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Drainage Basin Morphometry and Landforms Characteristic in Talata Mafara, Zamfara State, Nigeria Using Remote Sensing Approach

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Abstract

Issue: Landsat MSS image transparency for hydrologic mapping by Procum 2 device manual analysis framework, was used to generate drainage basin morphometry data in Talata Mafara, Zamfara State, Nigeria. **Method**: The device enlarges and registers image transparency at optional scales to collect primary data while secondary data used consists of pre-existing data online, in textbooks, journals, etc. The mapped details recorded from projected image registered on a topographical base map were mapped and used to define the drainage basins, sub basins and features for morphometric analyses. **Findings**: Bakolori Dam reservoir was the most prominent change detected with streams/rivers outflow that recorded decrease in the total drainage area from 20, 803.30 km$^{2)}$ (Image-A) to l7, l39.50 km^2 (Survey map -B). The values of Image-A Stream order indicate 4th order matured basin and the analysis of bifurcation ratio (Rb) is of low value between 0.14-0.68. This was due to the attribution of less structural disruptions which have not impacted the drainage pattern. Index of drainage Density (IDD) values of 2.50-8.10 (10^{-3}) in the sub-basins show low basic complexity within the terrain sub-basins, which is an indication of high vulnerability to erosion. Drainage density (Dd) shows low mean values of 0.227, which is an indication of the existence in the sub-basins of high permeable subsurface materials under sparsely covered vegetation with average relief that is prone to high erosion and gives the computative measurement of the topography analysis and high runoff potential. Stream frequency (Fs) shows high figures, 5.8-14.0 (10^{-3}) in the sub-basin, which is reflective of more captured streams using image. This also shows permeable geology, numerous tributaries and ephemeral streams. Length of over land flow (L) of 1.43-14.29 and T value of 3.26 indicate that the values of T is dependent on the soil texture of porous composition of the basic geology. Form factor (F) shows sub-basins having low F figures of (A) 0.03-0.025 to (B) 0.03-0.025, which is indicative of pervious geology, average relief with few stream flows of lower period and high major flow of higher duration prevails and does not cause elevated peak flows. Circularity ratio (Rc) figures, (A) 0.03-3.14, and (B) 0.78-3.14 approach one (1), which shows that the basin is matured due to their compact and near circular shape. Therefore, it gets confined for even infiltration and it takes considerable time for overflow to reach basin outlet. The elongation ratio (Be) analysis shows that the basin has high Re figures from 153.34-1030.32 with equal high infiltration capability and low runoff. The basin topography of the sub-basins is over 40/m estimates, which indicates high water infiltration and gravity flow with low runoff conditions. **Conclusion:** The implication of Rc figures approaching one (1) or unity is that, the basin is matured and in state of equilibrium, of compact shape and promotes synchronization of tributary flows. Hence, shorter duration for stream flow to reach the basin outlet. It also promotes high and rather sharp peak flows resulting from elongated basins.

Keywords: Basin morphometry, Hydrologic mapping, Image, Landforms characteristic, Landsat MSS

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1. Introduction

Du Prez and Berber (1965) stated that there have not been inadequate statistical data on the underground and surface water resources in the region to accurately estimate its reserve, although, the basement complex rocks, rivers and streams are now known to have prolific water especially during wet season. The water problem is primarily related to the complexity of problems arising from temporal dry season and its location in the semi-arid zone or Sudano-Sahelian region. This factor together with poor water resources assessment, planning and management of the Sokoto-Rima River complex to discharge an average of 4,467.36 million litres per day in the rainy season to less than 4.56 million litres per day in dry season and this dismal condition results in acute shortage observable in the area (Fig. 1).

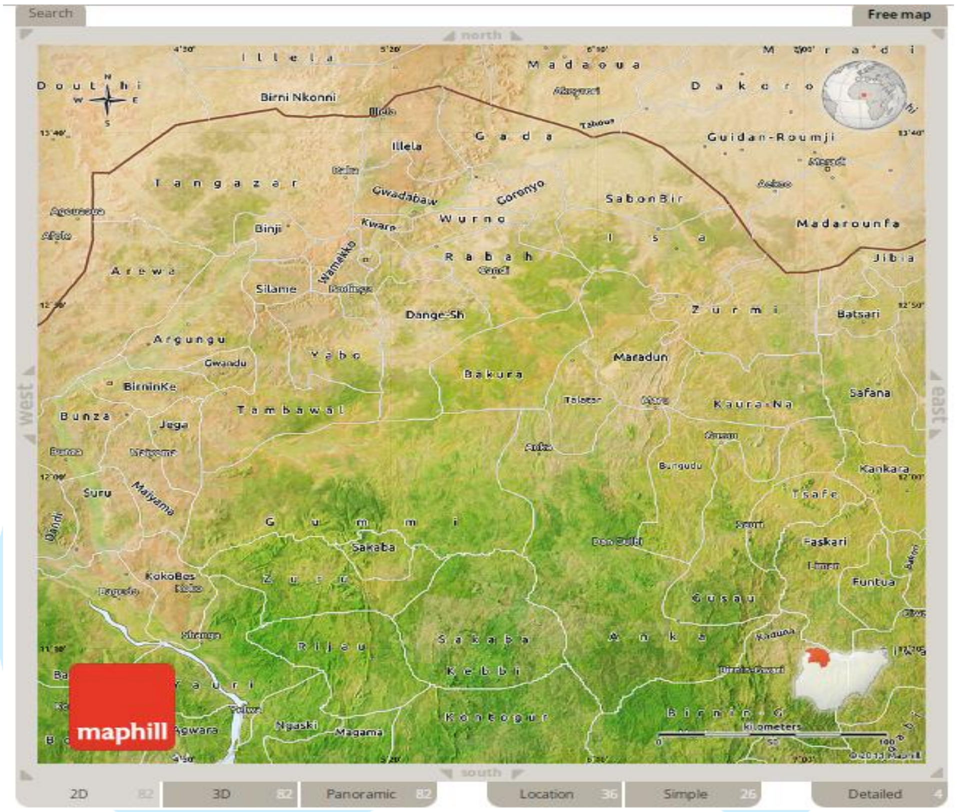

Fig. 1 Map of Talata Mafara and Environ [***Source***: Modified Google Map (2023)]

The climate of the study area is characterized by two distinct seasons-dry and wet. The area experiences arid climatic conditions with a long dry season from October-May and a short-wet season from June-October. The average annual rainfall is about 629mm, which usually occurs in short duration. The rainfall is mostly conventional and falls usually in the afternoon. The average annual temperature is about 35.5^{o}C. Due to the high temperatures, the area experiences high evapotranspiration rates and low humidity, which is below 45%, especially during the dry season.

The application of remote sensing in hydrological studies of surface water in Nigeria has not be fully realised or benefited from interpretation of remotely sensed data using manual and or digital software analyses. In view of the unavailability of useable maps in most developing countries and the vital roles of hydrologic mapping in the economic development of any nation, and considering the fact that the status of mapping is still low in Nigeria, coupled with the huge cost of acquisition and maintenance of mapping equipment, the potential application of satellite remote sensing for the analysis of water resource in Talata Mafara, Zamfara State was examined. Thus, data characteristic of the area was collected based on manual analysis of satellite image. This is to accurately map the spatial and temporal pattern of the resource in order to monitor and predict the rate at which the renewable resource is being depleted or replenished.

1.1 Objectives of the Study

This study used satellite image to generate, analyse and present hydrologic and other map data in the study area. It involves measurement of stream properties to evaluate parameters (catchment characteristics and measurement of intensity of dissection). The specific objectives include;

i. To use Landsat Multi-Spectral (MSS) data for hydrologic mapping using manual analysis techniques to map the catchments area, drainages networks for evaluation of morphometric data to infer the basin and landforms characteristics.

ii. To identify surface hydrological units based on the analyses, ancillary data to draw inferences on the geologic and geomorphologic features and processes in the area.

2. Empirical Literature

The review is based on the following subsections:

2.1 Remotely Sensed Data

Das and Mukhejee (2005); Reddy et al (2004); and Mesa (2006) 'applied high resolution spatial satellite data of infrared wavelengths radiation corrected for analysis, classification, and presentation of hydrologic and geomorphic properties and parameters". Ejemeyovwi and Ohwo (2015) worked in this area for hydrological baseline studies using this methodology. Also, Ejemeyovwi carried out Landuse / landcover mapping of Asaba, Delta State, Nigeria, between 1996 and 2015 using Landsat TMand Arc view software in the analysis. Additionally, Atubi, Awaretefe, and Ashima (2018) examined the features of landuse and land cover in the Niger Delta city of Warri. These studies outlined the many categories of landuse and landcover in terms of the composition of the land. Forthermore, Ejemeyovwi, Ashima and Akpovwovwo (2021) utilized remote sensing image with GIS software to map the prevalence of malaria in Abraka, Delta State, Nigeria.The land area was successfully divided into high, medium, and low infected areas using SPOT and Landsat ETM satellite image data and ArcGIS software. In addition, Ejemeyovwi, & Ashima (2020 a & b) employed remote sensing technology using multispectral data to map the lineament patterns, as well as utilized them for groundwater targeting in North West of Talata Mafara, Zamfara State, Nigeria. Additionally, in Udi Awgu Cuesta, South Eastern Nigeria, Ejemeyovwi (2020 c) determined drainage basin morphometric data and displayed the influence of landform characteristics using Nigeria Survey topo map aerial photos, Landsat ETM+, Digital Elevation Model (Aster-Linder DEM), and Archydrowizared GIS software. Based on remote sensing data and a GIS technique, Ejemeyovwi (2020 d) investigated Hortonian laws utilizing bivariate relationships with basin morphometric data in Udi Awgu Cuesta, South Eastern Nigeria. In the field of climate change, Ejemeyovwi. & Ashima, (2020 e) investigated the implications and consequences of global warming in Warri, Nigeria, while Ejemeyovwi (2020 f) used remote sensing and GIS to map the drainage basin in Udi-Awgu Cuesta, South Eastern Nigeria.

The spatial resolution is sufficient for geomorphic analysis, helpful in basin morphometric research, and satellite pictures are accessible at small scales of 1:250,000 and higher, using this approach. Furthermore, the extent of major flood inundation and the drainage network were thus mapped and analyzed from images with increased ground resolution, particularly with Landsat-TM (30m), Landsat-ETM+(30m), SPOT HRV (high resolution visible (32m) and HRV l0m), Ikonos image (3.2m) panchromatic (0.8m), Quick bird (2.4m) panchromatic (0.6ni), and Worldview (the world's highest resolution satellite) 0.5m resolutions. At ground receiving stations, they offer large-to-small-scale pictures that have been enhanced and preprocessed to account for the curvature of the earth and air attenuation. This improves the enhancing presentation (pictorially) for a sharper articulation of the landscape features in the image.

Remotely sensed data and applications of major works carried out on morphometric analyses in Nigeria are as follow: Ebisemiju (1976, 1978) used map of 1:50,000 scale and observed that the Nigeria drainage network analysis is based on blue lines that gives wrong picture of the drainage network and also stated that the mean field exterior drainage link length is found to be less depicted while aerial photograph gives true picture of the terrain. Odemorho and Ejemeyovwi (2008) and Ejemeyovwi (2014) used topographical map of 1:50,000 and ETM/DEM images for drainage network analyses based on ground portrayal, and found that the blue lines depict 18% less details and aerial photographs also give true picture of the true drainage network of the terrain.

2.2 Geologic Mapping and Geomorphologic Indicators

The underlying geology, rainfall, exogenic, endogenic geomorphic, and local dynamics all play a role in how a drainage basin develops. At higher elevations, the drainage pattern of the basin is sub-dendritic, whereas at lower elevations, the drainage is parallel to subparallel and radial. According to Strahler (1964), river basins are categorized based on drainage orders with at least third order basins (for its maturity and equilibrium) in the examination of linear, relief, and areal morphometric features. The geologic mapping and geomorphologic indicators are basic segmentations used in literature review as follow: Vijoen and Vijoen (1975) showed that post wet season image of enhanced Landsat band(s), generate good image for desired results of detailed interpretation, classification and mapping. According to Srinivasan, (1988) the data obtained from the image result from the recorded varying radiation from the land surface: that is, the aggregate refection of the different rock types, features, structures, vegetation, water bodies etc. and manual mapping applied using basic elements of interpretation techniques; colour, tone, texture, pattern, site and association (especially the varying shades of colours corresponding with the units is used to identify them. For this research, the rock classification and naming of the local rock types according to Oyawoye (1970) and Kogbe (1976) was used.

The distinctive shape and character of the landform are attributed to the dominance of a particular feature and structure captured by the image as a result of a particular process in contemporary environmental studies of the surface features of the terrain (Severgear, 1995), and their outline typically persists to the limit of the lithologic units. In order to further infer the geomorphic boundaries, a discontinuity defined by a break in slope and indicated as a visible color border is employed. The map shows the common symbols used to symbolize these units, and the geomorphic analysis helped with the interpretive mapping process.

2.3 Conceptual Framework

Remote sensing model and the concept of basin morphometry are adopted for this research study. This is to give insight and understanding of the remote sensing components involved in electromagnetic radiation that passes through the atmospheric medium for image acquisition using satellite methodology. The process involved in data generation for basin morphometric studies are explained as follow:

2.3.1 Remote Sensing Model

The model involves electromagnetic radiation (EMR), the carrier of light energy from the emitted source(s). The sun is a passive source of EMR as its illumination is during the day while some other active sources of energy (e.g Radar) provides light energy day and night. The emitted radiation (incident energy) strike a target (object) and reflect back (reflected energy) through atmosphere intervening medium, subjected to scattering, absorption and finally transmitted to sensor mounted on satellite orbit platform. In the entire process, energy is lost.

Thus, **Total Incident Energy (IE)** = Reflected Energy (RE) + Absorbed Energy (AE) +Transmitted Energy (TE).

Therefore, IE = RE+AE+TE, expressed in % (1)

And, IE= Reflectance + Absorbance + Transmittance (2)

In solid state physics, Transmittance = 0 and if Total Energy = 1

Thus, Reflectance = 1- Absorbance (3)

2.3.2 Basin Morphometry

Horton (1945) developed the idea of basin morphometry to describe the shape, form, or configuration of the basin quantitatively and accurately in order to comprehend basin features and their connections to the hydrological performance or response of a drainage basin (Goudie *et al.*, 1981). It offers a framework for precisely defining, comparing, and contrasting the basin morphological traits (within and between basins). and "in order to establish the relationship between specific morphometric linear properties (stream length, stream slope, and stream number) and basin order, from which the laws of drainage composition are derived, the interrelationship of basin morphometric properties that are examined in two major ways are expressed by various laws".

The bivariate link between the planmetric (linear), areal, and relief characteristics of a basin of the same order is examined. In order to demonstrate certain features of regularity between morphometric qualities and hydrological processes, Horton (1945) developed a number of morphometric rules. The hydrological maps, the characteristics of each sub-basin, and the channel network analysis are used to construct the linear, areal, and relief features of the basin. Table 1a and 1b include data on morphometric characteristics and parameters that were developed or assessed using the appropriate mathematical connection or equation for the qualities.

Table 1a Morphometric Properties Definition/Expression

Properties	Definition
Cumulative (∑L) of Stream	Summed Total length of streams of all order
Perimeter (P)	Total length of Streams of order u. LNu Measured basin peripheral limit
Number of streams (N)	Calculated from the total number of streams of order *u*
Basin Area(A)	This area of the basin surface projected into the horizontal plane of map
Stream order	Sequence of number in a hierarchy order of magnitude assigned to tributaries and the main river
Basin length (LB)	The length of the straight line from the south of the basin to the most distant basin perimeter point
Basin shape (BS)	The planimetric shape is the circle or pear-shape standard figure of
Bifurcation	This is ratio of no of stream segment of order u to the ratio of next Stream segment

Table 1b Morphometric Parameters and their Mathematical Expressions (Catchment characteristics Formula)

Parameter	Mathematical Expressions
Circularity (Shape) (Rc)	4irA/P2
Form Factor (Rf)	A/(Lb)2
Basin Elongation (Re)	(2/Lb) XA/31A/πV
Texture ratio (T)	N(1/p)
Ruggedness no (Rn)	Bh x Dd
Drainage Density (Dd), (Dd)	L/A
Stream Frequency (Fu)	N/A
Index of Drainage Density (Id)	Dd x Fs
Basin Relief (Bh)	Bhmax- Bhmin
Length of Overland Flow (Lof)	I/2Dd
Constant of Channel Maintenance (C)	Km^2/km
Bifurcation ratio (Rb)	NUINuH

3. Research Method

The research work emphasizes the analysis of Landsat image as the primary data source and ancillary data based on work done in form of journal publications, textbooks and online materials constitute secondary sources of data.

The data obtained from the image result from the recorded varying radiation from the land surface; that is, the aggregate reflection of the different rock types, features, structures, vegetation, water bodies etc. The data sources employed for this study and their characteristics are as follows: The Landsat 1 MSS FCC+VE image of scale 1:100,000 dated 2020 with acquisition source Code Eros Data Centre Sioux USA- B-12401-1023,1800 hydrologic bands 5, 6 and 7 were used. Federal Survey topographic maps at a scale of 1:50,000, Federal Ministry of Mines geologic maps, additional information about the area from scholarly works, weather information from meteorological stations in Lagos, the region's capital, and Procom 2, a specialized projection compositor program. According to the Gregory Geosciences Procom 2 manual from 1984, the device projects photo transparencies over the base map using selectable scales. To correspond with an area with consistent characteristics, rocks, lineaments, and hydrologic features are delineated and classified into recognized categories. To planimetrically register the projected image onto a topographical base map, the satellite image is enlarged. "The basic elements of interpretation are used to delineate the boundaries between the various units in the interpretative process and are limited, exclusive and exhaustive in a domain separated by a discontinuity in the range of observed properties to define the rocks unit, structures, water body, etc. (class)". The mapped rocks and lineament identification are carried out within the concept of geologic mapping with reference level, as geologists also identified other water bodies and their boundaries with identifiable colour. The geologic mapping, geomorphologic indicators, ground truthing are basic identification framework used in hydrologic mapping. "It has been established that unless ground truth is available, image basic identification elements tones and textures have the lowest relative confidence as indicator of the surface parameters in an enhanced images". Therefore, pre and post – fieldworks were undertaken to confirm mapped units and features. In the field, rock and soil samples were collected with structural on rocks observation made to include hydrology and vegetation characteristics. In the laboratory using satellite image, only data on geology and geomorphology were mapped together with lineaments for presentation.

4. Results

The mapping and identification of rock types, structures, etc. aided hydrologic mapping and the hydrologic generated maps shown in Fig. 2a & 2b.

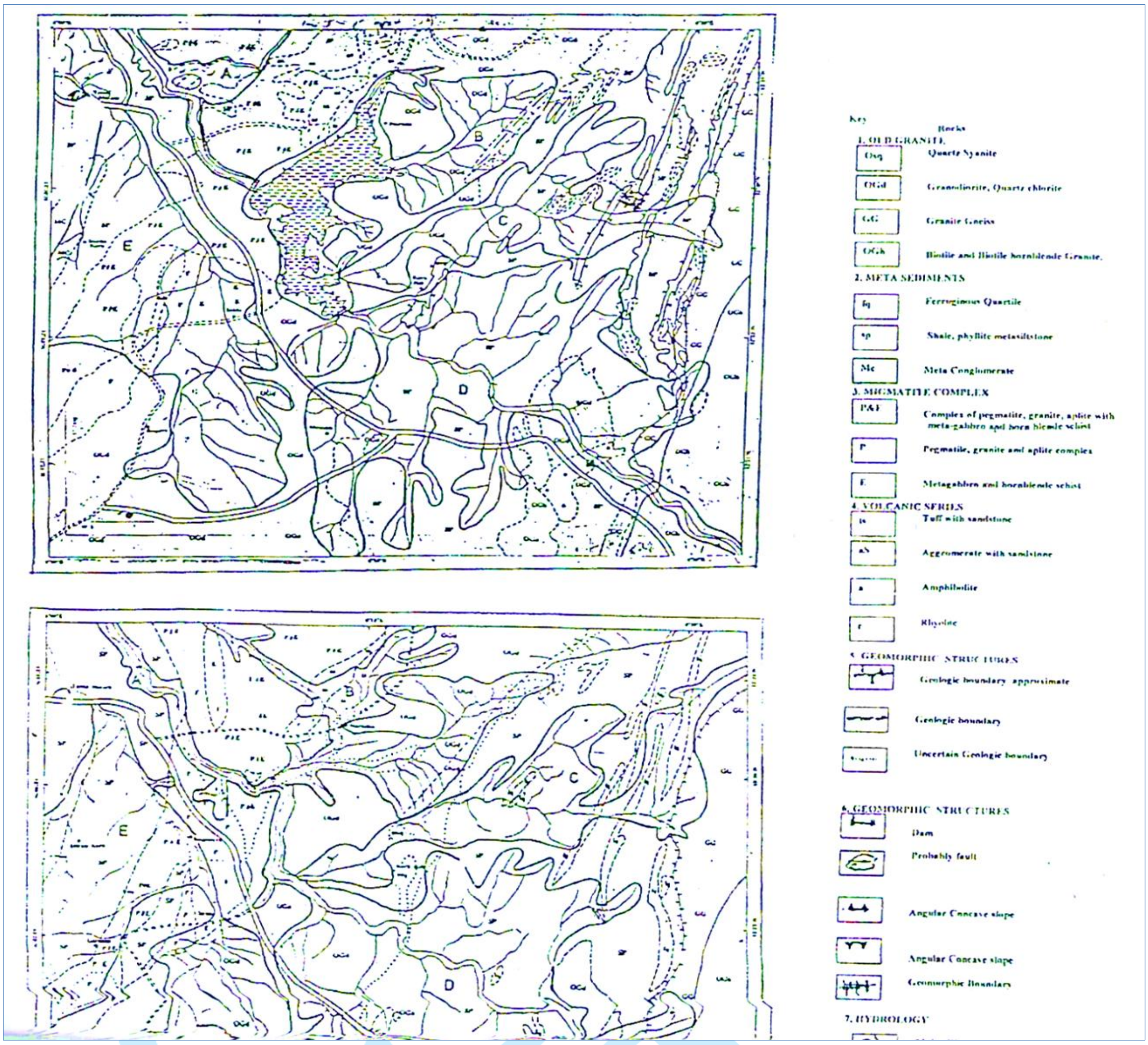

Fig. 2a, b Hydrologic generated Maps Landsat and Nigerian Survey Data

The data generated from standard equations employed in the morphometric data are shown below in tables 3 -7 for measured properties and determined values of parameters for Landsat MSS image (A) and Nigeria Survey topographical Map (B) in the area are presented as follow:

Table 3 showing the measurement lengths (1) of circumference of stream and calculated area (A) of basin

(A) LANDSAT IMAGERY PRODUCED MAP DATA		
Watershed	1(km)	A = (km^2)
A1	45.5	517.56
B1 (Reservoir)	140.0	4900.00
C1	900.0	2025.00
D1	162.0	6561.00
E1	112.00	3136.00
Total (watershed)	∑L=1359.90	∑A=17139.56

(B) GEOLOGICAL SURVEY MAP DATA		
Watershed	1(km)	A = (km^2)
A2	46.0	529.00
B2	150.0	5625.00
C2	140.0	4900.00
D2	165.0	6806.25
E2	108.5	2943.05
Total (watershed)	∑L=609.50	∑A=20803.30

Table4 Showing the sum of stream length (∑L)

(∑L) LANDSAT MAP (km)	
Watershed	(∑L)
A1	18
B1	106.0
C1	90.5
D1	228.5
E1	166.0
Total (watershed)	∑∑L=609.0

(B) GEOLOGICAL SURVEY MAP DATA	
Watershed	$(∑L)^2$
A2	24.5
B2	135.0
C2	114.0
D2	220.0
E2	172.5
Total (watershed)	∑∑L=666.0km^2

Table 5 Showing data on stream order (U)

(A) LANDSAT IMAGERY PRODUCED MAP DATA

Watershed	Number of stream segment (Nu)				
	1^0	2^0	3^0	4^0	$\sum x$
A1	1	2	-	-	3
B1 (Reservoir)	28	15	4	1	48
C1	20	14	3	1	38
D1	37	22	3	-	68
E1	24	16	4	2	44
$\sum y$	110	75	14	2	

(B) GEOLOGIC SURVEY MAP DATA

Watershed	Number of stream				
	1^0	2_0	3^0	4^0	$\sum x$
A2	3	1	1	-	5
B2	33	1	1	-	5
C2	22	16	1	-	39
D2	40	25	6	2	78
E2	31	20	23	4	78
$\sum y$	120	92	33	6	

Where $\sum x$ = Total No. of Stream order segment in the Watershed

Table 6: Show the catchment characteristics

(A) LANDSAT IMAGERY PRODUCED MAP DATA

Watershed	RC	BE	K	F
A1	3.14	153.34	4.0	0.25
B1 (Reservoir)	3.14	242.15	4.0	0.25
C1	0.03	273.0	3.93	0.03
D1	3.14	1030,32	4.0	0.25
E1	3.14	819.21	4.0	0.25

(B) GEOLOGICAL SURVEY MAP DATA

F	Watershed	RC	BE	K
0.25	A2	3.14	155.94	4
0.25	B2	3.14	918.0	4
0.03	C2	0.78	821.1	4
0.25	D2	3.14	1059.3	4
0.25	E2	3.14	568.0	4

RC = Basin Circularity, F= Form Factor BE = Basin Elongation and K= Lemmiscate

Table 7: Shows the intensity of dissection

(A) LANDSAT IMAGERY PRODUCED MAP DATA

Watershed	DD	FS	ID	L
A1	0.035	5.8×10^{-3}	5.01×10^{-4}	14.29
B1 (Reservoir)	0.025	9.7×10^{-3}	3.8×10^{-4}	2.0
C1	0.44	8.6×10^{-3}	8.1×10^{-3}	11.36
D1	0.35	10.4×10^{-3}	2.5×10^{-4}	1.43
E1	0.014	14.0×10^{-3}	5.01×10^{-3}	9.43

(B) GEOLOGICAL SURVEY MAP DATA

Watershed	DD	FS	ID	L
A1	0.046	9.45×10^{-3}	8.22×10^{-4}	10.87
B1 (Reservoir)	0.025	8.89×10^{-3}	3.08×10^{-4}	17.24
C1	0.44	8.9×10^{-3}	2.27×10^{-3}	21.74
D1	0.35	10.7×10^{-3}	2.56×10^{-4}	1.57
E1	0.014	25.5×10^{-3}	9.77×10^{-3}	47

DD= Drainage Density, FS – Stream Frequency, ID = Index of Drainage, L = Length of over land flow

5. Findings

5.1 Morphometric Data Analysis

Indicative of structural complexity, high permeability in the subsurface strata, and high erosion of the terrain are characteristics of the cumulative length of the stream (L), which has values of (A) 1359.90 km and (B) 609.50 km and (A) (Area of basin are (A) 17139.56 km2 and (B) 20803.30 km2). The values of the 4th order basin according to the stream order are (A) 1°(110), 2°(75), 3°(14), and 4°(2), and (B) 1°(120), 2°(92), 3°(33), and 4°(6). Additionally, the bifurcation ratio (Rb) analysis reveals low values of (A) 0.14–0.68 and (B) 0.18–0.76. This is explained by the features of less structural disturbances, which have also prevented the drainage pattern from being altered. The sub basins' low structural complexity and high sensitivity to erosion are shown by the Index of Drainage Density (ID) values of (A) 2.50-8.10(10-3) and (B) 3.08-9.77(10-3) in the sub basins. The drainage density (Dd) indicator shows low values of (A) 0.014-0.44 and (B) 0.014-0.44 to demonstrate the presence of sub-basins with highly permeable subsurface materials beneath sparse vegetation cover and medium to relief that is subject to high erosion. It also provides a numerical measurement of the dissection of the landscape and high runoff potential. Stream frequency (Fs) indicate high values in (A): 5.8-14.0 (10^{-3}) and low values in (B): 8.45-25.5 (10^{-3}) in the sub basin and is indicative of more captured using remote sensing than those obtained in the geological survey maps. The reduction in number is due to cartographic abstraction for aesthetic presentation of the map. This also indicates permeable geology, numerous tributaries and ephemeral streams. The length of the overland flow (L) (A) 1.43-14.29 and (B) 1.57-47 values of 3.26 and 4.24 demonstrate how the T values rely on the soil's permeable composition and texture. Form factor (F) analysis revealed sub-basins with low F values between (A) 0.03-0.025 and (B) 0.03-

0.025, indicating permeable geology, medium relief, and high main flow that predominates but does not lead to large peak flows. Circularity ratio (Rc) values of (A) 0.03-3.14 and (B) 0.78-3.14 are close to one (1), indicating that certain basins are mature because of their compact and almost circular forms. As a result, there is room for consistent infiltration and it takes a while for extra water to drain from the basin. The compact geometry of the basin enhances synchronization of tributary flows since the circularity ratio is close to one (1) or unity. Stream flow will therefore arrive at the basin exit in less time. Additionally, it encourages large and very acute peak flows rather than hydrograph peaks that are softened as a result of extended basins. Additionally, this is influenced by the local geology, slope, and land cover. The locations exhibit high Re values between (A) 153.34-1030.32 and (B) 155.94-1059.3, which are associated with strong infiltration capacity and low runoff, according to analysis of elongation ratio (Be). Actual estimations of the subbasins' basin relief, which exceeds 40 m, show strong gravity water flow, high infiltration, and low runoff conditions, which are consistent with the findings of works by Reddy *et al*. (2004) and Koul *et al*. (2007).

5.2 Landforms Characteristics

Five concentric basins (A to E) that span over much of the land and are numerously dissected are the characteristics that may be found there. large bifurcation ratios, large first, second, third, and fourth ordered stream cumulative lengths, and high drainage densities are all connected with these landforms. The permeable geology, moderate to nearly level plains, medium to low drainage density, and short cumulative lengths of third and fourth order streams all contribute to the occurrence of thick sedimentary veneers. Fadama farming and the development of ridge-valley systems dry-valley in dry season's, escarpment and undulating plateau are the results of deep weathering and multiple gentle slope dissections under the influence of gravity gradient along with high drainage density and precipitation conditions of numerous streams ephemeral of yearly high valley volume water. The main geomorphic process is slope wash, which is followed by rill and proto-gully erosional processes. These elongated and thin geomorphic units are seen in conjunction with dissected ridges in all of the sub-basins. The fluvial deposits on the rolling plains, foot slopes, and narrow valleys on the main valley floor are the result of worn and eroded loose sediments carried from highland locations. In detaching and carrying the eroded materials by fluvial processes and gravity fall to the lowland areas, the erosive activities and slope retreat processes at higher altitudes each contribute in their own way. On undulating plains and on the main valley floor, the sediments are mostly sandy and clayey in composition and somewhat shallow.

6. Conclusion

The methodological framework involved Landsat TM image and hinges on manual analysis to demonstrate results derived from the applications based basin morphometry using remotely sensed data. The data on the image produced map are compared with those generated from the Survey map (1966). (Fig 2a & b) and Tables 3 to 7 and it has been observed that the hydrological patterns are different. The reservoir Dam Bakolori is the most significant and prominent together with its stream/river flow pattern are either elongated or shortened due to combined effects of weathering and erosional agents which resulted in meandering as rivers tend to flow straight. There is marked decrease in the total drainage area from 20, 803.30 km^2 to l7, l39.50 km^2, in the sum of the stream

lengths due to adjustment or coalescing of most rivers within the dammed area as well as reductions in the number of first and second order streams in the produced map, but with increment in the second and third order segments in line with enhanced satellite data used by various researchers such Reddy et al (2004); Das and Makherjee (2007) and Koul et al (2007) for morphometric studies, this study further explores manual enhancement techniques and presented associated landforms in the basin.

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Declaration of Conflict

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