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RAINFALL-RUNOFF RELATIONSHIP AND MODEL DEVELOPMENT FOR IMO STATE NIGERIA

By

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Abstract

Understanding the rainfall-runoff relationship is critical for effective hydrological modeling and water resources management. This study examined the relationship between rainfall and runoff in Imo State, Nigeria, and developed a predictive regression model to estimate runoff based on rainfall data. Historical meteorological data (1984-2009) were collected from two gauging stations one in each state. Regression and fuzzy logic techniques were applied to establish the rainfall runoff relationship and evaluate their predictive accuracy. The regression model developed was $Y = 3.02 + 14.96X$ with a coefficient of determination (R^2) of 0.84, indicating a strong linear relationship. Comparisons between the regression and fuzzy approaches revealed relative errors of 21.07% and 13.40%, respectively, confirming the validity of the regression model for runoff prediction in the study area. The study concludes that locally developed regression models can effectively predict rainfall runoff dynamics under regional climatic conditions and support sustainable soil and water management.

Keywords: *Rainfall runoff modeling, Regression analysis, Fuzzy logic, Hydrology*

1. INTRODUCTION

The hydrologic cycle describes the continuous movement of water between the atmosphere, land, and oceans through processes such as precipitation, evaporation, infiltration, and runoff (Stanley, 2009). Obineche et al. (2023) noted that the potential for erosion is based on different factors which include soil type, slope, as well as the energy or force of precipitation expected during the period of surface disturbance. Furthermore, rainfall serves as the principal source of runoff over the land surface, while interception, infiltration, and surface storage reduce the portion of rainfall that becomes surface flow. Once these losses are satisfied, excess rainfall flows overland into rills, channels, and streams, collectively known as runoff. The interaction of these processes regulates water availability, soil erosion, and sediment transport in catchments. Water cycle or hydrologic cycle can also be defined as series movements of water above m and below the surface of the earth (Stanley 2008).

Over the years, human activities have significantly altered the hydrologic cycle. Excessive groundwater extraction, urbanization, deforestation, and dam construction have disrupted natural flow regimes, leading to flooding, declining water tables, and soil degradation. In Southeastern Nigeria, these effects are particularly severe, with intense rainfall events accelerating soil erosion and nutrient loss. According to Obi et al. (1989), erosion in the region has reached alarming levels, yet the underlying rainfall–runoff dynamics remain poorly quantified.

According to Emeka-Chris et al. (2024) a life-threatening rainfall happening endangers the quality of water, annihilation of assets, loss of lives due to flooding and pollution. Furthermore, rainfall is an important component in the hydrologic cycle. Similarly, Hoblit et al. (2006) posited that rainfall frequency analyses are desirable in the development plus designing of different water resources schemes, this includes storm sewers, culverts, and other hydraulic structures. Soil erosion and runoff constitute major environmental problems in Southeastern Nigeria. Rainfall intensity and poor land management accelerate the washing away of topsoil and nutrients, leading to reduced agricultural productivity and siltation of waterways (Aneke and Ude, 1990). Despite extensive erosion studies, limited quantitative data exist on the rainfall–runoff relationship for the region. Developing a locally based model is thus imperative to account for the specific climatic, soil, and hydrologic characteristics of Imo State. Such a model can guide water resource planning and erosion control strategies. The specific objectives of this study were to determine the relationship

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between rainfall and runoff in Imo State and hence develop a predictive model for estimating runoff from rainfall data in both states.

2. MATERIALS AND METHODS

THE STUDY AREA

The study area is Owerri, Imo State Nigeria. It is located between latitudes 5' 48" E and 7' 03" N, and longitudes 5' 3"E, and 9' 27" N. it has six major entrances and exit routes which are Okigwe, Orlu, Umuahia, Aba, Onitsha and Port Harcourt roads (Statistics and Planning Owerri Municipal, 2006). It was characterized by a main annual precipitation ranging from 2000 – 2500 mm, a mean temperature ranging from 26^{o}C – 28^{o}C and humidity ranging from 70% - 80% (Obineche et al., 2023). The rainy season commences from April to October, interrupted briefly by August break. The dry season spans from November to March. The Average monthly temperature is higher in February with a value of 30.1^{o}C, while the lowest is 26.7^{o}C which is recorded in August. (Duruanyim et al., 2025)

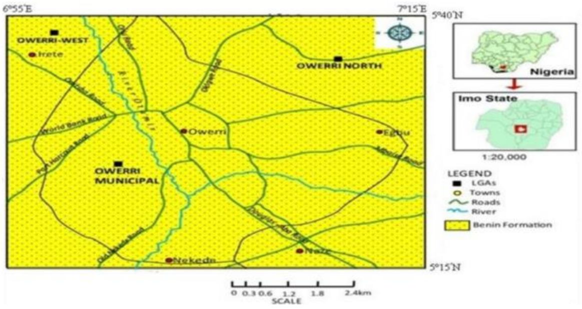

Figure 1. Map of Imo state showing the experimental location.

2.1 Geology of the Area

The geological material from which the soils of the study area developed is coastal plain sand (Benin formation). The landform of the study area is dominated by gentle rolling relief which stretch towards a plain usually with streams that govern the hydrology of the area. (Oriako et al 2022). Additionally, (Obineche et al., 2022) posited that the study area is a multifarious geological location in Imo State. The following stratigraphic units underlie the area: the Benin Formation, the Ogwashi – Asaba Formation, the Bende – Ameki Formation, Imo Shale Formation, Nsukka Formation, and Ajali Formation (Nwosu et al., 2010). In the same vein, (Imo State Govt. 1984) revealed that, there are three major soil groups observed in the study area, these are the ferralitc soils covering about 60% of the area, the hydromorphic soils which cover about 31%, and the alluvial soils covering 8%.

2.2 Data Collection

Meteorological and hydrological data including rainfall, temperature, evaporation, relative humidity, and sunshine duration were obtained from the National Root Crops Research Institute (NRCRI), Umudike, and other sources. Data spanned 25 years (1984-2009), although gaps existed between 2000 and 2008. Only high-quality records between 1988 and 1997 were used for calibration and validation. The event-based precipitation and discharge data were transformed to daily, weekly and monthly precipitation data in mm. the evaporation data were also preprocessed to daily, weekly and monthly values in mm the weekly and monthly data were obtained by summing up the daily data over the week and month periods, respectively. Two methods were used to model the rainfall-runoff relationship: (1) Linear Regression Analysis, where runoff was regressed against rainfall to establish a predictive equation, and (2) Fuzzy Logic Modeling, applied using SPSS software to handle nonlinearity and uncertainty inherent in hydrological data. The results of this study shows the outcome of different values of rainfall and other climatological variables, as data were collected for a period of 25 years and runoff was generated from these data using the Statistical, Programme in Social Sciences (SPSS) package with this formula below;

$$F = R - (11 + 0.29R)(0.035)T - 0.65$$

1

Where,

R = Rainfall amount (mm)

F = Runoff amount (mm)

T = Temperature

3.0 RESULTS AND DISCUSSION

3.1 Results

The fuzzy logic model developed for this study was implemented using a computational algorithm, Sen. (1998), and the resulting runoff predictions are presented in Table 2. The table also shows the relative errors obtained from both the classical regression model and the fuzzy approach. A comparison of the two methods reveals that the regression model generally produced lower relative errors, indicating improved prediction accuracy compared to fuzzy model approach.

Visual comparisons were carried out using scatter plots (Figures 1 and 2), which display the observed runoff values alongside the predictions from both models. These plots show that the regression model aligns more closely with the general trend of the measured data, although the fuzzy model also demonstrates acceptable performance. This shows that the fuzzy logic model exhibited a higher relative error (24.37%) compared to the regression model (22.69%), suggesting lower predictive accuracy, whereas regression model suggests higher predictive accuracy. This indicates that both methods can effectively simulate rainfall-runoff responses in Imo State.

Rainfall patterns observed across the 25-year period followed a consistent seasonal pattern for both states considered in the larger dataset. Rainfall was lowest from November to February, gradually increasing from March and peaking between June and September. Higher rainfall during this period corresponded to higher humidity and evaporation levels, whereas lower rainfall months were associated with reduced sunshine and lower temperatures.

3.2 Discussion

The rainfall-runoff analysis for Imo State revealed clear seasonal patterns consistent with the regions humid tropical climate. Rainfall was lowest between November and February and increased progressively from March, reaching a peak between June and September. These seasonal variations

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directly influenced runoff generation, as higher rainfall months produced noticeably greater runoff values. This pattern supports earlier assertions that rainfall intensity and temporal distribution strongly govern runoff response in southeastern Nigeria.

The results from the regression and fuzzy logic models further demonstrated the predominant influence of rainfall on runoff generation. Monthly averages show that even moderate increases in rainfall resulted in substantial rises in runoff, especially from March through October when precipitation exceeded 100 mm. this relationship validates the assumption that rainfall is the dominant driver of surface hydrological response in the study area.

A comparison of the predictive models shows that the regression model consistently produced lower relative errors, with an average error of 22.69%, compared to 24.37% for the fuzzy logic model. While both models captured the overall pattern of runoff generation, the regression model showed stronger agreement with observed values, particularly in months with moderate to high rainfall.

The fuzzy model, although useful for handling nonlinearity and uncertainty, tended to underestimate runoff during extreme rainfall months and slightly overestimate in low-rainfall periods. This suggests that the fuzzy logic system may require additional inputs to improve accuracy.

Overall, the results affirm that locally calibrated regression models are reliable tools for predicting runoff in regions with well-defined rainfall seasons.

Table 1. Average Value of Rainfall and Runoff for Imo State for the Period of 25 Years (1984 – 2009)

MONTH	RAINFALL (MM)	RUNOFF (MM)
January	21.6	0.3
February	33.5	1.7
March	96.1	5.7
April	193.1	15.6
May	239.0	17.8
June	320.9	20.3
July	292.1	18.6
August	309.3	21.9
September	333.6	20.0
October	293.5	15.7
November	58.8	3.1
December	17.8	0.2

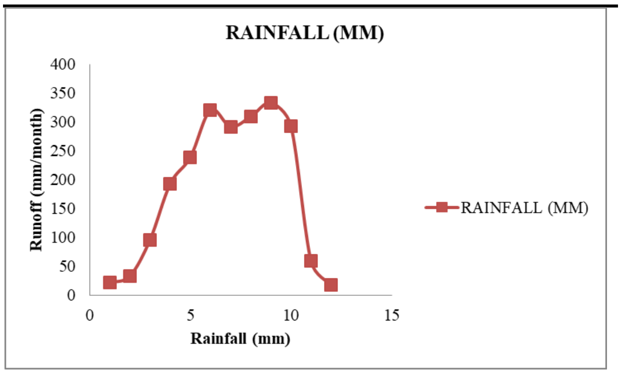

Figure 2.A graph of rainfall against runoff (mm/month)

Table 2: Comparison of Fuzzy-Regression Runoff Prediction For Imo State Combined For The Period of 25 Years (1984 – 2009)

	Observed Data		Runoff prediction		Relative error (%)	
Months	Rainfall (mm)	Runoff (mm)	Regression model (mm)	Fuzzy approach (mm)	Regression model (mm)	**Fuzzy approach (mm)**
Jan.	21.60	0.30	1.24	1.00	75.81	**70.00**
Feb.	33.60	1.70	2.04	1.80	16.67	**5.56**
Mar.	96.10	5.70	6.22	5.50	8.36	**3.51**
Apr.	193.10	15.60	12.18	12.00	21.92	**23.08**
May	239.00	17.80	15.77	18.00	11.40	**1.11**
Jun.	320.90	20.30	21.25	14.80	4.47	**27.09**
Jul.	292.10	18.60	18.28	15.00	1.72	**19.35**
Aug.	309.3	21.90	20.47	19.10	6.53	**12.79**
Sept.	333.60	20.00	22.10	14.90	9.50	**25.50**
Oct.	293.50	15.70	19.42	14.40	19.16	**8.28**
Nov.	58.80	3.10	3.73	2.60	16.89	**16.13**

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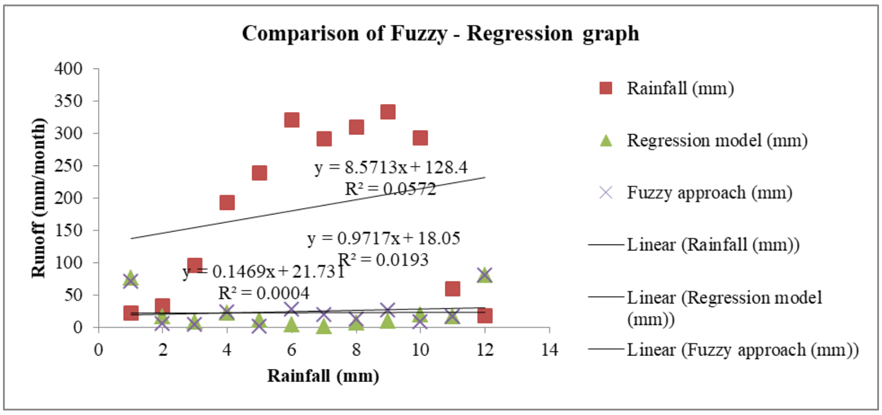
Dec.	17.80	0.20	0.99	1.00	79.80	**80.00**
		Average			**22.69**	**24.37**



CONCLUSION

This study evaluated the rainfall–runoff relationship in Imo State using long-term hydrometeorological data and two modeling approaches. Rainfall showed a strong seasonal pattern that directly influenced runoff production. The linear regression model demonstrated strong predictive capability with an R^2 of 0.84 and an average relative error of 22.69%, outperforming the fuzzy logic model.

Both approaches offered meaningful insights, but the regression model proved more reliable for estimating runoff under the region's climatic and hydrological conditions. The study concludes that locally developed regression models can serve as effective tools for hydrological planning, flood assessment, and water resource management.

Overall, the study demonstrates that locally developed regression models can adequately predict runoff in Imo State and can be deployed for watershed management, hydraulic design, erosion control, and climate-impact assessments. The combined use of regression and fuzzy modeling enhances the robustness of hydrological prediction in data-limited regions. Future studies should incorporate additional variables such as soil moisture, infiltration rates, and land-use changes to further improve model accuracy and applicability.

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