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Black-Scholes Method for Rainfall Index-Based Agricultural Insurance Premiums

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ABSTRACT

Agriculture plays an important role in national economic development. However, it has the highest risk of loss due to its dependence on climate conditions. One of the efforts to reduce the risk of crop failure is through an agricultural insurance program. This study aimed to analyze the value of the rainfall climate index used and the calculation of agricultural insurance premiums based on it. The method used to determine the rainfall climate index was the historical burn analysis method, while the method used to calculate agricultural insurance premiums was the Black-Scholes method. The study showed significant spatial variation in rainfall index-based agricultural insurance premiums across Sumatra. Premiums rose with higher percentiles, with North Sumatra the highest (IDR 3.28–3.55 million) and Aceh the lowest (IDR 100–137 thousand). The inclusion of all rainfall stations revealed a more detailed spatial pattern. Overall, premiums strongly reflect local climatic conditions and can aid risk assessment and insurance planning.

1. Introduction

The agricultural sector is one of Indonesia’s crucial sectors. Therefore, the farm sector is the government’s main focus in maintaining food security and supporting national economic growth. Historical data from the Statistics Indonesia (Badan Pusat Statistik, BPS) in 2014 indicated that this sector contributed approximately 14%–15% to Indonesia’s gross domestic product (GDP) during the 2009–2013 period. Subsequently, the sector demonstrated a significant growth trend between 2015 and 2019. However, according to a report by the Ministry of Agriculture, the sector faced challenges starting in 2020 due to the global impact of the COVID-19 pandemic. Despite this disruption, the sector exhibited resilience and showed a gradual recovery from late 2020 through 2023. By the third quarter of 2023, the agricultural contribution to GDP reached 13.57%, as stated in the latest report by the Ministry of Finance [1].

Natural disasters, climate change, the threat of plant diseases, and pest attacks are risk factors that can cause financial losses and endanger the agricultural sector in the future. Agricultural insurance is one instrument that can be used to transfer risks that farmers cannot manage, especially the crop failure risk caused by these risk factors [2]. In simple terms, transfer risk refers to a mechanism by which farmers transfer the financial consequences of crop failure to a third party (the insurer) in exchange for a premium payment. The ASEAN Guideline on Agricultural Insurance

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Implementation reports that the implementation of agricultural insurance is still relatively new in Southeast Asian countries, except for the Philippines, which has implemented agricultural insurance for 40 years in subsidies to small farmers. In the last decade, Thailand and Indonesia have also developed national agricultural insurance programs through subsidies to small farmers to develop land and provide coverage when losses occur due to crop failure. The national agricultural insurance program that Indonesia has developed seeks to protect farmers through Law Number 19 of 2013 concerning the implementation of agrarian insurance [3]. The protection provided includes coverage for losses due to crop failure due to natural disasters, climate change, plant diseases, and pest attacks. The spatial distribution of rainfall risk, which is a key factor in these natural disasters, can be seen in the map of rainfall forecast distribution for December 2023 in Indonesia, as shown in Fig. 1.

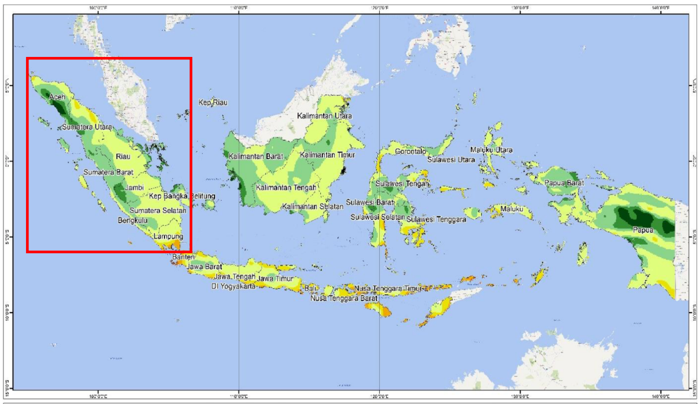

Fig. 1 Map of rainfall forecast distribution for December 2023 in Indonesia [1].

Climate risk in rice farming is closely related to extreme climate events such as floods and droughts. Floods can occur due to high rainfall in an area. The Meteorology, Climatology, and Geophysics Agency (Badan Meteorologi, Klimatologi, and Geofisika, BMKG) stated that most of Indonesia entered the rainy season in early Quarter IV 2023. While many zones experienced less rainfall than the long-term average, Fig. 1 shows that certain regions, particularly Sumatra, received relatively high rainfall intensity in December 2023.

The peak of the rainy season would occur in the first quarter of 2024, especially in southern Sumatra; according to the Ministry of Agriculture, floods disrupted rice plant growth from October to December 2023. Aceh was the most affected area, with floods affecting more than 7,500 Ha of rice fields in December 2023, causing crop failures of more than 1,800 Ha. Based on the distribution map of the March 2024 rainfall forecast, almost all parts of Indonesia had the potential for high rainfall ranging from 301-500 mm/month, such as in parts of Aceh Province, a small part of North Sumatra, part of West Sumatra, part of Jambi, Bengkulu, part of South Sumatra, Lampung.

One approach to developing agricultural insurance products is parameter- or index-based insurance (parametric index-based insurance). This type of insurance provides several payments to policyholders when the agreed parameters/indexes are met, without requiring evidence of crop failure. In other words, the crop and the index will be covered. The insured index can vary, including the climate in an agricultural area. In climate index-based insurance, insurance payments are given to farmers if the fulfilment of weather or climate conditions is not expected. One of the advantages of climate-based agricultural insurance is that there is no need to estimate the losses experienced by farmers [4].

Rainfall is usually recorded continuously every day, but sometimes, there are no rainfall records on certain days, even though it rains. A prior study showed that the historical burn analysis method could be used in areas with limited climate data. This method was used to compile an index and determine the lowest value of the average (exit) total rainfall based on adjusted ten-day (ten-day) rainfall data [5]. In addition, several previous studies have recently attempted to research the implementation of the Black-Scholes method in calculating stock price option prices. A similarity between insurance and put options is that both protect against the risk of loss. The put option holder

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can sell assets at a specific price, while the insurance policyholder will receive compensation payments if an insured event occurs. Obtaining protection in insurance and put options requires payment of a certain premium or fee. The premium in insurance is called the insurance premium, while input options are the option price [6]. One method that can be used to calculate the price of a put option is the Black-Scholes method, which can be adapted to calculate insurance premiums based on climate indexes. This approach is widely adapted for climate index insurance because the payout mechanism mirrors a put option strategy, where the insurance ‘strike price’ represents the minimum rainfall threshold required for successful harvest. This method allows for more accurate premium calculations by considering parameters such as rainfall volatility, threshold values (triggers), and probability distributions of extreme events. Based on this research, the Black-Scholes method can determine the calculation of option prices well, so in this study, it is hoped that the Black-Scholes method can be implemented well in calculating agricultural insurance premiums based on rainfall in several regions. This topic is increasingly getting attention along with the intensifying El Niño phenomenon. However, Sumatra presents a unique climatological challenge due to its exposure to El Niño phenomenon. The island’s complex topography, dominated by the Bukit Barisan mountain range, creates high spatial variability in rainfall patterns, making standard insurance models difficult to apply. Despite its role as a critical hub for national agricultural commodities, to date, no comprehensive index-based insurance mechanisms have been implemented across the region. Therefore, considering its high climate volatility and economic significance, Sumatra was selected as the focal point of this study.

In this study, agricultural insurance premiums were calculated based on the rainfall index using the Black-Scholes method to protect against crop failure due to extreme rainfall changes. If there is a payment to be made by the insurance company in the future, then there are several premiums that the insurance company must charge to the insured for an insurance policy [7]. In this study, several differences found in the value of agricultural insurance premiums based on the rainfall index in various regions on the island of Sumatra. These differences were caused by the rainfall of each region on the island of Sumatra. Therefore, in this study, each region’s exit and trigger values on the island of Sumatra were sought first using the historical burn analysis method. Then, the value of agricultural insurance premiums from each region was calculated using the Black-Scholes method [8]. Furthermore, the results of the premium calculation were connected to each area on the island of Sumatra.

2. Method

2.1. Rainfall Climate Index

Rain and rainfall are critical components in meteorology and climatology, affecting various aspects of human life and ecosystems. Agriculture, aviation, shipping, and several other fields involve climate factors as determining factors, especially rainfall. According to the BMKG, rainfall is defined as the depth of water accumulated on a flat horizontal surface, assuming no evaporation, infiltration, or runoff occurs during the measurement period [9]. Furthermore, BMKG specifies that one millimeter of rainfall equals one liter of rainwater in an area of one square meter (1mm = 1 liter/m2). Based on these measurements, the specific criteria for classifying daily rainfall intensity in Indonesia are presented in Table 1.

Table 1. Criteria for Rainfall Intensity in Indonesia [9]

Rain Criteria	Rainfall Intensity
Cloudy	0 mm/days
Light Rain	0.5-20 mm/ days
Moderate Rain	20-50 mm/ days
Heavy Rain	50-100 mm/ days
Very Heavy Rain	100-150 mm/ days
Extreme Rain	>150 mm/ days

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2.2. Linear Interpolation

Linear interpolation is a method used to estimate the value of a variable between two known data points [10]. Mathematically, linear interpolation between two points $P(x_0, y_0)$ and $P(x_1, y_1)$ can be expressed as shown in (1) [10]:

$$y = y_0 + \frac{y_1 - y_0}{x_1 - x_0} \times (x - x_0) \qquad (1)$$

Linear interpolation can be illustrated by two points, (x_0, y_0) and $P(x_1, y_1)$, connected by a line, as shown in Fig. 2.

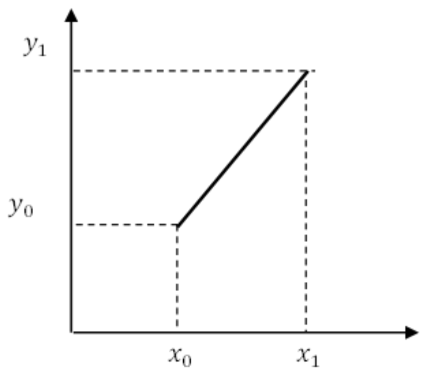

Fig. 2 Linear interpolation graph [10].

2.3. Historical Burn Analysis

The calculation of premium value when only rainfall data are available uses the historical burn analysis method developed by the International Research Institute (IRI), Columbia University. This method is highly recommended for use in areas that have limited climate parameter data information, so it relies on past data that are useful for providing an overview of the possibilities that will occur in the future. This approach assumes that the coming year will look like one of the years that have already occurred [11]. Therefore, long-time series data determines the trigger and exit for the upcoming season index. The total rainfall used to decide the rainfall index is the adjusted rainfall total. The conceptual framework of insurance payments based on this index, calculated through the historical burn analysis method, is illustrated in Fig. 3.

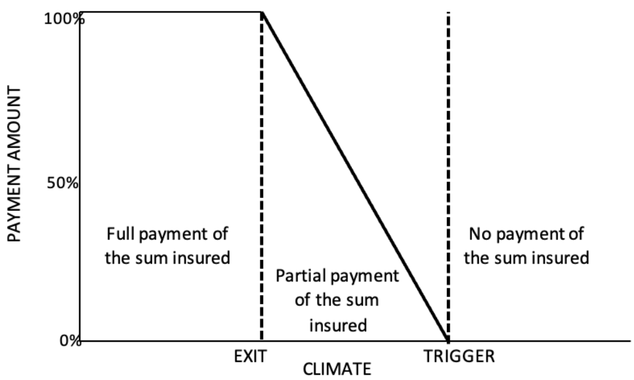

Fig. 3 Insurance payment concept using historical burn analysis method [11].

Based on Fig.3, insurance payments rely on trigger values and exit values to determine the compensation amount for farmers. There is an inverse relationship between the rainfall index and the payout: as the recorded rainfall falls below the trigger value and approaches the exit value, the insurance payout increases proportionally. The trigger value represents the rainfall threshold that initiates the payment, while the exit value is the lower limit at which the maximum (full) payout is granted. Each window or insured index, which spans a duration of to capture specific crop growth

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stages, has its own specific trigger and exit values [12]. The stages of analysis using the historical burn analysis method are as follows.

a. Determining the year and period to be insured or determining the window index.
b. Determining the value of $Cap_{dasarian}$ representing the maximum amount of rainfall calculated each *dasarian* period (ten days) [12]. The $Cap_{dasarian}$ value is determined using the daily potential evapotranspiration (ETp) value, as seen in the Table 2 [13].

Table 2. Average ET_p values (mm/day) for various agroclimatic regions [13].

Region	Average daily temperature (℃)		
	Cold (~**10**℃)	*Medium* (~**20**℃)	*Warm* (> **30**℃)
Tropical and Subtropical			
Moist and sub-moist	2-3	3-5	5-7
Dry and semi-dry	2-4	4-6	6-8
Temperate climate region			
Moist and sub-moist	1-2	2-4	4-7
Dry and semi-dry	1-3	4-7	6-9

Indonesia is a tropical country characterized by two distinct seasons: the rainy (wet) season and the dry season [14]. According to Table 2, the average daily temperature in Indonesia ranges from $2^{\circ}C$ to $8^{\circ}C$. To estimate the average ETp based on temperature, the Hargreaves method was utilized, yielding an average ETp value of 5 mm/day for Indonesia. In this study, the assumption of the ETp value was 5 mm/day [13]. Thus, the $Cap_{dasarian}$ value for 10 days was calculated using (2):

$$Cap_{dasarian} = ETp\ (mm) \times 10h\ . \quad (2)$$

c. Determine the adjusted rainfall total using the sum of rainfall for each decade and the $Cap_{dasarian}$ value. If the ten-day rain exceeded the $Cap_{dasarian}$ value, the total rainfall was used for the following period. Meanwhile, if the total rain in ten days was more than the $Cap_{dasarian}$value, then the $Cap_{dasarian}$value was used. The $Cap_{dasarian}$value represents the maximum rainfall calculated every ten days (decade).
d. Calculating the average adjusted rainfall total for each year aimed to determine the lowest and highest rainfall values.
e. Compiling rainfall data that had been adjusted each year from top to bottom, starting from the lowest to the highest rainfall.
f. The exit value was the lowest point value of the average adjusted rainfall total, while the trigger value was the percentile of the average adjusted rainfall total value that had been adjusted from the lowest value to the highest value using the single data percentile formula, as presented in (3).

$$P_i = The\ n^{th} - \frac{i(n+1)}{100}. \quad (3)$$

2.4. Black-Scholes Method

The Black-Scholes method is a mathematical description of financial markets and investment instrument derivatives. Derivatives are financial instruments whose value relies on underlying assets like stocks and commodities. For options, a specific class of derivatives, the Black-Scholes method is widely used for valuation. Derivatives are financial instruments whose value depends on the underlying asset's value, such as stocks, commodity prices, interest rates, and currencies [15]. One type of derivative is options; the Black-Scholes method is a valuation method for determining option prices.

The Black-Scholeuation is widely used in estimating the price of a European option over time [16]. A European Option is an option that can only be exercised at maturity. In the context of agricultural insurance, this European framework is particularly appropriate because the rainfall index

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is calculated based on cumulative precipitation over a fixed planting season. Consequently, the determination of payout (whether the index falls below the threshold) can only be finalized at the end of this period (maturity). Based on the type of rights granted to shareholders, stock options are divided into two types, namely call options and put options. In this study, a put option was used. In a put option, if the stock price at maturity is less than the strike price or $S_T < K$, the profit obtained is $K - S_T$. Meanwhile, if $S_T \geq K$, the put option holder does not exercise his rights, so the profit is zero [17]. The strike price is a fixed price determined in the option contract where the holder has the right to sell the underlying asset [18]. The mathematical equation for the cost of a European-type put option can be expressed as follows.

$$P = \begin{cases} K - S_T & ; jika\ S_T < K, \\ 0 & ; jika\ S_T \geq K, \end{cases}$$

so that,

$$P = maks(0, K - S_T). \tag{4}$$

Equation (4) can be shown in Fig. 4:

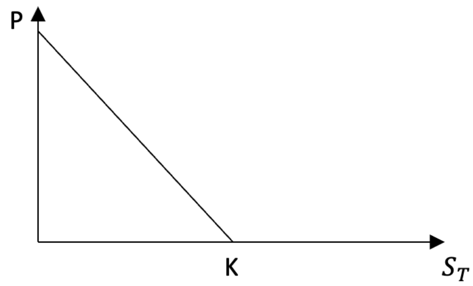

Fig 4. Put option price chart at expiration [16].

The Black-Scholes method was developed in 1973 by Fischer Black, Myron Scholes, and Robert Merton; this model is based on the Black-Scholes equation, which can estimate the price of a European option over time. The option used as a reference is a European-type put option, which can only be used at maturity. By adapting (5), formulated a European-type put option by considering the time and the opportunity for price differences in the future. In general, a European-type put option is written as in (5) [19].

$$P = e^{-rt} E\big(max(K - S_T, 0)\big). \tag{5}$$

The solution can be obtained through the put-call parity relationship to determine the solution of the Black-Scholes partial differential equation related to European-type put options. Put-call parity is the relationship between the price of a European-type call option (C) and the cost of a European-type put option (P) on a stock [18]. Generally, European type Put-Call parity is formulated (6) [18].

$$P = C + Ke^{-r(T-t)} - S. \tag{6}$$

Thus, the Black-Scholes partial differential equation for the European type put option is as follows.

$$P\ = Ke^{-r(T-t)} N(-d_2) - SN(-d_1) \tag{7}$$

where

$$d_1\ = \frac{ln\frac{S}{K} + \left[\left(r + \frac{\sigma^2}{2}\right)(T-t)\right]}{\sigma\sqrt{T-t}} \tag{8}$$

and

$$d_2 = \frac{ln\frac{S}{K} + \left[\left(r - \frac{\sigma^2}{2}\right)(T-t)\right]}{\sigma\sqrt{T-t}}. \tag{9}$$

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2.5. Premium

There are some similarities between option pricing and index-based insurance. Therefore, index-based insurance can be formulated in the same way as option pricing. In determining the price of index-based insurance using the Black-Scholes method, consider that the trigger value in index-based insurance is H and the payment is paid at once. Using (9), the premium value of index-based insurance can be calculated by first finding the cumulative distribution value d_2 using (10):

$$d_2 = \frac{ln\left(\frac{R_0}{H}\right)+\left(r-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{10}$$

where $R_0$is the last rainfall value, H is the trigger value (rainfall selected as the index), and r is the risk-free interest rate. Agricultural insurance is based on rainfall, the insured value of which depends on the rainfall realization and is designed as a European-type put option, which can be defined as follows.

$$Payout = \begin{cases} A & ,for\ R_0 > H \\ 0 & ,else \end{cases} \tag{11}$$

where A is the insurance value. Thus, the value of agricultural insurance premiums based on the rainfall index can be calculated using (12).

$$Premium = A\,e^{-rT}N(-d_2). \tag{12}$$

3. Results and Discussion

Data collection in this study utilized secondary data obtained from BMKG. The dataset comprised daily rainfall records sourced from 10 weather observation stations, with one representative station selected for each province across Sumatra Island. The observation period spanned from 2019 up to January 2024, specifically focusing on the harvest season windows of January–April and October–December. This time-series dataset was utilized to calculate agricultural insurance premiums based on climate indices for the region. The differences in the annual variation patterns of rainfall were visualized using a graph, as shown in Fig 5.

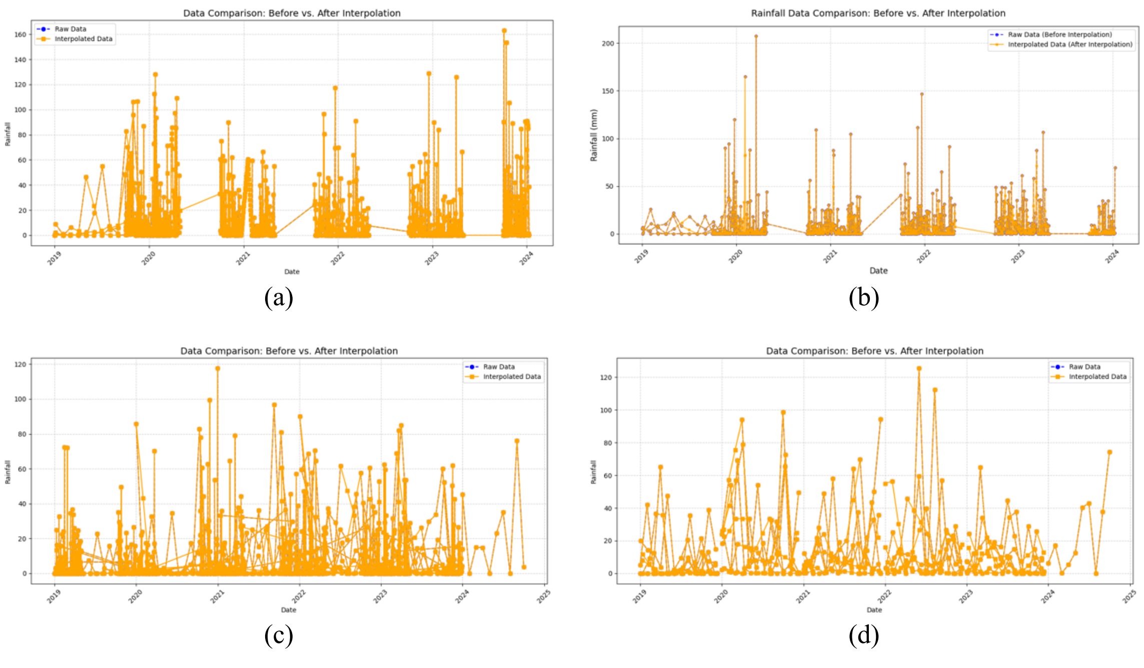

Fig. 5 Rainfall Data of (a) Aceh Province, (b) Bangka Belitung Province, (c) Riau Province, (d) Bengkulu Province.

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(e)

(f)

(g)

(h)

(i)

(j)

Fig. 5 (*Continued.*) Rainfall Data of, (e) North Sumatra Province, (f) Jambi Province, (g) West Sumatra Province, (h) Lampung Province, (i) South Sumatra Province, (j) South Sumatra Province.

To provide a comprehensive overview of the data distribution, the summary of descriptive statistics is provided in Table 3.

Table 3. Descriptive Statistics

	Aceh	**Bangka Belitung**	**Riau**	**Bengkulu**	**North Sumatra**	**Jambi**	**West Sumatra**	**Lampung**	**South Sumatra**	**Riau Islands**
Count	1071.00	1071.00	1071.00	1071.00	1071.00	1072.00	926.00	1071.00	1092.00	1071.00
Mean	14.62	9.67	8.66	11.44	12.86	13.10	12.61	9.06	8.89	10.80
Standard Deviation	22.93	17.97	15.82	16.59	22.28	19.85	25.04	15.38	16.34	23.80
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.05	0.00	0.00	0.60	0.00	0.84	0.00	0.00	0.00	0.00
Median	4.50	2.60	1.00	5.50	2.60	4.50	2.50	2.70	1.20	1.75
Q3	18.80	11.50	11.20	14.70	15.60	17.13	13.18	10.85	10.20	11.45
Maximum	163.00	207.50	117.60	125.40	158.70	137.90	239.00	151.00	135.20	282.60

Based on Fig. 5 and supported by the descriptive statistics in Table 3, rainfall intensity during the period 2019 to 2024 demonstrates varying patterns across the provinces of Sumatra Island. Quantitative analysis in Table 3 reveals that among the ten provinces, Riau Province recorded the lowest average rainfall intensity with a mean of 8.66 mm/day and a standard deviation of 15.82

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mm/day, indicating a lower precipitation level compared to other regions. Nevertheless, in general, all provinces display relatively similar rainfall patterns. Rainfall intensity tended to reach its peak in January and October, indicating two major periods of heavy rainfall within a year. The January peak reflects a strong rainy season at the beginning of the year, driven by the peak of the Asian Monsoon, whereas the October peak signifies substantial rainfall toward the end of the year, often associated with the transition period or the movement of the Inter-Tropical Convergence Zone (ITCZ). This pattern was consistent with the climatological normals (1991–2020) published by BMKG, which identified these months as periods of high precipitation intensity for the region [18]. The annual maximum rainfall intensity differed across years, with certain years, such as 2020 and 2021, showing extreme conditions, while other years presented a more stable and evenly distributed rainfall pattern. These variations reflect significant climatic variability, largely influenced by seasonal shifts. Periods of high rainfall intensity suggest potential disaster risks such as flooding, which may adversely affect the agricultural sector. Therefore, such changes in rainfall patterns warrant careful consideration by farmers and insurance companies, as they directly impact crop yields and elevate risks associated with extreme weather events.

This study applied the historical burn analysis method to construct a climate index from historical rainfall data, focusing on index windows of January–April and October–December during 2019–2023. Daily rainfall was aggregated into ten-day periods and summed to obtain decadal rainfall, which was then adjusted by comparing it with a decadal ($Cap_{dasarian}$). If rainfall exceeds the Cap, the adjusted value was set equal to the Cap; otherwise, it remained the actual rainfall. The Cap was determined based on an assumed ETp of 5 mm/day, resulting in a value of 50 mm, and adjusted rainfall totals were subsequently derived for each BMKG station.

The next stage involved calculating the average adjusted rainfall total. After obtaining the adjusted rainfall total for each decadal period, the subsequent step was to compute the annual average adjusted rainfall total. This annual average served to capture interannual variations in rainfall and provided the basis for determining other parameters. The lowest value of the annual average adjusted rainfall total was designated as the exit value. Table 4 presents the average adjusted rainfall totals for each BMKG station.

Table 4. Adjusted Rainfall Total Average

Year	Adjusted Rainfall Total Average by Province									
	Aceh	*Bangka Belitung*	*Riau*	*Bengkulu*	*North Sumatra*	*Jambi*	*West Sumatra*	*Lampung*	*South Sumatra*	*Riau Islands*
2022	43.07	42.73	39.83	47.21	46.80	42.58	40.11	38.83	40.18	46.14
2023	46.44	44.17	41.94	48.74	43.16	45.12	41.70	40.11	45.82	41.89
2021	47.88	36.97	43.59	41.35	49.28	47.51	38.64	41.01	44.79	36.14
2019	48.55	45.12	44.54	48.48	46.55	48.34	43.14	42.89	45.58	36.46
2020	49.38	46.82	47.49	47.30	43.49	43.71	41.12	43.89	44.82	39.69

Table 4 shows that adjusted rainfall totals across provinces in Sumatra vary both spatially and temporally. Aceh and Bengkulu consistently recorded higher averages (around 47–49 mm), while West Sumatra and Riau Islands tended to be lower (36–41 mm). Interannual variation was also evident, with 2020 showing relatively higher rainfall compared to other years. These results highlight the importance of considering rainfall variability in climate index determination for agricultural risk management.

The trigger value was determined using percentile calculations (20th–80th) of the adjusted rainfall total average after sorting the data from the smallest to the largest, as defined in (3). This trigger value served as a threshold for insurance claims, where rainfall below the specified percentile indicated a risk condition under which claims may be submitted. The trigger values for each province in Sumatra Island can be observed in Fig. 6.

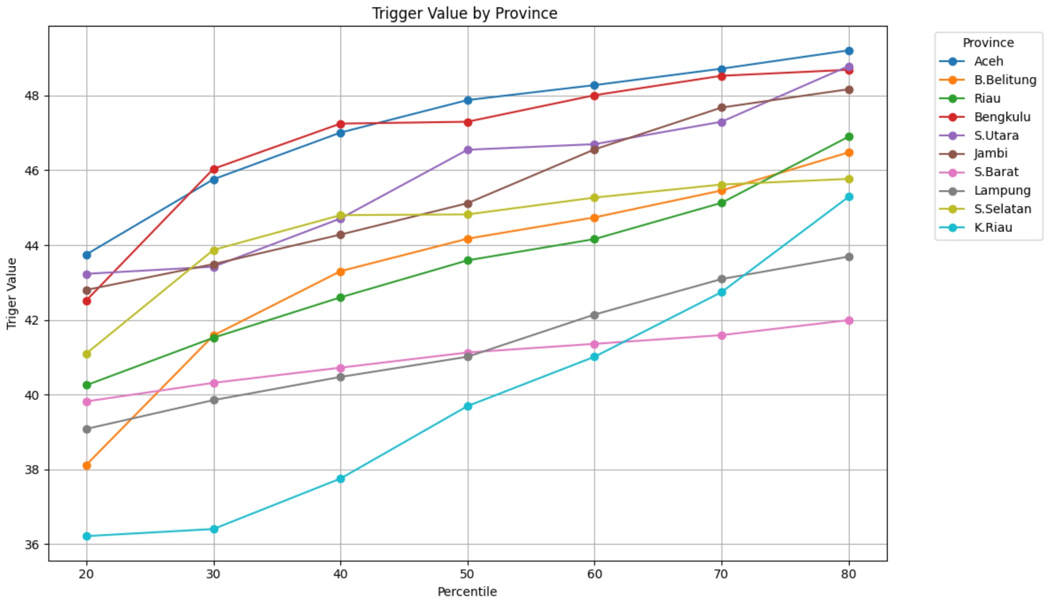

Fig 6. Trigger value.

The trigger values derived from rainfall percentiles (20th–80th) exhibited variation across provinces, reflecting the distinct climatological characteristics of each region. Analysis showed a strong positive alignment between the historical mean rainfall (Table 3) and the calculated trigger thresholds. For instance, Aceh, which had the highest mean rainfall, correspondingly yielded the highest trigger value of 49.21 mm. Conversely, Riau recorded a much lower trigger of 40.25 mm, confirming that the percentile-based method successfully adapted to the local hydrological baseline. Provinces with relatively high adjusted rainfall averages, such as Aceh and West Sumatra, recorded higher trigger thresholds, indicating that claims were less likely to be activated unless significant rainfall deficits occurred. In contrast, provinces with lower adjusted rainfall averages, such as Lampung or Riau, had lower trigger values, making insurance claims more sensitive to rainfall fluctuations. This variation highlights the importance of localized index calibration, as each province faces distinct climate risks that influence both claim probability and premium determination.

The Black-Scholes method was applied to calculate agricultural insurance premiums based on the rainfall index, where the premium value reflected the probability of rainfall falling below a critical threshold [20]. In this adaptation, the standard financial parameters were mapped to climatological variables: the current rainfall index (S) served as the underlying asset, the trigger value (K) functioned as the strike price, the risk-free interest rate (r) represented the time value of money, and the standard deviation of historical rainfall (σ) represented the volatility of the climate index [16]. This approach relies on the assumption that climate index fluctuations behave similarly to stock price movements. With an insured amount (A) of IDR 6,000,000, the rainfall probability $N(-d_2)$ was first determined using (11). The premium calculation results for each BMKG station are presented, while the provincial premium values in Sumatra are illustrated in Fig. 7.

The agricultural insurance premiums increased with higher percentiles (20–80) across all provinces. The highest premiums were consistently observed in North Sumatra, ranging from IDR 3.28 million to IDR 3.55 million, indicating the highest level of rainfall risk. In contrast, the lowest premiums were found in Aceh and Lampung, with values of approximately IDR100 thousand–IDR 137 thousand for Aceh and IDR 528 thousand–IDR 664 thousand for Lampung, suggesting relatively lower climatic risk compared to other provinces. Provinces such as Bangka Belitung and Riau Islands also exhibited relatively high premiums (around IDR 2.6 million–IDR 2.9 million and IDR 1.9 million–IDR 2.2 million, respectively), while other provinces fell within the mid-range. Overall, this table highlights significant inter-provincial variation, reflecting differences in local climatic risk in determining rainfall index-based insurance premiums.

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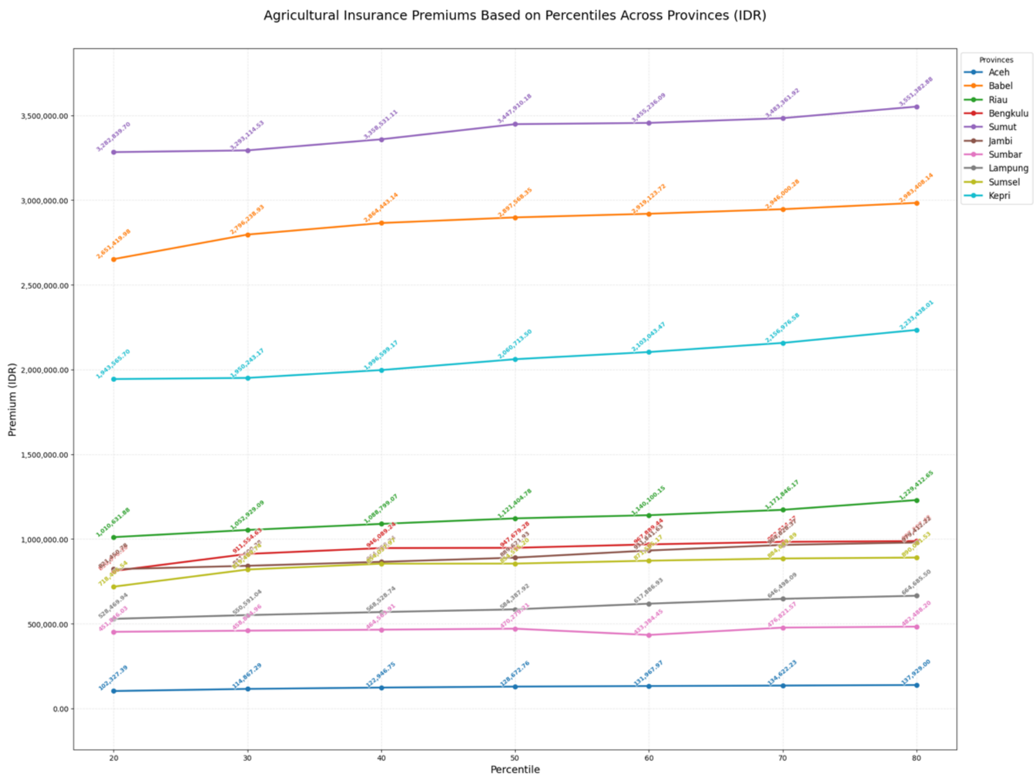
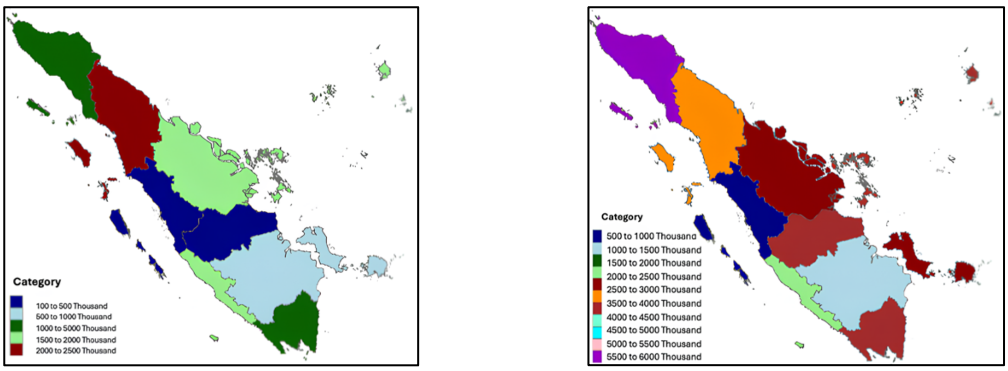


Fig. 7 Premium based on provinces.

In this study, the analysis was limited to selected rainfall stations representing each province. If all rainfall stations within each province in Sumatra were included in the dataset and the corresponding premium values estimated, the results would reveal a more comprehensive and detailed pattern. This pattern would more accurately reflect the spatial variation of rainfall risk across the provinces, as illustrated in Fig. 8, providing a more complete representation of the distribution of rainfall index-based insurance premiums.



(a) (b)

Fig. 8 Spatial pattern of agricultural insurance premiums: (a) minimum agricultural premiums and (b) maximum agricultural premiums.

4. Conclusion

The study of rainfall index-based agricultural insurance premiums across provinces in Sumatra reveals significant spatial variation in both risk and premium values. Premiums increased with higher percentiles (20–80), with North Sumatra recording the highest premiums (IDR 3.28–3.55 million), indicating the highest rainfall risk. In contrast, Aceh showed the lowest premiums (IDR 100–137 thousand), reflecting relatively lower climatic risk. Provinces such as Bangka Belitung and the Riau Islands also exhibited relatively high premiums, while other provinces fell within the mid-range. The analysis in this study was limited to selected rainfall stations. The inclusion of all rainfall stations in each province would provide a more detailed and comprehensive spatial pattern of premiums, accurately representing inter-provincial risk variation. Overall, the findings emphasize that agricultural insurance premiums are strongly influenced by local climatic conditions, and their spatial distribution can serve as a valuable tool for risk assessment and planning of agricultural insurance schemes.

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