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MODELING OF RAINFALL-RUNOFF RELATIONSHIP IN ABIA AND IMO STATE, NIGERIA

A.N. Ofoma[a]; L.C Orakwe[b]; C.C. Egwuonwu[a]; N.R. Nwakuba[a]; C.I. Nwachukwu[a]; *C.I. Obineche[c]

[a]*Department of Agricultural and Biosystem Engineering, Federal University of Technology Owerri, Imo State, Nigeria*

[b]*Department of Agricultural and Biosystem Engineering, Nnamdi Azikiwe University of Awka Anambra State, Nigeria*

[c*]*Department of Agricultural and Bioenvironmental Engineering, Federal College of Land Resources Technology Owerri, Imo State*

**Corresponding Author's E-mail: ikechiobineche@gmail.com*

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ABSTRACT

Rainfall–runoff relationships play a critical role in hydrological analysis, flood prediction, erosion control, and water resources management, particularly in humid tropical environments as Nigeria. This study evaluated the relationship between rainfall and runoff in Abia and Imo States, southeastern Nigeria, using long-term hydro-meteorological data spanning 25 years (1984–2009). Rainfall and associated climatological variables were analyzed, and runoff was estimated using two modeling approaches: linear regression analysis and fuzzy logic modeling. Monthly rainfall exhibited a distinct seasonal pattern, with peak values occurring between June and September, corresponding to higher runoff generation. Model performance assessment revealed that both approaches adequately simulated runoff responses; however, the fuzzy logic model demonstrated superior predictive capability with a lower average relative error of 13.40%, compared to 21.07% obtained from the regression model. The results confirm rainfall as the dominant factor influencing runoff generation in the study area and highlight the effectiveness of fuzzy logic techniques in capturing nonlinearity and uncertainty inherent in hydrological systems. The developed models provide a reliable framework for runoff prediction and can support erosion control planning, flood mitigation, and sustainable water resource management in southeastern Nigeria.

Keywords: Rainfall runoff modeling, Regression analysis, Fuzzy logic, Hydrology, Abia and Imo states

1.0 INTRODUCTION

Rainfall is the main source of surface runoff. How much rainfall becomes runoff depends on infiltration, interception, and land surface conditions. 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 essential 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. In recent years, the analysis of rainfall extremes and assertiveness has fascinated the interest of researchers across the world (Garcia-Oliva *et al*., 1995; Sauerborn *et al*., 1999). The aim of this study was to determine the relationship between rainfall and runoff in Abia and Imo State and to develop a prediction model for runoff from rainfall estimation data in the states.

2.0 MATERIALS AND METHODS

2.1 The Study Area

The study areas include, Abia and Imo state. Imo State is one of the state in Nigeria and 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). While, Abia State, lies between latitudes 4°45' and 6°00’N and longitudes 7°00' and 8°09'E respectively. The State is located east of Imo State and shares common boundaries with Anambra, Enugu and Ebonyi States to the North-West, North and North-East respectively. Abia and Imo States lie between latitudes 4^{o}45 and 6^{o}15N and longitude 6^{o}30 and 8^{o}09E. The area is bounded in the east by Cross River State, in the West by Delta state, in the South by Akwa–Ibom and Rivers States as well as in the North by Anambra and Enugu States. It was characterized by a main annual precipitation ranging from 1800 – 2500 mm, an average mean temperature ranging from 27^{o}C and relative humidity of 20% to 40% which increases between January and February (Imo State Government, 1984).

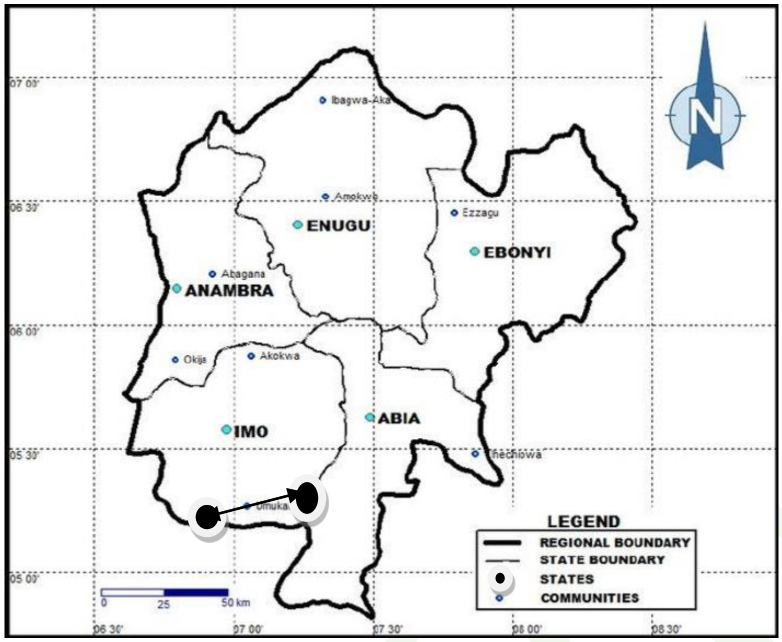

Figure 1: Map of Imo and Abia State meteorological locations. (Google map.com)

2.2 Geology of the Area

The geological material from which Imo state soils were developed is from the coastal plain sand (Benin formation). The landform of Imo State 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 Imo State is a multifarious geological zone. 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). While, in Abia State the rock system and geological history of this area are due to events that took place during the Mesozoic and Cenozoic eras respectively. Her geological structure is divided into three namely, upper coal measure, false-bedded sand stones, and lower coal measure. The upper coal measure formation is the largest geological formation in this region. It comprises mainly of coarse grains, alternating sediments of grey sands, dark shale which contains sands of impure coal in place of vertical horizon (Uluocha and Uwadiegwu, 2015). 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%.

2.3 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 NIMET (Nigerian meteorological station) Owerri. 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 in equation 1 and 2 for the estimation of rainfall and runoff.

$$F = R - (11 + 0.29R)(0.035)T - 0.65 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

Where,

R = Rainfall amount (mm)
F = Runoff amount (mm)
T = Temperature effect
Threshold for runoff = - 0.65

Where, F is the effective runoff/infiltration, R is rainfall (mm), and T is temperature (°C). This form of empirical relationship is consistent with modified hydrological loss models reported in similar studies (e.g., Ologhadien and Nwaogazie, 2020; Ajayi *et al*., 2018).

$$Y = 3.02 + 14.96x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Where, x = runoff, Y= rainfall

The fuzzy logic model which stated that since the rainfall-runoff relationship in general has a direct proportionality feature. Hence, the fuzzy approach is based on the linguistic uncertain expressions rather than numerical uncertainty measures. A detailed account of fuzzy logic and systems is presented by (Hooi and Nur, 2024 and Chang and Chan, 2001). It is possible to write the following five rule bases for the description of fuzzy rainfall-runoff modeling as thus;

R1: IF rainfall is L THEN runoff is L or
R2: IF rainfall is ML THEN runoff is ML or
R3: IF rainfall is M THEN runoff is M or
R4: IF rainfall is MH THEN runoff is MH or
R5: IF rainfall is h THEN runoff is H

Where, L, ML, M, MH and H are abbreviations for fuzzy subgroups of low, medium low, medium, medium high, and high respectively. 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.

3.0 RESULTS AND DISCUSSION

3.1 Results

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 lower relative error (13.40%) compared to the regression model (21.07%), which suggests higher predictive accuracy and favorably. This indicates that both methods can effectively simulate rainfall-runoff responses in both States. 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 Discussions

The rainfall–runoff characteristics observed in Abia and Imo States exhibit pronounced seasonal variability, consistent with the humid tropical climatic regime of southeastern Nigeria (Obineche *et al*., 2023). Rainfall amounts were minimal during the dry season months (November–February) and increased steadily from March, reaching peak values between June and September. This seasonal trend strongly influenced runoff generation, as higher rainfall volumes during the wet season resulted in increased surface runoff, while dry season rainfall produced negligible runoff responses. The strong correspondence between rainfall magnitude and runoff volume confirms rainfall as the primary driver of hydrological response within the study area. Monthly rainfall exceeding approximately 100 mm consistently generated significant runoff, particularly between March and October. This behavior aligns with earlier studies that link intense rainfall events in southeastern Nigeria to accelerated runoff and erosion, largely due to soil properties and land surface conditions (Obi *et al*., 1989; Aneke and Ude, 1990). Comparative analysis of the regression and fuzzy logic models revealed notable differences in predictive performance. Although both models successfully captured the general rainfall–runoff pattern, the fuzzy logic approach produced lower relative errors across most months, with an overall average error of 13.40%, compared to 21.07% for the regression model. The improved performance of the fuzzy model reflects its ability to handle nonlinear relationships and uncertainty inherent in hydrological processes (Sen, 1998). Hence, figure. 1 is the map of study area, while figures 2 and 3 are for the prediction models.

The regression model showed reasonable agreement with observed runoff during moderate rainfall periods but exhibited higher errors during extreme low and high rainfall months. This limitation may be attributed to its linear structure, which does not fully represent the complexity of runoff generation mechanisms in tropical catchments. In contrast, the fuzzy logic model demonstrated greater adaptability across different rainfall regimes, making it more suitable for rainfall–runoff simulation in data-scarce and climatically variable environments (Hoblit *et al*., 2006). Overall, the findings underscore the importance of locally calibrated hydrological models and confirm the applicability of fuzzy logic techniques for runoff estimation in southeastern Nigeria. The results provide valuable insight into seasonal runoff behavior and offer a robust analytical basis for water resource planning, erosion control, and flood risk management in the region (Emeka-Chris *et al*., 2024).

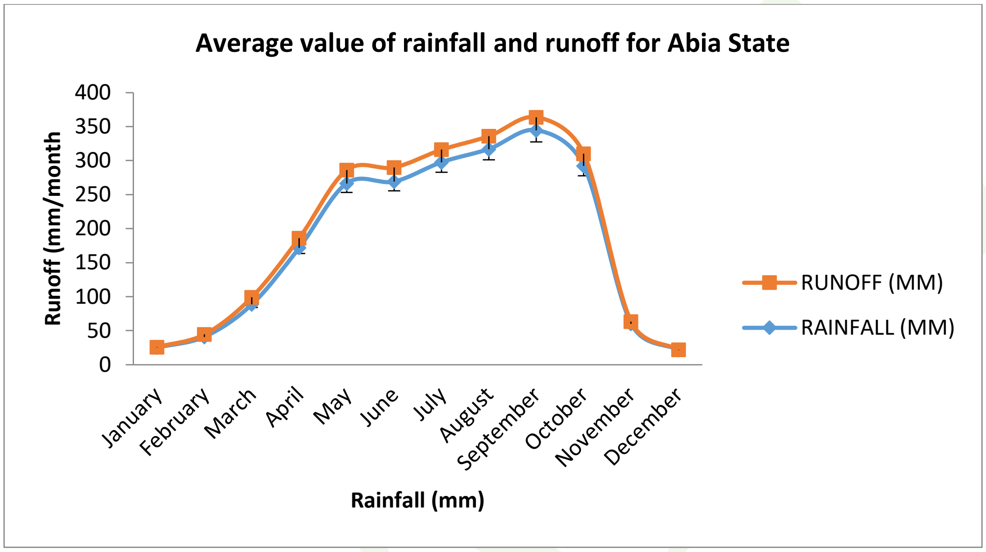

Figure 2: A graph of predicted rainfall value against runoff (mm/month) with errors bars in percentage for Abia State

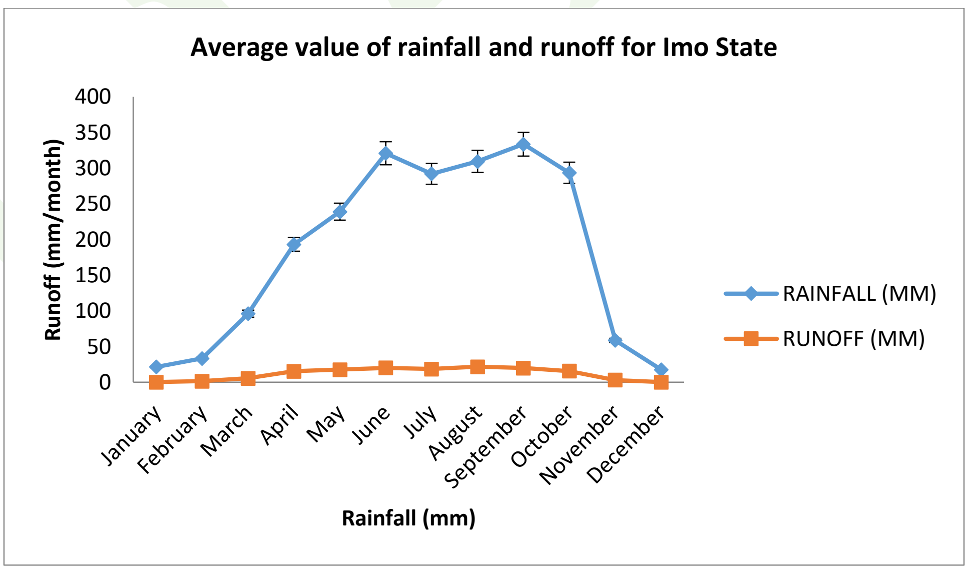

Figure 3: A graph of predicted rainfall value against runoff (mm/month) with errors bars in percentage for Imo State

Table 1: Combined average Value of Rainfall and Runoff for Abia and Imo State for the Period of 25 Years (1984 – 2009)

MONTH	RAINFALL (MM)	RUNOFF (MM)
January	23.3	0.6
February	37.2	2.6
March	92.3	8.2
April	182.5	14.9
May	252.8	18.7
June	295.1	20.6
July	294.8	18.6
August	313.1	20.5
September	339.1	19.7
October	292.9	16.8
November	59.5	3.2
December	19.7	0.4

Table 2: Comparison of Fuzzy-Regression Runoff Prediction for Abia and 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.	23	0.6	1.36	1.00	55.88	40
Feb.	37	2.6	2.28	2.80	12.31	7.14
Mar.	92.3	8.2	5.97	7.50	27.2	8.54
Apr.	182.5	14.9	12.00	14.00	9.6	6.04
May	252.8	14.7	16.70	20.00	10.7	6.5
Jun.	295.1	15.6	19.52	18.80	5.24	3.88
Jul.	294.8	1.6	19.50	19.00	4.62	2.11
Aug.	313.1	13.5	20.73	21.10	0.11	2.84
Sept.	339.1	19.7	15.03	17.90	23.7	9.14
Oct.	292.9	16.8	19.38	17.40	13.31	3.45
Nov.	59.5	3.2	3.78	3.60	15.31	11.11
Dec.	19.7	0.4	1.11	1.00	63.96	60
Average					**21.07**	**13.40**

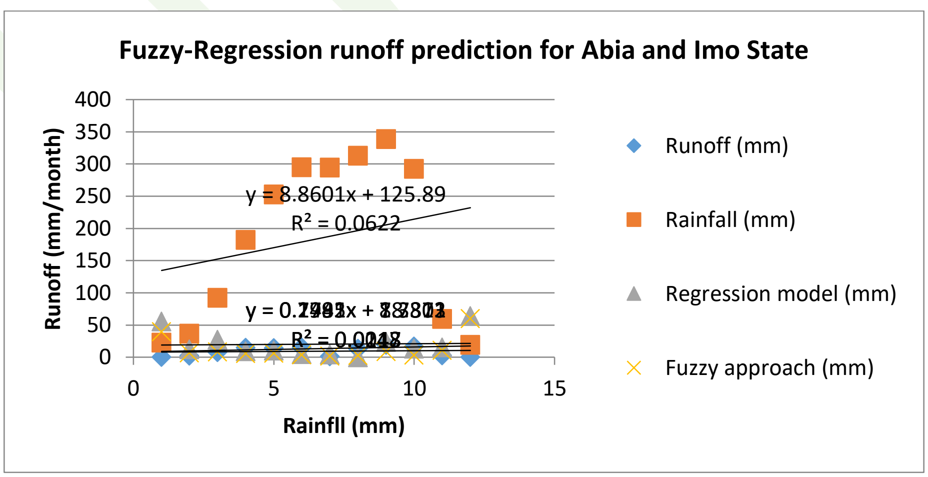

Figure 4: Comparison of Fuzzy-Regression Runoff Prediction for Abia and Imo State

4.0 CONCLUSION

This study investigated the rainfall–runoff relationship in Abia and Imo States using long-term hydro-meteorological data and two modeling approaches: linear regression and fuzzy logic. The results revealed a clear seasonal rainfall pattern, with peak precipitation and runoff occurring between June and September, and minimal runoff during the dry season months. Rainfall was confirmed as the dominant factor controlling runoff generation in the study area. Both modeling techniques demonstrated the capability to simulate runoff responses; however, the fuzzy logic model outperformed the regression model, yielding lower average relative errors and better overall prediction accuracy. The superior performance of the fuzzy approach highlights its effectiveness in capturing the nonlinear and uncertain nature of hydrological processes in humid tropical environments. The developed rainfall–runoff models provide a useful decision-support tool for hydrological forecasting, erosion control strategies, and sustainable water resource management in southeastern Nigeria. Adoption of fuzzy logic-based modeling is recommended for improved runoff prediction, particularly in regions characterized by complex climatic variability and limited hydrological data. Future studies should incorporate land-use dynamics and soil hydraulic properties to further enhance model reliability and applicability.

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