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THE APPLICATION OF CUBIC SPLINE IN RAINFALL MODELLING IN BOGOR AND ITS IMPACT ON PADDY PRODUCTION

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Abstract: Rice is a crop that serves as a primary food source to fulfill the carbohydrate needs of the population, especially in Indonesia. In the agricultural production process, several factors can influence the eventual yield. One of these factors is rainfall. Rainfall is the amount of precipitation in a specific area within a certain period. Rainfall can be classified based on its intensity, and the more extreme the rainfall is, the more it affects various activities, including agriculture. This research explores rainfall interpolation using the Cubic Spline and examines the correlation between rainfall and paddy productivity. Cubic Spline is one of interpolation methods used to approximate and calculate a function that is smooth and continuous but retains the shape of the data. This study demonstrates that Cubic Spline interpolation is suitable for modeling rainfall and illustrating the relationship between rainfall intensity and paddy production. This can provide insight into rainfall criteria, especially helping farmers in determining production periods, as well as providing important information for decision making in the agricultural sector.

Keywords: rainfall; interpolation; cubic spline; paddy production.

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1. INTRODUCTION

Weather is the atmospheric condition at a specific time and in a relatively narrow region for a short period. Weather parameters in a particular area are influenced by various factors, one of which is rainfall [1]. According to the Indonesian Agency for Meteorological, Climatological and Geophysics (Badan Meteorologi, Klimatologi, dan Geofisika or simply BMKG), rainfall is the height of accumulated rainwater in a rain gauge on a flat surface, which does not absorb, penetrate, or flow. Rainfall can also be interpreted as the amount of rainwater accumulated in a specific area over a certain period, measured in millimeters [2]. In 2022, the average rainfall in Indonesia reached 2,898 millimeters. Bogor serves as an example of a Rain City due to its high rainfall throughout the year, including during the dry season, with an average precipitation of about 3500-4000 mm per year and the peak usually occurring in January and December.

Asia produces 90.6% of the global rice production, making it the largest rice producer in the world. Indonesia, being recognized as an agrarian country with vast and fertile land, plays a significant role in contributing to the abundant global rice production [3]. However, several factors can affect agricultural production and yields. Agricultural production is vulnerable to extreme weather changes that can affect the required moisture levels for plants. Generally, to meet the water needs of a plant, a water content of 70 mm/month and rainfall of 120 mm/month are usually required. Meanwhile, for the water requirements of rice plants, 150 mm/month and rainfall of 220 mm/month are needed [4].

In the field of agriculture, it is crucial to understand weather forecasts, particularly rainfall estimates, one of which is by modeling rainfall using cubic spline interpolation. Cubic spline interpolation is a mathematical approach that can generate a smooth and continuous model of rainfall. Furthermore, cubic spline is a development of interpolation polynomial, providing more acceptable estimates [5].

Several previous studies have addressed cubic spline interpolation. Azizan, I., et al. conducted research on imputing missing data and generated a new prediction model using two types of

Cubic Spline implementation methods (natural and not-a-knot). The study focused on rainfall in Ipoh and Petaling, Malaysia [6]. Maryati, A., et al. conducted a study comparing the interpolation of the Newton and Cubic Spline methods, as well as the extrapolation of both methods, for the function of hydrogen and iodine gas content in the formation of acid iodide reaction [7]. Romadanova developed an algorithm that can be used to create a Spline interpolation that preserves positive values, focusing on wind speed variables [8].

Therefore, this research aims to model rainfall using the Cubic Spline interpolation method and analyze the influence of rainfall on paddy production in Bogor, Indonesia. It is hoped that the results of this study will provide valuable insights for determining the production period in agriculture and contribute information related to the urgency of farming strategies in diverse weather conditions.

2. MATERIALS AND METHODS

2.1. RAINFALL

Precipitation is the change of water vapor from gas to water that falls to the earth's surface in various forms. Precipitation can take the form of rain, sleet, snow, and other variations [9]. Rain has a significant impact on daily activities such as cooking, farming, washing, and others. In the context of agriculture, rain is a major factor influencing production. If rainfall is too high, plants will receive excess water, potentially resulting in crop failure. On the other hand, a lack of rainfall can also have a negative impact on agricultural production [10].

Rainfall is a quantitative parameter that measures the amount of recorded rainfall in a specific region during a particular period, measured in millimeters (mm). Variations in rainfall occur in limited geographical regions because of alterations in atmospheric circulation and natural topography. The amount of rainfall can change rapidly, reaching tens of millimeters per hour, fluctuating from minute to minute, and covering a distance of just a few dozen meters [11]. According to BMKG, rainfall measurement is conducted on a flat, non-absorbent, and nonflowing surface. The quantity of rainfall can provide an overview of the contribution of precipitation to the climate and hydrological conditions in a particular region. Rainfall can also be classified based on the types of precipitation. One classification that is relevant for the agricultural and plantation sectors is the Schmidt-Ferguson rainfall classification [12].

Table 1. Rainfall Classification.

Types	Description	Criteria (%)
A	Very Wet	$0 < P < 14.3$
B	Wet	$14.3 < P < 33.3$
C	Moderately Wet	$33.3 < P < 60$
D	Moderate	$60 < P < 100$
E	Moderately Dry	$100 < P < 167$
F	Dry	$167 < P < 300$
G	Very Dry	$300 < P < 700$
H	Extremely Dry	$P > 700$

The steps used in creating a rainfall classification according to Schmidt-Ferguson [12], are as follows:

a. Creating rainfall characteristic categories

Table 2. Rainfall Characteristics Categories.

Description	Rainfall
Dry month (K)	< 60 mm
Humid month (L)	60 – 100 mm
Wet month (S)	> 100 mm

b. Determining the average values

$$\overline{CH}_{K/S} = \frac{1}{n}\sum_{i=1}^{n} JH_i \tag{1}$$

$\overline{CH}_{K/S}$: Average of dry months (K) or wet months (S)

JH_i : Number of dry months (K) or wet months (S)

n : Number of years of observation

c. Determining the ratio value (P)

$$P = \frac{\overline{CH}_K}{\overline{CH}_S} \times 100\% \quad (2)$$

$\overline{CH}_K$: Average of dry month(K)

$\overline{CH}_S$: Average of wet month (S)

2.2. CUBIC SPLINE INTERPOLATION

Interpolation refers to a numerical method used to estimate a function and its value at an independent variable or data point outside the set of interpolation points but still within the specified interval [13]. The application of interpolation involves various disciplines, including statistics, applied mathematics, economics, and business issues [14]. In global interpolation, all available control points are used to predict values, and this method is effective when the observed field does not exhibit complex variations. The estimation results from global interpolation are general [15]. On the other hand, local interpolation only uses some control points rather than all available control points.

Cubic spline interpolation is a method used to approximate a smooth curve passing through a set of data points [16]. In addition to producing a smooth function without significant errors throughout the interval, cubic spline also preserves the pattern of the original data [17]. Theoretically, cubic spline can be referred to as a piecewise cubic function that is continuous, including its first and second derivatives, to create a smooth and less oscillating function. Cubic spline is fitted to a set of points (nodes) to form the basic shape of the created object.

The cubic spline interpolation $S(x)$ is a function that satisfies:

(a) $S(x)$ is a cubic polynomial, denoted as $S_j(x)$ on the subinterval $[x_j, x_{j+1}]$ for each $j = 0,1,2,3, \ldots, n-1$;

(b) $S_j(x_j) = y_j$ for each $j = 0,1,2,3, \dots, n-1$;

(c) $S_{j+1}(x_{j+1}) = S_j(x_{j+1})$ for each $j = 0,1,2,3, \dots, n-1$;

(d) $S'_{j+1}(x_{j+1}) = S'_j(x_{j+1})$ for each $j = 0,1,2,3, \dots, n-1$;

(e) $S''_{j+1}(x_{j+1}) = S''_j(x_{j+1})$ for each $j = 0,1,2,3, \dots, n-1$;

3. MAIN RESULTS

The data used in this study is the rainfall data for the Bogor region from January 2019 to December 2022, obtained from the website https://power.larc.nasa.gov. The rainfall data is listed in Table 3.

Table 3. Monthly Rainfall Data for Bogor from 2019-2022.

Month	**2019**	**2020**	**2021**	**2022**
January	369.14	379.69	321.68	220.38
February	321.68	595.9	564.26	230.21
March	263.67	464.06	485.16	253.55
April	305.86	263.67	206.77	323.17
May	174.02	226.76	168.97	186.48
June	31.64	58.01	157.14	159.57
July	15.82	84.38	60.87	124.29
August	15.82	47.46	84.7	105.22
September	5.27	137.11	147.35	173.86
October	58.01	311.13	210.12	296.8
November	163.48	195.12	321.58	263.27
December	358.59	221.48	306.26	265.53

It can be seen in Table 3 that rainfall data in the Bogor area fluctuates every month. Furthermore, Figure 1 shows that extreme values are shown at certain times.

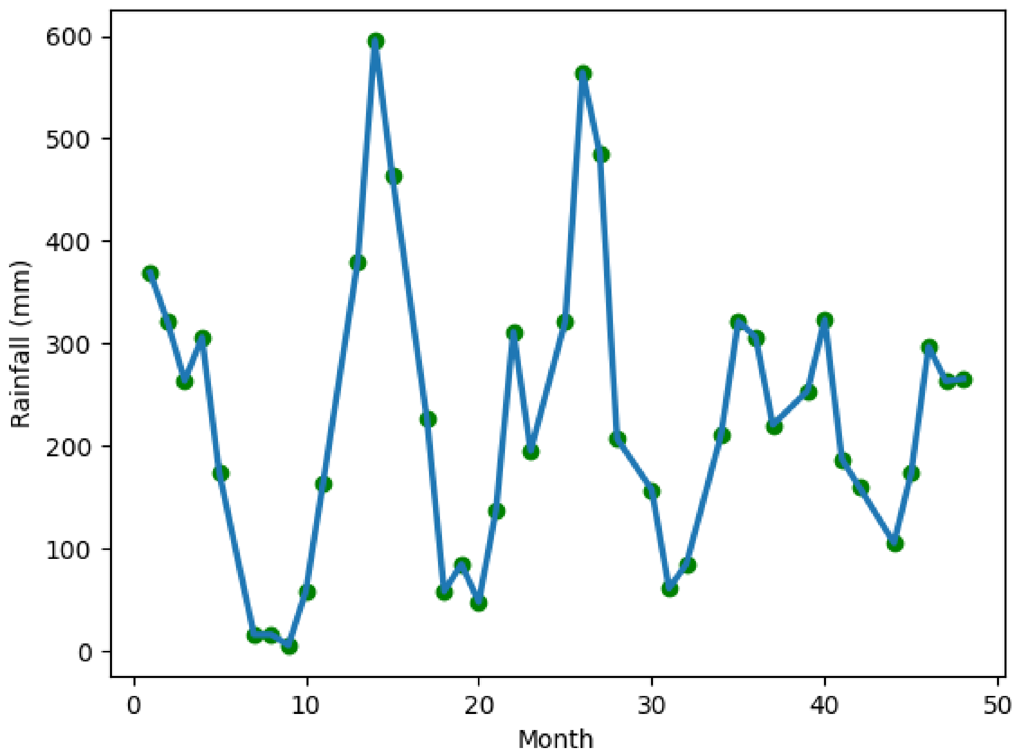

Figure 1. Rainfall Chart for the Bogor Region from 2019-2022.

From Table 3 (see also Figure 1), it is evident that the highest rainfall occurred in February 2020, amounting to 595.5 mm, while the lowest rainfall was recorded in September 2019 at 5.27 mm. Based on observation on Figure 1, the rainfall data samples were subsequently interpolated using cubic spline interpolation. The sample data to be interpolated is presented in Table 4.

Table 4. Sample data of Bogor's monthly rainfall data to be interpolated.

No	Month	Rainfall	No	Month	Rainfall
1	January 2019	369.14	21	January 2021	321.68
2	February 2019	321.68	22	February 2021	564.26
3	March 2019	263.67	23	March 2021	485.16
4	April 2019	305.86	24	April 2021	206.77
5	May 2019	174.02	25	June 2021	157.14
6	July 2019	15.82	26	July 2021	60.87
7	August 2019	15.82	27	August 2021	84.7
8	September 2019	5.27	28	October 2021	210.12
9	October 2019	58.01	29	November 2021	321.58
10	November 2019	163.48	30	December 2021	306.26
11	January 2020	379.69	31	January 2022	220.38
12	February 2020	595.9	32	March 2022	253.55
13	March 2020	464.06	33	April 2022	323.17
14	May 2020	226.76	34	May 2022	186.48
15	June 2020	58.01	35	June 2022	159.57
16	July 2020	84.38	36	August 2022	105.22
17	August 2020	47.46	37	September 2022	173.86
18	September 2020	137.11	38	October 2022	296.8
19	October 2020	311.13	39	November 2022	263.27
20	November 2020	195.12	40	December 2022	265.53

Interpolation is then performed on the sample data in Table 4 using cubic spline, and the visualization graph is obtained as shown in Figure 2.

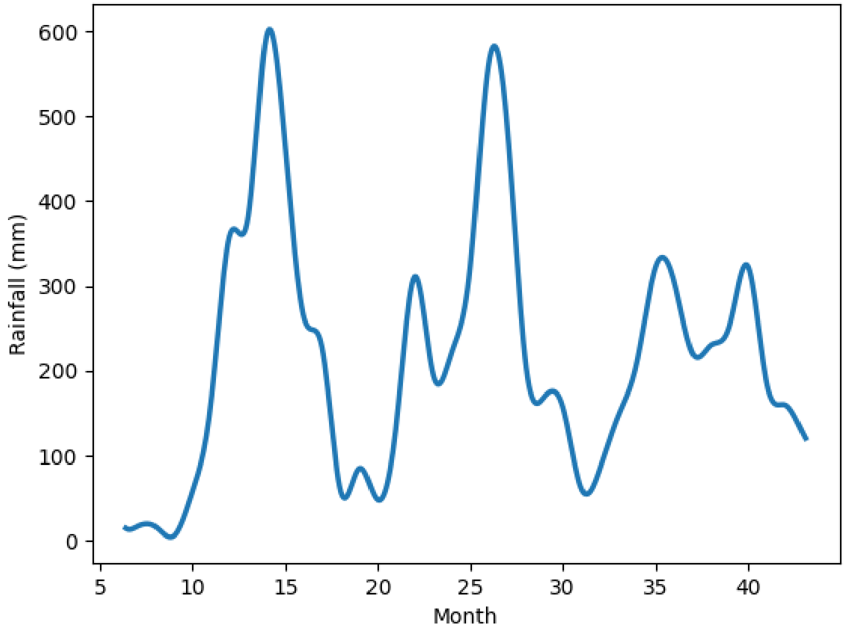

Figure 2. Cubic Spline Interpolation Graph.

Based on the pattern generated, the model is used to predict unknown values within the range of the interpolated sample. Table 5 shows the comparison between the prediction results and the actual data, and the obtained errors are quite small, around 0.1%-2.3%. In Figure 3, it can also be seen that the comparison to those values of cubic spline is generally very accurate. Thus, modeling using cubic spline interpolation can be considered accurate.

Table 5. Monthly Rainfall Data for Bogor from 2019-2022.

No	Month	Rainfall	Prediction	Relative Error
1	June 2019	31.64	31.56	0.2%
2	December 2019	358.59	356.92	0.5%
3	April 2020	263.67	258.82	1.8%
4	December 2020	221.48	221.77	0.1%
5	May 2021	168.97	165.11	2.3%
6	September 2021	147.35	149.98	1.8%
7	February 2022	230.21	234.13	1.7%
8	July 2022	124.29	123.34	0.7%

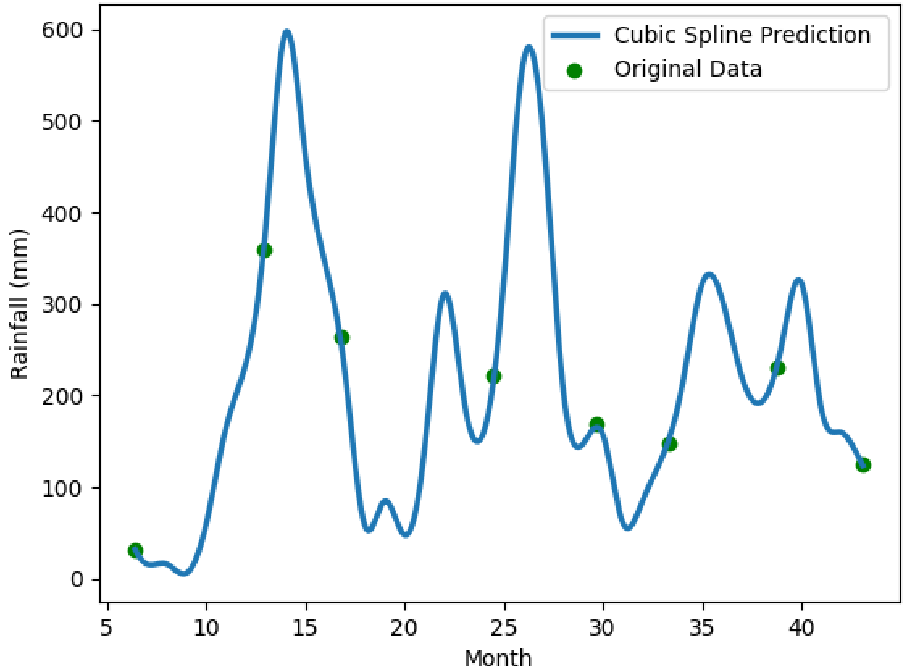

Figure 3. Comparison of Cubic Spline to the Actual Values.

After obtaining the prediction results using cubic spline interpolation and comparing them with the actual data, the next step is to analyze rainfall data related to paddy production in the Bogor region. Table 6 represents the annual paddy production data in the Bogor region.

Table 6. Annual Paddy Production Data for Bogor from 2019-2022.

	2019	**2020**	**2021**	**2022**
Paddy Production (Ton)	562259	406470	285326.1	300068

Rainfall data can be classified according to Schmidt-Ferguson (see Table 1), and the classification results are obtained as shown in Table 7. The results indicate that in 2019, the rainfall data has the highest percentage, which means it falls under type D (moderate). On the other hand in 2021 and 2022, it has the smallest percentage, namely 0%, which means it falls under type A (very wet).

Table 7. Results of Rainfall Classification.

	2019	**2020**	**2021**	**2022**
$\overline{CH}_K$	1.25	0.5	0	0
$\overline{CH}_S$	1.75	2.25	2.5	3
P	71%	22%	0%	0%

Furthermore, when we compare the results of rainfall classification (see Table 7) with paddy productivity (see Table 6), it is obtained that in 2019, Bogor has a moderate rainfall type, influencing increased paddy productivity. Meanwhile, in 2021 and 2022, it has very wet rainfall types, leading to a decrease in paddy productivity. Therefore, rainfall intensity significantly affects paddy productivity.

4. CONCLUSIONS

This research specifically focuses on analyzing the relationship between rainfall patterns and paddy production in Bogor, Indonesia. The variability of monthly rainfall is clearly visible, creating noticeable peaks and valleys. In February 2020 it was recorded as having the highest rainfall, meanwhile, in September 2019 it was recorded as having the lowest one. This research modeling rainfall data using cubic spline interpolation works quite well. This produces a smooth graph and the estimated model is very close to the actual values of data, other than the interpolated ones, with errors of around 0.1%-2.3%.

The natural dynamics associated with rainfall become a crucial factor in agricultural planning. Cubic Spline interpolation proves to be effective in approximating rainfall data, providing a strong foundation for modeling and predicting future patterns. In the context of impact analysis on paddy production, rainfall is classified into categories, ranging from very dry to very wet. In 2019, characterized by moderate rainfall, an increase in rice productivity is observed. Conversely, in 2021 and 2022, with extremely wet conditions, there is a correlation with a decrease in paddy productivity. These findings emphasize the significant role of rainfall intensity in shaping agricultural outcomes.

This research contributes valuable insights, particularly in the context of providing valuable information for decision-making in agriculture. Adaptive farming strategies to varying weather conditions become increasingly crucial to ensure resilience amid the uncertainty of weather patterns.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

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