ISSN: 2319-9490

Available online at http://www.ijcrls.com

International Journal of Current Research in Life Sciences
Vol. 07, No. 04, pp.1897-1902, April, 2018

RESEARCH ARTICLE

DRAINAGE NETWORK EXTRACTION FROM ASTER G DEM 1 ARC-SECOND RESOLUTION USING D8-MODEL FOR KAGUNUZI WATERSHED IN KIBIRA NATIONAL PARK NORTH-WESTERN PART OF BURUNDI

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Received 18th February, 2018; Accepted 29th March, 2018; Published 30th April, 2018

ABSTRACT

Drainage network extracted from Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation map available from NASA Reverb, LP DAAC Global Data Explorer and J-space systems ASTER G DEM are very useful for hydrological analysis and water resource management. In this paper, ASTER G DEM 1 arc-secondre solution was processed by the D8_deterministic eight-node method to derive stream network. The algorithm used is D8_model where the flow direction and flow accumulation algorithm for estimation of drainage were used to carry out the drainage network of Kagunuzi sub-basin from gridded digital elevation. This paper presents an approach to drainage direction assignment and it is often necessary to assign drainage directions over flats-that is, for each cell in which direction water is moving. The delineation and extraction of stream network are carried out with various ArcGIS hydrology tools. The results of drainage network showed: 1st order 319.085 km, 2nd order: 154.383 km, 3rd order: 94.562 km, 4th order: 25.638 km and 5th order: 38.934 km of length respectively: 50%, 24%, 15%,4% and 6% of the study area. The automatic drainage network extraction using DEM after sinks filled with the threshold value >500 for flow accumulation, were compared with the natural drainage network provided by topographic maps. The results demonstrate that the drainage network extracted from Digital Elevation map 1 arc-second resolution (2011) using D8_model is not very well matching with the natural network provided by Toposheet scale of 1:50000 (1973) for the whole sub-basin of Kaganuzi. However, this method can calculate the flow direction from high-resolution DEMs efficiently and extract high-precision continuous drainage networks. For drainage network of Kagunuzi sub-basin in Kibira National Park North-Western part of Burundi, it will be useful especially in the case of water resource management for hydropower study in downstream of Rwegura, flood risk and irrigation plan in Bubanza district and surroundings.

Key words: Digital Elevation Model, D8_Model, Drainage Network, Kagunuzi basin.

Citation: Alexis Sibomana and H. Gangadhara Bhat, 2018. "Drainage network extraction from ASTER G DEM 1 arc-second resolution using D8 model for Kagunuzi watershed in Kibira national park north-western of Burundi" *International Journal of Current Research in Life Sciences*, 7, (04), 1897-1902.

INTRODUCTION

Burundi has many sources of water; however, the management of those resources is deficient. Irrigation systems, hydropower generation remain insufficient. Better water resource planning and management in Kagunuzi sub-basin could increase agriculture production in Bubanza District and hydropower generation in downstream of Rwegura reservoir. There is no doubt that channel network delineation is a crucial process in environmental studies, mainly hydrological response and modeling, erosion processes, impact assessment, restoration processes, landscape depiction and other related studies.

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The topography of the river basin is very useful in water resource management and plays an important role in the hydrologic calculation, by providing information on different terrain attributes which enhance the assessment and enable the simulation of complex hydrological processes. In the past, topographical maps were as the major sources of information for the derivation of the catchment characteristics in hydrological models, now DEM is playing an important role in the hydrologic and topographic character analysis Drainage networks are useful for many types of researches and applications, of hydrological analysis. For the delineation of the watershed and drainage networks, a large number of techniques and algorithms have been implemented (Tarboton *et al.,* 1992; Montgomery and Foufoula-Georgiou, 1993; Heine *et al.,* 2004; Pelletier, 2013).

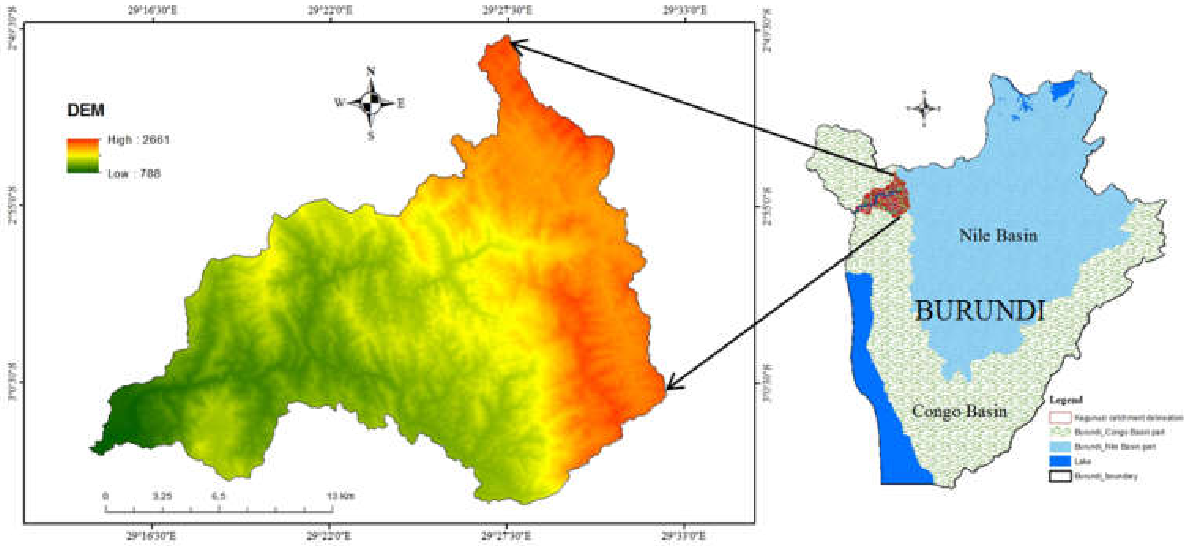


Fig.1. Study area location

A digital elevation model (DEM) in raster format, carries elevation information for many applications in hydrologic studies (Freeman, 1991; Vieux, 1993; Arun *et al.,* 2005). Cell-wise elevation information in a DEM can be used to find the drainage structure, which gives the basic information for runoff analysis and sediment transport studies (Jana *et al.,* 2007; Mandlburger, 2009). In this study, Geographic Information System (GIS) and Remote Sensing were used for extracting the river drainage pattern with D8-model. The hydrographical characteristics are extracted, including stream networks, delineation of the watershed boundary, catchments area, stream order, and gridding of Kagunuzi sub-basin using hydrological tools in Arc GIS with D8_model. In this study, ASTER G DEM 1 arc-second resolution is used and the accuracy of the stream network generated by D8_ method depends essentially on the accuracy and quality of the adopted DEM. The results carried out in this study, will be useful for water resource management especially for irrigation plan in areas located in downstream of the river and hydropower study in Kagunuzi sub-basin

Table 1. Study area, Kagunuzi sub-basin

Watershed area	424.694 km^2
Longitude	2^0 49' S to 3' S
Latitude	29^0 E to $29^0$34' E
Stream length	632.603 Km
Annualrainfall	888 mm to 1644 mm
Temperature	11°C to 25°C

Regional settings

Kagunuzi sub-basin is located in Congo basin and Kagunuzi river takes the source in Kibira National Park north- western part of Burundi: the altitude ranges from 788 to 2 661 m. (Fig. 1.) The area is characterized by monthly average precipitation between 74 and 137 mm (source: IGEBU-Burundi), and by an equatorial mountain climate with average annual temperatures from 11 to 25 ° C. On the highest peaks the temperature drops. The dry season lasts three months, from June to August, while the rainy season is characterized by almost daily rainfall, particularly abundant in April and November. Kibira National Park is the most watered area of the country.

It is the natural forest and real water tower from which source many rivers such as Gitenge, Mwokora, Kagunuzi, Masango, Munyiri and Ntamba.

Table 2. Details of data

Data type	ASTER G DEM
Entity ID	ASTDEMV2
Acquisition data	17-10-11
Resolution	1 arc-second
Source	USGS earth explorer

MATERIALS AND METHODS

Workflow

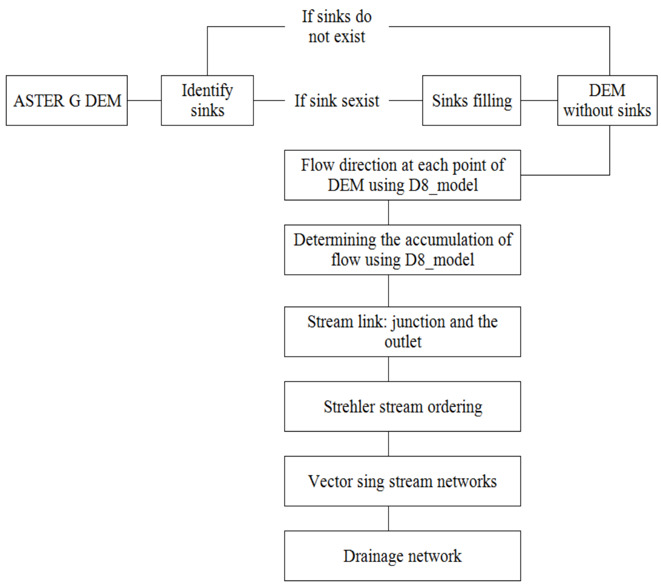


Fig. 2. Workflow for drainage network delineation

Sinks filling

In this study, Sinks (and peak) errors due to the resolution were filled to ensure proper delineation of basins and stream otherwise a discontinuous drainage network will be derived by using GIS tools. In this study, we used the method of filling sinks, which produced no flat, peak areas. For each fill/cut operation the volume is calculated by the formula:

$$\text{vol} = (\text{cell\_area} * \Delta Z)$$

For each of the cut/fill operation, the area is also calculated as the number of cells in the region multiplied by the cell size of the raster. According to the formula, in the region where material has been cut, the volume will be positive (larger value - smaller value> 0). When the material was added, the volume will be negative (smaller value - larger value< 0).

Flow direction

Flow Direction is tool incorporated in Arc Map hydrology tools and takes a surface as input and outputs a raster which shows the direction of flow out of each cell Fig.4. There are eight output directions relating to the eight adjacent cells where flow could travel.

The direction of flow is determined by the following equation:

$$\text{maximum\_drop} = \frac{\text{change\_in\_z} - \text{value}}{\text{distance} * 100}$$

Where:

The denominator is the height difference between two locations and the denominator is the horizontal difference. Two adjacent cells have a horizontal distance of 1; two diagonal cells have a horizontal distance of√2

0	0	0	0	0	0	0	[2^0]	=	1	(E)
0	0	0	0	0	0	[2^1]	0	=	2	(SE)
0	0	0	0	0	[2^2]	0	0	=	4	(S)
0	0	0	0	[2^3]	0	0	0	=	8	(SW)
0	0	0	[2^4]	0	0	0	0	=	16	(W)
0	0	[2^5]	0	0	0	0	0	=	32	(NW)
0	[2^6]	0	0	0	0	0	0	=	64	(N)
[2^7]	0	0	0	0	0	0	0	=	128	(NE)

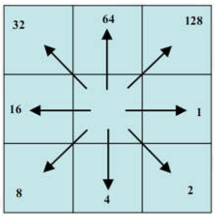


Fig. 3. Direction coding: the eight possible flow direction

Flow accumulation

This approach of deriving accumulated flow from a DEM is presented in Jenson and Domingue (1988). Stream raster which represents a linear stream network and flow direction raster were used as input data for creating the stream link raster.

Strahler ordering

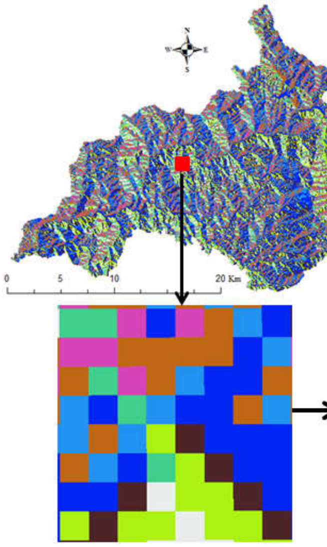
There are two methods proposed by Strahler (1957) and Shreve (1966). The Strahler method was used in this study, it is the most common stream ordering method. With Strahler method, we assign for all links without any tributaries an order of 1 and are referred to as the first order. The intersection of two first-order links creates a second-order link, the intersection of two second-order links create a third-order link, and so on.

Vectorising stream and drainage network

This step consists to converts a raster that represents a linear stream network to features representing the linear network. The direction of the output features points downstream Fig.7. In this study, the drainage network generated from DEM 1arc-second resolution is compared with the observed river network from Toposheet at 1:50000 scale. Fig.8.

RESULTS AND DISCUSSION

The landform surface modified by the removal or addition of surface material in other words the sinks filled area represents 26.88% of total area. The first important step to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster DEM. This is done with the Flow Direction tool. This model has been incorporated into Arc GIS by ESRI. DEM shows where water flows and define flow direction for each cell: 8 possibilities:E,SE,S,SW,W,NWN,NEFig.3.



1	1	2	16	2	4	8	16
2	2	4	4	4	4	16	8
4	1	2	4	8	16	16	4
8	16	1	8	16	16	4	8
8	4	8	64	32	16	16	16
4	8	16	1	64	32	16	16
16	16	32	128	64	64	32	16
64	32	64	64	128	64	64	32

Fig.4Example of flow direction matrix with numerical value for each direction

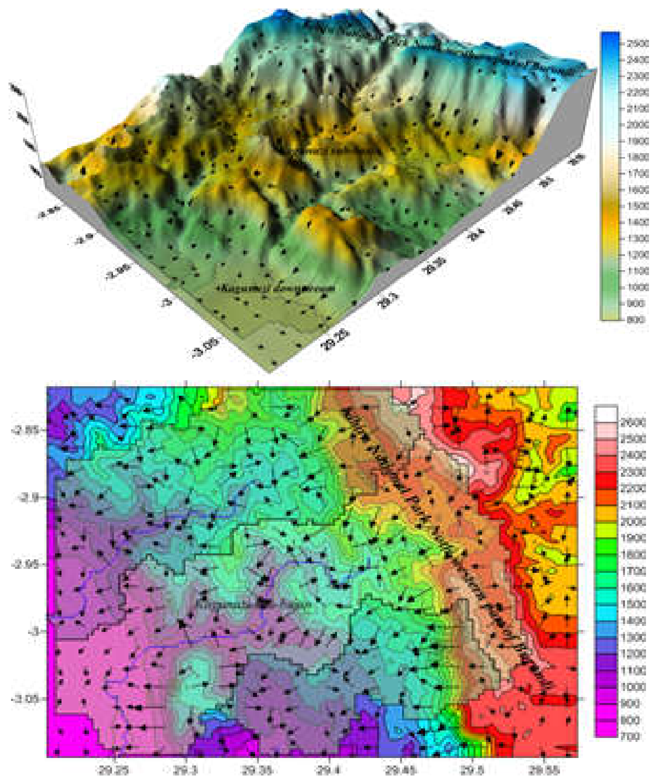


Fig. 5. Gridding data of Kagunuzi sub-basin generated by Inverse Distance to a Power_model

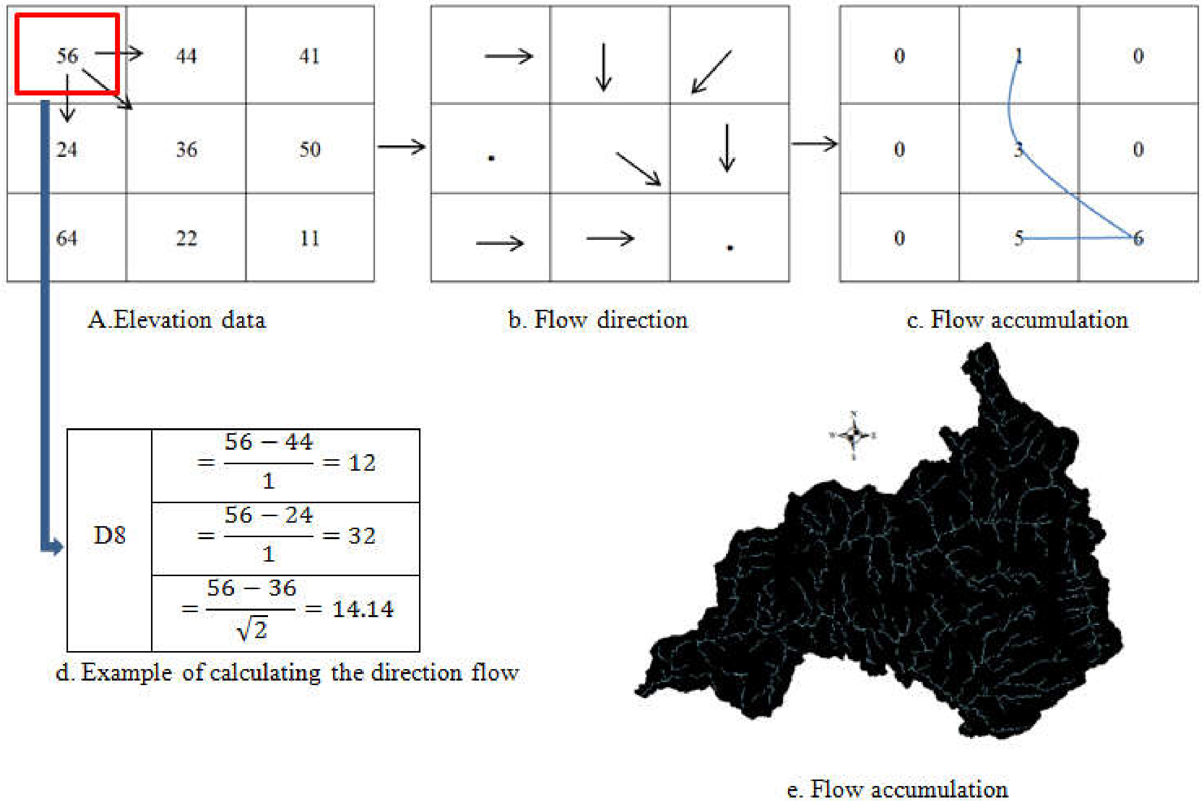


Fig. 6. Flow accumulation of Kagunuzi sub-basin result with threshold value >500

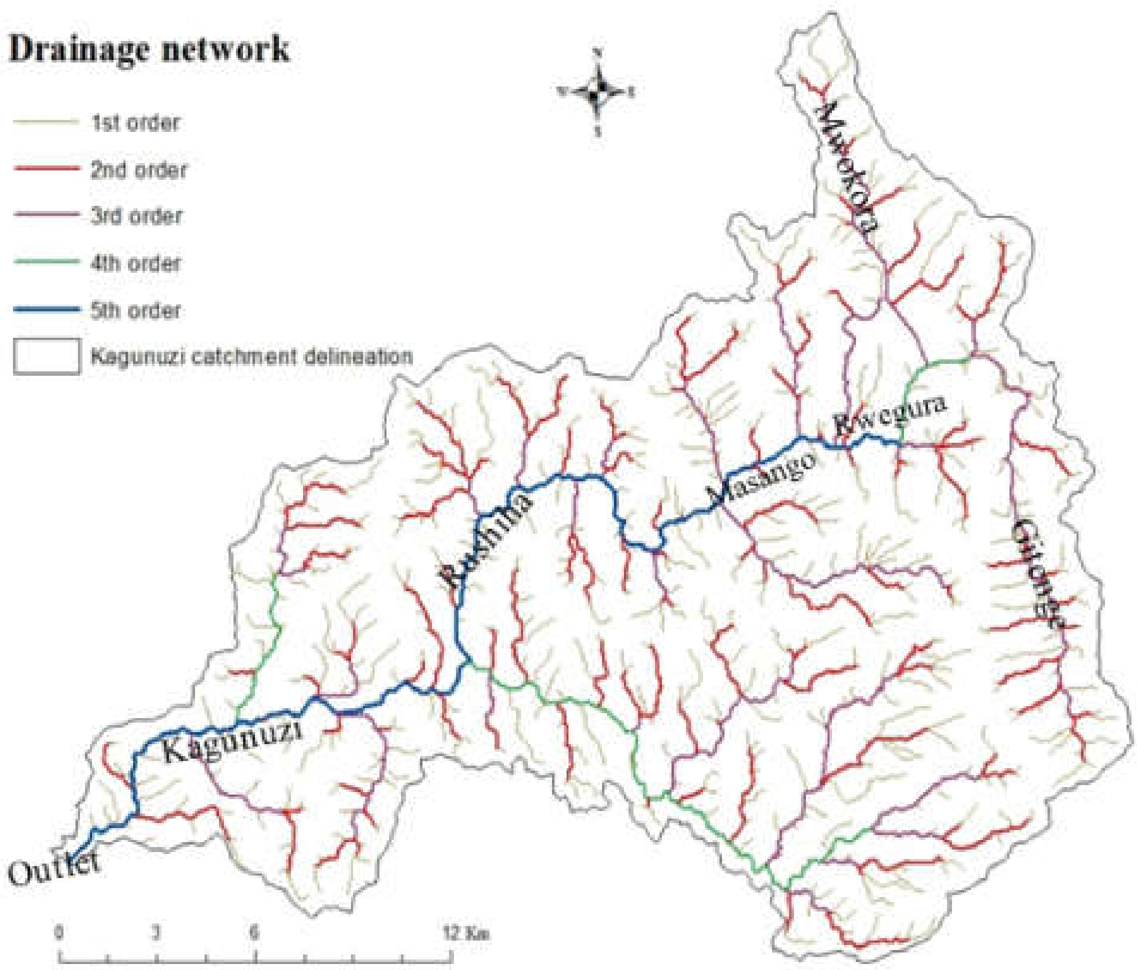


Fig.7. Stream ordering of Kagunuzi sub-basinwith Strahler_method

In each cell where we find a value of 0 means no water flowed through that cell. Identification of the flow direction for each grid Delineation of the flow network Calculation of low accumulation at each grid Stream network delineation of the stream links. The area with a high flow accumulation is an area of concentrated flow and can be used to identify stream network. The result of order-wise stream length in Kagunuzi sub-basin is shown in Fig.9. It is clearly identified that the cumulative stream length is higher in first-order streams and decreases as the stream order increases. In almost all cases, the basin length decreases as the order increases. This is due to the variation in relief over which the segments occur. The highest stream order (5th), i.e., for Kagunuzi River has a length of 38.934 km.

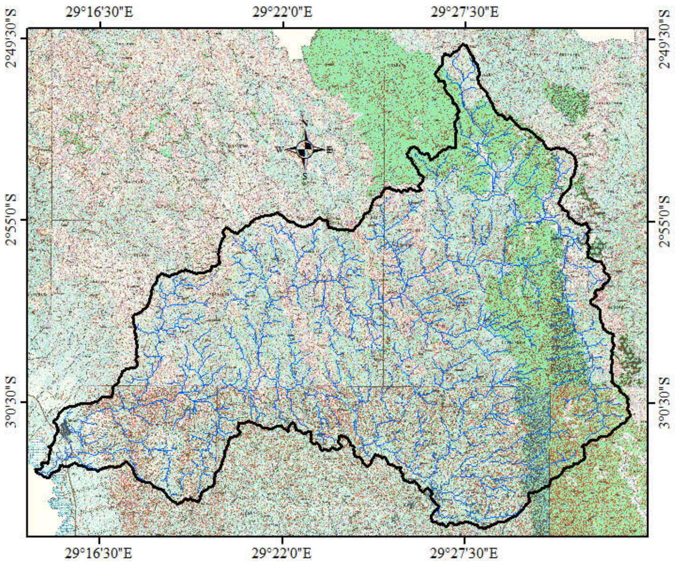


Fig.8 Drainage network extracted from DEM superimposed on Toposheet map: 1/50000

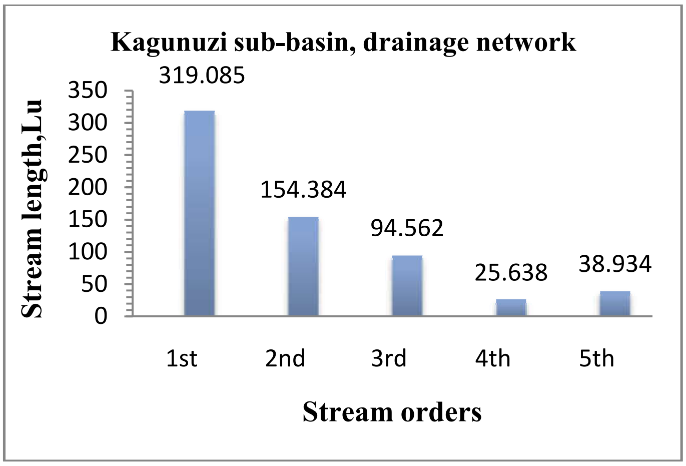


Fig. 9 Kagunuzi sub-basin Drainage network, Stream length

The results demonstrate that the drainage network extracted from Digital Elevation map 1 arc-second resolution (2011) using D8_model with a threshold value > 500 were compared with the natural network provided by Topo sheet scale 1:50000 (1973). The results are not very close match. The accuracy of the DEM-derived stream network and the catchment boundary depends on the following factors.

- The satellite which provides the DEM data,
- The horizontal resolution and vertical precision at which the DEM data is represented.
- The topographic map complexity of the landscape being represented. The model used to calculate different terrain attributes. For example, the watershed drainage structure modeled using a DEM does not fit with the actual drainage structure in flat areas.

In other ways, the Toposheet of 1973 doesn't correspond to the reality now especially because to the natural phenomena of surface erosion and climate change and its impacts (stress water in Kibira National Park the main source of water of many rivers in North-western part Burundi).

Conclusion

In this study, the sinks were identified (step1). To obtain an accurate representation of drainage network, flat and peak area were filled (step2) by using fill tools incorporated in hydrology tools in Arc map. Sinks filled area represented 26.88% of total area. This activity guided us through the initial hydrologic terrain analysis to calculate Flow Direction and Flow Accumulation. The Flow direction (step3) Fig.4&5 and flow accumulation (step4) Fig.6e were calculated by using D8_model (O'Callaghan and Mark, 1984; Jenson and Domingue, 1988; Martz and Garbrecht, 1998; Lin *et al.,* 2008).). An outlet point was used to define a watershed as all points upstream of the outlet (step 5)fig.1.Streams were defined using a flow accumulation threshold value >500. Next, the streams were converted into a vector representation (step6) and more hydrology toolbox functionality was used to evaluate stream order. The image Fig.7 is a resulting stream network derived from an elevation model1 arc second of resolution using D8_model. The DEM (in 2011) with 1arc-second of resolution using D8_model and hydrology tools incorporated in Arc GIS tool sprovided us the drainage network more recent and it will be useful for water resource management in Kagunuzi sub-basinfor hydropower study in downstream of Rwegura, flood risk and irrigation plan in Bubanza district and surroundings. The drainage network derived from Toposheet 1973 doesn't correspond to the realities of the land now.

Acknowledgments

The first author expresses his sincere gratitude to the Indian Council for Cultural Relations (ICCR) and the office in charge of the study, scholarships and internship of Burundi (BBES: Bureau des Bourses d'Etudes et de Stages) for their financial support during my PhD research. The satellite images were provided by USGS.

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