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Enhancing Food Security and Agricultural Planning Through Predictive Analytics: A Comparative ARIMA Modelling Approach to Rice Production Forecasting in the Bakalori Irrigation Scheme, Zamfara State

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ABSTRACT
Reliable forecasts of staple crop output are indispensable for national food security planning, input-supply budgeting, and irrigation-scheme management in food-insecure regions of northern Nigeria. This prototype empirical study demonstrates a comparative box-Jenkins Autoregressive Integrated Moving Average (ARIMA) modelling approach to forecasting annual paddy rice production in the Bakalori Irrigation Scheme (BIS), Zamfara State, using a simulated thirty-year (1994-2023) annual production series constructed to reflect the documented expansion, rehabilitation and shock history of the scheme. Following the Box-Jenkins methodology, the series is tested for stationarity using the Augmented Dickey-Fuller (ADF) test, differenced where necessary, and several candidate models are identified from the autocorrelation (ACF) and partial autocorrelation (PACF) functions. Competing specifications - ARIMA(1,1,0), ARIMA (0,1,1), ARIMA(1,1,1) and ARIMA (2,1,1) - are estimated and compared using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE) on a hold-out sample. The results are expected to identify ARIMA (1,1,1) as the parsimonious best-fit model, passing the Ljung-Box white-noise diagnostic on its residuals, and to project a gradual upward trajectory in BIS rice production over 2024-2030, consistent with ongoing rehabilitation of gravity-fed irrigation infrastructure. The study concludes that ARIMA-based predictive analytics offers scheme managers, extension agencies and food-security planners a low-cost, replicable early-warning tool, and recommends its integration into routine agricultural planning alongside complementary machine-learning and climate-adjusted models.
Keywords: ARIMA modelling; rice production forecasting; food security; Bakolori Irrigation Scheme; Box-Jenkins method; predictive analytics; Zamfara State.

1. INTRODUCTION
Rice (Oryza sativa L.) has become one of the most strategic staple crops in Nigeria's food system, with domestic demand consistently outpacing local supply and driving a persistent and costly import bill despite decades of government self-sufficiency programmes. Accurate, timely forecasts of production are therefore central to national food security planning, strategic grain reserve management, price stabilisation policy and the scheduling of input support to farmers.

Irrigation schemes occupy a special place in this planning problem because, unlike rain-fed farming, their output is shaped jointly by water availability, infrastructure condition and management decisions, making their production trajectories more tractable to statistical forecasting than rain-fed systems that are dominated by weather variability. The Bakalori Irrigation Scheme (BIS) in Zamfara State, north-western Nigeria, is one of the largest gravity- and sprinkler-fed irrigation projects in the country, supplying water from the Bakolori Dam to roughly 23,000 hectares across the Talata Mafara, Maradun and Bakura Local Government Areas, of which about 31 percent is served by gravity and 69 percent by sprinkler systems (Uphoff et al., 2023). The scheme supports thousands of smallholder rice, wheat and maize farmers and has recently been the focus of renewed federal investment, including rehabilitation of gravity-fed infrastructure under the Transforming Irrigation Management in Nigeria (TRIMING) project, targeted at raising rice output toward 100,000 metric tonnes annually (Federal Ministry of Water Resources, 2025). At the same time, the scheme remains vulnerable to recurrent production shocks, including reservoir siltation, input scarcity, market gluts at harvest and, most recently, large-scale bird invasions that destroyed farmland across the three host Local Government Areas (Nairametrics, 2026).

Against this backdrop of expansion, rehabilitation and recurring shocks, scheme managers, extension agencies and state food-security planners need a systematic, data-driven basis for anticipating near-term production rather than relying on anecdotal harvest reports. Time series forecasting techniques, and the Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) family of models in particular, have become the standard entry point for such problems in agricultural economics because they require only the historical production series itself, are transparent, and have repeatedly been shown to perform competitively against more data-intensive alternatives for national and sub-national crop output (Umar, Girei, & Aliyu, 2019; Sowunmi & Omigie, 2017). However, most existing Nigerian applications of ARIMA to rice have operated at the national level using FAO aggregate data; scheme-level forecasting studies that compare several ARIMA specifications and validate them out-of-sample for a specific irrigation project such as Bakalori remain scarce.

1.1 Statement of the Problem

Agricultural planning agencies in Zamfara State and at the Bakalori Irrigation Scheme currently lack a formal, empirically validated short-term forecasting tool for rice output. Planting decisions, fertilizer and input allocations, and post-harvest storage and marketing arrangements are consequently made with limited forward visibility, increasing the risk of both scarcity and glut, the latter of which has already been documented among BIS wheat and rice farmers who report distress sales at harvest due to poor price coordination (Daily Trust, 2025). A comparative, scheme-specific ARIMA forecasting exercise addresses this gap by providing a replicable statistical basis for anticipating production levels one to five years ahead.

1.2 Objectives of the Study

The broad objective of this study is to enhance food security and agricultural planning in the Bakolori Irrigation Scheme through predictive analytics based on comparative ARIMA modelling of rice production. The specific objectives are to:

I. describes the trend and structural properties of annual rice production in the Bakolori Irrigation Scheme, 1994-2023;
II. test the production series for stationarity and determine the appropriate order of differencing;
III. identify, estimate and compare competing ARIMA model specifications using standard information criteria and out-of-sample forecast accuracy measures; and
IV. generate and interpret short- to medium-term (2024-2030) forecasts of rice production from the selected best-fit model for use in agricultural planning.

1.3 Justification of the Study

The study is justified on three grounds. First, it operationalises predictive analytics at the scale most relevant to on-the-ground decision-making - the irrigation scheme - rather than the national aggregate level at which most Nigerian rice-forecasting studies have been pitched (Ben-Umeh & Ndubuisi, 2024; Sowunmi & Omigie, 2017). Second, by explicitly comparing multiple ARIMA specifications rather than fitting a single model, it follows current best practice in agricultural time series forecasting, which

emphasises rigorous model selection over ad hoc specification (Min, Sufahani, Abu, & Howe, 2025). Third, its outputs are directly usable: scheme managers and Zamfara State's Ministry of Agriculture can incorporate the resulting forecasts into seasonal planning, extension targeting and strategic reserve decisions, contributing to the wider goal of national food security envisaged under Nigeria's agricultural transformation policies.

2. LITERATURE REVIEW

2.1 Conceptual and Theoretical Framework

Food security, in the widely accepted FAO formulation, exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs. Production forecasting contributes primarily to the 'availability' pillar of this definition by allowing planners to anticipate supply shortfalls or surpluses before they materialise. The theoretical basis for the present study is the Box-Jenkins time series methodology (Box, Jenkins, Reinsel, & Ljung, 2016), which treats an observed series as a realisation of a stochastic process that can be approximated by a linear combination of its own past values (the autoregressive, AR, component) and past forecast errors (the moving average, MA, component), after differencing the series a sufficient number of times, d, to induce stationarity. A general ARIMA(p,d,q) model is written as Yt (after d-th differencing) being generated by p autoregressive terms and q moving-average terms plus a white-noise error, and is fitted through the three classical Box-Jenkins stages of identification, estimation and diagnostic checking.

2.2 Empirical Review

A substantial body of empirical work has applied ARIMA models to staple crop production and prices across Nigeria and other developing countries. Umar, Girei and Aliyu (2019) forecast Nigeria's national rice output using an autoregressive integrated moving-average approach and found an ARIMA specification adequate for short-term projection. In a closely related national-level study, an ARIMA(1,1,0) model was found suitable for Nigerian rice production while an ARIMA(0,1,1) model best fitted producer price, with both forecasts pointing to continued growth in output and price through the following two decades (Oyinbo, 2018). Similar Box-Jenkins applications have been reported outside Nigeria: an ARIMA(0,1,1) model with drift was identified as the best national rice-production forecaster in Bangladesh, although a tree-based XGBoost model outperformed it in the test sample (Paul, Rahman, & Hasan, 2023); in Malaysia, ARIMA was compared against naive, Holt's linear-trend and neural-network forecasts of national rice production, with ARIMA remaining a strong and interpretable benchmark (Min et al., 2025); and in the Benin Republic, a Box-Jenkins ARIMA(2,1,9) model was used to forecast rice self-sufficiency, showing the country remains import-dependent despite rising production (Zannou, Agli, & Honfoga, 2024).

Comparative studies that pit ARIMA against alternative forecasting techniques for Nigerian agricultural commodities generally find that no single method dominates across all crops: ARIMA fits stationary, relatively stable series such as maize and imported rice well, while crops with strong seasonality or erratic production patterns are better handled by seasonal trend-loess or hybrid models (Adenomon & Oyejola, 2022). This mixed evidence motivates the comparative model-selection approach adopted in the present study rather than the a priori adoption of a single ARIMA order. Beyond rice-specific work, ARIMA has also been validated for forecasting Nigerian rainfall and temperature series relevant to irrigated agriculture (Abatan, Abiodun, Lawal, & Gutowski, 2016) and for Nigerian agricultural commodity prices more broadly (Ogundari & Akinbode, 2021), underscoring the method's general applicability across the food-security value chain.

Scheme-level studies of the Bakalori Irrigation Scheme itself have so far concentrated on agronomic and socio-economic questions rather than statistical forecasting. Uphoff and colleagues documented the productivity gains achievable through a 'best-bet' System of Rice Intensification (SRI) package tailored to BIS soils and water-control conditions (Uphoff et al., 2023), while a related poverty-focused analysis found that BB-SRI adopters in the scheme experienced substantially lower monetary and non-monetary poverty than farmers using conventional practice (de Bruin et al., 2023). Sulaiman, Ahmed, Doris, Abubakar and Rabi'u (2026) examined the socio-economic and institutional determinants of farmers'

participation in SRI within BIS, while an earlier socio-economic assessment documented the scheme's broader contribution to community development in Talata Mafara, Bakura and Maradun (Abubakar & Sani, 2021). None of these studies, however, develops a time series production-forecasting model for the scheme, leaving open the gap that the present study addresses.

2.3 Gap in Literature

The reviewed literature establishes both the general validity of ARIMA for staple-crop forecasting and the socio-economic importance of the Bakalori Irrigation Scheme, but no identified study combines the two: a scheme-level, comparative ARIMA forecasting exercise for BIS rice production, benchmarked with formal information-criteria and out-of-sample accuracy measures, has not previously been undertaken. This study fills that gap.

3. METHODOLOGY

3.1 The Study Area

The study is set in the Bakalori Irrigation Scheme, located in Zamfara State, north-western Nigeria, and spanning parts of Talata Mafara, Maradun and Bakura Local Government Areas. Water is supplied from the Bakolori Dam, completed in 1979 with an original storage capacity of about 450 million cubic metres, since reduced by siltation to an estimated 350 million cubic metres (Uphoff et al., 2023). The dam presently irrigates approximately 23,000 hectares, of which about 31 percent is served by gravity and 69 percent by sprinkler systems. Rainfall in the area ranges from 500 to 1,300 mm annually, concentrated between June and September, with mean air temperature around 30°C and peaks near 35°C between March and May; soils are predominantly sandy loam to loamy sand (Typic Haplustalfs). The scheme is one of Nigeria's largest irrigation projects and a major contributor to rice, wheat and maize output in Zamfara State.

3.2 Data and Sources

The data for the study will be gathered to demonstrate the full empirical workflow; accordingly, the analysis will be illustrated through annual paddy-rice production series for BIS covering 1994-2023 (n = 30 observations), constructed to reproduce the documented growth trend, rehabilitation-driven step increases and shock-related dips of the scheme (e.g., the TRIMING rehabilitation and the 2026 bird-invasion losses) reported in scheme records and secondary sources. For a full empirical submission, the series would be replaced with actual annual paddy output (metric tonnes) obtained from the Bakalori Irrigation Scheme Management Office, the Zamfara State Ministry of Agriculture, the Fadama/TRIMING project monitoring unit, and cross-checked against National Bureau of Statistics and FAOSTAT records, following the data protocol used in comparable national-level studies (Umar et al., 2019). The last five years of the series are withheld as a hold-out (test) sample for out-of-sample forecast evaluation, with the remaining twenty-five years used for model estimation, consistent with standard Box-Jenkins practice.

3.3 Analytical Framework: The Box-Jenkins ARIMA Approach

An ARIMA(p,d,q) process for the rice-production series Yt is specified as:

$$\Phi(B)(1-B)^{d} Y_t = \Theta(B)\,\varepsilon_t$$

where B is the backshift operator, $\Phi(B) = 1 - \phi_1 B - \ldots - \phi_p B^p$ is the autoregressive polynomial of order p, $\Theta(B) = 1 + \theta_1 B + \ldots + \theta_q B^q$ is the moving-average polynomial of order q, d is the order of differencing required for stationarity, and ε_t is a white-noise error term. The model is fitted through the classical three-stage Box-Jenkins procedure:

(a) Identification: visual inspection of the time plot and correlogram, and formal testing of stationarity using the Augmented Dickey-Fuller (ADF) test; where the series is non-stationary in level, successive differencing is applied until the ADF test rejects the unit-root null at the 5 percent level. Candidate autoregressive and moving-average orders (p, q) are then read off the autocorrelation function (ACF) and partial autocorrelation function (PACF) of the (differenced) series.

(b) Estimation: each candidate ARIMA(p,d,q) specification is estimated by maximum likelihood, and the statistical significance of estimated coefficients is assessed.

(c) Diagnostic checking: model residuals are tested for remaining autocorrelation using the Ljung-Box Q-statistic; a model whose residuals cannot be distinguished from white noise is retained.

3.4 Comparative Model Selection Criteria

Consistent with the comparative design of the study, four plausible specifications - ARIMA(1,1,0), ARIMA(0,1,1), ARIMA(1,1,1) and ARIMA(2,1,1) - suggested by the correlogram of the differenced series are estimated and ranked using: the Akaike Information Criterion (AIC = -2 log L + 2k), the Bayesian/Schwarz Information Criterion (BIC = -2 log L + k log n), and, on the five-year hold-out sample, the Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE). Lower values on all four criteria indicate a better-fitting, more forecast-accurate model; the specification that is best, or near-best, on the largest number of criteria is selected as the preferred model for final forecasting, following the model-comparison protocol used in comparable ARIMA rice-forecasting studies (Min et al., 2025; Adenomon & Oyejola, 2022).

3.5 Forecast Generation and Evaluation

Once selected, the best-fit model is re-estimated on the full 1994-2023 series and used to generate point forecasts, with 95 percent confidence intervals, for 2024-2030. Forecast accuracy on the hold-out sample is additionally benchmarked against a naive (random-walk) forecast and a simple linear-trend forecast, to establish whether the ARIMA model adds predictive value beyond these simple alternatives. All analyses are envisaged to be conducted in R (forecast and tseries packages) or equivalent statistical software (E-Views/Stata), following standard practice in the reviewed literature.

4. RESULTS OF FINDING

4.1 Descriptive Statistics

Table 1 summarises the descriptive properties of the 1994-2023 annual rice production series for BIS. Production is expected to show a clear upward trend, from roughly 41,000 metric tonnes in the mid-1990s to about 128,000 metric tonnes by 2023, alongside episodic dips corresponding to documented shocks such as input scarcity and, most recently, bird-invasion losses.

Statistic	Value
Number of observations (years)	30 (1994-2023)
Mean annual production (MT)	78,450
Minimum (MT)	38,900 (1998)
Maximum (MT)	131,600 (2023)
Standard deviation (MT)	27,340
Coefficient of variation (%)	34.9
Skewness	0.21
Compound annual growth rate, 1994-2023 (%)	4.1

Table 1: Descriptive statistics of annual rice production, BIS, 1994-2023

4.2 Stationarity (Unit Root) Test

The Augmented Dickey-Fuller test is expected to fail to reject the null hypothesis of a unit root for the series in level form (consistent with the visible trend), but to reject it decisively after first differencing, indicating the series is integrated of order one, I(1) - see Table 2.

Table 2: Augmented Dickey-Fuller unit root test results

Series	ADF Statistic	Critical Value (5%)	p-value	Decision
Level, Yt	-1.84	-2.97	0.354	Non-stationary
First difference, ΔYt	-4.62	-2.97	0.001	Stationary

4.3 Model Identification and Comparison

Examination of the ACF and PACF of the first-differenced series is expected to show a significant spike at lag 1 in both functions with a sharp cut-off thereafter, suggesting mixed AR(1)-MA(1) dynamics. Four candidate models are accordingly estimated and compared in

Table 3: comparative performance of candidate ARIMA models

Model	AIC	BIC	RMSE (hold-out)	MAPE % (hold-out)
ARIMA(1,1,0)	486.2	489.4	9,820	8.7
ARIMA(0,1,1)	484.9	488.1	9,340	8.1
ARIMA(1,1,1)	480.3	484.7	7,110	5.9
ARIMA(2,1,1)	482.6	488.2	7,260	6.2

ARIMA (1,1,1) record the lowest AIC and BIC among the four candidates and the lowest out-of-sample RMSE and MAPE, and is therefore selected as the preferred model. Both simpler alternatives, ARIMA(1,1,0) and ARIMA(0,1,1), which correspond to specifications reported as best-fit for Nigerian national rice production and price respectively in prior studies (Oyinbo, 2018), are expected to be dominated at the scheme level once a richer mixed dynamic is present in the data, while the more heavily parameterized ARIMA(2,1,1) is expected to be penalized by the BIC for its additional complexity without a matching gain in forecast accuracy - an outcome consistent with the principle of parsimony in Box-Jenkins model selection (Box et al., 2016).

4.4 Diagnostic Checking

The residuals of the selected ARIMA(1,1,1) model are expected to show no significant autocorrelation at conventional lags, with a Ljung-Box Q-statistic of approximately 6.4 at lag 12 ($p = 0.62$), failing to reject the null of white-noise residuals and confirming model adequacy (Table 4).

Table 4: E residual diagnostic checks for ARIMA (1,1,1)

Diagnostic	Statistic	p-value	Conclusion
Ljung-Box Q (lag 12)	6.4	0.62	Residuals are white noise
Jarque-Bera normality	1.1	0.58	Residuals approx. normal

4.5 Forecast Results, 2024-2030

Using the selected ARIMA (1,1,1) model re-estimated on the full series, point forecasts and 95 percent confidence intervals for 2024-2030 are presented in Table 5. Production is expected to continue on a gradual upward trajectory, broadly consistent with the targeted gains from TRIMING gravity-system rehabilitation (Federal Ministry of Water Resources, 2025), while the widening confidence band reflects growing forecast uncertainty and the scheme's continued exposure to shocks such as pest and bird damage (Nairametrics, 2026).

Table 5: Expected ARIMA (1,1,1) point forecasts of BIS rice production, 2024-2030

Year	Point Forecast (MT)	95% CI Lower	95% CI Upper
2024	133,900	125,600	142,200
2025	138,700	126,400	151,000
2026	143,100	127,300	158,900
2027	147,400	128,100	166,700
2028	151,600	128,700	174,500
2029	155,800	129,200	182,400
2030	159,900	129,600	190,200

The ARIMA(1,1,1) forecasts are expected to outperform both a naive (random-walk) benchmark and a simple linear-trend forecast on the hold-out sample, indicating that the fitted autoregressive-moving-average dynamics capture genuine short-run persistence in the series beyond a constant trend, in line with comparative evidence from other rice-forecasting applications in which ARIMA improved materially on naive benchmarks (Min et al., 2025).

5. DISCUSSION

The findings are broadly consistent with, and extend, the existing empirical literature on ARIMA forecasting of Nigerian rice. National-level studies have generally found low-order ARIMA specifications - typically ARIMA(1,1,0) or ARIMA(0,1,1) - adequate for forecasting aggregate Nigerian rice production and price (Umar et al., 2019; Oyinbo, 2018). The selection of a mixed ARIMA(1,1,1) model at the scheme level suggests that production dynamics within a single, infrastructure-dependent irrigation

scheme may be somewhat richer than those of the national aggregate, plausibly because scheme-level output responds more directly and with some persistence to discrete events - rehabilitation works, water-release decisions, localised pest outbreaks - than the smoothing effect of national aggregation allows. This echoes findings from other single-location or single-country rice-forecasting studies, where model orders selected have varied with the specific production environment rather than converging on a single universal specification (Zannou et al., 2024; Min et al., 2025).

The upward forecast trajectory for 2024-2030 aligns with the stated rehabilitation targets under the TRIMING intervention, which aims to raise BIS-area rice output toward 100,000 metric tonnes annually from its rehabilitated gravity-fed hectares alone (Federal Ministry of Water Resources, 2025), and with the productivity gains documented for best-bet SRI adoption within the scheme (Uphoff et al., 2023; de Bruin et al., 2023). At the same time, the widening confidence interval and the scheme's recent, well-documented exposure to shocks - including the 2026 bird invasion affecting over 1,500 farmers and 250 hectares (Nairametrics, 2026) and recurrent post-harvest price gluts (Daily Trust, 2025) - caution against treating the point forecasts as certainties. A purely univariate ARIMA model, by construction, cannot anticipate such discrete exogenous shocks; it can only characterise the average historical persistence and trend of the series. This is a recognised limitation of the Box-Jenkins approach relative to structural or hybrid models that incorporate rainfall, input-price or pest-incidence covariates (Adenomon & Oyejola, 2022), and it should be communicated clearly to end-users of the forecasts.

From a food-security planning perspective, the practical value of the exercise lies less in the precision of any single point forecast than in the systematic early-warning signal it provides: a model-based expectation of continued production growth, bounded by a quantified uncertainty range, gives the Bakalori scheme management, the Zamfara State Ministry of Agriculture and federal food-security planners a defensible, updatable baseline against which to plan input distribution, storage capacity and market interventions, and against which subsequent actual harvests can be benchmarked to trigger early corrective action.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study set out to demonstrate a comparative box-Jenkins ARIMA modelling approach to forecasting rice production in the Bakalori Irrigation Scheme as a tool for enhancing food security and agricultural planning. Following formal stationarity testing, differencing and comparative evaluation of four candidate specifications on information-criteria and out-of-sample accuracy grounds, an ARIMA (1,1,1) model is expected to emerge as the preferred, diagnostically adequate specification, projecting continued but moderating growth in scheme output through 2030. The exercise confirms that univariate ARIMA modelling remains a practical, low-data-requirement forecasting tool that irrigation-scheme managers and state agricultural planning units can implement with routinely collected production data, provided its limitations regarding unforeseen shocks are recognised.

6.2 Recommendations

Based on the findings, the study recommends that:

I. the Bakalori Irrigation Scheme management office and the Zamfara State Ministry of Agriculture institutionalise routine collection and archiving of scheme-level annual (and where possible seasonal) rice production data to support continuous model re-estimation and forecast updating;

II. the ARIMA (1,1,1) forecasting framework developed here be adopted as a complementary early-warning input to, rather than a replacement for, agronomic and extension-based production estimates, and be re-run annually as new data become available;

III. future work extends the univariate model into a hybrid or explanatory framework incorporating rainfall, irrigated area, input-price and pest/bird-incidence data, given the demonstrated exposure of the scheme to such shocks, and benchmark ARIMA against machine-learning alternatives such as XGBoost or neural-network forecasts, as has been done for other rice-producing countries; and

IV. forecast outputs be disseminated to farmer associations (including the Bakalori Water Users Association) and grain marketing actors ahead of each planting season to support coordinated storage and marketing decisions and reduce the recurrence of post-harvest price gluts.

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