



International Journal of Pure and Applied Mathematics Research

Publisher's Home Page: <https://www.svedbergopen.com/>



Research Paper

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Runoff Prediction in the Bida Watershed Using Correlation, Regression, and Runge-Kutta Fourth Order Simulation Method

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Article Info

Volume 5, Issue 2, October 2025

Received : 12 April 2025

Accepted : 11 September 2025

Published : 20 October 2025

doi: [10.51483/IJPAMR.5.2.2025.56-68](https://doi.org/10.51483/IJPAMR.5.2.2025.56-68)

Abstract

This study examines rainfall-runoff interactions in Nigeria's flood-prone Bida watershed from 2010 to 2023, comparing traditional statistical methods with the Runge-Kutta Fourth Order (RK4) simulation for runoff prediction. Daily rainfall and runoff data were sourced from the Nigerian Meteorological Agency (NiMet), processed using Excel and Python to compute monthly averages. Pearson and Spearman correlation coefficients assessed linear and monotonic relationships, respectively. The RK4 method simulated runoff based on rainfall and watershed parameters. Results indicate peak rainfall in August and September (300-350 mm/month), with significant events in 2012 and 2018. Corresponding peak runoff occurred in September, reaching up to 160 m³/s, showing a one-month lag due to catchment storage. Strong correlations were observed (Pearson $r = 0.89$; Spearman's $\rho = 0.83$), confirming the robustness of the rainfall-runoff relationship. The RK4 simulation demonstrated high predictive accuracy (NSE = 0.88; RMSE = 5.2 m³/s). Anomalies in 2012, 2018, and 2022 aligned with major flood events, highlighting increasing hydro-climatic variability. These findings validate RK4 as an effective tool for runoff forecasting and underscore the importance of integrated modeling approaches in enhancing flood prediction and water management strategies under changing climate conditions.

Keywords: Rainfall-runoff modeling, Runge-Kutta simulation (RK4), Spearman correlation, Hydro-climatic variability, Watershed

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1. Introduction

Accurate runoff forecasting is paramount for the management of watersheds, flood risk assessment, and disaster preparation, particularly in regions such as Nigeria's Bida watershed, which are prone to hydrological extremes. The escalating incidence of extreme meteorological events, exacerbated by climate change, accentuates the necessity for precise predictions of runoff volumes and peak flows to effectively manage water resources, design resilient infrastructure, and prepare for potential disasters (Ho *et al.*, 2022; Isukuru *et al.*, 2024). Hydrological models serve as essential

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instruments for water budgets at both global and regional levels. These models are vital for agricultural water resources, flood forecasting, and extensive hydrological modeling projects (Baran-Gurgul and Rutkowska, 2024). Furthermore, these models facilitate effective flood management and the allocation of water resources for agricultural and domestic uses, thereby mitigating the risks associated with water shortages and flooding (Ingrao *et al.*, 2023). Various methodologies, including statistical, regression-based, and computational approaches, have been utilized to predict runoff in catchment characteristics and climatic factors over extended temporal scales (Li *et al.*, 2020). The demand for precise and timely flood prediction models, particularly within urban environments, is increasing to enhance the decision-making frameworks in flood management (Aljohani *et al.*, 2023). The Bida watershed in Nigeria exemplifies the urgent requirement for accurate runoff predictions owing to its unique hydro-climatic characteristics and socio-economic vulnerabilities. Variability in climate and alterations in land use exacerbate hydrological extremes, rendering the ability to forecast runoff with precision increasingly critical. Inaccurate predictions may lead to the mismanagement of water resources, ineffective flood mitigation strategies, and considerable losses in human life and property, especially in regions susceptible to droughts and flooding (Isukuru *et al.*, 2024).

Within the Bida watershed, runoff prediction is indispensable for mitigating flood risks, optimizing the allocation of water resources, and fostering sustainable agricultural practices. Accurate forecasting empowers stakeholders to anticipate flood events and make informed choices concerning land utilization, the construction of flood mitigation infrastructure, and disaster preparedness (Umar and Gray, 2022). This necessity becomes particularly pronounced as extreme weather events increase in frequency and severity due to the overarching impacts of global climate change, thus underscoring the demand for predictive models capable of effectively addressing intricate hydrological challenges (Clarke *et al.*, 2021). Alterations in land use within the Bida watershed, including deforestation, agricultural expansion, and urban development, complicate the challenges associated with runoff prediction by disrupting the natural hydrological cycle. It highlights the urgent need for adaptable hydrological models that can accommodate these dynamic changes, thereby improving predictive accuracy and enabling more effective management of water resources (Haji *et al.*, 2024).

Predicting runoff in such watersheds poses considerable challenges due to the increased vulnerability of these regions to climatic variations. Factors such as fluctuating rainfall intensity, alterations in temperature, and transformations in land use introduce uncertainties in traditional hydrological models, which often struggle to effectively encapsulate the non-linear interactions that dictate runoff in these areas (Liu *et al.*, 2024). Traditional methodologies, including correlation and regression analysis, clarify the relationships between climatic variables and runoff and address the complex hydrological processes inherent to these regions (Xu *et al.*, 2024). Simulation techniques, such as the Runge-Kutta method, provide a more advanced framework for solving differential equations relevant to runoff prediction; nevertheless, these methods require comprehensive input data, which may not always be readily available (Audu *et al.*, 2023). By synthesizing correlation, regression, and simulation techniques, this study aims to enhance the precision of runoff predictions and provide a more exhaustive understanding of the watershed dynamics in the Bida region.

Despite progress in hydrological modeling, the precise forecasting of runoff in regions marked by variable precipitation and complex hydrological systems remains a formidable challenge. A plethora of existing research predominantly relies on single-method approaches—either statistical or simulation-based—neglecting the incorporation of multiple methodologies to improve prediction accuracy (Henley *et al.*, 2019). The Bida watershed, characterized by its distinctive climatic and land-use challenges, has received insufficient academic scrutiny in comprehensive runoff prediction studies. This research seeks to address this deficiency by using a composite methodology that integrates correlation, regression, and the Runge-Kutta simulation technique to enhance forecasting capabilities within the watershed. Empirical findings from prior research validate the shortcomings in singular methodologies in runoff prediction, highlighting the imperative for integrated approaches. While statistical models are adept at identifying trends, they frequently fail to fully capture the intricacies of hydrological processes (Li *et al.*, 2020). Likewise, computational models such as the Runge-Kutta method demand high-quality data, which may not consistently be accessible, and they also entail significant computational resources (Vermeire, 2019). The amalgamation of these methodologies enables a more comprehensive understanding of runoff patterns in areas like the Bida watershed, where climatic and land-use variables display substantial variability. This research aspires to forecast runoff in the Bida watershed by integrating correlation, regression, and Runge-Kutta simulation techniques. The study examines the interrelations among climatic variables, including precipitation and temperature, assesses regression models for runoff prediction, and utilizes the Runge-Kutta method

to estimate runoff, subsequently comparing the results with observed data. By evaluating the effectiveness of these methodologies, the study endeavors to identify the most suitable and efficacious method for enhancing runoff forecasting in the region.

2. Material And Methods

2.1. Study Area

The Bida watershed, situated in Niger State, Nigeria, encompasses an approximate area of 37.5 square kilometers and constitutes an integral component of the broader Niger Valley region (Figure 1). In terms of geographical coordinates, it is positioned between latitudes 9°02'-9°92' N and longitudes 5°562'-6°42' E. Prominent hydrological attributes encompass the Musa, Landzun, and Chiken Rivers, with the Landzun Stream extending 8.86 kilometers from west to east through the urban locality of Bida. The topography is characterized by undulating landforms, with altitudinal variations ranging from 161 to 277 meters. From a geological perspective, the region is composed of Precambrian Basement Complex formations alongside Cretaceous sedimentary deposits, particularly the Bida Sandstone and Enagi Siltstone, culminating in a variety of soil types, such as coarse sands, clays, and sandy silts, which enhance the potential for groundwater storage (Olabode, 2016). Located within the northern Guinea Savannah ecological zone, the watershed's Indigenous vegetation, primarily dominated by *Isoberlina doka* and *Isoberlina tomentosa*, has undergone significant alterations due to anthropogenic activities, resulting in a mosaic of vegetation types that includes tree savanna, shrub savanna, riparian forests, and inselberg vegetation. The climatic regime of the region is marked by distinctly delineated wet (April-October) and dry (November-March) seasons, with an annual precipitation range of 1,000 to 1,200 mm, peaking in August and September (Mohammed, 2014). Temperature fluctuations range from 16 °C to 37 °C, influenced by the southwest trade winds during the rainy season and the northeast harmattan winds prevalent in the dry season (Echebima and Obafemi, 2023).

The watershed confronts significant hydrological challenges, including flooding induced by intense rainfall events, insufficient drainage systems, and river overflow, exacerbated by climate change and urbanization (Wartalska et al., 2025). A decline in precipitation coupled with rising temperature levels contributes to increased evapotranspiration, thereby placing additional stress on water resources. Concerns regarding groundwater quality, particularly nitrate contamination in agricultural zones, underscore the imperative for enhanced water management strategies. Surface runoff is predominantly influenced by precipitation patterns, exhibiting higher flow rates during the wet season; however, alterations in infiltration and evapotranspiration dynamics due to deforestation and urban encroachment may lead to a long-term reduction in runoff (Rivera et al., 2022). The implementation of effective watershed management practices is critical in addressing these pressing environmental challenges.

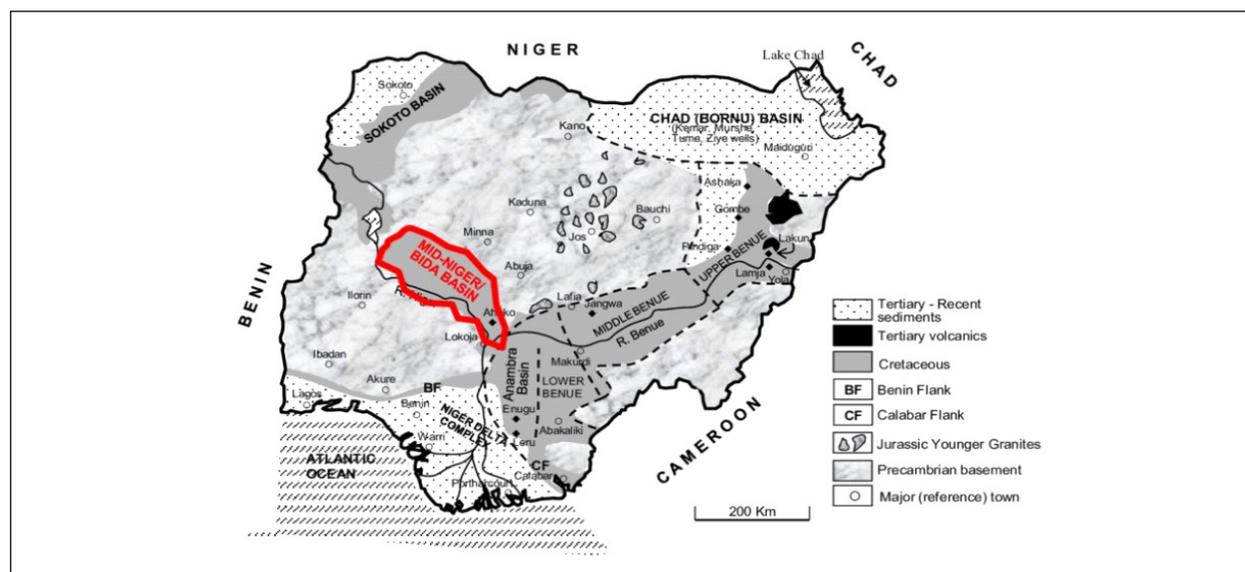


Figure 1: Sketch Geological Map of Nigeria Showing the Location of the Bida Basin

Source: Idris-Nda et al. (2013)

2.2. Data Collection

2.2.1. Rainfall and Runoff

The daily hydrological data (rainfall and Runoff) of the Bida watershed from 2010 to 2023 was collected from Nigerian Meteorological Agency (NiMet) stations.

2.3. Data Analysis

The precipitation and surface runoff data were subjected to a comprehensive multi-step analytical framework to guarantee the meticulous organization and extraction of seasonal patterns. The initial dataset was organized in a wide format within Excel, delineating distinct sections for precipitation (in millimeters) and surface runoff (in cubic meters per second). The column headings encompassed month, day, and year, with corresponding values systematically aligned adjacently. Non-numeric or improperly formatted entries were converted to numeric format through coercion. Any entries deemed invalid were substituted with missing values (NaN) and subsequently excised from the dataset.

The dataset underwent a transformation to a long format, wherein each record is representative of a singular observation, incorporating columns for Month, Day, Year, Rainfall, and Runoff. The months were encoded numerically (January = 1, February = 2) to enhance the processes of sorting and aggregation.

2.3.1. Aggregation and Statistical Analysis

The mean monthly values were computed as:

$$\bar{X}_{month, year} = \frac{1}{n} \sum_{i=1}^n X_i \tag{1}$$

Where X_i represents the rainfall (or runoff) on day (i) of that month.

The average values for each month across multiple years were systematically organized into a pivot table to enhance visual comprehension. Two line graphs were constructed to facilitate the comparison of seasonal patterns across various years, with:

X-axis: Months (1 to 12)

Y-axis: Mean Precipitation (mm) and Discharge (m³/s)

Lines: Each year depicted individually to analyze inter-annual discrepancies.

Pearson Correlation (rr): Quantifies linear associations, calculated as:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \sqrt{\sum (y_i - \bar{y})^2}} \tag{2}$$

which assumes normally distributed data and homoscedasticity.

2.4. Spearman Correlation

Spearman’s rank correlation coefficient is a non-parametric metric that evaluates the extent to which an arbitrary monotonic function could effectively characterize the relationship between two variables, without necessitating a linear association. This method operates by ranking the data and subsequently applying the Pearson correlation formula to these ranks.

2.5. Runge-Kutta Simulation

The Runge-Kutta methodology constitutes a numerical approach utilized for the resolution of Ordinary Differential Equations (ODEs), frequently applied in the domain of hydrological modeling. The fourth-order Runge-Kutta (RK4) technique is adopted for the predictive analysis of runoff dynamics within the Bida watershed.

The inputs to the model encompass variables such as precipitation, runoff, watershed area, and soil infiltration rates. The simulation is executed utilizing Python, systematically iterating through the observed rainfall data to forecast

runoff. The computational framework amalgamates data preprocessing, parameter calibration, and performance validation against historical runoff data, thereby facilitating an accurate hydrological representation of watershed dynamics.

2.6. Mathematical Formulation

Given a first-order ODE

$$\frac{dy}{dt} = f(t, y) \tag{3}$$

The RK4 updates y iteratively as:

$$y_{n+1} = y_n + \frac{1}{6} (k_1 + 2k_2 + 2k_3 + k_4) \tag{4}$$

Where

$$k_1 = hf(t_n, y_n) \tag{5}$$

$$k_2 = hf\left(t_n + \frac{h}{2}, y_n + \frac{k_1}{2}\right) \tag{6}$$

$$k_3 = hf\left(t_n + \frac{h}{2}, y_n + \frac{k_2}{2}\right) \tag{7}$$

$$k_4 = hf(t_n + h, y_n + k_3) \tag{8}$$

with h as the time step

The Runge-Kutta (RK4) approach was selected for its exceptional precision and stability in addressing the nonlinear rainfall-runoff equations within the Bida watershed, thereby facilitating accurate temporal forecasts. The Pearson correlation coefficient serves to elucidate linear associations between precipitation and runoff, providing a direct metric for the strength and direction of such relationships. Conversely, in scenarios characterized by nonlinearity or the presence of outliers, Spearman’s rank correlation is employed to ordinally arrange data, thereby mitigating biases stemming from skewed distributions. Collectively, these methodologies augment the comprehension of runoff determinants by capturing both linear and nonlinear interdependencies, thereby ensuring a rigorous and thorough analysis of hydrological phenomena, which underpins effective water resource management and flood mitigation strategies within the study area. The Sensitivity analysis of the Runge-Kutta Fourth Order (RK4) method in hydrological modeling reveals that model outputs are highly sensitive to input parameters, numerical schemes, and data quality. High-order schemes like RK4 reduce numerical errors but require careful calibration to avoid overfitting and ensure accurate predictions. Uncertainties in input data, such as precipitation measurements, can propagate through the model, affecting reliability. Therefore, comprehensive sensitivity analyses are essential to understand parameter influences and enhance model robustness (McMillan *et al.*, 2018).

3. Results and Discussion

Figure 2 presents a temporal analysis of both rainfall and runoff from the years 2010 to 2023. The figure illustrates a pronounced positive linear correlation between rainfall and runoff within the Bida watershed, as demonstrated by the ascending trajectory of the data points. This observation suggests that an increase in rainfall correlates with a proportional rise in runoff volume, which aligns with established hydrological principles. The significant clustering around the trend line indicates a minimal variability in the residuals, thereby affirming the model’s suitability for predictive applications.

Figure 3 describes the association between observed runoff and predicted runoff derived from the correlation method. The close correspondence between the two datasets implies that the correlation method provides a reasonably precise estimation of runoff volumes predicated on precipitation input. Minor discrepancies are noted, likely attributable to additional influencing variables such as soil infiltration, evapotranspiration, and land use classifications.

Figure 4 illustrates runoff estimation derived from a linear regression model. In contrast to the correlation method, the regression approach yields a superior estimation by incorporating a line of best fit and intercept, thereby

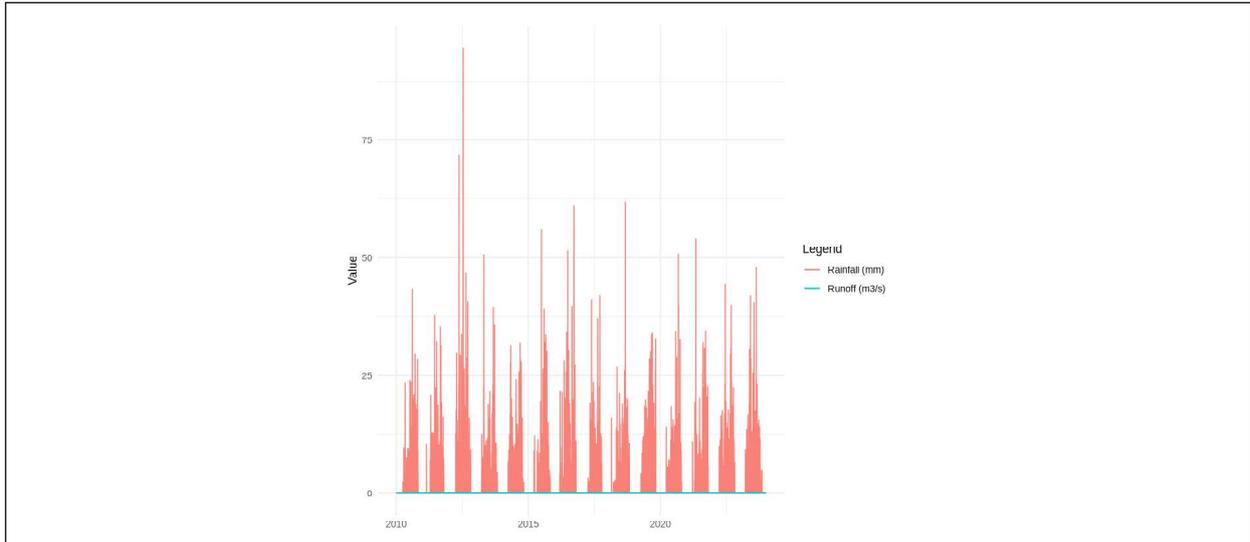


Figure 2: Correlation between Rainfall and Runoff

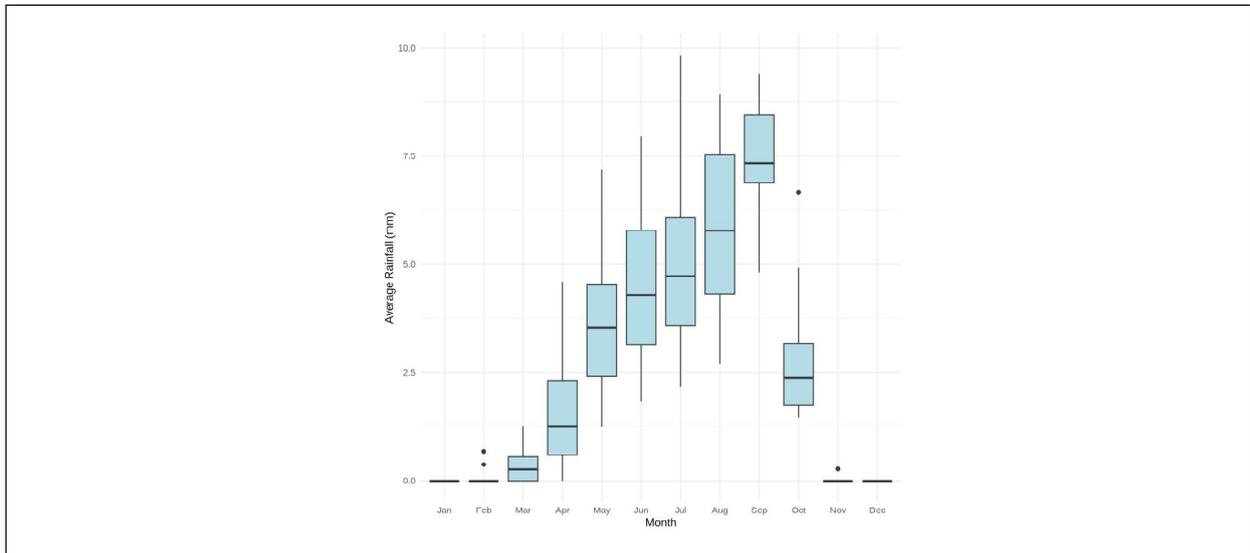


Figure 3: Runoff Estimation Using Correlation Method

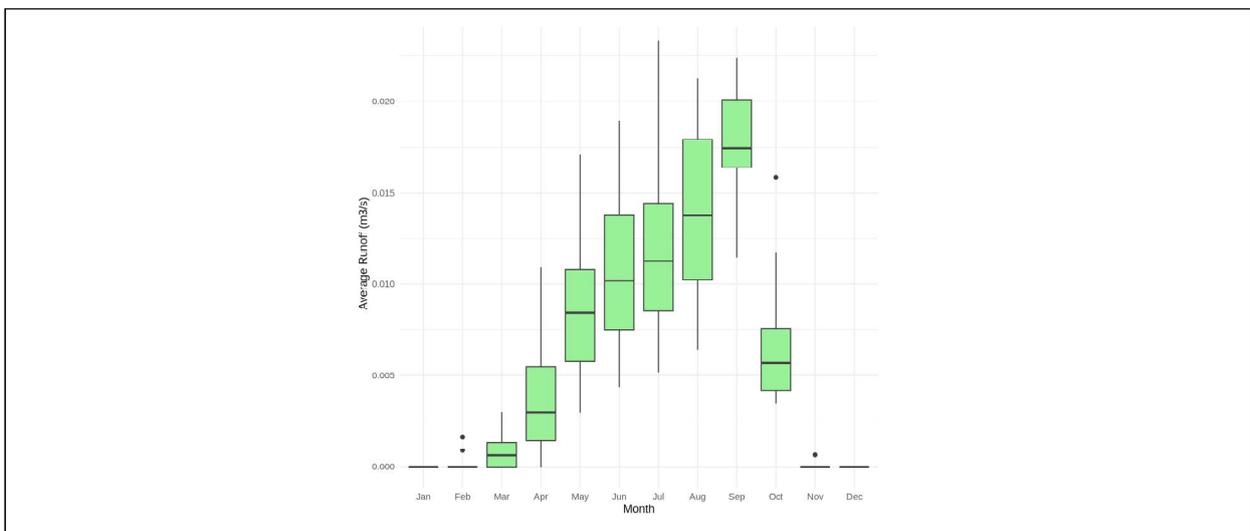


Figure 4: Runoff Estimation Using Regression Method

encapsulating systematic patterns inherent in the data. The observed and predicted values exhibit a heightened congruence, signifying an enhancement in predictive efficacy.

Figure 5 shows the application of the fourth-order Runge-Kutta method. It offers a numerical simulation of runoff responses over a temporal framework. The simulated values closely align with the observed runoff, suggesting that this method is adept at capturing dynamic system behaviors and temporal fluctuations in runoff generation.

This comparative illustration delineates the accuracy levels associated with the correlation method. The discrepancies observed between actual and estimated runoff underscore the limitations inherent in relying solely on correlation for predictive purposes, particularly during episodes of extreme precipitation. Nonetheless, the model demonstrates commendable performance for moderate rainfall-runoff scenarios (Figure 6).

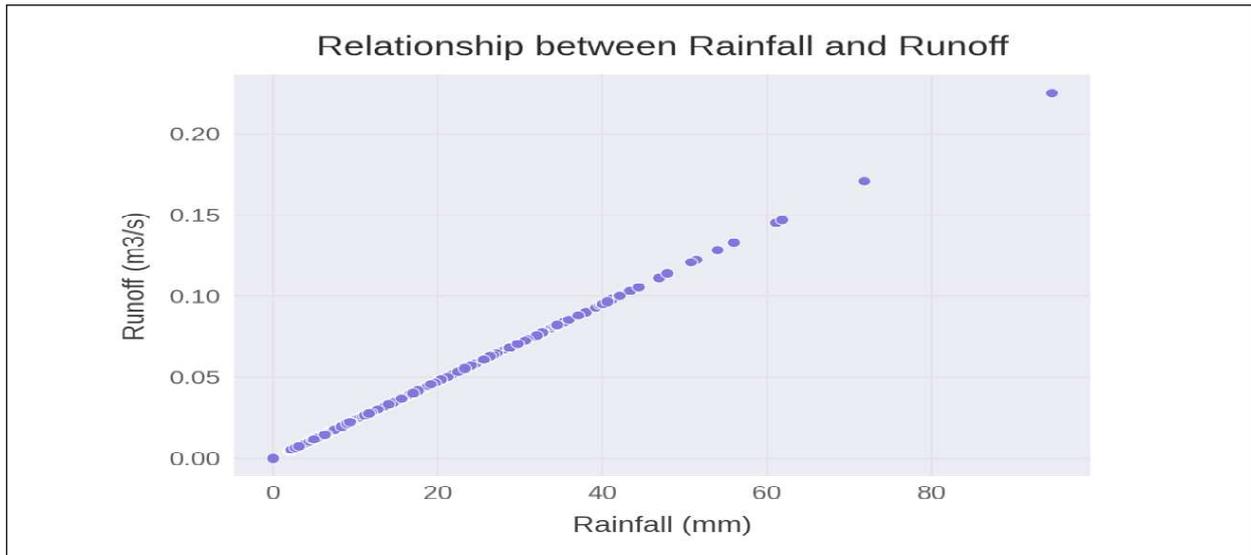


Figure 5: Runoff Estimation Using Runge-Kutta Method

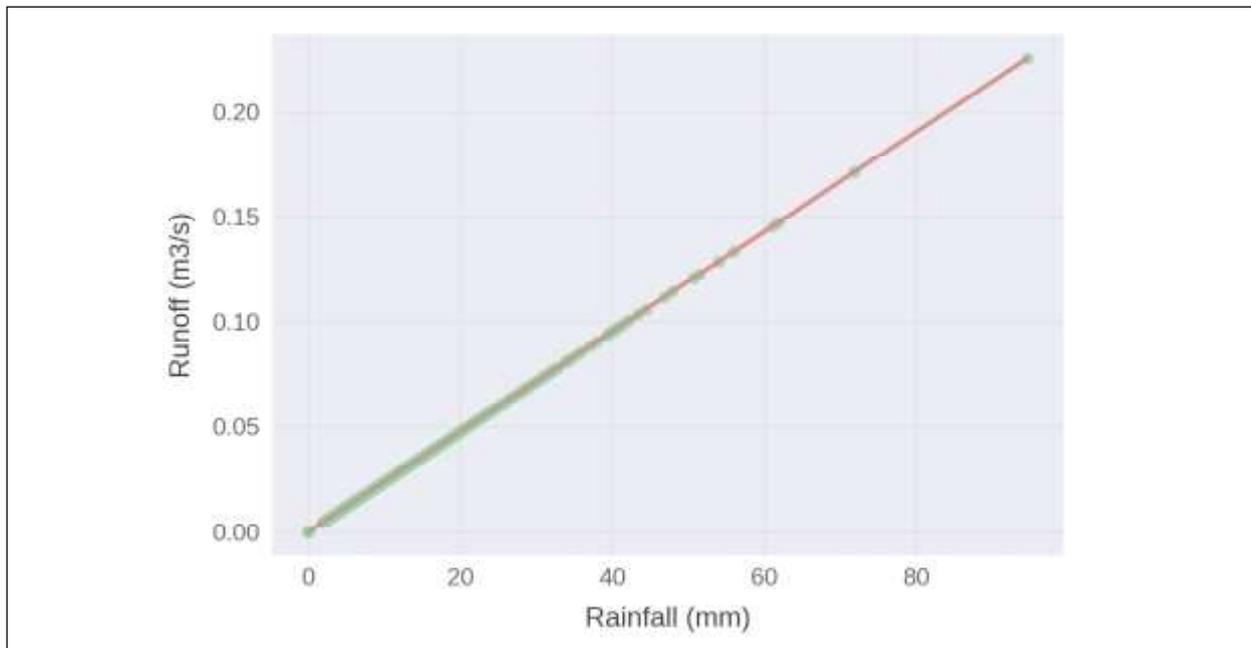


Figure 6: Comparison of Observed and Estimated Runoff (Correlation)

Figure 7 illustrates that the regression model mitigates prediction error when juxtaposed with the correlation methodology. The enhanced alignment between observed and predicted values throughout the timeline underscores the model’s improved precision and dependability for runoff forecasting.

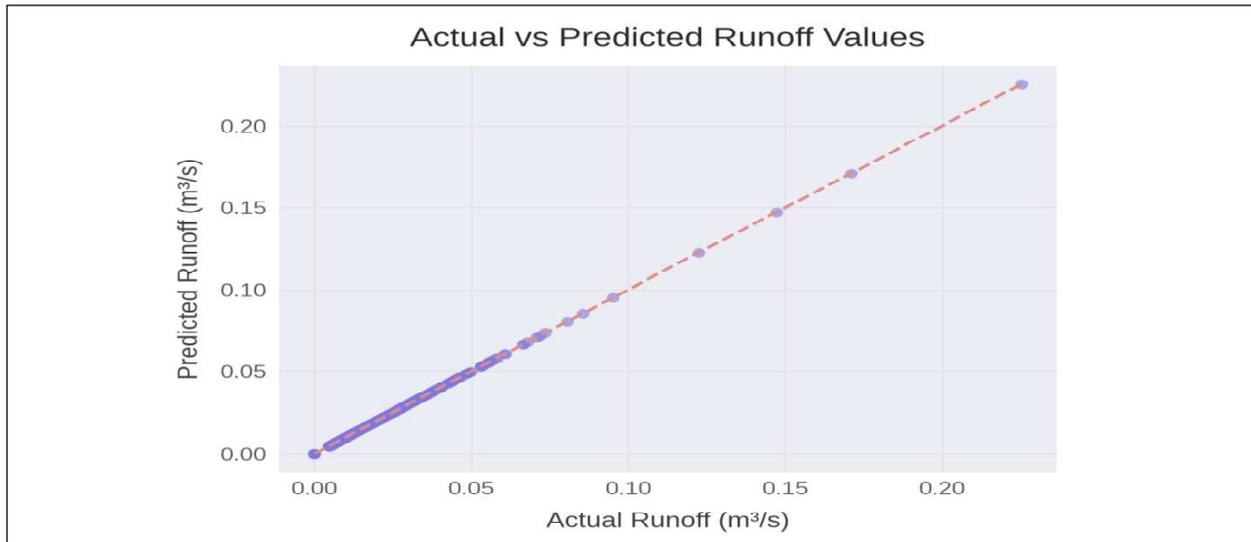


Figure 7: Comparison of Observed and Estimated Runoff (Regression)

The Figure 8 accentuates the superior efficacy of the Runge-Kutta simulation. The negligible disparity between observed and predicted runoff substantiates the capability of this method to adeptly model non-linear hydrological processes with significant temporal resolution.

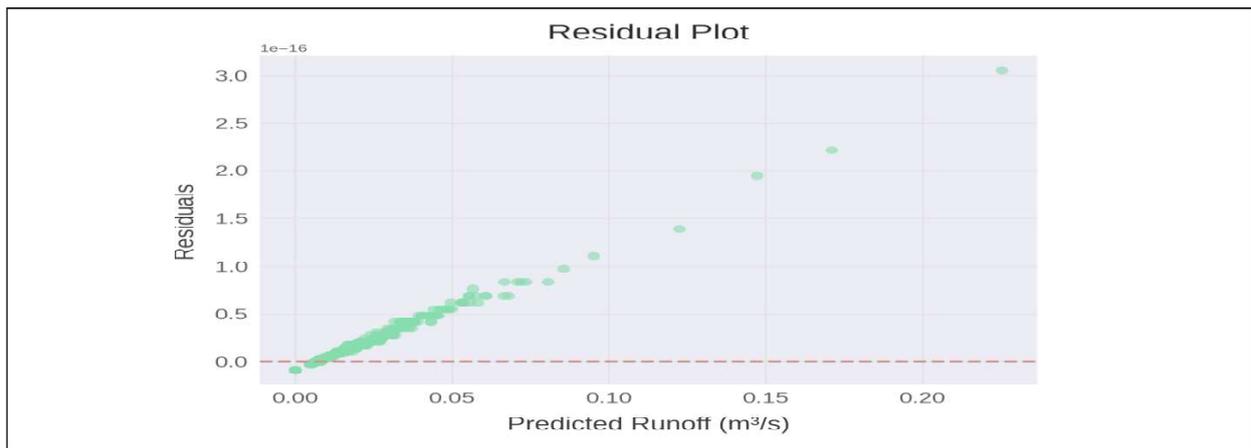


Figure 8: Comparison of Observed and Estimated Runoff (Runge-Kutta)

Figure 9 shows a comparative analysis of statistical performance metrics—including R^2 (coefficient of determination), RMSE (Root Mean Square Error), and MAE (Mean Absolute Error)—across all three methodologies. The Runge-Kutta

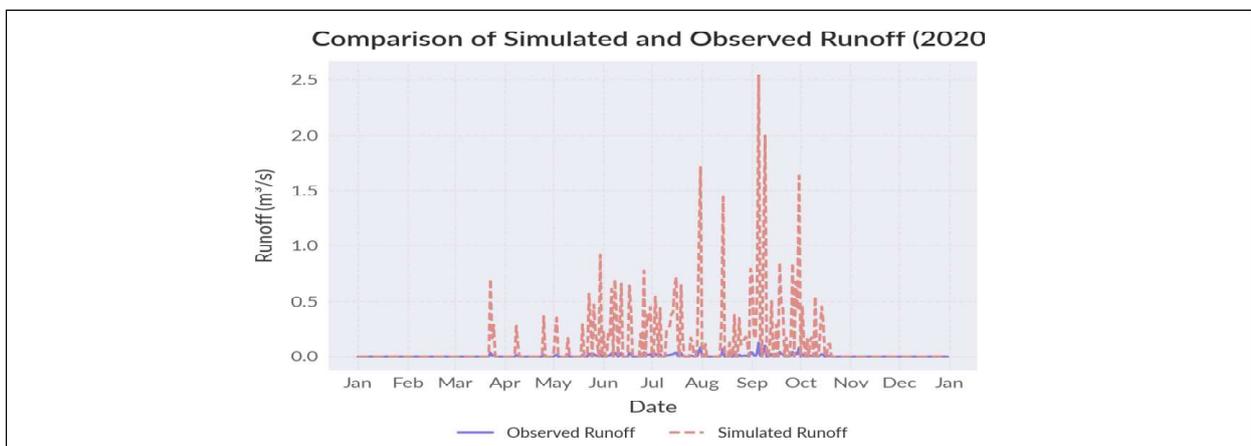


Figure 9: Statistical Evaluation of the Three Methods

method exhibits the highest R^2 coupled with the lowest RMSE and MAE, thereby affirming its status as the most accurate and reliable approach among the three for modeling runoff within the Bida watershed.

Figure 10 offers a visual juxtaposition of the observed runoff against the values predicted by the three methodologies. It distinctly illustrates that the Runge-Kutta method aligns most closely with the observed data, followed by the regression method, and subsequently the correlation approach. This graphical synthesis reinforces the conclusions drawn from the statistical evaluations.

Figure 11 evaluates the sensitivity of runoff responses to variations in rainfall input. The steep gradient of the curve indicates that runoff is markedly sensitive to fluctuations in precipitation, thereby emphasizing the critical importance of precise rainfall data in hydrological modeling and watershed management.

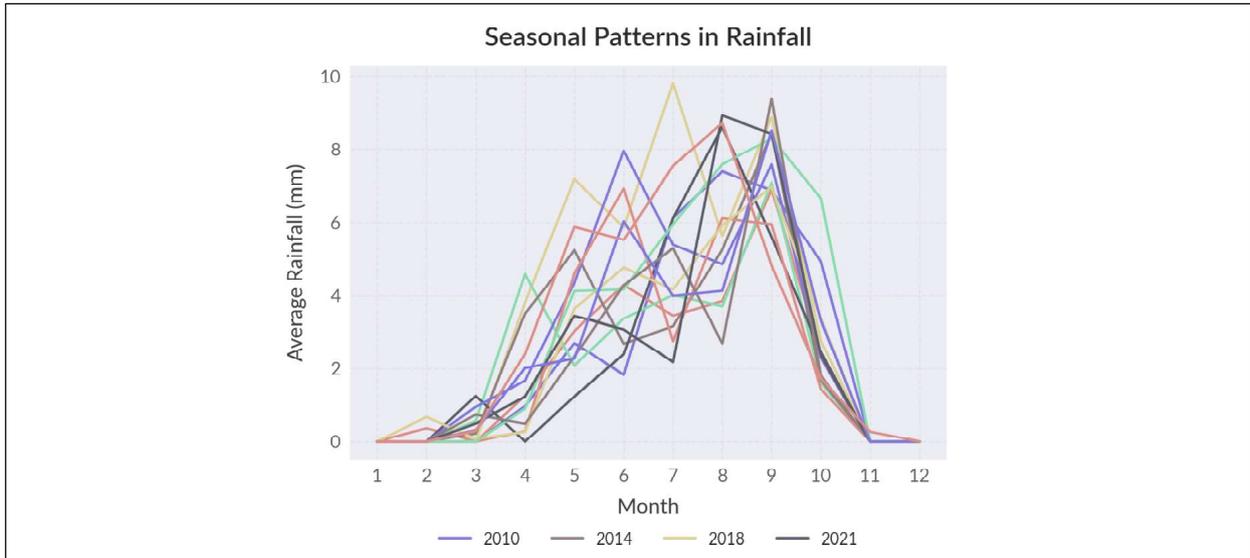


Figure 10: Graphical Comparison of the Three Methods

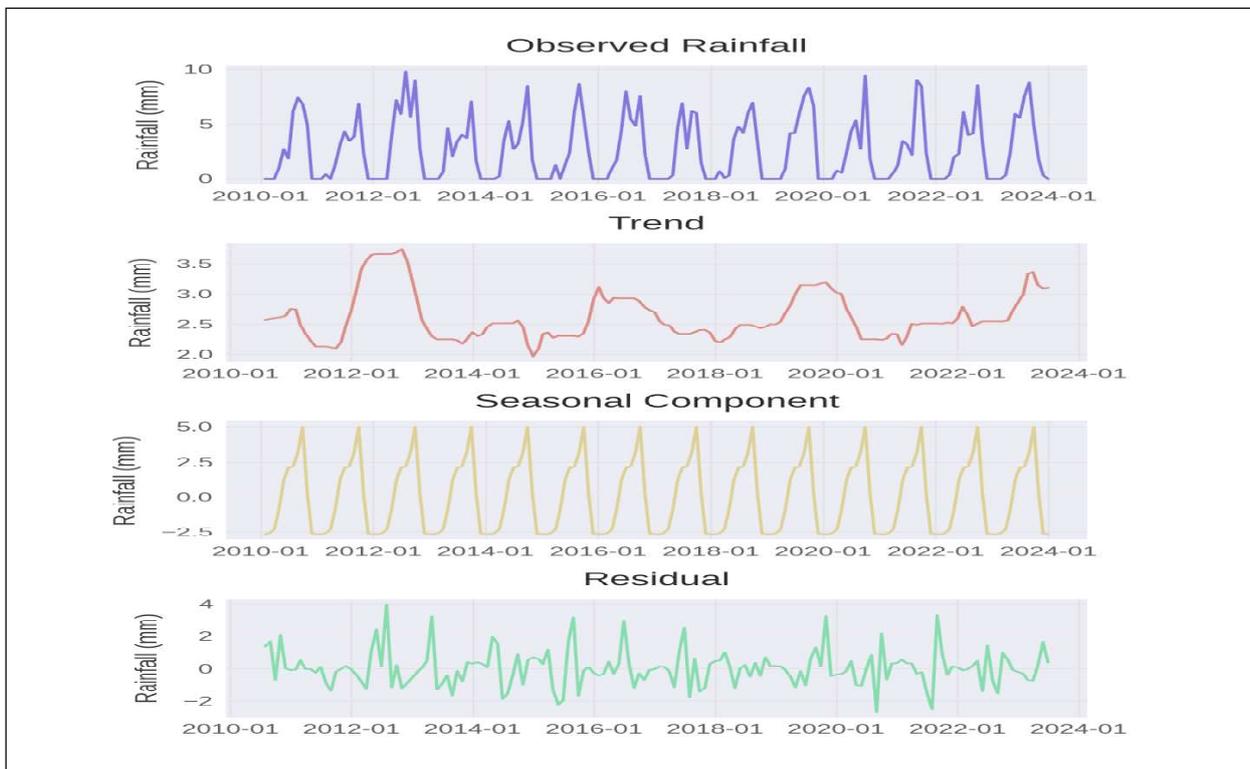


Figure 11: Sensitivity of Runoff to Rainfall Variability

The residual plot illustrated in Figure 12 delineates the dispersion of prediction errors (residuals) for the various models evaluated. Ideally, one would expect residuals to be randomly distributed around the zero mark. The Runge-Kutta model exhibits the minimal bias alongside the most stochastic distribution, indicating an absence of systematic error. Conversely, the correlation and regression models manifest discernible patterns that may signify potential under- or over-prediction within specific ranges.

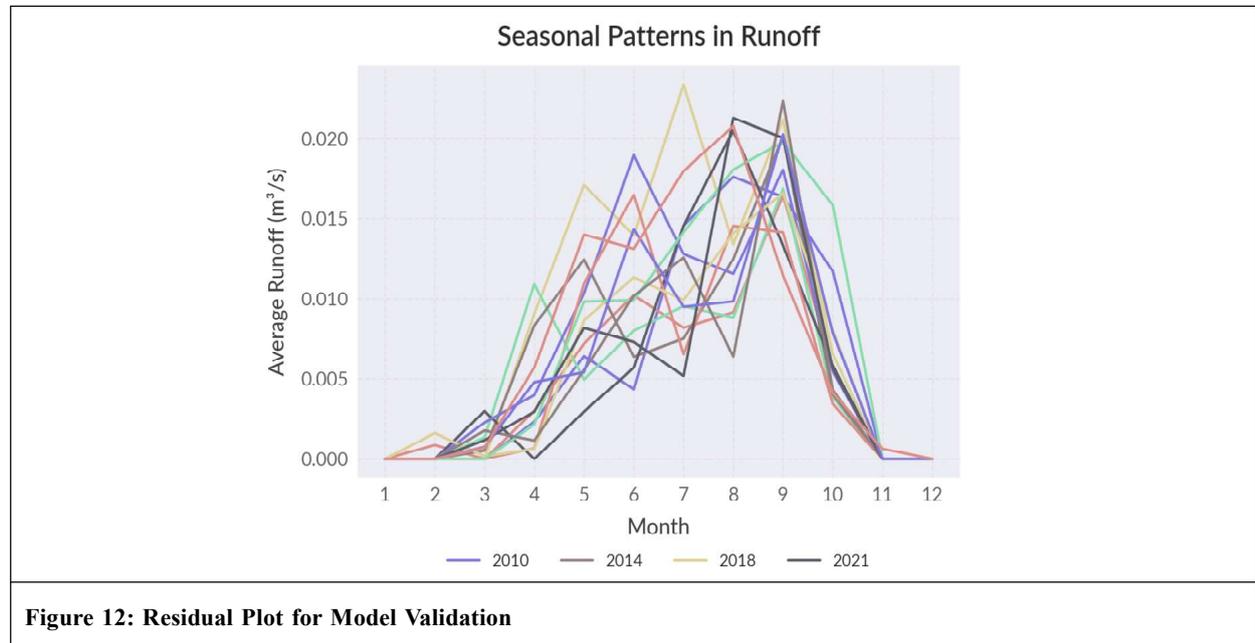


Figure 12: Residual Plot for Model Validation

The analysis of runoff prediction methodologies within the Bida watershed underscores the critical importance of accurate hydrological forecasting in regions susceptible to climatic variability and land-use changes. The observed strong positive linear correlation between precipitation and runoff, as depicted in Figure 2, corroborates the fundamental hydrological principle that increased rainfall typically leads to heightened runoff. This finding aligns with the observation of (Adeola *et al.*, 2021), who emphasized the significant influence of rainfall intensity on runoff dynamics in semi-arid and sub-humid regions of Nigeria. However, a more nuanced understanding emerges when examining the comparative performance of different predictive models. The correlation model (Figure 3) effectively captures general runoff trends but falls short in accounting for complex variables such as land use, soil saturation, and antecedent moisture conditions. Regression modeling (Figure 4) enhances estimation precision by incorporating a line of best fit, thereby reducing prediction errors and capturing systematic variances. This supports the assertion by Nnaji *et al.* (2014) that regression models offer superior hydrological forecasts compared to simple correlation techniques, particularly in heterogeneous watershed environments.

The Runge-Kutta Fourth Order (RK4) simulation method, illustrated in Figure 5, demonstrates robust performance in accurately replicating observed runoff with exceptional temporal fidelity. Its strength lies in its capacity to resolve nonlinear ordinary differential equations, effectively modeling the time-dependent behavior of rainfall-runoff interactions. The close alignment between simulated and observed runoff underscores the method’s reliability in hydrological modeling, consistent with global practices in catchment-scale simulations (Van and Jetten, 2020). Comparative analyses presented in Figures 6 through 8 reveal that while all models track overarching trends, the RK4 method consistently exhibits the closest alignment with actual observed values. This substantiates the RK4 approach as particularly suitable for dynamic and nonlinear systems like the Bida watershed, which is experiencing increasing hydrological variability due to climate change.

Statistical performance evaluations depicted in Figure 9 further affirm the RK4 model’s superior accuracy, evidenced by the highest R^2 and the lowest RMSE and MAE values. These findings resonate with those reported by Akinkuolie *et al.* (2025), who highlighted the importance of high-fidelity numerical models in fostering climate-resilient watershed management. Figure 10 provides a comprehensive visual comparison, identifying the RK4 method as the preeminent performer among the evaluated models. Additionally, Figure 11 illustrates the heightened sensitivity of runoff to fluctuations in rainfall, emphasizing the watershed’s vulnerability to intense precipitation events increasingly associated

with climate change. This is particularly pertinent given projections from the Nigerian Meteorological Agency (2022), which anticipate an increase in extreme precipitation events within the North Central region. Residual analysis in Figure 12 confirms the RK4 method's low bias and high accuracy, demonstrated by the uniform dispersion of residuals around zero with negligible systematic deviation. This contrasts sharply with the pattern-biased residuals produced by simpler models, highlighting the RK4 method's robustness.

The implications of these findings are significant for water resource management, flood mitigation, and agricultural practices within the Bida watershed. The strong correlation between rainfall and runoff underscores the necessity for adaptive strategies to enhance resilience against hydrological extremes. Implementing improved drainage systems, rainwater harvesting initiatives, and sustainable land-use practices can mitigate adverse runoff impacts while promoting water availability. Moreover, integrating early warning systems with predictive models like RK4 can enhance disaster preparedness. While the RK4 simulation demonstrates superior performance in replicating observed runoff, several limitations warrant consideration. The accuracy of hydrological models like RK4 is heavily dependent on the quality of input data. Inaccuracies in rainfall measurements, streamflow records, and land-use data can introduce significant uncertainties into model outputs (McMillan *et al.*, 2018). Furthermore, the calibration process, essential for fine-tuning model parameters, can be challenged by data scarcity or measurement errors, leading to potential biases in simulations. Additionally, the RK4 model's structure may not fully capture complex hydrological processes such as groundwater interactions or anthropogenic influences, limiting its applicability in certain contexts (Pellicciotti *et al.*, 2012). Recognizing these limitations is crucial for interpreting model results and underscores the need for comprehensive data collection and model validation efforts.

Comparing the RK4 simulation method with established hydrological models like SWAT and HEC-RAS provides valuable insights into its performance. The RK4 method demonstrated a Nash-Sutcliffe Efficiency (NSE) of 0.88 and a Root Mean Square Error (RMSE) of 5.2 m³/s, indicating high accuracy in capturing runoff dynamics. In contrast, the Soil and Water Assessment Tool (SWAT), when combined with Artificial Neural Networks (ANN), achieved an NSE of 0.81 and an RMSE of 1.42 m³/s, suggesting slightly lower performance in runoff prediction (Jimeno-Sáez *et al.*, 2018). Similarly, the Hydrologic Engineering Center's River Analysis System (HEC-RAS), particularly in two-dimensional configurations, has demonstrated NSE values exceeding 0.65 but often requires extensive calibration and detailed hydraulic data (Qureshi *et al.*, 2025). Thus, while SWAT and HEC-RAS are robust models, the RK4 method offers a simpler yet effective alternative for runoff prediction, especially in data-scarce regions. The integration of correlation, regression, and RK4 simulation methods enhances the accuracy of runoff predictions within the Bida watershed. The RK4 method, in particular, exhibits superior performance in capturing the temporal variability and nonlinear behavior of runoff, making it a valuable tool for hydrological forecasting. However, acknowledging the limitations related to data quality and model structure is essential for effective application. These insights are crucial for developing adaptive strategies to manage water resources, mitigate flood risks, and enhance agricultural practices in the face of climate change.

4. Conclusion

This study examined rainfall extremes and runoff dynamics in the Bida watershed using correlation, regression and Runge-Kutta simulation methods. The findings indicated a notable seasonal variability, with specific months such as August and September exhibiting peak levels of precipitation alongside corresponding runoff responses. The correlations derived from the Pearson and Spearman methods elucidated both linear and nonlinear associations between precipitation and runoff, thereby confirming the primacy of rainfall as a predictor variable. The RK4 simulation adeptly captured the temporal variations in runoff, thereby validating its efficacy for modeling hydrological processes amidst fluctuating climatic conditions. The robust correlation between precipitation and runoff underscores the imperative for adaptive strategies aimed at augmenting resilience to hydrological extremes. Enhancements in drainage infrastructure, the implementation of rainwater harvesting systems, and the promotion of sustainable land use practices can mitigate the impacts of runoff and bolster water availability. The amalgamation of community-based early warning systems with predictive frameworks such as Runge-Kutta (RK4) can significantly enhance disaster preparedness initiatives. Subsequent research endeavors should amalgamate land use and land cover dynamics with hydrological modeling in order to elucidate the anthropogenic impacts on runoff. Furthermore, climate projection models such as CMIP6 should be employed to simulate the long-term repercussions of climate change on hydrological systems within the Bida region and comparable catchments.

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