Plant calendar pattern based on rainfall forecast and the probability of its success in Deli Serdang regency of Indonesia

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Abstract. The objective of this study was to determine the pattern of plant calendar of three types of crops; namely, palawija, rice, and banana, based on rainfall in Deli Serdang Regency. In the first stage, we forecasted rainfall by using time series analysis, and obtained appropriate model of ARIMA (1,0,0) (1,1,1)12. Based on the forecast result, we designed a plant calendar pattern for the three types of plant. Furthermore, the probability of success in the plant types following the plant calendar pattern was calculated by using the Markov process by discretizing the continuous rainfall data into three categories; namely, Below Normal (BN), Normal (N), and Above Normal (AN) to form the probability transition matrix. Finally, the combination of rainfall forecasting models and the Markov process were used to determine the pattern of cropping calendars and the probability of success in the three crops. This research used rainfall data of Deli Serdang Regency taken from the office of BMKG (Meteorologist Climatology and Geophysics Agency), Sampali Medan, Indonesia.

1. Introduction

Agricultural sector, especially food provider sector for the basic needs of the Indonesian people, needs specific attention to decrease the State’s burden in importing food stuffs, rice in particular. This can be seen by the amount of rice imports, according to BPS statement that in 2011 the amount of rice imports in Indonesia amounted to 2,750,476.20 tons and subsequently decreased in the following years, namely 2012, 2013 and 2014 respectively of 1,810,372.30 tons, 472,664.70 tons and 844,163.7 tons, but in 2016 rose to 1.2 million tons [1]. In order to optimize the production in agricultural sector for basic needs such as rice, banana, and the other palawija (nonstaple food crops, subsidiary or secondary to rice) crops, it is necessary to study an appropriate plant calendar pattern. Admasu W et.al says that rainfall variability has major implications on crop production and productivity [2]. It means that the success in food production in palawija farming such as rice, cassava, and corn is highly influenced by climatic factor such as rainfall. Fuadi NA, et.al stated that the limited water availability for agricultural land might cause decrease in rice production [3]. So the need for water of this planting brings about a big problem for farmers, especially for those who use land dependent on rain water. Unstable rainfall is a real problem which can make farmers difficult to arrange planting calendar pattern. To meet water needs for plants, the determination of cropping pattern is necessary considered. Inaccuracy in arranging planting pattern may cause a threat to the success in the production such as the decrease in agricultural production and failure in harvesting. Natural phenomena such as extreme climatic change like long drought or abnormal rainfall become a real threat for the success in harvesting. The increase in the frequency of drought and flood is estimated to give negative impact on agricultural production in subtropical and tropical regions.
Mandal et al. said that the determination of dry and wet spells can prove to farmers its usefulness regarding improving crop productivity and intensity [4].

The existence of BMKG (Meteorologist Climatology and Geophysics Agency) that is responsible for recording climate, especially the data of rainfall, can be used to cope with this problem. These data can be used to analyze the characteristics of rainfall in a certain area. In this research, the data of rainfall in Deli Serdang Regency of Indonesia could be used as a case study to forecast rainfall in a certain area and as a basis for determining plant calendar pattern in that area. Nowadays, various models of climatic forecast are being developed, especially by statistics model, such as stochastic process, time series model, and the combination of both of them. The combination of stochastic process and time series model can be used to determine plant calendar pattern and give probability of the success in increasing harvesting production. Some researchers have previously used the data of rainfall to increase harvesting production. They are, for example, Abubakar, UY, et. al. used Markov chain model on the distribution of annual rainfall for plant production [5], N. Shahraki, et. al. used Markov chain model on the distribution of daily rainfall in order to get the probability of the change from dry season to rainy season [6], while Smith JA suggested a model of discrete point process of the incidence of rainfall which is called Markov Bernoulli process. Markov Bernoulli model can be easily generalized to more complex rainfall distribution model by the choice of accurate consecutive ‘random’ probability [7]. Elfeki A and Al-Amr N developed a model which analyzed rainfall in the drought and semi-drought areas by increasing estimated parameter technique [8]. Makokha L, et. al. applied Markov chain in a group of data from rainfall network in Bungoma, West Kenya for 36 years (1972-2013) in studying probability prediction transition of weekly rainfall, based on estimated technique of maximum likelihood [9]. Tamil S.S, and Samuel SR studied the variation of annual rainfall in Tamil Nadu by using Markov chain model [10]. Raheem, et. al. used Markov chain to find out the pattern and the distribution of daily rainfall in the metropolitan Uyo, Nigeria, with the data of rainfall within 15 years (1995-2009) which were obtained from the Meteorology Center of the Uyo University [11].

In this research, forecast modeling was done toward rainfall in Deli Serdang Regency by using time series method which would be used to make plant calendar pattern and to establish the probability transition matrix so that Markov chain method could be used. The combination of these two methods would be used to find out plant calendar pattern and the probability of success in the production of the types of plants, palawija, rice, and banana. The modeling was expected to be able to help farmers determine the types of plant which would be planted so that it could give more probability of success in harvesting production.

2. **Fundamental Theory**

2.1 **ARIMA and Seasonal (SARIMA) Model subsection**

Seasonal is defined as a recurrent series pattern in fixed intervals. A seasonal pattern exists when a series is influenced by seasonal factors (e.g., the quarter of the year, the month, or day of the week). Seasonality is always of a fixed and known period. The stationer data of seasonal factor can be determined by identifying auto-correlation coefficient in two or three time-lags which are significantly different from zero. Auto-correlation coefficient which is significantly different from zero indicates the existence of one pattern in the data. The existence of seasonal factor can be recognized by viewing it from its high auto-correlation. In general, ARIMA seasonal factor is annotated with ARIMA (p, d, q) (P, D, Q)s where (p, d, q) indicates the part of non-seasonal in the model, (P, D, Q) indicates the part of seasonal in the model and s indicates the number of periods per season. Special model, ARIMA (1,1,1) (1,1,1)12 which contains seasonal factor is \((1-\theta_1B)(1-\theta_2B^{12})(1-B)(1-B^{12})Y_t = (1-\phi_1B)(1-\phi_2B^{12})\epsilon_t\) where \((1-\theta_1B)\) is AR(1) model of non-seasonal, \((1-\theta_2B^{12})\) is AR(1) seasonal model, \((1-B)\) is non-seasonal difference, and \((1-B^{12})\) is seasonal model, \((1-\phi_1B)\) is MA(1) of non-seasonal, and \((1-\phi_2B^{12})\) is MA(1) seasonal.
2.2 Basic Concept of Markov Chain
A stochastic process is a sequence of events in which the outcome at any stage depends on some probability. Markov process is a stochastic process with the following properties:
(a) The number of possible outcomes or states is finite.
(b) The outcome at any stage depends only on the outcome of the previous stage.
(c) The probabilities are constant over time. The first paragraph after a heading is not indented.

Suppose a stochastic process \( \{X_n, n = 0,1,2,\ldots\} \) with discrete parameter index and states \( j, i \), has fulfilled the equation (1) as follows:

\[
P[X_{n+1} = j | X_0 = i_0, X_1 = i_1, \ldots, X_{n-1} = i_{n-1}, X_n = i] = P \{X_{n+1} = j | X_n = i\} = p_{ij}
\]

\( \forall i_0, i_1, \ldots, i_{n-1}, i, j \), and all \( n \geq 0 \). Stochastic process as it is seen above is called stationer Markov chain and \( p_{ij} \) is called transition probability.

Since the probability value is non-negative and the process has to do the transition to various states, \( 0 \leq p_{ij} \leq 1 \), and \( \sum p_{ij} = 1 \), for \( i = 0, 1, 2, \ldots \). Transition probability of \( p_{ij} \) can also be written in the form of transition matrix of \( P = [p_{ij}] \). Since \( P \) elements are non-negative then the sum of probabilities of all elements in each line is similar to 1, each line is a probability vector and \( P \) is a probability transition matrix. Probability transition matrix and initial state probability simultaneously complete the definition of Markov chain. Finally, for the Markov process where the information of both probability transition matrix and initial probability distribution is known, we can determine the probability of Markov process in each state for the \( n \)-step. In the matrix notation, this can be indicated as follows:

As \( p^{(0)} \) symbolizes distribution vector of initial probability, \( p^{(1)} = p^{(0)}p^1, p^{(2)} = p^{(0)}p^2, p^{(3)} = p^{(0)}p^3, \ldots, p^{(n)} = p^{0}p^n \).

Thus, when it starts at state \( i \), \( p^{(1)} \) will be the \( i \)-line of \( P \), \( p^{(2)} \) is the \( i \)-line of \( P^2 \) and \( p^{(n)} \) is the \( i \)-line of \( P^n \). The lines in \( p^{(n)} \) present the vectors of the incidence for various initial states. The probability of \( p_{ij} \) is the probability of a process which begins in state-\( i \) will exist in state \( j \) after \( n \) step. Empirically, it can be formulated as follows:

\[
p_{ij} = \frac{a_{ij}}{\sum_j a_{ij}}
\]

where \( a_{ij} \) is the number of movements from state-\( i \) to state-\( j \) in the period of a certain observation. The combination of Markov chain method and time series is applied by using the result of the forecasting of rainfall in 2016. It would then be used in making the plant calendar, followed by transition probabilities which were yielded by using Markov chain method.

3. Methods
The first step in this research was done by describing the highest and the lowest values of the rainfall data yearly in order to find out the inclination of rainfall volume each month. After that, the values of statistic data and plot graph of time series were presented. Finally, stationarity test was done on the rainfall data by using root unit analytical test by using E-views software program, followed by identifying the model for obtaining appropriate forecasting model. In the second part, Markov chain modeling was done by establishing rainfall data to become discrete data by referring to the nature of rainfall which was categorized in three categories: Below Normal (BN), Normal (N), and Above Normal (AN) in order to obtain probability transition matrix. The combination of the two methods was done by analyzing forecasting data in the form of plant calendar pattern by considering the probability of its success.

4. Result and Discussion
The data which would be analyzed in this research were rainfall data in Deli Serdang Regency of Indonesia within 10 years (2006-2015) taken from BMKG Office, Sampali Medan of North Sumatera. The next Table presented data of the highest and the lowest monthly rainfall for each observational year.
Table 1. The Highest and the Lowest Values of Rainfall per Year

| Years | Highest Value per Year | Lowest Value per Year |
|-------|------------------------|-----------------------|
|       | Months     | Rainfall | Months     | Rainfall |
| 2006  | Oct        | 282      | March      | 117      |
| 2007  | May        | 364      | Feb        | 67       |
| 2008  | Oct        | 322      | Jan        | 106      |
| 2009  | Oct        | 321      | Feb        | 56       |
| 2010  | Nov        | 346      | Feb        | 81       |
| 2011  | Aug        | 344      | Feb        | 107      |
| 2012  | Oct        | 315      | June       | 91       |
| 2013  | Oct        | 441      | July       | 114      |
| 2014  | Oct        | 363      | Feb        | 46       |
| 2015  | Nov        | 304      | March      | 53       |

Table 1 indicates that the highest rainfall occurs in October and November while the lowest rainfall occurs in February. In the initial analysis the plot of the rainfall data is given in Figure 1 and its statistical description is given in Table 2.

![Curah Hujan](image)

Figure 1. Plot of Rainfall Data

Table 2. Descriptive Statistics of Rainfall

| Descriptive Analysis | Rainfall (mm) |
|----------------------|---------------|
| Mean                 | 202.02500     |
| Median               | 198.50000     |
| Maximum              | 441.00000     |
| Minimum              | 46.00000      |
| Std. Dev.            | 84.20039      |
| Jarque-Bera          | 3.85565       |
| Probability          | 0.14546       |
| Observations         | 120.00000     |

Stationarity testing on rainfall data used E-views software program which result was presented in Table 3. This result showed that the data were stationar in the significance level of 0.05.
Table 3. Unit Root Analysis

| Null Hypothesis: RAINFALL has a unit root |
|------------------------------------------|
| Exogenous: Constant                      |
| Lag Length: 0 (Automatic - based on SIC, maxlag=12) |
| Augmented Dickey-Fuller test statistic   |
| t-Statistic                              |
| Prob.*                                   |
| 1% level                                 | -3.486064 | 0.0000 |
| 5% level                                 | -2.885863 |
| 10% level                                | -2.579818 |

Below Normal (BN) was from the lowest value until 85% of the average, Normal was 85% of the average until 115% of the average, and Above Normal (AN) was from 115% of the average until the highest value. The average calculation of rainfall data in Deli Serdang Regency within 10 years (2006-2015) was 202.025 mm so that BN interval was [46.171.7213], N interval was [171.7213, 232.3288], and AN interval was (232.3288, 441]. The result of discretization, using the three intervals on rainfall data was used to construct probability transition matrix P as follows:

\[
P = \begin{bmatrix}
0.5320 & 0.2340 & 0.2340 \\
0.3333 & 0.2727 & 0.3940 \\
0.3077 & 0.3077 & 0.3846
\end{bmatrix}
\]

and the distribution of the initial probability was \( p(0) = [0.3950, 0.2773, 0.3277] \). The condition of steady state of Markov chain model was as follows:

\[
\begin{bmatrix}
0.4055 & 0.2684 & 0.3260 \\
0.4055 & 0.2684 & 0.3260 \\
0.4055 & 0.2684 & 0.3260
\end{bmatrix}
\]

The last stage of this research was done by using steady state matrix combined with the result of forecasting model of rainfall in 2016 in order to obtain plant calendar pattern from the three types of plant and calculating the probability of its success. The result of the combination could be seen in Table 4.

Table 4. Forecasting the Combination of Time Series Method with Markov Chain Method

| Period | Month | Rainfall (mm/ Month) | Time Series | Markov Chain |
|--------|-------|----------------------|-------------|--------------|
| 121    | Jan   | 155.9422             | BN          | B N          |
| 122    | Feb   | 88.5527              | BN          | B N          |
| 123    | March | 134.6968             | BN          | B N          |
| 124    | April | 171.1288             | BN          | B N          |
| 125    | May   | 243.6804             | AN          | B N          |
| 126    | June  | 135.0265             | BN          | B N          |
| 127    | July  | 148.6619             | BN          | B N          |
| 128    | Aug   | 217.4467             | N           | B N          |
| 129    | Sept  | 211.3697             | N           | B N          |
| 130    | Oct   | 324.8760             | AN          | B N          |
| 131    | Nov   | 270.9490             | AN          | B N          |
| 132    | Dec   | 212.7703             | N           | B N          |

The result of the combination model showed that good plant calendar pattern for palawija and rice was presented in Table 5.
Table 5. Plant Calendar in Deli Serdang Regency in 2016

| Month   | Plant Calendar |
|---------|----------------|
| January | Palawija       |
| February|                |
| March   |                |
| April   |                |
| May     | Transition Period |
| June    | Rice           |
| July    |                |
| August  |                |
| September |              |
| October |                |
| November|                |
| December|                |

The results of the model combinations shown in the table indicate that the water requirements for crops will be available during January, February, March and April, while for rice, water availability will be from July to December. While in May and June is called a transitional period for land, it means that land is restored for its fertility restoration.

5. Conclusion
The result of the research showed that the nature of Below Normal (BN) rainfall had the biggest probability, compared to Normal (N) and Above Normal (AN) rainfalls in each month. Forecasting combination of ARIMA (1,0,0)(1,1,1)\textsuperscript{12} model with transition matrix in steady state showed that in January, February, March, and April it was recommended that farmers plant palawija with the probability of success of about 40%. In July, August, September, October, November, and December it was recommended that farmers plant rice with the probability of success from about 50% until 60%, while in May and June it was recommended that farmers prepare for the land which was usually called transition period.

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