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Application of the Historical Burn Analysis Method in Determining Rainfall Index for Crop Insurance Premium Using Black-Scholes

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Abstract— Indonesia is an agricultural country where the rice sector has a high risk of production loss or crop failure. Agricultural Insurance is one of the government programs that helps farmers secure their farms. This research aims to obtain a rainfall index to determine crop insurance premiums. The rainfall index is being carried out using Historical Burn Analysis, which will produce exit and trigger values for the January 2014 - December 2022 index using secondary data from the Bali Climatology Station. In this study, Microsoft Excel 2016 was used as an application tool. The Black-Scholes method is used to calculate the premium in Jembrana Regency. The calculation of the rainfall index using the Historical Burn Analysis formula in determining agricultural insurance premiums using Black-Scholes can be used very well. The results show that the insurance premium value is very high, where the lowest premium is IDR 6.654.075, and the highest premium is IDR 6.781.555.

Keywords— Rainfall index, Crop insurance premium, Historical Burn Analysis, Black-Scholes

I. INTRODUCTION

Indonesia is a country that lies in both two continents and two oceans, placing Indonesia in a cross position in world economic activity. The positive impact of this geographical location makes rice one of the agricultural products widely grown by the Indonesian people. The total rice production in 2022 in Indonesia is 54.75 million tons of GKG, an increase of 0.33% compared to 2021 [1]. These data demonstrate that rice production in Indonesia is still growing, although not significantly. Agriculture is a sector of the economy with a high risk of production loss or crop failure [2]. There are various causes for losses, such as attacks by plant-disturbing organisms, and natural disasters such as floods and droughts because agriculture depends on the weather and climate in Indonesia, which is highly prone to change.

Agricultural Insurance has been regulated in UU No. 19 of 2013 concerning the Protection and Empowerment of Farmers. The government cooperates with Pupuk Indonesia Holding Company (PIHC), Pupuk Petrokimia Gresik Company, Pupuk Sriwijaya Company, Pupuk Kujang Company and JICA (Japan International Cooperation Agency) to contribute 80% premium. It establishes Jasindo Insurance Company as the insurer insurance company [3]. The premium charged is Rp 180,000/Ha/planting season, where the government will provide assistance to pay a premium of 80% and the insured farmer is 20%. It means that farmer should pay Rp 54.000/Ha/per planting season to protect their farming activity.

Many studies have chosen Bali Province as the location of the research study; this has influenced the choice of a research location in the Province of Bali. For example, the Jembrana Regency is one of the regencies in Bali Province that uses the agricultural sector to strengthen the regional economy. This regency has the most non-irrigation rice fields in Bali province, around 469 HA out of 640 HA [4].

The Jembrana Regency is a disadvantaged area with highly high people and natural resources but has been unable to expand swiftly and is very trustworthy due to various shortcomings [5]. Farmers in the Babakan in Jembrana Regency apply three planting seasons, namely planting season I (September-December), planting season II (January-April), and planting season III (May-July) [6]. The Jembrana Regency Government has collaborated with the Agriculture Service since 2105 to develop a Rice Farming Insurance scheme to safeguard farmers from crop failure losses in the Jembrana Regency [7].

The premium charge designed by the government might not suit different regions in Indonesia. There must be a consideration to calculate the fair premium price for the Insurance in each region. Through this research, it is expected to produce new standard agricultural insurance calculations based on the Jembrana Vilage rainfall index.

The use of the rainfall index is beneficial; it is one type of modern agricultural insurance that helps protect farmers from high losses [8][9].

II. METHOD

The data used in this research is rainfall index-based agricultural insurance premiums. The data used in this study are secondary, namely daily rainfall data from 2014-2022 in Jembrana Regency, obtained from the online data of the Meteorology, Climatology, and Geophysics Agency.

A. *Historical Burn Analysis Method to Determining Rainfall Index*

The historical burn analysis approach looks to the past to predict what could happen in the future. The International Research Institute for Climate and Society from Columbia University created this method. Historical burn analysis is an excellent first step in pricing almost any contract [10].

There are several steps involved in applying Historical Burn Analysis to calculate the rainfall index, such as [11]:

1. Determine the period to be insured (index window)
2. Calculate the monthly rainfall every ten days *(dekad)* based on the period to be insured using the formula:

$$Dekad_1 = \sum_{x=1}^{10} day_x \tag{1}$$

$$Dekad_2 = \sum_{x=1+10}^{20} day_x \tag{2}$$

$$Dekad_3 = \sum_{x=1+20}^{30} day_x \tag{3}$$

3. Determine the stamp value. The cap value denotes the maximum rainfall per 10-day period (dekad). The daily potential evapotranspiration value is used to determine the cap value. The following is a table of ETp values for tropical areas based on [12] follows:

TABLE 1
Average ETp (mm/day)

Region	Tropical and Subtropical Average Daily Temperature Cold ~10°C	Medium ~20°C	Warm >30°C
Moist and sub-moist	2-3	3-5	5-7
Dry and semi-dry	2-4	4-6	6-8

Jembrana Regency has a type C to D climate with temperatures ranging from 20C to 39C and a humidity level of 74% - 87% [4]. Based on Table 3.1, the average ETp value in Jembrana Regency is 5mm/day. The formula for calculating the cap is:

$$Cap_{dekad} = ETp\ x\ 10\ day \tag{4}$$

4. Calculates adjusted rainfall that has been adjusted to the cap value. If the adjusted rainfall value is less than the cap value, then the adjusted rainfall value is used. If the adjusted rainfall value is greater than the

cap value, then the cap value is used. Then, determine the average adjusted total rainfall per year and arrange it from the lowest to the highest.

5. Determine the Exit value, which is the lowest value of the total adjusted rainfall, and the Trigger value, which is the percentile of the total adjusted rainfall

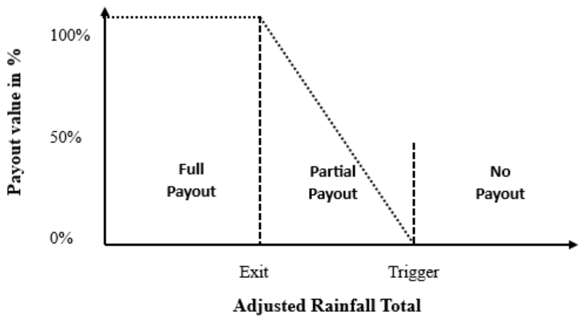

Figure 2.2 The concept of agricultural insurance payout

Payment will be given according to the total amount of rainfall for the contract date. If the amount of rainfall is less than the exit value, payment will be given in full. A partial payout will be given if the total rainfall is between the exit value and the trigger value. There will be no payment if the total rainfall exceeds the trigger value.

In conclusion, the Historical burn will calculate the rainfall index. While the premium calculation is calculated using the Black-Scholes Method.

B. *Black-Scholes Method to Determining Insurance Premium*

The Black–Scholes formulas allow us to determine a fair price at time zero for a European call or put option in terms of the initial asset price. Black-Scholes formula was published in a journal entitled "The Pricing of Option and Corporate Liabilities" by Fischer Black and Myron Scholes in 1973. The formula of the European Put Option using Black-Scholes is [13].

$$\mathrm{P} = \mathrm{K}\, \mathrm{e}^{-\mathrm{rt}}\Phi(-\mathrm{d}_2) - \mathrm{S}_0\Phi\,(-\mathrm{d}_1) \tag{5}$$

where,

$$\mathrm{d}_2 = \frac{\ln(\frac{\mathrm{S}_0}{\mathrm{K}}) + \left(\mathrm{r} - \frac{\sigma^2}{2}\right)\mathrm{t}}{\sigma\sqrt{t}} \tag{6}$$

$$\mathrm{d}_1 = \frac{\ln(\frac{\mathrm{S}_0}{\mathrm{K}}) + \left(\mathrm{r} + \frac{\sigma^2}{2}\right)\mathrm{t}}{\sigma\sqrt{t}} \tag{7}$$

The $\Phi(-\mathrm{d}_2)$ is the normal distribution cumulative density of d_2, and $\Phi(-\mathrm{d}_1)$ is the normal distribution cumulative density of d_1. In determining the price of insurance index using the Black-Scholes method, one can consider the following:

1. The crop insurance based on the climate index will give a payoff if the actual rainfall data (R_0) is less than equal to the triggered measurement(R_T). Therefore, R_T (triggered rainfall) will replace K as the triggered measurement in cash-or-nothing put options.
2. A lump sum (fixed payment) is the payout structure for the cash-or-nothing put option and the index insurance.
3. The index insurance follows a lognormal distribution

Thus, the value of agricultural insurance premiums based on rainfall index can be calculated by equation [14][15]:

$$\text{Premium} = \mathrm{P}\, \mathrm{e}^{-\mathrm{rt}}\Phi(-\mathrm{d}_2) \tag{8}$$

where P is the sum insured, r is the interest rate, t is time, $\Phi(-d_2)$ is the probability of rainfall is less than the trigger value.

III. RESULT AND DISCUSSION

A. *Determination of the rainfall index*

This research uses the Historical Burn Analysis method to measure the rainfall index and its performance in the Jembrana Regency. The initial step is determining the window index or daily rainfall data; the selected window index is January 2014 - December 2022. Then, calculate the essential rainfall, which is presented in Table 1.

TABLE 2
Dekad rainfall data in 2014 – 2022 in mm

Dekad	**Years**								
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	82,4	71,9	22	65	110,1	65,6	50,9	84,9	130,1
1	36,1	178,8	0,5	67,9	125,5	71,4	43,6	97,7	100,3
	125,8	23,7	79,7	228,8	242,5	103,2	14,2	106	12,3
	32,6	53,1	114,4	72,3	137,8	107,1	58,4	200,1	81,8
2	42,7	43,3	145,5	124,9	77,9	142	119,2	106,4	127,1
	66,5	34,5	132,9	8,7	79,9	54,3	69	140,1	37,7
	5	97,5	28	8,7	144,3	114,3	121,3	108	50,1
3	93	26,1	99,5	82,3	33,7	170,2	117	65,3	44,5
	56	35	20,4	67,1	54,8	136,9	57,8	22,2	198,7
	30	26,4	75,9	50,9	46	86,3	70,1	42,8	57,7
4	44	9,5	71,6	1	102,8	80,5	64	27	45,1
	34	128	33,1	14,1	55,3	37,4	16,8	0	42
	14	35,6	58,6	55,2	4,4	69,5	9,6	6,5	61,9
5	84	2,5	46,4	0	31,3	6,5	50	0	0,9
	13	43	17,4	173,2	41,6	223,1	204,4	16,4	36,4
	17,6	131,9	46	11,4	0	0,6	23,2	10,8	38,6
6	0	0	64,3	35,3	19	28,2	5,4	27,6	178,5
	1,5	0	45,9	187,3	34,5	0	19,5	75,8	11,4
	12	0	45,9	31,9	9,8	1,9	73,1	1,5	18
7	36	7	100,4	11,4	2,4	5,8	21,2	0	12,2
	9	5,1	56	45,8	4,8	2,5	30,9	2,4	0
	20	1,5	32,2	27,5	30,8	8,8	1,6	134,8	64,6
8	2	1,2	109,8	19,4	65,4	6,3	46,2	101	40,4
	1	0	7,1	14,9	33,8	4	8,2	1,7	14,5
	0	5	3,1	0,4	11,7	0	41,2	46,7	10,2
9	2,2	0	61,3	0,8	10,7	1,7	1,2	114,9	198,6
	1	0	56,5	48	0	0	51,3	181,9	26,1
	12	28,3	132,5	142,5	0	0	110,5	54,5	169,9
10	9	2,1	78,5	116,1	4	0	165,5	11,5	346,5
	0	5,9	81,1	14,9	0,3	0	68,8	114,2	94,1
	21	3,4	124,7	113,5	194,1	16,5	50,2	154,6	73
11	88	3,8	76,7	152,6	72,6	0	203,8	137,8	64,8
	77	0	88,9	289,2	319,4	8,9	200,2	176,4	171,3
	121,9	100,9	75,8	121,1	83,9	0	56,1	61,2	138,3
12	93,3	89,3	85,7	194,5	125,1	126,2	35,9	63,7	25,4
	163,7	52,9	39,5	153	89,3	15,1	58,6	87,1	93,2

The adjusted total rainfall value is determined based on the primary and cap rainfall data. The amount of the cap value is determined by the ETp value with the humidity category and the average daily temperature of the Jembrana Regency area; it can be calculated as Cap dekad = 50 mm.

TABLE 3
Adjusted Rainfall Total Data

Dekad	**Years**								
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	50	50	22	50	50	50	50	50	50
1	36,1	50	0,5	50	50	50	43,6	50	50
	50	23,7	50	50	50	50	14,2	50	12,3
	32,6	50	50	50	50	50	50	50	50
2	42,7	43,3	50	50	50	50	50	50	50
	50	34,5	50	8,7	50	50	50	50	37,7
	5	50	28	8,7	50	50	50	50	50
3	50	26,1	50	50	33,7	50	50	50	44,5
	50	35	20,4	50	50	50	50	22,2	50
	30	26,4	50	50	46	50	50	42,8	50
4	44	9,5	50	1	50	50	50	27	45,1
	34	50	33,1	14,1	50	37,4	16,8	0	42
	14	35,6	50	50	4,4	50	9,6	6,5	50
5	50	2,5	46,4	0	31,3	6,5	50	0	0,9
	13	43	17,4	50	41,6	50	50	16,4	36,4
	17,6	50	46	11,4	0	0,6	23,2	10,8	38,6
6	0	0	50	35,3	19	28,2	5,4	27,6	50
	1,5	0	45,9	50	34,5	0	19,5	50	11,4
	12	0	45,9	31,9	9,8	1,9	50	1,5	18
7	36	7	50	11,4	2,4	5,8	21,2	0	12,2
	9	5,1	50	45,8	4,8	2,5	30,9	2,4	0
	20	1,5	32,2	27,5	30,8	8,8	1,6	50	50
8	2	1,2	50	19,4	50	6,3	46,2	50	40,4
	1	0	7,1	14,9	33,8	4	8,2	1,7	14,5
	0	5	3,1	0,4	11,7	0	41,2	46,7	10,2
9	2,2	0	50	0,8	10,7	1,7	1,2	50	50
	1	0	50	48	0	0	50	50	26,1
	12	28,3	50	50	0	0	50	50	50
10	9	2,1	50	50	4	0	50	11,5	50
	0	5,9	50	14,9	0,3	0	50	50	50
	21	3,4	50	50	50	16,5	50	50	50
11	50	3,8	50	50	50	0	50	50	50
	50	0	50	50	50	8,9	50	50	50
	50	50	50	50	50	0	50	50	50
12	50	50	50	50	50	50	35,9	50	25,4
	50	50	39,5	50	50	15,1	50	50	50

From Table 3, look for the average total adjusted rainfall value each year and sort it from the smallest to the largest value to get the exit and trigger values.

TABLE 4
Average Adjusted Rainfall Total Data

Years	**Season I**	**Season II**	**Season III**
2014	39,53	14,68	24,60
2015	37,38	12,16	16,54
2016	37,83	40,91	45,22
2017	36,04	28,97	38,68
2018	48,31	21,87	27,23
2019	48,95	13,72	7,68
2020	43,72	26,32	44,03
2021	41,00	18,08	46,52
2022	44,30	26,87	42,64

The exit value is the lowest value of the average adjusted total rainfall presented in Table 4. This value is a benchmark for whether insurance claims will be paid. The trigger value is based on the percentile values of the average annual adjusted total rainfall, which have been sorted from lowest to highest. The exit values and trigger values obtained are presented in Table 5.

TABLE 5
Trigger and Exit value

Average Adjusted Rainfall Total Per Planting Season					
Years	**Season I**	**Years**	**Season II**	**Years**	**Season III**
2017	36,04	2015	12,16	2019	7,68
2015	37,38	2019	13,72	2015	16,54
2016	37,83	2014	14,68	2014	24,60
2014	39,53	2021	18,08	2018	27,23
2021	41,00	2018	21,87	2017	38,68
2020	43,72	2020	26,32	2022	42,64
2022	44,30	2022	26,87	2020	44,03
2018	48,31	2017	28,97	2016	45,22
2019	48,95	2016	41,58	2021	46,52

B. *Descriptive Statistic*

TABLE 6
Descriptive Statistic Adjusted Rainfall Data

Description	**Planting Season I**	**Planting Season II**	**Planting Season III**
Mean	41,89537037	22,69166667	32,56944444
Median	41	21,86666667	38,675
Standard Deviation	4,711341427	9,384860555	14,10991574

In this statistical calculation, the descriptive statistical results for each planting season are very different as the mean value, the average value, and the median, the middle value of the three planting seasons, are very different. For the standard deviation value, it is known that the smallest value came from planting season 1, namely 4.71. This shows that rice rainfall in planting season 1 has distribution data close to the mean compared to rainfall in planting seasons II and III.

C. *Sum Insured*

Determining the sum insurance value is based on production capital costs and operational costs was obtained from the research [16] sourced from the online data website of the Ministry of Agriculture in 2019, which has been deleted.

TABLE 7
CAPITAL COSTS PER HA

Item	Price (IDR)
Paddy seed 20kg	200.000
Manure fertiliser 100kg	1.000.000
Urea fertiliser 200kg	360.000
NPK Phonska Fertilizer 300kg	1.920.000
Pesticide	250.000
Total	**3.730.000**

TABLE 8
OPERATIONAL COSTS PER HA

Item	Price (IDR)
Wholesale land processing	1.000.000
Removing seeds + planting 20 working people days	1.000.000
1st wedding + fertilising six working people days	300.000
2nd wedding + fertilising six working people days	300.000
Spraying four working people days	200.000
Harvest and post-harvest 12 working people days	600.000
Drying six working people days	300.000
Total	**3.700.000**

From Table 7 and Table 8, it can be seen the total cost is IDR 7.430.000, where this value is used as the payout and is higher than the insured value set by the government at IDR 6,000,000.

D. *Determination of the crop insurance*

In this study, the determination of agricultural insurance premiums using the Black-Scholes method, cash-or-nothing put option type. Based on the Black-Scholes method, to determine the insurance premium with the sum insured (P) is IDR 7.430.000, the selected time (t) is 0,25. Interest rate (r) is 5,25%, based on the BI-7 Day Reserve Repo Rate on August 24th 2023. The most recent rainfall (R_0) is 25,90 mm, taken from the first dekad in January 2023. H is the trigger value used for each percentile. The first is to calculate the value of d_2.

For H = 37,11

$$\mathrm{d}_2 = \frac{\ln\left(\frac{25{,}90}{37{,}11}\right) + \left(5{,}25\% - \frac{4,71^2}{2}\right)0{,}25}{4{,}71\sqrt{0{,}25}} = -1{,}324916013$$

For H = 13,41

$$\mathrm{d}_2 = \frac{\ln\left(\frac{25{,}90}{13{,}41}\right) + \left(5{,}25\% - \frac{9{,}38^2}{2}\right)0{,}25}{9{,}38\sqrt{0{,}25}} = -2{,}203061132$$

For H = 14,77

$$\mathrm{d}_2 = \frac{\ln\left(\frac{25{,}90}{14{,}77}\right) + \left(5{,}25\% - \frac{14{,}10^2}{2}\right)0{,}25}{14{,}10\sqrt{0{,}25}} = -3{,}446008587$$

Once the value of 2 is obtained, the next is to calculate the value $\Phi(-\mathrm{d}_2)$ with the help of the command NORMSDIST in Microsoft Excel 2016 software.

$$\Phi(-1{,}324916013) = 0{,}907400495$$
$$\Phi(-2{,}203061132) = 0{,}98620478$$
$$\Phi(-2{,}203061132) = 0{,}999715534$$

What comes next is calculating the crop insurance premium value.

For $\Phi(-d_2) = 0{,}907400495$

$$\text{Premium} = (7.430.000)e^{-(0{,}0525)(0{,}25)}(0{,}907400495) = \text{IDR } 6.654.075$$

For $\Phi(-d_2) = 0{,}98620478$

$$\text{Premium} = (7.430.000)e^{-(0{,}0525)(0{,}25)}(0{,}98620478) = \text{IDR } 7.231.956$$

For $\Phi(-d_2) = 0{,}999715534$

$$\text{Premium} = (7.430.000)e^{-(0{,}0525)(0{,}25)}(0{,}999715534) = \text{IDR } 7.331.032$$

The amount of premium to be paid for other percentile values can be seen in Table 9 as follows.

TABLE 9
SUMMARY OF PREMIUM VALUE BASED ON RAINFALL INDEX

Percentiles	Season I	Season II	Season III	Benefit
10	6.654.075	7.231.956	7.331.032	6.687.000
20	6.661.527	7.235.431	7.331.402	5.944.000
30	6.673.063	7.241.416	7.331.561	5.201.000
40	6.689.854	7.249.246	7.331.674	4.458.000
50	6.704.134	7.255.990	7.331.870	3.715.000
60	6.728.948	7.262.316	7.331.923	2.972.000
70	6.738.581	7.264.187	7.331.947	2.229.000
80	6.757.440	7.265.712	7.331.962	1.486.000
90	6.781.555	7.270.352	7.331.976	743.000

From the three planting season calculations above, it is known that the results of calculating crop insurance premiums using Jembrana Regency rainfall data in the planting season I are the best premiums among other planting seasons. However, the premium value is still relatively high. The calculation above proves that the higher the rainfall used as a trigger value, the greater the premium that must be paid.

IV. CONCLUSION

In determining the rainfall index, the Historical Burn Analysis method by the International Research Institute for Climate and Society from Columbia University is used, which produces exit and trigger values. Rainfall index values, descriptive statistics values, and sum insured values previously searched will be used to find the value of agricultural insurance premiums using the Cash-or-nothing Put Option formula based on the Black-Scholes theory.

The application of the Historical Burn Analysis method in determining the rainfall index for crop insurance premiums using Black-Scholes cannot provide good premium results; one of the leading causes is the high standard deviation value of rainfall data in Jembrana Regency because to get the best premium the researcher must use rainfall data that has a small standard deviation value and high bulk value as stock price value. Hence, it’s not ideal to calculate the premium based on the Black-Scholes model under these circumstances. It suggested adding more concerns, such as barrier or another approach to find a fairly premium for Jembrana regency, such as surface temperature in determining the index using the Historical Burn Analysis method or Weibull distribution, Mean Reversion model, the Stochastic Weather Generator, etc.

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