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Implementation of Markov Chain in Detecting Opportunities for Natural Disasters in Klaten (Case Study: Number of Floods, Landslides, and Hurricanes 2019-2020)

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ABSTRACT

Java Island is one of the areas which is tremendously fertile and densely populated. Java Island is also one of the areas that is most frequently countered by natural disasters, one of which is Klaten Regency. Natural disaster is an event threatening and disrupting human life occurring from the nature. Some of the natural disasters which frequently occur simultaneously in Klaten Regency are floods, landslides, and hurricanes. These three disasters generally occur during the rainy season. It definitely makes the government need to perform action by perceiving the large probability of a disaster happening in order to optimize disaster management. Then, research was conducted which objective is to determine the probability of natural disasters ensuing in the next few years. Forecasting was performed using the Markov chain method. With this method, the probability value of the future period can be estimated employing the current period probability value based on the characteristics of the past period. Hence, the value of the steady state probability of floods and landslides in period 36 (December 2023) and hurricanes in period 15 (March 2022) with the probability of a disaster were revealed 34.21%, 15.38%, and 73.53%, respectively.

1. Introduction

Natural disasters are familiar to the Indonesian people considering that geographically, Indonesia is located on the meeting point of three major tectonic plates [1], which are a volcanic belt from Sumatra, Java, Nusa Tenggara, Sulawesi, thus, the area is dominated by volcanic mountains, lowlands, swamps [2], and a tropical climate with two seasons (hot and rainy) [3]. With these diverse climatic conditions, geographical conditions, and topography, besides establishing soil fertility, it also possesses the potential for natural disasters such as earthquakes, tsunamis, to hydrometeorological disasters as floods, droughts, fires, landslides, hurricanes, and others.

Natural disasters are disasters affected by a series of events due to nature activity, encompassing earthquakes, tsunamis, volcanic eruptions, floods, droughts, hurricanes, and landslides [4]. In Indonesia, there are numerous areas which potentially have been experiencing natural disasters, particularly the Java Island. As in Klaten Regency, during the rainy season, it frequently occurs from

September to April. There are several sub-districts classified as prone to flooding, and a number of areas which is also prone to landslides, hurricanes, and levees bursting at the same time.

In 2011, Badan Penanggulangan Bencana Daerah (BPBD) of Klaten Regency was established as one of the implementations of government programs in organizing a disaster management system in Klaten area with one of its missions is to enhance disaster management efforts before a disaster occurs, when a disaster occurs, and after the disaster.

Therefore, perceiving the phenomenon and one of the missions of BPBD Klaten Regency, the author is eager to examine the prediction of disaster events in Klaten Regency in which the prediction can be increasing, decreasing or even running out. In this case, the researcher administered a test using Markov chain forecasting method. Markov chain is a method which examines the variable properties in the present based on the properties of the past in estimating the properties of these variables in the future [5]. Markov chain analysis is one of the generally administered mathematical techniques to conduct modeling [6], and it is a comparatively simple statistical technique for detecting the repetitive processes in space or time [7] and produces probabilistic information which can later be utilized to assist decision making.

From the results of the forecasting performed, it is expected that it can be a reference for BPBD Klaten Regency in investigating the best disaster management system to minimize the number of victims and losses due to natural disasters which frequently occur simultaneously during the rainy months.

2. Method

2.1. Data and Data Sources

The data used in this study were secondary data, comprising of monthly time series data on the number of floods, landslides, and hurricanes in Klaten Regency in the period 2019 to 2020 which were collected from BPBD Klaten archive.

2.2. Research Stage

The flowchart of the research to be conducted is as follows:

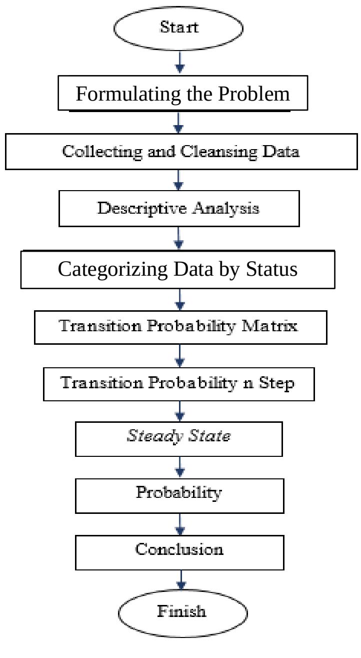

Fig. 1. Research stage.

The research method employed in this study was Markov chain method. The first stage was formulating the problem, then collecting and cleaning the data. The data was then being analyzed including descriptive statistical analysis and Markov chain analysis. In Markov chain analysis, the steps involved were categorizing data states, looking for n-step transition opportunities from the transition probability matrix to obtaining steady state conditions so that conclusions can be depicted.

2.3. Markov Chain Analysis

Markov occurs if the state in the future of the process merely depends on the present event. Hence, the state in the future has no dependence or relationship with the past [8]. This method was employed to estimate a movement happening every time [9]. Markov chain analysis produces information in probabilistic form administered in decision making or it can be categorized as a descriptive technique [10]. The Markov system can be defined as a state transition diagram which presents all the states and their transition probabilities [11]. Hence, at time t, the stochastic process {Xt, t=0,1,…} is in state i. It can be written [12]:

$$P\{X_{t-1}=j\ |X_0=i_0, \ldots X_t=i_{t+1}\}=P\{X_{t+1}=j\ |\ X_t=1 \quad (1)$$

where:

i : i-th state

j : j-th state

t : time

i_0, i_{t-1}, i, j and all t ≥ 0.

2.4. Transition Probability Matrix

The matrix with information governing the system movement from one state to another is a transition probability matrix. In a Markov chain with $\{X_t$, t=0, 1, 2,…} and state space {0, 1,…, m}, the probability that the system is in state i with respect to a state j in the previous observations is denoted by P. The probability of Markov chain transition matrix possesses positive elements (0) in the P matrix and the number of elements in one row of transition probability matrix is 1 with a matrix size of m x m [13].

Thus, Final State (j)

$$P\,[P_{ij}] = \text{Initial State (i)} \quad \begin{matrix} & i_0 & i_1 & \cdots & i_m \\ \begin{matrix} i_0 \\ i_1 \\ \vdots \\ i_m \end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} p_{0.0} & p_{0.1} & \cdots & p_{0.m} \\ p_{1.0} & p_{1.1} & \cdots & p_{1.m} \\ \vdots & \vdots & \vdots & \vdots \\ p_{m.0} & p_{m.1} & \cdots & p_{m.m} \end{bmatrix}} \end{matrix} \quad (2)$$

where:

m = number of state(s)

Every member in the matrix should be positive. Therefore, all the elements in the transition probability matrix are non-negative, and the elements in each row have to add up to 1 [14].

2.5. Transition Probability of n-step and Steady State

The n-step transition probability $P_{i,j}^{(n)}$ is a conditional probability that a system in state i will be in state j after the process encounters n transitions [10], in which the calculation implements the Chapman Kolmogorov equation, hence:

$$P_{i,j}^{(n)}=\{X_n=j|X_0=i, j, j\in\{0,1,2,\ldots\} \quad (3)$$

for n = 1, 2, … with $P_{i,j}^{(n)} = P_{i,j}$

$$P_{ij}^{(n)}=\sum_{k=0}^{M} P_{ik}^{(m)} P_{kj}^{(n-m)} \quad (4)$$

In the probability matrix, it will be written:

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$$P^{(n)}=P\times P\times\ldots\times P=P^n$$
$$=P\times P^{n-1}=P^{n-1}\times P \quad (5)$$

The Markov process is in a steady state condition which indicates that after the process operates for several periods, the status probability will constantly remain [15]. Thus, from the n-step calculation, the steady state probability value or equilibrium was obtained.

3. Results and Discussion

3.1. Descriptive Statistics

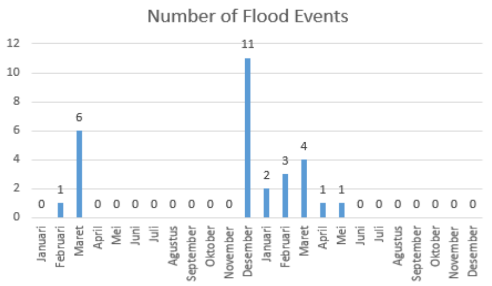

Fig. 2. Flood

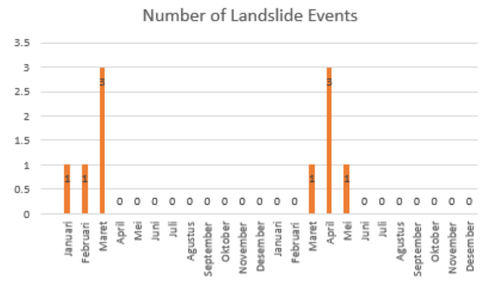

Fig. 3. Landslide

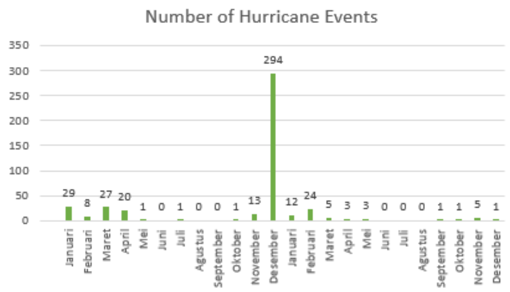

Fig. 4. Hurricane

In Fig. 2, Fig. 3, and Fig. 4 above are graphs of the number of floods, landslides and hurricanes in 2019-2020. It can be identified that there was flood incident in February-March 2019 and December 2019-May 2020, landslides occurred in January-March 2019 and March-May 2020, while hurricane incident occurred almost every month in the 2019-2020 period except in June, August, and September 2019 and June-August 2020. It is due to the rainy season, which frequently occurs from September to April.

3.2. Transition State

This analysis administered the variable number of natural disaster events, which are floods, landslides, and hurricanes in 2019-2020 to identify probability for the future period. Data were categorized into occurred and not occurred disaster events in that month. The data every month is an accumulation of events in the referred month. Here is the data employed:

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Table 1. Time Series Data for Natural Disasters 2019-2020

Time		Flood	State	Landslide	State	Hurricane	State
Month	**Year**						
January	2019	0	Not Occurred	1	Occurred	29	Occurred
February		1	Occurred	1	Occurred	8	Occurred
March		6	Occurred	3	Occurred	27	Occurred
April		0	Not Occurred	0	Not Occurred	20	Occurred
May		0	Not Occurred	0	Not Occurred	1	Occurred
June		0	Not Occurred	0	Not Occurred	0	Not Occurred
July		0	Not Occurred	0	Not Occurred	1	Occurred
August		0	Not Occurred	0	Not Occurred	0	Not Occurred
September		0	Not Occurred	0	Not Occurred	0	Not Occurred
October		0	Not Occurred	0	Not Occurred	1	Occurred
November		0	Not Occurred	0	Not Occurred	13	Occurred
December		11	Occurred	0	Not Occurred	294	Occurred
January	2020	2	Occurred	0	Not Occurred	12	Occurred
February		3	Occurred	0	Not Occurred	24	Occurred
March		4	Occurred	1	Occurred	5	Occurred
April		1	Occurred	3	Occurred	3	Occurred
May		1	Occurred	1	Occurred	3	Occurred
June		0	Not Occurred	0	Not Occurred	0	Not Occurred
July		0	Not Occurred	0	Not Occurred	0	Not Occurred
August		0	Not Occurred	0	Not Occurred	0	Not Occurred
September		0	Not Occurred	0	Not Occurred	1	Occurred
October		0	Not Occurred	0	Not Occurred	1	Occurred
November		0	Not Occurred	0	Not Occurred	5	Occurred
December		0	Not Occurred	0	Not Occurred	1	Occurred

3.3. Transition Probability Matrix

Based on Table 1, it can be implied that the data employed are time series data for disaster events in the period 2019-2020 with monthly time intervals. Then, the researcher determined the presence and absence status of disaster events which is presented in the following matrix:

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Table 2. Switching Period of Flood

	State of Transition		Total
	Not Occurred	***Occurred***	
Not Occurred	13	2	15
Occurred	2	6	8
Total	15	8	23

Table 3. Switching Period of Landslide

	State of Transition		Total
	Not Occurred	***Occurred***	
Not Occurred	16	1	17
Occurred	2	4	6
Total	18	5	23

Table 4. Switching Period of Hurricane

	State of Transition		Total
	Not Occurred	***Occurred***	
Not Occurred	3	3	6
Occurred	3	14	17
Total	6	17	23

Table 2 to Table 4 above demonstrates the period displacement derived from data on the occurrence of floods, landslides, and hurricanes. In the table above, it can be implied that the author owns a matrix with the status of none-none, non-existent, present-non-existent, and available, hence, the sum is as presented in the table above. Furthermore, from the displacement table, a Transition probability table (P) was formulated. The transition probability matrix P was obtained, as follows:

$$\text{PFlood} = \begin{matrix} & 0 & 1 \\ 0 & 0.87 & 0.13 \\ 1 & 0.25 & 0.75 \end{matrix}$$

$$\text{PLandslide} = \begin{matrix} & 0 & 1 \\ 0 & 0.94 & 0.06 \\ 1 & 0.33 & 0.67 \end{matrix}$$

$$P\text{Hurricane} = \begin{matrix} & 0 & 1 \\ 0 & 0.5 & 0.5 \\ 1 & 0.18 & 0.82 \end{matrix}$$

Value of P was employed in calculating the steady state probability, with initial period vector:

$$\mu_{1stflood} = \begin{matrix} 0 & 1 \\ [0.652173913 & 0.347826087\ ] \end{matrix}$$

$$\mu_{1stlands} = \begin{matrix} 0 & 1 \\ [0.73913043 & 0.26086957\ ] \end{matrix}$$

$$\mu_{1sthrcne} = \begin{matrix} 0 & 1 \\ [0.260869565 & 0.739130435\ ] \end{matrix}$$

The vector (μ) is the event vector or the initial vector in the form of probability, in which, value 0 = Not Occurred, and value 1 = Occurred as the initial value.

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3.4. Transition Probability Matrix of n-step and Steady State

From the transition probability, n-step and steady state transition probability was calculated as:

a) Flood

$$P^{(1)}=P\begin{bmatrix}0.87 & 0.13\\0.25 & 0.75\end{bmatrix}$$

$$P^{(2)}=P\begin{bmatrix}0.87 & 0.13\\0.25 & 0.75\end{bmatrix} \times P\begin{bmatrix}0.87 & 0.13\\0.25 & 0.75\end{bmatrix}$$

$$=P\begin{bmatrix}0.7894 & 0.2106\\0.4050 & 0.5950\end{bmatrix}$$

$$P^{(3)}=P^{(2)} \times P\begin{bmatrix}0.87 & 0.13\\0.25 & 0.75\end{bmatrix}$$

$$=P\begin{bmatrix}0.739428 & 0.260572\\0.501100 & 0.498900\end{bmatrix}$$

.
.
.

$$P^{(36)}=P^{(35)} \times P\begin{bmatrix}0.87 & 0.13\\0.25 & 0.75\end{bmatrix}$$

$$=P\begin{bmatrix}0.6578947 & 0.3421053\\0.6578947 & 0.3421053\end{bmatrix}$$

$$\mu_{final}= \overset{\quad 0 \qquad\qquad\quad 1}{[0.6578947 \ 0.3421053\ ]}$$

b) Landslide

$$P^{(1)}=P\begin{bmatrix}0.94 & 0.06\\0.33 & 0.67\end{bmatrix}$$

.
.
.

$$P^{(36)}=P^{(35)} \times P\begin{bmatrix}0.94 & 0.06\\0.33 & 0.67\end{bmatrix}$$

$$=P\begin{bmatrix}0.8695652 & 0.1304348\\0.8695652 & 0.1304348\end{bmatrix}$$

$$\mu_{final}= \overset{\quad 0 \qquad\qquad\quad 1}{[0.8461538 \ 0.1538462\ ]}$$

c) Hurricane

$$P^{(1)}=P\begin{bmatrix}0.5 & 0.5\\0.18 & 0.82\end{bmatrix}$$

.
.
.

$$P^{(15)}=P^{(14)} \times P\begin{bmatrix}0.5 & 0.5\\0.18 & 0.82\end{bmatrix}$$

$$=P\begin{bmatrix}0.2647059 & 0.7352941\\0.2647059 & 0.7352941\end{bmatrix}$$

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$$\mu_{final} = \begin{matrix} 0 & 1 \\ [0.2647059 & 0.7352941\ ] \end{matrix}$$

P^1 is the first probability period, to identify the probability of the P^2. The P^1 was multiplied by P^1. Then, for P^3, P^2 was multiplied by P^1. The calculation is stopped if the probability of P^n and P^{n+1} is the same. Based on the calculation of the Chapman-Kolmogorov equation to obtain the n-step transition probability value. The probability values for the three disaster events have been attained for the following periods until they achieve a steady state or a fixed value, which are for floods and landslides in the 36th period (December 2023) and for hurricane events in the 15th period (March 2022).

3.5. Forecasting Result Evaluation

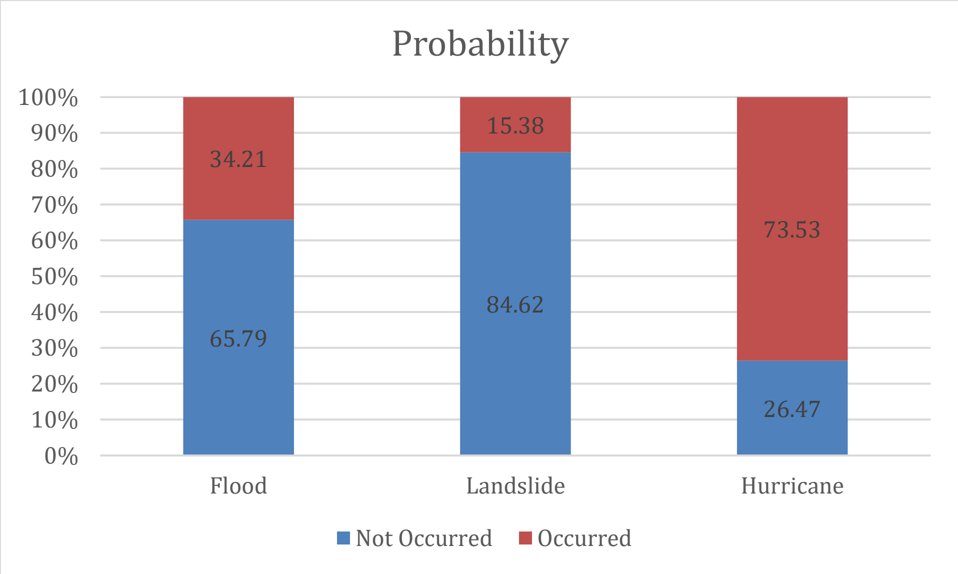

Fig. 5. Probability of Disaster Occurrence

In Fig. 5, it can be perceived that the comparison of the occurrence probability of the three disasters with the y-axis is the percentage of the presence and absence of natural disasters such as floods, landslides, and hurricanes. If compared, the probability of a hurricane is significantly high compared to the landslide and flood probability, which is 73.53% and the lowest occurrence probability of disaster is a landslide, which is 15.38%.

From the forecasting results after discussing with BPBD employees about the weather in Klaten Regency, it is understood that indeed in the rainy season, from September to April, apart from the rain that comes, hurricanes are consistently accompanied. It can be perceived in Fig. 4 which presents a graph of the hurricane events number. In the rainy month, there are quite a lot of hurricane events. It is also true for cases of floods increasing from December to March and landslides raising from January to April.

By predicting the probability of occurrence of floods, landslides, and hurricanes interconnected and occurring in the same period, it can be implied that the highest probability is hurricane. Efforts that can be conducted by BPBD, particularly in the field of emergency logistics, are by monitoring the trees around the housing of residents before the rainy month which originates to ensure that there are no trees which are not strong enough to be around residents, and also outreach to local residents in terms of building resilience. Meanwhile, for flood control, it is necessary to enhance the quality of rivers established by local communities, considering that some rivers have been treated but some have not. Meanwhile, for landslides, it is required to review locations with a high risk of landslides and strong trees to strengthen soil resilience. It is intended to minimize losses affected by disasters.

In dealing with the three disaster events which frequently occur in the rainy month in Klaten Regency, BPBD can also enhance the quality of response by organizing different special teams for floods, landslides, and hurricanes concerning that these three events intermittently occur

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simultaneously. BPBD can also conduct socialization and training with the theme “Responsive from Us” in which this socialization and training aim to educate the public regarding the quick response actions obtained by the community when a disaster occurs, be it floods, landslides, and hurricanes.

4. Conclusion

Based on the research which has been conducted, it can be concluded:

- The results of flood and landslide forecasting opportunities were obtained in fixed value opportunities from the 36th month forward, which will be December 2023 until the following month, with the probability value of non-existent status is 65.79% and 84.62% while the existing status is equal to 34.21% and 15.38%. Furthermore, for hurricane events, the probability of a hurricane possesses a fixed value from the 15th month forward, which are March 2022 until the following month, with an opportunity value of 26.47% for non-existent status and 73.53% for existing status. It will occur if the conditions in the future will remain the same as the previous conditions.
- Efforts which can be conducted by BPBD in disaster management to minimize losses and casualties based on forecasting results are establishing efforts such as “Responsive from Us” socialization and training, socialization of building strength, division of special teams for floods, landslides, and hurricanes, or monitoring trees around housing residents.

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