrologic characteristics and the relief ratio (Rh) of a drainage basin. High and low value shows the hilly and plain region in the basin. In the study area, the value of relief ratio is high (31.955).

Relative Relief (Rhp): Relative relief is calculated by using perimeter and total basin relief and introduced by Melton (1957). It comes to 14.368 for the Kagunuzi river basin.

Gradient Ratio (Rg): It is influenced by the slope of the basin and rock characteristics. High and low value shows the hilly and plain region in the basin. Kagunuzi sab-basin has aRg of 14.348 which reflects the mountainous nature of the terrain.

Ruggedness Number (Rn):Rn indicates the structural complexity of the terrain in association with relief and drainage density. Kagunuzi sab-basin has a ruggedness number of 2.953.

Melton Ruggedness Number (MRn): TheMRn is calculated by using total basin relief divided by total basin areas of the watershed (Melton, 1965). The Melton Ruggedness Number of Kagunuzi sab-basinis 90.887.

Slope (in degree)

The slope map of the Kagunuzi sab-basin is obtained by processing the DEM in ArcGIS. The slope map is classified into 5 classes: Flat 0-9.62 Gentle 9.62 -16.62 Moderate 16.62 - 23.19 Steep 23.19 -30.63and Very Steep 30.63-55.57. An understanding of slope distribution is essential, as a slope map provides data for planning, settlement, mechanization of agriculture, reforestation, deforestation, planning of engineering structures, etc. The slope can be expressed in degrees or percentage.

Lineament Density

The lineament density can be expressed in variable ways,in the present study it is expressed as the length of lineaments per unit area [km/km^2]. The result of lineament density has been classified into seven categories; extremely low (0 –0.2), very low (0.2 – 0.52), low (0.82 – 0.52), moderate (0.52–1.15), high (1.15–1.54), very high (1.54–2.08), andextremely high (2.08-2.74).The major part of Kagunuzi sab-basin is characterized by low to moderate lineament density. The lineament density increases toward the northern and southeastern sectors as shown in the rose diagram. (Fig.7)

Conclusion

Geospatial techniques of remote sensing (RS) and Geographic Information System (GIS) have demonstrated that they are very useful in the morphometric analysis of drainage system and hydrological study. The present study is based on Remote Sensing and GIS modeling and the morphometric parameters of Kagunuzi sub-basin have been computed and analyzed by GIS geoprocessing techniques. Morphometric analysis illustrated that the Kagunuzi River has high storage during floods and attenuation of the effect of erosion during elevated discharge, the basin is elongated and has the moderate time of concentration of flood water, has lower infiltration capacity and shows higher runoff and with mountainous nature of the terrain.

Remote sensing and GIS_ based techniques have helped in a better way to carry out the morphometric analysis and hydrological evaluation of the Kagunuzi watershed. Finally, the result of this present study will be useful for irrigation scheme in the downstream of KagunuziRiver in Bubanza district and for hydropower development plan in downstream of Rwegura reservoir and provide the solution for taking the decision on priority basin.

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