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Calculation of Rice Commodity Agricultural Insurance Premium Prices Based on Rainfall Index Using the Black-Scholes Method

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Abstract

This study applies the Black-Scholes method to calculate rice commodity insurance premiums based on rainfall indexes. By considering rainfall fluctuations as the primary risk in rice production, the Black-Scholes method provides a more accurate and efficient estimation of insurance premiums. The research involves historical rainfall data collection and statistical analysis, resulting in realistic premium pricing. This innovative approach enhances risk management and sustainability in the rice commodity sector, benefiting stakeholders such as insurance companies and farmers. Future research should explore additional factors, including agricultural technology and government policies, for further refinement of premium calculation models.

Keywords: Agricultural Insurance, Black-Scholes Method, Rainfall Index.

1. Introduction

In today's agriculture landscape, the ever-changing environtment and climate conditions pose significant challenges to the sustainability of the sector, particulary concering rice commodities (Reijntjes, 1992. In response, agricultural insurance has emerged as a crucial risk management tool for industry stakeholders (Hess, 2016).

This research delves into an innovative approach for calculating agricultural insurance premiums, applying the well-established Black-Scholes method (Achmad, 2022). While traditionally used in financial contexts, its application to rice commodities introduces a novel perspective on risk management and premium pricing (Dionne, 2013).

Specifically focusing on rice commodities, this study utilize rainfall indexes as a key parameter, recognizing the inherent risk of rainfall fluctuations in rice production (Khan, 2021). The Black-Scholes method is expected to yield more accurate premium estimates by considering volatility and probability distribution within the rainfall dynamics (Odening, 2007).

Beyond contributing to academic discourse, this research aims to offer practical insights for stakeholders, including insurance companies and farmers. By bridging the gap between financial and agricultural paradigms, the study seeks to establish a more resilient foundation for sustainable agricultural practices through intelligent and adaptive insurance strategies.

2. Research Methodology

2.1. Research Object

The object used in this research is premium, agricultural insurance based on rainfall index in Surabaya. The data used in this study is secondary data which is used, for rainfall for 4 years starting from 2018 - 2021 in the city of Surabaya, which is obtained from the Central Bureau of Statistics and BMKG. As for production costs and operational costs, which can be obtained online from the website of the agriculture and food needs office in Surabaya City. This research will be carried out assisted by using Microsoft excel 2010 software.

2.2. Stages of Research

The stages conducted in the research are as follows:

1. Collecting rainfall data in Surabaya from 2018 to 2021.
2. Determining the rainfall index using the history burn analysis method. The steps involved are as follows:

a. Determining the period to be insured.

b. Identifying the ten-day rainfall.

c. Determining the cap value.

d. Calculating the adjusted rainfall by considering the amount and average of ten-day rainfall, which has been adjusted each year.

e. Determining the exit value and trigger value.

3. Conducting a lognormal distribution test on the rainfall index.
4. Determining the insurance coverage premium for agriculture.

2.3. Black – Scholes Method

The Black-Scholes method is a technique used to determine the price of options. The Black-Scholes method was first developed in 1974 by Ficher Black and Myron Scholes. The use of the Black-Scholes method is based on several assumptions, namely:

1. The option used is a European option, as this method can only be applied at the expiration date.
2. Risk-free interest rate.
3. No dividends are paid.
4. There are no taxes or transaction costs.

Based on Black and Scholes (1973) and Merton (1974), the price of a European-type put option at time t is obtained as follows:

$$P = K\,e^{-rT}N(-d_2) - S_0 N(-d_1) \tag{1}$$

With

$$d_1 = \frac{(\ln\left(\frac{S_0}{K}\right) + (r + \frac{1}{2}\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}} \tag{2}$$

$$d_2 = \frac{(\ln\left(\frac{S_0}{K}\right) + (r - \frac{1}{2}\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}} \tag{3}$$

With

P : Option price
e^{-rT} : Discount
K : Option strike price/exercise price
R : Risk-free interest rate
N$(-d_1)$: Cumulative normal distribution function of d_1
N$(-d_2)$: Cumulative normal distribution function of d_2

Therefore, the agricultural insurance premium based on the rainfall index can be assumed that $\boldsymbol{S_0}$ is valued at 0 because at the beginning of planting, there is no rainfall value. Thus, the agricultural insurance premium based on the rainfall index can be calculated as follows: The index-based agricultural insurance premium can be calculated by first finding the cumulative distribution value $\boldsymbol{d_2}$ using the following equation:

$$d_2 = \frac{\ln\left(\frac{R_0}{H}\right)+\left(r-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{4}$$

$$Premi = Pe^{-rT}N(-d_2) \tag{5}$$

with

P : Insurance coverage premium

N($-d_2$) : Probability of rainfall less than the rainfall trigger value

R : Interest rate

T : Harvest time per year

3. Result and Discussion

3.1. Data

The data used in this study are secondary data consisting of daily rainfall data from 2018 to 2021 in Surabaya, obtained from online BMKG data. The data is presented in the form of graphs using Microsoft Excel 2010 software with the aim of providing a general overview of the data. The results from the data graphs can be observed as follows:

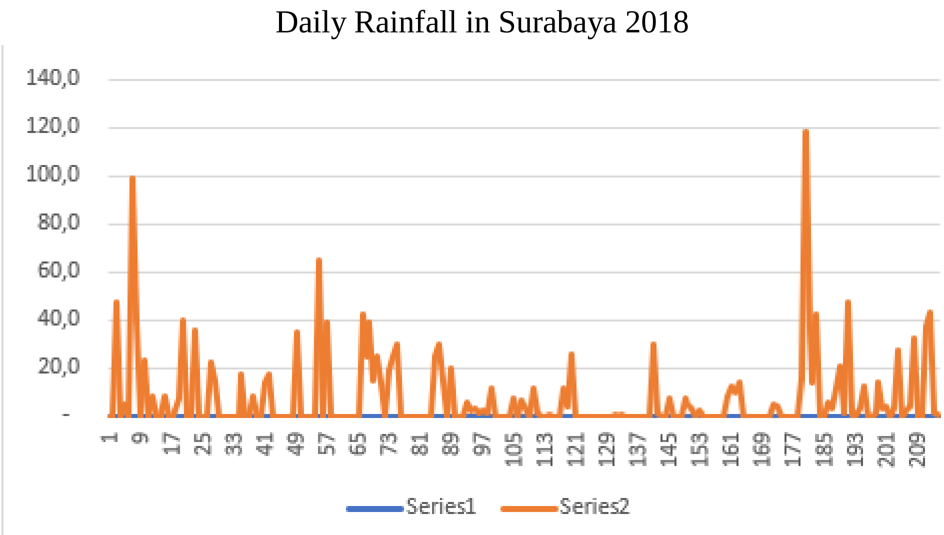

Figure 1: Daily Rainfall Data in Surabaya for the Year 2018

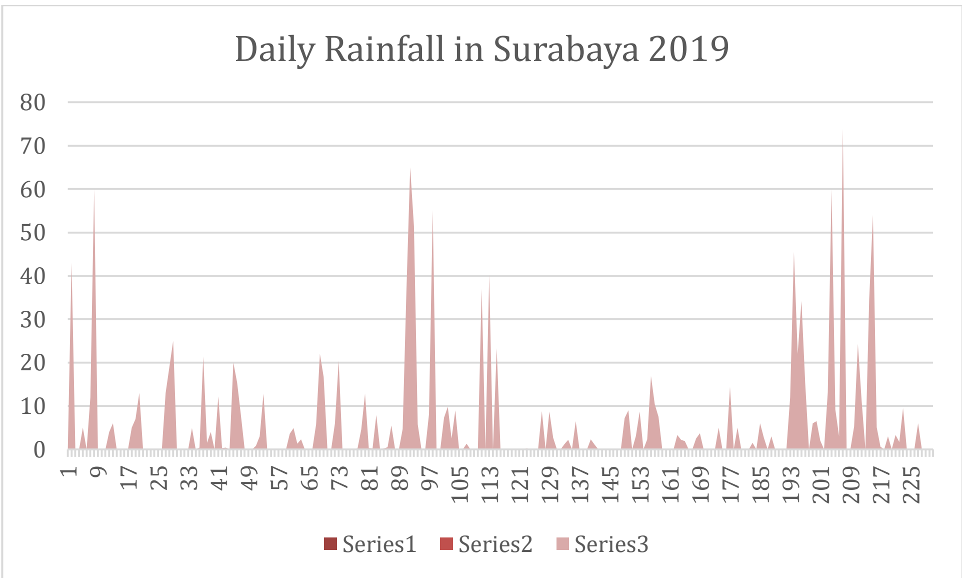

Figure 2: Daily Rainfall Data in Surabaya for the Year 2019

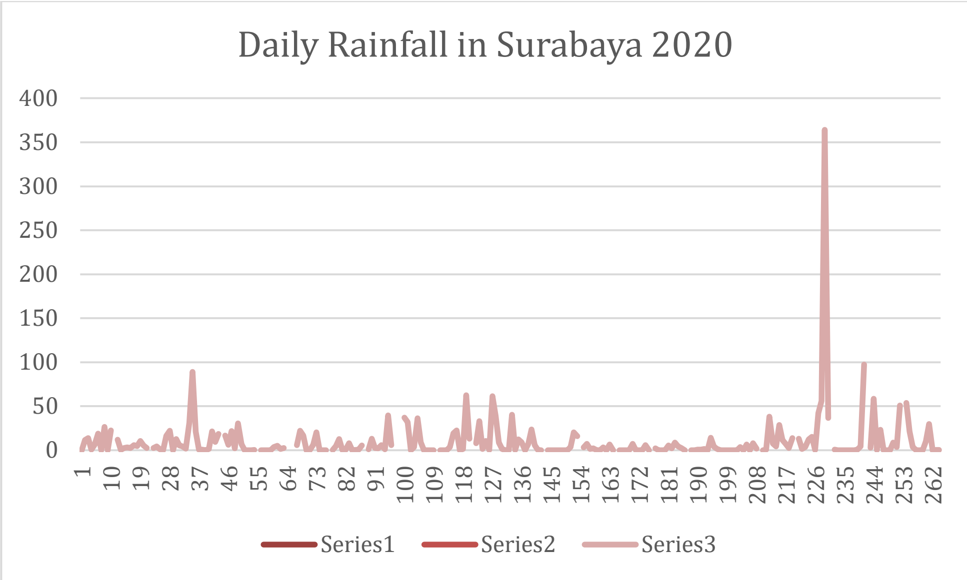

Figure 3: Daily Rainfall Data in Surabaya for the Year 2020

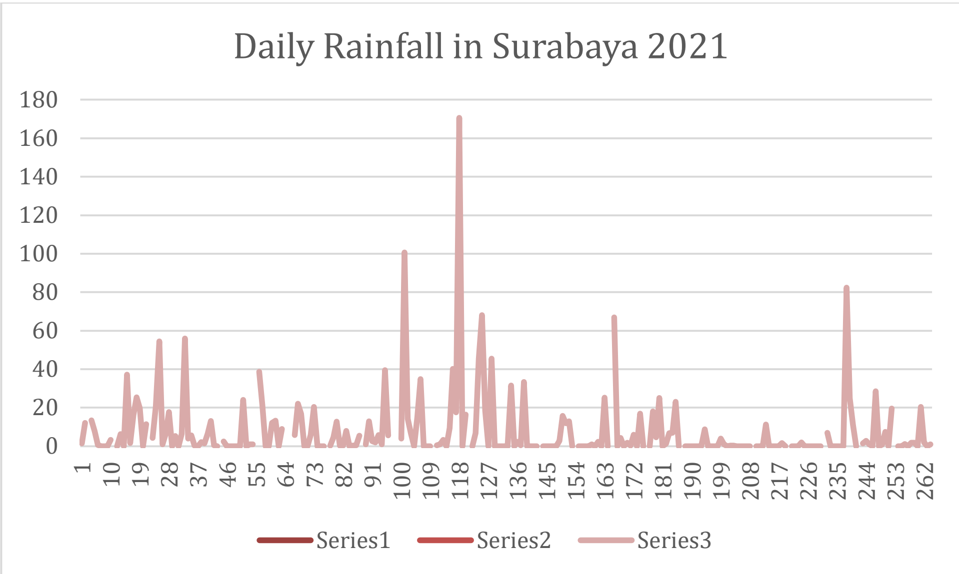

Figure 4: Daily Rainfall Data in Surabaya for the Year 2021

3.2. Determination of Rainfall Index

The determination of the climate index based on rainfall using the Historical Burn Analysis method can be carried out through the following steps:

a. This study is selected based on the rainy season, which is from October to April, covering the years 2018 to 2021.

b. The ten-day rainfall is calculated as the total rainfall over a 10-day period within the insured timeframe.

c. The cap value represents the maximum amount of rainfall calculated for a 10-day period. The determination of the cap value is related to the Potential Evapotranspiration (ETp) daily values, which can be seen in the table as follows:

Table 1: The value of Potential Evapotranspiration (ETp)

Region	Average Daily Temperature (°C)		
	Warm	Cold	Medium

	(~10°C) (>30°C)		(~20°C)
Tropical and Sub Tropical			
Moist and sub moist	2 – 3	3 – 5	5 – 7
Dry and semi-dry	2 – 4	4 – 6	6 – 8

The value of Potential Evapotranspiration (ETp) is a measure that describes the energy requirement obtained from the sun for the agricultural environment. Factors influencing it include air temperature and air pressure. The Surabaya region has an average temperature of 28 degrees Celsius with an air humidity level of 85% per day. Therefore, based on Table 1, the selected average ETp value is 5mm/day, resulting in a cap value of 50mm for every ten days. Thus, the ETp value used in this study is 5mm/day. Therefore, the ten-day stamp value is 50mm.

a. The adjusted total rainfall is determined as follows: if the total rainfall for a 10-day period is less than the cap, then the rainfall used is the actual rainfall. However, if the total rainfall exceeds the cap value within 10 days, the rainfall used is the cap value.

b. The adjusted rainfall values for each insured period are calculated by averaging the 10-day periods per year.

c. The arrangement of adjusted rainfall data (Annual) is done from top to bottom, starting from the highest to the lowest rainfall. The results of determining the climate index can be found in Table 2 below:

Table 2: Rainfall average

Year	Adjusted rainfall average
2021	37.09
2019	38.16
2018	39.72
2020	42.47

d. The exit value is the lowest point where no payments are made. The trigger value is the lowest rainfall amount in one year, rounded to the nearest whole number. The results of determining the exit and trigger values can be seen in Table 3 below:

Table 3: of determining the exit and trigger values

Percentil	Trigger	Exit
20	37.09	
30	37.62	
40	38.16	
50	38.94	37.9
60	39.72	
70	41.10	
80	42.47	

3.3 Determination of Insurance Coverage

P The determination of the amount of agricultural insurance coverage in this study is based on the production cost of rice, which includes both capital and operational costs. Therefore, the coverage amount is Rp. 6,260,000.00 per hectare.

3.4 Calculation of Premium Price

Determining the insurance premium amount using the Black-Scholes method, calculated in equation 4, with rainfall in the last year R_0 being 778,9 mm. being 778.9 mm. H is the trigger value used for each percentile. P is the selected time period, $T = 0.25$. R is the risk-free interest rate, $r = 0.0417$. The standard deviation (σ) of the climate index is 2.234. After obtaining the cumulative distribution value to calculate the agricultural insurance premium using equation 5, it can be seen as Table 4:

Table 4: Agricultural Insurance Premium

mean	39.36
standard deviation	2.338870576
max	42.47
min	37.09
T	0.25
r	0.0417

$$d_2 = \frac{(\ln\left(\frac{S_0}{K}\right) + (r - \frac{1}{2}\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}}$$

$$d_2 = \frac{\ln\left(\frac{778,9}{37,9}\right) + \left(0,0417 - \frac{2,234^2}{2}\right)0,25}{2,234\sqrt{0,25}}$$

$$d_2 = 2,02760228$$

$$N(-d_2) = N(2,02760228) = 0,021300428$$

Based on the cumulative function calculation with *H*=37.09 mm, the result is 0.021300428. The calculation of the premium that must be paid is:

$$Premi = Pe^{-rT}N(-d_2)$$

$$IDR.2.660.000\left(E^{-0,0417(0,25)}\right)(0,021300428)$$

$$Premi = IDR.131.958,92$$

So, based on the calculated premium amount, choosing H = 37.09 results in an insurance premium of IDR 131,958.92. The premium amounts to be paid for other percentiles can be seen in the Table 5:

Table 5: Premium amounts to be paid

Percentile	Trigger	d2	N(-d2)	PREMI	
20	37.09	2.02760228	0.021300428	IDR	131,958.92
30	37.62	2.01539395	0.021931694	IDR	135,869.70
40	38.16	2.00335747	0.022569467	IDR	139,820.78
50	38.94	1.98598048	0.023517745	IDR	145,695.49
60	39.72	1.96894960	0.024479439	IDR	151,653.31
70	41.10	1.93987621	0.026197368	IDR	162,296.10
80	42.47	1.91175889	0.027953564	IDR	173,175.96

Table 5 shows the agricultural insurance premiums that must be paid for each planting season. It is evident that with different rainfall values, the premium payments also vary. This information can be used by farmers to consider purchasing insurance based on the selected rainfall conditions.

4. Conclusion and Suggestion

From the rainfall index, various trigger values are obtained from percentiles. However, the exit value is the smallest value of the annual rainfall index. If the rainfall that occurs is between the exit and trigger values, only partial payments will be made. The calculation of premiums using the Black-Scholes method is based on varying trigger values, utilizing the cumulative nature of the standard normal distribution function approach, which results in varying premium amounts. The high premium values can occur due to the relatively short time duration per planting period. This could be a consideration for farmers, especially in Surabaya, when choosing agricultural insurance policies. A suggestion from the author is that the method used is a very simple one, so for future research, other methods that can provide premiums tailored to farmers can be considered

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