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Application of Black Scholes Method for Determining Agricultural Insurance Premiums Based on the Rainfall Index Using the Historical Burn Analysis Method

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Abstract

Indonesia is a tropical area where it often rains. Uncertain rainfall conditions can have an impact in the form of losses in agriculture, including for rice farmers. The total rice productivity in Indonesia, one of which is in Majalengka Regency, is thought to be quite high, so the losses will be significant. Therefore, it is necessary to make efforts to reduce the impact of losses experienced by farmers, one of which is through insurance programs in the agricultural sector. Rainfall index-based agricultural insurance provides protection to farmers in the form of capital assistance in the event of crop damage resulting in crop failure due to erratic rainfall. This study aims to calculate the agricultural insurance premium based on the rainfall index. The method used to calculate the premium is the Black-Scholes method, while the Historical Burn Analysis method is used to determine the rainfall index. The data used is rainfall data in Majalengka Regency in 2014–2021. The results showed that the premium price in Majalengka Regency depends on the value of the trigger obtained, with a price range between IDR 1,089,646.39 and IDR 1,266,213.02.

Keywords: Agricultural Insurance; Rainfall Index; Historical Burn Analysis; Black-Scholes

1. Introduction

The rainfall that occurs in Indonesia throughout the year is not the same because it is influenced by the monsoon winds, which alternate every six months (Sansenya & Wechakorn, 2021). According to the Head of the Meteorology, Climatology, and Geophysics Agency (BMKG), Dwikorita Karnawati, the average annual rainfall for Indonesia is 2,000 mm. According to Ankrah et al. (2021), technically, business activities in the agricultural sector will always be faced with a fairly high risk of uncertainty. The risk of uncertainty includes the level of crop failure caused by natural disasters such as floods, droughts, or attacks by plant-disturbing organisms, as well as climate change.

As a source of income for farmers, the agricultural sector is critical to food security. However, businesses in the agricultural sector are viewed as having a high risk of loss (Sholiha et al., 2021). The total productivity of rice in Indonesia is quite large, so it will also have a big impact on farmers' income. Losses experienced by farmers indirectly affect rice production, which can make them lose income. Based on this, efforts are required to reduce the amount of losses borne by farmers, one of which is through agricultural insurance programs.

Research on agricultural insurance was previously conducted by Ariyanti et al. (2020), who conducted research on determining agricultural insurance premiums based on rainfall. The research was conducted in Bandung Regency using the Black-Scholes method in determining insurance premiums. The difference between this research and previous research is the difference in choosing the research object; the difference lies in the choice of place and period studied. In this study, rainfall data and rice yield data were used in Majalengka Regency in 2014–2021.

In the early stages of the study, trigger and exit values were determined using the Historical Burn Analysis method based on rainfall data. The Historical Burn Analysis method is a recommended method for use in areas that have limited information on rainfall data. Based on the trigger and exit values, agricultural insurance premiums based on the rainfall index are calculated using the Black-Scholes method. The results of this study can be used to provide an overview of information for farmers, insurance companies, and related agencies for the development of agricultural insurance, especially in Majalengka Regency.

2. Literature Review

2.1 Agriculture and Rainfall in Indonesia

In Aliyar et al. (2022) states that the agricultural sector is very vulnerable to climate change because it affects cropping patterns, planting time, production, and yield quality. Climate change and global warming will reduce agricultural production by 5–20 percent. Climate change conditions are characterized by changing world climate patterns, which result in erratic weather phenomena.

Based on data from the Central Bureau of Statistics, the rice harvest area in 2021 will decrease to 10,515,323 ha. Even so, its productivity has increased to 52.56 ha, so that in 2021 it will be able to produce 55,269,619 tons of rice. The island in Indonesia that produces the most rice is Java. Rice production in Java is 56.50 percent of the total rice production in Indonesia. In Majalengka Regency, lowland rice production has increased from 556,315.00 tons in 2018 to 572,005.83 tons in 2019. This is in line with the increase in harvested area, namely from 129,663 ha in 2018 to 116,040 ha in 2019.

In an upload published by the Central Statistics Agency (BPS) entitled Statistics Indonesia in 2022 Infographics, it was stated that in 2021 most regions in Indonesia will experience an increase in the amount of rainfall, but there are 12 regions in Indonesia that will experience a decrease in the amount of rainfall. The province with the highest rainfall is West Sumatra, with a rainfall of 5,332.3 mm. According to the BPS upload for Majalengka Regency, which was published in 2021, throughout 2021 Majalengka Regency received rain, with the highest rainfall occurring in February, which reached 647.3 mm, and the lowest in June, only reaching 6.8 mm.

2.2 Lognormal Distribution Test

The Black-Scholes model assumes that the data is lognormally distributed. A variable X is said to be lognormally distributed if $\ln X$ (the natural logarithm of X) is normal. Therefore, before determining the amount of premium using the Black-Scholes model, it is necessary to test the normality of the rainfall index data. In this study, the Kolmogorov-Smirnov test will be used to test the normality of rainfall data. In statistics, the Kolmogorov-Smirnov test is a nonparametric test of continuous equations. The Kolmogorov-Smirnov test is carried out by comparing D and D_{table}.

$$D = maks\ |F_0(x) - S_n(x)| \qquad (1)$$

Where $F_0(x)$ is cumulative frequency distribution $S_n(x)$ is cumulative frequency distribution of observational scores

2.3 Metode *Historical Burn Analysis*

According to Hellmuth et al., (2009), the steps taken in data processing to determine the rainfall index are the Historical Burn Analysis method developed by the International Research Institute (IRI) at Columbia University. They are as follows:

a. Determine the period to be insure or window index
   The window index selection can be adjusted in the rainy or dry season.
b. Calculating dasarian rainfall
   Total monthly rainfall is the amount of rainfall every 10 days for the insured period. The total rainfall for months with 28 or 29 days and 31 days is calculated on the 21st through the last day of the month. To calculate the basic rainfall, equations (2) to (4) are used.

$$\text{Month}_{\text{dekade 1}} = \sum_{t=1}^{10} h_t \qquad (2)$$

$$\text{Month}_{\text{dekade 2}} = \sum_{t=11}^{20} h_t \qquad (3)$$

$$\text{Month}_{\text{dekade 3}} = \sum_{t=21}^{30} h_t \qquad (4)$$

   With h_t is daily rainfall.
c. Calculate the amount of "cap"
   The cap represents the maximum amount of rainfall calculated for each 10-day period. The determination of the "cap" value relates to the daily potential evapotranspiration (ETp) value. The ETp value is determined based on the daily temperature in the area studied. To calculate the cap value for 10 days is:

$$\text{Cap}_{\text{dasarian}} = \text{ETP value x 10 days} \qquad (5)$$

d. Calculates the amount of rainfall that has been adjusted for each year
   In the determination, the result of the sum of the base rainfall and the base cap value is used. If the total dasarian rainfall exceeds the cap, the total dasarian rainfall is used. The cap value is used if the total dasarian rainfall exceeds the cap.

e. Compile rainfall data
The adjusted rainfall value for each insured period is averaged using equation (6).

$$\lambda_x = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{6}$$

where λ_x is average rainfall every year; x_i is adjusted rainfall, n is amount of data.

f. Arrange exit and trigger values based on the selected reset period
The exit value is the lowest rainfall data after the preparation was carried out in the previous stage where payment was not made. The determination of triggers is based on the probability of rainfall that occurs in an area. The trigger calculation is based on the percentile value of the average rainfall per year, which has been sorted from the highest to the lowest rainfall that was calculated in the previous stage. Calculation of percentiles using equation (7).

$$P_i = \text{data sequence} - \frac{\mathrm{i(n+1)}}{100} \tag{7}$$

where n is amount of data and i is integer less than 100 (1, 2, 3, …, 99).

2.4 Metode Black-Scholes

In Ariyanti et al. (2020) the European type put option price determined by the Black-Scholes formula is as follows:

$$P = Ke^{-rT}N(-d_2) - S_0N(-d_1) \tag{8}$$

with,

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right)+\left(r+\frac{\sigma^2}{2}\right)T}{\sigma_T\sqrt{T}} \tag{9}$$

$$d_2 = \frac{\ln\left(\frac{S_0}{K}\right)+\left(r-\frac{\sigma}{2}\right)T}{\sigma_T\sqrt{T}} = d_1 - \sigma_T\sqrt{T} \tag{10}$$

Where P is option price, S_0 is initial stock price, K is option strike price, r is risk free interest rate, σ is standard deviation of the stock price, T is time until maturity, $N(-d_1)$ is cumulative density function of the normal distribution of d_1, $N(-d_2)$ is cumulative density function of the normal distribution of d_2.

There are several similarities between the price of options and index insurance. Therefore, index insurance can be formulated in the same way as option prices. In determining the price of index insurance using the Black-Scholes method, the following can be considered (Odilov, 2008):

1) The benchmark value for index insurance is H.
2) The payment structure for index insurance is one at a time.
3) The index follows a lognormal distribution.

By analogy with equation (10), the value of index-based agricultural insurance premiums can be calculated by first finding the cumulative distribution value d_2 with equation (11), as follows:

$$d_2 = \frac{\ln\left(\frac{R_0}{H}\right)+\left(r-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{11}$$

Where R_0 is the latest rainfall values, H is trigger value (rainfall selected as index), r is risk free interest rate, σ standard deviation of the climate index, and T is time.

Equation (12) can thus be used to calculate the agricultural insurance premium value based on the rainfall index.

$$Premi = Pe^{-rT}N(-d_2) \tag{12}$$

Where P is insurance coverage value, $N(-d_2)$ is the probability of rainfall is less than the trigger value of rainfall, r is risk free interest rate, T is time.

3. Materials and Methods

3.1 Materials

The data used in this study is secondary, namely, daily rainfall data in Majalengka Regency in 2014–2021 obtained online from the Meteorology, Climatology, and Geophysics Agency (BMKG) (https://dataonline.bmkg.go.id). Data on rice production costs and operational costs were also used, obtained from the website of the Agricultural Extension and Human Resources Development Agency (BPPSDM) of the Ministry of Agriculture (http://cybex.pertanian.go.id/).

3.2 Methods

The stages carried out in this study are as follows:

1) Collection of daily rainfall data in Majalengka Regency from 2014 to 2021 and data on rice production costs and operational costs.
2) Determine the climate index using the Historical Burn Analysis method. The steps for determining the climate index using the Historical Burn Analysis method developed by the International Research Institute (IRI) at Columbia University are as follows:
   a. Determine the period to be insure or window index.
   b. Calculating dasarian rainfall uses equation (2) to (4).
   c. Calculate the amount of "cap" uses equation (5).
   d. Calculates the amount of rainfall that has been.
   e. Compile rainfall data.
   f. Arrange exit and trigger values based on the selected reset period uses equation (7).
3) Performing a lognormal distribution test on the selected rainfall index as a condition for fulfilling the Black-Scholes method uses equation (1).
4) Using the price of agricultural insurance coverage as a reference price in determining insurance premiums.
5) Determining the price of agricultural insurance premiums in this study using the Black-Scholes method uses equation (12).

4. Results and Discussion

4.1 Determining the Rainfall Index

a. Determine the period to be insure or window index

The period used in this study is during the rainy season, which is between October and April.

b. Calculating dasarian rainfall

The calculated basis of rainfall is the amount of rainfall every 10 days in the insured period. The total rainfall for months with 28 or 29 days and 31 days is calculated on the 21st through the last day of the month.

c. Calculate the amount of "cap"

The determination of the "cap" value is related to the ETp value. The Majalengka Regency area has an average temperature of 28.02 and a humidity level of 74.75%, indicating that the air is quite humid, so an ETp value of 5 mm/day can be used. Using equation (5), the calculation of the stamp value is:

$$\text{Capdasarian} = \text{ETp value x 10 days}$$
$$\text{Capdasarian} = 5\text{mm/day x 10 days}$$
$$\text{Capdasarian} = 50\text{mm}$$

d. Calculates the amount of rainfall that has been adjusted for each year

If the total rainfall base is < cap, then the total rainfall is used; if the total rainfall is > cap, then the cap value is used. The stamp value used is 50 mm.

e. Compile rainfall data

The average is calculated from the amount of rainfall that has been adjusted according to the cap value for each year. Calculations are presented in Table 1.

Table 1: Adjusted rainfall amounts and averages

Year	Adjusted Rainfall Amount	Adjusted Average Rainfall
2014	849.4	40.44762
2015	828	39.42857
2016	927.3	44.15714
2017	986.6	46.98095
2018	813	38.71429
2019	761.9	36.28095
2020	937.4	44.6381
2021	910.8	43.37143

f. Arrange exit and trigger values based on the selected reset period

The adjusted average rainfall amounts are arranged from the smallest to the largest. The arrangement can be seen in Table 2.

Table 2: The average amount of rainfall that has been sorted

Year	Average amount of rainfall
2019	36.281
2018	38.7143
2015	39.4286
2014	40.4476
2021	43.3714
2016	44.1571
2020	44.6381
2017	46.981

The exit value is the lowest rainfall data after preparation, so an exit value of 36.281 is obtained. The trigger is the percentile of the adjusted rainfall amount. The trigger calculations based on percentiles for the calculation process are assisted by Microsoft Excel software with syntax =PERCENTILE.EXC (sorted average rainfall; percentile). The results of determining the trigger value are presented in Table 3.

Table 3: Trigger of Rainfall Index

Percentile	*Trigger*
20	38.22762
30	39.21429
40	40.04
50	41.90952
60	43.68571
70	44.30143
80	45.10667

4.2 Lognormal Distribution Test

The lognormal distribution test was carried out on the selected rainfall index, namely, on the adjusted rainfall amount data. A significance level of 0.05 was used. The hypothesis put forward is as follows:

H_0: Adjusted rainfall data has a lognormal distribution.

H_1: Adjusted rainfall data is not a lognormal distribution.

Testing was carried out with the help of EasyFit software, with the following results:

Table 4: Lognormal distribution test

Lognormal [#40]					
Kolmogorov-Smirnov					
Sample Size	8				
Statistic	0.19614				
P-Value	0.86372				
Rank	29				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.35831	0.40962	0.45427	0.50654	0.54179
Reject?	No	No	No	No	No

Based on the table above, it can be shown that the value of $D = 0.19614$ and $D_{table} = 0.45427$. Based on the decision rule that $D < D_{table}$, it can be concluded that H_0 is accepted and the adjusted amount of rainfall has a lognormal distribution.

4.3 Determination of The Sum Insured

The price of agricultural insurance coverage as a reference price in determining insurance premiums based on rice production costs and operational costs. The cost is calculated with a description of the area of 1 ha. Based on the capital and operational costs, the coverage is 7,430,000.00/Ha

4.4 Determination of The Amount of Premium

The descriptive statistics of the rainfall index for the premium calculation are presented first, which are presented in Table 5.

Table 5: Descriptive statistics of the rainfall index

Parameters	Value
Mean	41.752381
Standar Deviation	3.3604045
Minimun	36.280952
Maximum	46.980952

It is known that the latest rainfall (R_0) in 2021 was 910.8 mm. H is the trigger used for each percentile, with a value of 38.22762. T is the selected time period, and the harvest is assumed to occur four times in one year, so that the value of $T = 0.25$. $r = 0.0125$ is the risk-free interest rate. The standard deviation (σ) of the rainfall index is 3.3604045. Next, the calculation of the cumulative distribution value is carried out with equation 11.

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

$$d_2 = \frac{\ln\left(\frac{910.8}{38.22762}\right) + \left(0.0125 - \frac{3.3604045^2}{2}\right).0.25}{3.3604045\sqrt{0.25}}$$

$$d_2 = 1.048891721$$

$$N(-d_2) = N(-1.048891721\,) = 0.147113978$$

After that, the premium value is calculated using equation (13). Where the sum insured is IDR 7,430,000.00 and the value of $(-d_2) = 0{,}147114$.

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

$$Premium = (7{,}430{,}000)e^{-0.0125(0.25)}(0.147114)$$

$$Premium = \text{IDR } 1{,}089{,}646.39$$

So the amount of premium to be paid when choosing H = 38.22762 mm is 1,089,646.39. Table 6 shows the premium to be paid for various percentile values as follows:

Table 6: Amount of premium to be paid

Percentile	*Trigger*	Price Coverage (IDR)	Premium (IDR)
20	38.22762	7,430,000.00	1,089,646.39
30	39.21429	7,430,000.00	1,115,706.16
40	40.04	7,430,000.00	1,137,321.78
50	41.90952	7,430,000.00	1,185,621.78
60	43.68571	7,430,000.00	1,230,702.65
70	44.30143	7,430,000.00	1,246,149.53
80	45.10667	7,430,000.00	1,266,213.02

Table 6 shows that the premium price in Majalengka Regency depends on the trigger value obtained; the lowest trigger value is 38.22762 mm and the highest trigger value is 45.10667 mm. The range of premiums is between IDR 1,089,646.39 and IDR 1,266,213.02. The results of the premium calculation are used as a reference in determining the price of agricultural insurance premiums that must be paid. The amount of the premium price must be paid every planting season, with a planting area of 1 ha. Trigger values from rainfall and various premium prices can be used to consider purchasing insurance.

5. Conclusion

An exit value of 36.281 mm is obtained, which is the smallest rainfall where payment is not made. The determination of triggers is based on the probability of rainfall that occurs in the Majalengka Regency area. The lowest trigger value is 38.22762 mm, and the highest trigger value is 45.10667 mm. The price of agricultural insurance premiums based on the rainfall index is also obtained based on the appropriate trigger value for farmers in Majalengka Regency. The lowest premium price with a rainfall trigger of 38.22762 mm is IDR 1,089,646.39 and the highest premium price with a rainfall trigger of 45.10667 mm is IDR 1,266,213.02.

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