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Rainfall Variability, Return Periods and an ARIMA-Based Rainfall Forecasting Model for River Niger at Lokoja, Kogi State, Nigeria (1986–2020)

***Samuel Ogungbe; & **Shamsideen Ojoye PhD**

*Department of Meteorology, Federal University of Technology Minna. **Department of Meteorology, Federal University of Technology Minna

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Abstract

Flooding is the most damaging hydrometeorological hazard in Nigeria, and Lokoja, seated at the confluence of the Niger and Benue rivers is among the settlements most repeatedly affected by it. Because rainfall is the primary control on every other flood-generating mechanism in the basin, a defensible characterisation of rainfall magnitude, recurrence and short-horizon predictability is a prerequisite for any operational flood early-warning capability. This study examined the variability and return periods of annual rainfall over Lokoja between 1986 and 2020 and developed a univariate time series model capable of forecasting annual rainfall for the succeeding decade. Thirty-five years of monthly rainfall records obtained from the Nigerian Meteorological Agency were aggregated to annual totals, ranked in descending order of magnitude, and analysed for exceedance probability and return period using the Weibull plotting-position method. A Box–Jenkins autoregressive integrated moving average (ARIMA) model was then fitted after logarithmic transformation and first-order non-seasonal differencing, with the autoregressive order selected from the partial autocorrelation function. Results show a strongly asymmetric recurrence structure: rainfall in the 1500–1700 mm band carries an occurrence probability of 9.73 per cent and recurs on average once in about 14.7 years, whereas rainfall of 1097 mm and below carries a probability of 86.10 per cent and recurs roughly once in 1.2 years. The partial autocorrelation function was dominated by a single significant spike at lag 1 (−0.641), supporting an ARIMA (1,1,0) specification with an autoregressive coefficient of −0.621 ($t = -4.547$, $p < 0.001$) and a constant of 1.208. Forecast annual rainfall for 2021–2030 converges rapidly towards a long-run mean of approximately 1310 mm, ranging between 1262.8 mm and 1325.0 mm. The findings supply a quantitative recurrence baseline for flood preparedness planning in Lokoja and a parsimonious, operationally reproducible rainfall predictor that can drive a downstream river-stage model.

Keywords: annual rainfall; ARIMA (1,1,0); return period; Weibull method; partial autocorrelation; flood early warning; Lokoja; River Niger.

Introduction

Flooding is among the oldest, most widespread and most costly of natural hazards, and it remains the dominant hydrological disaster in Nigeria. Its contemporary character is being reshaped by a warming climate: the frequency and intensity of heavy precipitation events have increased over most land areas with sufficient observational coverage since the 1950s, and further increases are projected almost everywhere in Africa as global warming continues (IPCC, 2021). Nigeria has experienced recurrent inundation across its riverine corridors throughout that period. The 2012 episode, which began in July and did not recede until November of that year, long served as the reference event, having claimed some 363 lives and displaced more than 2.1 million people (National Emergency Management Agency [NEMA], 2013). Subsequent events in 2018 and 2020 reproduced the same damage signature at lower intensity, with the 2020 flood alone accounting for about 22 deaths in Kogi State (NEMA, 2020). The 2022 season then exceeded the 2012 benchmark: more than 3.2 million people were affected across 34 of the 36 states, at least 612 lives were lost and about 1.4 million people were displaced (United Nations Office for the Coordination of Humanitarian Affairs [OCHA], 2022). The regularity and escalating severity of these episodes indicate that flooding in the Niger corridor is no longer an anomaly to be absorbed after the fact, but a recurring condition that requires anticipatory management.

The consequences extend well beyond immediate loss of life and property. Repeated inundation of floodplain farmland in Nigeria damages standing crops, disrupts market access and erodes household food security, placing flood management squarely within the wider sustainable development agenda (Echendu, 2022). Where preparedness has been examined at household level in Kogi State, access to sensitisation resources from responsible agencies has been found to be poor, and readiness for future floods uneven across communities (Ogunwumi & Ihinegbu, 2025). These findings are consistent with the broader observation that flood early warning systems in the region frequently fail not for want of scientific sophistication but for want of institutional sustainability, data continuity and operator capacity (Sukhwani, Gyamfi, Zhang, AlHinai, & Shaw, 2019).

Lokoja occupies a position that concentrates this risk. The city lies at the confluence of the Niger and Benue rivers, which sweeps across the greater part of its land area and exposes it to fluvial inundation whenever the combined regime rises (Po et al., 2017). The physical setting compounds the exposure: Mount Patti rises to 485 m on the western flank of the settlement, producing a steep-to-gentle gradient towards the eastern lowlands adjoining the river, so that surface runoff is delivered rapidly to the channel with limited opportunity for infiltration (Ozulu, Ogbonna, & Ejikeme, 2021; Xie & Zhao, 2013). During the 2012 event, rainfall variability combined with releases from upstream storage raised the River Niger regime to 12.85 m against a discharge of about 30,676 cumecs (National Inland Waterways Authority [NIWA], 2018). Satellite-based mapping of the confluence region for the decade 2012 to 2022 confirms that severe inundation recurred in 2012, 2018, 2020 and 2022, and that the 2022 event surpassed 2012 in both spatial extent and affected population (Odiji et al., 2024). The floodplains immediately north-west of the confluence were inundated in more than nine of the ten years examined, which places a large share of Lokoja's built-up area and cropland within a

near-annual hazard zone. Rainfall is the proximate control on all of these mechanisms. Dam releases, channel blockage and bank overtopping are each conditioned by antecedent and concurrent precipitation, and rainfall remains the principal source of terrestrial water in the basin (Khan, 2011). A warming climate intensifies this control. Elevated surface temperatures raise evaporation over the river surface and strengthen deep convection over the adjoining land, increasing the moisture available for cloud formation and, in turn, the depth and intensity of rainfall (Oguntunde & Abiodun, 2013; Tabari, 2020). Approximately seven per cent more moisture can be held in the atmospheric column for each one-degree rise in air temperature (Trenberth, Koike, & Onogi, 2008), and heavier daily rainfall extremes are projected across West Africa under continued warming (IPCC, 2021). Rainfall recurrence therefore sits at the centre of any credible flood risk assessment for the study area.

Previous research on Lokoja has addressed adjacent but distinct questions. Audu (2012) described the temperature regime of the city using descriptive statistics; Egbenta, Udo and Otegbulu (2015) estimated the effect of flooding on real property values using a hedonic price model; Yussuf et al. (2017) evaluated the drainage system and identified heavy rainfall as the leading trigger of flood occurrence; Po et al. (2017) produced a flood vulnerability map classifying the metropolis into areas above flood level, more vulnerable areas and most vulnerable areas; Animashaun, Otache and Abatan (2020) examined rainfall trend and variability; Ojinnaka, Njoku and Baywood (2021) carried out a flood frequency analysis of the River Niger at Lokoja using the Log-Pearson Type III distribution; and Odiji et al. (2024) mapped a decade of flood inundation and damage in the confluence region using multi-sensor imagery. On the forecasting side, Ibrahim and Musa (2023) fitted seasonal ARIMA and SARIMAX models to monthly rainfall, temperature and relative humidity for the Lokoja station between 2010 and 2022, and reported that the exogenous-variable specification outperformed the univariate one at monthly resolution. That work establishes the value of Box-Jenkins methods for the station, but it operates on a thirteen-year monthly series and requires concurrent temperature and humidity inputs.

Two gaps remain. First, the recurrence structure of annual rainfall at Lokoja has not been quantified over a long record in a form that yields design magnitudes for stated planning horizons, as distinct from the discharge-based frequency analyses already available. Second, there is no explicit, reproducible annual rainfall forecasting component that operates on the single variable Nigerian agencies routinely archive and that can be coupled directly to a river-stage model. This article addresses both gaps using thirty-five years of station data, and a companion paper applies the resulting rainfall projections to a multiple regression model of River Niger stage at Lokoja.

Statement of the Problem

Flood preparedness planning in Lokoja is still organised around the memory of individual catastrophic years, principally 2012 and 2022, rather than around a quantified recurrence structure for the rainfall that drives them. Agencies responsible for evacuation, drainage design and shelter provision in Kogi State therefore lack two things: a defensible statement of how often rainfall of a given magnitude should be expected at the confluence, and a forward projection of annual rainfall that they can generate and maintain with the data and the technical capacity actually available to them. Existing studies supply either vulnerability maps, discharge-based frequency estimates, or monthly forecasting models that depend on additional climatic inputs, and none of these yields the annual recurrence baseline and parsimonious annual predictor that a stage model requires. In the absence of both, response remains reactive, design conditions remain implicit, and the moderate-magnitude events that account for most of the cumulative exposure over a planning cycle go unaddressed.

Aim and Objectives

The aim of this study is to characterise the variability, recurrence and short-horizon predictability of annual rainfall at Lokoja, and thereby to supply a quantitative basis for flood preparedness planning at the confluence. The specific objectives are:

- to examine the variability of annual rainfall over the study area between 1986 and 2020;
- to determine the exceedance probabilities and return periods of annual rainfall magnitudes over the same period;
- to develop and validate a univariate time series model for the annual rainfall series; and
- to generate annual rainfall projections for the period 2021 to 2030 for use as input to a river-stage model.

Research Questions

The study is guided by the following research questions:

- How variable is annual rainfall at Lokoja over the period 1986 to 2020?
- What are the exceedance probabilities and return periods associated with the observed annual rainfall magnitudes?
- Which Box-Jenkins specification best represents the annual rainfall series, and is that specification statistically adequate?
- What annual rainfall totals does the fitted model project for the period 2021 to 2030?

Study area

Lokoja, the capital of Kogi State, lies between longitudes 6°38′ and 6°48′E and latitudes 7°46′ and 7°52′N. It covers a land area of about 3,180 km² with a population of approximately 692,050. The River Niger enters the study area at Up Natako and merges with the River Benue in the vicinity of Ganaja village, making the Niger the dominant source of flood water in the metropolis (Figure 1).



Figure 1: River Niger at Lokoja, Kogi State, Nigeria

The climate is typical of the Guinea savannah belt, with a dry season and a rainy season. Mean annual rainfall is about 1150 mm, mean annual relative humidity is approximately 70 percent, and mean annual temperature is about 27.7 °C. The warmest year in the record was 2001 (about 29 °C) and the coolest was 1995 (about 27 °C); December is the coolest month, with a mean of 19.37 °C, while March and April are the warmest, at 25.56 °C and 25.31 °C respectively (Audu, 2012).

Topographically, the settlement sits between 45 m and 125 m above sea

level and is characterised by a steep-to-gentle gradient running from west to east (Figure 2). Elevation is an important conditioning variable: the lower the elevation, the greater the propensity to inundation, and the steeper the valley side, the more rapidly runoff is delivered to the channel (Xie & Zhao, 2013).

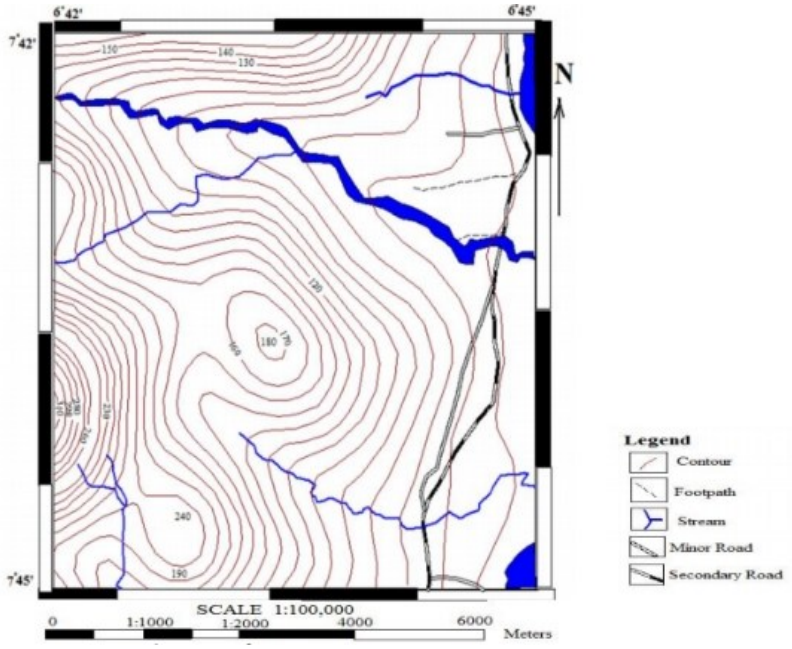


Figure 2: Topography of the study area (adapted from Ozulu et al., 2021)

Data and data sources

Secondary meteorological data were obtained from the Nigerian Meteorological Agency (NiMet), Abuja, and hydrological records were obtained from the headquarters of the National Inland Waterways Authority (NIWA), Lokoja. The dataset comprises thirty-five continuous years of monthly rainfall observations spanning 1986 to 2020. Ground-truthing was undertaken at the NIWA gauge station at Lokoja to confirm the water level benchmarks and peak monthly stage used in the companion analysis. Annual values were obtained as the arithmetic mean of the twelve monthly observations in each year, as expressed in Equation 1.

$$\bar{x} = \sum x / n \qquad (1)$$

where $\bar{x}$ is the annual mean, $\sum x$ is the sum of the monthly observations and n is the number of months in the year.

Return period analysis

To establish the recurrence structure of rainfall, the annual series was ranked in descending order of magnitude and the exceedance probability of each ranked value was computed using the Weibull plotting-position formula (Equation 2). The corresponding return period was obtained as the reciprocal of that probability (Equation 3).

$$P = m / (n + 1) \qquad (2)$$

$$T = 1 / P \qquad (3)$$

where P is the exceedance probability, m is the rank of the individual annual rainfall total, n is the number of observations in the series and T is the return period in years.

Time series modelling

A Box–Jenkins autoregressive integrated moving average (ARIMA) framework was adopted for the forecasting component. The procedure required, first, that the series be rendered stationary. A natural logarithmic transformation followed by first-order non-seasonal differencing was applied and the transformed series inspected for residual trend. The order of the autoregressive component was then identified from the partial autocorrelation function (PACF), which isolates the direct association between rainfall values separated by a given lag once the influence of all intervening lags has been removed.

The autoregressive process of order p expresses the current value as a linear function of its own past values plus a white-noise term (Equation 4), while the moving average process of order q expresses the current value as a function of past random error terms (Equation 5). The combined ARIMA (p, d, q) specification, incorporating the differencing order d, is given in Equation 6.

$$Y_t = a_0 + a_1 Y_{t-1} + a_2 Y_{t-2} + \ldots + a_p Y_{t-p} + \mu_t \quad (4)$$

$$Y_t = \beta_0 + \beta_1 \varepsilon_{t-1} + \beta_2 \varepsilon_{t-2} + \ldots + \beta_k \varepsilon_{t-k} + \mu \quad (5)$$

$$Y_t = \mu + \phi_1 y_{t-1} + \theta_1 e_{t-1} \quad (6)$$

Stationarity of the autoregressive component was verified through the characteristic equation, the roots of which must lie outside the unit circle for the series to be considered stationary. Model parameters were estimated by maximum likelihood and assessed using the t-statistic and its associated significance level.

Return periods of annual rainfall, 1986–2020

Table 1 presents the ranked annual rainfall totals for the study area together with their exceedance probabilities and return periods. The first column contains the observed totals sorted in descending order of magnitude, the second the corresponding rank, the third and fourth the exceedance probability expressed as a proportion and as a percentage, and the fifth the return period in years.

Table 1: Return periods of annual rainfall at Lokoja, 1986–2020

Rainfall (mm)	Rank (m)	Probability (P)	P (%)	Return period, T (years)
1767.1	1	0.03	2.78	36.00
1684.1	2	0.06	5.56	18.00
1643.2	3	0.08	8.33	12.00
1631.6	4	0.11	11.11	9.00
1520.1	5	0.14	13.89	7.20
1501.4	6	0.17	16.67	6.00
1495.0	7	0.19	19.44	5.14
1492.7	8	0.22	22.22	4.50
1490.7	9	0.25	25.00	4.00

Rainfall (mm)	Rank (m)	Probability (P)	P (%)	Return period, T (years)
1404.2	10	0.28	27.78	3.60
1387.1	11	0.31	30.56	3.27
1335.4	12	0.33	33.33	3.00
1334.6	13	0.36	36.11	2.77
1331.4	14	0.39	38.89	2.57
1314.4	15	0.42	41.67	2.40
1313.1	16	0.44	44.44	2.25
1291.1	17	0.47	47.22	2.12
1286.5	18	0.50	50.00	2.00
1276.0	19	0.53	52.78	1.89
1240.7	20	0.56	55.56	1.80
1207.0	21	0.58	58.33	1.71
1200.5	22	0.61	61.11	1.64
1176.0	23	0.64	63.89	1.57
1170.8	24	0.67	66.67	1.50
1136.3	25	0.69	69.44	1.44
1119.9	26	0.72	72.22	1.38
1083.1	27	0.75	75.00	1.33
1057.6	28	0.78	77.78	1.29
1031.0	29	0.81	80.56	1.24
1010.7	30	0.83	83.33	1.20
1003.8	31	0.86	86.11	1.16
995.6	32	0.89	88.89	1.13
939.4	33	0.92	91.67	1.09
931.5	34	0.94	94.44	1.06
923.6	35	0.97	97.22	1.03

Source: Author's analysis of NiMet rainfall records (1986–2020).

The recurrence structure is markedly asymmetric. Rainfall in the 1500–1700 mm band carries an occurrence probability of 9.73 per cent over the thirty-five-year record and recurs, on average, once in about 14.7 years. Rainfall between 1299 mm and 1499 mm carries a probability of 31.99 per cent and a return period of roughly 3.4 years. Rainfall between 1098 mm and 1298 mm has a probability of 59.72 per cent and recurs approximately once in 1.7 years, while rainfall of 1097 mm and below carries a probability of 86.10 per cent and a return period of about 1.2 years. The highest total in the record, 1767.1 mm, has an estimated return period of 36 years, and the lowest, 923.6 mm, a return period of just over one year.

Figure 3 plots the same information as a magnitude–frequency curve on a logarithmic recurrence axis. The curve rises steeply through the frequent, low-magnitude events and flattens across the mid-range before climbing again at the extreme tail, which is the signature of a small sample of high-magnitude years exerting disproportionate leverage on the upper end of the distribution. Practically, this means that the design rainfall associated with a ten-year planning horizon in Lokoja is of the order of 1630–1640 mm, while a two-year horizon corresponds to approximately 1286 mm.

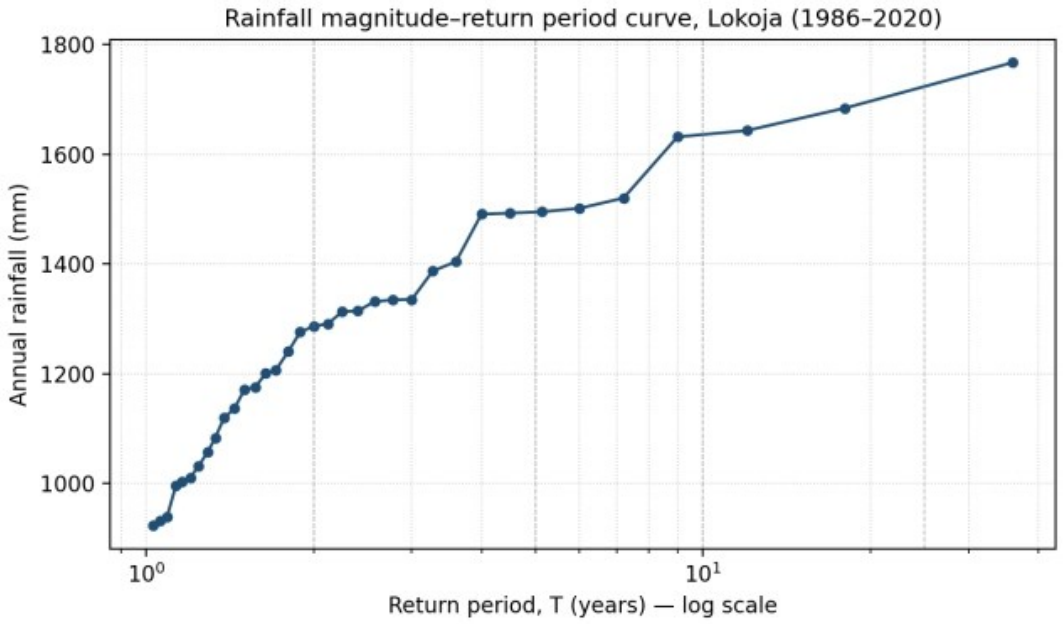


Figure 3: Rainfall magnitude–return period curve for Lokoja, derived from Table 1

These results are consistent with the vulnerability mapping of Po et al. (2017) and with the flood frequency analysis of Ojinnaka et al. (2021), both of which found that events of lower magnitude recur far more frequently than those of higher magnitude. They are also consistent with the decadal inundation record of Odiji et al. (2024), in which the floodplains adjoining the confluence were flooded in the majority of the years between 2012 and 2022 while the most extensive events were confined to two seasons. The operational implication is that preparedness planning cannot be calibrated solely on the memory of extreme years such as 2012; the high-frequency, moderate-magnitude band accounts for the greater part of the cumulative exposure over any planning cycle.

Stationarity of the rainfall series

Figure 4 displays the rainfall series after natural logarithmic transformation and one order of non-seasonal differencing. The seasonal differencing term was zero and the non-seasonal differencing term was one, indicating that a single differencing operation was sufficient to remove trend from the series. The largest positive departures occur in 2006 (0.55) and 2012 (0.54), while the largest negative departure occurs in 2000 (−0.54). The years 1996, 2004 and 2005 show departures averaging approximately ±0.34, and 1997 records the smallest departure at −0.12. The absence of any persisting drift after first differencing confirms that the series is stationary in the mean and therefore admissible for Box–Jenkins modelling.

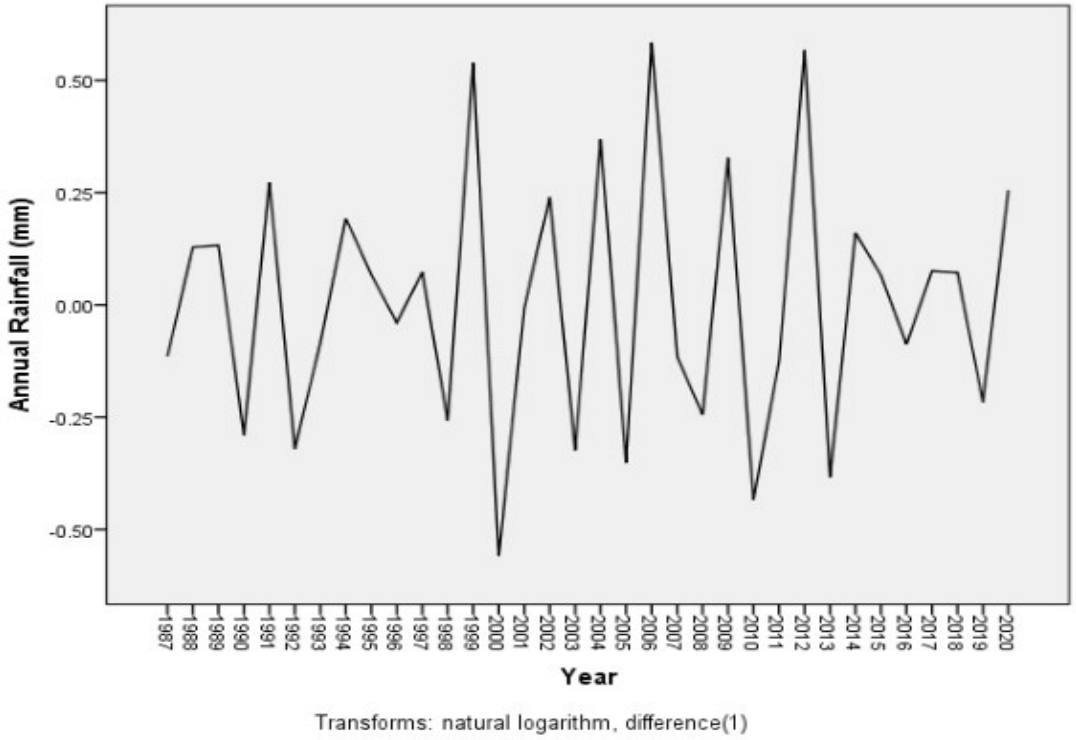


Figure 4: Stationarity of the annual rainfall series after logarithmic transformation and first differencing

Partial autocorrelation structure

Table 2 reports the partial autocorrelation function of the differenced series across thirty-two lags, together with the uniform standard error of 0.171. Figure 5 presents the same information graphically with the 95 per cent confidence bounds.

Table 2: Partial autocorrelation function (PACF) of annual rainfall, 1986–2020

Lag	Partial autocorrelation	Std. error	Lag	Partial autocorrelation	Std. error
1	-0.641	0.171	17	-0.042	0.171
2	-0.554	0.171	18	-0.037	0.171
3	0.061	0.171	19	0.197	0.171
4	-0.207	0.171	20	-0.017	0.171
5	-0.140	0.171	21	-0.096	0.171
6	-0.249	0.171	22	-0.145	0.171
7	-0.329	0.171	23	-0.065	0.171
8	-0.068	0.171	24	0.015	0.171
9	-0.154	0.171	25	0.059	0.171
10	0.009	0.171	26	-0.122	0.171
11	0.115	0.171	27	-0.017	0.171
12	0.070	0.171	28	-0.045	0.171
13	0.088	0.171	29	-0.081	0.171
14	-0.008	0.171	30	-0.048	0.171

Lag	Partial autocorrelation	Std. error	Lag	Partial autocorrelation	Std. error
15	0.138	0.171	31	0.000	0.171
16	0.026	0.171	32	-0.063	0.171

Source: Author's analysis (2021). Series: annual rainfall (mm), transformed and differenced.

At lag 1 the partial autocorrelation is −0.641, a strong inverse association indicating that a year of above-average rainfall tends to be followed by a year of below-average rainfall, and conversely. At lag 2 the coefficient is −0.554, again a strong inverse relationship once the influence of lag 1 has been removed. Beyond lag 2 the coefficients weaken substantially: lag 3 returns 0.061, lag 4 returns −0.207, lag 5 returns −0.140, lag 6 returns −0.249 and lag 7 returns −0.329. From lag 10 onwards the coefficients oscillate within a narrow band around zero, and by lags 33 to 35 the function has decayed entirely, indicating no direct association between rainfall values separated by those intervals.

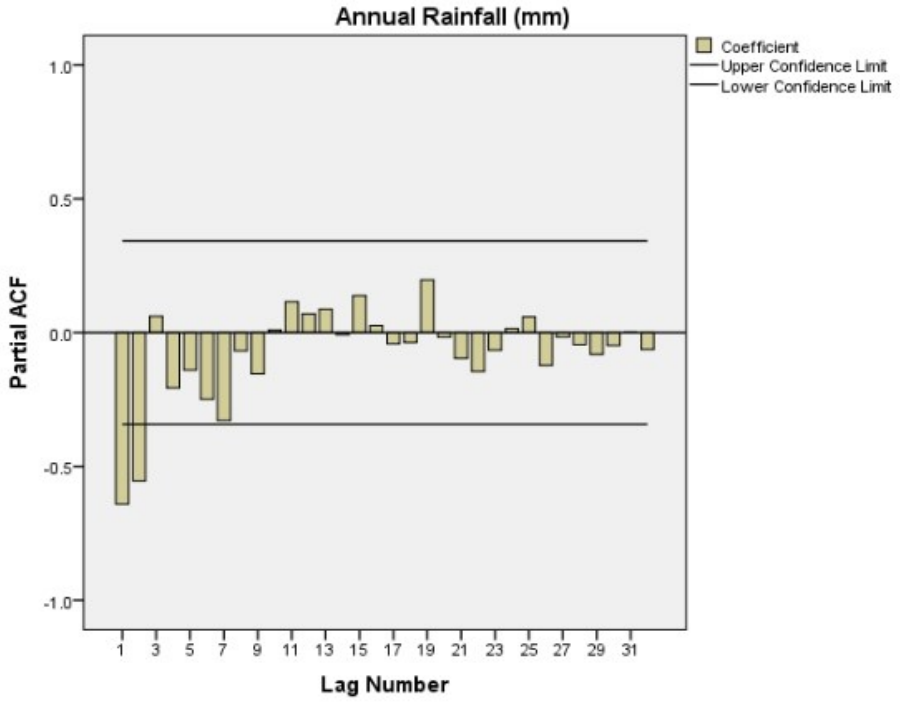


Figure 5: Partial autocorrelation function plot with 95 per cent confidence limits

Two spikes exceed the confidence bounds in Figure 5, but the spike at lag 1 is the more pronounced, and the lag-1 term substantially accounts for the partial autocorrelation observed at the remaining lags. The autoregressive order was therefore fixed at one, AR (1). This selection corroborates Olutimayin and Aribisala (2017), who likewise reported the highest partial autocorrelation at a single time lag and recommended a first-order autoregressive specification for rainfall in comparable settings; the present analysis extends that finding by explicitly accounting for the differencing order, which their model did not. Ibrahim and Musa (2023), working on monthly rainfall for the same station, likewise identified the autoregressive order from the partial autocorrelation function and required one order of differencing to attain stationarity, although the seasonal structure of monthly data obliged them to fit a seasonal specification that the annual series does not require.

The fitted ARIMA model

Table 3 reports the estimated parameters of the fitted model. The specification is ARIMA (1,1,0): one autoregressive term, one order of differencing and no moving average term. The absence of a moving average component reflects the fact that a single differencing operation was sufficient to stabilise the series, so no additional smoothing was required.

Table 3: ARIMA (1,1,0) model parameters for annual rainfall

Parameter	Estimate	Std. error	t	Sig.
Constant	1.208	31.114	0.039	0.969
AR, Lag 1	−0.621	0.137	−4.547	0.000
Difference (d)	1	—	—	—
Moving average (q)	0	—	—	—

Source: Author's analysis (2021). Series: annual rainfall (mm), no transformation applied at the estimation stage.

The resulting forecasting equation is given in Equation 7.

$Y_k = 1.208 - 0.621\ (y_t - y_{t-1})$ (7)

The autoregressive coefficient of −0.621 is significant at the one per cent level ($t = -4.547$, $p < 0.001$) and quantifies both the strength and the direction of the relationship between the current year's rainfall and the year-on-year difference. Its negative sign encodes the alternating behaviour already visible in the partial autocorrelation function: a wetter-than-usual year is systematically associated with a drier successor, and vice versa. The constant term of 1.208 represents the baseline level of annual rainfall that is not explained by the autoregressive and differencing components; it is not statistically significant in its own right ($p = 0.969$), which is expected in a differenced series where the mean has been largely removed by the differencing operation.

Rainfall forecast for 2021–2030

Table 4 presents the annual rainfall projections generated by Equation 7 for the decade 2021 to 2030, and Figure 6 sets those projections against the observed and fitted series for the calibration period.

Table 4: Forecast annual rainfall for River Niger at Lokoja, 2021–2030

S/N	Year	Forecast rainfall (mm)
1	2021	1262.8
2	2022	1325.0
3	2023	1288.3
4	2024	1313.1
5	2025	1299.6
6	2026	1309.9
7	2027	1305.5
8	2028	1310.2
9	2029	1309.2
10	2030	1311.8

Source: Author's analysis (2021), derived from ARIMA (1,1,0).

The forecast opens at 1262.8 mm in 2021 and peaks at 1325.0 mm in 2022 before oscillating with progressively damped amplitude 1288.3 mm in 2023, 1313.1 mm in 2024, 1299.6 mm in 2025 and converging towards a long-run mean of approximately 1310 mm by the end of the decade. This convergence is the expected behaviour of a stationary first-order autoregressive process: the alternating signal decays geometrically with the forecast horizon, so that beyond roughly five years the projection carries little information beyond the series mean. The practical corollary is that the model is most defensible as a one-to-three-year operational tool and should be re-estimated annually as new observations become available.

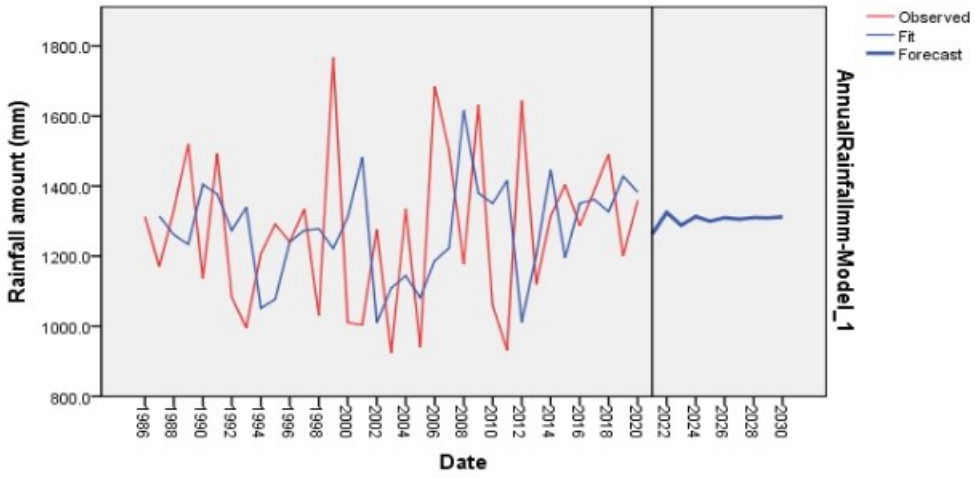


Figure 6: Observed, fitted and forecast annual rainfall for Lokoja, 1986–2030

Figure 6 shows that the fitted series reproduces the general amplitude of the observed record but systematically lags its turning points, understating the extreme wet years of 2000 and 2012 and overstating several of the dry troughs. The largest single-year departure occurs in 2000, with a mean square error of 6.48. This behaviour is characteristic of a differenced autoregressive model applied to a series whose extremes are driven by processes that lie outside the univariate rainfall signal in the case of Lokoja, most obviously the timing and volume of releases from the Kainji and Jebba reservoirs, together with the antecedent moisture condition of the upstream catchment.

Discussion

Taken together, the two strands of analysis yield a coherent picture of the rainfall regime that conditions flooding at Lokoja. The return period analysis establishes that the hazard is dominated not by rare catastrophic totals but by a dense band of moderate events recurring at intervals of one to three years, with genuinely extreme totals confined to a fifteen-year recurrence interval. The time series analysis establishes that the year-to-year signal is strongly anti-persistent at a single lag, which is both a modelling convenience, it justifies a highly parsimonious specification, and a substantive finding about the regime, since it implies that the memory of the rainfall system at annual resolution is essentially one year deep.

The parsimony of ARIMA (1,1,0) is an operational asset. The model requires only the current and preceding annual totals, both of which are routinely available from NiMet, and can be updated on a spreadsheet without specialist software or hydrological modelling capacity. This matters in a context

where flood early warning systems in the region frequently fail not for want of scientific sophistication but for want of institutional sustainability, data continuity and operator capacity (Sukhwani et al., 2019). Against that constraint, a model that a state emergency management agency can maintain in-house is preferable to a more accurate one that it cannot. The same constraint applies at the receiving end of the warning chain, where access to flood sensitisation resources in Kogi State communities has been found to be limited (Ogunwumi & Ihinegbu, 2025), so that gains in forecast accuracy yield little unless the output can be produced and disseminated routinely.

The limitations follow directly from the same parsimony. A univariate annual model cannot resolve within-year distribution, which is the variable that most directly determines whether a given total produces inundation: 1300 mm delivered evenly across seven months carries a very different flood signature from the same total concentrated in six weeks. Nor does the model incorporate upstream dam operation, land use change or catchment storage, each of which modulates the rainfall-runoff relationship (Aich, Kone, Hattermann, & Paton, 2016; Tefera, 2015). The point is not hypothetical: releases from the Lagdo reservoir in Cameroon, propagating down the Benue, were a material contributor to the 2022 inundation at the confluence (Odiji et al., 2024; OCHA, 2022). These omissions bound the interpretation of the results rather than invalidate them: the model forecasts rainfall, not flooding, and its value lies in supplying a defensible input to the stage model developed in the companion analysis.

Conclusion

This study examined rainfall variability and return periods over Lokoja for the period 1986 to 2020 and developed a univariate forecasting model for the annual series. Three conclusions follow. First, the recurrence structure of rainfall at Lokoja is strongly asymmetric: totals in the 1500–1700 mm band recur on average once in 14.7 years, whereas totals of 1097 mm and below recur roughly once in 1.2 years, so that preparedness planning must address a high-frequency moderate band as well as the rare extreme. Second, the annual rainfall series becomes stationary after a single non-seasonal differencing operation and exhibits a dominant, significant partial autocorrelation at lag 1 of −0.641, indicating a one-year, anti-persistent memory. Third, the resulting ARIMA (1,1,0) model, $Y_k = 1.208 - 0.621\ (y_t - y_{t-1})$, generates projections for 2021–2030 that range from 1262.8 mm to 1325.0 mm and converge on a long-run mean near 1310 mm.

Recommendations

The following recommendations follow from the findings reported above:

- Agencies responsible for flood preparedness in Kogi State should treat annual rainfall in the 1500 to 1700 mm band as a design condition expected at least once in every fifteen years, and should size evacuation planning, shelter provision and drainage capacity accordingly.
- Preparedness planning should give explicit weight to the moderate-magnitude band of 1098 to 1298 mm, which recurs on average once in about 1.7 years and accounts for the greater part of cumulative exposure over any planning cycle.
- The ARIMA (1,1,0) model should be adopted operationally as a one-to-three-year planning tool and re-estimated annually as each new observation becomes available, since the series was differenced at only one order and projections at longer lags converge on the series mean.
- Subsequent work should extend the specification to incorporate discharge from the Kainji and Jebba dams and releases from the Lagdo dam, so that upstream regulation enters the forecast explicitly rather than appearing as unexplained residual variance.

- The annual series should be disaggregated to monthly or seasonal resolution in future work, so that the model speaks to the timing of rainfall and not only to its volume.
- Forecast output should be paired with community-level dissemination channels in the most exposed settlements, since forecasting capacity delivers no protective benefit where warning information does not reach the households at risk.

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