

## PAPER 144 – ASSESSMENT OF THE SIGNIFICANCE OF GIS-BASED WATERSHED ANALYSIS FOR EFFECTIVE WATER RESOURCES MANAGEMENT

M. I. Alfa<sup>1\*</sup>, A. Ismail<sup>2</sup>, R. E. Daffi<sup>1</sup>, H. I. Owamah<sup>3</sup>, D. B. Adie<sup>2</sup> and B. Abdulraham<sup>1</sup>

<sup>1</sup>Department of Civil Engineering, University of Jos, Jos, Nigeria

<sup>2</sup>Department of Water Resources & Environmental Engineering, Ahmadu Bello University, Zaria, Nigeria

<sup>3</sup>Department of Civil Engineering, Delta State University, Abraka, Oleh Campus, Delta State, Nigeria

\*Email: meshilalfa@gmail.com

### ABSTRACT

Traditional techniques have been used over the years for the determination of watershed characteristics and runoff. Technological advancements in the area of remote sensing and Geographic Information Systems have proven to be more effective techniques that can produce more accurate results, save time and remove most human errors. The efficiency of using GIS-based techniques for watershed analysis was explored in this study, using the Galma River catchment as a case study. Characteristics such as Area, perimeter, time of concentration, length of overland flow, longest flow path, time to recession, and peak discharge amongst others were determined using traditional manual techniques and GIS-Based techniques. The results from both methods were compared using the student's *t*-test. In addition to a strong correlation of 0.98 observed for results from both methods, the results showed that the difference in the estimates from both techniques was not statistically significant at a 95% confidence level since the *t stat* (1.528) is less than the *t critical-two tail* (2.120) and the *P (T<=t) value* of 0.266 is greater than 0.005. It was concluded that the GIS-Based techniques for watershed analysis are reliable, accurate, and time-saving methods that should be explored in Water resources studies.

**KEYWORDS:** Discharge, Flood, Gamji catchment, GIS, Watershed analysis, Water resources

### 1. INTRODUCTION

Water resources management-related problems are central determinant for the attainment of a number of the Sustainable Development Goals (SDGs). Accurate determination of watershed characteristics and the resultant runoff from them is essential for optimum design and planning of water resource infrastructure (Boulos, 2017). While traditional technique has been used extensively over the years for delineation of watershed, determination of the characteristics and estimation of design flood especially for ungauged catchments, the method has become greatly undesirable. This is because of the amount of time spent, the great propensity for human errors amongst other factors. The advancement of technology especially in the area of remote sensing and Geographic Information systems have provided more effective techniques that can produce more accurate results, save time and remove most human errors (Dongquan *et al.*, 2009; Widaningrum *et al.*, 2015; Radwan *et al.*, 2017). Notwithstanding the aforementioned advantages of the GIS-based system, it becomes necessary to compare the output with that of the traditional system since it is significantly dependent on remotely sensed data. The efficiency of using GIS-based techniques for watershed analysis was therefore explored in this study, using Galma River catchment in Kaduna State, Nigeria as a case study.

### 2. THEORETICAL ANALYSIS

The comparison of the two methods was based on the morphometric and hydrologic characteristics of the Galma basin. The various mathematical principles are summarized in Table 1.

Table 1: Methods used for Estimation of Morphometric Parameters

Parameter	Symbol	Formula	Reference
Area	A	GIS Analysis	-
Perimeter	P	GIS Analysis	-
Longest Flow Path	$L_{fp}$	GIS Analysis	-
Basin Slope	S	GIS Analysis	-
Stream Number	$N_u$	GIS Analysis	Horton (1945)
Stream Length	$L_u$	GIS Analysis	Horton (1945)
Mean Stream Length	$N_{um}$	$L_{um} = L_u / N_u$	Strahler (1964)
Stream frequency	F	$F = \Sigma N_u / A$	Horton (1945)
Drainage Density	$D_d$	$D_d = \Sigma L_u / A$	Horton (1932; 1945)
Length of Overland Flow	$L_o$	$L_o = 1/2 D_d$	Langbein & Leopold (1964)
Form factor	$F_f$	$F_f = A/L_b^2$	Horton (1932)
Compactness coefficient	$C_c$	$C_c = 0.282038P/A^{0.5}$	Horton (1945)
Elongation ratio	$R_e$	$R_e = 2\sqrt{(A/n)/L_b}$	Schumm (1956)
Circularity ratio	$R_c$	$R_c = 4nA/P^2$	Miller (1953)
Time of Concentration	$T_c$	$T_c = 0.000323L_{fp}^{0.77}S^{-0.385}$	Kirpich (1940)
Time to Recession	N	$N = 0.84A^{0.2}$	Mustafa & Yusuf, 2012

### 3. MATERIALS AND METHODS

#### 3.1 Study Area

The area for this study is the Galma River Basin in Kaduna State, Nigeria (Figure 1). It is bounded by Longitudes 337152.18 - 473052.91 m and latitudes 1156258.19 - 1262840.39 m in UTM Zone 32. The Galma river drains parts of Kaduna, Kano and Katsina states with a significant portion of the catchment area (92.99%) in Kaduna State, 4.54% in Kano state and 2.47% in Katsina state.

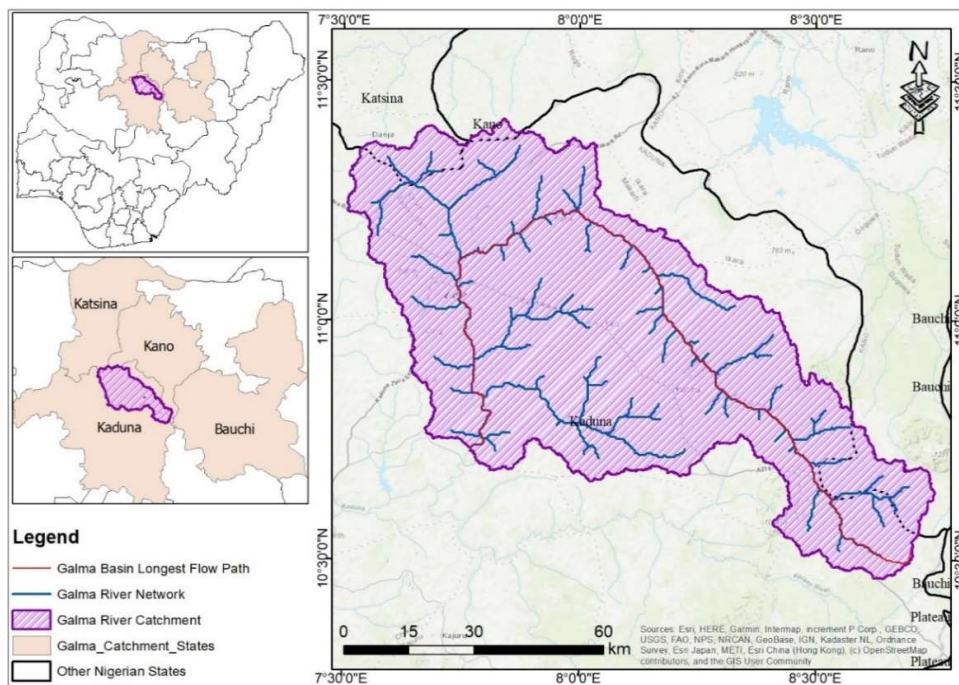


Fig 1: Map of Nigeria showing the Study Area

### 3.2 Determination of Morphometric Characteristics of the Catchment

The equations summarized in Table 1 were used to determine the respective morphometric characteristics of the watershed. These methods have been applied previously to other watersheds such as the Ofu River catchment in Kogi State, Nigeria (Alfa *et al.*, 2019).

### 3.3 Method of Determination of Peak Discharge

The rational equation method was applied for the estimation of the peak runoff for the galma river catchment. The rational equation has been described previously by various authors (Wang *et al.*, 2011; Wang *et al.*, 2012; Baiamonte, 2020). The method was recommended in and has been comprehensively described in the Federal Republic of Nigeria Highway Design Manual Part 1 (2013): Volume IV (Drainage Design). The rational equation is expressed by equation 1.

$$Q = 0.278CIA \quad (1)$$

In which, C is the composite runoff coefficient of the catchment, I is the rainfall intensity expressed in millimetres per hour for a certain time of concentration and A is the catchment area in square kilometres. The runoff coefficient, C was estimated following the methods described previously in Alfa *et al.*, (2018). It combines the terrain slope (Figure 2), the land cover characteristics (Figure 3) and soil characteristics (Figure 4) to develop a composite runoff coefficient for the entire catchment.

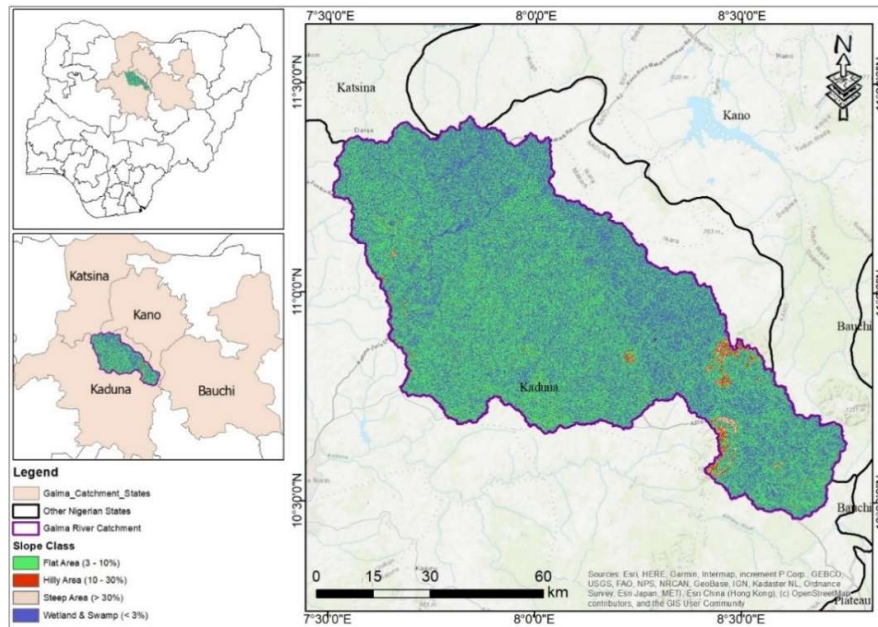


Fig 2: Terrain Slope Map of the Study Area

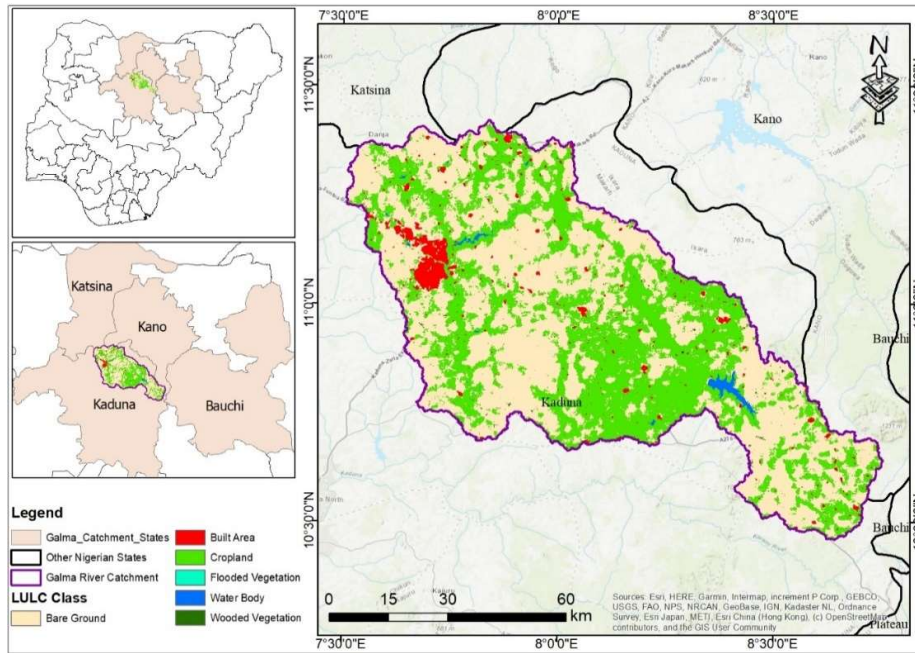


Fig 3: Land use/Landcover Map of the Study Area

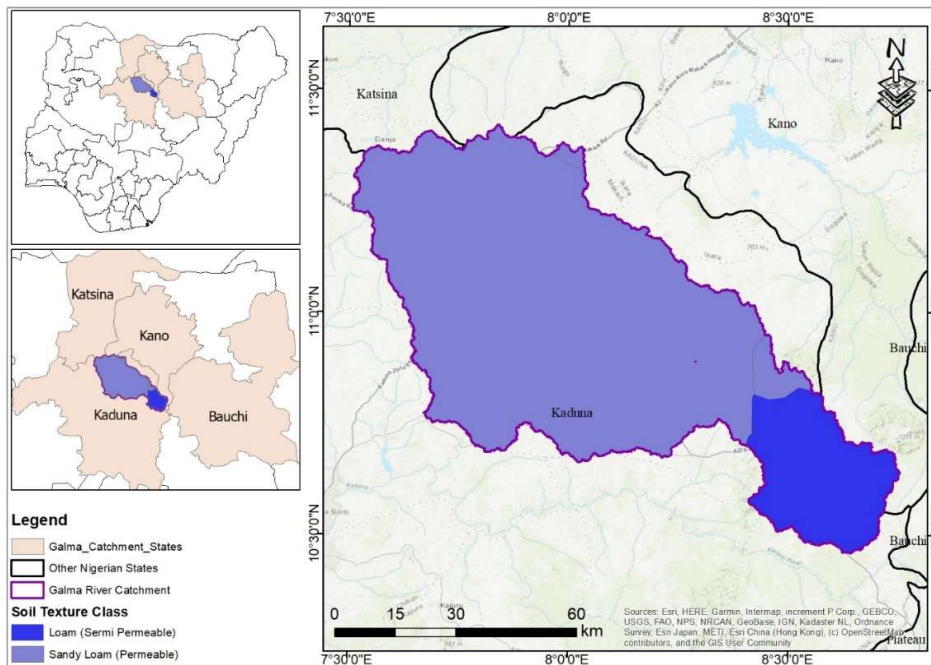


Fig 4: Soil Map of the Study Area

The slope was generated from the Shuttle Radar Topographic Mission digital elevation model (SRTM DEM) obtained from the *earthexplorer* portal of the United States Geological Survey, the land cover data was obtained from Environmental Systems Research Institute (ESRI) while the soil map was extracted from the FAO's digital soil map of the world.

### 3.4 Statistical Analysis

The student's t test was used to compare the catchment characteristics obtained using both methods at 95% confidence level.

## 4. RESULTS AND DISCUSSION

#### 4.1 Runoff Coefficient

The composite runoff coefficient for galma river catchment is presented in Table 1. The composite value of 0.57 was obtained.

Table 1: Runoff Coefficient for Galma River Catchment

Class	Area (m <sup>2</sup> )	Runoff Coefficient, C	
		Value	Composite
<b>Land use/Landcover</b>			
Water Body	43.97	0.3	0.18
Wooded Vegetation	12.44	0.05	
Flooded Vegetation	0.14	0.3	
Cropland	2,710.00	0.015	
Built Area	205.73	0.3	
Bare Ground	3,591.50	0.3	
<b>Slope</b>			
Wetland & Swamp (<3%)	2,828.68	0.05	0.09
Flat Area (3 - 10%)	3,584.12	0.11	
Hilly Area (10 - 30%)	107.58	0.2	
Steep Area (<30%)	26.19	0.3	
<b>Soil</b>			
Sandy Loam (Permeable)	5,562.67	0.1	0.12
Loam (Semi Permeable)	1,001.12	0.2	
<b>Catchment Value</b>			<b>0.38</b>

#### 4.2 Morphometric and Discharge Characteristics

The morphometric and discharge characteristics of the galma river catchment are presented in Table 2.

Table 2: Morphometric and Hydrologic Characteristics of Galma Basin

Parameter	Category	Manual	GIS-Based
Area (km <sup>2</sup> )	Areal (Basic)	6,781.00	6563.795
Perimeter (km)	Areal (Basic)	451.00	807.99
Longest flow path (km)	Areal (Basic)	115.00	256.97
Basin Slope	Relief	0.02	0.04
Stream Number	Linear	673.00	149.00
Stream Length (km)	Linear	2,266.40	917.09
Mean Stream Length (km)	Linear	3.367608	6.154938
Stream Frequency	Linear	0.10	0.02
Drainage Density	Areal (Derived)	0.33	0.14
Length of Overland Flow	Areal (Derived)	1.50	3.58
Form factor	Areal (Derived)	58.97	25.54
Compactness coefficient	Areal (Derived)	1.54	2.81
Elongation ratio	Areal (Derived)	0.81	0.36
Circularity ratio	Areal (Derived)	0.42	0.13
Time of Concentration	Areal (Derived)	15.00	17.27
Time to Recession from peak	Areal (Derived)	4.90	4.87
Peak discharge	Hydrologic	3,613.99	3,498.23

Similarly, the results of the statistical comparison of the characteristics of the catchment obtained using both methods is presented in Table 3.

Table 3: Results of Statistical Analysis

<i>Statistics</i>	<i>Manual</i>	<i>GIS-Based</i>
Mean	822.7850038	720.822612
Variance	3334012.226	3004452.887
Observations	17	17
Pearson Correlation	0.980344979	
Hypothesized Mean Difference	0	
df	16	
t Stat	1.152813806	
P(T<=t) one-tail	0.132959805	
t Critical one-tail	1.745883676	
P(T<=t) two-tail	0.26591961	
t Critical two-tail	2.119905299	

The results showed that a strong correlation (0.98) exist between the catchment characteristics obtained using both methods. More so, the results showed that the difference in the estimates from both techniques was not statistically significant at a 95% confidence level since the *t stat* (1.528) is less than the *t critical-two tail* (2.120) and the *P (T<=t) value* of 0.266 is greater than 0.005. The results obtained herein corroborates previous findings on the reliability of using GIS-based techniques for catchment-wide hydrological studies that can save time and produce more accurate results (Dongquan *et al.*, 2009; Widaningrum *et al.*, 2015; Radwan *et al.*, 2017).

## 5. CONCLUSION

It was concluded that the GIS-Based techniques for watershed analysis is a reliable, accurate and time saving methods that should be explored in Water resources studies. With a correlation coefficient of 0.98 and a P-value of 0.266, it can be concluded that the results obtained from the GIS-based study can be a safe replacement for the traditional manual techniques.

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