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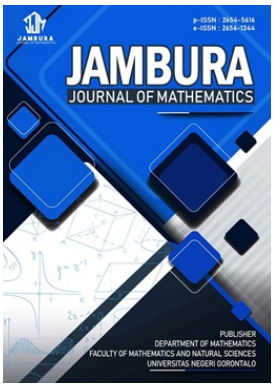

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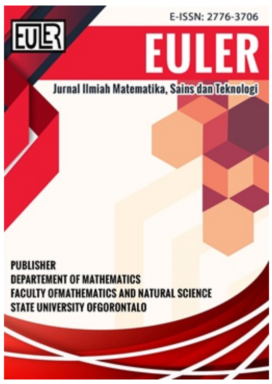

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Forecasting the Rupiah Exchange Rate Influenced by Several Factors Using the Improve Grey Model (1,3)

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ABSTRACT. *The rupiah exchange rate is one of the important indicators of a country's economic stability, but the rupiah exchange rate often fluctuates following the factors that influence it. Forecasting the rupiah exchange rate is very important for economic planning, it helps the government make monetary policy decisions to maintain the stability of the rupiah exchange rate. Common methods used to forecast the rupiah exchange rate are ARIMA, FTS Markov Chain, and exponential smoothing. These methods are widely used to show the relationship between variables, but these methods have the disadvantage that they must meet the assumptions of data patterns. The contribution of this research is the use of the improve Grey model (1,3) predict the rupiah exchange rate in 2024, which is influenced by inflation and the balance of payments. The improve Grey model (1,3) was chosen because it does not require data distribution assumptions and can consider several external factors, thus providing more specific results for certain fields. The improve Grey model (1,3) uses the Grey model (1,1) to calculate the parameter values of the independent variables in the calculation of the improve Grey model (1,3) whitening equation. The calculation of the improve Grey model (1,3) whitening equation is calculated using a first-order ordinary differential equation. The use of the improve Grey (1,3) model for forecasting the rupiah exchange rate is considered accurate based on the Mean Absolute Percentage Error (MAPE) value. The rupiah exchange rate influenced by inflation and the balance of payments using the improve Grey model (1,3) for 2024 is predicted to increase from the previous year to Rp. 18.076, which indicates a weakening in value. This weakening has a positive impact on the balance of payments and a negative impact on inflation.*

1. Introduction

Indonesia's economic stability can be measured by its rupiah exchange rate, which reflects its relationship with foreign currencies like the US dollar [1]. The rupiah appreciated by 2.03% from 2019 to 2022, but depreciated by 1.24% in December 2023 and then appreciated by 3.99% in January 2024. The Ministry of Finance reports more stable fluctuations compared to other ASEAN currencies like Malaysia and Thailand. The rupiah exchange rate is influenced by interest rates, exports imports, and other factors [2]. Inflation significantly impacts the rupiah exchange rate [1], with Bank Indonesia reporting a 2.61% inflation rate in December 2023. This was primarily due to a decline in food production, leading to increased imports of rice. Export earnings, which are part of the balance of payments, also influence the rupiah exchange rate [3]. In 2013, 2015, and 2018, Indonesia's balance of payments experienced a negative deficit due to decreased exports and services balance. This decreased export value weakened the balance of payments, weakening the rupiah exchange rate [4]. Therefore, forecasting the rupiah exchange rate is crucial for government and economic planning.

Rofi'i and Wijaya's research used the Error Correction Model (ECM) and multiple linear regression to analyze factors affecting the rupiah's exchange rate. While effective for long-term forecasting, it requires considering data patterns [5, 6]. Other classical time series forecasting methods, like ARIMA and Exponential Smoothing, also require data pattern determination. The Grey model offers an alternative method without distribution assumptions, uncertain conditions, and data with a limited amount of at least four historical data [7]. According to [8–10], the Grey model (1,1) is a model with one differential and one variable with a simple model structure that can be applied to data with a limited number (minimum 4), as well as data with incomplete assumptions. Zeng et al. [11] showed that the structure of the Grey model (1,N) uses free variables as drivers, resulting in extreme values affecting parameter estimation and structural inconsistency of the model.

The application of the Grey model (1,1) in forecasting electric vehicle sales [12] and prediction exchange rate [13] is considered accurate for short-term forecasting, but this model cannot be used on highly fluctuating data. Additionally, the application of the Grey model combined with polynomial terms forms a new model, namely the Grey model polynomial (2,1). The electricity consumption forecasting using the Grey model polynomial (2,1) is completed with the Tikhonov regularization method to address overfitting [14]. In addition, there is a combination of the Grey model and the Bernoulli model which shows effectiveness

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in showing the relationship between variables in long-term forecasting to exchange rate and economic growth [15, 16]. Cheng et al. [17] developed the conventional Grey model (1,N) into the improve Grey model (1,N). This development was carried out on parameter estimation and background value. Additionally, the improve Grey model (1,N) was tested with variable restrictions. The variable restrictions of the improve Grey model (1,N) to the improve Grey model (1,3) showed effective forecasting results in addressing inconsistencies in forecasting clean energy consumption in China.

The study forecast the rupiah's exchange rate for the next year using the Improve Grey model (1,3), addressing fluctuating data conditions affecting the rate. Annual data on the rupiah's exchange rate, inflation, and balance of payments were used as research objects. The model's performance was evaluated using the Mean Absolute Percentage Error (MAPE) value.

2. Methods

The method used in this research is the improve Grey model (1,3), which utilizes the Grey model (1,1) in calculating the parameter values of the independent variables. The improve Grey model (1,3) is applied to inflation data, the balance of payments, and the exchange rate of the rupiah from 2014 to 2023, sourced from the Bank Indonesia website www.bi.go.id and https://data.worldbank.org.

2.1. Grey Model (1,1)

The Grey model (1,1) is a popular model used in time series data forecasting with limited data criteria and incomplete assumptions [18, 19]. The Grey (1,1) model in the improve Grey model (1,3) is used to calculate the parameter values of the independent variables. In this study, there are two independent variables, namely inflation and the balance of payments. The calculation of the free variable parameter values is carried out separately using the Grey model. (1,1). Referring to Liu and Lin [20], the stages of calculating the value of the free variable parameter using the Grey model (1,1) are as follows:

1. Determine the sequence of actual data $\left(X^{(0)}\right)$ as follows:

$$X^{(0)} = \left(x^{(0)}(1), \, x^{(0)}(2), \, \ldots, \, x^{(0)}(n)\right), \tag{1}$$

   with $X^{(0)}(k) \geq 0, k = 1, \, 2, \, 3, \ldots, \, n$ where n is the number of data.

2. Determines the sequence of One-time Accumulated Generating Operation (1-AGO) of data $\left(X^{(1)}\right)$, i.e.:

$$X^{(1)} = \left(x^{(1)}(1), \, x^{(1)}(2), \, \ldots, \, x^{(1)}(n)\right), \tag{2}$$

   with $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), \; k = 1, \, 2, \ldots, \, n$ where $x^{(1)}(1) = x^{(0)}(1)$.

3. Determine the sequence of mid-value or Mean Generating Operation (MGO) $\left(Z^{(1)}\right)$ sequence from two data sequence of accumulation as follows:

$$Z^{(1)} = \left(z^{(1)}(1), \, z^{(1)}(2), \, \ldots, \, z^{(1)}(k)\right), \tag{3}$$

   with

$$z^{(1)}(k) = \frac{x^{(1)}(k) + x^{(1)}(k-1)}{2}, \; k = 2, \, 3, \, \ldots, n.$$

4. Calculating the parameter values a and b of the Grey model (1,1). The Grey model (1,1) consists of the combination of the actual data sequence and the mid-value sequence, such:

$$x^{(0)}(k) + az^{(1)}(k) = b, \tag{4}$$

   where a indicates the builder coefficient and b denotes the input. The parameter values of eq. (4) are obtained through calculations using the least squares method (MKT) and the results are:

$$a = \frac{A_1}{A_2}, \tag{5}$$

   where

$$A_1 = \frac{1}{(n-1)} \sum_{k=2}^{n} x^{(0)}(k) \sum_{k=2}^{n} z^{(1)}(k) - \sum_{k=2}^{n} x^{(0)}(k) \sum_{k=2}^{n} z^{(1)}(k)$$

$$A_2 = \sum_{k=2}^{n} \left(z^{(1)}(k)\right)^2 - \frac{1}{(n-1)} \left(\sum_{k=2}^{n} z^{(1)}(k)\right)^2,$$

   and

$$b = \frac{1}{(n-1)} \sum_{k=2}^{n} \left[x^{(0)}(k) + az^{(1)}(k)\right]. \tag{6}$$

2.2. Improve Grey Model (1,3)

The improve Grey model (1,3) is a form of model optimization from a univariate model to a multivariate model [17]. The optimization of the Grey model (1,1) to the improve Grey model (1,3) is carried out in the whitening equation and background value section to overcome the problem of the influence of extreme values on the independent variable.

Referring to Cheng et al. [17], the steps of working on the improve Grey model (1,3) in forecasting the rupiah exchange rate are as follows:

1. Determine the sequence actual data of the improve Grey model (1,3), which is:

$$X_r^{(0)}(k) = \left(x_r^{(0)}(1), \, x_r^{(0)}(2), \, \ldots, \, x_r^{(0)}(n)\right), \tag{7}$$

   with $X_r^{(0)}(k) \geq 0, k = 1, \, 2, \, 3, \ldots, \, n$ where n is the number of data and $r = 2, 3, \ldots, \, p$ with p show the number of variables.

2. Determine the sequence of one-time accumulation data of the improve Grey model (1,3), i.e.:

$$X_r^{(1)}(k) = \left(x_r^{(1)}(1), \, x_r^{(1)}(2), \, \ldots, \, x_r^{(1)}(n)\right), \tag{8}$$

   with $x_r^{(1)}(k) = \sum_{i=1}^{k} x_r^{(0)}(i), \; k = 1, \, 2, \ldots, \, n$ where $x_r^{(1)}(1) = x_r^{(0)}(1)$.
   The formed of the improve Grey model (1,3) based on eq. (7) and eq. (8), namely:

$$x_1^{(0)}(k) + u_1 x_1^{(1)}(k) = v_2 x_2^{(1)}(k) + v_3 x_3^{(1)}(k) + v. \tag{9}$$

3. Forming a sequence middle value or MGO sequence of the improve Grey model (1,3) calculated using the following equation:

$$Z_r^{(1)}(k) = \left(z_r^{(1)}(1),\ z_r^{(1)}(2),\ \ldots,\ z_r^{(1)}(k)\right), \quad (10)$$

with

$$z_r^{(1)}(k) = \alpha_k x_r^{(1)}(k-1) + (1-\alpha_k)\, x_r^{(1)}(k)$$

where: $z_r^{(1)}(k)$: the MGO sequence, $\alpha_k x_r^{(1)}(k-1)$: the $(k-1)$ term of the MGO sequence, $(1-\alpha_k)\, x_r^{(1)}(k)$: the (k) term of the MGO sequence, $k = 2,\ 3,\ \ldots, n,\ r = 2, 3, \ldots,\ p$, and $0 \le \alpha_k \le 1$.
Based on Liu and Lin [20], the weight values for the Grey model distribution are not known completely, so the weight value used is the average weight value, as follows $\alpha = \frac{1}{2}$.

4. Calculating the parameter values of the improve Grey model (1,3). The form of the improve Grey model (1,3) is determined by utilizing eq. (7) and eq. (10) obtained

$$x_1^{(0)}(k) + u_1 z_1^{(1)}(k) = v_2 z_2^{(1)}(k) + v_3 z_3^{(1)}(k) + v, \quad (11)$$

with u_1 is the development coefficient, v_2 and v_3 called the driving factor, and v is the driving force. Eq. (11) can be written in vector form:

$$\hat{\boldsymbol{h}} = \begin{bmatrix} u_1 \\ v_2 \\ v_3 \\ v \end{bmatrix} = \left(\boldsymbol{R}^T\boldsymbol{R}\right)^{-1}\boldsymbol{R}^T\boldsymbol{Q}, \quad (12)$$

where,

$$\boldsymbol{R} = \begin{bmatrix} -z_1^{(1)}(2) & z_2^{(1)}(2) & z_3^{(1)}(2) & 1 \\ -z_1^{(1)}(3) & z_2^{(1)}(3) & z_3^{(1)}(3) & 1 \\ \vdots & \vdots & \vdots & \\ -z_1^{(1)}(n) & z_2^{(1)}(n) & z_3^{(1)}(n) & 1 \end{bmatrix},$$

$$\boldsymbol{Q} = \begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(n) \end{bmatrix}.$$

The parameter values of the improve Grey model (1,3) were calculated using MKT, and the solutions for the parameter values u_1, v_2, v_3, and v were obtained as follows:

$$u_1 = \frac{U_1}{\sum_{k=2}^{n}\left(z_1^{(1)}(k)\right)^2}, \quad (13)$$

with

$$U_1 = \sum_{k=2}^{n}\left(v_2 z_2^{(1)}(k) + v_3 z_3^{(1)}(k) + v\right) z_1^{(1)}(k) - \sum_{k=2}^{n} x_1^{(0)}(k)\, z_1^{(1)}(k)$$

$$v_2 = \frac{\sum_{k=2}^{n}[V_2]\left(z_2^{(1)}(k)\right)}{\sum_{k=2}^{n}\left(z_2^{(1)}(k)\right)^2 + \sum_{k=2}^{n}\sum_{k=2}^{n} z_2^{(1)}(k)}, \quad (14)$$

with

$$V_2 = x_1^{(0)}(k) + u_1 z_1^{(1)}(k) - v_3 z_3^{(1)}(k) - \frac{\sum_{k=2}^{n}\left(x_1^{(0)}(k) + u_1 z_1^{(1)}(k) - v_3 z_3^{(1)}(k)\right)}{(n-1)},$$

$$v_3 = \frac{\sum_{k=2}^{n}\left[x_1^{(0)}(k) + u_1 z_1^{(1)}(k) - \left(v_2 z_2^{(1)}(k) + v\right)\right] Z_3}{\sum_{k=2}^{n}(Z_3)^2}, \quad (15)$$

with

$$Z_3 = z_3^{(1)}(k),$$

$$v = \frac{\sum_{k=2}^{n}\left(x_1^{(0)}(k) + u_1 z_1^{(1)}(k) - \left(v_2 z_2^{(1)}(k) + v_3 z_3^{(1)}(k)\right)\right)}{(n-1)}. \quad (16)$$

5. Determining the forecast value using the improve Grey model (1,3). Forecasting using the improve Grey model (1,3) for the next year is carried out by utilizing the following equation:

$$\hat{x}_1^{(0)}(k+1) = \hat{x}_1^{(1)}(k+1) - \hat{x}_1^{(1)}(k). \quad (17)$$

The calculation of the forecast value in eq. (17) utilizes the results of the calculation of parameter values in the Grey model (1,1). Based on Cheng et al. [17], the whitening equation form of the improve Grey model (1,3) is the solution to the differential form of eq. (9), which is solved using the first-order differential equation as follows:

$$\frac{dx_1^{(1)}(t)}{dt} + u_1 x_1^{(1)}(k) = \sum_{r=2}^{p} v_r[S] + v, \quad (18)$$

with

$$S = \left(x_r^{(1)}(1) - \frac{b_r}{u_r}\right)e^{-u_r(t-1)} + \frac{b_r}{u_r}.$$

E.g., $V_r = v_r e^{u_r}\left(x_r^{(1)}(1) - \frac{b_r}{u_r}\right)$ and $V_0 = \sum_{r=2}^{p}\left(\frac{v_r b_r}{u_r}\right) + v$, then eq. (18) simplifies to

$$\frac{dx_1^{(1)}(t)}{dt} + u_1 x_1^{(1)}(k) = \sum_{r=2}^{p} V_r e^{-u_r t} + V_0, \quad (19)$$

with $P(x) = u_1, r(x) = V_r e^{-u_r t}$, and $r(x) = V_0$, for which the initial condition $x^{(1)}(1) = c$. The solution of eq. (19) is:

$$x_1^{(1)}(t) = \sum_{r=2}^{p}\left[e^{u_1}\left(x^{(1)}(1) - F_1\right)e^{-u_1 t} + F_2\right] \quad (20)$$

$$+ e^{u_1 t_0}\left(x^{(1)}(1) - \frac{\sum_{r=2}^{p}\left(\frac{v_r b_r}{u_r}\right) + v}{u_1}\right) e^{-u_1 t}$$
$$+ \frac{\sum_{r=2}^{p}\left(\frac{v_r b_r}{u_r}\right) + v}{u_1},$$

with

$$F_1 = \frac{v_r e^{u_r}\left(x_r^{(1)}(1) - \frac{b_r}{u_r}\right)}{u_1 - u_r} e^{-u_r},$$
$$F_2 = \frac{v_r e^{u_r}(x_r^{(1)}(1) - \frac{b_r}{u_r})}{u_1 - u_r} e^{-u_r t}.$$

Afterward, eq. (20) is modified according to the specified time response:

$$\hat{x}_1^{(1)}(k+1) = \sum_{r=2}^{p}\left[e^{u_1}\left(x^{(1)}(1) - F_1\right) e^{-u_1 k} + F_2\right] \quad (21)$$
$$+ e^{u_1}\left(x^{(1)}(1) - F_3\right) e^{-u_1 k} + F_4,$$

with

$$F_3 = \frac{\sum_{r=2}^{p}\left(\frac{v_r b_r}{u_r}\right) + v}{u_1}, \; F_4 = \frac{\sum_{r=2}^{p}\left(\frac{v_r b_r}{u_r}\right) + v}{u_1}.$$

2.3. Mean Absolute Percentage Error (MAPE)

Forecasting is a method used to predict a condition in the future. One of the important stages is to evaluate the forecast results obtained, because it is expected that the results can provide relatively small errors [21, 22]. The accuracy of forecasting results using the Grey improve model (1,3) is calculated using the mean absolute percentage error (MAPE) with the formula [23]:

$$\text{MAPE} = \frac{\sum_{t=1}^{n} \frac{|Y(t) - \hat{Y}(t)|}{Y(t)}}{n} \times 100\%, \quad (22)$$

with,
n : number of data,
$Y(t)$: actual data at time t,
$\hat{Y}(t)$: the final forecast result data at time t.

The MAPE measure's forecast accuracy criteria [23] are shown in Table 1.

Table 1. Table of forecasting accuracy criteria

MAPE value	Category
$\leq 10\%$	Very accurate
$10\% < \text{MAPE} \leq 20\%$	Accurate
$20\% < \text{MAPE} \leq 50\%$	Quite accurate
$> 50\%$	Not accurate

3. Results and Discussion

This research uses data on inflation, balance of payments, and rupiah exchange rate as the forecasting object. Data recorded by Bank Indonesia shows that the factors affecting the rupiah exchange rate are experiencing fluctuation. Therefore, the use of the improve Grey model (1,3) in forecasting the rupiah exchange rate for one period ahead can be considered to overcome data inconsistencies. In addition, the improve Grey model (1,N) shows the effectiveness of short-term forecasting in previous studies.

3.1. Data

This study uses annual data from rupiah exchange rate data, inflation data, and balance of payments data from 2014 to 2023. The data is taken from the Bank Indonesia website. The data shows the stability of the rupiah exchange rate movement as shown in Figure 1, but the data is influenced by the fluctuating balance of payments as shown in Figure 2.

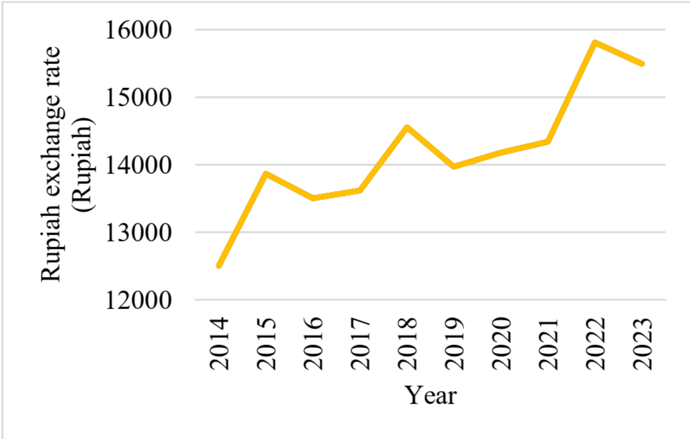

Figure 1. The rupiah exchange rate

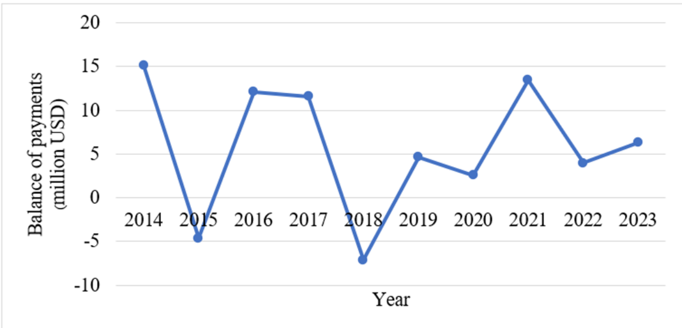

Figure 2. Balance of payment data

Therefore, the application of the improve Grey model (1,3), by utilizing the Grey model (1,1) can be considered as a suitable forecasting method to be used in overcoming data inconsistency conditions.

3.2. Application of the Grey Improve Model (1,3) in Forecasting the Rupiah Exchange Rate

Forecasting the rupiah exchange rate using the improve Grey model (1,3) is carried out following the steps outlined in Section 2.

Step 1. Determining the parameter values of inflation and balance of payments by utilizing the Grey model (1,1).

In this study, the calculation of the parameter values for inflation and balance of payments is conducted in two separate stages by utilizing the Grey model (1,1). The calculation of parameter values for inflation data with the Grey model (1,1) follows these steps:

1. Determines the sequence of actual data $\left(X^{(0)}\right)$ using the eq. (1).
2. Determines the sequence of one-time accumulated data $\left(X^{(1)}\right)$ using eq. (2).
3. Determine the sequence of mid-value or the sequence MGO $\left(Z^{(1)}\right)$ using the eq. (3).
   The results of the recapitulation of inflation data, including actual data, accumulated data, and mid-value data are listed in Table 2.

Table 2. The recapitulation of inflation data

Year	$X^{(0)}$	$X^{(1)}$	$Z^{(1)}$
2014	5.40	5.40	-
2015	4.00	9.40	7.40
2016	2.40	11.80	10.60
2017	4.30	16.10	13.90
2018	3.80	19.90	18.00
2019	1.60	21.50	20.70
2020	-0.40	21.10	21.30
2021	6.00	27.10	24.10
2022	9.60	36.70	31.90
2023	1.50	38.20	37.40

4. Calculating the values of parameters a and b using eq. (5) and eq. (6). Calculation of parameter values a and b is done with the help of MATLAB and obtained is the value of a = -0.0525 and b = 2.5628. These inflation parameter values are used for the calculation of the improve Grey model (1,3) whitening equation. Furthermore, the calculation of parameter values for the balance of payments with the Grey model (1,1) is done in the same way and the parameter values $a = -0.1009$ and $b = 1.4431$.

Step 2. Determines the sequence of actual data $\left(X_r^{(0)}\right)$ of the improve Grey model (1,3) using the eq. (7).

Step 3. Determines the sequence of one-time accumulated data $\left(X_r^{(1)}\right)$ using the eq. (8).

Step 4. Forms the sequence MGO of the improve Grey model (1,3) $\left(Z_r^{(1)}\right)$ using the eq. (10).

Based on the calculations carried out in **Step 2** to **Step 4**, a recap of the actual data, accumulation data, and middle value row data of the improve Grey model (1,3) is obtained as in Table 3.

The purpose of accumulating actual data and calculating the mid-value in the improve Grey model (1,3) is to form a more stable model [17]. In addition, calculations MGO are used to specify the relationship between inputs and outputs in the model [22].

Step 5. Calculating the parameter values of the improve Grey model (1,3)

The parameter values of the improve Grey model (1,3) are calculated using MKT equations (12). The parameter values of u_1, v_2, v_3, and v in the improve Grey model (1,3) are obtained by performing matrix multiplication, where matrix $\boldsymbol{R}$ contains the value of $Z_r^{(1)}$, and matrix $\boldsymbol{Q}$ contains the actual data $X_1^{(0)}$. The results obtained are as follows:

$$\mathbf{R} = \begin{bmatrix} -19434 & 7.40 & 12.90 & 1 \\ -33117 & 10.60 & 16.65 & 1 \\ -46677 & 13.95 & 28.50 & 1 \\ -60761 & 18.00 & 30.75 & 1 \\ -75023 & 20.70 & 29.53 & 1 \\ -89095 & 21.30 & 33.16 & 1 \\ -103353 & 24.10 & 41.19 & 1 \\ -118427 & 31.90 & 49.91 & 1 \\ -134078 & 37.45 & 55.06 & 1 \end{bmatrix}, \quad \mathbf{Q} = \begin{bmatrix} 13864 \\ 13503 \\ 13616 \\ 14553 \\ 13970 \\ 14175 \\ 14340 \\ 15809 \\ 15493 \end{bmatrix}$$

The calculation process was carried out using the help of MATLAB, and the results obtained were the values of $u_1 = 0.0000$, $v_2 = 0.0023$, $v_3 = 0.0132$ and $v = 1.2628$.

3.3. Forecasting Rupiah Exchange Rate using Improve Grey Model (1,3) for 2024

Forecasting the improve Grey model (1,3) is calculated using eq. (21). The parameter values of the independent variables obtained from the calculation results with the Grey model (1,1) are combined with the parameter values obtained from the calculation results with the improve Grey model (1,3). The calculation results from eq. (21) are then substituted in eq. (17) to get the rupiah exchange rate forecasting results. Table 4 shows the results of forecasting the rupiah exchange rate calculated with the help of MATLAB.

Following the results listed in Table 4, forecasting the rupiah exchange rate for the next one year by utilizing the improve Grey model (1,3) almost matches the actual data. A comparison of the results between the rupiah exchange rate forecasting and the actual rupiah exchange rate data is shown in Figure 3.

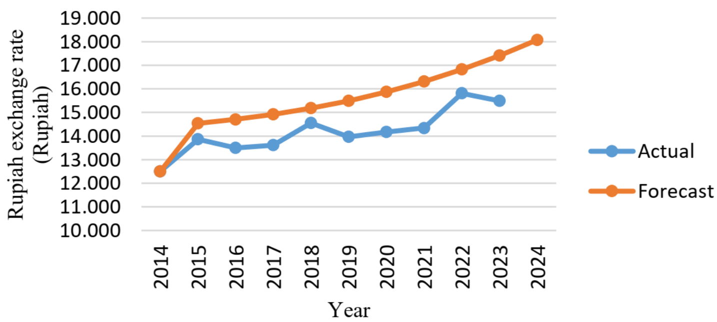

Figure 3. Comparison of rupiah exchange rate forecasting results with actual data

Syarifuddin [24] calculates the rupiah exchange rate's appreciation or depreciation against the dollar.

$$\begin{aligned} \text{appreciation/depreciation IDR/USD} &= \left(\frac{\text{IDR/USD}_{t-1}}{\text{IDR/USD}_t} - 1\right) \times 100 \\ &= \left(\frac{15493}{15904} - 1\right) \times 100 \\ &= -2.50. \end{aligned}$$

Table 3. Recapitulation results of improve Grey model (1,3)

Year	$X_1^{(0)}$	$X_2^{(0)}$	$X_3^{(0)}$	$X_1^{(1)}$	$X_2^{(1)}$	$X_3^{(1)}$	$Z_1^{(1)}$	$Z_2^{(1)}$	$Z_3^{(1)}$
2014	12502	5.40	15.20	12502	5.40	15.20	-	-	-
2015	13864	4.00	-4.60	26366	9.40	10.60	19434	7.40	12.90
2016	13503	2.40	12.10	39869	11.80	22.70	33117	10.60	16.65
2017	13616	4.30	11.60	53485	16.10	34.30	46677	13.95	28.50
2018	14553	3.80	-7.10	68038	19.90	27.20	60761	18.00	30.75
2019	13970	1.60	4.67	82008	21.50	31.87	75023	20.70	29.53
2020	14175	-0.40	2.59	96183	21.10	34.46	89095	21.30	33.16
2021	14340	6.00	13.46	110523	27.10	47.92	103353	24.10	41.19
2022	15809	9.60	3.99	126332	36.70	51.91	118427	31.90	49.91
2023	15493	1.50	6.30	141825	38.20	58.21	134078	37.45	55.06

Table 4. Forecasting results of the rupiah exchange rate

Year	Actual data	Estimated parameter value	Forecast result
2018	14553	71840	15180
2019	13970	87340	15496
2020	14175	103210	15871
2021	14340	119520	16310
2022	15809	136340	16819
2023	15493	153740	17405
2024	-	-	18076

The rupiah depreciates in 2024 due to inflation and balance of payments, increasing export demand and decreasing public consumption interest in local goods due to increased selling prices.

3.4. Forecasting Accuracy Calculation of Improve Grey Model (1,3)

The accuracy of forecasting the rupiah exchange rate using the improve Grey model (1,3) is calculated using eq. (22) and the following results are obtained:

$$\begin{aligned}\text{MAPE} &= \frac{\sum_{t=1}^{10}\left(\frac{|Y(t)-\hat{Y}(t)|}{Y(t)}\right)}{10} \times 100\% \\ &= \frac{1}{10}(1.8298)\ \times 100\% \\ &= 18.298\%.\end{aligned}$$

This result shows the effectiveness of the improve Grey model (1,3) for forecasting the rupiah exchange rate which is influenced by inflation and the balance of payments is accurate.

4. Conclusion

From this study, two things were produced, namely first, the rupiah exchange rate predicted using the improve Grey model (1,3) for 2024 was Rp 18.076. This value increased compared to 2023 meaning the rupiah exchange rate has weakened compared to the previous year. The weakening of the rupiah exchange rate will affect consumer demand or supply both domestically and abroad. Second, the accuracy of forecasting the rupiah exchange rate using the improve Grey model (1,3) is accurate with a MAPE value of 18.20%, showing the effectiveness of the improve Grey model (1,3) for short-term forecasting.

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