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APPLICATION OF THE BLACK SCHOLES METHOD FOR COUNTING AGRICULTURAL INSURANCE PREMIUM PRICE BASED ON RAINFALL INDEX IN KAPUAS HULU REGENCY

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ABSTRACT

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High-intensity rainfall is one of the factors that can interfere with the state of agriculture. Agricultural insurance is an insurance that can be used to reduce risks related to agricultural losses such as rice production. Climate-based agricultural insurance is a management of climate-related risks. This study aims to determine the rainfall index and calculate the value of agricultural insurance premiums based on the climate index (rainfall) in Kapuas Hulu Regency using the Black Scholes method. In calculating the value of agricultural insurance premiums based on the rainfall index, it starts by calculating the value of the correlation coefficient between rainfall and rice production. Then the value of the rainfall index is obtained, which then the value of the index is tested for lognormality to meet the assumptions on the Black Scholes method, after which it calculates the ln return value of the index value obtained, the last step is to calculate the value of agricultural insurance premiums. Based on case studies, the results obtained are when the risk-free interest rate is 3.5% and rainfall is 54.23 mm, the premium paid is IDR 2,386,824, and when the rainfall is 75.39 mm, the premium paid is IDR 3,898,142. If the risk-free interest rate is 4% and the bulk is 54.23 mm, the premium paid is IDR 2,383,842, and when the rainfall is 75.39 mm, the premium paid is IDR 3,893,272. When the risk-free interest rate is 5% and rainfall is 54.23 mm, the premium paid is IDR 2,377,890 and if the rainfall is 75.39 mm, the premium paid is IDR 3,883,551. So, the higher the rainfall, the greater the premium value payment. If the risk-free interest rate gets bigger then the premium payment will be smaller.

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1. INTRODUCTION

Indonesia is an agricultural country where the agricultural sector plays an important role in the national economy [1]. In 2021, in West Kalimantan, the agricultural sector provided the highest GRDP output. However, in Kapuas Hulu Regency, the agricultural potential is still low, especially in rice production [2]. The important role of the agricultural sector includes as a source of income for the community, especially the need for food, in addition to state investment and opening up job opportunities. However, businesses in the agricultural sector have a high risk when extreme rainfall occurs, which can result in a decrease in production yields due to crop failure, resulting in a decrease in farmers' income.

Unstable rainfall, such as decreased and increased rainfall, can result in poor yields. Farmers in Kapuas Hulu District have been given the training to increase knowledge and understanding related to climate change and the consequences associated with agriculture. In addition, the government also introduced agricultural insurance to farmers as a solution to reduce the risks caused by climate change.

Agricultural insurance is a special insurance protection and is one of the alternatives that farmers can use in reducing the risks associated with production results [3]. Thus, this insurance can be utilized for one of the government's efforts in reducing possible risks related to agriculture [4].

In general, the protection of farmers is carried out by protecting farmers traditionally and protecting farmers through insurance schemes [5]. Protecting farmers traditionally means that the government will allocate a special budget in the event of a natural disaster. Meanwhile, protecting farmers through insurance schemes means that the government will provide insurance premium assistance to farmers who are insurance participants. However, in this case, traditional agricultural insurance is not available in every country, especially Indonesia, because the cost of insurance is not economically adequate, this is because there are not many agricultural products and also the calculation of premiums can make it difficult for the insurer. Based on these weaknesses, new insurance will be introduced, namely index-based insurance.

Index-based insurance is part of parametric insurance, which is a type of insurance where the insurer will make payments to the insured party in the event of a triggering event [6]. In this index-based insurance, the insured party will pay a premium when experiencing losses triggered by natural events, in this case, rainfall. In this study, the Black Scholes method was used to calculate the value of insurance premiums based on the rainfall index. This method was introduced as one of the methods used to determine the price of an option. In this method, it is assumed that the interest rate used is the risk-free interest rate, does not provide dividends, and there are no transaction fees.

This study aims to calculate the value of insurance premiums based on the rainfall index in Kapuas Hulu Regency. The first part describes the background and purpose of the research. An explanation of the Black Scholes method is given in the second part. Then, the third part explains the results and discusses the calculation of the value of agricultural insurance premiums based on the rainfall index using the Black Scholes method. The last part is to lay out the conclusions.

2. RESEARCH METHODS

2.1. Insurance Premiums

The insurance premium is the payment that must be made by insurance members (insured) to the insurance party (insurer) under the coverage agreement signed on the insurance contract letter [7]. The system of this insurance premium is that the insured will collect funds from the insured with an agreed amount over a long period of time, so that the insured party can return the insured party to the position before the loss occurred or can also prevent the insured from bankruptcy [8].

2.2. Black Scholes Method

The Black Scholes model is used to assess options and set the price of a stock option. This model has a great influence on the way options and hedge options are calculated. This is very important in developments in the financial field [9].

An option is a contract or agreement that gives the contract holder the right not to buy or sell the underlying asset with an index agreed on or before maturity [10]. The reference options used in the Black Scholes method are European-type options that can only be used at maturity, volatility (price variance) is constant (fixed) as long as the age of the option is known to definitely not pay dividends, and taxes and transaction fees are ignored [11]. In determining the value of index-based insurance premiums using the Black Scholes method, there are several things that need to be considered, namely:

a. The trigger measurement in index-based insurance is R_T
b. The payment structure for index-based insurance is a lump sum
c. Index following lognormal distribution

In this study, the Black Scholes method was used to determine or calculate insurance premiums when production results decreased below standard because they were affected by rainfall. The Black Scholes method is written in the form of an equation this method is formulated as follows [12] :

$$C_{BS} = S_0 N(d_1) - Ke^{-rT} N(d_2) \quad (1)$$

$$\boldsymbol{P_{BS} = Ke^{-rt} N(-d_2) - S_0 N(-d_1)} \quad (2)$$

so that,

$$d_1 = \frac{ln\frac{S_0}{K} + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \quad (3)$$

$$\boldsymbol{d_2 = \frac{ln\frac{S_0}{K} + \left(r - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}} \quad (4)$$

Where:

C_{BS} : European type stock buy option price
P_{BS} : European type option stock selling price
S : current share price
K : Price Strike Options
r : risk-free interest rate
σ : standard deviation from the stock price
t : time until maturity
$N(-d_1)$: function of the cumulative density of the normal distribution of the d_1
$N(-d_2)$: function of the cumulative density of the normal distribution of the d_2

In rainfall index-based insurance, the coverage value (PO=Payoff) depends on rainfall realization and is designed as a put option, defined as follows:

$$Payoff = \begin{cases} K, if\ R_0 > R_T \\ 0,\ Other \end{cases} \quad (5)$$

With K is the value of insurance coverage for farmers due to changes in rainfall, R_T is a benchmark value defined as the average rainfall in the highest correlated month and R_0 is the latest rainfall average data obtained from the average rainfall data selected as an index. The value of the insurance premium index with K stating the payment from the coverage can be equations as follows [13]:

$$Premi = Ke^{-rt} N(-d_2) \quad (6)$$

so that,

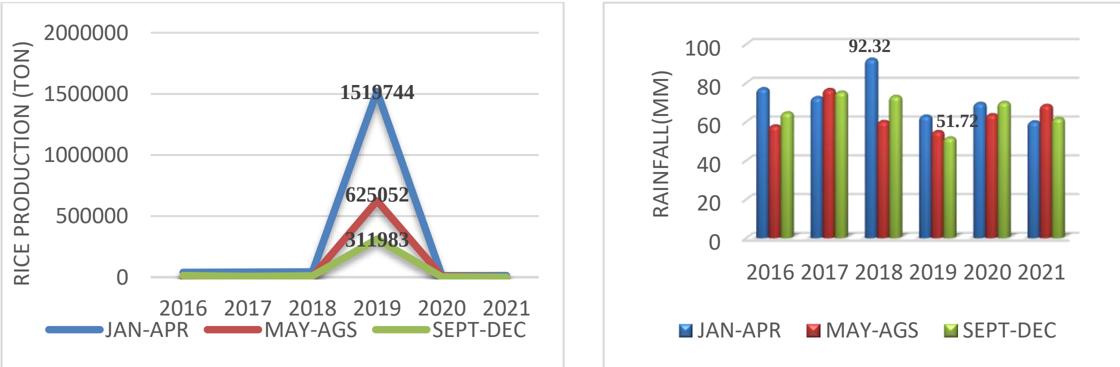
$$d_2 = \frac{ln\frac{R_0}{R_T} + (\mu)T}{\sigma\sqrt{T}} \quad (7)$$

Where:
K : insurance coverage price
r : risk-free interest rates
t : time (year)

R_0 : Latest Rainfall Data
R_T : Benchmark value of rainfall selected as an index
μ : average ln return rainfall data selected as index
σ : Standard Deviation LN Return Rainfall Data Selected as Index

3. RESULTS AND DISCUSSION

The data used in this study are secondary data obtained from the Food Crops and Horticulture Service of West Kalimantan Province, namely rice production data per sub-round in Kapuas Hulu Regency in 2016-2021 and BMKG online data for the Pangsuma III Meteorological Station, Kapuas Hulu Regency in the form of rainfall data for 2016-2021. Data on rice production and average rainfall are presented in **Figure 1**.



(a) **(b)**

Figure 1. Plot data (a) rice production, (b) average rainfall

In **Figure 1**, it can be seen that rice production and average rainfall in Kapuas Hulu Regency in 2016-2021 experienced fluctuations. Fluctuations in irregular average rainfall (low or high intensity) will affect rice production. Therefore, there is a need for steps in overcoming this.

3.1. Determination of Rainfall Index

The determination of the bulk index is carried out based on the average rainfall that is most strongly correlated to rice production. In this test, the Pearson Product Moment correlation coefficient test will be used to determine the relationship between rainfall and rice production. In calculating the correlation coefficient of Pearson Product Moment using the following equation **[14]**:

$$r_{xy} = \frac{n\sum x_i y_i - (\sum x_i).(\sum y_i)}{\sqrt{(nx_i^2 - (xn_i{}^2).(n\sum y_i^2 - (y_i)^2)}} \tag{8}$$

Where:
r_{xy} : correlation coefficient between x and y
x_i : x_i value
y_i : y_i value
$\sum y_i$: the sum of the y_i value
$\sum x_i$: the sum of the x_i value
n : number of samples

From **Equation (8)** using Microsoft Excel software obtained the value of the correlation coefficient between rainfall and rice production yield presented in **Table 1**.

Table 1. Value of correlation coefficient of rainfall and rice production yield

Production	Rainfall		
	Jan-Apr	May-Ags	Sep-Dec
1st Four months period	-0.38297	-0.53770	-0.80227
2nd Four months period	-0.39748	-0.53570	**-0.80690**
3rd Four months period	-0.37037	-0.55166	-0.80181

Based on **Table 1**, the highest correlation value of -0.80690 was obtained, which means that the average rainfall data of 2nd Four months period in September-December correlates most strongly with rice production, so that the average rainfall of 2nd Four months period in September-December was selected as the index. The correlation value obtained is a negative correlation value which means that rainfall and rice production have opposite relationships.

The correlation value that has been obtained will be tested for significance using the Significance test of the Pearson Product Moment correlation value. The correlation value is said to have a significant relationship if $|t_{test}| > -t_{\frac{\alpha}{2},n-2}$, with a degree of significance α = 10%, With the hypothesis used are the following:

$H_0: \rho = 0$ (There is no relationship between the variables X and Y)
$H_1: \rho \neq 0$ (There is a relationship between the variables X and Y)

In the significance level test using the Significance test, the Pearson Product Moment correlation value is obtained t_{test} as large as -2.73. Value t_{test} right compared to value t_{table} obtained from the table of distribution of t by -2.13 which means value $|t_{test}| > t_{\frac{\alpha}{2},n-2}$ means H_0 rejected.

3.2. Lognormality Test using Kolmogorov-Smirnov Test

The lognormality test is used to determine whether the data population is lognormal distributed or not. In this study, the rainfall data selected as an index must be lognormal distributed and this test was carried out to meet the assumptions in the Black Scholes method of calculating index-based premium values **[14]**. The test to be used is the Kolmogorov-Smirnov test with a degree of significance α = 5%. The data is said to be lognormal distributed if $p\text{-}value \geq \alpha$ and receive H_0. The hypotheses used are as follows:

H_0: Rainfall data selected as lognormal distributed index

H_1: Rainfall data selected as lognormal non-distributed index

The results of the lognormality test analysis on the rainfall data selected as an index will be presented in **Table 2**.

Table 2. Kolmogorov-Smirnov lognormality test results

N	6
Mean	66.1
Std. Deviation	8.705
KS	0.174
$p\text{-}value$	0.150

Based on **Table 2**, obtained values $p\text{-}value$ as large as 0.150, which means greater than the value α. Means H_0 not rejected Thus, the data can be used as an index that represents the overall data in determining the value of insurance premiums.

3.3. Calculation of ln Return value

In this study, the value that will be in ln return is the value of rainfall data of chess 2 which was selected as an index. The return value is calculated using the following equation **[15]**.

$$R_{i,t} = \left(\frac{P_{i,t}}{P_{i,(t-1)}}\right) \tag{9}$$

Where:
$R_{i,t}$: Return on assets to-i on time to-t
$P_{i,t}$: asset price to-i on time to- t
$P_{i,(t-1)}$: asset price to i on time to-$(t-1)$
Then, the return value in ln kan which will be presented in Table 3.

Table 3. Natural logarithm value return

Rainfall	Natural logarithms
64.64415	
75.39339	0.15382
73.11862	-0.03064
51.72778	-0.34609
70.04177	0.30310
61.73571	-0.12623

Based on Table 3 obtained for values μ = -0.00920 and value σ = 0.25087. Then the average value and standard deviation obtained will be used for the calculation of the value of agricultural insurance premiums based on the rainfall index.

3.4. Value of Agricultural Insurance Premiums Based on Rainfall Index

The determination of the value of insurance premiums based on the rainfall index will be calculated using Equation (6). The first step in calculating the premium value using the Black Scholes method is to calculate the value d_2 use formula 7 with the help of Microsoft Excel software. Then, determine the value R_0 or the latest rainfall data, R_0 =61.73571. The value of r used in the calculation of premiums is 3.5%, 4% and 5%, t = 0.25, value R_T the benchmark used is percentile 5 to 100 with an assumed coverage value from the Ministry of Agriculture of the Republic of Indonesia of IDR. 6,000,000 / hectare.

After calculating the value d_2, Next will find the value of the distribution function $-d_2$ which is the value of the distribution function $-d_2$ obtained from Table Z of normal distribution. The result of the distribution function $-d_2$ presented in Table 4 below:

Table 4. Value calculation results $N(-d_2)$

Percentile	R_T	d_2	$-d_2$
5	54.23	0.25	0.4013
10	56.73	0.16	0.4364
15	59.23	0.07	0.4271
20	61.74	-0.00	0.5000
25	62.46	-0.02	0.5080
30	63.19	-0.05	0.5199
35	63.92	-0.07	0.5279
40	64.64	-0.09	0.5359
45	65.99	-0.13	0.5517
50	67.34	-0.17	0.5675
55	68.69	-0.21	0.5832
60	70.04	-0.25	0.5948
65	70.81	-0.27	0.6064
70	71.58	-0.29	0.6141
75	72.34	-0.32	0.6255
80	73.11	-0.34	0.6331
85	73.69	-0.35	0.6368
90	74.26	-0.37	0.6443
95	74.82	-0.38	0.6480
100	75.39	-0.40	0.6554

Based on **Table 4** of the calculation results of the distribution function $-d_2$. In the 5th percentile, a value of 0.4013 is obtained, for example, the calculation of the premium value that must be paid at the time of the benchmark rainfall value in the 5th percentile using **Equation (6)** with a risk-free interest rate of 3.5%, 4% and 5% is as follows:

1. Risk-Free Interest Rate 3.5 %

$$\begin{aligned} Premium &= Ke^{-rt}N(-d_2) \\ &= 6{,}000{,}000 \times 2.71828183^{-0.035\times0.25} \times 0.4013 \\ &= \text{IDR } 2{,}386{,}824 \end{aligned}$$

2. Risk-Free Interest Rate 4 %

$$\begin{aligned} Premium &= Ke^{-rt}N(-d_2) \\ &= 6{,}000{,}000 \times 2.71828183^{-0.04.\times0.25} \times 0.4013 \\ &= \text{IDR } 2{,}383{,}842 \end{aligned}$$

3. Risk-Free Interest Rate 5 %

$$\begin{aligned} Premium &= Ke^{-rt}N(-d_2) \\ &= 6{,}000{,}000 \times 2.71828183^{-0.05\times0.25} \times 0.4013 \\ &= \text{IDR } 2{,}377{,}890 \end{aligned}$$

So, from this calculation, the premium value that must be paid by insurance customers when the benchmark rainfall value is the value in the 5th percentile with a risk-free interest rate of 3.5% of IDR 2,386,824, for a 4% risk-free interest rate of IDR 2,383,842 and for 5% of IDR 2,377,890. The premium value at the time of benchmark rainfall in the other percentiles will be presented in **Table 5**.

Table 5. The results of the calculation of the value of insurance premiums

Percentile	Rainfall (mm)	Coverage Value (IDR)	Premium (IDR)		
			Risk-Free Interest Rate		
			3,5%	4%	5%
5	54.23	6,000,000	2,386,824	2,383,842	2,377,890
10	56.73	6,000,000	2,595,589	2,592,346	2,585,874
15	59.23	6,000,000	2,540,275	2,537,102	2,530,767
20	61.74	6,000,000	2,973,865	2,970,150	2,962,733
25	62.46	6,000,000	3,021,446	3,017,672	3,010,137
30	63.19	6,000,000	3,092,224	3,088,361	3,080,650
35	63.92	6,000,000	3,139,806	3,135,884	3,128,054
40	64.64	6,000,000	3,187,388	3,183,406	3,175,458
45	65.99	6,000,000	3,281,362	3,277,263	3,269,080
50	67.34	6,000,000	3,375,336	3,371,120	3,362,702
55	68.69	6,000,000	3,468,716	3,464,382	3,455,732
60	70.04	6,000,000	3,537,709	3,533,290	3,524,468
65	70.81	6,000,000	3,606,703	3,602,197	3,593,203
70	71.58	6,000,000	3,652,500	3,647,938	3,638,829
75	72.34	6,000,000	3,720,305	3,715,657	3,706,379
80	73.11	6,000,000	3,765,507	3,760,803	3,751,413
85	73.69	6,000,000	3,787,514	3,782,782	3,773,337
90	74.26	6,000,000	3,832,122	3,827,335	3,817,778
95	74.82	6,000,000	3,854,128	3,849,314	3,839,702
100	75.39	6,000,000	3,898,142	3,893,272	3,883,551

Based on **Table 5** of agricultural insurance customers in this case, farmers can see, for example, that when the rainfall that occurs is 54.23 mm, the premium value that must be paid when the risk-free interest rate of 3.5% is IDR 2,386,824, if 4% is IDR 2,383,842 and if 5% the premium value paid is IDR 2,377,890. Meanwhile, if rainfall increases by 75.39 mm when the risk-free interest rate is 3.5%, the premium value that must be paid by agricultural insurance customers is IDR 3,898,142, if 4% is IDR 3,893,272 and if 5% the premium value paid is IDR 3,883,551, and with the existence of percentiles it can also make it easier for agricultural insurance customers in this case to see the amount of premium value that will be paid at the time of the stated rainfall benchmark.

4. CONCLUSIONS

Based on the formulation of the problem and the results of the analysis that has been carried out by the author, it can be concluded that:

1. The value of the rainfall index in agricultural insurance is seen from the highest correlation value between average rainfall and rice production. In this study, the rainfall index value in agricultural insurance in Kapuas Hulu Regency was obtained at 64.64415 mm, 75.39339 mm, 73.11862 mm, 51.72778 mm, 70.04177 mm, and 61.73571 mm.

2. The value of agricultural insurance premiums in Kapuas Hulu Regency, which is influenced by the rainfall index, has a value that varies in each percentile and has a risk-free interest rate. The higher the rainfall percentile, the greater the premium that must be paid by the farmers, and for each different risk-free interest rate, the greater the interest, the cheaper the premium paid. For the rainfall range at the 5th percentile to the 100th percentile with a risk-free interest rate of 3.5% the premium value paid at the time of 54.23 mm of rainfall is IDR 2,386,824, when the rainfall is 75.39 mm of IDR 3,898,142, for the risk-free interest rate of 4% at the time of 54.23 mm of IDR 2,383,842, when the rainfall is 75.39 mm IDR 3,893,272 and for the risk-free interest rate of 5% at the time of 54.23 mm bulk of IDR 2,377,890 and when the rainfall is rain of 75.39 mm at IDR 3,883,551.

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