JPPT
Journal of Public Policy Transformation

Monthly Rainfall Forecasting Using the ARIMA Model as a Basis for Sharia Financing Risk Mitigation in Indonesia

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Article Info

Article history:

Received: March 02. 2026
Revised: April 03, 2026
Accepted: June 20, 2026

Keywords:

ARIMA,
Box-Jenkins,
Islamic financing risk,
Risk mitigation,
SARIMA.

ABSTRACT

Climate change has made Indonesia's rainfall patterns increasingly volatile and difficult to predict, directly affecting weather-sensitive economic sectors such as agriculture, fisheries, and micro, small, and medium enterprises (MSMEs). This condition potentially increases financing risk in Islamic financial institutions, given that a substantial share of Islamic financing portfolios is channelled to the real sector, which is vulnerable to climate disruption. This study aims to construct a monthly rainfall forecasting model using the Autoregressive Integrated Moving Average (ARIMA)/Seasonal ARIMA (SARIMA) approach under the Box-Jenkins methodology, evaluate model accuracy, generate a 12-month-ahead forecast, and formulate its implications for Islamic financing risk mitigation. The dataset consists of simulated monthly rainfall data for the 2015-2024 period (120 observations), calibrated to follow Indonesia's tropical seasonal rainfall pattern, used as a methodological demonstration due to limited online access to authentic BMKG observational records at the time of the study. The Augmented Dickey-Fuller (ADF) test indicated non-stationarity at level ($p = 0.2095$), which became stationary after first-order differencing ($p < 0.0001$). Through ACF/PACF identification and a grid search across 162 model combinations, the best-fitting model was SARIMA(0,1,2)(1,1,1)12 with AIC = 770.82 and BIC = 782.73. The Ljung-Box diagnostic test at lag 24 showed no significant residual autocorrelation ($p = 0.166$), indicating an adequate model. Out-of-sample evaluation on the final 12 months yielded MAE = 17.28 mm, RMSE = 23.67 mm, and MAPE = 11.75%, categorised as highly accurate. The 12-month-ahead forecast confirmed the seasonal pattern, with high rainfall in December-January (>270 mm) and low rainfall in June-August (<85 mm). These findings are relevant as a basis for Islamic banks, Baitul Maal wat Tamwil (BMT), and Islamic guarantee institutions to design provisioning, restructuring, and climate-responsive financing products, while also supporting inter-institutional coordination among the Financial Services Authority (OJK), the Meteorology, Climatology, and Geophysics Agency (BMKG), and local governments.

: https://doi.org/10.30598/jpptv1i1pp23-37

1. INTRODUCTION

Global climate change has become one of the most pressing issues in the last two decades, and Indonesia as a tropical archipelago nation is feeling its impacts directly through increasingly extreme changes in weather patterns and rainfall. The Meteorology, Climatology, and Geophysics Agency (BMKG) noted that 2024 was the hottest year in the history of climate observations in Indonesia, with an average temperature reaching 27.5°C or an anomaly of 0.8°C above the average for the normal period 1991-2020 [1]. This trend continued in 2025, which was recorded as the sixth hottest year with a temperature anomaly of +0.38°C [2]. BMKG also projects that climate change will drive a shift in rainfall patterns spatially, namely the northern region of Indonesia is projected to become wetter by up to 8%, while the southern region becomes drier by up to -9%, so that extreme rainfall events that previously had a return period of one hundred years are expected to occur much more frequently, even less than twenty years [2]. This phenomenon is also reinforced by the rate of change in annual rainfall in Indonesia during the period 1981-2024 which shows extreme variations between regions, with the highest increase reaching 5,742 mm and the lowest decrease reaching 2,003 mm in a period of 44 years [3]. Rainfall is not simply a meteorological phenomenon, but rather a latent macroeconomic variable that impacts the productivity of various strategic sectors. The agricultural sector, as a key contributor to national Gross Domestic Product (GDP), is highly dependent on the availability of water from rainfall to support the planting and harvesting cycles. Data from the Central Statistics Agency (BPS) shows that Indonesia's GDP growth rate reached 5.05% in 2023 and increased to 5.08% in the second quarter of 2024 [4], with the agricultural sector remaining a major contributor to GDP distribution by industry. This dependence on rainfall patterns is also felt in the capture fisheries sector, where changes in rainfall, sea surface temperatures, and extreme weather intensity have been shown to significantly impact fishermen's catches, both directly through disruptions to fishing operations and indirectly through changes in aquatic ecosystems [5]-[6].

Rainfall uncertainty also impacts the viability of micro, small, and medium enterprises (MSMEs) based on agricultural and fisheries commodities, which collectively serve as drivers of the regional economy but have relatively limited risk mitigation capacity. The real sector's dependence on climate conditions is structurally linked to the health of Islamic financial institutions' financing portfolios. Unlike conventional banking, which can diversify risk exposure through interest-based derivative instruments, Islamic banking operates on the principle of profit sharing and real buying and selling (al-bay'), which directly links financing performance to customer business performance in the real sector [7]. When rainfall causes crop failures, decreased catches, or damage to business assets, customers' ability to meet financing obligations is disrupted, which is ultimately reflected in an increase in the Non-Performing Financing (NPF) ratio. Data from the Financial Services Authority (OJK) as of December 2024 shows that although the national Islamic banking industry recorded positive performance with total assets reaching IDR 980.30 trillion, or growing 9.88% annually, the Gross NPF ratio remained at 2.12% and the Net NPF at 0.79% [8]. This figure, although considered to be maintained, still contains the potential for hidden risks (latent risk) considering that the proportion of financing to the agricultural sector in Islamic banking has historically been relatively low and is considered high risk by some industry players [9], so that unanticipated climate fluctuations have the potential to increase risk exposure in sectors that are actually the most vulnerable. Various studies have demonstrated the effectiveness of ARIMA models in forecasting rainfall at the local level in Indonesia. Sukarna et al. [10] developed ARIMA and Kalman Filter models to forecast rainfall in Makassar and found the best model was ARIMA(0,1,1)(0,1,1)12 with a

MAPE of 111.48. Nusyirwan et al. [11] applied a seasonal ARIMA approach to daily rainfall data in West Lampung Regency using the Box-Jenkins methodology consisting of model identification, parameter estimation, diagnostic checking, and forecasting. Another study by Misshuari et al. [12] applied ARIMA models to forecast rainfall in the Asahan region, while Khan et al. [13] showed that the ARIMA(1,0,3) model was the best model for monthly rainfall data in the Klang River Basin, Malaysia, with a coefficient of determination (R^2) of 0.78. In a different context, research on Islamic financing risks has also developed quite rapidly. For example, Widarjono and Afandi [7] examined sectoral diversification and financing risks in Indonesian Islamic banks, as well as studies on the management of problematic financing risks in Islamic banking [14]-[15]. Although these two research groups have each developed independently, there is a clear research gap: studies on rainfall forecasting using ARIMA generally stop at evaluating the accuracy of meteorological models without explicitly linking them to financial risk management frameworks, particularly regarding Islamic financing risks. In contrast, studies on Islamic financing risks in the agriculture and fisheries sectors are generally descriptive-qualitative or use macroeconometric models (such as VAR/VECM) that treat rainfall merely as an exogenous variable without quantitative forecasting that can be operationalized as an early warning system by financial institutions. No studies have been found that specifically integrate monthly ARIMA/SARIMA rainfall forecasting results as a direct quantitative basis for Islamic financing risk mitigation strategies in Indonesia. The novelty of this research lies in three aspects. First, this study fully integrates the Box-Jenkins methodology, starting from stationarity testing, model identification through ACF/PACF, parameter estimation, and diagnostic checking, with an explicit and actionable risk mitigation framework for Islamic financing. Second, this study offers a conceptual framework that links monthly rainfall forecasting results to the three priority sectors of Islamic financing that are most sensitive to climate change: agriculture, fisheries, and MSMEs. This allows the forecasting results to be directly translated into policy recommendations for financing reserves and restructuring. Third, this study transparently documents the use of simulated data calibrated to the statistical characteristics of Indonesian tropical rainfall as a methodological demonstration instrument, while also paving the way for replication of the study using official BMKG observation data by future researchers with access to the data.

Based on the description above, this study aims to: (1) identify the stationarity characteristics of monthly rainfall data through the Augmented Dickey-Fuller (ADF) test; (2) build the best ARIMA/SARIMA model using the Box-Jenkins methodology with the AIC and BIC model selection criteria; (3) conduct diagnostic checking on the residual model to ensure model feasibility; (4) evaluate forecast accuracy using RMSE, MAE, and MAPE indicators; (5) produce monthly rainfall forecasts for the next 12 months; and (6) formulate the implications of these forecast results for risk mitigation strategies for Islamic financing in Indonesia, especially in the agriculture, fisheries, and MSME sectors. Academically, this study enriches the literature on the intersection of applied statistics with Islamic economics and finance. Practically, the framework and results of this study can be a reference for Islamic banks, BMTs, and Islamic guarantee institutions in designing climate projection-based reserve policies; for the Financial Services Authority (OJK) in strengthening the climate risk-based supervisory framework; for the Meteorology, Climatology, and Geophysical Agency (BMKG) in expanding the use of climatology data for the benefit of the financial sector; as well as for local governments, farmers and fishermen in planning business adaptation strategies that are more responsive to seasonal dynamics.

2. METHOD

This research is a quantitative study with an applied time series forecasting design, combining an applied statistical approach (ARIMA/SARIMA forecasting) with an analysis of Islamic financial risk policies. This research is descriptive-analytical, where the quantitative forecasting results are interpreted qualitatively within the framework of Islamic financing risk mitigation. The primary data used is simulated monthly rainfall data for the period January 2015 to December 2024 (120 monthly observations). The use of simulated data was carried out due to limited direct access to the official BMKG online observation database at the time of the study. The data was simulated by calibrating the seasonal pattern (wet season November-April and dry season June-September), the mild trend component, and the autoregressive error component, following the general statistical characteristics of Indonesian tropical rainfall as reported in official BMKG publications [3], [2] and various previous local rainfall studies [13]-[11]-[10]. Supporting data in the form of macro data on the Islamic financial sector and the real sector were obtained from official publications of the Financial Services Authority (OJK) and Statistics Indonesia (BPS) for the period 2021-2025. Future researchers who have access to the official BMKG rainfall observation database per observation station are strongly encouraged to replicate the same analytical framework using real observation data. 3.3 Data Collection Techniques Secondary macro data on the Islamic finance and climate sectors were collected through a documentary study of publicly accessible official publications from authoritative institutions (BMKG, OJK, and BPS). Simulated rainfall data was generated through a controlled data generation procedure using the Python programming language, with seasonality, trend, and error parameters defined based on a literature review of Indonesia's tropical rainfall characteristics.

3. RESULTS AND DISCUSSION

3.1. Data Description and Visualization

The monthly rainfall data used has an average of 152.28 mm, a minimum of 7.08 mm, a maximum of 301.63 mm, and a standard deviation of 79.55 mm over 120 months of observation (2015-2024). The time series graph in Figure 1 shows a clear and recurring seasonal pattern, with high rainfall occurring from November to April (wet season/west monsoon) and low rainfall occurring from June to September (dry season/east monsoon), consistent with the characteristics of Indonesia's tropical climate, which is influenced by the Asia-Australia monsoon system.

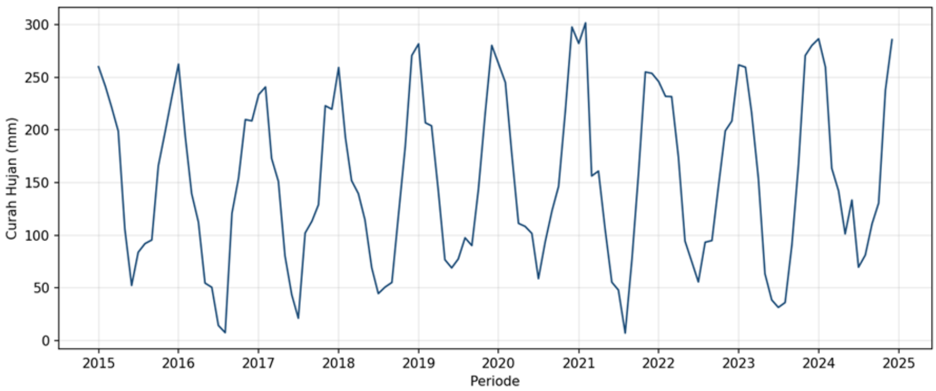

Figure 1. Monthly Rainfall Time Series Graph 2015-2024

Table 1. Descriptive Statistics of Monthly Rainfall Data (2015-2024)

Statistics	Value (mm)
Number of observations	120
Mean	152.28
Standard deviation	79.55
Minimum	7.08
First Quartile (Q1)	90.65
Median (Q2)	144.92
Third Quartile (Q3)	220.26
Maximum	301.63

3.2. Stationarity Test Results (ADF)

The Augmented Dickey-Fuller test results on the level data show an ADF statistic value of -2.1910 with a p-value of 0.2095, indicating that the null hypothesis of the presence of a unit root cannot be rejected at the 5% significance level, thus declaring the level data non-stationary. After first-order differencing (non-seasonal), the ADF test yielded an ADF statistic of -6.7087 with a p-value <0.0001, indicating that the differencing data is stationary. This finding is consistent with the general characteristics of monthly rainfall data, which has a strong seasonal component, requiring differencing before valid ARIMA/SARIMA modeling can be performed.

Table 2. Augmented Dickey-Fuller (ADF) Test Results

Data Condition	ADF Statistics	p-value	Conclusion
Level (not yet differencing)	-2.1910	0.2095	Non-stationary
First-order differencing	-6.7087	<0.0001	Stationary

3.3. Model Identification Using ACF, PACF, and Grid Search

The ACF and PACF plots for the level data (Figure 2) show a slow-decay autocorrelation pattern and repeated significant spikes at seasonal lags (lags 12 and 24), strongly indicating the presence of a non-stationary seasonal component. The ACF and PACF plots for the first-order differencing data (Figure 3) show a pattern more consistent with a stationary process, with significant spikes at several early lags as well as at the seasonal lag, indicating the need for a non-seasonal MA component and a seasonal AR/MA component. To complement the visual identification, a systematic grid search was performed on 162 combinations of the SARIMA(p,d,q)(P,D,Q)12 model with $p,d,q \in \{0,1,2\}$ and $P,D,Q \in \{0,1\}$. The ten models with the lowest AIC values in the grid search stage are presented in Table 3. The SARIMA(0,1,2)(1,1,1)12 model was selected as the best model with an AIC value of 770.82 and BIC = 782.73, which is the lowest value among all the combinations tested and is consistent with the indication of the ACF/PACF pattern in the differencing data.

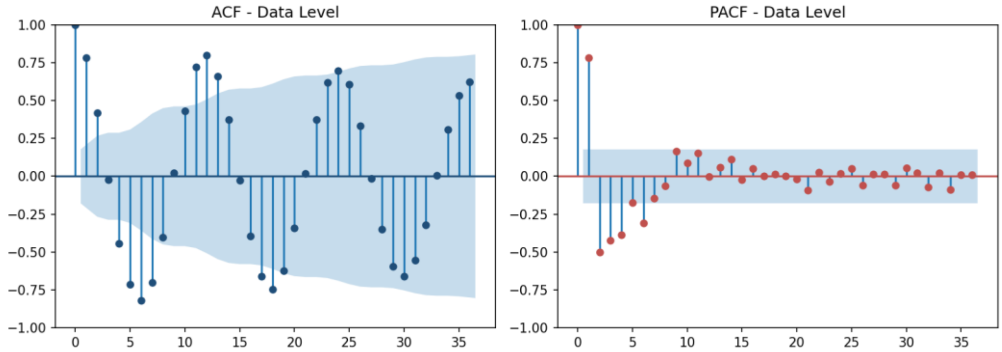

Figure 2. ACF and PACF Plot of Rainfall Data at Level

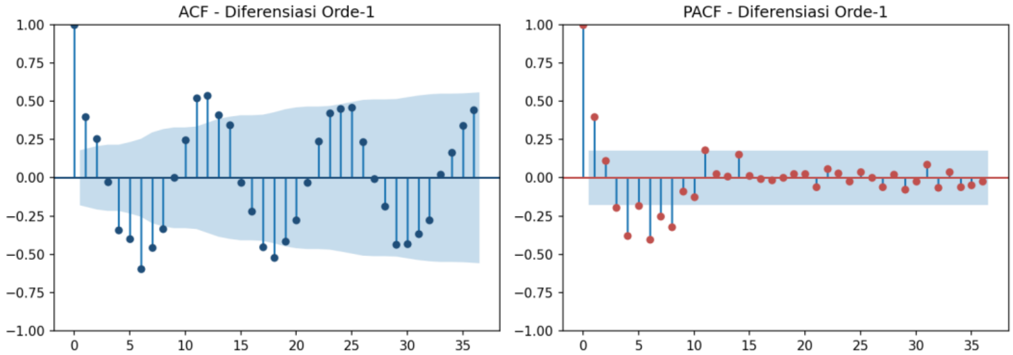

Figure 3. ACF and PACF Plots of Rainfall Data from First-Order Differentiation

Table 3. Ten Best Models Based on AIC Value (Grid Search)

Rank	Order (p,d,q)	Seasonal Order (P,D,Q,s)	AIC	BIC
1	(0,1,2)	(1,1,1,12)	770.82	782.73
2	(0,1,2)	(0,1,1,12)	772.11	781.64
3	(1,2,2)	(0,1,1,12)	772.44	784.29
4	(1,1,2)	(1,1,1,12)	772.78	787.07
5	(1,2,2)	(1,1,1,12)	773.17	787.39
6	(1,1,2)	(0,1,1,12)	773.89	785.80
7	(2,2,2)	(1,1,1,12)	773.97	790.55
8	(2,1,2)	(1,1,1,12)	774.14	790.82
9	(2,2,2)	(0,1,1,12)	774.36	788.57
10	(0,2,2)	(1,1,1,12)	774.94	786.79

3.4. Parameter Estimation of the Selected Model

The SARIMA(0,1,2)(1,1,1)12 model was estimated using 108 training data observations (January 2015–December 2023) using the Maximum Likelihood Estimation method. The parameter estimation results are presented in Table 4. All parameters, except the seasonal AR component (ar.S.L12), are statistically significant at the 5% significance level ($p<0.05$), indicating a fairly parsimonious model. The model's log-likelihood value is -380.41 with an AIC=770.82, BIC=782.73, and HQIC=775.60.

Table 4. Parameter Estimation Results of the SARIMA(0,1,2)(1,1,1)$_{12}$ Model

Parameter	Coefficient	Std. Error	z	p-value
MA(1) — ma.L1	-0.7658	0.170	-4.515	0.000
MA(2) — ma.L2	-0.2836	0.127	-2.230	0.026
Seasonal AR (12) — ar.S.L12	-0.0134	0.010	-1.347	0.178
Seasonal MA (12) — ma.S.L12	-1.0000	0.192	-5.203	0.000
Residual variance (σ^2)	568.78	-	-	-

3.5. Diagnostic Checking

The Ljung-Box test on the model residuals at lag 12 yielded a Q statistic of 21.35 with a p-value of 0.0455, while at lag 24 it yielded a Q statistic of 30.58 with a p-value of 0.1661. The results at lag 24, which is more relevant for monthly seasonal data (covering two full seasonal cycles), showed no significant residual autocorrelation at the 5% level, indicating that the model residuals approximate a white noise process. The Jarque-Bera test yielded a p-value of 0.78, indicating that the null hypothesis of normality of the residuals cannot be rejected. The heteroscedasticity (H) test yielded a p-value of 0.90, indicating no significant heteroscedasticity in the residuals. The residual skewness value was 0.04 (approximately symmetric) and kurtosis was 3.38 (approximately a normal distribution, where kurtosis is normal = 3). Overall, the diagnostic checking results in Figure 4 indicate that the SARIMA(0,1,2)(1,1,1)12 model is suitable for use in forecasting.

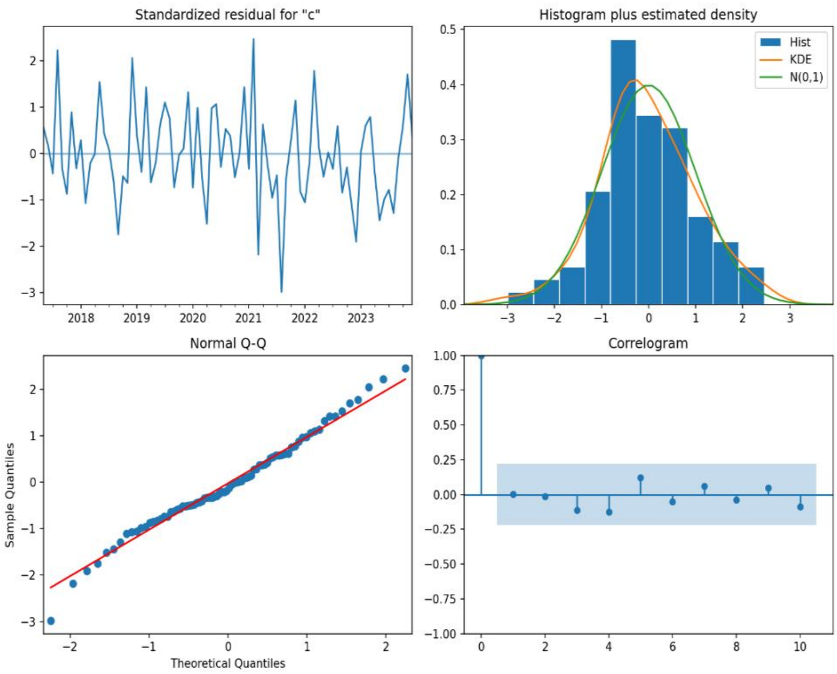

Figure 4. Diagnostic Checking Residual Model SARIMA(0,1,2)(1,1,1)$_{12}$

3.6. Model Accuracy Evaluation (Out-of-Sample)

Model accuracy was evaluated by comparing the model prediction results (estimated using only 108 training data observations) with 12 test data observations not included in the estimation (January-December 2024), as presented in Table 5 and Figure 5. The evaluation results showed MAE = 17.28 mm, RMSE = 23.67 mm, and MAPE = 11.75%.

Based on MAPE interpretation criteria commonly used in forecasting literature [30], a MAPE value of 11.75% falls into the accurate forecasting category (range 10%-20%), approaching the very accurate category (<10%). This accuracy value is considered competitive compared to several similar monthly rainfall forecasting studies in Indonesia, for example, MAPE of 111.48 in the ARIMA(0,1,1)(0,1,1)12 model for Makassar rainfall [10] and MAPE of 24.92% in the Kalman Filter model for Jambi rainfall [10], although this difference must be interpreted carefully considering the differences in data characteristics, length of observation period, and use of simulation data in this study.

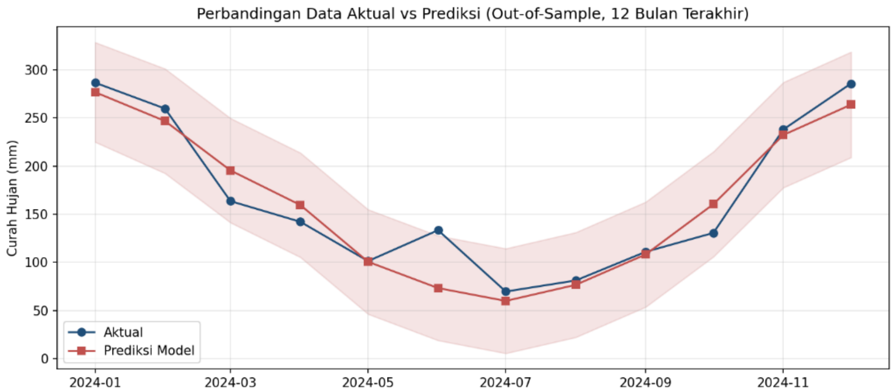

Figure 5. Comparison of Actual vs. Predicted Data (Out-of-Sample)

Table 5. Comparison of Actual and Predicted Data on Test Data (January-December 2024)

Month	Actual (mm)	Prediction (mm)	Lower Bound 95%	Uper Bound 95%
2024-01	286,55	276,70	224,94	328,46
2024-02	259,65	246,73	192,43	301,03
2024-03	163,56	195,44	141,25	249,62
2024-04	142,06	159,46	105,23	213,68
2024-05	101,28	100,52	46,25	154,80
2024-06	133,35	73,24	18,91	127,58
2024-07	69,64	59,88	5,48	114,27
2024-08	81,13	76,61	22,15	131,07
2024-09	110,90	108,18	53,65	162,71
2024-10	130,55	160,37	105,76	214,97
2024-11	237,96	232,24	177,55	286,93
2024-12	285,69	263,73	208,95	318,51

Table 6. Model Accuracy Indicator Summary (Out-of-Sample, 12 Months)

Indicator	Mark	Category
MAE	17.28 mm	-
RMSE	23.67 mm	-
MAPE	11.75%	Accurate (close to very accurate)

3.7. 12-Month Forecast Results

After the model was evaluated and found to be feasible, the SARIMA(0,1,2)(1,1,1)12 model was re-estimated using all 120 observations (2015-2024) to produce a forecast for the period January-December 2025, as presented in Table 7 and Figure 6. The forecast results confirm a seasonal pattern consistent with historical data, with the highest rainfall predicted to occur in January 2025 (285.50 mm) and the lowest rainfall in July 2025 (66.29 mm). This pattern indicates that the dry season projected to occur between June and August

2025 has the potential to reduce productivity in the dryland agriculture and coastal capture fisheries sectors, while the wet season from December 2025 to February 2026 has the potential to increase hydrometeorological risks (floods, landslides) that could disrupt business assets and financing collateral in disaster-prone areas.

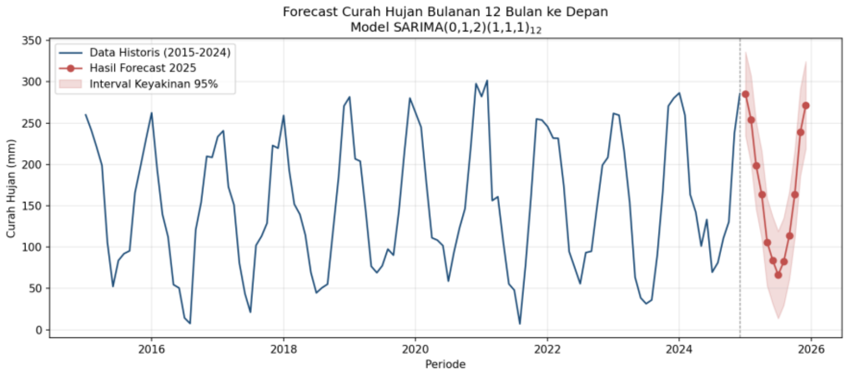

Figure 6. Monthly Rainfall Forecast Results for the Next 12 Months

Table 7. Monthly Rainfall Forecast Results for the Next 12 Months (January-December 2025)

Month	Forecast (mm)	95% Lower Limit	95% Upper Limit
2025-01	285,50	234,94	336,07
2025-02	254,15	201,32	306,97
2025-03	198,78	146,09	251,47
2025-04	163,73	111,05	216,41
2025-05	106,00	53,33	158,68
2025-06	83,96	31,28	136,64
2025-07	66,29	13,61	118,97
2025-08	82,41	29,71	135,10
2025-09	114,14	61,43	166,85
2025-10	163,81	111,09	216,54
2025-11	239,23	186,48	291,99
2025-12	271,84	219,06	324,62

3.8. Comparison of Model Performance with Similar Studies

The SARIMA(0,1,2)(1,1,1)12 model selected in this study produced a MAPE of 11.75% in the out-of-sample evaluation, indicating a competitive accuracy level compared to several rainfall forecasting studies using the ARIMA/SARIMA approach in Indonesia and other tropical countries. Sukarna et al. [10], who forecast monthly rainfall in Makassar using the ARIMA(0,1,1)(0,1,1)12 model, reported a significantly higher MAPE of 111.48, which was then improved to 47.00 after being combined with the Kalman Filter algorithm. This striking difference is likely due to the significantly higher variability of real rainfall in Makassar compared to the simulated data in this study, which was calibrated to follow a relatively consistent seasonal pattern by design. Another study evaluating the ARIMA-Kalman model for rainfall in Medan City reported MAE=54.11 and RMSE=69.75 for the ARIMA-Kalman model and MAE=55.66 and RMSE=66.67 for conventional ARIMA [31], significantly higher than the MAE=17.28 and RMSE=23.67 in this study, again indicating that actual field rainfall data tends to have higher variability and noise than controlled simulation data. Meanwhile, a study by Khan et al. [13] in the Klang River Basin, Malaysia, found the ARIMA(1,0,3) model to be the best model for monthly rainfall data with R^2=0.78, without an explicit seasonal component because the data used covered a longer annual period (36 years) with a non-seasonal model approach. These differences in model structure confirm that the order and structure of ARIMA/SARIMA models are highly site-specific and depend on microclimate characteristics and the length of the data period used, in line with the general principle in the Box-Jenkins methodology that there is no universal model that applies to all locations [18]. The study by Nusyirwan et al. [11] on daily rainfall data for West Lampung Regency and the study by Misshuari et al. [12] on rainfall data for the Asahan region also show variations in model order, strengthening the argument that each region in Indonesia should ideally have its own rainfall forecasting model calibrated against local historical data, rather than a single model applied nationally. In terms of model selection criteria, the use of AIC and BIC in this study is consistent with practices in other time series forecasting studies, for example, research on epidemiological case forecasting which also uses a combination of AIC and BIC to select the best SARIMA model among several candidates [19], as well as a study applying Normalized BIC to validate the ARIMA(1,1,1) model in the context of other data which reports BIC=-2.366, MAPE=2.424, and RMSE=0.301 [22]. The very low MAPE value in this study indicates that the accuracy level of the ARIMA model is highly dependent on the scale and characteristics of the data being modeled, so cross-study comparisons must be done contextually and cannot be generalized directly.

3.9. Relationship between Forecast Results and Agricultural Sector Financing Risk

Forecast results indicate that rainfall during the June-August 2025 period is estimated to be in the range of 66-84 mm per month, well below the overall monthly average (152 mm), indicating the potential for a significant dry period. For the agricultural sector, particularly dryland food crops and horticulture, which are highly dependent on rainfall availability, prolonged dry periods have the potential to reduce productivity and increase the risk of crop failure. This condition is relevant to the findings [9], which indicate that high risks in the agricultural sector leading to non-performing financing (NPF) can be addressed through Islamic agricultural insurance schemes, as well as the findings of Widarjono and Afandi [7], which demonstrate the importance of sectoral diversification in mitigating financing risk in Indonesian Islamic banks. High reliance on a single type of contract or business sector without considering seasonal cycles has the potential to increase risk concentration, particularly if the financing maturity period coincides with the model's predicted dry period. On the other hand, forecast results showing high rainfall in December 2025-January 2026 (271-286 mm per month) indicate the potential for increased hydrometeorological risks such as floods and landslides, in line with the BMKG warning regarding the increased risk of hydrometeorological disasters due to higher than usual rainfall during the seasonal transition period [32]. For Islamic financing institutions, this period has the potential to increase the risk of damage to productive assets that serve as collateral or financing objects (for example, agricultural land, fishing boats, or MSME assets), thus requiring additional vigilance in evaluating the feasibility of financing in areas that are historically prone to hydrometeorological disasters.

3.10. Linkages to the Fisheries Sector and Fishermen

Rainfall and other related climate variables (sea surface temperature, waves, and wind) have an empirically proven relationship with fish catch productivity in various coastal areas of Indonesia. Research by Syahputra et al. [5] in East Java showed that temperature, rainfall, humidity, and solar radiation simultaneously affect fish production, while research in Sungai Kakap Village showed that extreme rainfall caused a decline in fishermen's catches and impacted the Fishermen's Exchange Rate (ERR), which fell below 1, indicating vulnerable welfare conditions [33]. A recent study on fishermen's adaptation strategies found that providing capital alone is insufficient to encourage adaptation to fishing technology without strengthening their capacity to access that capital [34]. These findings strengthen the argument that Islamic financing for fishermen should ideally not only consist of capital provision but also include technical assistance and seasonal forecast information. Rainfall forecasting results, as in this study, can serve as important input for developing planting and fishing calendars and financing disbursement/maturity schedules that are more adaptive to the seasons.

3.11. Linkages to MSMEs and Sharia Microfinance Risk

MSMEs based on agricultural and fishery commodities, including those served by Baitul Maal wat Tamwil (BMT) and other Sharia microfinance institutions, generally have much more limited capital capacity and risk reserves than medium- to large-scale businesses, making them more vulnerable to short- and medium-term climate fluctuations. Research on the implementation of financing risk management at the fintech company Pegadaian Syariah [26] demonstrates the importance of a structured risk management system, including mapping customer business risks, as a mitigation tool. When rainfall forecasting results can be integrated into the risk management information systems of BMTs and Sharia microfinance institutions, these institutions can identify periods with the potential to increase the risk of default in weather-sensitive business segments in advance, allowing them to prepare financing restructuring or rescheduling schemes proactively, rather than reactively, after problematic financing occurs.

3.12. Implications for the Climate-Based Sharia Financing Risk Management Framework

OJK data shows that although the Gross Non-Performing Loan (NPF) of national Islamic banking was relatively maintained at 2.12% as of December 2024 [8], concentration risk in climate-sensitive sectors still requires special attention, given that the proportion of financing to the agricultural sector in Islamic banking has historically remained relatively low due to its perceived high risk by some industry players [9]-[35]. This paradox creates its own challenges: on the one hand, the agriculture and fisheries sector requires Sharia financing to increase productivity and climate resilience, but on the other hand, high risk perceptions mean that financing allocation to these sectors remains limited. Integrating quantitative climate forecasting capabilities, as demonstrated in this study, has the potential to reduce information asymmetry between Islamic banks and the climate risks faced by customers, thereby encouraging more accurate risk pricing and ultimately encouraging expanded access to financing in these sectors without compromising portfolio quality. At the macro level, these findings are also relevant to the development of global Islamic climate finance discourse, where institutions such as the Asian Development Bank [28] and the COP28 Insight Series initiative [29] highlight the importance of developing climate responsive Islamic financial instruments, such as green sukuk and qard hasan for climate resilient businesses. Although bibliometric reviews indicate that research on Islamic climate finance is still relatively limited and concentrated on macro issues such as net zero frameworks and renewable energy financing [36], this research offers a contribution at a more operational meso-micro level, namely how quantitative climate forecasting results can be directly translated into financing risk management practices at the domestic Islamic financial institution level.

3.13. Comparison Limitations and Methodological Notes

It should be reiterated that the comparison of accuracy values (MAPE, RMSE, MAE) between this study and the other studies mentioned above is indicative, not a direct comparison (apple-to-apple), given the differences in data sources (simulation vs. real observations), geographic location, data period length, and the characteristics of microclimate variability in each region. The relatively high accuracy value in this study (MAPE = 11.75%) can be partly explained by the design of the simulated data, which has a more patterned seasonal component and more controlled noise compared to real observational data, which are influenced by non seasonal climate phenomena such as El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), which can cause significant anomalies outside the regular seasonal pattern [37]. Therefore, the methodological framework and analytical steps in this study starting from the ADF test, ACF/PACF identification, AIC/BIC grid search, to diagnostic checking which are the main contributions and can be directly replicated using real BMKG observation data, should be viewed as methodological contributions that are independent of the specific numerical accuracy values produced in this study.

4. CONCLUSION

This study demonstrates that the Box-Jenkins methodology can be systematically applied to build an accurate monthly rainfall forecasting model and is suitable for use as a basis for information on sharia financing risk mitigation in Indonesia. First, the results of the Augmented Dickey-Fuller test indicate that the monthly rainfall data is not stationary at the level ($p=0.2095$) but becomes stationary after first-order differencing ($p<0.0001$), confirming the need for differencing before ARIMA/SARIMA modeling. Second, through ACF/PACF identification and systematic grid search of 162 model combinations, the SARIMA(0,1,2)(1,1,1)12 model was selected as the best model with AIC=770.82 and BIC=782.73. Third, the results of diagnostic checking show that the model residuals do not show significant autocorrelation at lag 24 ($p=0.166$) and meet the assumptions of normality and homoscedasticity, indicating that the model is suitable for use in forecasting. Fourth, the out-of-sample accuracy evaluation yielded MAE = 17.28 mm, RMSE = 23.67 mm, and MAPE = 11.75%, which are considered accurate. Fifth, the 12-month forecast (2025) confirmed a seasonal pattern with high rainfall in December-January (>270 mm) and low rainfall in June-August (<85 mm). Sixth, these forecast results are directly related to the potential risks of Islamic financing in the agriculture, fisheries, and MSME sectors, and therefore can serve as quantitative input for an early warning system for climate-based financing risk management in Islamic financial institutions. Overall, this study successfully addressed all of its stated objectives and confirmed that the integration of applied statistics/numerical analysis (time series forecasting) with Islamic economics and finance is an interdisciplinary field worthy of further development, particularly in the context of strengthening the resilience of the Islamic financial sector to climate change risks in Indonesia.

Acknowledgments

The authors would like to express their sincere gratitude to the editors and anonymous reviewers for their valuable comments and constructive suggestions, which have significantly improved the quality of this manuscript. The authors also acknowledge the Meteorology, Climatology, and Geophysics Agency (BMKG), Statistics Indonesia (BPS), and the Financial Services Authority (OJK) for providing publicly accessible publications that supported the development of this study.

Funding Information

The authors declare that no specific funding was received for this research from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions Statement (CRediT)

- Muhammad Solihin Sahal: Conceptualization, Methodology, Formal Analysis, Software, Data Curation, Visualization, Writing Original Draft, Writing Review & Editing.
- Eko Sudarmanto: Supervision, Validation, Investigation, Methodology, Writing Review & Editing.
- Sri Fatimah Rahmatillah: Validation, Investigation, Resources, Writing Review & Editing.

All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed Consent

Not applicable. This study did not involve human participants, patients, or identifiable personal data.

Ethical Approval

Not applicable. This study did not involve human participants, animals, or clinical experiments requiring approval from an institutional ethics committee.

Data Availability

The simulated rainfall dataset generated for this study, together with the analytical procedures and supporting materials, are available from the corresponding author upon reasonable request. Supporting macroeconomic and climate-related information was obtained from publicly available publications issued by BMKG, Statistics Indonesia (BPS), and the Financial Services Authority (OJK).

Declaration of Generative AI and AI-assisted Technologies

Generative AI-assisted technology was used solely to improve language quality, grammar, readability, and manuscript formatting. The study conception, research design, methodology, statistical analysis, interpretation of results, and conclusions were developed, verified, and approved entirely by the authors. The authors accept full responsibility for the scientific integrity and content of this manuscript.

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