

Vector Autoregression (Var) Model for Rainfall Forecast and Isohyet Mapping in Semarang – Central Java – Indonesia

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Abstract—Agricultural and plantation activities in Indonesia, especially in Semarang, Central Java, Indonesia rely on water supply from the rainfall. The rainfall in the future is basically influenced by rainfall patterns, humidity and temperature in the past. In this case, Vector Autoregression (VAR) multivariate model is applied to forecast the rainfall in the future, in which all along Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) generally uses ARIMA model (*Autoregressive Integrated Moving Average*) to carry out the same thing. The study applied the data, comprising the data of rainfall, humidity and temperature taken on a monthly basis during 2001-2013 periods from 5 measurement stations. Plotting of rainfall forecast result with VAR method is portrayed in the form of isohyet contour map to see the correlation between rainfall and coordinates of the area of the rainfall. The forecast result shows that VAR method is quite accurate to use for rainfall forecast in the study area as well as better than ARIMA method to forecast the same thing as having smaller Mean Absolute Error (MAE) and Mean Absolute Percentage Error(MAPE).

Keywords—Rainfall Forecast; VAR; Multivariate Time Series; Isohyet

I. INTRODUCTION

Indonesia has abundant natural resources in tropical areas with quite high rainfall as the islands are surrounded by the vast oceans, fairly high daily temperature and humidity [20]. Currently, there are approximately 40.6 million hectares of agricultural and plantation areas in Indonesia [22] which mostly rely the water supply on the rainfall. Regarding this matter, the western and northeast parts of Indonesia have geological condition and fertile soil which enables the agriculture/plantation can virtually be done as long as the water supply from the rainfall is sufficient [21].

Semarang, Central Java, Indonesia (the study area) is geographically located in Java island in the western part of Indonesia. The study area lies on the geographic position of $6^{\circ} 5' - 7^{\circ} 10' S$ and $110^{\circ} 34' - 110^{\circ} 35' E$ with a total area of

37.366.838 hectares or about 373.7 km²[19]. Generally, the rainfall in the study area follows the pattern of 2 seasons, namely dry season (April – September) and wet season (October – March)

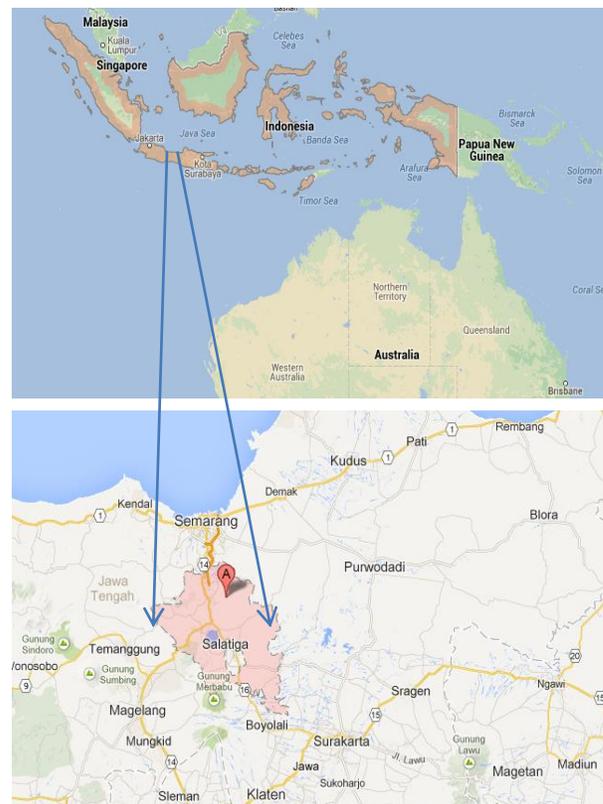


Fig. 1. Study Area Map

[20]. The conducted study tried the seasonal rainfall forecast (dry and wet season) 1 year forward (2014) based on monthly rainfall data taken along the span of the previous 13

years (2001-2013). The rainfall forecast is conducted by using multivariate time series method, or more particularly: **Vector Autoregression (VAR)**. Furthermore, for the sake of decision making accuracy, the rainfall forecast is portrayed in the form of isohyet contour map to see the portrait of rainfall amounts in each sub-district in Semarang.

II. PREVIOUS STUDY

VAR method that is introduced by **Christopher A. Sims**, a Nobel Prize winner in econometrics, is previously pretty much used to develop econometric models [5] [13], such as to see the correlation of Gross Domestic Product (GDP) to the inflation level in a country, the tourist arrival level to a country which is influenced by many factors, the correlation between Composite Stock Price Index (Indeks Harga Saham Gabungan/IHSG), currency exchange rates and prices [11], the market response to the marketing mix [16], the correlation between public expenditure and economic growth [1], etc. For natural phenomena, especially for rainfall forecasting, Dewi Retno, et al [14] have conducted a study of correlation between rainfall in a region and rainfall in other nearby regions. Meanwhile, in the study that we conducted, the rainfall is connected to the rainfall in the previous periods as well as its correlation with humidity and temperature data.

In general, rainfall (precipitation) is a part of hydrologic cycle (water cycle) consisting of: (1) evaporation and/or evapotranspiration, (2) precipitation, and (3) surface water flow [12]. At each stage, the air humidity (water vapor percentage in an air volume) and the temperature would be very influential. When the temperature is relatively high due to the sunlight, there would be an evaporation/evapotranspiration of surface water/vegetation and water vapor in an air volume would be formed in which this water vapor in certain altitude, in turn, would form a core of condensation to form clouds. Due to the influence of low temperature and relatively immense droplet, the clouds then would drop back to the ground in the form of rain, snow, dew, fog, etc., which in turn would form surface water flow to restart the hydrologic cycle.

In Indonesia, the studies related to the rainfall according to Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) were mostly conducted using ARIMA method in which the study area has 22,13% MAPE value [6]. The study that we conducted aims to find out if VAR method that we applied can reduce this MAPE value, where the result would enhance the prediction accuracy. Moreover, in our study, we intend to connect the values of rainfall forecast to geographic coordinates of the area where the rainfall would drop by portraying it in the form of isohyet contour map.

III. RESEARCH METHODOLOGY

Time series is basically a measurement data taken in chronological order in certain time [9]. In the conducted study, based on the characteristic of each time series with some different kinds of data (rainfall, humidity and temperature), Vector Autoregression (VAR) method is applied. VAR is basically a combination of Autoregressive (AR) method and frequently known as Box-Jenkins method as developed by George Box and Gwilym Jenkins in 1976 [9].

For instance, the following is the time series of AR.

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \dots + \beta_{p-1} y_{t-p+1} + \beta_p y_{t-p} + \varepsilon_t \quad (1)$$

In which y_t is the current value, while p is lag in autoregressive process; y_{t-1} to y_{t-p} is the measurement values from $t-1$ to $t-p$; β_0 is intercept value and β_1 to β_p is regression coefficient from $t-1$ to $t-p$; and ε_t is error value or frequently known as *white noise* which is assumed to be a normal distribution, independent of y_{t-1} and constant variance of σ^2 or equal to 0 [3] [7]. In terms of the use of VAR model in this conducted study, it required applying stationary condition criteria, which is defined as a condition where its mean and variance are constant and the covariance is not time-dependent [11]. The stationarity in this study was tested using unit root test with Augmented Dickey-Fuller (ADF) method. The ADF test has the following mathematical equation [8].

$$\Delta y_t = \beta_0 + \theta y_{t-1} + \sum_{i=2}^p \phi_i \Delta y_{t-1+i} + \varepsilon_t \quad (2)$$

In which Δy_t is time series value at the t time minus time series value in 1 previous measurement period (the $t-1$ time), θ is constant-valued ($\beta_1 + \dots + \beta_{p-1} - 1$) [8] which is used to determine whether or not the unit roots exist with hypothesis $H_0: \theta = 0$ (the data contain unit roots) and $H_1: \theta < 0$ (the data do not contain unit roots). Meanwhile, ϕ_i is trend coefficient on the time series data of which the value is equal to $\phi_i = -\sum_{j=1}^p \beta_j$ [8]. In this case, the criteria that can be drawn are non-stationary data will have unit roots, while stationary data will not have unit roots. If the data are not stationary, it required to conduct differencing process once or several times on the related data until the data turn out to be stationary [10] [17].

Prior to VAR model was completely formed eventually, the accuracy level should be evaluated by calculating its lag value, which is generally indicated by its p -value. In the conducted study, in order to assess the feasibility level of the rainfall forecast model, it required applying Aikake's Information Criterion (AIC) calculation for some k independent variables where the AIC value is generally defined using the following mathematical equation [15].

$$AIC = \log \sigma_k^2 + \frac{n+2k}{n} \dots \quad (3)$$

Where $\sigma_k^2 = \frac{SSE}{n}$ with $SSE = \sum_{i=1}^n (y_i - \hat{y}_r)^2$

In which y_i is observed value at the i time; k is the number of parameters in the model; \hat{y}_r is mean; and n is the number of observation times. In this case, it can be stated that in case the AIC calculation value is smaller, the taken lag value is the better lag value [5] [15] as well as can be used as forecasting basis.

After accomplishing to determine the (p) lag value with AIC, the VAR mathematical equation system which theoretically does not distinguish the number of dependent and independent variables [17], the combination of rainfall, humidity and temperature variables by considering the accuracy of autoregressive equation (equation (1)) can be noted in the form of a matrix equation as follows [5] [13].

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} a_{1,1}^1 & a_{1,2}^1 & a_{1,3}^1 \\ a_{2,1}^1 & a_{2,2}^1 & a_{2,3}^1 \\ a_{3,1}^1 & a_{3,2}^1 & a_{3,3}^1 \end{bmatrix} \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \\ y_{3,t-1} \end{bmatrix} + \dots + \begin{bmatrix} a_{1,1}^p & a_{1,2}^p & a_{1,3}^p \\ a_{2,1}^p & a_{2,2}^p & a_{2,3}^p \\ a_{3,1}^p & a_{3,2}^p & a_{3,3}^p \end{bmatrix} \begin{bmatrix} y_{1,t-p} \\ y_{2,t-p} \\ y_{3,t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix} \quad \dots(4)$$

The matrix equation above (equation (4)), using regression notation can also be noted as follows (for rainfall).

$$y_{1,t} = c_1 + a_{1,1}^1 y_{1,t-1} + a_{1,2}^1 y_{2,t-1} + a_{1,3}^1 y_{3,t-1} + \dots + a_{1,1}^p y_{1,t-p} + a_{1,2}^p y_{2,t-p} + a_{1,3}^p y_{3,t-p} + \varepsilon_{1,t} \quad (5)$$

In which $y_{1,t}$ is the rainfall at the-t time; $y_{2,t}$ is the humidity at the-t time; and $y_{3,t}$ is the temperature at the-t time. Meanwhile, c is the constant indicating the intercept; ε is the errors level; and p is the lag length. In this case, the parameter values $a_{1,1}^1$ to $a_{3,3}^p$ can be estimated by using Ordinary Least Square (OLS) method, by minimizing the value of squared error (minimizing ε^2 value) [13] [17]. The determination of the parameter values can be started from the-p matrix, and then recursively defined to the other parameters.

Once the best model was obtained and able to be used for forecasting, the forecast accuracy level of the model can also be evaluated mathematically using the following mathematical equation [5] [15] [17].

- Computing Mean Absolute Error (MAE)

MAE is a computation of mean absolute error to see how close the values between the forecast and the real value. MAE is generally defined as the following equation.

$$MAE = \frac{1}{n} \sum_{t=1}^n |F_t - Y_t| \quad (6)$$

Where F_t is the forecast value; Y_t is the actual data; and n is the length of time series of observation.

- Computing Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{Y_t - F_t}{Y_t} \right| 10 \quad (7)$$

Where F_t is the forecast value and Y_t is the actual data.

In terms of the MAE and MAPE computation, the good model will have the smallest possible value of MAE as well as MAPE (less than or equal to 10%) [5] [15].

After the rainfall forecast value for the following year was accomplished, in order to portray the rainfalls in the study area related to the geographical position which is different from the measurement station, the isohyet map of Semarang then needs to be composed. The isohyet map is actually a regular contour map drawn to connect the dots in Semarang map with the same rainfall (forecast) values [18].

IV. RESULTS AND DISCUSSION

The rainfall, humidity and temperature data used in this study were taken from Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) of Central Java, Indonesia. The obtained data are the data of monthly rainfall throughout 2001-2013 periods from 5 measurement stations, comprising Ungaran-Semarang, Semarang Kota, Bringin-Salatiga, Adisumarmo-Boyolali, and Borobudur-Magelang. At each measurement station, the rainfall forecast was carried out using VAR model, then (after the data from those 5 measurement stations were processed) the isohyet map for dry and wet season was composed by computing coordinates/geographic location of each station.

In order to apply VAR method to the existing data, we necessarily figure out the stationarity of data in each station initially using ADF calculation as the VAR[15]. ADF calculation for each time series data and interpretation of stationarity in each station are shown in Table 1.

TABLE I. RAINFALL, HUMIDITY AND TEMPERATURE STATIONARITY TEST IN VARIOUS MEASUREMENT STATIONS

Rainfall Station	ADF Of Rainfall	Hypothesis	ADF Of Humidity	Hypothesis	ADF of Temperature	Hypothesis
Ungaran Semarang	-8.8005	S	-4.6565	S	-5.8516	S
Bringin-Salatiga	-3.0617	S	-3.9083	S	-3.9435	S
Adisumarmo Boyolali	-2.8473	S	-3.7498	S	-3.4986	S
Borobudur Magelang	-3.6135	S	-3.7498	S	-4.1076	S
Semarang Kota	-3.0887	S	-5.0996	S	-3.4963	S

Note: S (stationary hypothesis) and not requiring differencing process.

TABLE II. TABLE OF AIC FOR VARIOUS VAR COMPUTATIONS

	VAR (3)	VAR (4)	VAR (5)	VAR (6)	VAR (7)	VAR (8)
Ungaran - Semarang	35	32	30	27	34	37
Bringin - Salatiga	25	23	20	17	22	26
Adisumarmo - Boyolali	26	24	21	17	23	27
Borobudur - Magelang	29	25	23	20	23	26
Semarang Kota	28	24	22	21	23	25

By following the stages that have been described previously, based on the rounded AIC calculation (Table 2), the final VAR model which can be obtained is VAR (6). VAR (6) with the smallest AIC value (shaded area) can be represented using mathematical equation model obtained through Ordinary Least Square (OLS) approach in the following equation (4).

- For measurement station of Ungaran-Semarang, $Y_{1,t} = -140,785646 + 0.182222205 Y_{1,t-1} - 0.01409596 Y_{1,t-2} - 0.09658367 Y_{1,t-3} - 0.100907471 Y_{1,t-4} - 0.118368817 Y_{1,t-5} - 0.118000286 Y_{1,t-6} + 0.019826927 Y_{2,t-1} + 0.2879448 Y_{2,t-2} - 0.04463891 Y_{2,t-3} - 0.013124160 Y_{2,t-4} - 0.017253552 Y_{2,t-5} + 0.139557736 Y_{2,t-6} + 0.01099009 Y_{3,t-1} + 0.1034915 Y_{3,t-2} + 0.48754994 Y_{3,t-3} - 0.104888805 Y_{3,t-4} + 0.032615013 Y_{3,t-5} + 0.131957736 Y_{3,t-6}$.
- For measurement station of Bringin – Salatiga, $Y_{1,t} = -349,0890 + 0.29781892 Y_{1,t-1} - 0.56327709 Y_{1,t-2} + 0.03872342 Y_{1,t-3} - 0.111907471 Y_{1,t-4} - 0.107368817 Y_{1,t-5} - 0.107000286 Y_{1,t-6} - 0.08397126 Y_{2,t-1} + 0.29326751 Y_{2,t-2} - 0.25521153 Y_{2,t-3} - 0.012024160 Y_{2,t-4} - 0.017253552 Y_{2,t-5} + 0.139557736 Y_{2,t-6} + 0.29648620 Y_{3,t-1} + 0.01739839 Y_{3,t-2} - 0.10278834 Y_{3,t-3} - 0.103788805 Y_{3,t-4} + 0.031515013 Y_{3,t-5} + 0.139557736 Y_{3,t-6}$.
- For measurement station of Adi Sumarmo - Boyolali, $Y_{1,t} = -468,738158 - 0.490667870 Y_{1,t-1} - 0.095312517 Y_{1,t-2} - 0.033233273 Y_{1,t-3} - 0.122907471 Y_{1,t-4} - 0.125368817 Y_{1,t-5} - 0.129000286 Y_{1,t-6} + 0.42273818 Y_{2,t-1} - 1.18946346 Y_{2,t-2} - 0.47307387 Y_{2,t-3} - 0.012244160 Y_{2,t-4} - 0.017475552 Y_{2,t-5} + 0.151757736 Y_{2,t-6} + 3.2756840 Y_{3,t-1} + 1.8152582 Y_{3,t-2} + 2.2411575 Y_{3,t-3} - 0.103999805 Y_{3,t-4} + 0.053715013 Y_{3,t-5} + 0.158579936 Y_{3,t-6}$.
- For measurement station of Borobudur - Magelang, $Y_{1,t} = -272,4933 + 0.04610669 Y_{1,t-1} - 0.43096825 Y_{1,t-2} - 0.35201372 Y_{1,t-3} - 0.100907471 Y_{1,t-4} - 0.107368817 Y_{1,t-5} - 0.107000286 Y_{1,t-6} + 0.99235069 Y_{2,t-1} - 0.52613470 Y_{2,t-2} - 1.16998137 Y_{2,t-3} - 0.018084160$

$$Y_{2,t-4} - 0.015033552 Y_{2,t-5} + 0.139225736 Y_{2,t-6} - 0.18096627 Y_{3,t-1} - 0.22172650 Y_{3,t-2} + 0.17670065 Y_{3,t-3} - 0.103566805 Y_{3,t-4} + 0.031515123 Y_{3,t-5} + 0.139535536 Y_{3,t-6}$$

- For measurement station of Semarang Kota, $Y_{1,t} = -638,137877 + 0.51796624 Y_{1,t-1} - 0.52963239 Y_{1,t-2} + 0.08272823 Y_{1,t-3} - 0.100907471 Y_{1,t-4} - 0.107368817 Y_{1,t-5} - 0.107000286 Y_{1,t-6} - 0.10935264 Y_{2,t-1} + 0.28539208 Y_{2,t-2} - 0.13033554 Y_{2,t-3} - 0.046224160 Y_{2,t-4} - 0.011693552 Y_{2,t-5} + 0.137787736 Y_{2,t-6} + 0.76188310 Y_{3,t-1} + 1.93032475 Y_{3,t-2} - 1.25373571 Y_{3,t-3} - 0.103722205 Y_{3,t-4} + 0.031559413 Y_{3,t-5} + 0.139591136 Y_{3,t-6}$.

Where

- $Y_{1,t}$ is rainfall value at the-t time.
- $Y_{2,t}$ is humidity value at the-t time.
- $Y_{3,t}$ is temperature value at the-t time.

TABLE III. MAE AND MAPE CALCULATION

Rainfall Station	MAE	MAPE (%)
Ungaran - Semarang	6.95128	2.139876
Bringin - Salatiga	13.15702	6.008978
Adisumarmo - Boyolali	10.23671	6.558561
Borobudur - Magelang	13.02692	5.713805
Semarang Kota	12.36196	6.707421

For calculating the accuracy of data processing, the calculation of MAE and MAPE value for each measurement station of which the result can be seen in Table 3 above is required. In general, the data processing result present the quite well values (the relatively small value of MAE and MAPE value that are below the range of 10%), hence VAR (6) model can be stated to be pretty well to forecast the rainfall in the study area (Semarang).

TABLE IV. RAINFALL FORECAST USING VAR (6) METHOD

Rainfall Station	Geographic Coordinate	Rainfall Forecast of Dry Season (mm/6 month)	Rainfall Forecast of Wet Season (mm/6 month)
Ungaran Semarang	426024.61, 9206491.87	1001.3251	2254.8765
Bringin Salatiga	448470.46, 9201746.57	1128.3067	2000.9843
Adisumarmo Boyolali	473139.18, 9168238.21	1171.3422	2222.9706
Magelang	412328.38, 9158961.91	1171.3422	2472.0129
Semarang Kota	435567.69, 9227421.87	994.2415	2230.9723

in certain area (sub-district) in dry and wet season as well, hence the plant that will be planted in the related area can be determined afterwards regarding the characteristic (water requirement) of the plant.

V. CONCLUSION

VAR (6) model can be applied well to forecast the rainfall in Semarang in dry and wet season. VAR (6) is used for the reason that through ADF calculation, each time series in the existing measurement stations is all stationary. Meanwhile, VAR (6) is taken as regarding the AIC calculation, this model has the lowest/smallest value than the other VAR models. VAR (6) can be applied well in Semarang as having the relatively small values of MAE and MAPE (valued below 10%) and smaller than ARIMA model used by BMKG (valued about 22,13%). Based on the mathematical model formulated with VAR (6) model based, isohyet map for each dry and wet season was made. It will be beneficial for the decision making stages as showing the correlation between certain areas (in this case – certain sub-districts in Semarang) and the rainfall (forecast) in the related areas.

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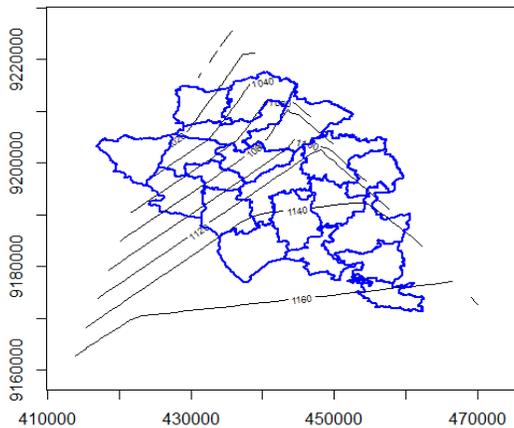


Fig. 2. Isohyet Map of Dry Season

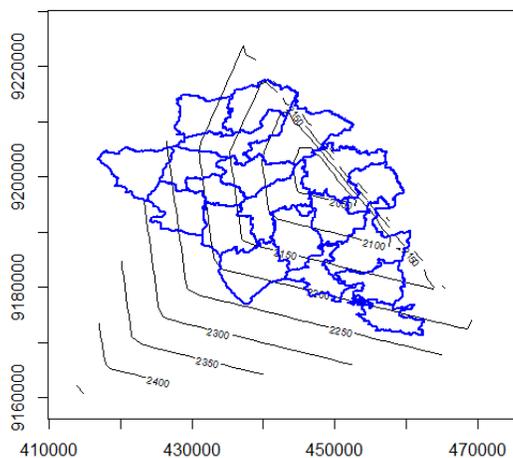


Fig. 3. Isohyet Map of Wet Season

For illustrating isohyet map in Semarang, it needs to figure out that the isohyet map [2] will be illustrated for dry season (April – September) and wet season (October – March) [4]. VAR model that was previously noted to forecast the rainfall in dry and wet season for each station was applied and the result is portrayed in Table 4 (the applied coordinate is UTM WGS84) [2]. In this case, the rainfall forecast for each of dry and wet season is the forecast cumulative number throughout the related season.

Isohyet map shown in Figure 2 and Figure 3 is the isohyet map for dry and wet season. The thick striped map is the map of Semarang with the boundaries of the existing sub-districts in the regency. The contour lines on the isohyet map portray the rainfall forecast associated with certain area (sub-district). By observing isohyet map as shown in Figure 2 and Figure 3, the decision makers can estimate/predict the rainfall that will drop

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