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Analysis of Rainfall Transition Probability Using Markov Chain Method

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ABSTRACT
This research applies the Markov Chain model to examine daily rainfall data in Medan City. Markov chain is one of the methods used for forecasting in various fields, such as economics, industry, and climate. This research uses secondary data of daily rainfall intensity from the BMKG Station of the Center for Meteorology, Climatology and Geophysics Region I. The purpose of this research is to determine the transition probability (probability of transition). This study aims to determine the chance of transition (displacement) of daily rainfall intensity, There are four conditions of rainfall intensity that are categorized, namely no rain, light rain, moderate rain, and heavy rain. The Markov Chain method used is the Champman-Kolmogorov Equation and the steady state equation. The fixed probability of not raining is 59.16%, the fixed probability of light rain is 17.67%, the fixed probability of moderate rain is 16.28%, and the fixed probability of heavy rain is 6.86%.

Keyword: *Markov Chain, rainfall, climatology, geophysics.*

1. Introduction

Rainfall is the height of rainwater that collects in a flat place, does not evaporate, does not seep, and does not flow. Rainfall of 1 (one) millimeter, means that in an area of one square meter on a flat place one millimeter of water is collected or one liter of water is collected. Cumulative rainfall (mm) is the amount of rain collected within the cumulative time span. In the seasonal period, the time span is the average length of the season in each Season Forecast Area (DPM) [1]. Rainfall in Indonesia is dominated by the influence of several phenomena, including the Asia-Australia Monsoon system, Equatorial, El-Nino, East-West circulation (Walker Circulation) and North-South (Hadley Circulation) as well as several circulations due to local influences [2] Rainfall conditions can change or remain constant on a daily basis, creating uncertainty in its movement. The number of possibilities for such transitions to occur needs to be known. Therefore, it is necessary to have a theory to determine the chance of rainfall in the future. One of the appropriate theories in determining the chance of future rainfall is Markov Chain [3].

The basic concept of chains was introduced in 1907 by Andrey A. Markov, this model relates to a series of processes in which the occurrence of an effect depends only on the series of events that preceded it and does not depend on previous events [4]. A special property of Markov chains is that the conditional transition probabilities of future events depend on ongoing events. And does not depend on previous or past events. Markov chains require a transition probability matrix to move from one state to the next [5]

There are several relevant studies, namely [6] in his research applying the Markov chain analysis method to forecast the rainfall pattern of each station in Makassar City, [7] by applying the Markov chain method to forecast daily weather in Ambon City, applying the discrete time Markov chain method in estimating the displacement of smartphone brand usage in Balikpapan [8]. Based on this research, the researcher is interested in examining the prediction or forecast of rainfall with the aim of applying the Markov Chain method to rainfall data by applying the Markov chain.

2. Research Method

In this study, the data analyzed includes daily rainfall data in Medan City from January 1, 2024 to December 31, 2024. This research uses the Markov Chain Method to analyze the data. This method is used to forecast or estimate changes that will occur in the future based on changes that occur in previous dynamic variables [10]. This data was obtained from the Meteorology, Climatology and Geophysics Agency (BMKG). The research variables are:

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$$X_t = \begin{cases} \text{Not raining for rain fall} <5 \text{ mm} \\ \text{Light rain for rainfall 5-20 mm} \\ \text{Moderate rain for rain fall 20-50 mm} \\ \text{Heavy rain for rain fall} >50 \text{ mm} \end{cases}$$

$$X_0 = i, X_1 = i, X_2 = i, \ldots, X_{366} = i$$

3. Research Stages

Compile a table of transitions of rainfall conditions from one state to another. from the first day to the next day until the thirtieth X_0, X_1,X2) ,..., X_{366}, in accordance with the provisions of the Markov Chain properties that third day only depends on the second day, does not depend with the first day$\{X_{t+1} = j \mid X_t = i\}$ for t= 0,1, 2, , 366 and i, j=0, 1, 2, 3 Determining the transition probability P_{ij} from the rainfall displacement table each cell is replaced with a probability value, by dividing the number of cell displacements you want to replace by the total number of cell displacements in the row you want to replace. This is done to fulfill the nature of the transition opportunitytransition opportunity $\sum_{j=0}^{3} P_{ij}$ = 1, i= 0, 1, 2, 3. Create a one-step transition probabilitymatrix P=$[P_{ij}]$ Draw a transition diagram of the one-step transition probability matrix. Determine the n-step transition probability matrix $P^{(n)}$from the one-step transition probability matrix by the Champan-Kolmogorov Equation. Determine the *steady-state* probability using the *steady-state* equation, then conclude the transition probability of rainfall in Kepahiang district in the future

3. Reult and Dicussion

This study uses daily rainfall data obtained from the station of the Center for Meteorology, Climatology, and Geophysics Region I as an analysis material for a year starting from January 1 to December 31, 2024 as many as 366 days. The rainfall data obtained has the lowest rainfall of 0 mm and 136 is the highest rainfall with a daily average of 11.5064846 mm. The information obtained from daily rainfall figures is converted into information or called rainfall intensity. The grouping for intensity has been determined by BMKG, where *state* 0 is for no rain which has less than 5 mm of rainfall per day, *state* 1 is for light rain which has 5 to 20 mm of rainfall per day, *state* 2 is for moderate rain which has 20 to 50 mm of rainfall per day, and *state* 3 is for heavy rain which has 50 to 100 mm of rainfall per day. In the year 2024 the rainfall intensity is

Table 2. Rainfall intensity table.

Rainfall Intensity	Many Days
No Rain	178
Light Rain	51
Moderate Rain	47
Heavy Rain	17
Total	293

Based on the table above, during the year there were 178 days of no rain, 51 days of light rain, 47 days of moderate rain, 17 days of heavy rain, 47 days of no measurement and 26 days that could not be measured.

The intensity of rain that occurs from day to day during 2024 changes erratically, some remain in the original state and some change to another state. In 2024 the displacement that occurred can be seen in Table 2

Table 3. Number of State Transition.

state	0	1	2	3	Total
0	82	29	19	8	138
1	22	3	8	5	38
2	18	4	6	1	29
3	7	3	2	1	13
Total					218

In today's *state* it doesn't rain moving to the same state tomorrow that is not raining occurs as many as 82 days, the same transfer or fixed in the state of light rain to light rain as many as 3 days, as well as occurring in the state of moderate rain which is 6 days, and the state of heavy rain to heavy rain as much as 1 day. As for today's state of no rain moving to tomorrow's state of light rain, moderate rain, and heavy rain are 29 days, 19 days, and 3 days respectively, while today's state of light rain to tomorrow's state of no rain, moderate rain, and heavy rain are 22 days, 8 days, and 5 days. Today's state of moderate rain moves to tomorrow's state of no rain, light rain, and heavy rain by 18 days, 2 days, and 1 day respectively, then for today's state of heavy rain to tomorrow's state of no rain, light rain, and moderate rain by 7 days, 3 days, and 2 days

Table 3. Number of State Transition.

state	0	1	2	3	Total Opportunity
0	$\frac{82}{138}$	$\frac{29}{138}$	$\frac{19}{138}$	$\frac{8}{138}$	$\frac{138}{138}=1$
1	$\frac{22}{38}$	$\frac{3}{38}$	$\frac{8}{38}$	$\frac{5}{38}$	$\frac{38}{38}=1$
2	$\frac{18}{29}$	$\frac{4}{29}$	$\frac{6}{29}$	$\frac{1}{29}$	$\frac{29}{29}=1$
3	$\frac{7}{13}$	$\frac{3}{13}$	$\frac{2}{13}$	$\frac{1}{13}$	$\frac{13}{13}=1$

The probability values from Table 3 can be presented/inserted into a 4x4 matrix called the one-step transition probability matrix and are as follows.

$$P = \begin{bmatrix} 0,5942 & 0,2104 & 0,1376 & 0,0579 \\ 0.5789 & 0,0789 & 0,2105 & 0,1315 \\ 0,6206 & 0,1379 & 0,2068 & 0,0344 \\ 0,5384 & 0,2307 & 0,1538 & 0,0769 \end{bmatrix}$$

The one-step transition Probability Matrix can also be presented in a transition diagram, where the arrows indicate transitions and the circles are states in the following figure

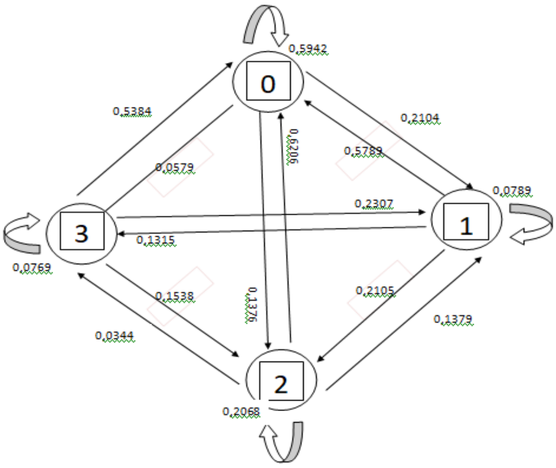

Figure1. *Transition Diagram*

The Champman-Kolmogorov equation is used to find the value of the transition probability matrix for several steps, as follows

$$P^{(2)} = P^{(1)}.P^{(1)} \begin{bmatrix} 0.5913 & 0.1740 & 0.1634 & 0.0713 \\ 0.5908 & 0,1873 & 0,1600 & 0,6120 \\ 0.5954 & 0,1779 & 0,2068 & 0,0344 \\ 0.5902 & 0,1707 & 0,1663 & 0,0727 \end{bmatrix}$$

$$P = \begin{bmatrix} 0,5942 & 0,2104 & 0,1376 & 0,0579 \\ 0.5789 & 0,0789 & 0,2105 & 0,1315 \\ 0,6206 & 0,1379 & 0,2068 & 0,0344 \\ 0,5384 & 0,2307 & 0,1538 & 0,0769 \end{bmatrix}$$

Based on the matrix multiplication, it shows that the transition opportunity matrix at step 1 (in 2024) to step 6 (in 2030) or$P^{(6)}$ the opportunity value changes or is different, but at step 7 and beyond the transition opportunity matrix value is the same as the value of $P^{(6)}$. Therefore, in 2030 until the next year the transition opportunity is the same or fixed

Steady state method is used to find a fixed probability value for each *state*. Completion by using the method of elimination and substitution and with the help of Microsoft Excell. elimination and substitution method to find the value of , ,π_0 π_1 π_2 , and π_3, and the initial opportunity write down

$$(\pi_0, \pi_1, \pi_2, \pi_3) = [\pi_0 \quad \pi_1 \quad \pi_2 \quad \pi_3] = \begin{bmatrix} P_{00} & P_{01} & P_{02} & P_{03} \\ P_{10} & P_{11} & P_{12} & P_{13} \\ P_{20} & P_{21} & P_{22} & P_{23} \\ P_{30} & P_{31} & P_{32} & P_{33} \end{bmatrix}$$

dan $\pi_0 + \pi_1 + \pi_2 + \pi_3 = 1$

$$(\pi_0, \pi_1, \pi_2, \pi_3) = [\pi_0 \quad \pi_1 \quad \pi_2 \quad \pi_3] \begin{bmatrix} 0,5942 & 0,2104 & 0,1376 & 0,0579 \\ 0.5789 & 0,0789 & 0,2105 & 0,1315 \\ 0,6206 & 0,1379 & 0,2068 & 0,0344 \\ 0,5384 & 0,2307 & 0,1538 & 0,0769 \end{bmatrix}$$

From the matrix multiplication above obtained

$(\pi_0$ - 0,5942) - 0,5789π_1 - 0,6206π_2 - 0,5384π_3 = 0

0,2104π_0 + (- π_1+ 0,0789π_1) + 0,1379π_2 + 0,2307π_3 = 0

$0{,}1376\pi_0 + 0{,}2105\pi_1 + (-\pi_2 + 0{,}2068\pi_2) + 0{,}1538\pi_3 = 0$

$0{,}05796\pi_0 + 0{,}1315\pi_1 + 0{,}0344\pi_2 - 0{,}0769\pi_3 = 0$

$\pi_0 + \pi_1 + \pi_2 + \pi_3 = 1$

Can be simplified to:

$0{,}4058\pi_0 - 0{,}5789\pi_1 - 0{,}6206\pi_2 - 0{,}5384\pi_3 = 0$

$0{,}2104\pi_0 - 0{,}9211\pi_1 + 0{,}1379\pi_2 + 0{,}2307\pi_3 = 0$

$0{,}1376\pi_0 + 0{,}2105\pi_1 - 0{,}7932S\pi_2 + 0{,}1538\pi_3 = 0$

$0{,}05796\pi_0 + 0{,}1315\pi_1 + 0{,}0357\pi_2 - 0{,}9231\pi_3 = 0$

$\pi_0 + \pi_1 + \pi_2 + \pi_3 = 1$

The results obtained from the *steady state* method above the fixed transition probability value of each *state* is $(\pi_0, \pi_1, \pi_2, \pi_3) = [0.5916 \quad 0.1767 \quad 0.1628 \quad 0.0686]$

4. Conclusion

Based on the results and discussion of the research, it can be concluded that the Markov Chain method can be used to estimate the transition probability of daily rainfall intensity. The probability of each state for a long period of time ahead is 59.16% for the chance of staying in a state of no rain, 17.67% for the chance of staying in a state of light rain, 16.28% for the chance of staying in a state of moderate rain, and 6.86% for the chance of staying in a state of heavy rain.

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