Original Research Article

ISSUES AND APPLICATION OF LINEARIZED MODELS IN GEOMORPHIC PROPERTIES OF THE IKPA WATERSHED, NIGERIA

Abstract

Though more geomorphological researches are being conducted and previous ideas are being reviewed among geographers and earth scientists, only limited attempts are focused on coupling the relationships among geomorphic attributes on the watersheds in the Humid Tropics. These invariably induced new trends and research directions at diverging scales. This paper is guided by three specific objectives: (1) to employ the Shuttle Radar Topography Mission (SRTM) in deriving the morphologic attributes of the Ikpa Watershed (11) to assess the association and effect of discharge on basin texture, infiltration rate, length of overland flow, and rainfall amount in the Ikpa Watershed, Akwa Ibom State. (111) To describe the relationship between discharge, rainfall amount, and morphologic attributes of the Ikpa Watershed. The watershed was stratified into six sub-basins and data (rainfall and discharge) systematically generated for three months each during the dry and rainy seasons; while the topographic attributes were generated indirectly using four topographic maps. The analysis using multiple linear regression yielded a coefficient of 0.986. Also, the R square value of 0.859 implied that 85.9 percent of the proportion of variation in discharge amount of the Ikpa watershed is accounted for by the four independent variables. A comparison of the computed ANOVA result (8.469) with the Table value $(0.05)_{1/4}$ *yielded 7.7086 which implied that variation in mean discharge have significant effect on basin texture, infiltration rate, length overland flow, and rainfall amount in the Ikpa watershed. The results of the curve estimate for logarithmic (0.535), quadratic (0.930), and power (0.615) equations suggested normal predictive ability and each significant at 0.05 level. This study concluded that the dominancy of peak-flood discharge at the middle and downstream region of the watershed are directly influenced by the rainfall events and morphology of the landform.*

Keywords: Linearized models, morphology, rainfall, discharge, watershed properties.

Introduction

Geomorphology is fundamentally concerned with the Earth's surface, the physical processes that act upon the surface, and the manner in which these processes vary across space and time to create distinctive landforms (1). Over time sequence, studies on landforms and fluvial processes have been subjected to dynamic paradigms in the conceptual, theoretical, philosophical, and methodological understanding of the surficial environment. Such paradigms often reflect in and influence the various research trends and directions prevalence over a period of time as illustrated in (2, 3), and other landform experts.

Climate (rainfall and wind) often played critical role in driving the flux of solutes and mass across eco-geomorphic systems during weathering and denudational processes. In context of geography, (4) observed that the research links between climatologists and geomorphologists are not quite strong to elucidate certain ambiguity in their connection; but more work is still needed on fluvial processes and basin form to elucidate the intriguing relationships which may vary across scale (5, 6).

The effect of landscape morphology on the lithology, climate, and life had been evaluated with a view to predicting their relationship but (7) suggested that the challenges of predicting surface evolution could be averted using the conservation mass equation. (8) investigated the influence of river discharge on tidal wave propagation with specific attention to residual water level slope, using a one dimensional analytical model for tidal hydrodynamics. Their study proposed an alternative analytical approach for estimating freshwater discharge on the basis of tidal observations along the estuary.

It is obvious that the success of research in this context has the potential of enhancing the understanding of the role of the climatic variable (rainfall) and discharge in modifying the morphology of the Earth’s surface (basin texture, infiltration rate, length of overland flow) and the feedbacks among the outlined attributes. Researches in the domains are rather eclipsed or not attracting the anticipating outcome. However, one of the best quantitative methods is the use of Multiple Linear Regression Models and is essential in predicting morphologic responses to the discharge scenarios in a medium watershed as attested for in (9). It is capable of enhancing the efficacy of geomorphic disaster management plans and mitigation efforts.

According to (10) the British Society for Geomorphologists had emphasized the need to understand the changing forms of communication and present challenges of development in geomorphology over half a century. One of the major agitating issues in this research is: what are these challenges confronting recent researches in geomorphology that stimulates trend in the 21st century?

Generally, the United States National Research Council (11) identified nine grand challenges in Earth's surface processes and landforms. These are:

> "*What does our planet's past tell us about its future? How do geo-patterns on Earth's surface arise and what do they tell us about processes? How do landscapes influence and record climate and tectonics? How does the biogeochemical reactor of the Earth's surface respond to and shape landscapes from local to global scales? What are the transport laws that govern the evolution of the Earth's surface? How do ecosystems and landscapes coevolve? What controls landscape resilience to change? How does the Earth's surface evolve in the anthropocene? How can Earth surface science contribute toward a sustainable Earth surface?*" (11).

Although each of the nine grand challenges in Earth surface processes, and geomorphology, in particular, have been identified by (11) and aspects of it re-envisioned in the annual themes of the conferences by the International Geomorphological Association and symposiums of British Society for Geomorphologists as cited in (1), the most cardinal of the issues and trends in geomorphological research that formed the focus of this article are in two critical and high-priority research areas. The two areas are as follows: (**1**) Quantitative reconstruction of fluvial landform at small scale because at large scale, details are left for specification. (**2**) Interactions between landforms morphology, climate, and discharge. Each of the identified areas is enriched in scientific investigation and capable of potentially transforming the field of geomorphology. Hence there is a need to quantitatively couple and model the effect of morphology and rainfall on water discharge in the Humid Tropics of the coastal plain sand/alluvium deposits, Southern Nigeria.

Aim and Objectives of the Study

The vulnerability of the Coastal Plain Sand (Tertiary) and the Alluvium deposits (quaternary) formations to the erosion, landslide, flood and allied geomorphologic hazard could be attributed to the nature of its geology, climate, and local geomorphology. The aim of this study is to evaluate the linearized interactions among the morphologic, rainfall, and discharge characteristics in the Ikpa watershed, Nigeria. To achieve the stated aim, the following are specific objectives:

(1) To employ the Shuttle Radar Topography Mission (SRTM) in deriving the morphologic attributes of the Ikpa Watershed.

(2) To assess the association and effect of watershed discharge on basin morphology, and climate in the Ikpa Watershed.

(3) To describe the linearized relationships between discharge, rainfall amount, basin texture, and infiltration rate in the Ikpa Watershed.

Research Hypotheses

This study is guided by a null research hypothesis which states that: "*Variations in watershed discharge have no significant association and effect on basin texture, infiltration rate, length overland flow, and rainfall amount in the Ikpa Watershed*".

The Study Area

The Ikpa Watershed is located within the coastal plain sands deposits of the Tertiary and the Quaternary times. It is a fifth order basin drained by the Great Cross River Basin of

Southeastern Nigeria. The watershed composed of two fourth-orders, ten third-order with numerous second and first-order sub-basins. The area is located within the Humid Tropics with the average annual rainfall of approximately 2648 mm, usually with double maxima during July and September. Absolutely, the Ikpa watershed is located between longitude $7^{0}46^{1}34.9^{ll}$ and 8^{0} $3^{1}11.9^{l1}$, East of Greenwich Meridian and latitudes $5^{0}0^{1}3.801^{l1}$ and 5^{0} 16^{1} 49.129^{11}, North of the Equator (12, 13, 14). The basin area covers parts of Ini, Ikono, Ibiono Ibom, Itu, Uruan and Uyo Local Government Areas of the Akwa Ibom State, Nigeria.

Relief of the basin comprises undulating lowland of the coastal plains which form one of the eco-geomorphologic units in the State. To (12, 14, 15), the terrain consists of the dissected coastal plains in the middle and Northern sections (Ikpa and Obotme) with an elevation ranging between 100 – 350 meters above mean-sea level with the prevalent steep slopes traversed by ravines and gullies. At the middle part of the watershed, there are valleys with the height of 50 – 80 meters above mean sea level, and broad plains sloping gently toward the Cross River channel with elevation less than 50 meters height (Figure 1).

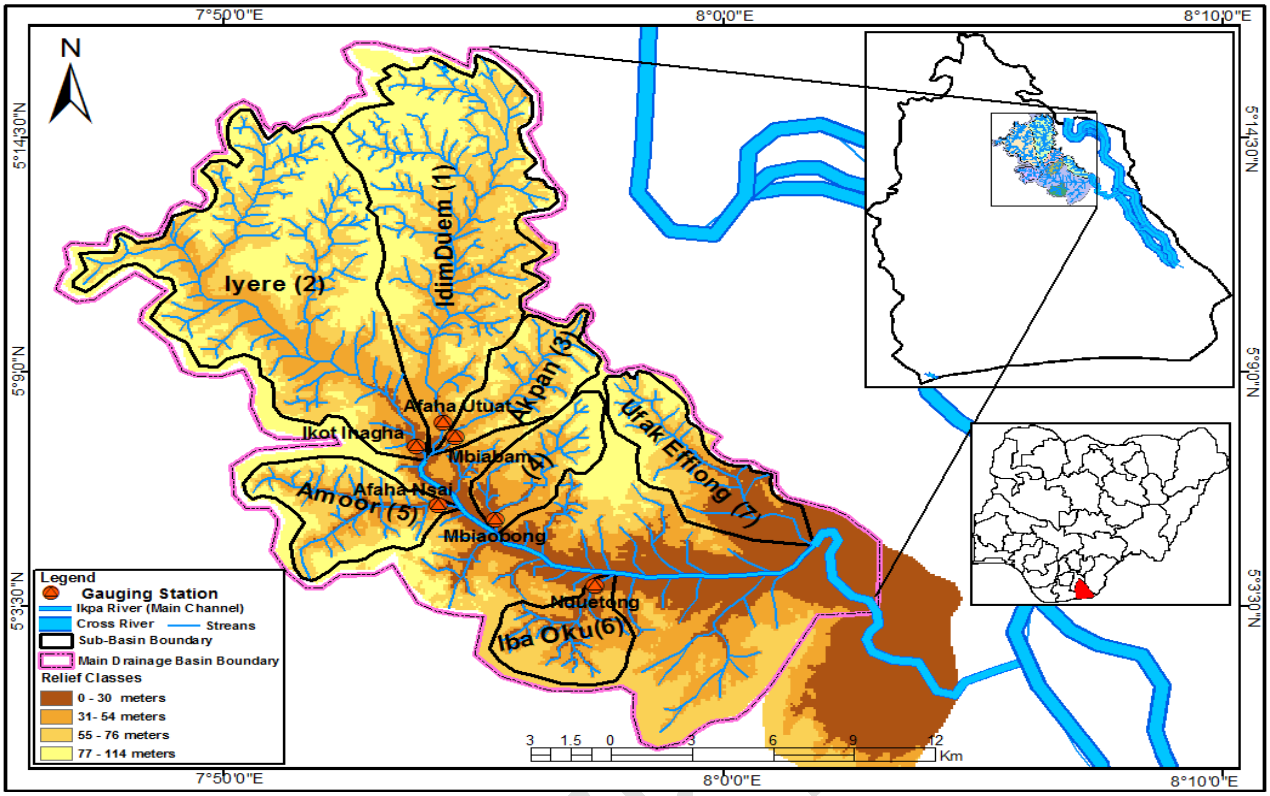

Figure 1: Location and Relief of Ikpa Watershed.

Materials and Methods

The study area was demarcated using Shuttle Radar Topography Mission (SRTM). Base on Strahler, 1952 classification scheme, two fourth-orders and four third-order sub-basins were selected using stratified sampling techniques for the determination of the morphologic attributes. The mapped area were rectified and geo-referenced in GIS environment with the help of Arc-GIS 10.2 software assigning Universal Transverse Mercator (UTM), World Geodetic System (WGS dating from 1984 and revised in 2004) and 32N Zone Projection System with ERDAS Imagine 8.5 as applicable in (15, 16). The sampled sub-basins composed {Idim Duem (1), Iyere Stream (2), Akpan Stream (3), Itam Stream (4), Amoor Stream (5), and Iba Oku Stream (6), as depicted in figure 1. The mathematical equations for computing each of the topographic parameters are summarized on Table 1.

Table 1: Summary of Selected Topographic Attributes and the Mathematical Equation.

Topographic Parameter	Mathematical Formula (Equation)	Reference
Basin Texture	$Dt = N\mu/P$; Where, $N\mu$ = Number of streams in a given order and P = Perimeter (Km^{-1})	(17)
Infiltration Number	$Ir = Dd \times Fs$; Where, Dd = Drainage density (Km) and Fs = Drainage frequency.	(18)
Length of Overland Flow	$Lf = 1/2D$; Where, D = Drainage density (Km/Km)	(17)

The velocity was measured by means of surface float using cork, for the three segments while the flow velocity was taken and the mean multiplied by 0.85 to overcome errors emanating from the effects of wind and cross-currents as recently emphasized in (9). The formulas developed in Agor cited in (14) was adopted and presented thus:

Discharge (Q) = AV. Where A = Cross-sectional Area; V = Velocity

$$\text{Cross-sectional Area} = \frac{\text{Total Stream Segment (depth)}\{a + b + c + d + e\}}{\text{Total Stream Segment}}$$

Where; a, b, c, d, and e represent average depths of the differential segments.

XY = Total width of the stream at the point of measurement. Velocity (V) = Flow Distant/Time.

Data generated from distinct sources were analyzed using linear regression models to examine the association among the dependent and independent variables; analysis of variance was used to for test of significant difference in the mean among the dependent and independent variables; t-statistic was used for test of significant difference between dependent and each independent and variable. Finally, the relationship between dependent variable (watershed discharge) and each independent variable (basin texture, infiltration rate, length of overland flow, rainfall amount) were analyzed using (linear logarithmic, quadratic) curve estimate.

Results and Discussions

The Effect of Variation in Independent Variables on the dependent Variable

The effect of mean watershed discharge (dependent variable) variation on the four independent variables was evaluated using a multiple linear regression model and the result summarized on Table 2. A coefficient of multiple determination offers a very high positive effect of 0.986. Also, the adjusted R square sustained the high value of 0.971 which implied that 97.1 percent of the variation in the mean watershed discharge is attributed to the effect of rainfall, infiltration rate, basin texture, length of overland flow. The standard error associated with model is 8.635.

Table 2: Multiple Linear Model of the Combined Effect of Mean Discharge on four Independent Variable ^{b}

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.986[a]	.971	.857	8.636

a. Predictors: (Constant), Mean_Rainfall, Length_Overland_Flow, Basin_Texture, Infiltration_Rate
b. Dependent Variable: Mean_Discharge

The ANOVA model is employed to examine the level of significant in the mean watershed discharge on the basin texture, infiltration rate, length of overland flow, and mean rainfall amount. The result summarized on Table 3 showed that the sum of squares is 2526.515. The residual associated with the model yields 74.577 while the total sum of squares of the ANOVA model is 2601.092. Similarly, the mean square offers 631.629 and the residual of the mean square value offers 4.577. The computed ANOVA value is 8.469. The Table value tested at $(0.05)_{1/4}$ offers 7.7086. Considering the results, the null hypothesis is rejected and alternative hypothesis is accepted. It is therefore declared that "*Variations in watershed discharge have significant effect on basin texture, infiltration rate, length overland flow, and rainfall amount in the Ikpa Watershed, Akwa Ibom State"*. This is an affirmation that increase in discharge pattern is associated with intra-watershed variables (notably rainfall amount, infiltration capacity of the landform, and topographic attributes that defined the flow pattern within the watershed). However, the eternal factors to this coupled variable in the model notably vegetation, sub-surface, anthropogenic interferences tend to contribute low proportion of 2.9% (see Table 2). The results is a strong affirmation of similar studies conducted by (9, 14) under the same area but with different parameters.

Table 3: ANOVA Model of Mean Watershed Discharge on the Four Independent Variables

Model		Sum of Squares	df	Mean Square	F
1	Regression	2526.515	4	631.629	8.469
	Residual	74.577	1	74.577	
	Total	2601.092	5		

a. Dependent Variable: Mean Discharge
b. Indepnedent Variables: Mean_Rainfall, Length_Overland_Flow, Basin_Texture, Infiltration_Rate

To establish the effect of each independent variable on the mean watershed discharge, a partial regression model is employed. The results of unstandardized coefficients presented on Table 4 reveals a constant negative value of (-45.775) for mean watershed discharge, 0.724 for basin texture, 12.435 for infiltration rate, 61.699 for length of overland flow, and 0.023 for mean rainfall. Similarly, the standardized coefficients yield 0.968 for basin texture, 0.257 for infiltration rate, 0.396 for length of overland flow, 0.099 for mean rainfall amount. The linearized equation is therefore modelled as following:

$$\mathbf{Y = -45.775 + 0.968x_1 + 0.257x_2 + 0.396x_3 - 0.099x_4 \ (e = 8.636)}.$$

Basin texture (x_1) exercised the highest positive effect, followed by length of overland flow (x_3), infiltration rate (x_2), while the lowest effect is rainfall amount (x_4). The test of significant using student t-test and zero-order correlations showed that only the effect of the mean watershed discharge on basin texture was significant at 0.05 level. However, the effect of rainfall, length of overland flow, and infiltration each was not significant at the 0.05 confidence level.

Table 4: Partial Regression Coefficients ^{a} and Zero-Order Correlation Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Zero-order Correlations
	B	Std. Error	Beta			
1 (Constant)	45.775	51.509		-.889	.537	
Basin_Texture	.724	.133	.968	5.444	.116	.963
Infiltration_Rate	12.435	18.519	.257	.671	.624	.104
Length_Overland_Flow	61.699	57.087	.396	1.081	.475	-.005
Mean_Rainfall	.023	.049	.099	.470	.720	.143

a. Dependent Variable: Mean_Discharge

Discounting the effect of distinct independent variables on the mean watershed discharge established on the preceding section, a curve estimate was employed in depicting the pattern of relationship existing between dependent variable and each independent variable using predictive models. The result of the linear relationship between mean discharge and basin texture is summarized in Appendix with a high positive linear model of 0.927 and the F value of 51.167. The quadratic equation yields 0.930 and the F value of 19.928 both are significant at 0.05 confidence level. The logarithmic model yields 0.535 and the F value of 4.606 express a moderate predictive ability but not significant at 0.05 confidence level. The detail of constant value and for the linear parameter estimate is shown in appendix A and the graphical relationship depicted in figure 2. The logarithmic equation show positive relationship between discharge and basin texture. The quadratic equation reveals a positive increase at the beginning but turn negative at middle, which is an affirmation of the moderate predictive ability expressed in the model.

In considering the relationship between mean watershed discharge and infiltration rate in the Ikpa Watershed using Logarithmic equations offer very valid negative relationships but quadratic equation turned positive with further increase in discharge. It is an affirmation that increase in the amount of water loss through surface infiltration affect the amount of water available on the surface as runoff (discharge) but as soon as the saturation level is attained the relationship turn to negative as depicted in figure 2 and appendix B respectively. Thus, geomorphological disaster such as flooding and erosion tend to reduce if the landform has high infiltration rate and vice versa.

Further assessment using mean rainfall and mean discharge reveals positive relationship but the relationship in the long run turned negative due to prolong storm event; an indication of flooding and loss of flow direction as depicted in figure 2 and detail calculations shown in appendix C. Rainfall is one of the major determinants of flow frequency, density, and intensity of the rivers in the Tropics and the Ikpa River in particular. Similar trend in the relationship exist between mean discharge and length of overland flow as depicted in figure 2 and appendix D.

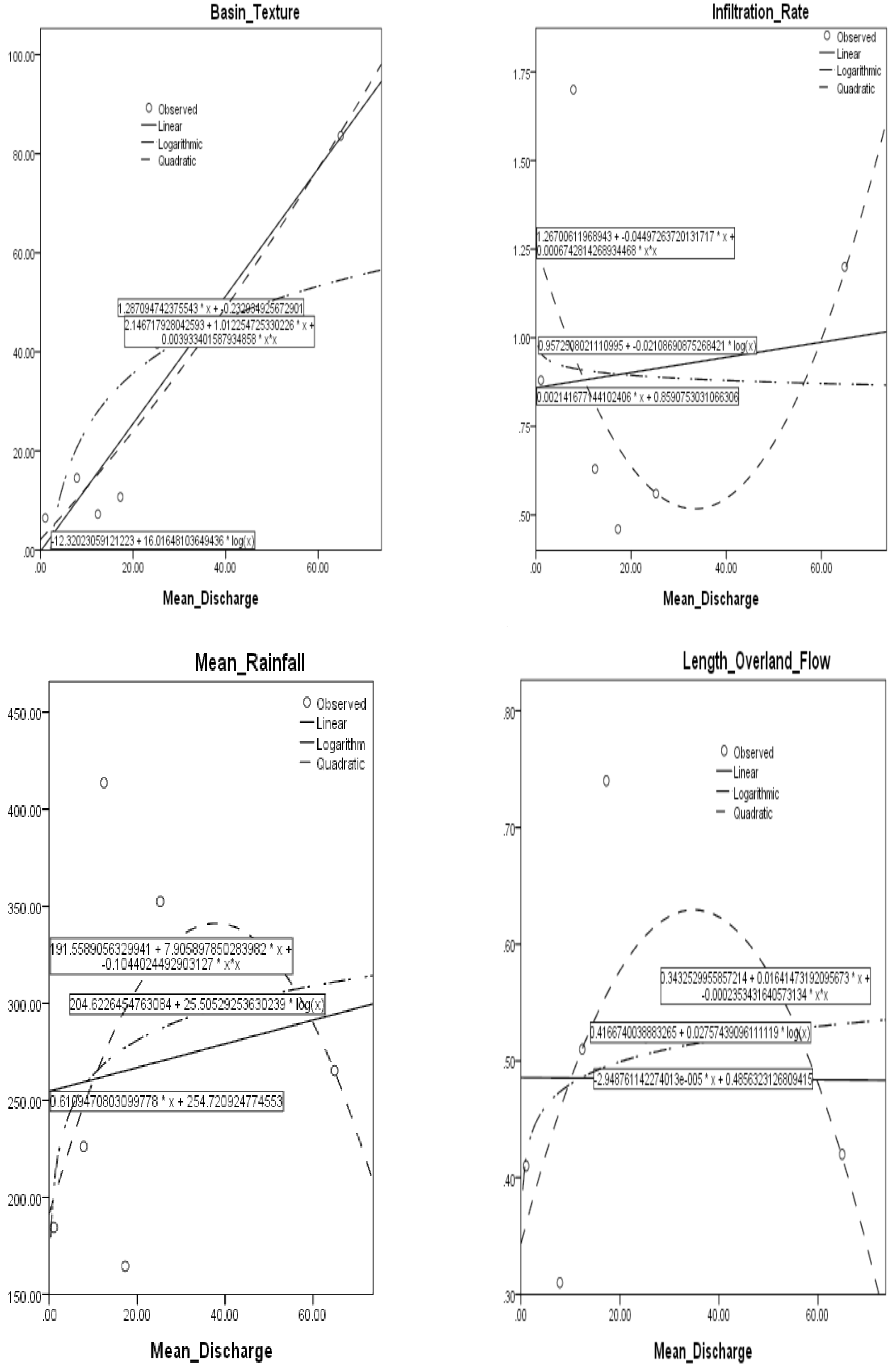

Figure 2: The Relationships between Mean Discharge and the Four Independent Variables.

Summary and Conclusion

The fluvial landforms and processes operating within the context of watersheds are complex yet vary in space and time. The findings presented on Table 2 and 3 showed that strong positive effect existed among the mean watershed discharge and the four distinct independent variables selected for study in the Ikpa watershed and was significant at 0.05 level. However, the assessment of the effect of variation in mean discharge on each independent variable tends to vary ranging from positive to negative and from low to high value; from one variable and was modelled as thus: $Y = -45.775 + 0.968x_1 + 0.257x_2 + 0.396x_3 - 0.099x_4$. A test of significant between discharge and each independent variable led to the conclusion that only basin texture was significant at 0.05 confidence level (Table 4).

Similarly, the quadratic equation showed a positive relationship between mean watershed discharge and basin texture. The relationship between mean discharge and infiltration rate using quadratic equation showed an increasing trend while a logarithmic equation depicted a decreasing trend and later an increasing trend. Besides, the relationship between discharge and rainfall using quadratic model showed positive trend while quadratic model showed a positive relationship at the beginning and later a decreasing pattern. Our findings implied that discharge in the Ikpa watershed is strongly related with the rainfall, basin texture, infiltration rate, and overland flow which together defined the pattern of geomorphic hazards in the area.

Considering the converging or diverging effects of variations existing among and between mean discharge and various independent variables at the Ikpa watershed, this study suggested the need to extend similar study to other watershed outside the study area with a focus on both linearized and non-linearized models.

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APPENDICES

Appendix A: **Model Summary and Parameter Estimates for Mean Discharge and Basin Texture**

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	.927	51.167	1	4	.002	-.233	1.287	
Logarithmic	.535	4.606	1	4	.098	-12.320	16.016	
Quadratic	.930	19.928	2	3	.019	2.147	1.012	.004

The dependent variable is Mean_Discharge.

Appendix B: Model Summary and Parameter Estimates for Discharge and Infiltration Rate

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	.011	.043	1	4	.845	.859	.002	
Logarithmic	.004	.016	1	4	.907	.957	-.021	
Quadratic	.318	.700	2	3	.563	1.267	-.045	.001

Appendix C: Model Summary and Parameter Estimates for Mean Discharge and Mean Rainfall

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	.020	.083	1	4	.788	12.533	.033	
Logarithmic	.044	.184	1	4	.690	-51.955	13.259	
Quadratic	.378	.912	2	3	.490	-145.725	1.254	-.002

Appendix D: Model Summary and Parameter Estimates for Mean Discharge and Length of Overland Flow

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	.000	.000	1	4	.993	21.790	-.714	
Logarithmic	.002	.006	1	4	.942	23.751	3.038	
Quadratic	.064	.103	2	3	.905	-50.309	289.855	-271.918