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Weather Forecasting Using Markov Chains in Bogor City: Software Implementation for Predicting Weather Patterns

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Abstract

This study presents the development and implementation of a Markov Chain-based model to analyze and forecast daily rainfall patterns in Bogor City, Indonesia, a region known for its high precipitation. Using daily rainfall data from July 22, 2024, to July 21, 2025, the rainfall intensities were classified into five categories according to BMKG standards. A transition probability matrix was constructed by calculating the relative frequencies of state changes, and multi-step forecasts were performed using the Chapman-Kolmogorov equation. The model reached a steady state after 16 iterations, with results showing an accuracy of 60%, a recall of 100%, and a precision of 55.56%. These findings indicate that the model performs well in identifying rainfall events, especially light rain, but also produces a notable number of false positives. To demonstrate practical application, a mobile weather prediction tool was developed using the Flutter framework, enabling users to input data and visualize forecast results interactively. The application offers a lightweight, cross-platform solution for localized weather prediction. While the current model is effective for early warning purposes, future improvements are necessary to enhance prediction precision. Overall, this research integrates mathematical modeling with mobile technology to support informed decision-making in high-rainfall regions like Bogor.

Keywords
Markov Chain, Rainfall Prediction, Steady State, Weather Forecasting, Flutter Application

1. Introduction

According to the Köppen climate classification, Indonesia is categorized as having a tropical rainforest climate, characterized by relatively uniform temperatures throughout the year and high, evenly distributed rainfall. One region in Indonesia renowned for its high precipitation is the city of Bogor, which is even nicknamed the "Rain City." This nickname stems from the high annual rainfall in the region, reaching approximately 4,000 to 4,500 mm, along with a high frequency of rainy days. Additionally, its location at the foot of Mount Salak and Mount Pangrango contributes to Bogor's relatively cool air temperatures, ranging from 26 to 27°C (Hidayat and Farihah 2020). On the other hand, the region has also experienced rapid land-use changes, which in turn influence the characteristics of its local microclimate.

Fransiska et al. (2022) Rainfall is one of the most important parameters in hydrology and climatology. Generally, rainfall is defined as the amount of water that falls within a specific period of time, usually measured in units of height (millimeters) over a horizontal surface, assuming no infiltration, runoff, or evaporation occurs(Nuhamiddin and Sulisa 2020) . Daily precipitation is a key indicator in climate analysis, and rainfall measurement considers the accumulation of water without losses due to physical processes. Ruswanti (2020) defines rainfall as the height of water that accumulates on a flat surface, without undergoing evaporation, absorption, or runoff, during a specific period.

Understanding the distribution of daily rainfall, especially in areas such as Bogor, is very important for various aspects of future planning (Hardianti et al.2024). This information is required for water resource management, irrigation systems, land suitability assessments, and effective groundwater management planning. In agriculture, daily rainfall patterns help determine appropriate planting times, fertilization schedules, and strategies for pest and disease control. Furthermore, knowledge of rainfall patterns can be used to predict and anticipate the impacts of extreme weather events such as floods or droughts.

However, rainfall patterns often change unpredictably due to uncertainties within the hydrological system. Therefore, a probabilistic approach is needed to model such complex rainfall behavior. One widely used method is the stochastic model based on the Markov Chain approach. This method allows prediction based on transition probabilities from one weather state to another, where the condition on the following day depends only on the condition of the current day. In this study, the Markov Chain model is applied to analyze the daily rainfall distribution in Bogor.

Rainfall data is categorized into three groups based on seasons and analyzed using the maximum likelihood method to construct a transition probability matrix. Then, the Chi-Square test is conducted to evaluate the independence of consecutive rainfall occurrences. After that, the long-term probabilities of rainy days and the average length of rainy spells are calculated for each season. This research refers to a study conducted by Raheem et al. (2015) in the Journal of Environmental Statistics titled A Markov Chain Approach on Pattern of Rainfall Distribution.

Based on the above background, the proposed title of this research is: "Weather Forecasting Using Markov Chains in Bogor City: Software Implementation for Predicting Weather Patterns."This research is expected to contribute to the development of practical and applicable probabilistic weather prediction systems, especially for high-rainfall areas such as Bogor.

1.1 Objectives

This study aims to:

- Analyze the pattern of daily rainfall distribution in Bogor City using the Markov Chain model.
- Construct a weather transition matrix based on historical daily rainfall data.
- Develop a simple software tool as an implementation of the Markov Chain model to analyze and predict weather patterns in Bogor.
- Provide an alternative probabilistic approach to weather forecasting that can be applied to other regions with similar characteristics.

1.2 Scope of Study

The data used in this study is secondary data obtained from the BMKG platform (https://dataonline.bmkg.go.id/data-harian) from July 22, 2024, to July 21, 2025. The dataset includes 365 daily observations of rainfall (in millimeters), reflecting consistently recorded daily rainfall accumulations during the observation period. The method used in this study is the Markov Chain model.

2. Literature Review

2.1 Markov Chain

A Markov Chain is a model in probability theory used to describe a stochastic system, a system that undergoes random state changes over time. In a Markov Chain, the future state depends only on the present state and not on the sequence of past states. Mathematically, a Markov Chain can be expressed as(Taylor, H.M. and Karlin, S. 1993):

$$P(X_{n+1} = x \mid X_0 = x_0, X_1 = x_1, \ldots, X_n = x_n) = P(X_{n+1} = x \mid X_n = x_n)$$

For all $n \geq 0$ and all states $x_0, x_1, \ldots, x_n, x$.
In the context of weather forecasting, this model is used to represent the probability of transitioning between weather states such as "rainy" or "not rainy" from one day to the next. For example, if today is rainy, the probability of tomorrow being rainy can be estimated using a transition matrix formed from historical data.
Transition probability matrix is the probability of X_{t+1} being in state *j* given that X_t is in state *i* is called the one-step transition probability and is denoted by $P_{ij}^{t,t+1}$, thus:

$$P_{ij}^{t,t+1} = \Pr\{X_t = j | X_t = i\}$$

When the one-step transition probability is independent of the time variable t, the Markov chain is said to have stationary transition probabilities. In this case, $P_{ij}^{t,t+1} = P_{ij}$ independent to t and P_{ij} Represents the conditional probability of transitioning from state i to state j in one step. These transition probabilities are typically arranged in matrix form:

$$P = \begin{bmatrix} P_{00} & P_{01} & \cdots & P_{0n} \\ P_{10} & P_{11} & \cdots & P_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{m0} & P_{m1} & \cdots & P_{mn} \end{bmatrix}$$

And $P = (P_{ij})$ is the Markov transition matrix or transition probability matrix for the process. This matrix must satisfy the following conditions(Taylor, H.M. and Karlin, S. 1993):

$P_{ij} \geq 0,$ for all *i,j* = 0,1,2,…..
$\sum_{j=0}^{\infty} P_{ij} = 0$ for all *i* = 0,1,2, …

The steady state is evaluated to determine the long-run distribution. The Chapman-Kolmogorov equation, which is used to predict multi-step transitions (m, n steps) transition prediction is as follows:

$$P_{ij}^{(v)} = \sum_{k=0}^{l} p_{ik}^{(w)} P_{kj}^{(v-w)}$$

2.2 Flutter

Flutter is a Software Development Kit (SDK) developed by Google to build mobile applications high-performance. Its main advantage is the ability to develop cross-platform applications for both Android and iOS using a single codebase. Flutter utilizes the Dart programming language, which features syntax similar to Java and JavaScript, making it relatively easy to learn especially for developers already familiar with those languages. Additionally, Flutter is equipped with a reactive-functional framework, an efficient 2D rendering engine, a rich set of prebuilt widgets, and various development tools to streamline the application development process (Muslim et al. 2022).

Flutter can be used to develop a weather prediction application based on Markov Chains for the city of Bogor. Its advantages enable the creation of interactive and responsive prediction visualizations, such as graphs, daily weather forecast tables, and categorized rainfall information displays. This approach allows the developed application to reach a broader user base across multiple devices while providing a consistent and informative user interface experience.

3. Methods

This study employs a probabilistic approach using the Markov Chain model to analyze and forecast daily weather patterns particularly rainfall in Bogor City. The overall methodological steps are outlined as follows in Figure 1:

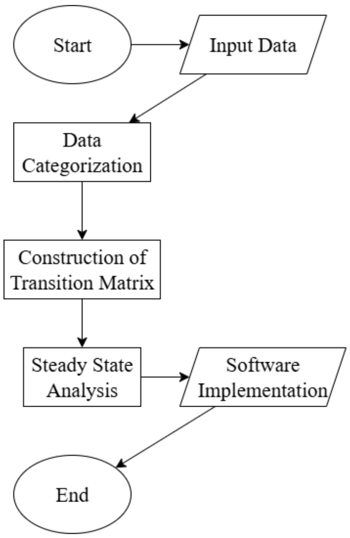

Figure 1. Flowchart

4. Data Collection

The following Table 1 is daily rainfall data from BMKG recorded between July 22, 2024, to July 21, 2025:

Table 1. Data Collection

Date	RI	State	Date	RI	State	Date	RI	State
22-07-2024	0	1	21-05-2025	1.2	2	21-06-2025	53	4
23-07-2024	0	1	22-05-2025	2.2	2	22-06-2025	25.2	3
24-07-2024	0	1	23-05-2025	3.2	2	23-06-2025	0	1
25-07-2024	0	1	24-05-2025	10.7	2	24-06-2025	0	1
26-07-2024	0.2	2	25-05-2025	0.2	2	25-06-2025	0	1
27-07-2024	0	1	26-05-2025	0	1	26-06-2025	2.7	2
28-07-2024	0	1	27-05-2025	1.4	2	27-06-2025	0	1
29-07-2024	0	1	28-05-2025	0	1	28-06-2025	0	1
30-07-2024	0	1	29-05-2025	0	1	29-06-2025	12	2
31-07-2024	0	1	30-05-2025	4.2	2	30-06-2025	0.9	2
01-08-2024	0	1	31-05-2025	0.2	2	01-07-2025	10.1	2
02-08-2024	48.8	3	01-06-2025	5.2	2	02-07-2025	2.4	2
03-08-2024	38	3	02-06-2025	0	1	03-07-2025	11.8	2
04-08-2024	11.7	2	03-06-2025	0	1	04-07-2025	51.6	4
05-08-2024	0	1	04-06-2025	0	1	05-07-2025	50	4
06-08-2024	0	1	05-06-2025	0	1	06-07-2025	86	4
07-08-2024	0	1	06-06-2025	8	2	07-07-2025	6.7	2
08-08-2024	0	1	07-06-2025	0	1	08-07-2025	53.8	4
09-08-2024	0	1	08-06-2025	6.4	2	09-07-2025	0.2	2
10-08-2024	0	1	09-06-2025	0	1	10-07-2025	1.4	2
11-08-2024	0.2	2	10-06-2025	0	1	11-07-2025	0	1

Date	RI	State	Date	RI	State	Date	RI	State
12-08-2024	0.8	2	11-06-2025	2	2	12-07-2025	0	1
13-08-2024	0	1	12-06-2025	0	1	13-07-2025	0	1
14-08-2024	0	1	13-06-2025	0	1	14-07-2025	2.7	2
15-08-2024	0	1	14-06-2025	0	1	15-07-2025	0.3	2
16-08-2024	0	1	15-06-2025	0	1	16-07-2025	0	1
17-08-2024	0	1	16-06-2025	0	1	17-07-2025	0.5	2
18-08-2024	0.4	2	17-06-2025	57	4	18-07-2025	0.2	2
19-08-2024	0	1	18-06-2025	34.7	3	19-07-2025	8.8	2
20-08-2024	0	1	19-06-2025	7.5	2	20-07-2025	0	1
…	…	…	20-06-2025	0.2	2	21-07-2025	0	1

The daily rainfall data recorded by BMKG from July 22, 2024, to July 21, 2025, reveals distinct seasonal patterns across three key periods. From late July to mid-August 2024, the weather was predominantly dry (State 1), with only occasional light to moderate rain, except for significant spikes on August 2 and 3 with 48.8 mm and 38 mm, respectively (State 3), indicating the onset of the rainy season. In the period from May to June 2025, rainfall intensities fluctuated more frequently, ranging from no rain to heavy rain, with the most intense event on June 17 (57 mm, State 4), reflecting a transitional phase with unstable weather. From late June to mid-July 2025, rainfall intensified further, marked by consistent light to heavy rain, including multiple days with over 50 mm, such as July 6 (86 mm) and July 8 (53.8 mm), classifying as heavy rain (State 4). Overall, the data highlights a progression from dry to increasingly wet conditions, with July 2025 representing peak rainy season activity.

5. Results and Discussion

In Bogor, West Java, Indonesia, there are two main seasons: the rainy season and the dry season. Generally, if the climate behaves normally, the rainy season occurs from October to March, while the dry season extends from April to September. The input data used in this study consists of daily rainfall records collected between February 1, 2025, and April 30, 2025, totaling 90 days of observations.

To build the model, the daily rainfall data were categorized into several groups based on rainfall intensity (in millimeters). The categorization was based on the official classification by BMKG, which defines rainfall conditions into five categories: No Rain, Light Rain, Moderate Rain, Heavy Rain, and Very Heavy Rain. The classification thresholds are shown in Table 2.

Table 2. BMKG Daily Rainfall Classification (Gustari et al.2012)

No.	Category/State	Daily Rainfall Intensity (mm/day)
1	No Rain (NR)	0
2	Light Rain (LR)	0.1 – 19.9
3	Moderate Rain (MR)	20.0 – 49.9
4	Heavy Rain (HR)	50.0 – 100.0
5	Very Heavy Rain (VHR)	>100.0

5.1 Numerical Results

The data were grouped into five categories: No Rain, Light Rain, Moderate Rain, Heavy Rain, and Very Heavy Rain. Transitions between weather conditions were then observed, such as from No Rain to Light Rain, or from Light Rain to Heavy Rain. The frequency of these transitions is shown in Table 3.

Table 3. Transition Frequency Matrix

Transition Frequency Matrix	**1**	**2**	**3**	**4**	**5**	**Total**
1	72	39	15	7	0	133
2	47	100	14	8	0	169
3	9	18	4	4	1	36
4	4	11	3	5	1	24
5	1	1	0	0	0	2

From the frequency matrix, the transition probability matrix P was calculated by dividing each row of the frequency matrix by the total sum of that respective row. Subsequently, the weather state changes were modeled into the following Markov Chain transition probability matrix:

$$P = \begin{bmatrix} 0.541 & 0.293 & 0.113 & 0.053 & 0 \\ 0.278 & 0.592 & 0.083 & 0.047 & 0 \\ 0.250 & 0.5 & 0.111 & 0.111 & 0.028 \\ 0.167 & 0.458 & 0.125 & 0.208 & 0.042 \\ 0.5 & 0.5 & 0 & 0 & 0 \end{bmatrix}$$

To analyze the system's behavior in the long term and to determine the transition probabilities between states after several steps (days), the Chapman-Kolmogorov equation is used. This equation states that the probability of transitioning from one state to another over two or more steps can be obtained by multiplying the transition probability matrix by itself v times:

$$P_{ij}^{(v)} = \sum_{k=0}^{l} p_{ik}^{(w)} P_{kj}^{(v-w)}$$

For all i = 0,1,2,…., l ; j= 0,1,2,…., l; and w = 1,2,…,v-1; v= w+1, w+2,…
This step is carried out to observe how the daily weather system gradually reaches a stable probability distribution over time. The transition matrix is successively computed for P^2, P^4, P^8, with the results presented below:

$$P^2 = \begin{bmatrix} 0.41158093 & 0.41276721 & 0.10445667 & 0.06586938 & 0.00532581 \\ 0.34371357 & 0.49479420 & 0.09550492 & 0.06171381 & 0.00427350 \\ 0.33457679 & 0.48953663 & 0.09585017 & 0.07232036 & 0.00771605 \\ 0.30449660 & 0.49889478 & 0.09669599 & 0.08775985 & 0.01215278 \\ 0.40972995 & 0.44247453 & 0.09781110 & 0.04998443 & 0 \end{bmatrix}$$

$$P^4 = \begin{bmatrix} 0.36846048 & 0.46047572 & 0.09931609 & 0.06618526 & 0.00556245 \\ 0.36402979 & 0.46612776 & 0.09869809 & 0.06571239 & 0.00543197 \\ 0.36321785 & 0.46673879 & 0.09863699 & 0.06591396 & 0.00549241 \\ 0.36085607 & 0.46903291 & 0.09839663 & 0.06614803 & 0.00556636 \\ 0.36866694 & 0.46087600 & 0.09926602 & 0.06575581 & 0.00543523 \end{bmatrix}$$

$$P^8 = \begin{bmatrix} 0.36539742 & 0.46426896 & 0.09890294 & 0.06593572 & 0.00549497 \\ 0.36537919 & 0.46429293 & 0.09890031 & 0.06593329 & 0.00549429 \\ 0.36537528 & 0.46429775 & 0.09889978 & 0.06593298 & 0.00549420 \\ 0.36536461 & 0.46431125 & 0.09889831 & 0.06593192 & 0.00549391 \\ 0.36539915 & 0.46426718 & 0.09890313 & 0.06593561 & 0.00549493 \end{bmatrix}$$

$$P^{16} = \begin{bmatrix} 0.36538462 & 0.46428571 & 0.09890110 & 0.06593407 & 0.00549451 \\ 0.36538462 & 0.46428571 & 0.09890110 & 0.06593407 & 0.00549451 \\ 0.36538462 & 0.46428571 & 0.09890110 & 0.06593407 & 0.00549451 \\ 0.36538462 & 0.46428571 & 0.09890110 & 0.06593407 & 0.00549451 \\ 0.36538462 & 0.46428571 & 0.09890110 & 0.06593407 & 0.00549451 \end{bmatrix}$$

The results show that after n = 16 steps (days), the probability values in each row of the transition matrix become nearly identical, indicating that the system has reached a steady state. This implies that the distribution of weather conditions on a given day becomes independent of the initial state. Mathematically, the distribution of weather states on day n is calculated using the formula $X_n = X_0 . P^n$, where X_0 represents the initial state distribution and P is the transition matrix. X_n converges to a stable distribution, confirming that the weather system modeled through the Markov Chain has stabilized over time. The historical rainfall data in Bogor City and forecasts based on the data testing can be seen in Table 4 below:

Table 4. Comparison of actual and prediction rainfall data in Bogor City

Date	Actual	Prediction
12-07-2025	No Rain	No Rain
13-07-2025	No Rain	Light Rain
14-07-2025	Light Rain	Light Rain
15-07-2025	Light Rain	Light Rain
16-07-2025	No Rain	Light Rain
17-07-2025	Light Rain	Light Rain
18-07-2025	Light Rain	Light Rain
19-07-2025	Light Rain	Light Rain
20-07-2025	No Rain	Light Rain
21-07-2025	No Rain	Light Rain

Based on the table above, a confusion matrix can be created as follows in Table 5:

Table 5. Confusion Matrix

Actual	Prediction	
	No Rain	Light Rain
No Rain	1	4
Light Rain	0	5

From the confusion matrix above, we can see that the model has:

- Accuracy = $\frac{(True\ Positive + True\ Negative)}{Total} = \frac{5+1}{10} = 60\%$
  Only 6 out of 10 predictions match the actual conditions. This indicates that the model is not yet accurate enough overall.
- Precision (Light Rain) = $True \frac{Positive}{True\ Positive + False\ Positive} = \frac{5}{5+4} = 55.56\%$
  Of all the predictions for "Light Rain," only about 56% were correct. suggests that the model produces a considerable number of false positives, reflecting a tendency to be overly cautious in predicting rainfall.
- Recall (Light Rain) = $True \frac{Positive}{True\ Positive + False\ Negative} = \frac{5}{5+0} = 100\%$
  All light rain events were successfully identified. This means the model is very good at detecting light rain, with no false negatives missed. This is suitable for the context of risk mitigation.
- F1 Score = $2 \times \frac{Precision \times Recall}{Precision + Recall} = 2 \times \frac{0.5556 \times 1}{0.5556+1} \approx 71.43\%$
  The combined precision and sensitivity of the model are quite good. This reflects the balance between the model's ability to recognize light rain and its prediction accuracy.

The model is very reliable in detecting light rain (high recall), but less accurate in distinguishing days without rain (low precision). This means the model tends to "play it safe" by frequently predicting light rain, even though it is sometimes wrong.
If this model is used for early warning or logistical preparation, high recall is very useful because it minimizes the risk of missed rain. However, for applications that require high efficiency or to avoid false alarms, improvements in precision are needed.

5.2 Software implementation

In this study, a weather prediction application was developed using the Flutter framework to implement the Markov Chain model for analyzing and forecasting daily rainfall patterns in Bogor City. The application allows users to input or upload daily rainfall data, which is then automatically categorized into five rainfall intensity levels based on BMKG standards. Using maximum likelihood estimation, the app generates a transition probability matrix and applies the Chapman-Kolmogorov equation to simulate multi-step transitions and steady-state behavior. The results are visualized through interactive tables and graphs, providing an intuitive dashboard for users to understand weather pattern predictions. Developed with Dart in a cross-platform environment, the Flutter-based software ensures lightweight performance, offline accessibility, and compatibility with both Android and iOS devices. This implementation demonstrates how mathematical modeling can be effectively translated into practical, user-friendly software tools, with future enhancements planned for real-time data integration and broader geographic scalability (Figure 2).

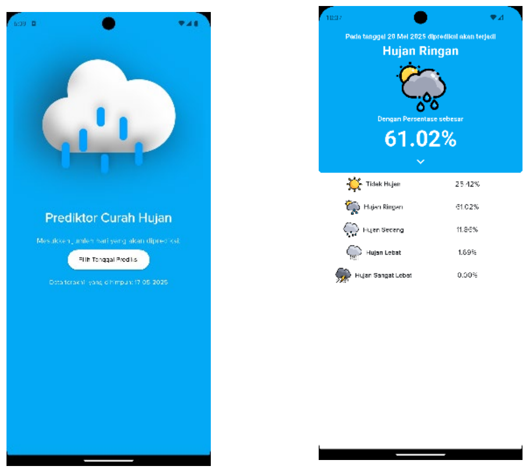

Figure 2. UI of Rainfall Predictor application in Bogor City

The figure illustrates two interface screens from a mobile application called *Prediktor Curah Hujan* (Rainfall Predictor), which forecasts daily rainfall using a Markov chain model. The first screen serves as the main page, featuring a rain cloud icon, a brief explanation of the app's function, and a button labeled *Lihat Hasil Prediksi* (See Prediction Results) that directs users to the forecast. The second screen displays the rainfall prediction result for a selected date, for example, April 30, 2025. On that date, the model predicts light rain with a probability of 61.02%. A full probability distribution for all rainfall states is also shown: no rain (25.42%), light rain (61.02%), moderate rain (10.61%), heavy rain (1.96%), and very heavy rain (0.99%). This figure demonstrates how the app presents probabilistic weather forecasts in a user-friendly visual format, supporting informed decision-making based on predicted rainfall intensity.

6. Conclusion

This study applied the Markov Chain model to analyze and predict daily rainfall patterns in Bogor City, a region characterized by high precipitation variability. By classifying rainfall intensities and constructing a transition probability matrix using historical data, the model effectively represented the probabilistic behavior of weather transitions. The system achieved steady state convergence after 16 steps, demonstrating long-term stability in its predictions. Evaluation of the model's performance revealed an overall prediction accuracy of 60%, with a perfect recall of 100% for light rain events. However, this came at the cost of lower precision (55.56%), indicating a tendency to over-predict light rain occurrences. This suggests that while the model is highly effective at identifying actual rain events, minimizing missed detections, it also generates a significant number of false positives. In practical terms, this cautious approach may be advantageous for early warnings and agricultural planning, where failing to predict rain can have more serious consequences than issuing a false alarm. The implementation of the Markov Chain model through a Flutter-based mobile application further illustrates its real-world applicability. The app enables users to access intuitive and probabilistic weather forecasts, offering a tool for decision-making in rain-sensitive activities.

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Biographies

Bandar Anzari is a fourth-semester undergraduate student majoring in Mathematics at the Faculty of Mathematics and Natural Sciences, Pakuan University. He has a deep interest in mathematical modeling and statistical analysis, with a passion for applying theoretical knowledge to practical and data-driven problems. His academic excellence is reflected in his perfect GPA of 4.00 (on a 4.00 scale), and his commitment to continuous growth is evident in both academic and extracurricular achievements. Bandar has served as a teaching assistant in practical classes for Statistical Methods and Elementary Linear Algebra, where he helped fellow students grasp essential mathematical concepts and techniques. His leadership is demonstrated through his role as Head of the Academic and Non-Academic Department in HIMATIKA (Mathematics Student Association), where he coordinated various student development and cultural programs. In addition to his academic pursuits, Bandar won 3rd place in a Scientific Writing Competition and was a semifinalist in a Mathematics Olympiad held by Universitas Terbuka. He also represented his university in the National Cultural Week Festival organized by the Ministry of Education, Culture, Research, and Technology, performing traditional Indonesian dance reflecting his appreciation for both science and culture. With a strong foundation in mathematics, teaching experience, and organizational involvement, he is committed to making meaningful contributions in both academic and applied fields.

Hagni Wijayanti holds a Doctorate in Mathematics from Padjadjaran University and a Master's degree in Applied Mathematics from the Bogor Agricultural Institute (IPB). Her expertise lies in mathematical modeling and optimization, with a strong focus on objective programming approaches to solve real-world problems in transportation, finance, and socio-economic analysis. She has published extensively in national and international journals, contributing to the development of robust optimization techniques. Her recent works include: A Goal Programming Approach to Vehicle Routing Problem for Optimal Route Determination in Bus Rapid Transit (2025, IJMMNO), Financial Optimization Modeling of Asset and Liability Management with Weighted Goal Programming (2024, Decision Science Letters), Robust Goal Programming for Non-Financial Companies: A Systematic Literature Review (2024, MDPI Computation), Corporate Financial Analysis Using Weighted Goal Programming and AHP (2024, Preprints.org), Income Level Analysis in Cikanyere Village Using Ordinal Logistic Regression (2024, J. Math Stat Computation), Asset and Liability Management Optimization in Textile and Garment Companies (2023, Springer Proceedings in Physics). Wijayanti, H. actively combines theoretical research with practical applications to support data-driven decision making across sectors. His work bridges academic and community engagement, particularly in promoting mathematical literacy in mathematical modeling and optimization for rural and industrial development.

Pilar Kukuh Bintang Rachmadi is a final-year Computer Science student at Pakuan University, Indonesia, with academic interests in data analysis, data science, machine learning, deep learning, and computer vision. He has been actively involved in applied research, including a published journal in JURIKOM (Jurnal Riset Komputer) titled "Identification of Empty Palm Oil Bunches Using Excess Green Index and Drone Image-Based DBSCAN Algorithm", which also received intellectual property recognition. His research projects have included the development of a real-time fruit maturity detection system using UAVs and deep learning, as well as customer segmentation and forecasting using RFM analysis, clustering, and time series modeling. Previously, Pilar participated in the MSIB Batch 6 program at Startup Campus, where he served as both a participant and a Batch Leader in the Data Science and AI track. He also mentored students in AI and machine learning at Lokpro Camp. In addition, he served in HIMAKOM, the Computer Science Student Association at Pakuan University, where he led educational initiatives that promoted peer learning and student engagement. Pilar's work focuses on applying artificial intelligence and data-driven methods to address real-world problems. He remains committed to advancing innovative solutions and sharing knowledge through applied research and technical writing in the field of computer science.