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Determination of Premium Price for Rice Crop Insurance in Gorontalo Province Based on Rainfall Index with Black Scholes Method

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ABSTRACT

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With its complex topography, Gorontalo Province experiences significant rainfall variations that impact the agricultural sector, particularly rice crops. These variations can cause substantial losses for farmers. One way to address uncertain probabilities caused by rainfall is through agricultural insurance. This research aims to calculate the value of agricultural insurance premiums based on the rainfall index. The Black- Scholes method is used to calculate the premiums, while the Burn Analysis method is employed to determine the rainfall index. The research results classify the rainfall index values in Gorontalo Province into 7 (seven) percentiles. The lowest is at the 20th percentile, with 17.37 mm and a premium value of IDR 1,574,190, while the highest is at the 80th percentile, with 17.65 mm and a premium value of IDR 2,154,574. This indicates that the higher the rainfall, the greater the premium to be paid.

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1. Introduction

Indonesia is a country with abundant natural resources. Indonesia is very dependent on the agricultural industry as an agricultural country. However, the agricultural sector has a fairly high risk of uncertainty regarding losses. Indonesia's agricultural industry is still very dependent on natural factors, including rain [1][2].

Gorontalo Province is one of the many regions in Indonesia that has a complex topography that has a significant impact on rainfall variations. According to the publication of the Central Statistics Agency of Gorontalo City, the average rainfall in Gorontalo City during the period 2012-2019 was recorded at 185.1454 mm. Rice plants themselves require around 60-70 mm or an average rainfall of around 200 mm/month [3] . Excessive rainfall can inhibit the growth of rice plants which ultimately causes crop failure. The amount of rainfall that falls on the surface varies depending on changes in rainfall conditions in each country [3] . If crop failure losses occur continuously and there is no protection for farmers, this situation can have a major impact on agricultural production and be risky for the country's economy. Agricultural insurance is one way to mitigate the risk of climate change uncertainty.

When unfavorable weather or rainfall conditions occur without any indication that the crop will fail, insurance payments are made to the policyholder based on the climate index. Rainfall is one of the many climate variables that have a close relationship with plants, rainfall data is calculated using a time derary [4] [6]. Therefore, a method is needed that can be applied to calculate premiums accurately by taking into account related risk factors. The *Black Scholes method*, which was originally developed in the context of financial markets to calculate option prices, offers a mathematical approach that can be applied in the context of agricultural insurance. Financial markets define options as the right given to the policy or contract holder to buy or sell a particular company asset to the option writer at a predetermined price and within a predetermined time period. [7]. The contract value of an option can be ascertained using the *Black-Scholes* method. This method is used because it has the same calculation as insurance and options. This insurance can occur when at some time there is a risk related to the production results on the farm, then insurance occurs. While in options, this calculation is also a form of calculation that is not certain because when the stock price increases or decreases, the option will be calculated.

Research on calculating insurance premium prices based on rainfall index has been widely conducted.Togatorop et al. (2022) used the *Black-Scholes* approach in calculating insurance premiums based on the rainfall index for cayenne pepper plants in Salatiga during the quarterly period [1]. The author used Microsoft Excel and the E-views application, the relationship between the resulting premium value is influenced by rainfall, the higher the rainfall indicates the higher the premium payment. Then, by using the *Burn Analysis* method to calculate the temperature index on the cocoa plant commodity object. Anggraeni et al. (2018) calculated the value of agricultural insurance premiums based on the surface temperature index [8]. Similar research was also conducted by Putri et al. (2017), who calculated agricultural insurance premiums using the rainfall index through the *Black-Scholes* method [7].This research was conducted in Gorontalo with a time span of five years (2018-2022). Gorontalo Province with its varied topographic, geographical and rainfall index conditions greatly influences the agricultural sector [9]. Based on this information, it is important to conduct more comprehensive research related to the calculation of insurance premiums using the *Black Scholes* method with the rainfall index value calculated using the *Burn Analysis* method.

2. Research methods

This research is a type of applied research. This research utilizes secondary data obtained from the Gorontalo Provincial Agriculture Service, the Central Statistics Agency (BPS), and the Gorontalo Meteorology, Climatology and Geophysics Agency. The data obtained are in the form of rice production data and rainfall data from 2018 to 2022. The following are the steps taken in this research:

1. Collecting rainfall data and rice production data for five years, namely from 2018 to 2022, which was converted into quarterly data.
2. Determining the rainfall index using the *Burn Analysis method*. The steps in the Burn Analysis method are as follows:
   a) Determining the window index, the window index is used to find the strongest correlation coefficient value to determine the year and period to be selected.
   b) Determining the Cap value, the Cap value is the maximum value set to obtain the average value of each decade during a certain period of time that can be used to represent the total value throughout a certain period. Determining the Cap value is related to the daily evaporation and transpiration value in the research area.
   c) Determine the Trigger value, the Trigger value is determined from the percentile of the previously simulated variable.
   d) Normality test of Trigger value data using the Shapiro-Wilk test Trigger value data normality test.
3. Determine the insurance value (P).
4. Calculating insurance premiums using the *Black-Scholes method*.

2.1 Black Scholes Method

The Black Scholes model, created by Fisher Black Mayor Scholes in 1973, is used to calculate the option value because it is easy to understand and only calculates the value of the European option at maturity. The basic assumptions of the model include: a risk-free interest rate, European-type options valid at maturity, no dividends, no taxes, and no transaction costs. The *Black-Scholes method* is used to calculate or determine the premium price when production results do not meet expectations due to the impact of rainfall. In this case, the premium price calculation is carried out using the *Black-Scholes approach*. The *Black Scholes method* determines the price of a European-type put option as follows:

$$P = Ke^{-rt}N(-d_2) - S_0\,N(-d_1) \quad (1)$$

Where

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

$$d_2 = \frac{ln\left(\frac{S_0}{K}\right)+\left(r-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \quad (3)$$

Information:

P : Option price
S_0 : Current stock price
K : Option strike price (Trigger Value)
r : Risk-free interest rate
σ : Standard deviation
T : Due date
d_1 : Cumulative density function of the distribution normal d_1
d_2 : Cumulative density function of the distribution normal d_2

There are two types of options, namely European type options and American type options, based on the method of execution. European type options can only be executed on the last day of the option contract or at its expiration. American type option contracts are contracts that allow execution at any time between the option execution date and its expiration **[10]**. A call option is a contract that gives the holder the right to sell an asset at a certain agreed price and time. **[7]** .

Index insurance is formulated the same as option pricing, because index insurance and option pricing have certain characteristics. The value of index insurance is , and its payment structure is a lump sum, which can be taken into account when calculating the cost of index insurance using the H*Black Scholes* method . **[5]**.

By analogy from **Equations (2)** and **(3)**, the value of agricultural insurance premiums based on the index using *Black Scholes* can consider the following things:

1. The benchmark value on the insurance index is$H$
2. The payment structure for index insurance is a lump sum payment.
3. The index follows a normal distribution

The following equation can be used to calculate the value of index-based insurance premiums by determining the cumulative distribution value d_2:

$$d_1 = \frac{ln\left(\frac{R_0}{H}\right)+\left(r+\frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t}$$

$$d_2 = \frac{ln\left(\frac{R_0}{H}\right)-\left(r-\frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t} \quad (4)$$

Information:

R_0 : Rainfall index
H : Trigger value (selected rainfall) as an index
r : Risk-free interest rate
σ : Standard deviation
T : Time
d_1 : Cumulative density function of the distribution normal d_1
d_2 : Cumulative density function of the distribution

normal d_2

The insured value (PO=Payout) for rainfall index-based insurance is intended to be a put option, which is explained as follows:

$$Payout = \begin{cases} P & , if\ R_0 < H \\ 0 & , other \end{cases} \quad (5)$$

The reference value $H$is the average rainfall that has the strongest correlation with the harvest or production, where P is the price received by farmers to obtain insurance coverage due to variations in rainfall. The following formula can be used to determine the value of crop insurance premiums based on the rainfall index:

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

Information:
P : Insurance value
$N(-d_2)$: Cumulative density function of normal distributiond_2
r : Risk-free interest rate
t : Time

2.2 Burn Analysis Method

The stages in the Burn Analysis method are, [12] as follows:

1. Looking for the strongest correlation coefficient value to determine the year and period to be selected as *the Index Window*. The Pearson Product Moment Correlation Coefficient used in this study is formulated as follows:

$$r_{xy} = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{(n\sum x^2 - (x)^2).(n\sum y^2 - (y)^2)}} \quad (7)$$

2. Determining the value of descriptive statistics of data. Data management, presentation, and classification are the main focus areas of descriptive statistics, namely statistical analysis procedures. Descriptive statistics will provide information contained in the data and its summary. The rainfall variable in this study is the variable that will be searched based on the value of descriptive statistics.

3. Determining the *Cap value*. The *Cap value* is the maximum value set to obtain the average value of each decade during a certain period of time that can be used to represent the total value throughout a certain period. Determining the *Cap value* is related to the daily potential evapotranspiration (ETp) value. Based on the average daily temperature in the research area, the ETp value is calculated. The dasarian value is calculated based on the daily potential evapotranspiration value listed in **Table 1**.

Table 1. Correlation Coefficient of Rainfall and Rice Production

Region	**Average daily temperature°C**		
	Cold(~10°C)	**(~20°C)**	**(> 30°C)**
Tropical and subtropical	2-3	3-5	5-7
Moist and sub-moist			
Dry and sub dry	2-4	4-6	6-8

Where the *Cap value* for 10 daily is:

$$\text{Cap dasarian} = \text{Rata} - \text{rata nilai ETp} \times 10 \text{ hari} \quad (8)$$

This Cap value will be used as a reference to compare with the decade rainfall value calculated using the following equation:

$$Dasarian\ 1 = \sum_{i=1}^{n=10} Cap_i$$

$$Dasarian\ 2 = \sum_{i=11}^{n=20} Cap_i$$

$$Dasarian\ 3 = \sum_{i=21}^{n=31} Cap_i \quad (9)$$

The calculation of the 3rd decade is carried out from the 21st day to the last day of the month, both for months with 28/29 days and 31 days, with the following assumptions:

a) If the decade rainfall value is less than the Cap value, then the value will be adjusted based on the existing rainfall.
b) If the decade rainfall value exceeds the Cap value, then the value will be adjusted to be the same as the Cap value.

From the Cap value that has been obtained, the total average value for each year is then sought, using the following equation:

$$\bar{R}_t = \frac{\sum_{t=1}^{n} R_t}{n} \quad (10)$$

where n is the number of basic periods and $R_i$is the Cap value.

4. Trigger values are determined from the percentiles of previously simulated variables. Percentiles are a measure of data dispersion that divides a data set into 100 equal parts .
5. The normality test is used to determine whether the data comes from a normally distributed population or not. In this study, the Kolmogorov-Smirnov test was used with a significance level of α = 5%. The data will be considered lognormal if the p-value ≥ α, which means the null hypothesis (H_0) is accepted.

3. Results and Discussion

3.1. Rainfall and Rice Production Data Plot

Rainfall and rice production data will be plotted into quarterly data [9] . This data division is based on the time from planting rice to production, namely January-April, May-August, and September-December.

Table 2. Rainfall Data for Gorontalo Province 2018-2022 (in mm)

Year	Quarter I	Quarter II	Quarter III
2018	2,147	2,201	2,166
2019	2,090	2,177	2,022
2020	2,135	2,236	2,165
2021	2,146	2,226	2,198
2022	2,140	2,211	2,176

Data source: *(https://power.larc.nasa.gov)*

Table 3. Rice Production Data for Gorontalo Province 2018-2022 (in tons)

Year	Quarter I	Quarter II	Quarter III
2018	116,422	95,673	57,426
2019	115,930	66,810	48,472
2020	82,575	78,919	66,132
2021	97,243	82,606	54,544
2022	98,243	94,561	47,331

Data source: *(Gorontalo Province Agriculture Service)*

Based on Table 2, it is explained that there is a fluctuation in rainfall every year. This can be caused by several factors such as the rainy season which generally occurs from October to February, and the dry season which generally occurs from March to September.

Table 3 explains that there is an irregular increase and decrease every year in rice production. This results in uncertainty in the results of rice production obtained each harvest season which is influenced by several factors such as natural disasters, outbreaks of infectious animal diseases, attacks by plant pests, and the impact of climate change (temperature and rainfall).

Window Index

The first step taken is to determine the window index based on the strongest correlation coefficient value. Based on Equation (7) with the help of Python Software, the results of the correlation coefficient calculation are presented in the following Table 4.

Table 4. Correlation Coefficient of Rainfall and Rice Production

Correlation Coefficient		
Quarter II	**Quarter II**	**Quarter III**
-0.392414647	0.291054449	0.380522703

In Table 4, it can be seen that the period of Quarter I has the highest correlation coefficient, which is -0.392414647 compared to other periods. A negative value indicates that there is an inverse relationship between the two variables, namely when rainfall increases, rice production decreases [10] . Therefore, -0.392414647 is the window index value that will be used for further calculations.

Determining the Cap Value

The calculation of the cap on this rainfall index insurance refers to Table 1 ETp value (daily potential evaporation and transpiration value). According to the Meteorology, Climatology and Geophysics Agency, Djalaludin Gorontalo Station, Gorontalo itself is located in a tropical region with an average air temperature in 2021 ranging from 27.1◦ C and an average air humidity of 85 percent. Thus, the daily potential evaporation and transpiration value used is for tropical regions, which is 6 mm/day, so the *Cap value* can be calculated using Equation (8).

$$\begin{aligned} cap\ dasarian &= 6\ mm\ \times 10\ hari \\ &= 60\ mm \end{aligned}$$

The Cap value will describe the maximum amount of rainfall calculated each day. Based on the selected index value, this period will be calculated in decadal (per ten days). In this calculation, the data used as a sample is January 2018 to April 2018. Based on the cap value used, which is 60 mm, the data in Table 5 will be adjusted to the cap value. If the rainfall value is less than or equal to 60 mm, then the rainfall value will be adjusted to that value. However, if the rainfall value is more than 60 mm, the value will be changed to 60 mm, as shown in Table 5.

Table 5. Adjusted 2018 Rainfall Values

No	January	February	Maret	April
1	18.31	17.76	15.56	17.21
2	18.13	17.88	16.78	17.52
3	19.17	17.40	17.52	17.70
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
29	17.76	0	17.64	18.62
30	17.64	0	17.97	17.27
31	17.70	0	17.27	0

Based on the rainfall data from January to April that has been adjusted in Table 5, the calculation of the decade cap value can be done. The calculation of the cap value from January 2018 data will be presented using Equation (9).

1st decade (day 1 to day 10)

$$Dasarian\ 1 = \sum_{i=1}^{n=10} Cap_i$$

$$= 18.31 + 18.13 + 19.17 + 17.40 + 17.82 + 18.07 + 18.82 + 18.01 + 17.09 + 17.40$$

$$= 179.22$$

2nd decade (day 11 to 20)

$$Dasarian\ 2 = \sum_{i=11}^{n=20} Cap_i$$

$$= 17.88 + 17.70 + 18.19 + 17.40 + 17.27 + 17.46 + 17.27 + 17.58 + 17.94 + 17.94$$

$$= 176.63$$

3rd decade (21st to 31st day)

$$Dasarian\ 2 = \sum_{i=11}^{n=20} Cap_i$$

$$= 18.19 + 18.07 + 18.01 + 17.33 + 18.25 + 18.62 + 18.68 + 18.25 + 17.76 + 17.64 + 17.70$$

$$= 176.63$$

The calculation of the Cap value for other months and years is done using the same equation. The results of the Cap value calculation for the 1st, 2nd, and 3rd decades will be presented in **Table 6** as follows:

Table 6. Results of the Calculation of the Basic Cap Value

No	Month	2018	2019	2020	2021	2022
			First Basic Stamp			
1	January	179.22	176.52	178.34	179.81	176.75
2	February	180.78	175.10	172.86	180.34	177.44
3	March	165.89	165.89	185.67	169.85	180.31
4	April	176.69	175.83	174.00	182.80	179.09
			II Basic Stamp			
1	January	176.63	176.88	178.96	181.53	175.17
2	February	176.45	164.91	174.19	179.44	174.14
3	March	168.13	168.13	173.70	176.28	184.38
4	April	183.48	178.34	174.51	176.11	181.58
			Cap Dasarian III			
1	January	198.50	195.39	189.76	193.36	200.64
2	February	142.14	134.83	158.01	143.14	137.09
3	March	189.77	189.77	194.95	200.94	191.59
4	April	182.55	188.53	180.41	182.50	181.57
	Amount	21210.23	2090.12	2146.10	2146.10	2139.73

Next, from the *Cap value* obtained in **Table 6**, the total average value for each year will be calculated using **Equation (10)**. The results of the average calculation obtained are then sorted based on the smallest to largest index numbers presented in **Table 7**.

Table 7. Average annual rainfall

No	Year	Average
1	2018	17.36
2	2019	17.42
3	2020	17.54
4	2021	17.59
5	2022	17.67

From Table 7, it can be seen that the index value with the highest average was 17.67 in 2018. This value is a benchmark for insurance claim payments that must be paid by farmers or used as a value R_0.

Determining Trigger Values

Different *trigger* values can be used as solutions or choices that can be taken by farmers (insured) or companies (insurers) [11] . The percentile of the average daily rainfall data simulation for five years will be used to find the *trigger* value. Table 8 shows the results of the *trigger* value calculation.

Table 8. Trigger values

No	Percentile	Trigger Value
1	20	17.37
2	30	17.41
3	40	17.47
4	50	17.54
5	60	17.57
6	70	17.61
7	80	17.65

Normality Test

The normality test is used as a requirement to meet the assumptions in the *Black-Scholes method* in calculating premiums [5] . The normal distribution of the population can be ensured using the normality test. To conduct the data normality test, SPSS software is used. In this study, the Shapiro-Wilk test was used because the data tested were less than 50 sample data. The significance level used was $\alpha = 5\%$ or 0.05.

Table 9. Correlation Coefficient of Rainfall and Rice Production

Shapiro Wilk		
Statistics	**df**	**sig**
0.956	7	0.785

Based on Table 9, the results of the normality test using the Shapiro-Wilk test for 7 samples of trigger value data show that the p-value = 0.785, which is greater than α. This indicates that the null hypothesis (H_0) is accepted so that the daily rainfall simulation data for five years is normally distributed. Thus, the data can be used as an index to calculate premiums based on the complete data set. The following presents descriptive statistics of the trigger value data.

Table 10. Descriptive statistical values

Shapiro Wilk	
df	**sig**
Mean	17.52
Variants	0.01
Standard Deviation	0.10
Skewwes	-0.19
Kurtosis	-1.34

Based on **Table 10**, the skewness value is -0.19, which means the curve is skewed to the left, then the kurtosis value is -1.34 <3, which means the trigger value does not have a fat tail or there are no extreme values in the data. Then the standard deviation value is 0.10, this value will be the value σin the next calculation.

Determining the Insurance Value

The amount of money that will be given by the insurance company to the insured or policyholder in the event of a risk or crop failure of the insured rice production is the insured value. The cost of rice seeds and fertilizers (both organic and NPK) are examples of variable costs used in calculating the insured value (P) of agricultural insurance. On the other hand, fixed production costs include labor, agricultural equipment costs, and other costs. Based on input costs, in this study the insured value is based on the value set by the Ministry of Agriculture in AUTP (Rice Farming Business Insurance), which is IDR 6,000,000 per hectare.

Calculating Premium Value Using the Black Scholes Method

Equation (8) is used to calculate the premium using the Black Scholes method for the European type put option. From the previous explanation, it is known that the insurance value (P) is 6,000,000/hectare. In determining the premium price for this agricultural insurance, the probability value of rainfall will be sought first $N(-d_2)$ using **Equation (4)**. To determine the $N(-d_2)$required value, it is (R_0)obtained from the average value of the highest rainfall in the selected period, which is 17.67 mm. Then in this study, the risk-free interest rate is assumed $(r)$to be 0.01693, then for the standard deviation value, which is (σ)0.10. The next data needed is the time period (t), because the data is formed into quarters, then for the time period (t)it is obtained from $t = \frac{4}{12} = 0.033$, and $(H)$is the trigger value of each percentile.

$$d_1 = \frac{ln\left(\frac{R_0}{H}\right) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t}$$

$$d_1 = \frac{ln\left(\frac{17.67}{17.37}\right) + \left(0.01961 + \frac{0.10^2}{2}\right)0.33}{0.10\sqrt{0.33}}$$

$$= 0.4394915$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

$$= 0.4394915 - 0.10\sqrt{0.33}$$

$$= 0.38201352$$

$$N(-d_2) = 0.35122567$$

The calculation of values $d_2$and $N(d_2)$others will be done using the same method, and the calculation results will be presented in the **Table 11** below.

Table 11. Calculation results $d_2$and$N(-d_2)$

Percentile	Trigger(H)	d_2	$N(-d_2)$
20	17.37 mm	0.38201352	0.351122567
30	17.41 mm	0.34197264	0.36618574
40	17.47 mm	0.28208348	0.38893975
50	17.54 mm	0.21247221	0.41586933
60	17.57 mm	0.18272382	0.42750736
70	17.61 mm	0.1431382	0.44309052
80	17.65 mm	0.10364241	0.45872657

After getting the value of the rainfall probability $N(-d_2)$, the calculation for the insurance premium will be carried out using **Equation (6).** The following is the calculation of the insurance premium for the 20th percentile with a trigger value of 176.18.

$$Premi = Pe^{-rt}N(-d_2)$$
$$= 6.000.000 \times e^{-0.01963(0.33)} \times 0.35122567$$
$$= 2{,}093{,}760$$

So, farmers at the 20th percentile are required to pay a premium of Rp $2{,}093{,}760$. The following table will show the results of calculations in the same way for other insurance premium values.

Table 12. Results of premium value calculations

Percentile	Trigger(H)	Liability(P)	Premium (Rp)
20	17.37 mm	Rp.6,000,000	Rp.2,093,760
30	17.41 mm	Rp.6,000,000	Rp.2,182,942
40	17.47 mm	Rp.6,000,000	Rp.2,318,585
50	17.54 mm	Rp.6,000,000	Rp.2,478,120
60	17.57 mm	Rp.6,000,000	Rp.2,548,498
70	17.61 mm	Rp.6,000,000	Rp.2,641,394
80	17.65 mm	Rp.6,000,000	Rp.2,734,605

Based on **Table 12**, the calculation results show that there is a difference in premium value with the *trigger value* of each percentile, the greater the percentile produced, the greater the amount of premium paid by farmers. It can be seen that at the 20th percentile, the premium payment generated is IDR 2,093,760 and at the 80th percentile the premium generated is IDR 2,734,605. The higher rainfall identifies the higher premium payment [7] [15]. The result of this study reinforces the findings of previous studies which state that rainfall-based insurance provides incentives for farmers to manage weather risk, although farmers have to play higher premiums when rainfall is extreme.

4. Conclusion

Based on the results of the discussion of the index values produced using the *Burn Analysis method*, it was obtained based on the percentiles, namely the 20th percentile was 17.37 mm, the 30th percentile was 17.41 mm, the 40th percentile was 17.47 mm, the 50th percentile was 17.54 mm, the 60th percentile was 17.54 mm. of 17.57 mm, 70th percentile of 17.61 mm, and 80th percentile of 17.65 mm. For premium calculation using the *Black-Scholes method* , it is shown that the higher the trigger value, the greater the premium payment generated. From the calculation results, the premium value at 20th percentile is Rp.2,093,760, at 30th percentile is Rp.2,182,942, at 40th percentile is Rp.2,318,585, at 50th percentile is Rp.2,478,120, at 60th percentile is Rp.2,548,498, at 70th percentile is 2,641,394, and at 80th percentile is Rp.2,734,605.

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