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Implementation of Fuzzy Logic Using The Tsukamoto Method to Forecast Gold Price in Indonesia

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A B S T R A C T

In the economy, gold is a commodity that has an important role. This indicates that gold is often used as an investment for investors and people involved in the business world. This research aims to determine how accurate gold price forecasting is using the Tsukamoto fuzzy method in Indonesia. Gold prices are influenced by several factors. These factors include exchange rates, interest rates, inflation, etc. Based on research results, fuzzy Tsukamoto determined the price of gold with a forecasting truth value of 99.91611654% and a MAPE value of 0.083883458%. The conclusion of this research is forecasting gold prices using the Tsukamoto fuzzy method is considered very good.

Keywords: Gold price, forecasting, fuzzy tsukamoto

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1. Introduction

Throughout the world, gold is widely used as a medium of exchange like money, and to store wealth in objects. In the exchange system, gold is minted to produce coins and gold bars, as well as in other forms with a fixed weight and purity. In the economy, gold is a commodity that has an important role. This indicates that gold is often used as an investment for investors and people involved in the business world [1]. The price of gold has a fluctuating nature, namely a tendency to go up and down which is influenced by several factors. These factors include exchange rates, interest rates, inflation, financial crises, rising demand, oil prices, world political situations, and so on [2]. Until April 2024, the price of gold in Indonesia has an upward trend. This requires investors to be able to quickly make the right and quick decisions to sell or buy their gold investments. This is where technology plays a role in predicting gold prices so that it can be used as a reference for investors. Forecasting is a system for predicting an event based on historical events [3]. In forecasting gold prices, one of the forecasting methods used is fuzzy logic. Fuzzy logic itself is logic that functions to find the truth "value" between 0 and 1, which is in contrast to Boolean logic which shows that everything can be expressed in binary

numbers (Yes or no, 0 or 1, black or white) [4]. The choice of fuzzy logic in predicting gold prices includes, among other things, the concept being simple, flexible, easy to apply, tolerating inaccurate data, and using linguistic language.

Forecasting using fuzzy logic has certainly been the subject of much research. Previous research by Fildzah, Dhea, and Ira [5] entitled "Implementation of the Fuzzy Sugeno Method in Determining the Price of 24 Carat Gold in the City of Medan". This research aims to determine the determination of the price of 24-carat gold in the city of Medan. The author used three variables, including price, quality, and demand. The research results show that the prediction of the gold price if the quality is 8 and the demand is 20 for 24-carat gold per gram in Medan City is IDR 516,272.4395. Based on these results, it can make it easier for gold shops in Medan to predict the price of gold per gram. Apart from that, it can predict other variables as in research by Dharmawati and Aprilianto [6] entitled "Application of the Fuzzy Tsukamoto Method to Predict the Rupiah Exchange Rate". The application of the Tsukamoto inference system in predicting the Rupiah exchange rate against the US Dollar, Pound Sterling, and Euro on 36 samples, namely data from January 2011 to December 2013, produces an average deviation value (AFER) for the US Dollar, namely 10.74%, Pound Sterling 13.26 %, and Euro. Meanwhile, the smallest deviation occurred in the prediction of the Euro exchange rate, namely 0.23% in August 2013 data. Therefore, the author is interested in conducting research with the research subject being gold prices and using the Tsukamoto fuzzy method. This research was conducted to determine how accurate gold price forecasting is using the Tsukamoto fuzzy method.

2. Research Methods

In this research, the data used is secondary data. The data used is monthly data on the rupiah exchange rate against the US dollar, interest rates, and gold prices from January 2023 to April 2024 from the official Bank Indonesia website and exchange-rates.org.

For the analysis method use the Tsukamoto method. In the Tsukamoto method, the implication of each rule is in the form of a "cause-effect" implication or "input-output" implication which must have a relationship [7]. There are four stages in analyzing using the Tsukamoto method.

1. Fuzzification
   Fuzzification is the process of changing firm values into fuzzy values. Fuzification is carried out by using the minimum and maximum values of a variable that can form a conversation universe and domain followed by the formation of fuzzy sets with membership functions for each set.
2. Formation of Fuzzy Rules
   The fuzzy rule is the "if-then" rule with the operator between input variables being the "and" operator.
3. Fuzzy Logic Analysis
   An implication statement is formed by each fuzzy rule. The implication used is the min implication function, because in forming fuzzy rules the operator "and" is used. The min implication function takes the smallest membership degree value between elements in the fuzzy set. The result of the implication function of each rule is called the α-predicate.

$$\alpha_i = \mu_{A\cap B} = \min\left(\mu_{A_i}[x], \mu_{B_i}[y]\right), \forall i = 1, 2, 3, \ldots \tag{1}$$

with

α_i : the minimum value of membership degree in rule i,
$\mu_{A_i}[x]$: degree of membership of fuzzy set A in the i-th rule,

$\mu_{B_i}[x]$: degree of membership of fuzzy set B in the i-th rule,
A_i : Fuzzy set A in the i-th rule,
B_i : Fuzzy set B in the i-th rule,
x : Members of fuzzy set A,
y : Members of fuzzy set B.

4. Defuzzification
Defuzzification is the stage of changing fuzzy output values into firm output values. The formula used is the weighted average.

$$Z = \frac{\sum_{i=1}^{n} x_i \cdot \alpha_i}{\sum_{i=1}^{n} \alpha_i}, \ \forall i = 1, 2, 3, \ldots \tag{2}$$

with

Z : weighted average value,
x_i : consequent value in the$i$-th rule,
α_i : α-predicate value in the$i$-th rule,
n : n-th fuzzy rule

The forecasting method aims to produce an optimum forecast that does not have a large error rate [8]. On forecasting, an evaluation method is needed to determine performance accuracy using Mean Absolute Percentage Error (MAPE). MAPE is a measure of forecasting accuracy. Mathematically, MAPE is formulated as follows [9].

$$\text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \frac{|y_i - t_i|}{y_i} \times 100\% \tag{3}$$

with

n : Total amount of actual data,
y_i : Number of data in a certain period,
t_i : Number of predictions for a certain period,
$||$: Absolute value

MAPE accuracy criteria are presented in Table 1 [10].

Table 1. MAPE Accuracy Criteria

No.	Accuracy	Accuracy Percentage (%)
1	Very Good	< 10
2	Good	$10 - 20$
3	Sufficient	$21 - 50$
4	Bad	> 50

Source: [10] with modifications

The research flow diagram can be seen in Picture 1.

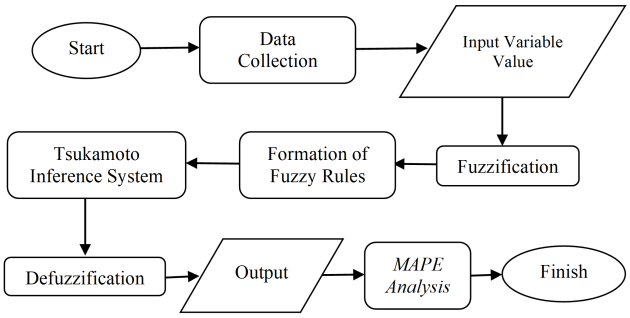

Figure 1. Research Flow Diagram

3. Result and Discussion

3.1. Fuzzification

This research contains three variables, namely two input variables including the interest rate variable, and the rupiah exchange rate variable against the US Dollar while for the output variable, there is one variable, namely the gold price variable. Based on the minimum and maximum values of the input variables and output variables can be seen in Table 2.

Table 2. Fuzzy Sets for Input and Output Variables

Function	Variable	Fuzzy Set	Universal Set	Domain
Input	Exchange Rate	Low	[14884,9 ; 16180,5]	[14884,9 ; 15261,49566]
		High		[15692,185 ; 16180,5]
	Interest Rate	Low	[5,75 ; 6,25]	[5,75 ; 5,75]
		High		[6 ; 6,25]
Output	Gold Price	Low	[903427 ; 1208940]	[903427 ; 942472]
		High		[1004177 ; 1208940]

A fuzzy set is a group that reflects a certain situation or condition in a fuzzy variable [11]. Fuzzy sets are needed to represent fuzzy variables by forming membership functions. The membership function defines fuzzy set points into membership degrees with a closed interval of 0 to 1 [0, 1] in a particular fuzzy variable. The following is an explanation of getting membership values based on three fuzzy variables.

Exchange Rate Variables

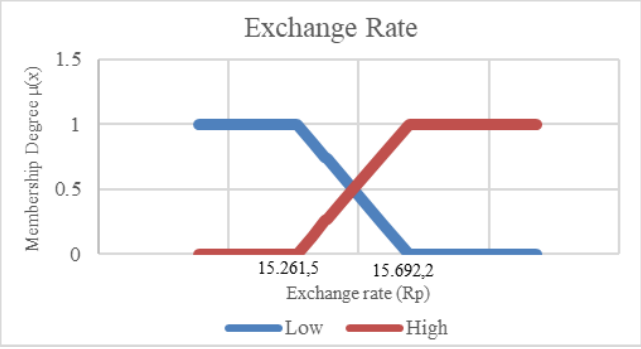

Figure 2. Membership Functions of Exchange Rate Variables

The fuzzy set image for the exchange rate variable is shown in Figure 2. In the exchange rate variable, two fuzzy sets are defined, namely low and high. To represent exchange rate variables, a left shoulder curve is used for low fuzzy sets, and a right shoulder curve is used for high fuzzy sets.

The membership function for exchange rate variables can be formulated as follows.

$$\mu_{\text{LOW}} = \begin{cases} 1 & ; x \leq 15.261,49 \\ \frac{(15.692,185-x)}{(15.692,185-15.261,49)} & ; 15.261,49 \leq x \leq 15.692,185 \\ 0 & ; x \geq 15.692,185 \end{cases}$$

$$\mu_{\text{HIGH}} = \begin{cases} 0 & ; x \leq 15.261,49 \\ \frac{(x-15.261,49)}{(15.692,185-15.261,49)} & ; 15.261,49 \leq x \leq 15.692,185 \\ 1 & ; x \geq 15.692,185 \end{cases}$$

Interest Rate Variables

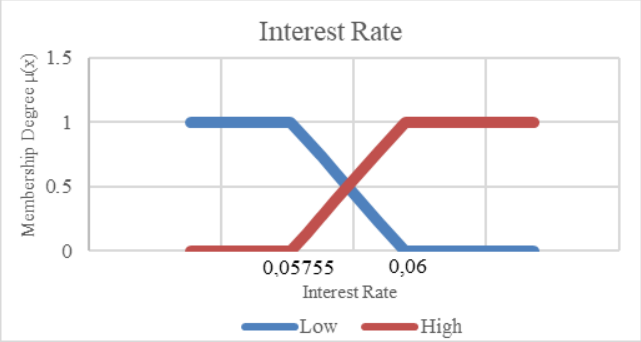

Figure 3. Membership Functions of Interest Rate Variables

The fuzzy set image for the exchange rate variable is shown in Figure 3. In the interest rate variable, two fuzzy sets are defined, namely low and high. To represent interest rate variables, a left shoulder curve is used for low fuzzy sets, and a right shoulder curve is used for high fuzzy sets.

The membership function for interest rate variables can be formulated as follows.

$$\mu_{\text{LOW}} = \begin{cases} 1 & ; x \leq 0,0575 \\ \frac{(0,06-x)}{(0,06-0,0574)} & ; 0,0575 \leq x \leq 0,06 \\ 0 & ; x \geq 0,06 \end{cases}$$

$$\mu_{\text{HIGH}} = \begin{cases} 0 & ; x \leq 0,0575 \\ \frac{(x-0,0575)}{(0,06-0,0575)} & ; 0,0575 \leq x \leq 0,06 \\ 1 & ; x \geq 0,06 \end{cases}$$

Gold Price Variables

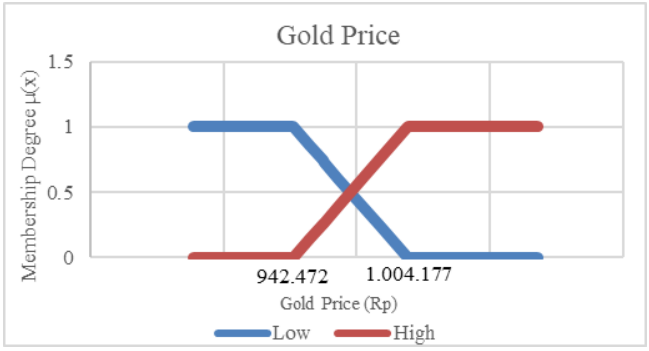

Figure 4. Membership Functions of Gold Price Variables

The fuzzy set image for the gold price variable is shown in Figure 4. In the gold price variable, two fuzzy sets are defined, namely low and high. To represent gold price variables, a left shoulder curve is used for low fuzzy sets, and a right shoulder curve is used for high fuzzy sets.

The membership function for gold price variables can be formulated as follows.

$$\mu_{\text{LOW}} = \begin{cases} 1 & ;x \leq 942.472 \\ \frac{(1.004.177-x)}{(1.004.177-942.472)} & ;942.472 \leq x \leq 1.004.177 \\ 0 & ;x \geq 1.004.177 \end{cases}$$

$$\mu_{\text{HIGH}} = \begin{cases} 0 & ;x \leq 942.472 \\ \frac{(x-942.472)}{(1.004.177-942.472)} & ;942.472 \leq x \leq 1.004.177 \\ 1 & ;x \geq 1.004.177 \end{cases}$$

3.2. Formation of Fuzzy Rules

Each rule that is formed is an implication statement [12]. Fuzzy rules are formed to express the relationship between output and input. The "AND" operator is used to connect output and input. Meanwhile, the mapping between input and output is "IF...THEN", the number of rules formed based on two fuzzy sets is eight rules. Next, an evaluation of the fuzzy rules is carried out to determine which are logic-appropriate and which are unlogic appropriate, based on the eight rules, four rules were found to be considered reasonable.

Table 3. Rules for Exchange Rate, Interest Rate, and Gold Price

Rules	Exchange Rate	Interest Rate	Gold Price
R1	Low	Low	Low
R2	Low	High	Low
R3	High	Low	High
R4	High	High	High

Rule 1 is considered reasonable because if the exchange rate is low and interest rates is low then the price of gold low. Rule 2 is considered reasonable because if the exchange rate is low, when interest rates are high it will reduce the price of gold because there is increased investment competition in providing higher returns. Rule 3 is considered reasonable because when interest rates are low, the price of gold has the potential to be high. After all, the exchange rate is high and this is not very

attractive to investors. Rule 4 is considered reasonable because the exchange rate is high so the price of gold is low even though interest rates are high because the exchange rate has a stronger influence than interest rates.

3.3. Solution Using The Tsukamoto Inference System

Based on exchange rate data and interest rates, gold price results will be searched using the Tsukamoto method. The gold price is searched every month from January 2023 to April 2024. The problem in January 2023, namely the exchange rate is 15371.71, and the interest rate is 5.75%. Membership degrees can be obtained as follows.

Exchance Rate Variables

$$\mu_{E.R\,\text{LOW}}(15.371,71) = \frac{(15.692,185 - 15.371,71)}{(15.692,185 - 15.261,49)} = 0,744088044$$

$$\mu_{E.R\,\text{HIGH}}(15.371,71) = \frac{(15.371,71 - 15.261,49)}{(15.692,185 - 15.261,49)} = 0,255902178$$

Interest Rate Variables

$$\mu_{I.R\,\text{LOW}}(0,0575) = \frac{(0,06 - 0,0575)}{(0,06 - 0,0574)} = 1$$

$$\mu_{I.R\,\text{HIGH}}(0,0575) = \frac{(0,0575 - 0,0575)}{(0,06 - 0,0575)} = 0$$

Based on rule R1: IF the exchange rate goes down AND interest rates go down THEN the gold price goes down, we will look for the α-predicate.

$$\begin{aligned}\alpha_1 &= \mu_{E.R\,\text{LOW}} \cap \mu_{I.R\,\text{LOW}} \\ &= \min\left(\mu_{E.R\,\text{LOW}}(15.371,71), \mu_{I.R\,\text{LOW}}(0,0575)\right) \\ &= \min(0,744088044; 1) \\ &= 0,744088044\end{aligned}$$

Seeing the set of gold prices LOW,

$$\begin{aligned}\mu_{G.P\,\text{LOW}} &= \frac{(1.004,177 - x)}{(1.004,177 - 942.472)} \\ 0,744088044 &= \frac{(1.004,177 - x)}{(1.004,177 - 942.472)} \\ 0,744088044 &= \frac{(1.004,177 - x)}{(61.705)} \\ 61.705 \times 0,744088044 &= 1.004.177 - x \\ 45.913,95275502 &= 1.004.177 - x \\ x &= 1.004.177 - 45.913,95275502 \\ x &= 958.263,04\end{aligned}$$

Then obtained, $x = 958.263,04$

Next, using the same steps as rule R1, rules R2 to R4 will be obtained. Then to get the defuzzification value, the centered average equation is used as follows.

$$
\begin{aligned}
Z &= \frac{\sum x_i \alpha_i}{\sum \alpha_i} \\
&= \frac{(958.263,040)(0,744088044) + (1.004,177)(0) + (958.263,040)(0,255590218) + (942,472)(0)}{0,744088044 + 0 + 0,255590218 + 0} \\
&= \frac{713.085,82 + 0 + 244.711,00 + 0}{0,999678262} \\
&= 958.262,82
\end{aligned}
$$

So the gold price obtained in January 2023 using the Tsukamoto fuzzy method is 978,359.73.

For the following month, the same method is used to obtain the gold price so that it is obtained as follows.

Table 4. Gold Prices Using The Fuzzy Tsukamoto Method

Period	Gold Price	Tsukamoto Fuzzy Output	Period	Gold Price	Tsukamoto Fuzzy Output
Jan-23	930.033	958.262,8209	Sep-23	946.636	966.752,82
Feb-23	903.427	942.472	Oct-23	971.939	1.004.177
Mar-23	940.847	959.049,2	Nov-23	994.943	1.004.177
Apr-23	957.635	942.472	Dec-23	1.013.411	989.695
May-23	950.500	942.472	Jan-24	1.021.584	1.003.705
Jun-23	932.807	942.472	Feb-24	1.020.467	1.004.177
Jul-23	943.647	942.472	Mar-24	1.095.347	1.004.177
Aug-23	941.297	951.048,98	Apr-24	1.208.940	1.004.177

3.4. Analysis with MAPE

The gold price by applying the Tsukamoto fuzzy method can be compared with the actual gold price using the average percentage or Mean Absolute Percentage Error (MAPE) as follows.

$$\text{MAPE} = \frac{\sum \frac{|Y_1 - Y_t|}{Y_1}}{n} \times 100\% = 0.083883458\%$$

Furthermore, to obtain the level of accuracy of the Tsukamoto fuzzy method it can be seen as follows.

$$100\% - 083883458\% = 99,91611654\%$$

So the gold price prediction results obtained using the average error percentage calculation from the Tsukamoto fuzzy method are 0.083883458%. Meanwhile, the level of truth is 99.91611654%. The MAPE value obtained is <10%, so it can be concluded that the accuracy of the gold price prediction results using the Tsukamoto fuzzy method is very good.

4. Conclusion and Recommendation

Based on the results and discussion, it is concluded that the Tsukamoto fuzzy method can be applied to predict gold prices based on interest rates and the rupiah exchange rate against the US dollar. The MAPE value is 0.083883458% or an accuracy level of 99.91611654%. This means that forecasting gold prices using the Tsukamoto fuzzy method is very good.

The recommendation for future research is that further research can be carried out regarding fuzzy inference systems. What can be done is comparing several fuzzy inference system methods, and increasing the number of input variables and fuzzy sets.

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References

[1] N. Nafi'iyah, "Perbandingan regresi linear, backpropagation dan fuzzy mamdani dalam prediksi harga emas," *Prosiding SENIATI*, vol. 2, no. 2, pp. 291–B, 2016. https://www.ejournal.itn.ac.id/index.php/seniati/article/view/840.

[2] F. A. Fathurrachman, F. A. Bachtiar, and I. Cholissodin, "Optimasi fungsi keanggotaan fuzzy tsukamoto dengan algoritme genetika pada peramalan harga emas untuk stock trading," *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer*, vol. 3, no. 4, pp. 3939–3948, 2019. https://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/5075.

[3] M. A. Maricar, "Analisa perbandingan nilai akurasi moving average dan exponential smoothing untuk sistem peramalan pendapatan pada perusahaan xyz," *Jurnal Sistem dan Informatika (JSI)*, vol. 13, no. 2, pp. 36–45, 2019. https://www.jsi.stikom-bali.ac.id/index.php/jsi/article/view/193.

[4] S. Pinontoan, I. A. Musdar, *et al.*, "Perbandingan metode fuzzy sugeno dengan fuzzy tsukamoto pada sistem prediksi harga smartphone bekas berbasis android di wilayah makassar," *KHARISMA Tech*, vol. 14, no. 1, pp. 34–42, 2019. https://jurnal.kharisma.ac.id/kharismatech/article/view/16.

[5] F. N. Arieni, D. Halimah, and I. Audita, "Implementasi metode fuzzy sugeno pada penentuan harga emas 24 karat pada kota medan," *Brahmana: Jurnal Penerapan Kecerdasan Buatan*, vol. 1, no. 2, pp. 116–120, 2020. https://doi.org/10.30645/brahmana.v1i2.27.

[6] A. Dharmawati and H. Aprilianto, "Penerapan metode fuzzy tsukamoto untuk prediksi nilai tukar rupiah," *Jutisi: Jurnal Ilmiah Teknik Informatika dan Sistem Informasi*, vol. 3, no. 3, 2015. https://ojs.stmik-banjarbaru.ac.id/index.php/jutisi/article/view/18.

[7] N. Hendiyani and A. W. Sugiyarto, "X. prediksi harga bawang merah rata-rata perbulan menggunakan logika fuzzy metode tsukamoto," *DEWAN REDAKSI*, p. 85, 2019. http://lsm.himatikauny.org/wp-content/uploads/2019/08/Buku_Prosiding_lsm27.pdf#page=92.

[8] I. Muhandhis, A. S. Ritonga, and M. H. Murdani, "Implementasi metode inferensi fuzzy tsukamoto untuk memprediksi curah hujan dasarian di sumenep," *Jurnal Ilmiah Edutic: Pendidikan Dan Informatika*, vol. 8, no. 1, pp. 01–10, 2021. https://doi.org/10.21107/edutic.v8i1.8907.

[9] R. P. Nugroho, B. D. Setiawan, and M. T. Furqon, "Penerapan metode fuzzy tsukamoto untuk menentukan harga sewa hotel (studi kasus: Gili amor boutique resort, dusun gili trawangan, nusa tenggara barat)," *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer*, vol. 3, no. 3, pp. 2581–2588, 2019. https://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/4755.

[10] P.-C. Chang, Y.-W. Wang, and C.-H. Liu, "The development of a weighted evolving fuzzy neural network for pcb sales forecasting," *Expert Systems with Applications*, vol. 32, no. 1, pp. 86–96, 2007. https://www.sciencedirect.com/science/article/abs/pii/S0957417405003106.

[11] S. A. Pasaribu and A. Rozy, "Penerapan metode sugeno dalam memprediksikan turun naiknya harga jual pada pt. yuki abadi," *Jurnal Minfo Polgan*, vol. 12, no. 2, pp. 2127–2134, 2023. https://doi.org/10.33395/jmp.v12i2.13171.

[12] S. Basriati, E. Safitri, and M. Mat, "Penerapan metode fuzzy tsukamoto dalam menentukan jumlah produksi tahu," *SITEKIN: Jurnal Sains, Teknologi dan Industri*, vol. 18, no. 1, pp. 120–125, 2020. https://doi.org/http://dx.doi.org/10.24014/sitekin.v18i1.11022.