Reservoir water availability potential assessment using SARIMA modeling of monthly local rainfall data

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Abstract. The uncertainty of water availability in rainfed reservoirs is one of the impacts of climate change which has become a serious environmental problem in reservoir management. The accuracy of local rainfall prediction is required in planning a sustainable reservoir management strategy. This study aims to construct a monthly local rainfall forecasting model to assess the potential water availability in the reservoir. The SARIMA (Seasonal Autoregressive Integrated Moving Average) forecasting techniques are used in this study to predict local rainfall based on daily rainfall data for the 2007-2019 period at monitoring stations in Gembong Reservoir, Pati, Indonesia. The results showed that the SARIMA model is a good forecasting model according to the MASE (Mean Absolute Scaled Error) criteria. Forecasting using the SARIMA model shows an increase in the accumulated average local rainfall, so there is a potential for water abundance in the reservoir. Reducing sedimentation in reservoirs and maintenance of sustainable reservoir infrastructure is one of the mitigation strategies that need to be prioritized to increase the carrying capacity of the reservoir.

1. Introduction

Water scarcity is a major issue in the management of food security[1], which affects sustainable economic growth[2,3]. Sustainable water availability is necessary for life in the world[4]. Moreover, the availability of water is needed for sanitation during the Covid-19 virus pandemic, in addition to agricultural irrigation [5]. The agricultural sector is directly affected by climate change that triggers floods or drought[6]. Climate change variability affects changes in agricultural ecosystems, which have an impact on their productivity[7,8].

The Gembong Reservoir is useful as flood control and irrigation water supply[9]. Increased sedimentation is a recent environmental problem, so mitigation of the potential for local hydrometeorology disasters is needed. Water abundance or scarcity depends on variability in rainfall[10].

The ARIMA forecast for the wet months shows an increase in the accumulated average rainfall in the following season, and fluctuates with high concentrations[11]. The increase in rainfall intensity increases the potential for flooding[12,13], which has an impact on the socio-economy of the community[14,15].

The characteristics of local rainfall determine water availability in the reservoir [16], so an accuracy of local rainfall forecasting is required in a sustainable reservoir management.
strategy[17,18]. This study aims to construct a monthly local rainfall forecasting model to assess the potential water availability in the reservoir. The main discussion focused on building the SARIMA model, forecasting the average monthly rainfall and assessing the potential water availability in the reservoir.

2. Method
Forecasting modeling based on local rainfall data for the 2007-2019 period, which was obtained from the Gembong Reservoir Management Office as learning and testing data. Data processing and analysis used statistical methods.

The SARIMA model is constructed based on these empirical data [19], with iterative steps which include: data stationarity testing, seasonal patterns, AR parameters, residual autocorrelation test, model selection based on the smallest MSE (Mean Squared Error).

Validation of forecasting models with MASE (Mean Absolute Scaled Error) criteria [20, 21]. Forecasting the average local monthly rainfall for the upcoming season using the selected model. The potential for water availability in the reservoir is assessed based on the results of this forecast.

3. Results and Discussion

3.1. Building SARIMA model
SARIMA is a time series technique developed from ARIMA [22] which contains seasonal and repetitive effects on each observation [21]. The stages taken in modeling SARIMA are

a. The local rainfall data fulfills the stationary characteristics in the mean according to the stationarity test

b. The ACF (Autocorrelation Function) graph is in the form of sine wave (sinusoidal), repeating starting from the 12th lag, illustrating that the data has an annual seasonal pattern (repeated every 12 months). The SARIMA (Seasonal Autoregressive Moving Average) model is chosen with the maximum lag for the MA model is 2 and for AR is 1 with s (season) is 12.

c. The parameters in the AR model are significant according to the t statistical test with a significance level of $\alpha = 5\%$. The selected SARIMA model parameters are presented in Table 1.

| Model                      | Parameters | Coefficient | P      | Explanation |
|----------------------------|------------|-------------|--------|-------------|
| SARIMA(1,0,0)(0,1,1)$^{12}$| AR 1       | 0.4238      | 0.000  | Significant |
|                            | SMA 12     | 0.9119      | 0.000  |             |

d. The results of autocorrelation testing using the Ljung Box-Pierce statistical test [21] with a significance level of $\alpha = 5\%$ indicate that the p value for all lags is $> 5\%$ are presented in Table 2. There is no residual correlation between lags in the SARIMA(1,0,0) (0,1,1)$^{12}$.

| Model                      | lag 12 | p-Ljung Box test | lag 24 | lag 36 | lag 48 | Explanation |
|----------------------------|--------|------------------|--------|--------|--------|-------------|
| SARIMA(1,0,0)(0,1,1)$^{12}$| 0.308  | 0.347            | 0.346  | 0.365  |        | Independent |

e. The SARIMA model (1,0,0) (0,1,1)$^{12}$ has the smallest MSE and meets the assumptions of a good forecasting model [23]. Based on the formulation of the SARIMA model $(p, d, q)$ $(P, D, Q)$ that is

$$\varphi_p(B)\theta_p(1-B)^d(1-B)^dX_t = \theta_q(B)\theta_q(B)Z_t$$

(1)

then model SARIMA(1,0,0)(0,1,1)$^{12}$ have equation

$$\varphi_1(B^{12})\theta_1(B)(1-B^{12})^1(1-B)^0X_t = \theta_1(B^{12})\theta_0(B)Z_t$$

(2)
Based on the AR1 and SMA12 values in Table 1 for the model SARIMA(1,0,0)(0,1,1)\textsuperscript{12}, then

\[
(1 - 0.42388)(1 - B^{12})X_t = (1 + 0.9119B)Z_t
\]

\[
(1 - B^{12} - 0.42388B + 4238B^{13})X_t = (1 + 0.9119B^{12})Z_t
\]

\[
X_t = X_{t-12} - 0.4238 + 0.4238X_{t-13} = Z_t + 0.9119Z_{t-12}
\]

\[
X_t = X_{t-12} + 0.4238X_{t-13} - 0.4238X_{t-13} + Z_t + 0.9119Z_{t-12}
\]

So model SARIMA(1,0,0)(0,1,1)\textsuperscript{12} have equation

\[
X_t = 0.4238X_{t-1} + X_{t-12} - 0.4238X_{t-13} + 0.9119Z_{t-12} + Z_t
\]

f. The 2019 local rainfall data is used as real data in model validation based on MASE criteria. The results in Table 3 show that the SARIMA(1,0,0)(0,1,1)\textsuperscript{12} model is a good forecasting model [20].

### Table 3: Model validation and forecast results.

| Month | Average rainfall 2019(data) | Average rainfall 2019(model) | Average rainfall 2020(forecast) |
|-------|----------------------------|----------------------------|-------------------------------|
| 1     | 14.51613                   | 9.62763                    | 14.4430                       |
| 2     | 4.71429                    | 9.13902                    | 11.0273                       |
| 3     | 6.87097                    | 5.49795                    | 6.1154                        |
| 4     | 8.40000                    | 5.38203                    | 5.6466                        |
| 5     | 0.00000                    | 2.11992                    | 2.1960                        |
| 6     | 0.00000                    | 0.66229                    | 0.6836                        |
| 7     | 0.00000                    | 0.54039                    | 0.5515                        |
| 8     | 0.00000                    | 0.10897                    | 0.1124                        |
| 9     | 0.00000                    | 0.13517                    | 0.1383                        |
| 10    | 0.00000                    | 0.40658                    | 1.4156                        |
| 11    | 0.00000                    | 2.98548                    | 4.0000                        |
| 12    | 3.22581                    | 8.40488                    | 9.4267                        |
| Accumulated | 37.72719                   | 45.01031                   | 55.7564                       |

MASE (testing)= 0.943266< 1

### 3.2. Assessment of potential reservoir water availability

The potential for water availability in the reservoir was assessed based on the selected SARIMA model. As an empirical model [19], the quality of the data affects the goodness of the forecast[21]. The absence of rain that falls in the dry months results in zero data, so the rainfall forecast for the wet months is better [11].

Based on Table 3, there is an increase in the accumulated average rainfall in the 2020 season. This forecasting is in line with the ARIMA forecast results for the wet month [11]. An increase in the accumulated monthly average of rainfall has the potential to cause an abundance of rainwater through the spillway due to the diminishing capacity of the reservoir. Uncontrolled abundance of water has the potential for flooding[12,13]. Mitigation of potential flooding needs to be considered in sustainable reservoir management.

Increased sedimentation will reduce the carrying capacity of the reservoir, so that an increase in accumulated rainfall has the potential to trigger flooding or landslides[12,13]. The availability of water in the reservoir which is shrinking due to the shrinking capacity of the reservoir has an impact on the supply of agricultural irrigation water has also decreased [5,9]. Efficient use of reservoir water is one of the adaptation strategies that must be carried out. The agricultural sector as the beneficiary of the reservoir will be most affected when a flood or drought occurs, so that food security will be disrupted [6-8]. The availability of water in reservoirs is essential for a sustainable agricultural sector [4,5].

The availability of water in reservoirs is not only affected by climate change, but sedimentation in reservoirs also plays a role in determining the volume of water that can be accommodated by the
reservoir. Maintenance of sustainable reservoir infrastructure as one of the mitigation strategies to ensure sustainable water availability in reservoirs.

4. Conclusion
Forecasting using the SARIMA model shows an increase in the accumulated average local rainfall, so there is a potential for water abundance in the reservoir. Reducing sedimentation in reservoirs and maintenance of sustainable reservoir infrastructure is one of the mitigation strategies that need to be prioritized to increase the carrying capacity of the reservoir.

The implementation of the new life adaptation of Covid-19 is a new challenge for managing reservoir water availability in the further research. The need for clean water increases with the habit of washing hands frequently with soap and running water. The formulation of local proactive policies on sustainable management of the Gembong Reservoir opens up opportunities for further research.

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