Journal of Engineering Research and Reports

20(2): 91-106, 2021; Article no.JERR.64836
ISSN: 2582-2926

Quantitative Analysis of Geomorphologic Characteristics for Surface Runoff Determination in Amala River Catchment in Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author SMK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JOO and RMW managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2021/v20i217268
Editor(s):
(1) Dr. Tian-Quan Yun, South China University of Technology, China.
Reviewers:
(1) M. C. Manjunatha, Maharaja Institute of Technology Thandavapura, India.
(2) R. K. Dubey, Indian Institute of Technology, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/64836

Original Research Article

Received 10 November 2020
Accepted 20 January 2021
Published 17 February 2021

ABSTRACT

Hydrological response of a catchment is a function of rainfall as influenced by catchment characteristics comprising geomorphology, land cover, and management practices. In this study, the analysis mainly focused on how geomorphological characteristics influence the catchment hydrological response. Geomorphological analyses of catchment geometry, stream patterns, relief, and slope can be used to characterize the catchment features that affect the drainage network. These characteristics are catchment specific and therefore unique to provide an insight into its hydrologic response. The objective of this research was to quantitatively analyze geomorphologic characteristics; linear, areal, drainage pattern, and relief aspect, of Amala River catchment, using ArcGIS tools and infer its hydrological behavior. The morphometry of the catchment was derived from the DEM within the ArcMap environment. These parameters as well as mathematical map equations were used to derive geomorphological characteristics such as bifurcation ratio, rho coefficient, drainage density, infiltration number, form factor among others. The results show that the Amala River catchment is elongated with uniform lithology and a higher probability of delayed peak hydrographs due to longer lag time and time of concentration. The catchment exhibits a

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dendritic drainage pattern with an average bifurcation ratio of 4.26 which is closer to the upper bound value of 5. This indicates a reduction in peak flows and a delayed time to peak. The surface runoff yield efficiency was low and non-uniform with an average drainage density of 1.073 km/km2. The catchment was characterized by higher infiltration characteristics as compared to surface flows, this varied spatially, with sub-basins far North of the outlet having high infiltration than those near the outlet. The catchment relief was characterized as steep and therefore high stream velocity was inferred. The investigation and findings of this study on catchment geomorphology and inferred hydrologic behavior will be of great importance in catchment management, water resource planning within the catchment, and water harvesting at a spatial scale. Thus, the outcomes provide a baseline for informed water pan and water harvesting structures site.

Keywords: Drainage density; geomorphologic characteristics; infiltration number; bifurcation ratio; dendritic drainage.

1. INTRODUCTION

Hydrology is an important study that entails the occurrence, distribution, and environmental aspects of water on, below, and above the surface of the Earth. A river catchment is a basic part of the runoff generation. The runoff resulting from a catchment is a response function of rainfall received within the catchment [1]. The hydrological response of a catchment depends on various physiographic features as such relief and slope [2]. Such features are well understood by geomorphological analysis [3] which characterize the catchment-based on geometrical properties, depicting the relationships among dimensional properties, and topological properties detailing the drainage network [4]. A quantitative analysis of drainage network patterns, relief, and slope can provide insights into the configuration of the earth's surface, the shape and dimension of its landforms, and a quantitative description of the drainage network [5,6]. As part of catchment physiography, land use land cover analysis characterizes the surface condition of the catchment. Generally, these characteristics influence the hydrologic properties of a catchment such as; drainage pattern, time of concentration, lag time, and intensity of erosional processes [7].

A detailed description of geomorphologic characteristics such as; drainage network, areal aspects of the catchment, relief aspects of the streams and slopes, of many river catchments, and their influence on the hydrologic response in Kenya are limited [1]. Globally, a lot of geomorphological analyses have been done [2,4,5,8]. However, geomorphologic characteristics and their relationship to hydrology are not transferrable [1]. These characteristics are catchment specific and therefore unique in nature. The geomorphologic characterization in nexus with land use land cover of a catchment provides insight into its hydrologic response [2].

Most studies have used topographic maps as the primary data for geomorphologic analysis. With advances in geographical information system (GIS) and the wide availability of digital elevation model (DEM) data, it possible to derive geomorphologic parameters based on DEM analysis [2]. GIS techniques are crucial in assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information [5]. Primary morphologic characteristics of a catchment such as a drainage network and catchment geometry can be derived from DEM in the GIS environment. ArcGIS is a key GIS environment for analyzing, visualizing, and interactive map analyzing. Geomorphologic characteristics of a catchment are important in exploring morphometry and surface drainage network patterns. These in turn can be used to quantify runoff, infiltration, soil erosion, surface water ponding, and other hydrological characteristics of a catchment. The objective of this research was to quantitatively analyze geomorphologic characteristics of the Amala River catchment using Shuttle Radar Topography Mission (SRTM) DEM, topographic maps, and ArcGIS tools.

2. MATERIALS AND METHODS

2.1 Study Area

The Amala river catchment is part of the Mara River basin. The study area is located between longitudes 35^0 22'' 30' and 35^0 52'' 30' East and latitudes 0^0 20'' 0' and 1^0 00'' 0' South (Fig. 1). Amala River is one of the two permanent tributaries of Mara River and its catchment is among the remnant of the largest indigenous montane forest in Kenya. The total catchment area is about 697.8 km^2. River source from the South Western Mau forest of Kenya at an elevation of 3065 m above mean sea level (a.m.s.l.) and its outlet is at 1845 m a.m.s.l in Mulot bridge gauging station. The catchment receives approximately an annual rainfall of 1400 mm [9].

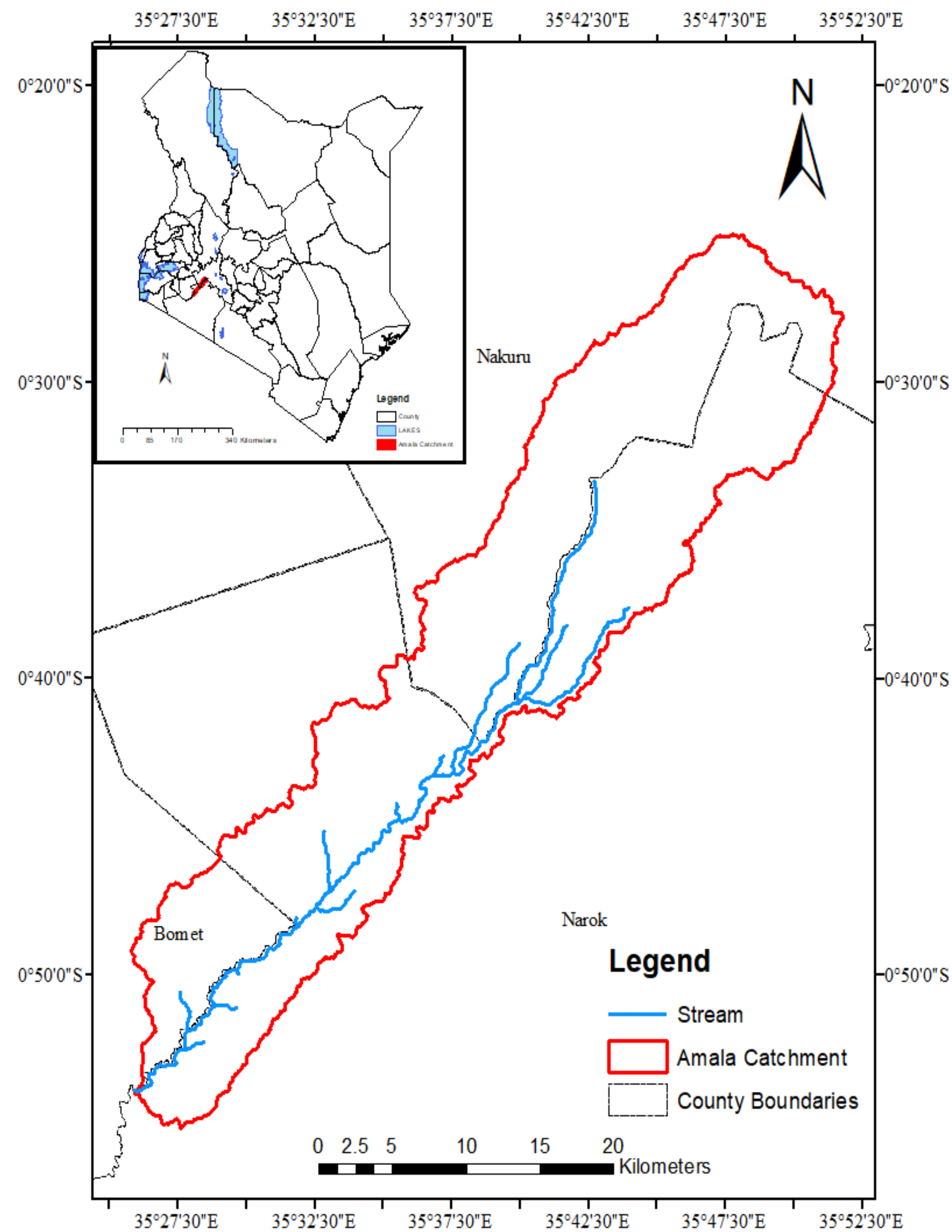

Fig. 1. Map of study area showing the location of Amala River catchment

2.2 Data Acquisition

The data required for quantitative geomorphologic analysis of the catchment included topographic maps and Digital Elevation Model (DEM) (Fig. 2). The Kenya Survey Topographic map sheets (117/4, 118/3, 118/4, 131/2, 132/1, 132/2, 131/4, 132/3, and 132/4) at a scale of 1:50000 were obtained, digitized, and georeferenced. SRTM-DEM 1 arcsec, 30-m spatial resolution was downloaded from USGS, Earth Explorer website.

2.3 Geomorphologic Analysis

To derive geomorphological parameters of the catchment, the morphometry of the catchment was computed from the DEM on the GIS environment (ArcMap). In this study, morphometric parameters were derived for the catchment and the sub-basins. These parameters were used in mathematical equations to derive geomorphological parameters. In the raster processing environment, the DEM was preprocessed to fill the sinks and a flow accumulation raster was developed. A drainage network map was generated by applying a pixel threshold to the flow accumulation raster using the map algebra tool. Fig. 5. shows a flow chart model in ArcMap used to derive a stream network and delineate the catchment for the morphometric analysis. To ensure the generated stream is representative of the natural stream, different thresholds were applied in the flow accumulation map algebra. A threshold value of 500 pixels gave a stream network closely overlaying with the topo sheet stream network (Fig. 3).

The stream network map (Fig. 4) indicates the streams of various orders and was used for the determination of morphometric parameters of the catchment and sub-basins. For stream network parameterizing, stream orders were derived from the generated stream network in the Spatial Analyst Tool interface of ArcGIS based on the Strahler model [10]. The morphometric parameter entails; linear properties, areal properties, and relief aspects of the channel network and of the catchment area. Parameters defining linear properties are; length of the catchment which is the distance in a straight line between pour point and the furthest point along the perimeter of a catchment, number of stream segments which is a count of the mapped individual stream channel, sum streams length defined as the total stream channel length within a catchment and perimeter of the catchment which is the length of a catchment divide. The area of the catchment defined as the total catchment area drained by a given stream length is the main areal properties. The mean slope which is the average angle of inclination of the local surface relative to the horizontal plane together with mean elevation which is the elevation difference between the highest and lowest points along the catchment represents the relief properties.

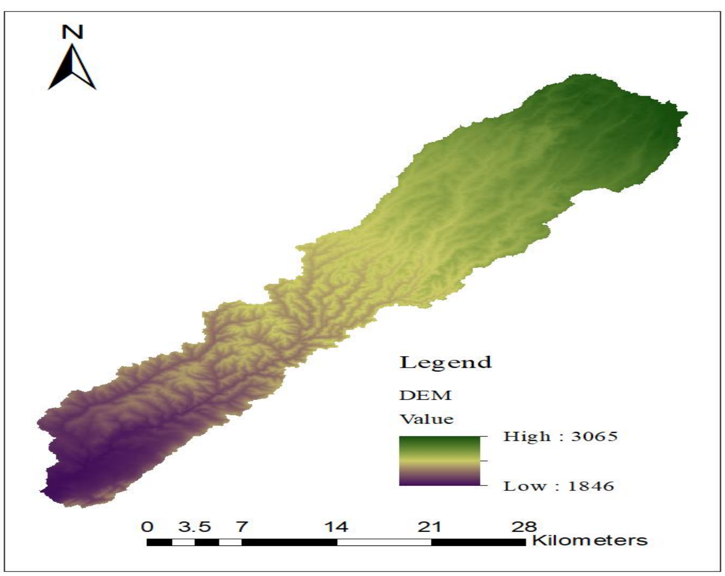

Fig. 2. Digital elevation model of the study area

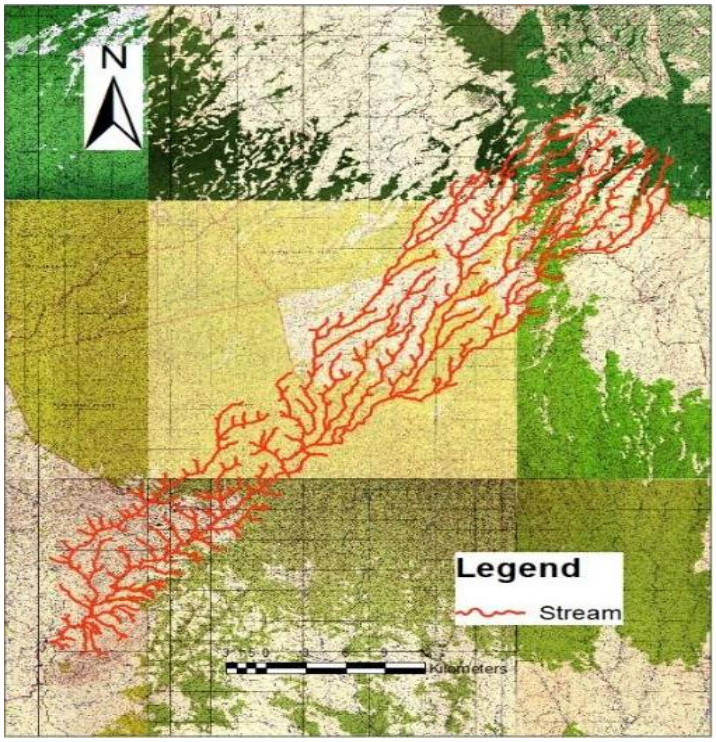

Fig. 3. An overlay of generated streams with toposheets

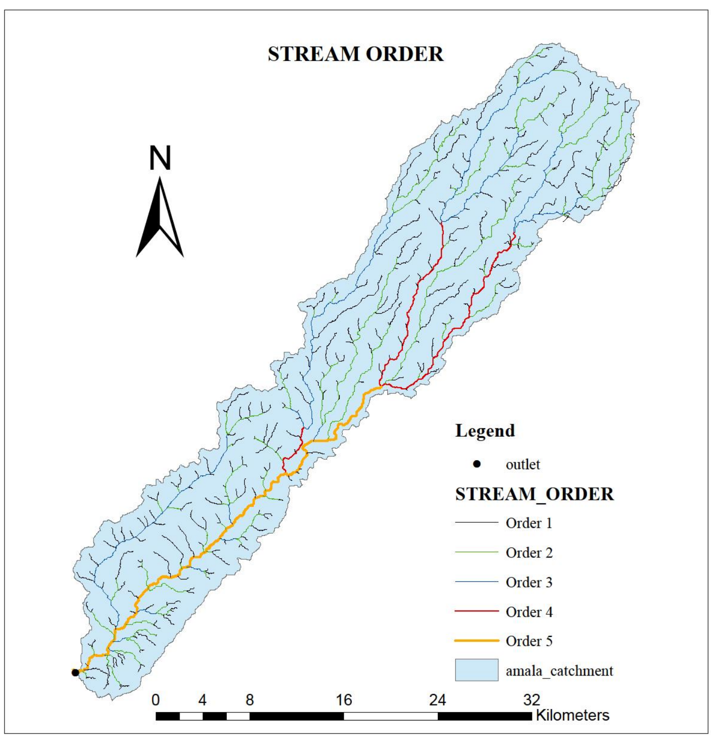

Fig. 4. Stream order based on Strahler's model for Amala River catchment

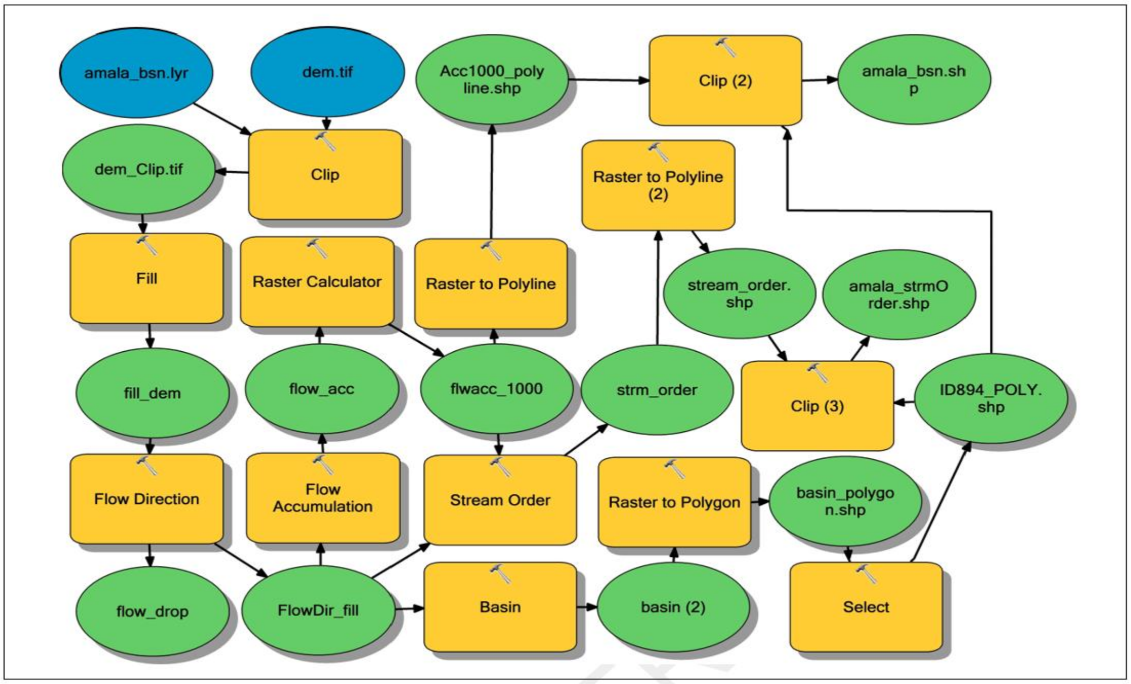

Fig. 5. A flow chart model used to generate stream network map

The values of morphometric parameters were derived from the attribute tables of the vector layers generated using the Spatial Analyst tool in the ArcMap environment. These parameters included; the number of stream segments of order u (Su), sum stream lengths of order u (Lu), length of the catchment (L), perimeter of the catchment (P), area of the catchment (A), maximum elevation (ELEVmax) and minimum elevation (ELEVmin). The sum of stream lengths of a given order was computed from the Amala stream shapefile using Spatial Analyst tools in ArcGIS. Mean stream length was computed by dividing the sum length of streams of a given order by the total number of streams in that order.

Geomorphologic characteristic is the geometric depiction and stream channels network arrangement of a catchment. These characteristics were categorized into: stream network characterization, catchment geometry, drainage parameters, and relief parameters.

2.3.1 Stream network characterization

Under this category the linear configuration of the drainage network was characterized by the following ratios;

i. Stream length ratio: It is a ratio of the mean length of streams of a given order to the mean length of streams of the previous lower order.
ii. Bifurcation ratio: It is a ratio of the number of streams of a given order to the number of streams of the next higher order.
iii. Rho coefficient: The coefficient relates drainage density to the physiographic development of a catchment this is instrumental in evaluating the storage capacity of the drainage network [5]. It is a ratio of length ratio to bifurcation ratio.

2.3.2 Catchment geometry analysis

The areal geometrical properties of the catchment were quantified using the following ratios and dimensionless number;

i. Form factor: It is a dimensionless ratio of catchment area to the square of catchment length indicates whether a catchment is elongated or circular.
ii. Elongation ratio: A ratio of the diameter of a circle of the same area as the catchment to the maximum catchment length.

iii. Compactness coefficient: A ratio of the perimeter of the catchment to the perimeter of a circumference whose area is equivalent to the surface of the corresponding catchment.

2.3.3 Drainage analysis

Drainage analysis quantify the areal drainage properties of the catchment as describe in the following characteristics;

i. Drainage density: It's a ratio of total stream segment lengths cumulated for all orders within a catchment to the catchment area.
ii. Drainage texture: Drainage texture is the relative spacing of drainage lines. It is the ratio of stream number of all orders to the perimeter of that area.
iii. Drainage frequency: It is the number of stream segments per unit area.
iv. Infiltration number: It is the product of drainage frequency and drainage density. This parameter gives an indication of the infiltration characteristics of a catchment.
v. Overland flow length: Average distance that water from precipitation will have to cover to reach a nearby stream. It is equivalent to one half the reciprocal of the drainage density.

2.3.4 Relief analysis

The relief of the catchment was expressed as;

i. Relief ratio: It is a ratio of relief to the length of a catchment. It describes steepness of relief in the catchment.
ii. Ruggedness number: A ratio of the catchment relief to the drainage density of the watershed.

In this study, thirteen geomorphologic characteristics were computed to characterize the Amala River catchment and its sub-basins. The computation equations and models for these characteristics are tabulated in Tables 6, 7, and 8, in later section.

3. RESULTS AND DISCUSSION

3.1 Stream Network Analysis

The stream network analysis included para meters that influence the flow of water. The geomorphologic parameters under this category are:

3.1.1 Stream order and stream number

Stream order is the basic step to stream network analysis. The main stream reaching the outlet of the catchment is shown as a 5th order. The stream order ranged from 1st to 5th with an order count of a sum ranging from 306 to 1 respectively (Table 1). The results indicate a total stream count of 396.

The results for stream number was found to obey Horton's law of stream numbers which states that the total number of stream counts decrease as stream order increases. Deviations indicate a high relief with steep slopes terrain. The logarithms of the number of streams of each order were plotted against the order and the points lie on a straight line (Fig. 6). There exists a geometric relationship between stream order and stream numbers, and between stream order and stream length. These indicate that the catchment is underlain by almost uniform lithology, and geologically there is no likelihood of uplift [7].

3.1.2 Stream length, mean stream length and stream length ratio

The total stream length for the catchment was found to be 740.898 km. The average length ratio for the basin was computed as 2.605 and the weighted average (using number of streams used to compute the ratio) as 2.728 (Fig. 7). The total steam length decreases exponentially as the stream order increases while the mean stream length increases exponentially with stream order (Fig. 7) and Equations 3.1 and 3.2 respectively

$$y = 574.44e^{-0.55x} \tag{3.1}$$

$$y = 0.454e^{-0.903x} \tag{3.2}$$

This indicates a dendritic drainage network in Amala River catchment. The flow of surface runoff depends only on the drainage characteristics [7].

3.1.3 Bifurcation Ratio

This is a characteristic that gives the relationship between the number of streams of a given order and the number of streams of the next higher order. It is computed as indicated in Table 6. It is a dimensionless characteristic generally ranging from 3 to 5. Weighted average bifurcation ratio was suggested by Strahler [10] as a more representative bifurcation number [5]. In Fig. 7, the variation with stream order is shown indicating Amala River catchment has a higher average bifurcation ratio of 4.26 and the computed weighted ratio of 4.40. The high values characterize the catchment as one that has suffered structural disturbances and the drainage network has been influenced by structural disturbances [5]. This ratio reflects the shape of the resulting hydrograph and therefore for Amala River catchment, higher value infers reduced peak discharge and increased time to peak [1].

Table 1. Stream order, stream number and stream length results

So	Nu	Lu
1	306	317506.12
2	71	222981.24
3	15	111261.15
4	3	44225.12
5	1	44924.83

3.1.4 Rho Coefficient (p)

The Rho coefficient relates drainage density to physiographic development of catchment which is instrumental to evaluate the storage capacity of drainage network [5]. It is a ratio of length ratio to bifurcation ratio as provided by the relation in Table 6. Rho coefficient of Amala River catchment is 0.62 (Table 2).

Table 2. The results of rho coefficient computation

	L_r	R_b	P
Simple average	2.605	4.260	0.612
Weighted average	2.728	4.399	0.620

The variation of this coefficient with stream order is similar to that of length ratio. This indicates a direct relationship between storage capacity of a drainage network and the stream length.

3.2 Catchment Geometry Analysis

The main catchment geometric analysis involved the length of the catchment, catchment area, perimeter, form factor, elongation ratio, and compactness coefficient which are described in the following respective paragraphs. Schumm [11] defined the length of the catchment as the longest distance parallel to the principal stream of the catchment. According to this definition, the length of the Amala River catchment is 68.28 km (Table 3). The catchment area was computed as 697.772 km^2 (Table 3). Catchment perimeter is the length of the divide that encloses the catchment area. It is an indicator of watershed size and shape. The catchment perimeter was computed as 207.263 km (Table 3).

The form factor describes the shape of the basin and it is defined as the ratio of catchment area to the square of its length as in Table 7. In this case, the catchment form factor is 0.15. The value varies from 0 to 1. This lower value indicates that the Amala River catchment is elongated rather than circular (higher value). Low values of form factor infer longer time of concentration and longer lag time for flows and thus delayed peak hydrograph [1].

Elongation ratio is the ratio of the diameter of a circle of equal area as the catchment to the length of the catchment (Table 7). This parameter indicates infiltration characteristics along the flow path and varies between 0.6 to 1.0 over varying climatic and geologic types [6]. A value between 0.9 and 0.8 shows that the catchment is circular, between 0.8 and 0.7 means that it is oval and a value less than 0.7 indicates an elongated catchment. For the present study it was computed as 0.437 (Table 3), this characterizes Amala River catchment as elongated. Elongated catchments are less efficient in discharge than the circular ones [6] therefore delayed time to peak.

The compactness coefficient is defined as the ratio of the perimeter of the catchment to the perimeter of a circumference whose area is equivalent to the surface of the corresponding catchment (Table 7). The computed compactness coefficient of the Amala River catchment is 2.23.

3.3 Drainage Analysis

Drainage analysis included main parameters such as drainage texture, drainage density, drainage frequency, infiltration number and length of overland flow as described in the following respective paragraphs.

Drainage texture is the relative spacing of drainage lines (Table 8). It is the ratio of stream number of all orders to the perimeter of that area. In this study, the drainage texture of the catchment is 1.91 (Table 3).

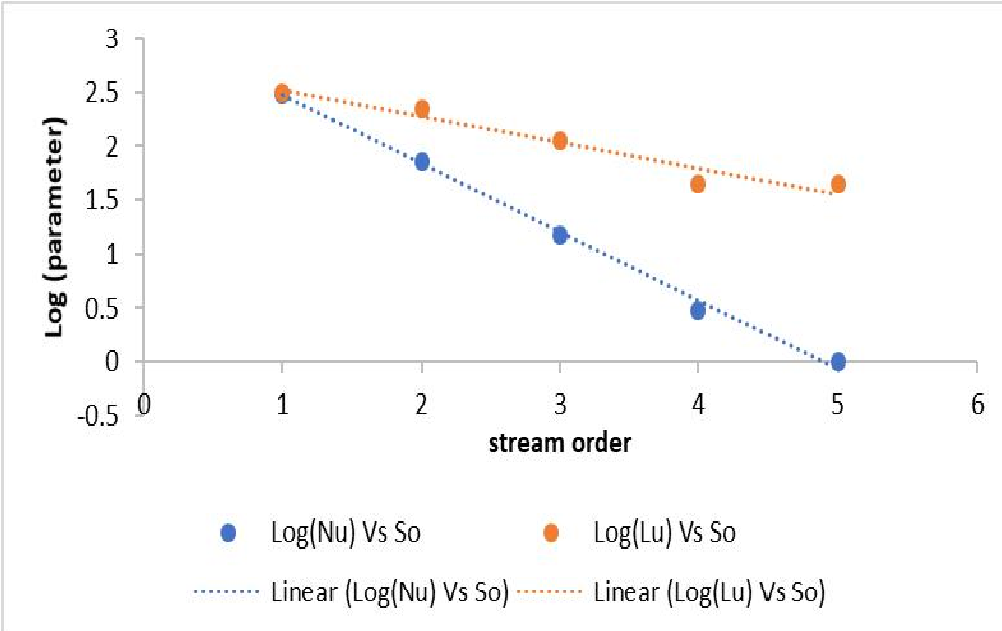

Fig. 6. Horton's law on stream number and stream length

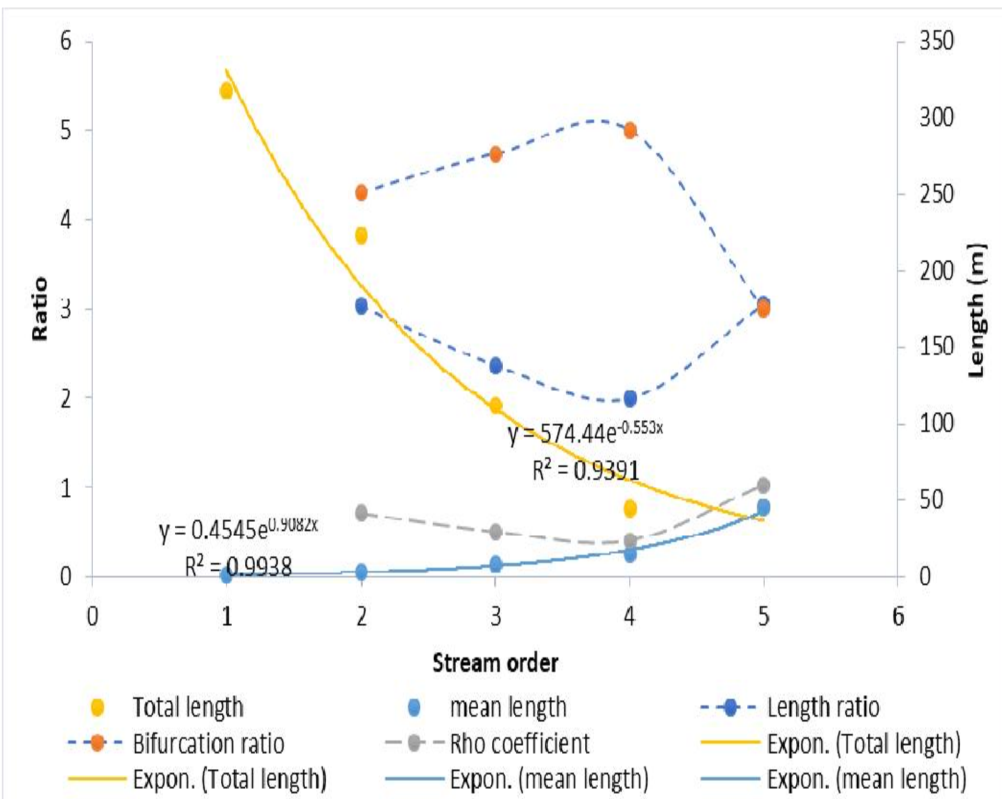

Fig. 7. Variation of total stream length, mean stream length, length ratio and bifurcation ratio with stream order

Drainage density is the sum length of the stream per unit catchment area (Table 8). The spatial distribution of drainage density is shown in (Fig. 8) computed using the Spatial Analyst Tool. The overall average drainage density of the Amala River catchment is 1.073 km/km^2 (Table 3). This is a low value indicating dense vegetation cover in most part of the catchment while its spatial distribution is controlled by the catchment lithology [6]. Also, low drainage density infers a hydrological behaviour dominated by infiltration and sub-surface flow compared to overland/ surface flow [1].

Drainage frequency indicates that the origin and development of stream in the catchment and that is directly depends on lithological characteristics (Table 8). The drainage frequency (Fd) is the number of stream segments per unit catchment area. The drainage frequency of the Amala River catchment is 0.58 streams/km^2 (Table 3). The low value of this parameter shows a coarse drainage texture [6].

The infiltration number was computed as the product of drainage frequency and drainage density (Table 8). This parameter gives an indication of the infiltration characteristics of a catchment. The higher value indicates reduced infiltration and more run-off. The infiltration number was computed as 0.61 (Table 3).

Table 3. Results related to catchment geometry and drainage analysis

S. no	Geometry parameter	Calculated value
1	Area (km2)	697.77
2	Perimeter (km)	207.26
3	Catchment length (km)	68.28
4	Form factor	0.15
5	Elongation ratio	0.44
6	Compactness coefficient	2.23
7	Drainage density	1.07
8	Drainage texture	1.91
9	Drainage frequency	0.57
10	Infiltration number	0.61
11	Overland flow length	0.47

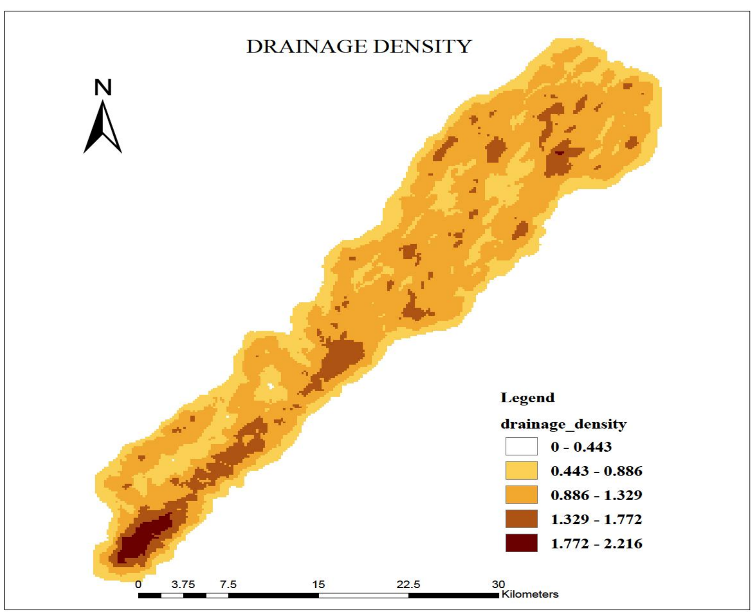

Fig. 8. Drainage density map for Amala River catchment

The length of overland flow refers to the length of the flow of rainwater on the surface before it joins definite channels. This parameter is taken as half the reciprocal of drainage density (Table 8). Length of overland flow for the Amala River catchment is shown as 0.47 km (Table 3). It depends on the physiographic and hydrologic conditions of the catchment. It is inversely related to slope hence higher value of the length of overland flow indicates more surface runoff.

3.4 Relief Analysis

Relief parameters are the three-dimension parameters as depicted in Table 9. The parameters under this category are the relief ratio and ruggedness number briefly explained in the following sub-section. The relief of a catchment is defined as difference in elevation between the point of maximum elevation and the floor elevation of the outlet point of the catchment. The total relief of the catchment is 1220 m, implying high potential energy of the drainage network. Relief ratio is the ratio of relief to the length of a catchment. It describes the steepness of relief in the catchment. In this study, the catchment relief ratio was determined as 0.02 (Table 4).

Ruggedness number according to Strahler is the product of relief and the drainage density of a catchment. For a given catchment the number combines slope steepness to its length. Depending on slope and drainage density, high value implies high stream flow velocity. Amala River catchment has a ruggedness number of 1.31 (Table 4).

3.5 Sub-Basin Level Analysis

Amala River catchment was delineated into 25 sub-basins by defining pour point for each sub-basin in the ArcHydo tool in ArcGIS (Fig. 9). The ones receiving flows from upstream sub-basins were ignored, only those with stream starting from first-order were used in the geomorphologic analysis. A total of 12 sub-basins were used in the analysis. The geomorphological characterizations of the sub-basins are as shown in Table 5.

Analysis at this level studied spatial variability of the geomorphologic characteristics within the Amala River catchment. In stream network analysis, sub-basins 1, 5, 7, and 21 show a higher stream length ratio of 16.41, 11.71, 8.26, and 7.80 respectively. The four sub-basins have a non-dendritic drainage structure, with one long main stream and thus longer lag time. The others have values lower than 3.5 and thus will likely experience shorter basin lag time. The bifurcation ratio spatially lies between 2.5 and 14.0 with high values indicating a fast hydrograph peak thus a likelihood of flash flooding after a storm [7]. The rho coefficient values lie between 0.52-2.34, higher values indicating a stronger relationship between drainage network storage capacity and the stream length.

From the geometric analysis, the form factor describes the shape of the basin. Lower values indicate much-elongated basin shape as in the case of sub-basin 1, sub-basin 5 and sub-basin 9. As the values increase the shape changes from elongated to circular. Much clearly characterization of the shape is given by the elongation ratio where all values below 0.7 characterize elongated basins and values above 0.7 are circular basins. The compactness coefficient (K_c) characterizes the time of concentration of a catchment before peak flow occurs. A K_c value of 1 indicates a catchment whose time of concentration equals that of a circular basin. Values $K_c > 1$ indicates a deviation of a circular catchment hydrological behavior. The sub-basin 15 has the minimum K_c value in the series of1.65 and sub-basin 9 has a maximum K_c value of 3.4). As per this parameter, sub-basin 9 will have the longest time of concentration (T_c) while sub-basin 15 will have the shortest T_c.

Low values for drainage density depict regions underlain with highly resistant permeable material with vegetative cover and low relief while as, high values imply weak and impermeable subsurface material and sparse vegetation and mountainous relief [7]. The spatial variation of the drainage density is shown in Fig. 8 and Table 5 with values are below 2 km/km^2. Variations in other drainage characteristics; drainage texture, infiltration number and length of overland flow are plotted in Fig. 10.

The relief expressed in meters varies between 341 and 732 for the sub basins, this parameter shows the maximum potential energy of water flow within the sub-basins. The steepness of this potential is indicated by the relief ratio. The relief ratio of each sub-basins had a positive relationship with the shape of the catchment, this is depicted by the similarity between elongation ratio curve and relief ratio as indicated in Fig. 11. Ruggedness number gives insight on the stream

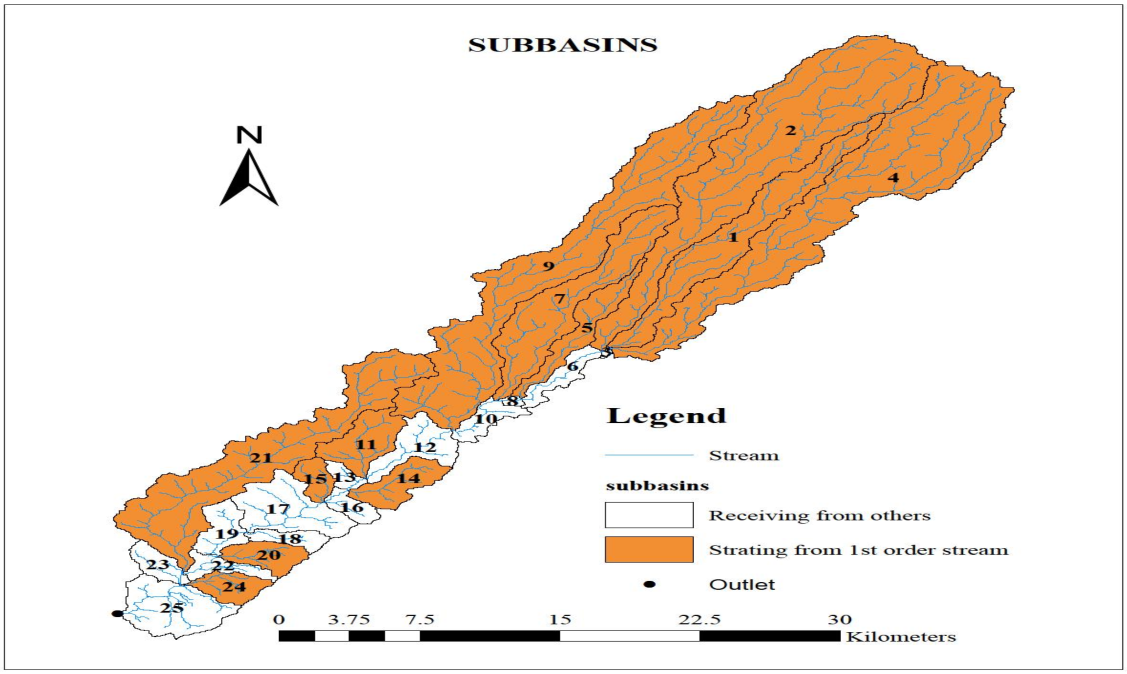

Fig. 9. Sub basins delineation and selection for geomorphologic analysis

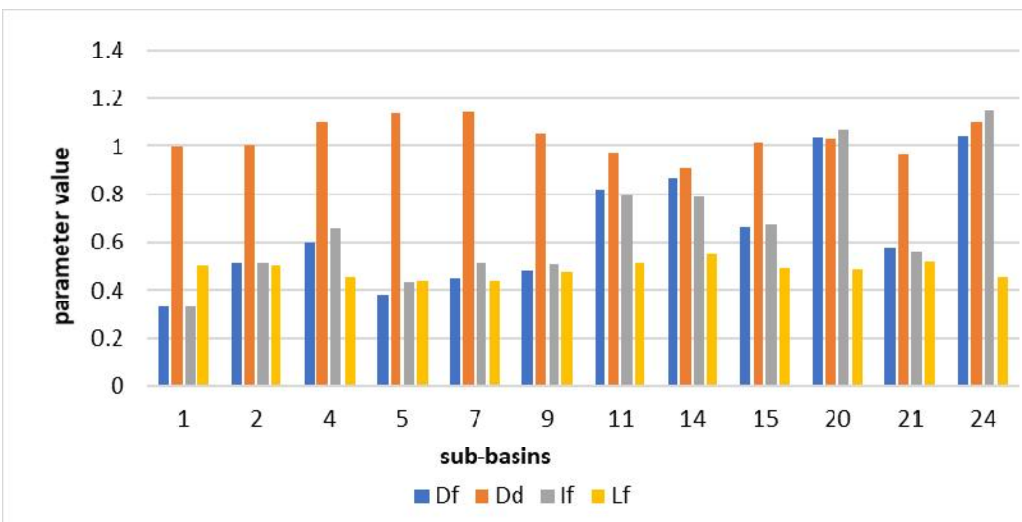

Fig. 10. Variations of drainage network parameters within sub-basins

Table 4. Catchment relief analysis parameters

Elevation at outlet (m)	Max elevation (m)	Relief (m)	Relief ratio	Ruggedness number
1845	3065	1220	0.02	1.31

Table 5. Sub basin level geomorphologic analysis result

Parameter	Sub-basins ID											
	1	**2**	**4**	**5**	**7**	**9**	**11**	**14**	**15**	**20**	**21**	**24**
Stream network analysis												
Total Nu	15	62	73	6	20	51	13	11	4	10	44	9
Total Lu (km)	45.82	121.16	133.76	17.99	51.07	112.48	15.44	11.49	6.16	9.95	73.73	9.52
Mean Lu(km)	3.05	1.95	1.83	3.00	2.55	2.21	1.19	1.04	1.54	1.00	1.68	1.06
Lu ratio	16.41	3.29	2.91	11.71	8.26	2.29	1.57	1.91	1.61	1.52	7.80	2.43
R_b	14	3.95	4.39	5	5.25	3.67	3	3	3	2.75	6.07	2.5
Rho coefficient	1.17	0.83	0.66	2.34	1.57	0.62	0.52	0.64	0.54	0.55	1.29	0.97
Catchment geometry analysis												
Lb(km)	26.21	32.96	32.59	14.71	20.42	35.45	6.46	5.54	4.18	4.74	23.64	4.97
Area(km^2)	45.86	121.01	121.68	15.78	44.57	106.47	15.86	12.66	6.04	9.63	76.33	8.63
Perimeter(M)	80.58	106.98	116.20	44.22	63.38	124.43	26.78	22.91	14.31	18.55	93.17	17.69
F_f	0.07	0.11	0.11	0.07	0.11	0.08	0.38	0.41	0.35	0.43	0.14	0.35
Elongation ratio	0.29	0.38	0.38	0.30	0.37	0.33	0.70	0.72	0.66	0.74	0.42	0.67
K_c	3.38	2.76	2.99	3.16	2.70	3.43	1.91	1.83	1.65	1.70	3.03	1.71
Drainage texture analysis												
Df (No./km^2)	0.33	0.51	0.60	0.38	0.45	0.48	0.82	0.87	0.66	1.04	0.58	1.04
Dd(km/km^2)	1.00	1.00	1.10	1.14	1.15	1.06	0.97	0.91	1.02	1.03	0.97	1.10
Infiltration number	0.33	0.51	0.66	0.43	0.51	0.51	0.80	0.79	0.68	1.07	0.56	1.15
Lf (Km)	0.50	0.50	0.46	0.44	0.44	0.47	0.51	0.55	0.49	0.48	0.52	0.45
Relief analysis												
Elevmin(M)	2340	2324	2333	2250	2220	2171	2064	2017	1991	1886	1876	1874
Elevmax(M)	2888	3006	3065	2562	2638	2792	2405	2370	2333	2259	2464	2230
Relief(M)	548	682	732	312	418	621	341	353	342	373	588	356
Relief ratio	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.06	0.08	0.08	0.02	0.07
Ruggedness number	0.55	0.68	0.81	0.36	0.48	0.66	0.33	0.32	0.35	0.39	0.57	0.39

Nu-stream number, Lu-stream length, Br-bifurcation ratio, Lb-length of the catchment, Ff-form factor, Kc-compactness coefficient, Df-drainage frequency, Dd-drainage density, Lf- Length of overland flow

flow velocity, it combines relief and drainage density. Higher values indicate high stream velocity and vice versa. Sub-basin 4 had the highest ruggedness number value of 0.805, thus higher stream velocity compared to other sub-basins. This further implies that sub-basin 4 is more prone to erosion than all the analyzed sub-basins.

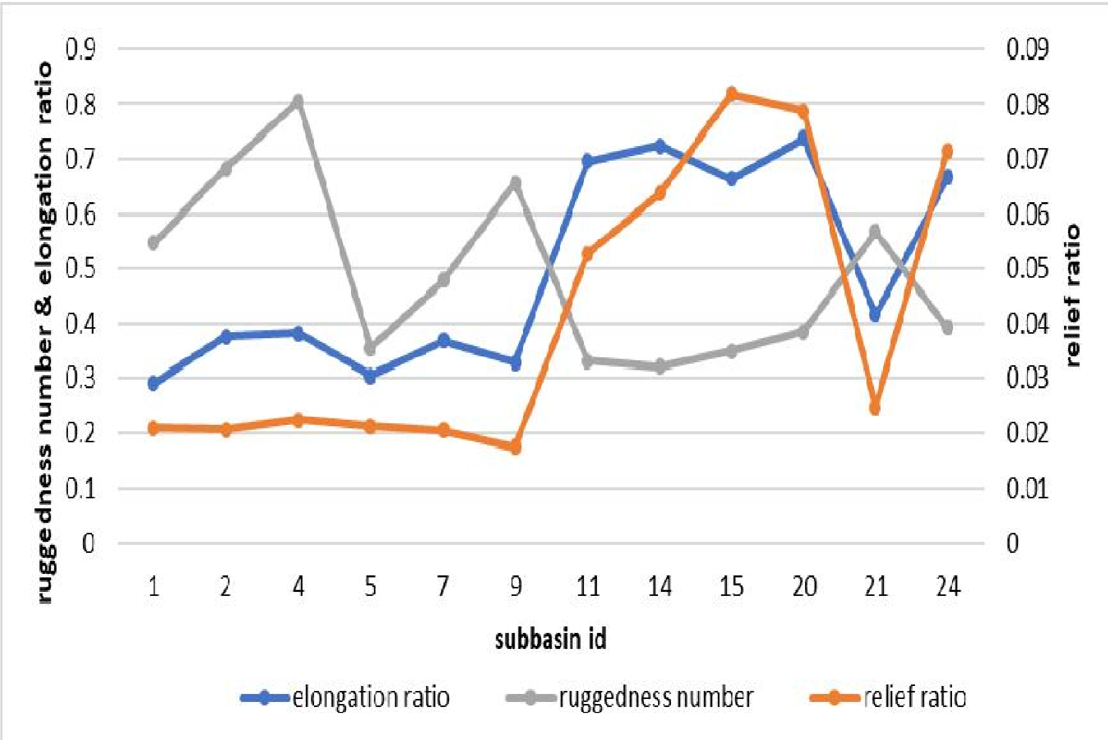

Fig. 11. A comparison of trends between relief parameters and shape of the sub basins

Table 6. Drainage network linear characteristics their symbols and computation formula

S. no.	Parameters	Abbreviation	Formula
1	Stream Order	*So*	*Strahler model*
2	Stream Number	*Nu*	$Nu = N_1 + N_2 + \ldots N_n$
3	Stream Length	*Lu*	$Lu = L_1 + L_2 + \ldots L_n$
4	Stream Length Ratio	*Lr*	$Lr = \frac{mean\_Lu_n}{mean\_Lu_{n-1}}$
5	Weighted length ratio	$\widehat{Lr}$	$\widehat{Lr} = \frac{1}{n}\sum_{i=1}^{n} (w_i * Lr_i)$
6	Bifurcation Ratio	R_b	$R_b = \frac{N_n}{N_{n+1}}$
7	Weighted bifurcation ratio	$\widehat{R_b}$	$\widehat{R_b} = \frac{1}{n}\sum_{i=1}^{n} (w_i * R_{bi})$
8	Rho coefficient	*P*	$\rho = \frac{Lr}{R_b}$

Table 7. Basin geometry characteristics parameter their symbols and computation formula

S. no.	Parameters	Abbreviation	Formula
1	Length of the basin	Lb	Schumm [11]
2	Basin Area	A	Spatial Analyst tool
3	Basin Perimeter	P	Spatial Analyst tool
4	Form Factor	F_f	$F_f = \frac{A}{L^2}$
5	Elongation Ratio	Re	$Re = (\frac{2}{Lb}) * (\frac{A}{\pi})^{0.5}$
6	Texture Ratio	Rt	$Rt = \frac{N1}{P}$
7	Circularity Ratio	Rc	$Rc = 12.57 * (A/P\text{^}2)$
8	Drainage Texture	Dt	$Dt = \frac{Nu}{P}$
9	Compactness Coefficient	K_c	$K_c = \frac{0.2841P}{A^{0.5}}$

Table 8. Drainage characteristics their symbols and computation formula

S. no.	Parameters	Abbreviation	Formula
1	Stream Frequency	Fs	$Fs = \frac{Nu}{A}$
2	Drainage Density	Dd	$Dd = \frac{Lu}{A}$
3	Infiltration number	I_f	$I_f = Fs * Dd$
4	Length of overland flow	L	$L = \frac{1}{2Dd}$
5	Drainage Intensity	Di	$Di = \frac{Fs}{Dd}$

Table 9. Relief characteristics their symbols and computation formula

S. no.	Parameters	Abbreviation	Formula
1	Maximum height of the watershed	Z	DEM processing
2	Minimum height of the watershed	Z	DEM processing
3	Total basin relief	H	$H = Z - z$
4	Relief Ratio	Rh	$Rh = \frac{H}{Lb}$
5	Ruggedness number	Rn	$Rn = Dd * H$

4. CONCLUSION

This study has characterized Amala River catchment on linear, geometry, drainage and relief aspect for surface runoff determination. The following conclusions are drawn:

i. On the linear aspect, a geometric relationship was found between stream order and stream numbers, and between stream order and stream length. These indicate that the catchment is underlain by almost uniform lithology. The catchment had a higher average bifurcation ratio of 4.26 indicating a reduced peak discharge and increased time to peak.

ii. The catchment geometry was defined as elongated given the low computed values of form factor and elongation ratio of 0.15 and 0.44 respectively. Thus, the catchment has a longer time of concentration, a longer lag time for flows, and delayed peak hydrograph.

iii. The drainage characteristic of the catchment was dominated by infiltration and sub-surface flow as compared to overland/ surface flows this was qualified by drainage density and infiltration number of 1.073 km/km^2 and 0.61 respectively.

iv. Amala River catchment had a steep, hilly, and mountainous relief with high potential energy, relief ratio and ruggedness number of 1220m, 0.02 and 1.31 respectively. This means high streamflow velocity within the catchment.

ACKNOWLEDGEMENTS

This research work was funded by the Centre of Excellency in Sustainable Agriculture and Agribusiness Management (CESAAM) under the ACE II project of the World bank. The Centre is hosted at Egerton University and some of university's resources were also used in this research work. The authors express their gratitude to the Centre and University for the resource assistance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nyadawa MO, Mwangi JK. Geomor phologic characteristics of Nzoia River Basin. JAGST. 2010;12(2):145-161.
2. Bansod RD, Ajabe GS. Determination of Geomorphological Characteristics of Karpri-Kalu Watershed Using GIS Techniques. Journal of Pharmacognosy and Phytochemistry. 2018;7(1):1940-1944.
3. Chethan BJ, Vishnu B. Determination of the geomorphologic parameters of the Thutha puzha River Basin in Central Kerala, India, Using GIS and Remote Sensing. Int J Curr Microbiol App Sci. 2018;7(09):1245-1260.
4. Mark DM. Geomorphometric parameters: A review and evaluation. Geografiska Annaler. Series A, Physical Geography, 1975;57(3/4):165-177.
5. Pareta K, Pareta U. Quantitative morphometric analysis of a watershed of Yamuna Basin, India using ASTER (DEM) Data and GIS. International Journal of Geomatics and Geosciences, 2011;2(1): 248-269.
6. Charizopoulos N, Psilovikos A Geomor phological Analysis of Scopia Catchment (Central Greece), Using DEM Data and GIS. Fresenius Environmental Bulletin. 2015;24(11b):3973 – 3983.
7. Altaf F, Meraj G, Romshoo SA. Morpho metric Analysis to Infer Hydrological Behaviour of Lidder Watershed, Western Himalaya, India. Hindawi Publishing Corporation Geography Journal. 2013;13: 1-14.
8. Gunal AY, Guven A. Determination of geomor phological parameters of damlıca basin using GIS. Acta Physica Polonica A. 2015;128(2):221-223.
9. Dutton CL, Subalusky AL, Anisfeld SC, Njoroge L, Rosi EJ, Post DM. The influence of a semi-arid sub-catchment on suspended sediments in the Mara River, Kenya. PLoS ONE. 2018;13(2):1-19.
10. Strahler AN. Hypsometric analysis of erosional topography. Bulletin of the geological society of America. 1952;63: 1117-1142.
11. Schumm S. Evolution of drainage systems and slopes in badland at Perth Amboy. New Jersey. Bulletin of Geological Society of America. 1956; 67:597-646.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/64836