Monthly rainfall modelling for Lombok island using global climate parameters predictor

by Jaya Negara Negara

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Monthly Rainfall Modelling for Lombok Island Using Global Climate Parameters Predictor

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Abstract. Rainfall model is required for various purposes such as water management, determination of the right cropping pattern, and anticipation of possible extreme floods and drought. Various global climate phenomena are significantly affecting rainfall in an area. Therefore, it is vital to study the effects of the global climate in a narrow region because the impact often appears stronger at the local level. This study aims to find the monthly rainfall model using global climate parameter predictors for Lombok Island. The monthly rainfall model was analyzed by simple regression using global climate parameters, such as IOD (Indian Ocean Dipole), El Nino Modoki, and climate change parameters as model predictors in the last 23 years collected from many sites providing climate data. The analysis results showed a significant relationship between eastward wind (ua) and soil temperature (tsl) at a depth of 0.643 - 1.728 m as predictors of monthly rainfall in Lombok Island to its correlation number of 0.73 and 0.74. Otherwise, IOD and El Niño Modoki did not significantly affect monthly rainfall, as indicated by the correlation number of -0.21 and -0.13. The best mathematical model for predicting monthly rainfall on the island of Lombok is MR = -8281 + 13.29ua + 27.7 tsl.

INTRODUCTION

The Indonesian archipelago is located around the equator and experiences two seasons each year, rainy and dry seasons. This changing season occurs regularly, but the onset and the length of the seasons may differ each year. Many latest studies have shown that this condition occurred due to the influence of various global climate phenomena such as the Indian Ocean Dipole (IOD) in the Indian ocean and El Niño Modoki in the Pacific Ocean [1-3].

ENSO is a phenomenon of ocean-atmosphere interactions in the tropical Pacific region. In normal conditions, the western Pacific region is warmer than the tropical east Pacific. Meanwhile, El Nino/La Nina is a hot/cold anomalous phenomenon in the central and eastern equatorial Pacific Ocean[4]. At the same time, IOD is the difference in sea surface temperature on the east coast of Africa and the west coast of Sumatra that causes inter-annual climate variability in the Indian Ocean and affects the climate of the area around the Indian Ocean [5]. Until now, the IOD phenomenon is still difficult to predict, and there is still needs to be studied about its existence. [6]

The ENSO and IOD are impacting a diverse effect on rainfall in Indonesia. During the dry season, 50% of rainfall in Indonesia is affected by ENSO and 25% by the Indian Ocean Dipole (IOD) [3-7]. The El Niño cycle usually occurs every 4-7 years, but recently it appears earlier and occurs more frequently. It was noted that within 12 years (1994–2006) there were six El Niños; 1994, 1997, 2002, 2003, 2006 [8], and this was related to climate change and global warming impacts [1].

Due to the difference in the impact of global parameters on rainfall in a wide area, the study in smaller areas is needed because the impacts will appear to be stronger than the wider area[4]. For this reason, this study aims to get

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the rainfall model for Lombok Island by determining the relationship between IOD, El Nino Modoki, and climate change parameters to rainfall over Lombok Island.

The Lombok island is often experiencing a drought that causes many severe crop failures. Therefore, it is vital to find a model that can predict rainfall by considering the impacts of climate change, IOD, and El Niño Modoki as an effort to mitigate and early anticipate future drought disasters that may happen.

METHOD

The study area is located over Lombok Island, West Nusa Tenggara, Indonesia (FIGURE 1). The region is located between Bali Island and Sumbawa Island and has an area of about 4,738.65 km^2. The Climate condition of Lombok is a transition from Bali island's wet climate in the west part and the dry climate of Sumbawa Island in the east part.

FIGURE 1. Study area

This study's data needs consist of measured daily rainfall in millimeters for a network of 14 primary rain stations over Lombok Island, climate change parameters data, The Dipole Mode Index, and El Nino Modoki Index data. All data used in this study is secondary data.

This research used a descriptive quantitative method approach. The types of data are secondary data collected from agencies and data provider sites, then analyzed using a simple regression method.

Starting with the measured daily rain data that were collected from BWS NT1 and climate change parameters data were collected from GCM using CMIP5 (Coupled Model Intercomparison Project 5) as the output of CSIRO-BOM ACCESS 1-3 provided by The German Climate Computing Centre (DKRZ: Deutsches Klimarechenzentrum GmbH) from this following link, https://cera-www.dkrz.de/. The climate change data is available in many options time, and we choose the monthly mean value by downscaling techniques. The climate change data we used here as well as air temperature, eastward wind, northward wind relative humidity, specific humidity, evaporation, sea level pressure, leaf area index, the temperature of the soil, surface air pressure surface temperature, water evaporation from the soil, and near-surface wind speed. IOD can be detected using Dipole Mode Index (DMI), and El Nino Modoki provided in El Nino Modoki Index (EMI). The DMI and EMI were provided by the Japan Agency for Marine-Earth Science and Technology and can be freely downloaded from http://www.jamstec.go.jp/.

Each of the data was then analyzed for its correlation to the monthly area rainfall. Only data with a correlation value of more than 0.4 were used in the next analysis. Then a functional relationship was made between data that had a sufficient or strong correlation with monthly rainfall using simple regression analysis. The resulting model is then validated using data outside the model, then choose the best model based on the highest correlation number and the smallest volume error.

RESULT AND DISCUSSION

This study's result is a mathematical model that describes the relationship between all climate parameters of IOD, El Nino Modoki, and climate change data to rainfall. The best-selected model was built from two variables, such as eastward winds (ua) and temperature of soil (tsl) at 0.643-1.728 meters below ground level. Meanwhile, El Nino Modoki and Indian Ocean Dipole do not have a good relationship with rainfall on the island of Lombok.

The best model than chosen using the highest determination number of the model to monthly rainfall, the lowest error, and the highest efficiency. The expression of the best-fitted model is $MR = -8281 + 13.29\ ua + 27.79tsl(e)$

where MR = Monthly Rainfall (mm); ua = eastward wind; tsl (e) = temperature of soil (tsl) at 0.643-1.728 meters below ground level. This model showed the determination number of 0.757, the number of roots mean squared errors 51.2, and efficiency using Nash Sutcliffe efficiency of about 0.76

Correlation number of the parameters

Rainfall measurement data is available at 14 rain stations spread over Lombok Island for 23 years between 1995-2017. The annual rainfall data were tested for their consistency then the regional average rainfall value was analyzed using the Thiessen method. The consistency test was performed using the RAPS method (Rescaled adjusted partial sums), and the results are presented in TABLE 1.

TABLE 1. The results of the consistency test of rain data from several rain stations over Lombok Island

No	Rain Station	Qc	Qt	Interpretation	Rc	Rt	Interpretation
1	Gunungsari	4.442	5.880	consistent	6.107	6.959	consistent
2	Kuripan	2.003	5.880	consistent	3.969	6.959	consistent
3	Sesaot	5.689	5.880	consistent	7.412	6.959	inconsistent
4	Jurang sate	2.548	5.880	consistent	4.502	6.959	consistent
5	Kabul	3.752	5.880	consistent	7.347	6.959	inconsistent
6	Lingkok lime	3.151	5.880	consistent	4.228	6.959	consistent
7	Loang make	4.047	5.880	consistent	6.509	6.959	consistent
8	Mangkung	2.833	5.880	consistent	4.439	6.959	consistent
9	Rembitan	3.926	5.880	consistent	4.554	6.959	consistent
10	Ijobalit	6.404	5.880	inconsistent	6.404	6.959	consistent
11	Perian	5.144	5.880	consistent	5.256	6.959	consistent
12	Pringgabaya	4.985	5.880	consistent	5.300	6.959	consistent
13	Sepit	4.801	5.880	consistent	5.388	6.959	consistent
14	Santong	6.865	5.880	inconsistent	6.865	6.959	consistent

The average rainfall data was analyzed using Thiessen method, and the polygon of the rain coverage area is shown in FIGURE 2.

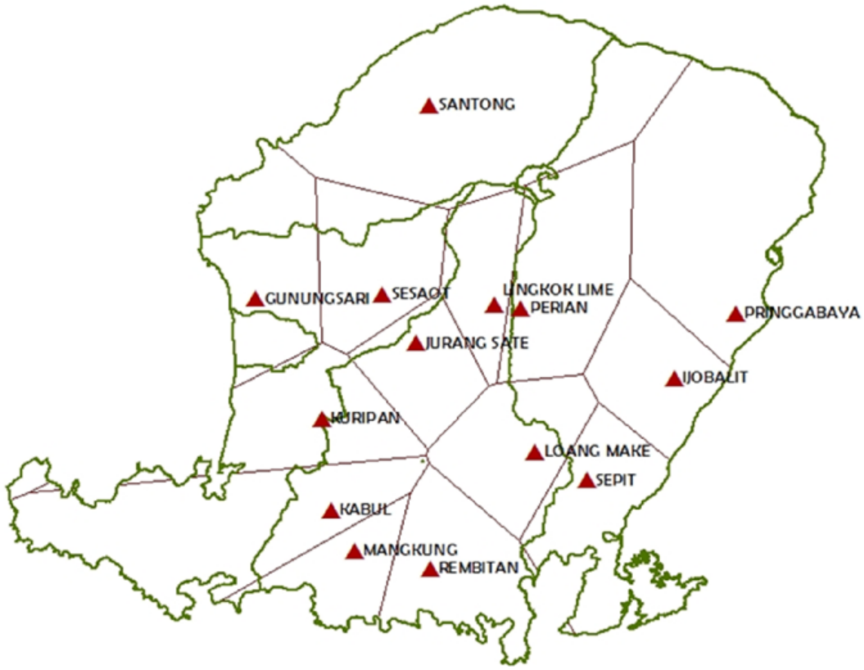

FIGURE 2. Rain station polygon coverage area of Thiessen Method

The daily rain data was then summed up monthly. Then the data of global climate change, Indian Ocean Dipole, and El Nino Modoki were used in modeling partially and simultaneously to predict monthly rainfall. All of these variables were then tested for their proximity to rain data by Spearman correlation analysis before chosen as independent variables of the model. The results of the Spearman correlation test were presented in TABLE 2.

TABLE 2. Spearman correlation number

Global Climate	**Correlation number**		
	Rainfall	**DMI**	**EMI**
Air Temperature	0.73	-0.09	0.00
Eastward Wind	0.73	-0.09	-0.10
Northward Wind	-0.53	0.13	0.15
Relative Humidity	0.19	-0.15	-0.05
Specific Humidity	0.59	-0.12	-0.03
Evaporation	-0.60	0.05	0.07
Sea Level Pressure	-0.63	0.12	0.03
Leaf Area Index	-0.57	-0.01	0.02
Temperature of Soil			
a. 0.00000 - 0.02200 (m)	0.43	0.03	0.00
b. 0.02200 - 0.08000 (m)	0.44	0.03	0.00
c. 0.08000 - 0.23400 (m)	0.48	0.02	-0.01
d. 0.23400 - 0.64300 (m)	0.56	0.00	-0.03

TABLE 2, Continued

Global Climate	Correlation number		
	Rainfall	DMI	EMI
e. 0.64300 - 1.72800 (m)	0.74	-0.07	-0.07
f. 1.72800 - 4.60000 (m)	0.54	-0.17	-0.13
Surface Air Pressure	-0.63	0.12	0.03
Surface Temperature	0.76	-0.09	-0.01
Water Evaporation from Soil	0.38	-0.11	-0.03
Near-Surface Wind Speed	-0.70	0.07	0.07
Indian Ocean Dipole (IOD)	-0.21		0.01
El Niño Modoki	-0.13	0.01	

Based on Table 2, it can be concluded that only global climate variables have a correlation value ≥ ± 0.40, as it is considered to have a moderate or sufficient relationship, and it will be used in the next analysis. While variables with correlation values <± 0.40 are not used because they are considered to have a low/very weak relationship, and they tend to be ignored.

Regression analysis

Regression analysis was used to obtain a mathematical model of a relationship between climate change variables, IOD, and El Niño Modoki on rainfall in Lombok Island. The analysis was performed using simple linear regression analysis and multiple linear regression. The simple and multiple regression analysis was carried out for all climate change variables, which have a correlation value of r ≥ ± 0.40 with monthly rainfall on the island of Lombok, either partially or simultaneously. The results of multiple linear regression analysis for climate change variables with a correlation number ≥ ± 0.40 are presented in Table 3.

Furthermore, it is necessary to do a multicollinearity test for multiple regression to see whether some of the independent variables in the multiple linear regression analysis used are related to other variables in one regression model. This does not happen in simple linear regression analysis because it only involves one independent variable.

The occurrence of multicollinearity can be detected by calculating the correlation coefficient between independent variables or by looking at the VIF (Variance Inflation Factor) value of more than ≥ 5 or ≥ 10 and p-value ≥ 5% in the analysis results. The VIF value will be greater if there is a higher correlation between the independent variables. A very high correlation between the independent variables resulted in an estimator of the regression model that is unstable and may be far from its predictive value.

From the results of the multiple linear regression analysis previously, there was multicollinearity where the variable tsl (b) has a VIF value = 13132160.38 > 5 (the largest value from the analysis results) and p-value = 0.731> 0.05, then to avoid multicollinearity, these variables are omitted. The analysis is continued while eliminating every variable that does not meet the requirements.

TABLE 3. Regression analysis results

Rainfall-Global Climate	Linear Regression
Air Temperature	R = - 19395 + 65.22 ta
Eastward Wind	R = 198.5 + 25.01 ua
Northward Wind	R = 229.6 - 40.43 va
Specific Humidity	R = - 554.9 + 42126 hus
Evaporation	R = 466.5 - 5187644 evspsbl
Sea Level Pressure	R = 38013 - 0.3750 psl
Leaf Area Index	R = 754.2 - 260.0 lai
Temperature of Soil	
a. 0.00000 - 0.02200 (m)	R = - 4963 + 16.80 tsl (a)
b. 0.02200 - 0.08000 (m)	R = - 5214 + 17.63 tsl (b)

TABLE 3, Continued

Rainfall-Global Climate	**Linear Regression**
c. 0.08000 - 0.23400 (m)	R = - 5900 + 19.89 tsl (c)
d. 0.23400 - 0.64300 (m)	R = - 7978 + 26.73 tsl (d)
e. 0.64300 - 1.72800 (m)	R = - 14824 + 49.29 tsl (e)
f. 1.72800 - 4.60000 (m)	R= - 26461 + 87.63 tsl (f)
Surface Air Pressure	R = 38044 - 0.3778 ps
Surface Temperature	R = - 22533 + 74.83 ts
Near-Surface Wind Speed	R = 394.4 - 57.32 sfcWind
Combination (2) and (8e)	R = -8281 + 13.29 ua + 27.79 tsl (e)
Combination (8e) and (8f)	R= -25725 + 43.92 tsl (e) + 41.3 tsl (f)

Model Validation

Model validation is used to see the accuracy of modeling based on all variables analyzed by simple or multiple regression. In order to find the best model, the RMSE, R^2, and NSE criteria can be used.

Root Mean Square Error (RMSE) is the difference (error) between the predicted results and the observation data. So, the best model is the model with the smallest RMSE value. The RMSE value is obtained by using [9]-[10].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_1)^2}{n}} \quad (1)$$

Where; Y_1 = the value of the response variable in the 1st validation data; $\hat{Y}i$ = the estimated value in the 1st validation data; n = number of observations.

The coefficient of determination or R^2 is a very simple tool to assess the quality of the fit in multiple linear regression, yet the most used by practitioners. The R^2 is usually presented as the quantity that estimates the percentage of the variance of the response variable explained by its (linear) relationship with the explanatory variables [11]

A reliable/accurate model is determined by small value errors and high correlation. Nash-Sutcliffe Efficiency (NSE) is also used to show the closeness of the relationship between observed data and simulation data (model). NSE has a value between $-\infty$ and 1. A value between 0 and 1 is usually seen as an acceptable level of performance, with NSE = 1 being optimal (perfect model), while a value <0 indicates unacceptable performance. Bias, mean error (ME), mean absolute error (MAE), Coefficient correlation, and Efficiency (Eff) are often used for evaluation at decadal and monthly time-scales[12]. The formula for calculating NSE[13] is given as follows, and the result is presented in TABLE 4.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right] \quad (2)$$

where: NSE = Nash Sutcliffe Efficiency; Y_i^{obs} = observed value of i^{th}; Y_i^{sim} = simulated value of i^{th}; Y_i^{mean} = mean observed value of n data; n= paired data.

TABLE 4. The result of model validation

Climate Change Variables	**RMSE**	**R² (%)**	**NSE**
Air Temperature	72.20	51.67	0.52
Eastward Wind	69.05	55.79	0.56
Northward Wind	84.42	33.91	0.34
Specific Humidity	86.15	31.17	0.31
Evaporation	83.60	35.20	0.35
Sea Level Pressure	86.56	30.68	0.31
Leaf Area Index	84.68	33.51	0.34

TABLE 4, Continued.

Climate Change Variables	RMSE	R^2 (%)	NSE
Temperature of Soil			
a. 0.00000 - 0.02200 (m)	86.65	30.39	0.30
b. 0.02200 - 0.08000 (m)	85.76	31.80	0.32
c. 0.08000 - 0.23400 (m)	83.29	35.67	0.36
d. 0.23400 - 0.64300 (m)	76.00	46.45	0.46
e. 0.64300 - 1.72800 (m)	56.99	69.90	0.70
f. 1.72800 - 4.60000 (m)	88.61	27.23	0.27
Surface Air Pressure	86.45	30.70	0.31
Surface Temperature	69.59	55.12	0.55
Near-Surface Wind Speed	72.73	50.95	0.51
Combination (2) and (8e)	51.20	75.70	0.76
Combination (8e) and (8f)	52.52	75.11	0.74

This study's validation was done by comparing the prediction and observation of regional average monthly rainfall of Lombok Island. The best model was selected by choosing the equation which has the smallest RMSE value, the largest R^2, and the closest NSE value to 1. Then the criterion for the best model, as shown in Table 4, is a model with a combination of eastward wind and soil temperature (depth 0.643-1.728 m). The regression equation resulted is: MR = -8281 + 13.29 ua + 27.79 tsl (e), where MR = monthly rainfall; ua = eastward wind; and tsl = temperature of soil under surface of 0.64300 m -1.72800 m. The model given the smallest RMSE about 52.52, the highest determination coefficient of 0.75, and the best efficiency about 0.74. So, it can be concluded that model performance or the skill of the product in estimating rainfall amounts is satisfaction (FIGURE 3).

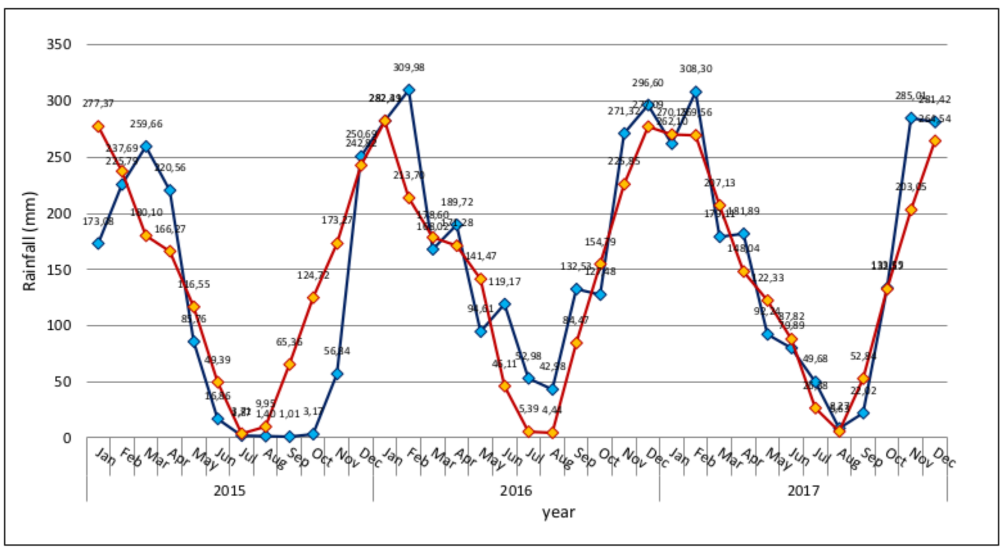

FIGURE 3. validation model

DISCUSSION

This work's main focus is to determine the most reliable predictor between Dipole Mode Index, El Nino Modoki Index, and global climate parameters to find the best monthly rainfall model for Lombok island. The selected predictor will significantly affect the productivity of resulted model. A study conducted using a machine learning-based model to see the relationship between various global variables shows that the global scale factors that influence Indonesia's territory differ in each location. The best combination of input models for Sumatra and Java is the combination of the Southern Oscillation Index (SOI) - Dipole Mode Index (DMI) - (Madden Julian Oscillation (MJO) index. The best model for the Kalimantan Island region is in the combination model between SOI - MJO and the Sulawesi Island region, the IOD - MJO combination model [2]. Meanwhile, [8] conducted a study to see the effect of the interaction of conventional El Niño and El Nino Modoki on monsoonal rainfall behavior in Indonesia by analyzing rainfall in five regions in Indonesia. The result obtained also shows different effects between various global factors for various regions in Indonesia. The SST anomaly of the Niño3.4 region is very good to be used as a predictor in-depth explain the behavior of monsoonal rainfall for Lampung, Indramayu, and Banjar Baru areas, while in Sumbawa Besar area, it is recommended to use EMI and the Sulawesi region to use predictor Nino 4. This is in line with the results obtained in this study, where the Dipole Mode Index and El Nino Modoki Index factors have no significant effect in determining the monthly rainfall model on the island of Lombok.

CONCLUSION

From the research results of Rainfall Modeling in Lombok Island based on Climate Change, IOD, and El Niño Modoki variables, it can be concluded that the most influential variables of climate change on monthly rainfall are the eastward wind (ua) and soil temperature (temperature of the soil, tsl, at a depth of 0.643 - 1,728 m), while IOD and El Niño Modoki have no significant effect on numbers correlation of -0.21 and -0.13 (very weak relationship, tends to be ignored). The best-fitted model for predicting monthly rainfall on the island of Lombok is MR = -8281 + 13.29ua + 27.7 tsl.

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