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APPLICATION OF MARKOV CHAIN IN MONTHLY RAINFALL PREDICTION IN AMBON CITY

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ABSTRACT

Asia has a tropical climate with two main seasons influenced by monsoons, namely the rainy season and the dry season. However, in recent years, seasonal patterns have shifted due to climate change, making it difficult to predict weather, including rainfall. Ambon City, as one of the regions with high and varied rainfall in eastern Indonesia, is highly dependent on weather conditions, especially since most of its inhabitants work as fishermen and farmers. Therefore, rainfall prediction is important to support appropriate decision-making in the marine, agriculture, and hydrometeorological disaster risk mitigation sectors. This study aims to model and predict the status of monthly rainfall in Ambon City in 2025 using the Markov chain method, a first-order probability-based approach that describes transitions between circumstances based on historical data, where the chances of subsequent events depend only on current circumstances. The data used is in the form of monthly rainfall from 2015 to 2024 obtained from the Pattimura–Ambon Meteorological Station. The data were classified into four categories of precipitation: light, medium, high, and very high, which were further used to compile a one-step probability transition matrix. The results showed that the steady-state distribution of rainfall in Ambon City tended to be in the moderate category (47.90%), followed by very high (26.5%), light (20.17%), and high (5.88%). The rainfall prediction for 2025 shows a transition pattern that is close to a steady state, where month after month there is a stable trend. With this information, fishermen can be wiser in determining safe times to go to sea, and the government can design climate change adaptation and mitigation policies more effectively.

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1. INTRODUCTION

Indonesia has a tropical climate with two main seasons, namely rain and drought, which are influenced by the monsoon wind system. However, in the last few decades, the pattern of the season has become increasingly difficult to predict due to several climate changes that cause seasonal shifts, such as longer rainy seasons or delayed droughts [1]. The weather in Indonesia does not always follow the season or run well due to several factors that can change rainfall. On the contrary, it is a frequent and sudden change [2]. Rainfall is one of the climatic parameters that is widely utilized in various fields such as agriculture, hydrology, and environment [3]. In rainfall measurement, it is usually considered the amount of rainwater that falls to the surface without considering evaporation, infiltration, or flow. Handoko (1995) and Arifin (2010) explained that 1 mm of rainfall means that there is 1 liter of water that falls on a surface of 1 m² without loss of water mass due to external processes.

In statistical analysis, rainfall has a vital role as an input in processes such as surface runoff, sedimentation, and river flow. Therefore, modeling and predicting rainfall is essential, especially in the face of increasing climate variables. One statistical approach that can be used is the Markov chain model, which is a probability method that describes events in sequence, where the probability of future events depends only on current circumstances, not on previous history [4][5].

Ambon City is one of the regions in eastern Indonesia that has high rainfall that varies throughout the year. In addition to having an impact on the agricultural sector and water resource management, the variability of rainfall in Ambon City also has a great influence on the community's economic activities. Most of the population of Ambon City works as fishermen, so bad weather in the rainy season can increase the risk of marine accidents and disrupt their livelihoods. Therefore, information about rainfall patterns is very important for determining a safe time for fishermen to go to sea, as well as avoiding shipping activities during extreme weather conditions. Through the application of the Markov Chain method, this study aims to predict the monthly rainfall conditions of Ambon City in 2025**,** based on historical data for the period 2015–2024. This model not only helps project transitions between rainfall categories (light, moderate, high), but also provides a long-term distribution picture that can be used by farmers, local governments, and communities in developing adaptation and mitigation strategies for climate change [6]. With this information, it is hoped that the public, especially fishermen, can be more vigilant and wise in determining safe times to go to sea, while the government and other stakeholders can develop appropriate policies to reduce the risk of disasters and economic losses due to extreme weather [7].

2. RESEARCH METHODOLOGY

This study aims to predict the status of monthly rainfall in Ambon City using the Markov chain analysis approach, with monthly rainfall data for 2015–2024 from the Pattimura–Ambon Meteorological Station. The following are the steps of the research carried out.

Data Source

This study used a total sampling technique that used monthly rainfall data from 2015 to 2024 obtained from The Pattimura–Ambon Meteorological Station. That data consisted of 120 data points (12 months for 10 years) and is expressed in millimeters (mm).

Research Variable

This study used variables in the form of monthly rainfall status, which are classified into four categories. Those categories are based on classification of the amount of rainfall per month compared to the Rainfall Limit (BCH), such as, Light, Moderate, High, and Very High [8]. The rainfall data analyzed covers the period from January 2015 to December 2024. Furthermore, this study calculated the probability of transitions between rainfall categories based on historical data to construct a transition matrix in the Markov chain model. This model was then used to calculate *steady-state* distribution, which described the long-term tendency to precipitation conditions. All these variables were used thoroughly in the process of building and analyzing predictive models of rainfall patterns in the study area.

Steps of Data Analysis

Data analysis was carried out using the Markov Chain approach, to recognize patterns of changes in rainfall status from month to month as well as to predict future rainfall conditions. The analysis steps could be explained as follows:

Classification

Monthly rainfall data was categorized into four states based on its rain intensity compared to BCH, as described follow:

i. Light : BCH < 100 mm/month
ii. Moderate : $100 \leq$ BCH < 300 mm/month
iii. High : $300 \leq$ BCH < 400mm/month
iv. Very high : BCH ≥ 400 mm/month

All numerical rainfall data is converted into a category according to the classification, thus forming a series of qualitative data based on the month.

Calculation of Transition Frequency

The number of transitions between states was calculated, for example, from "Light" to "Moderate," "Moderate" to "High," "High" to "Very High," and so on, based on movement between months during observation period.

Formation of One-Step Transition Probability Matrix

The one-step transition probability matrix $(\boldsymbol{P})$ in this study is constructed from a 4×4 square matrix, with element in the matrix represented probability of moving from one state to another in one month [9]. Each element was calculated by divide number of transitions between categories by the total transitions of each of origin states, used formula as follows:

$$P(A) = \frac{n(A)}{n(S)}, \qquad A \in S \tag{1}$$

Where $P(A)$ is the Probability of occurrence an event A, $n(A)$ is the Frequency of occurrence an event A, and $n(S)$ is the Total frequency of all possible events (sample space).

Visualization in Transition Diagram

The one-step transition probability matrix that was already developed in the previous stage can be visualized in the form of a transition diagram, where each sample represents a state, and the direction of the arrow indicates the direction and probability of transition between states.

Calculation of Transition Probability for n-Steps

To find out probability of transition between states in next few months, a repeated multiplication of the One-Step Transition Matrix with itself is performed. This step illustrated probability of a change in rainfall status after a certain time period [10]. So that has resulted **n-Steps Transition Probability Matrix** $(\boldsymbol{P}^{(\boldsymbol{n})})$, which describes probability of moving from one state to another after n time periods. The formula for the n-step transition matrix defined as follows:

$$\boldsymbol{P}^{(\boldsymbol{n})} = \underbrace{\boldsymbol{P} \times \boldsymbol{P} \times \dots \times \boldsymbol{P}}_{n-times} \tag{2}$$

Each element in $\boldsymbol{P}^{(\boldsymbol{n})}$ (we define as $p_{ij}^{(n)}$) represented probability that the system currently in state i, will be in state *j* after *n* months. The formula for $p_{ij}^{(n)}$ defined as follows:

$$p_{ij}^{(n)} = \sum_{k=0}^{M} p_{ik}^{(n-1)} \cdot p_{kj} \quad (3)$$

This formula shows that each element of the n-step matrix is obtained by multiplying and summing the corresponding elements of the $(n-1)$ step matrix and the One-Step Transition Probability Matrix.

Matrix Convergence Observations

The n-Steps Transition Probability Matrix ($\boldsymbol{P}^{(\boldsymbol{n})}$), is observed until it reaches a stable (convergent) value. This convergence shows that system has reached equilibrium state and its distribution has not changed again despite the passage of time.

Calculation of Steady State Distribution

Distribution steady state or called limiting probability (π_j) is long-term distribution of rainfall status achieved when the system has been balanced [11][12][13][14]. This term was calculated using formula defined as follows:

$$\lim_{n\to\infty} p_{ij}^{(n)} = \pi_j > 0 \quad (4)$$

where it must meet the π_j steady state equation, such as:

a) $\pi_j = \sum_{i=0}^{M} \pi_j \, p_{ij}\,;\qquad j = 0, 1, \dots M$ (5)

b) $\sum_{i=0}^{M} \pi_j = 0$ (6)

Prediction State of Monthly Rainfall

Prediction on state condition of monthly rainfall for upcoming months in 2025 was done by multiply last state distribution vector (December 2024) by n-Steps Transition Probability Matrix, gradually for each month of the year. This term was calculated using formula defined as follows [15]:

$$\boldsymbol{\pi}^{(n)} = \boldsymbol{\pi}^{(0)}.\boldsymbol{P}^{(\boldsymbol{n})} \quad (7)$$

where $\boldsymbol{\pi}^{(n)}$ is the Vector of state distribution at n time, $\boldsymbol{\pi}^{(0)}$ is the Initial distribution, and $\boldsymbol{P}^{(\boldsymbol{n})}$ is the n-Steps Transition Probability Matrix.

3. RESULTS AND DISCUSSIONS

Based on data showed in **Table 1,** it has been compiled in monthly order from January 2015 to December 2024. This arrangement was appropriate for Markov chain analysis approach with each month can be viewed as a *state* in a dynamic system.

Table 1. Monthly Rainfall at the Pattimura – Ambon Meteorological Station 2015-2024 (in millimeters)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	160	196	120	298	180	718	164	70	3	67	14	118
2016	71	34	153	355	239	199	914	347	342	185	37	119
2017	284	152	142	129	753	1,430	1,046	452	501	180	189	176
2018	236	120	203	292	797	847	542	298	411	29	27	146

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	235	47	221	316	268	534	272	96	102	172	27	14
2020	32.3	96.1	187.6	104.6	678.7	838.2	3,938.7	318	579.3	444.4	136.7	139.4
2021	124.7	81.4	97.7	122	814.5	514.3	1,309.7	912.8	672.6	205.7	157	260.7
2022	85.1	100.4	145.4	134.3	143.5	351.1	1,220.9	821.4	424.5	54.6	173.2	269.4
2023	173.6	180.7	166.7	296.4	124.7	651.1	536.9	221.5	194.8	93.9	49.2	135
2024	127.9	79.9	130.5	253.9	683	946.6	521.2	620.5	216.5	359.4	38	176.8

Source: https://maluku.bps.go.id

Rainfall Classification

To make data that could be defined as a Markov chain system, it was necessary to convert the numeric value of monthly rainfall into qualitative states. Based on the classification defined in the previous section, we also symbolized each of the states as follows: State 0 for "Light," State 1 for "Moderate," State 2 for "High," and State 3 for "Very High." All those values in the original data could be converted into states, resulting in what is shown in **Table 2**.

Table 2. Monthly Rainfall after Classification

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2015	1	1	1	1	1	3	1	0	0	0	0	1
2016	0	0	1	2	1	1	3	2	2	1	0	1
2017	1	1	1	1	3	3	3	3	3	1	1	1
2018	1	1	1	1	3	3	3	1	3	0	0	1
2019	1	0	1	2	1	3	1	0	1	1	0	0
2020	0	0	1	1	3	3	3	2	3	3	1	1
2021	1	0	0	1	3	3	3	3	3	1	1	1
2022	0	0	1	1	1	2	3	3	3	0	1	1
2023	1	1	1	1	1	3	3	1	1	0	0	1
2024	1	0	1	1	3	3	3	3	1	2	0	1

Formation of One-Step Transition Probability Matrix

At this stage, the frequency of transition from one state to another is calculated, for example, Step 0 (Light) to Step 1 (Moderate), Step 0 (Light) to Step 2 (High), and so on. showed the number of each transition for the monthly rainfall state based on data.

Table 3. Transition Frequencies for Each State

Origin State	Transition	Frequency	Number of Transition from Origin State
Light (0)	0 – 0	11	24
	0 – 1	13	
	0 – 2	0	
	0 – 3	0	
Moderate (1)	1 – 0	10	57
	1 – 1	33	
	1 – 2	4	
	1 – 3	10	

Origin State	Transition	Frequency	Number of Transition from Origin State
High (2)	$2-0$	1	7
	$2-1$	3	
	$2-2$	1	
	$2-3$	2	
Very High (3)	$3-0$	2	31
	$3-1$	8	
	$3-2$	2	
	$3-3$	19	
Total Transition			119

Based on **Table 3,** it showed a dynamic condition for state transition regarding monthly rainfall in Ambon City for the period 2015–2024. At first, from light conditions, there were 24 changes in conditions, which could be detailed as follows: 11 times remained in light conditions, 13 times changed to moderate conditions, and there were also no changes to high and very high conditions. Furthermore, from moderate conditions, 57 changes in conditions were recorded, which could also be detailed as follows: 10 times changed to light condition, 33 times remained in moderate condition, 4 times changed to high condition, and 10 times changed to very high condition.

Next, from high conditions, there were 7 changes in condition, which could also be detailed as follows: 1 time changed to light condition, 3 times changed to moderate condition, 1 time remained in high condition, and 2 times changed to very high condition. Moreover, from very high conditions, there were 31 changes in condition, which could also be detailed as follows: 2 times changed to light conditions, 8 times changed to moderate conditions, 2 times changed to high conditions, and 19 times remained in very high conditions.

Based on information on transition frequency shown in **Table 3**, the probability of transitions between each condition was calculated using the basic formula of the Markov chain defined in **Equation (1).** This calculation is done by dividing the number of transitions to a certain condition by the total displacement from the initial condition. All probabilities of each transition were then compiled, resulting in the form of the **One-Step Transition Probability Matrix** in this study as follows:

$$\boldsymbol{P} = \begin{bmatrix} 0.458333 & 0.541667 & 0 & 0 \\ 0.175439 & 0.578947 & 0.070175 & 0.175439 \\ 0.142857 & 0.428571 & 0.142857 & 0.285714 \\ 0.064516 & 0.258065 & 0.064516 & 0.612903 \end{bmatrix}$$

The resulting matrix is 4×4, each row represented current state and each column represented state in next month. This One-Step Transition Probability Matrix could also be represented visually with made a transition diagram as showed in **Figure 1**.

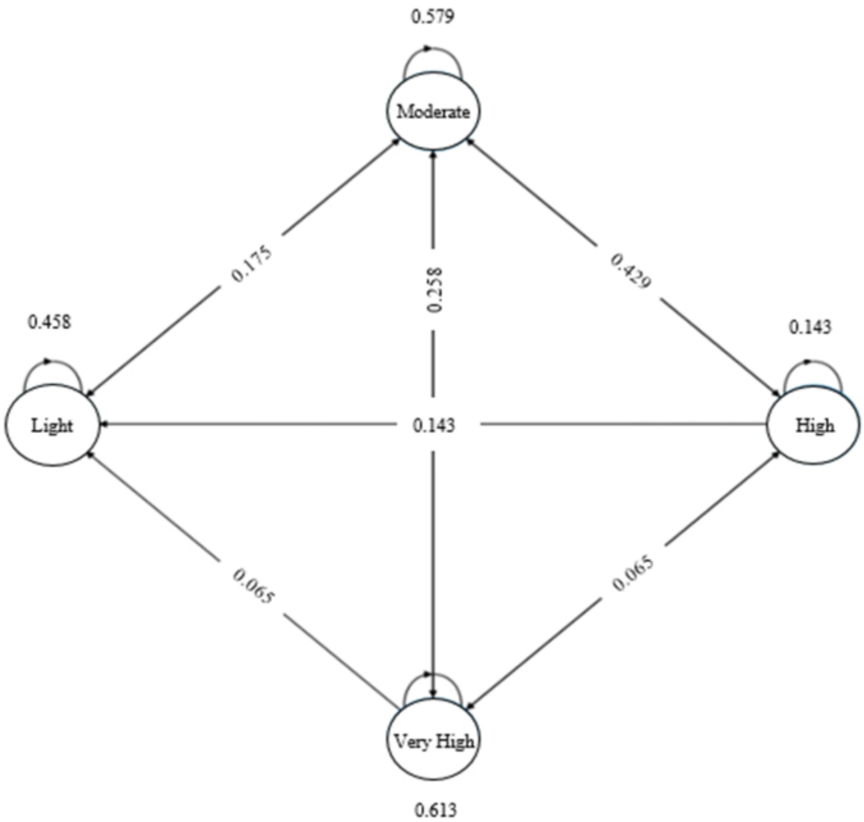

Figure 1. Transition Diagram of Monthly Rainfall States

Based on **Figure 1**. The transition diagram illustrates the monthly rainfall dynamics among four states: Light, Moderate, High, and Very High. Each arrow represents the possible transition from one rainfall state to another in the following month, including self-transitions that indicate persistence of the same condition over time. This visualization provides an intuitive representation of how rainfall conditions evolve from one period to the next.

Overall, the diagram shows that the moderate rainfall state plays a central role in the transition process, as it connects to all other states and frequently persists across consecutive months. This suggested that in the long run, rainfall conditions tend to fluctuate around a moderate state rather than extreme conditions, reflecting a relatively stable rainfall pattern in the study area.

Calculation of $\boldsymbol{P^{(n)}}$ and Convergence Assessment

To predict the probability of rainfall over a longer period of time, we calculated the n-Steps Transition Probability Matrix $\left(\boldsymbol{P^{(n)}}\right)$ that was defined in **Equation (2)**. Following this paragraph were the result of several calculations of $\boldsymbol{P^{(n)}}$ by multiplied the One-Step Transition Probability Matrix $(\boldsymbol{P})$ in several times to get predition of transition probability in several months ahead.

$$\boldsymbol{P^{(2)}} = \boldsymbol{P} \times \boldsymbol{P} = \begin{bmatrix} 0.305099 & 0.561860 & 0.038012 & 0.095029 \\ 0.203323 & 0.505559 & 0.061972 & 0.229147 \\ 0.179506 & 0.460458 & 0.068917 & 0.291120 \\ 0.123603 & 0.370170 & 0.066869 & 0.439358 \end{bmatrix}$$

$$\boldsymbol{P^{(3)}} = \boldsymbol{P^{(2)}} \times \boldsymbol{P} = \begin{bmatrix} 0.249970 & 0.531364 & 0.050990 & 0.116767 \\ 0.205521 & 0.488519 & 0.059115 & 0.246845 \\ 0.191683 & 0.468477 & 0.060940 & 0.278901 \\ 0.159492 & 0.423301 & 0.063875 & 0.353331 \end{bmatrix}$$

After multiplied $\boldsymbol{P}$ by several times, we found $\boldsymbol{P}^{(n)}$ in a balanced state, which means the transition probability reached convergence in terms all elements of $\boldsymbol{P}^{(n)}$ would not change with time that occurs. The final $\boldsymbol{P}^{(n)}$ in a balanced state resulted below:

$$\boldsymbol{P}^{(25)} = \boldsymbol{P}^{(24)} \times \boldsymbol{P} = \begin{bmatrix} 0.201681 & 0.478992 & 0.058824 & 0.260504 \\ 0.201681 & 0.478992 & 0.058824 & 0.260504 \\ 0.201681 & 0.478992 & 0.058824 & 0.260504 \\ 0.201681 & 0.478992 & 0.058824 & 0.260504 \end{bmatrix}$$

Based on last result of $\boldsymbol{P}^{(n)}$, we could interpretate those results as follows:

- Probability that in a month Ambon City will experience rainfall on light conditions regardless of the condition in previous month is 0.201681 or around 20.17%.
- Probability that in a month Ambon City will experience rainfall on moderate conditions regardless of the condition in previous month is 0.478992 or around 47.90%.
- Probability that in a month Ambon City will experience rainfall on high conditions regardless of the condition in previous month is 0.058824 or around 5.88%.
- Probability that in a month Ambon City will experience rainfall on very high conditions regardless of the condition in previous month is 0.260504 or around 26.05%.

Because steady state distribution achieved as mentioned before, it also could represent long-term characteristics of the Pattimura – Ambon Meteorological Station, which does not depend on the initial conditions. These results showed that naturally these regions tend to experience medium conditions more often than other conditions, which is in line with their geographical conditions. The calculation of limiting probability (π_j) based on **Equation (4)** and criteria defined in **Equation (5) and (6)** with matrix determinant method confirmed the result of that numerical convergence. Those following points were result of that analysis:

- Result of $\pi_0 = 0.201681$, which means probability that in long term Ambon City will experience light condition of rainfall is around 20.17%.
- Result of $\pi_1 = 0.478992$, which means probability that in long term Ambon City will experience moderate condition of rainfall is around 47.90%.
- Result of $\pi_2 = 0.058824$, which means probability that in long term Ambon City will experience moderate condition of rainfall is around 5.88%.
- Result of $\pi_3 = 0.260504$, which means probability that in long term Ambon City will experience moderate condition of rainfall is around 26.05%.

Monthly Prediction on State of Rainfall

After obtaining the long-term probability value that was mentioned in the previous analysis, the next step was applying the results to predict monthly rainfall conditions throughout the year 2025. With the assumption that the last condition recorded in December 2024 is in moderate condition (State 1), then the prediction of rainfall probability for the next 12 months (January to December 2025) can be calculated by multiplying the initial state vector $\pi_0 = [0\ 1\ 0\ 0]$ by $\boldsymbol{P}^{(n)}$ according to **Equation (7)**. **Table 4** showed a summary of calculations that have been performed for 12 months.

Table 4. Summary of Prediction on State of Rainfall in 2025

Month	Light Probability	Moderate Probability	High Probability	Very High Probability
January 2025	0.175439	0.578947	0.070175	0.175439
February 2025	0.203323	0.505559	0.061972	0.229147
March 2025	0.205521	0.488519	0.059115	0.246845
April 2025	0.204273	0.483188	0.058652	0.253887
May 2025	0.203153	0.481044	0.058667	0.257136

June 2025	0.202476	0.480041	0.058728	0.258755
July 2025	0.202103	0.479538	0.058771	0.259589
August 2025	0.201903	0.479278	0.058795	0.260024
September 2025	0.201798	0.479142	0.058809	0.260252
October 2025	0.201742	0.479070	0.058816	0.260372
November 2025	0.201713	0.479033	0.058819	0.260435
December 2025	0.201698	0.479013	0.058821	0.260468

The table shows the probability of each rainfall category (Light, Medium, High, Very High) for each month throughout 2025 based on a Markov Chain model. In general, the probability that rainfall in Ambon City was in a moderate state remained the most dominant in all months, at around 48% to 58%, although it gradually decreased to approach a steady-state value of around 47 to 48%. Meanwhile, the probability of very high rainfall tends to increase gradually from 17.5% in January to 26% in December, indicating a trend toward more extreme rainfall patterns. The probability of light rainfall also decreased slightly from around 17.5% to 20%, while the high rainfall is relatively stable at 5.8% to 7%.

This pattern indicated that throughout 2025, rainfall conditions in Ambon are moving toward a steady-state distribution, characterized by increasingly small changes from month to month and a consistent trend toward the dominance of medium rainfall and a gradual increase in very high rainfall.

4. CONCLUSION

Based on the results of the Markov chain analysis of rainfall data at the Pattimura–Ambon Meteorological Station, it can be concluded that in 2025 the monthly rainfall distribution shows the following trends: light rainfall has a probability of around 20.17%, moderate rainfall around 47.90%, high rainfall around 5.88%, and very high rainfall around 26.5%. The moderate rain category is the most dominant condition throughout the year, although its probability gradually decreases and is accompanied by an increase in the very high rainfall category, which begins to stabilize in the middle of the year. Furthermore, the prediction for 2025, assuming that conditions in December 2024 are in the moderate rainfall category, indicates that the monthly rainfall distribution progressively approaches a steady-state pattern from month to month.

These results have important implications for agricultural sector planning, water resource management, and hydrometeorological disaster risk mitigation in Ambon City, particularly in relation to the increasing tendency of very high rainfall frequency in 2025.

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