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ASSESSMENT OF GEOMORPHIC AND MORPHOMETRY CHARACTERISTICS OF PARTS OF SHASHA AND OPA RIVER BASINS IN OBAFEMI AWOLOWO UNIVERSITY CAMPUS, SOUTHWESTERN NIGERIA

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ABSTRACT

Geomorphic and morphometry characteristics of parts of Shasha and Opa Basins in Obafemi Awolowo University campus, Ile-Ife, southwestern Nigeria were assessed through the analysis of basin linear, areal and shape parameters with a view to quantitatively describe the hydrological characteristics of the area. The campus is drained by Rivers Shasha and Opa and their tributaries. Stream order, stream number, stream length, mean stream length, stream length ratio, length of over land flow, confluence factor, form factor, elongation ratio, stream segment density, drainage density, drainage texture and slope within the campus were determined through the evaluation of topographic, drainage, and land use and land cover maps. The campus is drained mostly by River Opa (4^{th} order channel) and its tributaries while the remaining part (i.e. northeastern and northwestern parts of the campus) is drained by River Shasha (3^{rd} order channel) and its tributaries. The mean stream length for the 1^{st}, 2^{nd} and 3^{rd} stream orders of River Shasha were 0.42, 0.54 and 1.03 km, respectively; while the mean stream length for the 1^{st}, 2^{nd}, 3^{rd} and 4^{th} stream orders of River Opa were 0.40, 0.64, 1.84 and 4.07 km, respectively. The average length of overland flow within the Shasha sub-basin was 0.25 km, while the average length of overland flow within the Opa sub-basin was 0.15 km. Stream segment density increased from 0.16 km^{-2} to 3.18 km^{-2} in River Shasha and 0.08 km^{-2} to 4.33 km^{-2} in River Opa. Increased stream segment density from lower to higher stream order could have been influenced by increased fracture control of streams from lower to higher stream order. The predominant trend of the streams were NE-SW and NW-SE, suggesting the influence of differing lithologies or tectonic activities, where streams must have developed by taking advantage of the local relief for the varying stream flow directions.

Keywords: Drainage pattern, Drainage system, OAU Campus, River Basin, River Opa, River Shasha.

INTRODUCTION

The surface and groundwater flow systems within an environment are largely influenced by the drainage basin characteristics. Drainage basin is an area whose surface runoff due to a storm drains into a river that is carried by a drainage system in the basin (Raghunat, 2006). Drainage basin is defined by a drainage divide and a system that collects the surface runoff and then transports it to a particular stream channel, lake, reservoir or other water bodies. The drainage basin in any given environment is responsible for providing runoff to, and sustaining part or all of the flow of a river and its tributaries. The geomorphic, morphometric and drainage characteristics of a drainage basin describe the basin form and its hydrological features (Zavoianu, 1985).

Drainage basin morphometry data are often used in the assessment of the geomorphic and morphological characteristics of a basin while hydrological information are used in assessment of hydrological features such as bankfull discharge and sediment load. The accuracy of geomorphic and morphological assessment of a basin depends on other factors such as the amount and quality of observed data within the region of interest.

It has become very essential to populate drainage basin morphometry data such as the fluvial landscape characteristics derived from stream network, and quantitative description of drainage basin, shape and pattern from local environments for better understanding of surface water flow system. Hydrological data could be used to predict the occurrence, movement and storage of surface water and groundwater. Drainage basin characteristics have been used in evaluation of temporal drainage basin changes and how these changes relate to surface water and groundwater occurrence. Although there have been a wide range of successes attributed to this concept, groundwater occurrence and accumulation especially in Basement Complex environment are largely controlled by the presence of secondary porosity (Konwea, 2021). The tectonic movements influence the drainage basin shape and drainage pattern, resulting in unique geomorphic, morphological and structural features in the basin (Aladejana and Fagbohun, 2018).

The geomorphic and morphological characteristics of drainage basins have been used to prescribe sustainable water conservation techniques where water scarcity is recurrent (Aladejana and Fagbohun, 2018). Water scarcity especially in Basement Complex environment could be attributed to climatic or geologic factors. The variability in rainfall due to climate change can lead to reduced quantity of water available for storage. Likewise, lack of secondary porosity in fresh basement rock hinders groundwater storage.

Evaluation of drainage basin features utilizes information from areal, linear and shape parameters obtained from remotely sensed data (e.g. Gioia *et al.*, 2001; Asode *et al.*, 2016; Anifowose and Aladejana, 2016). Some of these parameters include stream length, stream order, drainage density, confluence factor and form factor. Therefore, analyses of areal, linear and shape parameters provide a framework from which geomorphic and morphological features of an area can be understood.

This study thus aims to assess the geomorphic, morphometric and drainage characteristics of parts of Rivers Shasha and Opa Basin in the Obafemi Awolowo University Campus in order to quantitatively describe the basin form and its hydrological characteristics. This will entail the delineation of drainage sub-basins, quantitatively assess the geomorphic and morphometric characteristics of the study basins within the University Campus, and determine the influence of structural controls on the surface water flow system within the sub-basins.

STUDY AREA

The study area is the sub-basins of Rivers Shasha and Opa within the Obafemi Awolowo University Campus, Ile Ife, Osun State, Nigeria. The university, formerly known as the University of Ife, Ile-Ife is a comprehensive public institution having a student population of 31,000 and a campus comprising academic area and the Teaching, Research and Commercial Farms. The Campus is drained by tributaries of Rivers Shasha and Opa. The area of study also contains rural communities and their associated land use patterns. These latter comprise villages and farmsteads, patches of secondary forests, mosaics of farm lands cultivated to a variety of tropical tree and food crops, and fallow land.

Obafemi Awolowo University Campus is underlain by deeply weathered rocks of the Precambrian Basement Complex suite comprising mainly schists, granite-gneisses and pegmatite (see Figure 1). The gneisses occur mainly in the central part of the Obafemi Awolowo University Campus forming three (3) major hills (see Figure 2). About 50% of the Obafemi Awolowo University Campus is underlain by gneisses. Mica schist occurs at the flanks of the Obafemi Awolowo University Campus, in the eastern, southeastern and western parts of the Campus. About 40% of the Obafemi Awolowo University Campus is underlain by mica schist. Unlike gneiss, mica schist is easily weathered to clayey material, hence outcrops of mica schist rarely occur within the Obafemi Awolowo University Campus. Pegmatite occurs in the western part of the study area, underlying about 10% of the area. Other minor rock types found within the area of study include amphibolite, quartz vein and dolerite. Though inselbergs formed on granite gneisses occur in the central part of the Campus, and constitute drainage divides, the general topography is in the form of gently undulating plains with local relief of about 150 m (see Figure 1). Valleys are broad, and have short side slopes (5^{o} – 15^{o}) and alluvial floors. Many of the valleys have swampy reaches. The Obafemi Awolowo University Campus is drained by two major rivers; Rivers Shasha and Opa.

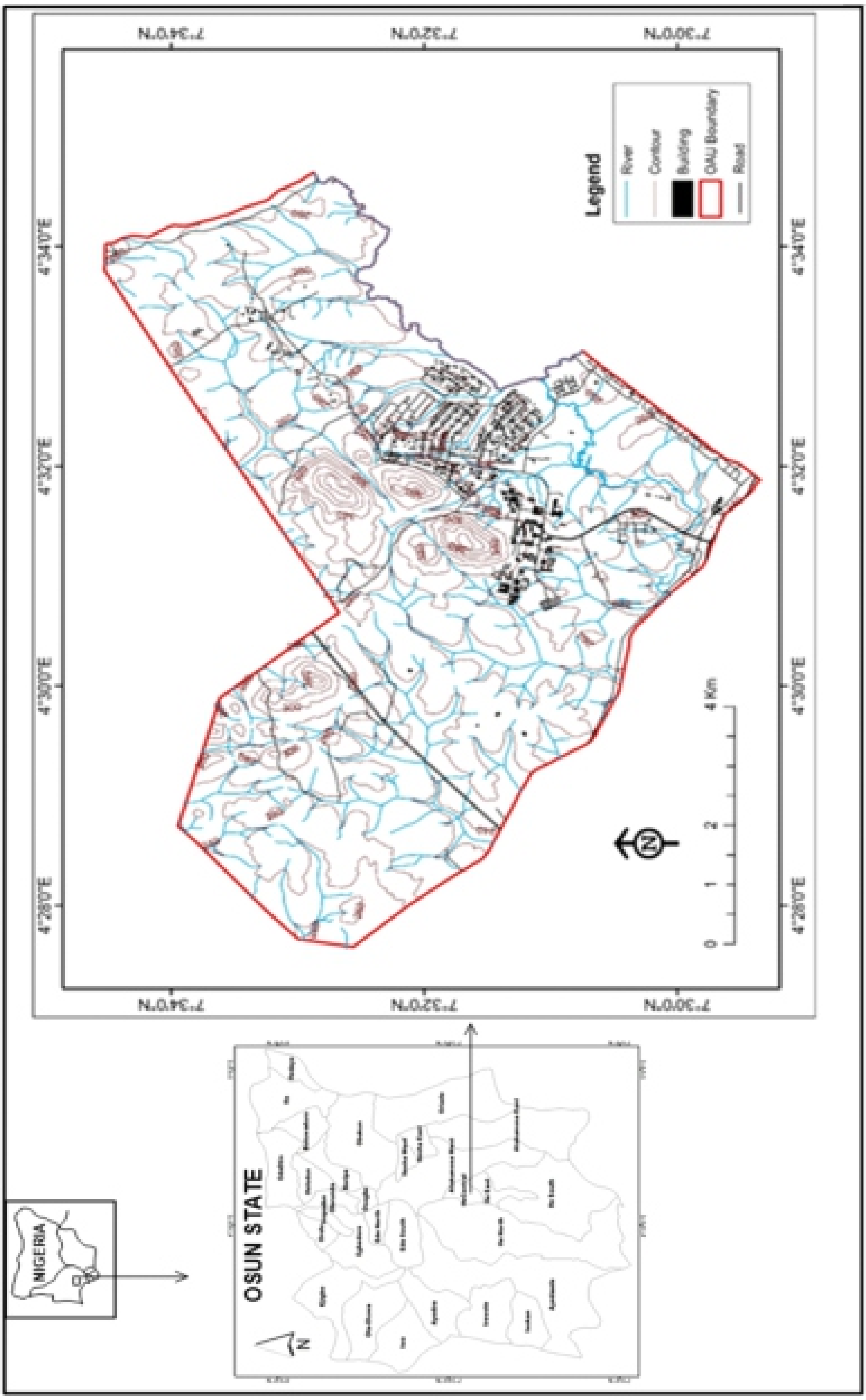


Figure 1: Location map of the Obafemi Awolowo University Campus.
Source: Adapted from Federal Survey Agency, 1966.

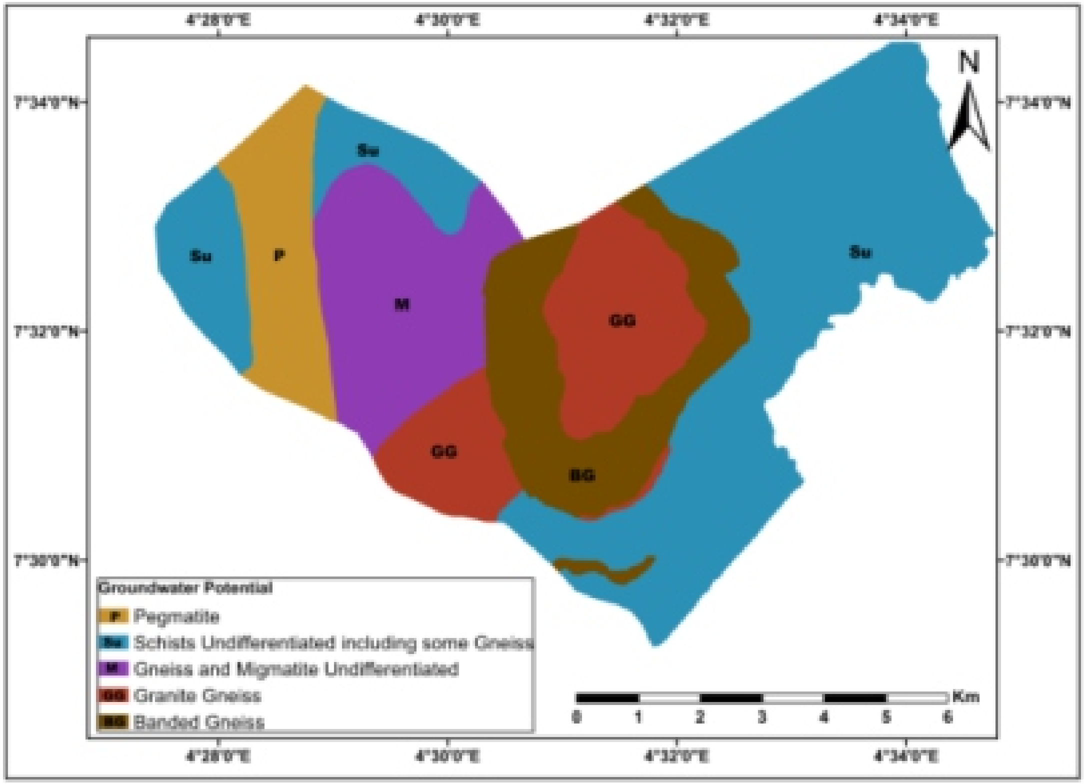


Figure 2: Geologic map of the Obafemi Awolowo University Campus
Source: Adapted from Konwea, 2021.

River Shasha drains the northern, northeastern and northwestern parts of the Campus, while River Opa drains the eastern part of the Campus, though its tributaries flow generally southward. The Rivers Shasha and Opa and their tributaries form dendritic, parallel and radial drainage patterns, both around the centrally placed hills and on the relatively flat terrains.

The climate is a dry species of the Koppen's A_f Humid Tropical type characterized by a short dry season (November – March) during which, mean maximum temperature is 33 °C. The rainy season extends from April to November and has a bimodal rainfall distribution marked by a break in rainfall in July-August, but during which humidity remains high. The mean annual rainfall is 1470 mm. Mean maximum temperature during the rainy season is 28 °C (Ogunkoya and Aboyeji, 2014).

The archetype vegetation is the Lowland Rain Forest, consisting of semi-deciduous species (Chukwuka and Isichei, 1997). This vegetation has however been so extensively disturbed that only small tracts remain in the more inaccessible sections of some inselbergs. The massive deforestation was caused by the long drought of 1968-1998, the large-scale artisanal farming on campus land, annual bush fires, and selective logging. These land use activities have led to the modification of the drainage characteristics in general. The transportation of eroded material has facilitated the widening and shallowing of river channels.

The landscape Opa drainage basin to which the Obafemi Awolowo University sub-basin belongs has been heavily denuded within the last four decades through cultivation, annual bush fires and construction activities. The un-regulated large scale land use conversion in the Opa drainage basin over time involving deforestation, cultivation, and uncontrolled/poorly planned urban development have promoted massive erosion (Ogunkoya, 2017).

MATERIALS AND METHODS

The sub-basins of Rivers Shasha and Opa in Obafemi Awolowo University Campus is considered for this study. The sub-basins, being real drainage basins are characterised and described separately based on their geomorphic and morphometric characteristics. The topographic map of scale (1:10,000) and drainage map of scale (1:50,000) obtained from the Department of Geography, Obafemi Awolowo University, Ile-Ife were used in this study. Smaller scale topographic map was used in order to extract geological features such as topographic variation in great detail. Drainage map of scale 1:50,000 was used because it captured all the branching of the rivers within the Obafemi Awolowo University Campus. The topographic and drainage maps were analysed to appraise the terrain, geomorphic, morphometric and drainage characteristics. Visual inspection of the maps and ground trothing to determine accurately topographic and drainage features such as spot heights, stream lengths and stream order were carried out to delineate the geomorphic features within the study area. Topographic map correction was carried out according to Gregory and Walling (1968) by supplementing all the marked drainage lines shown on the 1:10,000 topographic map by extensions into small rills indicated by contour crenulations. The drainage network within the study area was digitized in the GIS environment using ArcGIS 10.3 software and extracted according to Strahler (Strahler, 1964). Linear and areal morphometric analyses involving numeric calculation of number and length of streams within the study area were conducted in the GIS environment. The linear parameters analysed include stream order, stream number, stream length, mean stream length, stream length ratio, length of over land flow and confluence factor; the areal parameters analysed include stream segment density, drainage density, drainage texture and slope; while the shape parameters analysed include form factor and elongation ratio. The stream ordering system which had its origin with Horton (1945) and modified by Strahler (1964) was adopted. The outermost channels of the stream were ranked as first order. When two first order streams join together, a second order stream is made. This ranking continues until channels with equal ranking no longer join and the stream flows out of the basin. Topographic parameters including drainage density and slope gradient were derived from DEMs (using ENVI 5.0 software). Stream number is the total number of stream segment of a particular order.

The mean stream length of a stream is the total length of stream segments of a particular order divided by the total number of stream segment of the same order. The stream length ratio is the ratio of the mean length of stream of a particular order to the mean length of stream of one order less than the given order.

The length of over land flow which is the distance covered from the water divide to the nearest channel was approximated as half the reciprocal of the drainage density (Horton, 1945). Drainage density is the ratio of length of channel to basin area. The confluence ratio of a drainage basin is the ratio of the number of stream segments of a given order to the number of stream segments of the next higher order. The form factor of a drainage basin is the ratio of the basin area to the square of the basin length. Stream segment density is the ratio of the number of stream segments of a particular stream order to the area of the drainage basin. Drainage texture is the product of drainage density and stream segment density of a drainage basin. The elongation ratio of a drainage basin is the ratio of the diameter of a circle of the same area as the basin to the maximum drainage basin length. These parameters which cut across the major morphometric aspects of a basin: linear, areal and shape aspects, were selected based on ability of the parameters to provide quantitative description of the physical landform of the drainage basin and availability of data. Table 1 contains the formulae used in the calculation of the linear and areal morphometric parameters for this study.

Table 1: Definitions and formulae used for the computation of morphometric parameters.

Morphometric Parameter		Formula/definition	Source
Linear Parameter	Stream order	Hierarchical rank	Strahler, 1964
	Stream number	Number of stream segments of the order 'u'	Strahler, 1957
	Stream length	Length of stream segments of a particular order	Horton, 1945
	Mean stream length	$L_{sm} = \frac{\sum L_u}{N_u}$ where L_u = length of stream segment of a particular order and N_u = number of stream segments of that order (u)	Strahler, 1964
	Stream length ratio	$R_l = \frac{L_u}{L_{(u-1)}}$ where L_u = mean length of all stream segments of a particular order 'u' and $L_{(u-1)}$ = mean length of all stream segments of the next lower order	Horton, 1945
	Length of overland flow	$L = \frac{1}{2D}$ where D is drainage density	Horton, 1945
	Confluence factor	$R_b = \frac{N_u}{N_{(u+1)}}$ where N_u = number of stream segments of a particular order 'u' and $N_{(u+1)}$ = number of stream segments of one order greater to given order (u)	Schumm, 1956
Areal Parameter	Stream segment density	$D_s = \frac{\sum N_u}{A}$ where N_u = number of stream segments of the order 'u' and A = area of the basin (km^2)	Horton, 1945
	Drainage density	$D_d = \frac{\sum L_u}{A}$ where L_u = total length of stream segment of a particular order (u) and A = basin area (km^2)	Horton, 1945
	Drainage texture	$T_d = D_d \times D_s$ where D_d = drainage density and D_s = stream segment density	
Shape Parameter	Form factor	$F_f = \frac{A}{L_b^2}$ where A = basin area (km^2) and L_b = length of basin (km)	Horton, 1945
	Elongation ratio	$R_e = \frac{D}{L_b}$ where D = diameter of a circle of same area (A) as the basin, A = basin area (km^2) and L_b = length of basin (km)	Schumm, 1956

RESULTS AND DISCUSSION

Morphometric Analysis

Drainage System

River Shasha and its tributaries drain the northern, northeastern and western parts of the Obafemi Awolowo University Campus. Some of the tributaries of River Shasha take their source from the centrally located hills, flowing northward, westwards and northeastward to join other tributaries flowing westwards. The tributaries of River Shasha form dendritic and radial drainage patterns (see Figure 2). The dendritic drainage pattern is characteristic of crystalline rocks with uniform resistance and gentle slope either at the time of inception of the drainage or at present (Howard, 1967). River Opa drains the eastern, southern and southwestern parts of the Obafemi Awolowo University Campus creating dendritic, parallel and radial drainage patterns. The tributaries of River Opa flow generally southward to join the main river. The dendritic drainage pattern is due to the almost flat topography of the eastern and southern parts of the Obafemi Awolowo University Campus and not necessarily because of the underlying basement rock (schist). Schist is relatively less resistant to weathering, hence the few and unobtrusive outcrops in the southern part of the Obafemi Awolowo University Campus. The parallel drainage pattern around the foot of the centrally placed hills results from the moderately steep topography. Although parallel drainage pattern also occurs in areas of parallel, elongated landforms; with possible transition to dendritic and trellis patterns (Howard, 1967). The outward flow of Rivers Shasha and Opa from the hills gives rise to radial drainage pattern around the central part of the Obafemi Awolowo University Campus (see Figure 3). The radial drainage pattern is influenced by seepages from the hills due to secondary porosity in the crystalline rock and superficial deposits around the hills. These features support the heavy vegetation on the hills. The topographic divide separating Rivers Shasha and Opa, within the Obafemi Awolowo University Campus, trends NE-SW (see Figure 3) cutting through the Campus from the Teaching and Research Farm in the northeastern part, passing between Hills 2 and 3 to the Moro Campus, southwest of the Obafemi Awolowo University Campus. River Shasha drains 33% of the Obafemi Awolowo University Campus covering an area of 18 km^2, while River Opa drains the remaining 67% covering an area of 37 km^2 (Konwea, 2021).

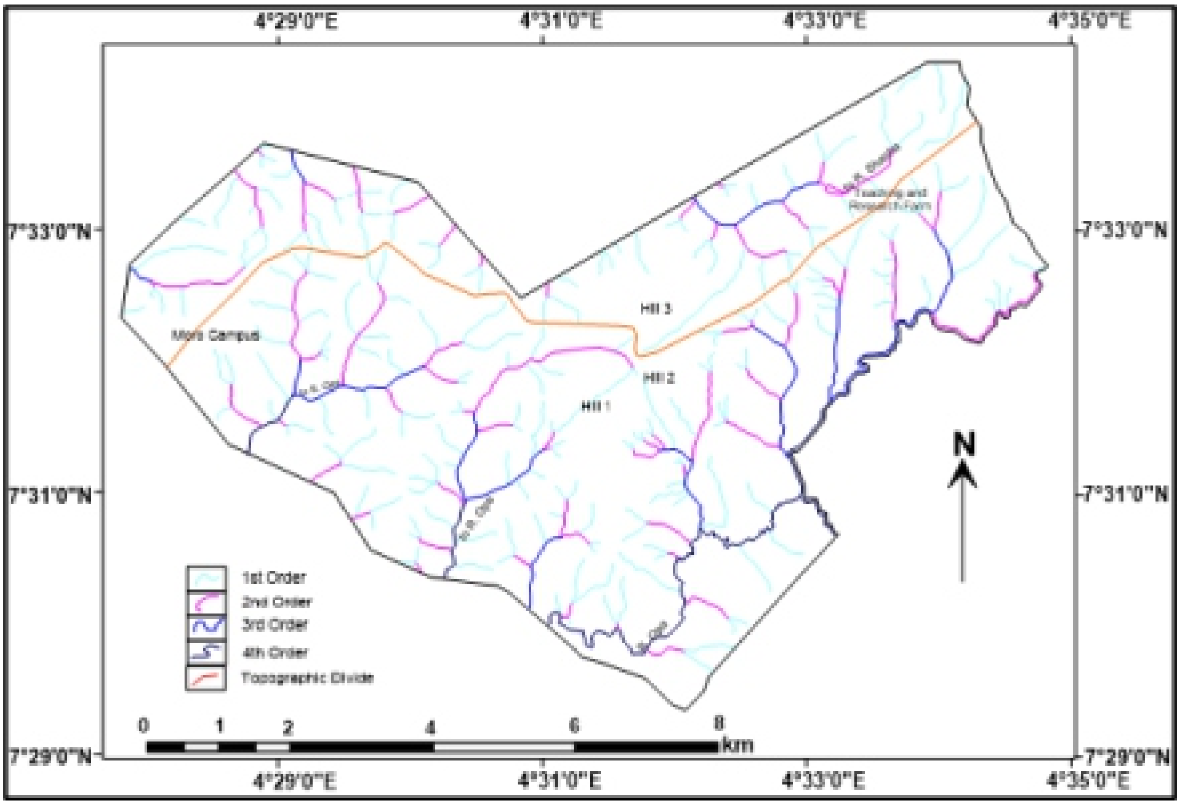


Figure 3: Drainage system of the Obafemi Awolowo University Campus. *Source*: Konwea, 2021.

Drainage Basin Description

River Shasha within the Obafemi Awolowo University Campus has a stream order of three (3) based on the Strahler (1964) stream ordering system, indicating a third-order sub-basin. Stream order is the degree of branching of a river within a drainage basin, giving an idea of the stage of development of the drainage basin. The higher the stream order, the more advanced the stage of development of the drainage basin. River Shasha sub-basin with a stream order of three (3) indicates a moderately-developed sub-basin (Gioia *et al.*, 2011). River Opa has a stream order of four (4), which is a fourth-order sub-basin. Stream order of four (4) indicates a moderately-developed sub-basin. The lesser numbers of streams in the 3rd and 4th orders of the Rivers Shasha and Opa (see Table 2) compared to the 1st and 2nd orders, indicate that mature topography occurs adjacent to the streams, while the higher numbers of streams in the 1st and 2nd orders indicate that the topography is still undergoing erosion (Gioia *et al.*, 2011).

The log normal plot of the stream order against total stream number revealed a linear relationship for both Rivers Shasha and Opa (see Figure 4). The linear relationship between the stream order and total stream number obeys the Horton (1945) law of stream numbers.

Table 2: Stream property.

Order	Number of stream		Stream length (km)		Mean stream length (km)		Stream length ratio	
	River Shasha	River Opa	River Shasha	River Opa	River Shasha	River Opa	River Shasha	River Opa
1st	58	161	24.2	64.2	0.42	0.40		
2nd	18	43	9.2	27.5	0.54	0.64	1.29	1.60
3rd	3	9	3.2	16.6	1.03	1.84	1.91	2.88
4th	0	3		12.2		4.07		2.21

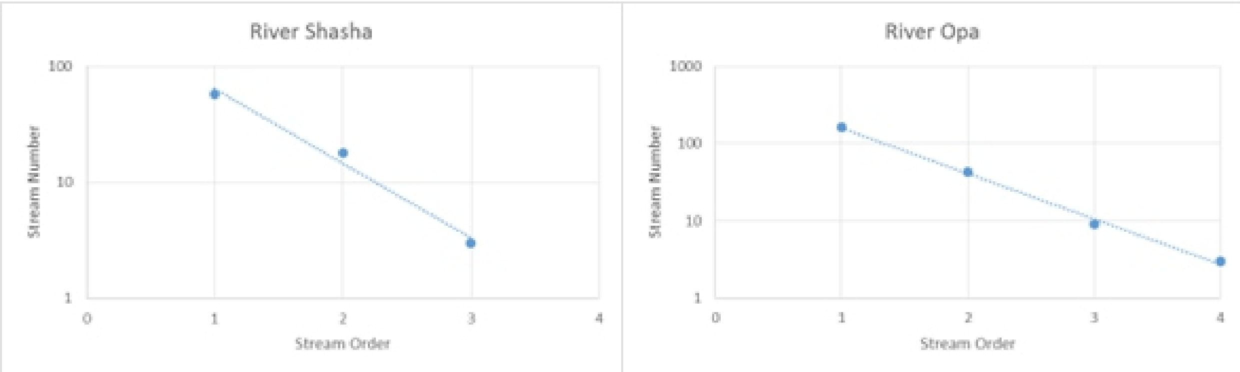


Figure 4: Log-Normal plot of stream number against stream order for Rivers Shasha and Opa.

The law states that the number of streams of each order forms an inverse geometric sequence with order number. The log normal plot shows a decreasing number of stream segment as the stream order increases.

Stream length is the length of a particular stream of given order, from source to confluence or where it drains into a lake or sea. Stream length defines the hydrologic characteristics of underlying rock within a drainage basin. Total stream length is the sum of the stream lengths of a particular order. The total stream lengths of the 1st, 2nd and 3rd orders of the River Shasha were 24.2 km, 9.2 km and 3.2 km, respectively; while the total stream lengths of the 1st, 2nd, 3rd and 4th orders of the River Opa were 64.2 km, 27.5 km, 16.6 km and 12.2 km, respectively (see Table 2). The total lengths of stream segments of the different stream orders of Rivers Shasha and Opa on the Obafemi Awolowo University Campus revealed that the total stream lengths decrease with increasing stream order. The maximum length of stream occurred in the 1st order streams, while the minimum length of stream occurred in the 4th order stream. Permeable rock formations facilitate infiltration and therefore low stream length, low drainage density and stream segment density; while less permeable rock formations restrict infiltration and therefore high stream length (Pakhmode *et al.*, 2003). The mean stream length is used to determine the general permeability of the of the underlying rock formation. The mean stream length for the 1st, 2nd and 3rd stream orders of River Shasha were 0.42 km, 0.54 km and 1.03 km, respectively. The mean stream length for the 1st, 2nd, 3rd and 4th stream orders of River Opa were 0.40 km, 0.64 km, 1.84 km and 4.07 km, respectively (see Table 2). The results revealed that both Rivers Shasha and Opa have low stream length of higher order and high stream length of lower order. The low stream length of the higher orders is an indication that the permeable rocks facilitate infiltration, while the high stream length of the lower orders is an indication of lesser infiltration compared to the higher stream orders.

The mean stream length obtained for Rivers Shasha and Opa revealed that the mean stream length generally increases with increasing stream orders. The longer mean stream length of the higher stream orders indicates a farther runoff flow path, while the shorter mean stream length of the lower stream orders indicates a smaller runoff flow path.

The stream length ratio between successive stream orders is used to establish any relationship between the different stream orders. The stream length ratio between the 1st and 2nd, and 2nd and 3rd orders of River Shasha were 1.29 and 1.91, respectively. The stream length ratio between the 1st and 2nd, 2nd and 3rd, and 3rd and 4th orders of River Opa were 1.60, 2.88 and 2.21, respectively (see Table 2). The stream length ratios between the different stream orders in the River Shasha were between 1.29 and 1.91, while the stream length ratios between the different stream orders in River Opa were between 1.60 and 2.88. This means that the mean stream length for both rivers varies and increases in no particular order. The maximum stream length ratio of 1.91 for River Shasha was obtained between the 3rd and 2nd order streams. The maximum stream length ratio of 2.88 for River Opa was obtained between the 3rd and 2nd order streams. The slight variation in stream length ratio in both sub-basins is an indication that the development of the fluvial geomorphic cycle of the sub-basins are still in the youthful stage (Singh *et al.*, 1977).

The length of overland flow is the length of water movement over the ground before it reaches the stream channel. Length of overland flow defines how coarse or fine the drainage system of an area is. Overland flow affects the water regime network as well as the long-term evolution of drainage basins. Length of overland flow is approximately half the average distance between stream channels hence, equal to half the reciprocal of the drainage density (Horton, 1945). The average length of overland flow within the Shasha sub-basin is 0.25 km, while the average length of overland flow within the Opa sub-basin is 0.15 km. The average length of overland flow within the Shasha sub-basin is larger than the length of overland flow within the Opa sub-basin indicating that the surface water runoff into streams within the Shasha sub-basin generally travels longer distance than the surface water runoff within the Opa sub-basin. This implies that the Shasha sub-basin has higher flooding potential than the Opa sub-basin because the longer the length of overland flow in an area, the higher the flooding potential. Overland flow is triggered when soil becomes saturated, hence any additional precipitation or irrigation causes runoff. The average lengths of overland flow indicate a coarser drainage system within the Shasha sub-basin than in the Opa sub-basin.

Confluence ratio is the index of relief and dissection of a drainage basin. Drainage basin with low confluence ratio of between 3 and 5 indicates that the geologic structures within the basin do not hold a dominant control over the drainage pattern (Strahler, 1964). Low confluence ratio indicates relatively less groundwater recharge from surface water due to non-connectivity of the geologic structures with the surface water flow system. Confluence ratio > 5 indicates a structurally controlled drainage network, where the groundwater is likely recharged from the surface water flow system (Strahler, 1964). The confluence ratio between the 1st and 2nd order streams, and 2nd and 3rd order streams within the Shasha sub-basin are 3.22 and 6.00, respectively. The confluence ratio between the 1st and 2nd order streams, 2nd and 3rd order streams, and 3rd and 4th order streams within the Opa sub-basin are 3.74, 4.78 and 3.00, respectively. The average confluence ratio of River Shasha within the Obafemi Awolowo University Campus is 4.61, while the average confluence ratio of River Opa within the Obafemi Awolowo University Campus is 3.84.

The confluence ratios of River Shasha increase from 3.22 in lower stream order to a maximum value of 6.00 in higher stream order, indicating that the influence of geologic structures on the drainage pattern of River Shasha increases from lower to higher stream order. The confluence ratios of River Opa decrease from 3.74 in the 1st stream order to 3.00 in the 3rd stream order. The lower confluence ratio in the Opa sub-basin indicates that geologic structures have moderate effect on the drainage pattern of the River Opa, with maximum effect occurring in the 2nd and 3rd stream orders. The generally moderate to high confluence ratios within the Obafemi Awolowo University Campus indicate that both Rivers Shasha and Opa are efficiently draining the

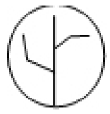
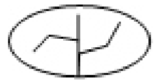
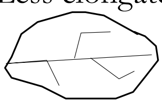
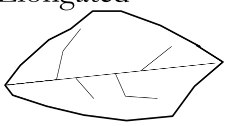
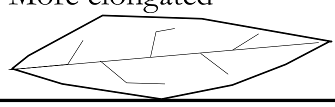
Obafemi Awolowo University Campus.

Form factor is an indication of the rate at which water enters the stream and it is a function of the basin shape. The value of form factor varies from zero (for highly shaped drainage basin) to one (for perfectly circular shaped drainage basin). Form factor has a direct relationship with stream flow intensity (Gregory and Walling, 1973). High river flow intensity translates to low groundwater recharge. The form factor value of > 0.75 indicates a perfectly circular basin with high flow intensity and short flow duration, while form factor of < 0.42 indicates an elongated basin with a long flow duration (Horton, 1932). Drainage basin with form factor of between 0.42 and 0.75 has moderate flow intensity and flow duration. The form factor obtained for Rivers Shasha and Opa are 0.13 and 0.36, respectively. The low form factor obtained are indications that the basin is elongated with a relatively large area of low relief. Hence the sub-basins have rapid response from precipitation but requires longer duration to reach peak flow.

Elongation ratios normally range between 0.1 and 1.0 under several climatic conditions and lithologic settings. A drainage basin can be circular, oval or elongated depending on the elongation ratio (Strahler, 1964). Frijlink (1959) emphasized the significance of basin shape in morphometric analysis. The expression of basin shape based on comparison with circles have been considered inappropriate and an insignificant factor influencing drainage basin hydrologic response as drainage basins are generally pear-shaped and sharply pointed at the outfall (Gregory and Walling, 1973; Morisawa, 1958). Elongated drainage basin with elongation ratio close to 1.0 indicates low relief, translating to lower runoff intensity and higher groundwater recharge, while lesser values indicate high relief and steep topography, translating to higher runoff intensity and lesser groundwater recharge (Strahler, 1964). The elongation ratio obtained for Shasha and Opa sub-basins are 0.41 and 0.67, respectively. These values indicate that both sub-basins are elongated (see Table 3).

The stream segment density of a drainage basin is the measure of the topographic texture of the basin such as degree of relief fragmentation or number of valley segments per unit area. Drainage basins with high stream segment density is influenced by resistance of erosion, low permeability, tectonic and structure of the rock types in the basin (Zavoianu, 1985). Stream segment density ranged between 0.16 km^{-2} and 3.18 km^{-2} for River Shasha, and between 0.08 km^{-2} and 4.33 km^{-2} for River Opa. The high stream segment density, especially in the higher orders of Rivers Shasha and Opa indicates the influenced of materials that are resistant to erosion and have low permeability. Clayey materials resulting from the weathering of feldspar, a major component of schists, granite-gneisses and pegmatite found within the study area are responsible for the cohesive nature of the weathered materials.

Table 3: Basin classification using elongation ratio (modified after Strahler, 1964).

Elongation Ratio	Basin shape
0.9 – 0.10	Circular 
0.8 – 0.9	Oval 
0.7 – 0.8	Less elongated 
0.5 – 0.7	Elongated 
< 0.5	More elongated 

Drainage density gives an idea of the length of the river channel per unit area. Drainage density is a reflection of the structural framework of underlying rocks through the expression of the closeness of the spacing between streams. Low drainage density usually occurs in an area underlain by low resistant bedrock, while high drainage density occurs in an area underlain by impermeable rocks (Strahler, 1964). An area underlain by low resistant bedrock will experience relatively higher groundwater recharge than area underlain by impermeable rocks. Drainage basins with high drainage density respond rapidly to rainfall input, while drainage basins with low drainage density reflect a poorly drained basin with slow hydrologic responses. Shasha and Opa sub-basins cover an area of 18 km^2 and 37 km^2, with drainage densites of 2.03 km^{-1} and 3.24 km^{-1}, respectively. Rivers Shasha and Opa have relatively high drainage densities. The high drainage densities suggest a well-drained basin, hence the dense vegetation in most parts of the Obafemi Awolowo University Campus. Although, the form factor indicates that the Obafemi Awolowo University Campus has high rapid response from precipitation, the dense vegetation could be one of the factors contributing to the slow peak flow within the basin.

Drainage texture also known as infiltration number is the product of the density of the drainage and the stream segment density of a drainage basin. Drainage texture is affected by climate, precipitation, vegetation, rock type, soil type, infiltration capacity and stage of development of the basin. Drainage texture measures the relative channel spacing in a fluvial dissected topography (Kale and Gupta, 2001). The smaller the drainage channel spacing the finer the drainage texture, while the larger the drainage channel spacing the coarser the drainage texture. Resistant rocks are characterised by fine drainage texture, while less resistant rocks are characterised by coarse drainage texture, especially when they are unprotected by vegetation. Rivers Shasha and Opa have drainage textures of 8.79 km^{-3} and 18.82 km^{-3}, respectively. The high values of drainage texture indicate a generally fine drainage texture resulting from the relatively low infiltration capacity of the weathered layer above the resistant basement rock.

Geomorphic Analysis

The major geomorphic units within the Obafemi Awolowo University Campus are the hills and pediments. There are three (3) major hills formed from the differential weathering and erosion of the granite gneiss at the central part of the Campus (see Figure 1). The differential weathering and erosion result in steep slope with an impervious surface that result in high runoff estimated at 37 % of annual rainfall (Ogunkoya, 2000) and limited infiltration. The eastern and northwestern parts of the study area are underlain by schist. The weathering of schist under tropical condition gives rise to pediments hence, outcrops are rare in the areas underlain by schist. These pediments occur adjacent to the hills comprising of more resistant rocks, at relatively lower elevation. The slope of a drainage basin is influenced by climate and morphogenic processes operating on the underlying rocks (Schumm, 1956). The higher the slope of an area the faster the rate of surface runoff, while the lower the slope of an area the slower the rate of the surface runoff.

The topography of an area is influenced by the action of climatic and morphogenic processes operating within the area (Yeh *et al.*, 2009). The Obafemi Awolowo University Campus shows two distinct zones based on the degree of slope, designated as A and B (see Figs. 5 and 6). Figure 4 was drawn from north to south along longitude 4° 31' 30", while Figure 5 was drawn from west to east along latitude 7° 31' 30". The peak elevation of 405 m above mean sea level (amsl) occurs towards the north within the granite gneiss and decreases towards the south to 235 m amsl within the schist, giving the study area a relief of about 170 m.

Zone A has a steeper slope of 11.1° (19.6 %), and falls around the slightly rugged hills close to the northern boundary of the study area. The elevations are generally above 280 m amsl and cover a small area of < 10 % of the study area. This zone is basically outcrops. The soil cover is non-existent to very thin. Zone A has rapid runoff from storm events with relatively small infiltration.

Zone B has a flat to gentle slope of 1.0° (1.6%). The area is characterised by relatively flat topography. The transition zone between Zones A and B is marked by several seepages from the underlying bedrock. These seepages were observed around the Department of Geology Car Park and the Department of Architecture (see Figure 7). The break in the slope between Zones A and B represents the area of maximum seepage. High infiltration characterize areas with low slopes. This is not the situation in Zone B as the area is underlain mostly by mica schist and its weathered derivatives. The clayey weathered material arising from the weathering of the mica schist inhibit infiltration, except in areas where discontinuities such as fractures, increase the permeability of the area.

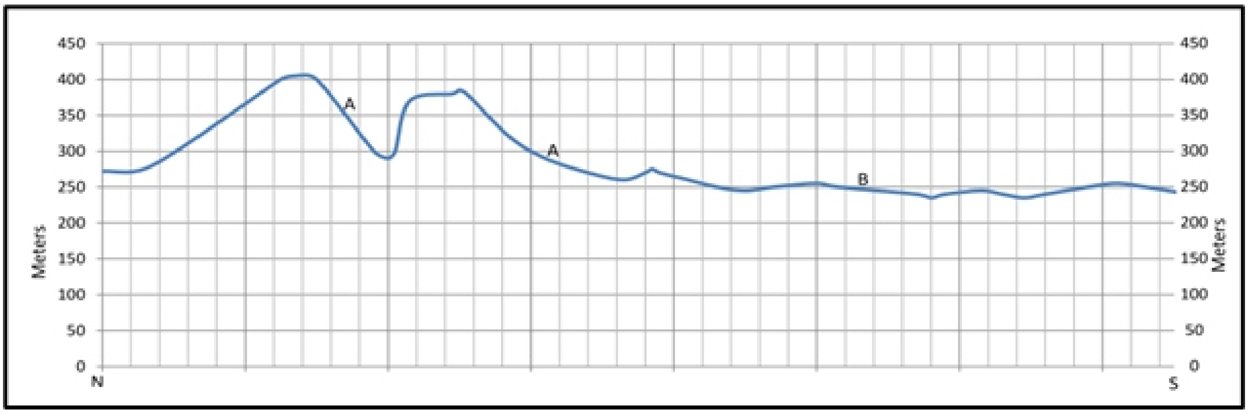


Figure 5: N-S Topographic profile of the study area along longitude 4° 31' 30".

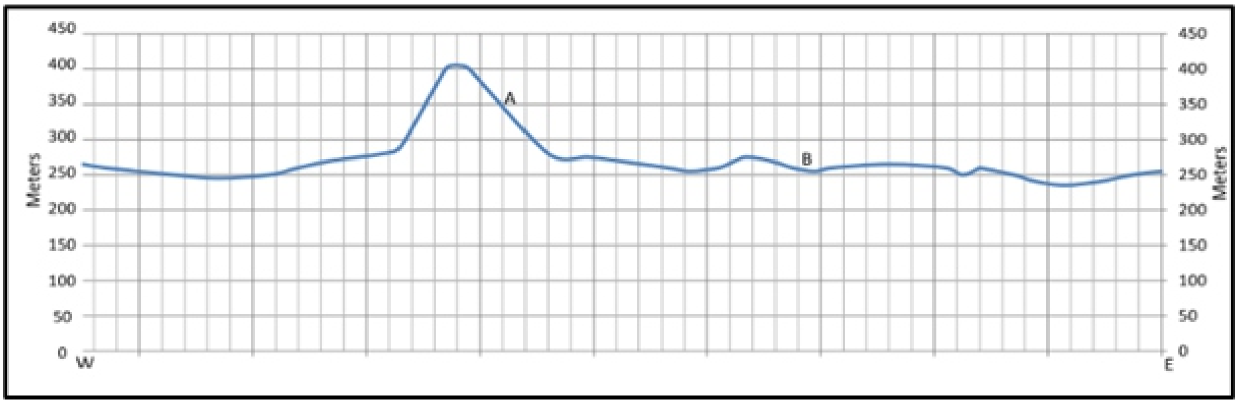


Figure 6: W-E Topographic profile of the study area along latitude 7° 31' 30".

Figure 7: Groundwater seepage at the Department of Geology car park.

Orientation of the Drainage System

The orientations of the different orders of the drainage system within the Obafemi Awolowo University Campus were assessed to establish any relationship between them and determine the general flow direction within the Obafemi Awolowo University Campus. From the rose diagram (see Figure 8), the 1st order streams within the Shasha sub-basin trend predominantly in the N-S direction at angles ranging from 000° to 010° and 340° to 355°. The orientation of the 2nd order steams were; N-S and NW-SE. The N-S trending streams occur at angles ranging from 000° to 005° and 345° to 360°. The NW-SE trending streams occur at angles ranging from 300° to 305° and 300° to 360°. The 3rd order streams within the Shasha sub-basin had no predominant trend, rather the streams occur in all directions (see Figure 8).

The 1st order streams within the Opa sub-basin trend predominantly in the NW-SE direction at angles ranging from 280° to 360°. The 2nd order streams trend predominantly in the NE-SW and NW-SE directions at angles ranging from 000° to 025° and 290° to 335°, respectively. The 3rd order streams trend predominantly in the NE-SW direction, at angles ranging from 000° to 005°. The 4th order streams within the Opa sub-basin trend predominantly in the NE-SW direction, at angles ranging from 015° to 045°.

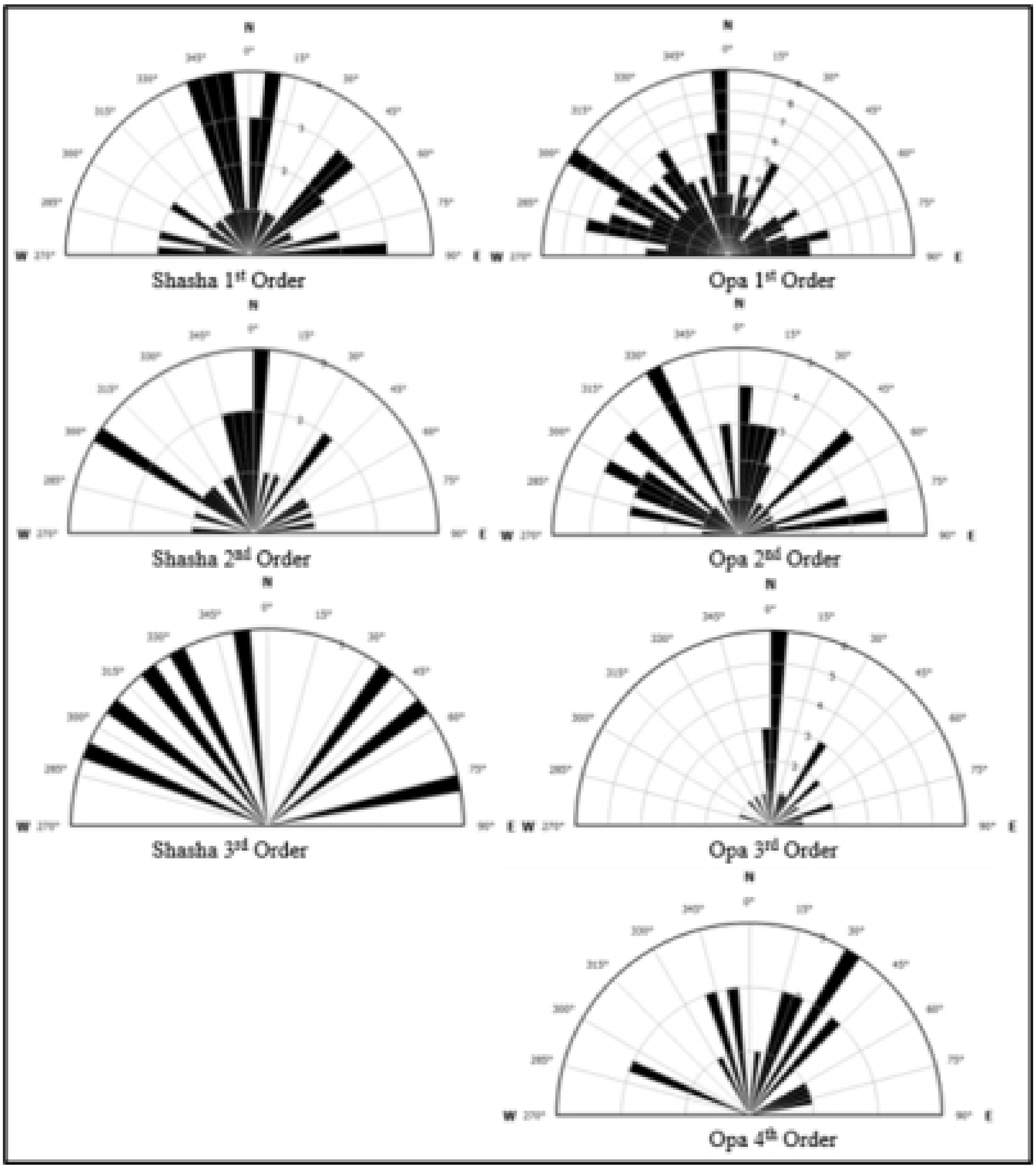


Figure 8: Rose diagram system of Obafemi Awolowo University Campus.

Generally, the streams in the Shasha and Opa drainage systems within the Obafemi Awolowo University Campus trend predominantly in two directions; NE-SW and NW-SE. These general stream flow directions could have been influenced by two possible factors. The first factor is the influence of the differing geologies where streams must have developed by taking advantage of the local relief. The second factor is attributed to different tectonic activities responsible for the varying stream flow directions.

CONCLUSION

Geomorphic and morphometric characteristics of Shasha and Opa sub-basins in Obafemi Awolowo University Campus were assessed in this study with a view to quantitatively describe the drainage basin characteristics of the area. Topographic, drainage, and land use and land cover maps were used in the assessment of the geomorphic and morphometric characteristics of the Campus. The geomorphic and morphometric characteristics assessed include stream order, stream number, stream length, mean stream length, stream length ratio, length of over land flow and confluence factor, stream segment density, drainage density, drainage texture, form factor and elongation ratio. The Campus is drained by Rivers Shasha and Opa and their tributaries. The drainage basin is moderately-developed with stream orders of 3 and 4 for Rivers Shasha and Opa, respectively. The mean stream length for the 1st, 2nd and 3rd stream orders of River Opa were 0.42, 0.54 and 1.03 km, respectively; while the mean stream length for the 1st, 2nd, 3rd and 4th stream orders of River Opa were 0.40, 0.64, 1.84 and 4.07 km, respectively. The average length of overland flow within the Shasha sub-basin was 0.25 km, while the average length of overland flow within the Opa sub-basin was 0.15 km. Stream segment density increased from 0.16 km^{-2} to 3.18 km^{-2} in River Shasha and 0.08 km^{-2} to 4.33 km^{-2} in River Opa. The increase in stream segment density from lower to higher stream order could be influenced by increase in fracture control of the streams from lower to higher stream order. The predominant trend of the streams were NE-SW and NW-SE, suggesting the influence of differing lithologies where streams must have developed by taking advantage of the local relief or the influence of different tectonic activities responsible for the varying stream flow directions. This study provides useful information on how geomorphic and morphometric characteristics of a drainage basin define the hydrological processes taking place within the drainage basin and their structural control on surface water flow system.

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