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Determination of North Sulawesi Agricultural Insurance Premiums Based on Rainfall Index Using the Black-Scholes Model

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Abstract

This article discusses the use of the Black Scholes model to calculate insurance premium prices based on the rainfall index. The Black Scholes model is one of the models used to determine option prices. The research method used is to study the material through mathematics journals and collect data. The data used in this study are rainfall data and rice production data in North Sulawesi from 2018 to 2020. Based on the results and discussion, the quarterly rainfall data that has a strong correlation is the third quarter rainfall. At the 5th percentile, the third quarter rainfall data is 450.22 mm. For the latest rainfall data size (450.22 mm) the premium obtained is IDR 231,912.09. From the calculation results, the higher the value for both sizes, the greater.

Keywords: Agricultural insurance, Rainfall, Rice production, Black Scholes model, Premiums.

1. Introduction

Indonesia is an agrarian country, which means that the agricultural sector plays an important role in the overall national economy(Rahman, 2017; Arham and Dai, 2020; Nasrun et al., 2020; Kanela, 2020). Agriculture plays an important role in food security as a source of livelihood for millions of farmers with various limitations. Since the first, Indonesia has always been rich in agricultural products such as rice, soybeans, corn, peanuts, cassava and sweet potatoes. However, business in the agricultural sector is seen as a business with a high risk of loss(Yazid et al., 2021; Gusti, 2019; Gursida, 2017; Devi et al., 2020). One of them is a business with high risk and uncertainty, namely rice which can experience a decline. The factor that can threaten the decline in rice production is rainfall.

Rainfall can disrupt agricultural conditions, unstable rainfall conditions can result in poor crop yields(Siregar and Crane, 2021; Caraka et al., 2018). One of the protections provided to farmers is agricultural insurance, this agricultural insurance is an alternative that can assist farmers in overcoming the risks that occur in agricultural businesses(Fadhil et al., 2021; Lopulisa et al., 2018;Supian and Ismail, 2022; Sujarwo, 2017). This agricultural insurance is used to cover losses caused by several factors, such as rainfall. Rainfall is the amount of water that falls on the subgrade surface during a certain period measured in millimeters (mm) above the horizontal surface. The rainfall will be represented by a rainfall index which is used as a reference to determine the amount of the premium.

Insurance premiums are the value paid to insurance companies to take over risks related to possible losses. So, this insurance premium aims to provide compensation as well as protection to the insured. In calculating the premium, the organizers are only based on one cause, such as rainfall, so it is called agricultural insurance based on the rainfall index(Dartanto et al., 2020; Wang et al., 2017). In addition, the amount (price) of the premium also depends on the amount (large) of the insured value and other factors such as interest rates and the time period for data formation. Similar to insurance, an option is a contract or agreement between two parties, namely one party gives the other the right to buy or sell an asset (eg shares) at a certain price and time period.

One of the models used to determine option prices is the Black-Scholes model. This method was developed by Fisher Black and Myron Scholes starting in 1073, in this case the method is used to determine the option value in a stock price contract. The equation between the option calculation and the calculation of agricultural insurance premiums causes the Black Sholes model to be used to determine the price of agricultural insurance premiums based on the rainfall index(Solihin et al., 2021; Frino et al., 2019). The determination of the premium is done by finding the largest correlation between rainfall data and rice production. The rainfall data with the largest correlation was chosen as the rainfall index. Thus, the insurance is called rain index-based agricultural insurance. So this study was conducted to calculate the price of agricultural insurance premiums based on the rainfall index using the Black Scholes model and using secondary data from the North Sulawesi region.

Researches relevant to the theme of the discussion in this article have been carried out by Wendra (2015), Putri et al (2016), and Dina et al (2020). The distinguishing factor is the data. The data used by Wendra (2015) are data for the Jambi region, Putri et al (2017) using rainfall data for the Bali region from 1998 to 2015. This article uses one reference data, namely the latest data and the overall average rainfall index data(Putri, 2016; Wendra, 2019).

2. Materials and Method

The materials used in this study are monthly rainfall and rice production data for the 2018-2020 time period in North Sulawesi Province. Data analysis was carried out with the help of Microsoft Excel. The method used is literature study and collecting secondary data. The research steps used are as follows:

1) Collecting literature study references such as previous books and journals;
2) Collecting data on rice production and monthly rainfall in North Sulawesi province from 2018-2020;
3) Make a plot of quarterly rainfall data and quarterly data on rice production for North Sulawesi province from 2018-2020;
4) Performing regression analysis and correlation of data to determine rainfall index;
5) Testing the normality for the natural logarithm of the rainfall data with the quarterly data with the strongest correlation (with the highest correlation value) on rice production; and
6) Calculating the price of insurance premiums using the Black Scholes model with the following equation:

$$P(S_t, t) = Ke^{-r(T-t)} - S_t + C(S_t, t)$$
$$= N(-d_2)Ke^{-r(T-t)} - N(-d_1)S_t$$

with

N	:	Cumulative distribution
$T-t$	:	Planting time (in years)
S_T	:	Asset base price
K	:	The price of compensation to be received
r	:	Level of risk free
σ	:	Standard deviation to be paid based on the data obtained

3. Results and Discussion

According to Prabowo et al. (2019), Rice Farming Business Insurance (AUTP) calculates the premium or price for one hectare of land per planting period at 3% of the maximum benefit value, which is IDR 6,000,000.00.

For insurance premiums based on the rainfall index, the premium calculation can be modeled using an equation with the European type of cash-or-nothing option, namely:

$$Premi = K.e^{rt}.N(-d_2) \qquad (1)$$

With,

$N(-d_2)$	:	Cumulative normal distribution
K	:	Payoff (the amount of compensation that farmers will receive in the event of a claim)
r	:	Interest rate per year
t	:	Time (yearly)

In this study, there are two rainfall reference sizes used R_o, namely [1] the average rainfall data and [2] the latest rainfall data. The amount of compensation that will be received by farmers (payoff) from insurance based on rainfall index can be paid if the actual rainfall R_o is smaller than the triggered measurement R_T. The payoff odds are.

$$d_2 = \frac{ln\frac{R_0}{R_T} + \mu.t}{\sigma\sqrt{t}} \qquad (2)$$

with,

R_0	:	Rainfall system last / latest (recent)

R_T : Triggered measurement (calculated by percentile data), namely rainfall data used to determine the premium
μ : Annual expected rate of price return
σ : Annual standard deviation of stock price changes

In this case , are the mean and standard deviation values of the lognormal distribution, respectively. To determine the parameters μ, σ in the lognormal distribution, the following procedure can be used. Suppose the rainfall data is denoted by $R_j; j = 1,2,3, \dots, n$

1) Calculate the average return from rainfall data, namely $\mu = \frac{1}{n-1} ln \frac{R_n}{R_1}$ (Filipiapusa, 2019)
2) Calculate the return value from the rainfall data with $u_j = \text{in}\left(\frac{R_j}{R_{j-1}}\right); j = 2,3, \dots, n$
3) Calculate the mean return $\bar{u} = \frac{\sum_{j=2}^{n} u_j}{n-1}$
4) Calculate the unbiased annual standard deviation of $\sigma = \sqrt{\frac{1}{n-2} \sum_{i=1}^{n} (u_i - \bar{u})^2}$

   If the time period t is not a year, then $\tilde{\mu} = \mu. t$ dan $\tilde{\sigma} = \sigma. \sqrt{t}$

3.1. Data

The rainfall data selected are monthly rainfall and rice production data for North Sulawesi Province for three years from 2018 to 2020. The data are shown in the following table.

Table 1. Rainfall data for North Sulawesi Province in 2018-2020 (mm)

Period	2018	2019	2020
January	111	195	68.9
February	259	127	163.4
March	145	106	139.2
April	265	369	211.4
May	132	102	353.9
June	149	130	102.5
July	47	38,4	135.1
Agust	36	65	76.6
September	72	1	230.2
October	182	131.8	229.6
November	251	171	127.1
December	147	124	298.3

Table 2. Rice production data for North Sulawesi Province in 2018-2020 (thousand tons)

Period	2018	2019	2020
January	26.68	18.93	15.23
February	14.65	12.41	18.66
March	41.61	27.96	27.7
April	29.07	31.45	33.01
May	33.35	25.95	19.8
June	25.91	22.27	13.77
July	30.87	18.46	22.69

Agust	32.35	36.1	25.36
September	25.04	22.17	24.4
October	21.23	22.56	26.32
November	21.66	19.3	21.89
December	24.52	20.2	34.65

3.2. Rainfall and Rice Production Data Plot

Table 3 presents rainfall data calculated every four months (quarterly). The first quarter starting in January 2018-April 2020 is the amount of each rainfall in that period. Likewise for other data.

Table 3. Quarterly rainfall data for North Sulawesi Province in 2018-2020 (mm)

Periode	2018	2019	2020
Quarter 1 (January-April)	780	797	582.9
Quarter 2 (May-August)	364	335.4	668.1
Quarter 3 (September-December)	652	427.8	885.2

The plot of quarterly rainfall data for North Sulawesi Province from 2018 to 2020 can be seen in Figure 1.

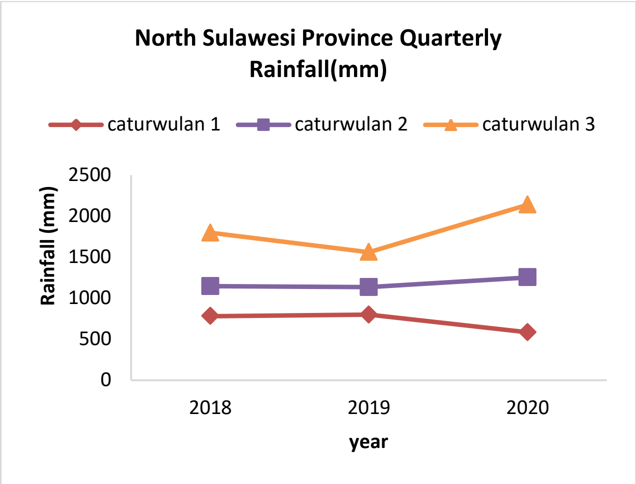

Figure 1. Plot of quarterly rainfall data for North Sulawesi Province in 2018-2020

Table 4 presents data on rice production per four months (quarterly). The data for the first quarter of rice production is the number of data on rice production from January to April. Likewise for other quarters.

Table 4. Quarterly rice production data for North Sulawesi Province in 2018-2020 (thousand tons)

Period	2018	2019	2020
Quarter 1 (January-April)	112.01	90.75	94.6
Quarter 2 (May-August)	122.48	102.78	81.62
Quarter 3 (September-December)	92.45	84.23	107.26

The plot of quarterly rice production data for North Sulawesi Province from 2018 to 2020 can be seen in Figure 2.

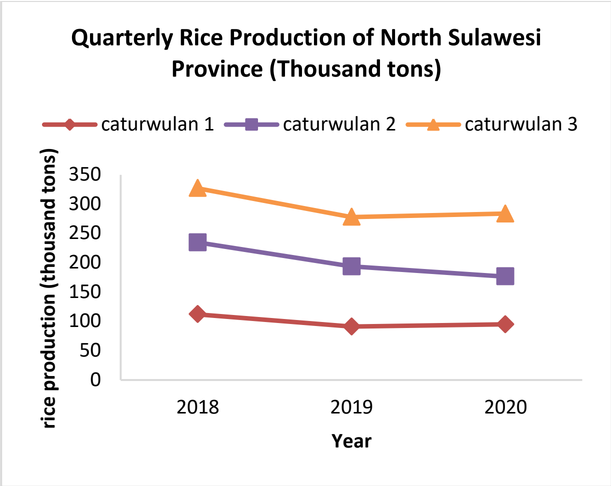

Figure 2. Plot of quarterly rice production data for North Sulawesi Province in 2018-2020

3.3. Determination of Rainfall Index

In determining the rainfall index, correlation test is used to determine the relationship between two variables. The rainfall index is based on rainfall with the strongest correlation to rice production. The calculation results can be seen in Table 5 below.

Table 5. Correlation value between quarterly rainfall and rice production

Rainfall	Rice Production		
	Quarter 1	Quarter 2	Quarter 3
Quarter 1	0.28	0.84	-0.96
Quarter 2	-0.27	-0.84	0.96
Quarter 1	0.16	-0.53	0.99

Table 5 shows that the third quarter rainfall data has a strong correlation with rice production, which is 0.99.

3.4. Normality test

Normality test is used to determine whether the data is normally distributed or not. In this study, the Kolmogorov-Smirnov test was used with a significance level of 0.05. The hypothesis is proposed as follows.

H_0 : The third quarter rainfall data ln is normally distributed

H_1: The third quarter rainfall data ln is not normally distributed

Table 6. Normality test results

	n	Count	Dtable
Rainfall	3	0.18615	0.798

3.5. Premium Price Calculation with Black-Scholes Model

The premium calculation uses equation (1). Then calculate the value of d_2 with equation (2). The value selected from the rainfall data is the one with the strongest correlation. Other data required is the risk-free interest rate r = 0.065 and the amount of compensation p = 6,000,000.00 rupiah.

The calculation of the premium for the 5th percentile with rainfall data is 450.22. With a risk-free interest rate of 6.5% per year and t = 0.25 and R_0 = 885.2 with equation (2), we get d_2 = 1.7590. From equation (1), the premium is 231912.09.

Table 7. Prices of agricultural insurance premiums for North Sulawesi Province in 2018-2020 with R_0 =885.2

Persentil		d2	(-d2)	N(-d2)	Premi
5%	450.22	1.759	-1.759	0.0393	231912
6%	454.7	1.7346	-1.7346	0.0414	244412
7%	459.19	1.7105	-1.7105	0.0436	257321
8%	463.67	1.6865	-1.6865	0.0458	270642
9%	468.16	1.6628	-1.6628	0.0482	284375
10%	472.64	1.6394	-1.6394	0.0506	298522
11%	477.12	1.6161	-1.6161	0.053	313082
12%	481.61	1.5931	-1.5931	0.0556	328055
13%	486.09	1.5703	-1.5703	0.0582	343442
14%	490.58	1.5476	-1.5476	0.0609	359241
15%	495.06	1.5252	-1.5252	0.0636	375451
16%	499.54	1.503	-1.503	0.0664	392071
17%	504.03	1.481	-1.481	0.0693	409099
18%	508.51	1.4592	-1.4592	0.0723	426533
19%	513	1.4376	-1.4376	0.0753	444369
20%	517.48	1,4162	-1.4162	0.0784	462607
25%	539.9	1.3117	-1.3117	0.0948	559681
30%	562.32	1.2115	-1.2115	0.1128	666178
35%	584.74	1.1152	-1.1152	0.1324	781443
40%	607.16	1.0226	-1.0226	0.1533	904695
45%	629.58	0.9333	-0.9333	0.1753	1035060
50%	652	0.8471	-0.8471	0.1985	1171599
55%	675.32	0.7606	-0.7606	0.2235	1319124
60%	698.64	0.677	-0.677	0.2492	1471172
65%	721.96	0.5961	-0.5961	0.2755	1626651
70%	745.28	0.5178	-0.5178	0.3023	1784505
75%	768.6	0.442	-0.442	0.3293	1943731
80%	791.92	0.3683	-0.3683	0.3563	2103391
85%	815.24	0.2969	-0.2969	0.3833	2262621
90%	838.56	0.2274	-0.2274	0.41	2420637
95%	861.88	0.1599	-0.1599	0.4365	2576737
100%	885.2	0.0941	-0.0941	0.4625	2730302

4. Conclusion

The implementation of AUTP stipulates that farmers only need to pay IDR 36,000.00 with government assistance of IDR 114,000.00 so that the total premium is IDR 180,000.00 per hectare per growing season. From the research results get a premium of IDR 231,912.09 at the 5% percentile.

From these results it can be concluded that the percentile and rainfall reference are very influential in calculating the amount of premium that must be paid. For suggestions that can be submitted is to try to use indexes other than rainfall such as climate index, temperature, humidity, etc. and determine quarterly based on conditions in Indonesia.

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